NONRESIDENT
TRAINING
COURSE

June 2001

Aerographer's Mate

Module 5—Basic Meteorology

NAVEDTRA 14312

Although the words "he," "him," and "his" are used sparingly in this course to enhance communication, they are not intended to be gender driven or to affront or discriminate against anyone.

PREFACE

By enrolling in this self-study course, you have demonstrated a desire to improve yourself and the Navy. Remember, however, this self-study course is only one part of the total Navy training program. Practical experience, schools, selected reading, and your desire to succeed are also necessary to successfully round out a fully meaningful training program.

COURSE OVERVIEW: In completing this nonresident training course, you will demonstrate a knowledge of the subject matter by correctly answering questions on the following subjects: Fundamentals of Meteorology, Atmospheric Physics, Atmospheric Circulation, Air Masses, Fronts, Atmospheric Phenomena, Climate and Climatology.

THE COURSE: This self-study course is organized into subject matter areas, each containing learning objectives to help you determine what you should learn along with text and illustrations to help you understand the information. The subject matter reflects day-to-day requirements and experiences of personnel in the rating or skill area. It also reflects guidance provided by Enlisted Community Managers (ECMs) and other senior personnel, technical references, instructions, etc., and either the occupational or naval standards, which are listed in the *Manual of Navy Enlisted Manpower Personnel Classifications and Occupational Standards,* NAVPERS 18068.

THE QUESTIONS: The questions that appear in this course are designed to help you understand the material in the text.

VALUE: In completing this course, you will improve your military and professional knowledge. Importantly, it can also help you study for the Navy-wide advancement in rate examination. If you are studying and discover a reference in the text to another publication for further information, look it up.

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Sailor's Creed

"I am a United States Sailor.

I will support and defend the Constitution of the United States of America and I will obey the orders of those appointed over me.

I represent the fighting spirit of the Navy and those who have gone before me to defend freedom and democracy around the world.

I proudly serve my country's Navy combat team with honor, courage and commitment.

I am committed to excellence and the fair treatment of all."

TABLE OF CONTENTS

SUMMARY OF THE AEROGRAPHER'S MATE TRAINING SERIES

The following training manuals of the AG training series are available:

AG MODULE 1, NAVEDTRA 12881, *Surface Weather Observations*

This module covers the basic procedures that are involved with conducting surface weather observations. It begins with a discussion of surface observation elements, followed by a description of primary and backup observation equipment that is used aboard ships and at shore stations. Module 1 also includes a complete explanation of how to record and encode surface METAR observations using WMO and NAVMETOCCOM guidelines. The module concludes with a description of WMO plotting models and procedures.

AG MODULE 2, NAVEDTRA 12882, *Miscellaneous Observations and Codes*

This module concentrates on the observation procedures, equipment, and codes associated with upper-air observations and bathythermograph observations. Module 2 also discusses aviation weather codes, such as TAFs and PIREPs, and includes a chapter on surf observation procedures. Radiological fallout and chemical contamination plotting procedures are also explained.

AG MODULE 3, NAVEDTRA 12883, *Environmental Satellites and Weather Radar*

This module describes the various types of environmental satellites, satellite imagery, and associated terminology. It also discusses satellite receiving equipment. In addition, Module 3 contains information on the Weather Surveillance Radar-1988 Doppler (WSR-88D). It includes a discussion of electromagnetic energy and radar propagation theory, and explains the basic principles of Doppler radar. The module also describes the configuration and operation of the WSR-88D, as well as WSR-88D products.

AG MODULE 4, NAVEDTRA 12884, *Environmental Communications and administration*

This module covers several of the most widely used environmental communications systems within the METOC community. It also describes the software programs and products associated with these systems. The module concludes with a discussion of basic administration procedures.

AG MODULE 5, NAVEDTRA 14312, *Basic Meteorology*

This training manual introduces the Aerographer's Mate to the basic fundamentals of meteorology, atmospheric physics, atmospheric circulation, air masses, fronts, atmospheric phenomena, climate and climatology.

NOTE

Additional modules of the AG training series are in development. Check the NETPDTC website for details at http://www.cnet.navy.mil/netpdtc/nac/neas.htm. For ordering information, check NAVEDTRA 12061, *Catalog of Nonresident Training Courses*, which is also available from the NETPDTC website.

INSTRUCTIONS FOR TAKING THE COURSE

ASSIGNMENTS

The text pages that you are to study are listed at the beginning of each assignment. Study these pages carefully before attempting to answer the questions. Pay close attention to tables and illustrations and read the learning objectives. The learning objectives state what you should be able to do after studying the material. Answering the questions correctly helps you accomplish the objectives.

SELECTING YOUR ANSWERS

Read each question carefully, then select the BEST answer. You may refer freely to the text. The answers must be the result of your own work and decisions. You are prohibited from referring to or copying the answers of others and from giving answers to anyone else taking the course.

SUBMITTING YOUR ASSIGNMENTS

To have your assignments graded, you must be enrolled in the course with the Nonresident Training Course Administration Branch at the Naval Education and Training Professional Development and Technology Center (NETPDTC). Following enrollment, there are two ways of having your assignments graded: (1) use the Internet to submit your assignments as you complete them, or (2) send all the assignments at one time by mail to NETPDTC.

Grading on the Internet: Advantages to Internet grading are:

- you may submit your answers as soon as you complete an assignment, and
- you get your results faster; usually by the next working day (approximately 24 hours).

In addition to receiving grade results for each assignment, you will receive course completion confirmation once you have completed all the assignments. To submit your assignment answers via the Internet, go to:

http://courses.cnet.navy.mil

Grading by Mail: When you submit answer sheets by mail, send all of your assignments at one time. Do NOT submit individual answer sheets for grading. Mail all of your assignments in an envelope, which you either provide yourself or obtain from your nearest Educational Services Officer (ESO). Submit answer sheets to:

COMMANDING OFFICER
NETPDTC N331
6490 SAUFLEY FIELD ROAD
PENSACOLA FL 32559-5000

Answer Sheets: All courses include one "scannable" answer sheet for each assignment. These answer sheets are preprinted with your SSN, name, assignment number, and course number. Explanations for completing the answer sheets are on the answer sheet.

Do not use answer sheet reproductions: Use only the original answer sheets that we provide—reproductions will not work with our scanning equipment and cannot be processed.

Follow the instructions for marking your answers on the answer sheet. Be sure that blocks 1, 2, and 3 are filled in correctly. This information is necessary for your course to be properly processed and for you to receive credit for your work.

COMPLETION TIME

Courses must be completed within 12 months from the date of enrollment. This includes time required to resubmit failed assignments.

PASS/FAIL ASSIGNMENT PROCEDURES

If your overall course score is 3.2 or higher, you will pass the course and will not be required to resubmit assignments. Once your assignments have been graded you will receive course completion confirmation.

If you receive less than a 3.2 on any assignment and your overall course score is below 3.2, you will be given the opportunity to resubmit failed assignments. **You may resubmit failed assignments only once.** Internet students will receive notification when they have failed an assignment—they may then resubmit failed assignments on the web site. Internet students may view and print results for failed assignments from the web site. Students who submit by mail will receive a failing result letter and a new answer sheet for resubmission of each failed assignment.

COMPLETION CONFIRMATION

After successfully completing this course, you will receive a letter of completion.

ERRATA

Errata are used to correct minor errors or delete obsolete information in a course. Errata may also be used to provide instructions to the student. If a course has an errata, it will be included as the first page(s) after the front cover. Errata for all courses can be accessed and viewed/downloaded at:

http://www.cnet.navy.mil/netpdtc/nac/neas.htm

STUDENT FEEDBACK QUESTIONS

We value your suggestions, questions, and criticisms on our courses. If you would like to communicate with us regarding this course, we encourage you, if possible, to use e-mail. If you write or fax, please use a copy of the Student Comment form that follows this page.

For subject matter questions:

E-mail: n315.products@cnet.navy.mil
Phone: Comm: (850) 452-1001, ext. 1782
DSN: 922-1001, ext. 1782
FAX: (850) 452-1370
(Do not fax answer sheets.)
Address: COMMANDING OFFICER
NETPDTC N315
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For enrollment, shipping, grading, or completion letter questions

E-mail: fleetservices@cnet.navy.mil
Phone: Toll Free: 877-264-8583
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DSN: 922-1511/1181/1859
FAX: (850) 452-1370
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Address: COMMANDING OFFICER
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NAVAL RESERVE RETIREMENT CREDIT

If you are a member of the Naval Reserve, you will receive retirement points if you are authorized to receive them under current directives governing retirement of Naval Reserve personnel. For Naval Reserve retirement, this course is evaluated at 9 points. (Refer to *Administrative Procedures for Naval Reservists on Inactive Duty,* BUPERSINST 1001.39, for more information about retirement points.)

Student Comments

Course Title: *Aerographer's Mate, Module 5—Basic Meteorology* ______________________________

NAVEDTRA: *14312* ______________________________________ **Date**: ________________________

<u>We need some information about you</u>:

Rate/Rank and Name: _________________________ SSN: ___________ Command/Unit __________________

Street Address: ______________________________ City: __________ State/FPO: _________ Zip ________

<u>Your comments, suggestions, etc</u>.:

Privacy Act Statement: Under authority of Title 5, USC 301, information regarding your military status is requested in processing your comments and in preparing a reply. This information will not be divulged without written authorization to anyone other than those within DOD for official use in determining performance.

NETPDTC 1550/41 (Rev 4-00)

CHAPTER 1

FUNDAMENTALS OF METEOROLOGY

Meteorology is the study of atmospheric phenomena. This study consists of physics, chemistry, and dynamics of the atmosphere. It also includes many of the direct effects the atmosphere has upon Earth's surface, the oceans, and life in general. In this manual we will study the overall fundamentals of meteorology, a thorough description of atmospheric physics and circulation, air masses, fronts, and meteorological elements. This information supplies the necessary background for you to understand chart analysis, tropical analysis, satellite analysis, and chart interpretation.

SYSTEM OF MEASUREMENT

LEARNING OBJECTIVE: Recognize the units of measure used in the Metric System and the English System and how these systems of measurement are used in Meteorology.

To work in the field of meteorology, you must have a basic understanding of the science of measurement (metrology). When you can measure what you are talking about and express it in numerical values, you then have knowledge of your subject. To measure how far something is moved, or how heavy it is, or how fast it travels; you may use a specific measurement system. There are many such systems throughout the world today. The Metric System (CGS, centimeter-gram-second) has been recognized for use in science and research. Therefore, that system is discussed in the paragraphs that follow, with brief points of comparison to the English System (FPS, foot-pound-second). The metric units measure length, weight, and time, respectively. The derivation of those units is described briefly.

LENGTH

To familiarize you with the conventional units of metric length, start with the meter. The meter is slightly larger than the English yard (39.36 inches vs. 36 inches). Prefixes are used in conjunction with the meter to denote smaller or larger units of the meter. Each larger unit is ten times larger than the next smaller unit. (See table 1-1.).

Table 1-1.—Common Prefixes in the Metric System

Prefix[1]	Symbol	Decimal Value	Scientific Notation
Kilo	K	1000	10^3
Hecto	H	100	10^2
Deka	D	10	10^1
Deci	d	.1	10^{-1}
Centi	c	.01	10^{-2}
Milli	m	.001	10^{-3}

[1]These prefixes are used with all metric units such as meters, grams, liters, and seconds (eg., kilometers, hectometers, centiliters, milliseconds).

Since the C in CGS represents centimeters (cm) you should see from table 1-1 that the centimeter is one-hundredth of a meter, .O1M, or 10^{-2} M. Conversely, 1 M equals 100 cm. To describe a gram, the G in the CGS system, you must first have a familiarization with area and volume.

AREA AND VOLUME

A square has four equal sides and it is a one-plane figure—like a sheet of paper. To determine how much surface area is enclosed within the square you multiply the length of one side by the length of the other equal side. If the sides were 1 centimeter (cm) in length the area of the square would be 1 cm × 1 cm = 1 square cm, or 1 cm^2. If squares having an area of 1 cm^2 were stacked on top of each other until the stack was 1 cm tall, you would end up with a cube whose sides were each 1-cm in length. To determine the volume of the cube you simply multiply the length by the width and height. Because each side is 1 cm you end up with a volume of 1 cubic centimeter (cm^3) (1 cm × 1 cm × 1 cm = 1 cm^3). More simply stated, multiply the area of one side of the cube by the height of the cube. Once you understand how the volume of a cube is determined, you are now ready to review the G in the CGS system.

WEIGHT

The conventional unit of weight in the metric system is the gram (gm). You could use table 1-1 and substitute the word gram for meter and the symbol (gm) for the symbol (M). You would then have a table for metric weight. The gram is the weight of 1 cm^3 of pure water at 4°C. At this point it may be useful to compare the weight of an object to its mass. The weight of the 1 cm^3 of water is 1 gin. Weight and mass are proportional to each other. However, the weight of the 1 cm^3 of water changes as you move away from the gravitational center of Earth. In space the 1 cm^3 of water is weightless, but it is still a mass. Mass is expressed as a function of inertia/acceleration, while weight is a function of gravitational force. When we express the movement of an object we use the terms mass and acceleration.

TIME

Time is measured in hours, minutes, and seconds in both systems. Hence, the second need not be explained in the CGS system. With knowledge of how the CGS system can be used to express physical entities, you now have all the background to express such things as density and force.

DENSITY

With the previous explanation of grams and centimeters, you should be able to understand how physical factors can be measured and described. For example, density is the weight something has per unit of volume. The density of water is given as 1 gram per cubic centimeter or 1 gm/cm. By comparison, the density of water in the English system is 62.4 pounds per cubic foot or 62.4 lb/ft^3.

FORCE

Force is measured in dynes. A dyne is the force that moves a mass of 1 gram, 1 centimeter per square second. This is commonly written as gin cm per sec^2, gin cm/sec/sec or gm/cm/sec^2. The force necessary for a gram to be accelerated at 980.665 cm/sec^2 at 45° latitude is 980.665 dynes. For more detailed conversion factors commonly used in meteorology and oceanography, refer to *Smithsonian Meteorology Tables*.

REVIEW QUESTIONS

Q1-1. What units does the metric (CGS) system measure?

Q1-2. What is the difference between weight and mass?

Q1-3. What does a dyne measure?

EARTH-SUN RELATIONSHIP

LEARNING OBJECTIVE: Describe how radiation and insolation are affected by the Earth-Sun relationship.

The Sun is a great thermonuclear reactor about 93 million miles from Earth. It is the original source of energy for the atmosphere and life itself. The Sun's energy is efficiently stored on Earth in such things as oil, coal, and wood. Each of these was produced by some biological means when the Sun acted upon living organisms. Our existence depends on the Sun because without the Sun there would be no warmth on Earth, no plants to feed animal life, and no animal life to feed man.

The Sun is important in meteorology because all natural phenomena can be traced, directly or indirectly, to the energy received from the Sun. Although the Sun radiates its energy in all directions, only a small portion reaches our atmosphere. This relatively small portion of the Sun's total energy represents a large portion of the heat energy for our Earth. It is of such importance in meteorology that every Aerographer's Mate should have at least a basic knowledge about the Sun and the effects it has on Earth's weather.

SUN

The Sun may be regarded as the only source of heat energy that is supplied to earth's surface and the atmosphere. All weather and motions in the atmosphere are due to the energy radiated from the Sun.

The Sun's core has a temperature of 15,000,000°K and a surface temperature of about 6,000°K (10,300°F). The Sun radiates electromagnetic energy in all directions. However, Earth intercepts only a small fraction of this energy. Most of the electromagnetic energy radiated by the Sun is in the form of light waves. Only a tiny fraction is in the form of heat waves. Even so, better than 99.9 percent of Earth's heat is derived from the Sun in the form of radiant energy.

Solar Composition

The Sun may be described as a globe of gas heated to incandescence by thermonuclear reactions from within the central core.

The main body of the Sun, although composed of gases, is opaque and has several distinct layers. (See fig. 1-1.) The first of these layers beyond the radiative zone is the convective zone. This zone extends very nearly to the Sun's surface. Here, heated gases are raised buoyantly upwards with some cooling occurring and subsequent convective action similar to that, which occurs within Earth's atmosphere. The next layer is a well-defined visible surface layer referred to as the photosphere. The bottom of the photosphere is the solar surface. In this layer the temperature has cooled to a surface temperature of 6,000°K at the bottom to 4,300°K at the top of the layer. All the light and heat of the Sun is radiated from the photosphere. Above the photosphere is a more transparent gaseous layer referred to as the chromosphere with a thickness of about 1,800 miles (3,000 km). It is hotter than the photosphere. Above the chromosphere is the corona, a low-density high temperature region. It is extended far out into interplanetary space by the solar wind—a steady outward streaming of the coronal material. Much of the electromagnetic radiation emissions consisting of gamma rays through x-rays, ultraviolet, visible and radio waves, originate in the corona.

Within the solar atmosphere we see the occurrence of transient phenomena (referred to as solar activity), just as cyclones, frontal systems, and thunderstorms occur within the atmosphere of Earth. This solar activity may consist of the phenomena discussed in the following paragraphs that collectively describe the features of the solar disk (the visual image of the outer

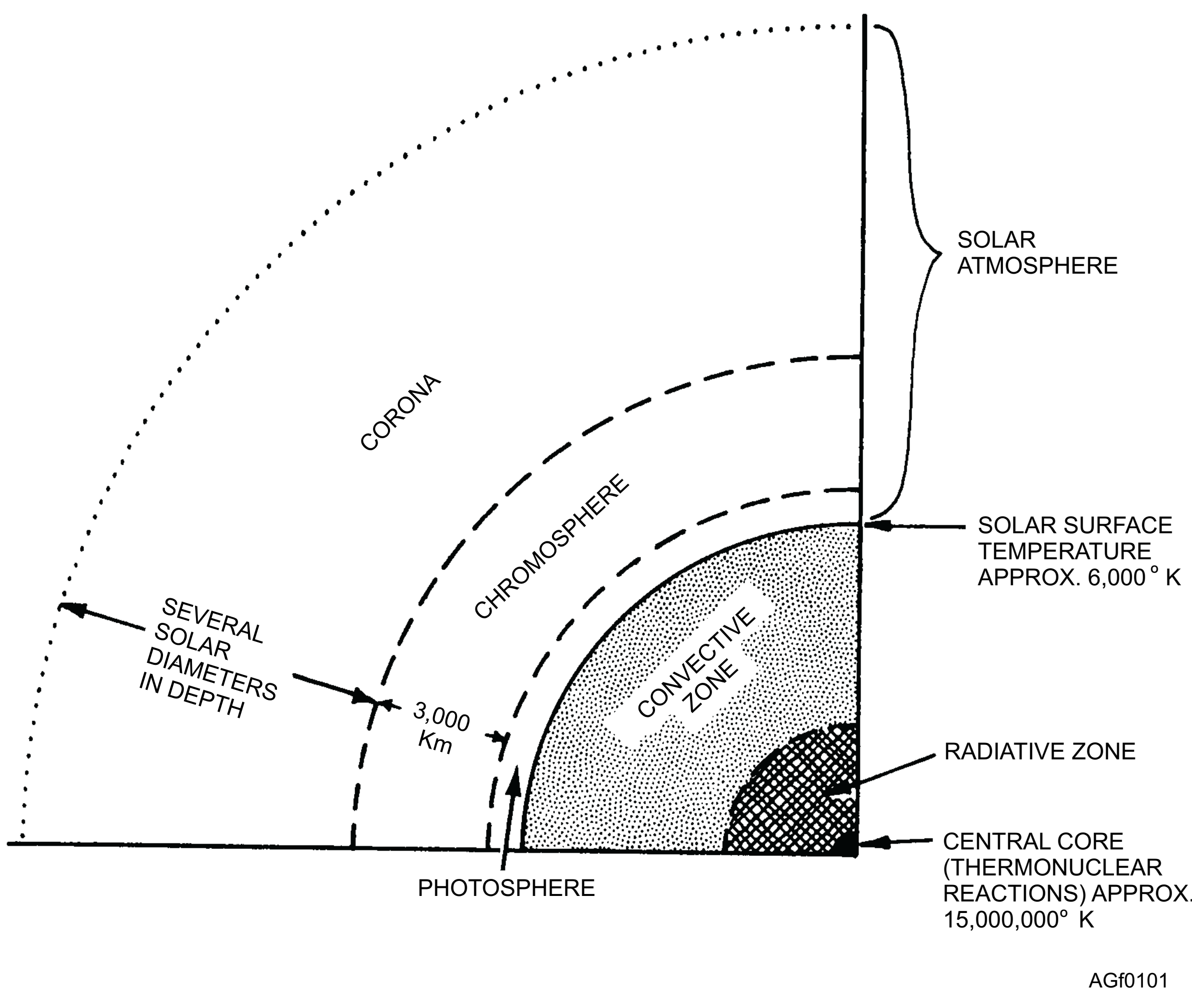


Figure 1-1.—One-quarter cross-section depicting the solar structure.

surface of the sun as observed from outside regions). (See fig. 1-2).

Solar Prominences/Filaments

Solar prominences/filaments are injections of gases from the chromosphere into the corona. They appear as great clouds of gas, sometimes resting on the Sun's surface and at other times floating free with no visible connection. When viewed against the solar disk, they appear as long dark ribbons and are called filaments. When viewed against the solar limb (the dark outer edge of the solar disk), they appear bright and are called prominences. (See fig. 1-2.) They display a variety of shapes, sizes, and activity that defy general description. They have a fibrous structure and appear to resist solar gravity. They may extend 18,500 to 125,000 miles (30,000 to 200,000 km) above the chromosphere. The more active types have temperatures of 10,000°K or more and appear hotter than the surrounding atmosphere.

Sunspots

Sunspots are regions of strong localized magnetic fields and indicate relatively cool areas in the photosphere. They appear darker than their surroundings and may appear singly or in more complicated groups dominated by larger spots near the center. (See fig. 1-2).

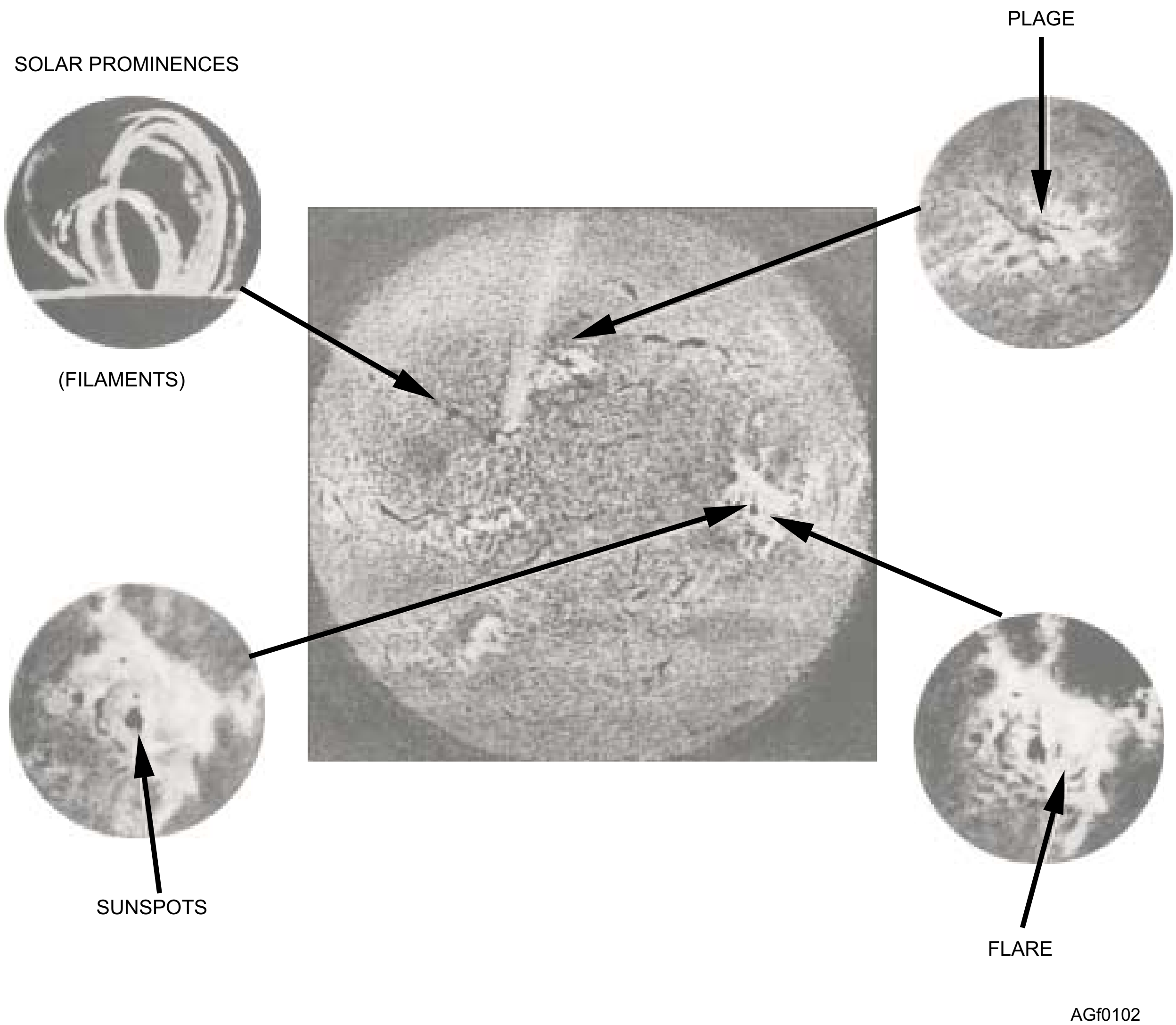


Figure 1-2.—Features of the solar disk.

Sunspots begin as small dark areas known as pores. These pores develop into full-fledged spots in a few days, with maximum development occurring in about 1 to 2 weeks. When sunspots decay the spot shrinks in size and its magnetic field also decreases in size. This life cycle may consist of a few days for small spots to near 100 days for larger groups. The larger spots normally measure about 94,500 miles (120,000 kin) across. Sunspots appear to have cyclic variations in intensity, varying through a period of about 8 to 17 years. Variation in number and size occurs throughout the sunspot cycle. As a cycle commences, a few spots are observed at high latitudes of both solar hemispheres, and the spots increase in size and number. They gradually drift equatorward as the cycle progresses, and the intensity of the spots reach a maximum in about 4 years. After this period, decay sets in and near the end of the cycle only a few spots are left in the lower latitudes (5° to 10°).

Plages

Plages are large irregular bright patches that surround sunspot groups. (See fig. 1-2). They normally appear in conjunction with solar prominences or filaments and may be systematically arranged in radial or spiral patterns. Plages are features of the lower chromosphere and often completely or partially obscure an underlying sunspot.

Flares

Solar flares are perhaps the most spectacular of the eruptive features associated with solar activity. (See fig. 1-2). They look like flecks of light that suddenly appear near activity centers and come on instantaneously as though a switch were thrown. They rise sharply to peak brightness in a few minutes, then decline more gradually. The number of flares may increase rapidly over an area of activity. Small flare-like brightenings are always in progress during the more active phase of activity centers. In some instances flares may take the form of prominences, violently ejecting material into the solar atmosphere and breaking into smaller high-speed blobs or clots. Flare activity appears to vary widely between solar activity centers. The greatest flare productivity seems to be during the week or 10 days when sunspot activity is at its maximum.

Flares are classified according to size and brightness. In general, the higher the importance classification, the stronger the geophysical effects. Some phenomena associated with solar flares have immediate effects; others have delayed effects (15 minutes to 72 hours after flare).

Solar flare activity produces significant disruptions and phenomena within Earth’s atmosphere. During solar flare activity, solar particle streams (solar winds) are emitted and often intercept Earth. These solar particles are composed of electromagnetic radiation, which interacts with Earth’s ionosphere. This results in several reactions such as: increased ionization (electrically charging neutral particles), photo chemical changes (absorption of radiation), atmospheric heating, electrically charged particle motions, and an influx of radiation in a variety of wavelengths and frequencies which include radio and radar frequencies.

Some of the resulting phenomena include the disruption of radio communications and radar detection. This is due to ionization, incoming radio waves, and the motion of charged particles. Satellite orbits can be affected by the atmospheric heating and satellite transmissions may be affected by all of the reactions previously mentioned. Geomagnetic disturbances like the aurora borealis and aurora Australia result primarily from the motion of electrically charged particles within the ionosphere.

EARTH

Of the nine planets in our solar system, Earth is the third nearest to (or from) the Sun. Earth varies in distance from the Sun during the year. The Sun is 94 million miles (150,400,000 km) in summer and 91 million miles (145,600,000 km) in winter.

Motions

Earth is subject to four motions in its movement through space: rotation about its axis, revolution around the Sun, processional motion (a slow conical movement or wobble) of the axis, and the solar motion (the movement of the whole solar system with space). Of the four motions affecting Earth, only two are of any importance to meteorology.

The first motion is rotation. Earth rotates on its axis once every 24 hours. One-half of the Earth's surface is therefore facing the Sun at all times. Rotation about Earth's axis takes place in an eastward direction. Thus, the Sun appears to rise in the east and set in the west. (See fig. 1-3.)

The second motion of Earth is its revolution around the Sun. The revolution around the Sun and the tilt of Earth on its axis are responsible for our seasons. Earth makes one complete revolution around the Sun in approximately 365 1/4 days. Earth's axis is at an angle of 23 1/2° to its plane of rotation and points in a nearly fixed direction in space toward the North Star (Polaris).

Solstices and Equinoxes

When Earth is in its summer solstice, as shown for June in figure 1-4, the Northern Hemisphere is inclined 23 1/2° toward the Sun. This inclination results in more of the Sun's rays reaching the Northern Hemisphere than the Southern Hemisphere. On or about June 21, direct sunlight covers the area from the North Pole down to latitude 66 1/2°N (the Arctic Circle). The area between the Arctic Circle and the North Pole is receiving the Sun's rays for 24 hours each day. During this time the most perpendicular rays of the Sun are received at 23 l/2°N latitude (the Tropic Of Cancer). Because the Southern Hemisphere is tilted away from the Sun at this time, the indirect rays of the Sun reach only to 66 1/2°S latitude (the Antarctic Circle). Therefore, the area between the Antarctic Circle and the South Pole is in complete darkness. Note carefully the shaded and the not shaded area of Earth in figure 1-4 for all four positions.

At the time of the equinox in March and again in September, the tilt of Earth's axis is neither toward nor away from the Sun. For these reasons Earth receives an equal amount of the Sun's energy in both the Northern Hemisphere and the Southern Hemisphere. During this time the Sun's rays shine most perpendicularly at the equator.

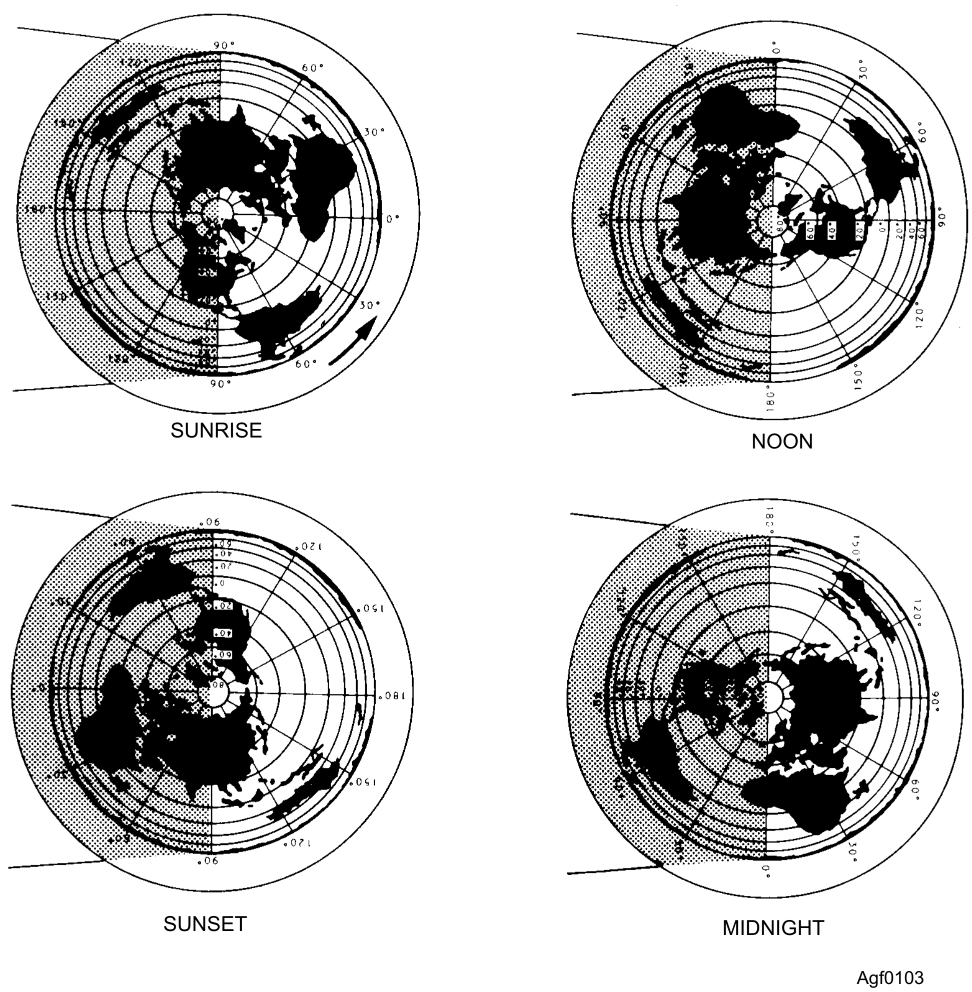


Figure 1-3.—Rotation of the Earth about its axis (during equinoxes).

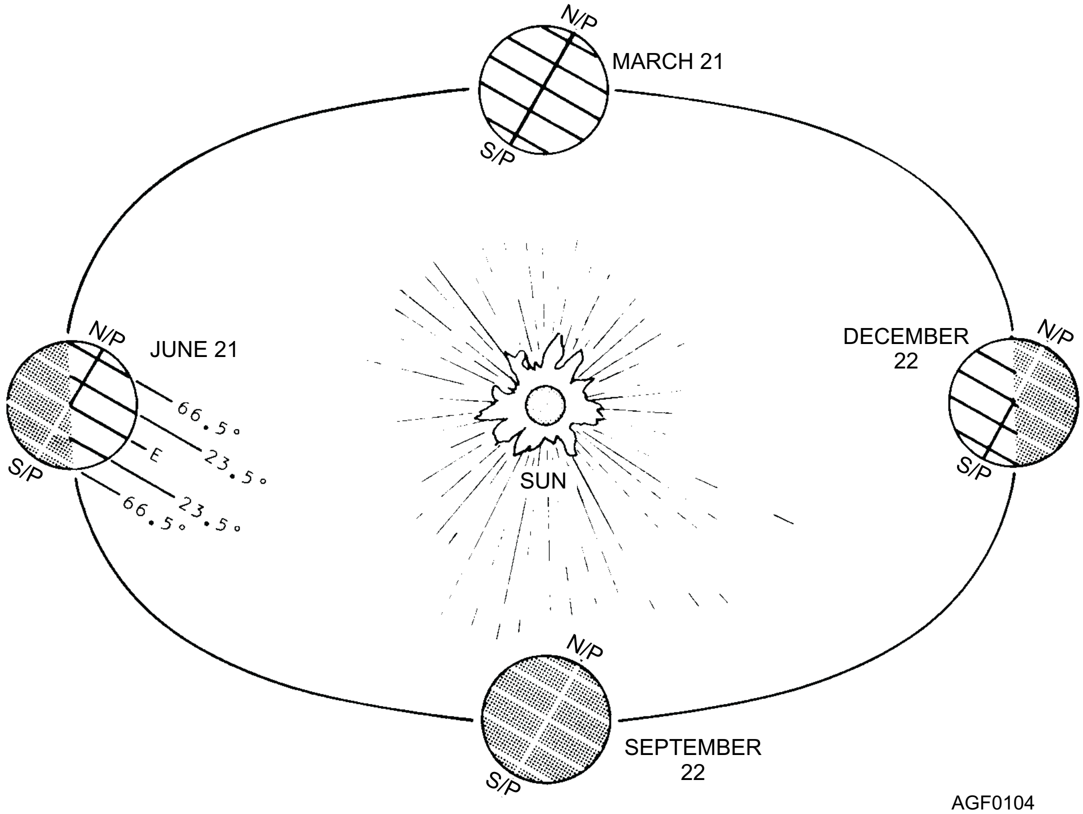


Figure 1-4.—Revolution of Earth around the sun.

In December, the situation is exactly reversed from that in June. The Southern Hemisphere now receives more of the Sun's direct rays. The most perpendicular rays of the Sun are received at 23 1/2°S latitude (the Tropic Of Capricorn). The southern polar region is now completely in sunshine and the northern polar region is completely in darkness.

Since the revolution of Earth around the Sun is a gradual process, the changes in the area receiving the Sun's rays and the changes in seasons are gradual. However, it is customary and convenient to mark these changes by specific dates and to identify them by specific names. These dates are as follows:

1. March 21. The vernal equinox, when Earth's axis is perpendicular to the Sun's rays. Spring begins in the Northern Hemisphere and fall begins in the Southern Hemisphere.

2. June 21. The summer solstice, when Earth's axis is inclined 23 1/2° toward the Sun and the Sun has reached its northernmost zenith at the Tropic of Cancer. Summer officially commences in the Northern Hemisphere; winter begins in the Southern Hemisphere.

3. September 22. The autumnal equinox, when Earth's axis is again perpendicular to the Sun's rays. This date marks the beginning of fall in the Northern Hemisphere and spring in the Southern Hemisphere. It is also the date, along with March 21, when the Sun reaches its highest position (zenith) directly over the equator.

4. December 22. The winter solstice, when the Sun has reached its southernmost zenith position at the Tropic of Capricorn. It marks the beginning of winter in the Northern Hemisphere and the beginning of summer in the Southern Hemisphere.

In some years, the actual dates of the solstices and the equinoxes vary by a day from the dates given here. This is because the period of revolution is 365 1/4 days and the calendar year is 365 days except for leap year when it is 366 days.

Because of its 23 1/2° tilt and its revolution around the Sun, five natural light (or heat) zones according to the zone's relative position to the Sun's rays mark Earth. Since the Sun is ALWAYS at its zenith between the Tropic of Cancer and the Tropic of Capricorn, this is the hottest zone. It is called the Equatorial Zone, the Torrid Zone, the Tropical Zone, or simply the Tropics.

The zones between the Tropic of Cancer and the Arctic Circle and between the Tropic of Capricorn and the Antarctic Circle are the Temperate Zones. These zones receive sunshine all year, but less of it in their respective winters and more of it in their respective summers.

The zones between the Arctic Circle and the North Pole and between the Antarctic Circle and the South Pole receive the Sun's rays only for parts of the year. (Directly at the poles there are 6 months of darkness and 6 months of sunshine.) This, naturally, makes them the coldest zones. They are therefore known as the Frigid or Polar Zones.

RADIATION

The term "radiation" refers to the process by which electromagnetic energy is propagated through space. Radiation moves at the speed of light, which is 186,000 miles per second (297,600 km per second) and travels in straight lines in a vacuum. All of the heat received by Earth is through this process. It is the most important means of heat transfer.

Solar radiation is defined as the total electromagnetic energy emitted by the Sun. The Sun's surface emits gamma rays, x-rays, ultraviolet, visible light, infrared, heat, and electromagnetic waves. Although the Sun radiates in all wavelengths, about half of the radiation is visible light with most of the remainder being infrared. (See figure 1-5.)

Energy radiates from a body by wavelengths, which vary inversely with the temperature of that body. Therefore, the Sun, with an extremely hot surface temperature, emits short wave radiation. Earth has a much cooler temperature (15°C average) and therefore reradiates the Sun's energy or heat with long wave radiation.

INSOLATION

Insolation (an acronym for INcoming SOLar radiATION) is the rate at which solar radiation is received by a unit horizontal surface at any point on or above the surface of Earth. In this manual, insolation is used when speaking about incoming solar radiation.

There are a wide variety of differences in the amounts of radiation received over the various portions of Earth's surface. These differences in heating are important and must be measured or otherwise calculated to determine their effect on the weather.

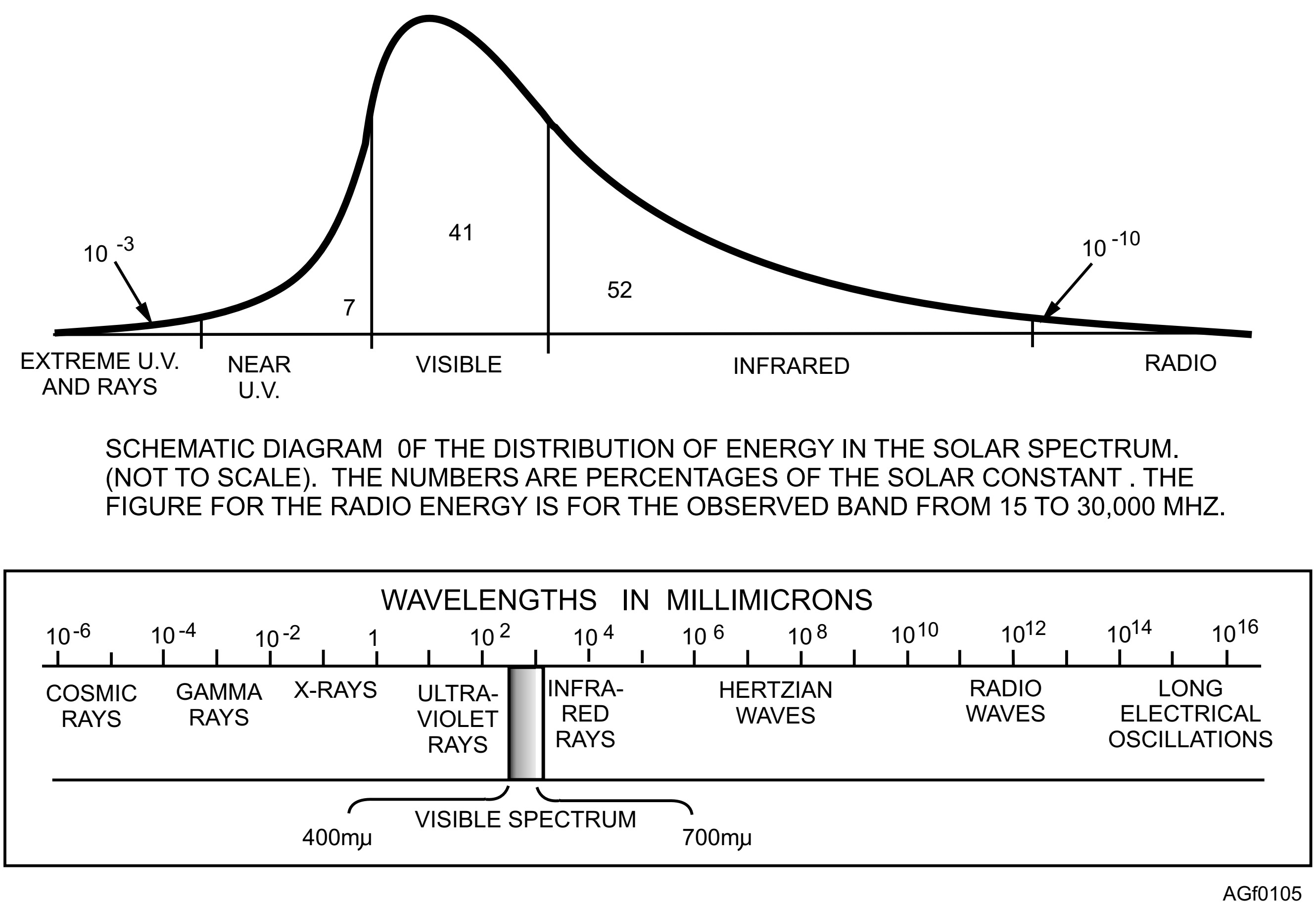


Figure 1-5.—Electromagnetic spectrum.

The insolation received at the surface of Earth depends upon the solar constant (the rate at which solar radiation is received outside Earth's atmosphere), the distance from the Sun, inclination of the Sun's rays, and the amount of insolation depleted while passing through the atmosphere. The last two are the important variable factors.

Depletion of Solar Radiation

If the Sun's radiation was not filtered or depleted in some manner, our planet would soon be too hot for life to exist. We must now consider how the Sun's heat energy is both dispersed and depleted. This is accomplished through dispersion, scattering, reflection, and absorption.

DISPERSION.—Earlier it was learned that Earth's axis is inclined at an angle of 23 1/2°. This inclination causes the Sun's rays to be received on the surface of Earth at varying angles of incidence, depending on the position of Earth. When the Sun's rays are not perpendicular to the surface of Earth, the energy becomes dispersed or spread out over a greater area (figure.1-6). If the available energy reaching the atmosphere is constant and is dispersed over a greater area, the amount of energy at any given point within the area decreases, and therefore the temperature is lower. Dispersion of insolation in the atmosphere is caused by the rotation of Earth. Dispersion of insolation also takes place with the seasons in all latitudes, but especially in the latitudes of the polar areas.

SCATTERING.—About 25 percent of the incoming solar radiation is scattered or diffused by the atmosphere. Scattering is a phenomenon that occurs when solar radiation passes through the air and some of the wavelengths are deflected in all directions by molecules of gases, suspended particles, and water vapor. These suspended particles then act like a prism and produce a variety of colors. Various wavelengths and particle sizes result in complex scattering affects that produce the blue sky. Scattering is also responsible for the red Sun at sunset, varying cloud colors at sunrise and sunset, and a variety of optical phenomena.

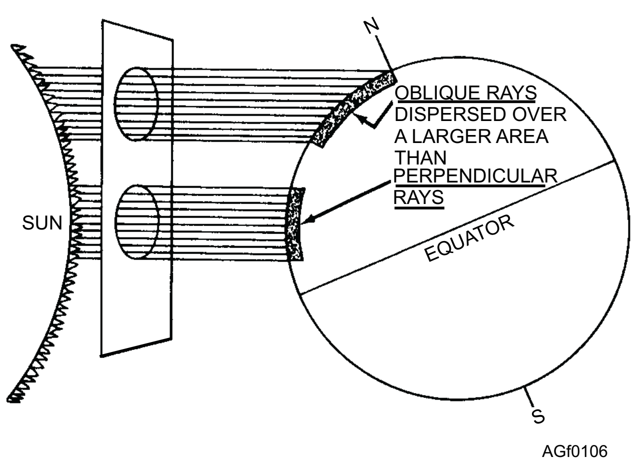


Figure 1-6.—Dispersion of insolation.

Scattering always occurs in the atmosphere, but does not always produce dramatic settings. Under certain radiation wavelength and particle size conditions all that can be seen are white clouds and a whitish haze. This occurs when there is a high moisture content (large particle size) in the air and is called diffuse reflection. About two-thirds of the normally scattered radiation reaches earth as diffuse sky radiation. Diffuse sky radiation may account for almost 100 percent of the radiation received by polar stations during winter.

REFLECTION.—Reflection is the process whereby a surface turns a portion of the incident back into the medium through which the radiation came.

A substance reflects some insolation. This means that the electromagnetic waves simply bounce back into space. Earth reflects an average of 36 percent of the insolation. The percent of reflectivity of all wavelengths on a surface is known as its albedo. Earth's average albedo is from 36 to 43 percent. That is, Earth reflects 36 to 43 percent of insolation back into space. In calculating the albedo of Earth, the assumption is made that the average cloudiness over Earth is 52 percent. All surfaces do not have the same degree of reflectivity; consequently, they do not have the same albedo. Some examples are as follows:

1. Upper surfaces of clouds reflect from 40 to 80 percent, with an average of about 55 percent.

2. Snow surfaces reflect over 80 percent of incoming sunlight for cold, fresh snow and as low as 50 percent for old, dirty snow.

3. Land surfaces reflect from 5 percent of incoming sunlight for dark forests to 30 percent for dry land.

4. Water surfaces (smooth) reflect from 2 percent, when the Sun is directly overhead, to 100 percent when, the Sun is very low on the horizon. This increase is not linear. When the Sun is more than 25°above the horizon, the albedo is less than 10 percent. In general, the albedo of water is quite low.

When Earth as a whole is considered, clouds are most important in determining albedo.

ABSORPTION.—Earth and its atmosphere absorb about 64 percent of the insolation. Land and water surfaces of Earth absorb 51 percent of this insolation. Ozone, carbon dioxide, and water vapor directly absorb the remaining 13 percent. These gases absorb the insolation at certain wavelengths. For example, ozone absorbs only a small percentage of the insolation. The portion or type the ozone does absorb is critical since it reduces ultraviolet radiation to a level where animal life can safely exist. The most important absorption occurs with carbon dioxide and water vapor, which absorb strongly over a broader wavelength band. Clouds are by far the most important absorbers of radiation at essentially all wavelengths. In sunlight clouds reflect a high percentage of the incident solar radiation and account for most of the brightness of Earth as seen from space.

There are regions, such as areas of clear skies, where carbon dioxide and water vapor are at a minimum and so is absorption. These areas are called *atmospheric windows* and allow insolation to pass through the atmosphere relatively unimpeded.

Greenhouse Effect

The atmosphere conserves the heat energy of Earth because it absorbs radiation selectively. Most of the solar radiation in clear skies is transmitted to Earth's surface, but a large part of the outgoing terrestrial radiation is absorbed and reradiated back to the surface. This is called the *greenhouse* effect. A greenhouse permits most of the short-wave solar radiation to pass through the glass roof and sides, and to be absorbed by the floor, ground or plants inside. These objects reradiate energy at their temperatures of about 300°K, which is a higher temperature than the energy that was initially received. The glass absorbs the energy at these wavelengths and sends part of it back into the greenhouse, causing the inside of the structure to become warmer than the outside. The atmosphere acts similarly, transmitting and absorbing in somewhat the same way as the glass. If the greenhouse effect did not exist, Earth's temperature would be 35°C cooler than the 15°C average temperature we now enjoy, because the insolation would be reradiated back to space.

Of course, the atmosphere is not a contained space like a greenhouse because there are heat transport mechanisms such as winds, vertical currents, and mixing with surrounding and adjacent cooler air.

RADIATION (HEAT) BALANCE IN THE ATMOSPHERE

The Sun radiates energy to Earth, Earth radiates energy back to space, and the atmosphere radiates energy also. As is shown in figure 1-7, a balance is maintained between incoming and outgoing radiation. This section of the lesson explains the various radiation processes involved in maintaining this critical balance and the effects produced in the atmosphere.

We have learned that an object reradiates energy at a higher temperature. Therefore, the more the Sun heats Earth, the greater the amount of heat energy Earth reradiates. If this rate of heat loss/gain did not balance, Earth would become continuously colder or warmer.

Terrestrial (Earth) Radiation

Radiation emitted by Earth is almost entirely long-wave radiation. Most of the terrestrial radiation is absorbed by the water vapor in the atmosphere and some by other gases (about 8 percent is radiated directly to outer space). This radiant energy is reradiated in the atmosphere horizontally and vertically. Horizontal flux (flow or transport) of energy need not be considered due to a lack of horizontal temperature differences. The vertical, upward or downward, flux is of extreme significance.

Convection and turbulence carry aloft some of this radiation. Water vapor, undergoing the condensation-precipitation-evaporation cycle (hydrological cycle), carries the remainder into the atmosphere.

Atmospheric Radiation

The atmosphere reradiates to outer space most of the terrestrial radiation (about 43 percent) and insolation (about 13 percent) that it has absorbed. Some of this reradiation is emitted earthward and is known as counterradiation. This radiation is of great importance in the greenhouse effect.

Heat Balance and Transfer in the Atmosphere

Earth does not receive equal radiation at all points as was shown in figure 1-4. The east-west rotation of Earth provides equal exposure to sunlight but latitude and dispersion do affect the amount of incident radiation received. The poles receive far less incident radiation than the equator. This uneven heating is called differential insolation.

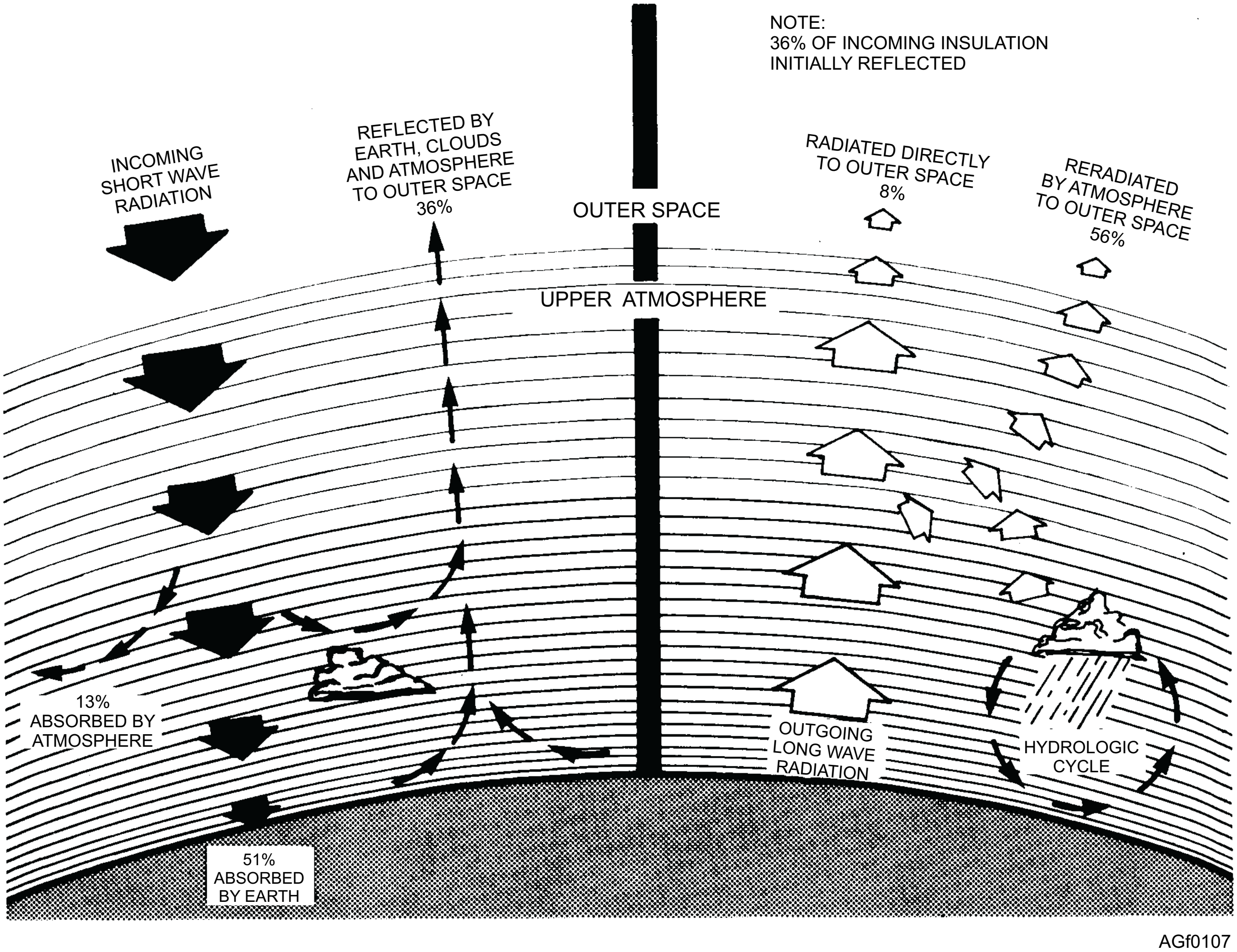


Figure 1-7.—Radiation balance in the atmosphere.

Due to this differential insolation the tropical atmosphere is constantly being supplied heat and the temperature of the air is thus higher than in areas poleward. Because of the expansion of warm air, this column of air is much thicker and lighter than over the poles. At the poles Earth receives little insolation and the column or air is less thick and heavier. This differential in insolation sets up a circulation that transports warm air from the Tropics poleward aloft and cold air from the poles equatorward on the surface. (See fig. 1-8.) Modifications to this general circulation are discussed in detail later in this training manual.

This is the account of the total radiation. Some of the radiation makes several trips, being absorbed, reflected, or reradiated by Earth or the atmosphere. Insolation comes into the atmosphere and all of it is reradiated. How many trips it makes while in our atmosphere does not matter. The direct absorption of radiation by Earth and the atmosphere and the reradiation into space balance. If the balance did not exist, Earth and its atmosphere, over a period of time, would steadily gain or lose heat.

Although radiation is considered the most important means of heat transfer, it is not the only method. There are others such as conduction, convection, and advection that also play an important part in meteorological processes.

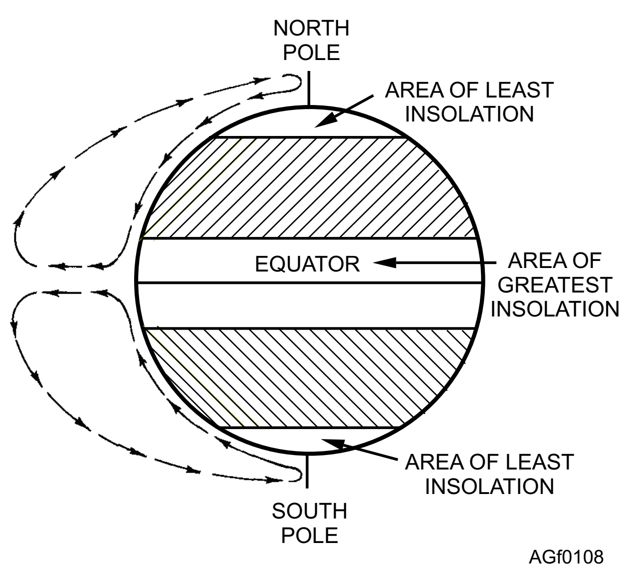


Figure 1-8.—Beginning of a circulation.

REVIEW QUESTIONS

Q1-4. What are sunspots?

Q1-5. In the Southern Hemisphere, approximately what date will the greatest amount of incoming solar radiation be received?

Q1-6. What percent of the earth's insolation do land and water absorb?

Q1-7. What is the effect on a polar air column in relation to a column of air over the equator?

PRESSURE

LEARNING OBJECTIVE: Describe how pressure is measured and determine how the atmosphere is affected by pressure.

DEFINITION AND FORMULA

Pressure is the force per unit area. Atmospheric pressure is the force per unit area exerted by the atmosphere in any part of the atmospheric envelope. Therefore, the greater the force exerted by the air for any given area, the greater the pressure. Although the pressure varies on a horizontal plane from day to day, the greatest pressure variations are with changes in altitude. Nevertheless, horizontal variations of pressure are ultimately important in meteorology because the variations affect weather conditions.

Pressure is one of the most important parameters in meteorology. Knowledge of the distribution of air and the resultant variations in air pressure over the earth is vital in understanding Earth’s fascinating weather patterns.

Pressure is force, and force is related to acceleration and mass by Newton’s second law. This law states that acceleration of a body is directly proportional to the force exerted on the body and inversely proportional to the mass of that body. It may be expressed as

$$a = \frac{F}{m} \text{ or } F = ma$$

“A” is the acceleration, “F” is the force exerted, and "in" is the mass of the body. This is probably the most important equation in the mechanics of physics dealing with force and motion.

NOTE: Be sure to use units of mass and not units of weight when applying this equation.

STANDARDS OF MEASUREMENT

Atmospheric pressure is normally measured in meteorology by the use of a mercurial or aneroid barometer. Pressure is measured in many different units. One atmosphere of pressure is 29.92 inches of mercury or 1,013.25 millibars. These measurements are made under established standard conditions.

STANDARD ATMOSPHERE

The establishment of a standard atmosphere was necessary to give scientists a yardstick to measure or compare actual pressure with a known standard. In the International Civil Aeronautical Organization (ICAO), the standard atmosphere assumes a mean sea level temperature of 59°F or 15°C and a standard sea level pressure of 1,013.25 millibars or 29.92 inches of mercury. It also has a temperature lapse rate (decrease) of 3.6°F per 1000 feet or 0.65°C per 100 meters up to 11 kilometers and a tropopause and stratosphere temperature of -56.5°C or -69.7°F.

VERTICAL DISTRIBUTION

Pressure at any point in a column of water, mercury, or any fluid, depends upon the weight of the column above that point. Air pressure at any given altitude within the atmosphere is determined by the weight of the atmosphere pressing down from above. Therefore, the pressure decreases with altitude because the weight of the atmosphere decreases.

It has been found that the pressure decreases by half for each 18,000-foot (5,400-meter) increase in altitude. Thus, at 5,400 meters one can expect an average pressure of about 500 millibars and at 36,000 feet (10,800 meters) a pressure of only 250 millibars, etc. Therefore, it may be concluded that atmospheric pressures are greatest at lower elevations because the total weight of the atmosphere is greatest at these points.

There is a change of pressure whenever either the mass of the atmosphere or the accelerations of the molecules within the atmosphere are changed. Although altitude exerts the dominant control, temperature and moisture alter pressure at any given altitude—especially near Earth’s surface where heat and humidity, are most abundant. The pressure variations produced by heat and humidity with heat being the dominant force are responsible for Earth’s winds through the flow of atmospheric mass from an area of higher pressure to an area of lower pressure.

PASCAL'S LAW

Pascal's Law is an important law in atmospheric physics. The law states that fluids (including gases such as Earth's atmosphere) transmit pressure in all directions. Therefore, the pressure of the atmosphere is exerted not only downward on the surface of an object, but also in all directions against a surface that is exposed to the atmosphere.

REVIEW QUESTIONS

Q1-8. What is the definition of pressure?

Q1-9. With a sea level pressure reading of 1000 mb, what would be the approximate pressure at 18,000 feet?

Q1-10. What environmental changes have the biggest effect on pressure changes?

TEMPERATURE

LEARNING OBJECTIVE: Describe how temperature is measured and determine how the atmosphere is affected by temperature.

DEFINITION

Temperature is the measure of molecular motion. Its intensity is determined from absolute zero (Kelvin scale), the point which all molecular motion stops. Temperature is the degree of hotness or coldness, or it may be considered as a measure of heat intensity.

TEMPERATURE SCALES

Long ago it was recognized that uniformity in the measurement of temperature was essential. It would be unwise to rely on such subjective judgments of temperature as cool, cooler, and coolest; therefore, arbitrary scales were devised. Some of them are described in this section. They are Fahrenheit, Celsius, and absolute (Kelvin) scales. These are the scales used by the meteorological services of all the countries in the world. Table 1-2 shows a temperature conversion scale for Celsius, Fahrenheit, and Kelvin.

Fahrenheit Scale

Gabriel Daniel Fahrenheit invented the Fahrenheit scale about 1710. He was the first to use mercury in a thermometer. The Fahrenheit scale has 180 divisions or degrees between the freezing (32°F) and boiling (212°F) points of water.

Celsius Scale

Anders Celsius devised the Celsius scale during the 18th century. This scale has reference points with respect to water of 0°C for freezing and 100°C for boiling. It should be noted that many publications still refer to the centigrade temperature scale. Centigrade simply means graduated in 100 increments, and has recently and officially adopted the name of its discoverer, Celsius.

Absolute Scale (Kelvin)

Another scale in wide use by scientists in many fields is the absolute scale or Kelvin scale, developed by Lord Kelvin of England. On this scale the freezing point of water is 273°K and the boiling point of water is 373°K. The absolute zero value is considered to be a point at which theoretically no molecular activity exists. This places the absolute zero at a minus 2730 on the Celsius scale, since the degree divisions are equal in size on both scales. The absolute zero value on the Fahrenheit scale falls at minus 459.6°F.

Scale Conversions

Two scales, Fahrenheit and Celsius, are commonly used. With the Celsius and Fahrenheit scales, it is often necessary to change the temperature value of one scale to that of the other. Generally a temperature conversion table, like table 1-2, is used or a temperature computer. If these are not available, you must then use one of the following mathematical methods to convert one scale to another.

Mathematical Methods

It is important to note that there are 100 divisions between the freezing and boiling points of water on the Celsius scale. There are 180 divisions between the same references on the Fahrenheit scale. Therefore, one degree on the Celsius scale equals nine-fifths degree on the Fahrenheit scale. In converting Fahrenheit values to Celsius values the formula is:

$$C = (F - 32°)\ \frac{5}{9}$$

In converting Celsius values to Fahrenheit values the formula is:

Table 1-2.—Temperature Conversion Scale

°C	°F[1]	°K
- 40	- 40.0	233
- 39	- 38.0	234
- 38	- 36.5	235
- 37	- 34.5	236
- 36	- 33.0	237
- 35	- 31.0	238
- 34	- 29.0	239
- 33	- 27.5	240
- 32	- 25.5	241
- 31	- 24.0	242
- 30	- 22.0	243
- 29	- 20.0	244
- 28	- 18.5	245
- 27	- 16.5	246
- 26	- 15.0	247
- 25	- 13.0	248
- 24	- 11.0	249
- 23	- 09.5	250
- 22	- 07.5	251
- 21	- 06.0	252
- 20	- 04.0	253
- 19	- 02.0	254
- 18	- 00.5	255
- 17	+01.5	256
- 16	+03.0	257
- 15	+05.0	258
- 14	+07.0	259
- 13	+08.5	260
- 12	+10.5	261
- 11	+12.0	262
- 10	+14.0	263
- 09	+16.0	264
- 08	+17.5	265
- 07	+19.5	266
- 06	+21.0	267
- 05	+23.0	268
- 04	+25.0	269
- 03	+26.5	270
- 02	+28.5	271
- 01	+30.5	272
00	+32.0	273
+01	+33.5	274
+02	+35.5	275
+03	+37.5	276
+04	+39.5	277
+05	+41.0	278
+06	+43.0	279
+07	+44.5	280
+08	+46.5	281
+09	+48.0	282
+10	+50.0	283
+11	+52.0	284
+12	+53.5	285
+13	+55.5	286
+14	+57.0	287
+15	+59.0	288
+16	+61.0	289
+17	+62.5	290
+18	+64.5	291
+19	+66.0	292
+20	+68.0	293
+21	+70.0	294
+22	+71.5	295
+23	+73.5	296
+24	+75.0	297
+25	+77.0	298
+26	+79.0	299
+27	+80.5	300
+28	+82.0	301
+29	+84.0	302
+30	+86.0	303
+31	+88.0	304
+32	+89.5	305
+33	+91.5	306
+34	+93.0	307
+35	+95.0	308
+36	+96.5	309
+37	+98.0	310
+38	+100.5	311
+39	+102.0	312
+40	+104.0	313
+41	+106.0	314
+42	+107.5	315
+43	+109.5	316
+44	+111.0	317
+45	+113.0	318
+46	+115.0	319
+47	+116.5	320
+48	+118.5	321
+49	+120.0	322
+50	+122.0	323
+51	+124.0	324
+52	+125.5	325
+53	+127.5	326
+54	+129.0	327
+55	+131.0	328
+56	+133.0	329
+57	+134.5	330
+58	+136.5	331
+59	+138.0	332
+60	+140.0	333

[1] Fahrenheit temperatures are rounded to the nearest 0.5 degree. For a more exact conversion, utilize the psychrometric computer or the mathematical method.

Table1-2

$$F = \frac{9}{5}C + 32°$$

One way to remember when to use 9/5 and when to use 5/9 is to keep in mind that the Fahrenheit scale has more divisions than the Celsius scale. In going from Celsius to Fahrenheit, multiply by the ratio that is larger; in going from Fahrenheit to Celsius, use the smaller ratio.

Another method of converting temperatures from one scale to another is the decimal method. This method uses the ratio 1°C equals 1.8°F. To find Fahrenheit from Celsius, multiply the Celsius value by 1.8 and add 32. To find Celsius from Fahrenheit, subtract 32 from the Fahrenheit and divide the remainder by 1.8.

Examples:

1. F = l.8C + 32

   Given: 24°C. Find: °F
   24 × 1.8 = 43.2
   43.2 + 32 = 75.2 or 75°F.

2. $C = \dfrac{F - 32}{1.8}$

   Given: 96°F. Find: °C.
   96 – 32 = 64
   64 + 1.8 = 35.5 or 36°C

To change a Celsius reading to an absolute value, add the Celsius reading to 273° algebraically. For example, to find the absolute value of -35°C, you would add minus 35° to 273°K algebraically. That is, you take 273° and combine 35° so you use the minus (-) function to arrive at 238°K.

To change a Fahrenheit reading to an absolute value, first convert the Fahrenheit reading to its equivalent Celsius value. Add this value algebraically to 273°. Consequently, 50°F is equivalent to 2830 absolute, arrived at by converting 50°F to 10°C and then adding the Celsius value algebraically to 273°.

VERTICAL DISTRIBUTION

Earth's atmosphere is divided into layers or zones according to various distinguishing features. (See fig. 1-9). The temperatures shown here are generally based on the latest "U.S. Extension to the ICAO Standard

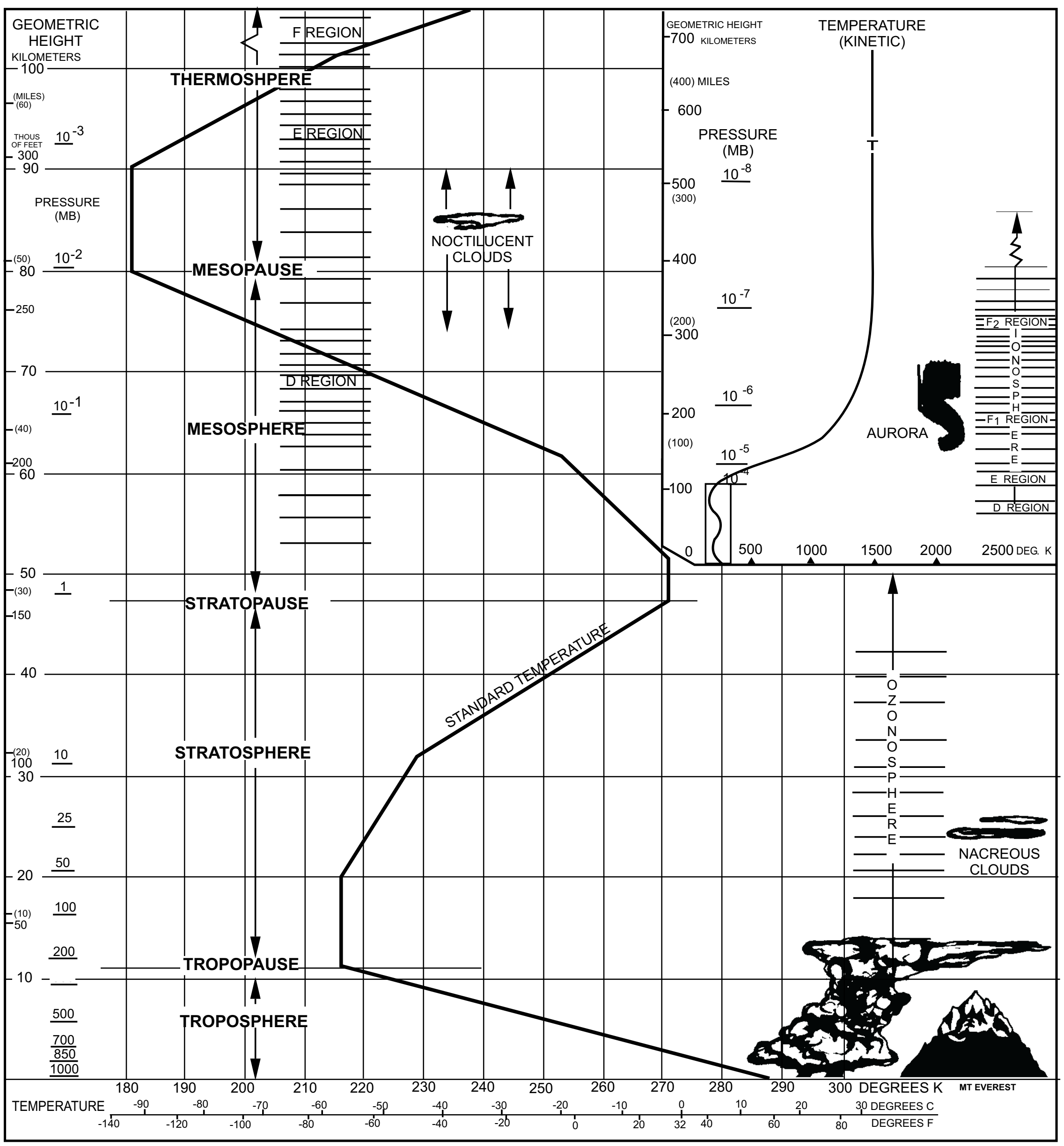


Figure 1-9.—Earth's Atmosphere.

Atmosphere" and are representative of mid-latitude conditions. The extension shown in the insert is speculative. These divisions are for reference of thermal structure (lapse rates) or other significant features and are not intended to imply that these layers or zones are independent domains. Earth is surrounded by one atmosphere, not by a number of sub-atmospheres.

The layers and zones are discussed under two separate classifications. One is the METEOROLOGICAL classification that defines zones according to their significance for the weather. The other is the ELECTRICAL classification that defines zones according to electrical characteristics of gases of the atmosphere.

Meteorological Classification

In the meteorological classification (commencing with Earth's surface and proceeding upward) we have the troposphere, tropopause, stratosphere, stratopause, mesosphere, mesopause, thermosphere, and the exosphere. These classifications are based on temperature characteristics. (See fig. 1-9 for some examples.)

TROPOSPHERE.—The troposphere is the layer of air enveloping Earth immediately above Earth's surface. It is approximately 5 1/2 miles (29,000 ft or 9 kin) thick over the poles, about 7 1/2 miles (40,000 ft or 12.5 kin) thick in the mid-latitudes, and about 11 1/2 miles (61,000 ft or 19 kin) thick over the Equator. The figures for thickness are average figures; they change somewhat from day to day and from season to season. The troposphere is thicker in summer than in winter and is thicker during the day than during the night. Almost all weather occurs in the troposphere. However, some phenomena such as turbulence, cloudiness (caused by ice crystals), and the occasional severe thunderstorm top occur within the tropopause or stratosphere.

The troposphere is composed of a mixture of several different gases. By volume, the composition of dry air in the troposphere is as follows: 78 percent nitrogen, 21 percent oxygen, nearly 1-percent argon, and about 0.03 percent carbon dioxide. In addition, it contains minute traces of other gases, such as helium, hydrogen, neon, krypton, and others.

The air in the troposphere also contains a variable amount of water vapor. The maximum amount of water vapor that the air can hold depends on the temperature of the air and the pressure. The higher the temperature, the more water vapor it can hold at a given pressure.

The air also contains variable amounts of impurities, such as dust, salt particles, soot, and chemicals. These impurities in the air are important because of their effect on visibility and the part they play in the condensation of water vapor. If the air were absolutely pure, there would be little condensation. These minute particles act as nuclei for the condensation of water vapor. Nuclei, which have an affinity for water vapor, are called HYGROSCOPIC NUCLEI.

The temperature in the troposphere usually decreases with height, but there may be inversions for relatively thin layers at any level.

TROPOPAUSE.—The tropopause is a transition layer between the troposphere and the stratosphere. It is not uniformly thick, and it is not continuous from the equator to the poles. In each hemisphere the existence of three distinct tropopauses is generally agreed upon—one in the subtropical latitudes, one in middle latitudes, and one in subpolar latitudes. They overlap each other where they meet.

The tropopause is characterized by little or no change in temperature with increasing altitude. The composition of gases is about the same as that for the troposphere. However, water vapor is found only in very minute quantities at the tropopause and above it.

STRATOSPHERE.—The stratosphere directly overlies the tropopause and extends to about 30 miles (160,000 ft or 48 kilometers). Temperature varies little with height in the stratosphere through the first 30,000 feet (9,000 meters); however, in the upper portion the temperature increases approximately linearly to values nearly equal to surface temperatures. This increase in temperature through this zone is attributed to the presence of ozone that absorbs incoming ultraviolet radiation.

STRATOPAUSE.—The stratopause is the top of the stratosphere. It is the zone marking another reversal with increasing altitude (temperature begins to decrease with height).

MESOSPHERE.—The mesosphere is a layer approximately 20 miles (100,000 ft or 32 kilometers) thick directly overlaying the stratopause. The temperature decreases with height.

MESOPAUSE.—The mesopause is the thin boundary zone between the mesosphere and the thermosphere. It is marked by a reversal of temperatures; i.e., temperature again increases with altitude.

THERMOSPHERE.—The thermosphere, a second region in which the temperature increases with height, extends from the mesopause to the exosphere.

EXOSPHERE.—The very outer limit of Earth's atmosphere is regarded as the exosphere. It is the zone in which gas atoms are so widely spaced they rarely collide with one another and have individual orbits around Earth.

Electrical Classification

The primary concern with the electrical classification is the effect on communications and radar. The electrical classification outlines three zones—the troposphere, the ozonosphere, and the ionosphere.

TROPOSPHERE.—The troposphere is important to electrical transmissions because of the immense changes in the density of the atmosphere that occur in this layer. These density changes, caused by differences in heat and moisture, affect the electronic emissions that travel through or in the troposphere. Electrical waves can be bent or refracted when they pass through these different layers and the range and area of communications may be seriously affected.

OZONOSPHERE.—This layer is nearly coincident with the stratosphere. As was discussed earlier in this section, the ozone is found in this zone. Ozone is responsible for the increase in temperature with height in the stratosphere.

IONOSPHERE.—The ionosphere extends from about 40 miles (200,000 ft or 64 kilometers) to an indefinite height. Ionization of air molecules in this zone provides conditions that are favorable for radio propagation. This is because radio waves are sent outward to the ionosphere and the ionized particles reflect the radio waves back to Earth.

HEAT TRANSFER

The atmosphere is constantly gaining and losing heat. Wind movements are constantly transporting heat from one part of the world to another. It is due to the inequalities in gain and loss of heat that the air is almost constantly in motion. Wind and weather directly express the motions and heat transformations.

Methods

In meteorology, one is concerned with four methods of heat transfer. These methods are conduction, convection, advection, and radiation. Heat is transferred from Earth directly the atmosphere by radiation, conduction, and advection. Heat is transferred within the atmosphere by radiation, conduction, and convection. Advection, a form of convection, is used in a special manner in meteorology. It is discussed as a separate method of heat transfer. As radiation was discussed earlier in the unit, this section covers conduction, convection, and advection.

CONDUCTION.—Conduction is the transfer of heat from warmer to colder matter by contact. Although of secondary importance in heating the atmosphere, it is a means by which air close to the surface of Earth heats during the day and cools during the night.

CONVECTION.—Convection is the method of heat transfer in a fluid resulting in the transport and mixing of the properties of that fluid. Visualize a pot of boiling water. The water at the bottom of the pot is heated by conduction. It becomes less dense and rises. Cooler and denser water from the sides and the top of the pot rushes in and replaces the rising water. In time, the water is thoroughly mixed. As long as heat is applied to the pot, the water continues to transfer heat by convection. The transfer of heat by convection in this case applies only to what is happening to the water in the pot. In meteorology, the term convection is normally applied to vertical transport.

Convection occurs regularly in the atmosphere and is responsible for the development of air turbulence. Cumuliform clouds showers and thunderstorms occur when sufficient moisture is present and strong vertical convection occurs. Vertical transfer of heat in the atmosphere (convection) works in a similar manner. Warmer, less dense air rises and is replaced by descending cooler, denser air, which acquires heat.

Specific Heat

The specific heat of a substance shows how many calories of heat it takes to raise the temperature of 1 gram of that substance 1°C. Since it takes 1 calorie to raise the temperature of 1 gram of water 1°C, the specific heat of water is 1. The specific heat of a substance plays a tremendous role in meteorology because it is tied directly to temperature changes. For instance, the specific heat of earth in general is 0.33. This means it takes only 0.33 calorie to raise the temperature of 1 gram of earth 1°C. Stated another way, earth heats and cools three times as fast as water. Therefore, assuming the same amount of energy (calories) is available, water heats (and cools) at a slower rate than land does. The slower rate of heating and cooling of water is the reason temperature extremes occur over land areas while temperatures over water areas are more consistent.

The specific heat of various land surfaces is also different, though the difference between one land surface and another is not as great as between land and water. Dry sand or bare rock has the lowest specific heat. Forest areas have the highest specific heat. This difference in specific heat is another cause for differences in temperature for areas with different types of surfaces even when they are only a few miles apart; this difference is important in understanding the horizontal transport of heat (advection) on a smaller scale.

Advection is a form of convection, but in meteorology it means the transfer of heat or other properties HORIZONTALLY. Convection is the term reserved for the VERTICAL transport of heat. In this manual the words convection and advection are used to mean the vertical and horizontal transfer of atmospheric properties, respectively.

Horizontal transfer of heat is achieved by motion of the air from one latitude and/or longitude to another. It is of major importance in the exchange of air between polar and equatorial regions. Since large masses of air are constantly on the move somewhere on Earth's surface and aloft, advection is responsible for transporting more heat from place to place than any other physical motion. Transfer of heat by advection is achieved not only by the transport of warm air, but also by the transport of water vapor that releases heat when condensation occurs.

REVIEW QUESTIONS

Q1-11. What is the definition of Temperature?

Q1-12. What are 20 C converted to Fahrenheit?

Q1-13. Name the zones of the earth's atmosphere in ascending order.

Q1-14. What are the four methods of heat transfer?

Q1-15. What is the horizontal transport of heat called?

MOISTURE

LEARNING OBJECTIVE: Describe how moisture affects the atmosphere.

ATMOSPHERIC MOISTURE

More than two-thirds of Earth's surface is covered with water. Water from this extensive source is continually evaporating into the atmosphere, cooling by various processes, condensing, and then falling to the ground again as various forms of precipitation. The remainder of Earth's surface is composed of solid land of various and vastly different terrain features. Knowledge of terrain differences is very important in analyzing and forecasting weather. The world's terrain varies from large-scale mountain ranges and deserts to minor rolling hills and valleys. Each type of terrain significantly influences local wind flow, moisture availability, and the resulting weather.

Moisture in the atmosphere is found in three states—solid, liquid, and gaseous. As a solid, it takes the form of snow, hail, and ice pellets, frost, ice-crystal clouds, and ice-crystal fog. As a liquid, it is found as rain, drizzle, dew, and as the minute water droplets composing clouds of the middle and low stages as well as fog. In the gaseous state, water forms as invisible vapor. Vapor is the most important single element in the production of clouds and other visible weather phenomena. The availability of water vapor for the production of precipitation largely determines the ability of a region to support life.

The oceans are the primary source of moisture for the atmosphere, but lakes, rivers, swamps, moist soil, snow, ice fields, and vegetation also furnish it. Moisture is introduced into the atmosphere in its gaseous state, and may then be carried great distances by the wind before it is discharged as liquid or solid precipitation.

WATER VAPOR CHARACTERISTICS

There is a limit to the amount of water vapor that air, at a given temperature, can hold. When this limit is reached, the air is said to be saturated. The higher the air temperature, the more water vapor the air can hold before saturation is reached and condensation occurs. (See fig. 1-10.) For approximately every 20°F (11°C) increase in temperature between 0°F and 100°F (-18°C and 38°C), the capacity of a volume of air to hold water vapor is about doubled. Unsaturated air, containing a given amount of water vapor, becomes saturated if its temperature decreases sufficiently; further cooling forces some of the water vapor to condense as fog, clouds, or precipitation.

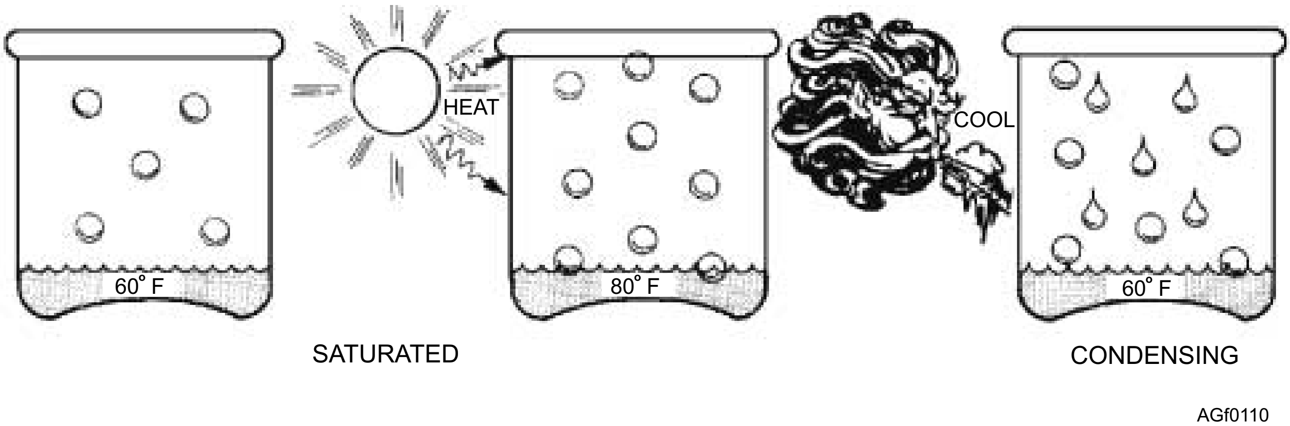


Figure 1-10.—Saturation of air depends on its temperature.

The quantity of water vapor needed to produce saturation does not depend on the pressure of other atmospheric gases. At a given temperature, the same amount of water vapor saturates a given volume of air. This is true whether it be on the ground at a pressure of 1000 mb or at an altitude of 17,000 ft (5,100 meters) with only 500 mb pressure, if the temperature is the same. Since density decreases with altitude, a given volume of air contains less mass (grams) at 5,100 meters than at the surface. In a saturated volume, there would be more water vapor per gram of air at this altitude than at the surface.

Temperature

Although the quantity of water vapor in a saturated volume of atmosphere is independent of the air pressure, it does depend on the temperature. The higher the temperature, the greater the tendency for liquid water to turn into vapor. At a higher temperature, therefore, more vapor must be injected into a given volume before the saturated state is reached and dew or fog forms. On the other hand, cooling a saturated volume of air forces some of the vapor to condense and the quantity of vapor in the volume to diminish.

Condensation

Condensation occurs if moisture is added to the air after it is saturated, or if cooling of the air reduces the temperature below the saturation point. As shown in figure 1-11, the most frequent cause of condensation is cooling of the air from the following results: (a) air moves over a colder surface, (b) air is lifted (cooled by expansion), or (c) air near the ground is cooled at night as a result of radiation cooling.

Pressure (Dalton's Law)

The English physicist, John Dalton, formulated the laws relative to the pressure of a mixture of gases. One of the laws states that the partial pressures of two or more mixed gases (or vapors) are the same as if each filled the space alone. The other law states that the total pressure is the sum of all the partial pressures of gases and vapors present in an enclosure.

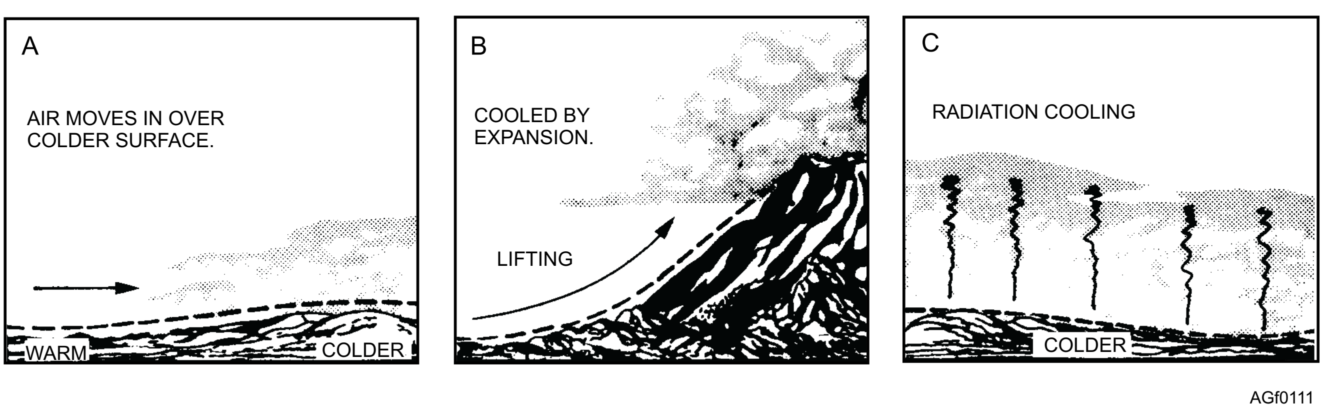


Figure 1-11.—Causes of condensation.

For instance, water vapor in the atmosphere is independent of the presence of other gases. The vapor pressure is independent of the pressure of the dry gases in the atmosphere and vice versa. However, the total atmospheric pressure is found by adding all the pressures—those of the dry air and the water vapor.

TERMS

The actual amount of water vapor contained in the air is usually less than the saturation amount. The amount of water vapor in the air is expressed in several different methods. Some of these principal methods are described in the following portion of this section.

Relative Humidity

Although the major portion of the atmosphere is not saturated, for weather analysis it is desirable to be able to say how near it is to being saturated. This relationship is expressed as relative humidity. The relative humidity of a volume of air is the ratio (in percent) between the water vapor actually present and the water vapor necessary for saturation at a given temperature. When the air contains all of the water vapor possible for it to hold at its temperature, the relative humidity is 100 percent (See fig. 1-12). A relative humidity of 50 percent indicates that the air contains half of the water vapor that it is capable of holding at its temperature.

Relative humidity is also defined as the ratio (expressed in percent) of the observed vapor pressure to that required for saturation at the same temperature and pressure.

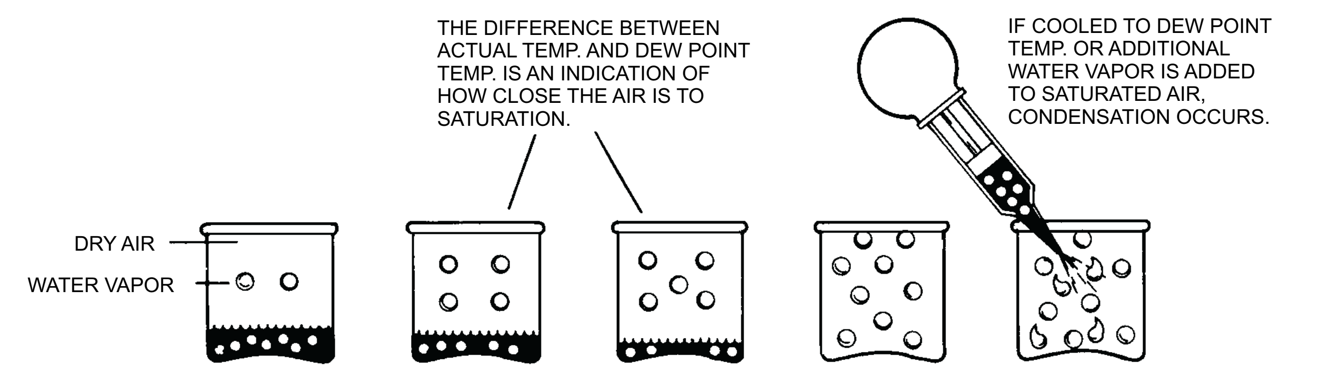
Relative humidity shows the degree of saturation, but it gives no clue to the actual amount of water vapor in the air. Thus, other expressions of humidity are useful.

Absolute Humidity

The mass of water vapor present per unit volume of space, usually expressed in grams per cubic meter, is known as absolute humidity. It may be thought of as the density of the water vapor.

Specific Humidity

Humidity may be expressed as the mass of water vapor contained in a unit mass of air (dry air plus the water vapor). It can also be expressed as the ratio of the density of the water vapor to the density of the air (mixture of dry air and water vapor). This is called the specific humidity and is expressed in grams per gram or in grams per kilogram. This value depends upon the measurement of mass, and mass does not change with temperature and pressure. The specific humidity of a parcel of air remains constant unless water vapor is added to or taken from the parcel. For this reason, air that is unsaturated may move from place to place or from level to level, and its specific humidity remains the same as long as no water vapor is added or removed. However, if the air is saturated and cooled, some of the water vapor must condense; consequently, the specific humidity (which reflects only the water vapor) decreases. If saturated air is heated; its specific humidity remains unchanged unless water vapor is added to it. In this case the specific humidity increases. The maximum specific humidity that a parcel can have occurs at saturation and depends upon both the temperature and the pressure. Since warm air can hold more water vapor than cold air at constant pressure, the saturation specific humidity at high temperatures is



AIR TEMP °F	40°	60°	80°	80°	80°
DEW POINT °F	40°	60°	60°	80°	80°
RELATIVE HUMIDITY	100%	100%	50%	100%	100%

Figure 1-12.—Relative humidity and dew point.

greater than at low temperatures. Also, since moist air is less dense than dry air at constant temperature, a parcel of air has a greater specific humidity at saturation if the pressure is low than when the pressure is high.

Mixing Ratio

The mixing ratio is defined as the ratio of the mass of water vapor to the mass of dry air and is expressed in grams per gram or in grams per kilogram. It differs from specific humidity only in that it is related to the mass of dry air instead of to the total dry air plus water vapor. It is very nearly equal numerically to specific humidity, but it is always slightly greater. The mixing ratio has the same characteristic properties as the specific humidity. It is conservative (values do not change) for atmospheric processes involving a change in temperature. It is non conservative for changes involving a gain or loss of water vapor.

Previously it was learned that air at any given temperature can hold only a certain amount of water vapor before it is saturated. The total amount of vapor that air can hold at any given temperature, by weight relationship, is referred to as the saturation mixing ratio. It is useful to note that the following relationship exists between mixing ratio and relative humidity. Relative humidity is equal to the mixing ratio divided by the saturation mixing ratio, multiplied by 100. If any two of the three components in this relationship are known, the third may be determined by simple mathematics.

Dew Point

The dew point is the temperature that air must be cooled, at constant pressure and constant water vapor content, in order for saturation to occur. The dew point is a conservative and very useful element. When atmospheric pressure stays constant, the dew point reflects increases and decreases in moisture in the air. It also shows at a glance, under the same conditions, how much cooling of the air is required to condense moisture from the air.

REVIEW QUESTIONS

Q1-16. Name the three states in which moisture in the atmosphere may be found.

Q1-17. What is the primary source of atmospheric moisture?

Q1-18. What is the difference between relative humidity and absolute humidity?

Q1-19. What is the definition of mixing ratio?

Q1-20. What information does the dew point temperature provide to meteorologists?

SUMMARY

In this chapter, we introduced the basic fundamentals of meteorology. It is important to have a basic knowledge of systems of measurement, how the earth and sun relate to each other, and how pressure, temperature and moisture are measured and calculated. An understanding of the basic fundamentals is necessary before proceeding on to the next chapter.

CHAPTER 2

ATMOSPHERIC PHYSICS

The science of physics is devoted to finding, defining, and reaching solutions to problems. It is the basic science that deals with motion, force, and energy. Physics, therefore, not only breeds curiosity of one's environment, but it provides a means of acquiring answers to questions that continue to arise. Atmospheric physics is a branch of physical meteorology that deals with a combination of dynamic and thermodynamic processes that account for the existence of numerous atmospheric conditions.

To understand the weather elements and to analyze meteorological situations you must know how to apply the fundamental principles of physics. This does not mean that you must be able to understand all of the complicated theories of meteorology. It does mean, however, that you should have a working knowledge of elementary physics. You should learn how to apply the rules of physics to understand how the atmosphere works. This is necessary to perform your duties as an Aerographer's Mate in a creditable manner.

MOTION

LEARNING OBJECTIVE: Describe the laws of motion and determine how motion is affected by external forces.

Any general discussion of the principles of physics must contain some consideration of the way in which mass, force, and motion are related. In physics, the laws of motion state that an object at rest never starts to move by itself; a push or a pull must be exerted on it by some other object. This also applies to weather. Weather has complex motions in the vertical and horizontal planes. To fully understand how and why weather moves, you must have a basic knowledge of motion and those external forces that affect motion.

TERMS

In dealing with motion several terms should be defined before you venture into the study of motion. These terms are inertia, speed, direction, velocity, and acceleration.

Inertia

An object at rest never moves unless something or someone moves it. This is a property of all forms of matter (solid, liquid, or gas). Inertia, therefore, is the property of matter to resist any change in its state of rest or motion.

Speed

Speed is the *rate* at which something moves in a given amount of time. In meteorology, speed is the term that is used when only the rate of movement is meant. If the rate of movement of a hurricane is 15 knots, we say its speed is 15 knots per hour.

Direction

Direction is the line along which something moves or lies. In meteorology, we speak of direction as *toward* or the direction *from* which an object is moving. For example, northerly winds are winds COMING FROM the north.

Velocity

Velocity describes both the *rate* at which a body moves and the *direction* in which it is traveling. If the hurricane, with its speed of 15 knots per hour, is described as moving westward, it now has velocity—both a rate and direction of movement.

Acceleration

This term applies to a rate of change of the speed and/or the velocity of matter with time. If a hurricane, which is presently moving at 15 knots, is moving at 18 knots 1 hour from now and 21 knots 2 hours from now, it is said to be accelerating at a rate of 3 knots per hour.

LAWS OF MOTION

Everything around us is in motion. Even a body supposedly at rest on the surface of Earth is in motion because the body is actually moving with the rotation of Earth; Earth, in turn, is turning in its orbit around the Sun. Therefore, the terms *rest* and *motion* are relative terms. The change in position of any portion of matter is motion. The atmosphere is a gas and is subject to much motion. Temperature, pressure, and density act to produce the motions of the atmosphere. These motions are subject to well-defined physical laws. An explanation of Newton's laws of motion can help you to understand some of the reasons why the atmosphere moves as it does.

Newton's First Law

Sir Isaac Newton, a foremost English physicist, formulated three important laws relative to motion. His first law, the law of inertia, states, every body continues in its state of rest or uniform motion in a straight line unless it is compelled to change by applied forces." Although the atmosphere is a mixture of gases and has physical properties peculiar to gases, it still behaves in many respects as a body when considered in the terms of Newton's law. There would be no movement of great quantities of air unless there were forces to cause that movement. For instance, air moves from one area to another because there is a force (or forces) great enough to change its direction or to overcome its tendency to remain at rest.

Newton's Second Law

Newton's second law of motion, force, and acceleration states, "the change of motion of a body is proportional to the applied force and takes place in the direction of the straight line in which that force is applied." In respect to the atmosphere, this means that a change of motion in the atmosphere is determined by the force acting upon it, and that change takes place in the direction of that applied force.

From Newton's second law of motion the following conclusions can be determined:

1. If different forces are acting upon the same mass, different *accelerations* are produced that are proportional to the forces.

2. For different masses to acquire equal *acceleration* by different forces, the forces must be proportional to the masses.

3. Equal forces acting upon different masses produce different *accelerations* that are proportional to the masses.

Newton's Third Law

Newton's third law of motion states, "to every action there is always opposed an equal reaction; or, the mutual actions of two bodies upon each other are always equal, and directed to contrary parts." In other words forces acting on a body originate in other bodies that make up its environment. Any single force is only one aspect of a mutual interaction between two bodies.

WORK

Work is done when a force succeeds in overcoming a body's inertia and moving the body in the direction the force is applied. The formula is

$$W = F \times d$$

where W is work, F is force and d is the distance moved. The amount of work done is the product of the magnitude of the force and the distance moved.

Work is measured in the English system by the foot-pound; that is, if 1 pound of force acts through a distance of 1 foot, it performs 1 foot-pound of work. In the metric CGS system, force is measured in dynes, distance is measured in centimeters, and work is denoted in ergs. An erg is the work done by a force of one dyne exerted for a distance of one centimeter. Another unit used to measure work is the joule. It is simply 10,000,000 ergs, and is equivalent to just under three-fourths of a foot-pound.

ENERGY

Energy is defined as the ability to do work. Energy is conservative, meaning it may be neither created nor destroyed. It is defined in two forms—potential energy and kinetic energy. As its name implies, potential energy is the amount of energy that MAY BE AVAILABLE to a body due to its position. It is primarily due to the force of gravity. The higher a body is raised above the surface, the greater its POTENTIAL energy. Kinetic energy is the energy available to a body due to its motion through a field. The total amount of energy a body possesses is the sum of its potential and kinetic energies. The total amount of energy available to a body determines how much work it can accomplish.

FORCE

There are two types of forces the AG deals with—contact force and action at a distance force. Contact force is the force that occurs when pressure is put on an object directly through physical contact. An example of contact force is the force your hand exerts when you push your coffee cup across a table. Contact force may act in several different directions at once as well. For example, the force exerted by water in a can is equally exerted on the sides and the bottom of the can. In addition, an upward force is transmitted to an object on the surface of the water. Forces that act through empty space without contact are known as action at a distance force. An example of this force is gravity.

Vectors

Problems often arise that make it necessary to deal with one or more forces acting on a body. To solve problems involving forces, a means of representing forces must be found. True wind speed at sea involves two different forces and is obtained through the use of the true wind computer. Ground speed and course of aircraft are computed by adding the vector representing aircraft heading and true air speed to the vector representing the wind direction and speed. In computation of the effective fallout wind and other radiological fallout problems, the addition of forces is used. From these examples, it is evident that the addition and subtraction of forces has many applications in meteorology.

A force is completely described when its magnitude, direction, and point of application are given. A vector is a line that represents both magnitude and direction; therefore, it may be used to describe a force. The length of the line represents the magnitude of the force. The direction of the line represents the direction in which the force is being applied. The starting point of the line represents the point of application of the force. (See fig. 2-1.) To represent a force of 10 pounds or 10 knots of wind acting toward due east on point A, draw a line 10 units long, starting at point A and extending in a direction of 090°.

Composition of Forces

If two or more forces are acting simultaneously at a point, the same effect can be produced by a single force of the proper size and direction. This single force, which is equivalent to the action of two or more forces, is called the resultant. Putting component forces together to find the resultant force is called composition of forces. (See fig. 2-2.) The vectors representing the forces must be added to find the resultant. Because a vector represents both magnitude and direction, the method for adding vectors differs from the procedure used for scalar quantities (quantities having only magnitude and no direction). To find the resultant force when a force of 5 pounds and a force of 10 pounds are applied at a right angle to point A, refer to figure 2-2.

The resultant force may be found as follows: Represent the given forces by vectors AB and AC drawn to a suitable scale. At points B and C draw dashed lines perpendicular to AB and AC, respectively. From point A, draw a line to the point of intersection X, of the dashed lines. Vector AX represents the resultant of the two forces. Thus, when two mutually perpendicular forces act on a point, the vector representing the resultant force is the diagonal of a rectangle. The length of AX, if measured on the same scale as that for the two original forces, is the resultant force; in this case approximately 11.2 pounds. The angle gives the direction of the resultant force with respect to the horizontal.

Mathematically, the resultant force of perpendicular forces can be found by using the Pythagorean theorem which deals with the solution of right triangles. The formula is $C^2 = a^2 + b^2$. This states that the hypotenuse, side "C" (our unknown resultant force) squared is equal to the sum of side "a" (one of our known forces) squared and side "b" (another of our known forces) squared.

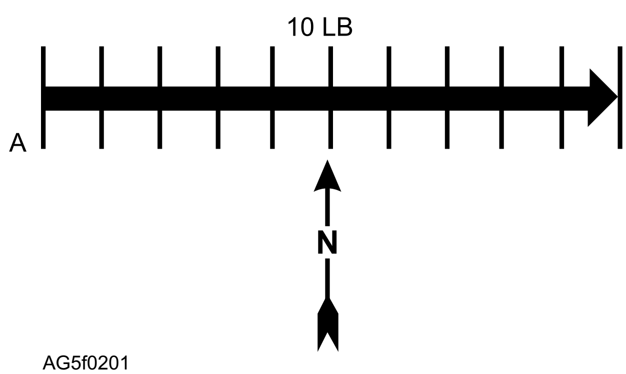


Figure 2-1.—Example of a vector.

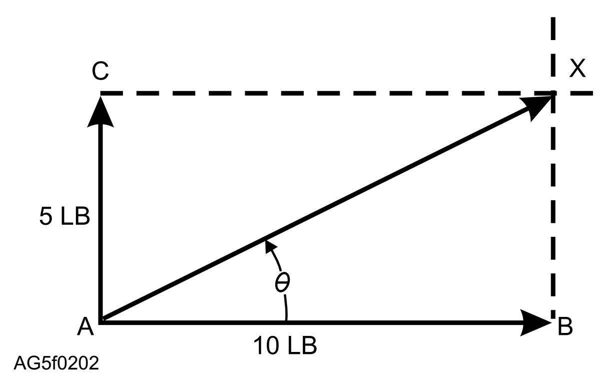


Figure 2-2.—Composition of two right angle forces.

If we substitute the known information in figure 2-2 we have the following:

C^2 = Unknown resultant force

a^2 = 5 lb or the known force on one side of our right triangle, side BX (same as side AC)

b^2 = 10 lb or the known force on the other side of our right triangle, side AB

Setting up the equation we have:

$$C^2 = a^2 +$$

$$C^2 = 5^2 + 10^2$$

$$C^2 = 25 + 100$$

$$C^2 = 125$$

$$C = \sqrt{125}$$

$$C = 11.18034$$

To find the resultant of two forces that are not at right angles, the following graphic method may be used. (See fig. 2-3).

Let AB and AC represent the two forces drawn accurately to scale. From point C draw a line parallel to AB and from point B draw a line parallel to AC. The lines intersect at point X. The force AX is the resultant of the two forces AC and AB. Note that the two dashed lines and the two given forces make a parallelogram ACXB. Arriving at the resultant in this manner is called the parallelogram method. The resultant force and direction of the resultant is found by measuring the length of line AX and determining the direction of line AX from the figure drawn to scale. This method applies to any two forces acting on a point whether they act at right angles or not. Note that the parallelogram becomes a rectangle for forces acting at right angles. With a slight modification, the parallelogram method of addition applies also to the reverse operation of subtraction. Consider the problem of subtracting force AC from AB. (See fig. 2-4.)

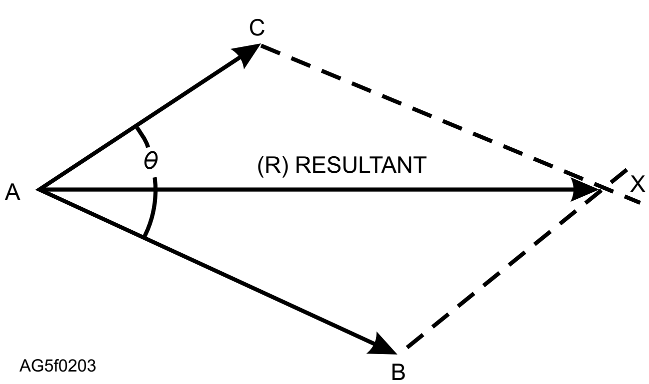


Figure 2-3.—Graphic method of the composition of forces.

First, force AC is reversed in direction giving -AC (dashed line). Then, forces -AC and AB are added by the parallelogram method, giving the resulting AX, which in this case is the difference between forces AB and AC. A simple check to verify the results consists of adding AX to AC; the sum or resultant should be identical with AB.

