TM 1-300

DEPARTMENT OF THE ARMY TECHNICAL MANUAL

METEOROLOGY FOR ARMY AVIATION

This copy is a reprint which includes current pages from Changes 1 and 2

HEADQUARTERS, DEPARTMENT OF THE ARMY
JUNE 1963

TECHNICAL MANUAL
No. 1–300

HEADQUARTERS,
DEPARTMENT OF THE ARMY
WASHINGTON 25, D.C., *10 June 1963*

METEOROLOGY FOR ARMY AVIATION

		Paragraph	Page
PART ONE. WEATHER PRINCIPLES AND THEORY			
CHAPTER 1.	INTRODUCTION	1–1 through 1–6	1–1
2.	THE ATMOSPHERE		
Section I.	General	2–1 through 2–3	2–1
II.	Temperature and heat energy	2–4 through 2–10	2–2
III.	Moisture	2–11 through 2–15	2–11
IV.	Pressure	2–16 through 2–23	2–18
CHAPTER 3.	CLOUDS		
Section I.	General	3–1, 3–2	3–1
II.	Cloud types	3–3 through 3–6	3–2
CHAPTER 4.	ATMOSPHERIC CIRCULATION		
Section I.	General circulation	4–1 through 4–6	4–1
II.	Secondary circulation	4–7 through 4–10	4–9
III.	Hurricanes	4–11 through 4–24	4–13
IV.	Other winds and weather	4–25 through 4–32	4–25
CHAPTER 5.	ATMOSPHERIC STABILITY AND INSTABILITY		
Section I.	Atmospheric stability	5–1 through 5–6	5–1
II.	Interpreting the atmospheric sounding diagram	5–7 through 5–9	5–7
CHAPTER 6.	AIR MASSES		
Section I.	General	6–1 through 6–6	6–1
II.	Air masses affecting the United States	6–7 through 6–11	6–4
CHAPTER 7.	FRONTAL WEATHER	7–1 through 7–7	7–1
8.	FOG	8–1 through 8–5	8–1

*This manual supersedes TM 1–300, 23 April 1958, including changes 1, 16 November 1960.

		Paragraph	Page
CHAPTER 9.	ICING	9-1 through 9-13	9-1
10.	THUNDERSTORMS	10-1 through 10-8	10-1
PART TWO.	WEATHER FACILITIES AND THEIR APPLICATIONS		
CHAPTER 11.	TELETYPE SEQUENCE REPORTS	11-1 through 11-15	11-1
12.	THE SURFACE WEATHER MAP	12-1 through 12-9	12-1
13.	WINDS ALOFT	13-1 through 13-5	13-1
14.	CONSTANT PRESSURE CHARTS AND HIGH ALTITUDE WEATHER	14-1 through 14-10	14-1
15.	RADAR AND WEATHER	15-1 through 15-7	15-1
16.	FORECASTS		
Section I.	Introduction	16-1, 16-2	16-1
II.	Teletype forecasts	16-3 through 16-6	16-1
III.	Locally prepared forecasts	16-7 through 16-9	16-6
IV.	Facsimile prognostic charts	16-10 through 16-12	16-10
V.	Inflight forecasts	16-13, 16-14	16-13
CHAPTER 17.	WEATHER FLIGHT PLANNING	17-1 through 17-6	17-1
APPENDIX I.	REFERENCES		I-1
II.	UNITS OF MEASUREMENT FOR METEOROLOGICAL ELEMENTS		II-1
III.	WEATHER OUTSIDE THE TEMPERATE ZONE		III-1
Section I.	Polar and subpolar regions		III-1
II.	Tropical weather		III-6
APPENDIX IV.	CLIMATOLOGY		IV-1
Section I.	Introduction		IV-1
II.	Climatological records		IV-7
III.	Regional climatology		IV-9
GLOSSARY			G-1
INDEX			1

PART ONE

WEATHER PRINCIPLES AND THEORY

CHAPTER 1

INTRODUCTION

1-1. Purpose

This manual provides the Army aviator and other interested personnel with the general principles of modern meteorology as applicable to Army aviation. It also provides information on various weather facilities and how to use them to best advantage.

1-2. Scope

a. This manual covers the theoretical aspects of meteorology which concern the Army aviator, the weather facilities available to him, and other information which will enable him to interpret weather conditions.

b. The material presented herein is applicable without modification to both nuclear and nonnuclear warfare.

c. Users of this manual are encouraged to submit recommended changes or comments to improve the manual. Comments should be keyed to the specific page, paragraph, and line of the text in which change is recommended. Reasons should be provided for each comment to insure understanding and complete evaluation. Comments should be forwarded direct to the Commandant, United States Army Aviation School, ATTN: AASPI, Fort Rucker, Ala.

d. For list of references, see appendix I.

1-3. Weather Requirements for Instrument Flight

To become instrument qualified and maintain his proficiency, the aviator must have knowledge of the factors which produce and control the weather. This does not mean that the aviator will fly in all types of extremely hazardous weather such as severe squall lines, tornado areas, freezing precipitation, and rapidly shifting gusty surface winds; flights into severe weather areas are to be avoided. It does mean, however, that he must have a sufficient knowledge of weather to plan his flight so as to avoid these hazardous conditions if possible. To obtain desired weather information the aviator must be able to converse intelligently with the forecaster. In addition, he must be able to interpret and use the weather station facilities. He must know what facilities are available to determine ceilings, visibilities, and surface weather conditions along his route. He must know how to determine temperatures aloft, the height of the freezing level, and the presence of potential icing conditions. Further, he must be able to locate the wind conditions for his flight, cloud tops, upper cloud layers, and areas of probable thunderstorm or fog formation.

1-4. Military Weather Support Functions

a. General. A wide variety of weather information is required to support the planning and operations of the many offensive and defensive military forces created by modern warfare. Requirements range from the accurate reporting of current weather conditions at a specific river crossing to an extended forecast of weather conditions expected at any point in the world. Effects of weather conditions which must be carefully weighed in planning and executing specific military aviation operations include—

(1) Winds aloft that modify the range and payload of aircraft.

(2) Moisture, in its various forms, that may affect ceilings, visibility, aircraft performance, and landing sites.

(3) Density altitude that affects payload and aircraft performance.

(4) Turbulence which affects in-flight aircraft performance.

(5) Climatic considerations which influence the selection of operating airfields and air routes.

(6) Weather factors which affect the efficiency of special aviation weapons and systems.

b. Nature of Services. The Air Weather Service is responsible for providing meteorological requirements for Army aviation. The extent of this service varies considerably to meet the peculiar requirements of each command being served and each operation and mission within the command. Weather support service is most effective when the weather personnel know the mission, capabilities, plans and procedures of the organization they serve. The demands placed upon the weather support organizations will be most realistic when commanders and personnel using the meteorological services understand the basic scientific principles of meteorology and recognize the capabilities, and the limitations, of a specific weather support organization.

1-5. Military Weather Service

A military weather service has two basic functions—

a. To Observe and Report Weather Data. This includes reports of current weather conditions, predictions of anticipated weather conditions, and climatological studies of weather probabilities applied to specific planning requirements. This function is performed through the collection, analysis, and interpretation of weather data at all required and available altitudes within and adjacent to areas of operational significance.

b. To Advise Commanders and Staff Officers on Weather Factors. This includes presenting and interpreting forecasts of weather conditions for mission planning and execution, and providing climatological probabilities of occurrence of weather conditions required for the execution of planned operations.

1-6. United States Meteorological Services

a. U.S. Weather Bureau. The U.S. Weather Bureau is responsible for providing the general public with weather information concerning conditions that affect their welfare. This service is made available by different means of commercial facilities. At civil airports, the Army aviator has access to Weather Bureau services within the continental United States and its possessions. The Weather Bureau also operates the National Meteorological Center, which provides basic weather analysis charts and prognostic charts for general meteorological use by all the weather services.

b. Flight Service Stations. The Federal Aviation Agency (FAA) maintains flight service stations throughout the United States to assist the aviation field with navigation, radio communications, and flight planning. These stations make supplementary weather observations and transmit their weather reports over FAA teletype circuits. Other teletype weather information (forecasts, NOTAMS, PIREPS, advisories, etc.) is available in flight service stations for aviation weather briefings. These stations also broadcast scheduled weather reports by radio every 30 minutes at 15 and 45 minutes past each hour. The HH + 15 radio broadcast range is approximately 150 miles along designated airways, and the HH + 45 broadcast range is approximately 400 miles in the geographical area around the station.

c. Air Weather Service. The Unification Act of 1947 provided for the Air Weather Service of the United States Air Force. Upon agreement between the services, the Air Weather Service was assigned the responsibility of providing required weather support to the United States Army, less ballistic meteorological support.

d. Naval Weather Service. The United States Navy operates a weather service to meet the specific requirements of naval air and surface operations. The Army aviator may use the Naval Weather Service when appropriate.

CHAPTER 2

THE ATMOSPHERE

Section I. GENERAL

2–1. General

a. The atmosphere is the great envelope of air which surrounds the earth. Over one-half of the air, by weight, is within the lower 18,000 feet of the atmosphere; the remainder is spread out over a vertical distance in excess of 1,000 miles. No definite outer atmospheric boundary exists: the air particles become less numerous with increasing altitude until they gradually overcome the earth's gravitational force and escape into space. The atmosphere rotates with the earth in space as a gaseous outer cover on the terrestrial ball.

b. Within the atmosphere, another type of air movement occurs in addition to the rotation of the air with the earth. Differences in the temperature of the earth's surface affect the density of the atmosphere and cause a continuous internal air movement called *circulation* (ch. 4).

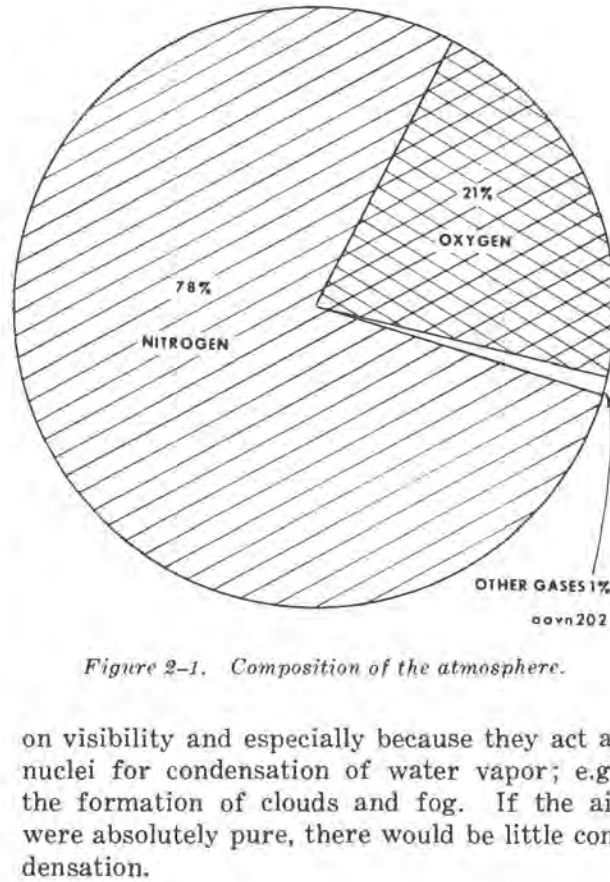


Figure 2–1. Composition of the atmosphere.

2–2. Composition

a. Gases. A given volume of dry air contains approximately 78 percent nitrogen, 21 percent oxygen, 1 percent argon, carbon dioxide, and minute amounts of other gases (fig. 2–1). Natural air contains, in addition to the gases present in dry air, a variable amount of water vapor (gaseous water), most of which is concentrated below 30,000 feet. The maximum amount of water vapor the air can hold depends primarily on the temperature of the air; the higher the temperature, the more water vapor it can hold.

b. Impurities. Air contains variable amounts of impurities such as dust, salt particles, and products of combustion. These impurities are important because of their effect on visibility and especially because they act as nuclei for condensation of water vapor; e.g., the formation of clouds and fog. If the air were absolutely pure, there would be little condensation.

2–3. Structure

a. Weight. Although extremely light and elastic, air has weight. Because of its weight the atmosphere, under standard conditions, exerts a pressure of 14.7 pounds per square inch at sea level (par. 2–17*a*).

b. Layers. Figure 2.2 illustrates the division of the atmosphere into concentric layers. The troposphere is the layer closest to the earth; most of our weather occurs in this layer.

Next are the stratosphere, ionosphere, and exosphere. The troposphere varies in height from an average of 60,000 feet above sea level over the Equator to 25,000 feet over the poles. Its height also varies with seasons; it is higher in summer than in winter. In the Temperate Zones, it is about 35,000 feet above sea level. The boundary zone between the troposphere and the stratosphere is known as the tropopause. The jet stream is generally located near the tropopause.

c. Weather Elements.

(1) Weather may be defined as the state of the meteorological elements in the atmosphere. The six major meteorological elements that interact in various combinations to produce weather are —*air temperature, humidity, clouds, precipitation, atmospheric pressure,* and *wind*. Normally, only air temperature, atmospheric pressure, and wind will be found above the troposphere. The remaining elements (humidity, clouds, and precipitation) are restricted to the troposphere because they require the presence of some form of water—either as a vapor, a liquid, a solid, or as combinations of these.

(2) Since the main weather hazards to flight (icing, hail, low visibility, low ceilings, and most turbulence) exist only where moisture is available, these conditions are primarily associated with processes occurring in the troposphere.

Section II. TEMPERATURE AND HEAT ENERGY

2-4. Temperature Measurement

According to the molecular theory of matter, all substances are composed of minute molecules which are in more or less rapid motion. Temperature is a measure of the average velocity of the molecules; as the velocity of molecular motion increases in a substance under constant pressure, the temperature of the substance increases. Temperature changes effected by pressure changes are discussed in chapter 5.

a. Measurement. Air temperature is usually measured with a liquid-in-glass thermometer. Other types of thermometers are used for recording surface and upper air temperatures.

b. Scales. Two fixed temperatures—the melting point of ice and the boiling point of water (at standard pressure)—are used to calibrate thermometers. The two scales in common use are *centigrade* and *Fahrenheit*. The relationship of the fixed points on each scale is shown in figure 2-3. Army aviators occasionally find it necessary to convert temperature readings from one scale to another because surface temperatures are given in the Fahrenheit scale and Army aircraft are equipped with centigrade thermometers. To convert from centigrade to Fahrenheit, use the equation: $F=9/5\ (°C+40)-40$; or, mentally, double the centigrade reading, subtract one-tenth of this product, and add 32. To convert from Fahrenheit to centigrade, use the equation: $C=5/9\ (°F+40)-40$.

2-5. Temperature Variation with Altitude

a. There will normally be an overall decrease of temperature in the troposphere as an aircraft gains altitude because the air nearest the source of heat (the earth) receives the largest amount of energy. The variation in temperature with altitude is called the temperature *lapse rate* and is usually expressed in degree per thousand feet. On one day, the air may cool 3° C. for each thousand feet gained in altitude. Another day may show a decrease of 1° C. per thousand feet. A third day may reveal the temperature increasing for a distance of one or two thousand feet above the ground (an example of an inverted lapse rate or *inversion*), and thereafter cooling at the rate of 3° C. per thousand feet. If such observations taken day after day over thousands of locations on the earth were averaged, the average lapse rate would be about 2° C. per thousand feet.

b. Variation of the lapse rate is the main reason that temperatures aloft are normally measured twice daily. Valuable information can be determined from observations aloft, such as—

(1) Levels at which freezing temperatures (possible icing hazards) occur.

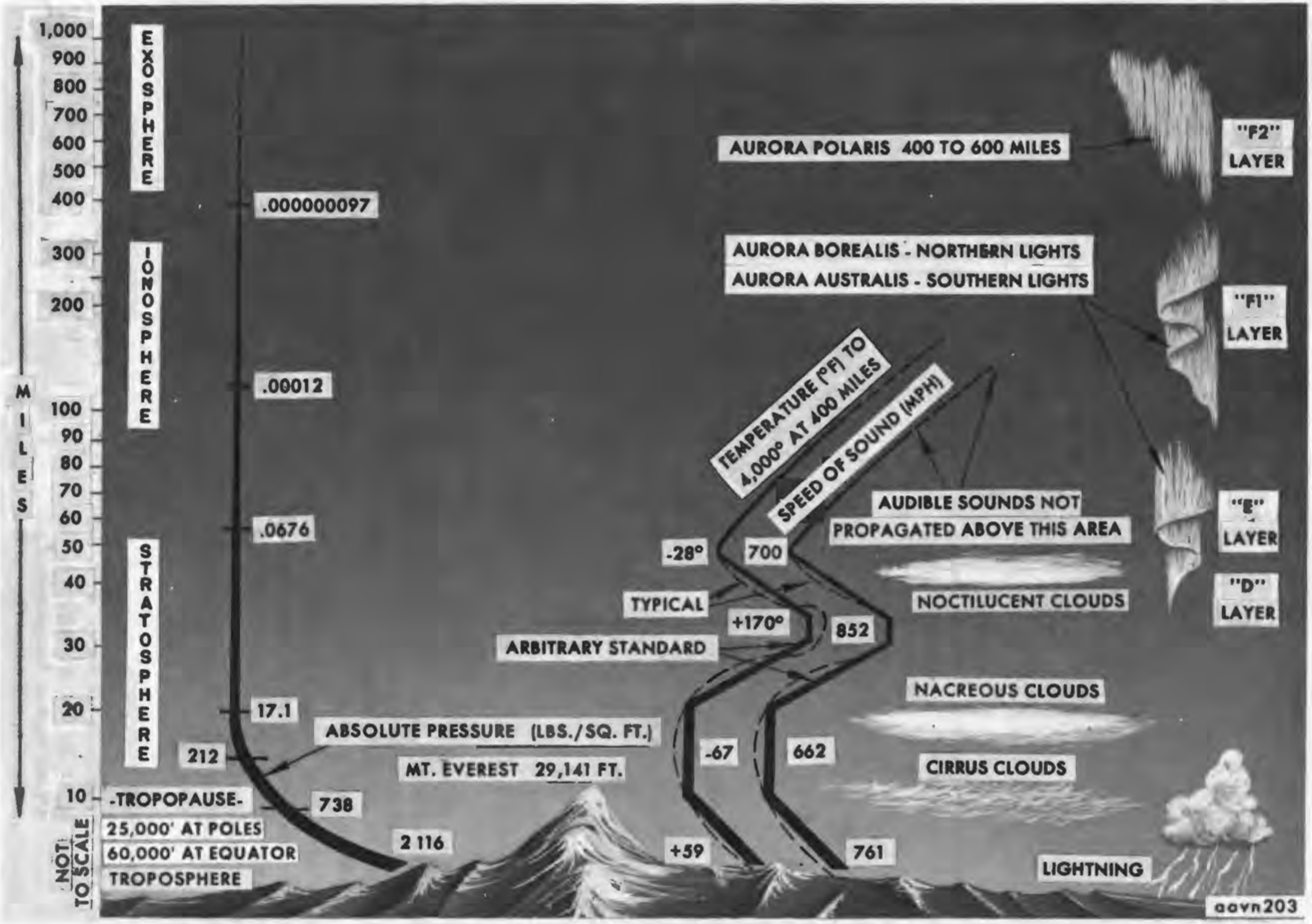


Figure 2–2. The earth's atmosphere.

TEMPERATURES													
C°	F°	C°	F°	C°	F°	C°	F°	C°	F°	C°	F°	C°	F°
-40	-40.0	-27	-16.6	-14	6.8	-1	30.2	12	53.6	25	77.0	38	100.4
-39	-38.2	-26	-14.8	-13	8.6	0	32.0	13	55.4	26	78.8	39	102.2
-38	-36.4	-25	-13.0	-12	10.4	1	33.8	14	57.2	27	80.6	40	104.0
-37	-34.6	-24	-11.2	-11	12.2	2	35.6	15	59.0	28	82.4	41	105.8
-36	-32.8	-23	-9.4	-10	14.0	3	37.4	16	60.8	29	84.2	42	107.6
-35	-31.0	-22	-7.6	-9	15.8	4	39.2	17	62.6	30	86.0	43	109.4
-34	-29.2	-21	-5.8	-8	17.6	5	41.0	18	64.4	31	87.8	44	111.2
-33	-27.4	-20	-4.0	-7	19.4	6	32.8	19	66.2	32	89.6	45	113.0
-32	-25.6	-19	-2.0	-6	21.2	7	44.6	20	68.0	33	91.4	46	114.8
-31	-23.8	-18	-0.4	-5	23.0	8	46.4	21	69.8	34	93.2	47	116.6
-30	-22.0	-17	1.4	-4	24.8	9	48.2	22	71.6	35	95.0	48	118.4
-29	-20.2	-16	3.2	-3	26.6	10	50.0	23	73.4	36	96.8	49	120.2
-28	-18.4	-15	5.0	-2	28.4	11	51.8	24	75.2	37	98.6	50	122.0

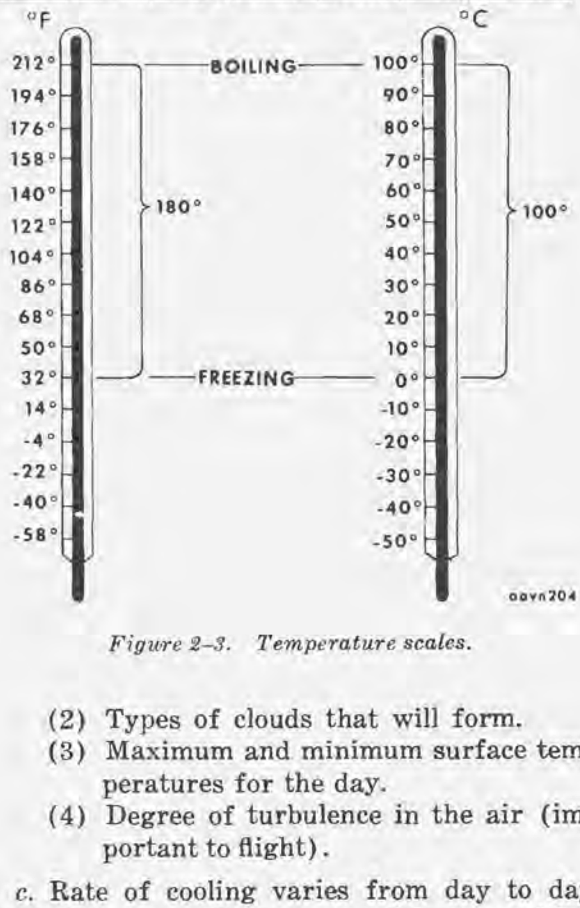


Figure 2-3. Temperature scales.

(2) Types of clouds that will form.
(3) Maximum and minimum surface temperatures for the day.
(4) Degree of turbulence in the air (important to flight).

c. Rate of cooling varies from day to day depending upon the amount of heat reaching the earth, the amount escaping from the earth, and the type and amount of *advection* (warmer or colder air moving into the area from other regions).

2-6. Temperature Inversions

When the temperature increases with altitude within a layer in the atmosphere, this layer is called an *inversion* (inverted lapse rate). Inversions vary in thickness from a few feet to several thousand feet and may occur in a layer of the troposphere at any altitude from the surface to the stratosphere. Inversions occur frequently, but are generally restricted to relatively small layers in the atmosphere. Normal and inverted temperature/altitude relationships are represented graphically in figures 2-4 and 2-5. Inversions near the earth's surface may be formed as follows:

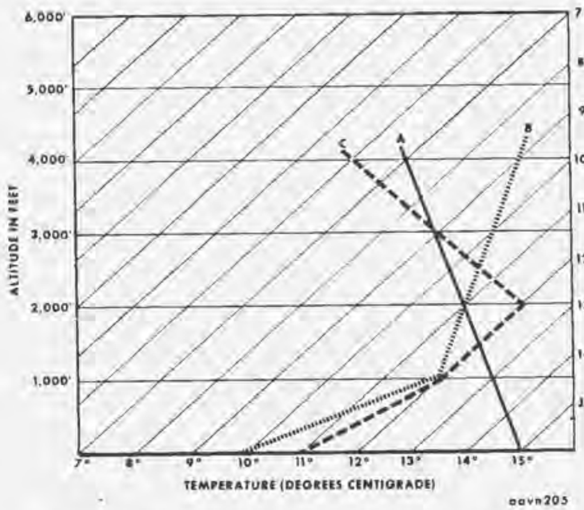


Figure 2-4. Temperature/altitude relationship.

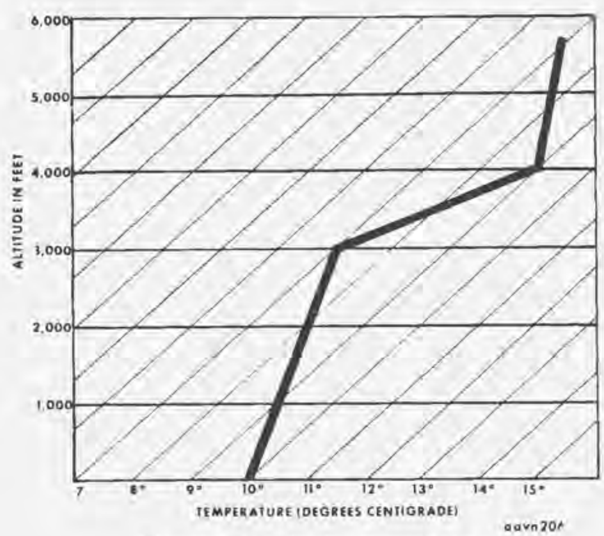


Figure 2-5. An inversion aloft.
(at 3,000 to 4,000 feet)

a. Advection of Warm Air Over a Colder Surface. Wind may move a mass of air from a warm region over a colder surface, such as wind from the warm ocean moving over the colder land area during the winter season. The air will be cooled quickly at the surface by contact with the cold land mass, while the air at and above 1,000 feet will not be affected for several hours. Thus the surface air will be colder than the air aloft, producing an inverted temperature lapse rate (line *B*, fig. 2-4).

b. Nocturnal Cooling. A more frequent type of inversion is caused when the earth cools at night under clear skies. During the afternoon hours, the ground is warm and a normal decrease in temperature with altitude generally exists. However, as the sun sets, the ground loses its heat to space through terrestrial radiation. This reradiation is not absorbed in significant quantities by clear, dry air. As the ground becomes colder, the air immediately above it is cooled by contact (*conduction*); since air is a poor conductor, this cooling does not extend very high. The air near the surface may become cool by 2400 hours, whereas the temperature of the air at 100 feet may still be as warm as it was during the afternoon hours, thus inverting the typical afternoon temperature lapse rate. As the surface cooling continues, the inversion layer deepens (fig. 2-6).

(1) With relatively strong winds over land, the mechanical turbulence from air moving over the rough surface may thoroughly mix the warm and cool air near the surface so that no well-defined inversion exists near the ground, although an inversion may exist several hundred feet above the ground (figs. 2-5 and 2-7).

(2) Inversion layers are stable and produce smooth flying conditions within them; however, fog, haze, smoke, and dust below and within inversion layers often restrict visibility. If skies are overcast, nocturnal cooling is reduced (greenhouse effect, par. 2-10*a*(3)), and it is unlikely that a nocturnal inversion will form.

Note. Inversions aloft are also caused by frontal activity (par. 7-2*a*), by subsidence in areas of high pressure (par. 4/10*d*), and by warm air advection aloft (par. 14-5*b*).

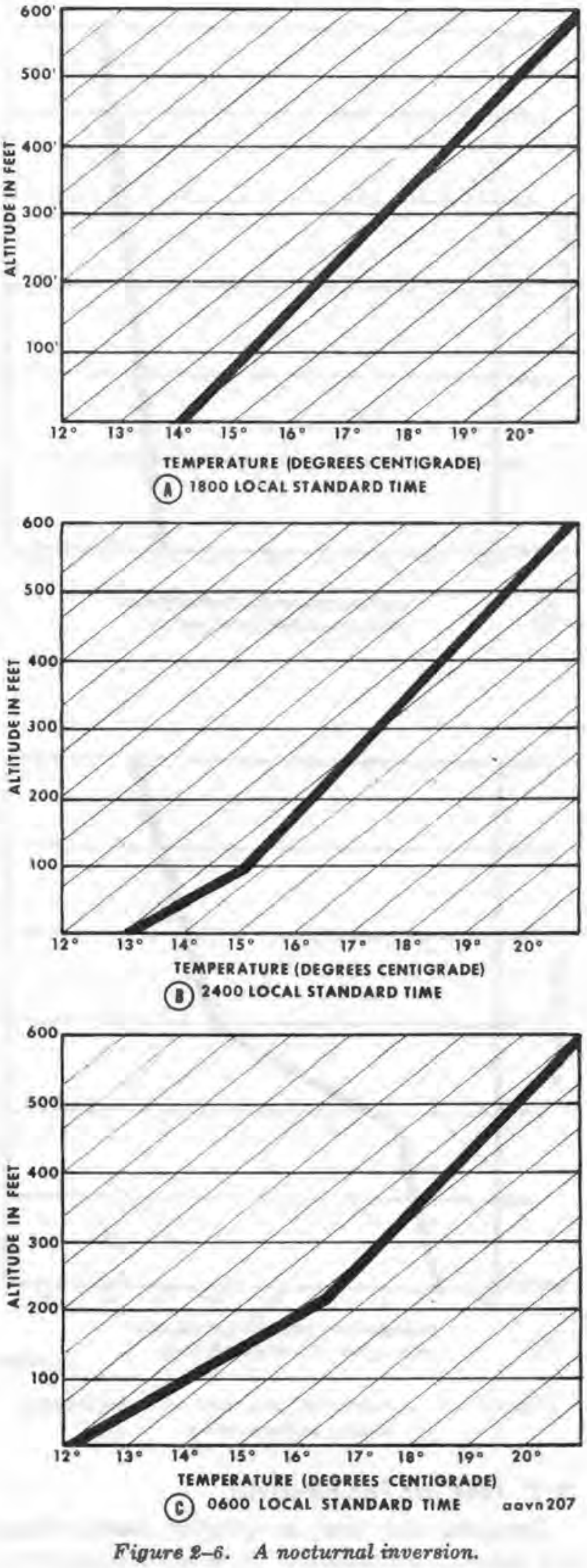


Figure 2-6. A nocturnal inversion.

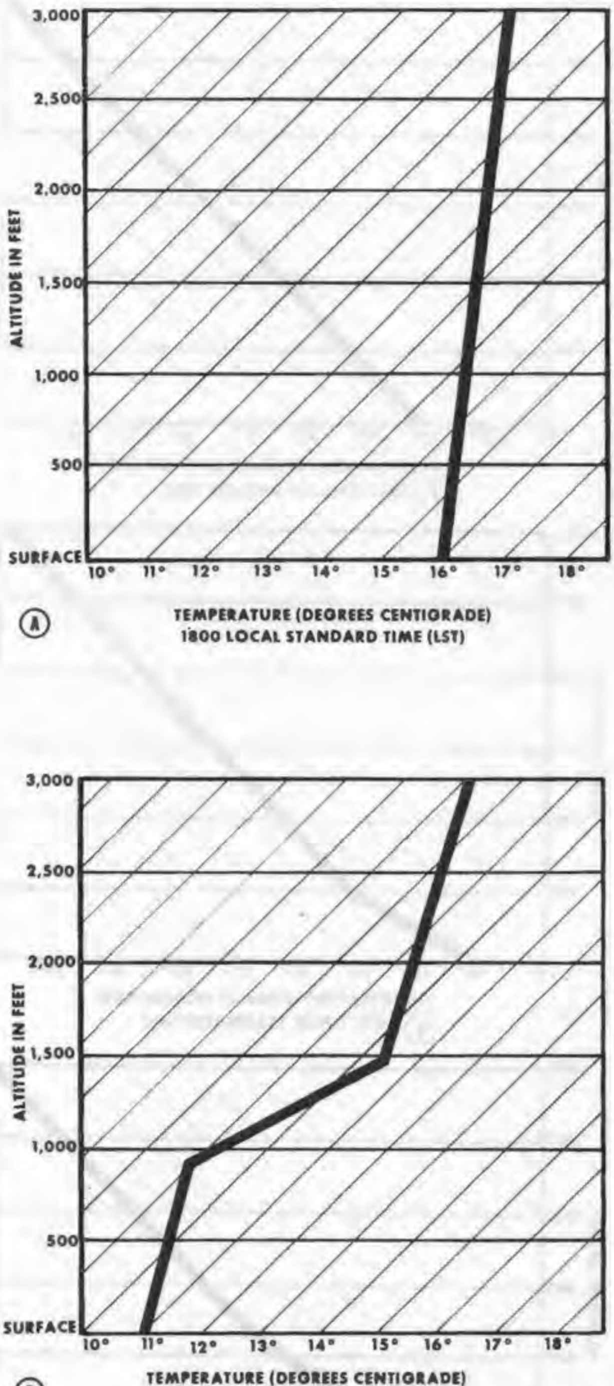


Figure 2-7. A nocturnal inversion with moderately strong surface wind.

2-7. Free Air Temperature

Temperatures used in aviation meteorology are those of the free air. Free air temperature measuring instruments are housed so that they are not in direct contact with sunlight. This housing also minimizes other effects which might cause inaccuracies in the readings.

Note. Measurement of outside air temperatures with standard aircraft thermometers is influenced by several factors (radiation, air pressure, and friction) which tend to decrease the accuracy of the indicated temperature. These factors may cause the reading to differ from the true free air temperature by more than 5° F.

2-8. Temperature Variation On the Earth's Surface

Three important factors responsible for temperature variation on the earth's surface are the earth's *daily rotation about its axis, yearly revolution around the sun, and variations in land mass and water mass heating.*

a. Daily Rotation. Daily surface heating and cooling results from the earth's rotation about its axis (fig. 2-8). As the earth turns, the side facing the sun is heated and the side away from the sun is cooled. Generally the lowest temperature occurs near sunrise, and the highest temperature is between 1300 and 1500 hours.

b. Yearly Revolution. The effects of the yearly revolution around the sun are modified by the tilt in the axis of the earth. Areas

Figure 2-8. Daily heating and cooling of the earth's surface.

under the direct or perpendicular rays of the sun receive more heat than those under the slanting rays (fig. 2-9). The slanting rays pass through more of the atmosphere, which absorbs, reflects, and scatters the sun's energy —fewer of these slanting rays reach the surface of the earth and the lower atmosphere. This accounts for the difference in the warmth of sunlight at 0800 when the rays are slanting, and at midday when they are more nearly perpendicular.

(1) Each year the perpendicular rays of the sun migrate from 23½° north latitude (June 21) to 23½° south latitude

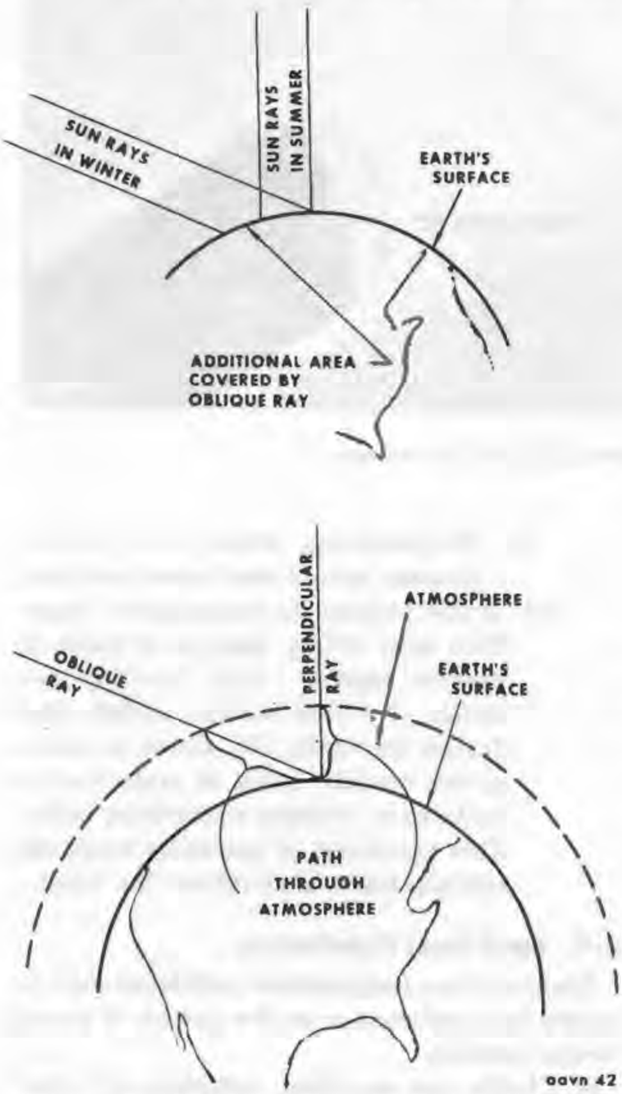


Figure 2-9. Variations in solar energy received by the earth.

(December 22), causing the seasons of the Northern and Southern Hemispheres. The warmest weather of the Northern Hemisphere comes 30 to 40 days after June 21 (see also *temperature lag*, glossary), when the most heat has been absorbed from the sun. This is the cold season in the Southern Hemisphere.

(2) The migration of the perpendicular rays of the sun results from the revolution of the earth around the sun while the earth's axis is tilted 23½° and remains parallel to its previous positions (fig. 2-10). The perpendicular rays of the sun strike the earth's surface at 23½° north latitude on June 21, at the Equator on September 22, at 23½° south latitude on December 22, and at the Equator again on March 21.

(3) Unequal duration of daylight contributes to the uneven distribution of heat. Each pole has 6 months of daylight and 6 months of night each year (fig. 2-10). On June 21, all territory within the Arctic Circle has 24 hours of daylight; on December 22, all territory within the Arctic Circle has 24 hours of darkness or twilight. For any given latitude, long days produce maximum heating and long nights produce maximum cooling.

c. Variations in Land Mass and Water Mass Heating. Land areas heat and cool more rapidly than water areas; water tends to have a more uniform temperature throughout the year. During the night, water retains its warmth while the land mass rapidly loses its heat to space. This difference between land and water heating rates also influences seasonal temperatures. In winter, oceanic climates are warmer than continental climates at the same latitude; in summer, the oceanic climates are cooler. Seattle, Wash., for example, has far warmer winters and somewhat cooler summers than Fargo, N. Dak., which is at the same latitude but farther inland.

(1) Water surfaces heat more slowly than land surfaces for the following reasons:

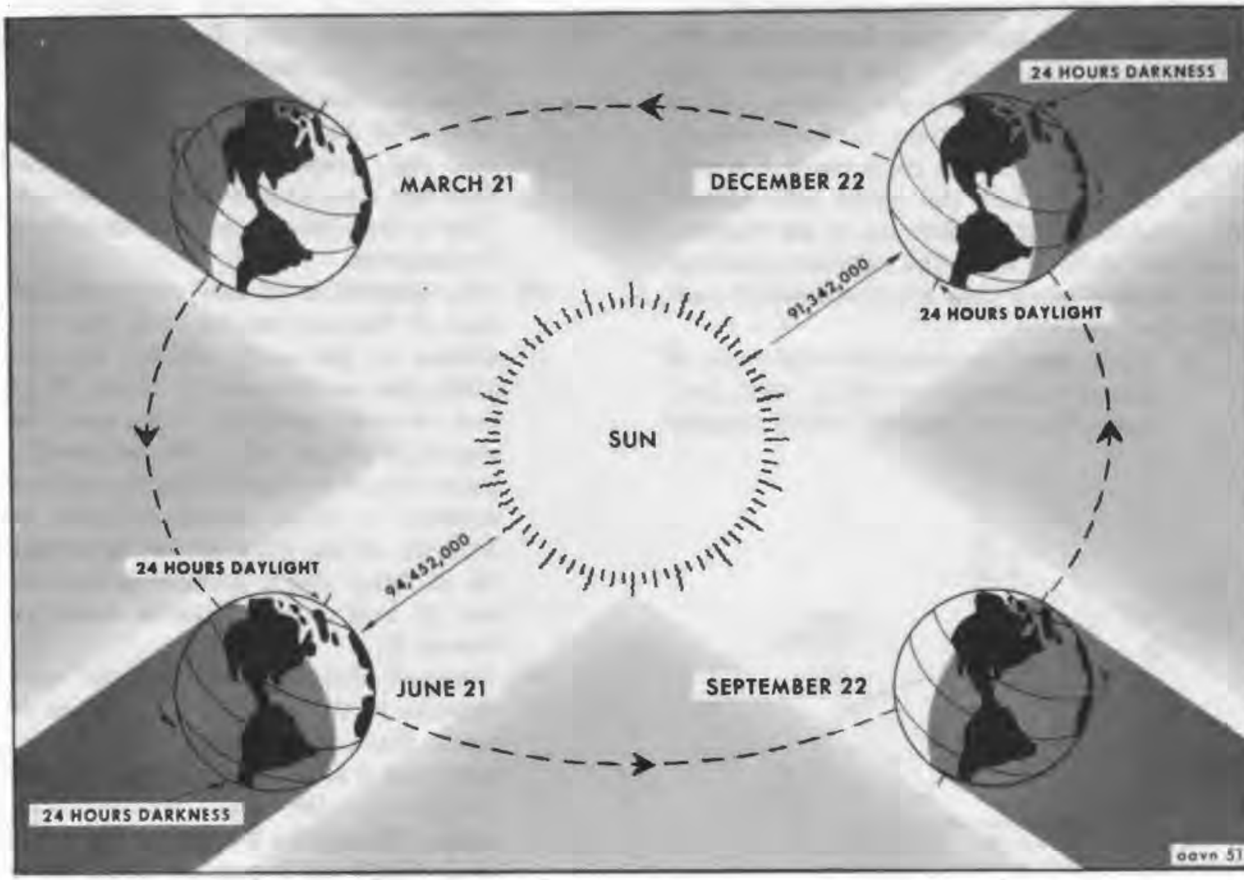


Figure 2–10. Effect of inclination of the earth on seasons.

(*a*) In early morning and late afternoon, water surfaces reflect more solar radiation than land surfaces reflect.

(*b*) Sun's rays penetrate 30 feet or deeper into water surfaces, but may affect only 4 inches of land surface.

(*c*) Ocean currents and turbulence within the water distribute the absorbed solar energy over large areas.

(*d*) The specific heat of water is four times that of land; that is, four times as much heat is required to raise the temperature of a given mass of water one degree as is required to raise the temperature of an equal mass of land one degree. Different specific heats result from variations in the molecular structure of the two substances.

(*e*) Evaporation, which is a cooling process, occurs over water surfaces.

(2) Water retains its temperature longer than land chiefly because it heats to greater depths. Only the top few inches of a land surface radiate heat during the night. However, as water at the surface cools, it sinks and is replaced by warmer water from below. This movement of the water keeps the surface warm throughout the night.

2–9. Local Heat Distribution

Local surface temperature variations may be caused by cloudiness or by the nature of a particular surface.

a. Clouds are excellent reflectors of solar radiation; also they are a factor in the retention of terrestrial radiation (fig. 2–11).

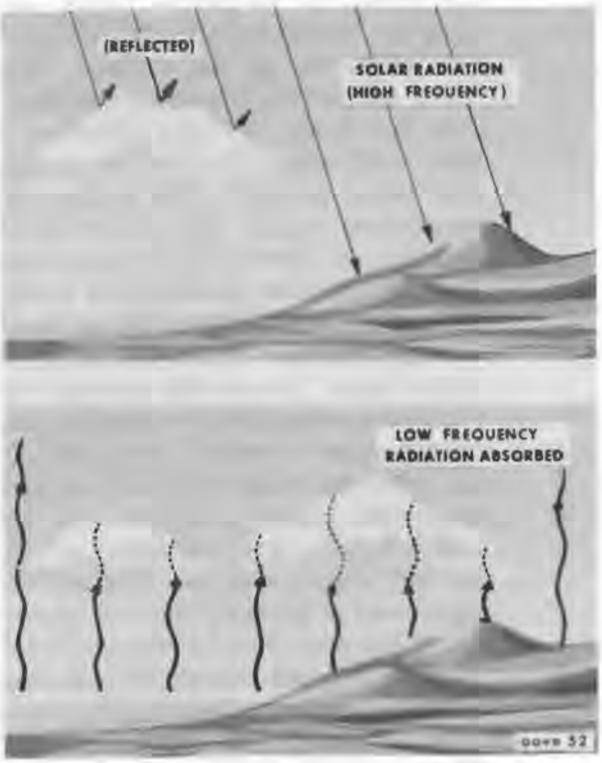


Figure 2–11. Reflection and absorption of radiation by clouds.

b. The earth's color, texture, and vegetation coverage influence the rate of heating and cooling. Generally, dry surfaces heat and cool faster than moist surfaces. Plowed fields, sandy beaches, and paved roads become hotter than surrounding meadows and wooded areas. During the day, air is warmer over a plowed field than over a forest or swamp; during the night, the heat distribution is reversed.

2–10. Methods of Heat Transfer

When a solid object or a given volume of liquid or gas loses more heat energy than it gains, its temperature decreases; when it acquires more heat energy than it loses, its temperature increases. At times, a complete change in the character of the weather occurs over land areas between early morning and midafternoon. This change takes place as a result of the heating and cooling of the earth and its atmosphere. The four effective methods of heat transfer in the heating and cooling of the earth and its atmosphere are *radiation, conduction, convection,* and *advection.* (See also *Cooling processes, major,* glossary.)

a. Radiation (Solar and Earth). Radiation is the process by which energy is transferred through space or through a material medium from one location to another in the form of electromagnetic waves. The high-frequency energy radiated by the sun is the primary source of weather phenomena on the earth. As energy passes through the atmosphere, about 42 percent is reflected back to space, about 15 percent is absorbed near the earth's surface, and about 43 percent reaches the surface. The 15 percent absorbed by the atmosphere has only a minor effect on atmospheric temperature. Primarily, the earth gets its heat from the 43 percent that reaches its surface.

(1) *Insolation.* The sun is the sole source of the heat energy that affects weather. Heat energy supplied by the sun is in the form of radiant energy called *insolation* (*in*coming *sol*ar radi*ation*), the majority of which is short wave radiation not absorbed by the atmosphere. The earth's surface is heated as it absorbs this radiant energy. The amount of insolation absorbed by the surface of the earth is affected by the—

(*a*) Inclination of the plane of the sun's rays to the plane of the horizon.

(*b*) Distance of the earth from the sun.

(*c*) Duration of daylight.

(*d*) Character of the earth's surface.

(*e*) Amount and type of clouds and impurities present.

(2) *Terrestrial radiation.* Because the earth's surface absorbs heat, it also radiates heat. The long wave radiation from the earth's surface is known as *terrestrial radiation.* Since low frequency, long wave radiation possesses a low penetration quality, the impurities in the atmosphere absorb a considerable amount of the earth's radiated heat. The reradiation process is fundamental to the heating of the earth's atmosphere. Since outgoing radiation remains in balance with incoming radiation, the earth becomes neither incandescent nor frozen.

(3) *Greenhouse effect.* Greenhouse effect refers to the ability of water vapor, smoke, haze, and particularly clouds to reduce or prevent the cooling of the earth during the night. These impurities to dry air readily absorb low-frequency terrestrial radiation and reradiate it to the earth. Thick overcast clouds return practically all of the terrestrial radiation, and the air temperature below them may drop as little as 2° F. during an entire night. These clouds produce an effect on radiation similar to that produced by the glass top on a greenhouse. They allow a large portion of high-frequency insolation to pass through and heat the earth, but they block the passage of low-frequency terrestrial radiation and retain the heat below them. High concentrations of water vapor and smoke cause a partial greenhouse effect and may also noticeably reduce nocturnal cooling.

b. Conduction. Conduction is the transfer of heat by contact. This process is important in meteorology because it causes the air close to the surface of the earth to heat during the day and cool during the night. However, air is a poor conductor (as shown by the use of dead airspace in thermopane glass and by airspace insulation in buildings), so only the air temperature at the immediate surface of the earth is affected directly by conduction.

c. Convection. When a parcel or mass of air moves upward or downward in the atmosphere, it carries its heat energy with it. This vertical movement of air produces the method of heat transfer known as *convection,* which is classified as *thermal* or *mechanical.*

(1) *Thermal convection.* The surface air, after being heated by conduction and terrestrial radiation, expands in volume and decreases in density. Because of expansion, a portion of the warmer, lighter column of air overflows aloft, thereby decreasing its own pressure at the surface and at the same time increasing the surface pressure of the adjacent cooler air. This causes a lifting of the warmer, lighter air column by the heavier, cooler, settling air which flows in and displaces the warm air at the surface. The warm surface air, expanded and therefore less dense, is like a cork that is held under water; i.e., it is unstable and tends to rise. The rising and descending air of this nature is referred to as *thermal* convection, since the convection is produced by a temperature contrast within the air layer. Strong thermal convective currents occur most frequently during the afternoon when surface heating and temperature contrasts are greatest; i.e., between water and land, plowed fields and grassy areas, swamps and rocky terrain, or in regions where the surface is extremely hot. The vertical movement of the air displaces aircraft flying through it and produces turbulence in varying degrees of intensity, generally strongest during the hours of maximum surface heating.

(2) *Mechanical convection.* Air passing from one side of a mountain range to the other side is forced into the vertical movement by the mechanical lifting from the land surface (*orographic lifting*). Flights over mountainous areas are frequently bumpy and turbulent because of mechanical convection. In areas where clouds are forming on the windward side of a slope, both thermal and mechanical convection often occur. The air is lifted orographically until it becomes warmer than the surrounding air at the same altitude, and then continues to rise by thermal convection. (See also *level of free convection* in paragraph 5–5*d.*) This action forms large billowy clouds and even thunderstorms when large amounts of water vapor are present.

d. Advection. The horizontal movement of air (wind) is called *advection* (compare with *e* below). Advection, like the other methods of heat transfer may produce either a heating or a cooling effect in a given area. This heating and cooling is most noticeable in the Temperate Zone during the winter months when cold and warm air masses alternately affect a given location, but advection occurs during all seasons.

(1) The movement of colder air into an area called *cold air advection*. During the winter months, for example, masses of cold air from Canada predominate in Central and Eastern United States. The movement of this cold Canadian air southward is cold air advection. Cold air advection usually produces good flying weather except during the winter on the lee sides of relatively large water bodies such as the Great Lakes.

(2) The movement of warmer air into an area is called *warm air advection*. During the winter months, for example, masses of warm air from the Gulf and Atlantic may affect areas in Southern and Eastern United States. The movement of this warm air northward is warm air advection. The advection of warm moist air over land during the winter is characterized by low overcast clouds and restricted visibility.

e. Advection and Isotherms. An *isotherm* is a line connecting points of equal temperature. The horizontal flow of air across isotherms is a type of advection. Wind flowing from the cold air side of the isotherms across to the warm air side produces *cold air advection,* since cold air is moving into an area previously occupied by warm air. Wind flowing across isotherms from the warm air side to the cold air side produces *warm air advection.* Warm air advection at the surface results in the air being *cooled* from below. Cold air advection at the surface results in the air being *heated* from below. This heating and cooling from below is a major governing factor in the analysis of air mass weather (ch. 6).

Section III. MOISTURE

2-11. Moisture Changes

Most weather hazards that interfere with the operation of aircraft are associated with water in one of its three states—vapor, liquid, or solid. Water vapor is water in the gaseous state and is not visible. When it changes into liquid water droplets, it becomes visible as clouds, fog, dew, rain, or drizzle. Some water droplets, remaining in the liquid state at temperatures well below freezing, change into ice only when disturbed by an outside force, such as an aircraft wing. These water droplets are supercooled and cause structural icing on aircraft. Water in the solid state appears either as frozen water droplets or as ice crystals, such as snow.

a. Evaporation. Evaporation is a change of state from a liquid to a gas. According to the molecular theory, all matter consists of molecules in motion. The molecules in a bottled liquid are restricted in their motion by the walls of the container. On a free surface exposed to the atmosphere, the motion of molecules in the liquid is restricted by the weight of the atmosphere (*atmospheric pressure*). The velocity of the liquid molecules causes them to escape from the surface of the liquid into the atmosphere as a vapor. 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 is also increased. During the process of evaporation, liquid water at a temperature of 100° C. will absorb approximately 540 calories of heat energy per gram as it turns to vapor at a temperature of 100° C. The *calorie* (a unit of heat energy) is the heat required to raise the temperature of 1 gram of water 1° C. under standard conditions. This energy is required to keep the water molecules in the vapor state, but does not affect the temperature of the water. Evaporation has a cooling effect on the immediate area in which the process is occurring. The heat energy required to effect the change in state from liquid to vapor must be taken from the environment in which the evaporation is taking place. For example, warm dry air moving through an evaporative air conditioner supplies heat to evaporate the water inside the air conditioning unit. The temperature of the water inside the unit does not change, but the air coming from the unit has lost heat energy to the evaporating water and is cool and humid. A similar cooling process occurs to the air in the atmosphere when clouds or fog evaporate.

b. Condensation. Condensation is the change of state from a gas to a liquid. Water vapor at 100° C. contains approximately 540 calories per gram more heat energy than liquid at the same temperature (*a* above). Since energy cannot be destroyed, the formation of water droplets from the vapor must release this quantity of heat energy to the environment. The process of condensation has a heating effect. In the atmosphere, condensation normally lessens the cooling effects of other processes (par. 5-4*b*). The latent heat energy released from the condensation in a single cloud may involve billions of calories. This energy produces the force required to develop the extreme winds and turbulence in thunderstorms, tornadoes, and hurricanes. Impurities must also be present in the atmosphere to act as a nucleus around which fog and cloud droplets can form. If air is free of impurities it can be cooled well below its normal capacity for maintaining its moisture in vapor state (supersaturation), but condensation does not occur.

c. Sublimation. The direct change of state from solid to vapor and vice versa, without passing through the intermediate liquid state, is called *sublimation.* This process takes place at temperatures below 0° C. and is similar to evaporation and condensation in that latent heat is liberated when solidification takes place and is absorbed when evaporization occurs. At temperatures below 0° C., ice or snow can sublimate directly into the air as water vapor, and when the required nuclei are present, the water vapor can sublime directly into ice crystals. Figure 2-12 illustrates the heat exchanges involved in the process of evaporation, condensation, and sublimation.

d. Heat Exchange. The amount of heat necessary to melt ice (heat of fusion) is 80 calories per gram of ice. As much heat is needed to change ice at 0° C. to water having the same temperature as is needed to heat the resulting water from 0° to 80° C. (fig. 2-12). Heat energy is also required to convert liquid water into vapor. At normal atmospheric temperatures, this requirement is about 600 calories per gram (590 calories per gram at 0° C. and 540 at 100° C.). Vapor condensing into water at normal atmospheric temperatures gives off about 600 calories of heat. This heat is called the *latent heat of vaporization* (or latent heat of condensation). For example, in the ordinary steam heating system, the steam produced in

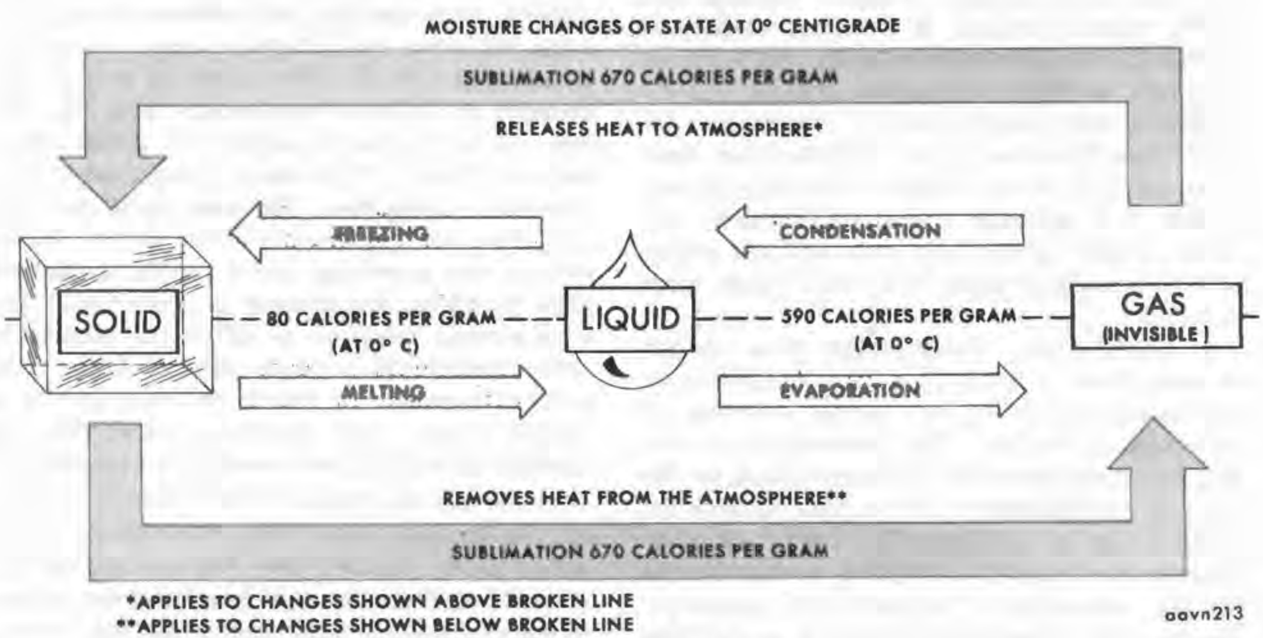


Figure 2-12. Heat exchanges.

the boiler gives off its heat of condensation to the radiator in which it condenses; the heat is radiated from the radiator into the room.

2-12. Water Vapor Content

a. Saturation. Saturation is a condition that exists when air at a given temperature and pressure is holding the maximum possible water vapor content. In the atmosphere, saturation occurs by (1) evaporation into the air from a free water surface (ocean, lake, river, raindrops) until vapor pressure equilibrium ((1) below) between the water and the air is reached; or (2) lowering of the air temperature, thereby decreasing the saturation vapor pressure until it is the same as the actual vapor pressure of the water vapor in the air.

(1) A condition near saturation must be reached before condensation will occur. In a vessel partially filled with water, and with a stationary column of air above it, the water molecules escape into the air and continue their motion as water vapor. These vapor molecules, because of their motion, exert an increased pressure (called the *partial pressure* of the water vapor in the air column) back on the liquid surface. The partial pressure of the water vapor is independent of the partial pressures of the other gases in the air. The rate at which the molecules from the air enter the liquid water surface depends upon the frequency with which they strike the surface, which in turn depends upon the number and velocity of the water molecules in the air (the partial pressure of the water vapor in the air). As more and more molecules enter the vapor state, some will return to the liquid surface. When a condition of equilibrium is reached wherein the number of molecules leaving the liquid equals the number returning, the space above the liquid is said to be saturated and the pressure exerted by the water vapor molecules is called the *saturation vapor pressure* for the particular air and water temperature existing. When the air temperature is raised, the number of molecules necessary for saturation and their individual velocities are increased, thus raising the saturation vapor pressure of the air; i.e., the air is able to hold more vapor molecules and is no longer saturated.

(2) As saturation in the atmosphere is approached, the presence of nuclei, such as those of dust and salt particles, is required to promote the actual condensation of the water vapor into liquid.

(3) Water vapor is a universal constituent of the atmosphere. There is a limit to the quantity of water vapor which can be contained in a given volume of air. If more and more water vapor is injected into a container of air, a condition will be reached in which the water will condense as fog in the container or as dew on its walls. If more water vapor is added, more will condense, and the total amount of vapor in the container will remain unchanged. The air in the container is then said to be saturated with water vapor.

(4) The quantity of water vapor in a saturated volume of air depends on the air temperature. The higher the temperature of the air, the greater is the tendency for liquid water to turn into vapor. At a higher temperature, more vapor must be injected into the given volume of air before the saturated condition will be reached. Conversely, cooling the saturated air will force some of the vapor to condense, and the quantity of vapor present will diminish.

b. Dew Point. The dew point is that temperature to which air (at constant pressure and with constant water vapor content) must be cooled to become saturated. For example, if the air temperature were 60° F. and the dew point 50° F., the air would be saturated if cooled to 50° F. If the air were further cooled to 49° F., it could no longer hold all the water vapor present—some of it would be virtually "squeezed out" in the form of liquid water; condensation would have taken place. If this cooling took place only in the fraction of an inch or so of the air above the ground, dew would form;

however, it is more likely that the cooling will affect a deeper layer of the lower troposphere and fog will form. The dew point is important to the Army aviator because it indicates the temperature at which fog will normally start to form. When the air is saturated, the relative humidity is 100 percent; if the air is not saturated, the temperature is a higher value than the dew point and the relative humidity is less than 100 percent. The greater the spread between the temperature (T) and the dew point (T_d), the more remote is the possibility of fog formation. Generally, condensation will not occur when the spread exceeds 4° F.

c. Specific Humidity.

(1) The moisture content of the air can be measured by expressing the humidity as the amount of water vapor (in grams) contained in one kilogram of natural air. This is called the *specific humidity*. A kilogram of air will carry the same number of grams of water vapor with it wherever it goes, unless more water vapor is added by evaporation or removed by cooling and condensation. The moisture content can also be expressed as a weight per unit volume (absolute humidity), but this ratio would change any time the atmospheric temperature or pressure changed.

(2) The Army aviator should be able to interpret and recognize the significance of specific humidity (high or low). The greatest quantity of water vapor for condensation and/or sublimation is available in air masses having a high specific humidity. To an aviator the temperature of the dew point (T_d) is an indicator of the quantity of moisture in the air; the higher the dew point, the greater the amount of moisture in the air. In the normal range of temperatures over the surface of the earth, a doubling of the moisture content of the air is represented by an approximate 20° F. rise in the dew point (fig. 2-13). If, for example, a kilogram of air with a dew point of 60° F. contains 11 grams of moisture (water vapor), a kilogram of air with a dew point of 80° F. contains about 22 grams of water vapor. Conversely, if a saturated parcel of air at 80° F. is cooled to 60° F., 11 grams of water would have to be released through the condensation process. This condensation gives off heat energy to the atmosphere, and the heat energy may be realized as turbulence in clouds.

d. Relative Humidity. Most of the atmosphere is not saturated; it contains less than the maximum possible quantity of water vapor. For weather analysis, it is desirable to be able to express how *near* the air is to being saturated.

(1) Relative humidity (RH) is defined as the ratio of the amount of water vapor contained in the air to the amount of water vapor that the air would contain when saturated at the same temperature. It is expressed as a percentage, with saturated air having 100 percent relative humidity.

(2) Relative humidity is related to the spread (difference) between the temperature (T) and the dew point (T_d). The temperature of the dew point is raised by increasing the actual moisture content of the air—actual vapor pressure. If the T_d were exactly equal to the T, the air would be saturated. The actual air temperature, therefore, controls the maximum amount of moisture the air could contain—saturation vapor pressure. Thus the equation for relative humidity may be expressed as—

$$RH = 100 \times \frac{\text{actual vapor pressure}}{\text{saturation vapor pressure.}}$$

(3) For example (fig. 2-13), and air parcel with T of 80° F., T_d of 60° F., and RH of 50 percent has a saturation vapor pressure corresponding to T=80° F.; however, it can hold twice as much water vapor as is present since the relative humidity is 50 percent. An RH of 100 percent can be obtained by increasing the amount of water (water vapor) in the air until T_d has been raised to 80° F.; an RH of 100 percent can also be reached by cooling the tem-

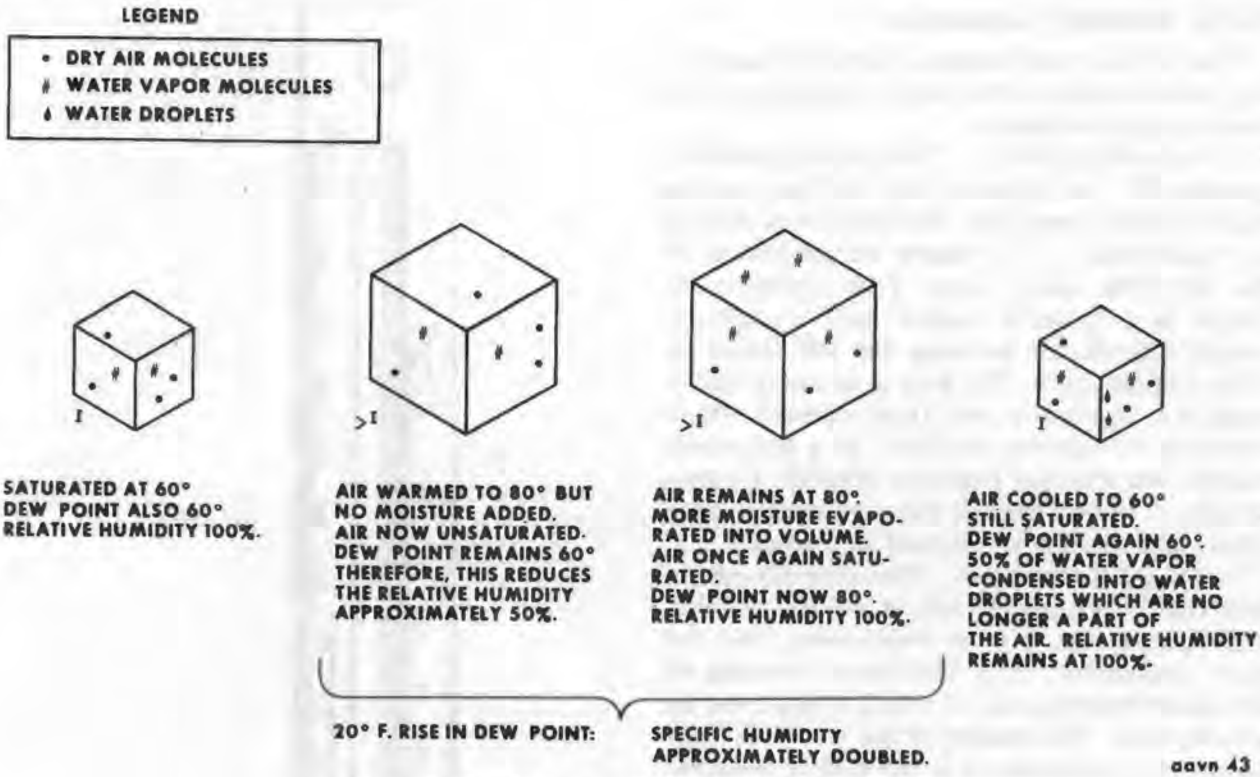


Figure 2–13. Diagrammatic illustration of dew point.

perature to 60° F. Although the saturated parcel of air at 60° F. contains only one-half the moisture that the saturated parcel of air of 80° F. contains, both of the parcels have 100 percent relative humidity—a relative value depending upon the percentage of saturation.

e. Mixing Ratio. When air rises, it expands and contains fewer molecules per cubic meter. Mixing ratio is the method of indicating the moisture content of the air so that the ratio of water vapor to air will not change when the atmospheric pressure or temperature changes. Mixing ratio is defined as the ratio of the density of the water vapor present to the density of the dry air; it is usually expressed as the number of grams of water vapor per kilogram of dry air. For practical purposes, the mixing ratio remains constant with changes in air temperature and pressure so long as no moisture is added or removed.

f. Saturated Mixing Ratio. Air at a given temperature can hold only a certain amount of water vapor before it is saturated. The total amount (weight) of vapor which a given weight of dry air will hold at a specific temperature and pressure is referred to as the *saturated mixing ratio*. The following relationship exists between mixing ratio, saturated mixing ratio, and relative humidity:

$$\text{relative humidity} = \frac{\text{mixing ratio}}{\text{saturated mixing ratio}} \times 100.$$

Note. If any two of the three components in this relationship are known, the third can be determined mathematically in the formula.

g. Distribution of Water Vapor. The part of the atmosphere which remains over tropical water may contain large amounts of water vapor (over 20 grams per kilogram) but, because of the high air temperature, will not be completely saturated. On the cther hand, very cold air (at approximately 0° F.) may contain only 1 gram per kilogram, and yet become saturated, producing sublimation. The maximum weight of the water vapor in the atmosphere is rarely more than 4 percent of the total weight of the natural air.