Application of Vectors and Resultant Forces

The methods presented for computing vectors and resultant forces are the simplest and quickest methods for the Aerographer's Mate. The primary purposes of using vectors and resultant forces are for computing radiological fallout patterns and drift calculations for search and rescue operations.

REVIEW QUESTIONS

Q2-1. What is the definition of speed?

Q2-2. What is the correct formula for work?

Q2-3. What are the two types forces that AGs deal with?

MATTER

LEARNING OBJECTIVE: Recognize how pressure, temperature, and density affect the atmosphere. Describe how the gas laws are applied in meteorology.

Matter is around us in some form everywhere in our daily lives—the food we eat, the water we drink, and the air we breathe. The weather around us, such as hail, rain, invisible water vapor (humidity), etc., are all

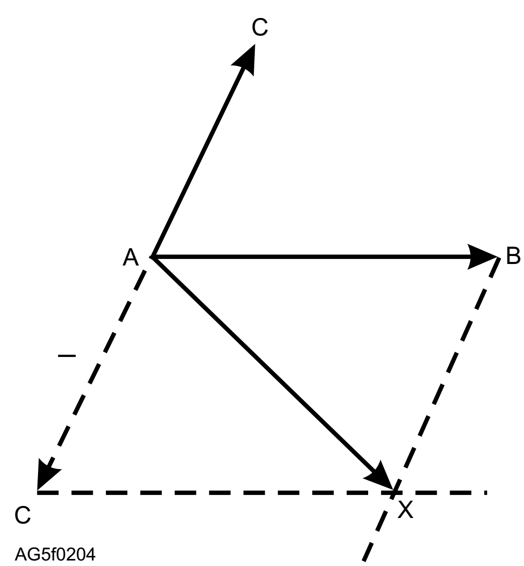


Figure 2-4.—Parallelogram method of subtracting forces.

matter. Matter is present in three forms—solids, liquids, and gases. A good working knowledge of the physical properties of matter and how matter can change from one form to another can help you understand what is happening in our atmosphere that produces the various meteorological occurrences we live with every day.

DEFINITIONS

Matter is anything that occupies space and has weight. Two basic particles make up the composition of all matter—the *atom* and the *molecule*. The molecule is the smallest particle into which matter can be divided without destroying its characteristic properties. In physics, the molecule is the unit of matter. Molecules are composed of one or more atoms. The atom is the smallest particle of an *element* of matter that can exist either alone or in combination with others of the same or of another element. The atom and atomic structure is constantly under study and has revealed a whole new array of subatomic particles. To date, a new definition for atom has not been developed.

A *compound* is a substance (or matter) formed by combining two or more elements. Thus, ordinary table salt is a compound formed by combining two elements—sodium and chlorine. Elements and compounds may exist together without forming new compounds. Their atoms do not combine. This is known as a *mixture*. Air is a familiar mixture. Every sample of air contains several kinds of molecules which are chiefly molecules of the elements oxygen, nitrogen, and argon, together with the compounds of water vapor and carbon dioxide. Ocean water, too, is another mixture, made up chiefly of water and salt molecules, with a smaller number of molecules of many other compounds as well as molecules of several elements.

STATES OF MATTER

Matter is found in all of the following three states:

1. Solid. Solids are substances that have a definite volume and shape and retain their original shape and volume after being moved from one container to another, such as a block of wood or a stone.

2. Liquid. A liquid has a definite volume, because it is almost impossible to put it into a smaller space. However, when a liquid is moved from one container to another, it retains its original volume, but takes on the shape of the container into which it is moved. For example, if a glass of water is poured into a larger bucket or pail, the volume remains unchanged. The liquid occupies a different space and shape in that it conforms to the walls of the container into which it is poured.

3. Gas. Gases have neither a definite shape nor a definite volume. Gases not only take on the shape of the container into which they are placed but expand and fill it, no matter what the volume of the container.

Since gases and liquids flow easily, they are both called fluids. Moreover, many of the laws of physics that apply to liquids apply equally well to gases.

PHYSICAL PROPERTIES

Since matter is anything that occupies space and has weight, it can be said that all kinds of matter have certain properties in common. These properties are inertia, mass, gravitation, weight, volume, and density. These properties are briefly covered in this section and are referred to as the general properties of matter.

Inertia

Inertia of matter is perhaps the most fundamental of all attributes of matter. It is the tendency of an object to stay at rest if it is in a position of rest, or to continue in motion if it is moving. Inertia is the property that requires energy to start an object moving and to stop that object once it is moving.

Mass

Mass is the quantity of matter contained in a substance. Quantity does not vary unless matter is added to or subtracted from the substance. For example, a sponge can be compressed or allowed to expand back to its original shape and size, but the mass does not change. The mass remains the same on Earth as on the sun or moon, or at the bottom of a valley or the top of a mountain. Only if something is taken away or added to it is the mass changed. Later in the unit its meaning will have a slightly different connotation.

Gravitation

All bodies attract or pull upon other bodies. In other words, all matter has gravitation. One of Newton's laws states that the force of attraction between two bodies is directly proportional to the product of their masses and inversely proportional to the square of the distance between their two centers. Therefore, a mass has less gravitational pull on it at the top of a mountain than it has at sea level because the center is displaced farther away from the gravitational pull of the center of Earth. However, the mass remains the same even though the gravitational pull is different. Gravity also varies with latitude. It is slightly less at the equator than at the poles due to the equator's greater distance from the center of Earth.

Weight

The weight of an object is a measure of its gravitational attraction. The weight depends upon the mass or quantity that it contains and the amount of gravitational attraction Earth has for it. Weight is a force, and as such it should be expressed in units of force. Since gravity varies with latitude and height above sea level, so must weight vary with the same factors. Therefore, a body weighs more at the poles than at the equator and more at sea level than atop a mountain. In a comparison of mass and weight, mass remains constant no matter where it is, but weight varies with latitude and height above sea level.

Volume

Volume is the measure of the amount of space that matter occupies. The volume of rectangular objects is found directly by obtaining the product of their length, width, and depth. For determining the volume of liquids and gases, special graduated containers are used.

Density

The mass of a unit volume of a substance or mass per unit volume is called density. Usually we speak of substances being heavier or lighter than another when comparing equal volumes of the two substances.

Since density is a derived quantity, the density of an object can be computed by *dividing* its mass (or weight) by its volume. The formula for determining the density of a substance is

$$D = \frac{M}{V} = (\text{or } D = M \div V)$$

where D stands for density, M for mass, and V for volume.

From this formula, it is obvious that with mass remaining unchanged, an increase in volume causes a decrease in density. A decrease in volume causes an increase in density.

The density of gases is derived from the same basic formula as the density of a solid. Pressure and temperature also affect the density of gases. This effect is discussed later in this unit under Gas Laws.

CHANGES OF STATE

A change of state (or change of phase) of a substance describes the change of a substance from a solid to a liquid, liquid to a vapor (or gas), vapor to a liquid, liquid to a solid, solid to vapor, or vapor to a solid. In meteorology you are concerned primarily with the change of state of water in the air. Water is present in the atmosphere in any or all of the three states (solid, liquid, and vapor) and changes back and forth from one state to another. The mere presence of water is important, but the change of state of that water in the air is significant because it directly affects the weather. The solid state of water is in the form of ice or ice crystals. The liquid state of water is in the form of raindrops, clouds, and fogs. The vapor state of water is in the form of unseen gases (water vapor) in the air.

Heat Energy

Energy is involved in the various changes of state that occur in the atmosphere. This energy is primarily in the form of heat. Each of the changes of state processes either uses heat from the atmosphere or releases heat into the atmosphere. The heat used by a substance in changing its state is referred to as the latent heat and is usually stated in calories.

The calorie is a unit of heat energy. It is the amount of heat required to raise the temperature of 1 gram of water 1°C. A closer look at some of the major changes of state of the atmosphere helps to clarify latent heat. Refer to figure 2-5 during the following discussions.

Liquid to Solid and Vice Versa

Fusion is the change of state from a solid to a liquid at the same temperature. The number of gram calories of heat necessary to change 1 gram of a substance from the solid to the liquid state is known as the *latent heat* of fusion. To change 1 gram of ice to 1 gram of water at a constant temperature and pressure requires roughly 80 calories of heat. This is called the latent heat of fusion. Fusion uses heat. The source of this heat is the surrounding air.

The opposite of fusion is freezing—a liquid changes into a solid. Since it requires 80 calories to change 1 gram of ice to 1 gram of water, this same amount of heat is released into the air when 1 gram of water is changed to ice.

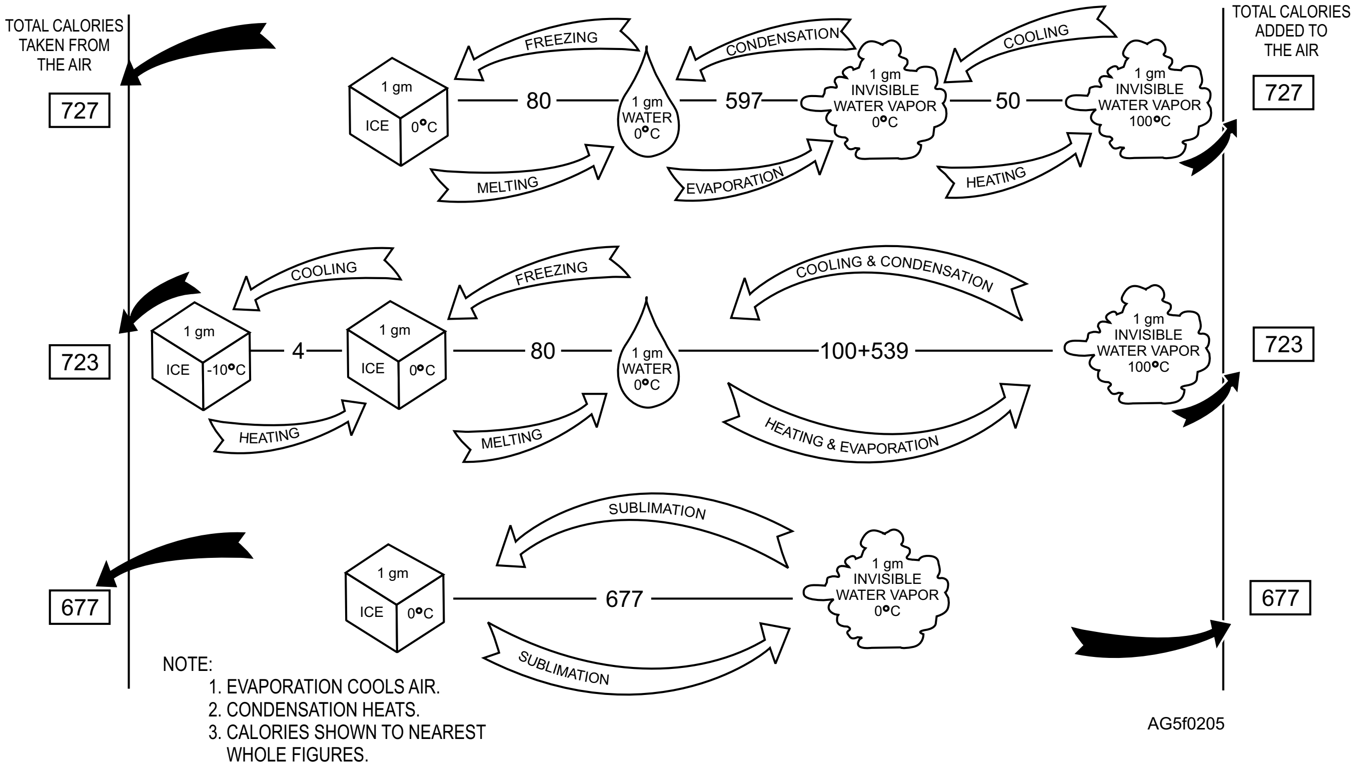


Figure 2-5.—Thermal history of 1 gram of ice during changes of state.

Liquid to Gas and Vice Versa

Water undergoes the process of evaporation when changing from the liquid to a gaseous state. According to the molecular theory of matter, all matter consists of molecules in motion. The molecules in a bottled liquid are restricted in their motion by the walls of the container. However, on a free surface exposed to the atmosphere, the motion of the molecules in the liquid is restricted by the weight of the atmosphere or, more precisely, by the atmospheric pressure. If the speed of the liquid molecules is sufficiently high, they escape from the surface of the liquid into the atmosphere. As the temperature of the liquid is increased, the speed of the molecules is increased, and the rate at which the molecules escape from the surface also increases. Evaporation takes place only from the free or exposed surface of a substance.

During the process of evaporation, heat is released. This heat is absorbed by the water that has vaporized. The amount absorbed is approximately 539 calories per gram of water at a temperature of 100°C. On the other hand, the amount is 597.3 calories, if the evaporation takes place at a water temperature of 0°C. This energy is required to keep the molecules in the vapor state and is called the latent heat of vaporization. Since the water needs to absorb heat in order to vaporize, heat must be supplied or else evaporation cannot take place. The air provides this heat. For this reason, evaporation is said to be a cooling process, because by supplying the heat for vaporization, the temperature of the surrounding air is lowered.

Condensation is the opposite of evaporation because water vapor undergoes a change in state from gas back to liquid. However, a condition of saturation must exist before condensation can occur. That is, the air must contain all the water vapor it can hold (100 percent relative humidity) before any of it can condense from the atmosphere. In the process of condensation, the heat that was absorbed in evaporation by the water vapor is released from the water vapor into the air and is called the latent heat of condensation. As you might expect, condensation warms the surrounding air.

Solid to Gas and Vice Versa

Sublimation is the change of state from a solid directly to a vapor or vice versa at the same temperature. In physics and chemistry, sublimation is regarded as the change of state from solid to vapor only, but meteorologists do not make this distinction. The heat of sublimation equals the heat of fusion plus the heat of vaporization for a substance. The calories required for water to sublime are: 80 + 597.3 = 677.3, if the vapor has a temperature of 0°C.

In the sublimation process of vapor passing directly into the solid form without going through the liquid phase, the calories released are the same as those for the sublimation of a solid to a gas. Sublimation of water vapor to ice frequently takes place in the atmosphere when supercooled water vapor crystallizes directly into ice crystals and forms cirriform clouds.

REVIEW QUESTIONS

Q2-4. What are the two basic particles that make up the composition of matter?

Q2-5. What is the correct formula for density?

Q2-6. What is fusion?

GAS LAWS

LEARNING OBJECTIVE: Recognize how pressure, temperature, and density affect the atmosphere and describe how the gas laws are applied in meteorology.

Since the atmosphere is a mixture of gases, its behavior is governed by well-defined laws. Understanding the gas laws enables you to see that the behavior of any gas depends upon the variations in temperature, pressure, and density.

To assist in comparing different gases and in measuring changes of gases it is necessary to have a standard or constant to measure these changes against. The standard used for gases are: a pressure of 760 millimeters of mercury (1,013.25 mb) and a temperature of 0°C. These figures are sometimes referred to as Standard Temperature and Pressure (STP).

KINETIC THEORY OF GASES

The Kinetic theory of gases refers to the motions of gases. Gases consist of molecules that have no inherent tendency to stay in one place as do the molecules of a solid. Instead, the molecules of gas, since they are smaller than the space between them, are free to move about. The motion is in straight lines until the lines collide with each other or with other obstructions, making their overall motion random. When a gas is enclosed, its pressure depends on the number of times the molecules strike the surrounding walls. The number of blows that the molecules strike per second against the walls remains constant as long as the temperature and the volume remain constant.

If the volume (the space occupied by the gas) is decreased, the number of blows against the wall is increased, thereby increasing the pressure if the temperature remains constant. Temperature is a measure of the molecular activity of the gas molecules and a measure of the internal energy of a gas. When the temperature is increased, there is a corresponding increase in the speed of the molecules; they strike the walls at a faster rate, thereby increasing the pressure provided the volume remains constant. Therefore, there is a close relationship of volume, pressure, and density of gases.

BOYLE'S LAW

Boyle's law states that the volume of a gas is inversely proportional to its pressure, provided the temperature remains constant. This means that if the volume is halved, the pressure is doubled. An example of Boyle's law is a tire pump. As the volume of the pump's cylinder is decreased by pushing the handle down, the pressure at the nozzle is increased. Another way of putting it is, as you increase the pressure in the cylinder by pushing down the handle, you also decrease the volume of the cylinder.

The formula for Boyle's law is as follows:

$VP = V'P'$
V = initial volume
P = initial pressure
V' = new volume
P' = new pressure

For example, assume 20 cm^3 of gas has a pressure of 1,000 mb. If the pressure is increased to 1,015 mb and the temperature remains constant, what will be the new volume? Applying the formula, we have

$V = 20\ cm^3$
$P = 1000$ mb
V' = Unknown in cm^3
$P' = 1015$ mb
$V \bullet P = V' \bullet P'$
$20 \bullet 1{,}000 = V' \bullet 1{,}015$
$20{,}000 = V' \bullet 1{,}015$
$$V' = \frac{20{,}000}{1{,}015}$$
$V' = 19.71\ cm^3$

Boyle's law does not consider changes in temperature. Since our atmosphere is constantly changing temperature at one point or another, temperature must be considered in any practical application and understanding of gas laws.

CHARLES' LAW

In the section on the kinetic theory of gases, it was explained that the temperature of a gas is a measure of the average speed of the molecules of the gas. It was also shown that the pressure the gas exerts is a measure of the number of times per second that the molecules strike the walls of the container and the speed at which they strike it. Therefore, if the temperature of a gas in a closed container is raised, the speed of the molecules within the gas increases. This causes the molecules to strike the sides of the container more often per second and with more force because they are moving faster. Thus, by increasing the temperature, the pressure is increased.

Charles' law states if the volume of an enclosed gas remains constant, the pressure is directly proportional to the absolute temperature. Therefore, if the absolute temperature is doubled, the pressure is doubled; if the absolute temperature is halved, the pressure is halved. Experiments show that the volume increases by 1/273 for a 1°C rise in temperature. (Remember, 0°C is equal to 273°K.) An example of Charles' law is a bottle of soda or beer. When the soda or beer is cold, very little pressure is released when the bottle is opened. When a warm soda or beer is opened, it often results in enough pressure buildup in the bottle to squirt soda or beer out of the top. Sometimes, warm soda or beer explodes spontaneously when exposed to too much direct heat such as sunlight.

The formulas for Charles' law are as follows:

VT' = V'T, where pressure is assumed to be constant, and
PT' = P'T, where volume is constant

V = initial volume
T = initial temperature (absolute)
V' = new volume
T' = new temperature (absolute)

For example, assume that 10 cm^3 of a gas has a temperature of 200° absolute. If the temperature is increased to 300° absolute, what will be the new volume? Applying the formula, we have

V = 10 cm^3
T = 200°K
V' = Unknown in cm^3
T' = 300°K
$10 \bullet 300 = V' \bullet 200$
$3000 = V' \bullet 200$
$$V' = \frac{3000}{200}$$
V' = 15 cm^3

The same type relationship can be computed by applying T' (new temperature) and P' (new pressure) using the formula PT' = P'T where the volume is assumed to remain constant.

UNIVERSAL GAS LAW

The universal gas law is a combination of Boyle's law and Charles' law. It states that the product of the initial pressure, initial volume, and new temperature (absolute scale) of an enclosed gas is equal to the product of the new pressure, new volume, and initial temperature. The formula is as follows:

PVT' = P'V'T

P = initial pressure
V = initial volume
T = initial temperature (absolute)
P' = new pressure
V = new volume (absolute)
T = new temperature (absolute)

For example, assume the pressure of a 500 cm^3 volume of gas is 600 mb and the temperature is 30°C (303 absolute). If the temperature is increased to 45°C (318° absolute) and the volume is decreased to 250 cm^3, what will be the new pressure of the volume? Applying the formula, we have

P = 600 mb
V = 500 cm^3
T = 303°K
P' = Unknown pressure in mb
V' = 250 cm^3
T' = 318°K
$600 \bullet 500 \bullet 318 = P' \bullet 250 \bullet 303$
95,400,000 = P'75,750
$$P' = \frac{95{,}400{,}000}{75{,}750}$$
P' = 1,259.4 mb

EQUATION OF STATE

The equation of state is a general gas law for finding pressure, temperature, or density of a dry gas. Rather than using volume, this formula uses what is called gas constant. A gas constant is a molecular weight assigned to various gases. Actually, air does not have a molecular weight because it is a mixture of gases and there is no such thing as an air molecule. However, it is possible to assign a so-called molecular weight to dry air that makes the equation of state work. The gas constant for air is 2,870 and for water vapor it is 1,800 when the pressure is expressed in millibars and the density is expressed in metric tons per cubic meter. The gas constant may be expressed differently depending on the system of units used.

The following formula is an expression of the equation of state:

$$P = \rho RT$$

P = pressure in millibars
ρ = density (Greek letter rho)
R = specific gas constant
T = temperature (absolute)

The key to this formula is the equal sign that separates the two sides of the formula. This equal sign means that the same value exists on both sides; both sides of the equation are equal. If the left side of the equation (pressure) changes, a corresponding change must occur on the right side (either in the density or temperature) to make the equation equal again. Therefore, an increase of the total value on one side of the Equation of State must be accompanied by an increase of the total value on the other side. The same is true of any decrease on either side.

NOTE: Since R is a constant it will always remain unchanged in any computation.

The right side of the equation can balance out any change in either density or temperature without having a change on the left side (pressure). If, for example, an increase in temperature is made on the right side, the equation may be kept in balance by decreasing density. This works for any value in the equation of state.

From this relationship, we can draw the following conclusions:

1. A change in pressure, density (mass or volume), or temperature requires a change in one or both of the others.

2. With the temperature remaining constant, an increase in density results in an increase in atmospheric pressure. Conversely, a decrease in density results in a decrease in pressure.

NOTE: Such a change could occur as a result of a change in the water vapor content.

3. With an increase in temperature, the pressure and/or density must change. In the free atmosphere, a temperature increase frequently results in expansion of the air to such an extent that the decrease in density outweighs the temperature increase, and the pressure actually decreases. Likewise, a temperature increase allows an increase in moisture, which in turn decreases density (mass of moist air is less than that of dry air). Couple this with expansion resulting from the temperature increase and almost invariably, the final result is a decrease in pressure.

At first glance, it may appear that pressure increases with an increase in temperature. Earlier, however, it was noted that this occurs when volume (the gas constant) remains constant. This condition would be unlikely to occur in the free atmosphere because temperature increases are associated with density decreases, or vice versa. The entire concept of the equation of state is based upon changes in density rather than changes in temperature.

HYDROSTATIC EQUATION

The hydrostatic equation incorporates pressure, temperature, density, and altitude. These are the factors that meteorologists must also deal with in any practical application of gas laws. The hydrostatic equation, therefore, has many applications in dealing with atmospheric pressure and density in both the horizontal and vertical planes. The hydrostatic equation itself will be used in future units and lessons to explain pressure gradients and vertical structure of pressure centers. Since the equation deals with pressure, temperature, and density, it is briefly discussed here.

The hypsometric formula is based on the hydrostatic equation and is used for either determining the thickness between two pressure levels or reducing the pressure observed at a given level to that at some other level. The hypsometric formula states that the difference in pressure between two points in the atmosphere, one above the other, is equal to the weight of the air column between the two points. There are two variables that must be considered when applying this formula to the atmosphere. They are temperature and density.

From Charles' law we learned that when the temperature increases, the volume increases and the density decreases. Therefore, the thickness of a layer of air is greater when the temperature increases. To find the height of a pressure surface in the atmosphere (such as in working up an adiabatic chart), these two variables (temperature and density) must be taken into consideration. By working upward through the atmosphere, the height of that pressure surface can be computed by adding thicknesses together. A good tool for determining height and thickness of layers is the Skew-T Log P diagram, located in AWS/TR-79/006.

Since there are occasions when Skew-Ts are not available, a simplified version of the hypsometric formula is presented here. This formula for computing the thickness of a layer is accurate within 2 percent; therefore, it is suitable for all calculations that the Aerographer's Mate would make on a daily basis.

The thickness of a layer can be determined by the following formula:

$$Z = (49{,}080 + 107t) \bullet \frac{Po - P}{Po + P}$$

Z = altitude difference in feet (unknown thickness of layer)

49,080 = A constant (representing gravitation and height of the D-mb level above the surface)

107 = A constant (representing density and mean virtual temperature)

t = mean temperature in degrees Fahrenheit

Po = pressure at the bottom point of the layer

P = pressure at the top point of the layer

For example, let us assume that a layer of air between 800 and 700 millibars has a mean temperature of 30°F. Applying the formula, we have

$$Z = (49{,}080 + 107 \times 30) \bullet \frac{800 - 700}{800 + 700}$$

$$Z = (49{,}080 + 3{,}210) \bullet \frac{100}{1{,}500}$$

$$Z = (52{,}290) \bullet \frac{1}{15}$$

Z = 3,486 feet (1,063 meters)
(1 meter = 3.28 feet)

REVIEW QUESTIONS

Q2-7. What three things does the behavior of gases depend on?

Q2-8. According to Boyle's Law, how is volume and pressure related?

Q2-9. According to Charles' Law, how is temperature and pressure related?

Q2-10. What is the formula for the Universal Gas Law?

ATMOSPHERIC ENERGY

LEARNING OBJECTIVE: Describe the adiabatic process and determine how stability and instability affect the atmosphere.

There are two basic kinds of atmospheric energy important to AGs—kinetic and potential. Kinetic energy is energy that performs work due *to present* motion while potential energy is energy that is *stored* for later action. Kinetic energy is discussed first in relation to its effect on the behavior of gases.

According to the kinetic theory of gases, the temperature of a gas is dependent upon the rate at which the molecules are moving about and is proportional to the kinetic energy of the moving molecules. The kinetic energy of the moving molecules of a gas is the internal energy of the gas; it follows that an increase in temperature is accompanied by an increase in the internal energy of the gas. Likewise, an increase in the internal energy results in an increase in the temperature of the gas. This relationship, between heat and energy, is called thermodynamics.

An increase in the temperature of a gas or in its internal energy can be produced by the addition of heat or by performing work on the gas. A combination of these can also produce an increase in temperature or internal energy. This is in accordance with the first law of thermodynamics.

FIRST LAW OF THERMODYNAMICS

This law states that the quantity of energy supplied to any system in the form of heat is equal to work done by the system plus the change in internal energy of the system. In the application of the first law of thermodynamics to a gas, it may be said that the two main forms of energy are internal energy and work energy. Internal energy is manifested as sensible heat or simply temperature. Work energy is manifested as pressure changes in the gas. In other words, work is required to increase the pressure of a gas and work is done by the gas when the pressure diminishes. It follows that if internal energy (heat) is added to a simple gas, this energy must show up as an increase in either temperature or pressure, or both. Also, if work is performed on the gas, the work energy must show up as an increase in either pressure or temperature, or both.

An example of the thermodynamic process is a manual tire pump. The pump is a cylinder enclosed by a piston. In accordance with the first law of thermodynamics, any increase in the pressure exerted by the piston as you push down on the handle results in work being done on the air. As a consequence, either the temperature and pressure must be increased or the heat equivalent of this work must be transmitted to the surrounding bodies. In the case of a tire pump, the work done by the force on the piston is changed into an increase in the temperature and the pressure in the air. It also results in some increase in the temperature of the surrounding body by conduction.

If the surrounding body is considered to be insulated so it is not heated, there is no heat transferred. Therefore, the air must utilize this additional energy as an increase in temperature and pressure. This occurs in the adiabatic process.

THE ADIABATIC PROCESS

The adiabatic process is the process by which a gas, such as air, is heated or cooled, without heat being added to or taken away from the gas, but rather by expansion and compression. In the atmosphere, adiabatic and nonadiabatic processes are taking place continuously. The air near the ground is receiving heat from or giving heat to the ground. These are nonadiabatic processes. However, in the free atmosphere somewhat removed from Earth's surface, the short-period processes are adiabatic. When a parcel of air is lifted in the free atmosphere, pressure decreases. To equalize this pressure, the parcel must expand. In expanding, it is doing work. In doing work, it uses heat. This results in a lowering of temperature as well as a decrease in the pressure and density. When a parcel of air descends in the free atmosphere, pressure increases. To equalize the pressure, the parcel must contract. In doing this, work is done on the parcel. This work energy, which is being added to the parcel, shows up as an increase in temperature. The pressure and density increase in this case also.

Terms

In discussing the adiabatic process several terms are used that you should understand.

LAPSE RATE.—In general, lapse rate is the rate of decrease in the value of any meteorological element with elevation. However, it is usually restricted to the rate of decrease of temperature with elevation; thus, the lapse rate of the temperature is synonymous with the vertical temperature gradient. The temperature lapse rate is usually positive, which means that the temperature decreases with elevation.

INVERSION.—Inversions describe the atmospheric conditions when the temperature increases with altitude, rather than decreases as it usually does. Inversions result from the selective absorption of Earth's radiation by the water vapor in the air, and also from the sinking, or subsidence, of air, which results in its compression and, therefore, heating. Either effect alone may cause an inversion; combined, the inversion is stronger.

When air is subsiding (sinking), the compressed air heats. This frequently produces a subsidence inversion. When subsidence occurs above a surface inversion, the surface inversion is intensified. Such occurrences are common in wintertime high-pressure systems. The air in the inversion layer is very stable, and the cold air above the inversion acts as a lid trapping fog, smoke, and haze beneath it. Poor visibility in the lower levels of the atmosphere results, especially near industrial areas. Such conditions frequently persist for days, notably in the Great Basin region of the western United States. An inversion is a frequent occurrence (especially at night) in the Tropics and in the Polar regions. For night conditions all over the world, polar and tropical regions included, it may be said that low- level inversions are the rule rather than the exception.

ISOTHERMAL.—In the isothermal lapse rate, no cooling or warming is noted and the rate is neutral with height—no change in temperature with height.

Adiabatic Heating and Cooling

Air is made up of a mixture of gases that is subject to adiabatic heating when it is compressed and adiabatic cooling when it is expanded. As a result, air rises seeking a level where the pressure of the body of air is equal to the pressure of the air that surrounds it. There are other ways air can be lifted, such as through the thermodynamic processes of a thunderstorm or mechanically, such as having colder, denser air move under it or by lifting as it flows up over a mountain slope.

As the air rises, the pressure decreases which allows the parcel of air to expand. This continues until it reaches an altitude where the pressure and density are equal to its own. As it expands, it cools through a thermodynamic process in which there is no transfer of heat or mass across the boundaries of the system in which it operates (adiabatic process). As air rises, it cools because it expands by moving to an altitude where pressure and density is less. This is called adiabatic cooling. When the process is reversed and air is forced downward, it is compressed, causing it to heat. This is called adiabatic heating, (See fig. 2-6.)

Remember, in an adiabatic process an increase in temperature is due only to COMPRESSION when the air sinks or subsides. A decrease in temperature is due only to EXPANSION when air rises, as with convective currents or air going over mountains. There is no addition or subtraction of heat involved. The changes in temperature are due to the conversion of energy from one form to another.

STABILITY AND INSTABILITY

The atmosphere has a tendency to resist vertical motion. This is known as stability. The normal flow of air tends to be horizontal. If this flow is disturbed, a stable atmosphere resists any upward or downward displacement and tends to return quickly to normal horizontal flow. An unstable atmosphere, on the other hand, allows these upward and downward disturbances to grow, resulting in rough (turbulent) air. An example is the towering thunderstorm that grows as a result of a large intense vertical air current.

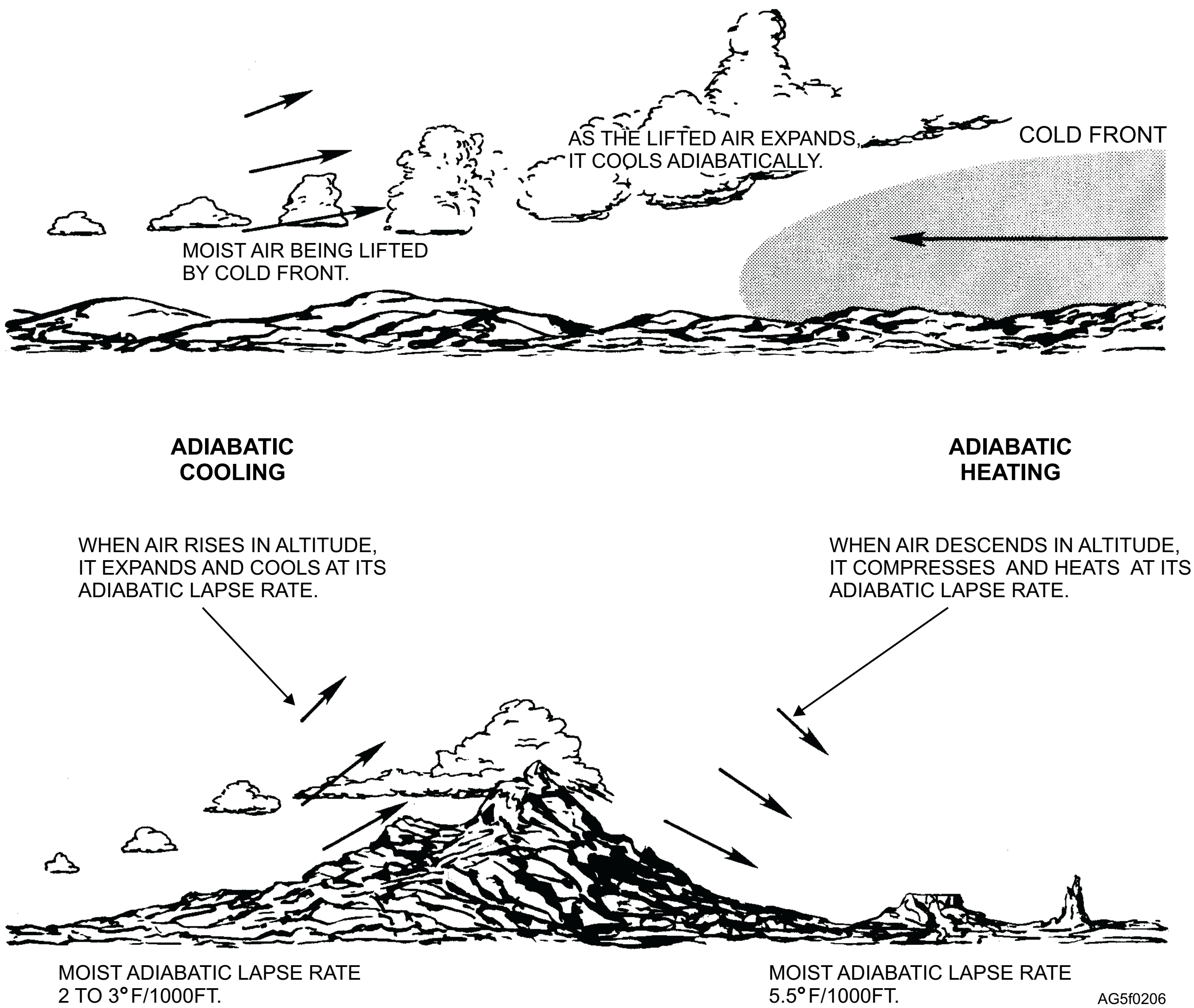


Figure 2-6.—Adiabatic cooling and heating process.

Atmospheric resistance to vertical motion (stability), depends upon the vertical distribution of the air's weight at a particular time. The weight varies with air temperature and moisture content. As shown in figure 2-7, in comparing two parcels of air, hotter air is lighter than colder air; and moist air is lighter than dry air. If air is relatively warmer or more moist than its surroundings, it is forced to rise and is unstable. If the air is colder or dryer than its surroundings, it sinks until it reaches its equilibrium level and is stable. The atmosphere can only be at equilibrium when light air is above heavier air—just as oil poured into water rises to the top to obtain equilibrium. The stability of air depends a great deal on temperature distribution and to a lesser extent on moisture distribution.

Since the temperature of air is an indication of its density, a comparison of temperatures from one level to another can indicate how stable or unstable a layer of air might be—that is, how much it tends to resist vertical motion.

Lapse Rates

In chapter 1, it was shown that temperature usually decreases with altitude and that the rate at which it decreases is called the lapse rate. The lapse rate, commonly expressed in degrees Fahrenheit per 1,000 feet, gives a direct measurement of the atmospheres s resistance to vertical motion. The degree of stability of the atmosphere may vary from layer to layer as

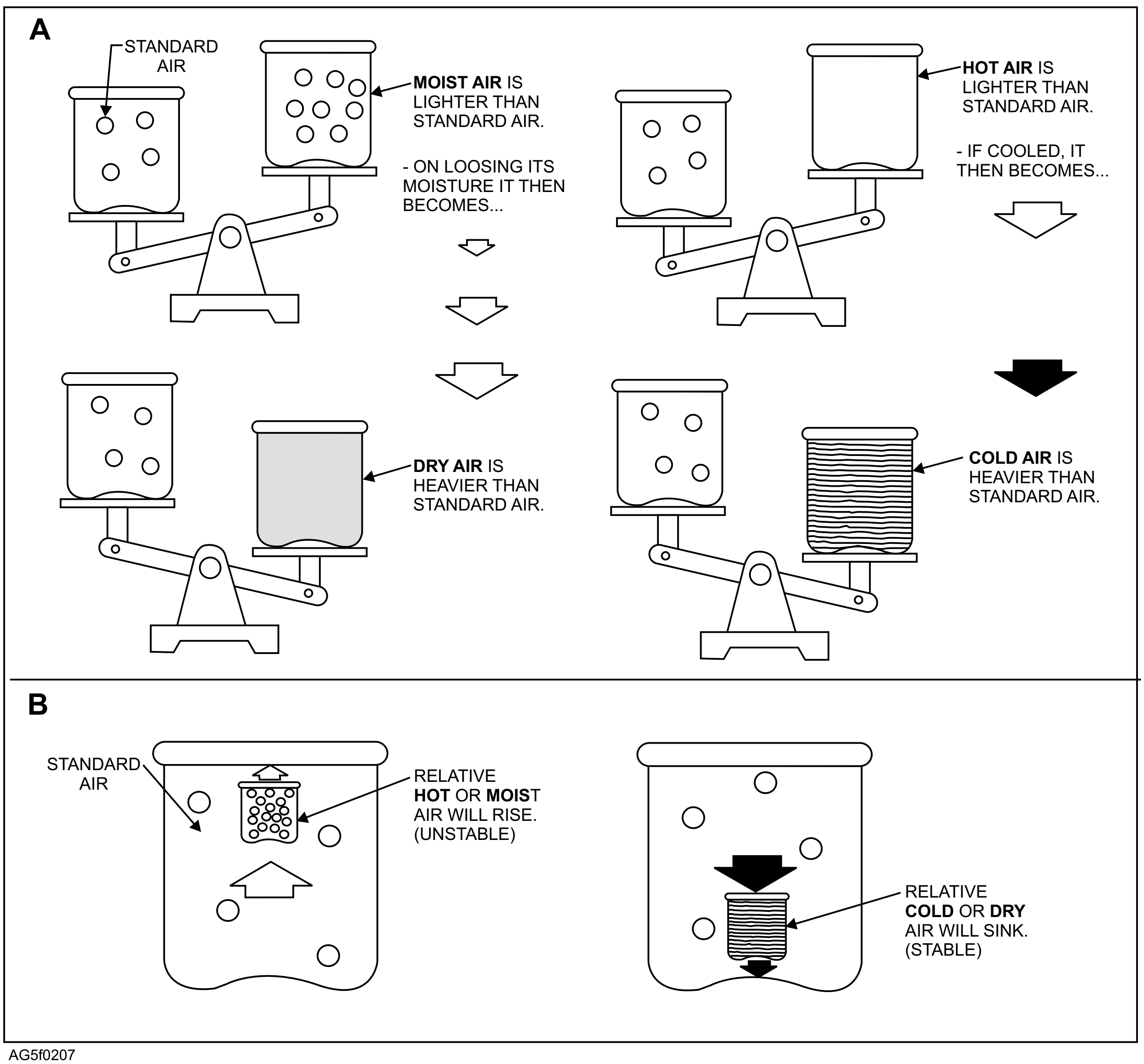


Figure 2-7.—Moisture content and temperature determines weight of air.

indicated by changes of lapse rate with height. (See table 2-1 and fig. 2-8.)

DRY ADIABATIC LAPSE RATE.—If a parcel of air is lifted, its pressure is DECREASED, since pressure decreases with height, and its temperature falls due to the expansion. If the air is dry and the process is adiabatic, the rate of temperature fall is 1°C per 100 meters of lift (10°C per Kin), or 5 l/2°F per 1,000 feet of lift. If that parcel descends again to higher pressure, its temperature then INCREASES at the rate of 1°C per 100 meters or 5 1/2°F per 1,000 feet. This is known as the dry adiabatic lapse rate.

MOIST (SATURATION) ADIABATIC LAPSE RATE.—When a mass of air is lifted, it cools at the dry adiabatic lapse rate of 5 1/2°F per 1,000 feet as long as it remains unsaturated (relative humidity below 100 percent). If the original moisture is being carried along with the mass as it ascends and it cools to its saturation temperature, the relative humidity reaches 100 percent. Condensation takes place with further cooling. For each gram of water condensed, about 597 calories of heat are liberated. This latent heat of condensation is absorbed by the air, and the adiabatic cooling rate is decreased to 20 to 3°F per 1,000 feet instead of 5 1/2°F per 1,000 feet. The process during the saturated expansion of the air is called the saturation adiabatic, the moist adiabatic, or the pseudoadiabatic process. The pseudoadiabatic process assumes that moisture falls out of the air as soon as it condenses.

Assume that a saturated parcel of air having a temperature of 44°F is at 5,000 feet and is forced over a 12,000-foot mountain. Condensation occurs from 5,000 to 12,000 feet so that the parcel cools at the moist adiabatic rate (3°F per 1,000 ft) and reaches a temperature of approximately 23°F at the top of the mountain. Assuming that the condensation in the form of precipitation has fallen out of the air during the ascent, the parcel heats at the dry adiabatic rate as it descends to the other side of the mountain. When it reaches the 5,000-foot level, the parcel has descended 7,000 feet at a rate of 5 1/2°F per 1,000 feet. This results in an increase of 38.5°F. Adding the 38.5°F increase to the original 12,000 feet temperature of 23°F, the parcel has a new temperature of 61.5°F.

Table 2-1.—Lapse Rates of Temperature

Lapse rate	Per 1,000 feet	Per 100 meters
Dry adiabatic	5 1/2° F	1° C
Saturation (moist) adiabatic	2-3° F	.55° C
Average	3.3° F	.65° C
Superadiabatic	5 1/2-15° F	1-3.42° C
Autoconvective	More than 15° F	More than 3.42° C

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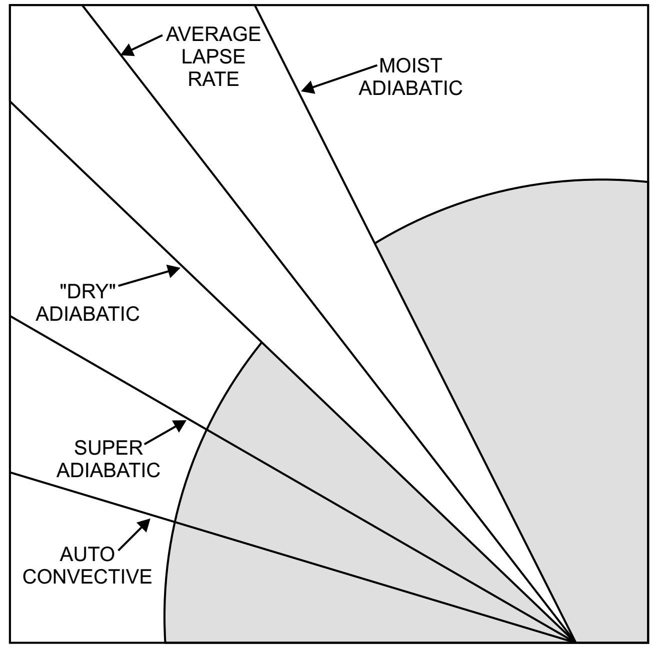

Figure 2-8.—Adiabatic lapse rates.

AVERAGE ADIABATIC LAPSE RATE.—The average lapse rate lies between the dry adiabatic and the moist adiabatic at about 3.3°F per 1,000 feet.

SUPERADIABATIC LAPSE RATE.—The superadiabatic lapse rate is a decrease in temperature of more than 5 1/2°F per 1,000 feet and less than 15°F per 1,000 feet.

AUTOCONVECTIVE LAPSE RATE.—The autoconvective lapse rate is the decrease of more than 15°F per 1,000 feet. This lapse rate is rare and is usually confined to shallow layers.

Types of Stability

In figure 2-9 a bowl is set on a flat surface with a ball placed inside it. The ball rests in the bottom of the bowl; but, if you push the ball in any direction, it seeks out the bottom of the bowl again. This is referred to as ABSOLUTE STABILITY (A in fig. 2-9). Turn the bowl upside down, position the ball anywhere on the bowl's bottom surface (B in fig. 2-9) and the ball starts moving on its own without any other force being applied. This is a condition of ABSOLUTE INSTABILITY. If you now remove the bowl and place the ball on the flat surface (C in fig. 2-9), you have NEUTRAL STABILITY—that is, if a force is applied to the ball, it moves; but if the force is removed, the ball stops.

Air in the atmosphere reacts in a similar manner when moved up or down. If it is moved up and becomes denser than the surrounding air, it returns to its original position and is considered STABLE. If it becomes less dense than the surrounding air, it continues to rise and is considered UNSTABLE. When density remains the same as the surrounding air after being lifted, it is considered NEUTRALLY STABLE, with no tendency to rise or sink.

Equilibrium of Dry Air

The method used for determining the equilibrium of air is the parcel method, wherein a parcel of air is lifted and then compared with the surrounding air to determine its equilibrium. The dry adiabatic lapse rate is always used as a reference to determine the stability or instability of dry air (the parcel).

ABSOLUTE INSTABILITY.—Consider a column of air in which the actual lapse rate is greater than the dry adiabatic lapse rate. The actual lapse rate is to the left of the dry adiabatic lapse rate on the Skew-T diagram (fig. 2-10). If the parcel of air at point A is displaced upward to point B, it cools at the dry adiabatic lapse rate. Upon arriving at point B, it is warmer than the surrounding air. The parcel therefore

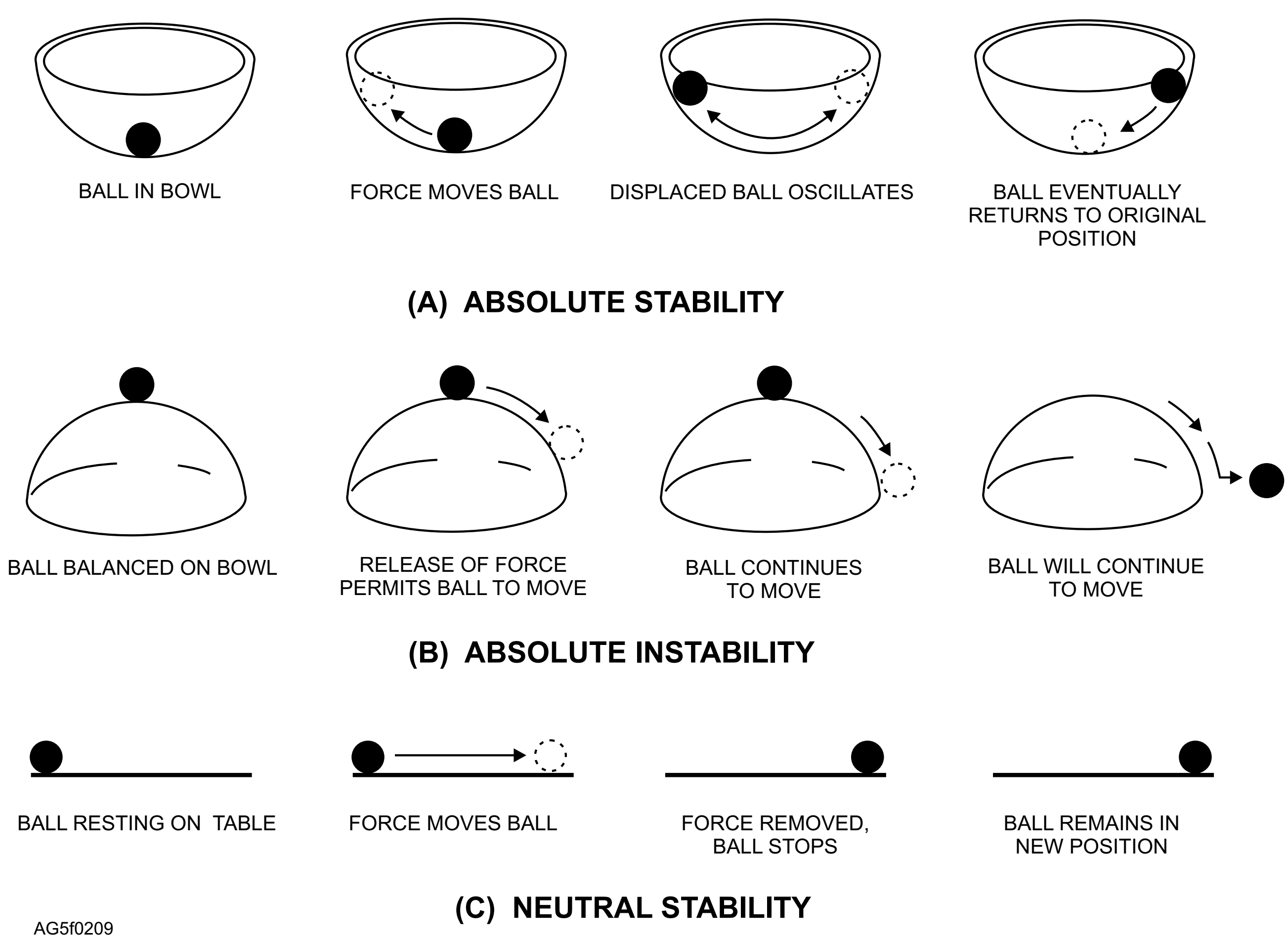

Figure 2-9.—Analogy depiction of stability.

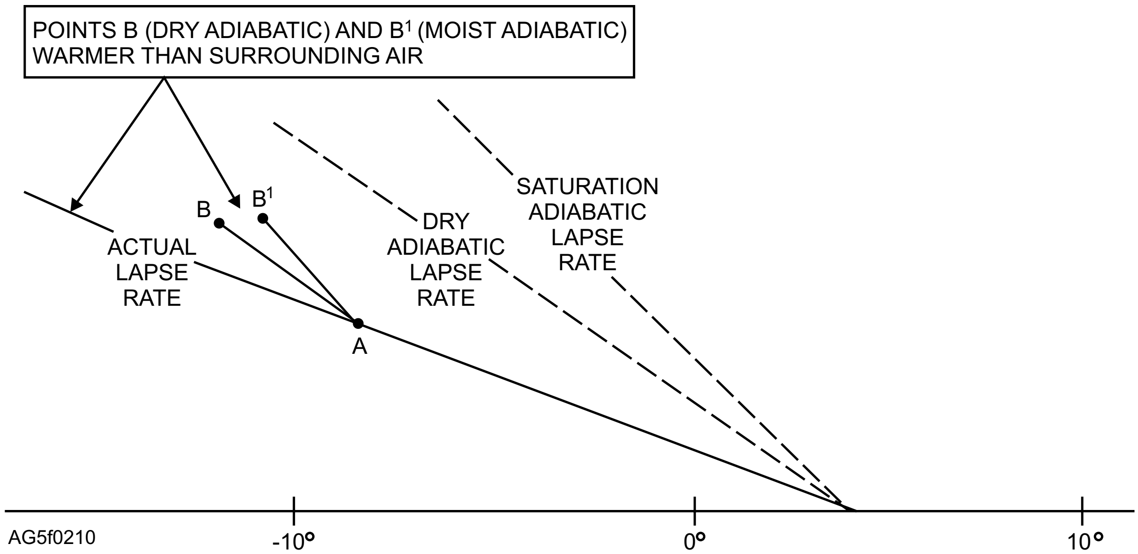

Figure 2-10.—Absolute instability (any degree of saturation).

has a tendency to continue to rise, seeking air of its own density. Consequently the column becomes unstable. From this, the rule is established that if the lapse rate of a column of air is greater than the dry adiabatic lapse rate, the column is in a state of ABSOLUTE INSTABILITY. The term absolute is used because this applies whether the air is dry or saturated, as is evidenced by displacing upward a saturated parcel of air from point A along a saturation adiabat to point B. The parce1 is more unstable than if displaced along a dry adiabat.

STABILITY.—Consider a column of dry air in which the actual lapse rate is less than the dry adiabatic lapse rate. The actual lapse rate is to the right of the dry adiabatic lapse rate on the Skew-T diagram (fig. 2-11).

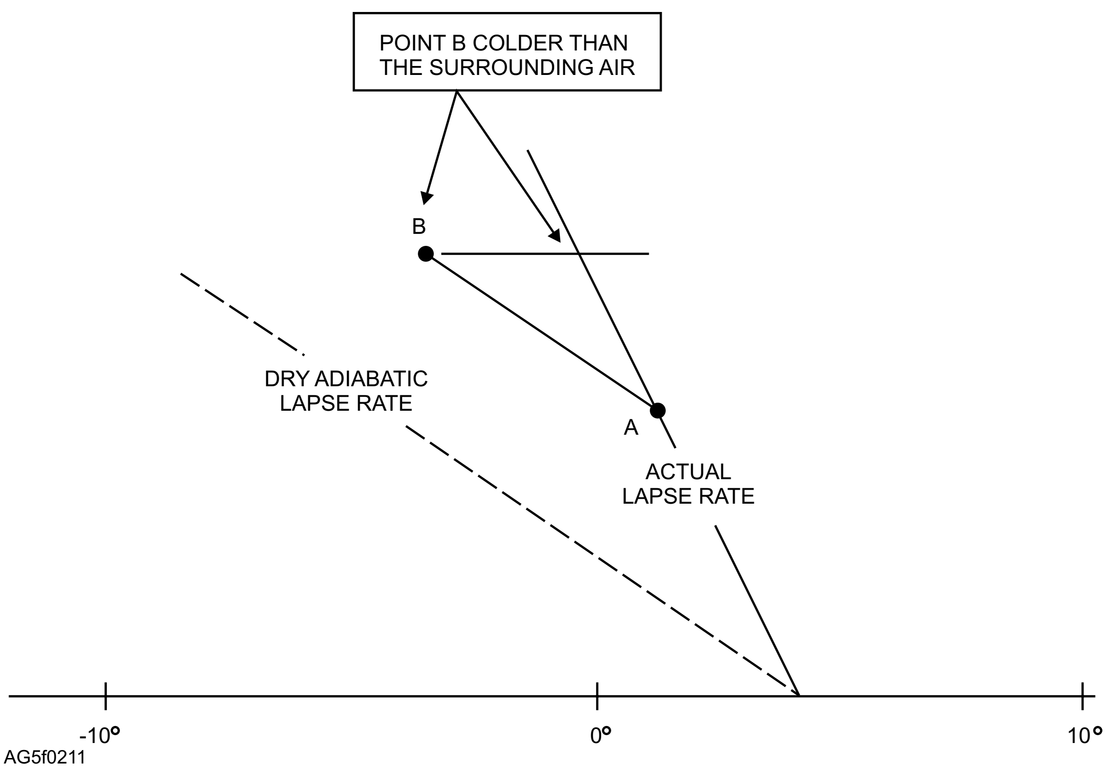

Figure 2-11.—Stability (dry air).

If the parcel at point A were displaced upward to point B, it would cool at the dry adiabatic lapse rate; and upon arriving at point B, it would be colder than the surrounding air. It would, therefore, have a tendency to return to its original level. Consequently, the column of air becomes stable. From this, the rule is established that if the actual lapse rate of a column of DRY AIR is less than the dry adiabatic lapse rate, the column is stable.

NEUTRAL STABILITY.—Consider a column of DRY AIR in which the actual lapse rate is equal to the dry adiabatic lapse rate. The parcel cools at the dry adiabatic lapse rate if displaced upward. It would at all time be at the same temperature and density as the surrounding air. It also has a tendency neither to return to nor to move farther away from its original position. Therefore, the column of dry air is in a state of NEUTRAL STABILITY.

Equilibrium of Saturated Air

When saturated air is lifted, it cools at a rate different from that of dry air. This is due to release of the latent heat of condensation, which is absorbed by the air. The rate of cooling of moist air is known as the saturation adiabatic lapse rate. This rate is used as a reference for determining the equilibrium of saturated air.

ABSOLUTE STABILITY.—Consider a column of air in which the actual lapse rate is less than the saturation adiabatic lapse rate. The actual lapse rate is to the right of the saturation adiabatic lapse rate on the Skew T diagram (fig. 2-12). If the parcel of saturated air at point A is displaced upward to point B, it cools at the saturation adiabatic lapse rate. The air upon arriving at point B becomes colder than the surrounding air. The layer, therefore, would be in a state of ABSOLUTE STABILITY. From this, the following rule is established: If the actual lapse rate for a column of air is less than the saturation adiabatic lapse rate, the column is absolutely stable and the parcel would return to its original position. Dry air cools dry adiabatically and is also colder than the surrounding air. Therefore, this rule applies to all air, as is evidenced when an unsaturated parcel of air is displaced upward dry adiabatically to point B. Here, the parcel is more stable than the parcel displaced along a saturation adiabat.

INSTABILITY.—Consider now a column of air in which the actual lapse rate is greater than the saturation adiabatic lapse rate (fig. 2-13). If a parcel of moist air at point A is displaced upward to point B, it cools at the

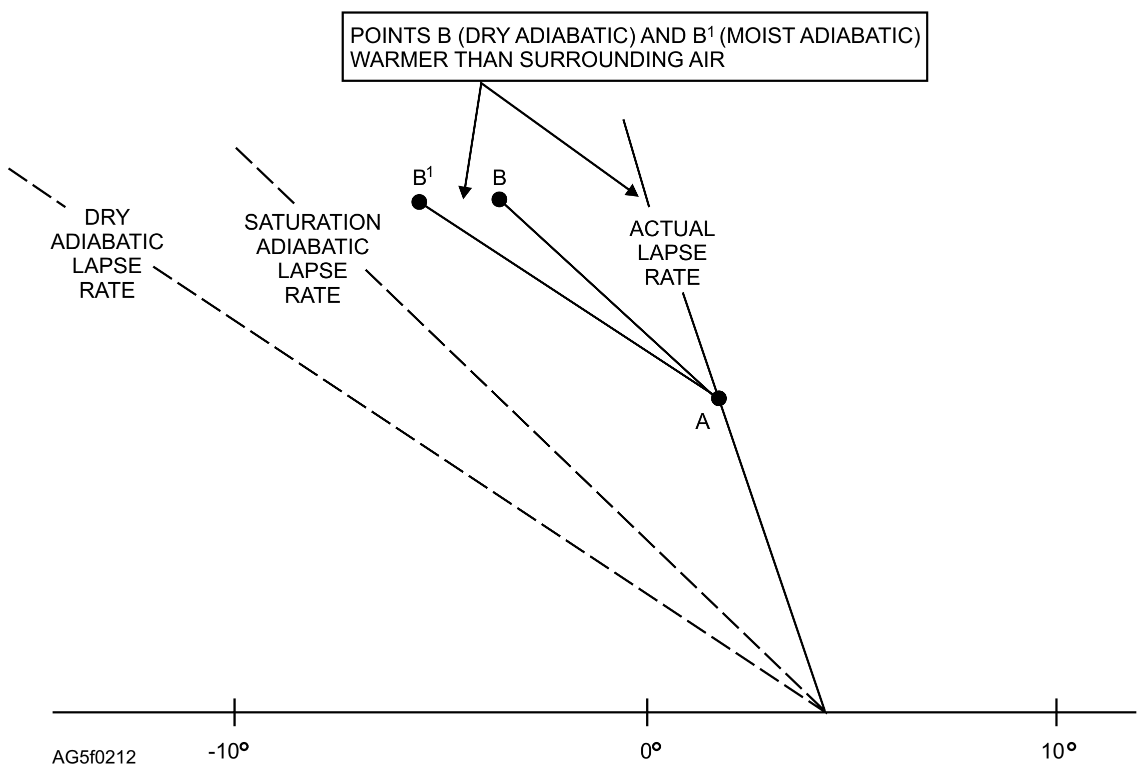

Figure 2-12.—Absolute stability (any degree of saturation).

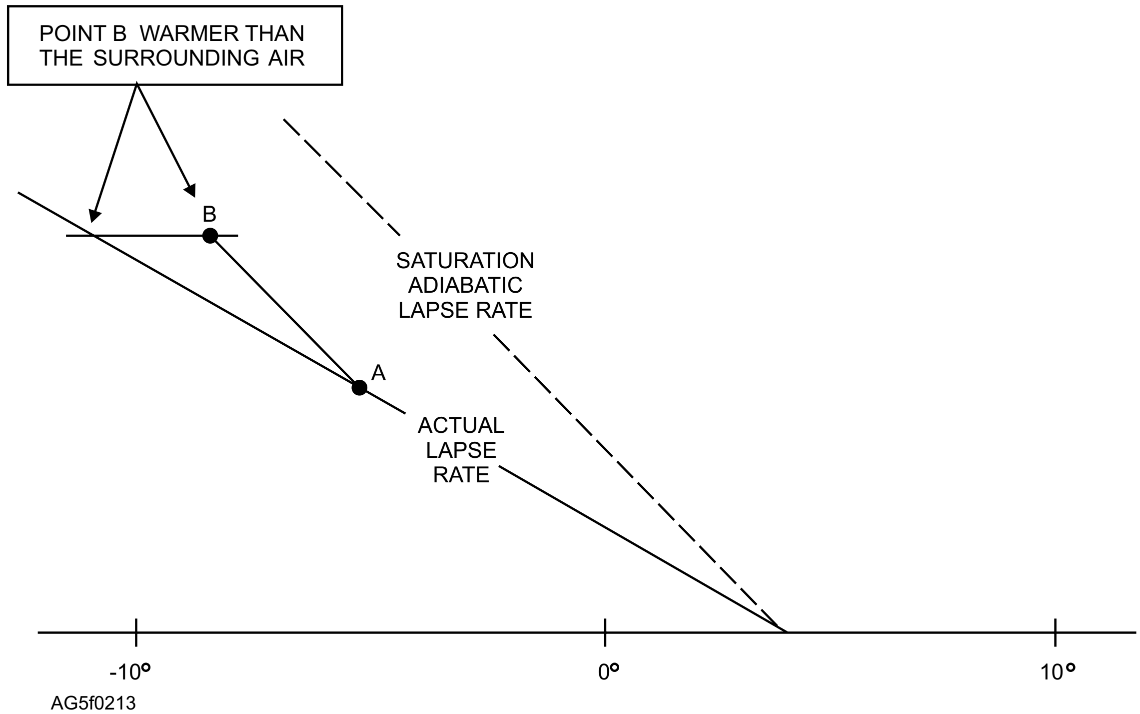

Figure 2-13.—Instability (saturated air).

saturation adiabatic lapse rate. Upon arriving at point B the parcel is then warmer than the surrounding air. For this reason, it has a tendency to continue moving farther from its original position. The parcel, therefore, is in a state of INSTABILITY. The following rule is applicable. If the actual lapse rate for a column of SATURATED (MOIST) AIR is greater than the saturation adiabatic lapse rate, the column is unstable.

NEUTRAL STABILITY.—Consider a column of saturated air in which the actual lapse rate is equal to the saturation adiabatic lapse rate. A parcel of air displaced upward cools at the saturation adiabatic lapse rate and is at all times equal in temperature to the surrounding air. On that account it tends neither to move farther away from nor to return to its original level. Therefore, it is in a state of NEUTRAL STABILITY. The rule for this situation is that if the actual lapse rate for a column of saturated air is equal to the saturation adiabatic lapse rate, the column is neutrally stable.

Conditional Instability

In the treatment of stability and instability so far, only air that was either dry or saturated was considered. Under normal atmospheric conditions natural air is unsaturated to begin with, but becomes saturated if lifted high enough. This presents no problem if the actual lapse rate for the column of air is greater than the dry adiabatic lapse rate (absolutely unstable) or if the actual lapse rate is less than the saturation adiabatic lapse rate (absolutely stable). However, if the lapse rate for a column of natural air lies between the dry adiabatic lapse rate and the saturation adiabatic lapse rate, the air may be stable or unstable, depending upon the distribution of moisture. When the actual lapse rate of a column of air lies between the saturation adiabatic lapse rate and the dry adiabatic lapse rate, the equilibrium is termed CONDITIONAL INSTABILITY, because the stability is conditioned by the moisture distribution. The equilibrium of this column of air is determined by the use of positive and negative energy areas as analyzed on a Skew-T, Log P diagram. The determination of an area as positive or negative depends upon whether the parcel is being lifted mechanically (by a front or orographic barriers) or by convective means and whether the environment is colder or warmer than the ascending parcel. Positive areas are conducive to instability. Negative areas are conducive to stability.

Conditional instability may be one of three types. The REAL LATENT type is a condition in which the positive area is larger than the negative area (potentially unstable). The PSEUDOLATENT type is a condition in which the positive area is smaller than the negative area (potentially STABLE). The STABLE type is a condition in which there is no positive area. Figure

2-14 shows an example of analyzed positive and the negative energy areas as they would appear on a Skew-T, Log P diagram.

Autoconvection

AUTOCONVECTION is a condition started spontaneously by a layer of air when the lapse rate of temperature is such that density increases with elevation. For density to increase with altitude, the lapse rate must be equal to or exceed 3.42°C per 100 meters. (This is the AUTOCONVECTIVE LAPSE RATE.) An example of this condition is found to exist near the surface of the earth in a road mirage or a dust devil. These conditions occur over surfaces that are easily heated, such as the desert, open fields, etc.; they are usually found during periods of intense surface heating.

Convection Stability and Instability

In the discussion so far of convection stability and instability, PARCELS of air have been considered. Let us now examine LAYERS of air. A layer of air that is

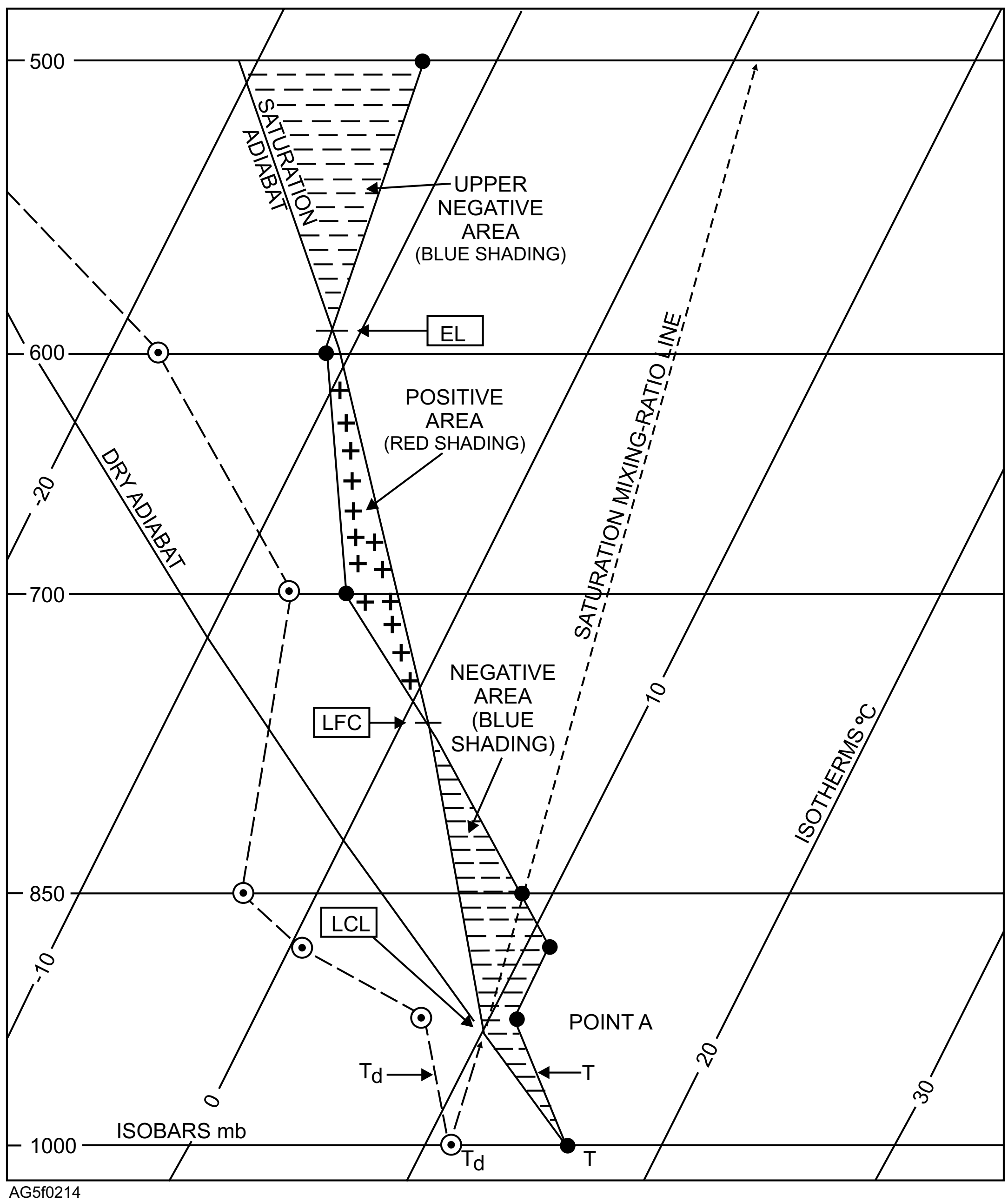

Figure 2-14.—Example of positive and negative energy areas (mechanical lifting).

originally stable may become unstable due to moisture distribution if the entire layer is lifted.

Convective stability is the condition that occurs when the equilibrium of a layer of air, because of the temperature and humidity distribution, is such that when the entire layer is lifted, its stability is increased (becomes more stable).

Convective instability is the condition of equilibrium of a layer of air occurring when the temperature and humidity distribution is such that when the entire layer of air is lifted, its instability is increased (becomes more unstable).

CONVECTIVE STABILITY.—Consider a layer of air whose humidity distribution is dry at the bottom and moist at the top. If the layer of air is lifted, the top and the bottom cool at the same rate until the top reaches saturation. Thereafter, the top cools at a slower rate of speed than the bottom. The top cools saturation adiabatically (.55°C/100 meters), while the bottom continues to cool dry adiabatically (1°C/100 meters). The lapse rate of the layer then decreases; hence, the stability increases. The layer must be initially unstable and may become stable when lifting takes place.

CONVECTIVE INSTABILITY.—Consider a layer of air in which the air at the bottom is moist and the air at the top of the layer is dry. If this layer of air is lifted, the bottom and the top cool dry adiabatically until the lower portion is saturated. The lower part then cools saturation adiabatically while the top of the layer is still cooling dry adiabatically. The lapse rate then begins to increase and instability increases.

To determine the convective stability or instability of a layer of air, you should first know why you expect the lifting of a whole layer. The obvious answer is an orographic barrier or a frontal surface. Next, determine how much lifting is to be expected and at what level it commences. Lifting of a layer of air close to the surface of the Earth is not necessary. The amount of lifting, of course, depends on the situation at hand. Figure 2-15 illustrates the varying degrees of air stability that are directly related to the rate at which the temperature changes with height.

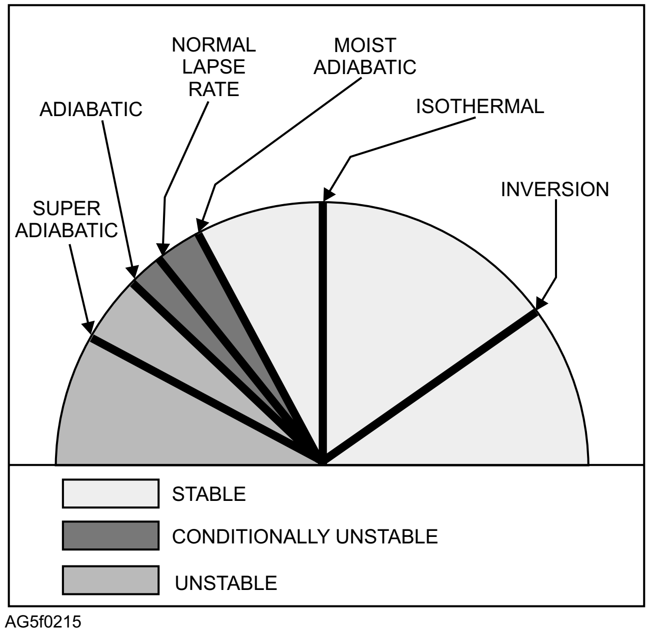

Figure 2-15.—Degrees of stability in relation to temperature changes with height.

Determining Bases of Convective Type Clouds

You have seen from our foregoing discussion that moisture is important in determining certain stability conditions in the atmosphere. You know, too, that the difference between the temperature and the dew point is an indication of the relative humidity. When the dew point and the temperature are the same, the air is saturated and some form of condensation cloud may be expected. This lends itself to a means of estimating the height of the base of clouds formed by surface heating when the surface temperature and dew point are known. You know that the dew point decreases in temperature at the rate of 1°F per 1,000 feet during a lifting process. The ascending parcel in the convective current experiences a decrease in temperature of about 5 1/2°F per 1,000 feet. Thus the dew point and the temperature approach each other at the rate of 4 1/2°F per 1,000 feet. As an example, consider the surface temperature to be 80°F and the surface dew point 62°F, a difference of 18°F. This difference, divided by the approximate rate the temperature approaches the dew point (4 1/2°F per 1,000 ft) indicates the approximate height of the base of the clouds caused by this lifting process (18 ÷ 4 1/2) ×

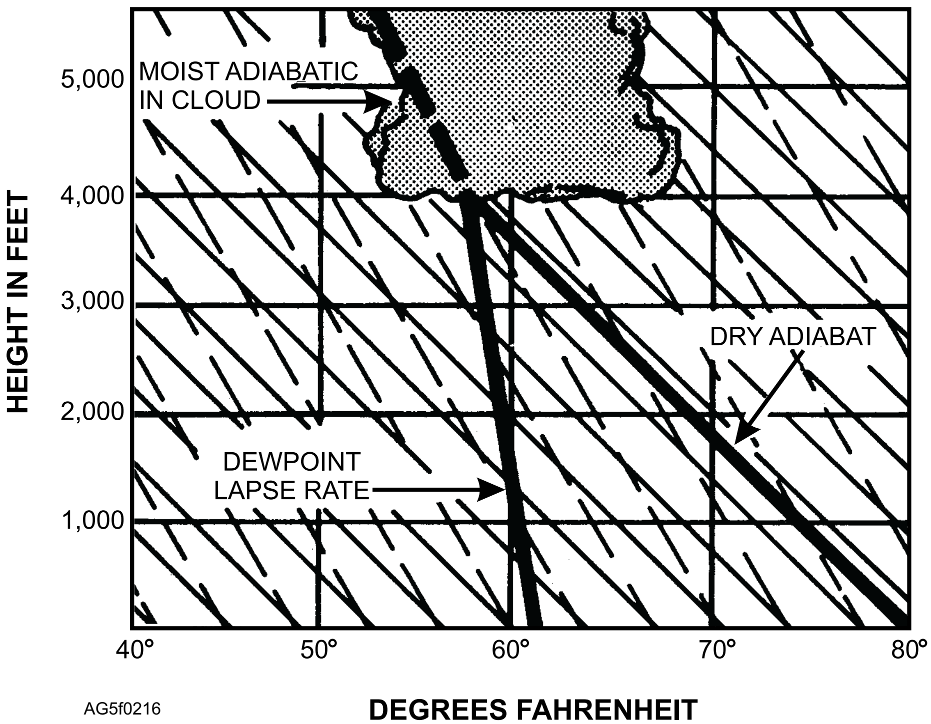

Figure 2-16.—Determine of cloud's base when the dew point and temperature are known.

1000 = 4,000 feet). This is graphically shown in figure 2-16.

This method cannot be applied to all cloud types. It is limited to clouds formed by convection currents, such as summertime cumulus clouds, and only in the locality where the clouds form. It is not valid around maritime or mountainous areas.

Stability in Relation to Cloud Type

The degree of stability of the atmosphere helps to determine the type of clouds formed. For example, figure 2-17 shows that if *stable* air is forced to ascend a mountain slope, clouds will be layerlike with little vertical development and little or no turbulence. *Unstable air*, if forced to ascend the slope, causes considerable vertical development and turbulence in the clouds. The base of this type of cloud can be determined by mechanical lifting as analyzed on a Skew-T.

REVIEW QUESTIONS

Q2-11. What are the two basic kinds of atmospheric energy?

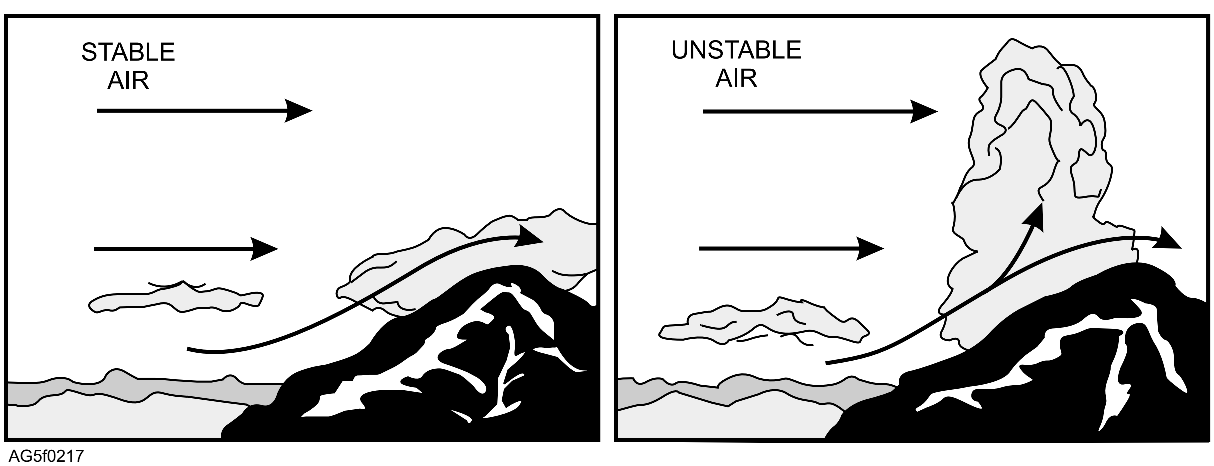

Figure 2-17.—Illustration showing that very stable air retains its stability even when it is forced upward, forming a flat cloud. Air which is potentially unstable when forced upward becomes turbulent and forms a towering cloud.

Q2-12. What is the definition of lapse rate?

Q2-13. What is the rate of rise and fall dry adiabatic lapse rate?

Q2-14. What are the three types of conditional instability?

SUMMARY

Understanding the basic principles of atmospheric physics is essential in order to comprehend how weather behaves. Analyzing meteorological situations properly depends upon what the Aerographer's Mate learns about atmospheric physics.

CHAPTER 3

ATMOSPHERIC CIRCULATION

To understand large-scale motions of the atmosphere, it is essential that the Aerographer's Mate study the general circulation of the atmosphere. The sun's radiation is the energy that sets the atmosphere in motion, both horizontally and vertically. The rising and expanding of the air when it is warmed, or the descending and contracting of the air when it is cooled causes the vertical motion. The horizontal motion is caused by differences of atmospheric pressure; air moves from areas of high pressure toward areas of low pressure. Differences of temperature, the cause of the pressure differences, are due to the unequal absorption of the Sun's radiation by Earth's surface. The differences in the type of surface; the differential heating; the unequal distribution of land and water; the relative position of oceans to land, forests to mountains, lakes to surrounding land, and the like, cause different types of circulation of the air. Due to the relative position of Earth with respect to the Sun, much more radiation is absorbed near the equator than at other areas, with the least radiation being absorbed at or near the poles. Consequently, the principal factor affecting the atmosphere is incoming solar radiation, and its distribution depends on the latitude and the season.

GENERAL CIRCULATION

LEARNING OBJECTIVE: Recognize how temperature, pressure, winds, and the 3-cell theory affect the general circulation of Earth's atmosphere.

The general circulation theory attempts to explain the global circulation of the atmosphere with some minor exceptions. Since Earth heats unequally, the heat is carried away from the hot area to a cooler one as a result of the operation of physical laws. This global movement of air, which restores a balance of heat on Earth, is the general circulation.

WORLD TEMPERATURE GRADIENT

Temperature gradient is the rate of change of temperature with distance in any given direction at any point. World temperature gradient refers to the change in temperature that exists in the atmosphere from the equator to the poles. The change in temperature or temperature differential, which causes atmospheric circulation can be compared to the temperature differences produced in a pan of water placed over a gas burner. As the water is heated, it expands and its density is lowered. This reduction in density causes the warmer, less dense water to rise to the top of the pan. As it rises, it cools and is forced to the edges of the pan. Here it cools further and then sinks to the bottom, eventually working its way back to the center of the pan where it started. This process sets up a simple circulation pattern due to successive heating and cooling.

Ideally, the air within the troposphere may be compared to the water in the pan. The most direct rays of the Sun hit Earth near the equator and cause a net gain of heat. The air at the equator heats, rises, and flows in the upper atmosphere toward both poles. Upon reaching the poles, it cools sufficiently and sinks back toward Earth, where it tends to flow along the surface of Earth back to the equator. (See fig. 3-1).

Simple circulation of the atmosphere would occur as described above if it were not for the following factors:

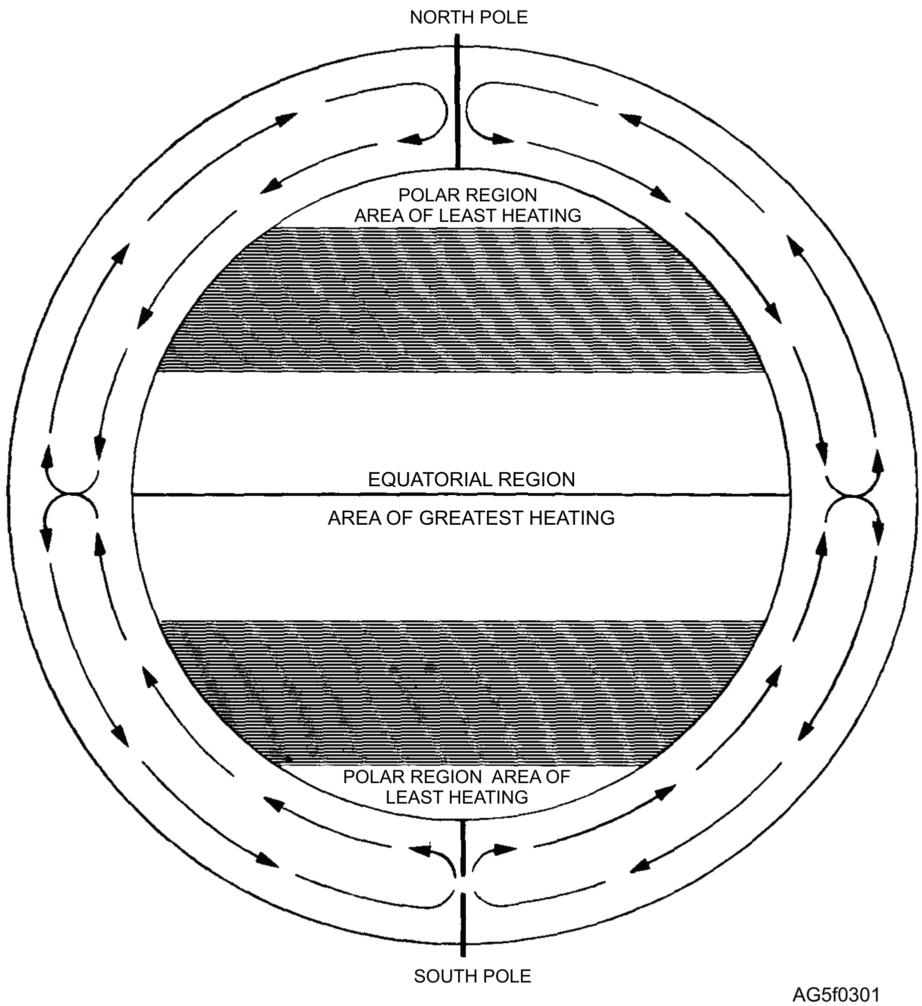

Figure 3-1.—Simple circulation.

1. Earth rotates, resulting in an apparent force known as the Coriolis force (a deflecting force). This rotation results in a constant change to the area being heated.

2. Earth is covered by irregular land and water surfaces that heat at different rates.

Regions under the direct rays of the Sun absorb more heat per unit time than those areas receiving oblique rays. The heat produced by the slanting rays of the Sun during early morning may be compared with the heat that is produced by the slanting rays of the Sun during winter. The heat produced by the more direct rays at midday can be compared with the heat resulting from the more direct rays of summer. The length of day, like the angle of the Sun's rays, influences the temperature. The length of day varies with the latitude and the season. Near the equator there are about 12 hours of daylight with the Sun's rays striking the surface more directly. Consequently, equatorial regions normally do not have pronounced seasonal temperature variations.

During the summer in the Northern Hemisphere, all areas north of the equator have more than 12 hours of daylight. During the winter the situation is reversed; latitudes north of the equator have less than 12 hours of daylight. Large seasonal variation in the length of the day and the seasonal difference in the angle at which the Sun's rays reach Earth's surface cause seasonal temperature differences in middle and high latitudes. The weak temperature gradient in the subtropical areas and the steeper gradient poleward can be seen in figures 3-2A and 3-2B. Note also how much steeper the gradient is poleward in the winter season of each hemisphere as compared to the summer season.

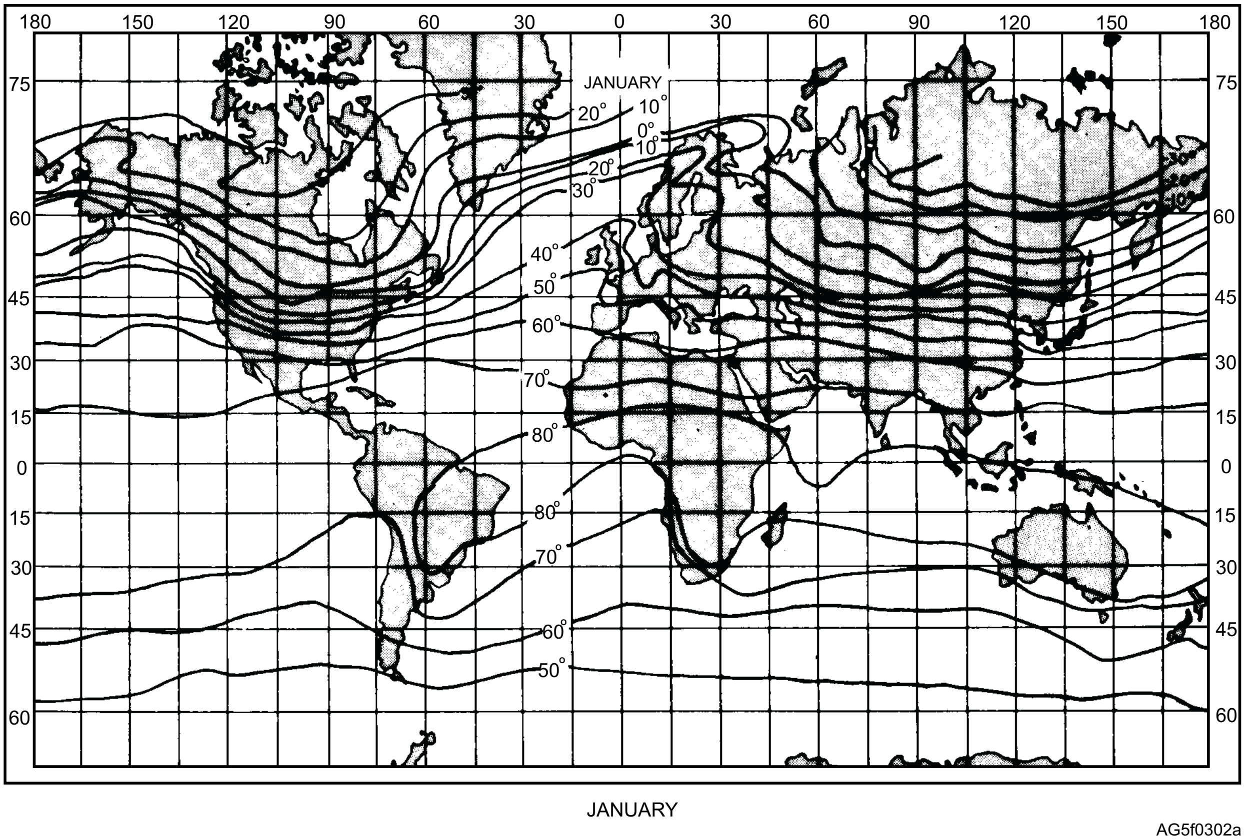

Figure 3-2A.—Mean world temperature for January.

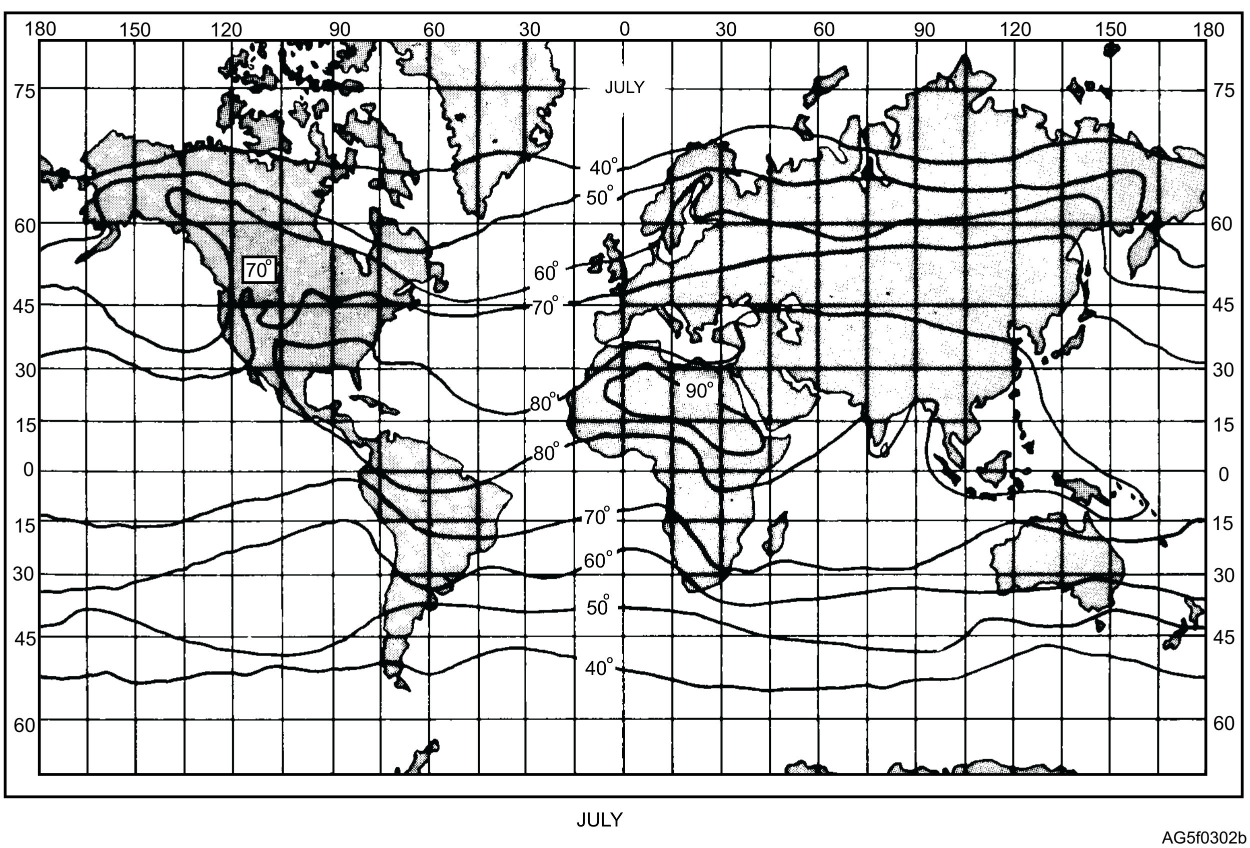

Figure 3-2B.—Mean world temperature for July.

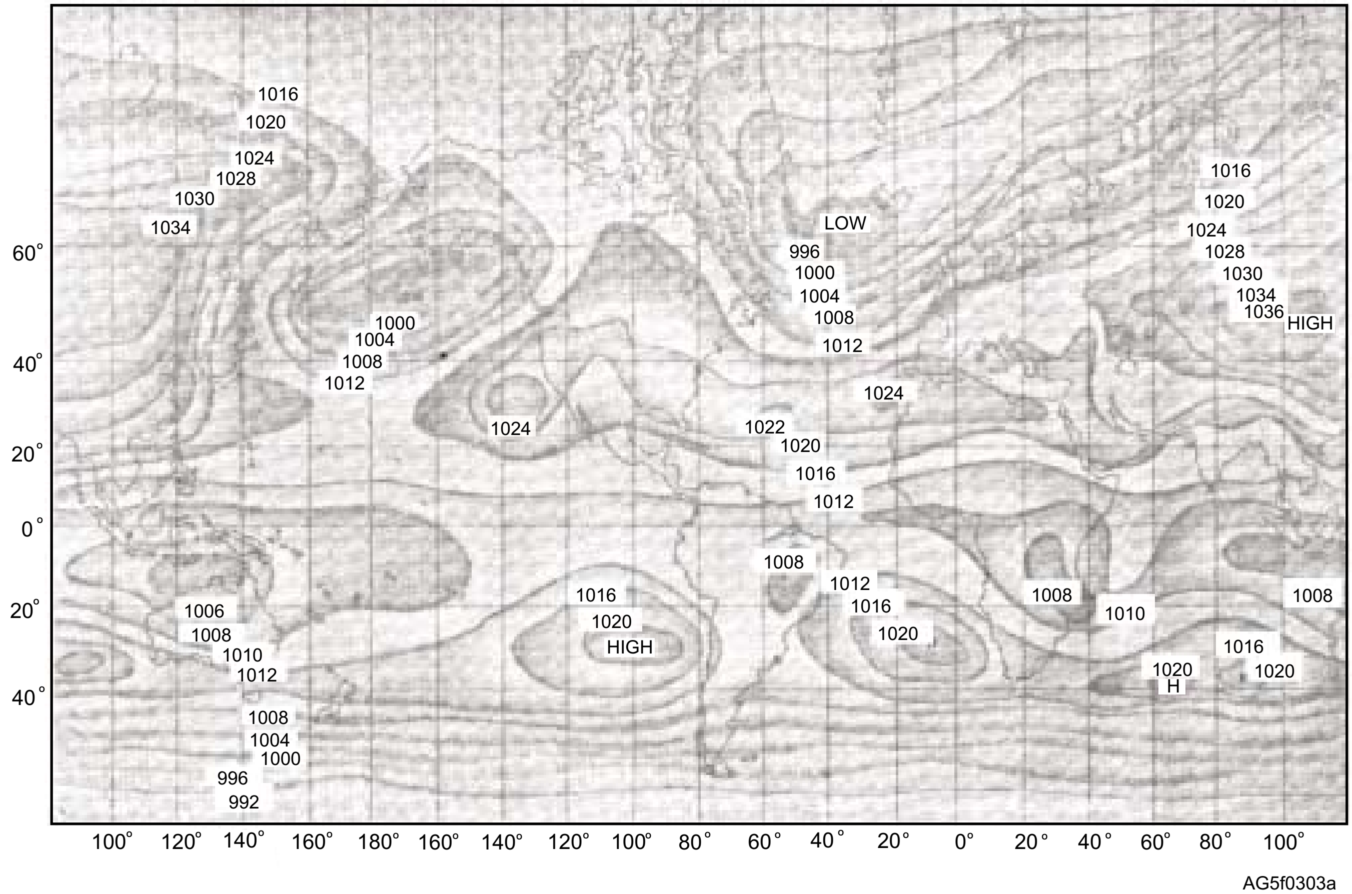

Figure 3-3A.—Mean world pressure for January.

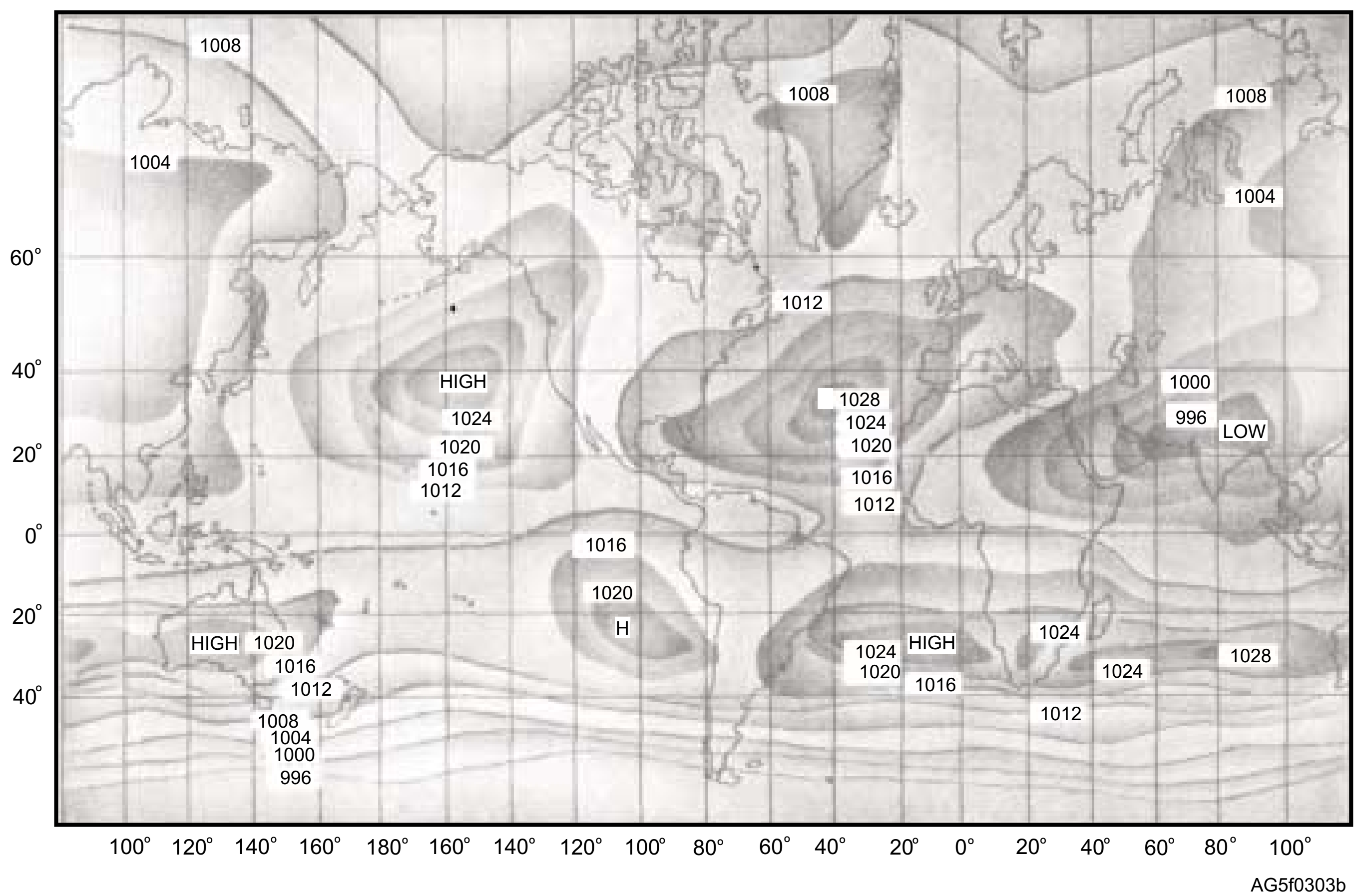

Figure 3-3B.—Mean world pressure for July.

PRESSURE OVER THE GLOBE

The unequal heating of Earth's surface due to its tilt, rotation, and differential insolation, results in the wide distribution of pressure over Earth's surface. Study figures 3-3A and 3-3B. Note that a low-pressure area lies along the intertropical convergence zone (ITCZ) in the equatorial region. This is due to the higher temperatures maintained throughout the year in this region. At the poles, permanent high-pressure areas remain near the surface because of the low temperatures in this area throughout the entire year. Mainly the "piling up" of air in these regions causes the subtropical high-pressure areas at 30°N and S latitudes. Relatively high or low pressures also dominate other areas during certain seasons of the year.

ELEMENTS OF CIRCULATION

Temperature differences cause pressure differences, which in turn cause air movements. The following sections show how air movements work and how they evolve into the various circulations—primary, secondary, and tertiary.

To explain the observed wind circulation over Earth, three basic steps are used. The first step is to assume Earth does not rotate and is of uniform surface; that is, all land or all water. The second step is to rotate Earth, but still assume a uniform surface. The third step is to rotate Earth and assume a non-uniform surface. For now, we deal with the first two steps, a non-rotating Earth of uniform surface and a rotating Earth of uniform surface.

Static Earth

The circulation on a non-rotating Earth is referred to as the thermal circulation because it is caused by the difference in heating. The air over the equator is heated and rises (low pressure); while over the poles the air is cooled and sinks (high pressure). This simple circulation was shown in figure 3-1.

Rotating Earth

In thermal circulation, the assumption was made that the Earth did not rotate, but of course this is not true. The rotation of Earth causes a force that affects thermal circulation. This rotation results in the deflection to the *right* of movement in the Northern Hemisphere, and to the *left* of the movement in the Southern Hemisphere. This force is called the *Coriolis* force. The Coriolis force is not a true force. It is an apparent force resulting from the west-to-east rotation of Earth. The effects, however, are real.

Arctic rivers cut faster into their right banks than their left ones. On railroads carrying only one-way traffic, the right hand rails wear out faster than the left-hand rails. Artillery projectiles must be aimed to the left of target because they deflect to the right. Pendulum clocks run faster in high latitudes than in lower latitudes. All these phenomena are the result of the Coriolis force, which is only an apparent force. The most important phenomena are that this force also deflects winds to the right in the Northern Hemisphere. Therefore, it is important to understand how this force is produced.

As Earth rotates, points on the surface are moving eastward (from west to east) past a fixed point in space at a given speed. Points on the equator are moving at approximately 1,000 miles per hour, points on the poles are not moving at all, but are merely pivoting, the points somewhere between are moving at speeds between 1,000 and zero miles per hour depending upon their relative position. Refer to view A in figure 3-4.

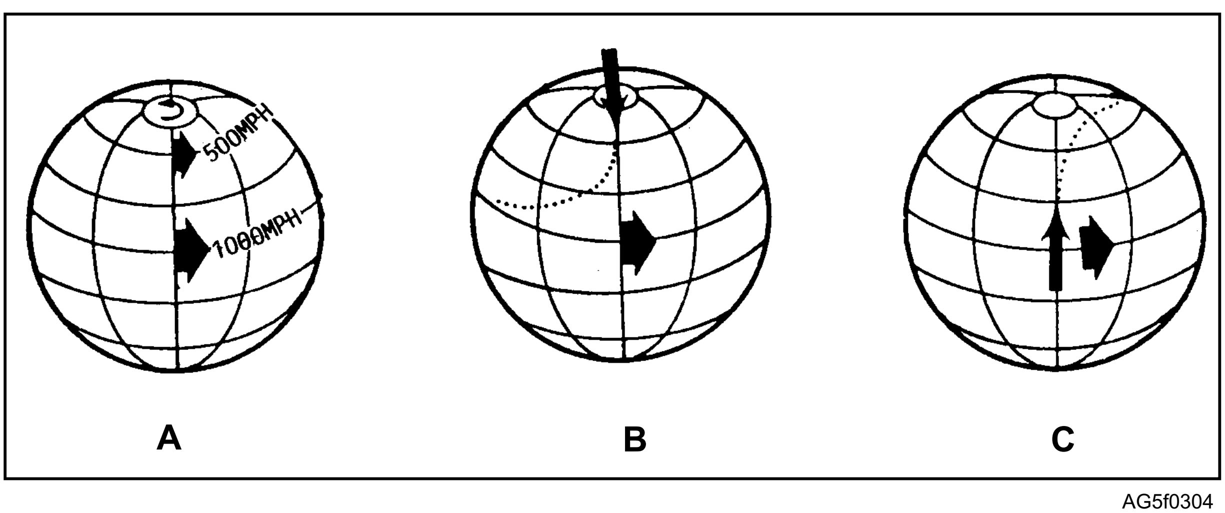

Figure 3-4.—Coriolis force.

Assume that a missile located at the North Pole is launched at a target on the equator. The missile does not have any eastward lateral velocity, but the target has an eastward velocity of 1,000 miles per hour. The result is that the missile appears to be deflected to the right as the target moves away from its initial position. Refer to view B in figure 3-4.

A similar condition assumes that a missile located on the equator is launched at a target at the North Pole. The missile has an eastward lateral velocity of 1,000 miles per hour, while the target on the pole has no lateral velocity at all. Once again the missile appears to be deflected to the right as a result of its initial eastward lateral velocity. Refer to view C in figure 3-4.

Due to Earth's rotation and the Coriolis effect, the simple circulation now becomes more complex as shown in figure 3-5. The complex on resulting from the interplay of the Coriolis effect with the flow of air is known as the theory. (See fig. 3-6.)

3-CELL THEORY

According to the 3-cell theory, Earth is divided into six circulation belts—three in the Northern Hemisphere and three in the Southern Hemisphere. The dividing lines are the equator, latitude, and 60°N and S latitude. The general circulation of the Northern Hemisphere is similar to those of the Southern Hemisphere. (Refer to fig. 3-6 during the following discussion.)

First, note the tropical cell of the Northern Hemisphere that lies between the equator and 30°N latitude. Convection at the equator causes the air to heat

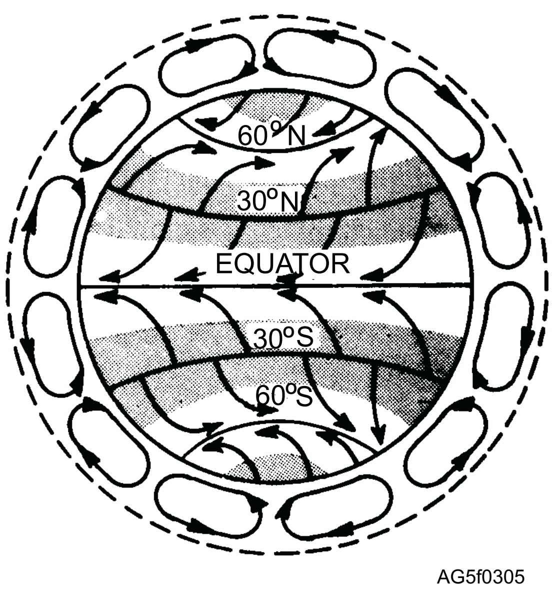

Figure 3-5.—Coriolis effect on windflow.

and rise, due to convection. When it reaches the upper portions of the troposphere, it tends to flow toward the North Pole. By the time the air has reached 30°N latitude, the Coriolis effect has deflected it so much that it is moving eastward instead of northward. This results in a piling up of air (convergence) near 30°N latitude and a descending current of air (subsidence) toward the surface which forms a belt of high pressure. When the descending air reaches the surface where it flows outward (divergence), part of it flows poleward to become part of the mid-latitude cell; the other part flows toward the equator, where it is deflected by the Coriolis effect and forms the northeast trades.