2-13. Humidity Instruments

Two of the most common humidity measuring instruments are the hair hygrometer and the sling psychrometer.

a. Hair Hygrometer. The hair hygrometer operates on the principle that oil-free human hair stretches when wet. The amount of stretch is proportional to the degree of saturation of the air with water vapor (the variation in length of a properly treated hair is approximately logarithmic between the RH limits of 20 to 100 percent). The hair is mounted under tension to operate a dial (hygrometer) which indicates the relative humidity, or a pen which records the relative humidity directly (hygrograph). The hair hygrometer is subject to large errors and is slow to respond to changes.

b. Sling Psychrometer. The sling psychrometer (fig. 2-14), also known as the wet and dry bulb hygrometer, is more satisfactory than the hair hygrometer. This instrument consists of two thermometers, one of which is kept wet by a linen wick. The cooling of the wet bulb thermometer is proportional to the rate of evaporation of the water from the wick. The rate of evaporation depends on the relative humidity and the temperature of the surrounding air. When the air is very dry, evaporation from the wick will cool the wet bulb thermometer and its temperature indication will be lower than that of the dry bulb thermometer. When the air is saturated, there is no evaporation, so both thermometers give the same readings. Psychrometric tables are provided to obtain dew point and relative humidity from the air temperature given by the dry bulb thermometer and the temperature given by the wet bulb thermometer.

2-14. Precipitation

a. General. Precipitation is the general term for all forms of falling moisture (e.g., rain, snow, hail, sleet, and their modification). The chain of events that lead up to precipitation include—

(1) Saturation of the air by cooling and/or increasing the water vapor content in the air.

(2) Condensation of the water vapor through the action of hygroscopic nuclei, forming clouds. Clouds may

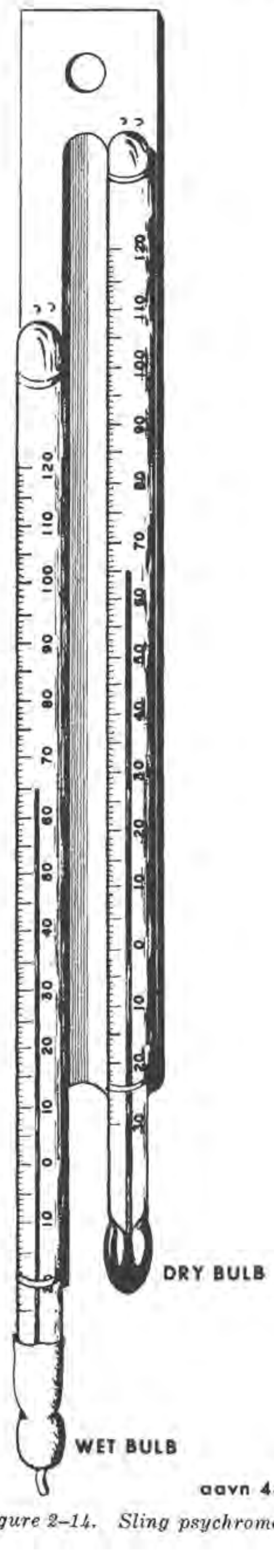


Figure 2-14. Sling psychrometer.

be composed of water droplets or ice crystals, or combinations of both, depending upon the temperature and the amount of convective activity in the cloud.

(3) Coalescence, or growth, of water droplets in size and weight. Much condensation occurs without producing precipitation; i.e., there are many clouds which do not result in rain. Clouds may be considered as colloidal suspensions of liquid and/or solid water in the air. The tendency for cloud particles to coalesce and produce larger droplets, which fall because of gravitational attraction, is furthered by the following five conditions: (a) nonuniform electrical charges in cloud droplets (electrical attraction), (b) differences in sizes of cloud droplets (mass attraction), (c) temperature differences between cloud droplets (vapor pressure differences), (d) motion of the droplets (turbulent mixing), and (e) ice crystals (water droplets will evaporate and sublime on ice crystals, increasing the size of the ice particles). Combinations of these five conditions will determine the size of the precipitation particles falling from the clouds. In highly turbulent clouds which extend above the freezing level, both ice crystals and water droplets are present, causing rapid transfer of water from droplet to crystal through evaporation and sublimation. These highly turbulent clouds produce large amounts of rainfall during short periods of time.

b. Liquid Precipitation.

(1) *Rain*—precipitation which reaches the earth's surface as relatively large droplets. Rain can be classified as light, moderate, or heavy. This classification is normally based on rate of fall or the affect it has on visible surfaces or on horizontal visibility.

(2) *Drizzle*—precipitation from stratiform clouds in the form of numerous drops of water much smaller in diameter than those occurring in rain. The fact that these minute drops reach the earth indicates the absence of turbulence. Drizzle is classified as light, moderate, or heavy. This classification is normally based on rate of fall or the restriction to horizontal visibility.

c. Freezing Precipitation.

(1) *Freezing rain*—precipitation in the form of super-cooled liquid raindrops, a portion of which freezes and forms a smooth coating of ice upon striking exposed objects (e.g., the wing of an airplane in flight or the surface of a runway).

(2) *Freezing drizzle*—precipitation in the form of super-cooled drizzle which freezes in a manner similar to freezing rain.

d. Frozen Precipitation.

(1) *Sleet*—frozen raindrops formed by rain falling through a layer of colder air with below freezing temperatures.

(2) *Hail*—precipitation of balls or irregular lumps of ice. Hail results when waterdrops below the freezing level are repeatedly carried above the freezing level by currents in a thunderstorm. The drops freeze into ice pellets, start falling, and accumulate a coating of water. Carried upward again by an ascending current of air, the coating freezes, enlarging the diameter of the hailstone. This process, repeated a number of times, can produce hailstones weighing as much as 2 pounds.

(3) *Snow*—precipitation composed of ice crystals. When atmospheric water vapor sublimates at temperatures below 0° C., ice crystals may form and fall to the ground, usually as snowflakes or combinations of individual ice crystals.

2-15. Hydrologic Cycle

Water at the earth's surface evaporates by absorbing heat energy. The water vapor is transported horizontally and vertically by atmospheric currents until it releases its energy to the atmosphere through condensation in forming clouds and fog. The water cycle is completed when precipitation returns the water to the surface. This evaporation-condensation cycle is a part of the thermodynamics involved in the series of water phenomena called the *hydrologic cycle*. The phases of the hydrologic cycle are—

a. Precipitation from clouds falls on sea and land.

b. Water flows from land to sea as runoff or seepage.

c. Evaporation from precipitation and all moist surfaces, and transpiration from plants and animals, supply water vapor for the atmosphere.

d. Condensation and sublimation of water vapor produces clouds, completing the cycle. Throughout the cycle, the earth and its atmosphere neither gains nor loses moisture.

Section IV. PRESSURE

2-16. Pressure

a. *Pressure* is force per unit area ($P = F/a$). The pressure exerted by a fluid (gas or liquid) varies with the height of the fluid column and the density of the fluid. A force (mass $\times$ acceleration) exerted on or by a fluid is distributed uniformly throughout the fluid in all directions, and is independent of the orientation of the surface on which it acts.

b. *Atmospheric Pressure* is the pressure exerted by the atmosphere as a result of gravitational attraction acting upon the column of air lying directly above a point. As a result of the constant and complex air movements and the changes in temperature and moisture content of the air, the weight of the air column over a fixed point is continually fluctuating. These changes in weight, and therefore pressure, are imperceptible to the human senses, but are measurable with pressure-sensitive instruments.

2-17. Pressure Instruments

The instruments commonly used in the measurement of atmospheric pressure are the mercurial barometer (or mercury barometer), the aneroid barometer, and the barograph.

a. *Mercurial Barometer*. Figure 2-15 shows the principle of the mercurial barometer. The weight of the atmosphere presses down on the mercury in container *A* and supports the column of mercury inside the glass tube *B* from which all air has been removed. The weight of the mercury column corresponds to the weight of the atmosphere. In the illustration (fig. 2-15) the column of mercury is 29.92 inches high; the atmospheric pressure, therefore, is equal to the weight of a column of mercury that is 29.92 inches in height. The conversion of height to weight exerted (force) per unit area may be accomplished as follows:

(1) A cubic inch of mercury (*C*, fig. 2-15) weighs 0.491 pounds.

(2) If three such cubes were placed in a container (*D*, fig. 2-15) the bottom surface would be under a pressure of 3×0.491, or 1.473 pounds per square inch.

(3) Replacing the 3 inches with the 29.92 inches of mercury in the glass tube results in the equation—$29.92 \times 0.491 =$ 14.69 pounds per square inch.

b. *Aneroid Barometer*. The activating unit of an aneroid barometer is a metal bellows containing a partial vacuum. The bellows expands or contracts in response to changes in atmospheric pressure. A pointer, linked to the bellows, moves across a calibrated dial, thereby constituting the indicator mechanism (fig. 2-16). Although not as accurate as the mercurial barometer, the aneroid barometer is useful because of its compact and rugged construction.

c. *Barograph*. The barograph is an aneroid barometer which records a continuous record of atmospheric pressure (fig. 2-17).

2-18. Units of Pressure Measurement

Inches of mercury and *millibars* are two pressure units of which every aviator must have a knowledge. He uses these units during each flight and in each weather briefing by the forecaster.

a. *Inches of Mercury (Hg)*. The most common unit is the inch of mercury, derived from the height of the mercury column in a mercurial barometer. Since the inch is a unit of length, this system does not directly express the force per unit area (pressure) that the atmosphere exerts.

b. *Millibar*. In meteorology, it is more con-

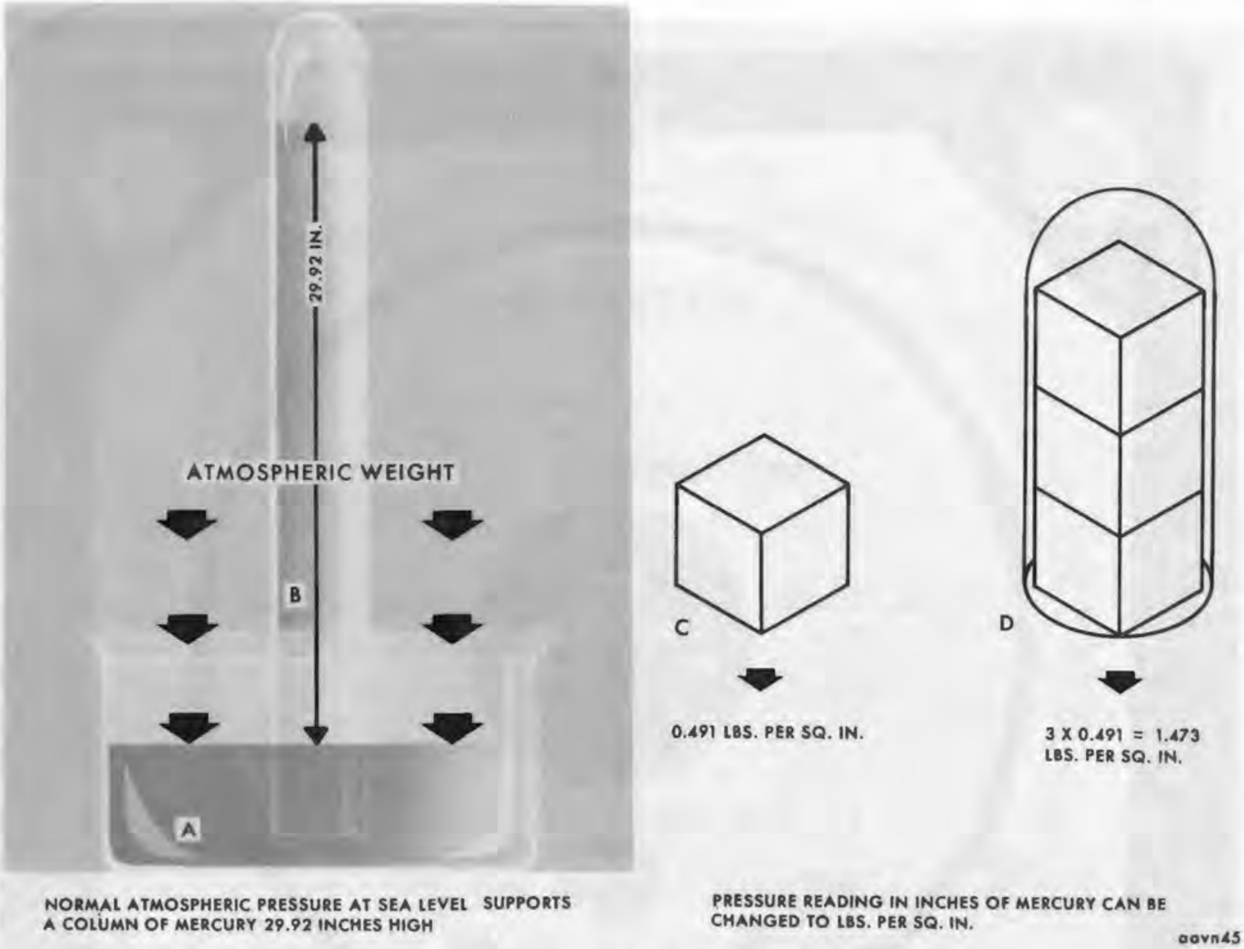


Figure 2–15. Principle of the mercurial barometer.

venient to express the pressure directly as a force per unit area. This is done by using a unit called the millibar (mb). This unit is one-thousandth of a bar. Since fluctuations in atmospheric pressure are small compared with the force represented by a bar, it is convenient to use the smaller unit. One bar represents a force of 1 million dynes per square centimeter. A dyne is the metric unit of force required to give a 1-gram mass an acceleration of 1 centimeter per second. When expressed in millibars, the atmospheric pressure is given directly as a force per unit area.

(1) Since the Kollsman window of pressure altimeters in United States aircraft is calibrated for settings in inches of mercury, aviation agencies of the United States government express altimeter settings in inches of mercury. However, many foreign nations use the millibar for altimeter settings. Aviators flying in these countries will need a conversion table (millibars to inches of mercury) in the aircraft and a general familiarity with the millibar as a unit of pressure.

(2) Standard atmospheric pressure at sea level is 1013.2 millibars, which is the equivalent of 29.92 inches of mercury. The pressure exerted by 1 inch of mercury is equivalent to approximately 34 millibars, and the pressure exerted by 1 millibar is equivalent to approximately 0.03 inch of mercury.

Figure 2-16. Aneroid barometer.

2-19. Sea Level Atmospheric Pressure

a. The observed pressure at an airfield is of little value to the meteorologist since altitude variations affect the pressure. The pressure at high elevations should be less than that at low elevations, even when standard atmospheric conditions exist over both points. Therefore, atmospheric pressure measurements can only be of value when they are corrected to a standard altitude reference level—the mean (average) sea level altitude.

b. Most reported pressures are corrected to mean sea level (MSL) by local weather stations. These MSL pressures are then used in plotting isobars and station data on surface weather maps to show the location, shape, and size of pressure systems.

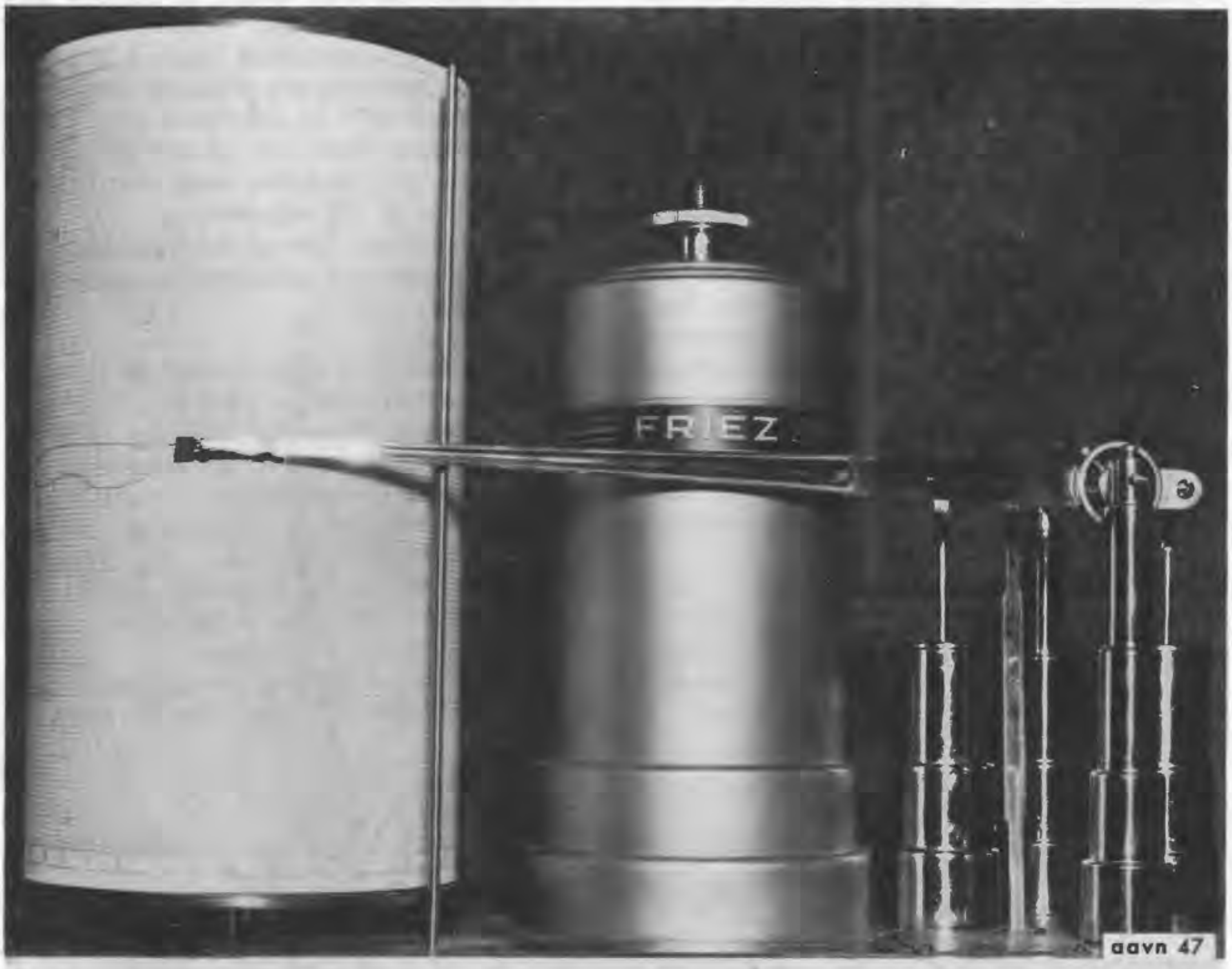


Figure 2-17. Barograph.

c. Altimeter settings are corrected to 10 feet above MSL to compensate for the average distance from the surface to the instrument in the aircraft.

d. The standard or normal atmospheric pressure at sea level at a standard air temperature of 15° C. is 1,013.2 millibars, 29.92 inches of mercury, or 14.7 pounds per square inch. However, standard atmospheric pressure seldom exists at a given station. Normal sea level pressures in the atmosphere vary from as low as 950 millibars (about 28 inches) to as high as 1,050 millibars (about 31 inches). Such variations in pressure indicate the dynamic nature of the atmosphere.

2-20. Determining Pressure Systems

To eliminate pressure variations caused by stations being at different altitudes, the mean sea level pressure is plotted in millibars at each reporting station on a surface weather map. Lines (isobars) are drawn connecting equal values of reported mean sea level pressure. The isobars and appropriate labels in millibars (mb) outline pressure areas in somewhat the same manner as contour lines outline terrain features on contour maps. Standard procedure on maps of North America is to draw isobars for every 4 millibars. The isobaric pattern is never the same on any two weather maps; however, they do show patterns of similarity. The pressure patterns and systems (shown by the configuration of the isobars) which have a definite meaning to the aviator are shown in figure 2-18.

a. Low.

(1) A low is a pressure system in which the barometric pressure decreases toward the center, and the windflow around the system is counterclockwise in the Northern Hemisphere. The terms *low* and *cyclone* are interchangeable. Any pressure system in the Northern Hemisphere with a counterclockwise (cyclonic) windflow is a cyclone.

(2) Low pressure systems with severe storm characteristics are called hurricanes, typhoons, tropical storms, tornadoes, or waterspouts to identify the exact nature of the storm.

(3) Unfavorable flying conditions in the form of low clouds, restricted visibility by precipitation and fog, strong and gusty winds, and turbulence are common in low pressure systems.

(4) Thermal lows caused by intense surface heating and resulting low air density over barren continental areas, are relatively dry with few clouds and practically no precipitation. These thermal lows are almost stationary and predominate over continental areas in the summer.

(5) Migratory lows of the secondary circulation are discussed in paragraph 4-7.

b. High.

(1) A high is a pressure system in which the barometric pressure increases toward the center, and the windflow around the system is clockwise in the Northern Hemisphere. The terms *high* and *anticyclone* (opposite of cyclone) are interchangeable. Any pressure system in the Northern Hemisphere with a clockwise (anticyclonic) windflow is an anticyclone.

(2) Flying conditions are generally more favorable in highs than in lows be-

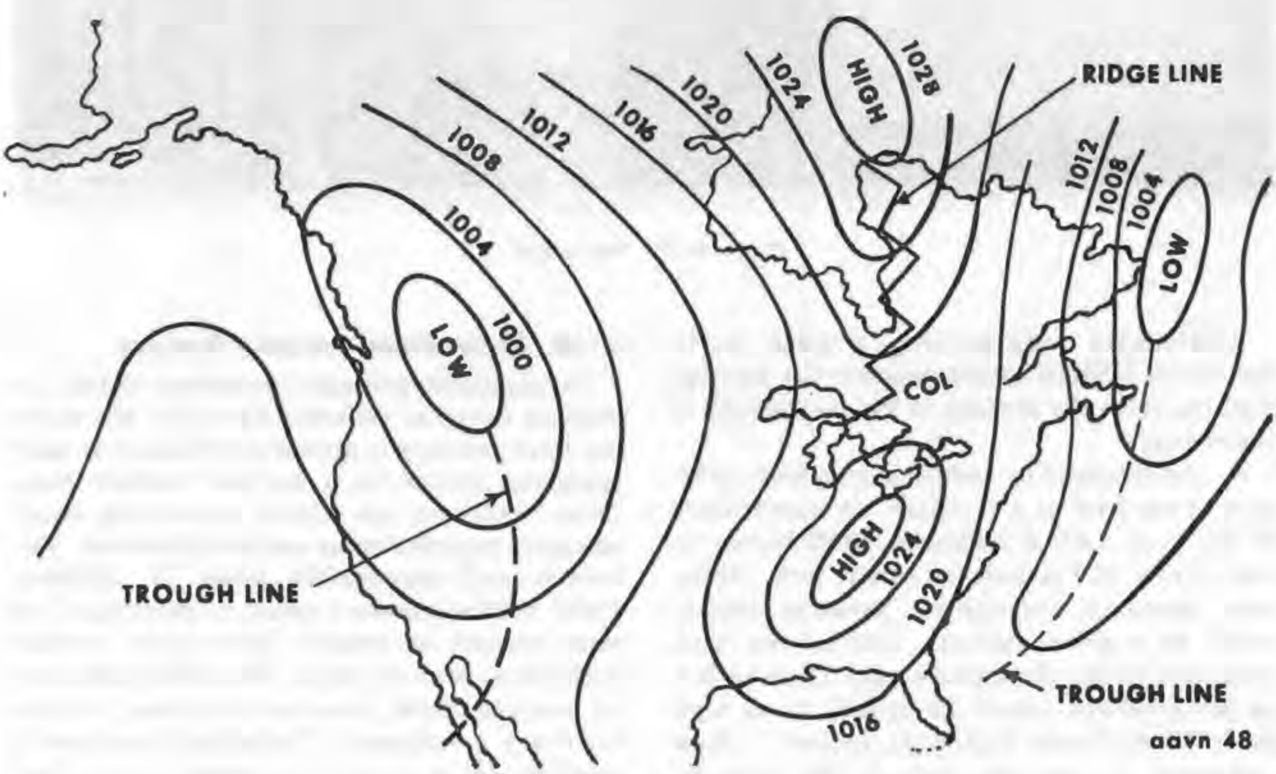


Figure 2-18. Pressure systems.

cause of less clouds, better daytime visibility, light or calm winds, and less-concentrated turbulent areas.

(3) High pressure systems predominate over cold surfaces (where the air is dense). They are more intense over continental areas in winter and oceanic areas in summer. Centers of high pressure rarely exist south of 23° N. latitude in the Northern Hemisphere.

(4) In the Northern Hemisphere, a general cycle of highs and lows moves through the Temperate Zones from west to east. The movement of the pressure systems is more rapid in winter season when the cyclones are most intense and the anticyclones extend farthest to the south (para 7-7).

c. Col. A *col* is a saddleback region between two highs or two lows. The weather is erratic and unpredictable because of the flat pressure gradient.

d. Trough. A *trough* is an elongated area of low pressure, with the lowest pressure along the trough line. The weather in a trough is frequently violent.

e. Ridge. A *ridge* is an elongated area of high pressure with highest pressure long the ridge line. The weather in a ridge is generally favorable for flying.

2-21. Pressure Gradient

The rate of change in pressure in a direction perpendicular to the isobars is called *pressure gradient.* Pressure applied to a fluid (gas or liquid) is exerted equally in all 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 outward in the atmosphere at the surface. Therefore, a pressure gradient exists in the horizontal (along the surface) as well as the vertical (with altitude) plane in the atmosphere.

a. Horizontal Pressure Gradient. The horizontal pressure gradient is *steep* or *strong* when the isobars determining the pressure system (fig. 2-19) are close together. It is *flat* or *weak* when the isobars are far apart.

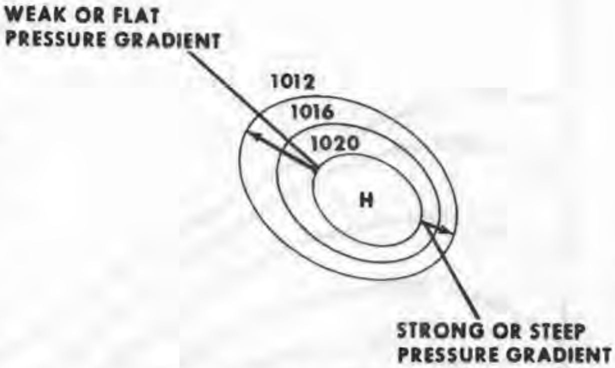


Figure 2-19. Principle of pressure gradient.

b. 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 per 1,000 feet in the standard atmosphere. The vertical cross section through a High and Low (A, fig. 2-20) depicts the vertical pressure gradient. A surface weather map (para 12-5) view of the horizontal pressure gradient in the same High and Low is illustrated by B of figure 2-20.

2-22. Pressure Altimeter

a. General. An altimeter is primarily an aneroid barometer calibrated to indicate altitude in feet instead of units of pressure. An altimeter reads accurately only in a standard atmosphere and when the correct altimeter setting is used. Since standard conditions seldom (if ever) exist, the altimeter reading usually requires correction. An altimeter is *only* a pressure-measuring device. It will *indicate* 10,000 feet when the pressure is 697 millibars, whether or not the altitude is *actually* 10,000 feet.

b. Adjustment for Nonstandard Pressure. Because of the variations in pressure at sea level, altimeters are designed to permit adjust-

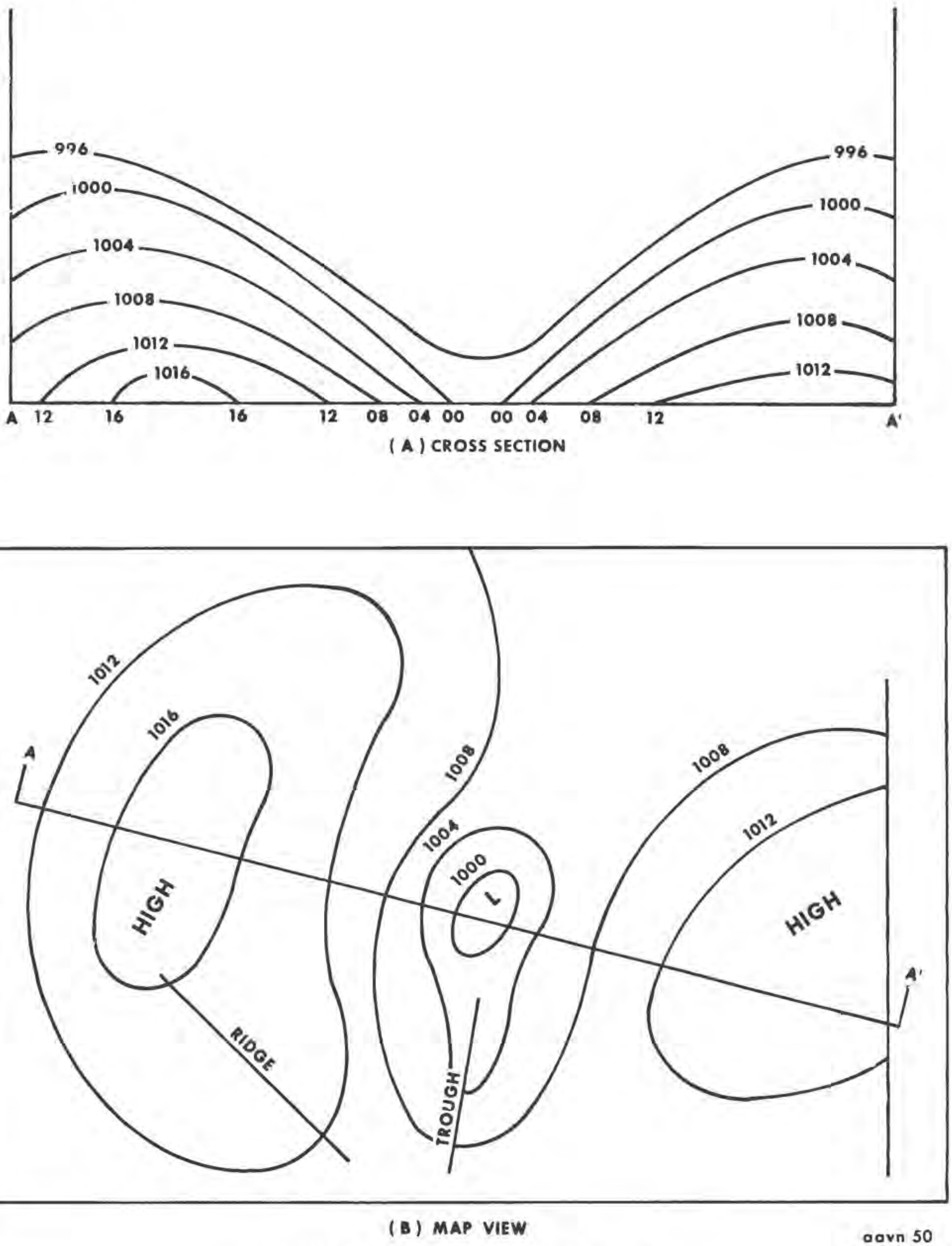


Figure 2-20. High and low pressure systems.

ment to correct for nonstandard sea level pressure.

(1) A procedure used in aircraft on the ground is to set the altimeter reading to the elevation of the airfield. The altimeter then reads the altitude above sea level and the Kollsman window indicates the current altimeter setting.

(2) The atmospheric pressure frequently differs at the point of landing from that at takeoff; therefore an altimeter correctly set at takeoff may be considerably in error at the time of landing. For a safe landing under conditions of poor visibility or low ceiling, it is essential that the altimeter be set to indicate the correct altitude. Altimeter settings can be obtained in flight by radio from navigational aids with voice facilities. Otherwise, the expected altimeter setting for landing should be obtained before takeoff. A knowledge of the existing pressure system will be helpful if an accurate setting is unobtainable.

(3) Figure 2–21 shows the pattern of isobars (or isobaric surfaces) in a cross section of the atmosphere from New Orleans, La., to Miami, Fla. The pressure at Miami is 1,019 millibars and the pressure at New Orleans is 1,009 millibars, a difference of 10 millibars. Assuming that an aircraft takes off from Miami to fly to New Orleans at an altitude of 500 feet, a decrease in mean sea level pressure of 10 millibars from Miami to New Orleans would cause the aircraft to gradually lose altitude, and although the altimeter would indicate 500 feet, the aircraft would actually be flying at approximately 200 feet over New Orleans. The correct altitude can be determined by obtaining the correct altimeter setting from New Orleans, resetting the altimeter to agree with the destination adjustment.

(4) The following relationships generally hold true up to approximately 15,000 feet:

34 millibars= 1 inch (Hg) =1,000 feet elevation.

Note. Since 1 millibar is equal to about 30 feet below 10,000 feet altitude, a change of 10 millibars (which is common) would result in an error of about 300 feet.

c. Error Due to Variation From Standard Temperature. Another type of altimeter error is due to nonstandard temperatures. Even though the altimeter is properly set for surface conditions, it often will be incorrect at higher levels.

(1) If the air temperature at flight altitude is warmer than standard (see

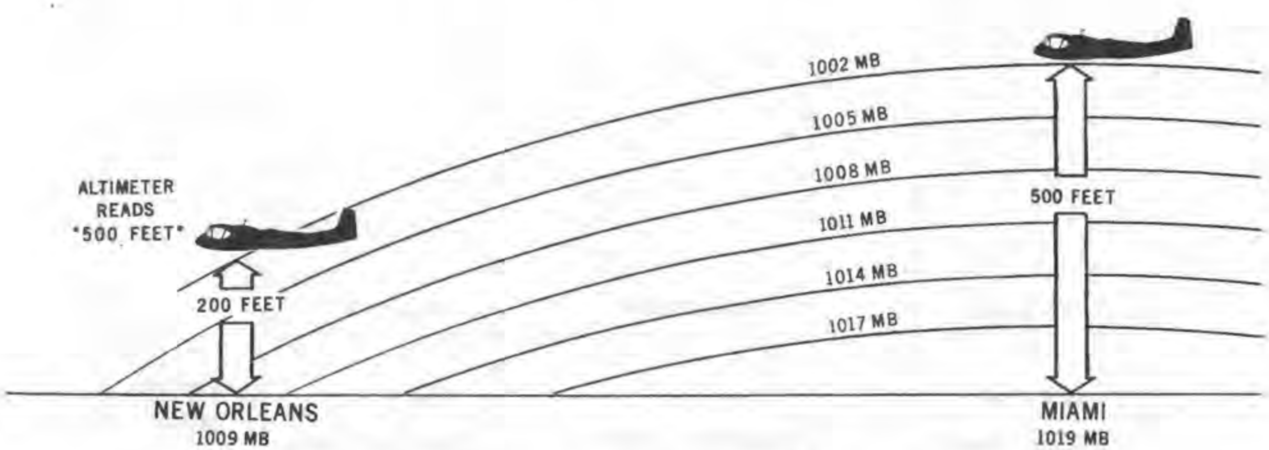


Figure 2–21. Altimeter errors due to change in surface pressure.

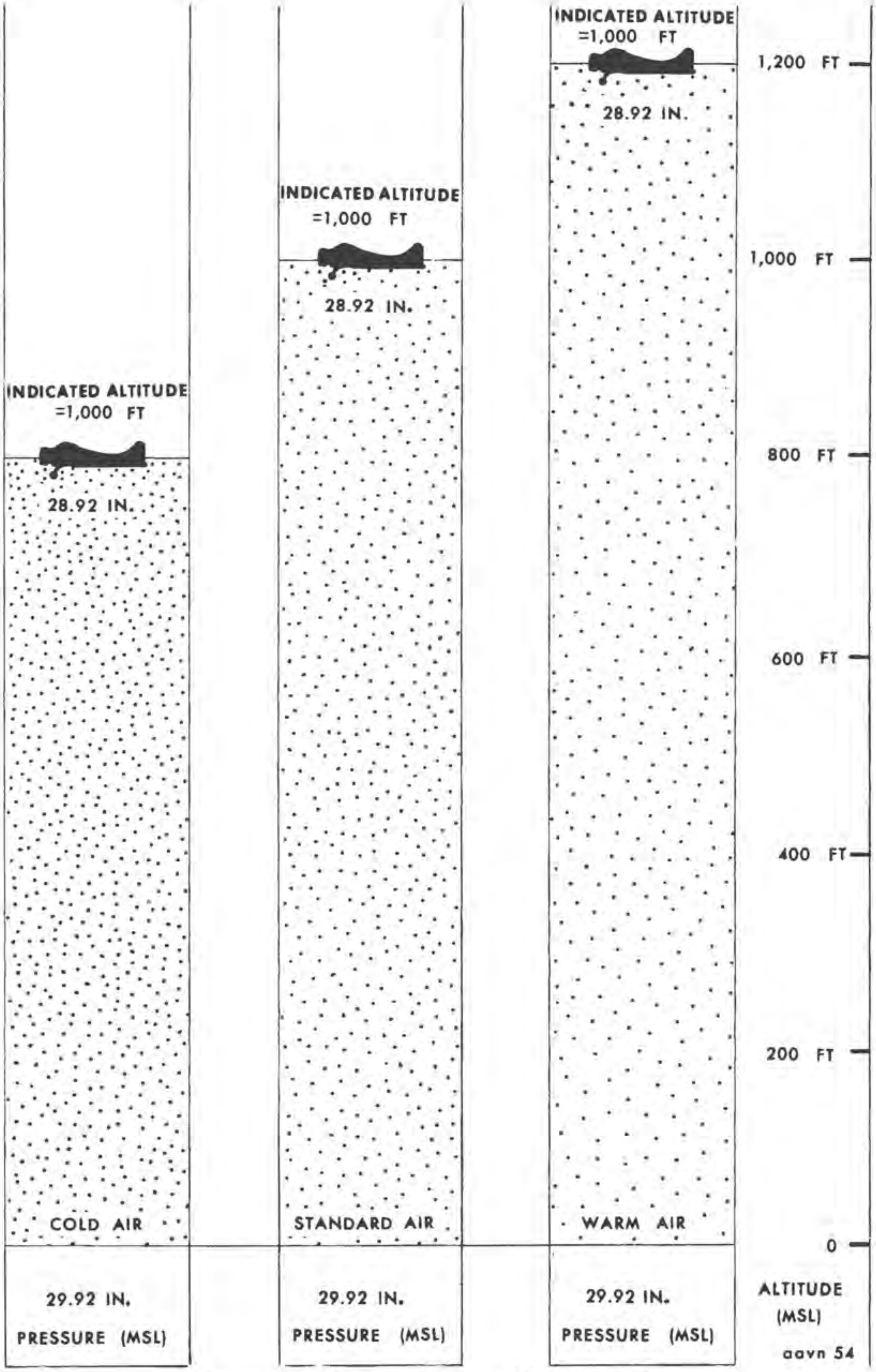


Figure 2-22. Density variation with temperature.

ICAO standard atmosphere, para 5–8*i*), the average temperature decrease with altitude is less than standard. Therefore, the average pressure decrease between the aircraft and the surface is also less than the standard 1 inch per thousand feet (fig. 2–22), and an aircraft flying in warmer than standard air will be higher than the altimeter indicates (A, fig. 2–23).

(2) Conversely, if the air temperature at flight altitude is colder than standard, the average temperature and pressure decrease with altitude is greater than standard (fig. 2–22). Therefore, an aircraft flying in colder than standard air will be lower than the altimeter indicates (B, fig. 2–33). Many accidents have occurred during instrument flight in cold weather because aviators did not understand or consider this altimeter error and failed to allow an adequate safety margin to clear mountainous terrain.

(3) The aviator does not attempt to correct his altimeter for nonstandard flight level temperatures (the reason is explained in TM 1–215). However, it is the aviator's responsibility to be aware of improper terrain clearance in temperatures much colder than standard (*altimeter error*, para 14–10).

2–23. Density Altitude

Density altitude is defined as the pressure altitude corrected for temperature. (Pressure altitude is the distance measured from the 29.92-inch pressure level—the *standard datum plane.*) The theoretical performance of aircraft is evaluated by using standard atmospheric conditions (standard densities). In actual flight, standard atmospheric conditions are rarely, if ever, encountered. The efficiency of aircraft performance is greatly affected by the varying densities of the atmosphere. Changes in air density are caused by variations in atmospheric pressure and temperature. Changes in the water vapor content also affect the density of the air, but the amount is negligible (*note* below) in density altitude computation. An airfield may have a density altitude that

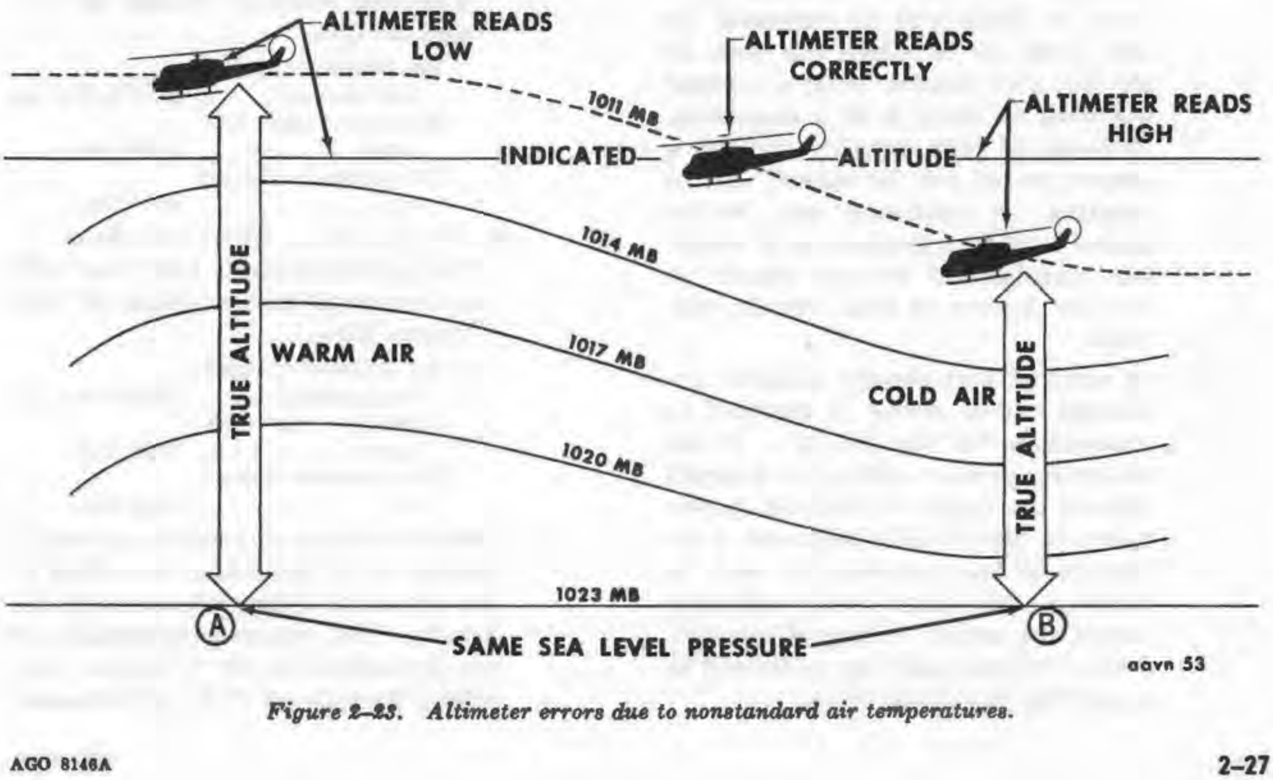


Figure 2–23. Altimeter errors due to nonstandard air temperatures.

varies several thousand feet from the mean sea level (MSL) elevation of the field. If the density altitude is higher than standard for the field, this field has a *high* density altitude (+). An example of this would be an airfield at 5,000 feet (MSL) with a density altitude of 10,000 feet. Aircraft operating from this field would be in the air of the same density that would normally be found in the standard atmosphere at 10,000 feet. The efficiency of the aircraft may be seriously affected in high density altitudes, especially when the aircraft is critically loaded. If the density altitude is lower (−) than normal for a given altitude, the efficiency of the aircraft is increased. An aviator operating from a field at 5,000 feet with a density altitude of 1,000 will be in the same air density at field elevation that normally exists at 1,000 feet.

Note. The moisture content increases the density altitude from approximately zero feet with a dew point temperature below 20° F. to (+) 250 feet with a dew point temperature.

a. Affects on Aircraft Performances.

(1) The lift of an aircraft wing or blade is affected by the speed of the air around it and the density of the air through which it moves. Lift of a wing or blade will be increased by cold dense air in which the mass of air per unit volume passing around the wing or blade is at a maximum. In areas of high density altitude, a longer ground run for takeoff will be required. A helicopter may be required to make a ground run to establish translational lift for takeoff in the low density of high density altitudes.

(2) In areas of high density altitude, additional engine power is required to compensate for the thin air. If the maximum gross weight of an aircraft exceeds the limits of available engine power in high density altitudes, a reduction in load (payload or fuel) is required. Since high density altitudes reduce the service ceiling of aircraft, density altitude must be considered in computing maximum loads.

(3) The density altitude usually varies throughout the day with the movement of pressure systems, diurnal heating and nocturnal cooling. The highest density altitudes are most common during the warmest hours. Air density decreases with an increase in altitude, temperature, or moisture content. Any change in air density will affect the performance of an aircraft.

(4) Wind velocity sufficient to afford translational lift while hovering will improve helicopter performance in areas of high density altitude. Strong winds also provide additional lift for fixed wing aircraft, and tend to counteract the effects of high density altitude.

b. Computing Density Altitude.

(1) The first step in computing density altitude is to determine the pressure altitude by setting 29.92 in the Kollsman window of the aircraft altimeter. Examples are as follows:

(*a*) *For pressures below standard.* If the field elevation is 1,500 feet with a current altimeter setting of 29.41 inches Hg—

Set altimeter to standard pressure	29.92 inches Hg.
Altimeter now indicates	2,010 feet.
The pressure altitude is	2,010 feet.

(*b*) *For pressures above standard.* If the field elevation is 2,000 feet with a current altimeter setting of 30.85 inches Hg—

Set altimeter to standard pressure	29.92 inches Hg.
Altimeter now indicates	1,070 feet.
The pressure altitude is	1,070 feet.

(2) The second step in computing density altitude is to determine the effect of the actual air temperature on the air density. The standard temperature of the atmosphere is 15° C. at sea level with a decrease of 2° C. per thousand

feet (standard temperature lapse rate). Each 1° C. variation from the standard temperature changes the density altitude approximately 120 feet. If the actual temperature is below standard for the pressure altitude, the density altitude is lowered; if the temperature is above standard for the pressure altitude, the density altitude is raised. Temperature variation is incorporated into a formula for obtaining density altitude from a known pressure altitude.

(*a*) PA+ $(120 \times V_t)$ = *DA*, where—

PA is pressure altitude.
120 is the temperature constant.
V_t is the variation of the actual air temperature from standard at the pressure altitude.
DA is density altitude.

(*b*) Sample problem for air temperature above standard:

Pressure altitude ---------2,010 feet.
Actual surface temperature ------------------30° C.
Standard temperature for the pressure altitude----11° C.
Temperature variation is-- +19° C.
2,010+ (120×18) = ------4,290 feet.
Density altitude is--------4,290 feet.

(*c*) Sample problem for air temperature below standard:

Pressure altitude ---------1,070 feet.
Actual surface temperature ------------------6° C.
Standard temperature for the pressure altitude---- 13° C.
Temperature variation is-- −7° C.
1,070+ (120×7) = 230.
Density altitude is 230 feet.

(3) Density altitude can also be determined by using a computer (TM 1-225). Density altitude charts are available in most weather stations (table X, app. II). Data on the length of runway necessary for fixed wing aircraft and power requirements for rotary wing aircraft in varying air densities can be found in the operator's manual (TM 55-aviation series-10) for the appropriate aircraft.

CHAPTER 3

CLOUDS

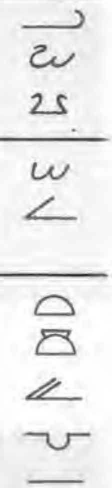
Section I. GENERAL

3–1. Cloud Formations and Definition

a. General. Cloud formations are the direct result of saturation-producing processes which take place in the atmosphere. The Army aviator must be able to identify those cloud formations which are associated with weather hazards. A close study of cloud types will also assist the Army aviator in his interpretation of weather conditions from weather reports. Table I lists the abbreviation and symbol of each cloud type discussed.

b. Cloud Definition. Clouds are visible condensed moisture, consisting of droplets of water or crystals of ice, having diameters varying from 0.0001 to 0.004 inch. They are easily supported and transported by air movements as slow as one-tenth of a mile per hour.

BASE ALTITUDE	CLOUD TYPE	ABBREVIATION	SYMBOL
BASES OF HIGH CLOUDS USUALLY ABOVE 20,000 FEET.	CIRRUS	Ci	
	CIRROCUMULUS	Cc	
	CIRROSTRATUS	Cs	
— 20,000 FEET —			
BASES OF MIDDLE CLOUDS RANGE FROM 6,500 FEET TO 20,000 FEET.	ALTOCUMULUS	Ac	
	ALTOSTRATUS	As	
— 6,500 FEET —			
BASES OF LOW CLOUDS RANGE FROM SURFACE TO 6,500 FEET.	*CUMULUS	Cu	
	*CUMULONIMBUS	Cb	
	NIMBOSTRATUS	Ns	
	STRATOCUMULUS	Sc	
	STRATUS	St	
— SURFACE —			



*CUMULUS AND CUMULONIMBUS ARE CLOUDS WITH VERTICAL DEVELOPMENT. THEIR BASE IS USUALLY BELOW 6,500 FEET BUT MAY BE SLIGHTLY HIGHER. THE TOPS OF THE CUMULONIMBUS SOMETIMES EXCEED 60,000 FEET.

aavn235

Table I. International Cloud Classification, Abbreviations, and Weather Map Symbols.

3–2. International Classification of Clouds

a. General. The international cloud classification (table I) is designed primarily to provide a standardized cloud classification. Within this classification, cloud types are usually divided into four major groups and further classified in terms of their forms and appearance. The four major groups are—

(1) High clouds.
(2) Middle clouds.
(3) Low clouds.
(4) Clouds with accentuated vertical development.

b. Subdivision. Within the high, middle, and low cloud groups are two main subdivisions. These are—

(1) Clouds formed when localized vertical currents carry moist air upward to the condensation level. These clouds are characterized by their lumpy or billowy appearance and are designated *cumuliform* type clouds, meaning "accumulation" or "heap." Turbulent flying conditions are usually found in and below cumuliform clouds.

(2) Clouds formed when complete layers of air are cooled until condensation takes place. These clouds are called *stratiform* type clouds, meaning "spread out," since they lie mostly in horizontal layers or sheets. Flight within stratiform clouds is relatively smooth.

Note. Cumuliform clouds may be merged with stratiform clouds.

c. Rainclouds and Fragmentary Clouds. In addition to the two main subdivisions discussed in *b* above, the word nimbus, meaning "raincloud," is added to the names of clouds that normally produce heavy precipitation, either liquid or solid. For example, a stratiform cloud producing precipitation is referred to as *nimbostratus,* and a heavy, swelling cumulus cloud that has grown into a thunderstorm is referred to as *cumulonimbus.* Clouds which are broken into fragments are identified by adding the prefix *fracto* to the classification name. For example, fragmentary cumulus is referred to as *fractocumulus.*

Section II. CLOUD TYPES

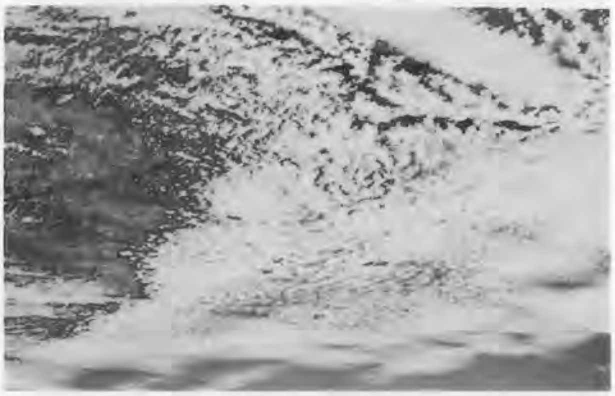
3–3. High Clouds

The high cloud group consists of *cirrus, cirrocumulus, and cirrostratus* clouds (figs. 3–1, 3–2, and 3–3). The mean base level of these three cloud types is 20,000 feet or higher. Cirrus clouds give indications of approaching changes

Figure 3–1. Cirrus clouds.

(*Description:* Detached clouds in the form of white, delicate filaments, or white or mostly white patches or narrow bands. These clouds have a fibrous (hairlike) appearance, or a silky sheen, or both.)

in weather. Cirriform clouds are composed of ice crystals and, because of this, do not present an icing hazard. These clouds are generally thin and the outline of the sun or moon may be seen through them, producing a halo effect.



(1) Cirrocumulus merging with cirrus.

(2) Cirrocumulus merging with cirrostratus.

Figure 3–2. Cirrocumulus clouds.

(*Description:* Thin clouds without shading, composed of white patches or a sheet or layer, with very small elements in the form of grains, ripples, etc., merged or separate, and more or less regularly arranged. They usually display brilliant and glittering quality suggestive of ice crystals.)

(1) Cirrostratus with wisps of cirrus.

(2) Cirrostratus over a layer of stratocumulus and upslope fog.

(3) Cirrostratus merged with cirrus.

Figure 3–3. Cirrostratus clouds.

(*Description:* Thin, whitish cloud layers appearing like a sheet or veil, covering part of the sky or its entirety, and often thread-like or fibrous. They may be so light as to be barely visible or may be relatively dense.)

3–4. Middle Clouds

The middle cloud group consists of *altocumulus* and *altostratus* clouds (figs. 3–4 and 3–5). The altocumulus has many variations in appearance and in formation; whereas the altostratus varies mostly in thickness, from very thin to several thousand feet. Bases of the middle clouds range from 6,500 to 20,000 feet above the terrain. These clouds may be composed of ice crystals or water droplets (which may be supercooled) and may contain icing conditions hazardous to aircraft. Altocumulus rarely produces precipitation, but altostratus usually indicates the proximity of unfavorable flying weather and precipitation.

3–5. Low Clouds

This group of clouds consists of *stratus, stratocumulus*, and *nimbostratus* clouds (figs. 3–6, 3–7, and 3–8). The bases of these clouds

(1) Thin, semitransparent cloud elements at a single level.

(2) Semitransparent cloud elements in bands spreading over the sky.

Figure 3–4. Altocumulus clouds.

(*Description:* White or gray clouds, or both white and gray, in patches or in sheets or layers, generally with shading and composed of rounded masses, rolls, etc., which are sometimes partly fibrous or diffuse and which may or may not be merged.)

Figure 3–5. Altostratus over a layer of stratocumulus.

(*Description:* Gray to bluish, in a dense veil or layer with a fibrous, uniform composition. Light colors indicate relative thinness while dark colors indicate relative thickness.)

range from near the surface to about 6,500 feet. Low clouds are of great importance to the aviator since they create low ceilings and poor visibility ranges. The heights of the cloud bases may change rapidly. If low clouds form below 50 feet, they are reclassified as fog (par. 8–1) and may completely blanket landmarks and landing fields. Low clouds have the same composition as middle clouds. In freezing or near freezing temperatures, they are a constant threat because of the probability of icing. When flying in these clouds, the Army aviator must be constantly alert to changes in cloud formation ceiling, and visibility; and be prepared to fly to an alternate field if the ceiling or visibility drops below minimums at his destination. (The navigation publications issued to Army aviators contain specific airport ceiling or visibility minimums.)

3-6. Clouds with Vertical Development

a. Types. Clouds with vertical development include the *cumulus* and *cumulonimbus* clouds (figs. 3-9 and 3-10). These clouds generally have their bases below 6,500 feet above the terrain and tops sometimes extend above 65,000 feet. Clouds with vertical development are caused by some type of lifting action, such as convective currents, convergence, orographic lift, or frontal lift.

b. Flight Conditions Associated With Vertical Development Clouds. Scattered cumulus or isolated cumulonimbus clouds seldom present a flight problem since these clouds can be circumnavigated without difficulty. However, these clouds may rapidly develop in groups or lines of cumulonimbus. They may also become embedded and hidden in stratiform clouds, resulting in hazardous instrument flight conditions. Turbulence within cumulonimbus clouds may be severe enough to cause structural failure to the aircraft.

Figure 3-6. Stratus clouds.

(*Description:* Generally gray cloud layers with a fairly uniform base. They may produce drizzle, ice prisms, or snow grains. When the sun is visible through these clouds their outline is clearly discernable. They sometimes appear in the form of ragged patches, and may be referred to as *fractostratus* or *scud.*)

Figure 3-7. Stratocumulus clouds.

(*Description:* Gray or whitish or both gray and whitish clouds that usually have dark spots. These clouds are composed of rounded masses, rolls, etc., which may or may not be merged. Stratocumulus is often, particularly in the early morning hours, a transitional stage of cloud development between stratus and cumulus.)

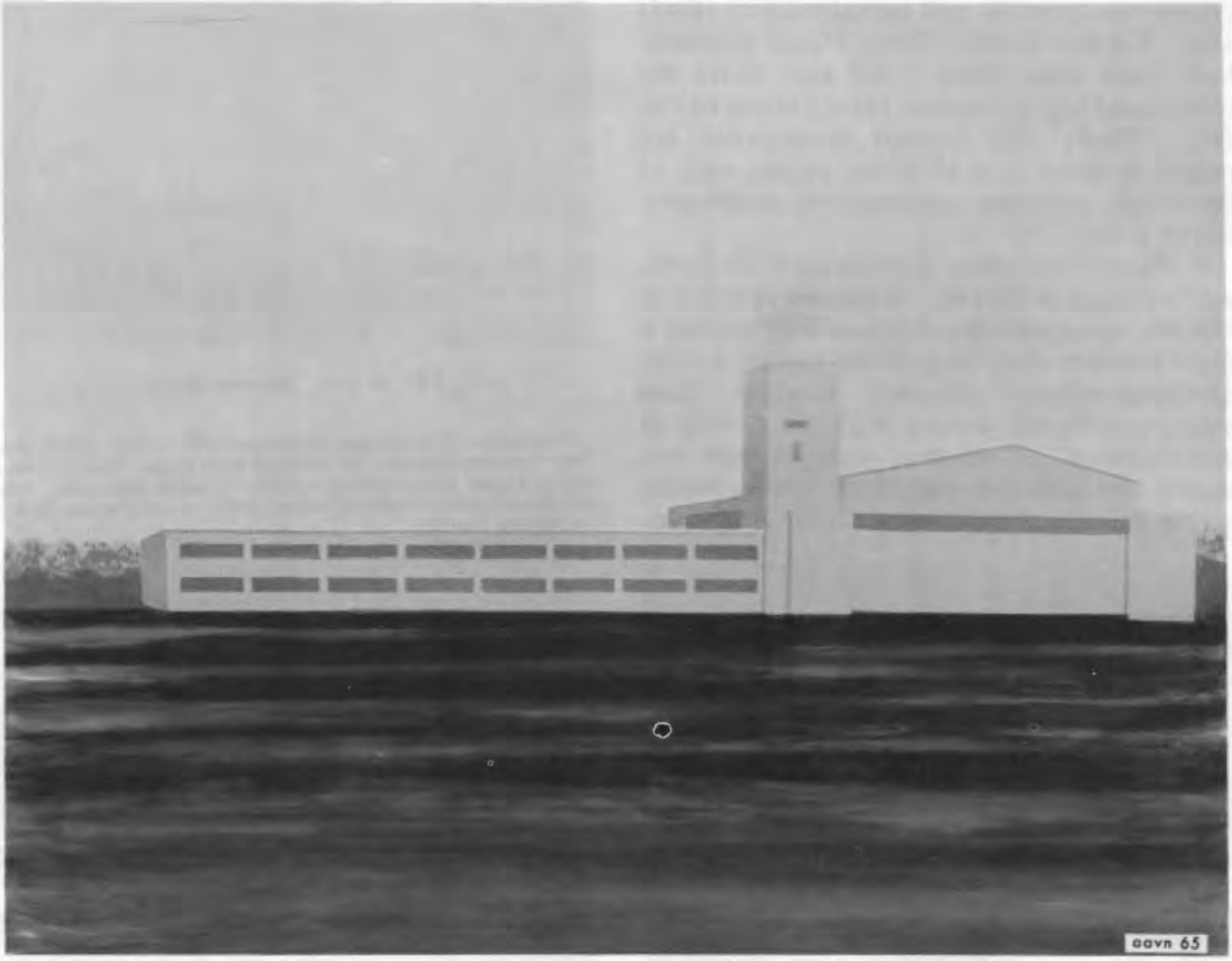


Figure 3-8. Nimbostratus clouds.

(*Description:* Gray cloud layers, often dark, the appearance of which is rendered diffuse by more or less continuously falling rain or snow, which in most cases reaches the ground. They are thick enough throughout to blot the sun. Low, ragged clouds (scud) frequently appear below the nimbostratus layer and may or may not merge with the nimbostratus.)

(1) Cumulus and towering cumulus.

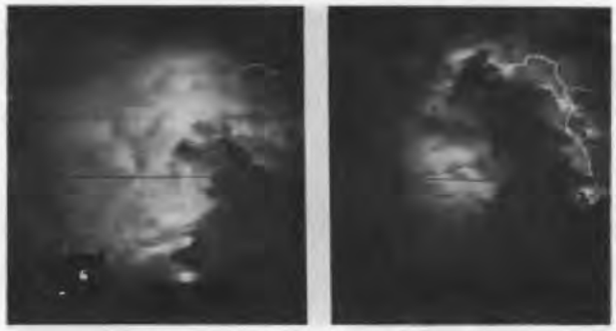
(2) Cumulus with limited vertical development.

(3) Developing cumulus.

Figure 3–9. Cumulus clouds.

(*Description:* Detached clouds that are generally dense and with distinct outlines, developing vertically in the form of rising mounds, domes, or towers. of which the bulging upper part often resembles a cauliflower. The sunlit parts of these clouds are mostly brilliant white, with their bases relatively dark and nearly horizontal. They vary in size from light, fluffy powder-puff forms to towering masses.)

(1) Isolated thunderstorm with cumulus.



(2) Thunderstorm activity at night.

(3) Cumulonimbus mammatus (generally indicates severe turbulence).

(4) Cumulus, towering cumulus (partially merged), and cumulonimbus.

(5) Extensive, isolated cumulonimbus.

Figure 3-10. Cumulonimbus (thunderstorm) clouds.

(*Description:* Heavy and dense clouds with considerable vertical extent in the form of mountains or huge towers. They may be isolated, may appear in groups, or may appear in lines extending hundreds of miles. At least part of their upper portion is usually smooth, fibrous, or striated, nearly always flattened, and often spreads out in the shape of an anvil or vast plume. Under the base of this type cloud, which is often very dark, there are frequently low ragged clouds, either merged or not. The intensity of precipitation varies from light showers to cloudbursts. Cumulonimbus produces lightning, thunder, gusty winds, and often hail.)

CHAPTER 4

ATMOSPHERIC CIRCULATION

Section I. GENERAL CIRCULATION

4-1. General

a. On all flights the Army aviator is concerned with the wind. Knowledge of winds near the surface is important in landing and taking off, and in low flight; knowledge of winds at higher levels is essential in computing flight headings, time en route, time over reporting positions, destinations, alternates, and in some situations the degree of turbulence.

b. The energy that sets the atmosphere into motion is obtained from the sun's radiation. Because of the relative position of the earth with respect to the sun, the earth receives much more radiation near the Equator than at the poles. This unequal heating by the sun's radiation at the earth's surface is the basis for atmospheric circulation. Variations in surface temperature in different localities, in the topography of the earth, and in rotational forces complicate the basic circulation pattern. For this reason, introducing atmospheric circulation as if the earth were a nonrotating sphere of uniform surface with the primary heat source at the Equator provides a good foundation for atmospheric circulation as it actually exists.

4-2. Simple Circulation

a. Definition. Circulation, in terms of meteorology, is the movement of air over the surface of the earth. This movement occurs throughout the entire atmosphere; however, this chapter will be limited to the movement of air in the troposphere.

b. Causes. The air within the troposphere (fig. 2-2) is subject to continuous changes in density and temperature. Since air is a fluid, it reacts to these changes in density in much the same manner as confined liquids. When there is a difference in density between two or more portions of a confined liquid, the fluid will begin to move (circulate) within the container. When the differences in density of the air occur in the atmosphere, the air will also begin to circulate. Differences in air density are normally the result of temperature differences, because gases vary in density with temperature changes.

c. Temperature Differential.

(1) The temperature differential in the atmosphere which causes atmospheric circulation can be compared to the temperature differences produced in a pan of water placed over a Bunsen burner. As the water is heated over the flame, it expands and its density is lowered. This reduction in density causes the water to rise to the top of the pan; as it rises, it cools and proceeds to the edges of the pan. Upon reaching the edges of the pan, it cools further and sinks to the bottom, eventually working its way back to the center of the pan where it started. This process of heating and cooling sets up a simple convective circulation pattern.

(2) Air within the limits of the troposphere may be compared to the water contained in the pan, with the sun acting as a Bunsen burner. The most direct rays of the sun strike the earth near the Equator. The air at the Equator is heated, rises, and flows along the upper extremities of the

troposphere toward both poles. Upon reaching the poles, it cools and sinks back toward the earth, where it tends to flow along the surface of the earth back to the Equator where it started (fig. 4-1).