The mid-latitude cell is located between 30° and 60°N latitude. The air, which comprises this cell, circulates poleward at the surface and equatorward aloft with rising currents at 60° (polar front) and descending currents at 300 (high-pressure belt). However, in general, winds both at the surface and aloft blow from the west. The Coriolis effect easily explains this for the surface wind on the poleward-moving surface air. The west wind aloft is not as easily explained. Most authorities agree that this wind is frictionally driven by the west winds in the two adjacent cells.

The polar cell lies between 60°N latitude and the North Pole. The circulation in this cell begins with a flow of air at a high altitude toward the pole. This flow cools and descends at the North Pole and forms a high-pressure area in the Polar Regions. After reaching the surface of Earth, this air usually flows equatorward and is deflected by the Coriolis effect so that it moves from the northeast. This air converges with the poleward flow from the mid-latitude cell and is deflected upward with a portion circulating poleward again and the remainder equatorward. The outflow of air aloft between the polar and mid-latitude cells causes a semi-permanent low-pressure area at approximately 60°N latitude. To complete the picture of the world's general atmospheric circulation, we must associate this prevailing wind and pressure belts with some basic characteristics.

WORLD WINDS

In the vicinity of the equator is a belt of light and variable winds known as the doldrums. On the poleward side of the doldrums are the *trade winds*; the predominant wind system of the tropics. These easterly winds are the most consistent on Earth, especially over the oceans. Near 30°N and 30°S latitudes lie the sub-tropical high-pressure belts. Winds are light and

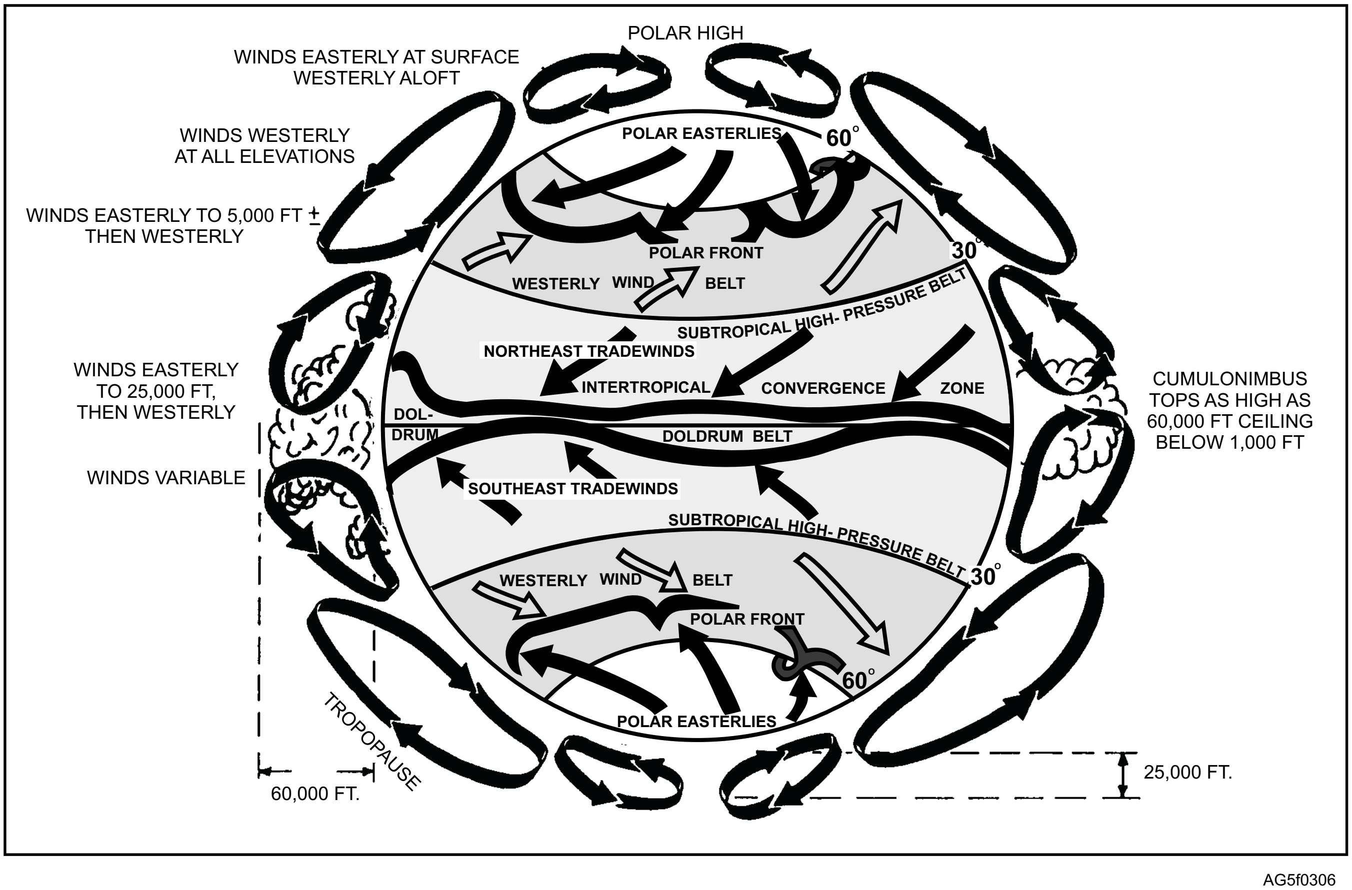

Figure 3-6.—Idealized pattern of the general circulation. (The 3-cell theory).

variable. These areas are referred to as the *horse latitudes*. The prevailing westerlies, which are on the poleward side of the subtropical high-pressure belt, are persistent throughout the mid-latitudes. In the Northern Hemisphere, the direction of the westerlies at the surface is from the southwest. In the Southern Hemisphere, westerlies are from the northwest. This is due to the deflection area resulting from the Coriolis effect as the air moves poleward.

Poleward of the prevailing westerlies, near 60°N and 60°S latitudes, lies the belt of low-pressure basic pressure known as the *polar front zone*. Here, converging winds result in ascending air currents and consequent poor weather.

WIND THEORY

Newton's first two laws of motion indicate that motion tends to be in straight lines and only deviates from such lines when acted upon by another force or by a combination of forces. Air tends to move in a straight line from a high-pressure area to a low-pressure area. However, there are forces that prevent the air from moving in a straight line.

Wind Forces

There are four basic forces that affect the directional movement of air in our atmosphere: pressure gradient force (PGF), the Coriolis effect, centrifugal force, and frictional force. These forces, working together, affect air movement. The forces that are affecting it at that particular time determine the direction that the air moves. Also, the different names given to the movement of the air (geostrophic wind, gradient wind, etc.) depends on what forces are affecting it.

Pressure Gradient

The rate of change in pressure in a direction perpendicular to the isobars is called *pressure gradient*. Pressure applied to a fluid is exerted equally in all

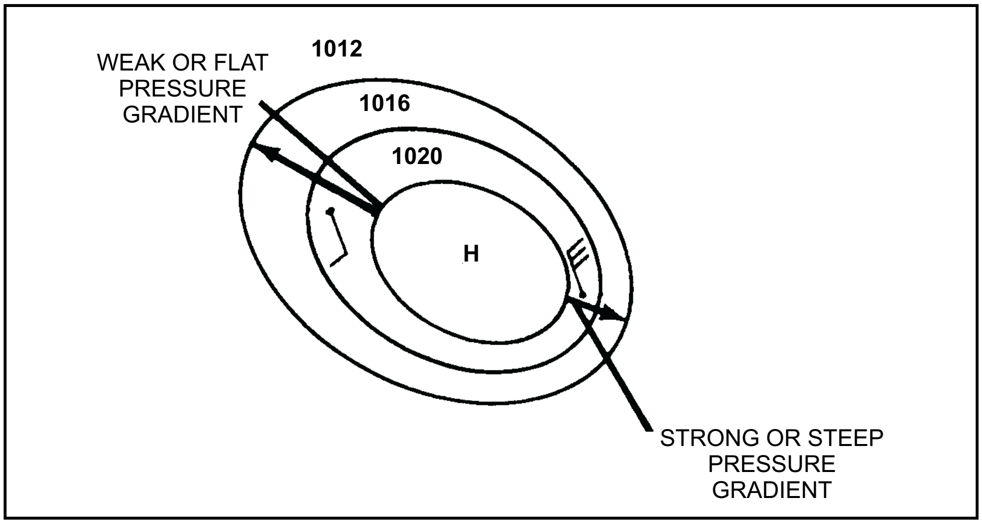

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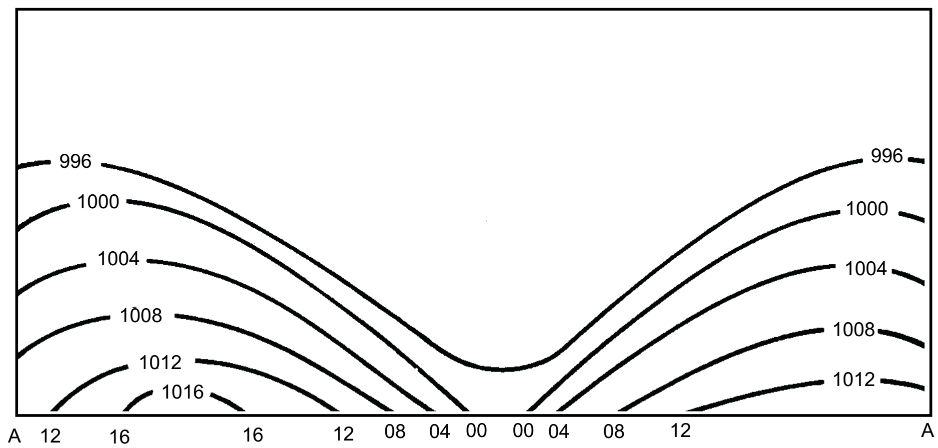
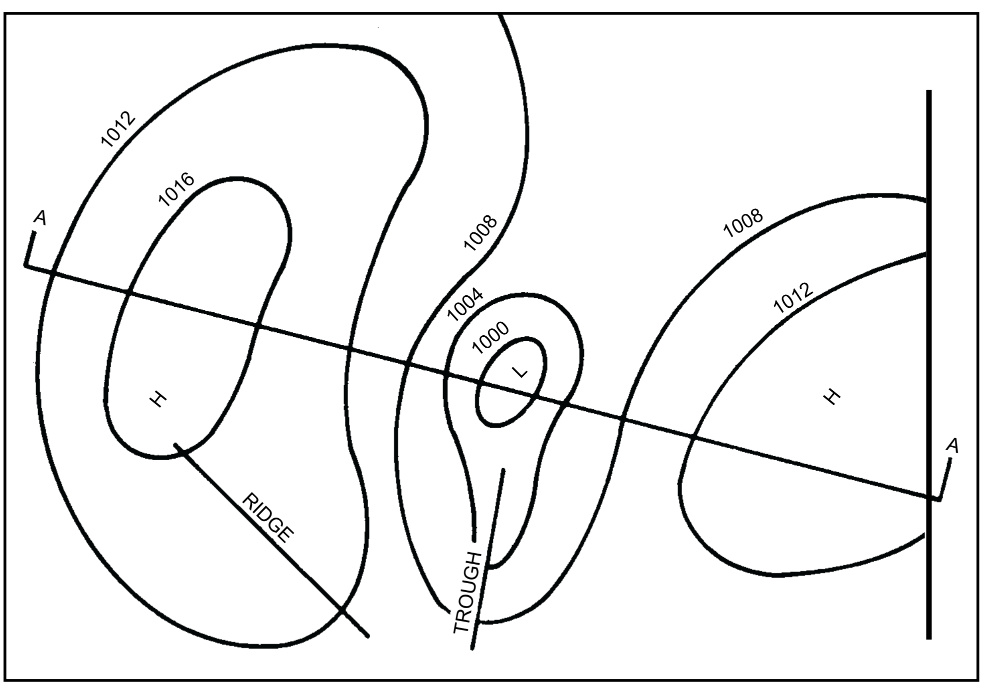
Figure 3-7.—Horizontal pressure gradient.



A. CROSS SECTION OF A VERTICAL PRESSURE GRADIENT ALONG LINE AA



B. HORIZONTAL PRESSURE GRADIENT

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Figure 3-8.—Cross section of a vertical pressure gradient along line AA.

directions throughout the fluid; e.g., if a pressure of 1013.2 millibars is exerted downward by the atmosphere at the surface, this same pressure is also exerted horizontally outward at the surface. Therefore, a pressure gradient exists in the horizontal (along the surface) as well as the vertical plane (with altitude) in the atmosphere.

HORIZONTAL PRESSURE GRADIENT.—The horizontal pressure gradient is *steep* or *strong* when the isobars determining the pressure system (fig. 3-7) are close together. It is *flat* or *weak* when the isobars are far apart.

VERTICAL PRESSURE GRADIENT.—If isobars are considered as depicting atmospheric topography, a high-pressure system represents a hill of air, and a low-pressure system represents a depression or valley of air. The vertical pressure gradient always indicates a decrease in pressure with altitude, but the rate of pressure decrease (gradient) varies directly with changes in air density with altitude. Below 10,000 feet altitude, pressure decreases approximately 1 inch of mercury per 1,000 feet in the standard atmosphere. The vertical cross section through a high and low (view A in fig. 3-8) depicts the vertical pressure gradient. A surface weather map view of the horizontal pressure gradient in the same high and low is illustrated in view B of the figure 3-8.

Pressure Gradient Force

The variation of heating (and consequently the variations of pressure) from one locality to another is the initial factor that produces movement of air or wind. The most direct path from high to low pressure is the path along which the pressure is changing most rapidly. The rate of change is called the pressure gradient. Pressure gradient force is the force that moves air from an area of high pressure to an area of low pressure. The velocity of the wind depends upon the pressure gradient. If the pressure gradient is strong, the wind speed is high. If the pressure gradient is weak, the wind speed is light. (See fig. 3-7.)

Figure 3-9 shows that the flow of air is from the area of high pressure to the area of low pressure, but it does not flow straight across the isobars. Instead the flow is circular around the pressure systems. Pressure gradient force (PGF) causes the air to begin moving from the high-pressure to the low-pressure system. Coriolis (deflective) force and centrifugal force then begin acting on the flow in varying degrees. In this example, frictional force is not a factor.

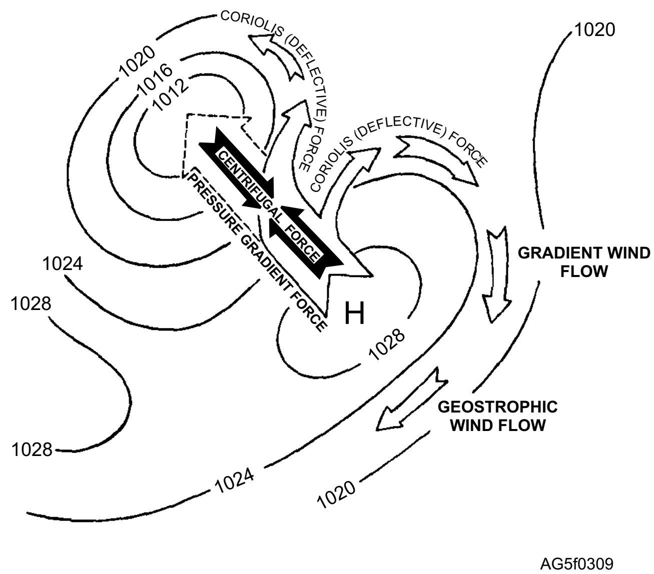

Figure 3-9.—Examples of circulation around high and low pressure systems.

Coriolis Effect

If pressure gradient force were the only force affecting windflow, the wind would blow at right angles across isobars (lines connecting points of equal barometric pressure) from high to low pressure. The wind actually blows parallel to isobars above any frictional level. Therefore, other factors must be affecting the windflow; one of these factors is the rotation of Earth. A particle at rest on Earth's surface is in equilibrium. If the particle starts to move because of a pressure gradient force, its relative motion is affected by the rotation of Earth. If a mass of air from the equator moves northward, it is deflected to the right, so that a south wind tends to become a southwesterly wind.

In the Northern Hemisphere, the result of the Coriolis effect is that moving air is deflected to the right of its path of motion. This deflection to the right is directly proportional to the speed of the wind; the faster the wind speed, the greater the deflection to the right, and conversely, the slower the wind speed, the less the deflection to the right. Finally, this apparent deflective force is stronger at the Polar Regions than at the equator.

Centrifugal Force

According to Newton's first law of motion, a body in motion continues in the same direction in a straight line and with the same speed unless acted upon by some external force. Therefore, for a body to move in a curved path, some force must be continually applied. The force restraining bodies that move in a curved path is called the *centripetal force*; it is always directed *toward* the center of rotation. When a rock is whirled around on a string, the centripetal force is afforded by the tension of the string.

Newton's third law states that for every action there is an equal and opposite reaction. *Centrifugal force* is the reacting force that is equal to and opposite in direction to the centripetal force. Centrifugal force, then, is a force directed *outward* from the center of rotation.

As you know, a bucket of water can be swung over your head at a rate of speed that allows the water to remain in the bucket. This is an example of both centrifugal and centripetal force. The water is held in the bucket by centrifugal force tending to pull it outward. The centripetal force, the force holding the bucket and water to the center, is your arm swinging the bucket. As soon as you cease swinging the bucket, the forces cease and the water falls out of the bucket. Figure 3-10 is a simplified illustration of centripetal and centrifugal force.

High- and low-pressure systems can be compared to rotating discs. Centrifugal effect tends to fling air out from the center of rotation of these systems. This force is directly proportional to the wind speeds, the faster the wind, and the stronger the outward force. Therefore, when winds tend to blow in a circular path, centrifugal effect (in addition to pressure gradient and Coriolis effects) influences these winds.

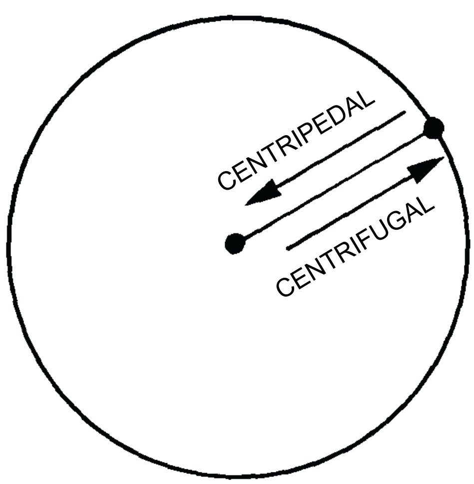

Figure 3-10.—Simplified illustration of centripetal and centrifugal force.

Frictional Force

The actual drag or slowing of air particles in contact with a solid surface is called friction. Friction tends to retard air movement. Since Coriolis force varies with the speed of the wind, a reduction in the wind speed by friction means a reduction of the Coriolis force. This results in a momentary disruption of the balance. When the new balance (including friction) is reached, the air flows at an angle across the isobars from high pressure to low pressure. (Pressure gradient force is the dominant force at the surface.) This angle varies from 10 degrees over the ocean to more than 45 degrees over rugged terrain. Frictional effects on the air are greatest near the ground, but the effects are also carried aloft by turbulence. Surface friction is effective in slowing the wind to an average altitude of 2,000 feet (about 600 meters) above the ground. Above this level, called the gradient wind level or the second standard level the effect of friction decreases rapidly and may be considered negligible. Air above 2,000 feet normally flows parallel to the isobars.

WIND TYPES

Since there is a direct relationship between pressure gradient and wind speed and direction, we have a variety of wind types to deal with. We discuss below the relationship of winds and circulations, the forces involved, and the effect of these factors on the general circulation.

Geostrophic and Gradient Wind

On analyzed surface weather charts, points of equal pressure are connected by drawn lines referred to as isobars, while in upper air analysis, points of equal heights are connected and called isoheights.

The variation of these heights and pressures from one locality to another is the initial factor that produces movement of air, or wind. Assume that at three stations the pressure is lower at each successive point. This means that there is a horizontal pressure gradient (a decrease in pressure in this case) for each unit distance. With this situation, the air moves from the area of greater pressure to the area of lesser pressure.

If the force of the pressure were the only factor acting on the wind, the wind would flow from high to low pressure, perpendicular to the isobars. Since experience shows the wind does not flow perpendicular to isobars, but at a slight angle across them and towards the lower pressure, it is evident that other factors are involved. These other factors are the Coriolis effect, frictional force, and centrifugal effect. When a unit of air moves with no frictional force involved, the movement of air is parallel to the isobars. This wind is called a gradient wind. When the isobars are straight, so only Coriolis and pressure gradient forces are involved, it is termed a geostrophic wind.

Let's consider a parcel of air from the time it begins to move until it develops into a geostrophic wind. As soon as a parcel of air starts to move due to the pressure gradient force, the Coriolis force begins to deflect it from the direction of the pressure gradient force. (See views A and B of fig. 3-11). The Coriolis force is the apparent force exerted upon the parcel of air due to the rotation of Earth. This force acts to the right of the path of motion of the air parcel in the Northern Hemisphere (to the left in the Southern Hemisphere). It always acts at right angles to the direction of motion. In the absence of friction, the Coriolis force changes the direction of motion of the parcel until the Coriolis force and the pressure gradient force are in balance. When the two forces are equal and opposite, the wind blows parallel to the straight isobars (view C in fig. 3-11). The Coriolis force only affects the direction, not the speed of the motion of the air. Normally, Coriolis force is not greater than the pressure gradient force. In the case of super-gradient winds, Coriolis force may be greater than the pressure gradient force. This causes the wind to deflect *more* to the right in the Northern Hemisphere, or toward higher pressure.

Under actual conditions, air moves around high and low pressure centers toward lower pressure. Turn back to figure 3-9. Here, the flow of air is from the area of high pressure to the area of low pressure, but, as we mentioned previously, it does not flow straight across the isobars (or isoheights). Instead, the flow is circular around the pressure systems.

The Coriolis force commences deflecting the path of movement to the right (Northern Hemisphere) or left (Southern Hemisphere) until it reaches a point where a balance exists between the Coriolis and the pressure gradient force. At this point the air is no longer deflected and moves forward around the systems.

Once circular motion around the systems is established, then centrifugal force must be considered. Centrifugal force acts outward from the center of both the highs and the lows with a force dependent upon the velocity of the wind and the degree of curvature of the isobars. However, the pressure gradient force is acting towards the low; therefore, the flow in that direction persists. When the flow is parallel to the curved portion of the analysis in figure 3-9, it is a *gradient wind*. When it is moving parallel to that portion of the analysis showing straight flow, it is a *geostrophic wind*.

We defined pressure gradient as being a change of pressure with distance. This means that if the isobars are closely spaced, then the pressure change is greater over a given distance; it is smaller if they are widely spaced. Therefore, the closer the isobars, the faster the flow. Geostrophic and gradient winds are also dependent, to a certain extent, upon the density of the atmosphere and the latitude. If the density and the pressure gradient remain constant and the latitude increases, the wind speed decreases. If the latitude

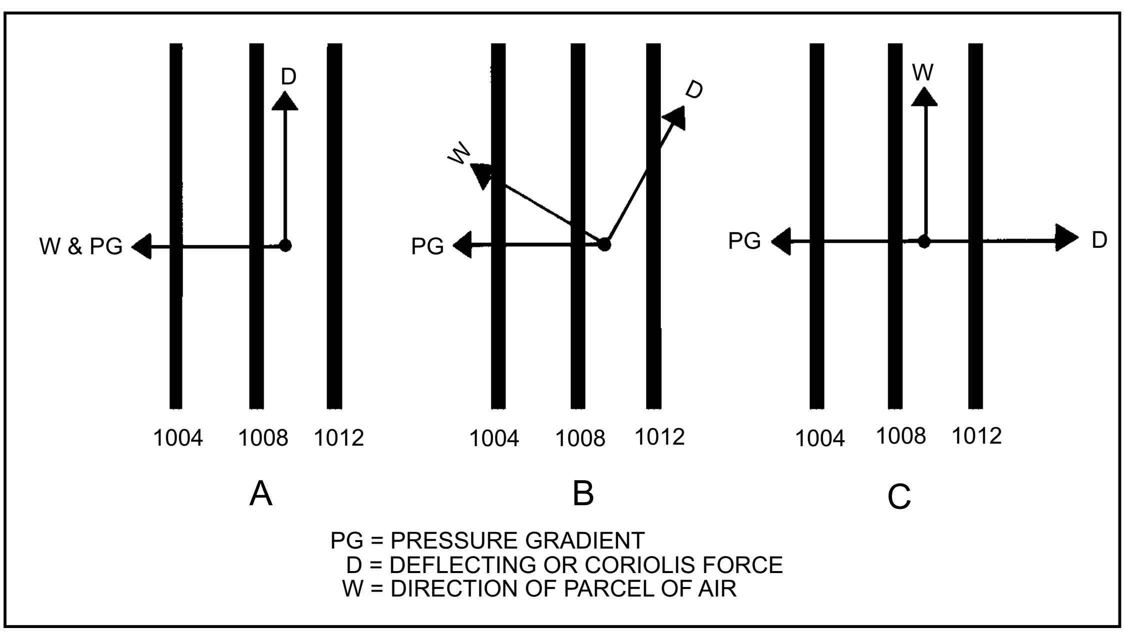

Figure 3-11.—Development cycle of a geostrophic wind.

decreases, the wind speed increases. If the density and the latitude remain constant and the pressure gradient decreases, the wind speed decreases. If the pressure gradient and the latitude remain constant and the density decreases, the wind speed increases. If the density increases, the wind speed decreases. True geostrophic wind is seldom observed in nature, but the conditions are closely approximated on upper-level charts.

Cyclostrophic Wind

In some atmospheric conditions, the radius of rotation becomes so small that the centrifugal force becomes quite strong in comparison with the Coriolis force. This is particularly true in low latitudes where the Coriolis force is quite small to begin with. In this case, the pressure gradient force is nearly balanced by the centrifugal force alone. When this occurs, the wind is said to be cyclostrophic. By definition, a cyclostrophic wind exists when the pressure gradient force is balanced by the centrifugal force alone.

This exact situation rarely exists, but is so nearly reached in some situations that the small Coriolis effect is neglected and the flow is said to be cyclostrophic. Winds in a hurricane or typhoon and the winds around a tornado are considered cyclostrophic.

Movement of Wind around Anticyclones

The movement of gradient winds around anticyclones is affected in a certain manner by the pressure gradient force, the centrifugal force, and the Coriolis force. The pressure gradient force acts from high to low pressure, and the Coriolis force acts opposite to the pressure gradient force and at right angles to the direction of movement of the parcel of air. The centrifugal force acts at right angles to the path of motion and outward from the center about which the parcel is moving. (See fig. 3-12.) In the case of a high-pressure center, the pressure gradient force and the centrifugal force balance the Coriolis force. This phenomenon may be expressed in the following manner:

$$PG + CF = D$$

Movement of Wind around Cyclones

As in the case of anticyclones, the pressure gradient force, the centrifugal force, and the Coriolis force affect gradient winds around cyclones, but the balance of the forces is different. (See fig. 3-12.) In a cyclonic situation the Coriolis force and the centrifugal force balance the pressure gradient force. This balance may be expressed in the following manner:

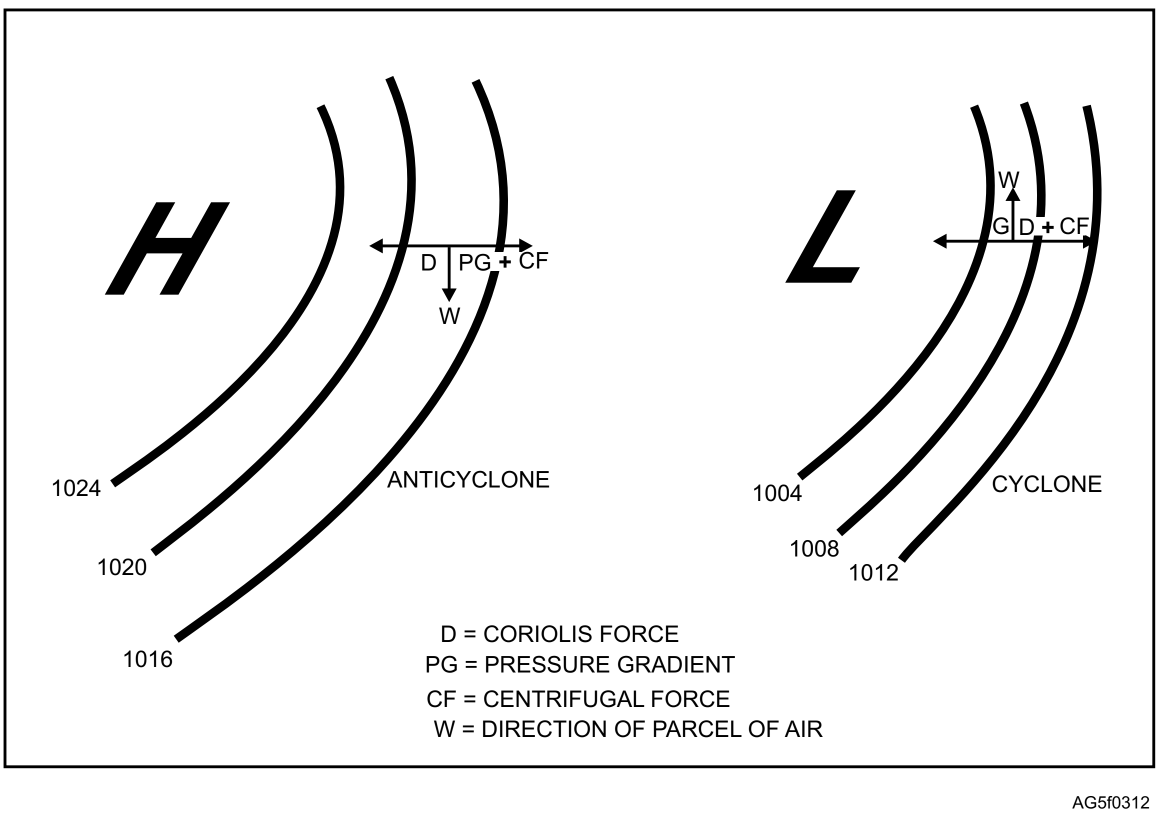

Figure 3-12.—Forces acting on pressure systems.

PG = D+ CF

Centrifugal force acts *with* the pressure gradient force when the circulation is anticyclonic and *against* the pressure gradient force when the circulation is cyclonic. Therefore, wind velocity is greater in an anticyclone than in a cyclone of the same isobaric spacing.

Variations

It has been determined that, given the same density, pressure gradient, and latitude, the wind is weaker around a low-pressure cell than a high-pressure cell. This is also true for gradient and geostrophic winds. The wind we observe on a synoptic chart is usually stronger around low cells than high cells because the pressure gradient is usually stronger around the low-pressure cell.

Geostrophic and Gradient Wind Scales

The geostrophic wind is stronger than the gradient wind around a low and is weaker than a gradient wind around a high. This is why the isobar spacing and contour spacing, for a curved flow, differs from that determined by a geostrophic wind scale. If the flow under consideration is around a high-pressure cell, the isobars are farther apart than indicated by the geostrophic wind scale. If the flow is around a low-pressure cell, the isobars are closer together than indicated by the geostrophic wind scale.

Geostrophic and gradient wind scales are used to determine the magnitude of these winds (based on isobar or contour spacing) and to determine the isobar or contour spacing (based on observed wind speeds). There are a number of scales available for measuring geostrophic and gradient flow of both surface and upper air charts.

Weather plotting charts used by the Naval Oceanography Command has geostrophic wind scales printed on them for both isobaric and contour spacing. The most common scales in general use can be used for both surface and upper air charts. The scales are in 4mb and 60m intervals. An example of a geostrophic wind scale is shown in figure 3-13. Note that latitude

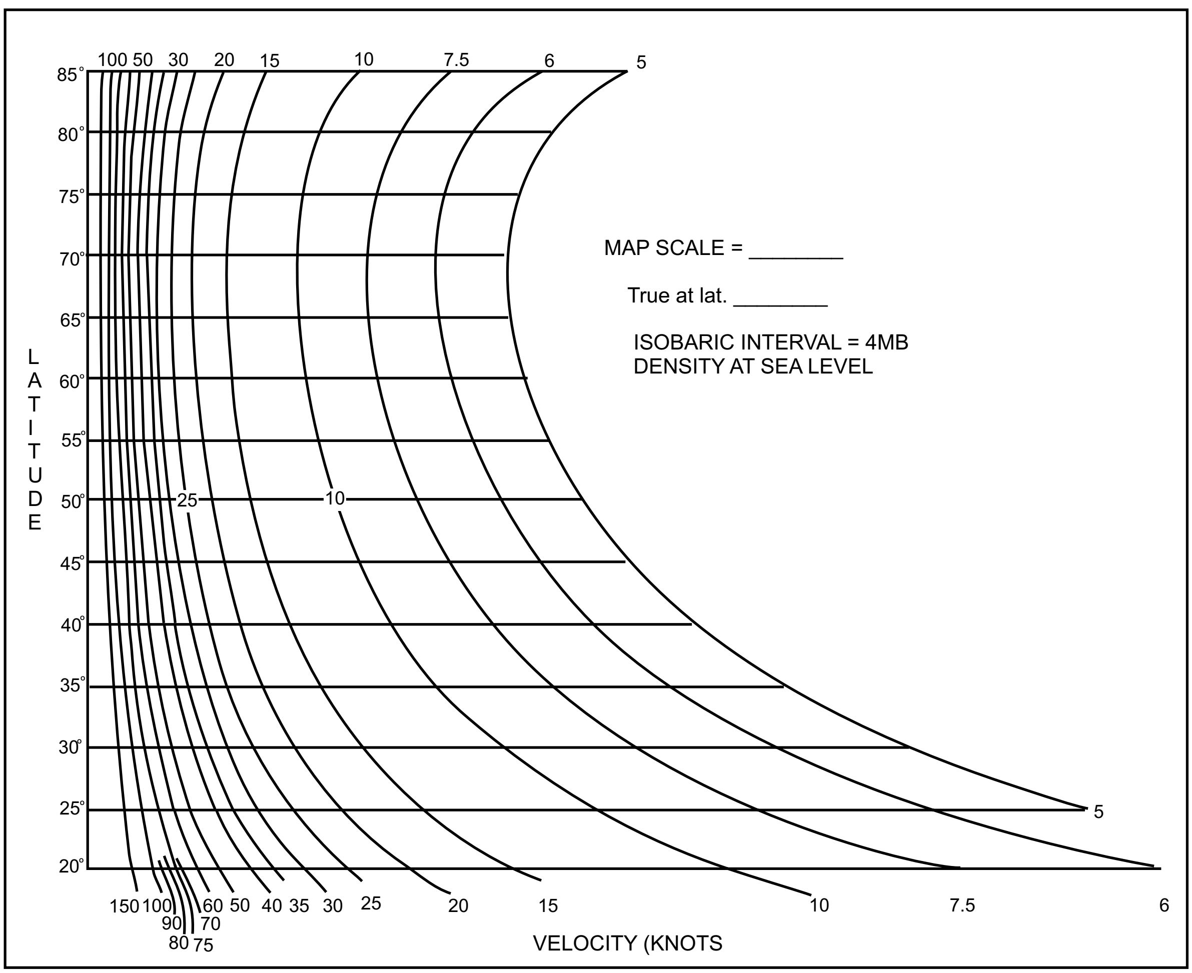

Figure 3-13.—Geostrophic wind scale.

accounts for the increases in gradients. In tropical regions, the geostrophic wind scales become less reliable because pressure gradients are generally rather weak.

REVIEW QUESTIONS

Q3-1. *Which two factors influence the Earth's temperature?*

Q3-2. *What are the major factors that result in the wide distribution of pressure over the earth's surface?*

Q3-3. *What effect does Coriolis force have on thermal circulation in the Northern Hemisphere?*

Q3-4. *According to the 3-cell theory, how many circulation belts are there?*

Q3-5. *According to the 3-cell theory, what type of pressure system would you normally find at 30 degrees north latitude?*

Q3-6. *What is the predominant wind system in the tropics?*

Q3-7. *Name two types of pressure gradient.*

Q3-8. *What is the difference between centrifugal force and centripetal force?*

Q3-9. *What is the difference between gradient wind and geostrophic wind?*

Q3-10. *What is the relationship between centrifugal force and pressure gradient force around anticyclones?*

SECONDARY CIRCULATION

LEARNING OBJECTIVE: Determine how centers of action, migratory systems, and seasonal variations affect secondary air circulations.

Now that you have a picture of the *general* circulation of the atmosphere over Earth, the next step is to see how land and water areas offset the general circulation. The circulations caused by the effect of Earth's surfaces, its composition and contour, are known as *secondary circulations*. These secondary circulations give rise to winds that often cancel out the normal effect of the great wind systems.

There are two factors that cause the pressure belts of the primary circulation to break up into closed circulations of the secondary circulations. They are the non-uniform surface of the earth and the difference between heating and cooling of land and water. The surface temperature of oceans changes very little during the year. However, land areas sometimes undergo extreme temperature changes with the seasons. In the winter, large high-pressure areas form over the cold land and the low-pressure areas form over the relatively warm oceans. *The reverse is true in summer when highs are over water and lows form over the warm land areas. The result of this difference in heating and cooling of land and water surfaces is known as the thermal effect.*

Circulation systems are also created by the interaction of wind belts of pressure systems or the variation in wind in combination with certain distributions of temperature and/or moisture. This is known as the dynamic effect. This effect rarely, if ever, operates alone in creating secondary systems, as most of the systems are both created and maintained by a combination of the thermal and dynamic effects.

CENTERS OF ACTION

The pressure belts of the general circulation are rarely continuous. They are broken up into detached areas of high and low pressure cells by the secondary circulation. The breaks correspond with regions showing differences in temperature from land to water surfaces. Turn back to figures 3-2A and 3-2B. Compare the temperature distribution in views A and B of figures 3-2 to the pressure distribution in views A and B of figure 3-3. Note the gradient over the Asian Continent in January. Compare it to the warmer temperature over the ocean and coastal regions. Now look at view A of figure 3-3 and note the strong region of high-pressure corresponding to the area. Now look at the same area in July. Note the way the temperature gradient flattens out and warms. Look at view B of figure 3-3 and see the low-pressure area that has replaced the high-pressure region of winter. These pressure cells tend to persist in a particular area and are called centers of action; that is, they are found at nearly the same location with somewhat similar intensity during the same month each year.

There is a permanent belt of relatively low pressure along the equator and another deeper belt of low-pressure paralleling the coast of the Antarctic Continent. Permanent belts of high pressure largely encircle Earth, generally over the oceans in both the Northern and Southern Hemispheres. The number of centers of action is at a maximum at about 30 to 35 degrees from the equator.

There are also regions where the pressure is predominantly low or high at certain seasons, but not throughout the year. In the vicinity of Iceland, pressure is low most of the time. The water surface is warmer (due to warm ocean currents) than the surface of Iceland or the icecaps of Greenland. The Icelandic low is most intense in winter, when the greatest temperature contrast occurs, but it persists with less intensity through the summer. Near Alaska, a similar situation exists with the Aleutian low. The Aleutian low is most pronounced when the neighboring areas of Alaska and Siberia are snow covered and colder than the adjacent ocean.

These lows are not a continuation of one and the same cyclone. They are, however, regions of low pressure where lows frequently form or arrive from other regions. Here they remain stationary or move sluggishly for a time, then the lows move on or die out and are replaced by others. Occasionally these regions of low pressure are invaded by traveling high-pressure systems.

Two areas of semi permanent high-pressure also exist. There is a semi permanent high-pressure center over the Pacific westward of California and another over the Atlantic, near the Azores and of the coast of Africa. Pressure is also high, but less persistently so, west of the Azores to the vicinity of Bermuda. These subtropical highs are more intense and cover a greater area in summer than winter. They also extend farther northward summer. In winter, these systems move soul toward the equator, following the solar equator.

The largest individual circulation cells in the Northern Hemisphere are the Asiatic high in winter and the Asiatic low in summer. In winter, the Asiatic continent is a region of strong cooling and therefore is dominated by a large high-pressure cell. In summer, strong heating is present and the high-pressure cell becomes a large low-pressure cell. (See fig. 3-3A and fig. 3-3B.) This seasonal change in pressure cells gives rise to the monsoon flow over India and Southeast Asia.

Another cell that is often considered to be a center of action is the polar high. Both Arctic and Antarctic highs have considerable variations in pressure, and these regions have many traveling disturbances in summer. For example, the Greenland high (due to the Greenland icecap) is a persistent feature, but it is not a well-defined high during all seasons of the year. The Greenland high often appears to be an extension of the polar high or vice versa. Other continental regions show seasonal variations, but are generally of small size and their location is variable. Therefore, they are not considered to be centers of action.

An average annual pressure distribution chart (figure 3-14) reveals several important characteristics. First, along the equator there is a belt of relatively low pressure encircling the globe with barometric pressure of about 1,012 millibars. Second, on either side of this belt of low pressure is a belt of high pressure. This high-pressure area in the Northern Hemisphere lies mostly between latitudes 30° and 40°N with three well-defined centers of maximum pressure. One is over the eastern Pacific, the second over the Azores and the third over Siberia; all are about 1,020 millibars. The belt of high pressure in the Southern Hemisphere is roughly parallel to 30°S. It, too, has three centers of maximum pressure. One is in the eastern Pacific, the second in the eastern Atlantic, and the third in the Indian Ocean; again, all are about 1,020 millibars. A third characteristic to be noted from this chart is that, beyond the belt of high pressure in either hemisphere, the pressure diminishes toward the poles. In the Southern Hemisphere, the decrease in pressure toward the South Pole is regular and very marked. The pressure decreases from, an average slightly above 1,016 millibars along latitude 35°S to an average of 992 millibars along latitude 60°S In the Northern Hemisphere, however, the decrease in pressure toward the North Pole is less regular and not as great. This is largely due to the distribution of land and water: note the extensive landmass in the Northern Hemisphere as compared to those of the Southern Hemisphere.

While the pressure belts that stand out on the average annual pressure distribution chart represent average pressure distribution for the year, these belts are rarely continuous on any given day. They are usually broken up into detached areas of high or low pressure by the secondary circulation of the atmosphere. In either hemisphere, the pressure over the land during the winter season is decidedly above the annual average. During the summer season, the pressure is decidedly below the average, with extreme variations occurring such as in the case of continental Asia. Here the mean monthly pressure ranges from about 1,033 millibars during January to about 999 millibars during July. Over the northern oceans, on the other hand, conditions are reversed; the summer pressure there is somewhat higher. Thus in January the Icelandic and Aleutian lows intensify to a depth of about 999 millibars, while in July these lows fill and are almost obliterated.

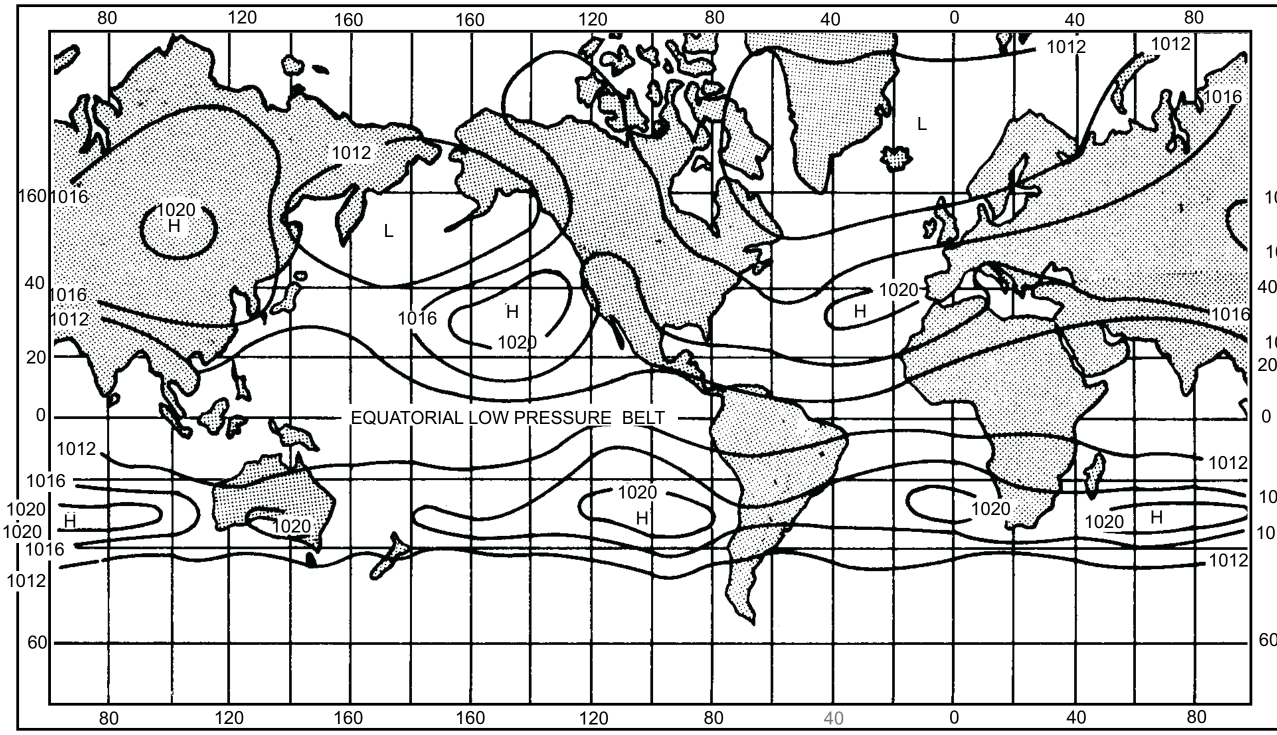

Figure 3-14.—Average annual pressure distribution chart.

The polar high in winter is not a cell centered directly over the North Pole, but appears to be an extension of the Asiatic high and often appears as a wedge extending from the Asiatic continent. The cell is displaced toward the area of coldest temperatures—the Asiatic continent. In summer, this high appears as an extension of the Pacific high and is again displaced toward the area of coolest temperature, which in this case is the extensive water area of the Pacific.

In winter over North America, the most significant feature is the domination by a high-pressure cell. This cell is also due to cooling but is not as intense as the Asiatic cell. In summer, the most significant feature is the so-called heat low over the southwestern part of the continent, which is caused by extreme heating in this region.

MIGRATORY SYSTEMS

General circulation, based on an average of wind conditions, is a more or less quasi-stationary circulation. Likewise, much of the secondary circulation depends on more or less static conditions that, in turn, depend on permanent and semi permanent high and low-pressure areas. Changes in the circulation patterns discussed so far have been largely seasonal. However, secondary circulation also includes wind systems that migrate constantly, producing rapidly changing weather conditions throughout all seasons, especially in the middle latitudes. The migratory circulation systems are associated with air masses, fronts, cyclones, and anticyclones. These are covered in detail in the next unit.

Anticyclones

An anticyclone (high) is an area of relatively high pressure with a clockwise flow (wind circulation) in the Northern Hemisphere and counterclockwise flow in the Southern Hemisphere. The windflow in an anticyclone is slightly across the isobars and away from the center of the anticyclone. (See fig. 3-15.) Anticyclones are commonly called highs or high-pressure areas.

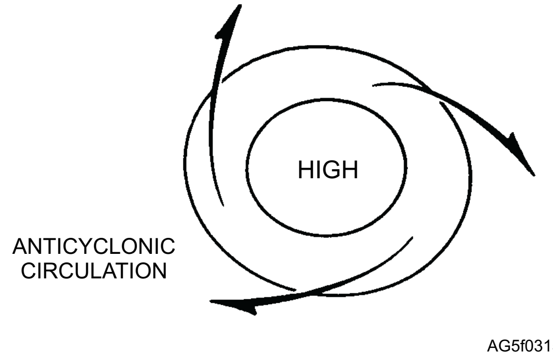

Figure 3-15.—Anticyclone.

The formation of an anticyclone or the intensification of an existing one is called *anticyclogenesis*. Anticyclogenesis refers to the development of anticyclonic circulation as well as the intensification of an existing anticyclonic flow. When a high-pressure center is increasing in pressure, the high is BUILDING or INTENSIFYING. Although a high can build (or intensify) without an increase in anticyclonic flow, it is rare. Normally, building and anticyclogenesis occur simultaneously. The weakening of anticyclonic circulation is *anticyclolysis*. When the pressure of a high is decreasing, we say the high is weakening. Anticyclolysis and weakening can occur separately, but usually occur together.

The vertical extent of pressure greatly depends on the air temperature. Since density increases with a decrease in temperature, pressure decreases more rapidly vertically in colder air than in warmer air. In a cold anticyclone (such as the Siberian high), the vertical extent is shallow; while in a warm anticyclone (such as the subtropical high), the vertical extent reaches high into the upper atmosphere due to the slow decrease in temperature with elevation.

Cyclones

A cyclone (low) is a circular or nearly circular area of low pressure with a counterclockwise flow. The flow is slightly across the isobars toward the center in the Northern Hemisphere and clockwise in the Southern Hemisphere. (See fig. 3-16.) It is commonly called a low or a depression. This use of the word cyclone should be distinguished from the colloquial use of the word as applied to the tornado or tropical cyclone (hurricane).

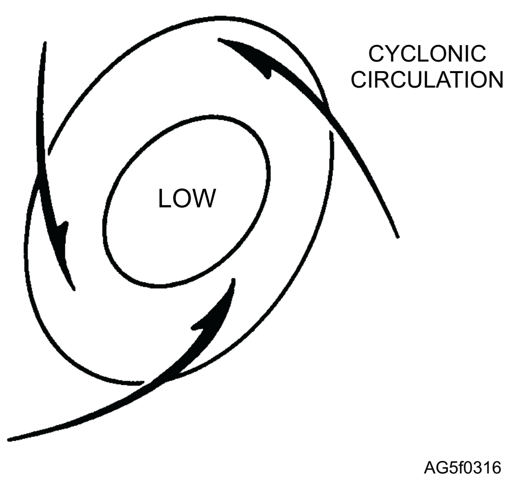

Figure 3-16.—Cyclone.

The formation of a new cyclone or the intensification of the cyclonic flow in an existing one is called *cyclogenesis*. When the pressure in the low is falling, we say the low is deepening. Cyclogenesis and deepening can also occur separately, but usually occur at the same time. The decrease or eventual dissipation of a cyclonic flow is called *cyclolysis*. When the pressure in a low is rising, we say the low is filling. Cyclolysis and filling usually occur simultaneously. Cyclones in middle and high latitudes are referred to as extratropical cyclones. The term *tropical cyclone* refers to hurricanes and typhoons.

VERTICAL STRUCTURE OF SECONDARY CIRCULATIONS (PRESSURE CENTERS)

To better understand the nature of the pressure centers of the secondary circulation, it is necessary to consider them from a three-dimensional standpoint. With the aid of surface and upper air charts, you will be able to see the three dimensions of these pressure systems as well as the circulation patterns of the secondary circulation as established at higher levels in the troposphere and lower stratosphere.

In Chapter 2, the study of gas laws showed that volume is directly proportional to temperature. Stated another way, we might say that the thickness of a layer between two isobaric surfaces is directly proportional to the mean virtual temperature of the layer. Because the atmosphere is always moist to some degree, virtual temperature is used. Mean virtual temperature is defined as the average temperature at which dry air would have the same pressure and density as moist air. Thus, lines representing thickness are also isotherms of mean virtual temperature. The higher the mean virtual temperature, the thicker the layer, or vice versa. The thickness between layers is expressed in geopotential meters. The shift in location, as well as the change of shape and intensity upward of atmospheric pressure systems, is dependent on the temperature distribution.

An example of the effects of virtual temperature can be demonstrated by placing two columns of air next to each other. One air column is cold and the other air column is warm. The constant pressure surfaces in the cold column are closer than the ones in the warm column. Figure 3-17 shows an increase in thickness between two pressure surfaces, resulting in an increase in mean virtual temperature. Note the increase in the distance between the constant pressure surfaces; P, P1, etc., from column A to column B. Using the hypsometric equation can derive the thickness value between two pressure surfaces. Thickness may also be determined from tables, graphs, etc.

VERTICAL STRUCTURE OF HIGH PRESSURE SYSTEMS

The topographic features that indicate the circulation patterns at 500 millibars in the atmosphere correspond in general to those at lower and higher level. However, they may experience a shift in location as well as a change in intensity and shape. For example, a ridge aloft may reflect a closed high on a surface synoptic chart. In addition, upper air circulation patterns may take on a wavelike structure in contrast to the alternate closed lows, or closed high patterns at the surface level. The smoothing of the circulation pattern aloft is typical of atmospheric flow patterns.

Cold Core Highs

A cold core high is one in which the temperatures on a horizontal plane decrease toward the center.

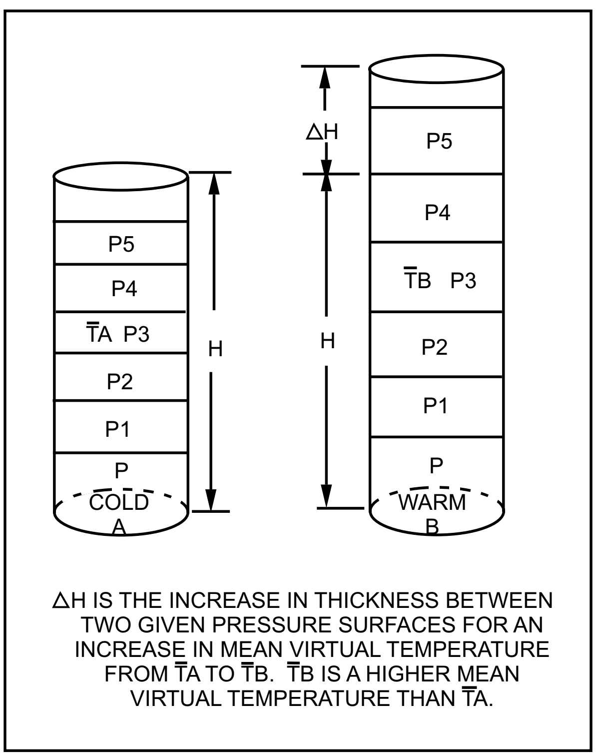

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Figure 3-17.—Thickness of two strata as a function of means virtual temperature.

Because the temperature in the center of a cold core high is less than toward the outside of the system, it follows that the vertical spacing of isobars in the center of this system is closer together than on the outside. Although the pressure at the center of these systems on the surface may be high, the pressure decreases rapidly with height. (See fig. 3-18.) Because these highs are often quite shallow, it is common for an upper level low to exist above a cold core high.

NOTE: For the purpose of illustration, figures 3-18 through 3-21 are exaggerated with respect to actual atmospheric conditions.

If the cold core high becomes subjected to warming from below and to subsidence from aloft, as it moves southward from its source and spreads out, it diminishes rapidly in intensity with time (unless some dynamic effect sets in aloft over the high to compensate for the warming). Since these highs decrease in intensity with height, thickness is relatively low. In the vertical, cold core highs slope toward colder air aloft. Anticyclones found in Arctic air are always cold cored, while anticyclones in polar air may be warm or cold core.

Examples of cold core highs are the North American High, the Siberian High and the migratory highs that originate from these anticyclones.

Warm Core Highs

A warm core high is one in which the temperatures on a horizontal level increase toward the center. Because the temperatures in the center of a warm core high are higher than on the outside of the system, it follows that the vertical spacing of isobars in the center is farther apart than toward the outside of the high. For this reason, a warm core high increases in intensity with altitude and has an anticyclonic circulation at all levels (see fig. 3-19). From a vertical view, warm core highs slope toward warmer air aloft. A warm core high is accompanied by a high cold tropopause. Since the pressure surfaces are spaced far apart, the tropopause is reached only at great heights. The temperature continues to decrease with elevation and is cold by the

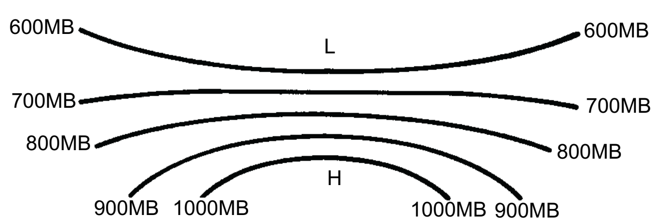

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Figure 3-18.—Cold core high.

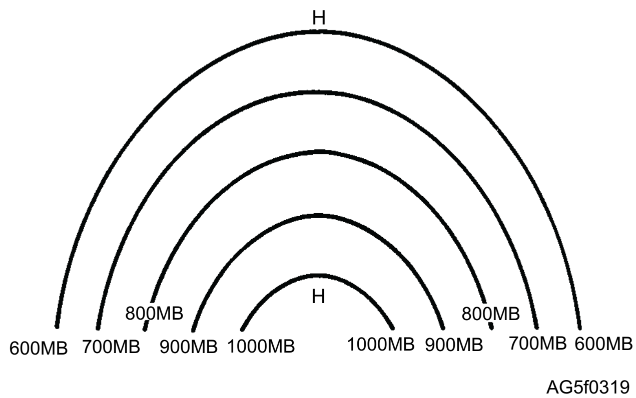

Figure 3-19.—Warm core high.

time the tropopause is reached. The subtropical highs are good examples of this type of high. Therefore, anticyclones found in tropical air are always warm core. Examples of warm core highs are the Azores or Bermuda High and the Pacific High.

VERTICAL STRUCTURE OF LOW-PRESSURE SYSTEMS

Low-pressure systems, like high-pressure systems, are generally a reflection of systems aloft. They, too, experience shifts in location and changes in intensity and shape with height. At times, a surface system may not be evident aloft and a well-developed system aloft may not reflect on a surface analysis.

Cold Core Lows

The cold core low contains the coldest air at its center throughout the troposphere; that is, going outward in any direction at any level in the troposphere, warmer air is encountered. The cold core low (figure 3-20) increases intensity with height. Relative minimums in thickness values, called cold pools, are found in such cyclones. The temperature distribution is almost symmetrical, and the axis of the low is nearly vertical. When they do slope vertically, they slope toward the coldest temperatures aloft. In the cold low, the lowest temperatures coincide with the lowest pressures.

The cold low has a more intense circulation aloft from 850 to 400 millibars than at the surface. Some cold lows show only slight evidence in the surface pressure field that an intense circulation exists aloft. The cyclonic circulation aloft is usually reflected on the surface in an abnormally low daily mean temperature often accompanied by instability and showery precipitation. A cold core low is accompanied by a low warm tropopause. Since the pressure surfaces are close together, the tropopause is reached at low altitudes where the temperature is relatively warm. Good examples of cold core lows are the Aleutian and Icelandic lows. Occluded cyclones are generally cold core in their later stages, because polar or arctic air has closed in on them.

At high latitudes the cold pools and their associated upper air lows show some tendency for location in the northern Pacific and Atlantic Oceans where, statistically, they contribute to the formation of the Aleutian and Icelandic lows.

Warm Core Lows

A warm core low (figure 3-21) decreases intensity with height and the temperature increases toward the center on a horizontal plane. The warm low is frequently stationary, such as the heat low over the southwestern United States in the summer; this is a result of strong heating in a region usually insulated from intrusions of cold air that tend to fill it or cause it to move. The warm low is also found in its moving form as a stable wave moving along a frontal surface. There is no warm low aloft in the troposphere. The tropical cyclone, however, is believed to be a warm low because its intensity diminishes with height. Because most warm lows are shallow, they have little slope. However, intense warm lows like the heat low over the southwest United States and hurricanes do slope toward warm air aloft.

In general, the temperature field is quite asymmetrical around a warm core cyclone. Usually the southward moving air in the rear of the depression is

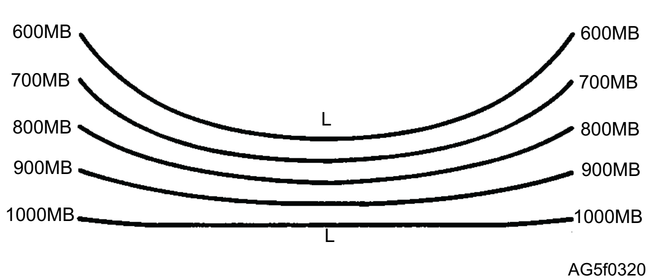

Figure 3-20.—Cold core low.

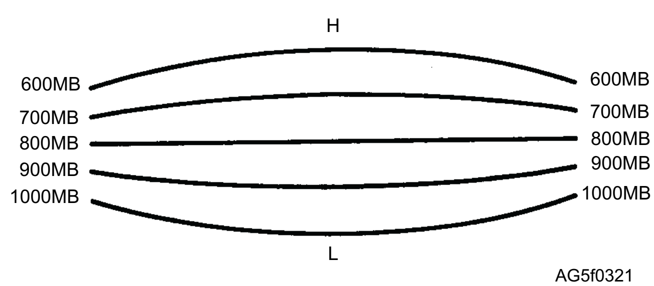

Figure 3-21.—Warm core low.

not as warm as that moving northward in advance of it. A warm core low decreases intensity with height or completely disappears and are often replaced by anticyclones aloft. The heat lows of the southwestern United States, Asia, and Africa are good examples of warm core lows. Newly formed waves are generally warm core because of the wide-open warm sector.

DYNAMIC LOW

Systems that retain their closed circulations to appreciable altitudes and are migratory are called dynamic lows or highs. A dynamic low is a combination of a warm surface low and a cold upper low or trough, or a warm surface low in combination with a dynamic mechanism aloft for producing a cold upper low or trough. It has an axis that slopes toward the coldest tropospheric air. (See figure 3-22.) In the final stage, after occlusion of the surface warm low is complete, the dynamic low becomes a cold low with the axis of the low becoming practically vertical.

DYNAMIC HIGH

The dynamic high is a combination of a surface cold high and an upper-level warm high or well-developed ridge, or a combination of a surface cold high with a dynamic mechanism aloft for producing high-level anticyclogenesis. Dynamic highs have axes that slope toward the warmest tropospheric air. (See fig. 3-22.) In the final stages of warming the cold surface high, the dynamic high becomes a warm high with its axis practically vertical.

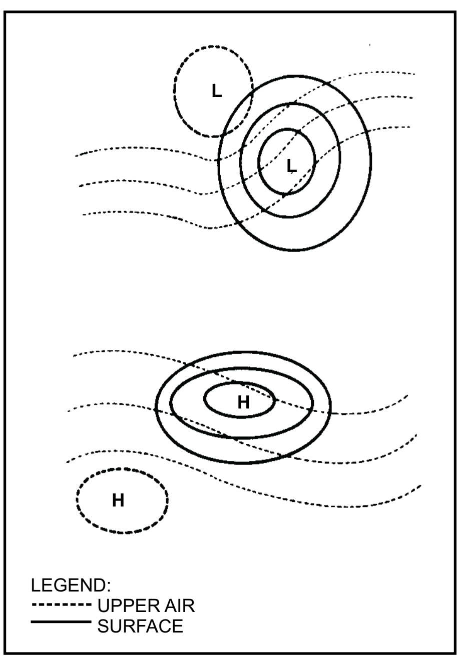

Figure 3-22.—Vertical slope of low -pressure systems.

REVIEW QUESTIONS

Q3-11. What is the term that defines the formation of an anticyclone or the intensification of an existing anticyclone?

Q3-12. What is the direction of the windflow around a cyclone?

Q3-13. How do temperatures change within a cold core low?

Q3-14. Low pressure due to intense heating over the southwestern United States is an example of which type of low-pressure system?

TERTIARY CIRCULATION

LEARNING OBJECTIVE: Define tertiary circulation and describe how tertiary circulations affect local weather and wind direction and speed.

Tertiary (third order) circulations are localized circulations directly attributable to one of the following causes or a combination of them: local cooling, local heating, adjacent heating or cooling, and induction (dynamics).

Many regions have local weather phenomena caused by temperature differences between land and water surfaces or by local topographical features. These weather phenomena show up as circulations. These tertiary circulations can result in dramatic local weather conditions and wind flows. The most common tertiary circulations are discussed in this lesson. However, there are numerous other circulations and related phenomena in existence around the world.

MONSOON WINDS

The term *monsoon* is of Arabic origin and means season. The monsoon wind is a seasonal wind that blows from continental interiors (or large land areas) to the ocean in the winter; they blow in the opposite direction during the summer. The monsoon wind is most pronounced over India, although there are other regions with noticeable monsoon winds.

Monsoon winds are a result of unequal heating and cooling of land and water surfaces. During winter a massive area of cold high pressure develops over the extensive Asiatic continent. This high pressure is due primarily to cold arctic air and long-term radiation cooling. To the south, the warm equatorial waters exist and, in contrast, the area has relatively lower surface pressures. The combination of high pressure over Asia

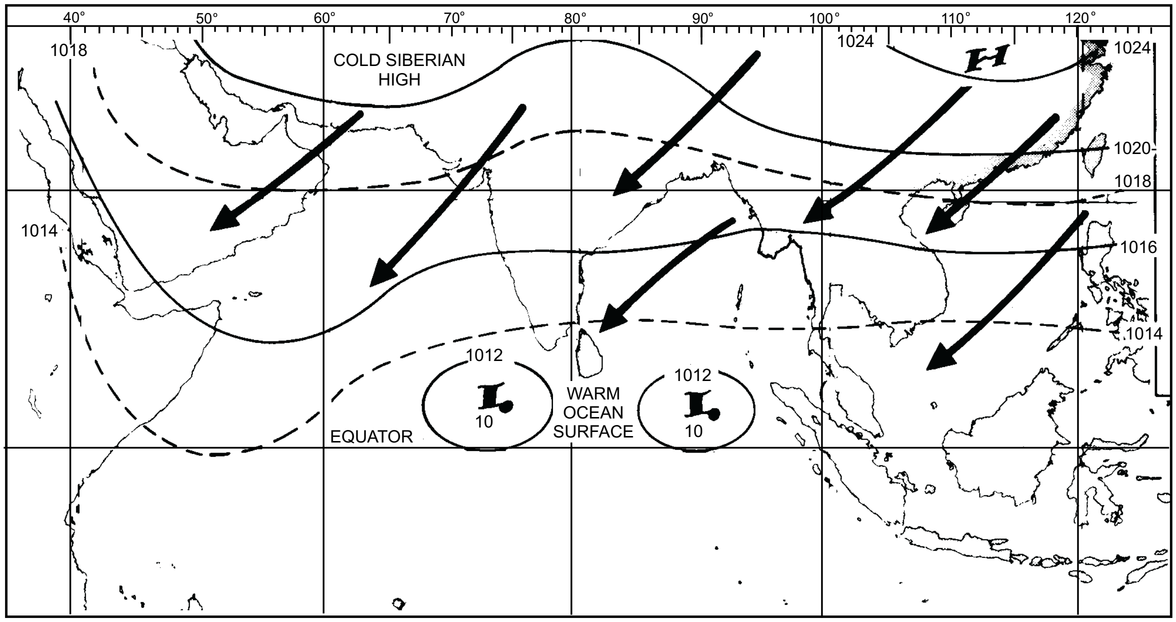

Figure 3-23.—Northeast monsoon (January).

and low pressure over the Equatorial Belt sets up a pressure gradient directed from north to south. Because of the flow around the massive Siberian high, northeast winds begin to dominate the regions from India to the Philippines. (See fig. 3-23).

During the winter months, clear skies predominate over most of the region. This is caused by the mass motion of air from a high-pressure area over land to an area of lower pressure over the ocean. As the air leaves the high-pressure area over land, it is cold and dry. As it travels over land toward the ocean, there is no source of moisture to induce precipitation. The air is also traveling from a higher altitude to a lower altitude; consequently, this downslope motion causes the air to be warmed at the adiabatic lapse rate. This warming process has a still further clearing effect on the skies.

During the summer the airflow over the region is completely reversed. The large interior of Asia is heated to the point where the continent is much warmer than the ocean areas to the south. This induces relatively low pressure over Asia and higher pressure over the equatorial region. This situation produces a southwesterly flow as shown in figure 3-24.

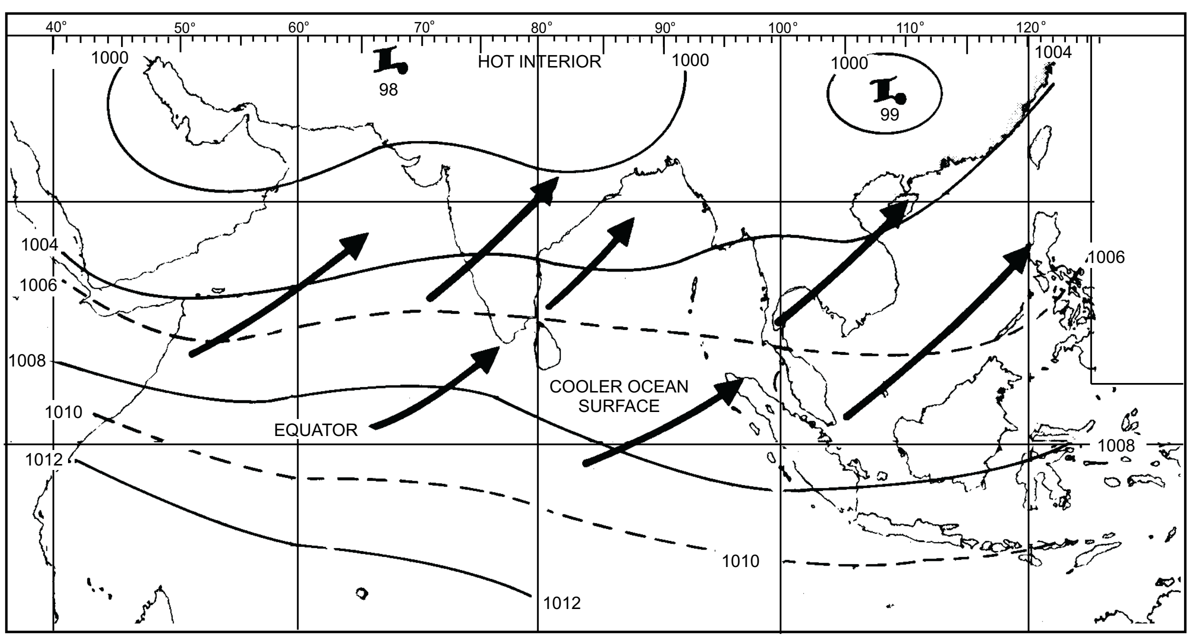

Figure 3-24.—Southwest monsoon (July).

The weather associated with the summer monsoon winds is thunderstorms, almost constant heavy rain, rain showers, and gusty surface winds. This condition is caused by mass motion of air from the relatively high-pressure area over the ocean to a low-pressure area over land. When the air leaves the ocean, it is warm and moist. As the air travels over land toward the low-pressure area, it is also traveling from a lower altitude to a higher altitude. The air is lifted by a mechanical force and cooled to its condensation point by this upslope motion (pseudo adiabatic process).

LAND AND SEA BREEZES

There is a diurnal (daily) contrast in the heating of local water and land areas similar to the seasonal variation of the monsoon. During the day, the land is warmer than the water area; at night the land area is cooler than the water area. A slight variation in pressure is caused by this temperature contrast. At night the wind blows from land to sea and is called a land breeze. During the day, the wind blows from water areas to land areas and is called a sea breeze.

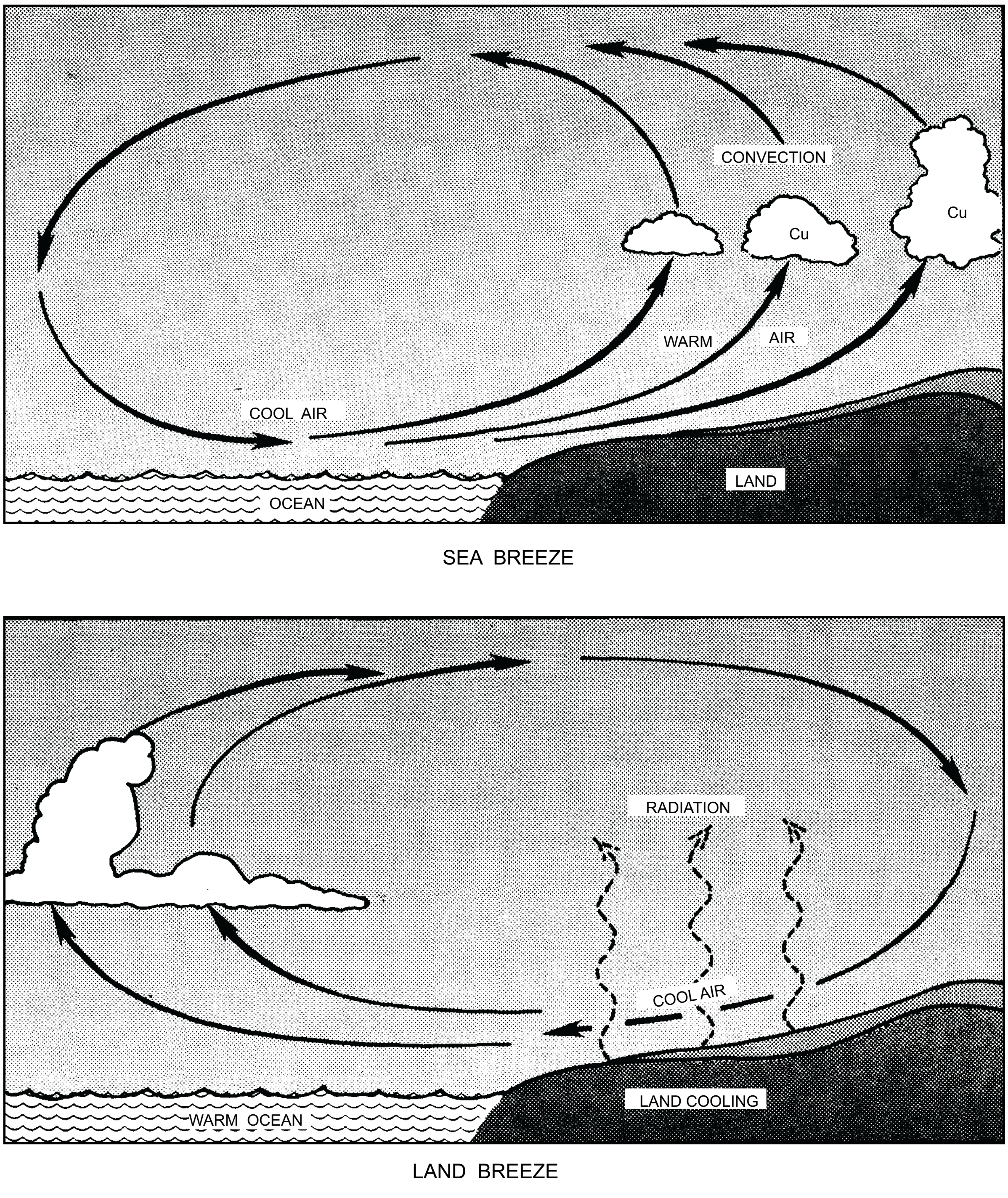

Figure 3-25.—Circulation of land and sea breezes.

The sea breeze usually begins during midmorning (0900-1100 local time) when the land areas become warmer than adjacent ocean waters (see fig. 3-25). This temperature difference creates an area of slightly lower surface pressures over land compared to the now cooler waters. The result is a wind flow from water to land. The sea breeze starts with a shallow flow along the surface; however, as maximum heating occurs, the flow increases with height. The height varies from an average of 3,000 feet in moderately warm climates to 4,500 (or more) in tropical regions. The effects of the sea breeze can be felt as far as 30 miles both onshore and offshore. In extreme cases, the sea breeze is felt 100 miles inland depending upon terrain. By mid afternoon (maximum heating) the sea breeze will reach its maximum speed and may be strong enough to be influenced by the Coriolis force, which causes it to flow at an angle to the shore. The sea breeze is most pronounced in late spring, summer, and early fall when maximum temperature differences occur between land and water surfaces. A decrease in temperature and an increase in humidity and wind speed mark the start of a sea breeze.

The sea breeze continues until the land area cools sufficiently to dissipate the weak low pressure. After sunset, the land cools at a faster rate than the adjacent waters and eventually produces a complete reversal of the winds. As the land continues to cool through the evening hours, a weak area of high pressure forms over the land. The water area, with its warmer temperatures, has slightly lower pressure and again a flow is established; however, the flow is now from land to water (offshore). (See fig. 3-25.)

The land breezes, when compared to the sea breezes, are less extensive and not as strong (usually less than 10 knots and less than 10 miles offshore). This is because there is less temperature contrast at night between land and water surfaces as compared to the temperature contrast during daytime heating. Land breezes are at maximum development late at night, in late fall and early winter. In the tropical land regions, the land and sea breezes are repeated day after day with great regularity. In high latitudes the land and sea breezes are often masked by winds of synoptic features.

WINDS DUE TO LOCAL COOLING AND HEATING

In the next sections we discuss tertiary circulations due to local cooling and heating effects. Under normal circumstances, these winds attain only light to moderate wind speeds; however, winds often occur in and near mountain areas that have undergone dramatic changes in normal character. At times, mountain areas tend to funnel winds through valleys and mountain passes. This funneling effect produces extremely dangerous wind speeds.

FUNNEL EFFECT

Winds blowing against mountain barriers tend to flatten out and go around or over them. If a pass or a valley breaks the barrier, the air is forced through the break at considerable speed. When wind is forced through narrow valleys it is known as the funnel effect and is explained by Bernoulli's theorem. According to Bernoulli's theorem, pressures are least where velocities are greatest; likewise, pressures are greatest where velocities are least. This observation is true for both liquids and gases. (See fig. 3-26.)

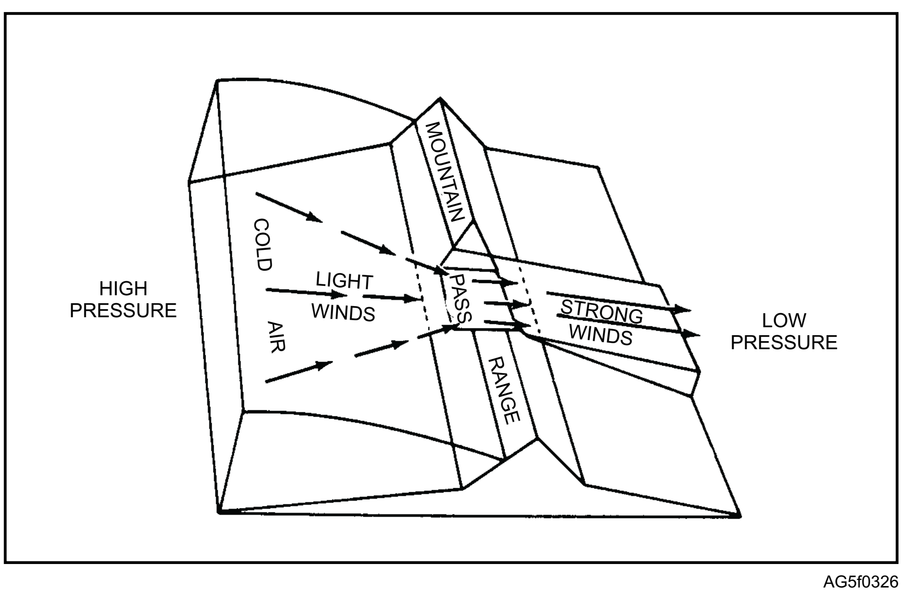

Figure 3-26.—Strong wind produced by funneling.

Bernoulli's theorem is frequently used to forecast tertiary winds in the mountainous western United States. The famous Santa Ana winds of southern California are a prime example. Winds associated with high pressure situated over Utah are funneled through the valley leading into the town of Santa Ana near the California coast. Low pressure develops at the mouth of the valley and the end result is hot, dry, gusty and extremely dangerous winds. When the Santa Ana is strong enough, the effects are felt in virtually every valley located along the coast of southern California. Visibility is often restricted due to blowing sand. It is common to see campers, trailers, and trucks turned over by the force of these winds. When funneled winds reach this magnitude, they are called jet-effect winds, canyon winds, or mountain-gap winds.

Winds Due to Local Cooling and Heating

There are two types of tertiary circulations produced by local cooling—glacier winds and drainage winds.

GLACIER WINDS.—Glacier winds, or fall winds (as they are sometimes called) occur in many varieties in all parts of the world where there are glaciers or elevated land masses that become covered by snow and ice during winter. During winter, the area of snow cover becomes most extensive. Weak pressure results in a maximum of radiation cooling. Consequently the air coming in contact with the cold snow cools. The cooling effect makes the overlying air more dense, therefore, heavier than the surrounding air. When set in motion, the cold dense air flows down the sides of the glacier or plateau. If it is funneled through a pass or valley, it may become very strong. This type of wind may form during the day or night due to radiation cooling. The glacier wind is most common during the winter when more snow and ice are present.

When a changing pressure gradient moves a large cold air mass over the edge of a plateau, this action sets in motion the strongest, most persistent, and most extensive of the glacier or fall winds. When this happens, the fall velocity is added to the pressure gradient force causing the cold air to rush down to sea level along a front that may extend for hundreds of miles. This condition occurs in winter on a large scale along the edge of the Greenland icecap. In some places along the icecap, the wind attains a velocity in excess of 90 knots for days at a time and reaches more than 150 nautical miles out to sea.

Glacier winds are cold katabatic (downhill) winds. Since all katabatic winds are heated adiabatically in their descent, they are predominantly dry. Occasionally, the glacier winds pick up moisture from falling precipitation when they underride warm air. Even with the adiabatic heating they undergo, all glacier or fall winds are essentially cold winds because of the extreme coldness of the air in their source region. Contrary to all other descending winds that are warm and dry, the glacier wind is cold and dry. It is colder, level for level, than the air mass it is displacing. In the Northern Hemisphere, the glacier winds descend frequently from the snow-covered plateaus and glaciers of Alaska, Canada, Greenland, and Norway.

DRAINAGE WINDS.—Drainage winds (also called mountain or gravity winds) are caused by the cooling air along the slopes of a mountain. Consequently, the air becomes heavy and flows downhill, producing the MOUNTAIN BREEZE.

Drainage winds are katabatic winds and like glacier winds; a weak or nonexistent pressure gradient is required to start the downward flow. As the air near the top of a mountain cools through radiation or contact with colder surfaces, it becomes heavier than the surrounding air and gradually flows downward (fig. 3-27). Initially this flow is light (2 to 4 knots) and only a few feet thick. As cooling continues, the flow increases achieving speeds up to 15 knots at the base of the mountain and a depth of 200 feet or more. Winds in excess of 15 knots are rare and only occur when the mountain breeze is severely funneled.

Drainage winds are cold and dry. Adiabatic heating does not sufficiently heat the descending air because of the relative coldness of the initial air and because the distance traveled by the air is normally short. Drainage winds have a very localized circulation. As the cold air enters the valley below, it displaces the warm air. Temperatures continue to fall. If the flow achieves speeds of 8 knots or more, mixing results between the warm valley air and the cold descending air that results in a slight temperature increase. Campers often prefer to make summer camps at the base of mountains to take advantage of the cooling effect of the mountain breeze.

Funnel Effects

VALLEY BREEZES.—The valley breeze is the anabatic (uphill) counterpart of the mountain breeze. When the sun heats the valley walls and mountain slopes during the morning hours, the air next to the ground is heated until it rises along the slopes. Rocky or

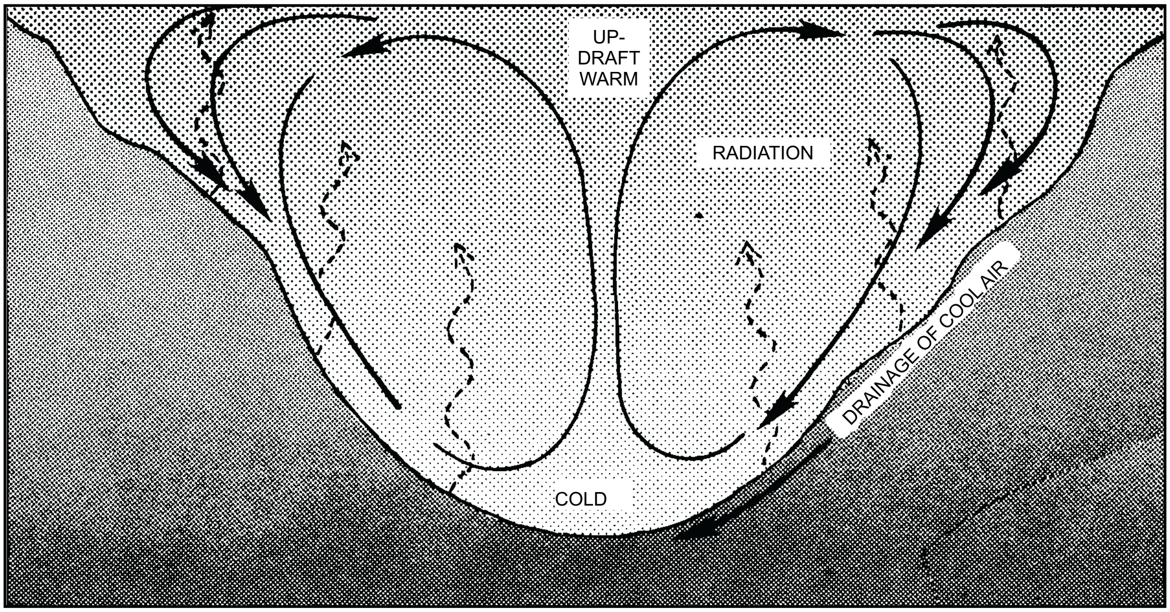

Figure 3-27.—Mountain breeze or katabatic wind. During the night outgoing radiation cools air along hillsides below free air temperature. The cooled air drains to lowest point of the terrain.

sandy slopes devoid of vegetation are the most effective heating surfaces. If the slopes are steep, the ascending breeze tends to move up the valley walls. The expansion of the heated air next to the surface produces a slight local pressure gradient against the ground surface. As the heating becomes stronger, convective currents begin to rise vertically from the valleys (figure 3-28). The updrafts along the valley walls continue to be active, particularly at the head of the valley. The valley breeze usually reaches its maximum strength in the early afternoon. It is a stronger and deeper wind than the mountain breeze. It is difficult to isolate the valley breeze effect because of the prevailing gradient winds. Consequently, the valley breeze is much more likely to be superposed as a prevailing wind than is the mountain breeze, which by its very nature can develop only in the absence of any appreciable gradient wind. The valley breezes are generally restricted to slopes facing south or the more direct rays of the sun, and they are more pronounced in southern latitudes. They are diurnally strongest in the late afternoon and are seasonally strongest in summer.

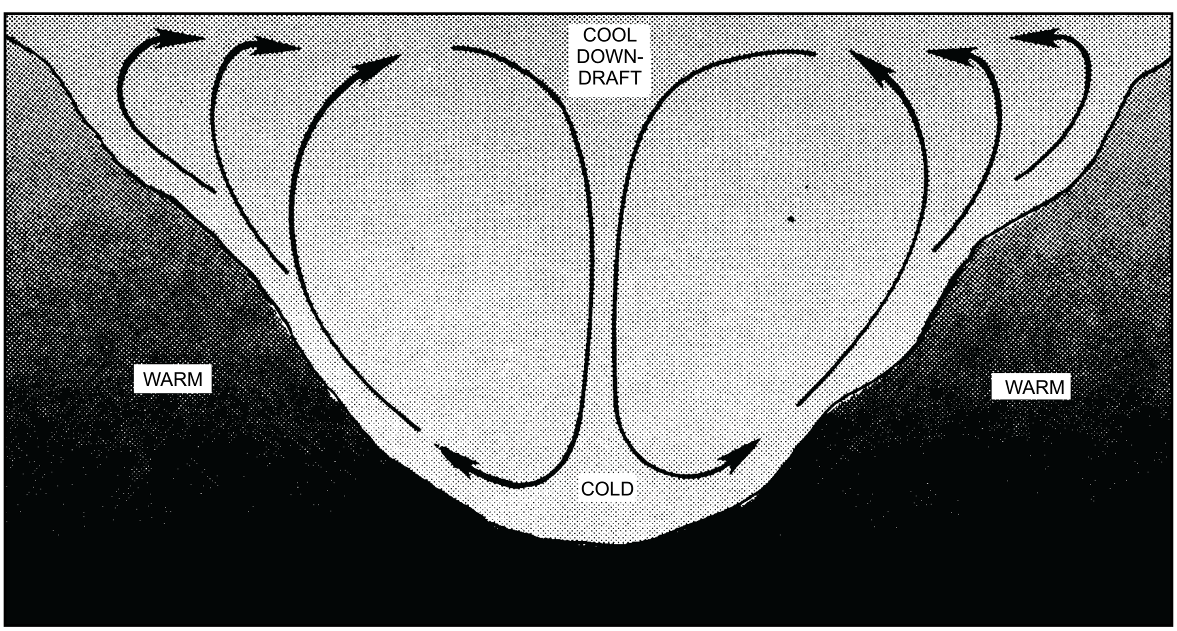

Figure 3-28.—Valley breeze or anabatic wind. During the daytime hillsides heat quickly. This heating effect causes updrafts along slopes—downdrafts in the center.

THERMALS.—Thermals are vertical convective currents that result from local heating. They stop short of the condensation level. Thermal convection is the usual result of strong heating of the lower atmosphere by the ground surface. A superadiabatic lapse rate immediately above the ground is necessary to the development of strong thermals. They form most readily over areas of bare rock or sand and in particular over sand dunes or bare rocky hills. In the presence of a moderate or fresh breeze, especially in a hilly terrain, it is impossible to distinguish between turbulent and thermal convection currents. Pure thermal convection normally occurs on clear summer days with very light prevailing wind. In the eastern United States, dry thermals are usually of only moderate intensity, seldom reaching an elevation in excess of 5,000 feet above the surface. The high moisture content of the air masses in this section in summer reduces the intensity of surface heating to some extent. This moisture content usually keeps the condensation level of the surface air near or even below a height of 5,000 feet above the ground. In the dry southwestern part of the country, where ground heating during clear summer days is extreme, dry thermal convection may extend to a height of 10,000 feet or more. Under these conditions, extremely turbulent air conditions can occur locally up to whatever heights the thermals extend, frequently without a cloud in the sky.

One variation of the dry thermal is seen in the dust or sand whirls, sometimes called dust devils. They are formed over heated surfaces when the winds are very light. Dust whirls are seldom more than two or three hundred feet high and they last only a few minutes at most. Over the desert on clear hot days as many as a dozen columns of whirling sand may be visible at once. The large desert sand whirls can become several hundred feet in diameter, extend to heights of 4,000 feet or higher, and in some cases last for an hour or more. They have been observed to rotate both anticyclonically and cyclonically, the same as tornadoes.

An almost identical phenomenon is observed over water in the form of the waterspout. Waterspouts occur frequently in groups and form in relatively cool humid air over a warm water surface when the wind is light. The waterspout is visible due to the condensed water vapor, or cloud formation, within the vortex. The condensation is the result of dynamic cooling by expansion within the vortex. In this respect it differs from the sand whirl, which is always dry. Both the sand whirl and the waterspout represent simple thermal convection of an extreme type. They are not to be confused with the more violent tornado.

When dry thermal convection extends to an elevation where the dry thermals reach the condensation level, then cumulus convection takes the place of the dry convection. A cumulus cloud, whose base is at the condensation level of the rising air, tops each individual thermal current. Beneath every building cumulus cloud a vigorous rising current or updraft is observed. Thus the local thermal convection pattern becomes visible in the cumulus cloud pattern. The cumulus clouds form first over the hills where the strongest thermals develop. Under stable atmospheric conditions, little convective cloud development occurs. However, under unstable conditions these thermals may develop cumulonimbus clouds.

INDUCED OR DYNAMIC TERTIARY CIRCULATIONS

There are four types of induced or dynamic tertiary circulations. They are eddies, turbulence, large-scale vertical waves, and Foehn winds.

Eddies

An eddy is a circulation that develops when the wind flows over or adjacent to rough terrain, buildings, mountains or other obstructions. They generally form on the lee (downwind or sheltered) side of these obstructions. The size of the eddy is directly proportional to the size of the obstruction and speed of the wind. Eddies may have horizontal or vertical circulations that can be either cyclonic or anticyclonic.

Horizontal eddies form in sheltered areas downwind of rough coastlines or mountain chains. An example of a horizontal eddy is the weak cyclonic circulation that develops in the channel off the coast of Santa Barbara, California. The winds frequently blow parallel to the northern California coastline during the winter fog and stratus season. The Santa Barbara channel often remains fog-free because the waters are protected from winds that transport the fog inland. However, when the winds are sufficiently strong, friction along the tough coastal range produces a weak cyclonic eddy over the channel. This cyclonic flow, though weak, is sufficient to advect fog into the region.

Vertical eddies are generally found on the lee side of mountains, but with low wind speeds, stationary eddies or rotating pockets of air are produced and remain on both the windward and leeward sides of obstructions. (See figure 3-29.) When wind speeds exceed about 20 knots, the flow may be broken up into irregular eddies that are carried along with a wind some distance downstream from the obstruction. These eddies may cause extreme and irregular variations in the wind and may disturb aircraft landing areas sufficiently to be a hazard.

A similar and much disturbed wind condition occurs when the wind blows over large obstructions such as mountain ridges. In such cases the wind blowing up the slope on the windward side is usually relatively smooth. On the leeward side the wind spills rapidly down the slope, setting up strong downdrafts and causing the air to be very turbulent. This condition is illustrated in figure 3-30. These downdrafts can be very violent. Aircraft caught in these eddies could be forced to collide with the mountain peaks. This effect is also noticeable in the case of hills and bluffs, but is not as pronounced.

Turbulence

Turbulence is the irregular motion of the atmosphere caused by the air flowing over an uneven surface or by two currents of air flowing past each other in different directions or at different speeds. The main source of turbulence is the friction along the surface of Earth. This is called mechanical turbulence. Turbulence is also caused by irregular temperature distribution. The warmer air rises and the colder air descends, causing an irregular vertical motion of air; this is called thermal turbulence.

Mechanical turbulence is intensified in unstable air and is weakened in stable air. These influences cause fluctuations in the wind with periods ranging from a few minutes to more than an hour. If these wind variations are strong, they are called wind squalls and are usually associated with convective clouds. They are an indication of approaching towering cumulus or cumulonimbus clouds.

Gustiness and turbulence are more or less synonymous. Gustiness is an irregularity in the wind speed that creates eddy currents disrupting the smooth airflow. Thus, the term *gust* is usually used in conjunction with sudden intermittent increases in the wind speed near the surface levels. Turbulence, on the other hand, is used with reference to levels above the surface. Gustiness can be measured; turbulence, however, unless encountered by aircraft equipped with a gust probe or an accelerometer, is usually estimated.

Large-Scale Vertical Waves (Mountain Waves)

Mountain waves occur on the lee side of topographical barriers and occur when the wind-flow is strong, 25 knots or more, and the flow is roughly perpendicular to the mountain range. The structure of the barrier and the strength of the wind determines the

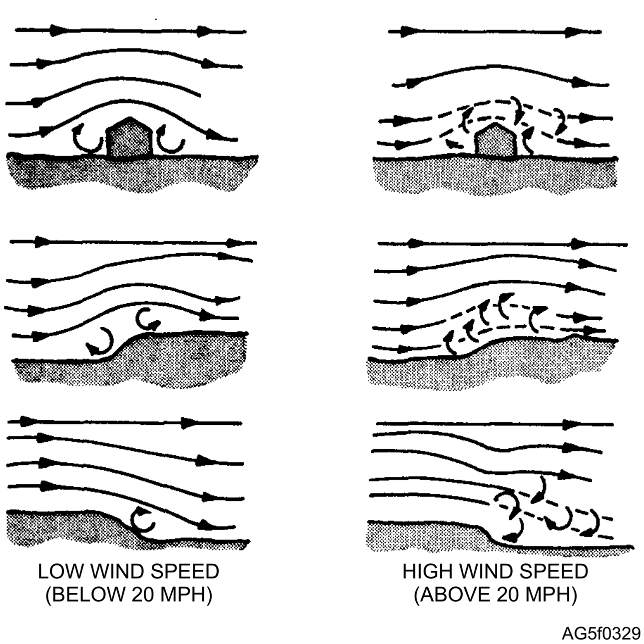

Figure 3-29.—Eddy currents formed when wind flows over uneven ground or obstructions.

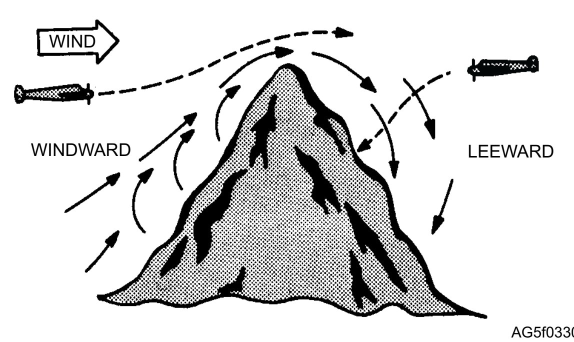

Figure 3-30.—Effect of windflow over mountains.

amplitude and the type of the wave. The characteristics of a typical mountain wave are shown in figure 3-31.

Figure 3-31 shows the cloud formations normally found with wave development and illustrates schematically the airflow in a similar situation. The illustration shows that the air flows fairly smoothly with a lifting component as it moves along the windward side of the mountain. The wind speed gradually increases, reaching a maximum near the summit. On passing the crest, the flow breaks down into a much more complicated pattern with downdrafts predominating. An indication of the possible intensities can be gained from verified records of sustained downdrafts (and also updrafts) of at least 5,000 feet per minute with other reports showing drafts well in excess of this figure. Turbulence in varying degrees can be expected and is particularly severe in the lower levels; however, it can extend to the tropopause to a lesser degree. Proceeding downwind, some 5 to 10 miles from the summit, the airflow begins to ascend in a definite wave pattern. Additional waves, generally less intense than the primary wave, may form downwind (in some cases six or more have been reported). These are similar to the series of ripples that form downstream from a submerged rock in a swiftly flowing river. The distance between successive waves usually ranges from 2 to 10 miles, depending largely on the existing wind speed and the atmospheric stability. However, wavelengths up to 20 miles have been reported.

It is important to know how to identify a wave situation. Pilots must be briefed on this condition so they can avoid the wave hazards. Characteristic cloud forms peculiar to wave action provide the best means of visual identification. The lenticular (lens shaped) clouds in the upper right of figure 3-31 are smooth in contour. These clouds may occur singly or in layers at heights usually above 20,000 feet, and may be quite ragged when the airflow at that level is turbulent. The roll cloud (also called rotor cloud) forms at a lower level, generally near the height of the mountain ridge, and can be seen extending across the center of the figure. The cap cloud, shown partially covering the mountain slope, must always be avoided in flight because of turbulence, concealed mountain peaks, and strong downdrafts on the lee side. The lenticular, like the roll clouds and cap clouds, are stationary, constantly forming on the windward side and dissipating on the lee side of the wave. The actual cloud forms can be a guide to the degree of turbulence. Smooth clouds generally show smoother airflow in or near them with light turbulence. Clouds appearing ragged or irregular indicate more turbulence.

While clouds are generally present to forewarn the presence of wave activity, it is possible for wave action to take place when the air is too dry to form clouds. This makes the problem of identifying and forecasting more difficult.

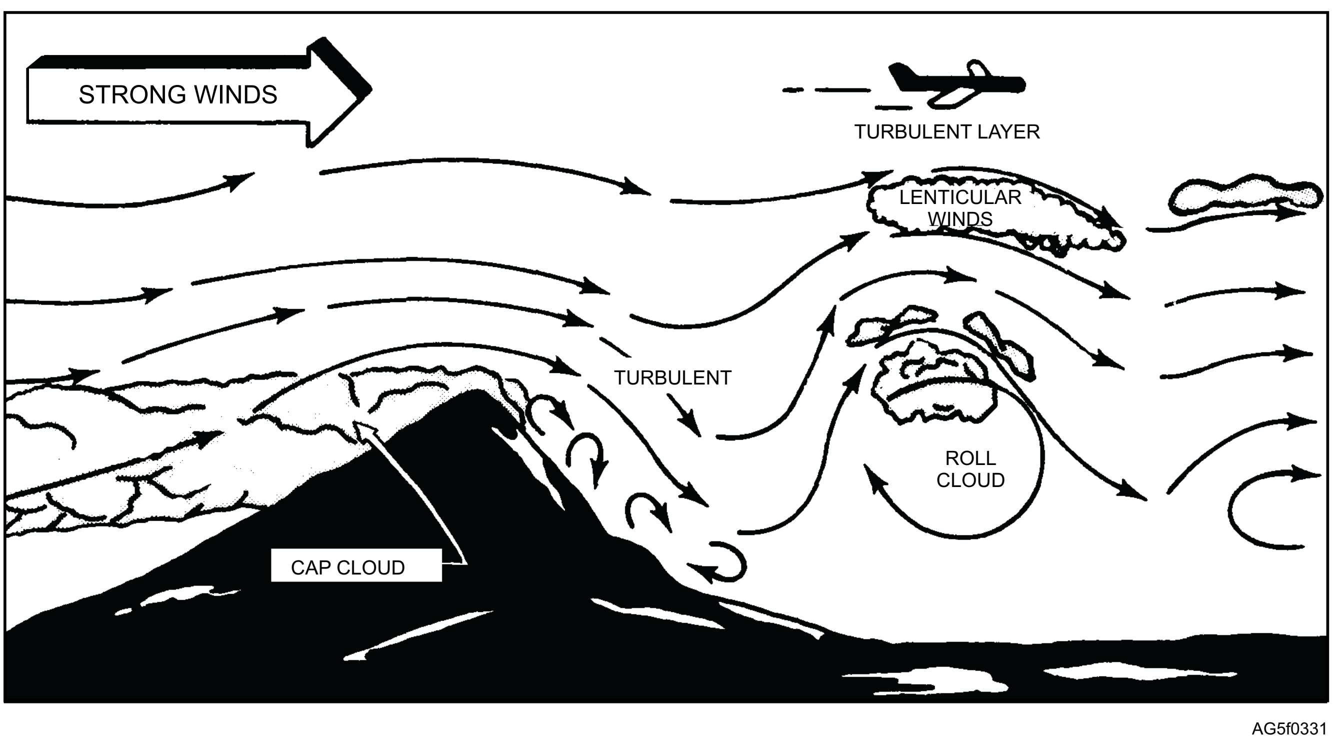

Figure 3-31.—Schematic diagram showing airflow and clouds in a mountain wave.

Foehn Winds

When air flows downhill from a high elevation, its temperature is raised by adiabatic compression. Foehn winds are katabatic winds caused by adiabatic heating of air as it descends on the lee sides of mountains. Foehn winds occur frequently in our western mountain states and in Europe in the late fall and winter. In Montana and Wyoming, the Chinook is a well-known phenomenon; in southern California, the Santa Ana is known particularly for its high-speed winds that easily exceed 50 knots. For the purpose of illustrating a Foehn wind, the Santa Ana is used.

The condition producing the Foehn wind is a high-pressure area with a strong pressure gradient situated near Salt Lake City, Utah. This gradient directs the wind flow into a valley leading to the town of Santa Ana near the coast of California. As the wind enters the valley, its flow is sharply restricted by the funneling effect of the mountainsides. This restriction causes the wind speed to increase, bringing about a drop in pressure in and near the valley. The Bernoulli effect causes this pressure drop in and near a valley.

Generally speaking, when the Santa Ana blows through the Santa Ana Canyon, a similar wind simultaneously affects the entire southern California area. Thus, when meteorological conditions are favorable, this dry northeast wind blows through the many passes and canyons, over all the mountainous area, including the highest peaks, and quite often at exposed places along the entire coast from Santa Barbara to San Diego. Therefore, the term Santa Ana refers to the general condition of a dry northeast wind over southern California.

In the Rocky Mountain states, the onset of Foehn winds have accounted for temperature rises of 50°F or more in only a few minutes. In southern California, the temperature, though less dramatically, also rises rapidly and is accompanied by a rapid decrease in humidity (to 20 percent or less) and a strong shift and increase in wind speeds. Although these winds may on occasion reach destructive velocities, one beneficial aspect is that these winds quickly disperse the severe air pollutants that plague the Los Angeles Basin.

REVIEW QUESTIONS

Q3-15. What is the cause of monsoon winds?

Q3-16. What causes land and sea breezes?

Q3-17. Describe Bernoulli's theorem.

Q3-18. When does a valley breeze usually reach its maximum?

Q3-19. What causes eddies?

Q3-20. What causes Foehn winds?

SUMMARY

In this chapter, we studied the primary, secondary and tertiary circulation of the atmosphere. We learned about large-scale circulations, worldwide locations of major pressure systems, horizontal and vertical pressure systems. We studied how pressure systems, temperature, and world winds relate to each other, and finally we studied small-scale effects, due to local features. A good understanding of atmospheric circulation is essential in order to understand the characteristics of air masses and fronts.

CHAPTER 4

AIR MASSES AND FRONTS

Temperature, in the form of heating and cooling, plays a key roll in our atmosphere's circulation. Heating and cooling is also the key in the formation of various air masses. These air masses, because of temperature contrast, ultimately result in the formation of frontal systems. The air masses and frontal systems, however, could not move significantly without the interplay of low-pressure systems (cyclones).

Some regions of Earth have weak pressure gradients at times that allow for little air movement. Therefore, the air lying over these regions eventually takes on the certain characteristics of temperature and moisture normal to that region. Ultimately, air masses with these specific characteristics (warm, cold, moist, or dry) develop. Because of the existence of cyclones and other factors aloft, these air masses are eventually subject to some movement that forces them together. When these air masses are forced together, fronts develop between them. The fronts are then brought together by the cyclones and airflow aloft. This produces the classic complex frontal systems often seen on surface weather maps.

AIR MASSES

LEARNING OBJECTIVE: Determine the conditions necessary for the formation of air masses and identify air mass source regions.

An air mass is a body of air extending over a large area (usually 1,000 miles or more across). It is generally an area of high pressure that stagnates for several days where surface terrain varies little. During this time, the air mass takes on characteristics of the underlying surface. Properties of temperature, moisture (humidity), and lapse rate remain fairly homogeneous throughout the air mass. Horizontal changes of these properties are usually very gradual.