4-3. Theoretical Atmospheric Circulation

Simple circulation in the atmosphere would occur as described in paragraph 4-2 above if it were not for the following considerations:

a. The earth is covered with an irregular surface of land and water areas.

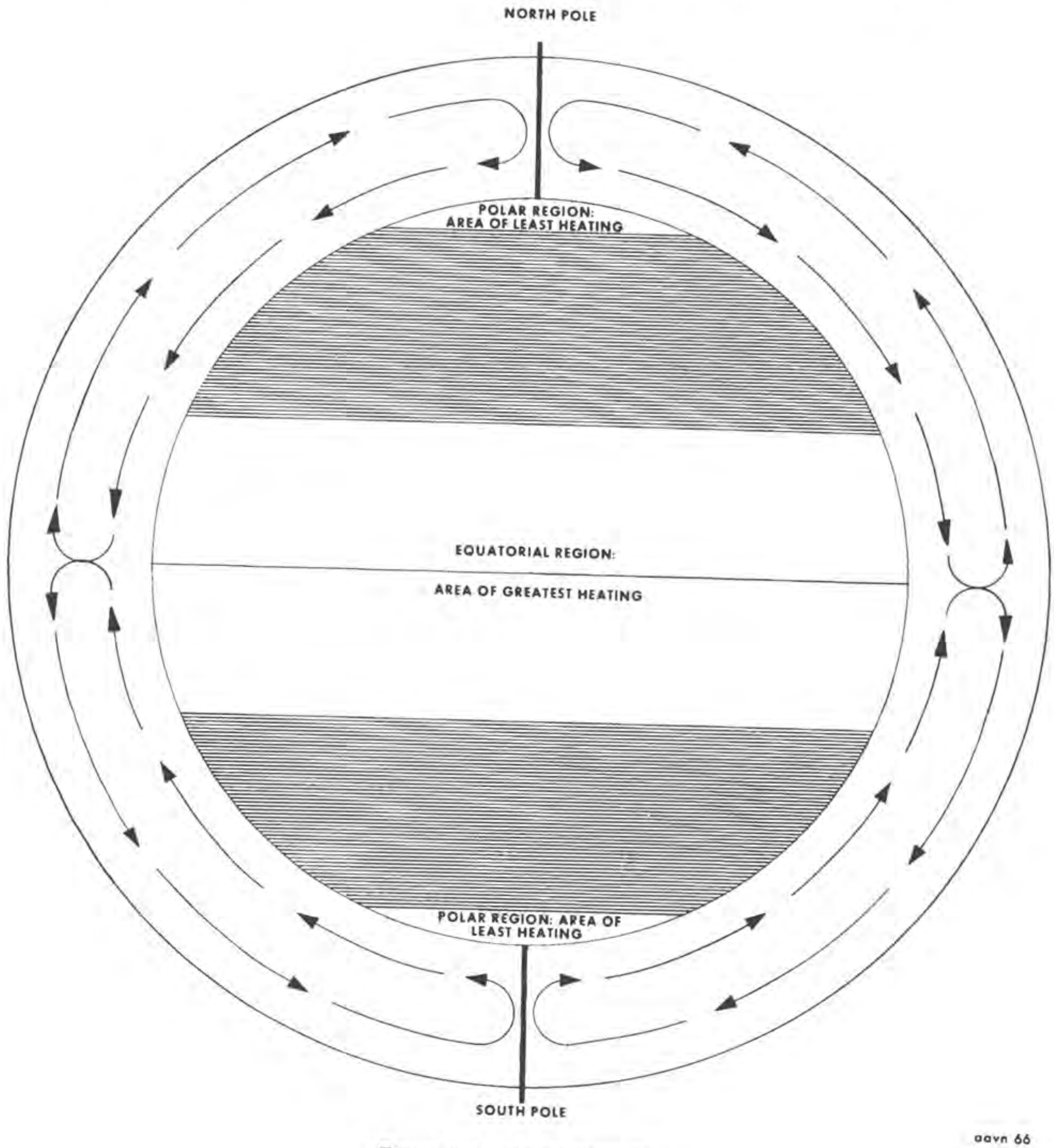


Figure 4-1. Simple circulation.

b. The earth rotates, so that the area of the atmosphere being heated changes position constantly. *Coriolis deflection* (par. 4–9*a*) further affects the motion of the air on the rotating earth.

c. The tilted axis of the earth causes seasonal changes in the amount of heat received by any specific area of the earth's surface.

4–4. Primary Circulation (Three-Cell Theory)

a. General. According to the *Three-Cell Theory* of atmospheric circulation, the earth is divided into six latitude belts—three in the Northern Hemisphere and three in the Southern Hemisphere. The dividing lines between the six belts are (1) the Equator, (2) latitude 30° N. and S., and (3) latitude 60° N. and S. Thus, there is one belt in each hemisphere between the Equator and 30° latitude, one between 30° and 60° latitude, and one between 60° latitude and the poles (fig. 4–2). This three-cell circulation pattern actually exists in the upper troposphere, but is frequently replaced at the surface by semipermanent cell structures and the secondary circulation of migratory highs and lows. To simplify explanation, further description in (1), (2), and (3) below will be limited to the Northern Hemisphere.

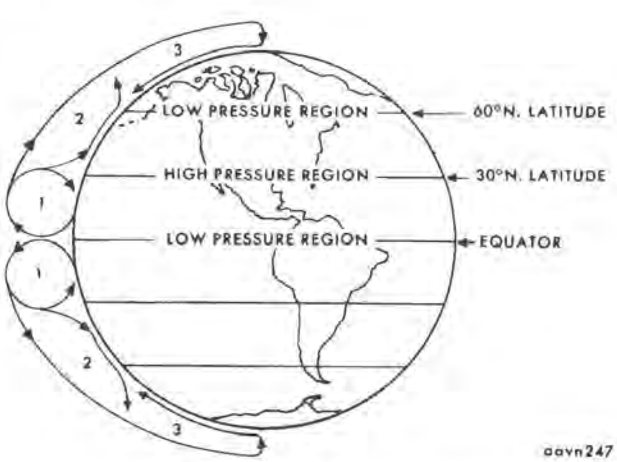


Figure 4–2. Three-Cell Theory of Circulation.

(1) *Equator to 30° latitude cell.* The air at the Equator is heated by the direct radiation from the sun. It rises to high altitudes and flows poleward, resulting in a region of low surface pressure at the Equator. This low pressure belt is referred to as the *equatorial trough.* As the air aloft flows northward, Coriolis force deflects it toward the east and causes it to begin piling up over the cool ocean surfaces near latitude 30° N. Some of the air becomes dense enough to descend to the surface around the 30° latitude belt. This descending air is part of the *subtropical high pressure belt* located between 25° and 35° latitude. Part of the descending air returns to the Equator, thus completing the first cell of the circulation. The air returning to the Equator at the surface is deflected to its right, and becomes a northeast wind called a *trade wind.* The remainder of the descending air at 30° latitude flows poleward at the surface, forming a part of the second cell of the primary circulation.

(2) *Cell between 30° and 60° latitudes.* The second cell is composed of poleward-moving air from the Equator in the upper troposphere and from the subtropical high pressure belt at the surface. As this air moves poleward, it is deflected to its right and, in theory, flows from west to east at all altitudes in the troposphere. This cell is known as the belt of prevailing westerlies. These westerly winds are not common at the surface, however, because of the difference in heating between the continents and oceans of the Temperate Zones, and because of migrating pressure systems (par. 4–7) in the lower levels of the troposphere. Therefore, these prevailing westerlies are usually upper altitude winds which are responsible for the general movement of the cyclonic storms at the surface from west to east.

(3) *Cell between 60° latitude and the pole.* The third cell of circulation lies between 60° latitude and the pole. Air flowing northward in the upper troposphere spirals northeastward toward

the polar region, where it converges aloft and descends. After descending, the air on the cold polar ice cap becomes very dense. This collection of cold dense air produces a region of high pressure at the pole. In theory, the outer limit of this cap of cold air and high pressure is 60° latitude. The belt around 60° latitude is, therefore, a region of relatively low pressure (called the *subpolar low pressure belt*) between the subtropical high pressure areas and the polar high pressure area. In this belt of low pressure, the polar front exists: a boundary between the cold polar air with its northeasterly winds and the warmer tropical air in the prevailing westerlies. The surface winds in this region are easterlies because air moving from the high pressure center at the poles toward the low pressure area at 60° latitude is deflected to the right of its path and flows from the northeast.

Note. The primary circulation theory of the third cell is not completely realistic in describing the pattern of (a) upper level westerly winds, (b) surface easterly winds, (c) the frontal boundary between the easterly and the westerly winds, and (d) the polar front at the surface in near 60° latitude. In practice, the cold, dense polar air flows southward in large polar outbreaks and runs down across the Temperate Zone, bringing frontal weather and migrating cyclonic storms over the entire region (par. 7-7).

b. Southern Hemisphere. The distribution of pressure areas and wind belts in the Southern Hemisphere is the same as in the Northern Hemisphere. However, the Coriolis force in the Southern Hemisphere deflects the wind to the left rather than to the right. The pressure belts in both hemispheres are shown in figure 4-3.

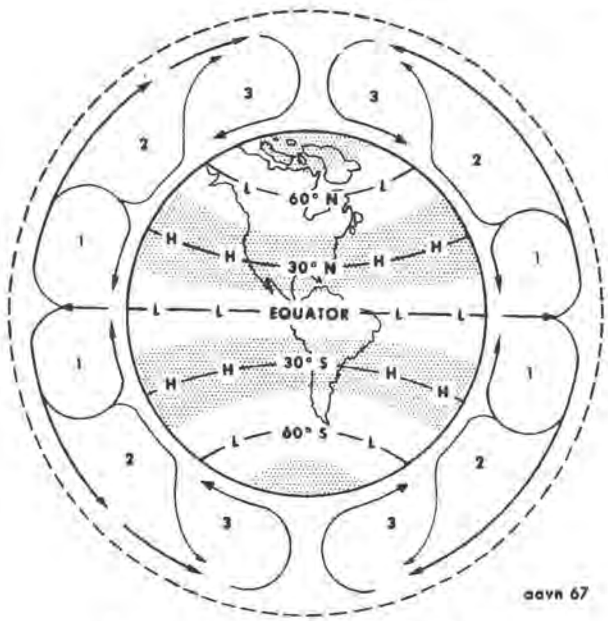


Figure 4-3. Pressure belts with the three-cell circulation.

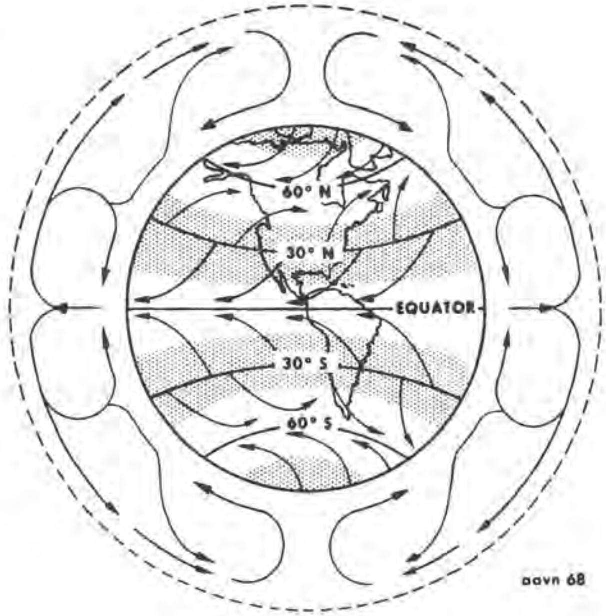


Figure 4-4. Prevailing wind belts with the three-cell circulation.

4-5. Effects of the Earth's Movement

a. Rotation. As the earth rotates, circulation is affected by the Coriolis force (par. 4-9*a*). The result is that the winds are deflected to the right of their original direction of movement in the Northern Hemisphere and to the left of their original direction of movement in the Southern Hemisphere (fig. 4-4).

b. Revolution. The earth's atmospheric circulation is based on a differential in heating. As a result of the seasonal variation in the intensity of the sun's rays on the surface of the earth, areas of differential heating fluctuate in the same geographical location with changes in season. The ideal circulation pattern (fig. 4–5) typifies the average position of differential heating areas and assumes a uniform surface of the earth in color, shape, and texture.

4–6. Semipermanent Pressure Areas

a. Large variation in the earth's physical characteristics causes many local surface deviations from the primary circulation pattern discussed above. Friction with the surface of the earth and with great mountain ranges towering up to 5 miles into the atmosphere produces definite changes in the airflow. Another important factor is the difference in specific heats of land and water surfaces. All of these variations from the basic circulation pattern require consideration in any realistic view of the atmospheric circulation in the lower troposphere. The average pressure distribution on the surface of the earth is shown in figure 4–6. The corresponding winter wind patterns over the ocean are shown in figure 4–7.

b. Two high pressure cells form in the Northern Hemisphere near 30° north latitude—one over the Pacific Ocean and one over the Atlantic Ocean (fig. 4–5). The presence of high pressure over the oceans is in agreement with the general circulation theory of the subtropical high pressure belt; however, over land at this latitude (due to low specific heat of land and its more immediate response to insolation), the theory breaks down and seasonal pressure changes occur.

c. Between the latitudes 45° to 60,° two high pressure cells exist over continental areas—one over Canada (the *North American high*), the other over Siberia (the *Siberian high*). In the summer, because of long hours of daylight (insolation) in northern regions and because the area of the thermal equator will have moved

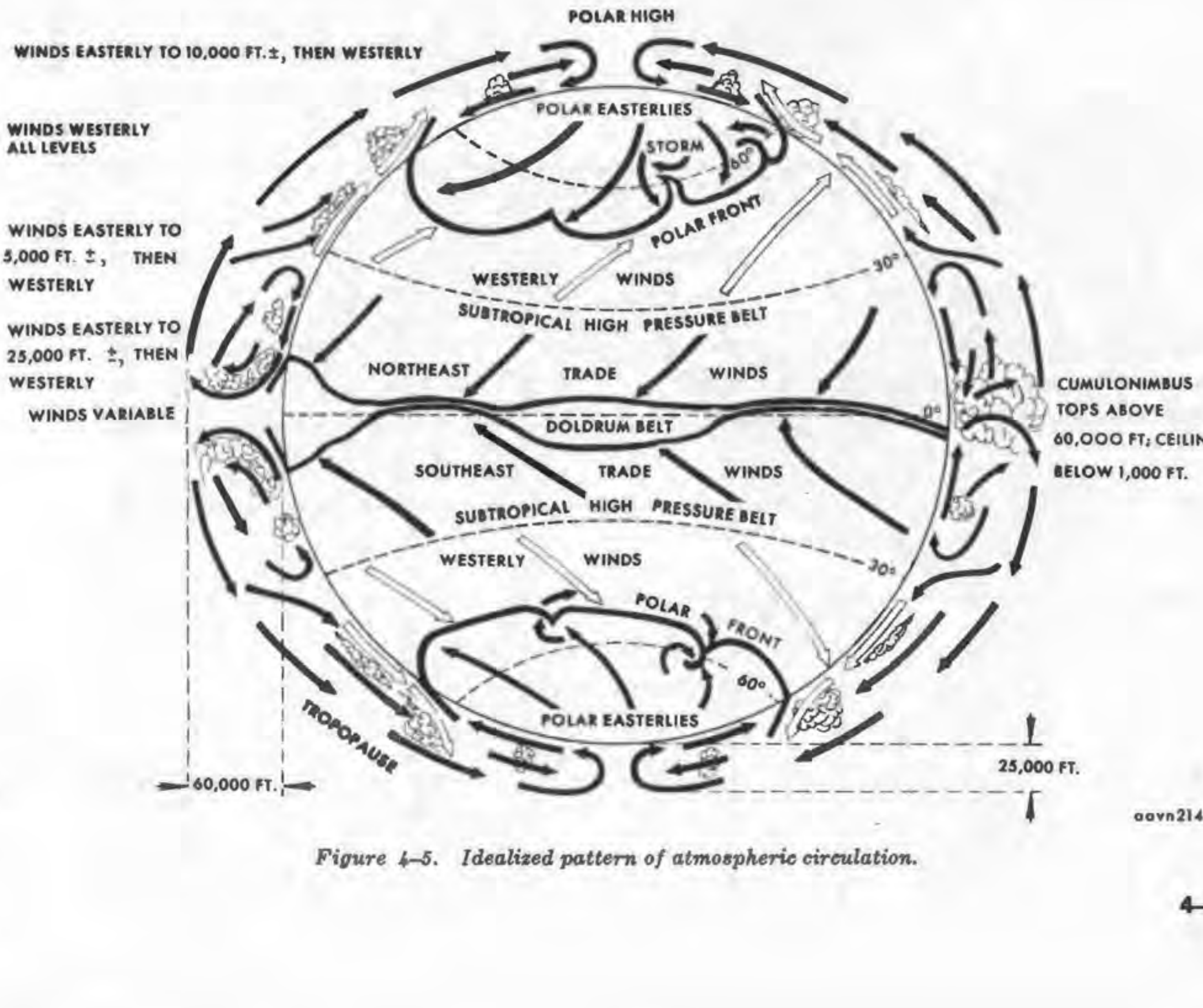


Figure 4–5. Idealized pattern of atmospheric circulation.

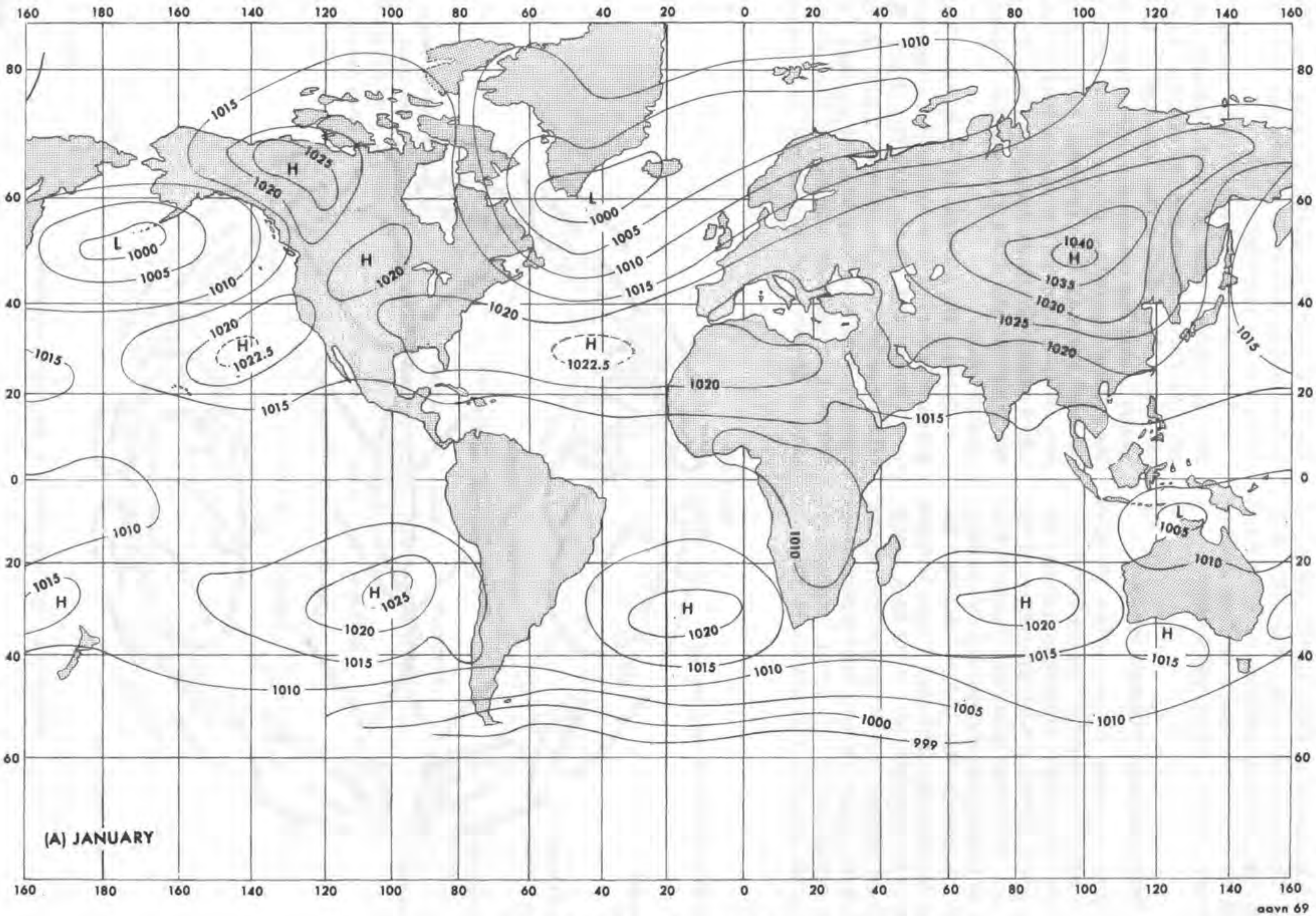


Figure 4–6 (A). Prevailing world pressure systems.

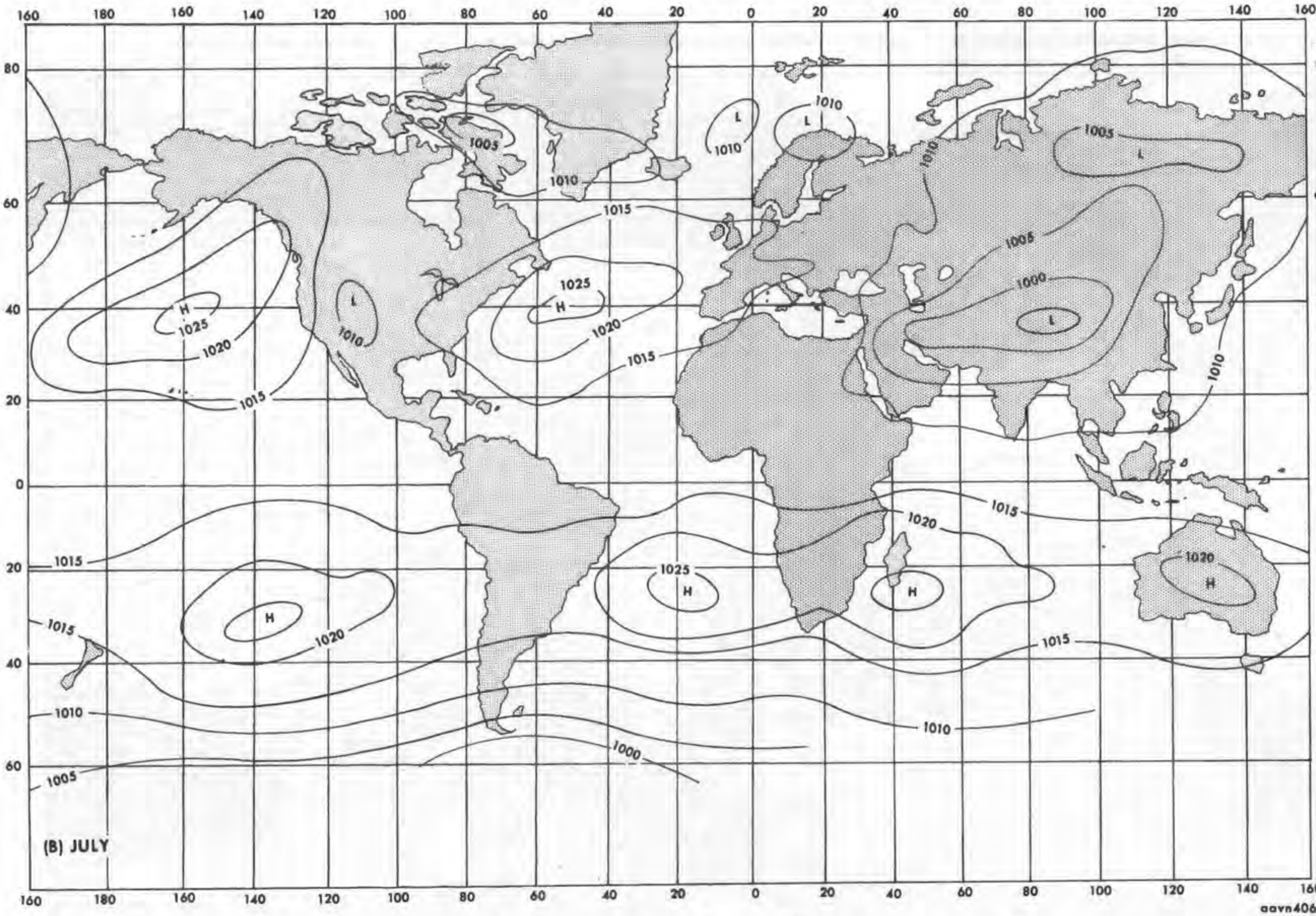


Figure 4–6 (B)—Continued.

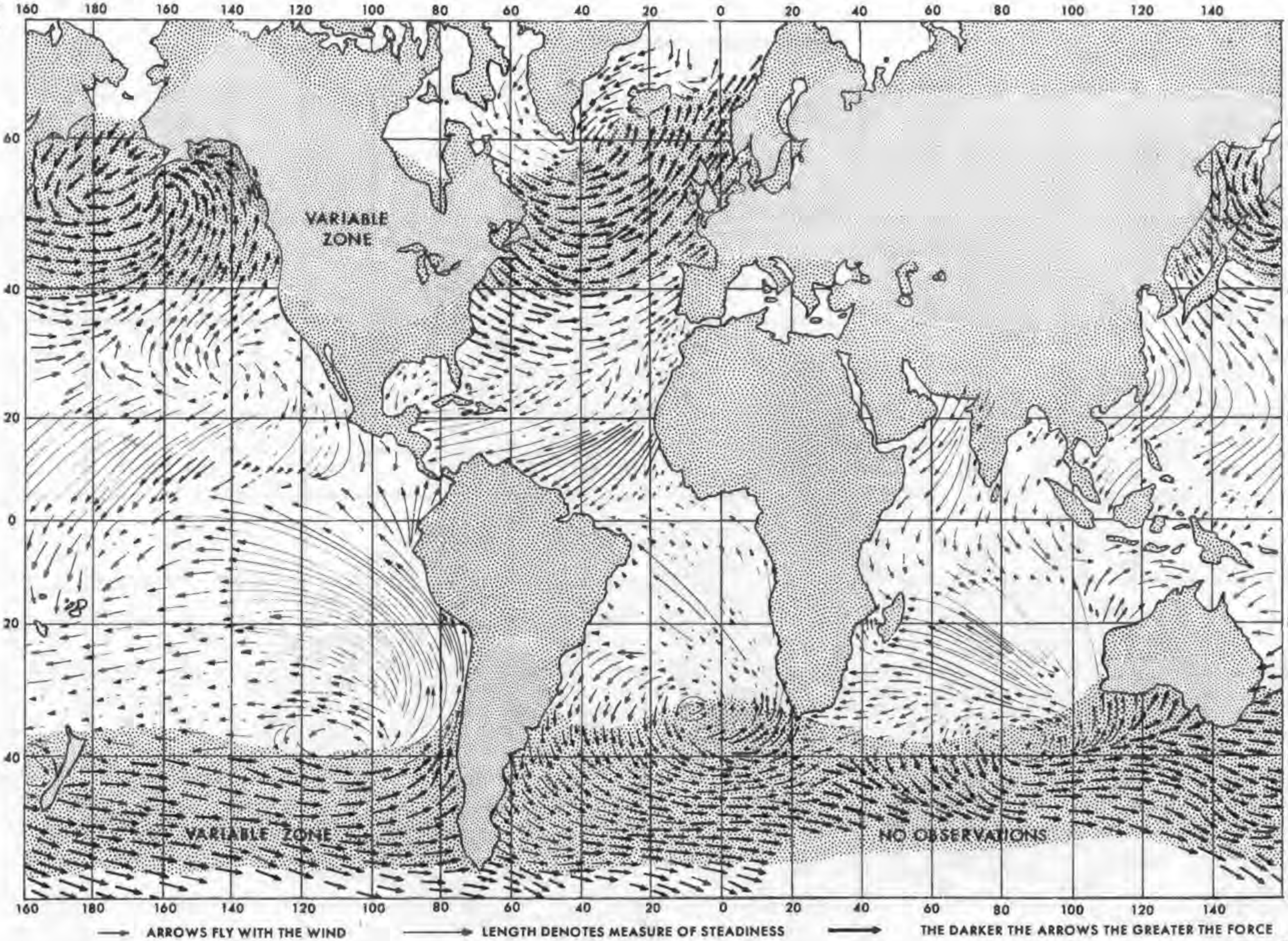


Figure 4–7. January and February world wind systems.

north of the Equator, these high pressure cells retreat to a more localized position near the pole and become less intense.

d. Two low pressure cells form in the Northern Hemisphere over the ocean near the Aleutian Islands and Iceland. The *Aleutian low* and *Icelandic low* are more intense during the winter season, and verify the location of the polar front with its associated low pressure in the vicinity of 60° latitude. In this area, the warmer air of the prevailing westerlies (northern portion of the subtropical highs) is forced to ascend over the colder dense air of the continental highs. *These lows act like planetary gears among the four high pressure cells; the highs have winds rotating clockwise and, to prevent clashing of the gears, some of the system (cyclones) must rotate counterclockwise.*

e. The six semipermanent pressure systems important in the origination and movement of air masses and frontal systems are—Siberian, Pacific, North American, and Bermuda high pressure areas; and the Icelandic and Aleutian low pressure areas.

Section II. SECONDARY CIRCULATION

4-7. General

The secondary circulation consists of a series of atmospheric disturbances and irregularities in the lower levels of the troposphere. It is brought about mainly by the movement of high and low pressure systems and the movement of air within the pressure systems. These moving pressure systems are smaller in extent than the semipermanent cells of the general circulation. They are frequently shallow in depth, and move generally from west to east with the prevailing westerly winds above the surface pressure systems. A pressure cell may move 500 miles in 24 hours, with some sections moving more rapidly than others. Some pressure cells remain stationary for several days, whereas others may move eastward at speeds of 50 miles per hour. The moving low pressure systems generally contain fronts, but frontal weather normally is not found within high pressure systems. The complete development of cyclones is explained in paragraph 7-7. The forces which affect the wind in the secondary circulation are discussed in this section.

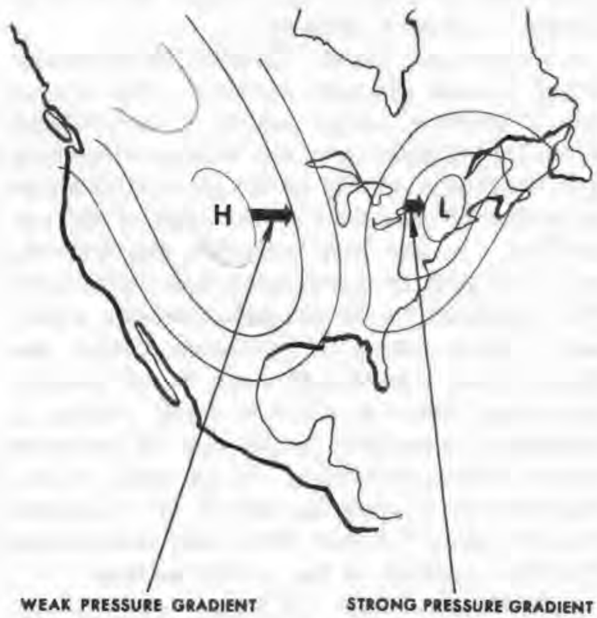


Figure 4-8. Pressure gradient.

4-8. Pressure Gradient Force

The intensity of the force acting toward low pressure determines wind speed and is indicated by the spacing between isobars—the *pressure gradient.* The pressure gradient force is the initiating force which produces wind. The closer the isobars, the stronger the pressure gradient. The greater the pressure gralient force, the stronger the wind will be. The pressure gradient force always acts directly across the isobars toward the lower pressure (fig. 4-8).

4-9. Forces Acting on Air In Motion

a. Coriolis Force. Coriolis force (named after the French mathematician who investigated it) is an *apparent force* acting on any freely moving body. It is brought about by the rotation of the earth. This apparent force causes a deflection of winds to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The Coriolis effect is zero at the Equator and greatest at the poles. It always acts at right angles to the direction of motion in the Northern Hemisphere. This force is directly proportional to the velocity of the moving body and is zero when the velocity is zero. Wind starting from south to north in the Northern Hemisphere will be deflected until it actually flows from west to east. Further deflection will not occur because the pressure gradient force and the Coriolis force are then in equilibrium (equal and opposite to one another). A similar deflection to the right of the original path of motion will occur with any wind in the Northern Hemisphere, regardless of its original direction (north, east, south, or west). The Coriolis force changes only the direction of the wind and does not change the wind speed. Winds produced only by the action of pressure gradient and Coriolis forces flow parallel to straight isobars.

b. Centrifugal Force. Isobars are generally curved around pressure systems. This curvature of isobaric values results in *centrifugal force.* Its influence upon the wind is dependent upon the linear velocity of the air particles and the radius of curvature of the path of the air particles. In the high latitudes, the Coriolis force is of greater significance than centrifugal force, particularly in pressure systems which have a large radius of curvature. Near the Equator, the centrifugal force is of greater importance than the Coriolis force (which is negligible), especially in the case of pressure systems with small radii. In all cases, winds produced by a combination of the pressure gradient force, Coriolis force, and centrifugal force flow parallel to the curved isobars.

c. Frictional Force. 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. This angle varies from 10° over the ocean to more than 45° 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 above the ground. Above this level, the effect of friction decreases rapidly and may be considered negligible. Air about 2,000 feet above the ground normally flows parallel to the isobars.