CONDITIONS NECESSARY FOR AIR MASS FORMATION

Two primary factors are necessary to produce an air mass. First, a surface whose properties, essentially temperature and moisture, are relatively uniform (it may be water, land, or a snow-covered area). Second, a large divergent flow that tends to destroy temperature contrasts and produces a homogeneous mass of air. The energy supplied to Earth's surface from the Sun is distributed to the air mass by convection, radiation, and conduction.

Another condition necessary for air mass formation is equilibrium between ground and air. This is established by a combination of the following processes: (1) turbulent-convective transport of heat upward into the higher levels of the air; (2) cooling of air by radiation loss of heat; and (3) transport of heat by evaporation and condensation processes.

The fastest and most effective process involved in establishing equilibrium is the turbulent-convective transport of heat upwards. The slowest and least effective process is radiation.

During radiation and turbulent-convective processes, evaporation and condensation contribute in conserving the heat of the overlying air. This occurs because the water vapor in the air allows radiation only through transparent bands during radiational cooling and allows for the release of the latent heat of condensation during the turbulent-convective processes. Therefore, the tropical latitudes, because of a higher moisture content in the air, rapidly form air masses primarily through the upward transport of heat by the turbulent-convective process. The dryer polar regions slowly form air masses primarily because of the loss of heat through radiation. Since underlying surfaces are not uniform in thermal properties during the year and the distribution of land and water is unequal, specific or special summer and/or winter air masses may be formed. The rate of air mass formation varies more with the intensity of insolation.

EFFECTS OF CIRCULATION ON ALL AIR MASS FORMATION

There are three types of circulation over Earth. However, not all of these are favorable for air mass development. They are as follows:

1. The anticyclonic systems. Anticyclonic systems have stagnant or slow-moving air, which allows time for air to adjust its heat and moisture content to that of the underlying surface. These

anticyclones have a divergent airflow that spreads the properties horizontally over a large area; turbulence and convection distribute these properties vertically. Subsidence (downward motion), another property of anticyclones, is favorable for lateral mixing, which results in horizontal or layer homogeneity.

Warm highs, such as the Bermuda and Pacific highs, extend to great heights because of a lesser density gradient aloft and thereby produce an air mass of relatively great vertical extent. Cold highs, such as the Siberian high, are of moderate or shallow vertical extent and produce air masses of moderate or shallow height.

2. Cyclonic systems. Cyclonic systems are not conducive to air mass formation because they are characterized by greater wind speeds than anticyclonic systems. These wind speeds prevent cyclonic systems from stabilizing. An exception is the stationary heat low.

3. Belts of convergence. Belts of convergence are normally not conducive to air mass formation since they have essentially the same properties as cyclonic systems. However, there are two areas of convergence where air masses do form. These are the areas over the north Pacific, between Siberia and North America, and the Atlantic, off the coast of Labrador and Newfoundland. These two areas act as source regions for maritime polar air.

AIR MASS SOURCE REGIONS

The ideal condition for the production of an air mass is the stagnation of air over a uniform surface (water, land, or ice cap) of uniform temperature and humidity. The length of time an air mass stagnates over its source region depends upon the surrounding pressures. From the surface up through the upper levels, such air acquires definite properties and characteristics. The resulting air mass becomes virtually homogeneous throughout, and its properties become uniform at each level. In the middle latitudes, the land and sea areas with the associated steep latitudinal temperature gradient are generally not homogeneous enough for source regions. These areas act as transitional zones for air masses after they have left their source regions.

The source regions for the world's air masses are shown in figure 4-1. Note the uniformity of the underlying surfaces; also note the relatively uniform climatic conditions in the various source regions, such as the southern North Atlantic and Pacific Oceans for maritime tropical air and the deep interiors of North America and Asia for continental polar air.

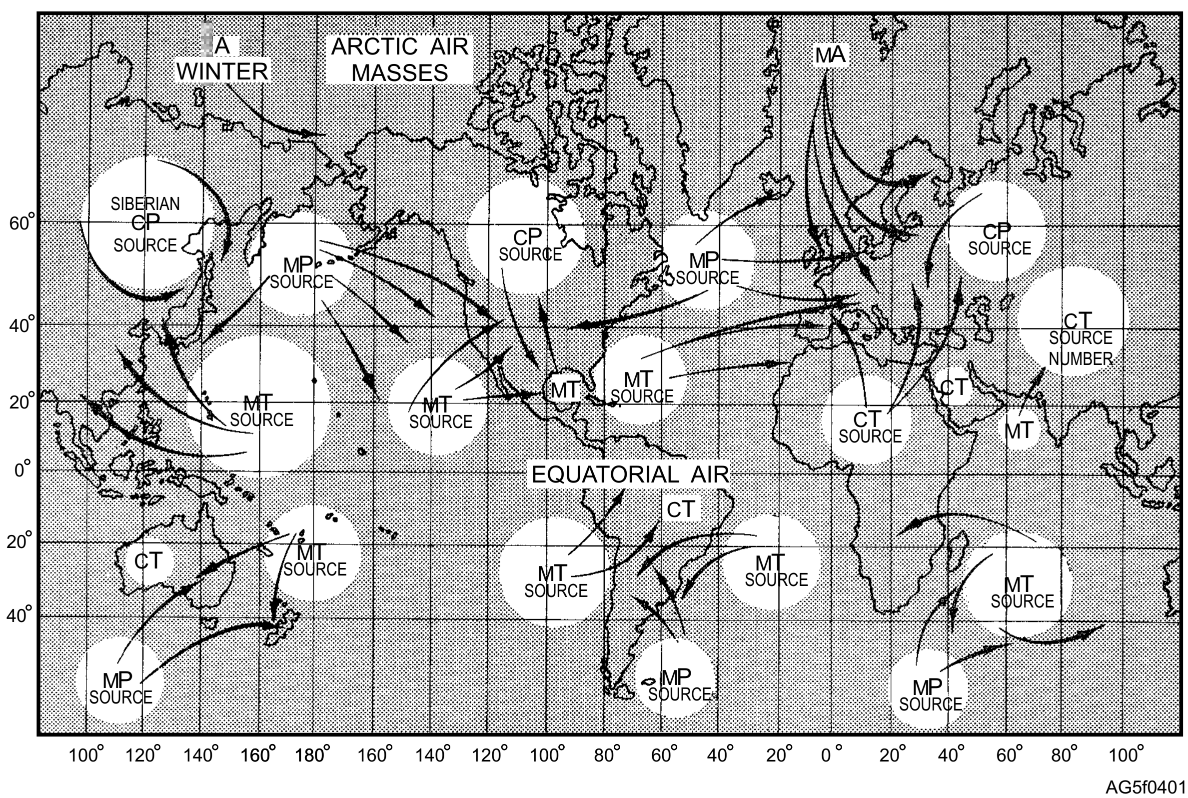

Figure 4-1.—Air mass source regions.

Characteristics of Air Masses

The characteristics of an air mass are acquired in the source region, which is the surface area over which the air mass originates. The ideal source region has a uniform surface (all land or all water), a uniform temperature, and is an area in which air stagnates to form high-pressure systems. The properties (temperature and moisture content) an air mass acquires in its source region are dependent upon a number of factors—the time of year (winter or summer), the nature of the underlying surface (whether land, water, or ice covered), and the length of time it remains over its source region.

ARCTIC (A) AIR.—There is a permanent high-pressure area in the vicinity of the North Pole. In this region, a gentle flow of air over the polar ice fields allows an arctic air mass to form. This air mass is characteristically dry aloft and very cold and stable in the lower altitudes.

ANTARCTIC (A) AIR.—Antarctica is a great source region for intensely cold air masses that have continental characteristics. Before the antarctic air reaches other land areas, it becomes modified and is properly called maritime polar. The temperatures are colder than in the arctic regions. Results of Operation Deepfreeze have revealed the coldest surface temperatures in the world to be in the Antarctic.

CONTINENTAL POLAR (cP) AIR.—The continental polar source regions consist of all land areas dominated by the Canadian and Siberian high-pressure cells. In the winter, these regions are covered by snow and ice. Because of the intense cold and the absence of water bodies, very little moisture is taken into the air in these regions. Note that the word *polar,* when applied to air mass designations, does not mean air at the poles (this area is covered by the words *arctic* and *antarctic).* Polar air is generally found in latitudes between 40 and 60 degrees and is generally warmer than arctic air. The air over northern and central Asia are exceptions to this.

MARITIME POLAR (mP) AIR.—The maritime polar source regions consist of the open unfrozen polar sea areas in the vicinity of 60° latitude, north and south. Such areas are sources of moisture for polar air masses; consequently, air masses forming over these regions are moist, but the moisture is sharply limited by the cold temperature.

CONTINENTAL TROPICAL (cT) AIR.—The continental tropical source regions can be any significant land areas lying in the tropical regions; generally these tropical regions are located between latitudes 25°N and 25°S. The large land areas located in these latitudes are usually desert regions (such as the Sahara or Kalahari Deserts of Africa, the Arabian Desert, and the interior of Australia). The air over these land areas is hot and dry.

MARITIME TROPICAL (mT) AIR.—The maritime tropical source regions are the large zones of open tropical sea along the belt of the subtropical anticyclones. High-pressure cells stagnate in these areas most of the year. The air is warm because of the low latitude and can hold considerable moisture.

EQUATORIAL (E) AIR.—The equatorial source region is the area from about latitudes 10°N to 10°S. It is essentially an oceanic belt that is <u>extremely warm</u> and that has a high moisture content. Convergence of the trade winds from both hemispheres and the intense insolation over this region causes lifting of the unstable, moist air to high levels. The weather associated with these conditions is characterized by thunderstorms throughout the year.

SUPERIOR (S) AIR.—Superior air is a high-level air mass found over the south central United States. This air mass occasionally reaches the surface; because of subsidence effects, it is the warmest air mass on record in the North American continent in both seasons.

Southern Hemisphere Air Masses

Air masses encountered in the Southern Hemisphere differ little from their counterparts in the Northern Hemisphere. Since the greater portion of the Southern Hemisphere is oceanic, it is not surprising to find maritime climates predominating in that hemisphere.

The two largest continents of the Southern Hemisphere (Africa and South America) both taper from the equatorial regions toward the South Pole and have small land areas at high latitudes. Maritime polar air is the coldest air mass observed over the middle latitudes of the Southern Hemisphere.

In the interior of Africa, South America, and Australia, cT air occurs during the summer. Over the remainder of the Southern Hemisphere, the predominating air masses are mP, mT, and E air. The structure of these air masses is almost identical with those found in the Northern Hemisphere.

AIR MASS CLASSIFICATION

LEARNING OBJECTIVE: Define air mass classification and describe how the classification will change when characteristics modify.

Air masses are classified according to geographic source region, moisture content, and thermodynamic process.

Geographic Origin

The geographical classification of air masses, which refers to the source region of the air mass, divides air masses into four basic categories: arctic or antarctic (A), polar (P), tropical (T), and equatorial (E). An additional geographical classification is the superior (5) air mass. The superior air mass is generally found aloft over the southwestern United States, but is sometimes located at or near the surface.

Moisture Content

The arctic (A), polar (P), and tropical (T) classifications are further broken down by moisture content. An air mass is considered to be maritime (m) if its source of origin is over an oceanic surface. If the air mass originates over a land surface, it is considered continental (c). Thus, a moist, maritime arctic air mass is designated m; and a drier, continental arctic air mass is designated c. Equatorial (E) air is found exclusively over the ocean surface in the vicinity of the equator and is designated neither c nor m but simply E.

Thermodynamic Process

The thermodynamic classification applies to the relative warmth or coldness of the air mass. A warm air mass (w) is warmer than the underlying surface; a cold air mass (k) is colder than the underlying surface. For example, a continental polar cold air mass over a warmer surface is classified as cPk. An mTw classification indicates that the air mass is a maritime tropical warm air mass and overlays a cooler surface.

Air masses can usually be identified by the type of clouds within them. Cold air masses usually show cumuliform clouds, whereas warm air masses contain stratiform clouds. Sometimes, and with some air masses, the thermodynamic classification may change from night to day. A particular air mass may show k characteristics during the day and w characteristics at night and vice versa. The designators and descriptions for the classifications of air masses are listed in table 4-1.

Table 4-1.—Classification of Air Masses

Designator	Description
cAk	Continental arctic air that is colder than the surface over which it lies.
cAw	Continental arctic air that is warmer than the surface over which it lies.
mAk	Maritime arctic air that is colder than the surface over which it lies.
cPw	Continental polar air that is warmer than the surface over which it is moving.
cPk	Continental polar air that is colder than the surface over which it is moving.
mPw	Maritime polar air that is warmer than the surface over which it is moving.
mPk	Maritime polar air that is colder than the surface over which it is moving.
mTw	Maritime tropical air that is warmer than the surface over which it is moving.
mTk	Maritime tropical air that is colder than the surface over which it is moving.
cTw	Continental tropical air that is warmer than the surface over which it is moving.
cTk	Continental tropical air that is colder than the surface over which it is moving.
Ek	Maritime equatorial air that is colder than the surface over which it is moving.
Ew	Maritime equatorial air that is warmer than the surface over which it is moving.
S	Superior air, found generally aloft over the southwestern United States, and occassionally at or near the surface.

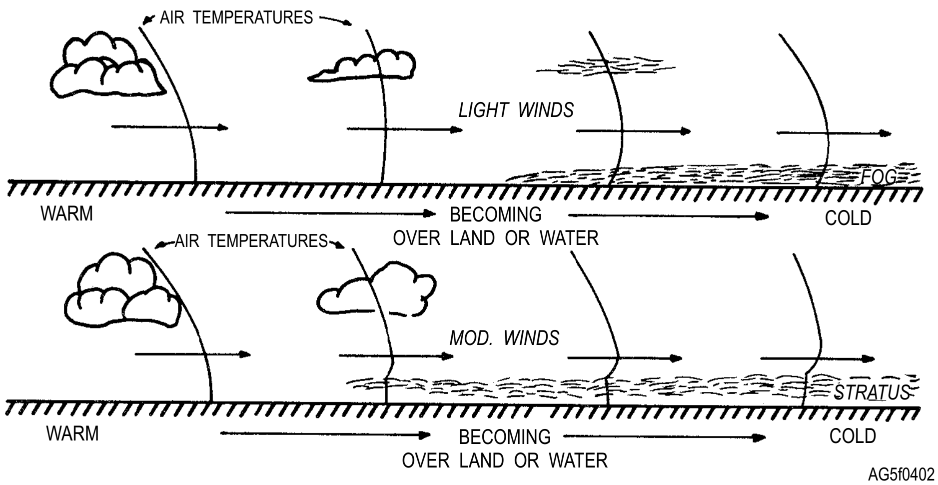

Figure 4-2.—Passage of warm air over colder surfaces.

AIR MASS MODIFICATION

When an air mass moves out of its source region, a number of factors act upon the air mass to change its properties. These modifying influences do not occur separately. For instance, in the passage of cold air over warmer water surfaces, there is not only a release of heat to the air, but also a release of some moisture.

As an air mass expands and slowly moves out of its source region, it travels along a certain path. As an air mass leaves its source region, the first modifying factor is the type and condition of the surface over which the air travels. Here, the factors of surface temperature, moisture, and topography must be considered. The type of trajectory, whether cyclonic or anticyclonic, also has a bearing on its modification. The time interval since the air mass has been out of its source region determines to a great extent the characteristics of the air mass. You must be aware of the five modifying factors and the changes that take place once an air mass leaves its source region in order to integrate these changes into your analyses and briefings.

Surface Temperature

The difference in temperature between the surface and the air mass modifies not only the air temperature, but also the stability of the air mass. For example, if the air mass is warm and moves over a colder surface (such as tropical air moving over colder water), the cold surface cools the lower layers of the air mass and the stability of the air mass increases. This stability extends to the upper layers in time, and condensation in the form of fog or low stratus normally occurs. (See fig. 4-2.)

If the air mass moves over a surface that is warmer (such as continental polar air moving out from the continent in winter over warmer water), the warm water heats the lower layers of the air mass, increasing instability (decreasing in stability), and consequently spreading to higher layers. Figure 4-3 shows the movement of cP air over a warmer water surface in winter.

The changes in stability of the air mass give valuable indications of the cloud types that will form, as

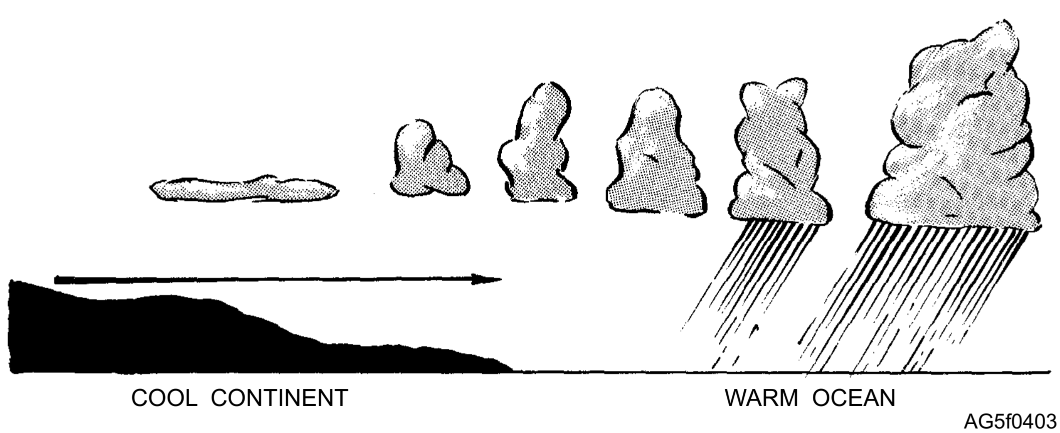

Figure 4-3.—Continental polar air moving from cool continent to warm ocean (winter).

well as the type of precipitation to be expected. Also, the increase or decrease in stability gives further indication of the lower layer turbulence and visibility.

Surface Moisture

An air mass may be modified in its moisture content by the addition of moisture as a result of evaporation or by the removal of moisture as a result of condensation and precipitation. If the air mass is moving over continental regions, the existence of unfrozen bodies of water can greatly modify the air mass; in the case of an air mass moving from a continent to an ocean, the modification can be considerable. In general (dependent upon the temperature of the two surfaces), the movement over a water surface increases both the moisture content of the lower layers and the relative temperature near the surface.

For example, the passage of cold air over a warm water surface decreases the stability of the air with resultant vertical currents. The passage of warm, moist air over a cold surface increases the stability and could result in fog as the air is cooled and moisture is added by evaporation.

Topography of Surface

The effect of topography is evident primarily in the mountainous regions. The air mass is modified on the windward side by the removal of moisture through precipitation with a decrease in stability; and, as the air descends on the other side of the mountain, the stability increases as the air becomes warmer and drier.

Trajectory

After an air mass has left its source region, the trajectory it follows (whether cyclonic or anticyclonic) has a great effect on its stability. If the air follows a cyclonic trajectory, its stability in the upper levels is decreased; this instability is a reflection of cyclonic relative vorticity. The stability of the lower layers is not greatly affected by this process. On the other hand, if the trajectory is anticyclonic, its stability in the upper levels is increased as a result of subsidence associated with anticyclonic relative vorticity.

Age

Although the age of an air mass in itself cannot modify the air mass, it does determine (to a great extent) the amount of modification that takes place. For example, an air mass that has recently moved from its source region cannot have had time to become modified significantly. However, an air mass that has moved into a new region and stagnated for some time is now old and has lost many of its original characteristics.

Modifying Influences on Air Mass Stability

The stability of an air mass often determines the type of clouds and weather associated with that air mass. The stability of an air mass can be changed by either thermodynamic or mechanical means.

THERMODYNAMIC.—The thermodynamic influences are reflected in a loss or gain in heat and in the addition or removal of moisture.

Heat Loss or Gain.—The air mass may lose heat by radiational cooling of Earth's surface or by the air mass passing from a warm surface to a cold surface. The air mass may gain heat by solar heating of the ground over which the air mass moves or by the air mass passing from a cold to a warm surface.

Moisture Increase or Decrease.—Moisture may be added to the air mass by evaporation. One source of evaporation may be the precipitation as it falls through the air; other sources may be a water surface, ice and snow surface, or moist ground. Moisture may be removed from the air mass by condensation and precipitation.

MECHANICAL.—Mechanical influences on air masses depend upon movement. The mechanical process of lifting an air mass over elevation of land, over colder air masses, or to compensate for horizontal convergence produces a change in an air mass. Turbulent mixing and the shearing action of wind also cause air mass modifications. The sinking of air from high elevations to relatively lower lands or from above colder air masses and the descent in subsidence and lateral spreading are also important mechanical modifiers of air masses.

The thermodynamic and mechanical influences on air mass stability are summarized in figure 4-4. The figure indicates the modifying process, what takes place, and the resultant change in stability of the air mass. These processes do not occur independently; instead, two or more processes are usually in evidence at the same time. Within any single air mass, the weather is controlled by the moisture content, stability, and the vertical movements of air.

THE PROCESS	HOW IT HAPPENS	RESULTS
A. THERMODYNAMIC		
1. Heating from below.	Air mass passes from over a cold surface to a warm surface, or surface under air mass is heated by sun.	Decrease in stability.
2. Cooling from below.	Air mass passes from over a warm surface to a cold surface, OR radiational cooling of surface under air mass takes place.	Increase in stability.
3. Addition of moisture.	By evaporation from water, ice, or snow surfaces, or moist ground, or from rain-drops or other precipitation which falls from overrunning saturated air currents.	Decrease in stability.
4. Removal of moisture.	By condensation and precipitation from the air mass.	Increase in stability.
B. MECHANICAL		
1. Turbulent mixing.	Up- and down-draft.	Tends to result in a thorough mixing of the air through the layer where the tur-bulence exists.
2. Sinking.	Movement down from above colder air masses or descent from high elevations to low-lands, subsidence and lateral spreading.	Increases stability.
3. Lifting.	Movement up over colder air masses or over elevations of land or to compensate for air at the same level converging.	Decreases stability.

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Figure 4-4.—Air mass changes.

WORLD AIR MASSES

LEARNING OBJECTIVE: Describe the trajectories and weather associated with world air masses.

NORTH AMERICAN AIR MASSES, TRAJECTORIES, AND WEATHER (WINTER)

The shape and location of the North American continent make it an ideal source region and also permit the invasion of maritime air masses. You must be able to identify these air masses and trace their trajectories to develop and present an in-depth weather briefing.

Within an air mass, weather is controlled primarily by the moisture content of the air, the relationship between surface temperature and air mass temperature, and terrain (upslope or downslope). Rising air is cooled; descending air is warmed. Condensation takes place when the air is cooled to its dew point. A cloud warmed above the dew point temperature evaporates and dissipates. Stability tends to increase if the surface temperature is lowered or if the temperature of the air at higher levels is increased while the surface temperature remains the same. Stability tends to be reduced if the temperature aloft is lowered. Smooth stratiform clouds are associated with stable air, whereas turbulence, convective clouds, and thunderstorms are associated with unstable air.

cPk and cAk Air in Winter

The weather conditions with cPk and cAk air over the United States depend primarily on the trajectory of the air mass after it leaves its source region. Trajectories, as observed on a surface chart, are indicated as one of the trajectories (A, B, C, D, E, F, G)

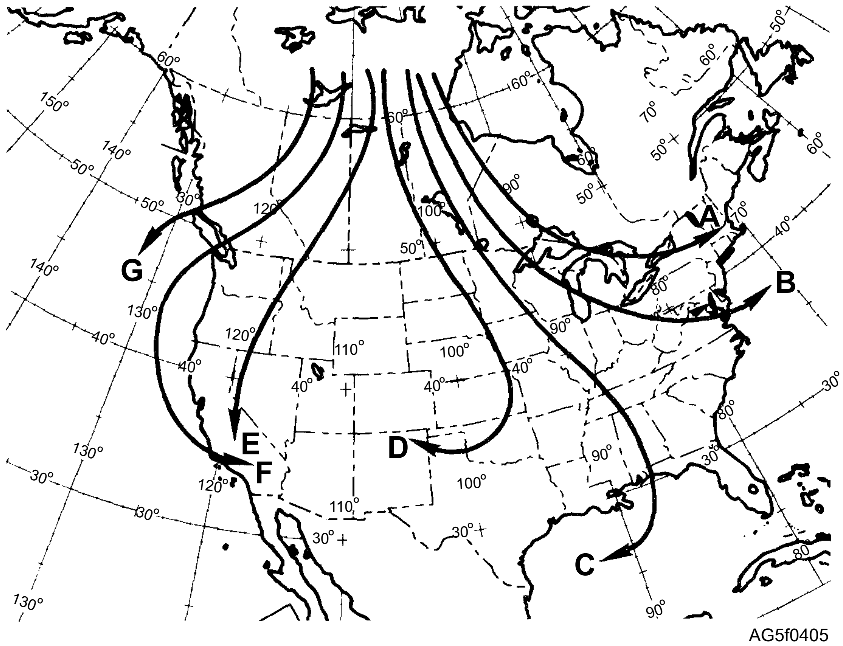

Figure 4-5.—Trajectories of cP and cA air in winter.

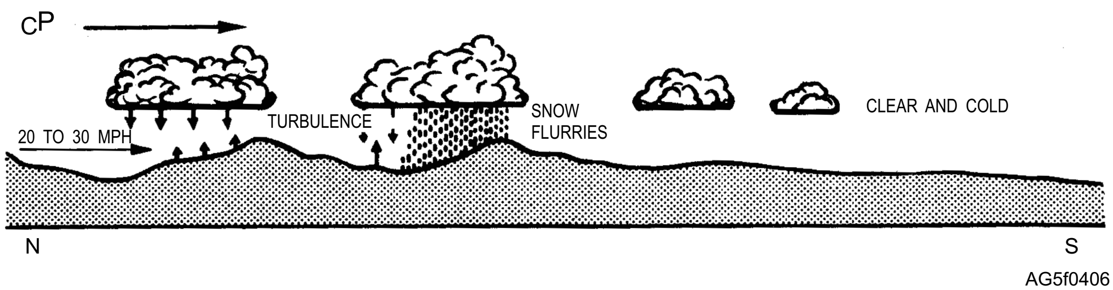

Figure 4-6.—cP air moving southward.

shown in figure 4-5. In the mid-latitudes, for an air mass to be classified as arctic, the surface temperature is generally 0 degrees Fahrenheit (-18 degrees Celsius) or below.

TRAJECTORY PATHS A AND B (CYCLONIC).—Paths A and B (fig. 4-5) are usually indicative of a strong outbreak of cold air and surface winds of 15 knots or more. This wind helps to decrease the stable conditions in the lower levels. If this modified air moves rapidly over rough terrain, the turbulence results in low stratocumulus clouds and occasional snow flurries (see fig. 4-6).

A particularly troublesome situation often arises when the cold air flows from a cold, snow-covered surface to a water surface and then over a cold, snow-covered surface again. This frequently happens with air crossing the Great Lakes. (See fig. 4-7.)

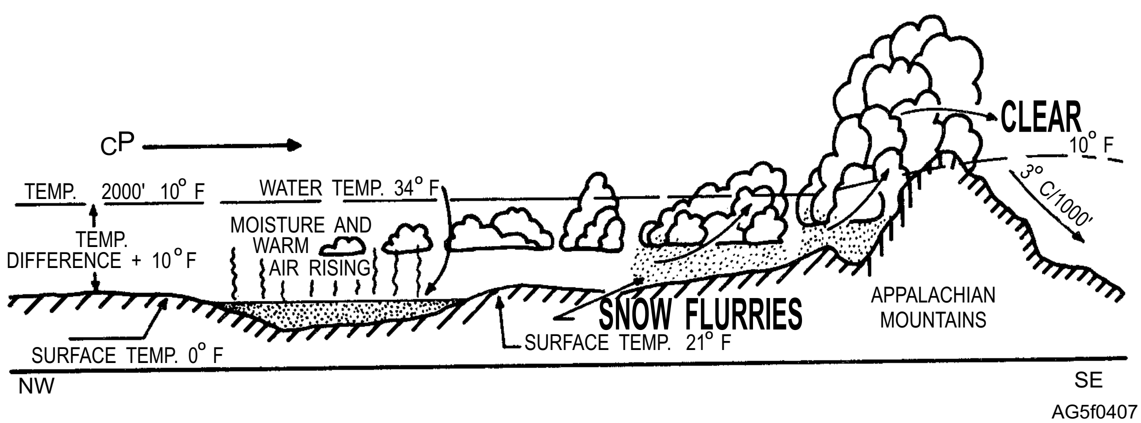

Figure 4-7.—cP air moving over the Great Lakes (winter).

On the leeward side of the Great Lakes and on the windward side of the Appalachians, you can expect a rather low, broken to overcast sky condition with frequent and widespread snow squalls. Stratocumulus and cumulus clouds with bases at 500 to 1,000 feet and tops at 7,000 to 10,000 feet form on the leeward side of the Great Lakes. Over the mountains, their tops extend to about 14,000 feet. Visibility ranges from 1 to 5 miles during rain or snow showers and occasionally lowers to zero in snow flurries.

Severe aircraft icing conditions may be expected over the mountains and light to moderate aircraft icing on the leeward side of the lakes. Moderate to severe flying conditions are the rule as long as the outflow of cold air continues.

East of the Appalachians, skies are relatively clear except for scattered stratocumulus clouds. Visibility is unrestricted and the surface temperature is relatively moderate because of turbulent mixing. In the Middle West, clouds associated with this type of air mass continue for 24 to 48 hours after the arrival of the cold mass, while along the Atlantic Coast rapid passage of the leading edge of the air mass produces almost immediate clearing.

TRAJECTORY PATHS C AND D (ANTI-CYCLONIC).—The weather conditions experienced over the central United States under the influence of trajectories similar to C and D (fig. 4-5) are quite different. Unusually smooth flying conditions are found in this region, except near the surface where a turbulence layer results in a steep lapse rate and some bumpiness. Low stratus or stratocumulus clouds in may form at the top of the turbulence layer. As the cold air stagnates and subsides under the influence of the anticyclonic trajectory, marked the haze layers develop indicating the presence of subsidence inversions. The surface visibility also deteriorates because of an accumulation of smoke and dust as the air stagnates and subsides. This is especially noticeable during the early morning hours when the stability in the surface layers is most pronounced. In the afternoon, when surface heating has reached a maximum, the visibility usually improves because of the steep lapse rate and resultant turbulence.

Movement of cPk and cAk air westward over the Rocky Mountains to the Pacific coast is infrequent. However, when successive outbreaks of cold air build up a deep layer of cP air on the eastern slopes of the Rocky Mountains, relatively cold air can flow toward the Pacific coast.

TRAJECTORY PATH E.—When the trajectory of the cold air is similar to E in figure 4-5, rather mild temperatures and low humidities result on the Pacific coast because adiabatic warming of the air flowing down the mountain slopes produces clear skies and good visibility.

TRAJECTORY PATHS F AND G.—Occasionally, the trajectory passes out over the Pacific Ocean (see fig. 4-5). The air then arrives over central and southern California as cold, convectively unstable air. This type is characterized by squalls and showers, cumulus and cumulonimbus clouds, visibility of 1 to 5 miles during squalls and showers, and snow even as far south as southern California.

Maritime Polar (mP) Air Pacific in Winter

Maritime polar air from the Pacific dominates the weather conditions of the west coast during the winter months. In fact, this air often influences the weather over most of the United States. Pacific coastal weather, while under the influence of the same general air mass, varies considerably as a result of different trajectories of mP air over the Pacific. Thus knowledge of trajectories is of paramount importance in forecasting west coast weather.

When an outbreak of polar air moves over only a small part of the Pacific Ocean before reaching the United States, it usually resembles maritime arctic cold (mAk). If its path has been far to the south, it is typically mP. Figure 4-8 shows some of the trajectories (A, B, C, D) by which mP air reaches the North American coast during the winter.

TRAJECTORY PATH A (CYCLONIC).—Trajectory path A air originates in Alaska or northern Canada and is pulled out over the Pacific Ocean by a low center close to British Columbia in the Gulf of Alaska. This air has a relatively short overwater path and brings very cold weather to the Pacific Northwest. When the air reaches the coast of British Columbia and Washington after 2 to 3 days over the water, it is convectively unstable. This instability is released when the air is lifted by the coastal mountain ranges. Showers and squalls are common with this condition. Ceilings are generally on the order of 1,000 to 3,000 feet along the coast and generally 0 over the coastal mountain ranges. Cumulus and cumulonimbus are the predominating cloud types, and they generally extend to very high levels. Visibility is generally good because of turbulence and high winds commonly found with this trajectory. Of course, in areas of precipitation, the

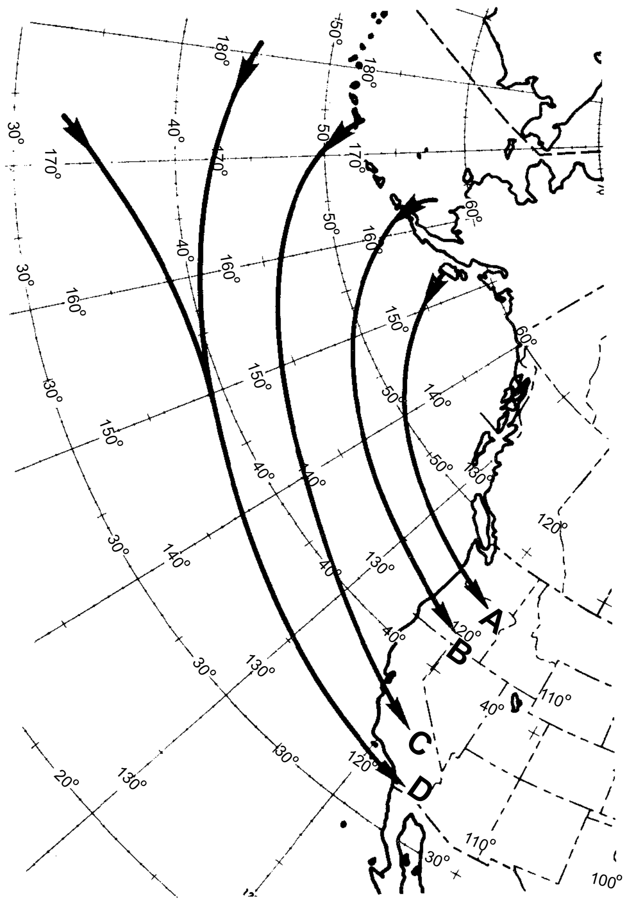

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Figure 4-8.—Trajectories of mP air over the Pacific Coast in winter.

visibility is low. Icing conditions, generally quite severe, are present in the clouds. After this mP air has been over land for several days, it has stabilized and weather conditions improve significantly.

TRAJECTORY PATHS B AND C (CYCLONIC).—Trajectory paths B and C air with a longer overwater trajectory dominate the west coast of the United States during winter months. When there is rapid west-to-east motion and small north-to-south motion of pressure systems, mP air may influence the weather over most of the United States. Because of a longer overwater trajectory, this mP air is heated to greater heights, and convective instability is present up to about 10,000 feet.

This air has typical k characteristics—turbulent gusty winds, steep lapse rate, good visibility at ground except 0 to 3 miles in precipitation, as well as cumulus and cumulonimbus clouds with showers. These showers are not as intense as those produced in the shorter trajectory mP air, but the total amount of precipitation is greater.

TRAJECTORY PATH D (ANTI-CYCLONIC).—This trajectory usually is over water long enough to permit modifications to reach equilibrium at all levels. When the air reaches the coast, it is very stable with one or two subsidence inversions. Stratus or stratocumulus clouds are frequently found. Ceilings are usually 500 to 1,500 feet and the tops of clouds are generally less than 4,000 feet. Visibility is fair except during the early morning hours when haze and smoke reduce the visibility to less than 1 mile. This type of air is found over the entire Pacific coast. It is incorrectly referred to as mT air, since it follows the northern boundary of the Pacific anticyclone. However, mT air does on rare occasions move into California along this path.

Gradually mP air drifts eastward with the prevailing west-east circulation. In crossing the coastal ranges and the Rocky Mountains, much of the moisture in the lower layers is condensed out; the heat of condensation liberated is absorbed by the intermediate layers of air. On the eastern slopes of the mountains, the air is warmed as it descends dry-adiabatically. As it flows over the cold and often snow-covered land surface east of the mountains, the warm mP air becomes stable in the lower layers.

The flying conditions in mP air east of the Rocky Mountains are in general the best that are experienced in winter. Relatively large diurnal temperature ranges are observed. Turbulence is almost absent and visibility is good, except for the smoke and haze in industrial areas. Ceilings are generally unlimited, since either no clouds or only a few high clouds are present. This type of mild winter weather occasionally spreads eastward to the Atlantic coast. When mP air crosses the Rocky Mountains and encounters a deep, dense dome of cP air, it is forced to overrun it and results in storm conditions that produce blizzards over the plains states.

Maritime Tropical (mT) Air Pacific in Winter

Maritime tropical (mT) air is observed only infrequently on the Pacific coast, particularly near the surface. Air flowing around the northern boundary of the Pacific anticyclone is at times mT air but is usually mP air. This air has the weather characteristics (as well as the low temperature) of mP air, having had a long trajectory over the water. (See fig. 4-9.)

Occasionally the eastern cell of the Pacific anticyclone splits, and one portion moves southward off the coast of southern California. This portion of the anticyclone is then able to produce an influx of mT air.

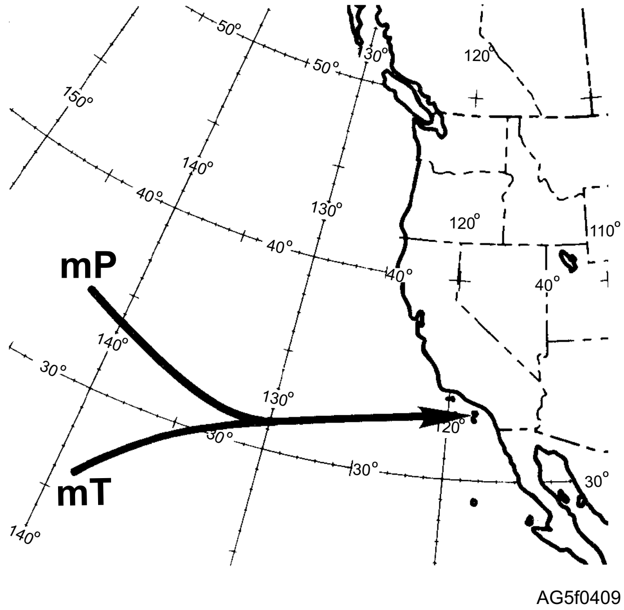

Figure 4-9.—Trajectory of mT air over the Pacific in winter.

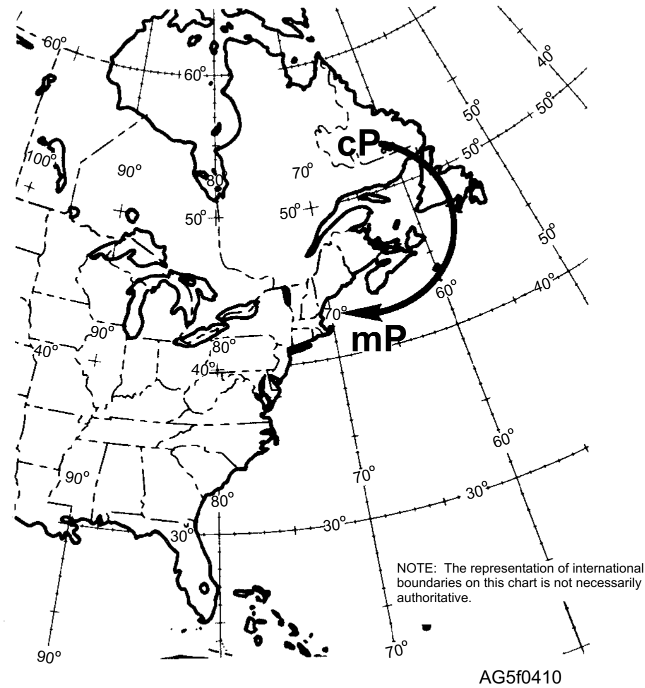

Figure 4-10.—Trajectory of mP air over the Atlantic in winter.

Generally the influx of mT air is carried aloft by a rapidly occluding frontal system somewhere over southern California, producing the heaviest precipitation recorded in that area. Occasionally mT air is seen above the surface with pronounced storm developments over the Great Basin. Since large, open, warm sectors of mT air do not occur along the west coast, representative air mass weather is not experienced. Flying conditions are generally restricted when this air is present, mainly because of low frontal clouds and reduced visibility in precipitation areas.

Maritime Polar (mP) Air Atlantic in Winter

Maritime polar air, which originates in the Atlantic, becomes significant at times along the east coast. It is not nearly so frequent over North America as the other types because of the normal west-east movement of all air masses. This type of air is observed over the east coast in the lower layers of the atmosphere whenever a cP anticyclone moves slowly off the coast of the maritime provinces and New England. (See fig. 4-10.) This air, originally cP, undergoes less heating than its Pacific counterpart because the water temperatures are colder and also because it spends less time over the water. This results in the instability being confined to the lower layers of this air. The intermediate layers of this air are very stable. Showers are generally absent; however, light drizzle or snow and low visibility are common. Ceilings are generally about 700 to 1,500 feet with tops of the clouds near 3,000 feet. Marked subsidence above the inversion ensures that clouds caused by convection will not exist above that level.

The synoptic weather condition favorable to mP air over the east coast is usually also ideal for the rapid development of a warm front with maritime tropical air to the south. Maritime tropical air then overruns the mP air and a thick cloud deck forms. Clouds extending from near the surface to at least 15,000 feet are observed. Ceilings are near zero and severe icing conditions exist in the cold air mass. Frequently, freezing rain and sleet are observed on the ground. Towering cumulus clouds prevail in the warm air and often produce thunderstorms.

Flying conditions are rather dangerous with mP air because of turbulence and icing conditions present near the surface. Poor visibility and low ceilings are additional hazards. The cloudiness associated with the mP air mass usually extends as far west as the Appalachians.

Maritime Tropical (mT) Air Atlantic in Winter

Temperature and moisture content are higher in mT air masses than in any other American air mass in winter. In the southern states, along the Atlantic coast

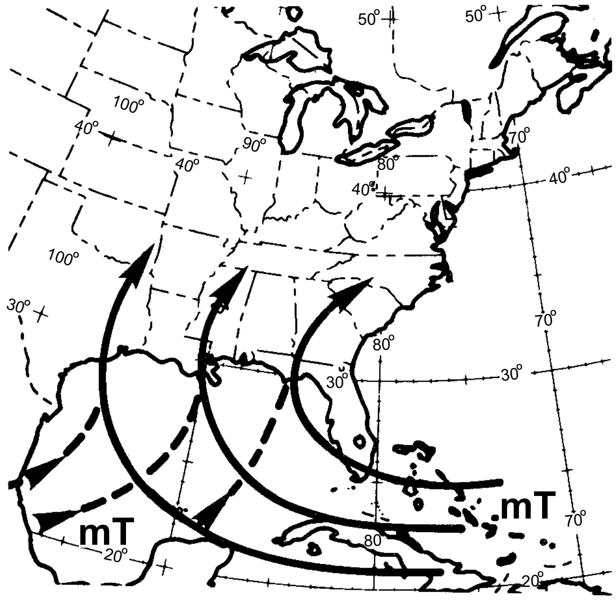

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Figure 4-11.—Trajectories of mT air over the Atlantic in winter.

and Gulf of Mexico (fig. 4-11), mild temperatures, high humidities, and cloudiness are found, especially during the night and early morning. This is the characteristic weather found in mT air in the absence of frontal conditions. The stratus and stratocumulus clouds that form at night tend to dissipate during the middle of the day and fair weather prevails. Visibility is generally poor when the cloudiness is present; however, it improves rapidly because of convective activity when the stratus clouds dissipate. The ceilings associated with the stratus condition generally range from 500 to 1,500 feet, and the tops are usually not higher than 3,500 to 4,500 feet. Precipitation does not occur in the absence of frontal action. With frontal activity, the convective instability inherent in this air is released, producing copious precipitation.

If mT air is forced over mountainous terrain, as in the eastern part of the United States, the conditional instability of the air is released at higher levels. This might produce thunderstorms or at least large cumuliform clouds. (See fig. 4-12.) Pilots must be aware that these clouds may develop out of stratiform cloud systems and therefore may occur without warning. Icing may also be present. Thus, in the Great Lakes area, a combination of all three hazards (fog, thunderstorms, and icing) is possible.

Occasionally when land has been cooled along the coastal area in winter, maritime tropical air flowing inland produces an advection fog over extensive areas. (See fig. 4-13.) In general, flying conditions under this situation are fair. Ceilings and visibilities are occasionally below safe operating limits; however, flying conditions are relatively smooth and icing conditions are absent near the surface layers.

As the trajectory carries the mT air northward over progressively colder ground, the surface layers cool and become saturated. This cooling is greatly accelerated if the surface is snow or ice covered or if the trajectory carries the air over a cold-water surface. Depending on the strength of the air mass, fog with light winds or a low stratus deck with moderate to strong winds forms rapidly because of surface cooling. Occasionally drizzle falls from this cloud form; and visibility, even with moderate winds, is poor. Frontal lifting of mT air in winter, even after the surface layers have become stabilized, results in copious precipitation in the form of rain or snow.

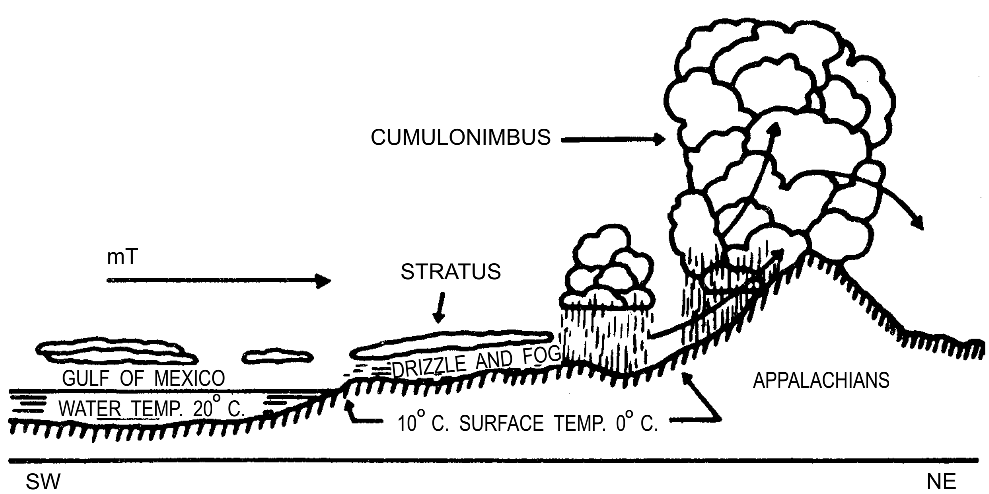

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Figure 4-12.—mT air moving northeastward.

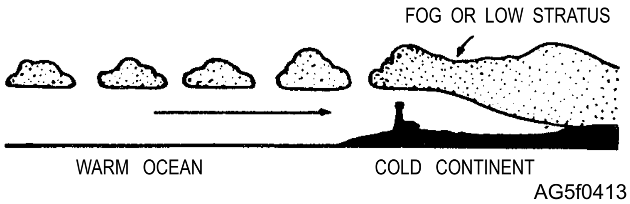

Figure 4-13.—mT (Gulf of Mexico or Atlantic) air of winter moving northward over cold continent.

During the winter, air resembling mT is occasionally observed flowing inland over the gulf and south Atlantic states. Generally the air that had a relatively short trajectory over the warm waters off the southeast coast is cP air. Clear weather usually accompanies cP air in contrast to cloudy weather accompanying a deep current of mT air. On surface synoptic charts, the apparent mT air can be distinguished from true mT air by the surface dew-point temperature value. True mT air always has dew-point temperature values in excess of 60°F. The highly modified cP air usually has dew-point values between 50°F and 60°F.

NORTH AMERICAN AIR MASSES, TRAJECTORIES, AND WEATHER (SUMMER)

During the summer most of the United States is dominated by either S or mT air, whereas Canada and the northwestern United States are dominated by polar air. Occasionally, tropical air is transported to the Canadian tundra and Hudson Bay region.

Continental Polar (cP) Air in Summer

Continental polar (cP) air has characteristics and properties quite different from those of its winter counterpart. Because of the long days and the higher altitude of the sun (as well as the absence of a snow cover over the source region), this air is usually unstable in the surface layers, in contrast to the marked stability found in cP air at its source in winter. By the time this air reaches the United States, it can no longer be distinguished from air coming in from the North Pacific or from the Arctic Ocean. (See fig. 4-14.)

Clear skies or scattered cumulus clouds with unlimited ceilings characterize this mass at its source region. Occasionally, when this air arrives over the central and eastern portion of the United States, it is

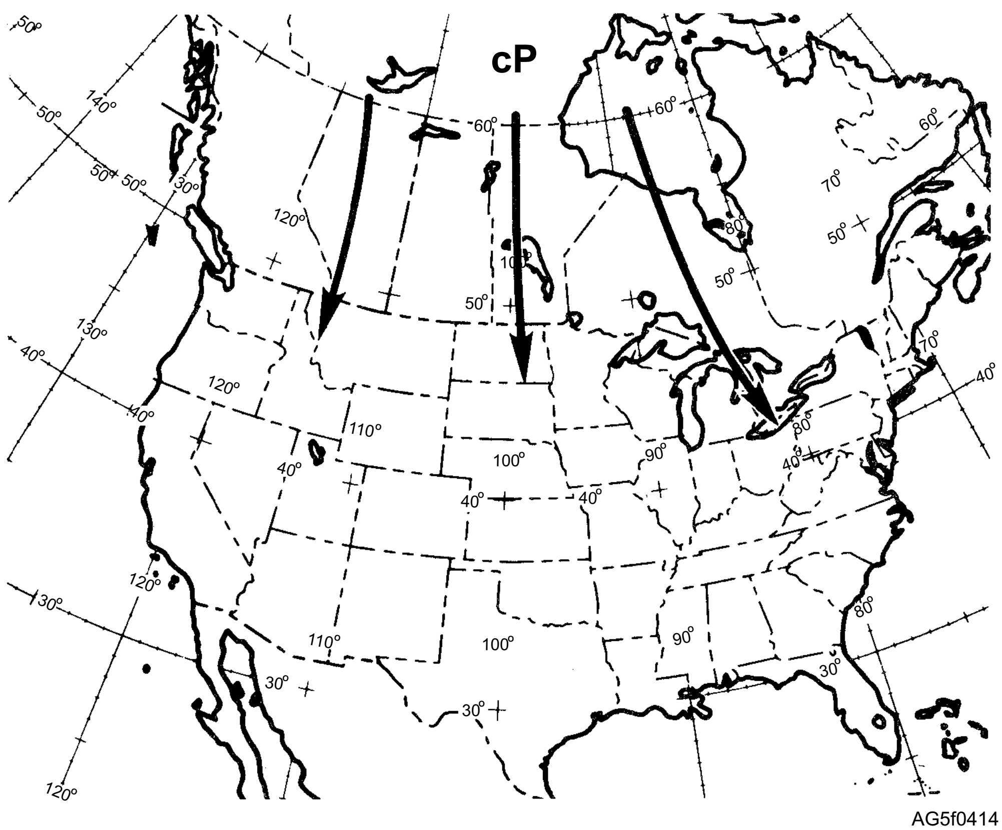

Figure 4-14.—Continental polar (cP) air in summer.

characterized by early-morning ground fogs or low stratus decks. Visibility is generally good except when haze or ground fog occurs near sunrise. Convective activity, usually observed during the daytime, ensures that no great amounts of smoke or dust accumulate in the surface layers. An exception to this is found under stagnant conditions near industrial areas, where restricted visibility may occur during the day and night. Pronounced surface diurnal temperature variations are observed in cP air during summer.

The convective activity of this air is generally confined to the lower 7,000 to 10,000 feet. Flying conditions are generally smooth above approximately 10,000 feet except when local showers develop. Showers, when observed, usually develop in a modified type of cPk over the southeastern part of the country. The base of cumulus clouds that form in this air is usually about 4,000 feet because of the relative dryness of this air mass.

Maritime Polar (mP) Air Pacific in Summer

The entire Pacific coast is usually under the influence of mP air in the summer. (See fig. 4-15.) With a fresh inflow of mP air over the Pacific coast, clear skies or a few scattered cumulus are generally observed over the coastal mountains. As this air flows southward along the coast, a marked turbulence inversion reinforced by subsidence from aloft is observed. Stratus or stratocumulus clouds generally form at the base of the inversion. Ceilings are generally 500 to 1,500 feet with tops of clouds seldom above 3,500 feet. The formation of the stratus condition along the coast of California is greatly enhanced by the presence of the upwelling of cold water along the coast. East of the Rocky Mountains, this air has the same properties as cP air.

Maritime Polar (mP) Air Atlantic in Summer

In spring and summer, mP air is occasionally observed over the east coast. Marked drops in temperature that frequently bring relief from heat waves usually accompany the influx of this air (fig. 4-16). Just as in winter, there is a steep lapse rate in the lower 3,000 feet of this mass. Stratiform clouds usually mark the inversion. Ceilings are from 500 to 1,500 feet, and the tops of the clouds are usually 1,000 to 2,500 feet. No precipitation occurs from these cloud types and visibility is usually good. This air usually does not constitute a severe hazard to flying.

Maritime Tropical (mT) Air Pacific in Summer

Maritime tropical (mT) Pacific air has no direct influence on the weather over the Pacific coast. During the summer season, the Pacific anticyclone moves northward and dominates the Pacific Coast weather with mP air. Occasionally mT air reaches the West Coast; for example, tropical storms or typhoons sometimes move northerly along the Baja Coast. This synoptic condition produces a great amount of cloudiness and precipitation.

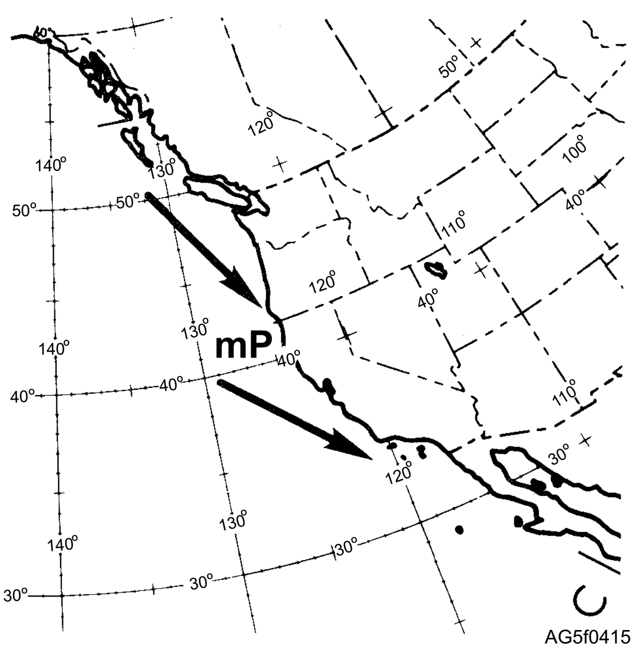

Figure 4-15.—Trajectories of mP air over the Pacific in summer.

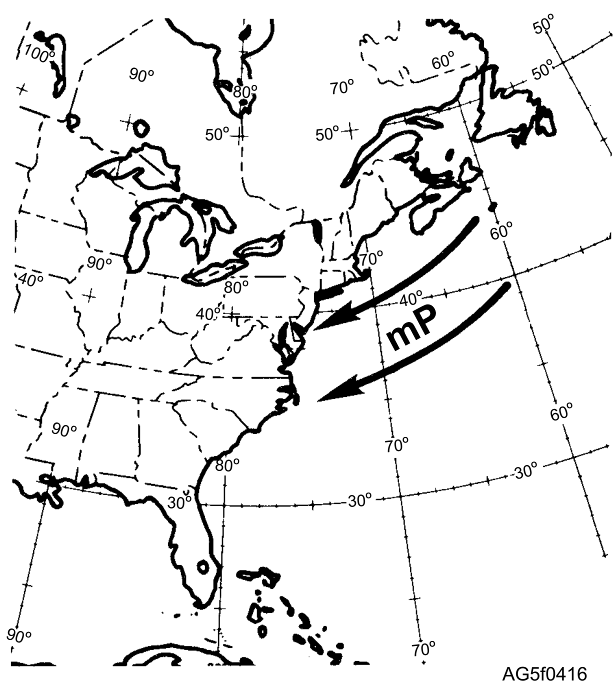

Figure 4-16.—Trajectories of mP air over the Atlantic in summer.

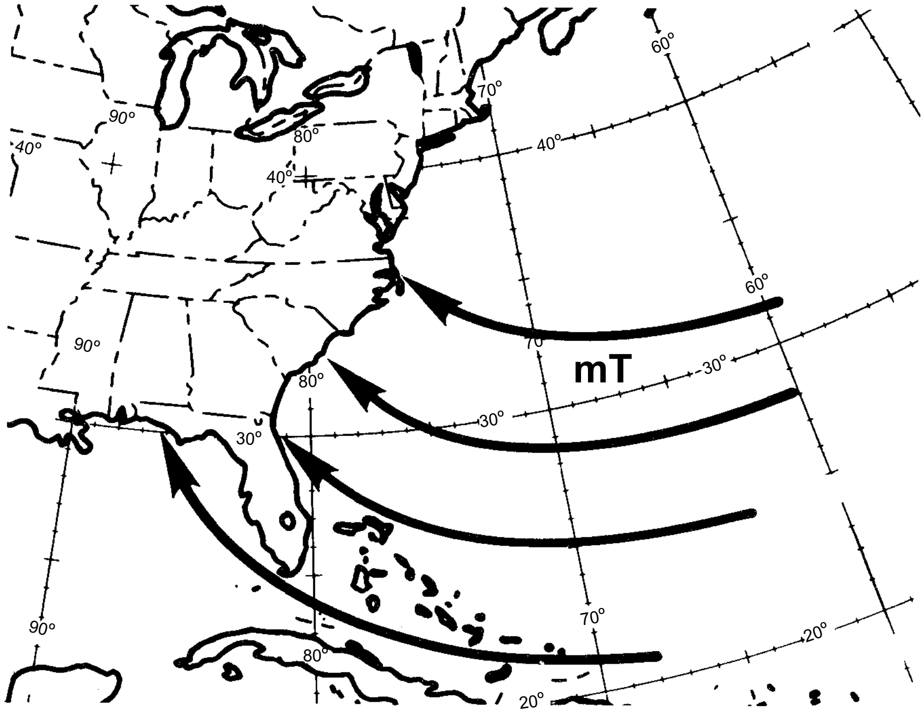

Figure 4-17.—Maritime tropical (mT) air, Atlantic, in summer.

Maritime Tropical (mT) Air Atlantic in Summer

The weather in the eastern half of the United States is dominated by mT air in summer (fig. 4-17). As in winter, warmth and high moisture content characterize this air. In summer, convective instability extends to higher levels; there is also a tendency toward increasing instability when the air moves over a warmer landmass. (See fig. 4-18.) This is contrary to winter conditions.

Along the coastal area of the southern states, the development of stratocumulus clouds during the early morning is typical. These clouds tend to dissipate during the middle of the morning and immediately reform in the shape of scattered cumulus. The continued development of these clouds leads to scattered showers and thunderstorms during the late afternoon. Ceilings in the stratocumulus clouds are generally favorable (700 to 1,500 feet) for the operation of aircraft. Ceilings become unlimited with the development of the cumulus clouds. Flying conditions are generally favorable despite the shower and thunderstorm conditions, since the convective activity is scattered and can be circumnavigated. Visibility is usually good except near sunrise when the air is relatively stable over land.

When mT air moves slowly northward over the continent, ground fogs frequently form at night. Sea fogs develop whenever this air flows over a relatively cold current such as that occurring off the east coast. The notorious fogs over the Grand Banks of Newfoundland are usually formed by this process.

In late summer, the Bermuda high intensifies at times and seems to retrograde westward. This results in a general flow of mT air over Texas, New Mexico, Arizona, Utah, Colorado, and even southern California. The mT air reaching these areas is very unstable because of the intense surface heating and orographic lifting it undergoes after leaving the source region in the Caribbean and Gulf of Mexico. Shower and thunderstorm conditions, frequently of cloudburst intensity, then prevail over the southwestern states. Locally this condition is termed sonora weather.

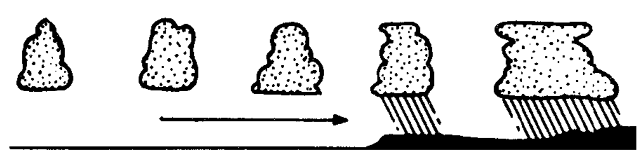

Figure 4-18.—mT (Gulf of Mexico or Atlantic) air in summer moving northward over a warm continental surface.

Continental Tropical (cT) Air in Summer

Continental tropical air is found over the United States only in the summer. Its source region is the relatively small area over the northern portion of Mexico, western Texas, New Mexico, and eastern Arizona. High surface temperatures and very low humidities are the main air mass characteristics. Large diurnal temperature ranges and the absence of precipitation are additional properties of cT air. Flying conditions are excellent. However, during the daytime turbulence sometimes extends from the surface throughout the average flying levels.

Superior (S) Air in Summer

Superior air usually exists over the southwestern states and is believed to be the result of strong subsiding motions. Most frequently this air is observed above an inversion layer at high levels; it rarely descends to the surface. Above the inversion layer, this superior air is the warmest air mass observed in the United States at its altitude; but, because of its steep lapse rate, its temperature at higher levels is less than that of tropical air. Relative humidity is usually less than 30 percent. Quite often they are too low to measure accurately.

Superior air is observed in both summer and winter. Flying conditions are excellent in this air mass, since no cloud forms are present and visibilities are usually very good because of the dryness. This type of air mass is very important because superior air frequently stops all convective activity caused by intruding maritime tropical air. This generally prevents the formation of showers and thunderstorms unless the mT air mass is deep.

NOTE: Views A and B of figure 4-19 show the properties of significant North American air masses during the winter and summer seasons from the standpoint of flying.

AIR MASSES OVER ASIA

The air masses commonly observed over Asia (especially eastern Asia) are continental polar, maritime tropical, and equatorial. Maritime polar and continental tropical air play a minor part in the air mass cycle of Asia.

Continental Polar (cP) Air

Continental polar air, as observed over the interior of Asia, is the coldest air on record in the Northern Hemisphere. This is brought about by the fact that the interior of Asia, made up of vast level and treeless regions, serves as an ideal source region. The Himalaya mountain range, across southern Asia, aids in the production of cP air. It tends to keep the polar air over the source region for a long time and to block the inflow of tropical air from the lower latitudes.

The weather conditions over eastern Asia are governed by this air mass throughout the winter. Successive outbreaks of this air occur over Siberia, China, and the Japanese Islands and establish the winter weather pattern. The weather conditions prevailing in this air are similar to those found in cP air over the eastern portion of North America.

The cold air that is forced southward over the Himalaya Mountains to India and Burma arrives in a highly modified form and is known as the winter monsoon. The weather conditions during the winter monsoon are dominated by the dry and adiabatically warmed polar air flowing equator-ward. It is while under the influence of these monsoon conditions that generally pleasant weather prevails over most of the area.

Maritime Tropical (mT) Air

Maritime tropical air is usually observed along the coast of China and over the Japanese Islands during the summer. In structure it is almost identical to the mT air observed off the east coast of North America. The weather conditions found in this air are similar to those of its North American counterpart.

Equatorial (E) Air

Equatorial air is observed over southeastern Asia. During the summer all of India and Burma are under the influence of E air, because of the summer monsoon circulation. In the wintertime, when offshore winds prevail, E air is not found over the landmasses but is found some distance offshore. Equatorial air is an extremely warm and moist air mass. It has great vertical depth, often extending beyond 20,000 feet in height. This entire column is unstable, and any slight lifting or small amount of surface heating tends to release the instability and produce showers and squalls. The equatorial air observed over India and Burma is almost identical in structure with E air found all along the equatorial zone over the entire Earth. Unmodified equatorial air is observed over India and Burma during the summer monsoon.

A

WINTER AIR MASSES	CLOUDS	CEILINGS	VISIBILITIES	TURBULENCE	SURFACE TEMPERA-TURE F.
cP (near source region)	None	Unlimited	Excellent (except near industrial areas, then 1-4 miles).	Smooth except with high winds velocities.	-10 to -60.
cP (southeast of Great Lakes)	Stratocumulus and cumulus tops 7,000-10,000 feet.	500-1,000 feet, 0 over mountains.	1-5 miles, 0 in snow flurries.	Moderate turbulence up to 10,000 feet.	0 to 20.
mP (on Pacific coast)	Cumulus tops above 20,000 feet.	1,000-3,000 feet, 0 over mountains.	Good except 0 over mountains and in showers.	Moderate to strong turbulence.	45 to 55.
mP (east of Rockies)	None	Unlimited	Excellent except near industrial areas, then 1-4 miles.	Smooth except in lower levels with high winds.	30 to 40.
mP (east coast)	Stratocumulus and stratus tops 6,000-8,000 feet.	0-1,000 feet	Fair except 0 in precipitation area.	Rough in lower levels.	30 to 40.
mT (Pacific coast)	Stratus or stratocumulus.	500-1,500 feet	Good	Smooth	55 to 60.
mT (east of Rockies)	Stratus or stratocumulus	100-1,5000 feet	Good	Smooth	60 to 70.

B

SUMMER AIR MASSES	CLOUDS	CEILINGS	VISIBILITIES	TURBULENCE	SURFACE TEMPERA-TURE F.
cP (near source region)	Scattered cumulus.	Unlimited	Good	Moderate turbulence up to 10,000 feet.	55-60
cP (Pacific coast)	Stratus tops, 2,000-5,000 feet.	100 feet-2,500 feet, unlimited during day.	1/2 - 10 miles	Slightly rough in clouds. Smooth above.	50-60
mP (east of Pacific)	None except scattered cumulus near mountains.	Unlimited	Excellent	Generally smooth except over desert regions in afternoon.	60-70
S (Mississippi Valley)	None	Unlimited	Excellent	Slightly rough up to 15,000 feet.	75-85
mT (east of Rockies)	Stratocumulus early morning; cumulonimbus afternoon.	500-1,000 feet a.m.; 3,000-4,000 feet p.m.	Excellent	Smooth except in thunder-strorms, then strong turbulence.	75-85

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Figure 4-19.—Properties of significant air masses over North America from the standpoint of flying—(A) Winter; (B) Summer.

The weather conditions during the summer monsoon consist of cloudy weather with almost continuous rain and widespread shower activity. High temperatures and high humidities further add to the discomfort.

AIR MASSES OVER EUROPE

Although, in general, the characteristics of air masses over Europe are much the same as those found over North America, certain differences do exist. One reason for this is that an open ocean extends between Europe and North America toward the Arctic. This allows an influx of mA air to reach Europe. This type of air is not encountered over North America. The location of an extensive mountain range in an east-west direction across southern Europe is an additional influence not present over North America, where the prevailing ranges are oriented in a north-south direction.

If the trajectory of the air is observed carefully and the modifying influences of the underlying surface are known, it is easy to understand the weather and flying conditions that occur in an air mass over any continent or ocean.

Maritime Arctic (mA) Air in Winter

Maritime arctic air is observed primarily over western Europe. Strong outbreaks of this air, originating in the Arctic between Greenland and Spitsbergen, usually follow a cyclonic trajectory into western Europe.

Because of their moisture content and instability, cumulus and cumulonimbus clouds are typical of this air mass, frequently producing widespread showers and squalls. Visibility is generally good, but moderate to severe icing often affects aircraft operations.

With the presence of a secondary cyclonic system over France or Belgium, mA air occasionally sweeps southward across France to the Mediterranean, giving rise to the severe mistral winds of the Rhone Valley and the Gulf of Lyons. Heavy shower and thunderstorm conditions are typical in this situation.

Maritime Arctic (mA) Air in Summer

In summer, this air is so shallow that in moving southward from its source region, it modifies to the point where it can no longer be identified and is then indicated as mP air.

Maritime Polar (mP) Air in Winter

Maritime polar air observed over Europe usually originates in the form of cP air over North America. It reaches the west coast of Europe by various trajectories and is found in different stages of modification; it produces weather similar to mP air over the west coast of North America.

Maritime Polar (mP) Air in Summer

Maritime polar air observed over Europe is similar to mP air observed on the west coast of North America. The weather conditions associated with this air are generally good. Occasionally, because of surface heating, a shower or thunderstorm is observed in the daytime over land.

Continental Arctic (cA) and Continental Polar (cP) Air in Winter

The source region for cA and cP air is over northern Russia, Finland, and Lapland. The cA and cP air masses are observed over Europe in connection with an anticyclone centered over northern Russia and Finland. Occasionally they reach the British Isles and at times extend southward to the Mediterranean.

Because of the dryness of cA and cP air, clouds are usually absent over the continent. Fair-weather cumulus are the typical clouds when cA and cP air are observed over the British Isles. Over the Mediterranean, cA and cP air soon become unstable and give rise to cumulus and cumulonimbus clouds with showers. Occasionally these air masses initiate the development of deep cyclonic systems over the central Mediterranean. Visibility is usually good; however, after this type becomes modified, haze layers form and reduce the visibility.

Continental Arctic (cA) and Continental Polar (cP) Air in Summer

The source region for cA and cP air is the same as for its counterpart in winter. It is a predominantly dry air mass and produces generally fair weather over the continent and the British Isles. The visibility is usually reduced because of haze and smoke in the surface layers. As cA and cP air stream southward, the lower layers become unstable; and eventually convective clouds and showers develop in the later stages of their life cycles.

Maritime Tropical (mT) Air in Winter

Maritime tropical air that arrives over Europe usually originates over the southern portion of the North Atlantic under the influence of the Azores anticyclone. Maritime tropical air is marked by pronounced stability in the lower layers and typical warm-mass cloud and weather conditions. Relatively high temperatures accompany the influx of mT air, and the moisture content is greater than in any other air mass observed in the middle latitudes of Europe. Visibility is, as a rule, reduced because of the presence of fog and drizzle, which are frequently observed with an influx of mT air. Maritime tropical air in winter exists only in western Europe. By the time it reaches Russia, it is generally found aloft and greatly modified.

Maritime Tropical (mT) Air in Summer

In general, mT air has the same properties as its counterpart in winter with the exception that it is less stable over land because of surface heating. Additionally, this air mass loses its maritime characteristics soon after passing inland.

Over water, mT air is still a typical warm air mass. Sea fog frequently occurs in the approaches to the English Channel during the spring and early summer. Visibility in mT air is generally better in summer than in winter, particularly over land where convection currents usually develop.

Maritime tropical air flowing over the Mediterranean in summer usually changes to a cold mass, since the water temperature of the Mediterranean is then slightly higher than that of the air. Weak convection currents prevail, usually sufficiently strong to form cumulus clouds but seldom sufficiently strong to produce showers.

Continental Tropical (cT) Air in Winter

The continental tropical air that arrives over Europe in winter originates over North Africa. By the time it reaches central Europe, it differs little from mT air. In general, a cT air mass is much more prevalent over southern Europe than over central or western Europe. Although the moisture content of cT air is less than that observed in mT air, the visibility is not much better, primarily because of the dust that cT air picks up while over Africa. This air mass constitutes the major source of heat for the development of the Mediterranean cyclonic storms, most common during the winter and spring months.

Continental Tropical (cT) Air in Summer

The cT air usually develops over North Africa, Asia Minor, and the southern Balkans. At its source region, the air is dry and warm as well as unstable. The North African air mass is the hottest air mass on record in the world. In its northward flow over southern Europe, cT air absorbs moisture and increases its convective instability. The summer showers and thunderstorms observed over southern Europe are often produced by a modified cT air mass. This air mass is much more prevalent over southern Europe than is its winter counterpart.

AIR MASSES IN THE SOUTHERN HEMISPHERE

The air masses of the Southern Hemisphere are predominantly maritime. This is because of the overwhelming preponderance of ocean areas. Great meridional (south-north and north-south) transports of air masses, as they are known in the Northern Hemisphere, are absent because the westerlies are much more developed in the Southern Hemisphere than in the Northern Hemisphere. Except for Antarctica, there are no large landmasses in the high latitudes in the Southern Hemisphere; this prevents sizable invasions of antarctic air masses. The large landmasses near the equator, on the other hand, permit the extensive development of warm air masses.

The maritime tropical air masses of the Southern Hemisphere are quite similar to their counterparts of the Northern Hemisphere. In the large area of Brazil, there are two air masses for consideration. One is the regular air mass from the Atlantic, which is composed of unmodified mT air. The other originates in the Atlantic; but by the time it spreads over the huge Amazon River basin, it undergoes two important changes—the addition of heat and moisture. As a result of strong summer heating, a warm, dry continental tropical (cT) air mass is located from 30° south to 40° south.

The maritime polar air that invades South America is quite similar to its counterpart in the United States. Maritime polar air occupies by far the most territory in the Southern Hemisphere, encircling it entirely.

Australia is a source region for continental tropical air. It originates over the vast desert area in the interior. Except along the eastern coast, maritime tropical air does not invade Australia to a marked degree. This air is brought down from the north, particularly in the summer, by the counterclockwise circulation around the South Pacific high.

Antarctica is a great source region for intensely cold air masses. The temperatures are colder than in the arctic regions. These air masses have continental characteristics, but before the air reaches other land areas, it becomes modified and is properly called maritime polar.

During the polar night the absence of insolation causes a prolonged cooling of the snow surface, which makes Antarctica a permanent source of very cold air. It is extremely dry and stable aloft. This polar air mass is referred to as continental antarctic (cA) air. In summer the continent is not as cold as in winter because of constant solar radiation but continues to function as a source for cold cA air.

In both winter and summer, the air mass is thermally modified as it flows northward through downslope motion and surface heating; as a result, it becomes less stable. It assumes the characteristics of maritime antarctic air. The leading edge of this air mass then becomes the northern boundary of the antarctic front.

To the north of the antarctic front is found a vast mass of maritime polar air that extends around the hemisphere between 40°S and 68°S in summer and between 34°S and 65°S in winter. At the northern limit of this air mass is found the Southern Hemisphere polar front. During summer this mP air is by far the most important cold air mass of the hemisphere because of the lack of massive outbreaks of cold continental air from Antarctica.

Different weather conditions occur with each type of air mass. The cA air produces mostly clear skies. The mA air masses are characterized generally by an extensive overcast of stratus and stratocumulus clouds with copious snow showers within the broad zone of the antarctic front. An area of transition that extends mainly from the coastline to the northern edge of the consolidated pack ice is characterized by broken to overcast stratocumulus clouds with somewhat higher bases and little precipitation.

REVIEW QUESTIONS

Q4-1. What is the definition of an air mass?

Q4-2. Name the two factors that are necessary to produce an air mass?

Q4-3. What type of air mass is mTk?

Q4-4. What are the two modifying influences on air masses?

Q4-5. What is the warmest air mass observed in the United States at its altitude?

FRONTS

LEARNING OBJECTIVE: Describe the specific parts that make up a front and identify how a front is classified as either cold, warm, occluded, or quasi-stationary.

A front, generally speaking, is a zone of transition between two air masses of different density and temperature and is associated with major weather changes, some of which can be violent. This fact alone is sufficient reason for an in-depth study of fronts and their relationship to air masses and cyclones.

DEFINITIONS AND CLASSIFICATIONS

A front is not just a colorful line drawn on a surface chart. A front is a three-dimensional phenomena with a very specific composition. Since a front is a zone of transition between two air masses of different densities, there must be some sort of boundary between these air masses. One of these boundaries is the frontal surface. The frontal surface is the surface that separates the two air masses. It is the surface next to the warmer air (less dense air). In reality, however, the point at which two air masses touch is not a nice, abrupt separation. This area is a zone of a large density gradient. This zone is called the frontal zone. A frontal zone is the transition zone between two adjacent air masses of different densities, bounded by a frontal surface. Since the temperature distribution is the most important regulator of atmospheric density, a front almost invariably separates air masses of different temperatures.

At this point you should be aware of the various types of fronts. The question in your mind should be how a front is classified. Whether it is cold, warm, or stationary. A front is classified by determining the instantaneous movement. The direction of movement of the front for the past 3 to 6 hours is often used. Classification is based on movement relative to the warm and cold air masses involved. The criterion is as follows:

Cold Front

A cold front is one that moves in a direction in which cold air displaces warm air at the surface. In other words the cold (or cooler) air mass is moving toward a warmer air mass. The cooler, denser air is sliding under the warmer, less dense air displacing it upward.

Warm Front

A warm front is one along which warmer air replaces colder air. In this case, a warmer air mass is moving toward a cooler retreating air mass. The warmer, less dense air moves only toward and replaces the colder, denser air if the colder air mass is also moving.

Quasi-Stationary Front

This type front is one along which one air mass does not appreciably replace the other. These fronts are stationary or nearly so (speed under 5 knots). They can move or undulate toward either the cold or warm air mass.

Occluded Front

An occluded front is one where a cold front overtakes a warm front, forcing the warm air upward. The occluded front may be either a warm front or a cold front type. a warm front type is one in which the cool air behind the cold front overrides the colder air in advance of the warm front, resulting in a cold front aloft. A cold front type is one in which the cold air behind the cold front under rides the warm front, resulting in a warm front aloft.

RELATION OF FRONTS TO AIR MASSES AND CYCLONES

LEARNING OBJECTIVE: Describe the relationship of fronts to air masses and stable and unstable wave cyclones.

RELATION OF FRONTS TO AIR MASSES

At this point you should have figured out that without air masses there would be no fronts. The centers of action are responsible for bringing the air masses together and forming frontal zones.

The primary frontal zones of the Northern Hemisphere are the arctic frontal zone and the polar frontal zone. The most important frontal zone affecting the United States is the polar front. The polar front is the region of transition between the cold polar air and warm tropical air. During the winter months (in the Northern Hemisphere), the polar front pushes farther southward, because of the greater density of the polar air, than during the summer months. During the summer months (in the Northern Hemisphere), the polar front seldom moves farther south than the central United States.

On a surface map a front is indicated as a line separating two air masses; this is only a picture of the surface conditions. These air masses and fronts extend vertically. (See fig. 4-20.)

A cold air mass, being heavier, acts like a wedge and tends to under run a warm air mass. Thus, the cold air is below and the warm air is above the surface of discontinuity. This wedge of cold air produces a slope of the frontal surface. This slope is usually between 1 to 50 (1-mile vertical for 50 miles horizontal) for a cold front and 1 to 300 (1-mile vertical for 300 miles horizontal) for a warm front. For example, 100 miles from the place where the frontal surface meets the ground, the frontal surface might be somewhere between 2,000 feet and 10,000 feet above Earth's surface, depending on the slope. The slope of a front is of considerable importance in visualizing and understanding the weather along the front.

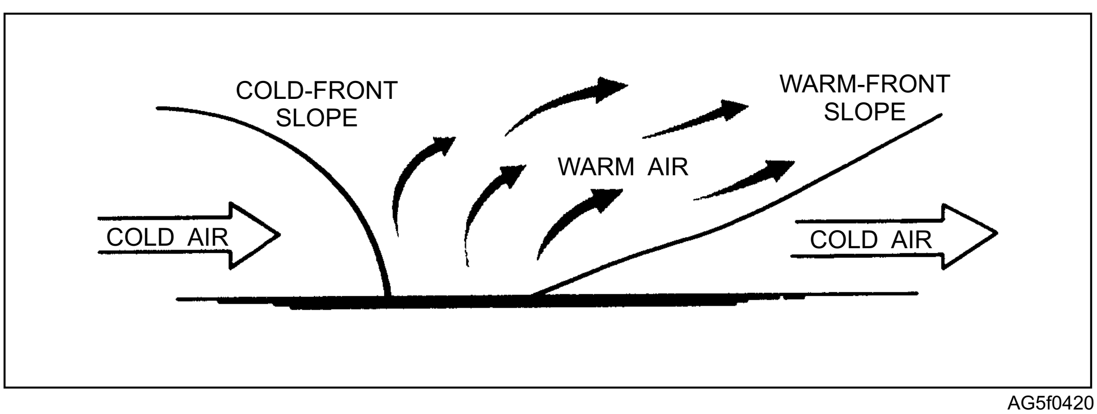

Figure 4-20.—Vertical view of a frontal system (clouds not shown).

RELATION OF FRONTS TO CYCLONES

There is a systemic relationship between cyclones and fronts, in that the cyclones are usually associated with waves along fronts—primarily cold fronts. Cyclones come into being or intensify because pressure falls more rapidly at one point than it does in the surrounding area. Cyclogenesis can occur anywhere, but in middle and high latitudes, it is most likely to occur on a frontal trough. When a cyclone (or simply low) develops on a front, the cyclogenesis begins at the surface and develops gradually upward as the cyclone deepens. The reverse also occurs; closed circulations aloft sometime work their way downward until they appear on the surface chart. These cyclones rarely contain fronts and are quasi-stationary or drift slowly westward and/or equatorward.

Every front, however, is associated with a cyclone. Fronts move with the counterclockwise flow associated with Northern Hemisphere cyclones and clockwise with the flow of Southern Hemisphere cyclones. The middle latitudes are regions where cold and warm air masses continually interact with each other. This interaction coincides with the location of the polar front.

When the polar front moves southward, it is usually associated with the development and movement of cyclones and with outbreaks of cold polar air. The cyclonic circulation associated with the polar front tends to bring polar air southward and warm moist tropical air northward.

During the winter months, the warm airflow usually occurs over water and the cold air moves southward over continental areas. In summer the situation is reversed. Large cyclones that form on the polar front are usually followed by smaller cyclones and are referred to as families. These smaller cyclones tend to carry the front farther southward. In an ideal situation these cyclones come in succession, causing the front (in the Northern Hemisphere) to lie in a southwest to northeast direction.

Every moving cyclone usually has two significant lines of convergence distinguished by thermal properties. The discontinuity line on the forward side of the cyclone where warm air replaces cold air is the warm front; the discontinuity line in the rear portion of the cyclone where cold air displaces warm air is the cold front.

The polar front is subject to cyclonic development along it. When wind, temperature, pressure, and upper level influences are right, waves form along the polar front. Wave cyclones normally progress along the polar front with an eastward component at an average rate of 25 to 30 knots, although 50 knots is not impossible, especially in the case of stable waves. These waves may ultimately develop into full-blown low-pressure systems with gale force winds. The development of a significant cyclone along the polar front depends on whether the initial wave is stable or unstable. Wave formation is more likely to occur on slowly moving or stationary fronts like the polar front than on rapidly moving fronts. Certain areas are preferred localities for wave cyclogenesis. The Rockies, the Ozarks, and the Appalachians are examples in North America.

Stable Waves

A stable wave is one that neither develops nor occludes, but appears to remain in about the same state. Stable waves usually have small amplitude, weak low centers, and a fairly regular rate and direction of movement. The development of a stable wave is shown in views A, B, and C of figure 4-21. Stable waves do not go into a growth and occlusion stage.

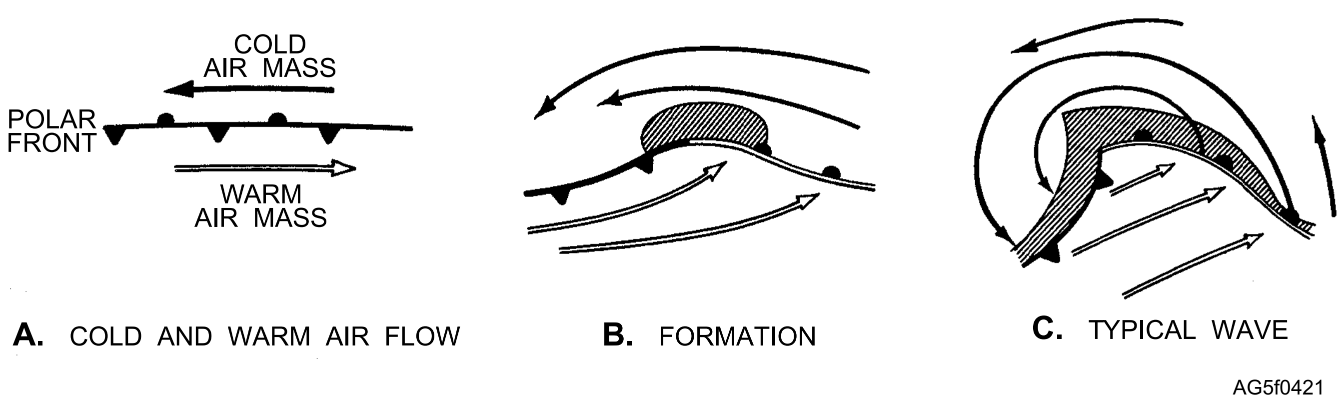

Figure 4-21.—Life cycle of a stable wave cyclone.

Unstable Waves

The unstable wave is by far the more common wave that is experienced with development along the polar front. The amplitude of this wave increases with time until the occlusion process occurs. The formation of a deep cyclone and an occluded front breaks up the polar front. When the occlusion process is complete, the polar front is reestablished. This process is shown in figure 4-22. Views A through G of figure 4-22, referred to in the next three paragraphs, show the life cycle of the unstable wave.

In its initial stage of development, the polar front separates the polar easterlies from the mid-latitude westerlies (view A); the small disturbance caused by the steady state of the wind is often not obvious on the weather map. Uneven local heating, irregular terrain, or wind shear between the opposing air currents may start a wavelike perturbation on the front (view B); if this tendency persists and the wave increases in amplitude, a counterclockwise (cyclonic) circulation is set up. One section of the front begins to move as a warm front while the adjacent sections begin to move as a cold front (view C). This deformation is called a frontal wave.

The pressure at the peak of the frontal wave falls, and a low-pressure center is formed. The cyclonic circulation becomes stronger; the wind components are now strong enough to move the fronts; the westerlies turn to southwest winds and push the eastern part of the front northward as a warm front; and the easterlies on the western side turn to northerly winds and push the western part southward as a cold front. The cold front is moving faster than the warm front (view D). When the

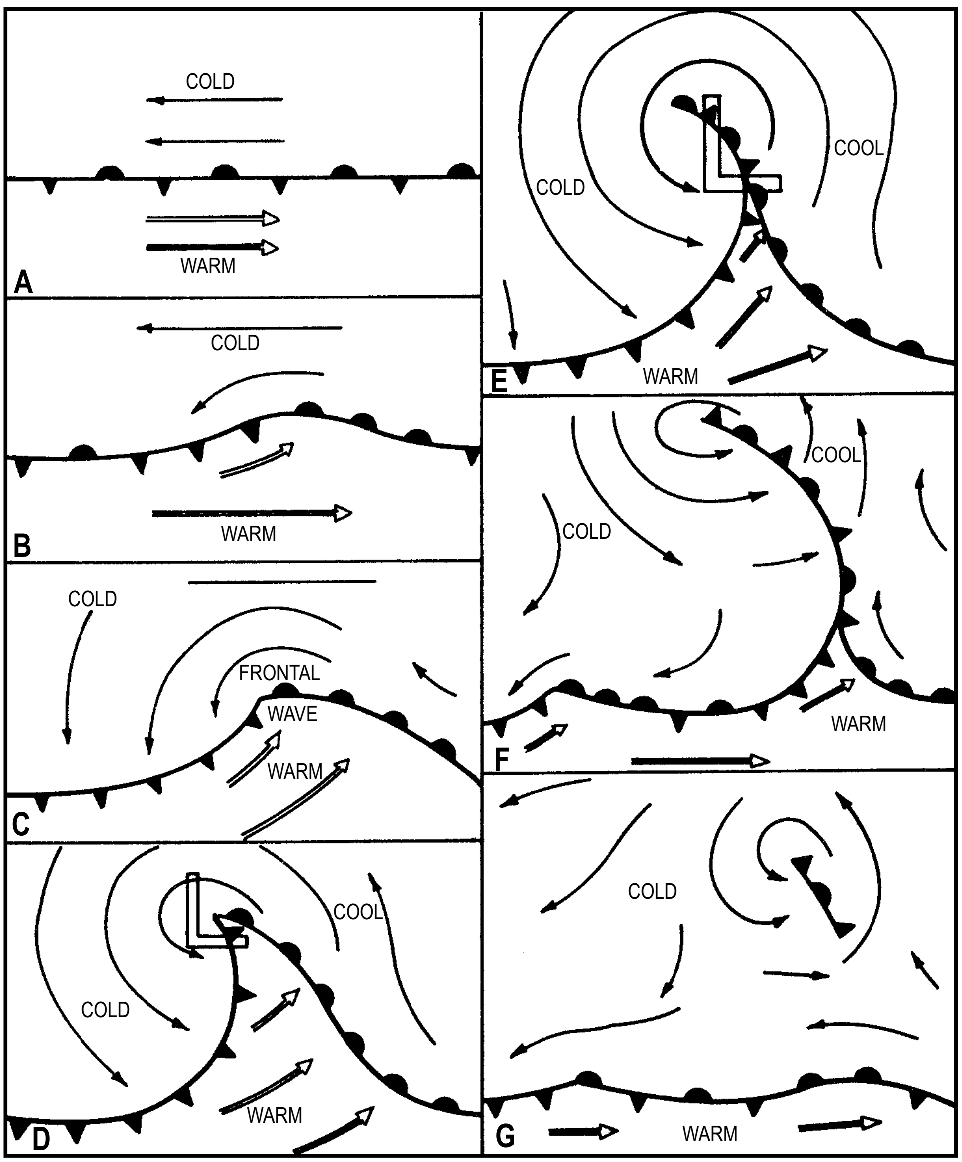

Figure 4-22.—Life cycle of an unstable frontal wave.

Table 4-2.—Numerical Characteristics of the Life Cycle of an Unstable Wave Cyclone

	Wave Cyclone	Occlusion	Mature Occlusion	Cyclolysis
Time (hours)	0	12-24	24-36	36-72
Central Pressure (mb)	1,012-1,000	1000-988	984-968	998-1,004
Direction of Movement (toward)	NE to SE or (quad)	NNE to N (arc)	N to NNW (arc)	
Speed of Movement (knots)	30-35	20-25	10-15	0-5

The symbol indicates that the filling center drifts slowly in a counterclockwise direction along an approximately circular path about a fixed point.

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cold front overtakes the warm front and closes the warm sector, an occlusion is formed (view E). This is the time of maximum intensity of the wave cyclone.

As the occlusion continues to extend outward, the cyclonic circulation diminishes in intensity (the low-pressure area weakens), and the frontal movement slows down (view F). Sometimes a new frontal wave may begin to form on the westward trailing portion of the cold front. In the final stage, the two fronts become a single stationary front again. The low center with its remnant of the occlusion has disappeared (view G). Table 4-2 shows the numerical average life cycle of a typical unstable wave cyclone from initial development to cyclolysis. It is only intended to be used as a guide in areas where reports are sparse.

FRONTOGENESIS AND FRONTOLYSIS

LEARNING OBJECTIVE: Describe the conditions necessary for frontogenesis and frontolysis, and identify the world fronto-genetical zones.

CONDITIONS NECESSARY FOR FRONTOGENESIS

Frontogenesis is the formation of a new front or the regeneration of an old one. Frontogenesis takes place only when two conditions are met. First, two air masses of different densities must exist adjacent to one another; and second, a prevailing wind field must exist to bring them together. There are three basic situations, which are conducive to frontogenesis and satisfy the two basic requirements.

The windflow is cross isothermal and flowing from cold air to warmer air. The flow must be cross isothermal, resulting in a concentration of isotherms (increased temperature gradient). The flow does not have to be perpendicular; however, the more perpendicular the cross isothermal flow, the greater the intensity of frontogenesis.

The winds of opposite air masses move toward the same point or line in that cross-isothermal flow. A classic example of this situation is the polar front where cold polar air moves southward toward warmer

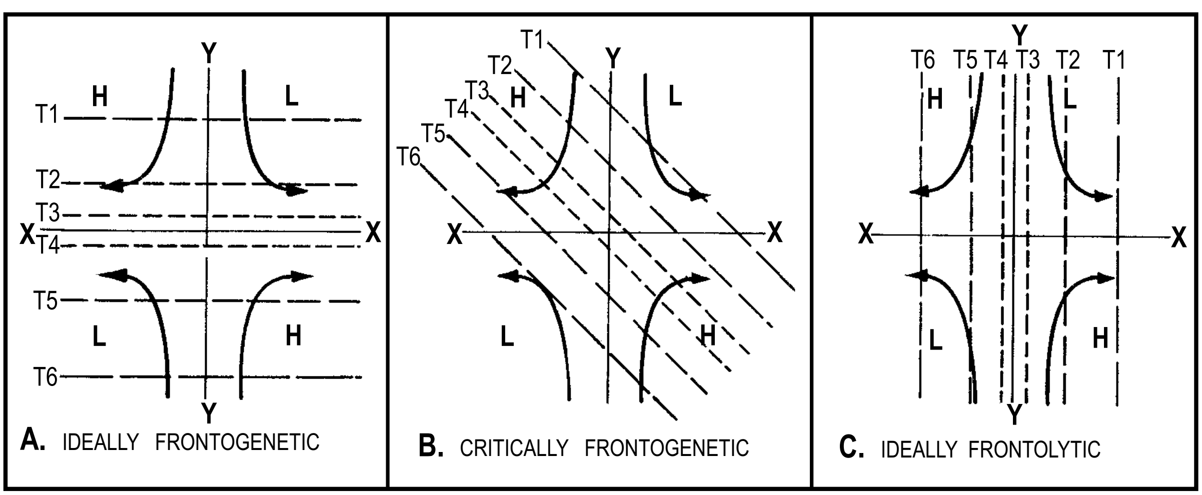

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Figure 4-23.—Perpendicular deformation field.

temperatures and warm tropical air moves northward toward colder temperatures.

The wind flow has formed a deformation field. A deformation field consists basically of an area of flat pressure between two opposing highs and two opposing lows (also called a COL or saddle). It has two axes that have their origin at a neutral point in the COL (view A in fig. 4-23). The y axis, or axis of contraction, lies between the high and low that bring the air particles toward the neutral point. (Note the flow arrows in fig. 4-23.) The x axis lies between the high and low that take air particles away from the neutral point and is known as the axis of dilation.

The distribution and concentration of isotherms T1 through T6 in this deformation field determine whether frontogenesis results. If the isotherms form a large angle with the axis of contraction, frontogenesis results. If a small angle exists, frontolysis (the dissipation of a front) results. It has been shown that in a perpendicular deformation field, isotherms must form an angle of 450 or less with the axis of dilation for frontogenesis to occur as shown in views A and B of the figure. In a deformation field not perpendicular, the critical angle changes correspondingly as illustrated in views A and B of figure 4-24. In most cases, frontogenesis occurs along the axis of dilation. Frontogenesis occurs where there is a concentration of isotherms with the circulation to sustain that concentration.

CONDITIONS NECESSARY FOR FRONTOLYSIS

Frontolysis, or the dissipation of a front, occurs when either the temperature difference between the two air masses disappears or the wind carries the air particles of the air mass away from each other. Frontolytical processes are more common in the atmosphere than are frontogenetical processes. This comes about because there is no known property of the air, which is conservative with respect to all the physical or dynamical processes of the atmosphere.

Frontolytical processes are most effective in the lower layers of the atmosphere since surface heating and turbulent mixing are the most intense of the nonconservative influences on temperature.

For frontolysis to occur, only one of the two conditions stated above need be met. The simultaneous happening of both conditions results in more rapid frontolysis than if only one factor were operative. The shape and curvature of the isobars also give valuable indications of frontolysis and frontogenesis, and, therefore, possible cyclolysis or cyclogenesis.

On a cold front, anticyclonically curved isobars behind the front indicate that the FRONT is slow moving and therefore exposed to frontogenesis.

Cyclonically curved isobars in the cold air behind the cold front indicate that the front is fast moving and exposed to frontolysis. On the warm fronts the converse is true.

Anticyclonically curved isobars in advance of the warm front indicate the front is fast moving and exposed to frontolysis.

With cyclonically curved isobars the warm front is retarded and exposed to frontogenesis.

WORLD FRONTOGENETICAL ZONES

Certain regions of the world exhibit a high frequency of frontogenesis. These regions are

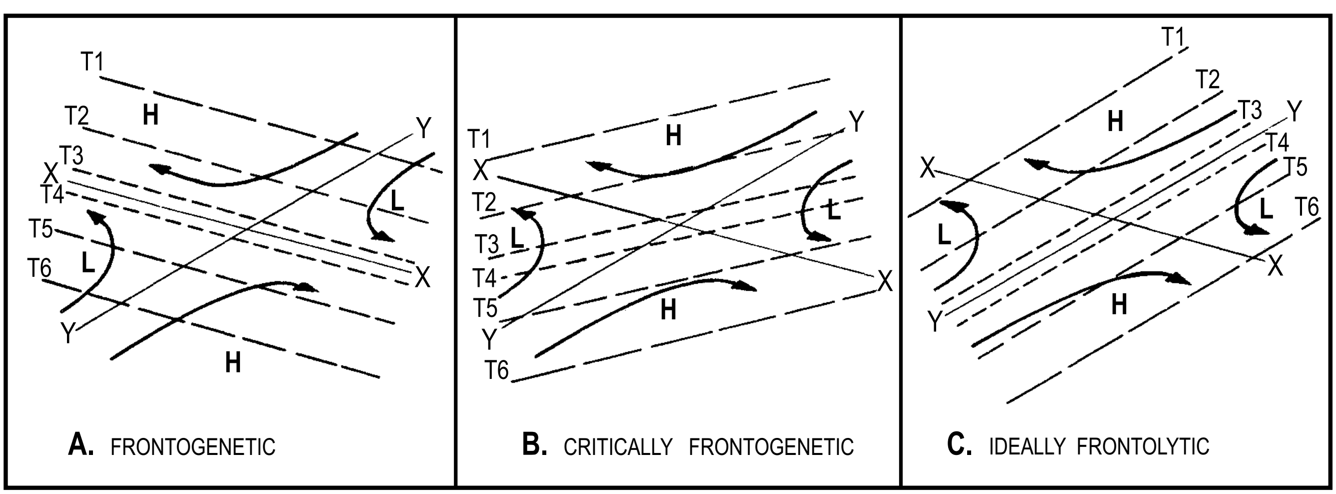

Figure 4-24.—Nonperpendicular deformation field.

coincident with the greatest temperature contrasts. Two of the most important frontal zones are those over the north Pacific and north Atlantic Oceans. In winter, the arctic front, a boundary between polar and arctic air, forms in high latitudes over northwest North America, the north Pacific, and near the Arctic Circle north of Europe (fig. 4-25). In summer, the arctic front mainly disappears, except north of Europe. (See fig. 4-26.)

The polar front, on the other hand, is present the year round, although it is not as intense in the summer as in the winter because of a lessening temperature contrast between the opposing air masses. The polar front forms wherever the wind flow and temperature contrast is favorable. Usually this is the boundary between tropical and polar air, but it may form between maritime polar and continental polar air. It also may exist between modified polar air and a fresh outbreak of polar air. The polar front is common over North America in the continental regions in winter in the vicinity of 50°N latitude.

The polar front in winter is found most frequently off the eastern coasts of continents in areas of 30° to 60° latitude. It is also found over land; but since the temperature contrasts are greater between the continent and the oceans, especially in winter, the coastal areas are more favorable for formation and intensification of the polar front.

The intertropical convergence zone (ITCZ), though not truly a front but a field of convergence between the opposing trades, forms a third semipermanent frontal type. This region shows a seasonal variation just as do the trade winds.

FRONTAL CHARACTERISTICS

LEARNING OBJECTIVE: Describe the frontal elements and general characteristics of fronts.

FRONTAL ELEMENTS

From our previous discussion and definitions of fronts, it was implied that a certain geometrical and meteorological consistency must exist between fronts

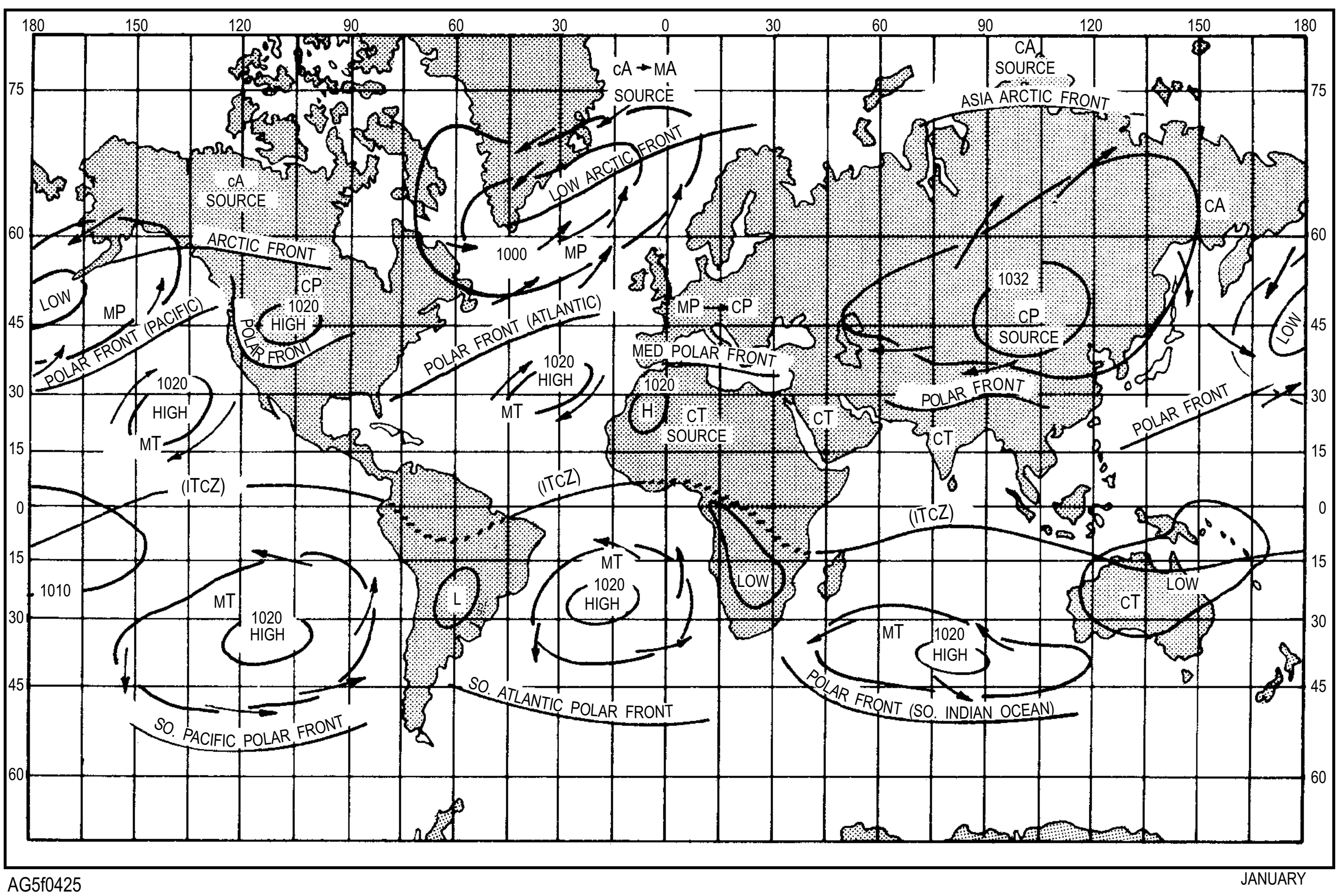

Figure 4-25.—Chart showing world air masses, fronts and centers of major pressure systems in January.

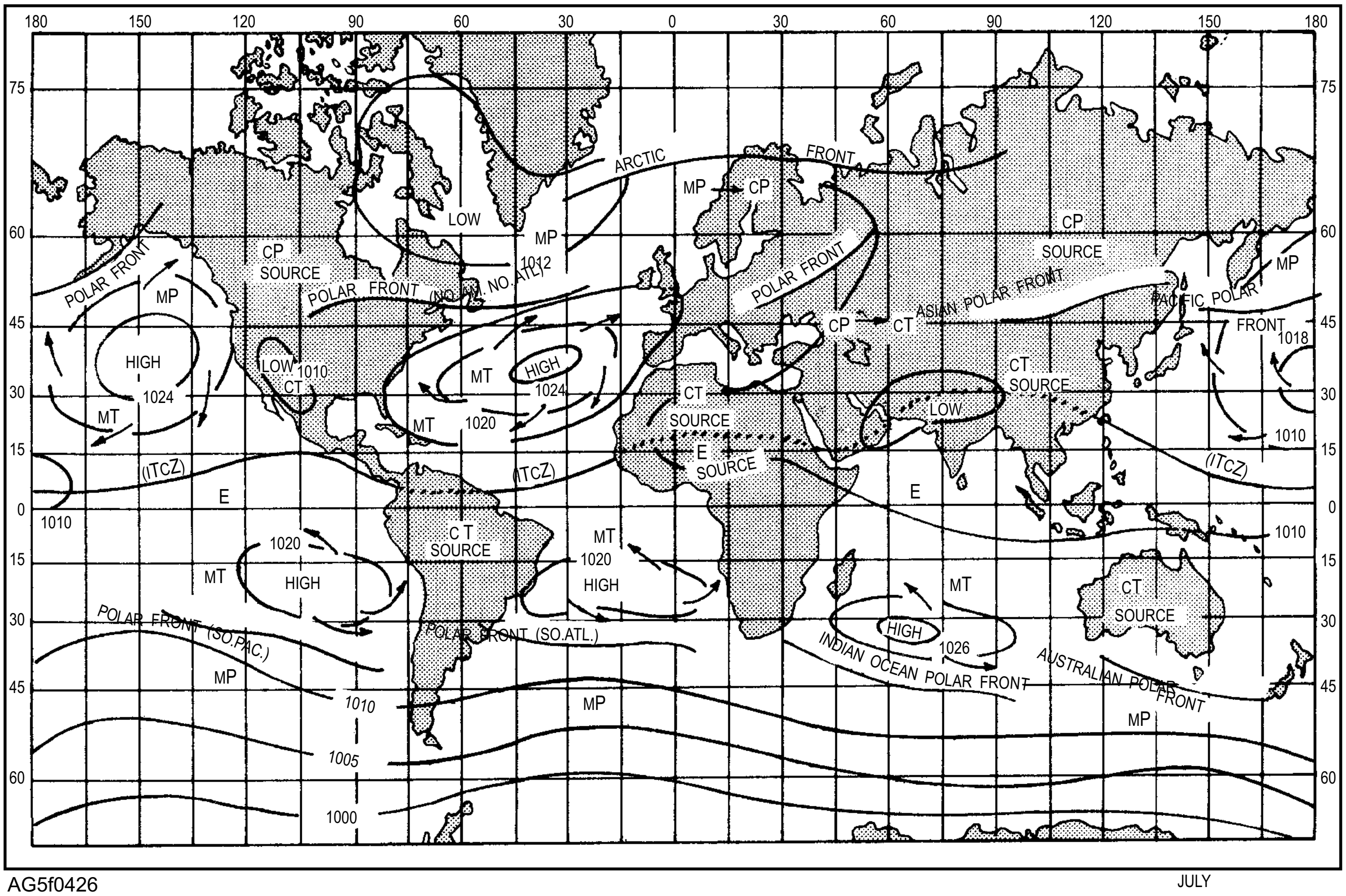

Figure 4-26.—Chart showing world air masses, fronts and centers of major pressure systems in July.

at adjoining levels. It can also be inferred that the data at no one particular level is sufficient to locate a front with certainty in every case. We must consider the horizontal and vertical distribution of three weather elements (temperature, wind, and pressure) in a frontal zone.

Temperature

Typical fronts always consist of warm air above cold air. A radiosonde observation taken through a frontal surface often indicates a relatively narrow layer where the normal decrease of temperature with height is reversed. This temperature inversion is called a frontal inversion; its position indicates the height of the frontal surface and the thickness of the frontal zone over the particular station. The temperature increase within the inversion layer and the thickness of the layer can be used as a rough indication of the intensity of a front. Strong fronts tend to have a distinct inversion; moderate fronts have isothermal frontal zones; and weak fronts have a decrease in temperature through the frontal zone.

Frontal zones are often difficult to locate on a sounding because air masses become modified after leaving their source region and because of turbulent mixing and falling precipitation through the frontal zone. Normally, however, some indication does exist. The degree to which a frontal zone appears pronounced is proportional to the temperature difference between two air masses.

The primary indication of a frontal zone on a Skew T diagram is a decrease in the lapse rate somewhere in the sounding below 400 mb. The decrease in lapse rate may be a slightly less steep lapse rate for a stratum in a weak frontal zone to a very sharp inversion in strong fronts. In addition to a decrease in the lapse rate, there is usually an increase in moisture (a concurrent dew-point inversion) at the frontal zone. This is especially true when the front is strong and abundant cloudiness and

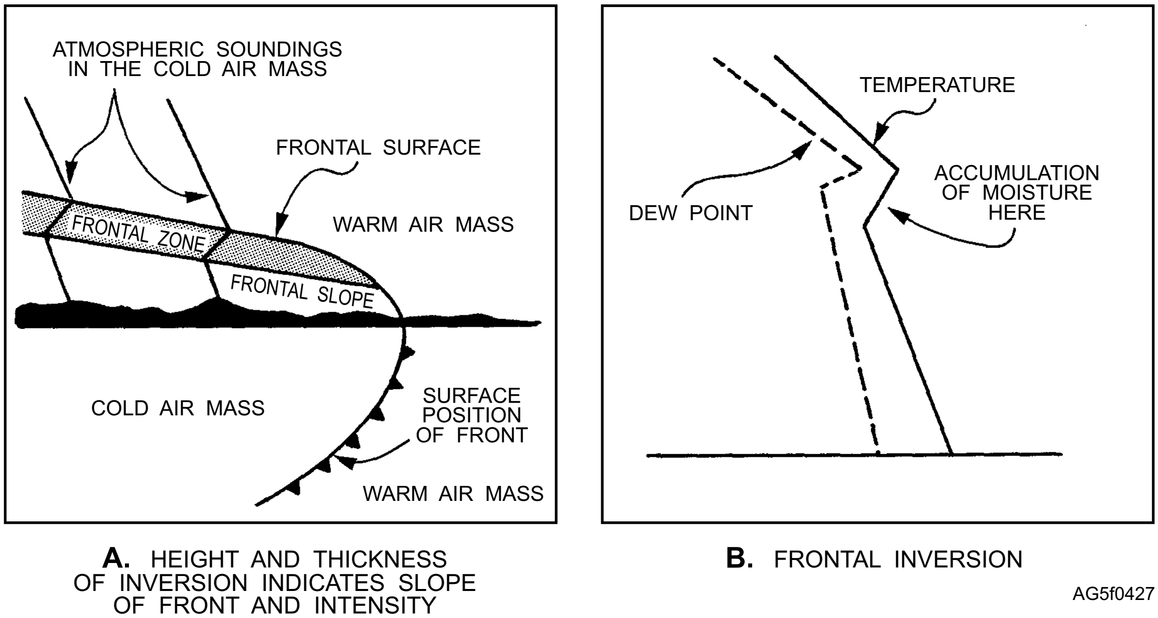

Figure 4-27.—Inversions.

precipitation accompany it. View A of figure 4-27 shows the height of the inversion in two different parts of a frontal zone, and view B of figure 4-27 shows a strong frontal inversion with a consequent dew-point inversion.

A cold front generally shows a stronger inversion than a warm front, and the inversion appears at successively higher levels as the front moves past a station. The reverse is true of warm fronts. Occluded fronts generally show a double inversion. However, as the occlusion process continues, mixing of the air masses takes place, and the inversions are wiped out or fuse into one inversion.

It is very important in raob analysis not to confuse the subsidence inversion of polar and arctic air masses with frontal inversions. Extremely cold continental arctic air, for instance, has a strong inversion that extends to the 700-mb level. Sometimes it is difficult to find an inversion on a particular sounding, though it is known that a front intersects the column of air over a given station. This may be because of adiabatic warming of the descending cold air just under the frontal surface or excessive local vertical mixing in the vicinity of the frontal zone. Under conditions of subsidence of the cold air beneath the frontal surface, the subsidence inversion within the cold air may be more marked than the frontal zone itself.

Sometimes fronts on a raob sounding, which might show a strong inversion, often are accompanied by little weather activity. This is because of subsidence in the warm air, which strengthens the inversion. The weather activity at a front increases only when there is a net upward vertical motion of the warm air mass.

Wind

Since winds near Earth's surface flow mainly along the isobars with a slight drift toward lower pressure, it follows that the wind direction in the vicinity of a front must conform with the isobars. The arrows in figure 4-28 indicate the winds that correspond to the pressure distribution.

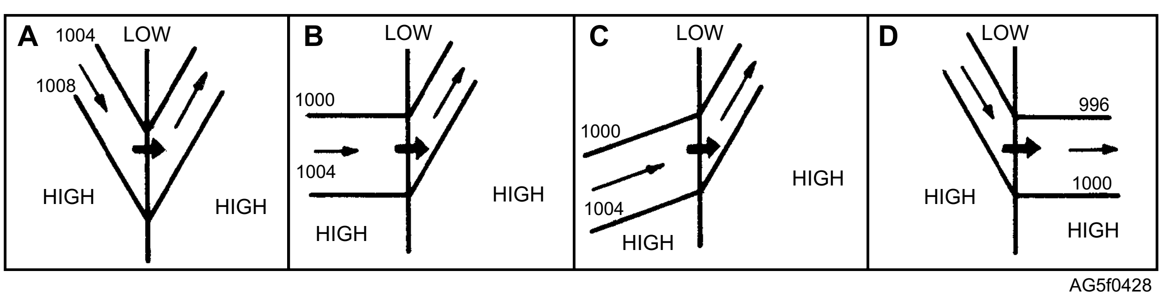

Figure 4-28.—Types of isobars associated with fronts.

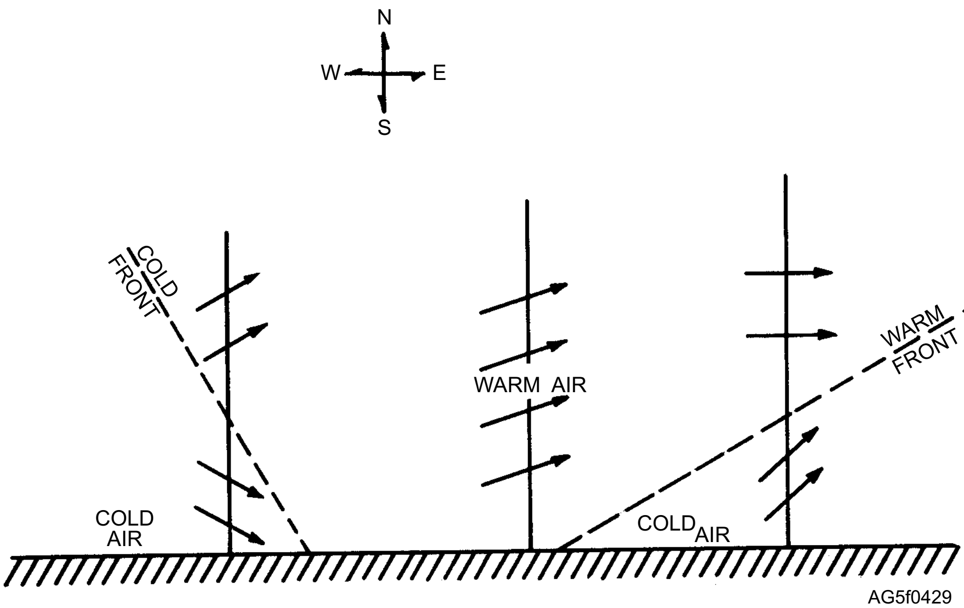

Figure 4-29.—Vertical distribution of wind direction in the vicinity of frontal surfaces.

From this it can be seen that a front is a wind shift line and that wind shifts in a cyclonic direction. Therefore, we can evolve the following rule: *if you stand with your back against the wind in advance of the front, the wind will shift clockwise as the front passes.* This is true with the passage of all frontal types. Refer back to figure 4-22.

NOTE: The wind flow associated with the well-developed frontal system is shown in figure 4-22, view E. Try to visualize yourself standing ahead of each type of front depicted as they move from west to east. The terms *backing* and *veering* are often used when discussing the winds associated with frontal systems.

BACKING.—Backing is a change in wind direction—counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. The opposite of backing is veering.

VEERING.—Veering is a change in wind direction—clockwise in the Northern Hemisphere, counterclockwise in the Southern Hemisphere. The opposite of veering is backing.

The speed of the wind depends upon the pressure gradient. Look at figure 4-28. In view A, the speed is about the same in both air masses; in views B and C, a relatively strong *wind* is followed by a weaker wind; and in view D, a weak wind is followed by a strong wind. An essential characteristic of a frontal zone is a wind discontinuity through the zone. The wind normally increases or decreases in speed with height through a frontal discontinuity. Backing usually occurs with height through a cold front and veering through a warm front. The sharpness of the wind discontinuity is proportional to the temperature contrast across the front and the pressure field in the vicinity of the front (the degree of convergence between the two air streams). With the pressure field constant, the sharpness of the frontal zone is proportional to the temperature discontinuity (no temperature discontinuity—no front; thus, no wind discontinuity). The classical picture of the variation in wind along the vertical through a frontal zone is shown in figure 4-29. An example of a frontal zone and the winds through the frontal zone is shown in figure 4-30.

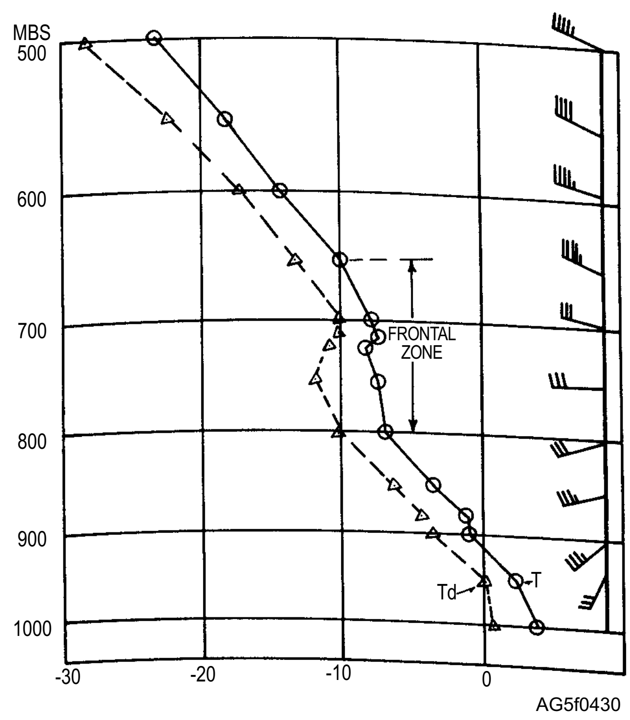

Figure 4-30.—Distribution of wind and temperature through a warm frontal zone.

On this sounding the upper winds that show the greatest variation above the surface layer are those between the 800- to 650-mb layers. This indication coincides closely with the frontal indications of the temperature (T) and dew point (T*d*) curves (see fig. 4-30). Since the wind veers with height through the layer, the front would be warm. The vertical wind shift through a frontal zone depends on the direction of the slope. In cold fronts the wind backs with height, while in warm fronts the wind veers with height. At the surface the wind always veers across the front, and the isobars have a sharp cyclonic bend or trough that points toward higher pressure. Sometimes the associated pressure trough is not coincident with the front; in such cases there may not be an appreciable wind shift across the front—only a speed discontinuity.

Pressure

One of the important characteristics of all fronts is that on both sides of a front the pressure is higher than at the front. This is true even though one of the air masses is relatively warm and the other is relatively cold. Fronts are associated with troughs of low pressure. (A trough is an elongated area of relatively low pressure.) A trough may have U-shaped or V-shaped isobars. How the pressure changes with the passage of a front is of prime importance when you are determining frontal passage and future movement.

Friction causes the air (wind) near the ground to drift across the isobars toward lower pressure. This causes a drift of air toward the front from both sides. Since the air cannot disappear into the ground, it must move upward. Hence, there is always a net movement of air upward in the region of a front. This is an important characteristic of fronts, since the lifting of the air causes condensation, clouds, and weather.

GENERAL CHARACTERISTICS OF FRONTS

All fronts have certain characteristics that are common and usually predictable for that type of front. Cold frontal weather differs from warm frontal weather, and not every cold front has the same weather associated with it. The weather, intensity of the weather, and the movement of fronts are, to a large degree, associated with the slope of the front.

Frontal Slope

When we speak of the slope of a front, we are speaking basically of the steepness of the frontal surface, using a vertical dimension and a horizontal dimension. The vertical dimension used is normally 1 mile. A slope of 1:50 (1 mile vertically for every 50 miles horizontally) would be considered a steep slope, and a slope of 1:300 a gradual slope. Factors favoring a steep slope are a large wind velocity difference between air masses, small temperature difference, and high latitude.

The frontal slope therefore depends on the latitude of the front, the wind speed, and the temperature difference between the air masses. Because cold air tends to under run warm air, the steeper the slope, the more intense the lifting and vertical motion of the warm air and, therefore the more intense the weather.

Clouds and Weather

Cloud decks are usually in the warm air mass because of the upward vertical movement of the *warm air. Clouds forming* in a cold *air mass* are caused by the evaporation of moisture from precipitation from the overlying warm air mass and/or by vertical lifting. Convergence at the front results in a lifting of both types of air. The stability of air masses determines the cloud and weather structure at the fronts as well as the weather in advance of the fronts.

Frontal Intensity

No completely acceptable set of criteria is in existence as to the determination of frontal intensity, as it depends upon a number of variables. Some of the criteria that may be helpful in delineating frontal intensity are discussed in the following paragraphs.

TURBULENCE.—Except when turbulence or gustiness may result, weather phenomena are not taken into account when specifying frontal intensity, because a front is not defined in terms of weather. A front may be intense in terms of discontinuity of density across it, but may be accompanied by no weather phenomena other than strong winds and a drop in temperature. A front that would otherwise be classified as weak is considered moderate if turbulence and gustiness are prevalent along it, and an otherwise moderate front is classified as strong if sufficient turbulence and gustiness exist. The term *gustiness* for this purpose includes convective phenomena such as thunderstorms and strong winds.

TEMPERATURE GRADIENT.—Temperature gradient, rather than true difference of temperature across the frontal surface, is used in defining the frontal intensity. Temperature gradient, when determining frontal intensity, is defined as the difference between the representative warm air immediately adjacent to the front and the representative surface temperature 100 miles from the front on the cold air side.

A suggested set of criteria based on the horizontal temperature gradient has been devised. A weak front is one where the temperature gradient is less than 100F per 100 miles; a moderate front is where the temperature gradient is 10 0F to 20 0F per 100 miles; and a strong front is where the gradient is over 20 0F per 100 miles.

The 850-mb level temperatures may be used in lieu of the surface temperatures if representative surface temperatures are not available and the terrain elevation is not over 3,000 feet. Over much of the western section of the United States, the 700-mb level temperatures can be used in lieu of the surface temperatures.

Speed

The speed of the movement of frontal systems is an important determining factor of weather conditions. Rapidly moving fronts usually cause more severe weather than slower moving fronts. For example, fast-moving cold fronts often cause severe prefrontal squall lines that are extremely hazardous to flying. The fast-moving front does have the advantage of moving across the area rapidly, permitting the particular locality to enjoy a quick return of good weather. Slow-moving fronts, on the other hand, may cause extended periods of unfavorable weather. A stationary front that may bring bad weather can disrupt flight operations for several days in succession. The specific characteristics of each of the types of fronts is discussed in lessons 3 through 6.

Wind Component

The speed of a front is controlled by a resultant component of wind behind a front. The wind component normal to a front is determined by the angle at which the geostrophic winds blow toward the front, resulting in a perpendicular force applied to the back of the front. For example, the component of the wind normal to a front that has a geostrophic wind with a perpendicular flow of 30 knots behind the front has a 30-knot component. However, a 30-knot geostrophic wind blowing at a 450 angle to the front has only a 15-knot component that is normal to or perpendicular to the front. The greater the angle of the wind to the front, the greater the wind component normal to that front. The smaller the angle, the less the wind component normal to the front.

REVIEW QUESTIONS

Q4-6. What is the definition of a frontal surface?

Q4-7. Where is the frontal zone located?

Q4-8. What is the difference between a stable wave and an unstable wave?

Q4-9. Where does frontogenesis occur?

Q4-10. Where is the polar front normally found during the winter?

THE COLD FRONT

LEARNING OBJECTIVE: Describe slow-moving cold fronts, fast-moving cold fronts, secondary cold fronts, and cold fronts aloft.

A cold front is the leading edge of a wedge of cold air that is under running warm air. Cold fronts usually move faster and have a steeper slope than other types of fronts. Cold fronts that move very rapidly have very steep slopes in the lower levels and narrow bands of clouds that are predominant along or just ahead of the front. Slower moving cold fronts have less steep slopes, and their cloud systems may extend far to the rear of the surface position of the fronts. Both fast-moving and slow-moving cold fronts may be associated with either stability or instability and either moist or dry air masses.

Certain weather characteristics and conditions are typical of cold fronts. In general, the temperature and humidity decrease, the pressure rises, and in the Northern Hemisphere the wind shifts (usually from southwest to northwest) with the passage of a cold front. The distribution and type of cloudiness and the intensity and distribution of precipitation depend primarily on the vertical motion within the warm air mass. This vertical motion is in part dependent upon the speed of that cold front.

SLOW-MOVING COLD FRONTS (ACTIVE COLD FRONT)

With the slow-moving cold front, there is a general upward motion of warm air along the entire frontal surface and pronounced lifting along the lower portion of the front. The average slope of the front is approximately 1:100 miles. Near the ground, the slope is often much steeper because of surface friction.

Figure 4-31 illustrates the typical characteristics in the vertical structure of a slow-moving cold front. The lower half shows the typical upper airflow behind the front, and the upper half shows the accompanying surface weather. This is only one typical case. Many variations to this model can and do occur in nature. The slow-moving cold front is an active front because it has widespread frontal cloudiness and precipitation at and behind the front caused by actual frontal lifting.

Surface Characteristics

The pressure tendency associated with this type of frontal passage is indicated by either an unsteady or steady fall prior to frontal passage and then weak rises behind. Temperature and dew point drop sharply with the passage of a slow-moving cold front. The wind veers with the cold frontal passage and reaches its highest speed at the time of frontal passage. Isobars are usually curved anticyclonically in the cold air. This type of front usually moves at an average speed between 10 and 15 knots. Slow-moving cold fronts move with 100% of the wind component normal to the front.

Weather

The type of weather experienced with a slow-moving cold front is dependent upon the stability of the warm air mass. When the warm air mass is stable,

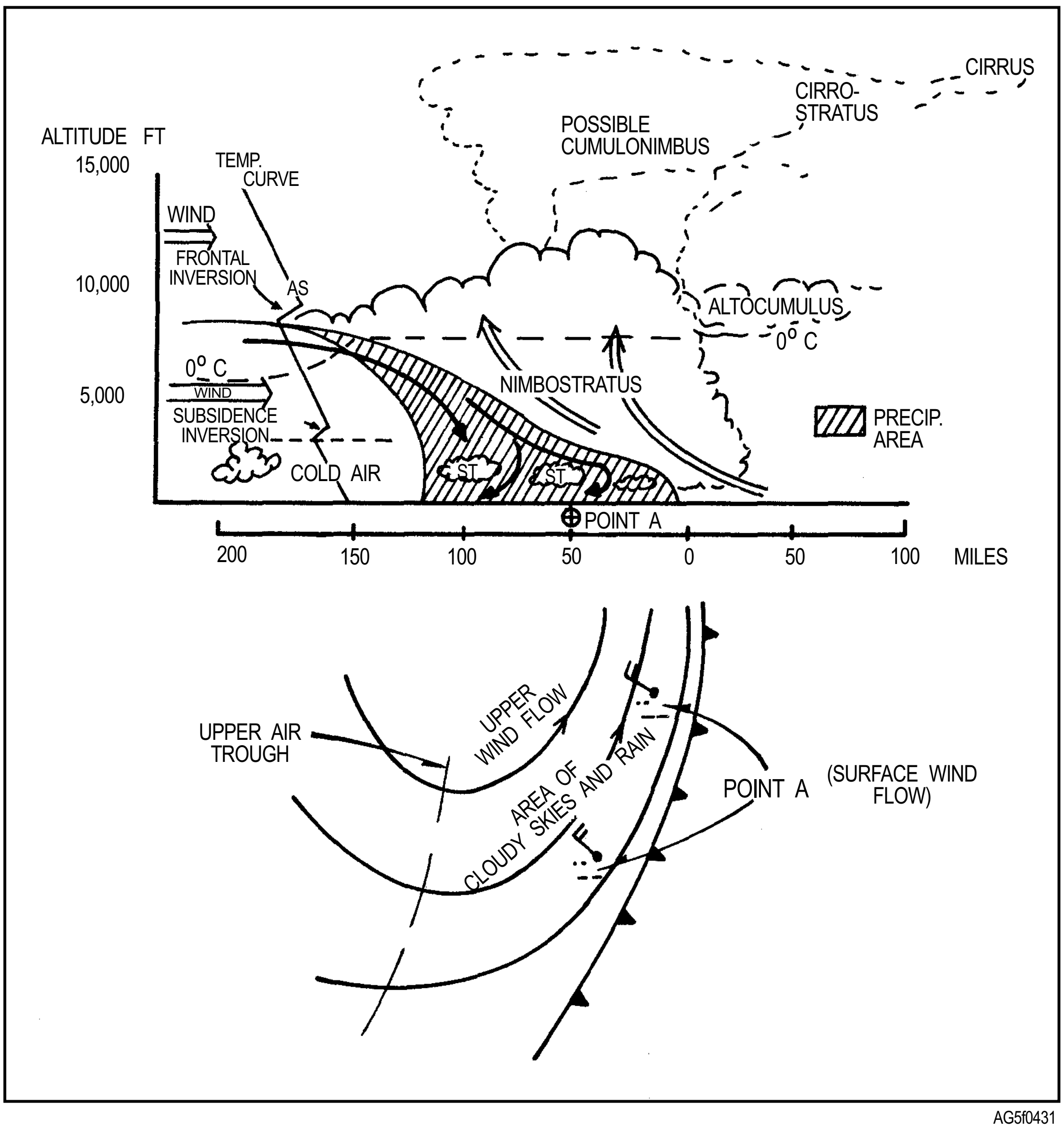

Figure 4-31.—Typical vertical structure of a slow-moving cold front with upper windflow in back of the front.

a rather broad zone of altostratus and nimbostratus clouds accompany the front and extend several hundred miles behind the front. If the warm air is unstable (or conditionally unstable), thunderstorms and cumulonimbus clouds may develop within the cloud bank and may stretch for some 50 miles behind the surface front. These cumulonimbus clouds form within the warm air mass. In the cold air there may be some stratus or nimbostratus clouds formed by the evaporation of falling rain; but, generally, outside of the rain areas, there are relatively few low clouds. This is because of the descending motion of the cold air that sometimes produces a subsidence inversion some distance behind the front.

The ceiling is generally low with the frontal passage, and gradual lifting is observed after passage. Visibility is poor in precipitation and may continue to be reduced for many hours after frontal passage as long as the precipitation occurs. When the cold air behind the front is moist and stable, a deck of stratus clouds and/or fog may persist for a number of hours after frontal passage. The type of precipitation observed is also dependent upon the stability and moisture conditions of the air masses.

Upper Air Characteristics

Upper air contours show a cyclonic flow and are usually parallel to the front as are the isotherms. The weather usually extends as far in back of the front as these features are parallel to it. When the orientation changes, this usually indicates the position of the associated upper air trough. (A trough is an elongated area of relatively low pressure.)

The temperature inversion on this type of front is usually well marked. In the precipitation area the relative humidity is high in both air masses. Farther behind the front, subsidence may occur, giving a second inversion closer to the ground.

The wind usually backs rapidly with height (on the order of some 60 to 70 degrees between 950 and 400 mb), and at 500 mb the wind direction is inclined at about 15 degrees to the front. The wind component normal to the front decreases slightly with height, and the component parallel to the front increases rapidly.

On upper air charts, slow-moving cold fronts are characterized by a packing (concentration) of isotherms behind them. The more closely packed the isotherms and the more nearly they parallel the fronts, the stronger the front.

FAST-MOVING COLD FRONTS (INACTIVE COLD FRONT)

The fast-moving cold front is a very steep front that has warm air near the surface being forced vigorously upward. At high levels, the warm air is descending downward along the frontal surface. This front has a slope of 1:40 to 1:80 miles and usually moves rapidly; 25 to 30 knots may be considered an average speed of movement. They move with 80 to 90 percent of the wind component normal to the front. As a result of these factors, there is a relatively narrow but often violent band of weather.

Figure 4-32 shows a vertical cross section of a fast-moving cold front with resultant weather. Also indicated in the lower half of the diagram is the surface weather in advance of the front and the upper airflow above the front.

If the warm air is moist and unstable, a line of thunderstorms frequently develops along this front. Sometimes, under these conditions, a line of strong convective activity is projected 50 to 200 miles ahead of the front and parallel to it. This may develop into a line of thunderstorms called a squall line. On the other hand, when the warm air is stable, an overcast layer of altostratus clouds and rain may extend over a large area ahead of the front. If the warm air is very dry, little or no cloudiness is associated with the front. The front depicted is a typical front with typical characteristics.

The fast-moving cold front is considered an inactive front because lifting occurs only at and ahead of the front. The lifting is caused by descending air ahead of the front and only in part by the frontal surface.

Surface Characteristics

Pressure tendencies fall ahead of the front with sudden and strong rises after frontal passage. If a squall line lies some distance ahead of the front, there may be a strong rise associated with its passage and a shift in the wind. However, after the influence of the squall line has passed, winds back to southerly and pressures level off. The temperature falls in the warm air just ahead of the front. This is caused by the evaporation of falling precipitation. Rapid clearing and adiabatic warming just behind the front tend to keep the cold air temperature near that of the warm air. An abrupt temperature change usually occurs far behind the front near the center of the high-pressure center associated with the cold air mass. The dew point and wind

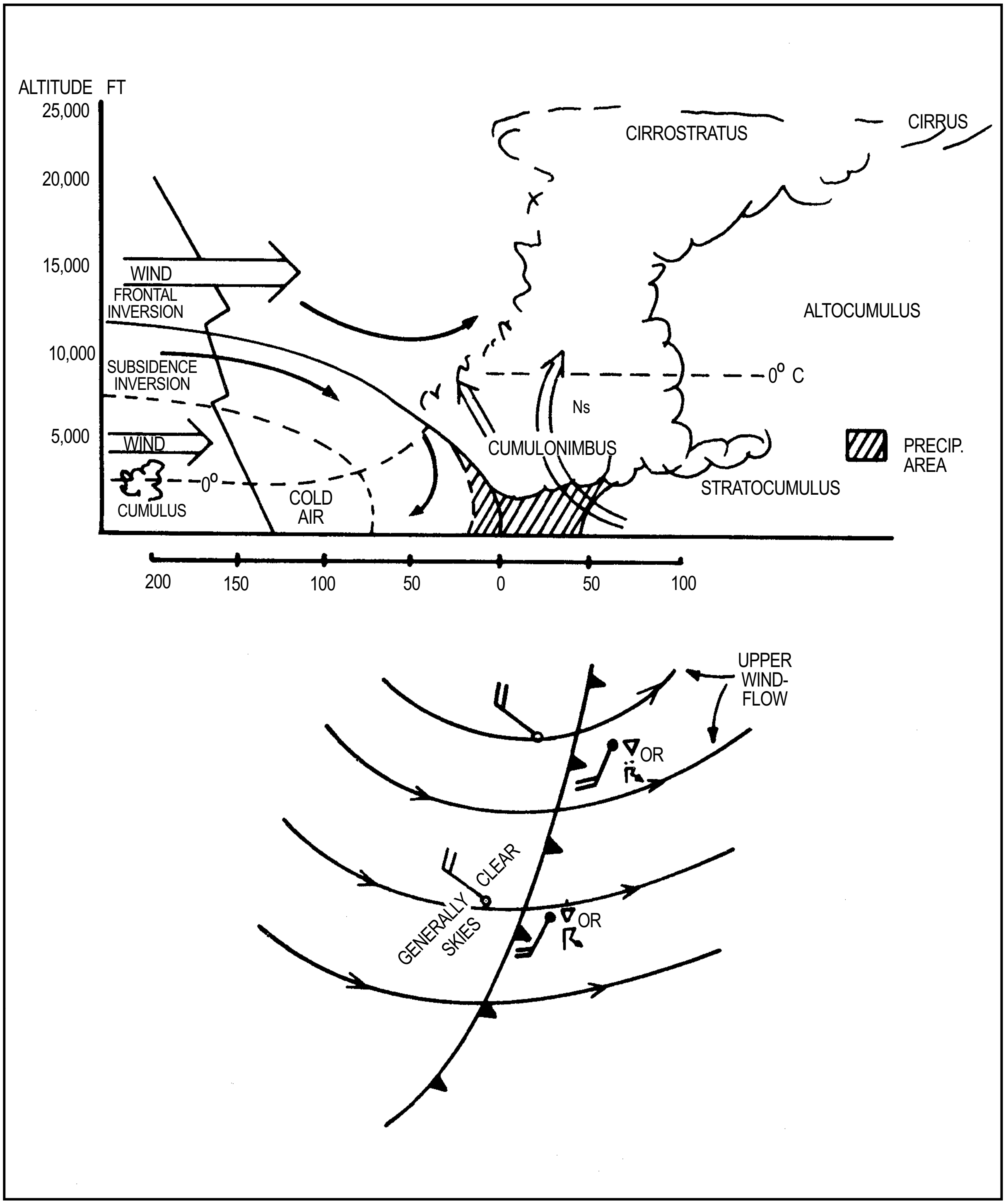

Figure 4-32.—Typical vertical structure of a fast-moving cold front with upper windflow across the front.

directions are a good indication of the passage of a fast-moving cold front. The wind veers with frontal passage and is strong, gusty, and turbulent for a considerable period of time after passage. The dew point decreases sharply after frontal passage.

Weather

Cumulonimbus clouds are observed along and just ahead of the surface front. Stratus, nimbostratus, and altostratus may extend ahead of the front in advance of the cumulonimbus and may extend as much as 150 miles ahead of the front. These clouds are all found in the warm air. Generally, unless the cold air is unstable and descending currents are weak, there are few clouds in the cold air behind the front. Showers and thunderstorms occur along and just ahead of the front. The ceiling is low only in the vicinity of the front. Visibility is poor during precipitation but improves rapidly after the frontal passage.

Upper Air Characteristics

Because of the sinking motion of the cold air behind the front and the resultant adiabatic warming, the temperature change across the front is often destroyed or may even be reversed. A sounding taken in the cold air immediately behind the surface front indicates only one inversion and an increase in moisture through the inversion. Farther back of the front, a double inversion structure is evident. The lower inversion is caused by the subsidence effects in the cold air. This is sometimes confusing to the analyst because the subsidence inversion is usually more marked than the frontal inversion and may be mistaken for the frontal inversion.

In contrast to the slow-moving cold front, the wind above the fast-moving cold front exhibits only a slight backing with height of about 20 degrees between 950 and 400 mb; the wind direction is inclined toward the front at an average angle of about 45 degrees. The wind components normal and parallel to the front increase with height; the wind component normal to the front exceeds the mean speed of the front at all levels above the lowest layers. On upper air charts, the isotherms are NOT parallel to the front. Instead they are at an angle of about 30 degrees to the front, usually crossing the cold front near its junction with the associated warm front.

SECONDARY COLD FRONTS

Sometimes there is a tendency for a trough of low pressure to form to the rear of a cold front, and a secondary cold front may develop in this trough. Secondary cold fronts usually occur during outbreaks of very cold air behind the initial outbreak. Secondary cold fronts may follow in intervals of several hundred miles to the rear of the rapidly moving front. When a secondary cold front forms, the primary front usually tends to dissipate and the secondary front then becomes the primary front. Secondary fronts usually do not occur during the summer months because there is rarely enough temperature discontinuity.

COLD FRONTS ALOFT

There are two types of upper cold fronts. One is the upper cold front associated with the warm occlusion that is discussed later in this unit. The other occurs frequently in the areas just east of mountains in winter. This cold front aloft is associated with mP air crossing the mountains behind a cold front or behind a cold trough aloft and a very cold layer of continental polar air lying next to the ground over the area east of the mountains. The area east of the Rocky Mountains is one such area in the United States. When warm maritime tropical air has moved northward from the Gulf of Mexico and has been forced aloft by the cold cP air, and cool mP air flows over the mountains, it forces its way under the warm mT air aloft. The resulting front then flows across the upper surface of the colder cP air just as if it were the surface of the ground. All frontal activity in this case takes place above the top of the cP layer. Figure 4-33 shows an example of this type of front and the synoptic structure. Weather from cold

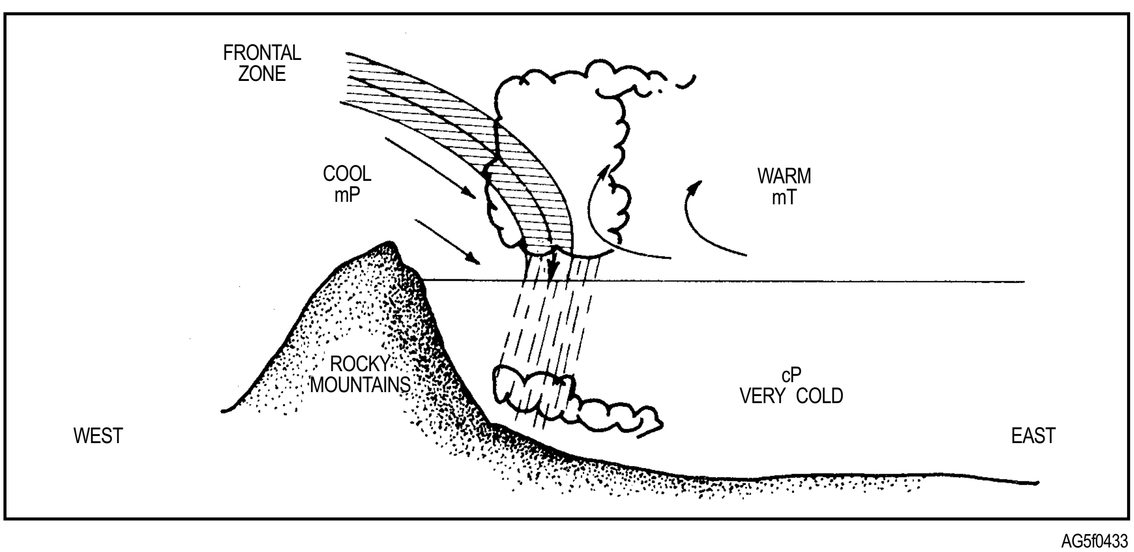

Figure 4-33.—Cold front aloft.

fronts aloft can produce extensive cloud decks and blizzard conditions for several hundred miles over the mid western plains.

INSTABILITY AND SQUALL LINES

The terms instability line and squall line are synonymous with violent winds, heavy rain, lightning, thunder, hail, and tornadoes. The terms are often used interchangeably and are incorrectly applied to any severe weather phenomena that moves through a region. However, there is a difference between an instability line and a squall line.

Instability Line

An instability line is any nonfrontal line or band of convective activity. This is a general term and includes the developing, mature, and dissipating stages of the line of convective activity. However, when the mature stage consists of a line of active thunderstorms, it is properly termed a squall line. Therefore, in practice, the instability line often refers only to the less active phases.

Squall Line

A squall line is a nonfrontal line or band of active thunderstorms (with or without squalls). It is the mature, active stage of the instability line. From these definitions, instability and squall lines are air mass phenomenon because they are both nonfrontal occurrences. However, they are frequently associated with the fast-moving cold front.

NOTE: The term instability line is the more general term and includes the squall line as a special case.

Prefrontal Squall Lines

A prefrontal squall line is a squall line located in the warm sector of a wave cyclone. They form about 50 to 300 miles in advance of fast-moving cold fronts and are usually oriented roughly parallel to the cold front. They move in about the same direction as the cold front; however, their speed is, at times, faster than the cold front. You can roughly compute the direction and speed by using the winds at the 500-mb level. Squall lines generally move in the direction of the 500-mb wind flow and at approximately 40% of the wind speed.

FORMATION.—There are several theories on the development of prefrontal squall lines. A generally accepted theory is that as thunderstorms develop along the fast-moving front, large quantities of cold air from aloft descend in downdrafts along the front and form a wedge of cold air ahead of the front. The wedge of cold air then serves as a lifting mechanism for the warm, moist, unstable air; and a line of thunderstorms develops several miles in advance of the front. Since the thunderstorms form within the air mass and not along the front, the squall line is considered as air mass weather (fig. 4-34). In the United States, squall lines form most often in spring and summer. They are normally restricted to the region east of the Rocky Mountains with a high frequency of occurrence in the southern states.

WEATHER.—Squall-line weather can be extremely hazardous. Its weather is usually more severe than the weather associated with the cold front behind it; this is because the moisture and energy of the warm air mass tends to be released at the squall line prior to the arrival of the trailing cold front. Showers and thunderstorms (sometimes tornadoes) occur along the squall line, and the wind shifts cyclonically with their passage (fig. 4-35). However, if the zone is narrow, the wind shift may not be noticeable on surface charts. There is generally a large drop in temperature because of the cooling of the air by precipitation. Pressure rises after the passage of the squall line, and, at times, a

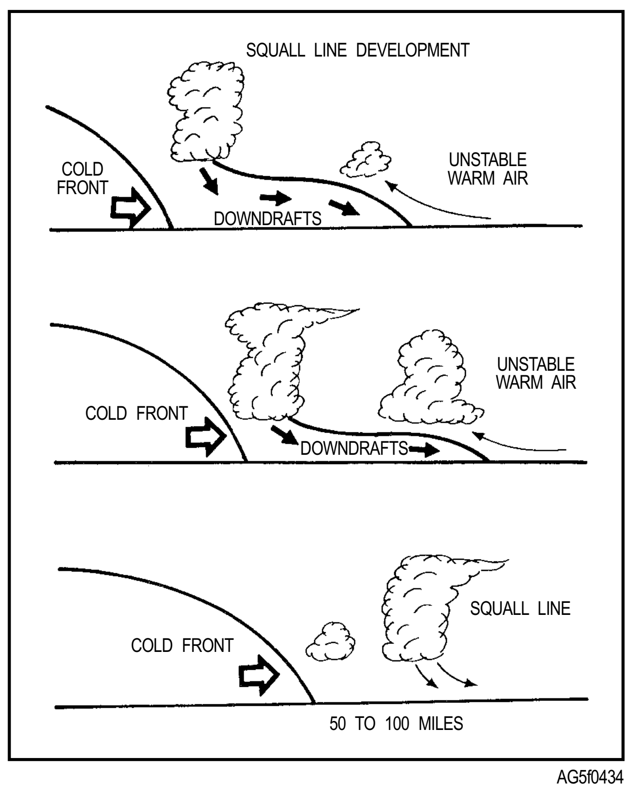

Figure 4-34.—Prefrontal squall line development.

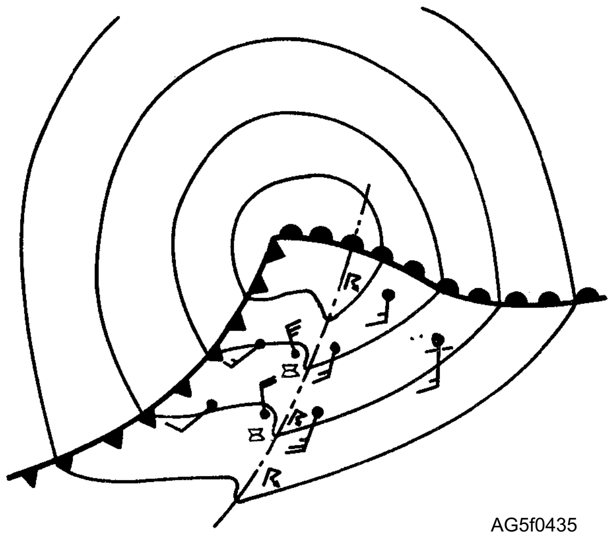

Figure 4-35.—Typical isobaric pattern associated with a prefrontal squall line.

micro-high (small high) may form behind it. After passage of the squall line, the wind backs to southerly before the cold frontal passage. When the squall line dissipates, severe weather may develop along the fast-moving cold front.

Turbulence is severe in the squall-line thunderstorms because of violent updrafts and downdrafts. Above the freezing level, icing may occur. Hail is another possibility in the squall-line thunderstorm and can do extensive structural damage to an aircraft. Under the squall line, ceiling and visibility may be reduced because of heavy rain showers. Fog is a rare occurrence because of the strong wind and gusts, but it may be found in isolated cases. Tornadoes frequently occur with squall lines when the warm air mass is extremely unstable.

Great Plains Squall Lines

Not all instability lines that reach the mature or squall-line stage develops in advance of a fast-moving cold front. The Great Plains region of the United States has a high frequency of these squall lines. The Great Plains type of squall lines also develop in warm, moist, unstable air masses. The necessary lifting or trigger may be supplied by intense thermal heating, orographic lifting, or convergent winds associated with a low-pressure area.

FORMATION.—The Great Plains squall line forms when an extremely unstable condition develops—normally in spring and summer. Extremely unstable conditions exist when moist mP air cools in the upper levels because of the evaporation of falling precipitation. This cooler air aloft then moves over warm moist mT air (or even warm, moist, highly modified mP air) at the surface. If a sufficient trigger such as a steep lapse rate of a lifting mechanism exists, this extremely unstable situation rapidly develops into a squall line.

WEATHER.—The weather associated with the Great Plains squall line is the same as that found with the prefrontal squall line. Because of the extreme instability, tornadoes are a common occurrence.

REVIEW QUESTIONS

Q4-11. What is the pressure tendency with the passage of a slow moving cold front?

Q4-12. What is the normal slope of a fast moving cold front?

Q4-13. Where do prefrontal squall lines normally form?

THE WARM FRONT

LEARNING OBJECTIVE: Describe the characteristics and weather of warm fronts at the surface and aloft.

A warm front is the line of discontinuity where the forward edge of an advancing mass of relatively warm air is replacing a retreating relatively colder air mass. The slope of the warm front is usually between 1:100 and 1:300, with occasional fronts with lesser slopes. Therefore, warm fronts have characteristically shallow slopes caused by the effect of surface friction that retards the frontal movement near the ground.

SURFACE CHARACTERISTICS

Warm fronts move slower than cold fronts. Their average speed is usually between 10 and 20 knots. They move with a speed of 60 to 80 percent of the component of the wind normal to the front in the warm air mass.

The troughs associated with warm fronts are not as pronounced as those with cold fronts and sometimes make location difficult on the surface chart. The pressure tendency ahead of the front is usually a rapid or unsteady fall with a leveling off after frontal passage. A marked decrease in isallobaric gradient is noticed in the warm sector except when rapid deepening is taking place. The wind increases in velocity in advance of warm fronts because of an increase in pressure gradient and reaches a maximum just prior to frontal passage. The wind veers with frontal passage, usually from a southeasterly direction to a southwesterly direction behind the front. This shift is not as pronounced as with the cold front.

Temperature generally is constant or slowly rising in advance of the front until the surface front passes, at which time there is a marked rise. This rise is dependent upon the contrast between the air masses. Dew point usually increases slowly with the approach of the front with a rapid increase in precipitation and fog areas. If the warm sector air is maritime tropical, the dew point shows a further increase.

WEATHER

A characteristic phenomenon of a typical warm front is the sequence of cloud formations (fig. 4-36). They are noticeable in the following order: cirrus, cirrostratus, altostratus, nimbostratus, and stratus. The cirrus clouds may appear 700 to 1,000 miles or more ahead of the surface front, followed by cirrostratus clouds about 600 miles ahead of the surface front and altostratus about 500 miles ahead of the surface front.

Precipitation in the form of continuous or intermittent rain, snow, or drizzle is frequent as far as 300 miles in advance of the surface front. Surface precipitation is associated with the nimbostratus in the warm air above the frontal surface and with stratus in the cold air. However, when the warm air is convectively unstable, showers and thunderstorms may occur in addition to the steady precipitation. This is especially true with a cyclonic flow aloft over the warm front. Fog is common in the cold air ahead of a warm front.

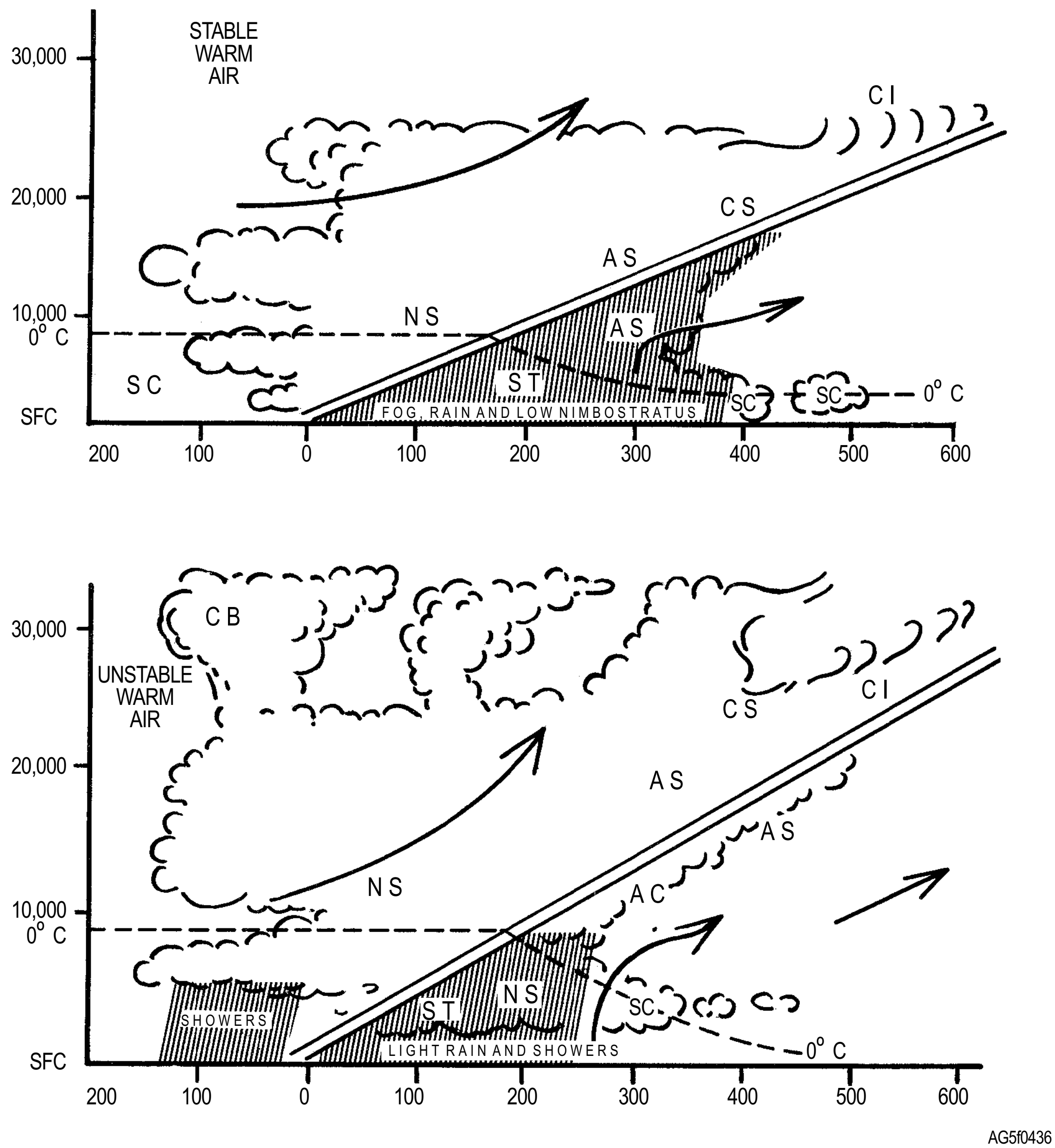

Figure 4-36.—Vertical cross section of a warm front with stable and unstable air.

Clearing usually occurs after the passage of a warm front, but under some conditions drizzle and fog may occur within the warm sector. Warm fronts usually move in the direction of the isobars of the warm sector; in the Northern Hemisphere this is usually east to northeast.

The amount and type of clouds and precipitation vary with the characteristics of the air masses involved and depending on whether the front is active or inactive. Generally, with warm fronts, an increase of the wind component with height perpendicular to the front gives an active front. This produces strong overrunning and pronounced prefrontal clouds and precipitation. Inactive fronts, characterized by broken cirrus and altocumulus, are produced by a decrease with height of the wind component perpendicular to the front.

When the overrunning warm air is moist and stable, nimbostratus clouds with continuous light to moderate precipitation are found approximately 300 miles ahead of the front. The bases of the clouds lower rapidly as additional clouds form in the cold air under the frontal surface. These clouds are caused by evaporation of the falling rain. These clouds are stratiform when the cold mass is stable and stratocumulus when the cold air is unstable.

When the overrunning air is moist and unstable, cumulus and cumulonimbus clouds are frequently imbedded in the nimbostratus and altostratus clouds. In such cases, thunderstorms occur along with continuous precipitation. When the overrunning warm air is dry, it must ascend to relatively high altitudes before condensation can occur. In these cases only high and middle clouds are observed. Visibility is usually good under the cirrus and altostratus clouds. It decreases rapidly in the precipitation area. When the cold air is stable and extensive, fog areas may develop ahead of the front, and visibility is extremely reduced in this area.

UPPER AIR CHARACTERISTICS

Warm fronts are usually not as well defined as cold fronts on upper air soundings. When the front is strong and little mixing has occurred, the front may show a well-marked inversion aloft. However, mixing usually occurs and the front may appear as a rather broad zone with only a slight change in temperature. Quite frequently there may be two inversions—one caused by the front and the other caused by turbulence. Isotherms are parallel to the front and show some form of packing ahead of the front. The stronger the packing, the more active the front. The packing is not as pronounced as with the cold front.

WARM FRONTS ALOFT

Warm fronts aloft seldom occur, but generally follow the same principles as cold fronts aloft. One case when they do occur is when the very cold air underneath a warm front is resistant to displacement and may force the warm air to move over a thinning wedge with a wave forming on the upper surface. This gives the effect of secondary upper warm fronts and may cause parallel bands of precipitation at unusual distances ahead of the surface warm front. Warm air advection is more rapid and precipitation is heaviest where the steeper slope is encountered. Pressure falls rapidly in advance of the upper warm front and levels off underneath the horizontal portion of the front. When a warm front crosses a mountain range, colder air may occur to the east and may move along as a warm front aloft above the layer of cold air. This is common when a warm front crosses the Appalachian Mountains in winter.

REVIEW QUESTIONS

Q4-14. What is the average speed of a warm front?

Q4-15. What cloud types, and in what order usually form in advance of a warm front?

THE OCCLUDED FRONTS

LEARNING OBJECTIVE: Describe the formation, structure, and characteristics of cold and warm air occluded fronts.

An occluded front is a composite of two fronts. They form when a cold front overtakes a warm front and one of these two fronts is lifted aloft. As a result, the warm air between the cold and warm front is shut off. An occluded front is often referred to simply as an occlusion. Occlusions may be either of the cold type or warm type. The type of occlusion is determined by the temperature difference between the cold air in advance of the warm front and the cold air behind the cold front.

A cold occlusion forms when the cold air in advance of a warm front is warmer than the cold air to the rear of the cold front. The overtaking cold air undercuts the cool air in advance of the warm front. This results in a section of the warm front being forced aloft. A warm occlusion forms when the air in advance of the warm front is colder than the air to the rear of the cold front. When the cold air of the cold front overtakes

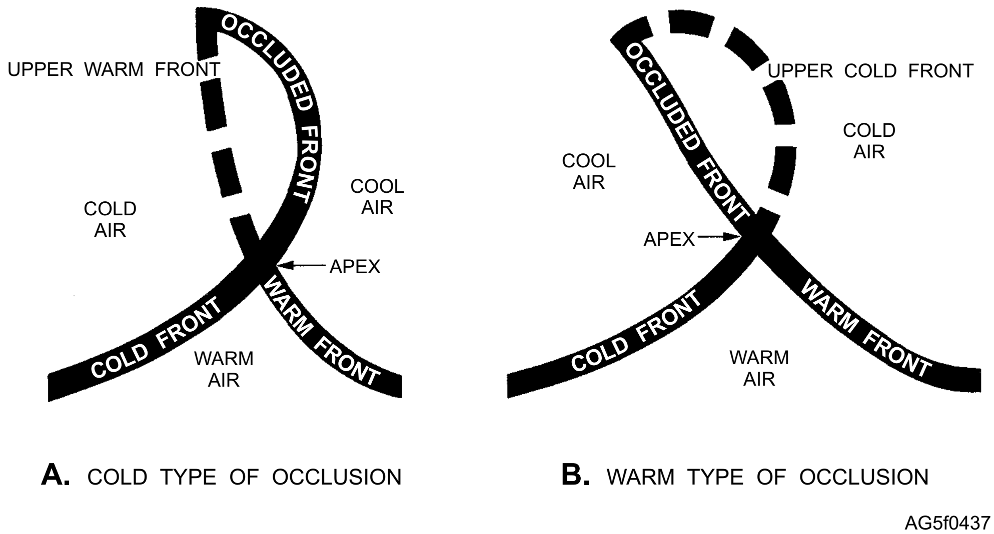

Figure 4-37.—Sketch of occlusions (in the horizontal) and associated upper fronts.

the warm front, it moves up over this colder air in the form of an upper cold front.

The primary difference between a warm and a cold type of occlusion is the location of the associated upper front in relation to the surface front (fig. 4-37). In a warm type of occlusion, the upper cold front precedes the surface-occluded front by as much as 200 miles. In the cold type of occlusion the upper warm front follows the surface-occluded front by 20 to 50 miles.

Since the occluded front is a combination of a cold front and a warm front, the resulting weather is that of the cold front's narrow band of violent weather and the warm front's widespread area of cloudiness and precipitation occurring in combination along the occluded front. The most violent weather occurs at the apex or tip of the occlusion. The apex is the point on the wave where the cold front and warm front meet to start the occlusion process.

COLD OCCLUSIONS

A cold occlusion is the occlusion that forms when a cold front lifts the warm front and the air mass preceding the front (fig. 4-38). The vertical and horizontal depiction of the cold occlusion is shown in figure 4-39. Cold occlusions are more frequent than warm occlusions. The lifting of the warm front as it is underrun by the cold front implies existence of an upper warm front to the rear of the cold occlusion; actually such a warm front aloft is rarely discernible and is seldom delineated on a surface chart.

Most fronts approaching the Pacific coast of North America from the west are cold occlusions. In winter these fronts usually encounter a shallow layer of surface air near the coastline (from about Oregon northward) that is colder than the leading edge of cold air to the rear of the occlusion. As the occluded front nears this wedge of cold air, the occlusion is forced aloft and soon is no longer discernible on a surface chart. The usual practice in these cases is to continue to designate the cold occlusion as though it were a surface front because of the shallowness of the layer over which it rides. As the occlusion crosses over the mountains, it eventually shows up again on a surface analysis.

The passage of the cold type of occlusion over the coastal layer of colder air presents a difficult problem of analysis in that no surface wind shift ordinarily occurs at the exact time of passage. However, a line of stations

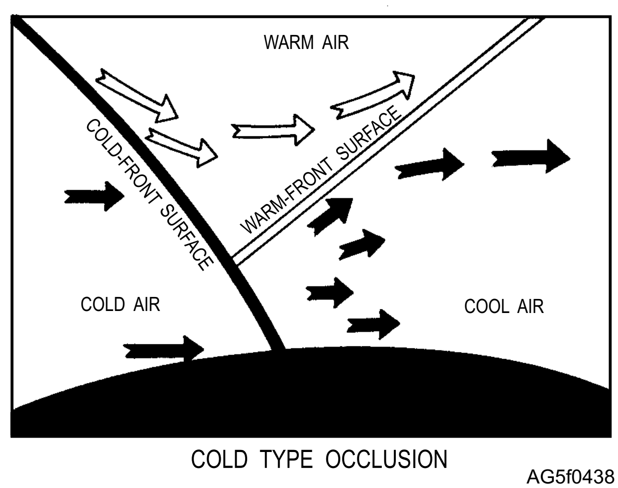

Figure 4-38.—Vertical cross section of a cold type of occlusion.

reporting surface-pressure rises is the best criterion of its passage. This should be verified by reference to plotted raob soundings where available. When a Pacific cold occlusion moves farther inland, it sometimes encounters colder air of appreciable depth over the Plateau or Western Plains areas; in this case, it should be redesignated as an upper cold front.

Surface Characteristics

The occlusion lies in a low-pressure area; and in the latter stages, a separate low center may form at the tip of the occlusion, leaving another low-pressure cell near the end of the occlusion. The pressure tendency across the cold occluded front follows closely with those outlined for cold fronts; that is, they level off, or more often, rapid rises occur after the passage of the occluded front.

Weather

In the occlusion's initial stages of development, the weather and cloud sequence ahead of the occlusion is quite similar to that associated with warm fronts; however, the cloud and weather sequence near the surface position of the front is similar to that associated with cold fronts. As the occlusion develops and the warm air is lifted to higher and higher altitudes, the warm front and prefrontal cloud systems disappear. The weather and cloud systems are similar to those of a cold front. View A of figure 4-39 shows the typical cloud and weather pattern associated with the cold occlusion. Most of the precipitation occurs just ahead of the occlusion. Clearing behind the occlusion is usually rapid, especially if the occlusion is in the advanced stage. Otherwise, clearing may not occur until after the passage of the warm front aloft.

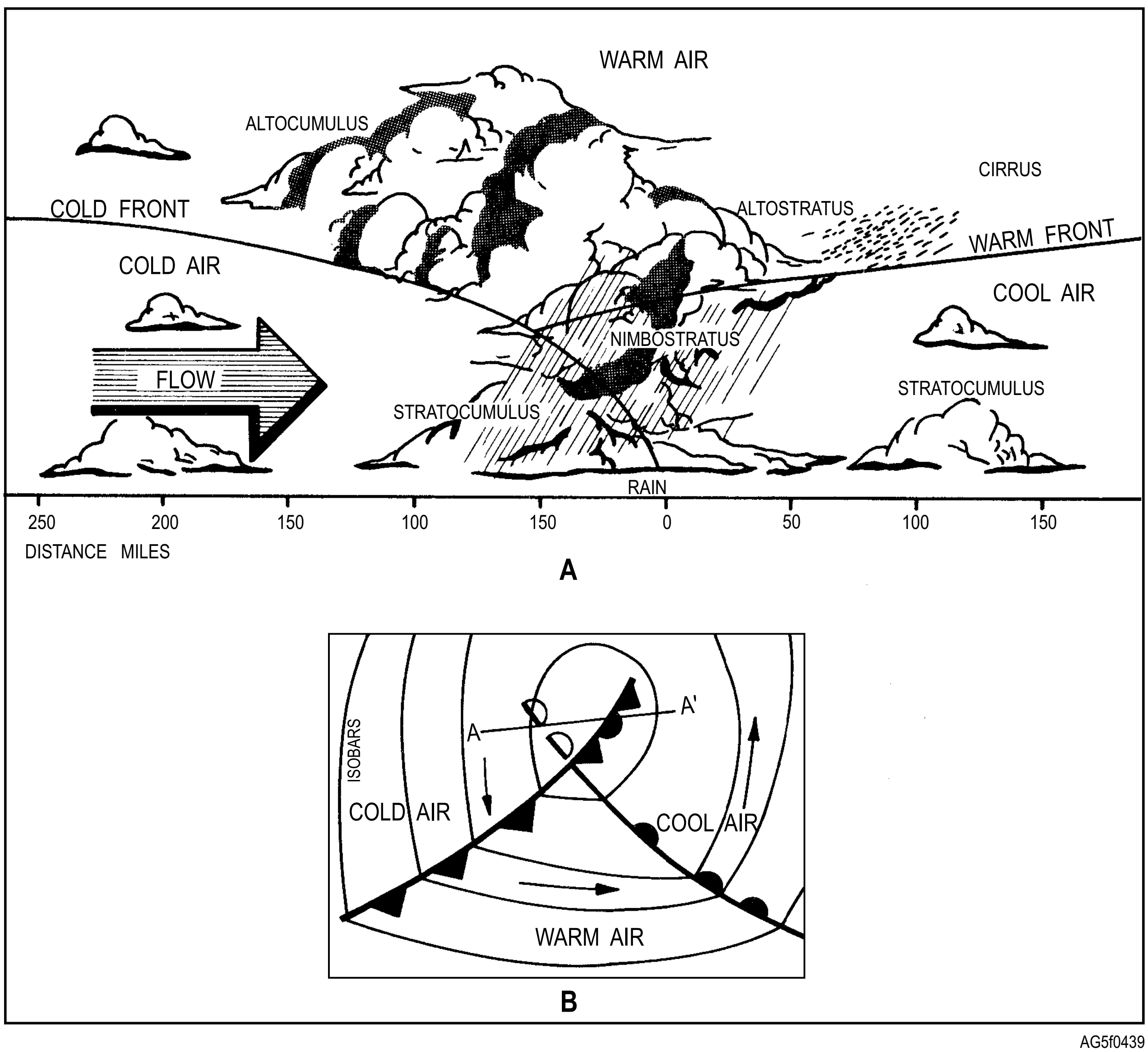

Figure 4-39.—Cold front type of occlusion. (A) Vertical structure through points A and A'; (B) horizontal structure.

Upper Air Characteristics

If only one upper air sounding were taken so that it intersected either the cold or warm front, the sounding would appear as a typical warm or cold front sounding. However, if the sounding were taken so that it intersected both the cold and warm air, it would show two inversions.

The occlusion may appear on some upper air charts. It usually appears on the 850-mb chart, but rarely on the 700-mb chart. As the two air masses are brought closer together and as the occlusion process brings about gradual disappearance of the warm sector, the isotherm gradient associated with the surface front weakens. The degree of weakening depends on the horizontal temperature differences between the cold air to the rear of the cold front and that ahead of the warm front. The angle at which the isotherms cross the surface position of the occluded fronts becomes greater as the temperature contrast between the two cold air lasses decreases. A typical illustration of the isotherms shows a packing of isotherms in the cold mass behind the cold front and less packing in the cool mass in advance of the warm front. A warm isotherm ridge precedes the occlusion aloft.

WARM OCCLUSIONS

A warm occlusion is the occlusion that forms when the overtaking cold front is lifted by overrunning the colder retreating air associated with the warm front. This is shown in figure 4-40. The warm occlusion usually develops in the Northern Hemisphere when conditions north and of ahead of the warm front are such that low pa temperatures exist north of the warm front. This usually occurs along the west coasts of continents when a relatively cool maritime cold front overtakes a warm front associated with a very cold continental air mass of high pressure situated over the western portion of the continent. The cold front then continues as an upper cold front above the warm front surface. The occlusion is represented as a continuation of the warm front. The cold front aloft is usually represented on all surface charts. Figure 4-41 depicts a typical warm type of occlusion in both the vertical and horizontal.

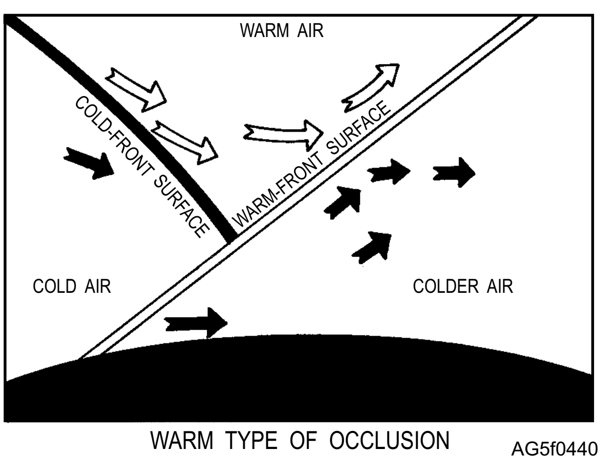

Figure 4-40.—Vertical cross-section of a warm type of occlusion.

Surface Characteristics

The warm type of occlusion has the same type of pressure pattern as the cold type of occlusion. The most reliable identifying characteristics of the upper front are a line of marked cold frontal precipitation and clouds ahead of the occluded front, a slight but distinct pressure trough and a line of pressure-tendency discontinuities.

NOTE: The pressure tendency shows a steady fall ahead of the upper cold front and, with passage, a leveling off for a short period of time. Another slight fall is evident with the approach of the surface position of the occlusion. After passage the pressure shows a steady rise.

The pressure trough is often more distinct with the upper front than with the surface front.

Weather

The weather associated with warm front occlusions has the characteristics of both warm and cold fronts. The sequence of clouds ahead of the occlusion is similar to the sequence of clouds ahead of a warm front; the cold front weather occurs near the upper cold front. If either the warm or cool air that is lifted is moist and unstable, showers and sometimes thunderstorms may develop. The intensity of the weather along the upper front decreases with distance from the apex. Weather conditions change rapidly in occlusions and are usually most severe during the initial stages. However, when the warm air is lifted to higher and higher altitudes, the weather activity diminishes. When showers and thunderstorms occur, they are found just ahead and with the upper cold front. Normally, there is clearing weather after passage of the upper front, but this is not always the case.

Upper Air Characteristics

Upper air soundings taken through either front show typical cold or warm front soundings. Those

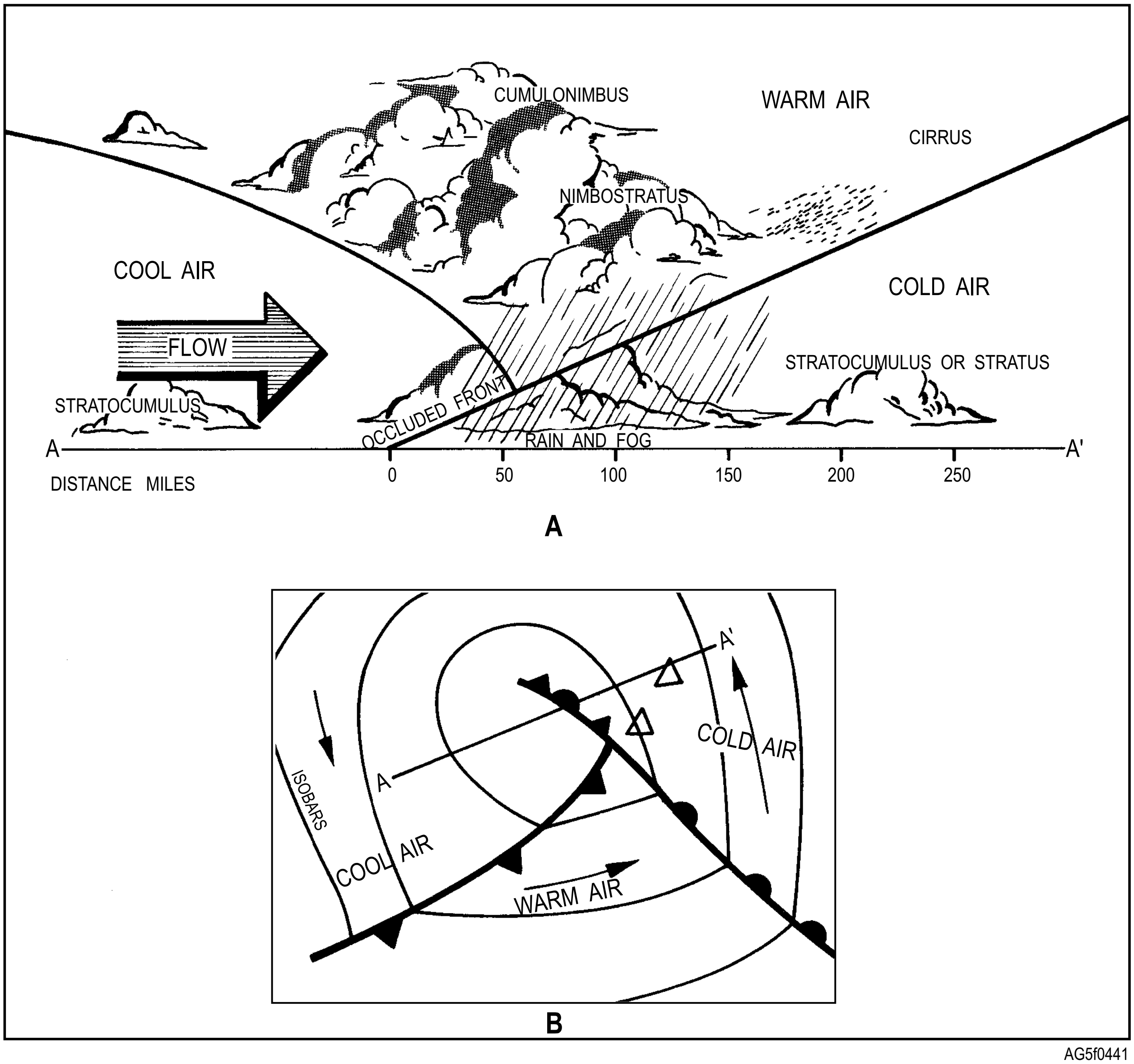

Figure 4-41.—Illustration of warm type of occlusion. (A) Vertical structure through points A and A'; (B) Horizontal structure.

taken that intersect both fronts show two inversions. The warm type of occlusion (like the cold type) appears on upper air charts at approximately the same pressure level. However, one distinct difference does appear in the location of the warm isotherm ridge associated with occlusions. The warm isotherm ridge lies just to the rear of the occlusion at the peak of its development.

REVIEW QUESTIONS

Q4-16. What is the difference between warm and cold occlusions?

Q4-17. Where does the most violent weather occur with the occlusion?

THE QUASI-STATIONARY FRONT

LEARNING OBJECTIVE: Describe the characteristics of stable and unstable quasi-stationary fronts.

A quasi-stationary front, or stationary front as it is often called, is a front along which one air mass is not appreciably replacing another air mass. A stationary front may develop from the slowing down or stopping of a warm or a cold front. When this front forms, the slope of the warm or cold front is initially very shallow. The dense cold air stays on the ground, and the warm air is displaced slowly upward. The front slows or stops moving because the winds behind and ahead of the front become parallel to the stationary front. It is quite unusual for two masses of different properties to be side by side without some movement, so the term stationary is a misnomer. Actually the front, or dividing line between the air masses, is most likely made up of small waves undulating back and forth; hence the term quasi-stationary. The important thing is that the front is not making any appreciable headway in any one direction. A front moving less than 5 knots is usually classified as a stationary front.

CHARACTERISTICS

When a front is stationary, the whole cold air mass does not move either toward or away from the front. In terms of wind direction, this means that the wind above the friction layer blows neither toward nor away from the front, but parallel to it. The wind shift across the front is usually near 180 degrees. It follows that the isobars, too, are nearly parallel to a stationary front. This characteristic makes it easy to recognize a stationary front on a weather map.

STABLE STATIONARY FRONT

There is frictional inflow of warm air toward a stationary front causing a slow upglide of air on the frontal surface. As the air is lifted to and beyond saturation, clouds form in the warm air above the front. If the warm air in a stationary front is stable and the slope is shallow, the clouds are stratiform. Drizzle may then fall; and as the air is lifted beyond the freezing level, icing conditions develop and light rain or snow may fall. At very high levels above the front, ice clouds are present. (See fig. 4-42).

If, however, the slope is steep and significant warm air is being advected up the frontal slope, stratiform clouds with embedded showers result (view B of fig. 4-42). Slight undulation or movement of the quasi-stationary front toward the warm air mass adds to the amount of weather and shower activity associated with the front.

UNSTABLE STATIONARY FRONT

If the warm air is conditionally unstable, the slope is shallow, and sufficient lifting occurs, the clouds are then cumuliform or stratiform with embedded towering cumulus. If the energy release is great (warm, moist, unstable air), thunderstorms result. Within the cold air mass, extensive fog and low ceiling may result if the cold air is saturated by warm rain or drizzle falling

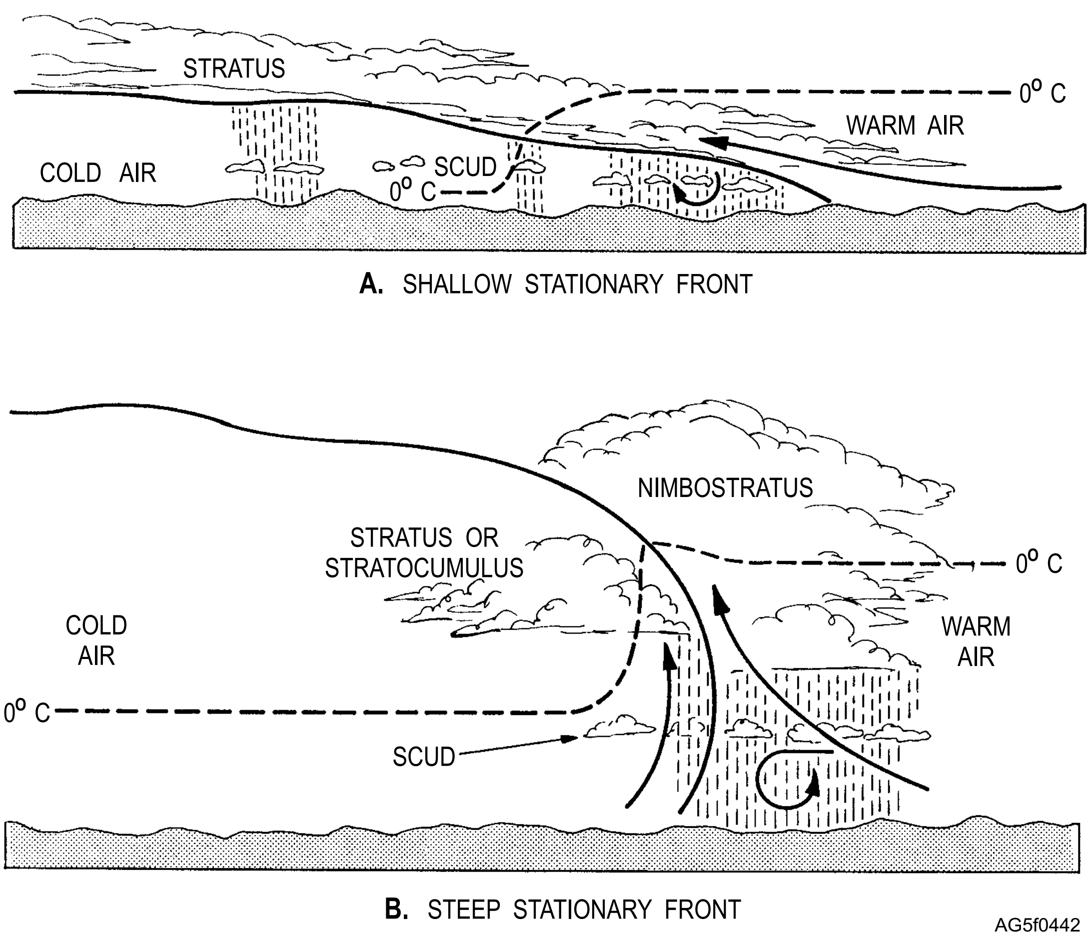

Figure 4-42.—Types of stable stationary fronts.

through it from the warm air mass above. If the temperature is below 0°C, icing may occur; but generally it is light (view A of fig. 4-43). The shallow slope of an unstable stationary front results in a very broad and extensive area of showers, fog, and reduced visibility.

If the slope of an unstable stationary front is steep and sufficient warm air is advected up the slope or the front moves slowly toward the warm air mass, violent weather can result (view B of fig. 4-43). Heavy rain, severe thunderstorms, strong winds, and tornadoes are often associated with this front. The width of the band of precipitation and low ceilings vary from 50 miles to about 200 miles, depending upon the slope of the front and the temperatures of the air masses. One of the most annoying characteristics of a stationary front is that it may greatly hamper and delay air operations by persisting in the area for several days.

REVIEW QUESTIONS

Q4-18. When a quasi-stationary front moves, if it does, what is the normal speed?

Q4-19. What type of weather is normally associated with an unstable stationary front?

MODIFICATIONS OF FRONTS

LEARNING OBJECTIVE: Describe how fronts are modified by their movement, orographic features, and underlying surfaces.

The typical fronts we have just covered can and do undergo modifications that strengthen or weaken them. Such things as frontal movement, orographic effects, and the type of surface the fronts encounter contribute to the modification of fronts.

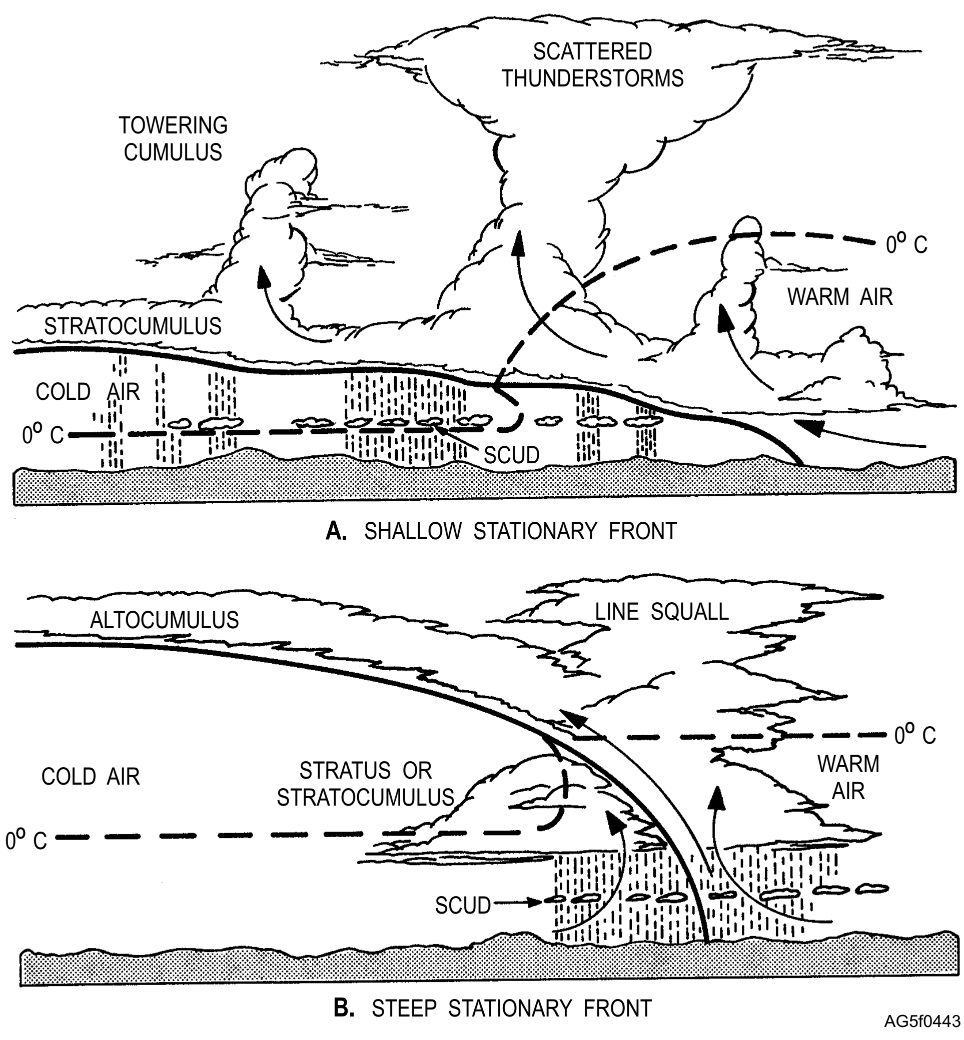

Figure 4-43.—Types of unstable stationary fronts.

EFFECTS CAUSED BY MOVEMENT

The weather is greatly affected by the movement of frontal systems. From the time the front develops until it passes out of the weather picture, it is watched closely. The speed of the movement of frontal systems is an important determining factor of weather conditions. Rapidly moving fronts usually cause more severe weather than slower moving fronts. Fast-moving cold fronts often cause severe prefrontal squall lines that are extremely hazardous to flying. The fast-moving front does have the advantage of moving across the area rapidly, permitting the particular locality to enjoy a quick return of good weather. Slow-moving fronts, on the other hand, may cause extended periods of unfavorable weather. A stationary front may bring bad weather and can disrupt flight operations for several days if the frontal weather is sitting over your station.

Knowledge of the speed of the frontal system is necessary for accurate forecasting. If the front has a somewhat constant speed, it makes your job and the forecaster’s job comparatively easy. However, if the speed is erratic or unpredictable, you may err as far as time and severity are concerned. If a front was ultimately forecast to pass through your station and instead becomes stationary or dissipates, the station forecast will be a total bust.

OROGRAPHIC EFFECTS

Mountain ranges affect the speed, slope, and weather associated with a front. The height and horizontal distance of the mountain range along with the angle of the front along the mountain range are the influencing factors. Mountain ranges can affect cold fronts, warm fronts, and occluded fronts differently.

Cold Fronts

As a cold front approaches a mountain range, the surface portion of the front is retarded and the upper portion pushes up and over the mountain. On the windward side of the mountain, warm air is pushed up along the mountain slope because of the additional lift of a now steeper frontal slope and the mountain itself (view A of fig. 4-44). After the front passes the crest of the mountain, the air behind the front commences to

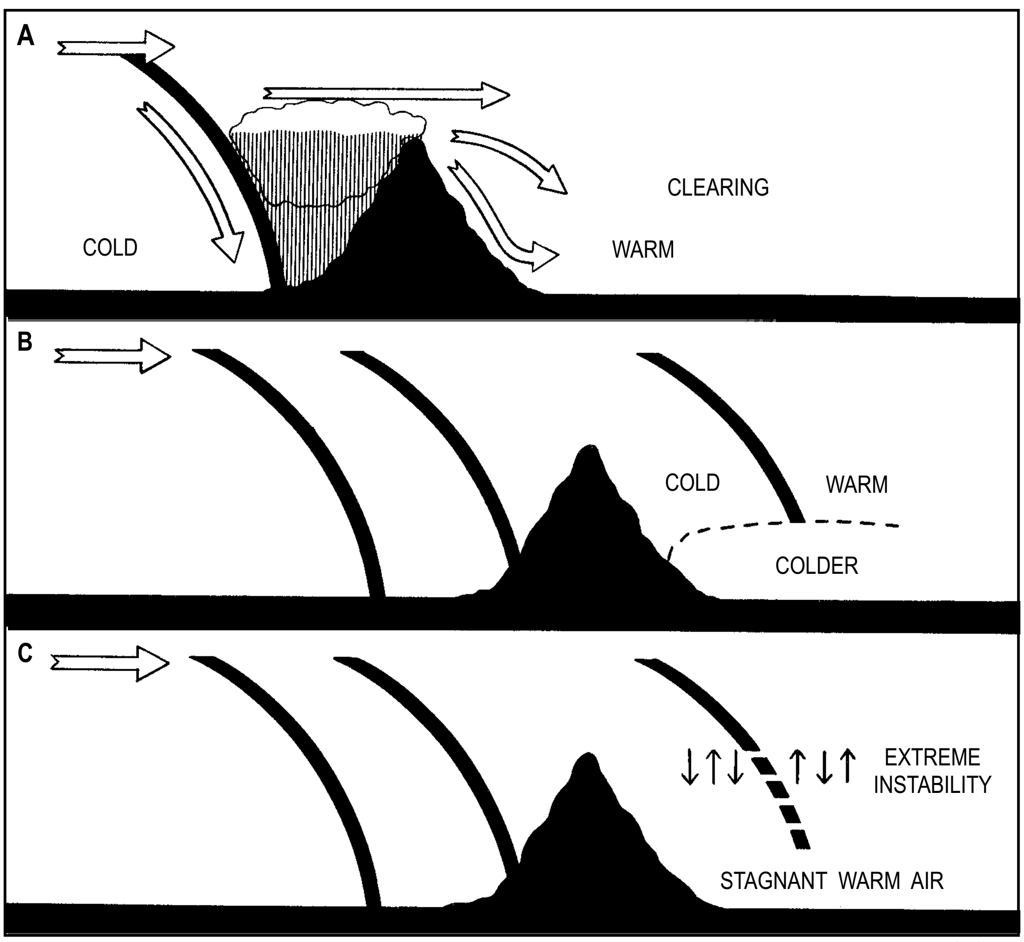

Figure 4-44.—Orographic effects on a cold front.

flow down the leeward side of the range. The warmer air on the leeward side of the mountain is displaced by the colder air mass. As this cold air descends the leeward side of the mountain, the air warms adiabatically (view A of fig. 4-44) and clearing occurs within it. However, since the cold air is displacing warm air, typical cold frontal clouds and precipitation may occur within the warm air if the warm air is sufficiently moist and conditionally unstable. In some cases maritime polar air that has crossed the Rockies is less dense than maritime tropical air from the Gulf of Mexico that may lie just east of the mountains. If the maritime polar air is moving with a strong westerly wind flow and the maritime tropical air is moving with a strong southerly wind flow, the maritime polar air may overrun the maritime tropical air. This results in extremely heavy showers, violent thunderstorms, and possible tornadoes.

If COLDER stagnant air lies to the leeward side of the mountain range, the cold front passing over the mountain range does not reach the surface but travels as an upper cold front (view B of fig. 4-44). Under this condition, frontal activity is at a minimum. This situation does not continue indefinitely; either the stagnant air below mixes with the air above or the upper cold front breaks through to the ground when the stagnant surface air has warmed sufficiently. Then the front returns to a normal classic front and begins to lift the now warm air. This ultimately results in the development of thunderstorms and squall lines (view C of fig. 4-45). In the summer, this occurs frequently in one form along the eastern United States. When a cold sea breeze occurs and a cold front crosses the Appalachian Mountains, the associated cold wedge of on-shore flow forces the warm air in advance of the cold front aloft, producing intense thunderstorm activity.

Generally, the area of precipitation is widened as a cold front approaches a mountain range. There is an increase in the intensity of the precipitation and cloud area on the windward side of the range and a decrease on the leeward side.

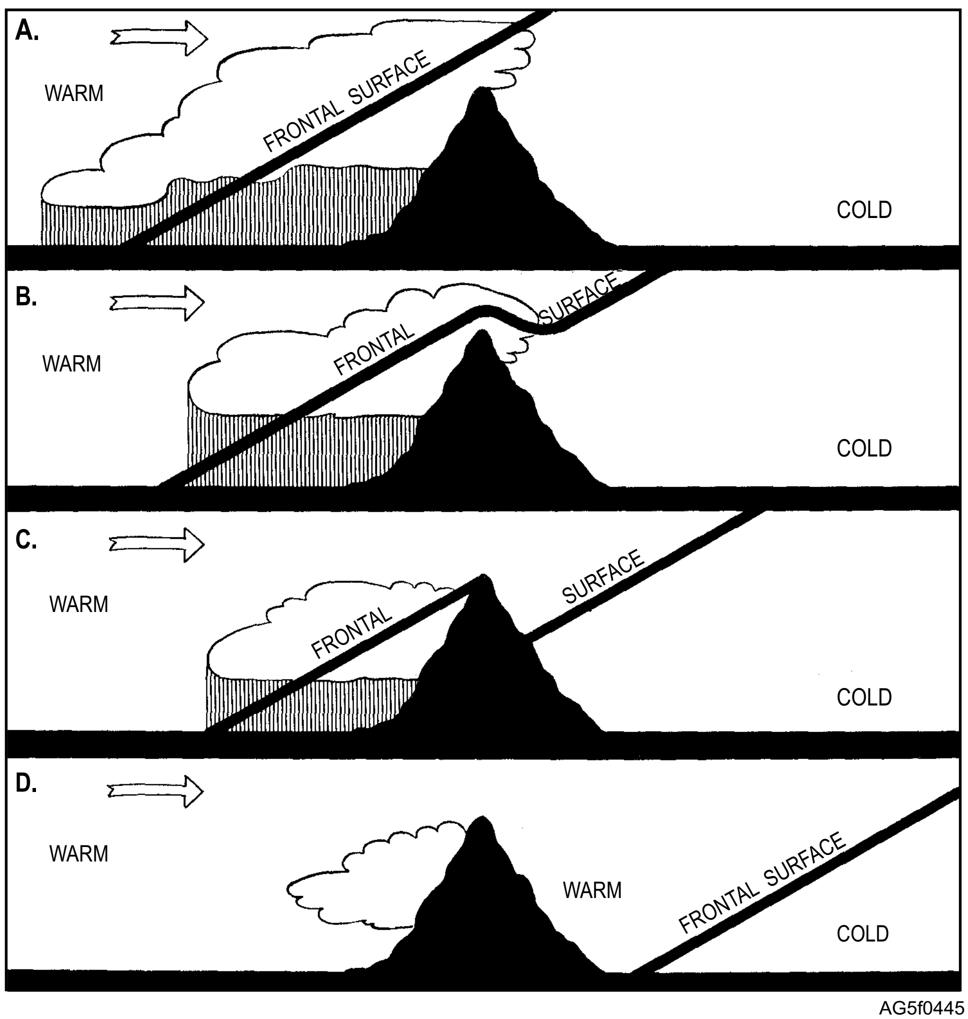

Figure 4-45.—Orographic effects on a warm front.

Warm Fronts

When a warm front approaches a mountain range, the upper section of the frontal surface is above the effects of the mountain range and does not come under its influence (view A of fig. 4-45). As the lower portion of the frontal surface approaches the range, the underlying cold wedge is cut off, forming a more or less stationary front on the windward side of the range. The inclination of the frontal surface above the range decreases and becomes more horizontal near the mountain surfaces, but the frontal surface maintains its original slope at higher altitudes (view B of fig. 4-45). While the stationary front on the windward side of the range may be accompanied by prolonged precipitation, the absence of ascending air on the leeward side of the range causes little or no precipitation. The warm air descending the leeward side of the range causes the cloud system to dissipate and the warm front to travel as an upper front.

Frontogenesis (the formation of a new front or the regeneration of an old front) may occur in the pressure-trough area that accompanies the front. The frontal surface then gradually forms downward as the frontal system moves away from the mountain and extends to the earth's surface again (views C and D of fig. 4-45). The effect of the mountain range on a warm front is to widen and prolong the precipitation on the windward side of the range, while on the leeward side the precipitation band is narrowed and weakened, or is nonexistent.

Occluded Fronts

Mountain ranges have much the same effect on occluded fronts as they do on warm and cold fronts. Cold type occlusions behave as cold fronts, and warm type occlusions behave as warm fronts. The occlusion process is accelerated when a frontal wave approaches a mountain range. The warm front is retarded; but the cold front continues at its normal movement, quickly overtaking the warm front (views A and B of fig. 4-46).

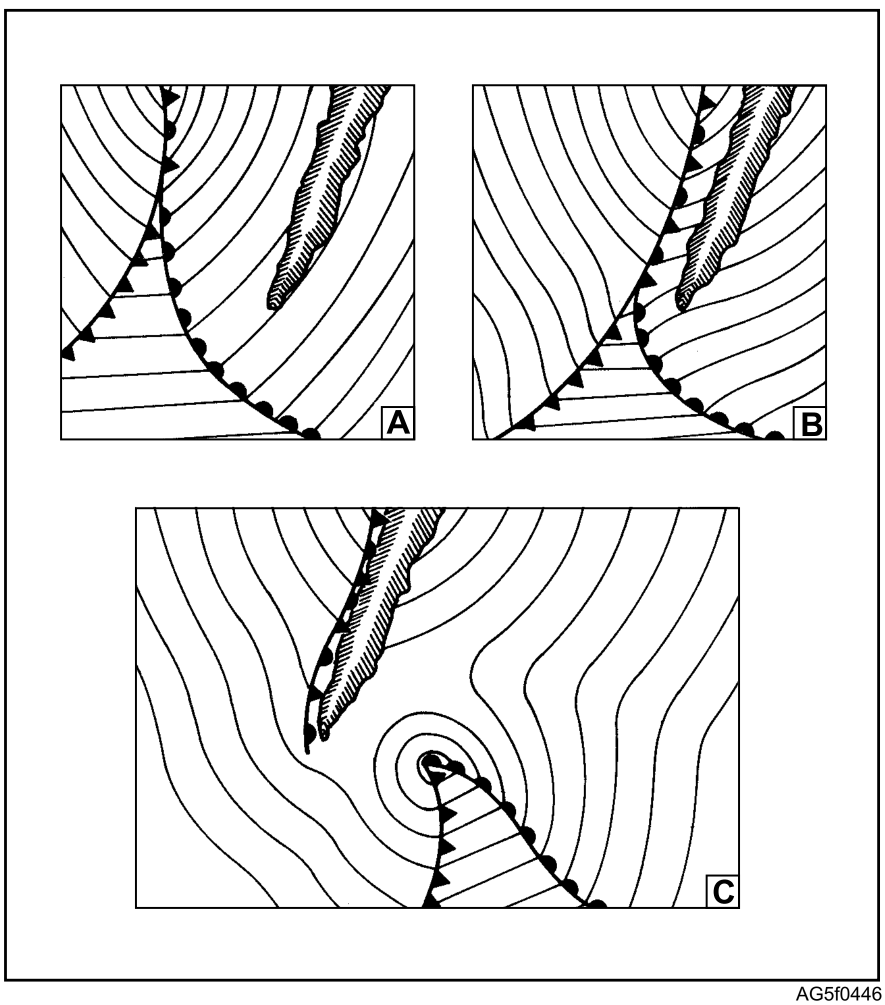

Figure 4-46.—Acceleration of the occlusion process and development of a frontal wave cyclone.

When a cold front associated with an occluded frontal system passes a mountain range, the cold front may develop a bulge or wave. In the case of an occlusion, a new and separate low may form at the peak of the warm sector as the occluded front is retarded by a mountain range (view C of fig. 4-46). The low develops on the peak of the wave because of induced low pressure that results when air descends on the leeward side of the mountain and warms adiabatically.

The development of a new low on a frontal wave and ultimate separation from its original cyclone is a fairly common occurrence. This can occur over open oceans but occurs more frequently along the west coast of mountainous continents and along the west coast of Japan. The typical stages of this type of frontal modification are shown in figure 4-47. Orographic features play a great role in certain preferred areas of this phenomena, but over the ocean some other factors must be operative. In some cases, a rapidly moving wave overtakes the slow moving occlusion and may be the triggering mechanism for this cyclogenesis.

Whatever the exact nature of its causes, this type of cyclogenesis proceeds with great rapidity. Initially, the old occlusion in view A of figure 4-47 either moves against a mountain range or is overtaken by another cyclone. The occlusion then undergoes frontolysis (view B of fig. 4-47). The new occlusion forms immediately and soon overshadows its predecessor in both area and intensity (view C of fig. 4-47). However, the cold occlusion, having greater vertical extension, exerts a certain control on the movement of the new center, which at first follows the periphery of the old center. Later, the two centers pivot cyclonically (view D of fig. 4-47) about a point somewhere on the axis joining them until the old center has filled and loses its separate identity.

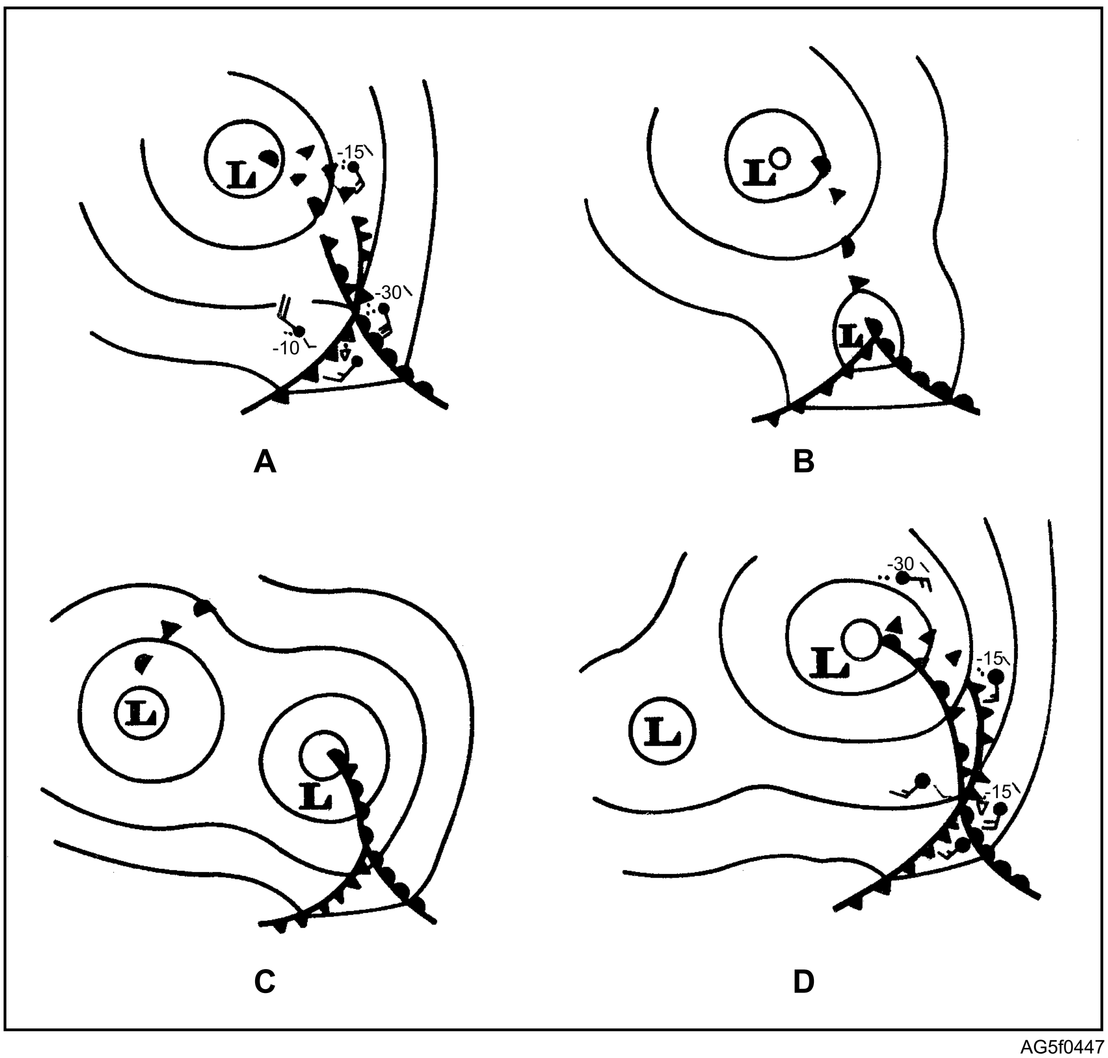

Figure 4-47.—Stages in the development of a secondary wave cyclone.

This can take place with either a warm or cold occlusion. If it occurs near a west coast in winter, there is a good chance the new occlusion is warm. This formation of a secondary wave cyclone, the dissipation of the original occluded front, and the rapid development of a new occlusion is sometimes called skagerraking, pressure jump, or bent-back occlusion.

EFFECTS OF UNDERLYING SURFACES

The migration of a frontal system from one area and type of underlying surface to another often has a great modifying effect. It may cause the front to be regenerated in some instances or to dissipate in others. This transition affects cyclones, air masses, and fronts.

Movement Over Land Surfaces

So far, we have established that frontal systems generally weaken when moving from water to land surfaces. Once these systems are over land, further modification can be expected. A front that has just crossed the mountains and has weakened remains weak or dissipates unless something occurs to strengthen the contrast between the air masses. If a cold front has just moved onshore in winter and encounters ice and snow cover over the western half of the United States, the maritime air behind the front quickly takes on colder continental properties. The cold underlying surface may totally destroy the cold front, especially if the associated air mass is moving slowly. On the other hand, if the front is moving quickly enough that it is not totally destroyed or modified by the colder surface, it may quickly regenerate as it approaches a warmer underlying surface and air mass. These normally exist over the eastern half of the United States. In this particular situation, the air behind the front is much colder than when it started. As the front arrives at the edge of the snow field, it probably will encounter warmer moist air from the gulf or the ocean. This situation quickly results in frontogenesis because of a sharp air mass contrast. Strong lifting by the wedge of approaching cold air results in severe thunderstorms and abundant precipitation along the frontal surface.

If the ice and snow field does not exist over the western half of the United States, then the weakened front gradually strengthens as it approaches the warmer eastern United States. The weather will not be as intense; however, the cold front will have a much wider band of clouds and precipitation. With this situation, air mass contrast is not strong. If the air masses behind and ahead of the front are weak, the front becomes stationary over the extreme southeast United States. The frontal systems are usually oriented in a northeast-southwest direction and occur mostly during the summer and autumn months. Frequently, stable waves develop and travel along this frontal system, causing unfavorable weather conditions. When these waves move out to sea and warmer moist air is brought into them, they become unstable waves and are regenerated as they move across the ocean.

As the cold fronts cross the Appalachian Mountains, they normally weaken once again because warm moist air is cut off. After passage over the mountains, warm Gulf Stream waters quickly resupply the frontal surface with the moisture and warm air needed for the front to strengthen.

Land to Water Migration

Once a cold front moves offshore, most forecasters and analysts forget about them and concentrate on the next approaching weather. When a front moves into the Atlantic, the weather generally becomes more intense, especially during fall and winter. While your station may be relaxing to some degree and enjoying the clear skies after frontal passage, Bermuda and ships at sea are most likely bracing for gale force wind and severe thunderstorm activity.

In middle latitudes, ocean currents carry warm water away from the equator along the eastern coasts of continents and carry cold water toward the equator along the western coasts of continents. The most active frontal zones of the winter season are found where cold continental air moves over warm water off eastern coasts. This situation is noticeable off the eastern coast of the United States over the Atlantic Ocean. As a cold front moves off the coast and over the Gulf Stream, it intensifies, and frequently wave development occurs near the Cape Hatteras area. This gives the eastern coast of the United States much cloudiness and precipitation. This system and its newly intensified front eventually reaches Bermuda. A similar situation occurs off the eastern coast of Japan. That area in the Pacific generates more cyclones than any other area in the world.

REVIEW QUESTIONS

Q4-20. What two effects cause the modification of fronts?

Q4-21. What normally happens to a cold front that moves off the eastern coast of the United States in the winter?

CHAPTER 5

ATMOSPHERIC PHENOMENA

Atmospheric phenomena include all hydrometeors, lithometeors, photo-meteors, and electrometeors and their associated effects. As an observer, you have the opportunity to observe and record some of these phenomena on a daily basis; however, as an analyst you must understand how and why these phenomena occur and what effects they can have on naval operations. Some phenomena have little effect on naval operations, but others such as extensive sea fogs and thunderstorm activity can delay or cancel operations.

HYDROMETEORS

LEARNING OBJECTIVE: Identify the characteristics of hydrometeors (precipitation, clouds, fog, dew, frost, rime, glaze, drifting and blowing snow, spray, tornadoes, and waterspouts).

Hydrometeors consist of liquid or solid water particles that are either falling through or suspended in the atmosphere, blown from the surface by wind, or deposited on objects. Hydrometeors comprise all forms of precipitation, such as rain, drizzle, snow, and hail, and such elements as clouds, fog, blowing snow, dew, frost tornadoes, and waterspouts.

PRECIPITATION

Precipitation includes all forms of moisture that fall to Earth's surface, such as rain, drizzle, snow, and hail, etc. Dew, frost, clouds, fog, rime, glaze, spray, tornadoes, and waterspouts are not forms of precipitation, although they are hydrometeors. Precipitation is classified according to both form (liquid, freezing, and solid) and size (rate of fall). The size of precipitation drops determines their rate of fall to a large extent.

Rain

Precipitation that reaches Earth's surface as water droplets with a diameter of 0.02-inch (0.5 mm) or more is classified as rain. If the droplets freeze on contact with the ground or other objects, the precipitation is classified as freezing rain. Rain falling from convective clouds is referred to as rain showers. Showers are usually intermittent in character, are of large droplet size, and change rapidly in intensity.

Drizzle

Drizzle consists of very small and uniformly dispersed droplets that appear to float while following air currents. Sometimes drizzle is referred to as mist. Drizzle usually falls from low stratus clouds and is frequently accompanied by fog and reduced visibility. A slow rate of fall and the small size of the droplets (less than 0.5-mm) distinguish drizzle from rain. When drizzle freezes on contact with the ground or other objects, it is referred to as freezing drizzle. Drizzle usually restricts visibility.

Snow

Snow consists of white or translucent ice crystals. In their pure form, ice crystals are highly complex hexagonal branched structures. However, most snow falls as parts of crystals, as individual crystals, or more commonly as clusters and combinations of these. Snow occurs in meteorological conditions similar to those in which rain occurs, except that with snow the initial temperatures must be at or below freezing. Snow falling from convective clouds is termed snow showers.

Snow Pellets

Snow pellets are white, opaque, round (or occasionally conical) kernels of snow-like consistency, 0.08 to 0.2 inch in diameter. They are crisp, easily compressible, and may rebound or burst when striking hard surfaces. Snow pellets occur almost exclusively in snow showers.

Snow Grains

Snow grains consist of precipitation of very small, white, opaque grains of ice similar in structure to snow crystals. They resemble snow pellets somewhat, but are more flattened and elongated. When the grains hit hard ground, they do not bounce or shatter. Snow grains usually fall in small quantities, mostly from stratus clouds, and never as showers.

Ice Pellets

Ice pellets are transparent or translucent pellets of ice that are round or irregular (rarely conical) and have a diameter of .02 inch (.5 mm) or less. They usually rebound upon striking hard ground and make a sound on impact. Ice pellets are generally subdivided into two groups, sleet and small hail. Sleet is composed of hard grains of ice, which has formed from the freezing of raindrops or the refreezing of largely melted snowflakes; it falls as continuous precipitation. Small hail is composed of pellets of snow encased in a thin layer of ice that has formed from the freezing of either droplets intercepted by the pellets or water resulting from the partial melting of the pellets; small hail falls as showery precipitation.