4–10. Wind Systems

a. Winds Aloft.

(1) *Gradient wind.* Pressure gradients initiate the movement of air. As soon as the air acquires velocity, the Coriolis force deflects it to the right in the Northern Hemisphere. As the speed of the air along the isobars increases (fig. 4–9), the Coriolis force becomes equal and opposite to the pressure gradient force. After a period of time, the air moves directly parallel to the curved isobars if there is no frictional drag with the surface. The air no longer moves toward lower pressure because the pressure gradient force is completely neutralized by the Coriolis force and the centrifugal force. The resultant wind is called the *gradient wind.*

(2) *Geostrophic wind.* Computations of wind velocity on the basis of pressure gradient and Coriolis force are usually based on the assumption that the isobars are straight and that the centrifugal force is zero. Such a wind, blowing parallel to straight isobars, is called the *geostrophic wind* (fig. 4–10). For practical purposes, the gradient wind and the geostrophic wind are considered equivalent and can be assumed to exist near and above 2,000 or 3,000 feet.

b. Surface Winds. Friction will reduce the surface wind speed to about 40 percent of the velocity of the gradient wind and cause the surface wind to flow across the isobars instead of parallel to them. This is because the Coriolis force and the centrifugal force are governed by the speed of the air particles making up the wind, while pressure force depends only upon the horizontal spacing of the isobars. The forces that were in balance with the pressure gradient aloft are weakened when introduced to the friction layer over the earth: the pressure force becomes the dominant force on the surface, and the resultant surface windflow will be somewhat toward the lower pressure.

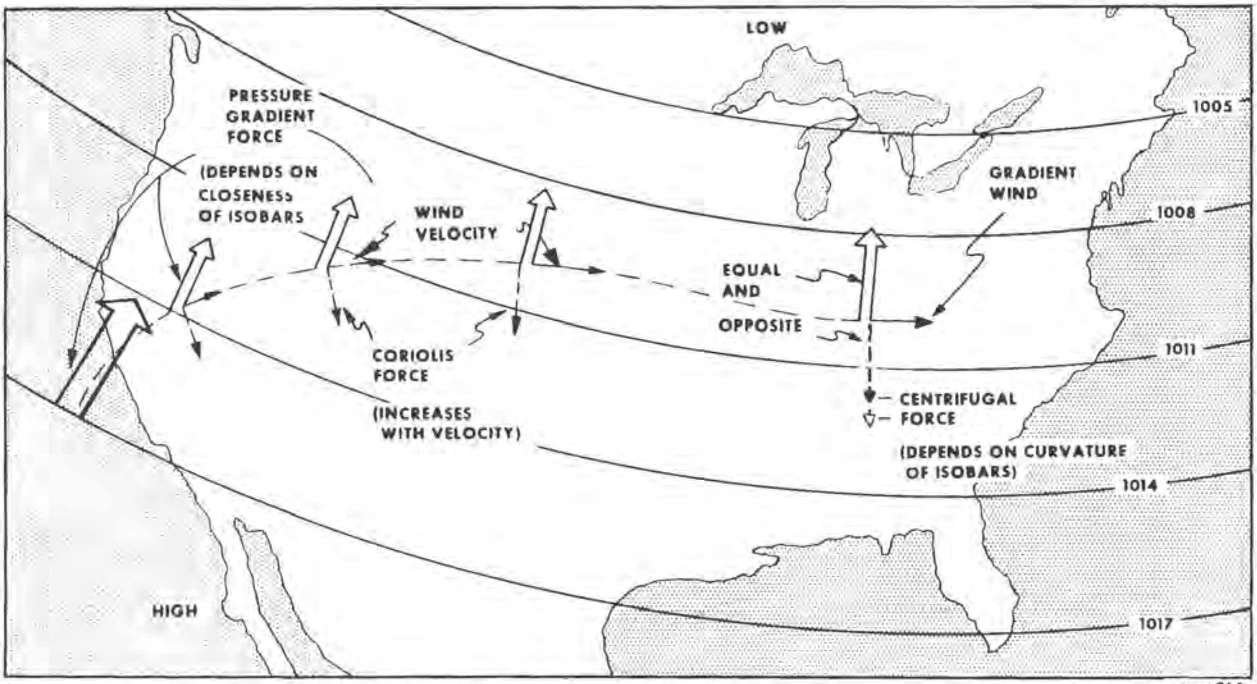


Figure 4–9. Gradient wind.

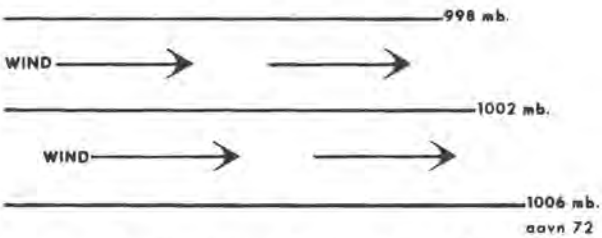


Figure 4–10. Geostrophic wind.

(1) *The friction layer.* Surface wind is acted upon by pressure gradient force, Coriolis force, and centrifugal force; however, in practice it tends to flow across the isobars from high toward low pressure (right hand side of figure 4–11). This deviation from the gradient wind pattern is caused by friction, which affects the air to approximately 2,000 or 3,000 feet. The amount of friction depends upon the nature of the surface. It is least over water and greatest over mountainous terrain. The average surface wind will flow across the isobars toward lower pressure at about a 30° angle. The surface friction gradually decreases with altitude until the gradient or geostrophic level is reached.

(2) *Wind versus altitude.* Since the frictional force decreases with altitude, the wind velocity will increase with an increase in altitude. This increase in wind speed tends to continue above the friction layer up to the tropopause. Beyond the friction layer, increases in wind speed are due to variations in the pressure force with elevation. The normal variations in wind speed and direction with height are shown in figures 4–12 and 4–13.

c. Winds and Pressure Systems.

(1) In the Northern Hemisphere the gradient wind flows parallel to isobars in a clockwise pattern around high pressure centers (anticyclones) and in a counterclockwise pattern around low pressure centers (cyclones).

(2) Surface winds (fig. 4–14) in the Northern Hemisphere flow clockwise

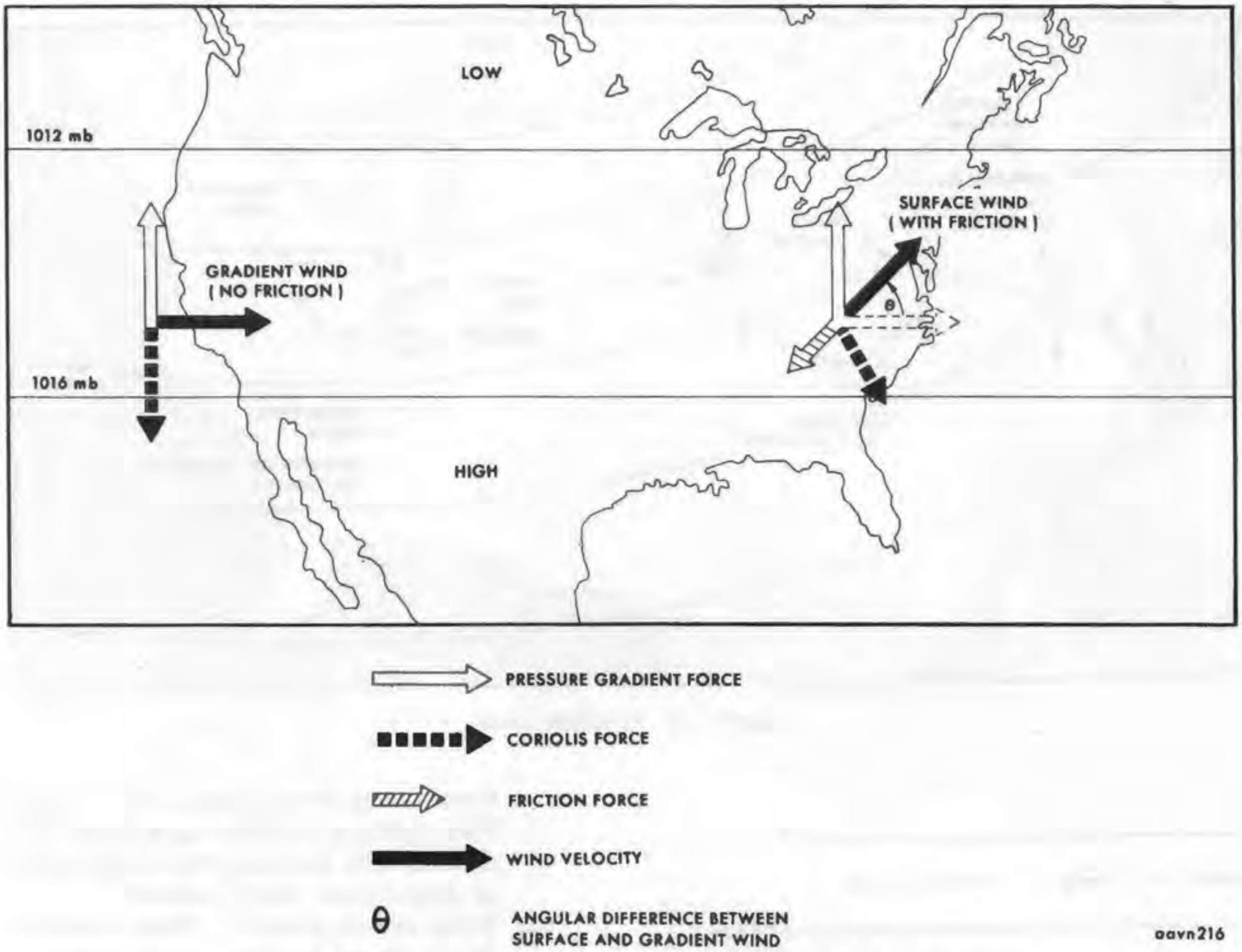


Figure 4-11. Comparison of gradient and surface winds.

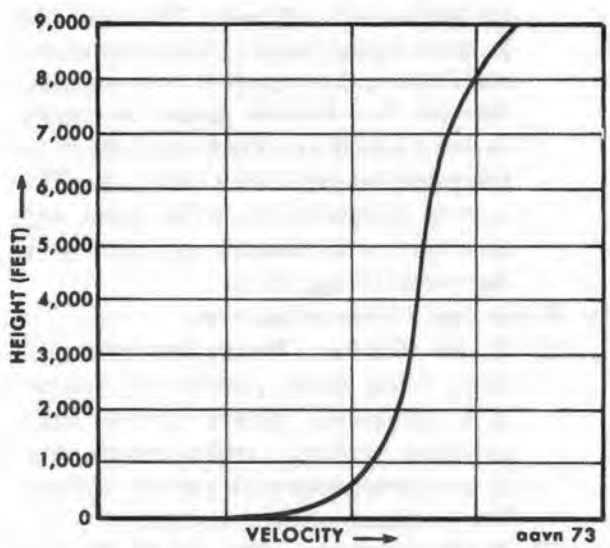


Figure 4-12. Approximate variation of wind velocity with height.

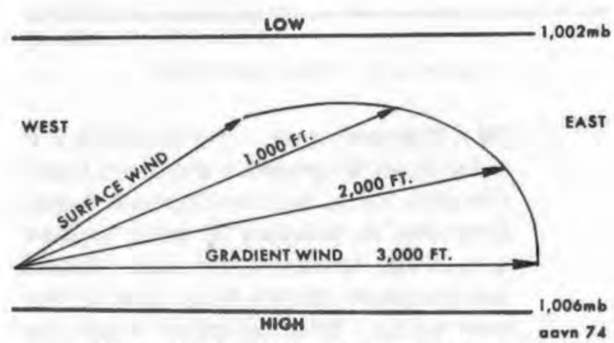


Figure 4-13. Approximate variation of wind direction with height.

around and away from a center of high pressure and counterclockwise around and toward a center of low pressure.

(3) An aviator flying above the friction layer in the Northern Hemisphere

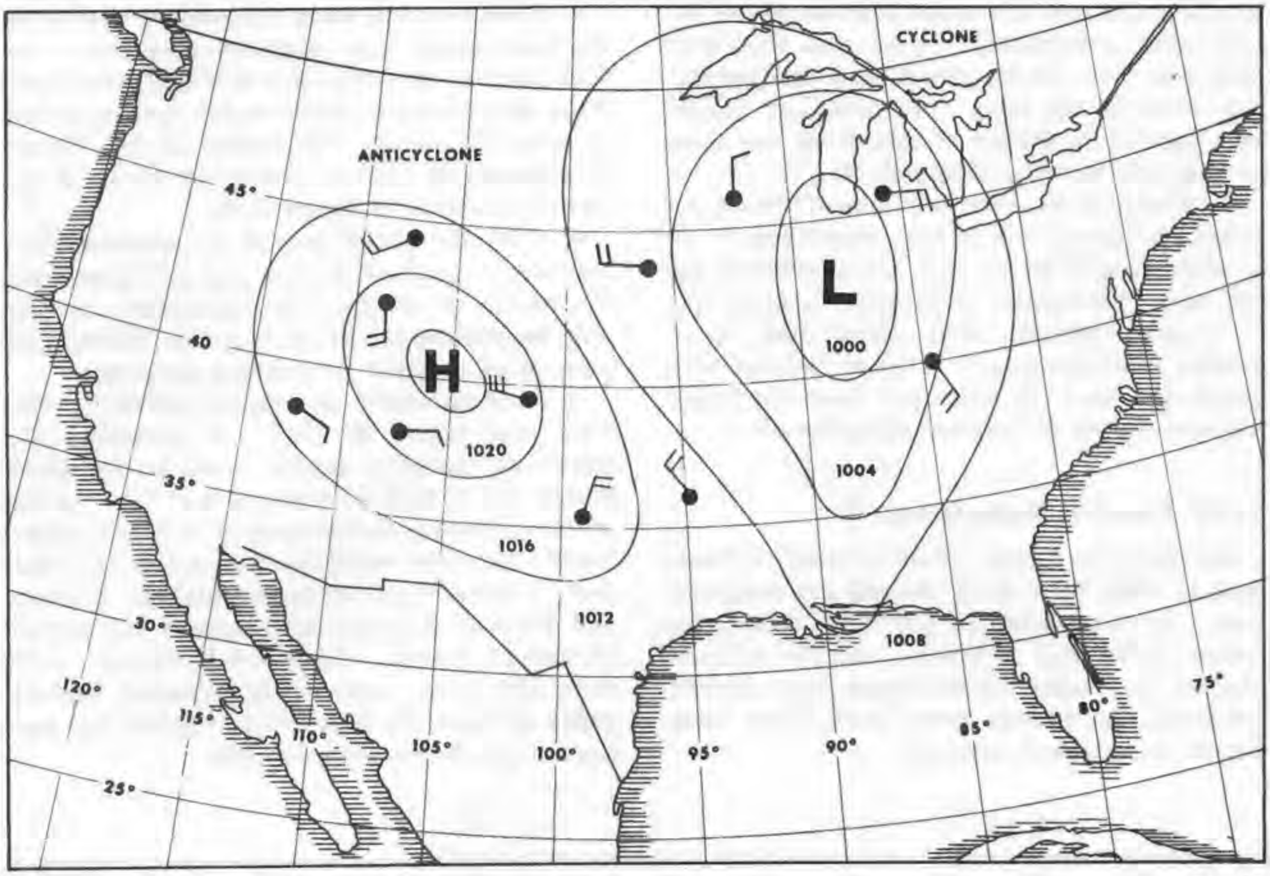


Figure 4-14. Surface windflow in pressure systems.

with his back to the wind is to the right of an area of low pressure; i.e., with a tailwind, lower pressure is to the left of the aircraft. Similarly, if an aircraft has a tendency to drift off-course to the right, it is crossing the isobars toward an area of lower atmospheric pressure.

(4) The relationship of windflow and pressure systems was discovered by Buys-Ballot in 1857, and is called *Buys-Ballot's Law* (par. 4-21).

d. Convergence and Divergence. The inflow of air toward a cyclone is called *convergence;* the outflow of air from an anticyclone is called *divergence.* Both processes result from the flow of air across isobars.

(1) The flow of air outward from an anticyclone causes a simultaneous descending action of the air within the high pressure area: this descending process is called *subsidence.* As the air subsides, adiabatic heating (ch. 5) decreases the relative humidity and produces generally good weather.

(2) Convergence in low pressure areas forces the air to rise, expand, and cool adiabatically. This cooling increases the relative humidity and produces cloudiness, precipitation, turbulence, strong winds, and generally poor weather.

Section III. HURRICANES

4-11. General

a. A *hurricane* is a tropical cyclone, accompanied by winds of 75 miles per hour or higher, originating over the Atlantic Ocean, the Caribbean Sea, the Gulf of Mexico, the eastern North Pacific (along the coasts of Central America and Mexico), and the tropical areas of the Pacific Ocean (typhoons). In general, the hurricane will move in the direction of the prevailing winds of the area. The principal regions and general directions of movement for these storms are shown in figure 4-15.

b. Winds of 75 miles per hour or more are called *hurricane-force winds,* regardless of the type storm with which they are associated; but the term "hurricane" is properly applied only to tropical cyclones with winds equal to or greater than this speed. Tropical cyclones with winds less than 75 miles per hour are called *tropical storms* or *tropical disturbances.*

4-12. Charting Background

Although the history of these storms extends back to 1494, these early records are fragmentary. As the islands of the West Indies, the shores of the Gulf of Mexico, and the Atlantic coast of the United States became more densely populated, hurricanes were more often mentioned in historical records.

a. Studies of the paths followed by storms of the West Indies and neighboring regions were first made in the early part of the 19th century. Thus the records available today span a period of over 160 years. The course of the "Great Hurricane" of 1780 as plotted by an early observer is shown in figure 4-16.

b. With the establishment of meteorological stations in the West Indies, and still later with the advent of wireless communication, noticeable improvement was made in the charting of tropical storms for forecasting purposes.

c. Reconnaissance of tropical storms by aircraft was begun in 1943. It furnished the hurricane warning service with an excellent means of detecting the presence and tracking the center of tropical hurricanes, as well as for estimating the wind velocities within their circulation. Coastal radar stations (military, private, and Weather Bureau) also observe and report on tropical storms. Figures 4-17 through 4-20 show the radar scope of the Weather Bureau radar at Cape Hatteras, N.C., during the passage of hurricane Ione, in 1955.

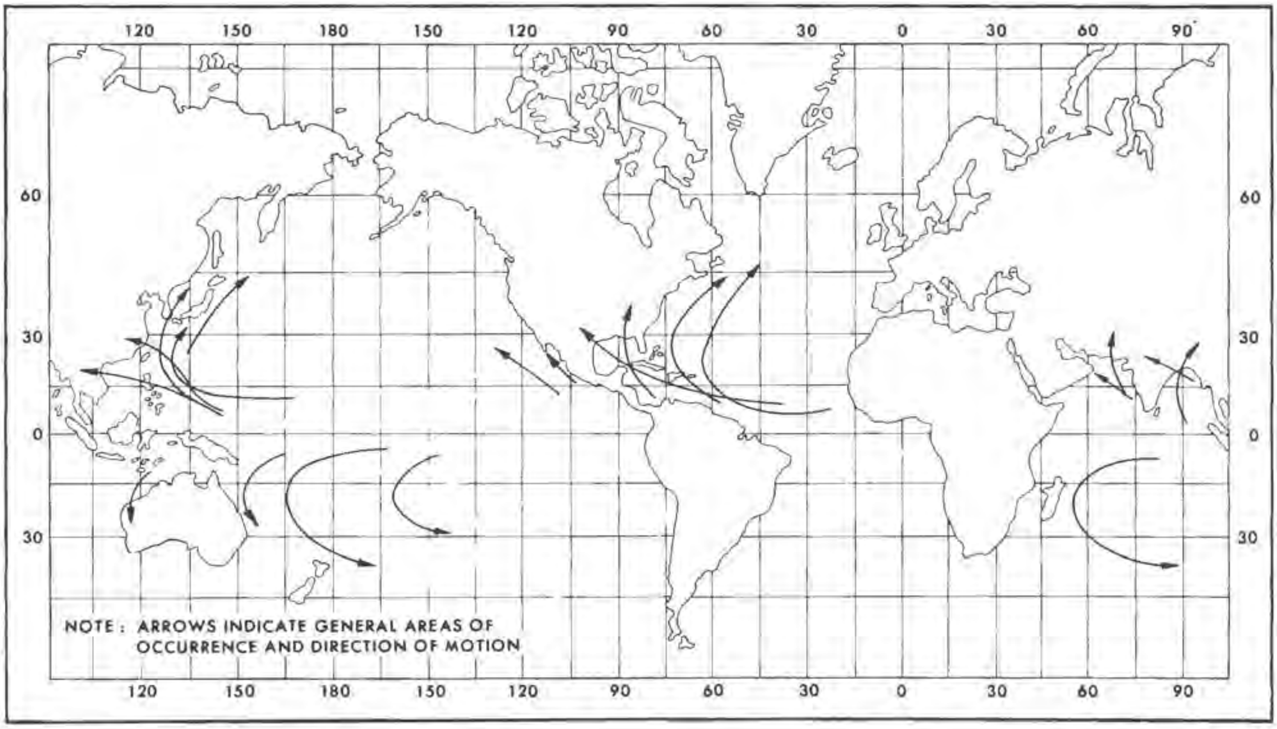


Figure 4-15. Principal world regions of tropical cyclones.

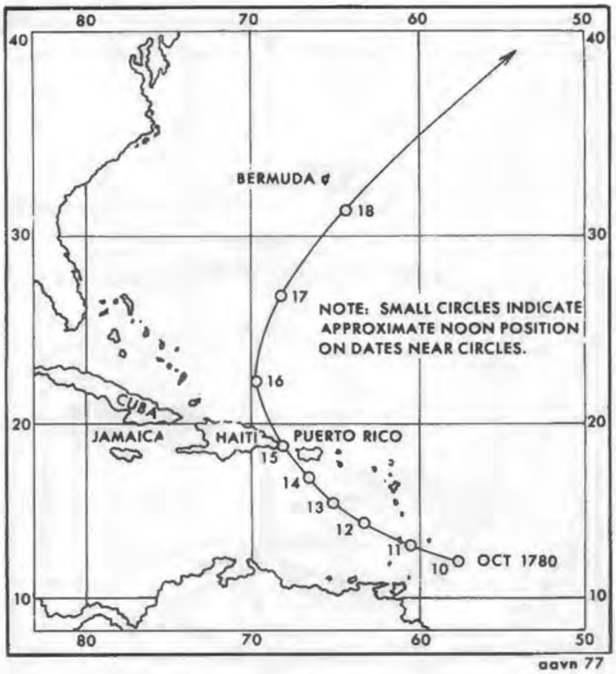


Figure 4-16. Track of the "Great Hurricane" of October 1780.

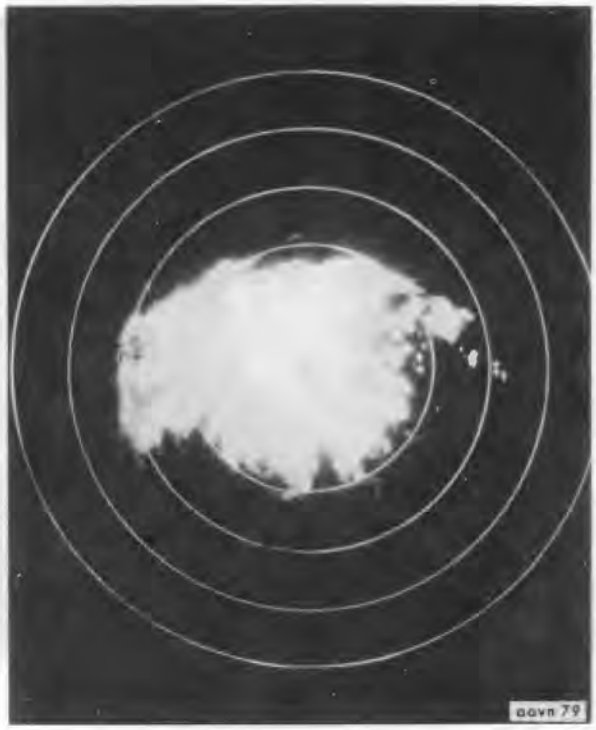


Figure 4-18. Radar view of hurricane Ione at 1:45 a.m., September 19, 1955.

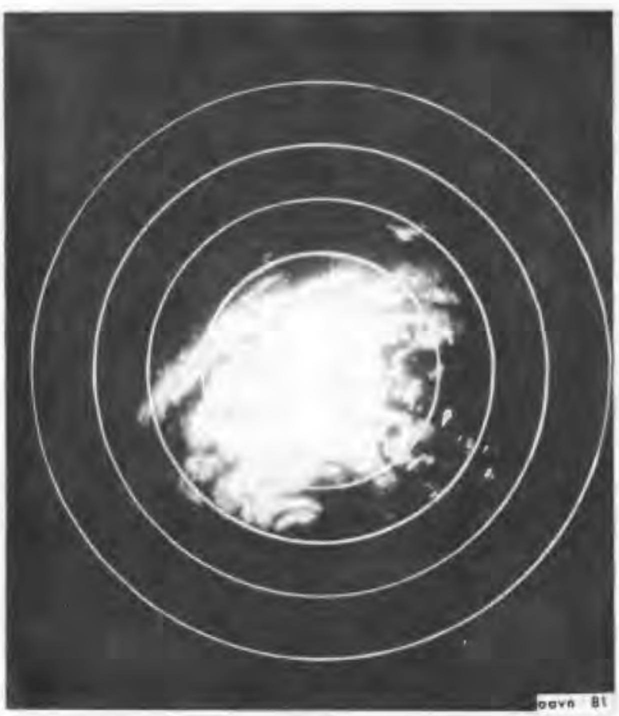


Figure 4-17. Radar view of hurricane Ione at 9:05 p.m.,. September 18, 1955.

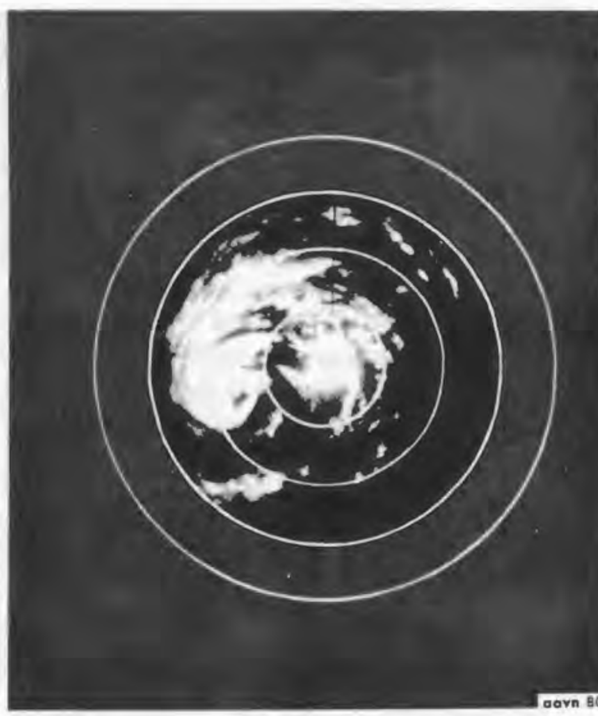


Figure 4-19. Radar view of hurricane Ione at 8:52 a.m., September 19, 1955.

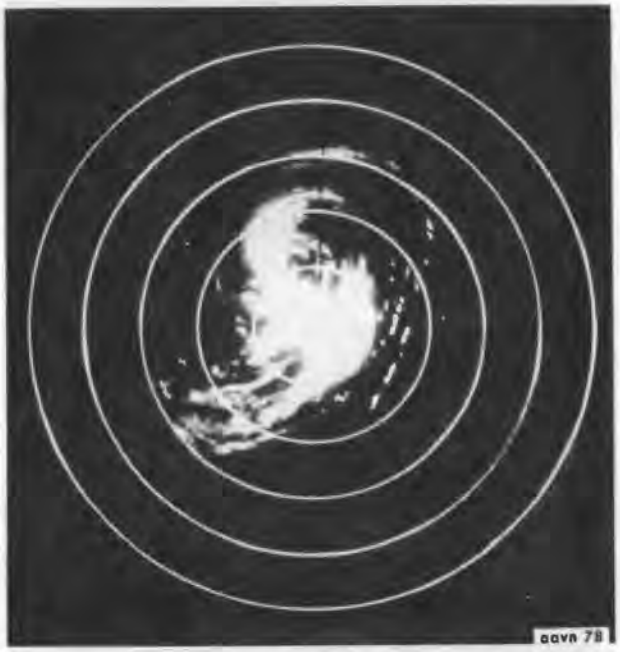


Figure 4-20. Radar view of hurricane Ione at 11:11 p.m., September 19, 1955.

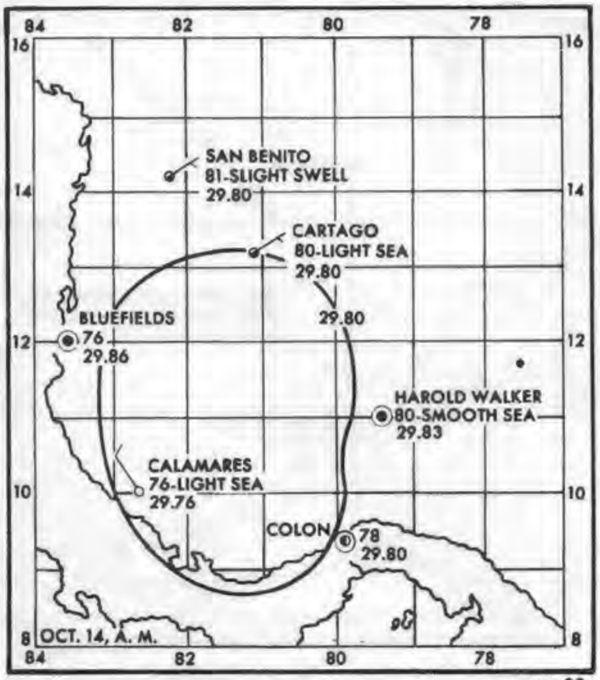


Figure 4-21. Pressure and wind conditions at 7 a.m., October 14, 1926, showing gentle cyclonic (counterclockwise) wind circulation of incipient disturbance.

4-13. Causes and Formation

Many tropical storms develop from small disturbances carried westward in the easterly trade wind belts (fig. 4-21). When an area of widespread showers is established, atmospheric pressure in the shower area is usually lower than in surrounding areas and a gradual inflow of air takes place. Because of the effect of the earth's rotation, the winds, which otherwise would blow directly toward the storm center, are deflected to the right in the Northern Hemisphere. A cyclonic system with counterclockwise winds inclined inward is thus established. When this process takes place over an area of several thousand square miles, it results in a circulation characteristic of a tropical storm. Observations during the formation of a hurricane are shown in figures 4-21 through 4-24. Some of these cyclonic disturbances develop into violent storms (fig. 4-25) within 24 to 36 hours; others reach hurricane intensity only after several days, while by far the largest number become no more than mild wind systems with unsettled weather.

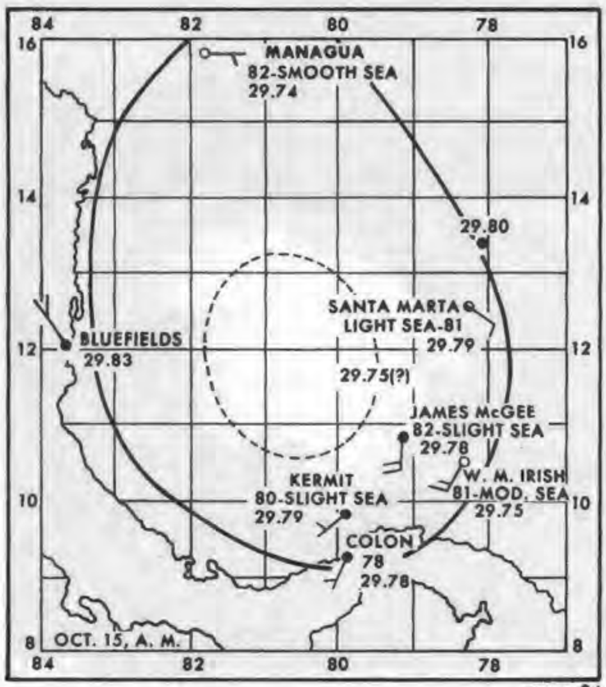


Figure 4-22. Pressure and wind conditions at 7 a.m., October 15, 1926.

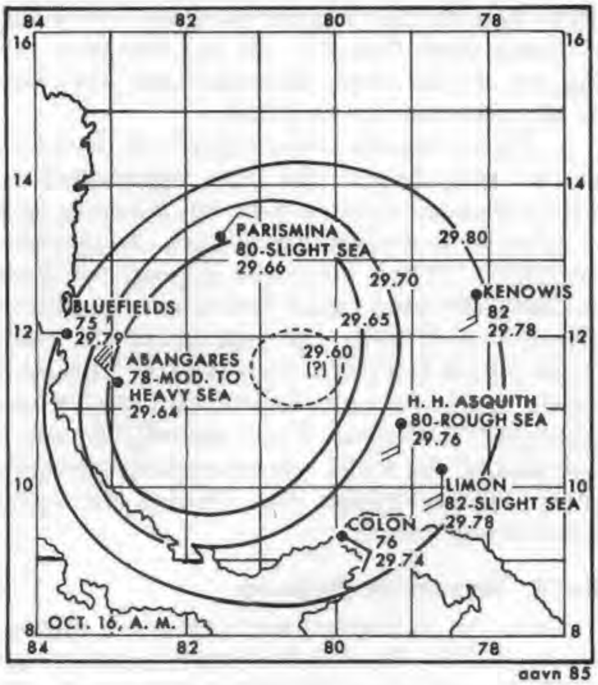


Figure 4-23. Pressure and wind conditions at 7 a.m., October 16, 1926.

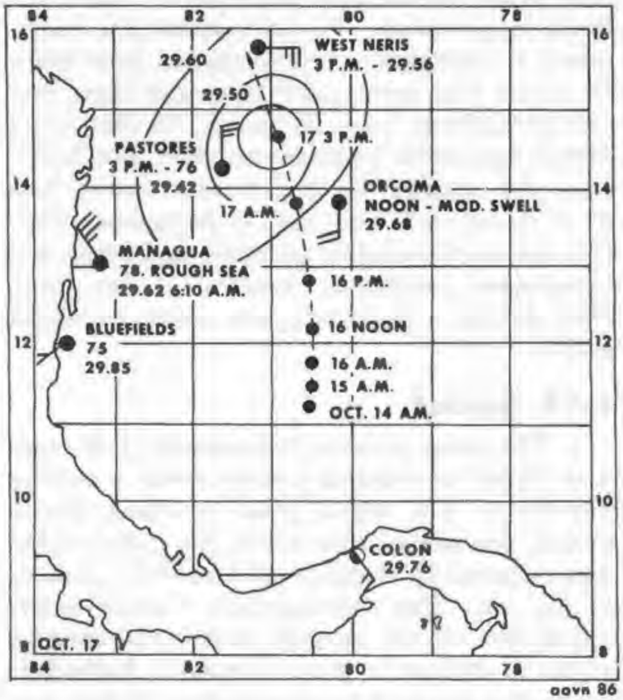


Figure 4-24. Wind and pressure conditions on October 17, 1926, and track of the center of the disturbance.

Figure 4-25. Typhoon as photographed by TIROS I weather satellite.

4-14. Formation Regions for Hurricanes Affecting the United States

Hurricanes develop in the belt of light winds south of the main trade winds of the southern North Atlantic Ocean, western Caribbean Sea, and in the Gulf of Mexico.

4-15. Motions of Storms

a. At the same time that the cyclonic circulation is established and the winds begin increasing in force, the disturbance, as a whole, also moves. Thus, there are two movements to be considered—(1) the winds directed around and slightly inward toward the center of the cyclone, and (2) the forward movement of the entire counterclockwise wind system. The circulatory movement in the fully developed hurricane is violent, with the speeds of the wind near the center sometimes exceeding 150 miles an hour. The progressive movement of the entire system while in the Tropics averages only 12 to 14 miles an hour. This movement usually increases somewhat as the storm approaches higher latitudes, especially after it has recurved to a more northeasterly direction. During the recurving, many tropical storms move very slowly; some remain almost stationary for a day or more.

After the recurve (which usually takes place at or a little south of 30° north latitude), the storm generally moves in a direction between north and east, with increasing speed, sometimes at a rate of 40 to 50 miles an hour in higher latitudes. The generally accepted explanation of these movements is that the storms drift with the air currents in which they are imbedded. At the surface of the earth, the general circulation of the winds is from an easterly direction in the Tropics and, from a westerly direction in middle and higher latitudes.

b. Storms may come under the influence of disturbances in either the easterly trade winds or the prevailing westerly winds and may alternate between the influence of these two major air currents. Such variable influences may result in a number of loops, abrupt turns, and unusual movements (fig. 4-26).

4-16. Hurricane Winds

a. Preparation of average hurricane tracks has been undertaken many times. Because of the large variation in paths, these averages are not representative of individual storms or seasons. Tracks of centers of some of the most devastating storms on record are shown in figure 4-27.

b. The wind system of the hurricane is more or less circular. At the outer limits of the storm, the winds are only moderate breezes with irregular speed and direction. They increase in force toward the center of the storm to a point about 5 to 15 miles from the center of rotation. From this point inward, the winds fall off abruptly. The strongest winds often reach a sustained speed of 75 to 100 miles per hour at the surface, and occasionally even 125 to 150 miles per hour, with gusts of still higher speeds.

4-17. Center of the Storm

a. At the center of a tropical cyclone there is an area (known as the "eye" of the storm) with little or no wind. In this central area, the sky sometimes clears so that the sun or stars become visible. The temperature usually rises and the air is dry. All around this relative calm is the encircling wall of hurricane winds, which produces a rumbling or roaring sound. The diameter of the relatively calm center averages 15 to 20 miles, but may be less than 7 miles and is rarely more than 30. At sea, the waves in the eye of the storm commonly are described as mountainous and confused.

b. When the calm center ("eye") of the storm passes over a place, the calm is preceded by winds of great violence from one direction and is followed by violent winds from the opposite direction. If the hurricane approaches from the east, the wind blows first from a northerly direction and, after the passage of the calm center, shifts to a southerly direction. This calm center causes many to believe that the "storm came back"; whereas, it was actually the opposite side of the whirl. Ignorance of the calm-center characteristics has resulted in many injuries and deaths.

4-18. Barometric Pressure

Normally, in tropical and subtropical regions frequented by West Indian hurricanes, the barometer reads about 30 inches at sea level. As the hurricane approaches, the barometer falls. The rate of fall is slow at first but increases as the center draws near. The rate of fall depends upon the depth of the barometric depression in the storm and the rate at which the storm approaches. In fully developed hurricanes, the barometer nearly always falls below 29 inches (sea level), and there are many records of readings below 28 inches. In the United States, the lowest pressure recorded in a hurricane at a regular Weather Bureau station was 27.61 inches at Miami, Fla., in September 1926. Changes in barometric pressure and other meteorological conditions observed at San Juan, P.R., during a hurricane, are shown on figure 4-28.

4-19. Rainfall

a. The radar pictures in figures 4-17 through 4-20 show the rainfall pattern about a mature hurricane. The white areas on these photographs are areas from which the radar signal was reflected by waterdrops (rainfall) present in the air. The characteristic "spiral band" appearance of the rainfall distributed about a storm is evident in these pictures. Individual convective showers become aligned in this pattern about the center of most well-developed tropical storms. The heaviest rainfall is

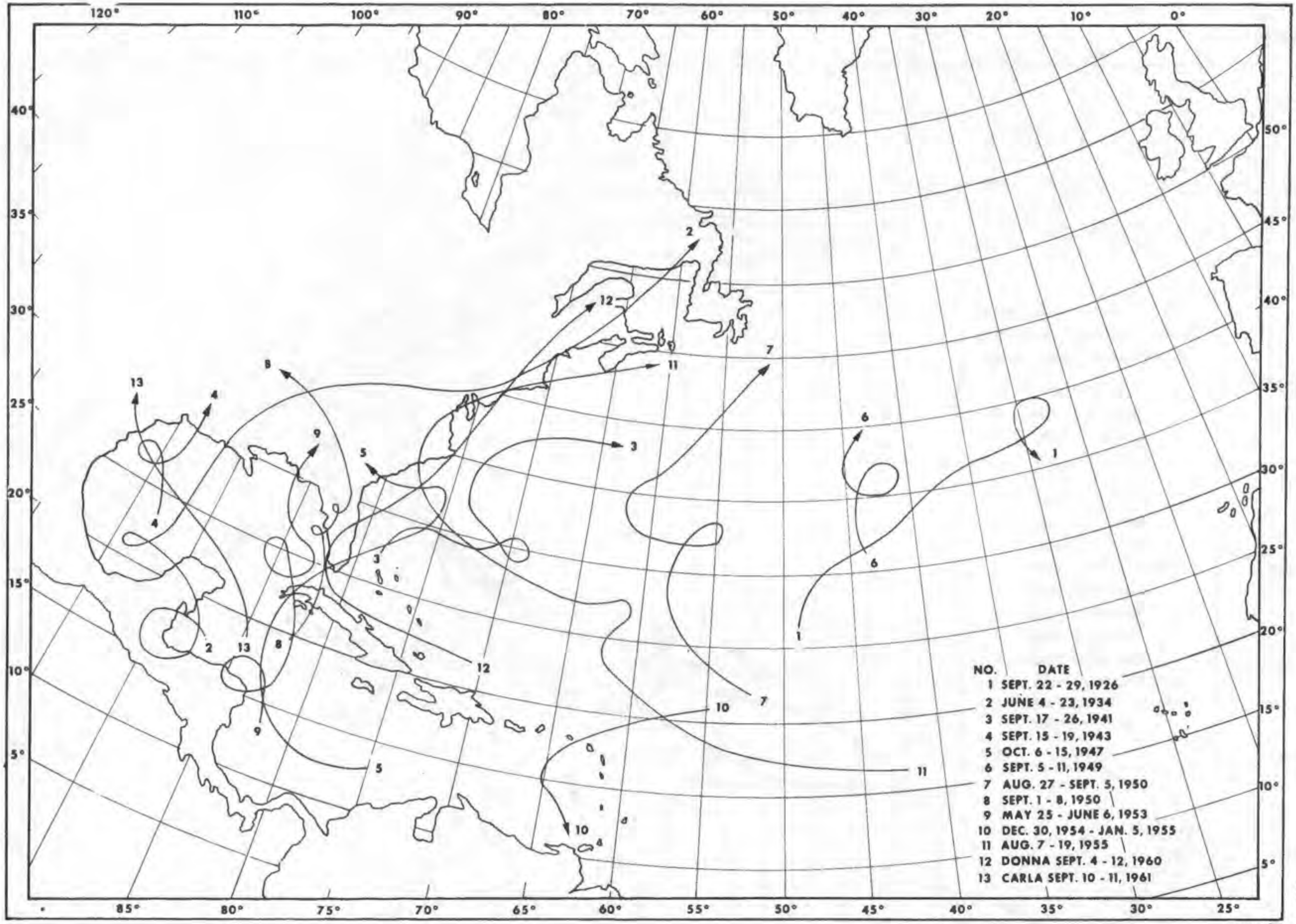


Figure 4–26. Tracks of some tropical storms showing irregular motions.

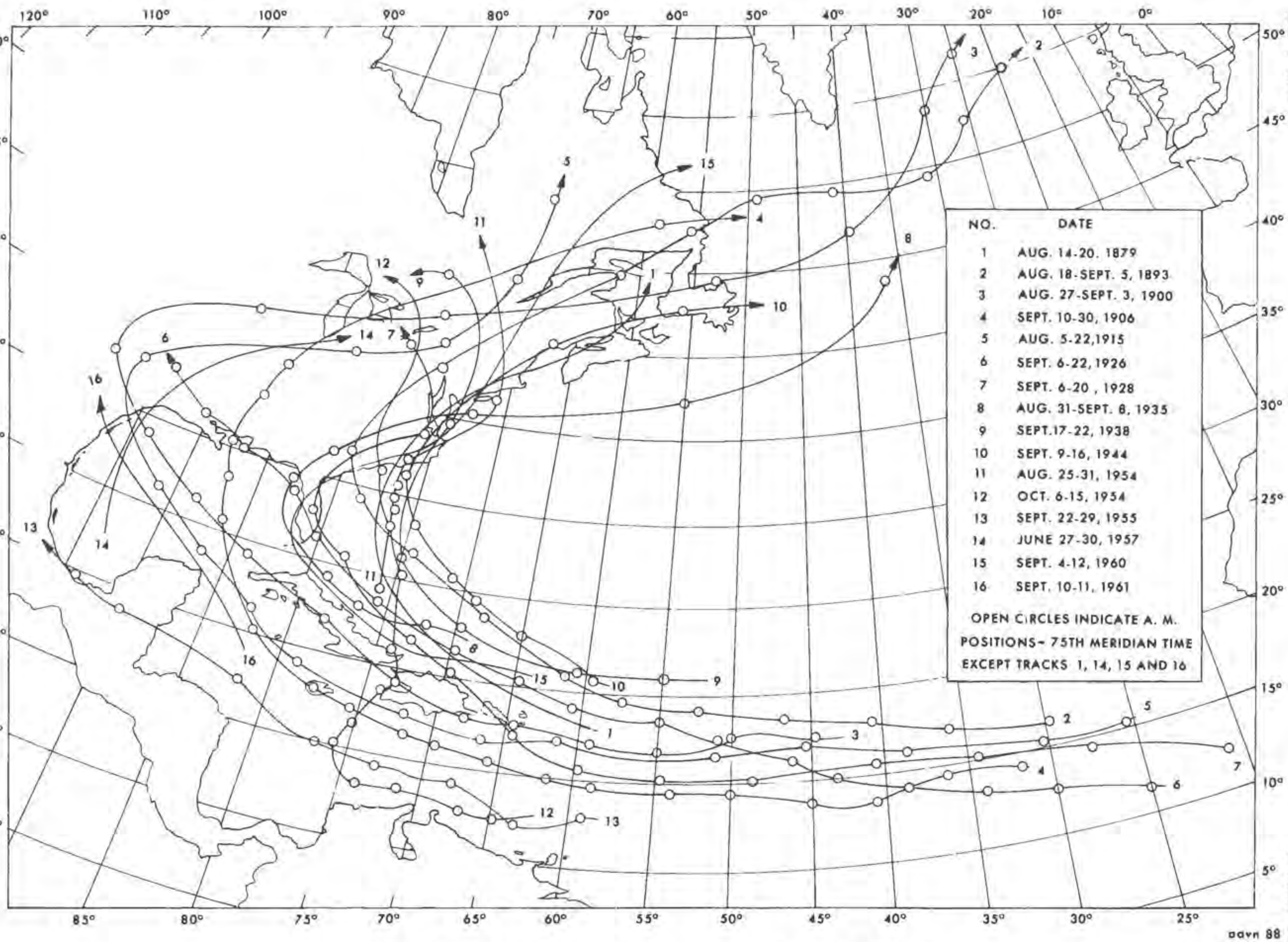


Figure 4–27. Tracks of some devastating North Atlantic hurricanes.

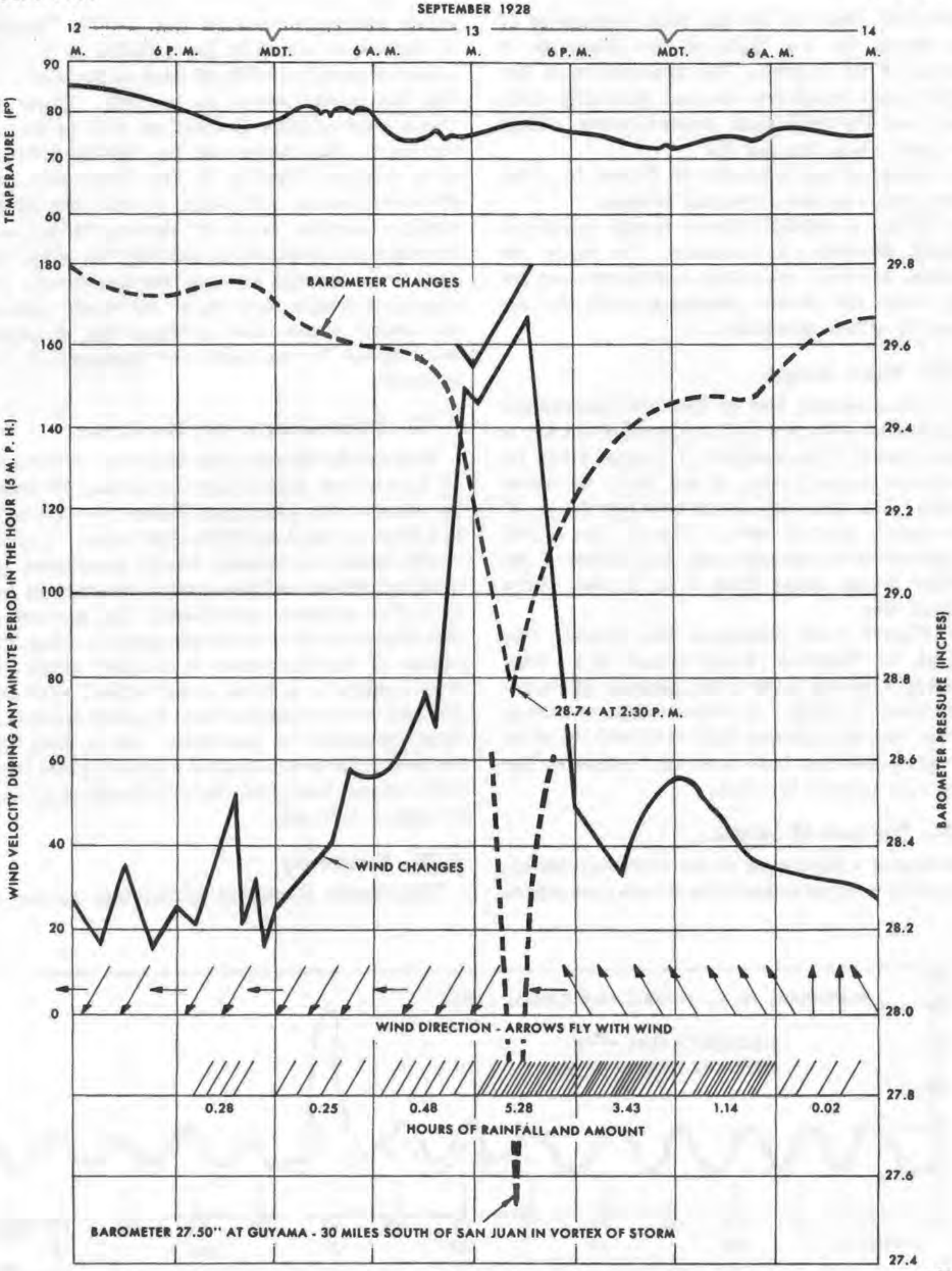


Figure 4–28. Changes in barometric pressure and other conditions at San Juan, P.R., during the passage of a hurricane.

ordinarily observed in the right semicircle of the storm (to the right of the direction of motion of the storm). The appearance of the spiral band structure changes gradually with time, and the individual showers move within the band along the spirals.

b. Rainfall has exceeded 40 inches in a 24-hour period in some tropical storms.

c. When a tropical storm moves inland, it usually decreases in intensity. In many instances, however, much rain continues over the land from the clouds associated with the decreasing storm circulation.

4-20. Storm Surges

a. The greatest loss of life and destruction of property produced by hurricanes is usually a direct result of inundation of coastal areas by hurricane-induced rises in sea level, or *storm surges.* The rise may be as much as 10 to 15 feet above normal tide. Usually the storm surges along the Atlantic and Gulf coasts of the United States range from 4 to 12 feet above normal tide.

b. Figure 4-29 compares the normal tide heights at Montauk, Long Island, N.Y. with the tide observed during the passage of hurricane Carol in 1954. A storm surge occurring at the time of a normal high tide will result in far more flooding than a similar surge at the time of a normal low tide.

4-21. The Law of Storms

Winds of a hurricane in the Northern Hemisphere blow counterclockwise around the storm center and spiral inward (fig. 4-30). The *law of storms,* as stated by Buys-Ballot, is that the observer standing with his back to the wind will find the storm center on his left. Since the winds blow slightly inward, as well as around the storm, the center will be slightly forward of a position directly to the observer's left. Strongest winds will occur on the side of the storm where the winds are blowing in the same direction as the storm is moving; i.e., when the cyclone is moving toward the northwest, the counterclockwise movement of winds around the storm center will produce the strongest wind speed in the northeast quadrant of the cyclone.

4-22. Dimensions of the Hurricane

In small hurricanes, the diameter of the area of destructive winds may not exceed 25 miles. In some of the great hurricanes, the diameter has been as much as 400 to 500 miles. In relatively small hurricanes, winds sometimes become as strong and the center pressure as low as in the greatest hurricanes. The pattern of the isobars, or lines of equal pressure, about the center of the hurricane is circular, while the wind system is a cross-isobar spiral, with the amount of cross-isobar flow varying somewhat from quadrant to quadrant. As a rule, the tropical cyclone approaches a true circular form more closely than does the extratropical cyclone of higher latitudes.

4-23. Frequency

The annual frequency of *tropical storms* in

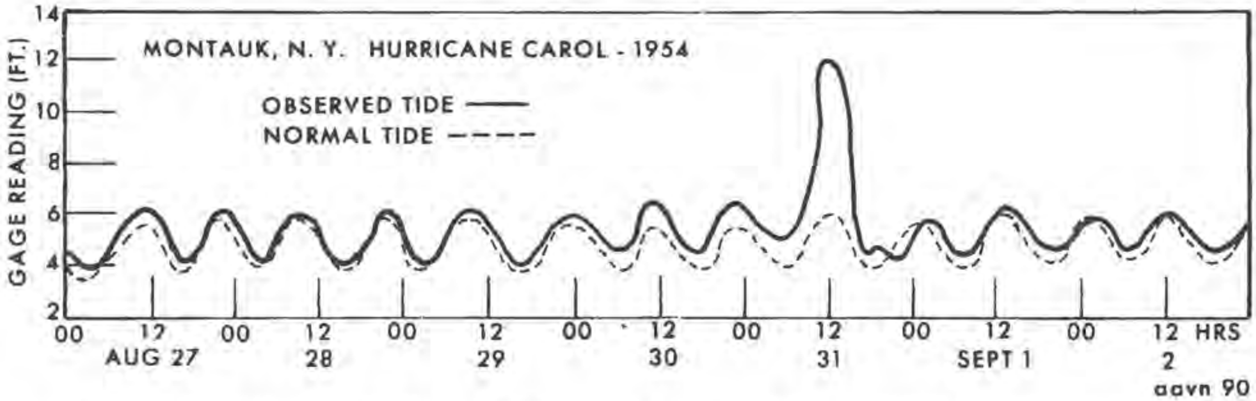


Figure 4-29. Tide record at Montauk, N.Y., during hurricane Carol, August 27 to September 2, 1954.

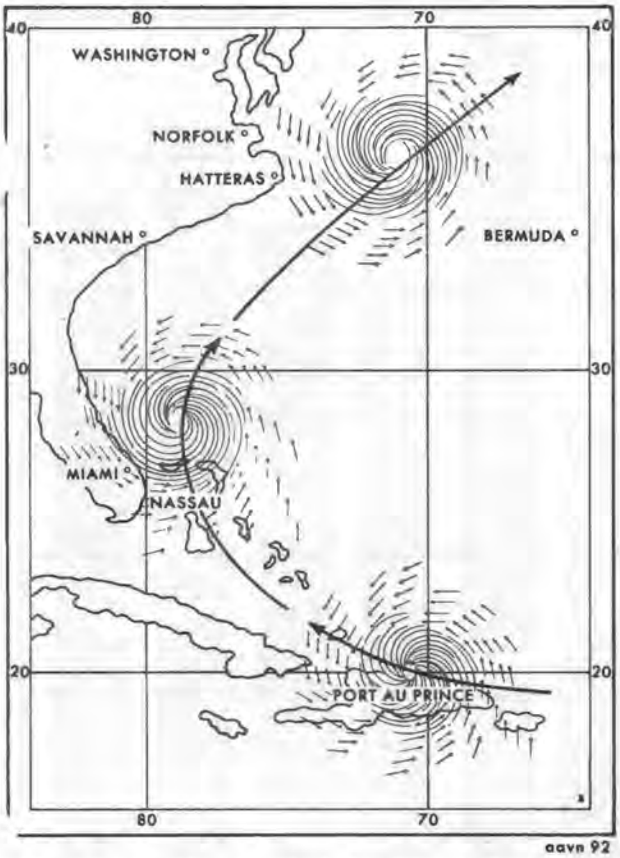


Figure 4-30. Track and wind system of a hurricane.

the North Atlantic from 1879 through 1955 is shown in figure 4-31. The average annual frequency for the entire period is 7.4. During the 27 years from 1879 to 1905, the average annual frequency was 6.9; for the years 1906 to 1930 the average was 5.5; and during the years 1931 to 1955 the average was 9.9 storms per years. Figure 4-32 represents these same data grouped into 5-year periods from 1901 through 1955.

4-24. Hurricane Warnings

a. General. The United States weather services are constantly striving to improve the effectiveness of the hurricane warning system. Modern techniques of aerial reconnaissance, the development of long-range radar sets, and marine automatic meteorology observation stations, along with the data received from weather satellites, are permitting an accelerated research program on the study of hurricanes. Presently, the U.S. Weather Bureau uses three types of hurricane warnings. These are—

(1) *Hurricane watch.* This is an alert to the general population, warning them that the area may be under the influence of a hurricane within 36 hours. Indications are not present to definitely justify a hurricane warning.

(2) *Gale and whole gale warnings.* A gale warning is issued to alert the general population and marine interests that the area is subject to a wind condition from 39 to 54 miles per hour; whole gale warnings are issued when winds from 55 to 74 miles per hour are predicted within the next 24 hours. These warnings are frequently first issued in connection with a hurricane, although a hurricane watch may have been issued earlier to the same general area. These warnings may be issued when only the fringe of a hurricane is expected to affect the area.

(3) *Hurricane warning.* This warning is issued to warn the general population and marine interests that winds of 75 miles per hour or higher are expected, with a possibility of full hurricane

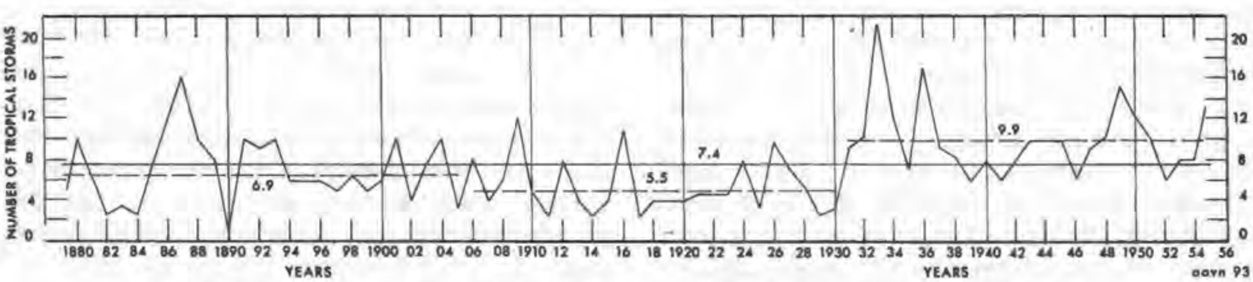


Figure 4-31. Frequency of North Atlantic, Gulf of Mexico, and Caribbean tropical storms per year from 1879 to 1955.

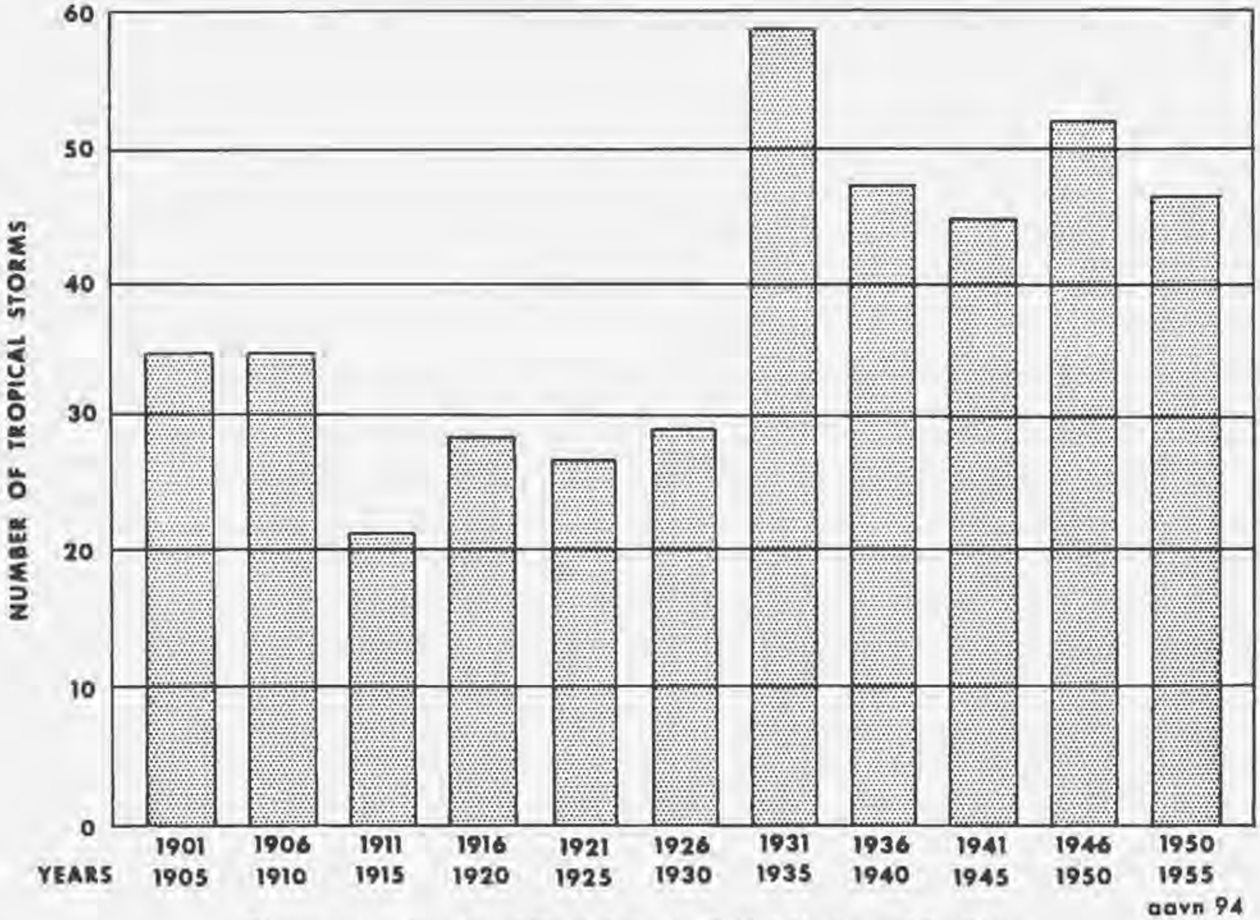


Figure 4-32. Number of North Atlantic, Gulf of Mexico, and Caribbean tropical storms by 5-year periods from 1901 to 1955.

conditions. The hurricane warning is also used to alert the general population of unusually high seas in the coastal area (tides and waves).

b. Military Installations. Military installations with aircraft are confronted with additional problems when hurricanes threaten the area. Many installations do not have sufficient hangar space to protect the aircraft; therefore, it is necessary to fly the aircraft to safe areas before the hurricane arrives. Moving the aircraft from one installation would not present a great problem; however, when a hurricane threatens Florida and the adjacent States, large numbers of aircraft must be evacuated from several installations. The movement of a large number of aircraft requires the coordination of several agencies. Frequently, it is difficult to obtain airspace during mass evacuation under the instrument flight conditions that exist in large areas ahead of the storm. Evacuation problems can be alleviated to a degree by coordination between the installations involved in selecting different points of refuge. Care also must be taken during the planning stage in selecting a refuge to prevent the overcrowding of airfields. In the past, the lack of prior planning has resulted in some airfields receiving more aircraft than they could serve. Working out the minute details for the evacuation requires considerable time and effort. Most installations now have a warning system that goes through different steps as the hurricane moves toward the area, (e.g., condition A, condition B, and condition C). Complete details are prepared for each condition and the personnel involved are kept informed of their assigned duties in the evacuation plans.

Section IV. OTHER WINDS AND WEATHER

4-25. Land and Sea Breezes

During the daytime, coastal lands generally become warmer than the adjacent water and a lower density will exist in the surface layer of air over land than in the surface layer over the water (fig. 4-33). This slight difference in pressure over the land and water surfaces establishes a flow of wind landward (a sea breeze) during the day. The force of the sea breezes depends upon the amount of insolation and terrestrial radiation. Sea breezes are most pronounced on clear days, in the summer, and in low latitudes. Land breezes (from land to sea) occur at night due to the rapid nocturnal cooling of the land surface. In areas where a well-developed pressure pattern exists, the air will be moving along the isobars with sufficient speed to overcome surface temperature variations in coastal regions. Under these conditions, no land or sea breeze will exist: it will be overpowered by the prevailing winds.

4-26. Valley and Mountain Breezes

On warm days, winds tend to flow up slopes during the day and down slopes during the night. This is because air in contact with the mountain slopes is warmer than the free atmosphere at the same level during the day and colder during the night. Since cold air tends to sink and warm air tends to rise, a system of winds develops and flows up the mountain side during the day and down during the night. The daytime movement is a valley breeze; the nighttime motion is a mountain breeze.

4-27. The Monsoon

a. General. An important factor in the consideration of world weather phenomena is the monsoon and the mechanics of monsoonal circulation. Monsoons are large-scale phenomena which result from the same heating and cooling processes that cause the smaller scale land and sea breezes.

b. Temperatures. In winter, the land is usually colder than the sea in monsoon areas. This results in an outflow of air from land to sea. In summer the situation is reversed. In large landmass areas (part of which lies near the border of the Tropics and thus get a large amount of solar heating), the thermal low pressure cells developing in the summer may become so intense that a large-scale flow of moist air from sea to land results. This is the summer monsoon. It is characterized by abnormally persistent winds and large amounts of precipitation as moist maritime air rises up the inland slope of the land mass. Monsoonal circulation is extremely well developed in the India-Burma-China region. The southerly circulation in summer brings the warm moist air to the continent (fig. 4-34). The winter pressure pattern causes a flow of very dry air from the north (fig. 4-35). A similar monsoon circulation is found in North America, but it is not as well developed as the circulation found in Asia.