Hail

Ice balls or stones, ranging in diameter from that of a medium-size raindrop to two inches or more are referred to as hail. They may fall detached or frozen together into irregular, lumpy masses. Hail is composed either of clear ice or of alternating clear and opaque snowflake layers. Hail forms in cumulonimbus cloud, and is normally associated with thunderstorm activity and surface temperatures above freezing. Determination of size is based on the diameter (in inches) of normally shaped hailstones.

Ice Crystals (Ice Prisms)

Ice crystals fall as unbranched crystals in the form of needles, columns, or plates. They are often so tiny they seem to be suspended in the air. They may fall from a cloud or from clear air. In a synoptic observation, ice crystals are called ice prisms. They are visible mainly when they glitter in the sunlight or other bright light; they may even produce a luminous pillar or other optical phenomenon. This hydrometeor is common in Polar Regions and occurs only at low temperatures in stable air masses.

PRECIPITATION THEORY

Several valid theories have been formulated in regard to the growth of raindrops. The theories most widely accepted today are treated here in combined form.

Raindrops grow in size primarily because water exists in all three phases in the atmosphere and because the air is supersaturated at times (especially with respect to ice) because of adiabatic expansion and radiation cooling. This means that ice crystals coexist with liquid water droplets in the same cloud. The difference in the vapor pressure between the water droplets and the ice crystals causes water droplets to evaporate and then to sublimate directly onto the ice crystals. Sublimation is the process whereby water vapor changes into ice without passing through the liquid stage. Condensation alone does not cause droplets of water to grow in size. The turbulence in cloud permits and aids this droplet growth processes. After the droplets become larger, they start to descend and are tossed up again in turbulent updrafts within the cloud. The repetition of ascension and descension causes the ice crystals to grow larger (by water vapor sublimating onto the ice crystals) until finally they are heavy enough to fall out of the cloud as some form of precipitation. It is believed that most precipitation in the mid-latitudes starts as ice crystals and that most liquid precipitation results from melting during descent through a stratum of warmer air. It is generally believed that most rain in the tropics forms without going through the ice phase.

In addition to the above process of droplet growth, simple *accretion* is important. In this process, the collision of ice crystals with super-cooled water droplets causes the droplets to freeze on contact with the ice crystals. As the droplets freeze on the ice crystals, more layers accumulate. This process is especially effective in the formation of hail. There are other factors that explain, in part, the growth of precipitation, but the above processes are the primary ones.

OTHER HYDROMETEORS

The hydrometeors that follow, are not precipitation; however, they are equally important.

Clouds

A cloud is a visible mass of minute water droplets (or ice particles) suspended in the atmosphere. It differs from fog in that it does not reach the surface of Earth. Clouds are a direct expression of the physical processes taking place in the atmosphere. An accurate description of both type and amount plays an important part in the analysis of the weather and in forecasting the changes that take place in the weather.

CLOUD FORMATION.—To be able to thoroughly understand clouds, the Aerographer's Mate must know the physical processes that form clouds. Three conditions must be met before clouds can form as a result of condensation—presence of sufficient moisture, hygroscopic or sublimation nuclei in the atmosphere, and a cooling process. Moisture is supplied to the atmosphere by evaporation and is distributed horizontally and vertically by the winds and vertical currents. The first task is to consider the hygroscopic and sublimation nuclei.

Hygroscopic nuclei are particles of any nature on which condensation of atmospheric moisture occurs. It can be said that hygroscopic nuclei have an affinity for water or that they readily absorb and retain water. The most effective hygroscopic nuclei are the products of combustion (sulfuric and nitric acids) and salt sprays. Some dust particles are also hygroscopic, but not effectively so. The presence of hygroscopic nuclei is a must; water vapor does not readily condense without their presence. Air has been supersaturated in laboratories to over 400 percent before condensation began when there were no hygroscopic nuclei present. On the other hand, condensation has been induced with relative humidity of only 70 percent when there was an abundance of hygroscopic nuclei.

The condensation, which results when all three mentioned conditions are fulfilled, is usually in the form of mist, clouds, or fog. Fogs are merely clouds on the surface of Earth.

In our industrial cities, where byproducts of combustion are abundant, the distinction between smoke, fog, and haze is not easily discernible. A combination of smoke and fog gives rise to the existence of the so-called smog characteristic of these industrial areas.

Little is known about the properties of sublimation nuclei, although it is believed they are essential for sublimation to occur at all. It is assumed sublimation nuclei are very small and very rare, possibly of a quartz or meteoric dust origin. All cirriform clouds are composed of ice crystals and are believed to be formed as a result of direct sublimation. In the atmosphere, water clouds, water and ice crystal clouds, and pure ice crystal clouds may coexist at the same time.

Next under consideration is the cooling process that may induce condensation. There are several processes by which the air is cooled: convective cooling by expansion, mechanical cooling by expansion, and radiation cooling. Any of the three methods may work in conjunction with another method, making it even more effective. The methods are as follows:

1. Convective cooling. The ascent of a limited mass of air through the atmosphere because of surface heating is called thermal convection. If a sample of air is heated, it rises (being less dense than the surrounding air) and decreases in temperature at the dry adiabatic lapse rate until the temperature and dew point are the same. This is the saturation point at which condensation begins. As the parcel of air continues to rise, it cools at a lesser rate—called the moist/saturation adiabatic lapse rate. The parcel of air continues to rise until the surrounding air has a temperature equal to, or higher than, the parcel of air. At this point convection ceases. Cumuliform clouds are formed in this way. Cloud bases are at the altitude of saturation and tops are at the point where the temperature of the surrounding air is the same as, or greater than, the temperature of the parcel of air.

2. Mechanical cooling. Orographic and frontal processes are considered mechanical means of cooling which result in cloud formation.

a. Orographic processes. If air is comparatively moist and is lifted over mountains or hills, clouds may be formed. The type of cloud depends upon the lapse rate (the rate of decrease in temperature with increase in height, unless otherwise specified) of the air. If the lapse rate is weak (that is, a low rate of cooling with an increase in altitude), the clouds formed are of the stratiform type. If the lapse rate of the air is steep (that is, a high rate of cooling with increasing altitude), the clouds formed are of the cumuliform type.

b. Frontal processes. In the previous unit, you learned that, at frontal surfaces, the warmer, less dense air is forced to rise along the surfaces of the colder air masses. The lifted air undergoes the same type of adiabatic cooling as air lifted orographically. The type of cloud formed depends on the lapse rate and moisture of the warm air and the amount of lifting. The slope of the front determines lifting; when the slope is shallow, the air may not be lifted to its saturation point and clouds do not form. When the slope steep, as with a fast-moving cold front, and the warm air is unstable, towering cumuliform cloud form.

3. Radiation cooling. At night Earth releases long-wave radiation, thereby cooling rapidly. The air in contact with the surface is not heated by the outgoing radiation, but rather is cooled by contact with the cold surface. This contact cooling lowers the temperature of the air near the surface, causing a surface inversion. If the temperature of the air is cooled to its dew point, fog and/or low clouds form. Clouds formed in this manner dissipate during the day because of surface heating.

CLOUD CLASSIFICATION.—The international classification of clouds adopted by most countries is a great help to both meteorological personnel and pilots. It tends to make cloud observations standard throughout the world, and pilots that can identify cloud types will normally take the necessary steps to avoid those types dangerous to their aircraft.

Clouds have been divided into etages, genera, species, and varieties. This classification is based primarily on the process that produces the clouds. Although clouds are continually in a process of development and dissipation, they do have many distinctive features that make this classification possible.

Etages.—Observations have shown that clouds generally occur over a range of altitudes varying from sea level to about 60,000 feet in the tropics, to about 45,000 feet in middle latitudes, and to about 25,000 feet in Polar Regions. By convention, the part of the atmosphere in which clouds are usually present has been vertically divided into three etages—high, middle, and low. The range of levels at which clouds of certain genera occur most frequently defines each etage.

Cirrus, cirrocumulus, and cirrostratus are always found in the high etage. Altocumulus and altostratus are found in the middle etage, but altostratus may often extend into the high etage. Nimbostratus is always found in the middle etage but may extend into the high, and especially the low etage. Cumulus, cumulonimbus, stratus, and stratocumulus are always associated with the low etage, but the tops of cumulus or cumulonimbus may extend into one or both of the two other etages.

The HIGH ETAGE extends from about 10,000 to 25,000 feet in polar regions, 16,500 to 45,000 feet in temperate regions, and 20,000 to 60,000 feet in tropical regions.

The MIDDLE ETAGE extends from about 6,500 to 13,000 feet in polar regions, 6,500 to 23,000 feet in temperate regions, and 6,500 to 25,000 feet in tropical regions.

The LOW ETAGE extends from near Earth's surface to 6,500 feet in all regions of Earth.

Genera (Types).—As a weather analyst, interpreter, and briefer, you will be viewing the state of the sky with distinctly different objectives in mind. A review of the various cloud types can help you to associate past observer experiences with synoptic conditions and trends.

High clouds. High clouds are described as follows:

1. Cirrus (CI). Cirrus are detached clouds of delicate and fibrous appearance, are generally white (cirrus are the whitest clouds in the sky), and are without shading. They appear in the most varied forms, such as isolated tufts, lines drawn across the sky, branching feather-like plumes, and curved lines ending in tufts. Since cirrus is composed of ice crystals, their transparent character depends upon the degree of separation of the crystals. Before sunrise and after sunset, cirrus may still be colored bright yellow or red. Being high altitude clouds, they light up before lower clouds and fade out much later. Cirrus often indicates the direction in which a storm lies.

2. Cirrocumulus (CC). Cirrocumulus, commonly called mackerel sky, looks like rippled sand or like cirrus containing globular masses of cotton, usually without shadows. Cirrocumulus is an indication that a storm is probably approaching. The individual globules of cirrocumulus are rarely larger than 1 degree as measured by an observer on the surface of Earth at or near sea level.

3. Cirrostratus (CS). Cirrostratus form a thin, whitish veil, which does not blur the outlines of the Sun, or the Moon but does give rise to halos. A milky veil of fog, thin stratus, and altostratus are distinguished from a veil of cirrostratus of similar appearance by the halo phenomenon, which the Sun or Moon nearly always produces in a layer of cirrostratus. The appearance of cirrostratus is a good indication of rain. In the tropics, however, cirrostratus is quite often observed with no rain following.

Middle clouds. Middle clouds are described as follows:

1. Altocumulus (AC). Altocumulus appear as a layer (or patches) of clouds composed of flattened globular masses, the smallest elements of the regularly arranged layer being fairly small and thin, with or without shading. The balls or patches usually are arranged in groups, lines, or waves. This cloud form differs from cirrocumulus by generally having larger masses, by casting shadows, and by having no connection with cirrus forms. Corona and irisation are frequently associated with altocumulus.

2. Altostratus (AS). Altostratus looks like thick cirrostratus, but without halo phenomena; altostratus forms a fibrous veil or sheet, gray or bluish in color. Sometimes the Sun or Moon is completely obscured. Light rain or heavy snow may fall from an altostratus cloud layer. Altostratus can sometimes be observed at

two different levels in the sky and sometimes in conjunction with altocumulus, which may also exist as two different layers in the sky.

3. Nimbostratus (NS). Nimbostratus appears as a low, amorphous, and rainy layer of clouds of a dark gray color. They are usually nearly uniform and feebly illuminated, seemingly from within. When precipitation occurs, it is in the form of continuous rain or snow. However, nimbostratus may occur without rain or snow reaching the ground. In cases in which the precipitation does not reach the ground, the base of the cloud is usually diffuse and looks wet. In most cases, nimbostratus evolve from altostratus layers, which grow thicker and whose bases become lower until they become a layer of nimbostratus.

Low clouds. Low clouds are described as follows:

1. Stratocumulus (SC). Stratocumulus appear as a layer (or patches) of clouds composed of globular masses or rolls. The smallest of the regularly arranged elements is fairly large. They are soft and gray with darker spots.

2. Stratus (ST). Stratus appears as a low, uniform layer of clouds, resembling fog, but not resting on the ground. When a layer of stratus is broken up into irregular shreds, it is designated as stratus fractus. A veil of stratus gives the sky a characteristically hazy appearance. Usually, drizzle is the only precipitation associated with stratus. When there is no precipitation, the stratus cloud form appears drier than other similar forms, and it shows some contrasts and some lighter transparent parts.

3. Cumulus (CU). Cumulus is dense clouds with vertical development. Their upper surfaces are dome shaped and exhibit rounded protuberances, while their bases are nearly flat. Cumulus fractus or fractocumulus resemble ragged cumulus in which the different parts show constant change.

4. Cumulonimbus (CB). Cumulonimbi are heavy masses of cumulus-type clouds with great vertical development whose cumuliform summits resemble mountains or towers. Tops may extend higher than 60,000 feet. Their upper parts are composed of ice crystals and have a fibrous texture; often they spread out in the shape of an anvil.

Cumulonimbi are the familiar thunderclouds, and their precipitation is of a violent, intermittent, showery character. Hail often falls from well-developed cumulonimbus. On occasion, cumulonimbus clouds display several readily apparent supplementary features. Examples are (1) mamma or hanging pouch-like protuberances on the under surface of the cloud; (2) tuba (commonly called the funnel cloud), resembling a cloud column or inverted cloud cone/pendant from the cloud base; and (3) virga, wisps or streaks of water or ice particles falling out of a cloud but evaporating before reaching Earth's surface as precipitation.

The Aerographer's Mate must learn to recognize the various cloud types and associated precipitation as seen from Earth's surface. Figure 5-1 shows the various types of clouds in a tier with each cloud type at its average height. Although one never sees all cloud types at once, quite frequently two or three layers of clouds of different types may be present simultaneously.

Species.—The following species of clouds are referred to frequently; others may be found in the *International Cloud Atlas* or in the newer publication, *Cloud Types for Observers.*

Castellanus. Clouds which present, in at least some portion of their upper part, cumuliform protuberances in the form of turrets. The turrets, which are generally taller than they are wide, are connected to a common base. The term applies mainly to cirrocumulus, altocumulus, and stratocumulus, but especially altocumulus.

Stratiformis. Clouds which are spread out in an extensive horizontal sheet or layer. The term applies to altocumulus, stratocumulus, and occasionally to cirrocumulus.

Lenticularis. Clouds having the shape of lenses or almonds, often elongated and having well-defined outlines. The term applies mainly to cirrocumulus, altocumulus, and stratocumulus.

Fractus. Clouds in the form of irregular shreds, which have a clearly ragged appearance. The term applies only to stratus and cumulus.

Humilis. Cumulus clouds of only a slight vertical extent; they generally appear flattened.

Congestus. Cumulus clouds which are markedly sprouting and are often of great vertical extent. Their bulging upper part frequently resembles cauliflower.

Varieties and Supplementary Features.—Cloud varieties are established mainly on the basis of the cloud's transparency or its arrangement in the sky. A detailed description of the nine varieties can be found in the *International Cloud Atlas.*

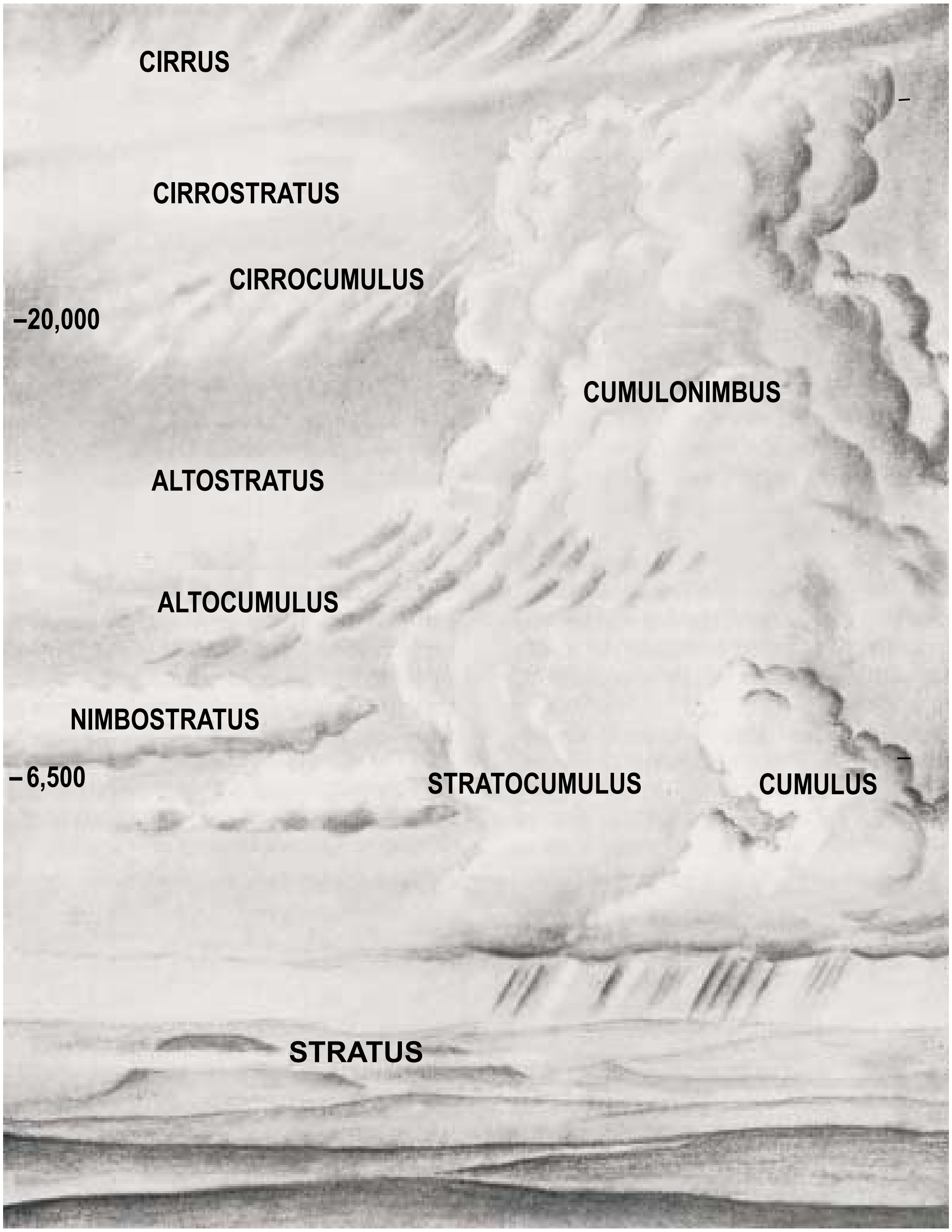

Figure 5-1.—Layer diagram of clouds at various levels.

Supplementary features and accessory clouds, like the varieties, aid in the clear identification of clouds. The most common supplementary features are mamma, tuba, and virga. They are defined and associated with the parent clouds in the general section.

Fog

Fog is a cloud on Earth's surface. It is visible condensation in the atmosphere. Fog varies in depth from a few feet to many hundreds of feet. Its density is variable resulting in visibility from several miles to near zero. It differs from rain or mist in that its water or ice particles are more minute and suspended and do not fall earthward.

The forecasting of fog is frequently a difficult task. In addition to knowledge of the meteorological causes of fog formation, it is necessary to have a thorough knowledge of local geography and topography. A slight air drainage (gravity induced, downslope flow of relatively cold air) may be enough to prevent fog formation, or a sudden shift in the wind direction may cause fog to cover an airfield.

The temperature to which air must be cooled, at a constant pressure and a constant water vapor content, in order for saturation to occur is the dew point. This is a variable, based upon the amount of water vapor present in the atmosphere. The more water vapor present, the higher the dew point. Thus, the dew point is really an index of the amount of water vapor present in the air at a given pressure.

Temperature and dew point may be made to coincide either by raising the dew point until it equals the temperature of by lowering the temperature to the dew point. The former results from the addition of water vapor to the air by evaporation from water surfaces, wet ground, or rain falling through the air. The latter results from the cooling of the air by contact with a cold surface underneath. There are several classifications of fog: radiation fog, advection fog, upslope fog, and frontal fog.

RADIATION FOG.—Radiation fog, which generally occurs as ground fog, is caused by the radiation cooling of Earth's surface. It is primarily a nighttime occurrence, but it often begins to form in the late afternoon and may not dissipate until well after sunrise. It never forms over a water surface. Radiation fog usually covers a wide area.

After sunset, Earth receives no heat from the Sun, but its surface continues to reradiate heat. The surface begins to cool because of this heat loss. As Earth cools, the layer of air adjacent to the surface is cooled by conduction (the transfer of heat from warmer to colder matter by contact). This causes the layer near Earth to be cooler than the air immediately above it, a condition called an inversion. If the air beneath the inversion layer is sufficiently moist and cools to its dew point, fog forms. (See fig. 5-2.) In case of a calm wind, this cooling by conduction affects only a very shallow layer (a few inches deep), since air is a poor conductor of heat. Wind of low speed (3 to 5 knots) causes slight, turbulent currents. This turbulence is enough to spread the fog through deeper layers. As the nocturnal cooling continues, the air temperature drops further, more moisture is condensed, and the fog becomes deeper and denser. If winds increase to 5 to 10 knots, the fog will usually thicken vertically. Winds greater than 10 knots usually result in the formation of low scud, stratus, or stratocumulus.

After the Sun rises, Earth is heated. Radiation from the warming surface heats the lower air, causing evaporation of the lower part of the fog, thereby giving the appearance of lifting. Before noon, heat radiated from the warming surface of Earth destroys the inversion and the fog evaporates into the warmed air. Radiation fog is common in high-pressure areas where the wind speed is usually low (less than 5 knots) and clear skies are frequent. These conditions permit maximum radiation cooling.

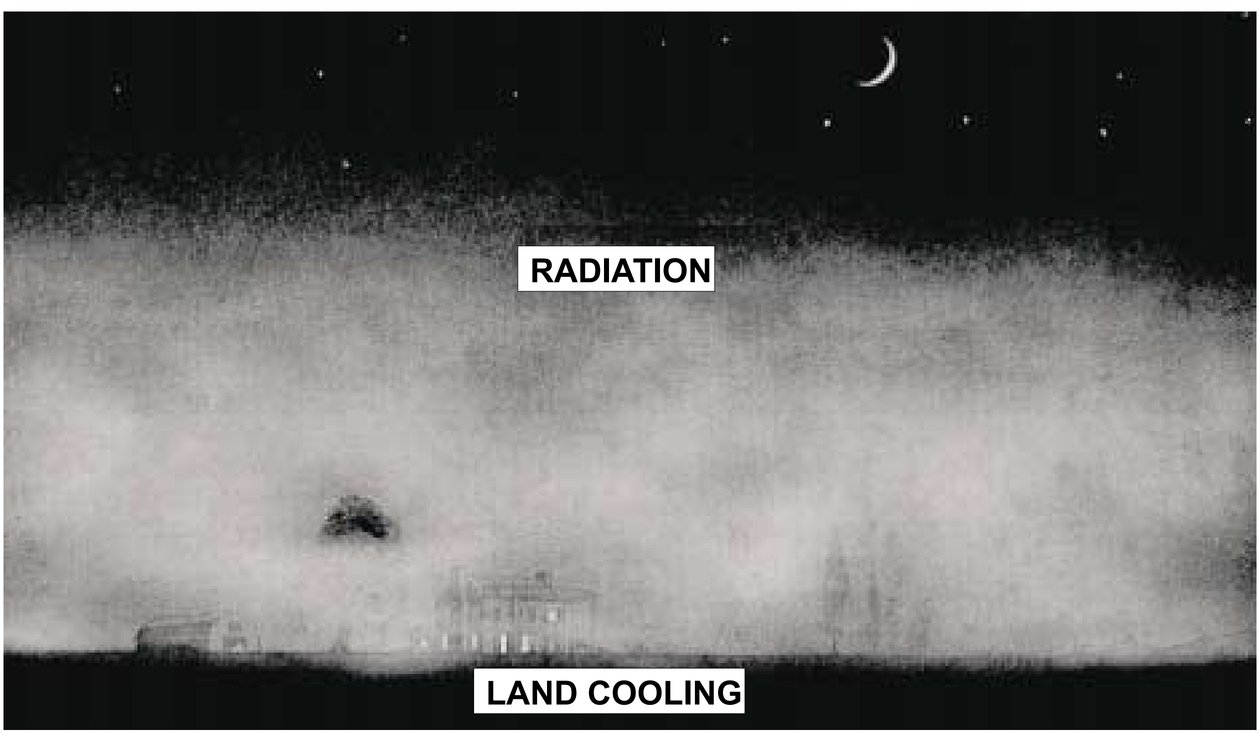

Figure 5-2.—Radiation fog.

ADVECTION FOG.—Advection fog is the name given to fog produced by air in motion or to fog formed in one place and transported to another. This type of fog is formed when warmer air is transported over colder land or water surfaces. Cooling from below takes place and gradually builds up a fog layer. The cooling rate depends on the wind speed and the difference between the air temperature and the temperature of the surface over which the air travels.

Advection fog can form only in regions where marked temperature contrasts exist within a short distance of each other, and only when the wind blows from the warm region toward the cold region. (See fig. 5-3.) It is easy to locate areas of temperature contrast on the weather map, as they are usually found along coastlines or between snow-covered and bare ground.

Sea Fog.—Sea fog is always of the advection type and occurs when the wind brings moist, warm air over a colder ocean current. The greater the difference between the air temperature and the ocean temperature, the deeper and denser the fog. Sea fog may occur during either the day or night. Some wind is necessary, not only to provide some vertical mixing, but also to move the air to the place where it is cooled. Most advection fogs are found at speeds between 4 and 13 knots. Sea fogs have been maintained with wind speed as high as 26 knots. They persist at such speeds because of the lesser frictional effect over a water surface. Winds of equal speed produce less turbulence over water than over land.

Sea fogs, which tend to persist for long periods of time, are quite deep and dense. Since the temperature of the ocean surface changes very little during the day, it is not surprising to hear of sea fogs lasting for weeks. A good example of sea fog is that found off the coast of Newfoundland.

Land Advection Fog.—Land advection fog is found near large bodies of water; that is, along seacoasts and large lakes. Onshore breezes bring maritime air over a land surface, which has cooled by radiation at night. (See fig. 5-4.) Also, fogs may form over the ocean and be blown over the land during either the day or the night. Another situation favorable to fog formation is one in which air flows from warm, bare ground to snow-covered ground nearby.

Land advection fog cannot exist with as high wind speed as the sea type because of the greater turbulence. It dissipates in much the same fashion as radiation fog. However, since it is usually deeper, it requires a longer time to disperse.

Steam Fog.—Steam fog occurs within air masses; but, unlike other air-mass fogs, which are formed by the cooling of the air temperature to the dew point, steam fog is caused by saturation of the air through evaporation of water. It occurs when cold air moves

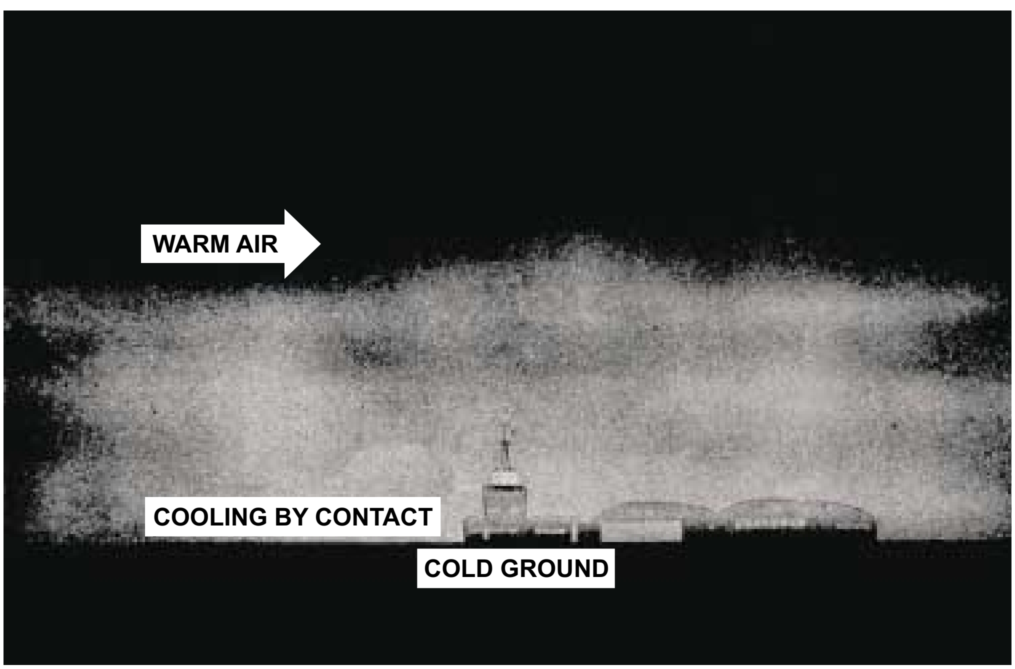

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Figure 5-3.—Advection fog.

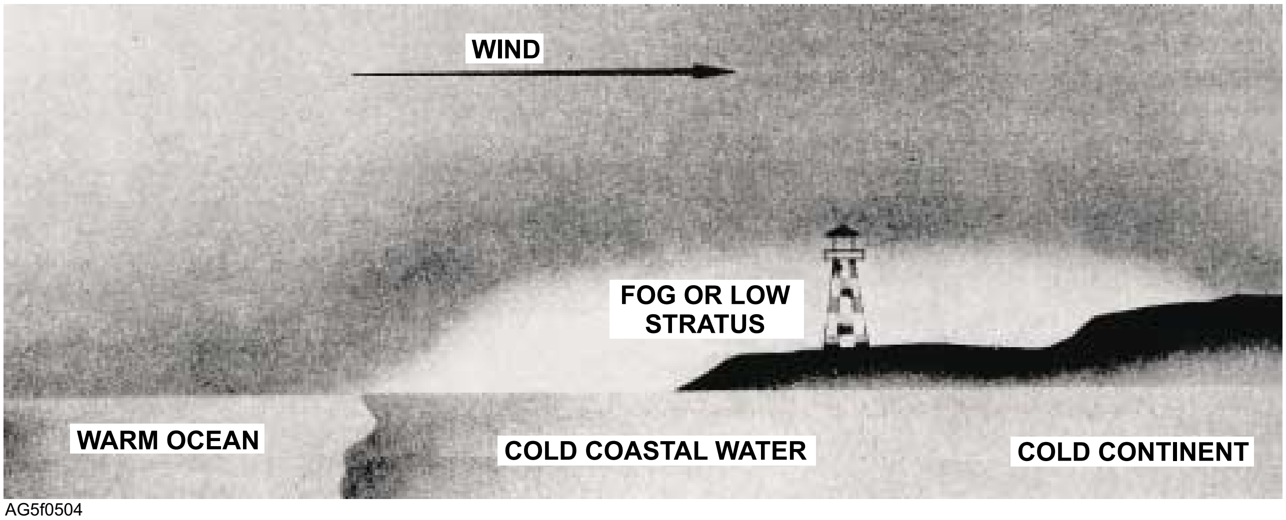


Figure 5-4.—Land advection fog caused by an onshore flow over cold coastal water.

over warm water. Evaporation from the surface of the warm water easily saturates the cold air, causing fog, which rises from the surface like smoke. It should be noted that the actual process of heating cold air over a warm surface tends to produce instability. The presence of an inversion above the surface prevents steam fog from rising very high; it is usually fairly dense and persistent.

This type of fog forms on clear nights over inland lakes and rivers in late fall before they freeze. It is prevalent along the Mississippi River and Ohio River at that time of year. Arctic sea smoke is the name given to steam fogs in the arctic region. It forms when cold air moves over a warmer water surface, which is most often found in breaks of the surface ice. It may also occur over the ocean surface following a cold frontal passage when the water is approximately 40°F warmer than the air passing over it.

Upslope Fogs.—Upslope fog is caused by adiabatic cooling of rising air. It is formed when moist, warm air is forced up a slope by the wind. The cooling of the air is almost entirely adiabatic, since there is little conduction taking place between the air and surface of the slope. The air must be stable before it starts its motion so that the lifting does not cause convection, or vertical currents, which would dissipate the fog.

Some wind speed is needed, of course, to cause the upslope motion. Upslope fog is usually found where the air moves up a gradual slope. This type of fog is deep and requires considerable time to dissipate. The most common fog of this type is called *Cheyenne fog* and is caused by the westward flow of air from the Missouri Valley, which produces fog on the eastern slope of the Rockies.

Frontal Fog.—Frontal fog is another hazard, which must be added to the list of weather problems associated with fronts. The actual fog is due to the evaporation of falling rain and occurs under the frontal surface in the cold air mass. This additional water vapor gradually saturates the air. Precipitation falls from the lifted warm air through the cold air. Evaporation from the rain continues as long as the temperature of the raindrops is higher than the temperature of the air, even though the cold air is already saturated. Naturally, the upper regions become saturated first because the temperature and dew point are lower at the higher altitude. As the evaporation from the rain continues, a layer of clouds begins to build down from the frontal surface. Eventually, this cloud layer extends to the ground and becomes fog.

During the day, there may be enough turbulence caused by solar heating to keep this cloud off the ground. However, after dark, because of dying convection currents and the nocturnal cooling of the air, the ceiling drops suddenly. It is this sudden closing in after dark that makes frontal fog so dangerous.

Cold fronts usually move so rapidly and have such narrow bands of precipitation and high wind speeds that *cold-front fog* is comparatively rare and short lived. *warm-front fog*, on the other hand, is fairly common. Since warm frontal systems are quite extensive, warm-front fog may cover a wide area. This type fog is also deep because it extends from the ground to the frontal surface. The clouds above the frontal surface also slow down the dissipating effect of solar heating.

These factors make the warm-front fog among the most dangerous. (See fig. 5-5.)

Dew

Dew does not actually fall; rather the moisture condenses from air that is in direct contact with the cool surface. During clear, still nights, vegetation often cools by radiation to a temperature at or below the dew point of the adjacent air. Moisture then collects on the leaves just as it does on a pitcher of ice water in a warm room. Heavy dew is often observed on grass and plants when there is none on the pavements or on large, solid objects. These objects absorb so much heat during the day or give up heat so slowly, they may not cool below the dew point of the surrounding air during the night.

Another type of dew is white dew. White dew is a deposit of white, frozen dew drops. It first forms as liquid dew, then freezes.

Frost

Frost, or hoarfrost, is formed by the process of sublimation. It is a deposit of ice having a crystalline appearance and generally assumes the form of scales, needles, feathers, or fans. Hoarfrost is the solid equivalent of dew and should not be confused with white dew, which is dew frozen after it forms.

Rime (Rime Icing)

Rime is a white or milky opaque granular deposit of ice. It occurs when supercooled water droplets strike an object at temperatures at or below freezing. Factors favoring the formation of rime are small drop size, slow accretion, a high degree of supercooling, and rapid dissipation of latent heat of fusion. Rime is a result of freezing drizzle and looks like frost in a freezer. Rime icing, which forms on aircraft, can seriously distort airfoil shape, therefore diminishing lift and performance. Rime icing is more likely to form in

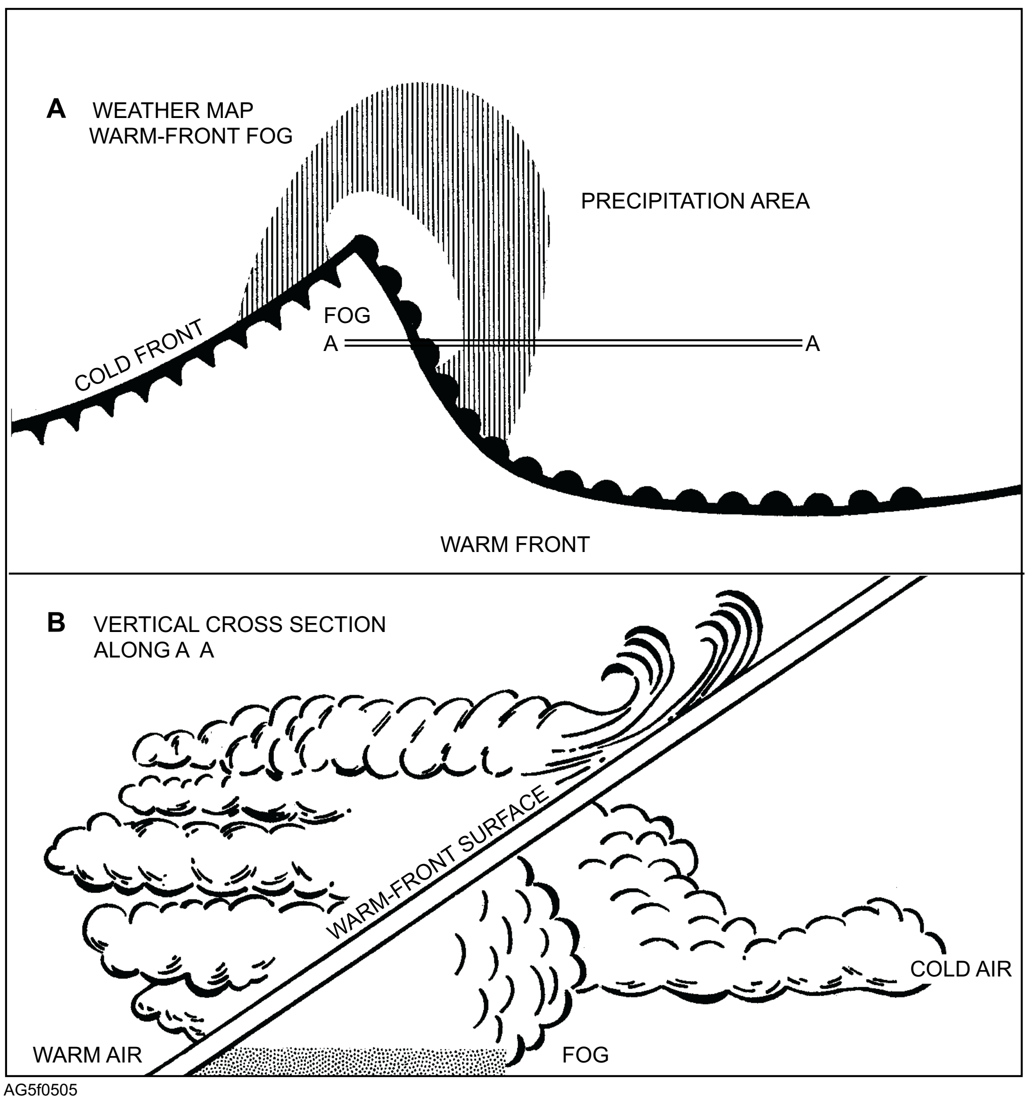


Figure 5-5.—Warm-front fog.

stratus-type clouds with temperatures between 0°C and minus 22°C. When formed in cumuliform-type clouds, temperatures range from minus 9°C to minus 15°C and are accompanied by clear icing which is then termed mixed icing.

Glaze (Clear Icing)

Glaze is a coating of ice, generally clear and smooth. It occurs when supercooled water droplets deposited by rain, drizzle, fog, or condensed water vapor strike an exposed object at temperatures at or below freezing. Factors favoring formation of glaze are large drop size, rapid accretion, slight supercooling, and slow dissipation of the latent heat of fusion. Glaze is denser, harder, and more transparent than rime and looks similar to an ice cube. Clear icing forms on aircraft and adds appreciably to the weight of the craft. This additional weight has an even greater effect in reducing the performance of the aircraft than does rime icing. Clear icing occurs in cumuliform-type clouds at temperatures between 0°C and a minus 9°C. It also occurs with rime icing in cumuliform clouds at temperatures between minus 9°C and minus 15°C.

Drifting and Blowing Snow

Drifting and blowing snow are the result of snow particles being raised from the ground by the wind. To classify wind-driven snow as drifting snow, the particles will only be lifted to shallow heights (less than 6 feet) and the horizontal visibility will remain at 7 miles or more at eye level (6 feet). When the wind drives snow to levels 6 feet or higher and the visibility is restricted to 6 miles or less, it is classified as blowing snow.

Spray and Blowing Spray

Spray and blowing spray occurs when the wind is of such force that it lifts water droplets from the water surface (normally the wave crests) and carries them into the air. To be classified as spray, the wind-driven water droplets will not obstruct visibility at eye level (6 feet on shore and generally 33 feet at sea). Blowing spray occurs when the water droplets are lifted in such quantities that they reduce visibility to 6 miles or less at eye level.

TORNADOES

A tornado is an extremely violent whirling storm with a small diameter, usually a quarter of a mile or less. The length of the track of a tornado on the ground may be from a few hundred feet to 300 miles; the average is less than 25 miles. When not touching the ground, it is termed *a funnel cloud* or *tuba.* The velocities of tornado winds are in the general range of 125 to 250 knots. A large reduction of pressure in the center due to the spiraling of the air seems to cause buildings in the path of the storm to explode. The speed of the storm over Earth's surface is comparatively slow—usually 22 to 34 knots.

Most of the tornadoes in the United States occur in the late spring and early summer in middle and late afternoon, and they are associated with thunderstorm activity and heavy rain. Tornadoes occur on all continents but are most common in Australia and the United States. They can occur throughout the year and at any time of day. Tornadoes have been observed with various synoptic situations but are usually associated with overrunning cold air. Statistics show that the majority of tornadoes appear about 75 to 180 miles ahead of a cold front along the prefrontal squall line. Figure 5-6 shows the various stages of development of a tornado.

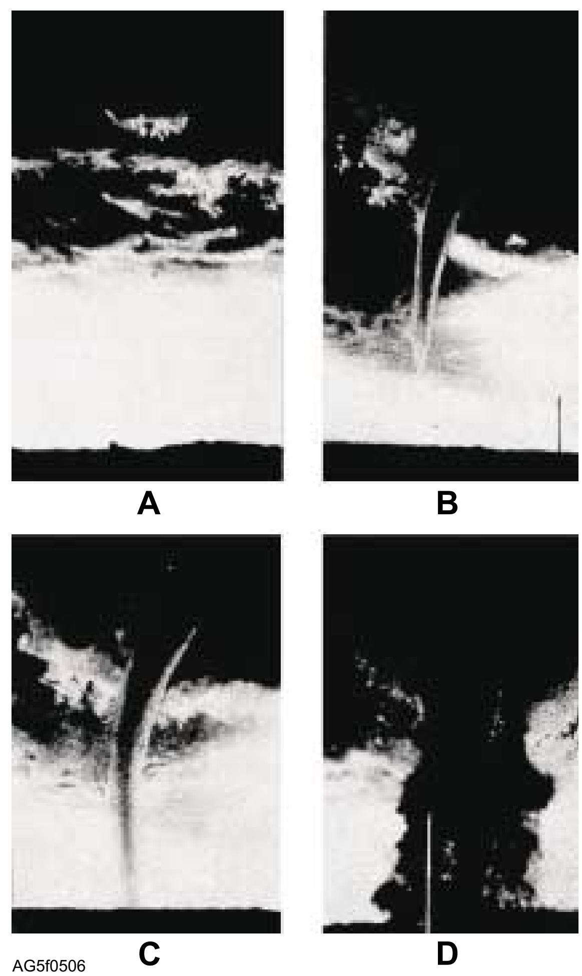


Figure 5-6.—Stages of development of a tornado.

A situation that is noticeably favorable to tornado activity is cold air advection aloft. When mP air moves across the United States, it becomes heated in the low levels in the western plateaus. The resulting density of the now warm mP air is then equal to or less than that of mT air moving northward over the Mississippi Valley. The mP air rides up over the mT air. The mP air still maintains low temperatures at higher altitudes causing extreme instability.

The following conditions may indicate possible tornado activity:

1. Pronounced horizontal wind shear. (Wind shear is the rate of change of wind velocity with distance.)

2. Rapidly moving cold front.

3. Strong convergent flow at the surface.

4. Marked convective instability.

5. Dry air mass superimposed on a moist air mass and abrupt change in moisture content, usually below 10,000 feet.

6. Marked convection up to the minus 10°C isotherm.

WATERSPOUTS

Waterspouts are tornadoes that form over ocean areas. This phenomenon consists of two types: tornado in origin and locally induced. The difference between the two types is significant in that the tornado type has potential for inducing substantial damage and injury over a broad area, while the local type has potential for causing only minor damage in a small area. The following information is provided to help you to better understand the two types of waterspouts.

Tornado Type

These waterspouts form at the cloud and extend down to the surface. They originate from severe convective cells associated with a cold front, squall line, or large convective cluster. Whenever the conditions for tornado development are present over coastal areas and the triggering mechanism extends into the adjacent maritime area, then potential for waterspout development is high. The tornado waterspout has a relatively short life span and usually stays over water. However, when one does come ashore, there is potential for it to assume the characteristics of a tornado; although its life span is limited, the initial intensity is sufficient to cause property damage and injury to personnel.

Local Type

These waterspouts originate from convective clouds of moderate vertical extent which form a line or a small cluster. Their existence is sensitive to wind and temperature in that surface winds of 20 knots or greater, or a cooling of the atmosphere by precipitation, dissipates them. Additionally, when local waterspouts come ashore, the friction induced by the land rapidly dissipates them. The biggest threat posed by these waterspouts is to small craft, recreational boating, and to support facilities such as harbor operations and marinas.

REVIEW QUESTIONS

Q5-1. Describe the major difference between rain and drizzle.

Q5-2. What altitude range do clouds occur in the tropics?

Q5-3. What is the altitude range of middle clouds in the temperate regions?

Q5-4. Describe the difference between sea fog and steam fog.

Q5-5. What criteria must be met for a hydrometeor to be classified as blowing spray?

LITHOMETEORS

LEARNING OBJECTIVE: Identify the characteristics of lithometeors (haze, smoke, dust, sand, and dust devils).

Lithometeors comprise a class of atmospheric phenomena of which dry haze and smoke are the most common examples. In contrast to hydrometeors, which consist largely of water, lithometeors are composed of solid dust or sand particles, or the ashy products of combustion.

HAZE

Haze is composed of suspended dust or salt particles that are so small that they cannot be individually felt or seen by the unaided eye. They reduce visibility and lend a characteristic opalescent appearance to the air. Haze resembles a uniform veil over the landscape that subdues all colors. This veil has a bluish tinge when viewed against a dark background and a dirty yellow or orange tinge when viewed against a bright background. Differences in air temperature may cause a shimmering veil over the landscape called optical haze.

SMOKE

Smoke is fine ash particles suspended in the atmosphere. When smoke is present, the disk of the Sun at sunrise and sunset appears red, and during the daytime has a reddish tinge. Smoke at a distance, such as from forest fires, usually has a light grayish or bluish color and is evenly distributed in the upper air.

DUST

Dust is finely divided solid matter uniformly distributed in the air. It imparts a tan or grayish hue to distant objects. The Sun's disk is pale and colorless or has a yellow tinge during the day. Blowing dust consists of dust raised by the wind to moderate heights above the ground and restricting horizontal visibility to less than 7 miles. When visibility is reduced to less than five-eighths of a mile but not less than five-sixteenths of a mile, it is classified as a dust storm and, if less than five-sixteenths of a mile, as a severe dust storm.

SAND

Fine particles of sand picked up from the surface by the wind and blown about in clouds or sheets constitute a troublesome lithometeor in some regions. Blowing sand consists of sand raised by the wind to moderate heights above the ground, which reduces horizontal visibility to less than 7 miles. When the visibility is reduced to less than five-eighths of a mile but not less than five-sixteenths of a mile, it is classed as a sandstorm and, if less than five-sixteenths of a mile, as a severe sandstorm.

DUST DEVILS

Dust devils, or whirling, dust-laden air, are caused by intense solar radiation, which sets up a steep lapse rate near the ground. They are best developed on calm, hot, clear afternoons and in desert regions. As the intense surface heating sets up a steep lapse rate, a small circulation is formed when the surrounding air rushes in to fill the area of the rising warm air. This warm ascending air carries dust, sand, leaves, and other small material to a height of a few hundred feet.

REVIEW QUESTIONS

Q5-6. Name one way that smoke is distinguished from haze.

Q5-7. When and where are dust devils usually observed?

PHOTOMETEORS

LEARNING OBJECTIVE: Identify the characteristics of photometeors and describe the characteristics of light, reflection, and refraction.

Photometeors are any of a number of atmospheric phenomena that appear as luminous patterns in the sky. While they constitute a variety of fascinating optical phenomena, photometeors are not active elements; that is, they generally do not cause adverse weather. However, many are related to clouds that do cause adverse weather. Therefore, they help in describing the state of the atmosphere.

LIGHT

Light, acting in conjunction with some of the elements of the atmosphere, produces a variety of atmospheric phenomena, such as halos, coronas, mirages, rainbows, and crepuscular rays. This lesson discusses the theories of light and the resulting photometeors.

Light is the portion of the electromagnetic spectrum that can be detected by the human eye. It travels at the same speed as all other electromagnetic radiation (186,000 miles per second). However, the characteristics of light are considerably different from other regions of the electromagnetic spectrum because of the differences in wavelength and frequency.

Sources of Light

There are two sources of light—natural and artificial. Nearly all natural light is received from the Sun. Artificial light is light such as that produced by electric lamps, fires, or fluorescent tubes. Luminous bodies are those bodies that which produce their own light, such as the Sun and the stars. Illuminated or non luminous bodies are those bodies which merely reflect the light they receive and are therefore visible because of this reflection. The Moon is an example of an illuminated body.

Theory

When light is emitted from a source, waves of radiation travel in straight lines and in all directions. Dropping a pebble into a pool of water can see a simple example of motion, similar to that of radiation waves. The waves spread out in expanding circles; similarly, light waves spread out in all directions to form a sphere. The boundary formed by each wave is called a *wave front*. Lines, or rays, drawn from the light source to any point on one of these waves indicate the direction in which the wave fronts are moving. Light radiates from its source in all directions until absorbed or diverted by coming in contact with some substance or object.

Wavelength

The wavelength of a light wave is the distance from the crest of one wave to the crest of the following wave. Wavelength, frequency (the number of waves which pass a given point in a unit of time), and speed are related by the simple equation:

$$C = \lambda F$$

Where:

C = speed
λ = wavelength
F = frequency

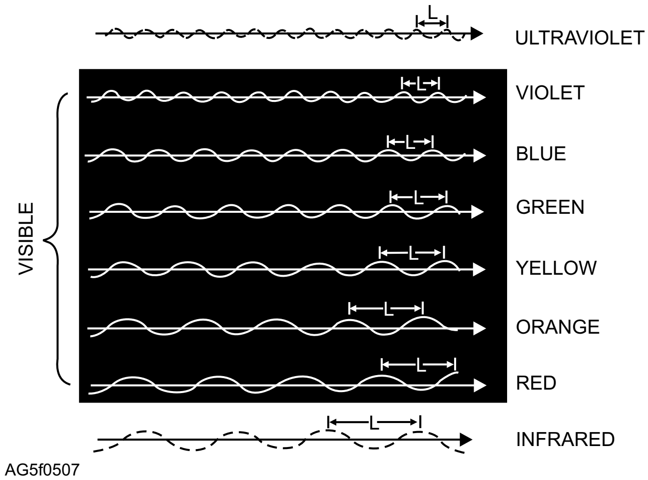


Figure 5-7.—Wavelength of various visible and invisible colors.

Because the speed of electromagnetic energy is constant, the frequency must increase if the wavelength decreases and vice versa.

Wavelength is measured in angstrom units (A). They may also be measured in millimicrons, or millionths of millimeters (mA). Figures 5-7 and 5-8 show the visible and invisible spectrum's colors in relation to their wavelengths. Figure 5-8 shows that the visible spectrum occupies only a small portion of the complete electromagnetic spectrum extending between 4,000 and 7,000 angstroms only.

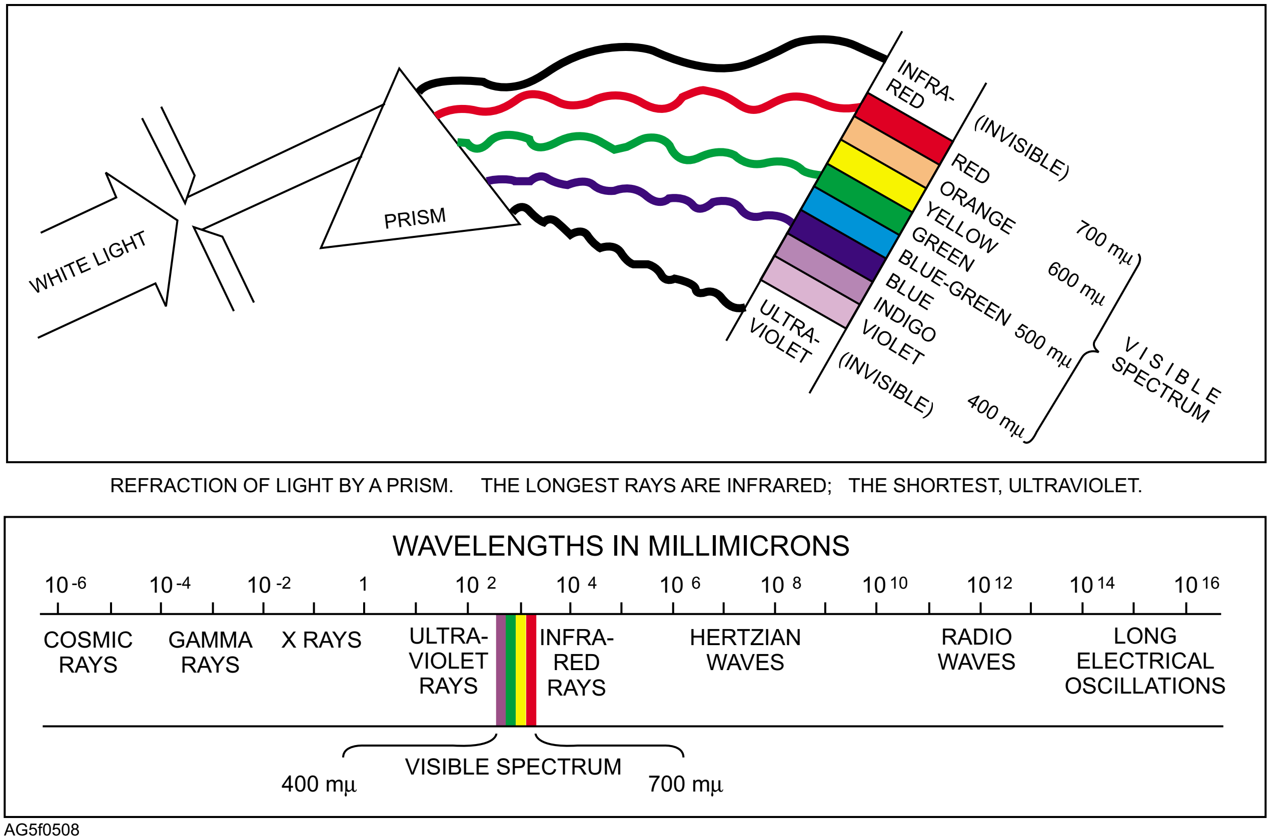


Figure 5-8.—Wavelengths and refraction.

Characteristics

When light waves encounter any substance, they are either reflected, absorbed, or refracted. (See fig. 5-9.) Substances that permit the penetration of clear vision through them and transmit almost all the light falling upon them, such as glass and air, are transparent. There is no known substance that is perfectly transparent, but many are nearly so. Those substances that allow the passage of part of the light but appear clouded and impair vision substantially, such as frosted light bulbs, are considered translucent. Those substances that do not transmit any light are termed opaque.

All objects that are not light sources are visible only because they reflect all or some part of the light reaching them from a luminous source. If light is neither refracted nor reflected, it is absorbed or taken up by the medium. When light strikes a substance, some absorption and some reflection always takes place. No substance completely refracts (transmits), reflects, or absorbs all the light that reaches its surface. Figure 5-9 illustrates this refraction, absorption, and reflection of light using a flat pane of glass.

Candlepower and Foot-candles

Illumination is the light received from a light source. The intensity of illumination is measured in foot-candles. A foot-candle is the amount of light falling upon a 1-square-foot surface, which is 1 foot away from a 1-candlepower light source.

REFLECTION

The term *reflected light* refers to those light waves that are neither transmitted nor absorbed but are thrown back from the surface of the medium they encounter. If a ray of light is directed against a mirror, the light ray that strikes the surface is called the *incident ray;* the one that bounces off is the *reflected ray* (see fig. 5-10). The imaginary line perpendicular to the mirror at the point where the ray strikes is the *normal.* The angle between the incident ray and the normal is the *angle of incidence.* The angle between the reflected ray and the normal is the *angle of reflection.*

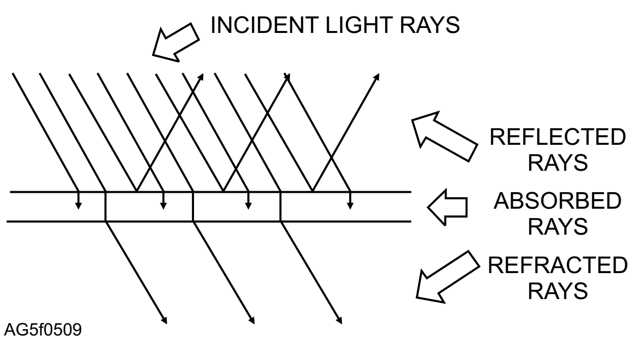


Figure 5-9.—Light rays reflected, absorbed, and refracted.

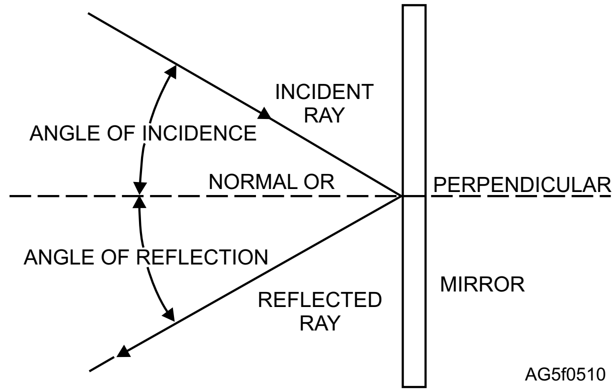


Figure 5-10.—Terms used to describe the reflection of light.

If the surface of the medium contacted by the incident light ray is smooth and polished, such as a mirror, the reflected light is thrown back at the same angle to the surface as the incident light. The path of the light reflected from the surface forms an angle exactly equal to the one formed by its path in reaching the medium. This conforms to the law of reflection, which states that the angle of incidence is equal to the angle of reflection.

Reflection from a smooth-surfaced object presents few problems. It is a different matter, however, when a rough surface reflects light. The law of reflection still holds but because the surface is uneven, the angle of incidence is different for each ray of light. The reflected light is scattered in all directions as shown in figure 5-11 and is called irregular or diffused light.

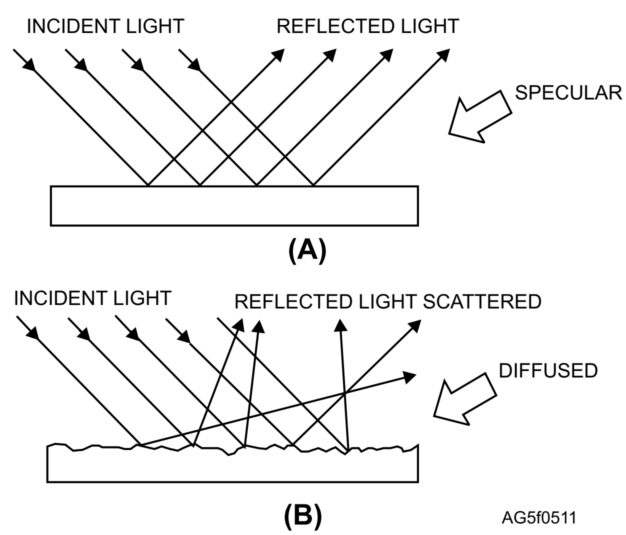


Figure 5-11.—Reflected light. (A) Regular (specular); (B) Irregular (diffused).

REFRACTION

The change of direction that occurs when a ray of light passes at an oblique angle (less than 90°) from one transparent substance *into* another substance of different density is called refraction. Refraction occurs because light travels at various speeds in different transparent substances of different densities. The greater the density of a substance, the slower the light travels through it.

Refraction (or change of direction) always follows a simple rule: when the light ray passes from one transparent substance into another of greater density, refraction is toward the normal. In this context, the normal means a line perpendicular to the surface of the medium at the point of entrance of the light ray. (See fig. 5-12.) In passing from one transparent substance into another of lesser density, refraction is away from the normal. (See fig. 5-13.)

When a ray of light enters a denser medium at an angle of 90°, as shown in figure 5-14, the wave fronts slow down but remain parallel. When this same light ray enters a *denser* medium at an oblique angle, the portion of the wave front that first enters the water moves slower than the other part of the wave front that is still in the air. Consequently, the ray bends toward the normal. (See fig. 5-12).

If the light ray enters a *less dense* medium at an oblique angle, the ray bends away from the normal as shown in figure 5-13. The portion of the wave front that enters the less dense substance travels faster than the other part of the wave front. Consequently, the ray bends away from the normal.

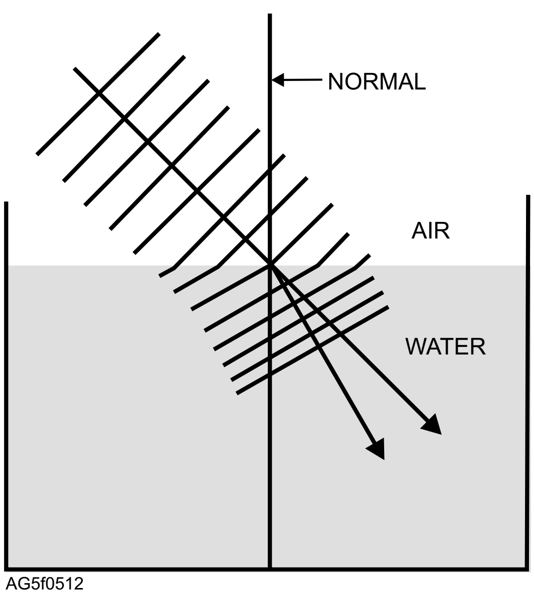


Figure 5-12.—Wave front diagram illustrating refraction of light at an air-water boundary. Ray is entering a more dense substance.

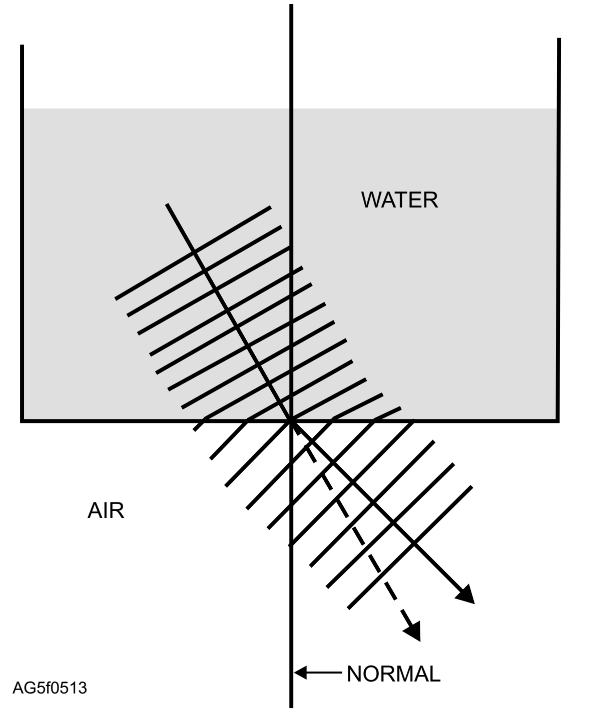


Figure 5-13.—Wave front diagram illustrating refraction of light at an air-water boundary. Ray is entering a less dense substance.

When a beam of white light is passed through a prism, as shown in figure 5-8, it is refracted and dispersed into its component wavelengths. Each of these wavelengths reacts differently on the eye, which then sees the various colors that compose the visible spectrum.

The visible spectrum ranges in color from violet at one end to red at the other end. (See fig. 5-8.) There are

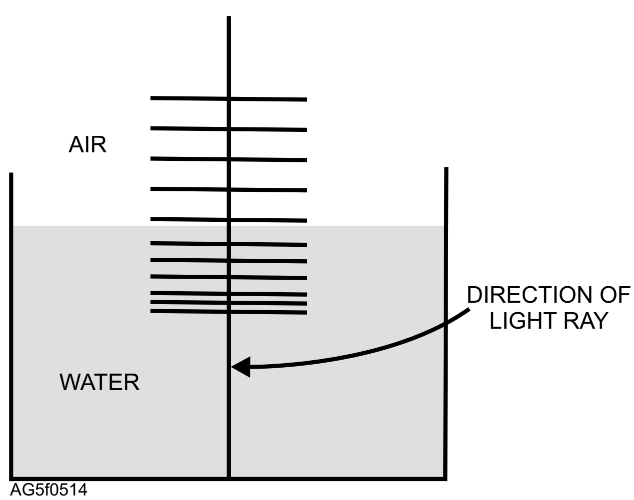


Figure 5-14.—Wave front diagram illustrating the difference in the speed of light in air and water.

six distinct colors in the spectrum: red, orange, yellow, green, blue, and violet. However, a mixture of these colors is also present.

ATMOSPHERIC OPTICAL PHENOMENA

LEARNING OBJECTIVE: Identify the characteristics of atmospheric optical phenomena (halos, coronas, rainbows, fogbows, mirages, looming, scintillation and crepuscular rays).

ATMOSPHERIC LAWS

Atmospheric optical phenomena are those phenomena of the atmosphere that can be explained in terms of optical laws. Some of the atmospheric elements, such as moisture, serve as a prism to break a light source down into its various component colors. The resulting phenomena can be spectacular as well as deceptive.

Halos

A halo is a luminous ring around the Sun or Moon. When it appears around the Sun, it is a solar halo; when it forms around the Moon, it is a lunar halo. It usually appears whitish (caused by reflection), but it may show the spectral colors, from refraction (red, orange, yellow, green, blue, indigo, and violet) with the red ring on the inside and the violet ring on the outside. The sky is darker inside the ring than outside. Halos are formed by *refraction* of light as it passes through ice crystals. This means that halos are almost exclusively associated with cirriform clouds. Refraction of light means that the light passes through prisms; in this case, ice crystals act as prisms. Some reflection of light also takes place.

Halos appear in various sizes, but the most common size is the small 22-degree halo. The size of the halo can be determined visually with ease. Technically, the radius of the 22-degree halo subtends an arc of 22°. This simply means that the angle measured from the observation point between the luminous body and the ring is 22°. Halos of other sizes are formed in the same manner.

Coronas

A corona is a luminous ring surrounding the Sun (solar) or Moon (lunar) and is formed by *diffraction* of light by water droplets. It may vary greatly in size but is usually smaller than a halo. All the spectral colors may be visible, with red on the outside, but frequently the inner colors are not visible. Sometimes the spectral colors or portions of them are repeated several times and are somewhat irregularly distributed. This phenomenon is called iridescence.

Rainbows

The rainbow is a circular arc seen opposite the Sun, usually exhibiting all the primary colors, with red on the outside. Diffraction, refraction, and reflection of light cause it from raindrops or spray, often with a secondary bow outside the primary one with the colors reversed.

Fogbows

A fogbow is a whitish circular arc seen opposite the Sun in fog. Its outer margin has a reddish tinge; its inner margin has a bluish tinge; and the middle of the band is white. An additional bow, with the colors reversed, sometimes appears inside the first.

Mirages

Mirages are images of objects that are made to appear displaced from their normal positions because of refraction. These images may be only a partial image of the object, and they may appear in either an upright or an inverted position, depending upon the atmospheric condition that exists at the time of observation. Mirages occur when adjacent layers of air have vastly different densities because of great temperature differences. Whether these layers exist side by side and horizontally or vertically determines the type of mirage.

Mirages are often seen in desert areas where air near the surface becomes very hot. Cool air overlies this hot layer resulting in a large difference in the densities of the two layers. Three types of mirages result from the refraction of light rays through layers of air with vastly different densities.

INFERIOR MIRAGE.—The inferior mirage, the most common of the three, appears as a mirrored image below the object being viewed by the observer. In this case, you can associate the word *inferior* with *beneath* or *below.*

SUPERIOR MIRAGE.—In the superior mirage, the mirrored image appears above the object being viewed. In this case, associate the word *superior* with *above* or *over.*

LATERAL MIRAGE.—Since the positions of above and below represent superior and inferior mirages respectively, the lateral mirage then appears to the side of the object being viewed.

Looming

Looming is similar to a mirage in that it brings into view objects that are over a distant horizon. Looming occurs when there is superrefraction in the lower atmosphere, which makes reflected light travel a path similar to the curvature of Earth. Objects over the horizon may be seen when light reflected from them takes this path. Looming is somewhat rare and is normally observed over flat surfaces, such as oceans and deserts.

Scintillation

Scintillation is caused by variations in atmospheric density near the horizon. It produces the appearance of rapid changes in the position, brightness, and color of distinct luminous objects, such as stars. Stars flickering and changing color near the horizon shortly after sunset are good examples of scintillation and are a reasonably common phenomenon.

Crepuscular Rays

Crepuscular rays are another common phenomena. They are simply sunbeams that are rendered luminous by haze and dust particles suspended in the atmosphere. They are seen before and after sunrise and sunset as they pass through small breaks or openings in or around clouds. The sunbeams are actually parallel but appear to diverge from the Sun.

REVIEW QUESTIONS

Q5-8. Name the two sources of light.

Q5-9. What is the difference between natural and artificial light?

Q5-10. What is the difference between reflection and refraction?

Q5-11. What is a mirage?

ELECTROMETEORS

LEARNING OBJECTIVE: Identify the characteristics of electrometeors (thunderstorms, lightning, auroras, and airglow).

An electrometeor is a visible or audible manifestation of atmospheric electricity. The more important electrometeors are thunderstorms, lightning, and auroras.

THUNDERSTORMS

The thunderstorm represents one of the most formidable weather hazards in temperate and tropical zones. Though the effects of the thunderstorm tend to be localized, the turbulence, high winds, heavy rain, and occasional hail accompanying the thunderstorm are a definite threat to the safety of flight operations and to the security of naval installations. The Aerographer's Mate must be acquainted with the structure of thunderstorms and the types of weather associated with them.

Formation

The thunderstorm represents a violent and spectacular atmospheric phenomenon. Lightning, thunder, heavy rain, gusty surface wind, and frequent hail usually accompany it. A certain combination of atmospheric conditions is necessary for the formation of a thunderstorm. These factors are conditionally unstable air of relatively high humidity and some type of lifting action. Before the air actually becomes unstable, it must be lifted to a point where it is warmer than the surrounding air. When this condition is brought about, the relatively warmer air continues to rise freely until, at some point aloft, its temperature has cooled to the temperature of the surrounding air. Some type of external lifting action must be introduced in order to raise the warm surface air to a point where it can rise freely. Many conditions satisfy this requirement; heating, terrain, fronts, or convergence may lift an air mass.

Structure

The fundamental structural element of the thunderstorm is the unit of convective circulation known as the convective cell. A mature thunderstorm contains several of these cells, which vary in diameter from 1 to 6 miles. By radar analysis and measurement of drafts, it has been determined that, generally, each cell is independent of surrounding cells of the same storm. Each cell progresses through a cycle, which lasts from 1 to 3 hours. In the initial stage (cumulus development), the cloud consists of a single cell, but as the development progresses, new cells form and older cells dissipate. The life cycle of the thunderstorm cell

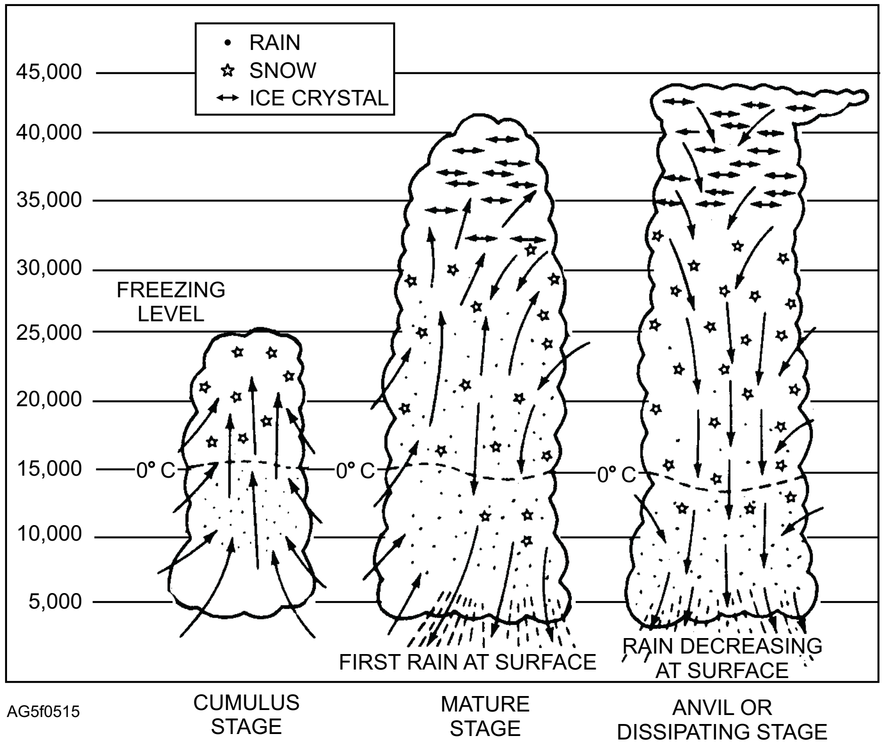


Figure 5-15.—Life cycle of a thunderstorm cell.

consists of three distinct stages; they are the cumulus. stage, the mature stage, and the dissipating or anvil stage. (See fig. 5-15.)

CUMULUS STAGE.—Although most cumulus clouds do not become thunderstorms, the initial stage of a thunderstorm is always a cumulus cloud. The chief distinguishing feature of this cumulus or building *stage is an updraft, which* prevails throughout the entire cell. Such updrafts vary from a few feet per second in the early cells to as much as 100 feet per second in mature cells.

MATURE STAGE.—The beginning of surface rain, with adjacent updrafts and downdrafts, initiates the mature stage. By this time the top of the average cell has attained a height of 25,000 feet or more. As the raindrops begin to fall, the frictional drag between the raindrops and the surrounding air causes the air to begin a downward motion. Since the lapse rate within a thunderstorm cell is greater than the moist adiabatic rate, the descending saturated air soon reaches a level where it is colder than its environment; consequently, its rate of downward motion is accelerated, resulting in a downdraft. (See fig. 5-16.)

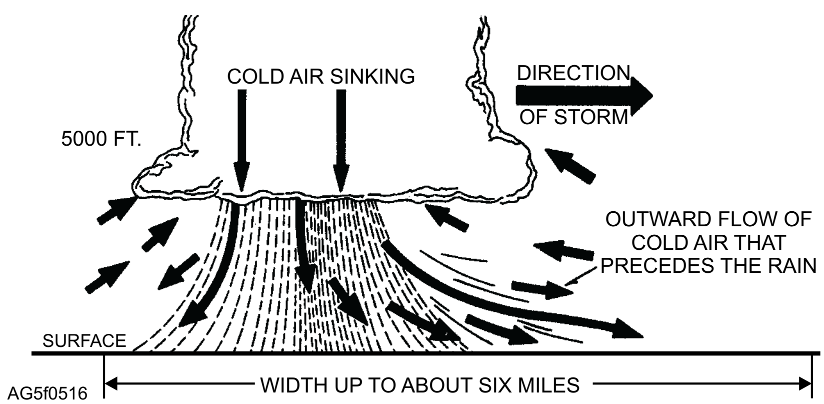


Figure 5-16.—Downdraft beneath a thunderstorm cell in the mature stage. Arrows represent wind flow. Dashed lines indicate rainfall.

A short time after the rain starts its initial fall, the updraft reaches its maximum speed. The speed of the updraft increases with altitude. Downdrafts are usually strongest at the middle and lower levels, although the variation in speed from one altitude to another is less than in the case of updrafts. Downdrafts are not as strong as updrafts; downdraft speeds range from a few feet per second to 40 feet per second or more. Significant downdrafts seldom extend to the top of the cell because, in most cases, only ice crystals and snowflakes are present, and their rate of fall is insufficient to cause appreciable downdrafts.

The mature cell, then, generally extends far above 25,000 feet, and the lower levels consist of sharp updrafts and downdrafts adjacent to each other. Large water droplets are encountered suspended in the updrafts and descending with the downdrafts as rain.

DISSIPATING (ANVIL) STAGE.—Throughout the life span of the mature cell, the falling raindrops are dragging down more and more air aloft. Consequently, the downdraft spreads out to take the place of the dissipating updraft. As this process progresses, the entire lower portion of the cell becomes an area of downdraft. Since this is an unbalanced situation and since the descending motion in the downdraft effects a drying process, the entire structure begins to dissipate. The high winds aloft have now carried the upper section of the cloud into the anvil form, indicating that gradual dissipation is overtaking the storm cell.

Vertical Development

Thunderstorms have been accurately measured as high as 67,000 feet and some severe thunderstorms attain an even greater height. More often the maximum height is from 40,000 to 45,000 feet. In general, air-mass thunderstorms extend to greater heights than do frontal storms.

Rising and descending drafts of air are, in effect, the structural bases of the thunderstorm cell. A draft is a large-scale vertical current of air that is continuous over many thousands of feet of altitude. Downdraft speeds are either relatively constant or gradually varying from one altitude to the next. Gusts, on the other hand, are smaller scaled discontinuities associated with the draft proper. A draft may be compared to a great river flowing at a fairly constant rate, whereas a gust is comparable to an eddy or any other random motion of water within the main current.

Thunderstorm Weather

The hydrometeors and turbulence of a thunderstorm that we observe and record at the surface are easily recognized. The weather within the thundercloud itself is another story. Visual observations from aircraft are difficult because of the speed with which they pass through the thunderclouds, and man has yet to devise an instrument that will measure all hydrometeors in the cloud. Let us look at those forms of precipitation turbulence and icing occurring with and within thunderclouds as we know them today.

RAIN.—Liquid water in a storm may be ascending if encountered in a strong updraft; it may be suspended, seemingly without motion, yet in an extremely heavy concentration; or it may be falling to the ground. Rain, as normally measured by surface instruments, is associated with the downdraft. This does not preclude the possibility of a pilot entering a cloud and being swamped, so to speak, even though rain has not been observed from surface positions. Rain is found in almost every case below the freezing level. In instances in which no rain is encountered, the storm probably has not developed into the mature stage. Statistics show that although heavy rain is generally reported at all levels of a mature storm, the greatest incidence of heavy rain occurs in the middle and lower levels of a storm.

HAIL.—Hail, if present, is most often found in the mature stage. Very seldom is it found at more than one or two levels within the same storm. When it is observed, its duration is short. The maximum occurrence is at middle levels for all intensities of hail.

SNOW.—The maximum frequency of moderate and heavy snow occurs several thousand feet above the freezing level. Snow, mixed, in many cases, with supercooled rain, may be encountered in updraft areas at all altitudes above the freezing level. This presents a unique icing problem: wet snow packed on the leading edge of the wing of the aircraft resulting in the formation of rime ice.

TURBULENCE.—There is a definite correlation between turbulence and precipitation. The intensity of associated turbulence, in most cases, varies directly with the intensity of the precipitation.

ICING.—Icing may be encountered at any level where the temperature is below freezing. Both rime and clear ice occur, with rime predominating in the regions of snow and mixed rain and snow. Since the freezing level is also the zone of greatest frequency of heavy turbulence and generally heavy rainfall, this particular altitude appears to be the most hazardous for aircraft.

SURFACE WIND.—A significant hazard associated with thunderstorm activity is the rapid change in surface wind direction and speed immediately before storm passage. The strong winds at the surface accompanying thunderstorm passage are the result of the horizontal spreading out of downdraft current from within the storm as they approach the surface of Earth.

The total wind speed is a result of the downdraft divergence plus the forward velocity of the storm cell. Thus, the speeds at the leading edge, as the storm approaches, are greater than those at the trailing edge. The initial wind surge, as observed at the surface, is known as the *first gust.*

The speed of the first gust is normally the highest recorded during storm passage, and the direction may vary as much as 180° from the previously prevailing surface wind. First-gust speeds increase to an average of about 16 knots over prevailing speeds, although gusts of over 78 knots (90 mph) have been recorded. The average change of wind direction associated with the first gust is about 40°.

In addition to the first gust, other strong, violent, and extremely dangerous downdraft winds are associated with the thunderstorm. These winds are referred to as *downbursts*. Downbursts are subdivided into *macrobursts* and *microbursts*.

Macrobursts.—Macrobursts are larger scale downbursts. Macrobursts can cause widespread damage similar to tornadoes. These damaging winds can last *5* to 20 minutes and reach speeds of 130 knots (150 mph) or more.

Microbursts.—Microbursts are smaller scale downbursts. A microburst can last 2 to 5 minutes and can also reach wind speeds in excess of 130 knots. Microbursts produce dangerous tailwinds or crosswinds and wind shear for aircraft and are difficult to observe or forecast.

Downbursts are not the same as first gusts. First gusts occur in all convective cells containing showers and are predictable and expected. Downbursts, however, do not occur in all convective cells and thunderstorms.

Classifications

All thunderstorms are similar in physical makeup, but for purposes of identification, they may be divided into two general groups, frontal thunderstorms and air-mass thunderstorms.

FRONTAL.—Frontal thunderstorms are commonly associated with both warm and cold fronts. The warm-front thunderstorm is caused when warm, moist, unstable air is forced aloft over a colder, denser shelf of retreating air. Warm-front thunderstorms are generally scattered; they are usually difficult to identify because they are obscured by other clouds.

The cold-front thunderstorm is caused by the forward motion of a wedge of cold air, into a body of warm, moist unstable air. Cold-front storms are normally positioned aloft along the frontal surface in what appears to be a continuous line.

Under special atmospheric conditions, a line of thunderstorms develops ahead of a cold front. This line of thunderstorms is the prefrontal squall line. Its distance ahead of the front ranges from 50 to 300 miles. Prefrontal thunderstorms are usually intense and appear menacing. Bases of the clouds are very low. Tornadoes sometimes occur when this type of activity is present.

AIR MASS.—Air-mass thunderstorms are subdivided into several types. In this text, however, only two basic types are discussed, the convective thunderstorm and the Orographic thunderstorm.

Convective.—Convective thunderstorms may occur over land or water almost anywhere in the world. Their formation is caused by solar heating of various areas of the land or sea, which, in turn, provides heat to the air in transit. The land type of convective thunderstorm normally forms during the afternoon hours after Earth has gained maximum heating from the Sun. If the circulation is such that cool, moist, convective, unstable air is passing over the land area, heating from below causes convective currents and results in towering cumulus or thunderstorm activity. Dissipation usually begins during the early evening hours. Storms that occur over bodies of water form in the same manner, but at different hours. Sea storms usually form during the evening after the Sun has set and dissipate during the late morning.

Both types of convective thunderstorms occur in Florida. The anticyclonic circulation around the Bermuda high advects moist air over the land surface of Florida in its easterly flow. Thunderstorms off the East Coast of Florida at night occur when this easterly flow passes over the warm axis of the Florida current. In those areas where the air is cooler than the water below it, the air is heated and convective currents (lifting) begin. Any nocturnal cooling of the easterly flow aloft aids in establishing the unstable lapse rate necessary for thunderstorm development. After sunrise, the air is heated and becomes warmer than the water, thereby destroying the balance necessary to sustain or build similar storms. As the day progresses, the land surface becomes considerably warmer than the air. Convective currents again result, and Florida’s common afternoon thunderstorms are observed. After sunset the land cools, convective currents cease, and the thunderstorms dissipate. The apparent movement of the storms to sea at night, and to shore during the day, is in reality the reformation of storms in their respective areas. As a general rule, convective thunderstorms are scattered and easily recognized. They build to great heights, and visibility is generally excellent in the surrounding area.

Orographic.—Orographic thunderstorms form in mountainous regions, particularly adjacent to individual peaks. A good example of this type of storm occurs in the northern Rocky Mountain region. When the circulation of the air is from the west, moist air from the Pacific Ocean is transported to the mountains where it is forced aloft by the upslope of the terrain. If the air is conditionally unstable, this upslope motion causes thunderstorm activity on the windward side of the mountains. This activity may form a long, unbroken line of storms similar to a cold front. The storms persist as long as the circulation causes an upslope motion. They tend to be more frequent during afternoon and early evening when convective lifting coincides with the mechanical lifting of the terrain.

LIGHTNING

Lightning is obviously the most spectacular of electrometeors and is directly related to the thunderstorm even though classified independently. It is the bright flash of light accompanying a sudden electrical discharge. Most lightning has its beginning in clouds; however, it generates from high structures on the ground and mountains, although much less frequently.

The thunderstorm changes the normal electric field, in which the ground is negatively charged with respect to the air above it. Because the upper portion of the thunderstorm cloud is positive and the lower part is negative, the negative charge induces a positive charge on the ground. The distribution of the electric charges in a typical thunderstorm is shown in figure 5-17. The

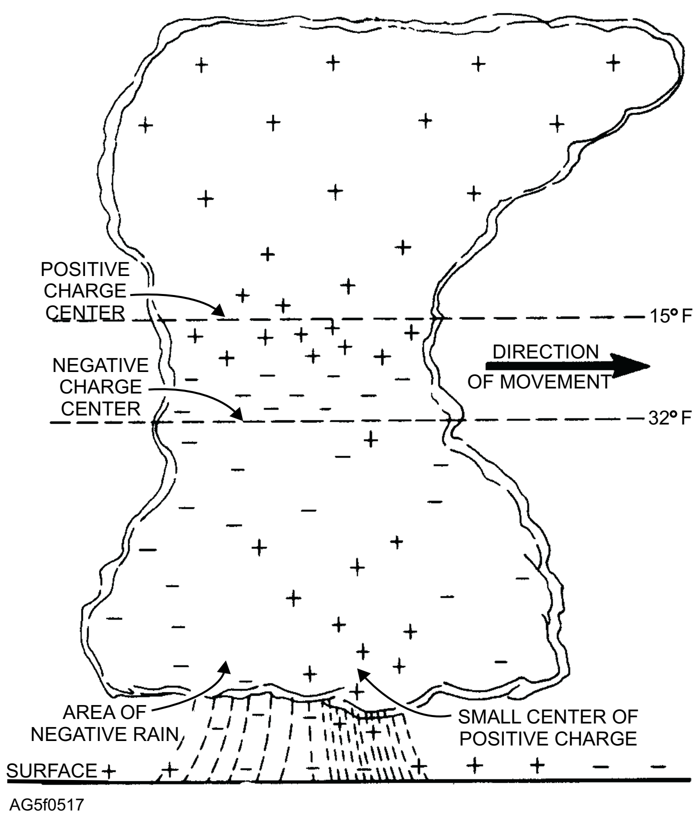


Figure 5-17.—Location of electric charges inside a typical thunderstorm cell.

lightning first occurs between the upper positive charge area and the negative charge area immediately below it. Lightning discharges are considered to occur most frequently in the area bracketed roughly by the 32°F and the 15°F temperature levels. However, this does not mean that all discharges are confined to this region; as the thunderstorm develops, lightning discharges may occur in other areas and from cloud to cloud, as well as from cloud to ground.

There are four main types of lightning. All can do considerable damage to aircraft, especially to radio equipment.

1. Cloud To Ground Lightning (CG). Lightning occurring between cloud and ground.

2. Cloud Discharges (IC). Lightning taking place within the cloud.

3. Cloud To Cloud Discharges (CC). Streaks of lightning reaching from one cloud to another.

4. Air Discharges (CA). Streaks of lightning passing from a cloud to the air that do not strike the ground.

AURORAS

Auroras are luminous phenomena, which appear in the high atmosphere in the form of arcs, bands, draperies, or curtains. These phenomena are usually white but may have other colors. The lower edges of the arcs or curtains are usually well defined while the upper edges are not. Polar auroras are caused by electrically charged particles, ejected from the Sun, which act on the rarefied (select) gases of the higher atmosphere. The particles are channeled by Earth's magnetic field, so auroras are observed mainly near the magnetic poles. In the Northern Hemisphere they are known as aurora borealis; in the Southern Hemisphere they are known as aurora australis.

AIRGLOW

Airglow is similar in origin and nature to the aurora; it, too, is an upper atmospheric electrical phenomenon. The main differences between airglow and aurora are that airglow is quasi-steady (quasi means seemingly) in appearance, is much fainter than aurora, and appears in the middle and lower altitudes.

REVIEW QUESTIONS

Q5-12. What is the diameter range of a mature thunderstorm cell?

Q5-13. During what stage of a thunderstorm is rain observed at the surface?

Q5-14. What is the difference between a macroburst and a microburst?

Q5-15. Describe the two different types of thunderstorms?

CHAPTER 6

CLIMATOLOGY AND WORLD WEATHER

One of the major tasks of the Aerographer's Mate and the Naval Meteorology and Oceanography Command is providing long-range weather information and predictions based on recognized meteorological occurrences in a particular area or region of the world. Naval exercises both at sea and ashore is planned months and sometimes years in advance. To carry out these exercises successfully, we must have an idea of the normal weather conditions for the operational area (OPAREA) at that time of year. It is both dangerous and unwise to conduct costly training exercises if the weather conditions for the OPAREA are known to be adverse at that time of year.

During wartime, an extensive knowledge of weather conditions can be a decisive advantage. Naval and land forces can use their knowledge of weather to surprise the enemy and predict when the enemy will strike. Historically, man wages war when the weather permits. When Napoleon invaded Russia, his defeat was not due to the wisdom of his opponents, but rather to his lack of knowledge of the severe Russian winters. He was beaten by the weather.

As you gain more experience, your job will include the preparation of long-range weather forecasts based on climatological studies. You must prepare charts, tables and/or graphs that include sky cover, temperatures, winds, sea conditions, etc. This climatological information is needed for long-range naval exercises, ship deployments overseas, and actual combat operations.

CLIMATE AND CLIMATOLOGY

LEARNING OBJECTIVE: Define climate, climatology, and related terminology.

Before starting any discussion about climate and climatology, we must become familiar with these and other related terms. In this lesson, we define climate, various types of climatology, and climatology as it relates to other sciences such as ecology.

CLIMATE

Climate is the average or collective state of Earth's atmosphere at any given location or area over a long period of time. While weather is the sum total of the atmosphere's variables for a relatively short period of time, the climate of an area is determined over periods of many years and represents the general weather characteristics of an area or locality. The term *climate* applies to specific regions and is therefore highly geographical.

CLIMATOLOGY

Climatology is the scientific study of climate and is a major branch of meteorology. Climatology is the tool that is used to develop long-range forecasts. There are three principal approaches to the study of climatology: physical, descriptive, and dynamic.

Physical Climatology

The physical climatology approach seeks to explain the differences in climate in light of the physical processes influencing climate and the processes producing the various kinds of physical climates, such as marine, desert, and mountain. Physical climatology deals with explanations of climate rather than with presentations.

Descriptive Climatology

Descriptive climatology typically orients itself in terms of geographic regions; it is often referred to as regional climatology. A description of the various types of climates is made on the basis of analyzed statistics from a particular area. A further attempt is made to describe the interaction of weather and climatic elements upon the people and the areas under consideration. Descriptive climatology is presented by verbal and graphic description without going into causes and theory.

Dynamic Climatology

Dynamic climatology attempts to relate characteristics of the general circulation of the entire atmosphere to the climate. Dynamic climatology is used by the theoretical meteorologist and addresses dynamic and thermodynamic effects.

Climatology as Related to Other Sciences

Three prefixes can be added to the word *climatology* to denote scale or magnitude. They are micro, meso, and macro and indicate small, medium, and large scales, respectively. These terms (micro, meso, and macro) are also applied to meteorology.

MICROCLIMATOLOGY.—Microclimatological studies often measure small-scale contrasts, such as between hilltop and valley or between city and surrounding country. They may be of an extremely small scale, such as one side of a hedge contrasted with the other, a plowed furrow versus level soil, or opposite leaf surfaces. Climate in the microscale may be effectively modified by relatively simple human efforts.

MESOCLIMATOLOGY.—Mesoclimatology embraces a rather indistinct middle ground between macroclimatology and microclimatology. The areas are smaller than those of macroclimatology are and larger than those of microclimatology, and they may or may not be climatically representative of a general region.

MACROCLIMATOLOGY.—Macroclimatology is the study of the large-scale climate of a large area or country. Climate of this type is not easily modified by human efforts. However, continued pollution of the Earth, its streams, rivers, and atmosphere, can eventually make these modifications.

Climate has become increasingly important in other scientific fields. Geographers, hydrologists, and oceanographers use quantitative measures of climate to describe or analyze the influence of our atmospheric environment. Climate classification has developed primarily in the field of geography. The basic role of the atmosphere in the *hydrologic cycle* is an essential part of the study of hydrology. Both air and water measurements are required to understand the energy exchange between air and ocean (heat budget) as examined in the study of oceanography.

ECOLOGY

Ecology is the study of the mutual relationship between organisms and their environment. Ecology is briefly mentioned here because the environment of living organisms is directly affected by weather and climate, including those changes in climate that are gradually being made by man.

During our growing years as a nation, our interference with nature by diverting and damming rivers, clearing its lands, stripping its soils, and scarring its landscape has produced changes in climate. These changes have been on the micro and meso scale and possibly even on the macro scale.

REVIEW QUESTIONS

Q6-1. What is the definition of climate?

Q6-2. What type of climatology is typically oriented to a geographic region?

Q6-3. What type of climatology applies to a small area such as a golf course or a plowed field?

CLIMATIC ELEMENTS

LEARNING OBJECTIVE: Describe the climatic elements of temperature, precipitation, and wind.

The weather elements that are used to describe climate are also the elements that determine the type of climate for a region. This lesson presents a brief explanation of the importance of these elements. The climatic elements of temperature, precipitation, and wind are not the only parameters included in a climatology package; however, they are the most significant elements used to express the climate of a region.

TEMPERATURE

Temperature is undoubtedly the most important climatic element. The temperature of an area is dependent upon latitude or the distribution of incoming and outgoing radiation; the nature of the surface (land or water); the altitude; and the prevailing winds. The air temperature normally used in climatology is that recorded at the surface.

Moisture, or the lack of moisture, modifies temperature. The more moisture in a region, the smaller the temperature range, and the drier the region, the greater the temperature range. Moisture is also influenced by temperature. Warmer air can hold more moisture than can cooler air, resulting in increased evaporation and a higher probability of clouds and precipitation.

Moisture, when coupled with condensation and evaporation, is an extremely important climatic element. It ultimately determines the type of climate for a specific region.

PRECIPITATION

Precipitation is the second most important climatic element. In most studies, precipitation is defined as water reaching Earth's surface by falling either in a liquid or a solid state. The most significant forms are rain and snow. Precipitation has a wide range of variability over the Earth's surface. Because of this variability, a longer series of observations is generally required to establish a mean or an average. Two stations may have the same amount of annual precipitation, but it could occur in different months or on different days during these months, or the intensity could vary. Therefore, it often becomes necessary to include such factors as average number of days with precipitation and average amount per day. Precipitation is expressed in most studies in the United States in inches, but throughout the rest of the world, millimeters are normally used.

Since precipitation amounts are directly associated with amount and type of clouds, cloud cover must also be considered with precipitation. Cloud climatology also includes such phenomena as fog and thunderstorms.

WIND

Wind is the climatic element that transports heat and moisture into a region. The climate of an area is often determined by the properties of temperature and moisture that are found upstream of that region.

Climatologists are mostly interested in wind with regard to its direction, speed, and gustiness. Wind is therefore usually discussed in terms of *prevailing* direction, average speeds, and maximum gusts. Some climatological studies use *resultant* wind, which is the vectorial average of all wind directions and speeds for a given level, at a specific place, and for a given period.

REVIEW QUESTIONS

Q6-4. What is the most important climatic element?

Q6-5. Which climatic element transports heat and moisture into a region?

EXPRESSION OF CLIMATIC ELEMENTS

LEARNING OBJECTIVE: Define the terms used to express climatic elements and the methods used to derive these terms.

Climatic elements are observed over long periods of time; therefore, specific terms must be used to express these elements so they have definite meaning. This lesson defines the most commonly used terms and discusses how they are used to express climatic elements.

MEAN (AVERAGE)

The mean is the most commonly used climatological parameter. The term *mean* normally refers to a mathematical averaging obtained by adding the values of all factors or cases and then dividing by the number of items. For example, the average daily temperature would be the sum of the hourly temperatures divided by 24.

Other methods are used for computing various meteorological elements. For example, the mean temperature for 1 day has been devised by simply adding the maximum and minimum values for that day and dividing by 2. Assume the maximum temperature for a certain day is 75°F and the minimum temperature is 57°F. The mean temperature for the day is 66°F.

Unfortunately, the term *mean* has been used in many climatological records without clarification as to how it was computed. In most cases, the difference in results obtained is slight. In analyzing weather data, the terms *average* and *mean* are often used interchangeably.

NORMAL

In climatology, the term *normal* is applied to the average value over a period of time, which serves as a standard with which values (occurring on a date or during a specified time) may be compared. These periods of time may be a particular month or other portion of the year. They may refer to a season or to a year as a whole. The normal is usually determined over a 20- or 30-year period.

For example, if the average temperature for your station on 10 June has been 80°F over a specified period of time, the *normal* temperature for your station on 10 June is 80°F. If the temperature on 10 June this year was only 76°F, then the temperature for that day is 4°F below normal.

ABSOLUTE

In climatology, the term *absolute* is usually applied to the *extreme* highest and lowest values for any given meteorological element recorded at the place of observation and are most frequently applied to temperature. Assume, for example, that the extreme highest temperature ever recorded at a particular station was 106°F and the lowest recorded was -15°F. These values are called the absolute maximum and absolute minimum, respectively.

EXTREME

The term *extreme* is applied to the highest and lowest values for a particular meteorological element occurring over a period of time. This period of time is usually a matter of months, seasons, or years. The term may be used for a calendar day only, for which it is particularly applicable to temperature. For example, the highest and lowest temperature readings for a particular day are considered the temperature extremes for that day. At times the term is applied to the average of the highest and lowest temperatures as mean monthly or mean annual extremes.

RANGE

Range is the *difference* between the highest and lowest values and reflects the extreme variations of these values. This statistic is not recommended for precise work, since it has a high variability. Range is related to the extreme values of record and can be useful in determining the extreme range for the records available. For example, if the highest temperature recorded yesterday was 76°F and the lowest was 41°F, then the range for the day was 35°F.

FREQUENCY

Frequency is defined as the number of times a certain value occurs within a specified period of time. When a large number of various values need to be presented, a condensed presentation of data may be obtained by means of a frequency distribution.

MODE

Mode is defined as the value occurring with the greatest frequency or the value about which the most cases occur.

MEDIAN

The median is the value at the midpoint in an array. In determining the median, all values are arranged in order of size. Rough estimates of the median may be obtained by taking the middle value of an ordered series; or, if there are two middle values, they may be averaged to obtain the median. The position of the median may be found by the following formula:

$$\text{Median} = \frac{n+1}{2}$$

where n is the number of items.

The median is not widely used in climatological computations. However, some sources recommend the use of the median instead of the mean or average for some climatic elements to present more representative pictures of distribution and probability. A longer period of record might be required to formulate an accurate median.

DEGREE-DAY

A degree-day is the number of degrees the mean daily temperature is above or below a standard temperature base. The base temperature is usually 65°F; however, any temperature, Celsius or Fahrenheit, can be used as a base. There is one degree-day for each degree (°C or °F) of departure above or below the standard.

Degree-days are accumulated over a *season*. At any point in the season, the total can be used as an index of past temperature effect upon some quantity, such as plant growth, fuel consumption, power output, etc. This concept was first used in connection with plant growth, which showed a relationship to cumulative temperature above a standard of 41°F. Degree-days are frequently applied to fuel and power consumption in the form of heating degree-days and cooling degree-days.

AVERAGE AND STANDARD DEVIATIONS

In the analysis of climatological data, it may be desirable to compute the deviation of all items from a central point. This can be obtained from a computation of either the mean (or average) deviation or the standard deviation. These are termed measures of dispersion and are used to determine whether the average is truly representative or to determine the extent to which data vary from the average.

Average Deviation

Average deviation is obtained by computing the arithmetic average of the deviations from an average of the data. First we obtain an average of the data, then the deviations of the individual items from this average are determined, and finally the arithmetic average of these deviations is computed. The plus and minus signs are disregarded. The formula for computation of the average deviation is as follows:

$$\text{Average deviation} = \frac{\Sigma d}{n}$$

where the Greek letter $\underline{\Sigma}$ (sigma) means the sum of $\underline{d}$ (the deviations) and $\underline{n}$ is the number of items.

Standard Deviation

The standard deviation, like the average deviation, is the measure of the scatter or spread of all values in a series of observations. To obtain the standard deviation, square each deviation from the arithmetic average of the data. Then, determine the arithmetic average of the squared deviations. Finally, derive the square root of this average. This is also called the root-mean-square deviation, since it is the square root of the mean of the deviations squared.

The formula for computing standard deviation is given as follows:

$$\text{Standard deviation} = \sqrt{\frac{\Sigma d^2}{n}}$$

where d^2 is the sum of the squared deviations from the arithmetic average, and $\underline{n}$ is the number of items in the group of data.

An example of the computations of average deviation and standard deviation is given in table 6-1 and in the following paragraphs.

Table 6-1.—Computation of Average and Standard Deviation

January year	Mean temperature	Deviations from mean	Deviations squared
1978	47	– 4	16
1979	51	+ 0	0
1980	53	+ 2	4
1981	50	– 1	1
1982	49	– 2	4
1983	55	+ 4	16
1984	46	– 5	25
1985	52	+ 1	1
1986	57	+ 6	36
1987	50	– 1	1
Totals **Mean**	510 51	26 2.6	104 3.2

Suppose, on the basis of 10 years of data (1978-1987), you want to compute the average deviation of mean temperature and the standard deviation for the month of January. First, arrange the data in tabular form (as in table 6-1). Given the year in the first column, the mean monthly temperature in the second column, the deviations from an arithmetic average of the mean temperature in the third column, and the deviations from the mean squared in the fourth column.

To compute the average deviation:

1. Add all the temperatures in column 2 and divide by the number of years (10 in this case) to get the arithmetic average of temperature.

2. In column 3, compute the deviation from the mean or average determined in step 1. (The mean temperature for the 10-year period was 51°F.)

3. Total column 3, disregarding the negative and positive signs. (Total is 26.)

4. Apply the formula for average deviation:

$$\frac{\Sigma d}{n} = \frac{26}{10} = 2.6°\text{F}$$

The average deviation of temperature during the month of January for the period of record, 10 years, is 2.6°F.

To compute the standard deviation:

1. Square the deviations from the mean (column 3).

2. Total these squared deviations. In this case, the total is 104.

3. Apply the formula for standard deviation:

$$\text{Standard deviation} = \sqrt{\frac{\Sigma d^2}{n}} = \sqrt{\frac{104}{10}}$$

$$\sqrt{10.4} = 3.225 \text{ or } 3.2°\text{F}$$

The standard deviation of temperature for the month and period in question is 3.2°F (rounded off to the nearest one-tenth of a degree).

From the standard deviation just determined, it is apparent that there is a small range of mean temperature during January. If we had a frequency distribution of temperature available for this station for each day of the month, we could readily determine the percentage of readings which would fall in the 6.4-degree spread (3.2 either side of the mean). From these data we could then formulate a probability forecast or the number of days within this range on which we could expect the normal or mean temperature to occur. This study could be broken down further into hours of the day, etc., as required.

REVIEW QUESTIONS

Q6-6. If one adds all the daily high temperatures for the week and divides by 7, what climatological parameter would be determined by this calculation?

Q6-7. A temperature of 124 degrees Fahrenheit was the highest temperature ever recorded at a particular station. What type of climatological parameter was determined?

Q6-8. What is a degree-day?

CLASSIFICATION OF CLIMATE

LEARNING OBJECTIVE: Recognize climatic zones and climatic types as they relate to the classification of climate.

The climate of a given region or locality is determined by a combination of several meteorological elements and not by just one element. For example, two regions may have similar temperature climates but very different precipitation climates. Their climatic difference, therefore, becomes apparent only if more than one climatic factor is considered.

Since the climate of a region is composed of all of the various climatic elements, such as dew, ice, rain, temperature, wind force, and wind direction, it is obvious that no two locations can have exactly the same climate. However, it is possible to group similar areas into what is known as a climatic zone.

CLIMATIC ZONES

The basic grouping of areas into climatic zones consists of classifying climates into five broad belts based on astronomical or mathematical factors. Actually they are zones of sunshine or solar climate and include the torrid or tropical zone, the two temperate zones, and the two polar zones. The tropical zone is limited on the north by the Tropic of Cancer and on the south by the Tropic of Capricorn, which are located at 23 1/2° north and south latitude, respectively. The Temperate Zone of the Northern Hemisphere is limited on the south by the Tropic of Cancer and on the north by the Arctic Circle located at 66 1/2° north latitude. The Temperate Zone of the Southern Hemisphere is bounded on the north by the Tropic of Capricorn and on the south by the Antarctic Circle located at 66 1/2° south latitude. The two polar zones are the areas in the Polar Regions which have the Arctic and Antarctic Circles as their boundaries.

Technically, climatic zones are limited by isotherms rather than by parallels of latitude (fig. 6-1). A glance at any chart depicting the isotherms over the surface of the earth shows that the isotherms do not coincide with latitude lines. In fact, at some places the isotherms parallel the longitude lines more closely than they parallel the latitude lines. The astronomical or light zones therefore differ from the zones of heat.

CLIMATIC TYPES

Any classification of climate depends to a large extent on the purpose of the classification. For instance, a classification for the purpose of establishing air stations where favorable flying conditions are important would differ considerably from one for establishing the limits of areas that are favorable for the growing of crops. There are three classifications that merit particular attention. They are the classifications of C. W. Thornthwaite, W. Köppen, and G. T. Trewartha.

Thornthwaite's classification of climates places a great deal of emphasis on the effectiveness of precipitation. Effectiveness of precipitation refers to the relationship between precipitation and evaporation at a certain locality. Thornthwaite classified climates into eight main climatic groups; five groups give primary emphasis to precipitation and the other three groups are based on temperature.

Köppen's classification includes five main climatic types. They are *tropical rain, dry, warm temperate rainy, cool snow forest (boreal*), and *polar* climates. These main types are further divided into climatic provinces. The Köppen classification is based mainly on temperature, precipitation amount, and season of maximum precipitation. Numerical values for these elements constitute the boundaries of the above types, which were selected primarily according to their effect on plant growth. Figure 6-2, shows Köppen's climatic types.

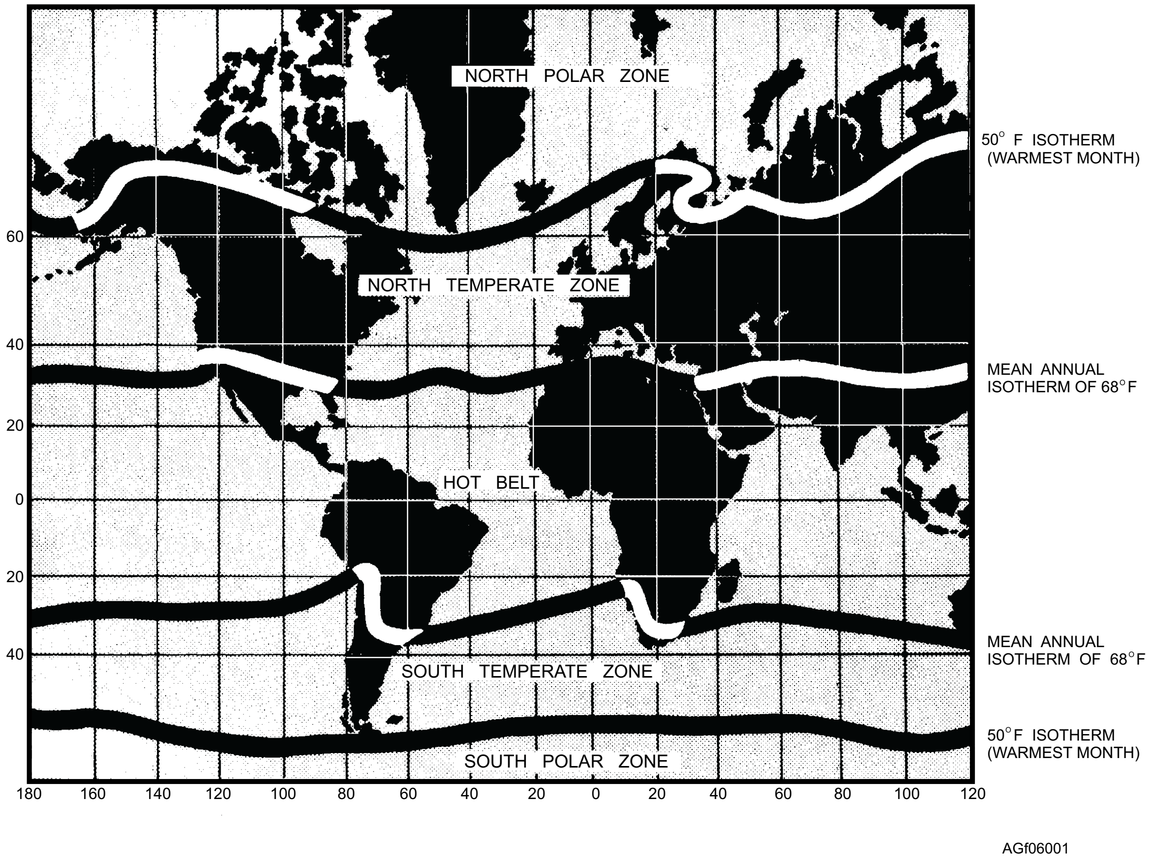


Figure 6-1.—Temperature zones.

Köppen's climatic types are still considered valid today. His climatic zones, like others, are by no means static. Climatic zones shift with long-range weather patterns. The most noticeable shifts in these climatic zones have been observed over the northern portions of North America and Asia and over Africa. Russia and Canada, for example, have been able to conduct farming at higher latitudes over the past 200 years due to milder temperatures. Recent studies, however, indicate a general return of cooler temperatures at high latitudes, and now the growing region is gradually moving southward again where temperatures are more moderate. In Africa, desert regions have made notable shifts southward due to decreasing precipitation.

Trewartha is the most recent classifier of climate. Initially, his climatic classifications were based on Köppen's; however, over the years, he has made significant changes and is now recognized for developing his own six climatic groups. These six groups are *tropical, dry, subtropical, temperate, boreal, and polar.* Five of these groups are based on temperature and one is based on precipitation (see Table 6-2). Trewartha's climatic groups, like Köppen's, are also further broken down into climatic types and subtypes.

REVIEW QUESTIONS

Q6-9. List the five climatic belts and their boundaries.

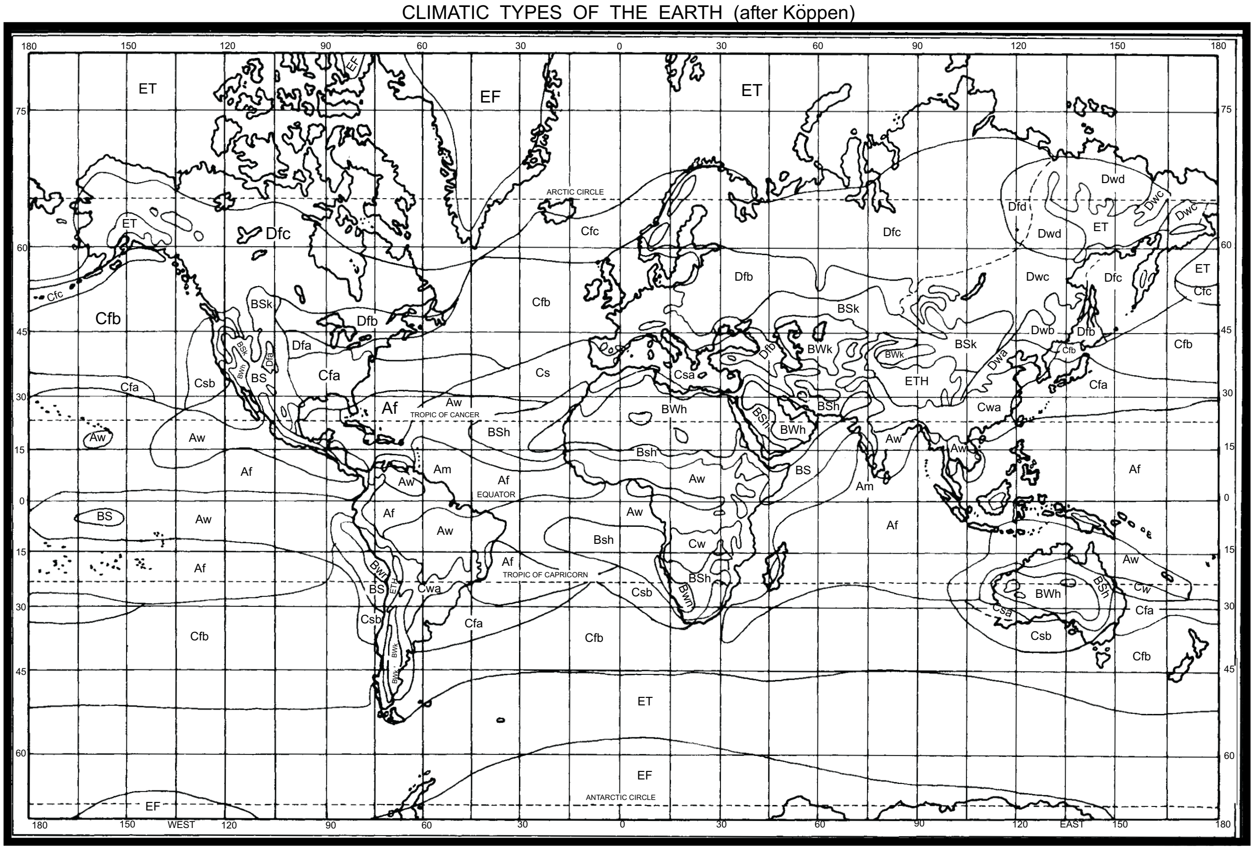
Q6-10. Name the three classifications of climatic types.

Q6-11. What are the five climatic types according to Köppen?

CLIMATIC CONTROLS

LEARNING OBJECTIVE: Identify the controlling factors that affect climate.

The variation of climatic elements from place to place and from season to season is due to several factors called climatic controls. The same basic factors that cause weather in the atmosphere also determine the



LEGEND TO CLIMATIC TYPES

A. TROPICAL RAINY CLIMATES
- Af TROPICAL RAIN FOREST CLIMATE
- Am TROPICAL MONSOON CLIMATE
- Aw TROPICAL SAVANNA CLIMATE

B. DRY CLIMATES
- BW DESERT CLIMATE
- BS STEPPE CLIMATE
- h Denotes a Hot B Climate
- k Denotes a Cool B Climate
- k' Denotes a Cold B Climate
- n Denotes a B Climate with Frequent Fog

C. WARM TEMPERATE RAINY CLIMATES
- Cs SUMMER-DRY
- Cw WINTER-DRY
- Cfa WITHOUT DRY SEASON, HOT SUMMERS
- Cfb WITHOUT DRY SEASON, WARM SUMMERS
- Cfc WITHOUT DRY SEASON, COOL SUMMERS

D. COOL SNOW-FOREST CLIMATES (BOREAL)
- Dfa, Dwa HOT SUMMERS
- Dfb, Dwb WARM SUMMERS
- Dfc, Dwc COOL SUMMERS
- Dfd, Dwd VERY COLD WINTERS
- w Denotes a Dry Season in Winter
- f Indicates the Absence of a Dry Season

E. POLAR CLIMATES
- ET TUNDRA CLIMATE
- EF FROST CLIMATE
- H Denotes Polar Climates E due to High Altitude

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Figure 6-2.—Köppen's climatic types.

Table 6-2.—Trewartha's Climatic Groups and their Poleward Boundaries

Basis for Classification	Climate Group	Poleward Boundary
Temperature	A. Tropical	Frost line over continents and 65°F (18°C) over oceans (coolest months)
Precipitation	B. Dry	Bounded by the outer limits where potential evaporation is equal to precipitation
Temperature	C. Subtropical	50°F (10°C) or above for 8 months of the year
Temperature	D. Temperature	50°F (10°C) or above for 4 months of the year
Temperature	E. Boreal	50°F (10°C) or above for 1 month (warmest month)
Temperature	F. Polar	Below 50°F (10°C) entire year

climate of an area. These controls, acting in different combinations and with varying intensities, act upon temperature, precipitation, humidity, air pressure, and wind to produce many types of weather and therefore climate.

Four climatic controls largely determine the climate of every ocean and continental region. These controls are latitude, land and water distribution, topography, and ocean currents. Another factor, which is now significant in determining a region's climate, is man. Man’s influence on climate through pollution, deforestation, and irrigation, is now considered a climatic factor.

LATITUDE

Perhaps no other climatic control has such a marked effect on climatic elements as does the latitude, or the position of Earth relative to the Sun. The angle at which rays of sunlight reach Earth and the number of *Sun* hours each day depends upon the distance of the Sun from the equator. (See fig. 6-3.) Therefore, the latitude directly influences the extent to which an air mass is heated. Latitude influences the sources and direction of air masses and the weather they bring with them into a region.

Comparing an equatorial area to a polar area can show the importance of latitude as a climatic control. In the former, the Sun is close to being directly overhead during the day throughout the year. Therefore, there is little difference between mean temperatures for the coldest and warmest months. In the polar area, however, the Sun never rises far above the horizon; that is, the angle of the Sun to Earth’s surface is always acute. The radiant energy received per unit area is therefore slight, and the warming effects of the Sun are relatively weak.

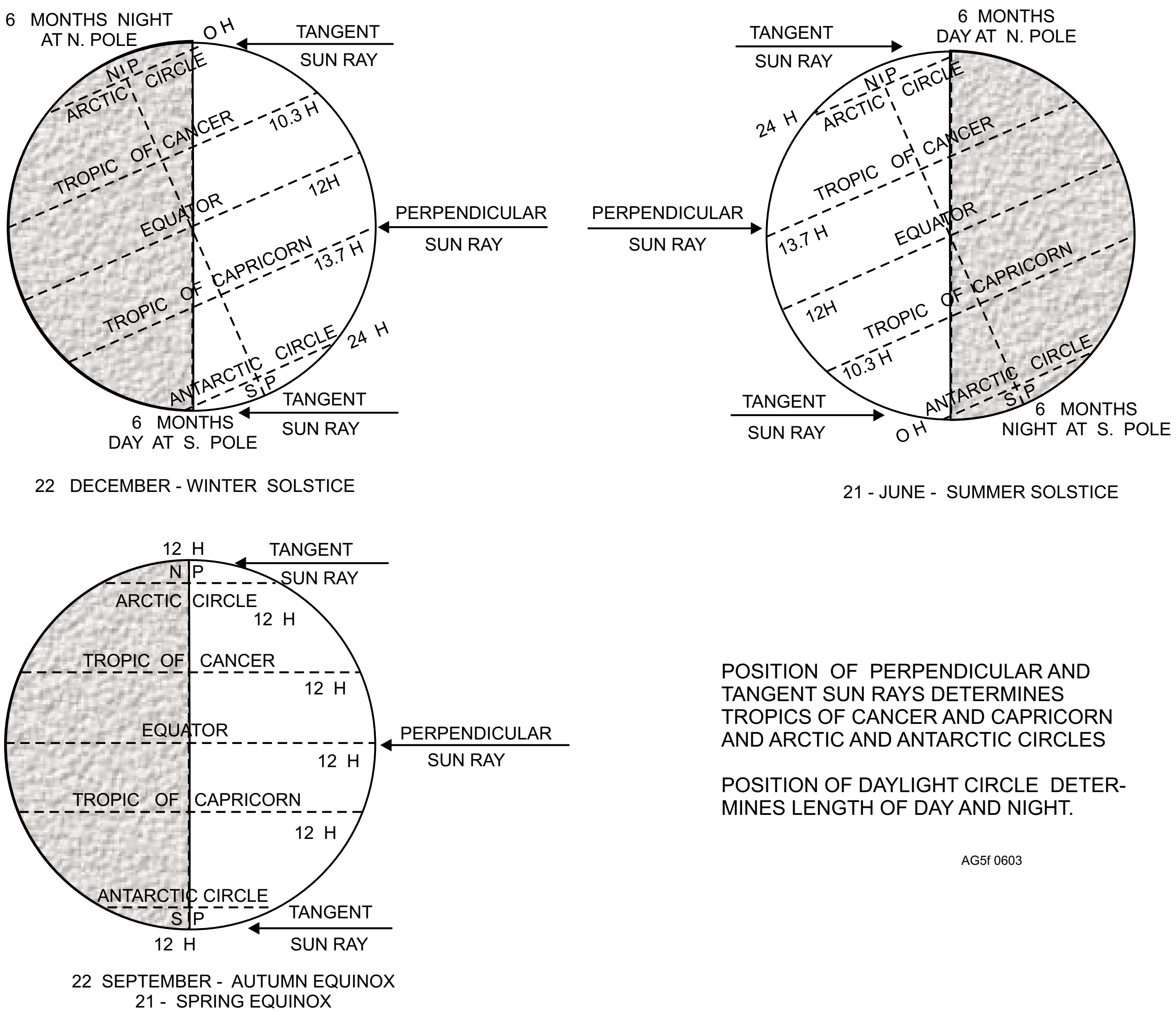

Figure 6-3.—Latitude differences in amount of insolation.

In chapter 3, the average world surface temperatures are represented on two world charts for January and July in figures 3-2A and 3-2B. These are mean charts and are not meant to be an accurate portrayal of the temperatures on any one particular day. Note that in general the temperatures decrease from low to high latitudes.

LAND AND WATER DISTRIBUTION

Land heats and cools about four times faster than water. Therefore, the location of continents and oceans greatly influences Earth's pattern of air temperature as well as the sources and direction of movement of air masses.

Influence on Air Temperature

Coastal areas assume the temperature characteristics of the land or water that is on their windward side. In latitudes of prevailing westerly winds, for example, west coasts of continents have oceanic temperatures and east coasts have continental temperatures. These temperatures are determined by the wind flow.

Since the upper layer of the ocean is nearly always in a state of mixing, heat losses or heat gains occurring at the surface are distributed throughout a large volume of water. This mixing process sharply reduces air temperature contrasts between day and night and between winter and summer over oceanic areas.

Over land, there is almost no redistribution of heat by turbulence; also, the effect of conduction is negligible. Thus strong seasonal and diurnal contrasts exist in the interiors of continents. During the winter, a large part of the incident solar radiation is reflected back toward space by the snow cover that extends over large portions of the northern continents. For this reason, the northern continents serve as source regions for dry polar air.

The large temperature difference between the land and water surfaces, which reverses between the two seasons, determines the seasonal weather patterns to a great extent.

In chapter 3, figures 3-2A and 3-2B, the isotherms over the Northern Hemisphere are more closely spaced and parallel in winter than in summer. In the Southern Hemisphere, the temperature gradient does not have as great a seasonal change as it does in the Northern Hemisphere. These conditions are due to the unequal distribution of land and water on the two hemispheres. Since the Southern Hemisphere has less land and more water surface than the Northern Hemisphere, the change due to the greater water surface is less with consequently more nearly uniform isotherms. Also, the continents of the Southern Hemisphere taper toward the poles and do not extend as far poleward as do those in the Northern Hemisphere.

The nature of the surface affects local heat distribution. Color, texture, and vegetation influence the rate of heating and cooling. Generally, a dry surface will heat and cool faster than a moist surface. For instance, plowed fields, sandy beaches, and paved roads become hotter than surrounding meadows and wooded areas during the day. During the night, however, the situation is reversed.

The distribution of water vapor and clouds is another important factor influencing air temperature. Although areas with a high percentage of cloud cover have a high degree of reflectivity, the energy, which is not reflected, is easily trapped in the lower layers due to the greenhouse effect. Thus, areas of high moisture content have relatively high temperature.

Influence on Air Circulation

The higher mean temperature of the Northern Hemisphere is an effect not only of its higher percentage of land, but also of the fact that its oceans are also warmer than those in the Southern Hemisphere are. This is partly due to the movement of warm equatorial waters from the Southern Hemisphere into the Northern Hemisphere caused by the southeast trades crossing the equator. Another factor conducive to higher mean temperatures in the Northern Hemisphere is the partial protection of its oceans from cold polar waters and arctic ice by land barriers. There is no such barrier between the Antarctic region and the southern oceans.

TOPOGRAPHY

Climates over land may vary radically within very short distances because of the elevation and variations in landforms. Therefore, topography plays an extremely important role in determining the climate of a region.

The height of an area above sea level exerts a considerable influence on its climate. For instance, the climate at the equator in the high Andes of South America is quite different from that found a few feet above sea level at the same latitude. All climatic values are affected by surface elevation.

An important influence on climate is mountainous terrain, especially the long, high chains of mountains that act as climatic divides. These obstacles deflect the tracks of cyclones and block the passage of air masses at the lower levels. If the pressure gradients are strong enough to force the air masses over the mountains, the forced ascent and descent modifies the air masses to a great extent, thus modifying the climate on both the windward and leeward sides of the range.

The orientation of the mountain range may block certain air masses and prevent them from reaching the lee side of the mountains. For example, the Himalayas and the Alps, which have east-west orientations, prevent polar air masses from advancing southward. Therefore, the climates of India and Italy are warmer in winter than are other locations of the same latitude. The coastal ranges in North America, running in a north-south line, prevent the passage of unmodified maritime air masses to the lee side.

The most noted effect of mountains is the distribution of precipitation. The precipitation values, level for level, are much higher on the windward side than on the leeward side.

In regions where the prevailing circulation flows against a mountain barrier, the amount of precipitation increases more or less uniformly with elevation on the windward side of the range. This steady increase normally occurs up to elevations of about 10,000 feet. However, in the trade wind zone (such as at the Hawaiian Islands), precipitation increases only to about 3,000 feet and then decreases gradually. Even with this decrease in amount, more rain is received at 6,000 feet than at sea level.

Another important topographical feature is the presence of lakes. The lake effect can be notable for large unfrozen bodies of water. The lee sides of lakes show considerable diurnal and annual modification in the form of more moderate temperatures; increased moisture, clouds, and precipitation; and increased winds (due to less friction) and land and sea breeze effects.

OCEAN CURRENTS

Ocean currents play a significant role in controlling the climate of certain regions. Ocean currents transport heat moving cold polar water equatorward into warmer waters and moving warm equatorial water poleward into cooler waters.

Currents are driven by the major wind systems; therefore, cold southward-moving currents flow along the west coasts of continents, and warm northward moving currents flow along the east coasts of continents. This is true in both hemispheres. Basically, this results in cooler climates along the west coasts and warmer climates along the east coasts.

A brief explanation of the effects of ocean currents is presented here.

Effects on the West Coasts

The northern portions of the west coasts of continents generally have cool summers and warm winters. The summers are cool because of the presence of cold northern waters along their shores. However, the winters are generally mild because of the transport of warm ocean waters to these latitudes. For example, the south and southeast coasts of Alaska and the west coasts of Canada, Washington, and Oregon have relatively warm currents flowing along their shores. These currents are the Aleutian and North Pacific currents, which are branches of the warm northward-flowing Kuroshio Current. The currents flow along the West Side of the Pacific high and bring warm water into southern Alaska and the Pacific Northwest.

As these currents merge and flow southward along the British Columbia coast, they move into warmer waters and become the cold California Current.

The southern portions of the west coasts of continents generally have cooler climates than do the east coasts of the same latitude. For example, during summer, the cold California Current flows southward along the shores of California. Due to the Pacific high, the winds normally flow either across the cold current toward shore (onshore) or parallel to the coastline. This results in cool air being advected inland allowing cities such as San Francisco and Seattle to enjoy relatively cool summers. Unfortunately, when the warm, moist air from the Pacific high does move over the underlying cold current, extensive fog and stratus develop which also move inland. This situation is typical along the southern portions of the west coasts in both hemispheres.

Another factor affecting west coasts is upwelling. Upwelling is the process by which cold subsurface waters are brought to the surface by wind. It occurs in areas where the wind causes the surface water to be transported away from the coast. The colder subsurface water then replaces the surface water. In the Northern

Hemisphere, upwelling is common where the wind blows parallel to the coast and the surface water is transported away from the coast. In the process of upwelling, the exchange of water takes place only in the upper layers.

Generally, the following statements are true regarding the effects of ocean currents along the west coasts of continents:

- The west coasts of continents in middle and higher latitudes are bordered by warm waters, which cause a distinct maritime climate characterized by cool summers and relatively mild winters with small annual range of temperatures (upper west coasts of the United States and Europe).

- The west coasts of continents in tropical and subtropical latitudes (except close to the equator) are bordered by cool waters and their average temperatures are relatively low with small diurnal and annual ranges. There are fogs, but generally the areas (southern California, Morocco, etc.) are arid (dry).

Effects on the East Coasts

The effects of currents along the eastern coasts of continents are less dramatic than those of the west coasts because of the west-to-east flow of weather. The effects, however, are just as significant.

In the tropical and subtropical regions, warm ocean currents introduce warm, rainy climates, especially on the windward sides of mountainous landmasses. As the warm currents progress northward into middle latitudes, warm, moist air produces a hot, humid climate with frequent rain showers during the summer. Winters are relatively moderate (but still cold) along the coast due to the transport of warm water. The higher latitudes along eastern shores normally have cold waters flowing southward from the polar region; warm ocean currents rarely extend very far north. The regions where the two currents meet have cool summers and cold winters with extensive fogs. This is especially true along the Grand Banks of Newfoundland and the Kamchatka Peninsula of eastern Asia.

The following general statements are true regarding the effects of ocean currents along the eastern coasts of continents:

- The east coasts in the tropics and subtropical latitudes are paralleled by warm currents and have resultant warm and rainy climates. These areas lie in the western margins of the subtropical anticyclone regions (Florida, Philippines, and Southeast Asia).

- The east coasts in the lower middle latitudes (leeward sides of landmasses) have adjacent warm waters with a modified continental-type climate. The winters are fairly cold, and the summers are warm and humid.

- The east coasts in the higher middle latitudes typically experience cool summers with cool ocean currents paralleling the coasts.

Other Effects

Ocean currents also affect the location of primary frontal zones and the tracks of cyclonic storms. Off the eastern coast of the United States in the winter, two of the major frontal zones are located in areas where the temperature gradient is strong and where a large amount of warm water is being transported into the middle latitudes. The fact that these frontal zones are located near large amounts of energy suggests that cyclones developing in these regions along the primary front may be of thermodynamic origin. The main hurricane tracks in the Atlantic and Pacific also appear to follow warm waters. Extratropical cyclones also tend to occur in warm waters in fall and early winter.

CLIMATIC FACTORS

Human activity and vegetation can have marked effects on the climates of local areas. Eventually man’s activities could affect larger areas and ultimately whole continents.

It has been known for years now that urban areas and industrial complexes have an influence on climate. Atmospheric pollution is increased, for example, and the radiation balance is thereby altered. This change affects the daily maximum and minimum temperatures in cities, where they tend to be generally higher than in nearby suburbs. A higher concentration of hygroscopic condensation nuclei in cities results in an increased number of fogs. Also, with the greater heat source found in cities, increased convection gives rise to greater amounts of cloudiness and precipitation. An apparent benefit of this increased heat is a slight decrease in severe weather occurring in large cities (Chicago, for example) as compared to adjacent areas.

Areas of heavy vegetation generally have distinct climates, which may differ considerably from climates of nearly open areas. Falling precipitation caught in trees before reaching the ground may be evaporated, but precipitation, which reaches the ground, does not evaporate or run off readily. Heavily forested areas can absorb and store considerable quantities of water. Snow in forests can be protected from direct insolation by the trees and may stay on the ground for much longer periods than snow on open, exposed surfaces. In forests, temperature maximums and minimums are higher than over open land at the same latitude. Relative humidity is also higher and wind speeds are considerably lower.

REVIEW QUESTIONS

Q6-12. Which climatic control has the biggest effect on climatic elements?

Q6-13. A weather station on the western coast of the United States will receive the characteristics of what type air as compared to a weather station on the eastern coast?

Q6-14. Generally, how do ocean currents effect climate?

CLIMATOLOGICAL DATA

LEARNING OBJECTIVE: Describe the use of climatological data in meteorology and what references and services are available.

Climatological records are based on the meteorological observations that are taken at a particular locality. This information may be presented in a number of ways.

Temperature records generally include the following temperature values: daily maximums and minimums by months; the extremes; the average temperature by year and month; the mean monthly and annual temperature; the mean monthly maximum and minimum temperature; and (sometimes) the monthly and seasonal degree-days. Of great climatic significance is the range between the mean temperature of the warmest month and the coldest month. Other temperature data are sometimes given. These may include the number of days with the following temperatures: maximum of 90°F and above; maximum of 32°F and below; minimum of 32°F and below; and minimum of 0°F and below.

Precipitation records include the mean annual and monthly totals. The range between the highest and the lowest annual rainfall for a locality is the best indication of the dependability of the precipitation. The records often show the absolute maximum rainfall and snowfall for a 24-hour period by months, as well as the maximum and minimum precipitation for each month.

Climatic records usually show data on winds. Such information indicates the mean hourly speed and the prevailing direction by month. Also shown are the speed and direction of the strongest wind for the 12 months and the year in which it occurred.

Data on cloudiness, humidity, thunderstorms, and heavy fog are often included. Other helpful data would be the frequency and distribution of cyclones and anticyclones; passage of fronts; proportion of rainfall and snowfall received from cyclonic storms and local, air mass thunderstorms; and climatological data on upper air conditions.

METHODS OF PRESENTATION

Climatological information is presented in many different ways. Tables are frequently used. Maps are particularly useful in presenting climatic information in cases where geography is an important factor. Wind data can be given by means of a device called a wind rose, which presents information on the prevailing wind directions. (See fig. 6-4.)

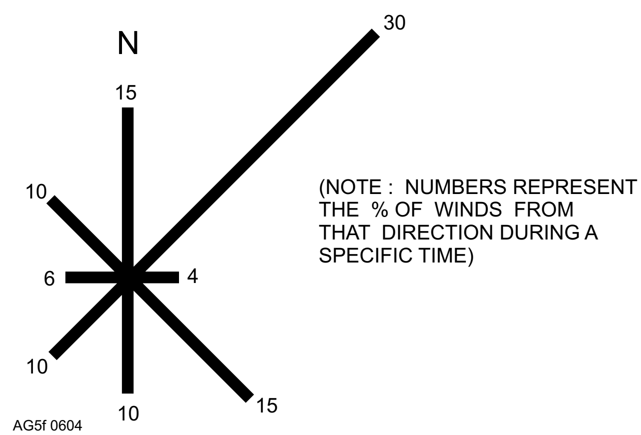

Figure 6-4.—A wind rose.

Graphs are usually divided into bar and line graphs, or the graph may be a combination of the two. Figure 6-5 is an example of a bar graph and a line graph showing the same information. Figure 6-6 shows a combination of a bar and line graph used to depict cloud cover. This type of depiction is used in the most recent *U.S. Navy Marine Climatic Atlas of the World.*

AVAILABILITY OF DATA

Every Naval Meteorology Oceanography Command activity should have climatological records available for their area and for such other areas as may be necessary to provide climatological support at the local command level. Various climatological records are available from Fleet Numerical Meteorology and Oceanography Detachment (FNMOD), Asheville, NC 28801-2696, or by contacting their website. These records include the *Summary of Meteorological Observations, Surface* (SMOS); *Local Climatological Data* (LCD); *Summary of Synoptic Meteorological Observations* (SSMO); and *Summary of Meteorological Observations, Radiosonde* (SMOR).

Frequency SMOS

Frequency SMOS summaries are prepared for all naval observing stations from navy monthly meteorological records (MMRs). Each SMOS is for a specific station. Frequency distributions for various parameters are presented by time of day, month, and year. SMOS are revised every *5* years.

Local Climatological Data Summary

The LCD summary is prepared only for selected civilian stations in the continental U.S.A. (CONUS). It consists of means and extremes (temperature, precipitation, wind, etc.) by month, mean temperature and total precipitation by month for specific years of record, and monthly and seasonal degree-days. The LCD is revised annually.

Cross-Wind Summary

The Cross Wind Summary presents the percentage of occurrence of cross winds for a given location. It is produced only on request.

Summary of Synoptic Meteorological Observations (SSMO)

The SSMO presents useful monthly and annual tabulations of surface climatological data and various combinations of the included parameters. SSMOs were last updated in the mid-seventies and are supplemented by the Near Coastal Zone Studies.

Near Coastal Zone Studies

Near Coastal Zone Studies are currently being developed by FNMOD, Asheville, to supplement the SMOS by providing detailed climatological data for areas of higher interest. Near Coastal Zone Studies present data in both graphic and tabular formats.

Summary of Meteorological Observations, Radiosonde (SMOR)

The SMOR is used to prepare monthly winds aloft summaries, which generally include various constant height and constant pressure levels. The summaries contain winds aloft data, giving speeds and directions over the period covered.

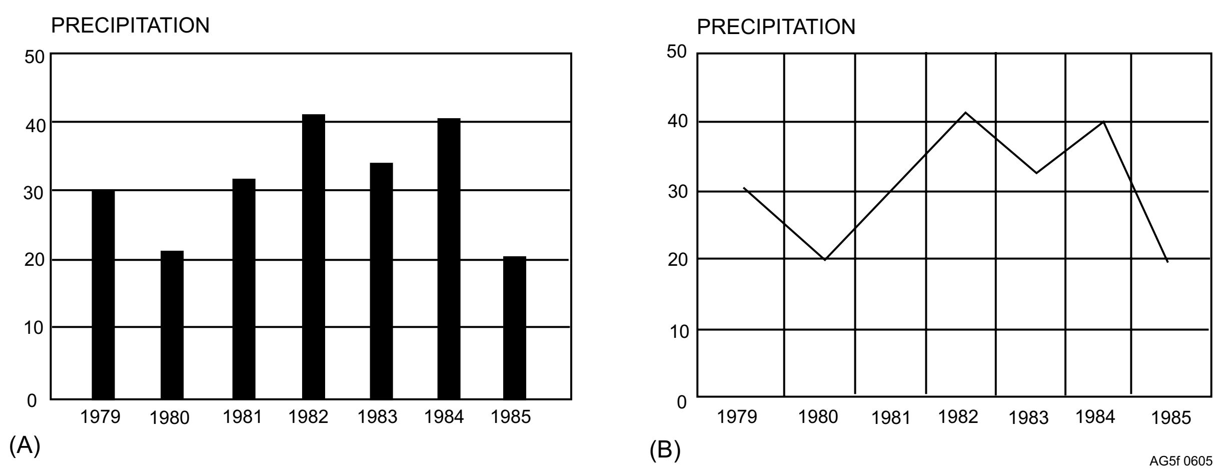

Figure 6-5.—A comparison of the bar and line graph method of showing the variable annual precipitation in a time series. (A) Bar graph; (B) Line graphs.

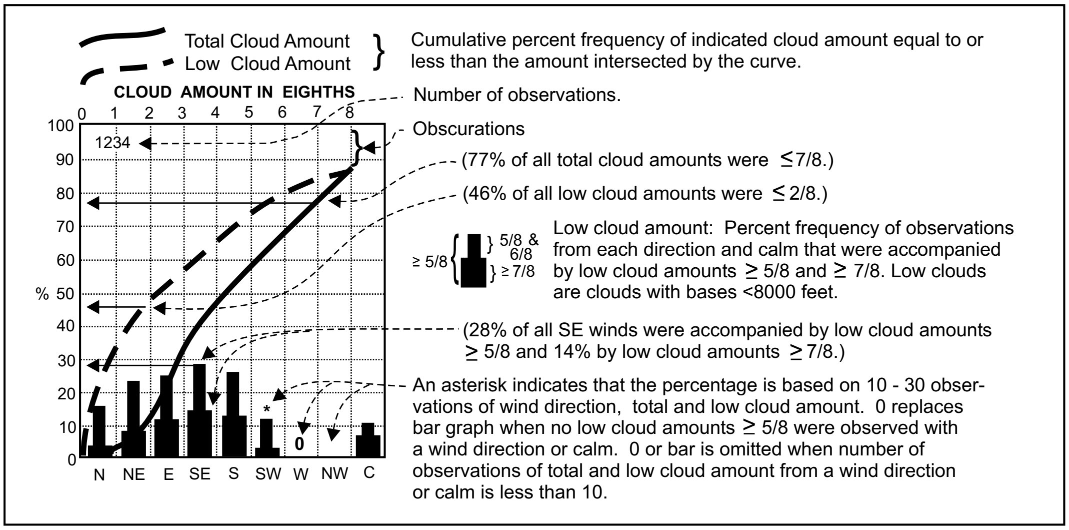

Figure 6-6.—Combination bar and line graph (with legend and instructions for use).

Worldwide Airfield Summary

The *Worldwide Airfield Summary* provides climatological data for airfields and geographical areas throughout the world. There are 10 volumes, some published in two or more parts.

CLIMATOLOGICAL REFERENCES

There are many references, which can be used in climatological work, so many in fact that they would be too numerous to list here. They are tabularized in the following publications:

- *Guide to Standard Weather Summaries* (NAVAIR 50-1C-534) contains an index of all the standard machine-tabulated summaries available through FNMOD, Asheville.

In addition, many navy climatic references are listed in the *Navy Stock List of Forms and Publications*, NAVSUP publication 2002, section 2B. Navy climatology publications are found under the NA-SO-1C-series.

The following publications can also be used to prepare climatological briefings and packets:

- *U.S. Navy Marine Climatic Atlas of the World,* volumes 1 through 7 and 9 (NAVAIR 50-1C-528 through 533, 550, 554, s and 565). These publications contain climatic data for all the principal ocean areas of the world. They have both land and ocean sections. The surface section contains data presented by graphs, tables, and isopleths on such elements as surface winds, visibility, precipitation, storm tracks, etc. The oceanographic section includes charts of tidal data, currents, and ice.
- *U.S. Navy Hindcast Spectral Ocean Wave Model Atlases*, volume 1, North Atlantic (NAVAIR 50-1C-538), volume 2, Pacific (NAVAIR 50-1C-539). These atlases represent ocean wave data by tables, bar graphs, and isopleths. Data is based on numerically derived historical data in the form of wind and wave climatology. These publications are designed to provide a more accurate representation of overall ocean wave climatic data for some applications. They are designed to supplement but not supersede the conventional Marine climatic atlases.

Local Area Forecaster's Handbooks

The *Local Area Forecaster's Handbooks*, as required by NAVMETOCCOM Instruction 3140.2( ), contain valuable information on local and area weather as follows: A description of the local topography, terrain and general synoptic characteristics of weather occurrences in the area. Mean storm tracks for the region, a limited amount of climatological data, and local forecasting rules and techniques are also available. A handbook can serve as a composite summary of expected weather events and the effects of certain parameters on local weather.

Naval Intelligence Survey (NIS) Publications

The Naval Intelligence Survey (NIS) publications have been discontinued, and distribution is limited. However, when available, these classified publications are a valuable source of information about general climatic influences and topographic/oceanic effects on regions from which unclassified data may no longer be available.

Miscellaneous Publications

The following publications contain generally the same type of climatological information or specific data. They have proven to be extremely useful.

1. *Climatic Summaries for Major Seventh Fleet Ports and Waters,* NAVAIR 50-1C-62.

2. *Climatic Summaries of Indian Ocean Ports and Waters,* NAVAIR 50-IC-63.

3. *A Climatic Resume of the Mediterranean Sea,* NAVAIR 50-1C-64.

4. *Upper Wind Statistics of the Northern Hemisphere,* volumes 1, 2, and 3, NAVAIR 50-1C-535.

5. *Marine Climatic Guide to Tropical Storms at Sea,* NAVAIR 50-IC-61.

6. *Sea Ice Climatic Atlases,* volume 1, *Antarctic,* NAVAIR 50-1C-540. Volume 2, *Arctic East,* NAVAIR 50-IC-541. Volume 3, *Arctic West,* NAVAIR 50-1C-542.

CLIMATOLOGICAL SERVICES

Requests for climatic support should be made to the Meteorology Oceanography Facility or Center in your chain of command. Requests that cannot be fulfilled are forwarded to:

Fleet Numerical Meteorology and
Oceanography Facility
Asheville, NC 28801-5014

Additional Climatic Sources

In addition to navy climatic publications, there are other sources for air/ocean climatology data, which are available to the Aerographer's Mate for preparing climatic studies. They are as follows:

- The Warfighting Support Center (WSC), Stennis Space Center Mississippi, provides oceanographic support. Available data includes tides, currents, and water structure, etc.

- The Air Weather Service Environmental Technical Application Center (ETAC) provides climatic information for Air Force operations. However, data produced by ETAC can be used for naval applications. A listing of climatology studies available from the Air Weather Service can be found in *Index of Air Weather Service Technical Publications* (AWS/TI-84/00 1). Requests for Air Weather Service publications must be made to Commander, Naval Meteorology Oceanography Command, Stennis Space Center, Mississippi.

INTERPRETATION

Climatological records must be interpreted correctly to gain the needed information. Proper interpretation requires that all of the meteorological elements be studied so they present a composite picture. One meteorological element alone may mean very little. For instance, it is possible to conclude that Cairo, Egypt, and Galveston, Texas, has about the same kind of weather based solely on the temperature, since the yearly and monthly means and annual range are approximately the same. However, Galveston has about 40 times as much precipitation. Thus, their weather conditions over the year differ greatly.

To interpret just one meteorological element requires a study of several factors. For example, the temperature of a particular locality must be studied from the standpoint not only of the mean but also of the extremes and the diurnal and annual ranges. The effectiveness of precipitation also depends on several factors, such as amount, distribution, and evaporation. The mean precipitation for a particular month for a locality may be several inches, but the interpreter may find from a study of the locality's records that in some years the precipitation for that month is less than an inch, possibly not even a trace.

APPLICATION TO WEATHER PREDICTION

Climatology is introduced where operational planning is required for a length of time beyond the range covered by weather-forecasting techniques. A study of the climate of an area or region may well foretell the general weather pattern to be expected.

Both the experienced and the inexperienced forecaster and assistant forecaster can make a more direct application of climatology. Those personnel having personal experience at a particular station can use climatology as a refresher for the overall weather patterns that can be expected for the ensuing season. This knowledge can help them to be more perceptive in their everyday analyses, to be alert for changing patterns with the seasons, and to produce a higher quality forecast.

The personnel who have had no experience at a particular station must rely on climatology as a substitute for their experience. Forecasters and assistant forecasters cannot be expected to become familiar overnight with the weather peculiarities of their new area of responsibility. The station certification period can be greatly reduced if the new people are furnished with "packaged experience" in a form that can place them more nearly on a par with those forecasters already experienced at that station. *The Local Area Forecaster's Handbooks* are good examples of this type of packaged information.

The Naval Meteorology Oceanography Command makes many uses of climatological data. In using the data, however, it must be clear that climatology has its limitations in the field of meteorology. It may be put this way. *Climatology is an essential supplement to meteorology, but it must never be considered a substitute for the meteorological situation that constitutes current weather conditions.*

REVIEW QUESTIONS

Q6-15. What is the correct method to obtain climatology information?

Q6-16. What publication is also useful for obtaining climatology information for a particular weather station?

WORLD WEATHER

LEARNING OBJECTIVE: Identify the various types of weather and climate of the oceans and continents.

Aerographer's Mates are stationed, and may travel, around the world. Ships and aircraft are constantly in global transit. Therefore, the Aerographer's Mate must have a general knowledge of types of weather encountered during various seasons in regions all around the world. This knowledge also increases insight into atmospheric circulation, weather development and movement, weather effects on the environment, and credibility as a knowledgeable analyst, interpreter, and briefer.

NOTE: You will find that a world atlas can be extremely useful and informative if used in conjunction with the information that follows.

OCEANIC WEATHER

Naval vessels of the United States operate in virtually all the oceanic areas of the world; therefore, the Aerographer's Mates must be acquainted with oceanic weather. Some general considerations of the weather encountered over ocean areas are discussed in this lesson.

Because land and water heat and cool at different rates, the location of continents and oceans greatly affects the Earth's pattern of air temperature and therefore influences the weather. The upper layers of the ocean are almost always in a state of motion. Heat loss or gain occurs at the sea surface and is distributed throughout large volumes of water. This mixing process sharply reduces the temperature contrasts between day and night and between winter and summer.

Oceanic Weather Control

It has long been recognized that the ocean plays an important part in climate and weather, particularly in the realms of temperature, humidity, and precipitation. This is only natural, since three-fourths of Earth's surface is covered by water.

The two climatic extremes that relate to water and land distribution over Earth are *maritime* and *continental*. A wide range in annual and diurnal temperatures, little cloudiness, and little precipitation generally evidences Continental climate. Continental climate is a product of a minimal influence from the oceans. Maritime climate prevails over the oceans and is characterized by a small temperature range, both annual and diurnal, and considerable precipitation and cloudiness.

Water vapor is considered one of the most important variables in meteorology. The state of the weather is largely expressed in terms of the amount of water vapor present and what is happening to the water vapor. Two principal elements of climate, precipitation and humidity are dependent upon water vapor. Since the oceans are the main source of water vapor, it follows that the oceans largely control weather.

Effects of Air-Sea Interchange

The atmosphere and the oceans have tremendous effects on each other. These effects are principally in the realms of temperature and water vapor. The processes of radiation, the exchange of sensible heat, and the evaporation and condensation of water vapor on the sea surface maintain the heat balance of the oceans.

The amount of radiant energy absorbed by the sea depends upon the amount of energy reaching the surface and the amount of reflection by the surface. When the Sun is directly overhead, the amount of its energy reflected amounts to only about 3 percent. Even when the Sun is 30° above the horizon, the amount of reflection is just 6 percent. However, there is a reflection of about 25 percent of the energy when the Sun is 10° above the horizon. (See fig. 6-7.) Reflection loss is especially great in the presence of waves when the Sun is low.

Much of the insolation is absorbed in the first meter of seawater. This is true of the clearest water as well as of quite turbid (opaque) water. In water that is extremely turbid, the absorption is in the very uppermost layers. Foam and air bubbles are two major causes of a proportionately greater amount of absorption in the uppermost meter of the sea. However, due to vertical mixing, the heat absorbed in the upper layer is carried to great depths of the ocean, which acts as a great heat storage reservoir.

There is an exchange of energy between the oceans and the atmosphere. The surface of the oceans emits long-wave heat radiation. The sea surface at the same time receives long-wave radiation from the atmosphere. Although some of this incoming radiation from the atmosphere is reflected from the surface of the oceans, most of it is absorbed in a very thin layer of the water surface. The difference between the incoming long-wave atmospheric radiation and the outgoing long-wave radiation from the sea surface is known as the *effective back radiation*. The effective back radiation depends primarily on the temperature of the sea surface and on the water vapor content of the atmosphere. The time of day and the season have little effect on effective back radiation, since the diurnal and annual variation of the sea-surface temperature and of the relative humidity of the air above the oceans is slight.

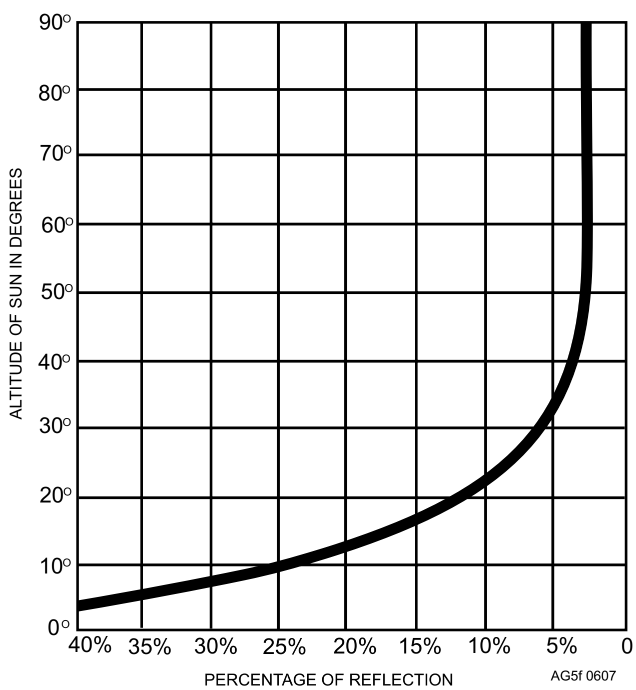

Figure 6-7.—Percentage of reflected radiation.

For conduction to take place between the oceans and the atmosphere there must be a temperature difference between the ocean surface and the air immediately overlying it. On the average, the temperature of the surface of the oceans is higher than that of the overlaying air. It might be expected that all of the ocean's surplus of heat is either radiated or conducted to the atmosphere. This is not the case. Only a small percentage of the ocean's surplus heat is actually conducted to the atmosphere. About 90 percent of the surplus are used for evaporation of ocean water.

Due to the processes of radiation and mixing, the oceans act as a thermostat relative to the atmosphere. The energy stored at one place during one season may be given off at another locality and during a later season. Hence, there seems to be a constant effort by the atmosphere and the oceans to keep their temperatures in balance by an interchange of heat.

STABILITY.—The deciding factor of most weather phenomena is the stability of the atmosphere. Air masses may become more stable or less stable as they move over ocean surfaces. The temperature contrast between the ocean surface and the lowest layers of the overlying air determines whether the ocean will promote stability or instability.

When the air moving over the ocean has a higher temperature than that of the ocean surface, the lower layers of the air become stable in time. On the other hand, when the air mass is colder than the ocean surface over which it is moving, instability results. As the colder air is warmed by the ocean, convective activity eventually develops. If the warming is sufficiently intense, thunderstorms develop.

MOISTURE CONTENT.—The interchange of moisture between the atmosphere and the oceans is one of the most important features of the whole meteorological picture. Without this interchange, weather, as we know it, could not exist; there would be no clouds and no precipitation. The oceans are by far the greatest source of moisture for the atmosphere. Other moisture sources are negligible in comparison.

Whether the atmosphere gives up some of its moisture to the ocean or vice versa depends greatly upon vapor pressure. Vapor pressure is the pressure exerted by the molecules of water vapor in the atmosphere or over the surface of liquid water. When the vapor pressure of a liquid is equal to that of the atmosphere above the liquid, there is little or no apparent interchange of moisture. In other words, at equal vapor pressure, just as many molecules escape from the liquid to the atmosphere and vice versa. This is the case when air becomes saturated. The saturation vapor pressure increases with increasing temperature.

If the temperature of the surface water is warmer than that of the air, the vapor pressure of the water at its surface is greater than that of the air. When this condition exists, there can be abundant evaporation from the ocean surface. This evaporation is aided by the turbulence of the air brought on by the unstable condition of the lower layers. It follows, then, that the greatest evaporation takes place when cold air flows over warm ocean waters.

Let us consider the opposite condition—warm air flowing over a relatively cold body of water. When this happens, there is stable stratification in the lower layers of the atmosphere. The vapor pressure of the air soon reaches a state of equilibrium with that of the water surface. Evaporation stops. However, if the warm air is quite moist, it is possible for the moisture in the air to condense on the water surface. Contact of the warm air with the cold water may result in the formation of fog by lowering the air temperature to the dew point.

The direct interchange of moisture from the atmosphere to the oceans occurs through precipitation and, to a lesser extent, condensation. The direct interchange, however, is not as important meteorologically as the indirect interchange. The indirect interchange is a sequence of events beginning with the evaporation of water from the ocean surfaces and ending with the subsequent condensation and precipitation over land areas.

Generally, precipitation occurs more frequently over land than over the oceans. Though the oceans are a source of abundant moisture, they normally lack the required precipitation mechanisms, such as vertical mixing, strong temperature contrasts, and orographic lifting.

Equatorial and Tropical Weather

In the Temperate Zone, where westerly winds predominate, pressure patterns move in an easterly direction. In the tropics, however, weather usually moves in the opposite direction. Normally, a moist layer, 5,000 to 8,000 feet deep exists in this region. During unfavorable weather, this layer deepens to more than 12,000 feet. Convergence occurs in opposing trade wind streams, northward flowing air, and areas of cyclonic curvature. The presence of a deep, moist layer and convergent winds account for the weather in equatorial and tropical regions.

North Atlantic and North Pacific Oceans

In the winter, the most favorable conditions for vigorous frontal activity are concentrated along the east coasts of North America and Asia. These conditions are associated with polar front activity. Cold air masses from continental sources meet warm, moist air from over the oceans. The warm ocean currents along these coasts greatly accentuate the frontal activity. The great temperature difference of the air masses, caused by the contrasting characteristics and proximity of their sources and the moisture that feeds into the air from the warm ocean currents, accounts for the intensity and persistence of these frontal zones off the east coasts in the winter. Modification of the air masses as they sweep eastward across the ocean leads to modified frontal activity on the west coasts. Refer back to chapter 4, to figures 4-25 and 4-26 for the location of the following frontal zones:

1. Polar fronts in the Atlantic. In the Atlantic, in winter, polar fronts are found situated in various locations between the West Indies and the Great Lakes area. Intensity is at a maximum when the fronts coincide with the coastline. Waves, with cold and warm fronts, form along the polar front and move northeastward along the front. Like all cyclonic waves, they develop low-pressure centers along the frontal trough. They may grow into severe disturbances and go through the usual stages of development: formation, growth, occlusion, and dissipation.

These cyclonic waves occur in families. Each family of waves is associated with a southward surge, or outbreak, of cold polar air. The polar front commonly extends approximately through the Great Lakes area. As the polar air advances, it pushes the front southward. The outbreak occurs, and polar air, joining the trade winds, spills equatorward.

There is no regular time interval for these large outbreaks of polar air, but the average period is about 5 1/2 days between them. Under average conditions, there are from three to six cyclonic waves on the polar front between each outbreak of polar air. The first of these usually travels along the front that lies farthest to the north. As the polar air accumulates north of the front, the front is pushed southward, and the last wave therefore follows a path that starts farther south than the path followed by the first wave. These families of polar front cyclones appear most frequently over the North Atlantic and North Pacific in the winter.

During the summer months, the polar fronts of the Atlantic recede to a location near the Great Lakes region, with the average summer storm track extending from the St. Lawrence Valley, across Newfoundland, and on toward Iceland. Polar outbreaks, with their accompanying family groupings of cyclones, are very irregular in summer and often do not exist at all. Frontal activity is more vigorous in the winter than in the summer because the polar and tropical air masses have greater temperature contrasts in the winter, and polar highs reach maximum development in the winter. Both of these factors increase the speed of winds flowing into fronts. Over oceans of middle latitudes, a third factor helps to make winter fronts more vigorous than summer fronts. In the winter, continental air becomes very unstable when it moves over the comparatively warm ocean surface; in the summer, it remains relatively stable over the comparatively cool ocean. Summer frontal activity (in middle latitudes) is therefore weak over oceans as well as over land. The high moisture content of maritime air causes much cloudiness, but this moisture adds little energy to frontal activity in the relatively stable summer air.

2. The polar fronts in the Pacific. These fronts are similar to those of the Atlantic, except that in the winter there are usually two fronts at once. When one high dominates the subtropical Pacific in the winter season, the pacific polar front forms near the Asiatic coast. This front gets its energy from the temperature contrast between cold northerly monsoon winds and the tropical maritime air masses, and from the warm, moist Kuroshio Current. In moving along this polar front of the Asiatic North Pacific in winter, storms occlude before reaching the Aleutian Islands or the Gulf of Alaska. Because of its steady cyclonic circulation, the Aleutian low becomes a focal center, or a gathering point, for cyclones. The occluded fronts move around its southern side like wheel spokes. This frontal movement is limited to the southern side of the Aleutian low because mountains and the North American winter high-pressure center prevent fronts from passing northward through Alaska without considerable modification.

In the winter the cyclones reach the Aleutians and the Gulf of Alaska. Here, Arctic air from the north meets the relatively warmer maritime air from the south. The Pacific arctic front of winter is found in this region. Although many occluded storms dissipate in the Gulf of Alaska, others strongly regenerate with waves developing on what were once occluded fronts.

When the Pacific subtropical high divides into two cells or segments (as it does 50 percent of the time in the winter and 25 percent of the time in the summer), a front forms in the vicinity of Hawaii. Along this front, storms develop and move northeastward. These storms called Kona storms, have strong southwest winds and bring heavy rains to the islands. Those storms that succeed in moving beyond the realm of the northeast trade winds, which stunt them, may develop quite vigorously and advance to the North American coast, generally occluding against the mountains. When this second polar front exists, two systems of cyclonic disturbances move across the Pacific. Because of their greater sources of energy, however, storms that originate over the Kuroshio Current and move toward the Aleutians are almost always more severe. In the Atlantic, a second polar front, similar in nature and source to the second polar front of the Pacific, sometimes—though rarely—develops.

During the summer months, the Pacific polar front lies to the north of Kamchatka and the Aleutians and shows no rhythmic polar outbreaks.

Air-Mass Weather

Flying weather is usually best in tropical maritime air, at its source, within the subtropical highs. Scattered cumulus and patches of stratocumulus clouds may develop, but the sky is almost never overcast. Scant precipitation falls in scattered showers and variable, mild winds prevail.

The excellent flying weather in these mT source regions commonly extends through the moving air masses some distance from the sources. Cloudiness in the mT air increases with an increase in distance from the source.

On flights from Hawaii or from the Azores northward, through northward-moving mT air, stratiform clouds increase. On flights from Hawaii or the Azores southward, through southward-moving mT air (or the northeast trades), cumuliform clouds increase. Here we are considering only Northern Hemisphere situations; however, a comparable pattern exists in the Southern Hemisphere.

A typical breakdown of the weather conditions you may encounter in air masses around the subtropical highs (fig. 6-8) is as follows:

1. North of a subtropical high. Any mT air that moves northward becomes cooled over the cool ocean surface. A stratus overcast may form, and drizzle may fall. Farther north, low ceilings (usually below 1,000 feet) may reach the surface, producing fog. The mT air surges farthest north in summer because subtropical highs are best developed and polar fronts lie farthest north. This mT air brings most of the summer fogginess to northern seas and coasts. It brings the greatest fogginess in the Atlantic where it blows from the warm Gulf Stream over the cold Labrador Current (near Newfoundland), and in the Pacific where it blows from the warm Kuroshio Current over the cold Oyashio current (near the Kamchatka peninsula).

2. East of a subtropical high. Along the California coast, and along the Atlantic coast of North Africa, the mT air blows from the west and the northwest. This air tends to remain stable for the following reasons:

a. It is coming from the northern, cooler portion of the source region.

b. Its surface layers remain cool because it moves over cold ocean currents.

c. Its upper portions warm adiabatically because of subsidence.

Throughout the year, airways are smooth. The skies are clear to partly cloudy. Clouds are generally patches of stratocumulus, and rain is rare. The chief flight hazard in this air is coastal fog, which often hides the California or European coastal land. Stratus and stratocumulus clouds may cause the sky to be overcast, develop low ceilings, and produce drizzle that reduces visibility.

3. South of a subtropical high. Where the mT air moves southward or southwestward (as trade winds), its lower layers are warmed by the tropical ocean surface. This produces scattered cumulus. Near the equator, after absorbing much moisture and being heated, this air may develop cumulonimbus.

4. West of a subtropical high. This mT air blows from the east and the southeast. Since it flows over warm water all of the way, the air neither cools nor warms. Over the ocean near the Philippines (and near Florida and the West Indies), this trade wind brings good flying weather—clear or scattered cumulus clouds. When it is moving over land, this warm, moist air becomes unstable and turbulent and is a source of thunderstorms. When it moves over cold land (for example, southeastern United States in the winter), it becomes stable and produces stratus clouds or fog. Over cold ocean surfaces, such as the Sea of Japan and the Kamchatka and Labrador currents, it develops the persistent low stratus and fogs characteristic of these areas.

ARCTIC AND ANTARCTIC WEATHER

Geographically, the arctic zone is north of the Arctic Circle (66.5°N) and the Antarctic zone is south of Antarctic Circle (66.5°S) The Arctic is extremely important to the military defense of Canada and the United States and is the subject of ever-increasing military operations. Therefore, Aerographer's Mates must familiarize themselves with the prevailing weather and peculiarities of these regions.

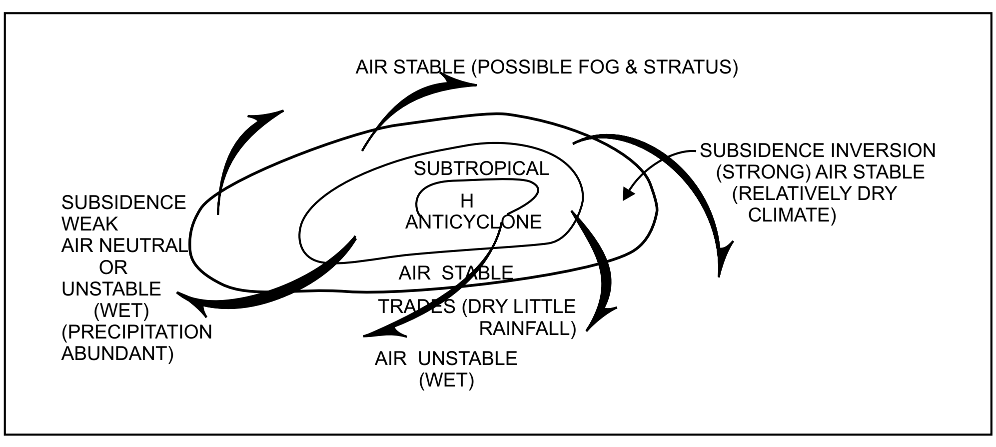

Figure 6-8.—Weather, winds, and stability conditions around the subtropical high.

Arctic Weather

The Arctic is the aerial crossroads of the world. This is not only due to the shorter arctic routes between some of the major cities of the world, but also because flying weather over the Arctic is generally better than that encountered over the familiar ocean routes. To understand some of the important weather and problems of the Arctic, you must understand the broad underlying causes of the arctic climate.

SEASONAL TEMPERATURE VARIATIONS.—From our previous discussion of climatic controls, we have seen that the most important factor that determines the climate of an area is the amount of energy it receives from the Sun. During the winter much of the Arctic receives little or no direct heat from the Sun. The cold winter temperatures common in the Arctic result from a lack of the Sun's energy.

The Sun is not the only factor responsible for the arctic climate. Two other factors, the land-sea-ice distribution and mountain barriers, contribute to the tremendous variation in climate at different points of similar latitude.

1. Land-sea-ice features. In the Northern Hemisphere, the water features include the Arctic, North Atlantic, and North Pacific oceans. These bodies of water act as temperature moderators since they do not have large temperature variations. A major exception occurs when large areas are covered by ice in winter. The land features are the northern continents of Eurasia, North America, the island of Greenland, and the Canadian Archipelago. As opposed to the water areas, the land areas tend to show the direct results of the extremes of seasonal heating and cooling by their seasonal temperature variations.

2. Mountains. The arctic mountain ranges of Siberia and North America are factors, which contribute to the climate and air mass characteristics of the regions. These mountain barriers, as in mid-latitudes, restrict the movement of air from west to east. During periods of weak circulation, the air is blocked by the ranges and remains more or less stagnant over the area. It is during these periods that the air acquires the temperature and moisture characteristics of the underlying surface. Thus, these areas are air-mass source regions, and they are particularly effective as source regions during the winter when the surface is covered with snow and ice.

The Greenland ice cap is essentially a mountain range more than 10,000 feet above mean sea level. It restricts the movement of weather systems, often causing low-pressure centers to move northward along the West Coast of Greenland. Some of the largest rates of falling pressure in the world (other than hurricanes and tornadoes) are recorded here. The deep, low centers that move along the west coast of Greenland are primarily responsible for the high winds that are recorded occasionally in that area.

At times, winter temperatures in the Arctic are unusually high. This situation is brought about by deep, low centers moving into the Arctic, coupled with compression of air (the Foehn effect) as it often blows down off the sloping edges of the ice caps, primarily the Greenland ice cap.

ARCTIC AIR MASSES.—The moisture content of air masses that originate over land is low at all altitudes in the winter. The distinction between air masses almost disappears during the summer because of the nearly uniform surface conditions over the arctic and subpolar regions. The frozen surface thaws under the influence of lengthened or continual daylight, the snow melts from the glaciers and pack ice, the ice melts in the lake areas in the Arctic, and the water areas of the polar basin increase markedly. Thus, the polar area becomes mild, humid, and semimaritime in character. Temperatures are usually between freezing and 50°F. Occasionally, strong disturbances from the south increase the temperature for short periods. Daily extremes, horizontal differences, and day-to-day variability are slight.

During the winter months, air masses are formed over areas that are completely covered by ice and snow. The air masses are characterized by very cold surface air and a large temperature inversion in the lowest few thousand feet. Since the amount of moisture the air can hold depends on the air temperature, the cold arctic air is very dry (low absolute humidity). The air mass that originates over oceans does not have a surface temperature inversion in the winter, the surface air temperature is warmer, and there is a corresponding increase in the moisture content of the air. It is during movement inland of moist air from the warmer waters that most of the rather infrequent arctic cloudiness and precipitation occurs during this season.

During the summer months, the large expanse of open water and warmer temperatures in the Arctic result in increased moisture. Consequently, the largest amount of cloudiness and precipitation occurs during these summer months.

ARCTIC FRONTS.—The weather associated with fronts in the Arctic has much the same cloud structure as with polar fronts, except that the middle and high cloud types are generally much lower, and the precipitation is usually in the form of snow.

Periods of maximum surface wind usually occur during and just after a frontal passage. This strong wind flow often creates hazards, such as blowing snow and turbulence, which make operational flying difficult.

The best flying weather in the Arctic over land usually occurs in midsummer and midwinter; the worst (low ceilings and visibility) is during the transitional periods between the two seasons. Winter is characterized by frequent storms and well-defined frontal passages, but because of the dryness of the air, cloudiness and precipitation are at a minimum. In the summer, there are fewer storm passages and fronts are weaker; however, the increased moisture in the air results in more widespread clouds and precipitation. Over the sea areas the summer weather is very foggy, but winds are of lower speeds than in the winter.

During the transitional periods of spring and fall, operational flying conditions are usually the worst. Frontal systems are usually well defined, active, and turbulent. Icing may extend to high levels.

TEMPERATURES IN THE ARCTIC.—Temperatures in the Arctic, as one might expect, are very cold most of the year. But contrary to common belief, the interior areas of Siberia, northern Canada, and Alaska have pleasantly warm summers with many hours of sunshine each day. There are large differences in temperature between the interior and coastal areas.

In the interior during the summer days, temperatures climb to the mid 60s or low 70s and frequently rise to the high 70s or low 80s, occasionally even into the 90s. Fort Yukon, Alaska, which is just north of the Arctic Circle, has recorded an extreme high temperature of 100°F, while Verkhoyansk in north central Siberia has recorded 94°F.

During the winter, the interior areas of Siberia, northern Canada, and Alaska act as a source region for the cold arctic air that frequently moves southward into the middle latitudes. The coldest temperatures on record over the Northern Hemisphere have been established in Siberia.

In the northern areas of the interior regions, temperatures are usually well below zero during the winter months. In fact, during these long periods of darkness and near darkness, the temperature normally falls to –20°F or –30°F, and in some isolated areas the normal daily minimum temperature may drop to –40°F. In north central Siberia the normal minimum daily temperature in the winter is between –45°F and –55°F.

The arctic coastal regions, which include the Canadian Archipelago, are characterized by relatively cool, short summers. During the summer months the temperatures normally climb to the 40s or low 50s and occasionally reach the 60s. There is almost no growing season along the coasts, and the temperatures may fall below freezing during all months of the year. At Point Barrow, Alaska, the minimum temperature rises above freezing on no more than about 42 days a year.

Over the Arctic Ocean, the temperatures are very similar to those experienced along the coast; however, the summer temperatures are somewhat lower. Winter temperatures along the Arctic coast are very low but not nearly as low as those observed in certain interior areas. Only on rare occasions does the temperature climb to above freezing during the winter months. The coldest readings for these coastal areas range between –60° and –70°F.

These figures may seem surprising. At first one might think that the temperatures near the North Pole would be lower than those over the northern continental interiors. Actually the flow of heat from the water under the ice has a moderating effect upon the air temperature along the coast.

CLOUDINESS.—Cloudiness over the Arctic is at a minimum during the winter and spring and at a maximum during the summer and fall, again due to the low-moisture capacity of cold air. The average number of cloudy days for the two 6-month periods on climatic charts shows a general decrease in cloudiness in the entire arctic area during the winter months. The greatest seasonal variation is found in the interior, and the least is found along the coasts.

During the warm summer afternoons in the interior regions, scattered cumulus form and occasionally develop into thunderstorms. The thunderstorms are normally widely scattered and seldom form continuous lines. Along the arctic coast and over the Arctic Ocean, thunderstorms occur infrequently. Although tornadoes have been observed near the Arctic Circle, their occurrence is extremely rare. In these areas, summers are quite cloudy, with stratiform clouds predominating.

Seasonal changes in cloudiness take place quite rapidly. Winters are characterized by extensive cloudiness in the coastal regions. These clouds are associated with migratory lows and generally disperse inland as the systems lose their moisture.

WINDS.—Wind speeds are generally light in the continental arctic interior throughout the year. The strongest winds in the interior normally occur during the summer and fall. During the winter, the interior continental regions are areas of strong anticyclonic activity that produce only light surface winds.

Strong winds occur more frequently along the arctic coast than in the continental interiors. The frequency with which these high winds occur in coastal areas is greater in the fall and winter than in the summer. These winds frequently cause blowing snow.

Very strong wind speeds have been observed at many arctic coastal stations. Strong winds are infrequent over the ice pack, but the wind blows almost continuously because there are no natural barriers (such as hills and mountains) to retard the wind flow. As a result, the combination of wind speed and low temperatures produces equivalent wind chill temperatures that are extreme and severely limit outdoor human activity.

PRECIPITATION.—Precipitation amounts are small, varying from 5 to 15 inches annually in the continental interior and 3 to 7 inches along the arctic coastal area and over the ice pack. The climate over the Arctic Ocean and adjoining coastal areas is as dry as some of the desert regions of the mid-latitudes. Most of the annual precipitation falls as snow on the Arctic Ocean and adjacent coastal areas and ice caps. On the other hand, most of the annual precipitation falls as rain over the interior.

RESTRICTION TO VISIBILITY.—Two factors make the visibility in the Polar Regions a very complex matter. Arctic air, being cold and dry, is exceptionally transparent, and extreme ranges of visibility are possible. On the other hand, there is a lack of contrast between objects, particularly when a layer of new snow covers all distinguishable objects. Limitations to visibility in the Arctic are primarily blowing snow, fog, and local smoke. Local smoke is serious only in the vicinity of larger towns and often occurs simultaneously with shallow radiation fogs of winter.

1. Blowing snow. Blowing snow constitutes a more serious hazard to flying operations in the Arctic than in mid-latitudes because the snow is dry and fine and is easily picked up by moderate winds. Winds in excess of 8 knots may raise the snow several feet off the ground, and the blowing snow may obscure surface objects such as runway markers.

2. Fog. Of all the elements that restrict flying in the Arctic regions, fog is perhaps most important. The two types of fog most common to the Polar Regions are advection fog and radiation fog.

Fog is found most frequently along the coastal areas and usually lies in a belt parallel to the shore. In the winter, the sea is warmer than the land, and relatively warm, moist air is advected over the cool land causing fog. This fog may be quite persistent. In the summer, warm, moist air is advected over sea ice, which is now melting, creating the same situation, which is found over land in winter.

3. Ice fog. A fog condition peculiar to Arctic climates is ice fog. Ice fog is composed of minute ice crystals rather than water droplets of ordinary fog and is most likely to occur when the temperature is about –45°C (–50°F) or colder but can occur when temperatures are as warm as -30°C (–20°F).

4. Sea smoke or steam fog. The cold temperatures in the Arctic can have effects, which seem peculiar to people unfamiliar with the area. During the winter months, the inability of the air to hold moisture results in an unusual phenomenon called sea smoke. Open bodies of comparatively warm water existing simultaneously with low air temperature cause this. Actually, this phenomenon is similar to that of steam forming over hot water.

In the case of sea smoke, the temperatures of both the air and the water are quite low, but the air temperature is still by far the lower of the two, causing steam to rise from the open water to form a fog layer. This fog occurs over open water, particularly over leads (navigable passages) in the ice pack and is composed entirely of water droplets.

5. Arctic haze. This is a condition of reduced horizontal and slant visibility (but good vertical visibility) encountered by aircraft in flight over arctic regions. Color effects suggest this phenomenon to be caused by very small ice particles. Near the ground, it is called arctic mist or frost smoke; when the sun shines on the ice particles, they are called diamond dust.

ARCTIC WEATHER PECULIARITIES.—The strong temperature inversions present over the Arctic during much of the winter causes several interesting phenomena. Sound tends to carry great distances under these inversions. On some days, when the inversion is very strong, human voices can be heard over extremely long distances as compared to the normal range of the voice. Light rays are bent as they pass through the inversion at low angles. This may cause the appearance above the horizon of objects that are normally below the horizon. This effect, known as *looming,* is a form of mirage. Mirages of the type that distort the apparent shape of the Sun, Moon, or other objects near the horizon are common under inversion conditions.

One of the most interesting phenomena in the Arctic is aurora borealis (northern lights). These lights are by no means confined to the Arctic but are brightest at the arctic locations. Their intensity varies from a faint glow on certain nights to a glow, which illuminates the surface of the Earth with light almost equal to that of the light from a full moon. The reactions resulting in the auroral glow have been observed to reach a maximum at an altitude of approximately 300,000 feet.

The amount of light reflected from a snow-covered surface is much greater than the amount reflected from the darker surfaces of the middle latitudes. As a result, useful illumination from equal sources is greater in the Arctic than in lower latitudes. When the sun is shining, sufficient light is often reflected from the snow surface to nearly obliterate shadows. This causes a lack of contrast, which, in turn, results in an inability to distinguish outlines of terrain or objects even at short distances. The landscape may merge into a featureless grayish-white field. Dark mountains in the distance may be easily recognized, but a crevasse immediately ahead may be obscured by the lack of contrast. The situation is even worse when the unbroken snow cover is combined with a uniformly overcast sky and the light from the sky is about equal to that reflected from the snow cover. In this situation, all sense of depth and orientation is lost in what appears to be a uniformly white glow; the term for this optical phenomenon is *whiteout.*

Pilots have reported that the light from a half-moon over a snow-covered field is sufficient for landing aircraft at night. It is possible to read a newspaper on occasions by the illumination from a full moon in the Arctic. Even the illumination from the stars creates visibility far beyond what one would expect elsewhere. It is only during periods of heavy cloud cover that the night darkness begins to approach the degree of darkness in lower latitudes. In lower latitudes, south of 65° north latitude, there are long periods of moonlight, since the Moon may stay above the horizon for several days at a time.

Antarctic Weather

Many of the same peculiarities prevalent over the arctic regions are also present in the Antarctic. For instance, the aurora borealis has its counterpart in the Southern Hemisphere, called aurora australis. The same restrictions to visibility exist over the Antarctic regions as over the Arctic. Some other characteristics of the Antarctic regions are as follows:

Precipitation occurs in all seasons, with the maximum occurring in summer. The amount of precipitation decreases poleward from the coast. Temperatures are extremely low. The lowest temperature in the world, –127°F, was recorded at Vostok, Antarctica. In the winter, temperatures decrease from the coast to the pole, but there is some doubt that this is true in the summer. The annual variation of temperature as indicated by Macmurdo station shows the maximum in January and the minimum in early September. A peculiar, and to date unexplained, feature of Antarctic temperature variations during the Antarctic night is the occurrence of maximum temperatures on cloudless days in the early hours after midnight. On cloudy days, however, the day is warmer than the night.

UNITED STATES WEATHER

The weather in the United States, with minor exceptions, is typical of all weather types within the temperate regions of the North American, European, and Asiatic continents. The general air circulation in the United States, as in the entire Temperate Zone of the Northern Hemisphere, is from west to east. All closed surface weather systems (highs and lows) tend to move with this west-to-east circulation. However, since this is only the average circulation and weather systems move with the general flow, the fronts associated with the migratory lows also tend to move southward if they are cold fronts and northward if they are warm fronts. Surface low-pressure centers, with their associated weather and frontal systems, are referred to as cyclones. Knowledge of the mean circulation in the temperate region makes it possible to observe and plot average storm tracks and to forecast future movement with a reasonable degree of accuracy.

Certain geographical and climatic conditions tend to make specific areas in the United States favorable for the development of low-pressure systems such as west Texas, Cape Hatteras, central Idaho, and the northern portions of the Gulf of Mexico. Once a low has formed, it generally follows the same mean track as the last low that formed in that area. The averages, or mean paths, are referred to as storm tracks.

These storms (lows) are outbreaks on the polar front or the generation or regeneration of a storm along the trailing edge of an old front. The low pressure along these fronts intensifies in certain areas as the front surges southward ahead of a moving mass of cold polar air. Much of the weather, especially the winter weather, in the Temperate Zone is a direct result of these storms.

Air-mass weather also affects temperate climates. Air-mass weather is the name given to all weather other than the frontal weather in the temperate region. Air-mass weather is the net effect of local surface circulation, terrain, and the modifying effect of significant water bodies.

There are many subdivisions of weather regions in the United States. For the purpose of this discussion, we have divided the continental United States into seven regions as indicated in figure 6-9.

Northwest Pacific Coast Area

The northwest pacific coast area has more precipitation than any other region in North America. Its weather is primarily the result of frontal phenomena, consisting mainly of occlusions, which move in over the coast from the area of the Aleutian low and orographic lifting of moist, stable maritime air. Predominant cloud forms are stratus and fog, which are common in all seasons. Rainfall is most frequent in the winter and least frequent in the summer.

Southwest Pacific Coast Area

The southwest pacific coast area experiences a Mediterranean-type climate and is distinctively different from any other North American climate. This climate occurs exclusively in the Mediterranean and southern California in the Northern Hemisphere. In the Southern Hemisphere, it occurs over small areas of Chile, South Africa, and southern Australia.

This climate is characterized by warm to hot summers, tempered by sea breezes, and by mild winters during which the temperatures seldom go below freezing. Little or no rainfall occurs in the summer and only light to moderate rain in the winter.

Cold fronts rarely penetrate the southwest pacific coast region. The weather over this region is due to the circulation of moist pacific air from the west being forced up the slope of the coastal range. In the summer, air is stable, and stratus and fog result. In the winter, unstable air, which is forced over the mountain ranges causes showers or snow, showers in the mountains.

Intermountain West Central Area

The intermountain west central area includes the Great Plains region. This region is located east of the Cascade and coastal ranges, west of the Mississippi Valley, and north of the southwest desert area. The climate is generally cold and dry in the winter, and warm and dry in the summer. Most of the region is

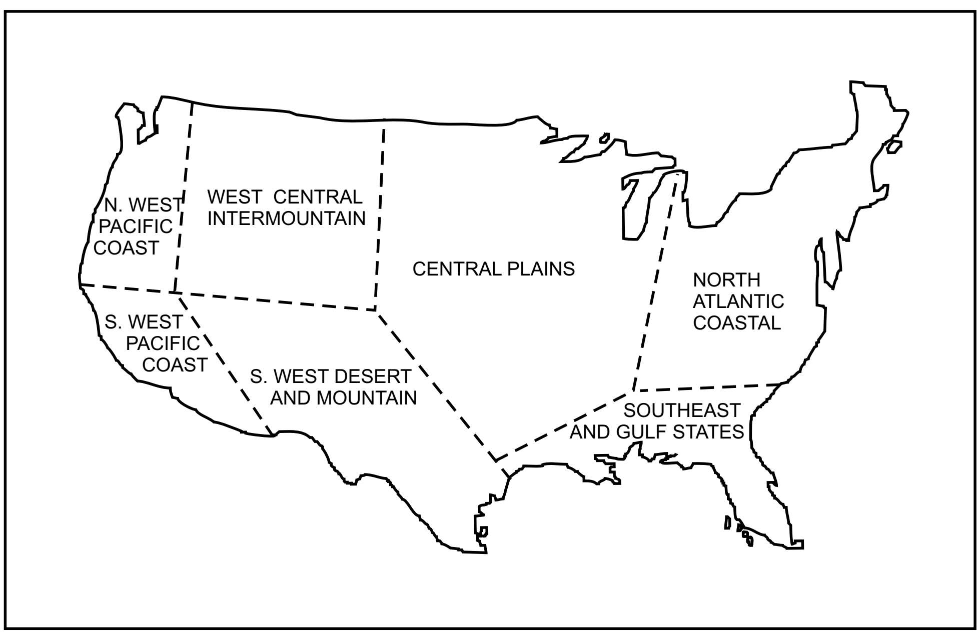

Figure 6-9.—United States weather regions.

semiarid. The western mountain range, which acts as a climatic barrier, has an extreme drying effect on the air in the westerly circulation.

Maximum rainfall occurs in the spring and is due mainly to the predominance of cyclonic storm passages during this season. In midwinter a cold high is generally centered in this region which prevents the possibility of storm passages. Annual precipitation is normally light.

Southwest Desert and Mountain Area

The southwest desert and mountain area includes Lower California and some of southeast California as well as the southern portions of Arizona, New Mexico, and Texas. It is an area almost completely surrounded by high mountains and is either very arid or actual desert. Annual rainfall seldom exceeds 5 inches. The more northerly sections have cold winters, and all parts have extremely hot summers. The chief flying hazard results from a predominance of summer and spring thunderstorms caused mainly by maritime tropical air being forced aloft at the mountains. For this reason nearly all significant peaks and ranges have thundershowers building over them in the spring and summer. The thunderstorms are generally scattered and are almost always severe; however, pilots can usually avoid them by circumnavigating them.

Central Plains Area

The Central Plains area includes the continental climate regions of the Great Plains, Mississippi Valley, and Appalachian Plateau between the Rocky Mountains to the west, the Appalachians to the east, and the Gulf States to the south. The western section is generally drier than the eastern section. Wintertime outbreaks and associated wave phenomena along polar fronts cause the main weather hazards. Convective air-mass thunderstorms, which are prevalent over this area in summer, also pose a threat to flying.

Frontal passages, both cold and warm, and associated weather is common in this area. Thunderstorms are usually of convective origin and are most violent if they have developed in maritime tropical air. This occurs often in the spring, and tornado activity becomes a climatic feature due to its frequency.

Southeast and Gulf States Area

The southeast and Gulf States area includes all the states bordering on the Gulf of Mexico as well as South Carolina and Georgia. Stagnating southbound cold fronts, rapidly moving squall lines, air-mass thunderstorms, and stratus clouds occur in various combinations to make this area an especially complex one for the forecaster.

Frontal passages can be expected only in the late fall, winter, and early spring. A circulation phenomenon known as gulf stratus affects this area. In the winter, when the circulation near the surface is southerly, the warm, moist gulf air is cooled from below to saturation. When this occurs, fog and the gulf stratus may form and may persist over the area for several days. The southerly circulation in summer causes warm, moist air to be heated from below, and convective thunderstorms are common. Since the air is generally quite moist and unstable, these storms are generally severe.

North Atlantic Coastal Area

The North Atlantic coastal area is an area of storm track convergence, and cyclonic storm activity is frequent in winter. Moreover, the heating and addition of moisture to the air intensify these storms over the Great Lakes. The lake effect is directly accountable for the large amounts of snowfall often found over this area in the winter. Generally good weather prevails in summer due to the predominant influence of the Bermuda high.

EUROPEAN WEATHER

Most of Europe has a relatively mild climate, which is largely due to its oceanic exposure to the north, west, and south. The east-west orientation of the mountains in Europe normally prevents extremely cold arctic air from penetrating southward to the Mediterranean. As a result, very cold weather is limited to the northern limits. The southern coast and Mediterranean countries enjoy moderate temperatures year round because relatively warm maritime air masses move inland from the Atlantic and because of the moderating influence of the Mediterranean Sea. However, this inflow of maritime air also brings frequent cloudiness, considerable precipitation, and high humidity.

When continental air masses dominate, Europe is subjected to low-temperature extremes, low humidity, and clear skies much the same as North America. This is especially true north of the Alpine Mountains. South of this region, somewhat normal migratory patterns do exist. The end result is relatively dry summers and wet winters characteristic of the western coastal region of North America and Canada.

Temperatures are highest in Europe during the summer; Athens, Greece averages 80°F; Granada, Spain 77°F; Greenwich, England 63°F; and Paris, France 65°F. Farther north, summer temperatures average as much as 20 to 25 degrees less. During the winter, the Mediterranean temperatures average in the upper 40°F to low 50°F range while the extreme northern sections average 10°F or less. The Atlantic coastal countries with their predominantly maritime climates maintain far less temperature extremes between summer and winter.

Precipitation in the form of rain and drizzle is common along the European Atlantic coast and near the Mediterranean Sea. Snow does occur at times in areas east of Spain and north of the Mediterranean Sea. At higher elevations inland, snow is common and frequently abundant. Central Spain and southern Russia, by contrast, experience semiarid and arid climates.

ASIATIC WEATHER

Asia's climate is predominantly continental. The only exceptions are the heavily populated coastal areas that have tropical and maritime climates during the summer. This primarily continental climate results in limited precipitation and large temperature ranges both daily and seasonally.

Asia is a huge continent with large expanses of land extending far northward. The Himalaya Mountains stretch across the southern portion in an east-west direction; mountains also parallel the eastern coast. These geographical features often contain continental arctic and polar air inland, resulting in the most extreme temperature ranges found in the Northern Hemisphere. Northeastern Siberia's temperatures often range from –60°F in the winter to above 60°F in the summer. Extremes range as high as 98°F and as low as –90°F. The large interior of Asia also results in extreme pressure difference. In the winter, a cold high-pressure area dominates the continent. In the summer, a warm low-pressure area dominates the continent. This accounts for the northeast winter monsoons and southwest summer monsoons.

In the winter the interior is dry, receiving less than 1 inch of precipitation. Coastal areas under maritime influence receive normal amounts (about 8 inches) of precipitation. In the summer, precipitation is plentiful except well inland. Rain is so abundant in some regions, such as India, that the yearly rainfall average (425 inches or more) is among the highest in the world.

The extreme south and southeast regions of Asia differ sharply from its northern neighbors. These southern regions enjoy the tropical and maritime climates that feature only minor seasonal temperature variations. Eastern Asia enjoys a climate very similar to that found along the eastern coast of North America from the Florida Keys to eastern Canada. East and Southeast Asia, like the eastern and southeastern United States, is also subject to an occasional tropical cyclone (typhoon) in the summer and in the fall.

SOUTH AMERICAN WEATHER

South America has a variety of climates but lacks the severe weather of North America. Continental polar air does not exist here because the continent tapers sharply from north to south. The larger northern area is close to the equator and does not experience the influx of cold maritime polar air from the south. Tropical climates prevail over much of the continent. Yet, due to the high Andes Mountains along the western coast, there are areas that are extremely dry and others that are extremely wet.

Northeastern Climate

The South American northeast's climate consists mainly of high temperature and humidity and copious rainfall throughout the year. September is the warmest month with average temperatures of around 82°F. January is the coolest month with average temperatures of around 79°F. Nighttime temperatures rarely fall below 65°F. Rainfall averages 87 inches annually with 12 inches falling in June and just over 2 inches falling in October. The higher elevations of northeastern South America have greater ranges of temperature, humidity, and precipitation; however, these ranges are not extreme.

Southern Climate

In the southern region, below 200 south latitude, South America has distinct seasons very similar to those in the southeastern United States. These seasons, however, are reversed. The warmest month is January, which averages 74°F; July, which averages 49°F is the coolest month. Precipitation occurs fairly evenly throughout the year and averages 38 inches. There is no distinct rainy season.

Below 40° south latitude, the climate is progressively drier and cooler. However, the extreme southern tip of South America is characterized by year round cold and damp climate due to a strong maritime influence.

West Coast Climate

The West Coast, from northern Peru to the middle of Chile, is a desert. North and south of this desert midsection, the climate is quite humid. The northwest coast has a typical tropical climate with wet and dry seasons.

Below central Chile, the climate again shows a typical Southern Hemisphere seasonal reversal of that found in North America. The weather in this region is similar to that found along the northwest coast of North America. The climate is generally rainy and cool. Summer does not seem to exist as we know it. Yet, winter temperatures average above freezing.

AFRICAN WEATHER

Africa's climate is unlike that of any other continent for several reasons. The most important is the fact that the entire continent is within the tropical zone. The equator bisects the continent; therefore, in the area north and south of the equator, the climates are similar, yet they differ because the region north of the equator is much larger than the southern region. Since the northern area is so broad in the east-west direction, maritime effects inland are minimal. Also, an extensive low-pressure area develops inland due to extreme land mass heating. A belt of high pressure, however, with its maritime influences dominates the southern section, during winter and by low pressure during summer.

Another factor is the cold currents, which exist along its western shores. These currents allow an influx of cool winds and associated weather to the West Coast. The final factor involves the lack of high mountain ranges common to other continents. Since there are no prominent mountain ranges, the various climate types in Africa blend together, showing no sharp distinctions.

The most important climatic element in Africa is precipitation. Precipitation is greatest near the equator (60 to 80 inches to over 120 inches in places). It decreases sharply to the north (less than 10 inches), and decreases gradually south of the equator (average of 20 to 40 inches). Because Africa is in the tropical zone, the precipitation belt of the intertropical convergence zone (ITCZ) moves with the seasons. This belt of precipitation moves northward in the summer and southward in the winter. Africa does have distinct climatic regions. Air-mass movement and influences allow for a division of eight climatic regions.

Northern Region

The northern region includes the great Sahara desert. The desert is a source region for dry continental-type air masses. While maritime air may transit the area, the air masses are highly modified and often exhibit continental properties after moving inland. This desert region is extremely hot during the day throughout the year but is very cool at night due to a lack of moisture; hence, strong radiational cooling.

Southwestern Region

The southwest region is an arid to semiarid area, which is known as the Kalahari Desert. The temperatures are not as extreme as in the Sahara because the land area involved is much smaller.

North Central Region

The north central region is a semiarid area located along the edge of the Sahara. While the temperatures are similar to those of the neighboring desert (50°F in winter to well above 80°F in summer), this area occasionally gets precipitation in the winter. The source of this precipitation for the northern area is maritime air from the Mediterranean; in the south, it is the spotty rainfall provided by the meandering ITCZ.

Sub-Equatorial Region

The sub-equatorial region extends toward the equator from the semiarid region in the north. The region is marked by seasonal rainfall associated with the position of the ITCZ. The region is wet for about 5 months (Nov-Mar), and dry during the rest of the year. Temperatures show little seasonal variation (68°F to 86°F) because of the close proximity to the equator. The only exception to this temperature stability occurs in the western portion which, during the winter, is occasionally influenced by cool weather from the north.

Equatorial Region

The equatorial region includes the southwest tip of northern Africa and the region between 5° north and south latitudes, extending from the western coast to Lake Victoria. It is the wettest climate in all Africa.

These areas have two distinct rainy seasons associated with the northward and southward movement of the ITCZ. Rainfall averages over 120 inches annually in some areas. Throughout the rest of the year, precipitation remains plentiful because of the influx of maritime air from the west. There are no significant mountains in the region to prevent this maritime air from migrating inland. Temperatures are moderate year round.

Southeast Coastal Region

The southeast coastal region has a humid subtropical climate. This region has rainfall all year (45 inches on the average) and temperatures remain generally moderate all year, ranging from an average maximum of 72°F in winter (July) to 89°F in summer (January).

Southeastern Interior Region

This region has a wet-and-dry type of maritime climate; however, it is considered temperate because of the lower temperatures common to the higher elevation.

AUSTRALIA AND NEW ZEALAND WEATHER

Australia has a generally mild climate with cool winters in the south and warm winters in the north. Summers are warm along the coasts and generally hot in the interior. Freezing temperatures are infrequent. Australia's climatic zones are relatively uncomplicated due to the lack of high mountain ranges.

The northern third of Australia is located within the tropical zone. The region has a rainy season that runs from January to April. Annual precipitation is greatest (nearly 100 inches) in the extreme north and tapers off to the south and inland toward the semiarid interior. The interior, along the Tropic of Capricorn, is very hot and dry in the summer with average maximum temperatures at or above 90°F. In the winter, average maximum temperatures in some areas drop to 68°F.

The southern two-thirds of Australia is under the influence of the high-pressure belts of the Southern Hemisphere as well as of the migratory lows found farther southward. The southwest and southern portions of this region have rainy winters and near-drought conditions in the summer similar to the Mediterranean climate. Temperatures average 80°F in January and 55°F in July. The climate of the southeast corner is very similar to the southwest region except it experiences a shorter winter and less annual precipitation.

New Zealand is located southeast of Australia. It is a very narrow country with a southwest to northeast orientation and is exposed to the prevailing westerlies. Therefore, the climate is moderate and predominantly maritime with moderate precipitation occurring throughout the year. The northern part of New Zealand has a subtropical climate; however, winter frost and occasional snow can occur at locations farther south in highland areas. Fog is often widespread and very persistent over much of the country in advance of approaching frontal systems. Precipitation averages 49 inches in the northern half of the country and up to 170 inches in the southern half. Temperatures range from an annual average of 59°F in the north and 55°F in the central region to 50°F in the south.

REVIEW QUESTIONS

Q6-17. *What are the two climatic extremes that relate to water and land distribution over the earth?*

Q6-18. *What region in the United States experiences Mediterranean type climate?*

Q6-19. *What is the major cause of the winter and summer monsoons near Asia?*

Q6-20. *Why does South America lack the severe weather that is common in North America?*

APPENDIX I

GLOSSARY

ABSOLUTE INSTABILITY—The state of a column of air in the atmosphere when it has a superadiabatic lapse rate of temperature. An air parcel displaced vertically would be accelerated in the direction of the displacement.

ABSOLUTE STABILITY—The state of a column of air in the atmosphere when its lapse rate of temperature is less than the saturation adiabatic lapse rate. An air parcel will be denser than its environment and tend to sink back to its level of origin.

ADVECTION—The horizontal transport of an atmospheric property solely by the mass motion (velocity field) of the atmosphere.

ADVECTION FOG—Fog caused by the advection of moist air over a cold surface, and the consequent cooling of that air to below its dew point.

AIR MASS—A widespread body of air that is approximately homogeneous in its horizontal extent, with reference to temperature and moisture.

ANABATIC WIND—An upslope wind; usually applied only when the wind is blowing up a hill or mountain as the result of surface heating.

ANTARCTIC FRONT—The semi permanent, semi continuous front between the Antarctic air of the Antarctic Continent and the polar air of the southern oceans; generally comparable to the arctic front of the Northern Hemisphere.

ANTICYCLOGENESIS—The strengthening or development of an anticyclonic circulation in the atmosphere.

ANTICYCLOLYSIS—The weakening of an anticyclonic circulation in the atmosphere.

ANTICYCLONE—A closed circulation in the atmosphere that has a clockwise rotation in the Northern Hemisphere and a counterclockwise rotation in the Southern Hemisphere. Used inter-changeably with *high.*

ANTICYCLONIC—Refers to the rotation pattern of anticyclones. See ANTICYCLONE.

ARCTIC FRONT—The semi permanent, semi continuous front between the deep, cold arctic air and the shallower, basically less cold polar air of northern latitudes; generally comparable to the Antarctic front of the Southern Hemisphere.

AUTOCONVECTIVE LAPSE RATE—The temperature lapse rate in an atmosphere where density is constant with height.

BACKING—A change in wind direction in a counterclockwise manner in the Northern Hemisphere and a clockwise manner in the Southern Hemisphere.

BLOCKING HIGH—An anticyclone that re-mains stationary or moves slowly westward so as to effectively block the movement of migratory cyclones across its latitudes.

BUYS BALLOT'S LAW—The law describing the relationship of horizontal wind direction to pressure: In the Northern Hemisphere, with your back to the wind, the lowest pressure will be to your left; in the Southern Hemisphere, the reverse is true.

CENTER OF ACTION—Any one of the semi permanent high or low-pressure systems.

CENTRAL PRESSURE—The atmospheric pressure at the center of a high or low; the highest pressure in a high, the lowest in a low.

CHROMOSPHERE—A thin layer of relatively transparent gases above the photosphere of the Sun.

CLOSED HIGH—A high that is completely encircled by an isobar or contour line.

CLOSED LOW—A low that is completely encircled by an isobar or contour line.

COLD-CORE HIGH—Any high that is generally characterized by colder air near its center than around its periphery at a given level in the atmosphere.

COLD-CORE LOW—Any low that is generally characterized by colder air near its center than around its periphery at a given level in the atmosphere.

CONDENSATION—The physical process by which a vapor becomes a liquid or solid.

CONDITIONAL INSTABILITY—The state of a column of air in the atmosphere when its temperature lapse rate is less than the dry adiabatic lapse rate but greater than the saturation adiabatic lapse rate.

CONVECTION—Atmospheric motions that are predominantly vertical, resulting in the vertical transport and mixing of atmospheric properties.

CORONA—(1) A set of one or more prismatically colored rings of small radii, concentrically surrounding the disk of the Sun, Moon, or other luminary when veiled by a thin cloud. A corona maybe distinguished from the relatively common 22° halo by its color sequence, which is from blue inside to red outside, the reverse of that of the 22° halo. Diffraction and reflection of light from water droplets produce coronas. (2) The pearly outer envelope of the Sun.

COUNTERRADIATION—(also called back radiation) The downward flow of atmospheric radiation passing through a given level surface, usually taken as Earth's surface. It is the principal factor in the GREENHOUSE EFFECT.

CUT-OFF HIGH—A warm high displaced and lying poleward of the basic westerly current.

CUT-OFF LOW—A cold low displaced and lying equatorward of the basic westerly current.

CYCLOGENESIS—Any development or strengthening of cyclonic circulation in the atmosphere. The initial appearance of a low or trough, as well as the intensification of an existing cyclonic flow.

CYCLOLYSIS—Any weakening of cyclonic circulation in the atmosphere.

CYCLONIC—A counterclockwise rotation in the Northern Hemisphere and a clockwise rotation in the Southern Hemisphere.

DISPERSION—The process in which radiation is separated into its component wavelengths. It results when an optical process, such as diffraction, refraction, or scattering, varies according to wavelength. All of the coloration displayed by atmospheric optical phenomena are the result of dispersion.

DOLDRUMS—A nautical term for the equatorial trough, with special reference to the light and variable nature of the winds.

DOWNWIND—The direction toward which the wind is blowing; with the wind.

DRY AIR—In atmospheric thermodynamics and chemistry, air that contains no water vapor.

ELECTROMAGNETIC WAVES—Disturbances in electric and magnetic fields in space or in material media, resulting in the propagation of electromagnetic energy (radiation).

EQUINOX—(1) Either of the two points of intersection of the Sun's apparent annual path and the plane of Earth's equator. (2) Popularly, the time at which the Sun passes directly above the equator; the "time of the equinox." In the Northern Hemisphere, the vernal equinox falls on or about 21 March, and the autumnal equinox on or about 22 September. These dates are reversed in the Southern Hemisphere.

EVAPORATION—The physical process by which a liquid or solid is transformed to the gaseous state.

FRONT—The interface or transition zone between two air masses of different density. Since temperature distribution is the most important regulator of atmospheric density, a front almost invariably separates air masses of different temperature.

FRONTAL INVERSION—A temperature inversion in the atmosphere, encountered upon vertical ascent through a sloping front.

FRONTAL SURFACE—Refers specifically to the warmer side of the frontal zone.

FRONTAL SYSTEM—Simply, a system of fronts as they appear on a synoptic chart. This is used for (a) a continuous front and its characteristics along its entire extent, including its warm, cold, stationary, and occluded sectors, its variations of intensity, and any frontal cyclones along it; and (b) the orientation and nature of the fronts within the circulation of a frontal cyclone.

FRONTAL ZONE—The transition zone between two adjacent air masses of different densities bounded by a frontal surface.

FRONTOGENESIS—The initial formation of a front or frontal zone.

FRONTOLYSIS—The dissipation of a front or frontal zone.

GENERAL CIRCULATION—(also called planetary circulation) In its broadest sense, the complete statistical description of atmospheric motions over Earth.

GEOSTROPHIC FLOW—A form of gra-dient flow where the Coriolis force exactly balances the horizontal pressure force.

GEOSTROPHIC WIND The wind velocity for which the Coriolis acceleration exactly balances the horizontal pressure force. The geostrophic wind is directed along the contour lines on a constant-pressure surface (or along the isobars in a geopotential surface) with low pressure to the left in the Northern Hemisphere and to the right in the Southern Hemisphere.

GEOSTROPHIC-WIND SCALE—A graphical device used for the determination of the speed of the geostrophic wind from the isobar or contour line spacing on a synoptic chart.

GRADIENT—The space rate of decrease of a function. It is often used to denote the magnitude of pressure change in the horizontal pressure field.

GRADIENT WIND—Any horizontal wind velocity tangent to the contour line of a constant-pressure surface (or the isobar of a geopotential surface) at the point in question. At such points, where the wind is gradient, the Coriolis acceleration and centripetal acceleration together exactly balance the horizontal pressure force.

GRAVITY WIND—(also called drainage wind; sometimes called katabatic wind) A wind (or component thereof) directed down the slope of an incline and caused by greater air density near the slope (caused by surface cooling) than at the same levels some distance horizontally from the slope.

GREENHOUSE EFFECT—The heating effect exerted by the atmosphere upon Earth by virtue of the fact that the atmosphere (mainly, its water vapor) absorbs and re-emits infrared radiation. In detail: The shorter wavelengths of insolation are transmitted rather freely through the atmosphere to be absorbed at Earth's surface. Earth then re-emits this as long-wave (infrared) terrestrial radiation, a portion of which is absorbed by the atmosphere and again emitted as atmospheric radiation. The water vapor (cloud cover) acts in the same way as the glass panes of a greenhouse; the heat gained during the day is trapped beneath the cloud cover, and the counter-radiation adds to the warming of Earth.

HALO—Any one of a large class of atmospheric optical phenomena (luminous meteors) that appear as colored or whitish rings and arcs about the Sun or Moon when seen through an ice crystal cloud or in a sky filled with falling ice crystals. The halos experiencing prismatic coloration are produced by refraction of light by the ice crystals, and those exhibiting only whitish luminosity are produced by reflection from the crystal faces.

HEAT BALANCE—The equilibrium, which exists on the average, between the radiation received by Earth and its atmosphere and that emitted by Earth and its atmosphere.

HEATING DEGREE-DAY—A form of degree-day used as an indication of fuel consumption; in United States usage, one heating degree-day is given for each degree that the daily mean temperature departs below the base of 65°F.

HEAT TRANSFER—The transfer or ex-change of heat by radiation, conduction, or convection in a fluid and/or between the fluid and its surroundings. The three processes occur simultaneously in the atmosphere, and it is often difficult to assess the contributions of their various effects.

HIGH—An "area of high pressure," refer-ring to a maximum of atmospheric pressure in two dimensions (closed isobars) on the synoptic surface chart, or a maximum of height (closed contours) on the constant-pressure chart. Highs are associated with anticyclonic circulations, and the term is used interchangeably with anticyclone.

HORSE LATITUDES—The belts of latitude over the oceans at approximately 30 to 35 degrees north and south where winds are predominantly calm or very light and the weather is hot and dry.

ICELANDIC LOW—The low-pressure center located near Iceland (mainly between Iceland and southern Greenland) on mean charts of sea-level pressure. It is a principal center of action in the atmospheric circulation of the Northern Hemisphere.

INACTIVE FRONT—(or passive front) A front or portion thereof that produces very little cloudiness and no precipitation, as opposed to an active front.

INFERIOR MIRAGE—A spurious image of an object formed below the true position of that object by abnormal refractive conditions along the line of sight; one of the most common of all types of mirage, and the opposite of a superior mirage.

INSOLATION—(contracted from *incoming solar radiation*) In general, solar radiation received at Earth's surface.

INSTABILITY—A property of the steady state of a system such that certain disturbances or perturbations introduced into the steady state will increase in magnitude, the maximum perturbation amplitude always remaining larger than the initial amplitude.

INSTABILITY LINE—Any non-frontal line or band of convective activity in the atmosphere.

INVERSION—The departure from the usual decrease or increase with altitude of the value of an atmospheric property. The layer through which this departure occurs is known as the inversion layer, and the lowest altitude at which the departure is found is known as the base of the inversion. The term is almost always used in reference to temperature, but may be applied to moisture and precipitation.

KATABATIC WIND—Any wind blowing down an incline; the opposite of anabatic wind. If the wind is warm, it is called a foehn; if cold, it may be a fall or gravity wind.

KINETIC ENERGY—The energy that a body possesses as a consequence of its motion, defined as the product of one-half of its mass and the square of its speed, 1/2mv squared.

LAND BREEZE—A coastal breeze blowing from land to sea, caused by the temperature difference when the sea surface is warmer than the adjacent land.

LAPSE RATE—The decrease of an atmospheric variable with height, the variable being temperature, unless otherwise specified.

LATERAL MIRAGE—A very rare type of mirage in which the apparent position of an object appears displaced to one side of its true position.

LIGHT—Visible radiation (about 0.4 to 0.7 micron in wavelength) considered in terms of its luminous efficiency.

LOOMING—A mirage effect produced by greater-than-normal refraction in the lower atmosphere, thus permitting objects to be seen that are usually below the horizon.

LOW—An "area of low pressure," refer-ring to a minimum of atmospheric pressure in two dimensions (closed isobars) on a constant-height chart or a minimum of height (closed contours) on a constant-pressure chart. Lows are associated with cyclonic circulations, and the term is used interchangeably with *cyclone.*

MACROCLIMATE—The general large-scale climate of a large area or country, as distinguished from the mesoclimate and microclimate.

MAGNETIC NORTH—At any point on Earth's surface, the horizontal direction of the Earth's magnetic lines of force (direction of a magnetic meridian) toward the north magnetic pole, i.e., a direction indicated by the needle of a magnetic compass. Because of the wide use of the magnetic compass, magnetic north, rather than TRUE NORTH, is the common 0° (or 360°) reference in much of navigational practice, including the designation of airport runway alignment.

MARITIME AIR—A type of air whose characteristics are developed over an extensive water surface and which, therefore, has the basic maritime quality of high moisture content in at least it's lower levels.

MEAN SEA LEVEL—The average height of the sea surface, based upon hourly observation of tide height on the open coast or in adjacent waters which have free access to the sea. In the United States, mean sea level is defined as the average height of the surface of the sea for all stages of the tide over a 19-year period.

MESOCLIMATE—The climate of small areas of Earth's surface that may not be representative of the general climate of the district. The places considered in mesoclimatology include small valleys, "frost hollows," forest clearings, and open spaces in towns, all of which may have extremes of temperature differing by many degrees from those of adjacent areas. The mesoclimate is intermediate in scale between the microclimate and microclimate.

MESOPAUSE—The top of the mesosphere. This corresponds to the level of minimum temperature at 70 to 80 km.

MESOSPHERE—The atmospheric shell between about 20 km and about 70 or 80 km, ex-tending from the top of the stratosphere to the upper temperature minimum (the menopause). A broad temperature maximum at about 50 km characterizes it, except possibly over the winter polar regions.

METEOROLOGY—The study dealing with the phenomena of the atmosphere. This includes not only the physics, chemistry, and dynamics of the atmosphere, but is extended to include many of the direct effects of the atmosphere upon Earth's surface, the oceans, and life in general.

MICROCLIMATE—The fine climate structure of the air space that extends from the very surface of Earth to a height where the effects of the immediate character of the underlying surface no longer can be distinguished from the general local climate (mesoclimate or microclimate).

MIGRATORY—Moving; commonly applied to pressure systems embedded in the wastrels and, therefore, moving in a general west-to-east direction.

MILLBRAE—(abbreviated MB) A pressure unit of 1,000 dynes per centimeter, convenient for reporting atmospheric pressures.

MIRAGE—A refraction phenomenon wherein an image of some object is made to appear displaced from its true position.

MOISTURE—A general term usually refer-ring to the water vapor content of the atmosphere, or to the total water substance (gas, liquid, and solid) present in a given volume of air.

MONSOON—A name for seasonal wind. It was first applied to the winds over the Arabian Sea, which blow for 6 months from the northeast and 6 months from the southwest, but it has been extended to similar winds in other parts of the world.

MONSOON CLIMATE—The type of climate that is found in regions subject to monsoons. It is best developed on the fringes of the tropics.

NEUTRAL STABILITY—The state of an unsaturated or saturated column. of air in the atmosphere when its environmental lapse rate of temperature is equal to the dry-adiabatic lapse rate or the saturation-adiabatic lapse rate, respectively. Under such conditions a parcel of air displaced vertically will experience no buoyant acceleration.

OCCLUDED FRONT—(commonly called occlusion; also called frontal occlusion) A composite of two fronts, formed as a cold front overtakes a warm front or quasi-stationary front. This is a common process in the late stages of wave cyclone development, but it is not limited to occurrence within a wave cyclone.

OCCLUSION—Same as OCCLUDED FRONT.

OROGRAPHIC LIFTING—The lifting of an air current caused by its passage up and over mountains.

OVERRUNNING—A condition existing when an air mass is in motion aloft above another air mass of greater density at the surface. This term is usually applied in the case of warm air ascending the surface of a warm or quasi-stationary front.

PARTIAL PRESSURE—The pressure of a single component of a gaseous mixture, according to Dalton's Law.

PERTURBATION—Any departure introduced into an assumed steady state of a system. In synoptic meteorology, the term most often refers to any departure from zonal flow within the major zonal currents of the atmosphere. It is especially applied to the wave-like disturbances within the tropical easterlies.

PHOTOSPHERE—The intensely bright portion of the Sun visible to the unaided eye. It is a shell a few hundred miles in thickness marking the boundary between the dense interior gases of the Sun and the more diffuse cooler gases in the outer portions of the Sun.

PLANETARY BOUNDARY LAYER—(also called friction layer or atmospheric boundary layer) That layer of the atmosphere from Earth's surface to the geostrophic wind level, including therefore, the surface boundary layer and the Eckman layer.

PLANETARY CIRCULATION—The sys-tem of large-scale disturbances in the troposphere when viewed on a hemispheric or worldwide scale. Same as GENERAL CIRCULATION.

POLAR AIR—A type of air whose characteristics are developed over high latitudes, especially within the subpolar highs. Continental polar air (cP) has low surface temperature, low moisture content, and, especially in its source regions, great stability in the lower layers. It is shallow in comparison with arctic air.

POLAR EASTERLIES—The rather shallow and diffuse body of easterly winds located poleward of the subpolar low-pressure belt. In the mean in the Northern Hemisphere, these easterlies exist to an appreciable extent only north of the Aleutian low and Icelandic low.

POLAR FRONT—According to the polar-front theory, the semi permanent, semi continuous front separating air masses of tropical and polar origin. This is the major front in terms of air mass contrast and susceptibility to cyclonic disturbance.

POLAR-FRONT THEORY—A theory originated by the Scandinavian school of meteorologists whereby a polar front, separating air masses of polar and tropical origin, gives rise to cyclonic disturbances, which intensify and travel along the front, passing through various phases of a characteristic life history.

POLAR OUTBREAK—The movement of a cold air mass from its source region; almost invariably applied to a vigorous equatorward thrust of cold polar air, a rapid equatorward movement of the polar front.

POLAR TROUGH—In tropical meteorology, a wave trough in the wastrels having sufficient amplitude to reach the tropics in the upper air. At the surface it is reflected as a trough in the tropical easterlies, but at moderate elevations it is characterized by westerly winds. It moves generally from west to east and is accompanied by considerable cloudiness at all levels. Cumulus congests and cumulonimbus clouds are usually found in and around the trough lines. The early and late season hurricanes of the western Caribbean frequently form in polar troughs.

POTENTIAL ENERGY—The energy that a body possesses as a consequence of its position in the field of gravity; numerically equal to the work required to bring the body from an arbitrary standard level, usually taken as mean sea level, to its given position.

PRE-FRONTAL SQUALL LINE—A squall line or instability line located in the warm sector of a wave cyclone, about 50 to 300 miles in advance of the cold front, usually oriented roughly parallel to the cold front and moving in about the same manner as the cold front.

PRESSURE CENTER—On a synoptic chart, a point of local minimum or maximum pressure; the center of a low or high. It is also a center of cyclonic or anticyclonic circulation.

PRESSURE GRADIENT—The rate of decrease (gradient) of pressure in space at a fixed time. The term is sometimes loosely used to denote simply the magnitude of the gradient of the pressure field.

PRESSURE GRADIENT FORCE—The force due to differences of pressure within a fluid mass. In meteorological literature the term usually refers only to horizontal pressure force.

PRESSURE PATTERN—The general geo-metric characteristics of atmospheric pressure distribution as revealed by isobars on a constant-height chart, usually the surface chart.

PRESSURE SYSTEM—An individual cyclonic scale feature of atmospheric circulation; commonly used to denote either a high or low, less frequently a ridge or trough.

PRIMARY CIRCULATION—The prevailing fundamental atmospheric circulation on a planetary scale that must exist in response to (a) radiation differences with latitude, (b) the rotation of Earth, and (c) the particular distribution of land and oceans; and which is required from the viewpoint of conservation of energy.

PROMINENCE—A filament-like Protuberance from the chromosphere of the Sun.

QUASI-STATIONARY FRONT—(Commonly called stationary front) A front that is stationary or nearly so. Conventionally, a front that is moving at a speed less than about 5 knots is generally considered to be quasi-stationary. In synoptic chart analysis, a quasi-stationary front is one that has not moved appreciably from its position on the last (previous) synoptic chart (3 or 6 hours before).

RADIATION—(1) The process by which electromagnetic radiation is propagated through free space by virtue of joint undulatory variations in the electric and magnetic fields in space. This concept is to be distinguished from convection and conduction. (2) The process by which energy is propagated through any medium by virtue of the wave motion of that medium, as in the propagation of sound waves through the atmosphere, or ocean waves along the water surface.

RADIATIONAL COOLING—The cooling of Earth's surface and adjacent air, accomplished (mainly at night) whenever Earth's surface suffers a net loss of heat due to terrestrial radiation.

RADIATION FOG—A major type of fog, produced over a land area when radiational cooling reduces the air temperature to or below its dew point.

RAINBOW—Any one of a family of circular arcs consisting of concentric colored bands, arranged from red on the inside to blue on the outside, which may be seenona‘‘sheet” of water drops (rain, fog, or spray).

REDUCTION—In general, the transforma-tion of data from a "raw" form to some usable form. In meteorology, this often refers to the con-version of the observed value of an element to the value that it theoretically would have at some selected or standard level, usually mean sea level. The most common reduction in observing is that of station pressure to sea level pressure.

REFLECTION—The process whereby a surface of discontinuity turns back a portion of the incident radiation into the medium through which the radiation approached.

REFLECTIVITY—A measure of the fraction of radiation reflected by a given surface; defined as the ratio of the radiant energy reflected to the total that is incident upon that surface. The reflectivity of a given surface for a specified broad spectral range, such as the visible spectrum or the solar spectrum, is referred to as albino.

REFRACTION—The process in which the direction of energy propagation is changed as the result of a change in density within the propagating medium, or as the energy passes through the interface representing a density discontinuity between two media.

RESULTANT WIND—In climatology, the vectorial average of all wind directions and speeds for a given level at a given place for a certain period, as a month. It is obtained by resolving each wind observation into components from north and east, summing over the given period, obtaining the averages, and reconverting the average components into a single vector.

SCATTERING—The process by which small particles suspended in a medium of a different index of refraction diffuse a portion of the incident radiation in all directions.

SEA BREEZE—A coastal local wind that blows from sea to land, caused by the temperature difference when the sea surface is colder than the adjacent land. Therefore, it usually blows on relatively calm, sunny, summer days; and alternates with the oppositely directed, usually weaker, night land breeze.

SEA-BREEZE FRONT—A sea breeze that forms out over the water, moves slowly toward the coast and then moves inland quite suddenly. Often associated with the passage of this type of sea breeze are showers, a sharp wind shift from seaward to landward, and a sudden drop in temperature. The leading edge of such a sea breeze is sometimes called the sea breeze front.

SEA LEVEL—The height or level of the sea surface.

SEASON—A division of the year according to some regularly recurrent phenomena, usually astronomical or climatic. Astronomical seasons extend from an equinox to the next solstice (or vice versa). Climatic seasons are often based on precipitation (rainy and dry seasons).

SECONDARY CIRCULATION—Atmos-pheric circulation features of synoptic scale.

SECONDARY FRONT—A front that forms within a baroclinic cold air mass that itself is separated from a warm air mass by a primary frontal system. The most common type is the secondary cold front.

SHEAR—The variation (usually the directional derivative) of a vector field along a given direction in space. The most frequent context for this concept is wind shear.

SHEAR LINE—A line or narrow zone across which there is an abrupt change in the horizontal wind component parallel to this line; a line of maximum horizontal wind shear.

SHORT-WAVE RADIATION—A term used loosely to distinguish radiation in the visible and near-visible portions of the electromagnetic spectrum (roughly 0.4 to 1.0 micron in wavelength) from long-wave radiation.

SIBERIAN HIGH—A cold-core high--pressure area that forms over Siberia in winter, and which is particularly apparent on mean charts of sea-level pressure.

SINGULAR POINT—In a flow field, a point at which the direction of flow is not uniquely determined, hence a point of zero speed, e.g., a col.

SMOOTHING—An averaging of data in space or time, designed to compensate for random errors or fluctuations of a scale smaller than that presumed significant to the problem at hand; the analysis of a sea-level weather map smoothes the pressure field on a space-scale more or less systematically determined by the analyst by taking each pressure as representative not of a point but of an area about the point.

SOLAR CONSTANT—The rate at which solar radiation is received outside Earth's at-mosphere on a surface normal to the incident radiation, and at Earth's mean distance from the Sun.

SOLSTICE—(1) Either of two points on the Sun's apparent annual path where it is displaced farthest, north or south, from Earth's equator. The Tropic of Cancer (north) and Tropic of Capricorn (south) are defined as the parallels of latitude that lie directly beneath a solstice. (2) Popularly, the time at which the Sun is farthest north or south; the "time of the solstice." In the Northern Hemisphere, the summer solstice falls on or about 21 June, and the winter solstice on or about 22 December. The reverse is true in the southern latitudes.

SPECIFIC HEAT—The heat capacity of a system per unit mass. That is, the ratio of the heat absorbed (or released) by unit mass of the system to the corresponding temperature rise (or fall).

SPECIFIC HUMIDITY—In moist air, the ratio of the mass of water vapor to the total mass of the system. For many purposes it may be approximated by the mixing ratio.

SQUALL LINE—Any non-frontal line or narrow band of active thunderstorms.

STANDARD ATMOSPHERE—A hypothetical vertical distribution of atmospheric temperature, pressure, and density which, by international agreement, is taken to be representative of the atmosphere for purposes of pressure altimeter calibrations, aircraft performance calculations, aircraft and missile design, ballistic tables, etc. The air is assumed to obey the perfect gas law and the hydrostatic equation, which, taken together, relate temperature, pressure, and density variations in the vertical. It is further assumed that the air contains no water vapor and that the acceleration of gravity does not change with height.

STRATOSPHERE—The atmospheric shell above the troposphere and below the mesosphere. It extends, therefore, from the tropopause to the height where the temperature begins to increase in the 20- to 25-km region.

SUBLIMATION—The transition of a substance from the solid phase directly to the vapor phase, or vice versa, without passing through an intermediate liquid phase.

SUBSIDENCE—A descending motion of air in the atmosphere, usually with the implication that the condition extends over a rather broad area.

SUBSIDENCE INVERSION—A temperature inversion produced by the adiabatic warming of a layer of subsiding air. Vertical mixing of the air layer below the inversion enhances this inversion.

SUBTROPICAL HIGH—One of the semi-permanent highs of the subtropical high-pressure belt. They appear as centers of action on mean charts of surface pressure. They lie over oceans and are best developed in summer.

SUBTROPICAL HIGH-PRESSURE BELT—One of the two belts of high atmospheric pressure that are centered, in the mean, near 30°N and 30°S latitudes.

SUNSPOT—A relatively dark area on the surface of the Sun, consisting of a dark central umbra surrounded by a penumbra, which is intermediate in brightness between the umbra and the surrounding photosphere.

SUPERADIABATIC LAPSE RATE—An environmental lapse rate greater than the dry-adiabatic lapse rate, such that potential temperature decreases with height.

SUPERCOOLING—The reduction of temperature of any liquid below the melting point of that substance's solid phase, that is, cooling beyond its nominal freezing point.

SUPERIOR AIR—An exceptionally dry mass of air formed by subsidence and usually found aloft but occasionally reaching Earth's surface during extreme subsidence processes.

SUPERIOR MIRAGE—A spurious image of an object formed above its true position by abnormal refractive conditions; opposite of *inferior mirage.*

SUPERSATURATION—The condition existing in a given portion of the atmosphere (or other space) when the relative humidity is greater than 100 percent, that is, when it contains more water vapor than is needed to produce saturation with respect to a plane surface of pure water or pure ice.

SURFACE BOUNDARY LAYER—That thin layer of air adjacent to Earth's surface, extending up to the so-called anemometer level (the height above the ground at which an anemometer is exposed; usually 10 meters to 100 meters).

SURFACE CHART—(also called surface map, sea-level chart, sea-level pressure chart) An analyzed synoptic chart of surface weather observations. It shows the distribution of sea level pressure (positions of highs, lows, ridges, and troughs) and the location and nature of fronts and air masses. Often added to this are symbols of occurring weather phenomena, analysis of pressure tendency (isallobars), indications of the movement of pressure systems and fronts, and perhaps others, depending on the use of the chart.

SURFACE INVERSION—A temperature in-version based at Earth's surface; that is, an in-crease of temperature with height beginning at ground level.

SURFACE OF DISCONTINUITY—A surface separating two fluids across which there is a discontinuity of some fluid property, such as density, velocity, etc., or of some derivative of one of these properties in a direction normal to the interface. An atmospheric front is represented ideally by a surface of discontinuity of velocity, density, temperature, and pressure gradient; the tropopause is represented ideally by a surface of discontinuity of, for example, the derivatives: lapse rate and wind shear.

SYNOPTIC—In general, pertaining to or affording an overall view. In meteorology, this term has become somewhat specialized in referring to the use of meteorological data obtained simultaneously over a wide area for the purpose of presenting a comprehensive and nearly instantaneous picture of the state of the atmosphere.

SYNOPTIC CHART—In meteorology, any chart or map on which data and analyses are presented that describe the state of the atmosphere over a large area at a given moment in time.

SYNOPTIC SCALE—The scale of the migratory high- and low-pressure systems (or cyclonic waves) of the lower troposphere, with wavelengths of 1,000 to 2,500 km.

SYNOPTIC SITUATION—The general state of the atmosphere as described by the major features of synoptic charts.

TEMPERATURE INVERSION—A layer in which temperature increases with altitude.

TERTIARY CIRCULATION—The generally small, localized atmospheric circulations. They are represented by such phenomena as the local winds, thunderstorms, and tornadoes.

THERMAL—(1) Pertaining to temperature or heat. (2) A relatively-small-scale rising current of air produced when the atmosphere is heated enough locally by Earth's surface to produce absolute instability in its lower layers. The use of this term is usually reserved to denote those currents either too small and/or too dry to produce convective clouds; thus, thermals are a common source of low-level clear-air turbulence.

THERMAL GRADIENT—The rate of variation of temperature either horizontally or vertically.

THERMAL HIGH—An area of high pressure resulting from the cooling of air by a cold underlying surface, and remaining relatively stationary over the cold surface.

THERMAL LOW—An area of low atmospheric pressure resulting from high temperatures caused by intense surface heating. They are stationary with a generally weak and diffuse cyclonic circulation. They are non-frontal.

THERMOSPHERE—The atmospheric shell extending from the top of the mesosphere to outer space. It is a region of more or less steadily increasing temperature with height, starting at 70 or 80 km.

TORNADO—A violently rotating column of air, pendant from a cumulonimbus cloud, and nearly always observable as a "funnel cloud" or tuba.

TRIPLE POINT—Term commonly used to denote the apex of an occlusion.

TROPICAL AIR—A type of air whose characteristics are developed over low latitudes. Maritime tropical air (mT) is produced over the tropical and subtropical seas, while continental tropical air is produced over subtropical arid regions.

TROPOPAUSE—The boundary between the troposphere and stratosphere, usually characterized by an abrupt change of lapse rate.

TROPOSPHERE—That portion of Earth's atmosphere extending from the surface to the tropopause; that is, the lowest 10 to 20 km of the atmosphere.

TROUGH—An elongated area of low atmospheric pressure; the opposite of a ridge.

TRUE NORTH—The direction from any point on Earth's surface toward the geographic North Pole; the northerly direction along any projection of Earth's axis upon Earth's surface, for example, along a longitude line. Except for much of navigational practice (which uses magnetic north), true north is the universal 0° (or 360°, mapping reference).

UPSTREAM—In the direction from which a fluid is flowing.

UPWIND—In the direction from which the wind is blowing.

VECTOR—Any quantity, such as force, velocity, or acceleration, that has both magnitude and direction at each point in space, as opposed to a scalar, which has magnitude only. Geometrically, it is represented by an arrow of length proportional to its magnitude, pointing in the assigned direction.

VEERING—A change in wind direction in a clockwise sense in the Northern Hemisphere and counterclockwise direction in the Southern Hemisphere.

VERNAL EQUINOX—For either hemisphere, the equinox at which the Sun's most direct rays approach from the opposite hemisphere. In northern latitudes, this occurs approximately on 21 March; the Sun's most direct rays are centered over the equator and moving north.

VIRTUAL TEMPERATURE—In a system of moist air, the temperature of dry air having the same density and pressure as the moist air. It is always greater than the actual temperature.

WARM-CORE HIGH—At a given level in the atmosphere, any high that is warmer at its center than at its periphery.

WARM-CORE LOW—At a given level in the atmosphere, any low that is warmer at its center than at its periphery.

WARM FRONT—Any non-occluded front or portion thereof that moves in such a way that warmer air replaces colder air.

WARM SECTOR—That area within the circulation of a wave cyclone where the warm air is found. It lies between the cold front and the warm front of the storm; and, in the typical case, the warm sector continually diminishes in size and ultimately disappears (at the surface) as the result of occlusion.

WAVE CYCLONE—A cyclone that forms and moves along a front.

WAVE THEORY OF CYCLONES—A theory of cyclone development based upon the principles of wave formation on an interface between two fluids. In the atmosphere, a front is taken as such an interface.

WEATHER—The state of the atmosphere, mainly with respect to its effect upon life and human activities.

WESTERLIES—(also known as circumpolar westerlies, counter-trades, middle-latitude westerlies, midlatitude westerlies, polar westerlies, subpolar westlies, subtropical westerlies, temperate westerlies, zonal westerlies, and zonal winds) Specifically, the dominant west-to-east motion of the atmosphere, centered over the middle latitudes of both hemispheres. At the surface, the westerly belt extends, on the average, from about 35° to 65° latitude. At upper levels, the westerlies extend farther equatorward and poleward. The equatorward boundary is fairly well defined by the subtropical high-pressure belt; the poleward boundary is quite diffuse and variable.

WIND-CHILL FACTOR—The cooling effect of any combination of temperature and wind, expressed as the loss of body heat, in kilogram calories per hour per square meter of skin surface. The wind-chill: factor. is based on the cooling rate of a nude body in the shade; It is only an approximation, because of individual body variations in shape, size, and metabolic rate.

WIND ROSE—Any one of a class of diagrams designed to show the distribution of wind direction experienced at a given location over a considerable period; it thus shows the prevailing wind direction. The most common form consists of a circle from which 8 or 16 lines emanate,one for each compass point. The length of each line is proportional to the frequency of wind from that direction, and the frequency of calm conditions is entered in the center.

WINTER SOLSTICE—For either hemisphere, the solstice at which the Sun is above the opposite hemisphere. In northern latitudes, the time of this occurrence is approximately 22 December.

APPENDIX II

ANSWERS TO REVIEW QUESTIONS

CHAPTERS 1 THROUGH 6

CHAPTER 1

A1-1. The metric (CGS centimeter-gram-second) system measures length, weight and time respectively.

A1-2. Weight is a function of gravitational force. Mass is a function inertia/acceleration.

A1-3. A dyne is a measure of force.

A1-4. Sunspots are regions of strong localized magnetic fields and indicate relatively cool areas in the photosphere.

A1-5. The Southern Hemisphere receives the greatest amount of incoming solar radiation around December 22.

A1-6. Land and water surfaces absorb 51 percent of the earth's insolation.

A1-7. An air column over the poles is thinner than an air column over the equator.

A1-8. Pressure is the force per unit area.

A1-9. With a sea level pressure reading of 1000 MB, the approximate pressure at 18,000 ft will be 500 MB.

A1-10. Temperature change has the biggest effect on pressure change.

A1-11. Temperature is the measure of molecular motion.

A1-12. 20 degrees C converted to Fahrenheit is 68 degrees.

A1-13. The earth's meteorological atmospheric zones in ascending order are the troposphere, tropopause, stratosphere, stratopause, mesosphere, mesopause, thermosphere, and the exosphere.

A1-14. The four methods of heat transfer are conduction, advection, convection, and radiation.

A1-15. Advection is the horizontal transport of heat.

A1-16. The three states in which moisture in the atmosphere is found are solid, liquid and gaseous.

A1-17. The primary sources of atmospheric moisture are the oceans.

A1-18. The difference between relative humidity and absolute humidity is that relative humidity is the ratio (in percent) between the water vapor actually present and the water vapor necessary for saturation at a given temperature. Absolute humidity is the amount of water vapor present per unit volume of space.

A1-19. The mixing ratio is defined as the ratio of the mass of water vapor to the mass of dry air.

A1-20. The dew point is the temperature that the air must be cooled, at a constant pressure and constant water vapor content, in order for saturation to occur.

CHAPTER 2

A2-1. Speed is the rate at which something moves in a given amount of time.

A2-2. The amount of work done is the product of the magnitude of the force and the distance moved. W=F·d.

A2-3. The two types of forces that AGs deal with are contact force and action at a distance forces.

A2-4. The two basic particles that make up the composition of matter are the atom and the molecule.

A2-5. The correct formula for density is $D = \frac{M}{V} = (\text{or } D = M \div V)$*, whereas the density equals the mass divided by its volume.*

A2-6. Fusion is the change of state from a solid to a liquid at the same temperature.

A2-7. The behavior of gases depend on the variations in temperature, pressure, and density.

A2-8. According to Boyle's Law, the volume of a gas is inversely proportional to its pressure, provided the temperature remains constant.

A2-9. According to Charles' Law, if the volume of an enclosed gas remains constant, the absolute temperature is directly proportional to the pressure.

A2-10. The universal gas law states that the product of the initial pressure, initial volume, and new temperature (absolute scale) of an enclosed gas is equal to the product of the new pressure, the new volume and the initial temperature. PVT' = P'V'T

A2-11. The two basic kinds of atmospheric energy important to AGs are kinetic energy and potential energy.

A2-12. The definition of lapse rate is the rate of decrease in the value of any meteorological element with elevation.

A2-13. The dry adiabatic lapse rate is 5 1/2°F per 1,000 feet, or 1°C per 100 meters.

A2-14. The two types of conditional instability are real latent and pseudolatent.

CHAPTER 3

A3-1. The length of day and the angle of the Sun's rays influences the Earth's temperature.

A3-2. The unequal heating of Earth's surface due to it's tilt, rotation, and differential insolation, results in the wide distribution of pressure over Earth's surface.

A3-3. The rotation of Earth causes a force that affects thermal circulation, causing it to be deflected to the right of the direction of movement in the northern hemisphere.

A3-4. According to the 3-cell theory, Earth is divided into six circulation belts.

A3-5. According to the 3-cell theory, subsidence or high pressure is usually found at 30 degrees north latitude.

A3-6. The trade winds are the predominant winds in the tropics.

A3-7. Two types of pressure gradients are horizontal and vertical.

A3-8. The difference between centripetal force and centrifugal force is that centripetal force is directed toward the center of rotation, and centrifugal force is directed outward from the center of rotation.

A3-9. The difference between gradient wind and geostrophic wind is that gradient wind flow is parallel to the curved portion of the analysis. Geostrophic wind is the windflow that is parallel to that portion of the analysis showing straight flow.

A3-10. The relationship between centrifugal force and pressure gradient force around anticyclones is that the centrifugal force acts with the pressure gradient force.

A3-11. Anticyclogenesis is the term defined as the formation of an anticyclone or the intensification of an existing one.

A3-12. The direction of windflow around a cyclone is counterclockwise in the northern hemisphere.

A3-13. The temperatures in a cold core low decrease toward the center.

A3-14. Low pressure due to intense heating in the southwestern United States is an example of a warm core low.

A3-15. Monsoon winds are caused by the unequal heating and cooling of land and water surfaces.

A3-16. Land and sea breezes are caused by the diurnal (daily) contrast in the heating of local water and land areas.

A3-17. Bernoulli's theorem states that pressures are least where velocities are greatest, and pressures are greatest where velocities are least.

A3-18. A valley breeze usually reaches it's maximum strength in the early afternoon.

A3-19. An eddy is caused when the wind flows over or adjacent to rough terrain, buildings, mountains or other obstructions.

A3-20. Foehn winds are caused by adiabatic heating of descending air on the lee sides of mountains.

CHAPTER 4

A4-1. An air mass is a body of air extending over a large area (usually 1,000 miles or more across).

A4-2. The two primary factors necessary to produce an air mass are a surface whose properties are relatively uniform and a large divergent flow.

A4-3. Maritime tropical air that is colder than the surface over which it is moving is written as mTk.

A4-4. The modifying factors on air mass stability are thermodynamic and mechanical.

A4-5. Superior air is the warmest air mass observed in the United States at its altitude.

A4-6. A frontal surface is the surface that separates the air masses.

A4-7. The frontal zone is located between the air masses of different densities.

A4-8. The difference between a stable wave and an unstable wave is that a stable wave neither develops nor occludes. An unstable wave develops along the polar front and usually occludes.

A4-9. Frontogenesis occurs where there is a concentration of isotherms with the circulation to sustain that concentration.

A4-10. The polar front in winter is usually found off east coasts of continents between 30 and 60 degrees latitude.

A4-11. The pressure tendency with the passage of a slow moving cold front is indicated by a steady or unsteady fall prior to frontal passage, followed by weak rises after passage.

A4-12. The slope of a fast moving cold front is usually 1:40 to 1:80 miles.

A4-13. Prefrontal squall lines form about 50 to 300 miles in advance of fast-moving cold fronts.

A4-14. The average speed of a warm front is usually between 10 and 20 knots.

A4-15. The cloud types in advance of a warm front, in order, are cirrus, cirrostratus, altostratus, nimbostratus, and stratus.

A4-16. The difference between warm and cold occlusions is that warm occlusions form when the air in advance of the warm front is colder than the air to the rear of the cold front. A cold occlusion forms when the cold air in advance of a warm front is warmer than the cold air to the rear of the cold front.

A4-17. The most violent weather associated with an occlusion occurs near the apex or tip of the occlusion.

A4-18. When a stationary front moves, the speed is normally less than 5 knots.

A4-19. The weather associated with an unstable stationary front depends on the frontal slope. Severe thunderstorms and heavy rain showers usually occur with steep slopes. Broad or extensive areas of showers, fog, and reduced visibility occur with shallow slopes.

A4-20. The modifications of fronts are caused by movement and orographic effects.

A4-21. When a cold front moves off the eastern coast of the United States, it intensifies and waves develop along the frontal boundary.

CHAPTER 5

A5-1. Rain is precipitation that reaches the ground as water droplets and the droplet size measures .5 mm or greater. Drizzle is very small and appears to float with the air currents and the droplet size measures less than .5 mm.

A5-2. The altitude range of cloud occurrence in the tropics is from sea level to 60,000 feet.

A5-3. The altitude range of middle clouds, in the temperate regions, is from 6,500 to 25,000 feet.

A5-4. Sea fog occurs when the wind brings moist, warm air over a colder ocean current. Steam fog is caused by saturation of the air through the evaporation of water, when cold air moves over warm water.

A5-5. Blowing spray occurs when the water droplets are lifted in such quantities that they reduce visibility to six miles or less at eye level.

A5-6. Haze appears as a bluish tinge when viewed against a dark background and a dirty yellow or orange tinge when viewed against a bright background. Smoke appears as a reddish tinge when viewed against the solar disk during sunrise and sunset.

A5-7. Dust devils are usually observed on clear, hot afternoons in desert regions.

A5-8. The two sources of light are natural and artificial.

A5-9. Natural light is received from the sun and electric lamps, fire, or fluorescent tubes produce artificial light.

A5-10. Reflection occurs when light waves that are neither transmitted nor absorbed, but are thrown back from the surface of the medium they encounter. Refraction occurs when a ray of light passes at an oblique angle from one transparent substance into another substance of different density.

A5-11. Mirages are images of objects that are made to appear displaced from their normal positions because of refraction.

A5-12. The diameter range of a mature thunderstorm cell is 1 to 6 miles.

A5-13. Rain is observed at the surface during the mature stage.

A5-14. A macroburst is a larger scale downburst with winds that can last 5 to 20 minutes with speeds that reach 130 knots. Microbursts are smaller scale downbursts with winds that last 2 to 5 minutes with speeds that may reach 130 knots.

A5-15. Two types of thunderstorms are air mass and frontal.

CHAPTER 6

A6-1. Climate is the average or collective state of Earth's atmosphere at any given location or area over a long period of time.

A6-2. Descriptive climatology is typically oriented in terms of geographic regions.

A6-3. Microclimatology is measured in small-scale areas such as golf courses or plowed fields.

A6-4. The most important climatic element is temperature.

A6-5. Wind is the climatic element that transports heat and moisture into a region.

A6-6. The mean or average is the climatological parameter that is determined by adding all values together and dividing by the number of values calculated.

A6-7. Absolute is the term that is usually applied to the extreme highest or lowest value ever recorded at a location.

A6-8. A degree day is the number of degrees the mean daily temperature is above or below a standard temperature base.

A6-9. The climatic belts or zones are the torrid or tropical zone, the two temperate zones, and the two polar zones.

A6-10. The three climatic classification types are C.W. Thornthwaite, W. Köppen, and G.T. Trewartha.

A6-11. The five climatic types according to Köppen are tropical rain, dry, warm temperate rainy, cool snow forest (Boreal), and polar.

A6-12. Latitude is the climatic control that has the biggest effect on climatic elements.

A6-13. Coastal areas assume the temperature characteristics of the land or water that is on their windward side. Therefore, in the middle latitudes, the western coast of the United States will normally receive maritime temperature characteristics from the Pacific Ocean, and the eastern coast will normally receive continental temperature characteristics from the mainland.

A6-14. Ocean currents transport heat by moving cold polar water equatorward into warmer waters and moving warm equatorial water poleward into cooler waters.

A6-15. Requests for climatic support should be made to the Oceanography Facility or Center in your chain of command. Requests that cannot be fulfilled are forwarded to FMOD Asheville, N.C.

A6-16. The Local Area Forecaster's Handbook contains climatic information for a particular weather station.

A6-17. The two climatic extremes that relate to water and land distribution are over Earth are maritime and continental.

A6-18. The southwest pacific coastal area experiences a Mediterranean-type climate.

A6-19. The cause of the summer monsoon is the major warm low-pressure center over Asia (Asiatic Low) during the summer, and the cause of the winter monsoon is the major cold high-pressure center over Asia during the winter (Siberian High).

A6-20. South America lacks the severe weather of its North American counterpart because of the absence of continental polar air. This is due to the tapering of the continent toward Antarctica.

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E

Assignment Questions

<u>Information</u>: The text pages that you are to study are provided at the beginning of the assignment questions.

ASSIGNMENT 1

Textbook Assignment: "Fundamentals of Meteorology"; "Atmospheric Physics." Chapters 1 and 2, Pages 1-1 through 2-11.

1-1. The metric (cgs) system has been adopted by meteorologists to measure units of

1. gravity, density, and force
2. length, weight, and time
3. centimeters, grams, and seconds
4. circular motion, gravity, and speed

1-2. Approximately how many inches are there in 25 centimeters?

1. 0.984 in.
2. 9.840 in.
3. 98.400 in.
4. 984.000 in.

1-3. Weight and mass are synonymous, except one is English and the other metric.

1. True
2. False

1-4. A dyne is a measure of

1. length
2. force
3. area
4. density

1-5. Earth receives the majority of its heat from the Sun. What percent is NOT received from the Sun?

1. 1.0 %
2. 0.1 %
3. 0.3 %
4. 0.5 %

1-6. What are solar winds?

1. Winds generated on Earth by the Sun's appearance above the horizon
2. Streams of solar particles emitted from the Sun's surface
3. Winds generated by the pressure differences between hot and cool spots on the Sun's surface
4. Interplanetary winds created by the constellations

1-7. What are sunspots?

1. Hot spots known as solar flares
2. Irregular bright patches on the Sun's surface
3. Areas where the convective zone is exposed
4. Regions of strong localized magnetic fields

1-8. It takes Earth approximately 365 1/4 days to circle the Sun. Approximately how many times will Earth rotate about its own axis during this time?

1. 15 1/4
2. 30 1/2
3. 182 1/2
4. 365 1/4

1-9. In the Southern Hemisphere, on or about what date will the greatest amount of incoming solar radiation be received?

1. January 21
2. March 21
3. June 21
4. December 22

1-10. The Sun's most direct rays reach their poleward limit twice in the year. What dates and names mark these occurrences?

1. March 21 and September 22; the spring and autumnal equinoxes
2. June 21 and December 22; the summer and winter equinoxes
3. March 21 and September 22; the spring and autumnal solstices
4. June 21 and December 22; the summer and winter solstices

1-11. Which of the following statements is/are correct concerning latitude 23 1/2 N?

1. It is known as the Tropic of Cancer
2. It is the northern extent of the Sun's most direct rays
3. It represents one-half of the total range of motion of the Sun's most direct rays
4. All of the above

1-12. The temperate zone in the Southern Hemisphere receives sunshine all year, but receives more sunshine when winter is being experienced in the Northern Hemisphere.

1. True
2. False

1-13. If the Sun's radiation (Earth's incoming solar radiation) was not dispersed or filtered, Earth would eventually become too hot for life to exist as we now know it. Which of the following factors plays the major role in dispersing Earth's insolation?

1. Scattering
2. Earth's inclination
3. Earth's rotation
4. Reflection

1-14. Earth's average albedo is between 36 and 43 percent. Which of the following terms most accurately defines albedo as it pertains to Earth and its atmosphere?

1. Sky cover
2. Scattering capability
3. Absorption capability
4. Reflective capability

1-15. What percentage of Earth's insolation is absorbed by land and water?

1. 13 %
2. 36 %
3. 43 %
4. 51 %

1-16. Through its atmosphere's ability to absorb and lose heat, Earth enjoys an average temperature of 15°C/59°F. If it failed to absorb short-wave radiation and radiate long-wave radiation, Earth's average temperature would be

1. -04°F
2. -04°C
3. -35°F
4. -35°C

1-17. The poles receive far less incident radiation than the equator. What is the effect on a polar air column in relation to a column of air over the equator?

1. It is more shallow and lighter
2. It is more shallow and heavier
3. It is thicker and heavier
4. It is thicker and lighter

1-18. Which of the following sea level pressure(s) is/are the standard used by the International Civil Aeronautical Organization?

1. 1013.25 millibars
2. 29.92 inches of mercury
3. 14.7 lbs. per square inch
4. All of the above

1-19. With a sea-level pressure reading of 1000 mb, one would expect the pressure at 18,000 feet to read

1. 200 mb
2. 300 mb
3. 500 mb
4. 750 mb

1-20. Pressure readings vary to the greatest degree with changes in

1. latitude
2. altitude
3. temperature
4. humidity

1-21. Convert 18° Celsius to Fahrenheit.

1. 85°F
2. 74°F
3. 64°F
4. 57°F

1-22. Convert 91° Fahrenheit to Celsius.

1. 27°C
2. 30°C
3. 33°C
4. 36°C

1-23. Minus 5° Celsius equates to what Kelvin (K) scale temperature?

1. 250°K
2. 268°K
3. 278°K
4. 283°K

1-24. Which of the following statements is/are correct concerning the troposphere?

1. Temperature inversions are not uncommon
2. Its thickness varies with latitude
3. Its thickness varies with the seasons
4. All of the above

1-25. For meteorological purposes, Earth's atmosphere is classified into zones or layers by its thermal structure. Working upward through the atmosphere, which of the following lists of zones is correct in its vertical order?

1. Troposphere, tropopause, mesosphere, mesopause
2. Troposphere, stratosphere, mesosphere, exosphere
3. Mesosphere, mesopause, thermosphere, exosphere
4. Stratosphere, mesosphere, exosphere, thermosphere

1-26. On some atmospheric soundings, it is sometimes possible to have more than one tropopause recorded.

1. True
2. False

1-27. The rise in temperature in the upper portion of the stratosphere is attributed to

1. the absence of water vapor
2. excessive amounts of water vapor
3. the presence of ozone
4. its relative closeness to the Sun

1-28. Which of the following zones marks the outer limit of Earth's atmosphere?

1. Mesosphere
2. Troposphere
3. Stratosphere
4. Exosphere

1-29. Which of the following zones is an electrical classification?

1. Exosphere
2. Mesosphere
3. Troposphere
4. Thermosphere

1-30. At night, the Earth's surface radiates some of the heat it gains during the day, and it cools. by what process does the layer of air in contact with the Earth's surface cool?

1. Radiation
2. Conduction
3. Convection
4. Advection

1-31. The specific heat of water is 1. What does 1 represent?

1. The temperature of the water
2. The calorie requirement to raise the temperature of 1 gram of water 1° Celsius
3. The weight of the substance used in the ratio
4. The time requirement (in minutes) to raise the temperature of 1 gram of water 1° Celsius

1-32. The horizontal transport of heat is known as

1. radiation
2. conduction
3. convection
4. advection

1-33. Earth's atmosphere is capable of holding more water vapor (water in its gaseous state) at which of the following latitudes?

1. 5°N
2. 30°N
3. 60°N
4. 80°N

1-34. Which of the following statements concerning saturation is correct?

1. Water vapor does not exist in a volume of the atmosphere that is saturated
2. To saturate air at the Earth's surface requires less water vapor per unit mass than at 500 mb.
3. The degree of saturation is dependent on pressure
4. If equal amounts of water vapor are injected into the atmosphere, saturation is more likely to occur in polar regions before it occurs in equatorial regions

1-35. Which of the following occurrences will result in the condensation of water vapor?

1. Air moved over a colder surface
2. Air lifted mechanically
3. Air-cooled by the radiational cooling process
4. Each of the above

1-36. Someone says that it is very humid outside (high relative humidity). What does this statement imply?

1. It is very hot out
2. Precipitation will occur
3. Water vapor content is diminished
4. The air is very moist

1-37. To determine the degree of saturation of the air, you must compute

1. absolute humidity
2. specific humidity
3. relative humidity
4. mixing ratio

1-38. In a given mass of dry air, the ratio of the mass of water vapor to the given mass of dry air is expressed in grams per gram or grams per kilogram and is known as the

1. mixing ratio
2. specific humidity
3. saturation mixing ratio
4. relative humidity

1-39. Under which of the following conditions will the specific humidity of unsaturated air change?

1. Temperature changes
2. Pressure changes
3. Air is compressed
4. Water vapor content changes

1-40. Knowing that the mixing ratio of a parcel of air is 6.3 g/kg and the saturation mixing ratio is 9.0 g/kg, what is the relative humidity of the parcel?

1. 56 %
2. 63 %
3. 70 %
4. 90 %

1-41. Which of the following statements concerning dew point is most correct?

1. Saturation only occurs if the air temperature is cooled to its dew point
2. Saturation only occurs if the air temperature is increased to its dew point
3. Saturation occurs if the air temperature is cooled to its dew point and there are corresponding changes in the pressure and water vapor content
4. Saturation occurs if the air temperature is cooled to its dew point and the pressure and water vapor content do not change

1-42. A tropical depression moved 360 nautical miles in 24 hours. This movement is referred to as

1. acceleration
2. speed
3. velocity
4. inertia

1-43. A low-pressure center is stationary over the south central North Atlantic Ocean for three days. On day four, the low moves 250 miles north. Which law of motion applies to the low's change in position?

1. Newton's first law
2. Newton's second law
3. Newton's third law
4. Dalton's law

1-44. A stationary high-pressure center begins to move, and in 12 hours, the upper-level winds move the center 60 nautical miles. What property did the high exhibit when it was stationary, and what was necessary to move it 60 nautical miles?

1. Acceleration and inertia
2. Inertia and acceleration
3. Inertia and work
4. Kinetic energy and potential energy

1-45. A destroyer is dead in the water. Which of the following forces is NOT acting upon the ship?

1. Gravity
2. A contact force
3. An at-a-distance force
4. A resultant force

1-46. A line that represents magnitude and direction is known as a

1. force
2. composite force
3. vector
4. contact force

1-47. Your ship is moving south (180°) at 15 knots, and the apparent wind reads 090 degrees at 05 knots. What is the true wind, and what name defines the forces used to compute it?

1. 160/16, component
2. 160/16, resultant
3. 340/20, component
4. 340/20, resultant

1-48. What two basic particles make up the composition of all matter?

1. The atom and molecule
2. The molecule and element
3. The compound and mixture
4. The element and atom

1-49. When elements and compounds exist together without forming new compounds, they are known as a

1. mixture
2. compound
3. compounded element
4. state

1-50. Which of the following forms of matter are called fluids?

1. Solids only
2. Liquids only
3. Gases only
4. Liquids and gases

1-51. Air density can be critical to a pilot whose aircraft must take of f on a short runway and/or whose aircraft is heavily loaded. Which, if any, of the following factors affects the density of the air at a given location?

1. Pressure only
2. Temperature only
3. Pressure and temperature
4. None of the above

1-52. What is the name given to heat that is given off or absorbed in a substance's change of state?

1. Energy
2. Fusion
3. Freezing
4. Latent

1-53. Water molecules in the oceans are more apt to move into the atmosphere at which of the following latitudes?

1. 5°S
2. 25°S
3. 25°N
4. 60°N

1-54. You are with someone who is wearing glasses in an air-conditioned space. When you leave the space and go outside into much warmer air, the person's glasses fog over. What process has taken place?

1. Evaporation
2. Condensation
3. Sublimation
4. Fusion

1-55. Just after reveille, you go up on deck and find the rails and outer bulkheads wet. There has been no precipitation or fog, and the winds and sea have been relatively calm. What do you attribute morning dampness to?

1. Humidity only
2. Humidity and condensation
3. Evaporation only
4. Humidity and evaporation

1-56. All cirriform clouds form through the process of sublimation.

1. True
2. False

1-57. Which, if any, of the following relationships concerning enclosed gases is correct?

1. Increasing the temperature decreases the pressure
2. Increasing the temperature and decreasing the volume decreases the pressure
3. Decreasing the volume decreases the pressure
4. None of the above

1-58. Boyle's law and the Universal gas law are very similar except

1. temperature is not considered in the Universal gas law
2. pressure is not considered in Boyle's law
3. the Universal gas law applies to the free atmosphere vice enclosed gases
4. Boyle's law is dependent on a constant temperature

1-59. The molecular weight of dry air is greater than moist air. How do their densities compare?

1. Moist air is more dense than dry air
2. Moist air is less dense than dry air
3. Moist air is occasionally more dense than dry air
4. Moist air and dry air do not differ in their density

1-60. What is/are the purpose(s) of the hypso-metric equation?

1. To reduce pressure
2. To determine the thickness between two layers
3. Both 1 and 2 above apply
4. To determine pressure and temperature variations

1-61. What is the approximate thickness of the 1000-500-mb layer when the layer has a mean temperature of -10°C?

1. 5,140 meters
2. 5,097 meters
3. 4,878 meters
4. 4,778 meters

ASSIGNMENT 2

Textbook Assignment: “Atmospheric Physics" (Continued); “Atmospheric Circulation.” Chapters 2 and 3, Pages 2-11 through 3-29.

2-1. When a parcel of air rises in the atmosphere, what happens to the parcel and the surrounding air?

1. The parcel expands due to lessening pressure, and its temperature, pressure, and density increase
2. The parcel contracts due to increasing pressure, and its temperature, pressure, and density decrease
3. The parcel expands due to lessening pressure, and its temperature, pressure, and density decrease
4. The parcel contracts due to lessening pressure, and its temperature, pressure, and density increase

2-2. With regards to Earth’s atmosphere, which of the following definitions pertains to temperature lapse rate?

1. The rate at which temperatures decrease or increase with altitude
2. The rate at which temperatures decrease at night
3. The rate of temperature decrease with latitude
4. The rate of temperature decrease horizontally

2-3. What is an inversion?

1. A decrease in temperature with height
2. An isothermal lapse rate
3. An increase in temperature due to subsidence
4. An increase in temperature with height

2-4. If a parcel of air is lifted and remains unsaturated, it will cool at which of the following rates?

1. 1°C per 100 meters
2. 2° or 3°C per 100 meters
3. 5°C per 100 meters
4. 10°C per 100 meters

2-5. When the actual lapse rate of a column of air is less than the dry adiabatic lapse rate but greater than the moist adiabatic lapse rate, what can we say about the air?

1. It is absolutely stable
2. It is absolutely unstable
3. It is conditionally stable, only
4. It may be conditionally stable or unstable

2-6. A maritime polar air mass moves into western Canada and is forced aloft by the mountains of British Columbia. Prior to being lifted by the mountains, the layer of air between 850 mb and 500 mb was guite moist up to 600 mb and dry above. What should you expect concerning the stability of this layer?

1. Instability to remain the same
2. Instability to decrease
3. Instability to increase
4. Stable conditions to prevail throughout the layer

2-7. Where would you most likely be able to determine the bases of convective clouds using surface temperatures and dew points?

1. Adak, AK
2. San Antonio, TX
3. San Diego, CA
4. South China Sea

2-8. Stratified cloud layers on the western slope of the Appalachian Mountains of Virginia would be an indication of which of the following conditions?

1. Little or no turbulence
2. Unstable air
3. Hazardous flying conditions along the mountains due to strong vertical currents
4. All of the above

2-9. The unequal heating of Earth’s surface is due to which of the following factors?

1. Its axis (inclination)
2. Its rotation
3. Differential isolation
4. All of the above

2-10. Incoming solar radiation is greatest at the equator and least at the poles. What affect, if any, does this have on the atmospheric pressure in these areas?

1. Pressure is high in both areas
2. Pressure is higher at the poles than at the equator
3. Pressure is lower at the poles than at the equator
4. Incoming solar radiation has no effect on pressure in these locations

2-11. If Earth did not rotate and its surface was uniform, in the Northern Hemisphere its surface winds would blow in what direction?

1. West to east
2. East to west
3. North to south
4. South to north

2-12. Coriolis force is an apparent force created by

1. temperature variations between the poles and equator
2. the tilt of the Earth's axis
3. the Earth's rotation
4. pressure variation between the poles and equator

2-13. How does Coriolis force affect moving objects?

1. It produces positive temperature changes on them
2. It lessens the pressure gradient on them
3. It increases and decreases their speed
4. It forces objects to the right of their intended path in the Northern Hemisphere

2-14. The three cells of the tri-cellular theory are the

1. tropical, subtropical, and polar
2. equatorial, subtropical, and polar
3. tropical, midlatitude, and polar
4. equatorial, midlatitude, and polar

2-15. The surface wind generated by the Earth's general circulation pattern is

1. westerly at all latitudes
2. northeasterly in the tropics and poleward of 60°N/S and westerly in the midlatitudes
3. northwesterly in the tropics and poleward of 60°N/S and westerly in the midlatitudes
4. northwesterly poleward of 60°N/S, northeasterly in the midlatitudes and easterly in the tropics

2-16. Which of the following regions feature(s) light and variable winds?

1. The doldrums
2. The horse latitudes
3. The regions near 30°N and 30°S
4. All of the above

2-17. What force moves air in a straight line from areas of high pressure to areas of low pressure?

1. Friction
2. Centrifugal
3. Pressure gradient
4. Coriolis

2-18. What is inferred from horizontal pressure gradients classified as flat or weak?

1. Isobars are closely spaced
2. Isobars are widely spaced
3. The winds are light
4. Both 2 and 3 above are correct

2-19. The latest upper-air sounding shows the 1000-700 mb layer over your station has decreased in thickness over the last 24 hours. What does this change in thickness tell you, if anything, about the vertical pressure gradient within this stratum?

1. It has increased
2. It has decreased
3. The gradient remains unchanged because the pressures have not changed
4. Nothing without height figures

2-20. Which of the following forces has the greatest effect on wind speed?

1. Centrifugal
2. Pressure gradient
3. Friction
4. Coriolis

2-21. Which of the following forces causes the wind to begin moving from areas of high pressure toward areas of low pressure?

1. Centrifugal
2. Pressure gradient
3. Friction
4. Coriolis

2-22. What effect does centrifugal force have on cyclonic circulation?

1. It forces air out away from the center
2. It pulls air toward the center
3. It pushes air toward the center
4. It forces air from high to low pressure

2-23. What effect, if any, does the wind speed have on the centrifugal force in a high-pressure system?

1. The higher the wind speed, the greater the force
2. The higher the wind speed, the smaller the force
3. The force is inversely proportional to the wind speed
4. None, the force is independent of the wind speed

2-24. Friction affects wind velocities at what levels?

1. The surface only
2. All levels
3. All levels up to the gradient level
4. The gradient level only.

2-25. At 40,000 feet, which of the following balance of forces causes the wind to blow parallel to curved isoheights?

1. The centrifugal force and Coriolis force are in balance
2. The centrifugal force and pressure gradient forces are in balance
3. The centrifugal and centripetal forces are balanced
4. The pressure gradient force and centripetal force are in balance

2-26. A low-pressure system over the Virginia Capes moves northeast without any changes occurring in the density of the air or to the pressure gradient. What happens to the gradient wind speed?

1. It decreases due to the easterly movement
2. It increases due to the northerly movement
3. It decreases due to the northerly movement
4. It remains the same

2-27. An extratropical low-pressure system is stationary 200 n. mi. south of Kainchatka. With the density of the air remaining the same and the pressure gradient decreasing, what happens to the gradient wind speed associated with this low?

1. It decreases
2. It increases
3. It remains the same
4. Both 2 and 3 are possible

2-28. Around high-pressure systems, Coriolis force opposes the

1. gradient force only
2. centrifugal force only
3. pressure gradient force and centrifugal force
4. centripetal force

2-29. Coriolis force always opposes the pressure gradient force around cyclones and anticyclones.

1. True
2. False

2-30. When measuring the gradient winds around low- and high-pressure systems using a geostrophic wind scale, how do geostrophic wind speeds compare to gradient wind speeds?

1. Geostrophic winds are stronger than the gradient winds around both systems
2. Geostrophic winds are weaker around lows and stronger around highs
3. Geostrophic winds are stronger around lows and weaker around highs
4. They do not differ

2-31. What are the most common geostrophic wind scale increments?

1. 2 mb and 15 meters
2. 4 mb and 30 meters
3. 4 mb and 60 meters
4. 8 mb and 120 meters

2-32. Which of the following statements defines Earth's secondary circulation?

1. The circulation is created and maintained by the effect of Earth's non-uniform surface and composition
2. The circulation is created by thermal differences in the atmosphere
3. It is that portion of the tertiary circulation caused by thermal differences between land and water
4. The circulation is created and maintained by the effects of Earth's non-uniform surface and composition and Earth's thermal differences

2-33. Centers of action are created by

1. wind
2. seasonal temperature differences
3. temperature differences between land and water
4. pressure belts

2-34. What is the name given to the permanent and semi-permanent high- and low-pressure cells?

1. Thermal cells
2. Migratory cells
3. Centers of action
4. Primary circulations

2-35. Some centers of action disappear at certain times of year.

1. True
2. False

2-36. In winter, what pressure systems are found in the Northern Hemisphere over Siberia, the eastern Pacific Ocean, and the eastern Atlantic Ocean?

1. High pressure at all three locations
2. Low pressure covers Siberia, while high pressure is found over the eastern Pacific and Atlantic
3. Low pressure at all three locations
4. High pressure covers Siberia, while low pressure is found over the eastern Pacific and Atlantic

2-37. How are the subtropical high-pressure systems affected, if at all, by seasonal changes?

1. They are weaker in summer and farther poleward
2. They are stronger in summer and farther poleward
3. They are stronger in summer and nearer the equator
4. They are not affected

2-38. Which of the following pressure systems is NOT classified as a center of action?

1. Aleutian low
2. Bermuda high
3. Polar high
4. Hatteras low

2-39. Where is the largest individual secondary circulation cell in the Northern Hemisphere located?

1. North American continent
2. Asian continent
3. African continent
4. European continent

2-40. Migratory wind circulations are not classified as centers of action. Why?

1. They are seasonal
2. They are not as intense
3. They are found only in midlatitudes
4. They are not persistent in location or intensity

2-41. Pressure-system movement, shape and intensity are dependent on what factor?

1. Circulation
2. Temperature
3. Height
4. Thickness

2-42. An anticyclonic circulation in the Southern Hemisphere whose temperature pattern is such that colder temperatures are located at the circulation center is known as a

1. warm-cored low
2. warm-cored high
3. cold-cored low
4. cold-cored high

2-43. Which of the following systems have the greatest vertical extent?

1. Cold-cored lows and highs
2. Warm-cored lows and highs
3. Warm-cored lows and cold-cored highs
4. Cold-cored lows and warm-cored highs

2-44. Well-developed cyclonic and anticyclonic closed circulations at the surface may or may not be evident on upper-level charts, and the same type circulations may appear on upper-level charts and not be evident at the surface.

1. True
2. False

2-45. How does a closed cyclonic circulation in the Northern Hemisphere with warmer temperatures toward the circulation center' differ from a similar circulation with colder temperatures toward the center?

1. It does not extend as far into the atmosphere
2. Its intensity lessens with height
3. It is classified as a warm-cored low
4. All of the above

2-46. A migratory closed circulation that extends well into the atmosphere is classified as

1. warm-cored
2. cold-cored
3. dynamic
4. vertically axised

2-47. Tertiary circulations are small, localized circulations created by which of the following conditions?

1. Local heating and cooling
2. Adjacent heating and cooling
3. Induction
4. All of the above

2-48. The monsoons of India and southeast Asia are seasonal in nature, and in winter, the monsoon winds are normally accompanied by what weather conditions?

1. Constant heavy rain
2. Heavy rain showers and thunderstorms
3. Both 1 and 2 are correct
4. Mostly clear skies

2-49. A sea breeze can be expected to reach its maximum intensity between what hours?

1. 0600 to 0800 local
2. 0900 to 1100 local
3. 1400 to 1600 local
4. 2000 to 2200 local

2-50. Sea breezes are most pronounced during which of the following seasons?

1. Winter
2. Late winter and early spring
3. Late spring, summer and early autumn
4. Late autumn to early spring

2-51. Mountains act as barriers to wind; however, if there are valleys or passages through the mountains, the wind may pass through at great speeds. Which of the following factors controls the wind speeds through such openings?

1. The orientation of the mountain range
2. The pressure difference on each side of the mountain
3. The pressure pattern on each side of the mountain
4. Each of the above

2-52. Which of the following names applies to the cold dense air of the Greenland ice cap (10,000 feet above sea level) when it is set in motion and rushes down the cap to sea level?

1. Glacier wind
2. Mountain wind
3. Gravity wind
4. Each of the above

2-53. What is a thermal?

1. A warm dry wind that begins at the base of a mountain and ascends the mountain slope
2. A warm moist wind that begins at the base of a mountain and ascends the mountain slope
3. A relatively small 1-scale convective current produced by strong local heating
4. Turbulence created by moderate to strong airflow over rough or hilly terrain

2-54. Which of the following types of rotation is/are induced in eddies, dust devils and waterspouts?

1. Cyclonic in the Northern Hemisphere; anticyclonic in the Southern Hemisphere
2. Anticyclonic in the Northern Hemisphere; cyclonic in Southern Hemisphere
3. Cyclonic only
4. Cyclonic or anticyclonic, indeperxlent of the hemisphere

2-55. When winds in excess of 20 knots blow perpendicular to a mountain range, what wind conditions might be expected on the lee side?

1. Updrafts only
2. Strong downdrafts
3. Very turbulent conditions
4. Both 2 and 3

2-56. Under which of the following wind conditions may turbulence be expected?

1. Winds blow in the same direction but at different speeds
2. Wind currents blow past each other in opposite directions
3. Winds blow over uneven surfaces
4. Each of the above

2-57. Mountain waves are an example of

1. large-scale vertical eddies
2. small-scale vertical eddies
3. large-scale horizontal eddies
4. small-scale horizontal eddies

ASSIGNMENT 3

Textbook Assignment: "Air Masses and Fronts." Chapter 4, Pages 4-1 through 4-31.

3-1. What two factors are necessary to produce an air mass?

1. Anticyclonic circulation and non-homogeneous properties of temperature, lapse rate and moisture
2. Large divergent flow and a widespread body of relatively uniform air
3. Uniform surface and relative humidity
4. Moisture and heat

3-2. Why are anticyclonic circulations most favorable for air mass development?

1. The horizontal outflow of air affects a much larger area
2. The air moves slowly or is stagnant, making it easier for the air to assume the characteristics of the underlying surface
3. The subsidence associated with these circulations is favorable for lateral mixing, thereby bringing about horizontal homogeneity
4. All of the above are reasons

3-3. The properties an air mass acquires in its source region are dependent on a number of factors. Which of the following is NOT a factor in determining air mass properties?

1. Time of year
2. Type of surface (land, water, ice)
3. Length of time the air mass remains over the region
4. Circulation pattern

3-4. Which air mass has its source region between 10°N lat. and 10°S lat.?

1. T
2. A
3. P
4. E

3-5. Monsoon air is REALLY one of two air masses depending on the time of year. Which two air masses make up monsoon air?

1. cP and mT
2. cP and E
3. mP and E
4. mP and mT

3-6. On what factors are air mass classifications based?

1. Temperature, humidity, and wind
2. Season, latitude, and source region
3. Geographic origin, moisture content, and thermodynamic process
4. Geographic origin, temperature, and humidity

3-7. A cP air mass moves south out of its source region in Canada and invades the south central U.S. How would this air mass most likely be classified thermodynamically?

1. Moist Cm)
2. Cold (k)
3. Warm (w)
4. Cool (c)

3-8. How is the stability of an air mass affected, if at all, when it leaves source region?

1. It is increased only
2. It is decreased only
3. It may be increased or decreased
4. It is not affected

3-9. It is February, and a very cold continental polar air mass pushes south over tropical waters. Which, if any, of the following changes is most likely to occur within the air mass?

1. A decrease in water vapor content takes place
2. The lower layers are cooled by conduction
3. An increase in stability occurs
4. None of the above

3-10. Air mass stability can be changed thermodynamically or mechanically.

1. True
2. False

3-11. Over the midlatitudes of North America in winter, an air mass exhibiting surface temperatures of -18°C or colder is generally classified as

1. cPk
2. mPk
3. cAk
4. cPw

3-12. Much can be gained from knowing the path cP and cA air masses take on leaving their source regions in North America. Which of the following statements pertains to the winter outbreaks of these air masses when their path is cyclonic?

1. Good flying conditions are the rule
2. Cloud cover lingers along the Atlantic coast until the air mass clears the Appalachian mountains
3. Frequent and widespread snow squalls can be expected on the leeward side of the Great Lakes
4. Unrestricted visibilities are common on the windward side of the Appalachian mountains

3-13. Weather along the U.S. west coast in winter is predominantly the result of which air mass?

1. mP
2. cP
3. cA
4. mT

3-14. What air mass is generally responsible for relatively mild weather across the U.S. in winter, and is often incorrectly referred to as mT?

1. cP with a short cyclonic trajectory over the Pacific
2. cP with a long cyclonic trajectory over the Pacific
3. mP with an anticyclonic trajectory along the northern border of the Pacific high
4. Highly modified equatorial (E) air

3-15. The heaviest precipitation recorded in Southern California in winter is produced from what air mass?

1. mP
2. cP
3. mT
4. cT

3-16. Maritime polar (mP) air is far more frequent along the west coast of the U.S. than the east coast. Why?

1. mP air of the Atlantic and Pacific are both more apt to move in an easterly direction, and in the Atlantic, this movement takes mP air away of the U.S. east coast
2. cP air is heavier and more dense than mP air, and it acts as a barrier over North America
3. The Greenland ice cap blocks mP air from moving west to the North American continent (U.S. east coast)
4. The very warm water temperatures of the Gulf Stream rapidly modify mP air requiring it to be reclassified as mT air

3-17. After a week of colder than average temperatures, the southeastern U.S. comes under the influence of much warmer mT air over the Gulf of Mexico. Which of the following types of weather will likely be produced by the mT air?

1. Snow flurries
2. Thunderstorms and tornadoes
3. Widespread advection fog
4. Copious rain

3-18. True mT air does not have dew point temperatures below what value?

1. 60°F
2. 65°F
3. 70°F
4. 75°F

3-19. Which of the following air masses dominates most of the U.S. during the summer season?

1. mT or cP
2. mT or mP
3. mT or S
4. E or mP

3-20. Which of the following air masses dominates the U.S. Pacific coast during summer?

1. mT
2. mP
3. cP
4. S

3-21. In summer, east of the Rocky Mountains, mP air and cP air exhibit the same properties.

1. True
2. False

3-22. When mT air moves north over the Grand Banks area of Newfoundland in summer, which of the following types of weather is most likely to occur?

1. Fog
2. Heavy rain
3. Convective thunderstorms
4. Mechanical thunderstorms

3-23. Which of the following air masses is NOT found over the North American continent during winter?

1. cT
2. S
3. mT
4. cPk

3-24. Which of the following statements concerning superior air is correct?

1. It is found in the northwest U.S.
2. It is an exceptionally moist air mass
3. It is rarely found at the surface
4. Each of the above

3-25. In winter, Japan's weather is primarily influenced by which of the following air masses?

1. cP
2. mT
3. mP
4. cT

3-26. The summer monsoon of India and Burma is the result of what air mass?

1. mT
2. cP
3. mP
4. E

3-27. In winter, Great Britain occasionally experiences the effects of cA and cP air. Where do these air masses originate?

1. Iceland
2. North America
3. Greenland and Spitsbergen
4. Siberia, Finland and Lapland

3-28. Which of the following air masses originates over the Atlantic Ocean but moves over land and is classified as a continental air mass?

1. cP
2. cT
3. cA
4. S

3-29. Australian weather is dominated by cT air; however, mT air is more of a factor along one of its four coasts. Which coast is most affected by mT air?

1. East
2. West
3. North
4. South

3-30. Which of the following air masses is the coldest on record and where is it found?

1. cP - North America
2. cA - Arctic
3. cA - Antarctica
4. mP - Weddell Sea

3-31. In the Southern Hemisphere, which of the following air masses is the most important in providing relief from the oppressive summer heat?

1. cP
2. cA
3. mP
4. mA

3-32. What is a front?

1. A boundary between two air masses
2. A zone of transition between two adjacent air masses bounded by a frontal surface
3. A zone of transition between two air masses of different densities
4. A point where two air masses touch

3-33. What determines frontal classification?

1. Density differences
2. Temperature differences
3. Frontal movement
4. Involved air masses

3-34. What classification is given to the front that separates a warm air mass from a retreating mass of cold air?

1. Warm
2. Cold
3. Quasi-stationary
4. Occluded

3-35. What are the primary frontal zones in the Northern Hemisphere?

1. Polar and tropical
2. Polar and arctic
3. Arctic and tropical
4. Polar and equatorial

3-36. Cold air being heavier than warm air will either underrun the warm air or be overrun by warm air.

1. True
2. False

3-37. Which of the following statements refer(s) to frontal slope?

1. A front's position along the Earth's surface
2. The zone of discontinuity between air masses
3. The ratio of a frontal surface's elevation to horizontal extent
4. All of the above

3-38. Which of the following statements concerning the relationship between fronts and cyclones (low-pressure centers) is correct?

1. All surface fronts develop a closed cyclonic circulation at the surface and aloft
2. Upper-level cyclones that lower to the Earth's surface always contain fronts
3. Every front is associated with a cyclone and travels with it
4. Fronts can occur anywhere but cyclones cannot

3-39. What is the average speed of wave cyclones along the polar front?

1. 10 - 15 knots
2. 15 - 20 knots
3. 20 - 25 knots
4. 25 - 30 knots

3-40. When is a frontal wave most intense?

1. When a cyclonic circulation develops
2. When a cyclonic circulation causes the cold air to overtake the warm air and forms an occlusion
3. When the pressure in the wave cyclone begins to lower
4. When the pressure in the wave cyclone reaches its lowest point

3-41. When two air masses having different densities are brought together by the prevailing wind field, what takes place?

1. A front forms
2. There's a decrease in the temperature grient
3. The windflow parallels the isotherms
4. Each of the above

3-42. What is cross-isothermal flow?

1. The flow of wind across isobars
2. The flow of wind across isotherms
3. The flow of wind across fronts
4. A col.

3-43. Frontogenesis is most likely to occur where there is a concentration of isotherms and a circulation that sustains the concentration.

1. True
2. False

3-44. Which of the following statements concerning frontolytical processes is correct?

1. They are most effective in the lower layers of the atmosphere
2. They are more common than frontogenetical processes
3. They bring about frontal dissipation
4. Each of the above

3-45. During summer in the Northern Hemisphere, where would you most likely find the Arctic front?

1. In the North Atlantic
2. In the North Pacific
3. North of Europe
4. Northeastern Asia

3-46. Which of the following statements concerning polar fronts is correct?

1. They separate polar air from tropical air only
2. They are stronger in summer than winter
3. They are more common along eastern coasts of continents in summer
4. They are present throughout the year

3-47. What three elements are used to determine whether or not a front actually exists?

1. Visibility, temperature, and pressure
2. Clouds, temperature, and wind
3. Temperature, pressure, and wind
4. Present weather, temperature, and pressure

3-48. The temperature increase within a frontal inversion and the thickness of the inversion layer provide a rough indication of

1. frontal slope
2. frontal intensity
3. turbulent mixing
4. precipitation within a frontal zone

3-49. Which of the following statements concerning frontal inversions is correct?

1. Cold fronts generally show stronger inversions than warm fronts
2. They normally show up as a decrease in the lapse rate below 400 millibars
3. Double inversions are often evident with occluded fronts
4. Each of the above

3-50. Which of the following occurrences causes a front to exhibit a strong inversion layer and little or no weather activity?

1. Subsidence in the warm air above the frontal surface
2. Subsidence in the cold air beneath the frontal surface
3. Adiabatic warming of the cold air beneath the frontal surface
4. Upward vertical motion in the warm air

3-51. In the Northern Hemisphere when a front passes your station, what change takes place in the wind direction?

1. It veers
2. It backs
3. It shifts in a counterclockwise direction
4. It shifts in a clockwise direction

3-52. In a frontal zone, what, if anything, normally happens to the wind speeds?

1. They increase with height only
2. They decrease with height only
3. They may increase or decrease with height
4. They vary on either side of the frontal zone, but maintain a steady state through the zone

3-53. At the surface, when a front moves beyond its associated pressure trough, how, if at all, are the winds across the front affected?

1. The wind speeds do not change, but the wind shift becomes far more apparent
2. The wind speeds show a drastic change, and the wind shift becomes far more apparent
3. The wind speed difference across the front continues, but the wind shift can become almost undetectable
4. Movement out of the pressure trough affects neither wind speeds or direction

3-54. Which of the following factors causes frontal clouds, condensation, and weather?

1. Low pressure
2. Friction between front and Earth's surface
3. Vertical displacement of air along the front
4. Each of the above

3-55. Which of the following frontal slopes is classified as being the steepest?

1. 1:35
2. 1:50
3. 1:150
4. 1:300

3-56. What factor(s) contribute(s) to a steep frontal slope?

1. High wind velocity difference across the front
2. Small temperature contrast across the front
3. High latitude
4. All of the above

3-57. In the warm air ahead of a cold front, the temperatures average 82°F/28°C. In the cold air 100 miles to the rear of the cold front, the temperatures average 64°F/l8°C. What is the front's intensity based on temperature gradient?

1. Very weak
2. Weak
3. Moderate
4. Strong

3-58. Frontal movement is determined by the

1. temperature gradient behind the front
2. pressure difference across the front
3. wind speed component ahead of the front
4. wind velocity component behind the front

ASSIGNMENT 4

Textbook Assignment: "Air Masses and Fronts" (continued); "Atmospheric Phenomena." Chapters 4 and 5, Pages 4-31 through 5-6.

4-1. What is the average slope of a slow-moving cold front?

1. 1:50
2. 1:100
3. 1:150
4. 1:300

4-2. Which of the following indications is representative of the passage of a slow-moving cold front?

1. Wind backs
2. Sharp rise in pressure
3. Marked temperature rise
4. Sharp drop in the dew point

4-3. What is the average range of speed of a slow-moving cold front?

1. 5 to 10 knots
2. 10 to 15 knots
3. 15 to 20 knots
4. 20 to 25 knots

4-4. When the cold air to the rear of a slow-moving cold front is moist and stable, and the warm air that it is displacing is also moist and stable, which of the following weather conditions is most likely to occur in the vicinity of the front?

1. Thunderstorms at and ahead of the front
2. Thunderstorms at and behind the front
3. Rapid clearing with the frontal passage
4. Low ceilings of stratus and fog

4-5. Which of the following statements describes a characteristic of slow-moving cold fronts?

1. The frontal inversion is usually very evident
2. Isotherms parallel the front and are concentrated in the cold air
3. Cloudiness and precipitation normally extend back into the cold air as far as the wind and isotherms parallel the front
4. Each of the above

4-6. The winds that push a slow-moving cold front are more parallel to the front at lower levels than aloft.

1. True
2. False

4-7. Where do squall lines develop?

1. In advance of a slow-moving cold front
2. To the rear of a slow-moving cold front
3. In advance of a fast-moving cold front
4. To the rear of a fast-moving cold front

4-8. Which of the following factors determines the type of weather associated with a fast-moving cold front?

1. The moisture content of the cold air only
2. The stability of the cold air only
3. The moisture content and stability of the cold air
4. The moisture content and stability of the warm air

4-9. A fast-moving cold front has an average range of speed of

1. 15 to 20 knots
2. 20 to 25 knots
3. 25 to 30 knots
4. 30 to 35 knots

4-10. Which of the following indications is/are associated with the passage of a fast-moving cold front?

1. The dew point changes little if at all
2. The temperature changes little, if at all, until the front is well past
3. Rapid clearing
4. Answers 2 and 3 are both correct

4-11. Which of the following upper air characteristics is associated with the passage of a fast-moving cold front?

1. Slight backing of the wind with height
2. A double inversion; the frontal inversion and a subsidence inversion some distance to the rear of the front
3. Isotherms are well spaced and cross the front at an angle of about 30 degrees
4. Each of the above

4-12. What is a secondary cold front?

1. A fresh outbreak of very cold air to the rear of a fast-moving cold front
2. A trough of low pressure
3. The classification given to any summertime cold front
4. Any cold front that is classified as unimportant meteorologically

4-13. Which of the following occurrences leads to the formation of a cold front aloft?

1. The mP air to the rear of a cold front crosses a mountain range and rides atop warm moist mT air
2. Cool air overtakes colder more dense air and rides up over it
3. Cold dense air overtakes cooler less dense air and forces it aloft
4. Each of the above

4-14. A squall line is an instability line, but an instability line is NOT necessarily a squall line.

1. True
2. False

4-15. Which of the following statements concerning prefrontal squall lines is correct?

1. They form about 50 to 300 miles in advance of fast-moving cold fronts
2. Their speed is roughly equal to 40% of the 500-mb wind speed
3. They are most common in spring and summer in the United States
4. Each of the above

4-16. Which of the following weather changes occurs with the passage of a prefrontal squall line?

1. The temperature rises significantly
2. The pressure falls
3. The wind shifts cyclonically
4, The wind shifts anticyclonically

4-17. What air mass(es) is/are involved in the development of Great Plains squall lines?

1. mT only
2. mT and mP
3. mT and cP
4. mP and cP

4-18. What is the average speed of warm fronts?

1. 5 to 10 knots
2. 10 to 20 knots
3. 15 to 25 knots
4. 20 to 30 knots

4-19. In the Northern Hemisphere, how are the surface winds affected before and after the passage of a warm front?

1. They are generally southeasterly ahead of the front and shift to southwesterly after passage
2. They are strongest after passage
3. They shift in a counterclockwise direction

4-20. Where is nimbostratus and its accompanying precipitation most frequently found in relation to the warm front?

1. Within 300 miles of the front in the cold sector
2. Within 300 miles of the front in the warm sector
3. 500 miles in advance of the front
4. 500 miles to the rear of the front

4-21. What is produced when the winds perpendicular to a warm front increase with height?

1. Strong overrunning of the warm air across the top of the retreating cold air mass
2. Pronounced prefrontal cloudiness
3. Precipitation
4. Each of the above

4-22. When overrunning occurs, and the air is moist and unstable, which of the following weather phenomena occurs?

1. Clear skies
2. High and mid clouds only
3. Stratus and fog
4. Thunderstorms

4-23. When a warm front crosses a mountain range and encounters colder air on the lee side of the mountain, which of the following phenomena may occur?

1. The warm front moves across the top of the cold air as an upper warm front
2. Overrunning
3. Inversions are wiped out
4. Each of the above

4-24. Occluded fronts are classified as which of the following types?

1. Cold only
2. Warm only
3. Cold or warm
4. Cold, warm or cool

4-25. What is the primary difference between a warm and cold occlusion?

1. The temperature of the warm air
2. The temperature of the cold air
3. The temperature of the cool air
4. The location of the associated upper front in relation to the surface front

4-26. Which of the following occurrences takes place in the cold-occlusion process?

1. Cold air displaces the warm air to the rear of a warm front and then undercuts the relatively cooler air in advance of the warm front
2. Cool air displaces the warm air to the rear of a warm front and then rides up over the colder retreating air ahead of the warm front
3. Warm air displaces the cold air in advance of the warm front and rides up over cool air behind the cold front
4. Cold air replaces warm air and then overruns relatively cooler air ahead of the warm front

4-27. How is a cold occlusion designated that crosses the Rocky Mountains and encounters deep, cold air over the Plateau or Western Plains?

1. As an occlusion
2. As a cold front
3. As an upper cold front
4. As a warm front

4-28. Where does MOST of the precipitation occur with a cold occlusion?

1. Ahead of the occlusion, if the occlusion is old
2. To the rear of the occlusion in the occlusion's initial stages of development
3. Just ahead of the occlusion
4. Just to the rear of the occlusion

4-29. How are the isotherms affected as an occlusion matures?

1. They become more parallel to the occlusion on the cold air side
2. They become more parallel to the occlusion on the warm air side
3. They become more perpendicular as they cross the front
4. Warm and cold pockets form, and no isotherms cross the front

4-30. Which of the following situations is conducive to the formation of a warm occlusion?

1. The presence of a cPk air mass in the Gulf of Mexico
2. The invasion of mPk air into the Great Plains
3. The presence of cpk air over Canada, a warm front along its western periphery, and an approaching mPk air mass
4. The development of a low at the southern tip of the Appalachian Mountains

4-31. Where are the pressure falls associated with a warm occlusion located?

1. In advance of the upper warm front
2. In advance of the occlusion's surface position only
3. In the pressure trough behind the occlusion
4. In advance of the upper cold front and the surface occlusion

4-32. In a warm occlusion, where is the most severe weather located?

1. At the apex during the developmental stage
2. At the point where the warm air is at its highest altitude
3. In the warm sector equatorward of the apex of the occlusion
4. At the northernmost extension of a mature occlusion

4-33. The wind shift across a quasi-stationary front is on the order of how many degrees?

1. 45
2. 90
3. 135
4. 180

4-34. Which of the following statements is true concerning the winds above the friction level over a quasi-stationary front?

1. They parallel the front
2. They are more or less perpendicular to the front
3. They are non-existent
4. They parallel the front in the warm air only

4-35. The weather along a quasi-stationary front is dependent on which of the following conditions?

1. The steepness of the frontal slope
2. The stability of the warm air
3. Undulations of the front toward the warm air
4. All of the above conditions

4-36. Which, if any, of the following types of weather is associated with a quasi-stationary front when stable, warm air is advected up a steep frontal slope?

1. Tornadoes
2. Thunderstorms
3. Embedded showers
4. None of the above

4-37. The most violent weather associated with quasi-stationary fronts occurs when

1. stable warm air is advected up a steep frontal slope
2. unstable warm air is advected up a shallow frontal slope
3. unstable warm air is advected up a steep frontal slope
4. stable warm air is advected up a shallow frontal slope

4-38. Which, if any, of the following effects of frontal speed on weather is correct?

1. Fast-moving fronts usually produce the most violent weather
2. The return to favorable weather conditions takes place much quicker with a slow-moving front
3. A front whose speed is erratic creates varying weather conditions, and is much easier to forecast
4. None of the above

4-39. Which of the following aspects of a front is affected by mountain ranges?

1. Speed
2. Slope
3. Weather
4. Each of the above

4-40. With regard to precipitation, a cold front that approaches and crosses a mountain range will generally

1. show a decrease in precipitation intensity
2. have its area of precipitation narrowed
3. produce greater amounts of precipitation on the leeward side
4. produce greater amounts of precipitation on the windward side

4-41. Which of the following occurrences takes place when a warm front encounters a mountain range?

1. The warm air above the frontal surface is mechanically lifted producing severe thunderstorms
2. The frontal slope is drastically changed at higher altitudes
3. The front becomes more or less stationary on the leeward side
4. The cold air beneath the frontal surface gets cut off on the windward side

4-42. Mountain ranges prolong warm frontal precipitation and widen the precipitation area.

1. True
2. False

4-43. Which of the following statements concerning skagerraking and occlusions is correct?

1. Skagerraking occurs most frequently on the west coast of mountainous continents
2. The new low develops very rapidly
3. Skagerraking can occur with either cold or warm occlusions
4. Each of the above

4-44. When an air mass leaves its source region, it may be modified by the underlying surface in which of the following manners?

1. Moisture may be added and taken away
2. Temperatures may be increased or decreased
3. Frontal characteristics may be completely destroyed
4. All of the above

4-45. In the western Atlantic and Pacific Oceans, cold fronts of fall and winter are of greater concern, to shipping than at other times of the year. Why?

1. Air mass contrast is magnified thereby producing more severe weather
2. Gale force winds are common in the cold air to the rear of these fronts
3. Low-pressure systems are often spawned and develop over the warm northerly flowing waters of these regions
4. All of the above

4-46. To be classified as rain, the water droplets that reach the Earth's surface will have a diameter of

1. 001 to .01 inch
2. .005 to .02 inch
3. .010 to .02 inch
4. .020 inch and greater

4-47. How is precipitation that falls from convective clouds classified?

1. Rain
2. Snow
3. Showery
4. Steady

4-48. Which of the following hydrometeors appears as a fine mist, floats rather than falls through the air, and is frequently accompanied by fog and restricted visibilities?

1. Light rain
2. Snow
3. Drizzle
4. Rain

4-49. Which of the following hydrometeors is considered to be the frozen equivalent of drizzle?

1. Snow grains
2. Snow pellets
3. Ice pellets
4. Ice crystals

4-50. What is another name for sleet?

1. Snow grains
2. Snow pellets
3. Ice pellets
4. Ice crystals

4-51. How, if at all, does sleet differ from small hail?

1. Sleet rebounds on striking the ground, hail does not
2. Sleet is composed of snow encased in an ice layer, and hail is the exact opposite
3. Sleet is a continuous type of precipitation, while small hail is showery
4. They are both ice pellets and do not differ

4-52. Hail forms in what type of cloud?

1. Cumulus mediocris
2. Altocumulus castellanus
3. Nimbostratus
4. Cumulonimbus

4-53. Which of the following hydrometeors is common in polar regions and mainly visible in sunlight?

1. Ice prisms
2. Ice pellets
3. Snow pellets
4. Snow grains

4-54. What occurs when water droplets in a cloud evaporate and then sublimate directly onto ice crystals within the cloud?

1. The ice crystals always melt
2. Precipitation begins
3. Nothing until the ice crystals melt, then the original droplets will have grown in size
4. Turbulence

4-55. In order for water vapor to condense and form clouds, which of the following conditions is NOT necessary?

1. Sufficient moisture
2. Hygroscopic or sublimation nuclei
3. Turbulent air currents
4. A cooling process

4-56. Why are hygroscopic and sublimation nuclei so important in the cloud formation process?

1. They determine the type of cloud that will form
2. Cloud formation is all but impossible without them
3. They trigger the precipitation process
4. All of the above

4-57. What clouds are believed to be the result of direct sublimation?

1. Cirriform
2. Stratiform
3. Cumuliform
4. Nacreous

4-58. What are the upper limits of cirriform clouds (based on etage classification) in the tropics, middle latitudes, and polar regions?

1. 80,000, 45,000, and 25,000 feet
2. 60,000, 45,000, and 25,000 feet
3. 60,000, 30,000, and 16,600 feet
4. 20,000, 16,500, and 10,000 feet

4-59. Which of the following clouds is classified as belonging to one etage but may extend into other etages?

1. Altocumulus
2. Altostratus
3. Nimbostratus
4. Stratus

4-60. The cloud species castellanus applies mainly to which of the following cloud genera?

1. Cumulus
2. Stratus
3. Altocumulus
4. Cirrus

4-61. A cumulonimbus cloud that produces hanging pouchlike protuberances is known as

1. tuba
2. castellanus
3. mammatus
4. congestus

4-62. Elongated cloud masses in the shape of lenses or almonds are classified as

1. humilis
2. stratiformis
3. fractus
4. lenticularis

4-63. The fair weather cumulus clouds of the tropics have little vertical extent and are classified as

1. humilis
2. mediocris
3. fractus
4. castellanus

ASSIGNMENT 5

Textbook Assignment: "Atmospheric Phenomena" (continued); "Climatology and World Weather." Chapters 5 and 6, Pages 5-6 through 6-6.

5-1. Which of the following facts about fog is incorrect?

1. Fog is most easily described as a cloud at the Earth's surface
2. All fogs are composed of minute water particles only
3. Fog depth and density are quite variable
4. Local geography and topography can play a major role in the formation and dissipation of fog

5-2. Where and when is the formation of radiation fog most common?

1. Over cold waters at night
2. Over land at night
3. Over land in the early afternoon
4. Over coastal waters in the early morning

5-3. How does wind speed affect radiation fog?

1. Calm winds cause a shallow fog layer to form
2. Winds of 5 to 10 knots create turbulent currents that increase the depth of the fog
3. Winds greater than 10 knots usually cause the fog to lift, thereby forming low scud, stratus, or stratocumulus
4. All of the above

5-4. Which of the following conditions is most conducive to the formation of radiation fog?

1. Low pressure, light winds, and overcast skies
2. Low pressure, light winds, and clear skies
3. High pressure, light winds, and clear skies
4. High pressure, light winds, and overcast skies

5-5. What are advection fogs?

1. Fogs produced by the movement of warm air over a colder land or water surface
2. Fogs that form in the clear night air over warm waters
3. Fogs produced across air mass frontal boundaries
4. Fogs of the tropics

5-6. Which of the following types of fog is not classified as advection fog?

1. Sea fog
2. Arctic sea smoke
3. Upslope fog
4. Steam fog

5-7. Most fog is destroyed (lifted) when the wind speed over a fog enshrouded area increases. Which of the following classifications/types of fog is most likely to persist in wind up to 26 knots?

1. Land advection fog
2. Sea fog
3. Upslope fog
4. Radiation fog

5-8. Which of the following classifications/types of fog is most likely to occur in winter, when an arctic outbreak pushes off the U.S. east coast over warm Gulf Stream waters?

1. Sea fog
2. Steam fog
3. Land advection fog
4. Radiation fog

5-9. Which of the following statements concerning frontal fog is correct?

1. Frontal fog is the result of evaporation of falling rain
2. It forms in the cold air mass
3. This fog begins as low clouds that eventually lower to the ground
4. Each of the above

5-10. On some mornings, grass, plants, and possibly your car will be wet with dew while the road and some large objects will be dry. Why do some surfaces remain dry?

1. Micro air temperature differences
2. Micro dew point variations
3. Some surfaces retain heat longer and fail to cool to the dew point
4. Some surfaces cool far too fast for the moisture to accumulate on them

5-11. With regard to classification, how does spray differ from blowing spray?

1. Wind speed
2. Visibility
3. Wave heights
4. Droplet size

5-12. Tornadoes travel at what average range of speed?

1. 0 to 5 knots
2. 7 to 15 knots
3. 12 to 20 knots
4. 22 to 34 knots

5-13. Which of the following areas is most conducive for the formation of tornadoes?

1. Cols
2. 30 miles to the rear of short-wave troughs
3. 75 to 180 miles in advance of fast-moving cold fronts
4. In areas of warm air overrunning cold air

5-14. Which of the following conditions is NOT indicative of tornado formation?

1. Strong convergent winds at the surface
2. Suppressed convection up to the minus 10°C isotherm
3. Marked convective instability
4. Strong horizontal wind shear

5-15. Upon observing the development of a waterspout, how can an observer tell, if it is of the local or tornadic variety?

1. Size
2. Stability index
3. Development process
4. Vertical extent of convective clouds

5-16. Which of the following lithometeors reduce(s) visibility in a veil-like cover?

1. Smoke
2. Dust storms
3. Haze
4. Sand storms

5-17. Your station's visibility markers are set at 1/8, 1/4, 3/8, 1/2, 3/4, 1, 1 1/2, 2, 2 1/2, 3, 4, 5, 6, 7, and 15 miles. What is the maximum distance (by marker) that your observer will be able to see in a severe dust storm?

1. 1/8 mi
2. 1/4 mi
3. 3/8 mi
4. 1/2 mi

5-18. Which of the following statements is NOT a characteristic of photometeors?

1. They appear as luminous patterns in the sky
2. Many are cloud related
3. They help in describing the state of the atmosphere
4. They are all precursors of bad weather

5-19. When light encounters any substance, which of the following occurrences might take place?

1. Refraction only
2. Reflection or refraction
3. Absorption or refraction
4. Absorption, reflection, or refraction

5-20. Visible light occupies that portion of the electromagnetic spectrum between

1. 4000 and 7000 angstroms
2. 2500 and 4000 angstroms
3. 1200 and 2500 angstroms
4. 400 and 1100 angstroms

5-21. How does the Moon produce moonlight?

1. It is a luminous body and produces its own light
2. It absorbs light from the Sun and regenerates it at night
3. It reflects the light it receives from the Sun
4. Through a combination of reflection, absorption, and refraction

5-22. A substance permits the passage of light through it, but the light appears clouded, and viewing things through such a substance is impaired. This substance is described as being

1. transparent
2. translucent
3. opaque
4. fluorescent

5-23. An object that allows virtually 100 percent of the light striking it to pass through exhibits the property of

1. opacity
2. translucency
3. transparency
4. absorptivity

5-24. When none of the light waves that strike a medium pass through it, the medium is termed

1. opaque
2. absorbent
3. translucent
4. transparent

5-25. A ray of light striking a mirror perpendicularly is referred to as the

1. angle of reflection
2. angle of refraction
3. normal
4. reflected light

5-26. What is the term given to the angle between a reflected light ray and a perpendicular light ray?

1. Angle of incidence
2. Angle of reflection
3. Angle of refraction
4. The normal angle

5-27. When light passes through a medium that changes the direction of the light, the light is being

1. refracted only
2. reflected only
3. reflected or refracted
4. absorbed and reflected

5-28. When a light ray passes from one medium into another of greater density at an angle of 45 degrees, how is the light ray affected?

1. It slows and bends away from the normal
2. It slows and bends toward the normal
3. It is reflected at a 45-degree angle
4. It slows, but its path is not altered

5-29. What are the six distinct colors of the visible spectrum?

1. Red, orange, yellow, green, blue, and brown
2. Yellow, green, blue, orange, violet, and red
3. Blue, green, yellow, orange, black, and white
4. White, black, gray, yellow, blue, and red

5-30. Halos are almost exclusively associated with which of the following cloud forms?

1. Cumuliform
2. Stratiform
3. Cirriform

5-31. Which of the following differences distinguishes coronas from halos?

1. Coronas are usually much larger than halos
2. The outer ring of a corona is red, while a halo's is violet
3. Coronas are formed by refraction of light through ice crystals, while halos are caused by the diffraction of light by water droplets
4. Coronas form around the Sun and Moon while halos form only around the Sun

5-32. What color is usually seen on the outer arc of a rainbow?

1. Blue
2. Red
3. Yellow
4. Green

5-33. Mirages are produced when light is

1. absorbed in a very dense cold air mass
2. reflected off a very hot surface such as a desert
3. refracted when passing through layers of air with highly different densities
4. reflected, refracted, and diffracted in hot air

5-34. What is the term given to the phenomena that causes stars near the horizon to twinkle and change color?

1. Iridescence
2. Looming
3. Superior mirage
4. Scintillation

5-35. What is “looming”?

1. An atmospheric phenomenon that causes objects over the horizon, which would otherwise not be seen, to become visible
2. A phenomenon that causes stars to twinkle and change color near the horizon
3. An inferior mirage
4. A form of iridescence

5-36. A luminous beam of sunlight passing through a break in the clouds and extending to the Earth like a spotlight is known as

1. iridescence
2. scintillation
3. a crepuscular ray
4. a sunstroke

5-37. Which of the following atmospheric conditions is necessary for the formation of thunderstorms?

1. High temperatures and contrasting air masses
2. Conditionally stable air and high humidity
3. Moist, conditionally unstable air and a lifting mechanism
4. A weak horizontal temperature gradient, low-level turbulence, and high humidity

5-38. Which of the following statements is NOT true concerning the makeup of thunderstorms?

1. In the initial stages of development updrafts prevail throughout the cell
2. A cell’s life cycle usually lasts 1 to 3 hours
3. There are three distinct stages in the life cycle of a cell
4. They consists of only one convective cell

5-39. Which of the following lapse rates would most likely NOT be found in a thunderstorm?

1. .45/100 meters
2. .75/100 meters
3. 7.0/1000 meters
4. 7.5/1000 meters

5-40. What is considered to be the most hazardous level for flying in a thunderstorm?

1. The base
2. The middle level
3. The upper level
4. The freezing level

5-41. Which of the following statements concerning the winds associated with thunderstorms is correct?

1. Microbursts, macrobursts, and first gusts occur in all convective cells
2. Microbursts are produced by violent updrafts
3. The wind speed of the first gust is usually the highest recorded in a storm
4. Macrobursts normally last 2 to 3 hours

5-42. What is the Earth’s normal electrical field?

1. Ground negative and air positive
2. Ground positive and air negative
3. Ground and air both positive
4. Ground and air both negative

5-43. Within a thunderstorm cloud, where is lightning most frequently encountered?

1. Several thousand feet below the freezing level
2. At the freezing level
3. Between the freezing level and 15°F
4. Between the freezing level and the base of the cloud

5-44. Auroras most commonly occur

1. in thunderstorms
2. near the Earth’s magnetic poles
3. when rarefied gases invade the lower atmosphere
4. near the equator

5-45. Which of the following factors distinguishes airglow from an aurora?

1. Airglow is fainter
2. Airglow does not shimmer as much as an aurora
3. Airglow appears in middle and lower altitudes, while auroras are a feature of high altitudes
4. Each of the above

5-46. Which of the following definitions best describes climate?

1. The scientific study of the weather of a region
2. The sum total of the Earth’s atmospheric variables
3. The average state of the Earth’s atmosphere over any given location over a long period of time
4. The general weather of a region

5-47. Which approach to climatology provides the most useful information to Aerographer's Mates in their travels around the world?

1. Physical climatology
2. Descriptive climatology
3. Dynamic climatology
4. Mesoclimatology

5-48. Which of the following types of climatic studies is usually likely be used to position runways for a new naval air station?

1. Microclimatology
2. Mesoclimatology
3. Macroclimatology
4. Physical climatology

5-49. Of the following climatic elements, which is considered to be the most important?

1. Pressure
2. Temperature
3. Wind
4. Precipitation

5-50. Moisture modifies temperature, while, at the same time, it is also influenced by temperature.

1. True
2. False

5-51. In most countries of the world, the amount of precipitation in climatic studies is expressed in what increments?

1. Inches
2. Centimeters
3. Millimeters
4. Centiliters

5-52. What are resultant winds?

1. The wind directions and speeds for a given level in the atmosphere
2. The vectorial average of all wind directions and speeds for a given period of time
3. The vectorial average of all wind directions and speeds for a given period of time, at a specific place
4. The wind directions and speeds for a specific place

5-53. Which of the following climatic terms is being determined when the highest and lowest temperatures of the day are added together and divided by 2?

1. Mean
2. Mode
3. Median
4. Normal

5-54. The extreme lowest temperature ever recorded at your station is -22°F. Which of the following climatic terms applies to this temperature?

1. Extreme low
2. Absolute low
3. Absolute minimum
4. Extreme absolute minimum

5-55. What temperature is normally used as the standard base temperature in computing heating degree days?

1. 85°F
2. 75°F
3. 65°F
4. 60°F

5-56. On the first day of your local power company's heating season, five heating degree days are measured. What does this number represent?

1. The number of kilowatts of energy used above the average number required to cool to a standard temperature
2. The difference between the first day's mean temperature and a temperature standard
3. An index of required energy
4. Standard deviation

5-57. Which of the following statements is correct with regard to average and standard deviation?

1. (+ or -) signs are critical in these computations
2. Average deviations use arithmetic averages of data, while standard deviations use actual measurements
3. A standard deviation is the square root of an average of squared mean deviations

IN ANSWERING QUESTIONS 5-58 THROUGH 5-65, USE THE FOLLOWING MONTHLY INFORMATION. (HIGHS AND LOWS ARE DEGREES FAHRENHEIT).

	High	Low	February	High	Low
1	41	21	15	27	11
2	39	21	16	25	09
3	39	19	17	25	10
4	29	15	18	26	11
5	27	12	19	18	05
6	30	13	20	16	03
7	32	15	21	16	04
8	37	19	22	17	08
9	37	21	23	19	13
10	40	23	24	23	14
11	40	26	25	26	16
12	41	27	26	29	18
13	39	19	27	32	21
14	37	16	28	33	22

5-58. What is the mean high temperature (rounded off) for the month?

1. 37°
2. 32°
3. 30°
4. 26°

5-59. What is the range of the high temperatures?

1. 24° to 26°
2. 41° to 29°
3. 30°
4. 25°

5-60. What is the extreme mean monthly temperature?

1. 15°
2. 22°
3. 31°
4. 32°

5-61. What is the mode of the low temperatures?

1. 15°
2. 19°
3. 21°
4. 27°

5-62. What are the medians of the high and low temperatures?

1. 29.0 and 15.0°
2. 29.5 and 15.5°
3. 30.0 and 15.5°
4. 32.0 and 16.0°

5-63. When you use 41°F as the standard, what is the number of degree days for the first seven days of the month?

1. 71
2. 86
3. 109
4. 133

5-64. What is the average daily temperature deviation?

1. 6°
2. 7°
3. 8°
4. 9°

5-65. What is the standard deviation (rounded off) of the temperature for the month?

1. 6°
2. 7°
3. 8°
4. 9°

ASSIGNMENT 6

Textbook Assignment: "Climate and Climatology." Chapter 6, Pages 6-6 through 6-30.

6-1. Which of the following lists represents the climatic zones?

1. Arctic, Antarctic, Polar, Mid-latitudes, Tropical, and Equatorial
2. Arctic, Polar, Midlatitudes, and Tropical only
3. Arctic, Temperate, Equatorial
4. Polar, Temperate, and Tropical

6-2. Which of the following factors is most commonly used to limit the extent of each climatic zone?

1. Lines of latitude based on solar (light) zones
2. Isotherms
3. Precipitation lines
4. Lines depicting plant growth differences

6-3. Climatic classifiers use the same factors when classifying types of climate.

1. True
2. False

6-4. Which of the following climatic classifiers places a great deal of emphasis on the relationship between precipitation and evaporation?

1. C. W. Thornthwaite
2. W. Koppen
3. G. T. Trewartha
4. Each of the above

6-5. Koppen's five climatic types are based on

1. temperature only
2. precipitation amounts only
3. the effectiveness of precipitation
4. the effect of temperature and precipitation on plant growth

6-6. Which of the following climatic controls has the greatest effect on climatic elements?

1. Latitude
2. Ocean currents
3. Topography
4. Lard and water distribution

6-7. Compared to water, approximately how many times faster does lard heat aid cool?

1. 6
2. 2
3. 8
4. 4

6-8. Air temperature contrasts over oceans are relatively minimal between day and night and winter and summer because of

1. water's higher absorption rate of insolation
2. the subtropical anticyclones' positions
3. the constancy of sea surface temperatures due to mixing processes
4. Earth's land and water distribution

6-9. The seasonal change in the worldwide temperature gradient is greater in the Northern Hemisphere than in the Southern Hemisphere. Why?

1. The differences in the land and water distribution between the two hemispheres
2. The Southern Hemisphere's longer summers
3. The absence of cP air in-the Southern Hemisphere
4. All of the above

6-10. Mountains affect which climatic element the most?

1. Wind
2. Temperature
3. Precipitation
4. Cloud cover

6-11. Why are climates cooler along west coasts of continents than along east coasts of continents?

1. Prevailing westerly winds
2. Presence of mountain ranges which impede cold air
3. Cold ocean currents flow along the west coasts, while warm ocean currents flow along east coasts
4. Higher albedoes

6-12. The infamous fog that invades San Francisco Bay during the summer is caused by

1. upwelling
2. contrasting temperatures between the Bay and the California current
3. radiational cooling
4. warm, moist air being advected over the cold California current

6-13. Climatically, the Grand Banks of Newfoundland and the Kamchatka Peninsula of eastern Asia are well known for

1. upwelling
2. their extensive fogs
3. extremely cold summers
4. cyclogenesis

6-14. When comparing climates of heavily wooded areas to nearly open areas in the same region, how do the heavily wooded areas differ, if at all?

1. They have lower humidities
2. The wind speeds are considerably higher
3. The maximum and minimum temperatures are higher
4. They will not differ if in the same region

6-15. Worldwide climatological records are maintained at which of the following commands?

1. NAVLANTMETOCCEN Norfolk, VA.
2. COMNAVMETOCCOM Stennis, Space Center, MS
3. FLENUMOCEANCEN Monterey, CA.
4. FLENUMOCEANCEN Asheville, NC

6-16. Which of the following climatic information is available aid produced only upon request?

1. Summary of Meteorological Observations (SMOS)
2. Cross-Wind Summary
3. Local Climatological Data Summary (LCD)
4. Worldwide Airfield Summary

6-17. How often is the SMOS updated?

1. Annually
2. Biannually
3. Triennially
4. Every 5 years

6-18. A complete listing of climatological references is available in which of the following publications?

1. Climatic publications prepared for Commander, Naval Oceanography Command
2. Guide to Standard Weather Summaries (NAVAIR 50-lC-534)
3. Navy Stock List of Forms and Publications, NAVSUP 2002
4. All of the above

6-19. A prospective graduate of AG C-l has orders to Guantanamo Bay, Cuba. Which of the following publications provides a limited amount of climatology but provides valuable information on local and area weather with regard to this station?

1. *U.S. Navy Marine Climatic Atlas of the World*
2. *Guantanamo Bay's Local Area Forecasters s Handbook*
3. *Naval Intelligence Survey*
4. *Worldwide Airfield Summaries*

6-20. Forecaster's guides for data-sparse areas and areas of high naval interest may be available from

1. NAVLANTMETOCDET Asheville, NC
2. COMNAVMETOCCOM
3. Naval Environmental Prediction Research Facility, Monterey, CA
4. Air Weather Service Environmental Technician Application Center

6-21. In two months, your ship is scheduled to embark on a 6-month Mediterranean deployment. The meteorological officer wants climatic data on each port that is scheduled to be visited. What step(s) do you take to get this data?

1. Task the nearest NAVLANTMETOCFAC
2. Draft a request for climatic support to COMNAVMETOCCOM through your chain of command
3. Use your ship's climatic publications; then, if required, request assistance from the nearest Naval Oceanography Command activity
4. Request the data from COMNAVMETOCCOM Stennis, Space Center, MS

6-22. Climatology should always come into play in operational planning that extends beyond the range of forecasting techniques.

1. True
2. False

6-23. Which of the following characteristics is associated with maritime climates?

1. Minimal cloudiness
2. Little precipitation
3. Small diurnal temperature range
4. Large annual temperature range

6-24. The amount of radiant energy absorbed by the sea when the Sun is directly overhead is approximately what percent?

1. 3
2. 6
3. 25
4. 91

6-25. Which, if any, of the following statements is characteristic of the interchange of radiation between Earth's oceans and the atmosphere?

1. The interchange is a short-wave radiation exchange
2. The interchange is primarily dependent on the sea-surface temperature and the amount of water vapor in the atmosphere
3. The interchange is solely dependent on the time of day and season of the year
4. None of the above apply

6-26. Convective activity is most likely to occur when

1. warm air moves over cold ocean waters
2. cold air moves over warm ocean waters
3. warm air moves over warm ocean waters
4. cold air moves over cold ocean waters

6-27. When is evaporation of Earth's surface waters most intense?

1. When the vapor pressure of the atmosphere is greater than that of the surface water
2. When the vapor pressure of the atmosphere and the surface water coincide
3. When the vapor pressure of the surface water exceeds the vapor pressure of the atmosphere
4. When the air temperature exceeds the water temperature

6-28. Oceans are an abundant source of moisture, but precipitation occurs much more frequently over land than over the oceans for which of the following reasons?

1. Orographic influences
2. Stronger temperature contrasts
3. Greater vertical mixing
4. All of the above

6-29. Atmospheric soundings show that a layer of moist air exists in the tropics. During favorable weather, what is the mean depth of this layer?

1. 2,000 to 3,000 feet
2. 3,000 to 5,000 feet
3. 5,000 to 8,000 feet
4. 5,000 to 12,000 feet

6-30. Within the temperate latitudes of the North Atlantic and Pacific Oceans, where are the most active frontal systems found?

1. Along the west coasts of North America and Asia
2. Along the east coasts of North America and Asia
3. Along the northern boundary of the subtropical high-pressure systems
4. Along the eastern boundary of the subtropical high-pressure systems

6-31. In winter in the North Atlantic Ocean, what is the average number of days that passes between polar outbreaks?

1. 3 1/2
2. 5 1/2
3. 3
4. 4

6-32. What are cyclone families?

1. Polar outbreaks
2. A series of midwestern tornadoes
3. The fronts associated with polar outbreaks
4. A series of cyclonic waves that form along the polar front

6-33. Which of the following occurrences is synonymous with the splitting of the Pacific subtropical high in winter?

1. A more vigorous polar-front off the Asiatic east coast
2. Severe cyclones in the Gulf of Alaska
3. Two polar fronts coexist in the North Pacific
4. The northeast trade winds are reinforced

6-34. What is the primary flight hazard associated with mT air on the east side of a subtropical high?

1. Coastal fog
2. Turbulence
3. Thunderstorms
4. Heavy rain and low ceilings

6-35. Which, if any, of the following factors is the primary controller of Arctic weather and climate?

1. Land-sea-ice distribution
2. Mountain barriers
3. Insolation
4. None of the above

6-36. During the Arctic summer, the distinction between Arctic and polar air masses almost disappears.

1. True
2. False

6-37. Which of the following statements is correct concerning Arctic air masses in winter?

1. Humidity is high
2. Cloudiness and precipitation increase
3. Temperatures are usually between 0° and 10°C
4. A large temperature inversion exists in the lower few thousand feet over land

6-38. Which of the following statements is characteristic of the flying weather in the Arctic?

1. It is worst during the transition period between the seasons
2. Fog is a major problem over land in summer
3. Low ceilings and visibilities are most frequent in winter
4. High winds, blowing snow, and turbulence are more frequent in summer

6-39. The summers of the Canadian Archipelago are best classified as

1. hot and long
2. cold and long
3. cool and short
4. warm and short

6-40. Strong surface winds are most likely to occur within the interior of the Arctic region during which of the following seasons?

1. Winter
2. Fall and winter
3. Spring and fall
4. Summer and fall

6-41. Which of the following annual precipitation amounts is representative of Arctic coastal areas and the Arctic ice pack?

1. 3 to 7 in.
2. 5 to 15 in.
3. 8 to 17 in.
4. 10 to 20 in.

6-42. Ice fog is most likely to occur when the air temperature is around how many degrees Celsius?

1. 0
2. -15
3. -30
4. -45

6-43. Diamond dust is a name that applies to

1. Arctic smoke
2. Arctic sea smoke
3. Arctic haze
4. ice fog

6-44. In the Arctic, the Sun, Moon, and other objects near the horizon often appear distorted. Why?

1. Aurora borealis
2. Inversion induced mirages
3. The highly transparent air
4. Whiteouts

6-45. In addition to equal amounts of skylight and reflected light, what other conditions are necessary to bring about a whiteout?

1. Broken snow cover, and clear sky
2. Broken snow cover, and an overcast sky
3. Unbroken snow cover, and clear sky
4. Unbroken snow cover, and a uniformly overcast sky

6-46. The lowest recorded temperature in the world was observed in

1. Siberia
2. Greenland
3. Canadian Archipelago
4. Antarctica

6-47. Which of the following areas of the United States is favorable for the development of storm (low-pressure) centers?

1. Ohio Valley
2. Tennessee Valley
3. Central Idaho
4. Great Plains

6-48. Which of the following regions of the United States has a cold, dry climate in winter and a warm, dry climate in summer?

1. Central Plains
2. Intermountain West Central
3. Southwest Pacific Coast
4. Southeast and Gulf States

6-49. The chief flight hazard in the southwestern desert and mountain area of the United States is

1. high level turbulence
2. spring and summer thunderstorms
3. haze
4. dust devils

6-50. Tornadoes are a climatic feature of which of the following areas of the United States?

1. Central Plains
2. Southeast United States
3. Intermountain west central area
4. Southwest Pacific coast area

6-51. Why is the southeast and Gulf states area of the United States an especially difficult area for making forecasts?

1. Stagnating frontal systems, fog, and Gulf stratus
2. Air-mass thunderstorms
3. Rapidly moving squall lines
4. Various combinations of all the above reasons

6-52. The influx of maritime air into western Europe results in

1. low-temperature extremes
2. infrequent precipitation
3. high humidity
4. mostly clear skies

6-53. Which of the following European areas experiences the least amount of change in its temperature extremes between summer and winter?

1. European Atlantic coast
2. The Rhine Valley
3. Eastern Europe
4. The northern Alpine region

6-54. The Asian continent is dominated by

1. high pressure in winter and low pressure in summer
2. low pressure in winter and high pressure in summer
3. low pressure year round
4. high pressure year round

6-55. If a relatively dry excursion into northeast South America is planned, which month would be most suitable?

1. January
2. June
3. October
4. November

6-56. Southern Chile experiences a climate similar to that experienced by what area of the United States?

1. Northwest coast
2. Southwest coast
3. Northeast coast
4. Southeast coast

6-57. Why do the climatic zones of Africa lack sharp distinction?

1. Africa is an island continent
2. There are no prominent mountain ranges in Africa
3. In Africa, the zones are controlled by the ITCZ
4. Africa is under the influence of only one air mass

6-58. Which of the following climatic elements is the most important in Africa?

1. Temperature
2. Wind
3. Precipitation
4. Cloud cover

6-59. The sub-equatorial region of Africa experiences marked seasonal rainfall. What five-month period is associated with the rainy season?

1. Jan - May
2. Apr - Aug
3. Aug - Dec
4. Nov - Mar

6-60. Climatically, where is the wettest region of Africa?

1. North central
2. Equatorial
3. Southwestern
4. Southeast coastal

6-61. What is the average variation in maximum temperatures in the interior of Australia between summer and winter?

1. 15°F
2. 22°F
3. 28°F
4. 31°F

6-62. What portion of Australia is under the influence of mT air?

1. Northern 1/3
2. Eastern 1/3
3. Southern 2/3
4. Western 3/4

6-63. Climatically, southern New Zealand is wetter than northern New Zealand.

1. True
2. False