4-28. The Mountain Wave

a. Numerous aircraft accidents have occurred in mountainous areas in strong wind situations,

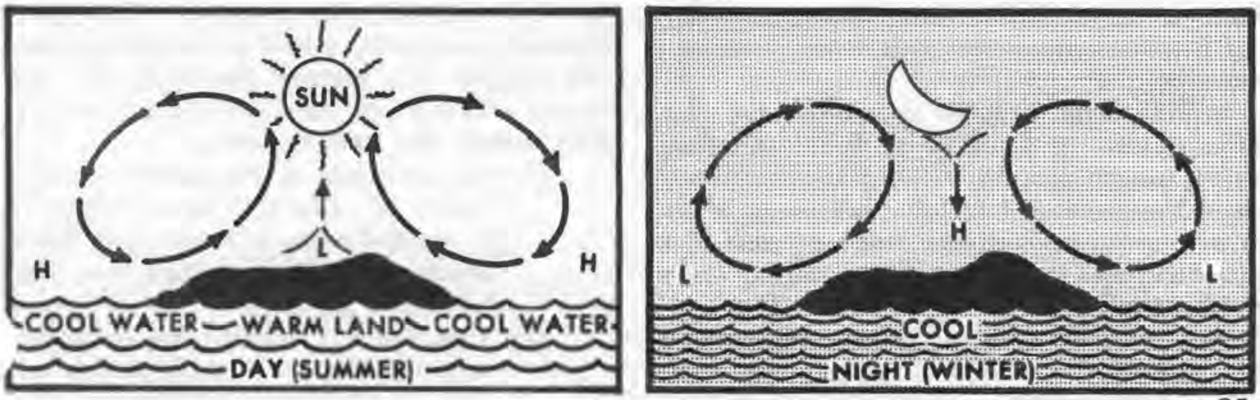
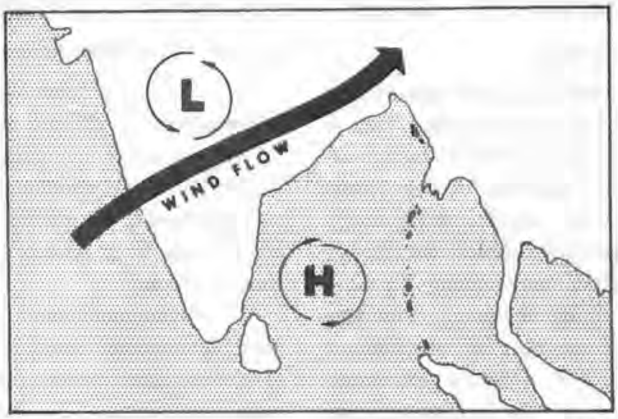
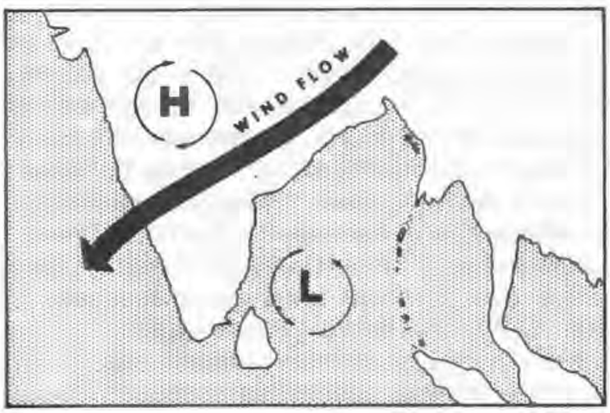


Figure 4-33. Land-sea effect.



aavn 96

Figure 4–34. Summer monsoon.



aavn 97

Figure 4–35. Winter monsoon.

often without a satisfactory explanation at the time. In an effort to make mountain flying safer, a considerable amount of research is underway to gain a better understanding of airflow over mountain barriers. Although much has been learned, present knowledge is far from complete.

b. First indications of mountain-wave phenomena came from sailplane pilots searching for rising air currents. Gliding and slope-soaring enthusiasts had long taken advantage of the rising air currents on the windward side of a mountain, and had known that generally there is a descending flow on the lee side. However, during the 1930's pilots observed that strong air currents, rising to great heights, were occasionally encountered to the lee of a mountain. Following this discovery, record flights (30,000 feet and higher) were made by using the strong currents of the lee of the Alps. In 1952, an altitude record of 44,500 feet was established in the United States during a period of strong mountain wave activity to the lee of the Sierra Nevada mountains near Bishop, Calif. From theoretical studies and firsthand observations by many aviators, a better understanding of the typical mountain wave pattern gradually emerged. It became apparent that the ascending currents were fairly systematic wave patterns rather than random updrafts.

c. The characteristics of a typical mountain wave are represented in figures 4–36 and 4–37. Figure 4–36 shows the cloud formations normally found with wave development; figure 4–37 illustrates the airflow in a similar situation. These figures demonstrate that the air flows with relative smoothness in its lifting component as the wave current moves along the windward side of the mountain. Wind speed gradually increases, reaching a maximum near the summit. On passing the crest, the flow breaks into a much more complicated pattern, with downdrafts predominating.

(1) An indication of the possible intensities in the mountain wave is reflected in verified records of sustained downdrafts (and also updrafts) of at least 3,000 feet per minute.

(2) Turbulence in varying degrees can b expected (fig. 4–37), with particularly severe turbulence in the lower levels.

(3) Proceeding downwind 5 to 10 miles

Figure 4-36. Typical cloud formations with mountain wave.

Figure 4-37. Schematic diagram showing airflow in a mountain wave.

from the summit, the airflow begins to ascend as part of a definite wave pattern. Additional waves, generally less intense than the primary wave, may form downwind. This event is much like the series of ripples that form downstream from a rock submerged in a swiftly flowing river.

(4) Manifestations of three waves can be seen in figure 4-38. The Army aviator is mainly concerned with the first wave, because of its more intense action and its proximity to the high mountain terrain. The distance between successive waves (wave length) usually ranges from 2 to 10 miles, largely depending on the existing wind speed and atmospheric stability, although waves up to 20 miles apart have been reported.

d. The Army aviator should know how to identify a wave situation and how to plan his flight to avoid wave hazards. Characteristic cloud forms peculiar to wave action provide the best means of visual identification.

(1) The lenticular (lens shaped) clouds in the upper right of figure 4-36 are smooth in contour. These clouds may occur alone or in layers at heights above 20,000 feet (MSL), and may be quite ragged when the airflow at that level is turbulent. The roll cloud forms at a lower level, generally near the height of the mountain ridge, and can be seen extending across the center of figure 4-36. The cap cloud, shown partially covering the mountain slope on the left in figure 4-36, must always be avoided in flight because of turbulence, concealed mountain peaks, and strong downdrafts on the lee slope. The lenticulars, like the roll clouds and cap cloud, are stationary. They are constantly forming on the windward side and dissipating on the lee side of the mountain wave.

(2) The cloud forms are generally a good guide to the degree of turbulence; i.e., smooth airflow occurs in and near smooth clouds and turbulent conditions occur where clouds are ragged or irregular. Smoother conditions exist at the lenticular level than near the roll clouds (fig. 4-36). However, close proximity of smooth and turbulent areas is a characteristic of the mountain wave. Smooth flight conditions at the entry of a wave is no assurance of continued smooth conditions. *Wave action also may occur when the air is too dry to form clouds.* Thus, the

Figure 4-38. Multiple wave formation to the lee of a mountain range.

aviator may fly into a wave area unexpectedly when clouds are not present to indicate the location of wave activity.

e. In planning a flight where wave activity is suspected, several indications of wave development and intensity are—

(1) Windflow of about 25 knots or more perpendicular to the mountain range. Wave action rapidly decreases as the winds shift from this direction.

(2) An increase in wind speed with altitude up to and above the mountain-top height. Within limits, wave action becomes more intense with stronger winds. However, very strong winds (over 100 knots in the free air above the ridge) may eliminate smooth waveflow patterns entirely, causing very severe but chaotic turbulence.

(3) For sustained wave action, the air must be stable for a thickness of several thousand feet in the vicinity of the mountain ridge. In unstable air, the inherent irregular vertical motions tend to break up the wave action.

f. If practicable, avoid flight into the wave area. Suggested *safeguards* for flight into an area of suspected wave conditions are to—

(1) Avoid ragged and irregular-shaped lenticular and roll clouds.

(2) Approach the mountain range at a 45° angle, particularly when flying upwind, so that a quick turn can be made away from the ridge when flight continuation appears impracticable.

(3) Avoid flight into a cloud deck lying on the mountain ridge *(cap cloud)* since it can be expected to contain strong downdrafts, turbulence, and the hazards of instrument flight near mountain level.

(4) Fly clear of the roll cloud to avoid its heavy turbulence and downdrafts.

(5) Be suspicious of all altimeter readings. *In a wave condition, the altimeter may indicate more than 1,000 feet higher than actual altitude.*

(6) When flying into the wind, use updraft areas to gain a safe altitude for crossing the mountain range. In particular, look for rising currents upwind of the roll cloud and of lenticular altocumulus if these are near flight level. Since apparent updraft areas can be misleading, care should be used in employing this procedure.

4-29. Foehn (Chinook) Winds

Foehn winds have a strong downwind component, are dry and warm for the season, and are characteristic of many mountainous regions. Along the eastern slopes of the Rockies, they are known as the *chinook*. When air flows up the side and over a mountain barrier, it undergoes expansion and cools at the *dry adiabatic lapse rate of 3° C. per 1,000 feet* until its temperature has dropped to the dew point (par. 2-12*b*). Condensation then occurs, leading to the formation of clouds on the windward side of the mountains. As the air containing clouds rises to the top of the range, the rate of cooling is reduced by the latent heat of condensation given to the air, so that the air temperature decreases on the average of 1.5° C. per 1,000 feet. Through the course of descent on the lee side of the range, warming (caused by compression) of the air takes place at the dry adiabatic lapse rate of 3° C. per 1,000 feet. Thus, during ascent the air gains heat and, having lost its moisture, arrives on the plains beyond the mountain as a dry, warm wind. For example, if a mass of air with a temperature of 68° F. and a relative humidity of 60 percent is lifted over a 10,000-foot mountain, it will arrive at the base on the lee side as a dry air mass with a temperature of approximately 86° F. The Foehn wind may greatly modify cold winter weather, and has an almost magical power to melt snow and ice.

4-30. Fall Winds (Katabatic Winds)

Not all descending air produces a wind that is warm. Where a very cold inland plateau is adjacent to a coastal region, the force of gravity may cause the dense air to drain for several days into the surrounding lower elevations. These gravity winds heat adiabatically as they descend but are still extremely cold. Such cold winds are called *fall winds* or *katabatic winds*. They are usually rather shallow, but wind velocities over 100 knots may occur. Two examples of a fall wind are the Bora of the Adriatic coast and the Mistral of the northwest coast of the Mediterranean Sea.

4-31. Tornado and Waterspout

a. Tornado. The tornado (fig. 4-39) is the most violent of all storms. It is a whirlpool of air ranging in diameter from 200 feet to 2 miles with an average diameter of 250 yards. It is generally associated with severe squall-line conditions (lines of thunderstorms) and is most frequently found in the southeastern quadrant of a well-developed cyclone and the northeastern quadrant of hurricanes. Within the tornado's funnel-shaped cloud, wind speeds are estimated to be from 100 to more than 400 knots, but the forward speed of the tornado averages only 40 knots. Not only is the tornado small in area, but usually it dissipates its energy in less than an hour; its average life is less than 15 minutes.

b. Waterspout. The waterspout is normally a tornado that occurs over the ocean. It contains much moisture; whereas, the continental tornado is laden with dust and debris from the land surface. Waterspouts are also associated with thunderstorm activity or extreme atmospheric instability. The waterspout in figure 4-40 is a rare phenomena composed of two funnels merged near the ocean.

Figure 4-39. Funnel of tornado.

Figure 4-40. Waterspout.

4-32. Eddy Winds

When air near the surface flows over obstructions such as irregular terrain and buildings, the normal horizontal airflow is disrupted and transformed into a complicated pattern of mechanical turbulence called *eddies* (air currents). The size of the eddies varies with the wind velocity, the roughness of the terrain, and the stability of the air.

a. With low wind speeds (less than 10 knots), small stationary eddies from 10 to 50 feet in depth are produced on both the windward and leeward sides of the obstructions. Wind speeds between 10 and 20 knots usually produce currents several hundred feet in depth. With stronger wind speeds (20 knots or greater), larger currents form, usually on the lee side of the obstructions. These larger currents may be carried by the wind for considerable distances beyond the obstruction.

b. The amount and extent of currents are affected by the roughness of the terrain. Over smooth water surfaces, only a few minor air currents form. In mountainous areas, even though the wind is light, many currents form. Large obstructions to airflow tend to produce more extensive air currents than small obstructions.

c. When the air is unstable, once currents are formed they continue to grow in height. Such currents may extend to altitudes above 10,000 feet and produce turbulent en route flight conditions.

d. The variation in wind speed and direction within the eddies frequently causes considerable difficulty for aviators landing or taking off in small aircraft. The aviator should anticipate eddy winds when operating on fields where large hangars or similar buildings are located near the runways.

e. A series of air currents (eddies) may also affect an aircraft taking off or landing in the wake of another aircraft.

CHAPTER 5

ATMOSPHERIC STABILITY AND INSTABILITY

Section I. ATMOSPHERIC STABILITY

5-1. General

To analyze the atmosphere from data gathered by upper-air soundings (par. 5-7), it is necessary to determinc the stability of the atmosphere. The temperature lapse rate determines the stability of the atmosphere. Atmospheric stability is comparable to mechanical stability which may be exemplified by using a ball, a round-bottomed bowl, and a table. The ball may be placed in three states of equilibrium —*absolutely stable, neutrally stable, and absolutely unstable.*

a. Absolute Stability. Set the bowl on the table in its normal position, and place the ball in the bowl (fig. 5-1). If the ball is forced to move by some outside influence which is later removed, the ball will, after a series of oscillations, return to its original position. If the ball resists displacement from its original position, it is in a state of absolute stability.

b. Neutral Stability. Place the ball on the table top (fig. 5-2). If the ball is forced to move by some outside influence, it will continue to move as long as that influence is present. When the influence is removed, the ball will come to rest. It has no tendency to continue moving away from its original position nor to return to its original position; it is in a state of neutral stability.

c. Absolute Instability. Invert the bowl on the table top, and balance the ball on the bottom of the inverted bowl (fig. 5-3). If the ball is released when it is in this position, it immediately begins moving away from its original position and does not return. This condition is absolute instability.

5-2. Types of Atmospheric Stability

As used in meteorology, *stability* is atmospheric resistance to vertical motion. For practical purposes, the atmosphere is always in one of three states of stability: it is either *absolutely stable, absolutely unstable,* or *conditionally unstable.*

a. Stable air is able to resist vertical motion. If it is lifted, it will return to its original level in the atmosphere when the lifting force is removed.

b. Unstable air is not able to resist vertical motion. Once a lifting action has set the air in motion, it tends to rise by itself.

c. Conditionally unstable air will act like stable air as long as it is not saturated. Once clouds begin to form, conditionally unstable air will act like unstable air.

Note. The state of neutral stability (par. 5-1*b*), where the air which is lifted will neither rise nor sink

Figure 5-1. Absolute stability.

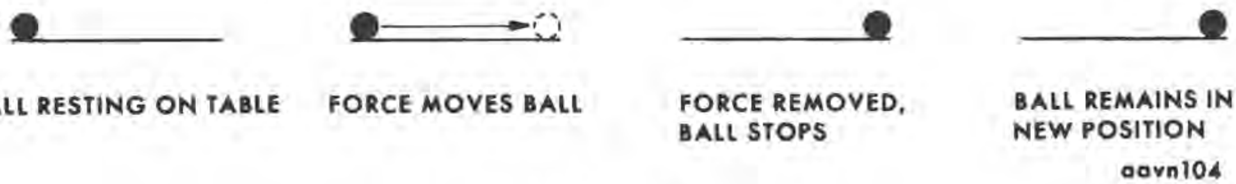


Figure 5–2. Neutral stability.

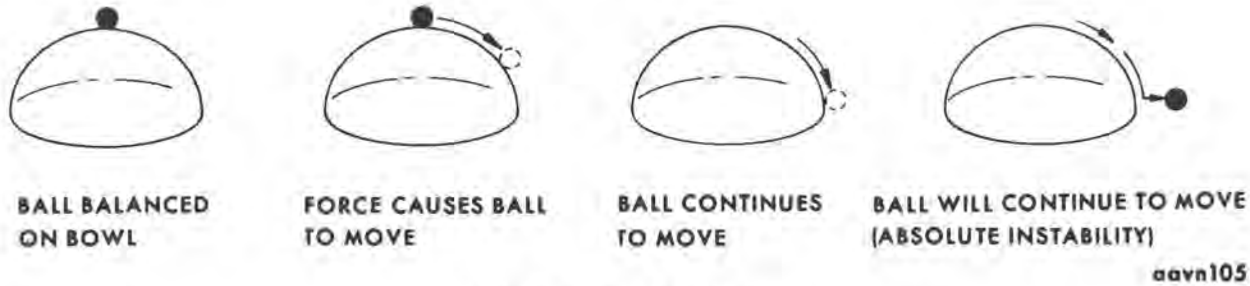


Figure 5–3. Absolute instability.

from the position to which it is lifted, is seldom significant in large areas of the atmosphere. Where it does occur, it is generally in a transitional state between stability and instability. When the temperature lapse rate is 3° C. per thousand feet, the air has a strong tendency to become unstable; but when the lapse rate is 1.5° C. per thousand feet, the air tends to become stable.

5–3. Lifting Processes

a. Atmospheric currents (turbulence) may be induced by any one of the following processes:

(1) *Thermal convection (par. 2–10c).* Air which is resting on the earth's surface may be set in motion by surface heating which is most noticeable during the afternoon. Vertical currents may also result when cool air moves over a warm surface and is heated by contact with the warm surface.

(2) *Mechanical convection (par. 2–10c).* Air may be lifted by one of two physical barriers:

(*a*) *Orographic lifting.* As air moves across the earth's surface, it is frequently forced to rise over hill or mountain barriers. Even mechanical turbulence caused by the passage of air at high speeds over rough terrain features such as buildings, ridges, gulleys, and similar obstructions may extend to altitudes of 10,000 to 14,000 feet in clear air.

(*b*) *Frontal lifting.* Where air mass boundaries (fronts) exist, the warmer air is forced to rise over the denser cold air mass.

(3) *Convergence.* Convergence is the inflow of air into an area. It may result from different wind velocities in relatively straight line flow or from the flow of wind across the isobars at the surface into regions of low barometric pressure. As the air rushes into the cyclonic center from all sides, it rises in great volumes to compensate for the convergent action (par. 4–10*d*).

b. Extent of Vertical Currents. Although the air may be forced to rise by any of the forms of lifting action, the stability of the atmosphere governs the height to which the air currents will continue to rise. If the air is stable, the vertical currents will stop a short distance above the upper limit of the lifting action. If the air is unstable, the currents will continue to rise as long as the atmospheric instability exists. These currents may continue up to the tropopause. If the air is conditionally unstable, clouds must form before the currents can continue to rise above the upper limit of the initiating lifting action.

5-4. The Adiabatic Process

As a parcel of air moves upward in the atmosphere, the pressure around the parcel decreases (par. 2-21*b*). The rising parcel of air expands as the pressure around it decreases. This expansion allows the air molecules to move farther apart than they were at the surface. They collide less frequently and produce less temperature. When air rises 1,000 feet in the atmosphere, the resultant expansion of the air causes the temperature of the air parcel to decrease 3° C. in unsaturated air and approximately 1.5° C. in saturated air. If air descends in the atmosphere, the pressure around it increases and it is compressed. When air expands, it cools; when compressed, it warms. Outside heat energy is neither supplied to nor withdrawn from the air during the expansion or compression. Such a change in temperature, produced solely by a change in pressure, is known as an *adiabatic process.* The constant rate of cooling and heating in the rising or descending parcel of air is known as the *adiabatic lapse rate.* Because air is such a poor conductor of heat, the parcel is thermally insulated as it rises or descends. Changes in adiabatic temperature are independent of those that occur in the atmospheric layer through which the air parcel is rising or descending.

a. The Dry Adiabatic Lapse Rate. As a parcel of unsaturated air moves away from the surface, the adiabatic process produces a temperature change (decrease) of 3° C. per thousand feet of rise. This is called the *dry adiabatic lapse rate* (DALR). *Dry,* in this case, does not mean that the air is free of water vapor; it means that no condensation is taking place. The adiabatic lapse rate is unaffected by water vapor in the air because all gases expand at the same rate as the pressure on them decreases.

b. The Moist Adiabatic Lapse Rate. As a parcel of air rises in the atmosphere and cools adiabatically, its ability to maintain moisture in the vapor state decreases. As the temperature lowers, relative humidity increases until the rising parcel of air becomes saturated. At this point, the water vapor begins to condense from gas to liquid (par. 2-11*b*). This change of state releases latent heat (par. 2-11*d*) to the rising parcel of air, so that two processes work simultaneously—(1) cooling from the expansion of the air, and (2) condensation which adds heat energy to the air parcel. The addition of heat reduces the rate of cooling and, as the air continues to rise, the resultant temperature decreases at the rate of approximately 1.5° C. per thousand feet. This new rate of cooling is called the *moist adiabatic lapse rate* (MALR). It is used for any rising parcel of air in which clouds are forming.

5-5. Stability and Temperature Lapse Rate

The stability of an atmospheric layer is governed by the temperature lapse rate within the layer. The *observed lapse rate* (OLR) is the temperature change with altitude which occurs in air that is not moving vertically. The OLR is usually measured with radiosonde equipment. Over the United States the average rate of temperature decrease with altitude is 2° C. per thousand feet. The actual change in temperature with altitude may vary from an inversion to a decrease of more than 3° C. per thousand feet. The relationship between stability and the temperature lapse rate is illustrated in figures 5-4 through 5-6.

a. Absolute Instability (fig. 5-4). Figure 5-4(A) shows a parcel of unsaturated air at the surface with a temperature of 15° C. The OLR is 4° C. per thousand feet, being 15° C. at the surface and 11° C. at 1,000 feet. If parcel *E* (approximately 1 cubic foot of air) is lifted by some force to an altitude of 1,000 feet, it will expand and cool adiabatically to a temperature of 12° C. at 1,000 feet ((B), fig. 5-4). The rising parcel of air *E′* is now warmer than its surroundings, and will continue to rise even though the original lifting force is removed. The air is not able to resist vertical motion but, once lifted, will continue to rise by itself—it is unstable. If the OLR is greater than 3° C. per thousand feet, air is absolutely unstable.

b. Absolute Stability (fig. 5-5). Figure 5-5(A) shows a parcel of unsaturated air at the surface with a temperature of 15° C. The OLR is 1° C. per thousand feet, being 15° C. at the surface and 14° C. at 1,000 feet. If parcel *F* is lifted by some force to an altitude of 1,000 feet, it will expand and cool adiabatically to a temperature of 12° C. at 1,000 feet

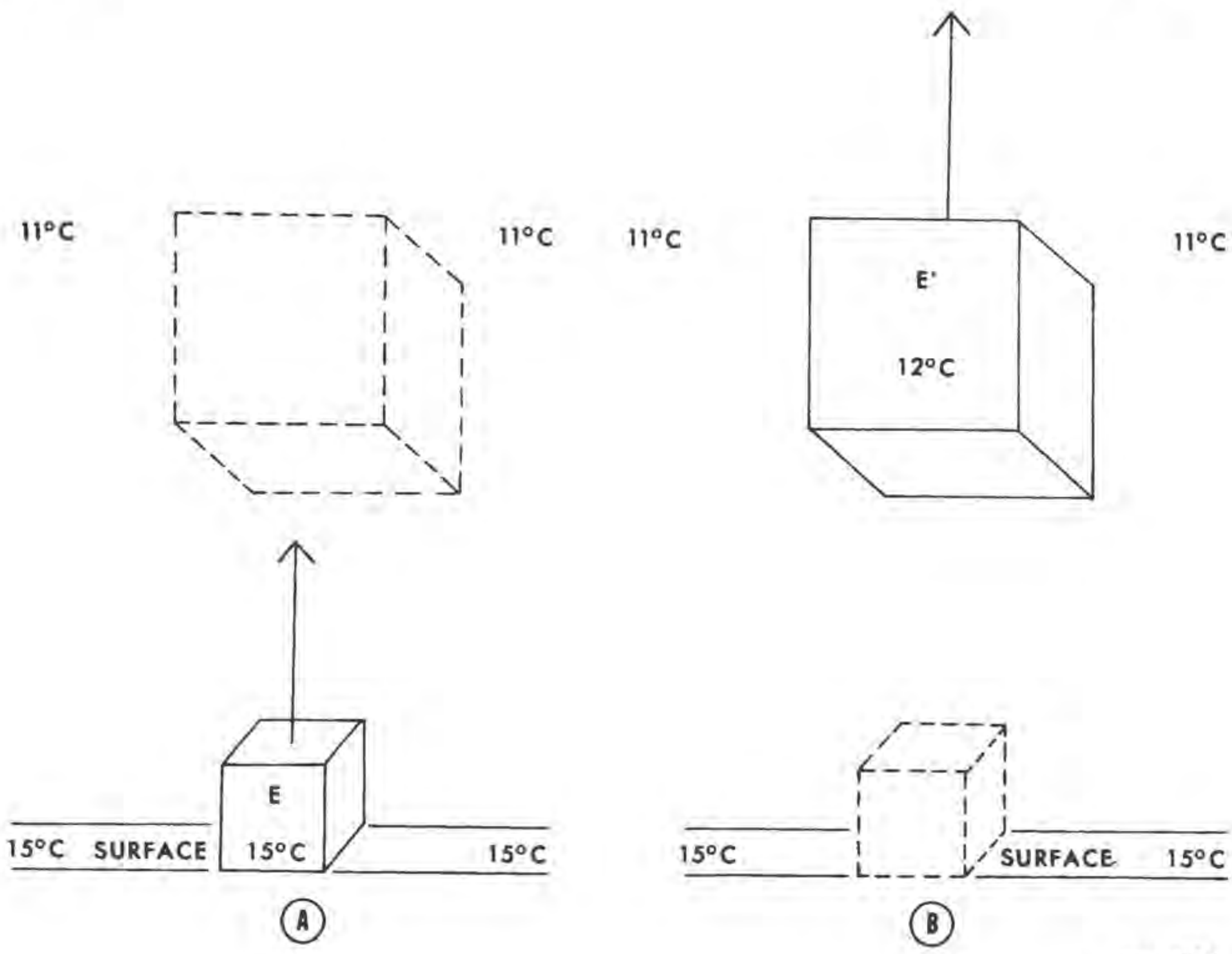


Figure 5-4. Absolute instability in the atmosphere.

((B), fig 5-5). The rising parcel of air *F'* is now colder and heavier than its surroundings. As soon as the lifting force is removed, parcel *F'* will sink back to its original level at the surface. The air resists vertical motion—it is stable. When the OLR is less than 1.5° C. per thousand feet, the air is absolutely stable.

c. Conditional Instability (fig. 5-6). Normally air has an OLR between 1.5° C. and 3° C. per thousand feet. This means that the air is neither absolutely stable nor absolutely unstable. If the OLR is between the moist and dry adiabatic lapse rates, the air is *conditionally unstable.* Figure 5-6(A) shows a parcel of unsaturated air *G* at 2,000 feet with a temperature of 11° C. The OLR is 2° C. per thousand feet, being 11° C. at 2,000 feet and 9° C. at 3,000 feet. If parcel *G* is lifted to an altitude of 3,000 feet, it will expand and cool adiabatically to a temperature of 8° C. ((B), fig. 5-6). The rising parcel of air *G'* is colder and heavier than its surroundings, and will return to 2,000 feet once the lifting force is removed. As long as the parcel of rising air remains unsaturated (no clouds forming), it acts like stable air and will tend to resist vertical displacement. However, if the air at 2,000 feet becomes saturated, clouds will form throughout the entire lifting process. The heat released from condensation will change the adiabatic rate of cooling from 3° C. to 1.5° C. per thousand feet ((C) and (D), fig. 5-6). With the same surface temperature and OLR as used in ((A) and (B), fig. 5-6), but with clouds forming, the air will no

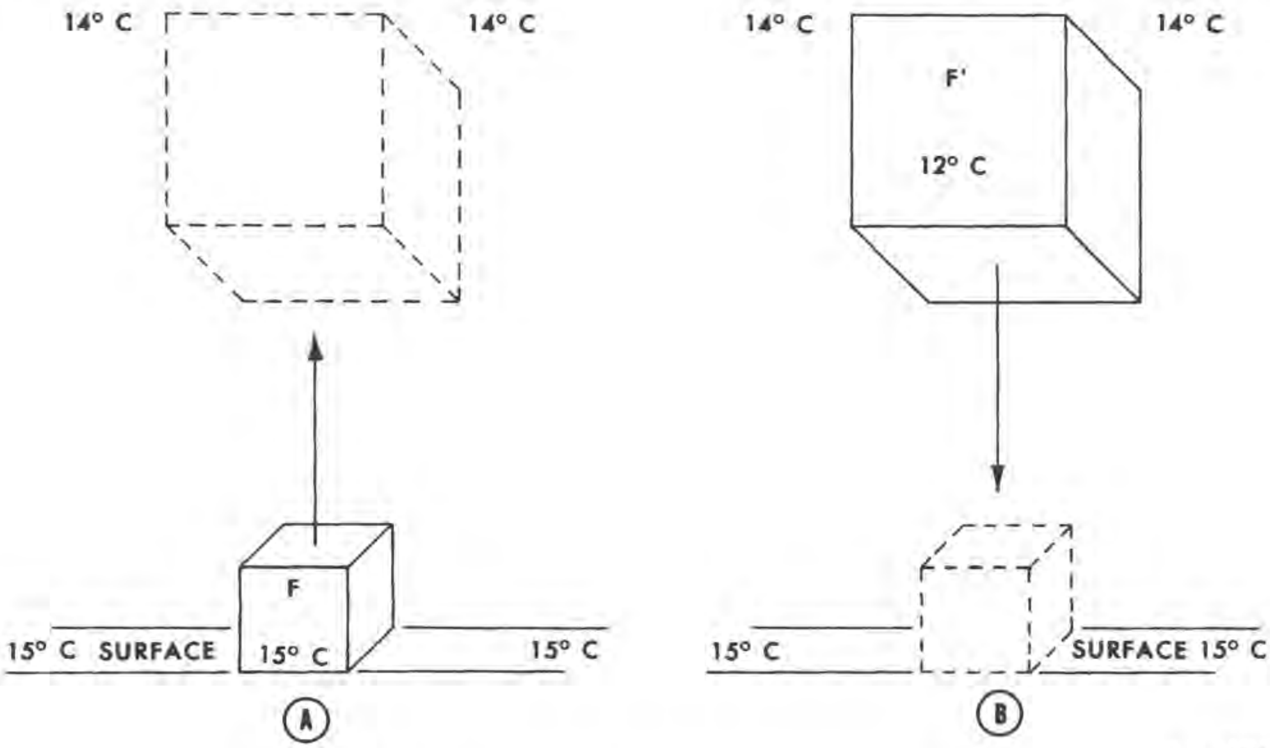


Figure 5–5. Absolute stability in the atmosphere.

longer have stable characteristics. If parcel *H* is lifted to 3,000 feet altitude ((D), fig. 5–6), it will expand and cool to 9.5° C. At the 3,000-foot altitude, parcel *H'* will have a temperature one-half a degree warmer than the surrounding air layer. Since parcel *H'* is warmer and lighter than its surroundings, it will continue to rise, and the cloud will continue to develop. The air will act like unstable air if it becomes saturated (if clouds form). This air is said to be conditionally unstable. Clouds forming in this type of air will be of the cumuliform type. Conditional instability is the most common state of stability in the atmosphere.

d. Lifting Condensation Level and the Level of Free Convection. The *lifting condensation level* is the altitude to which a parcel of air must be lifted for saturation to occur. This altitude is controlled by the temperature-dew point spread of the air at the surface. The *level of free convection* is the altitude to which air must be lifted by some outside force before it will continue to rise by itself. Figure 5–7 illustrates the lifting condensation level and level of free convection in a parcel of conditionally unstable air which is displaced 4,000 feet (vertically) by a mountain.

(1) At the surface, parcel *X* (fig. 5–7) has a temperature of 15° C. and a dew point of 12° C. As the air is lifted up the windward side of the mountain, it will expand and cool at the appropriate adiabatic rates (3° C. per thousand feet while unsaturated, 1.5° C. per thousand feet when saturated). At the 1,000-foot level the air will have cooled to its dew point temperature. Any further lifting beyond this altitude will produce clouds. Therefore, 1,000 feet is the lifting condensation level for parcel of air *X*. At this 1,000-foot level the parcel of air would act like stable air because it is colder than the surrounding air layer (13° C.).

(2) As the parcel is further lifted by the upslope flow over the mountain, its temperature gradually becomes the same as that of the surrounding air

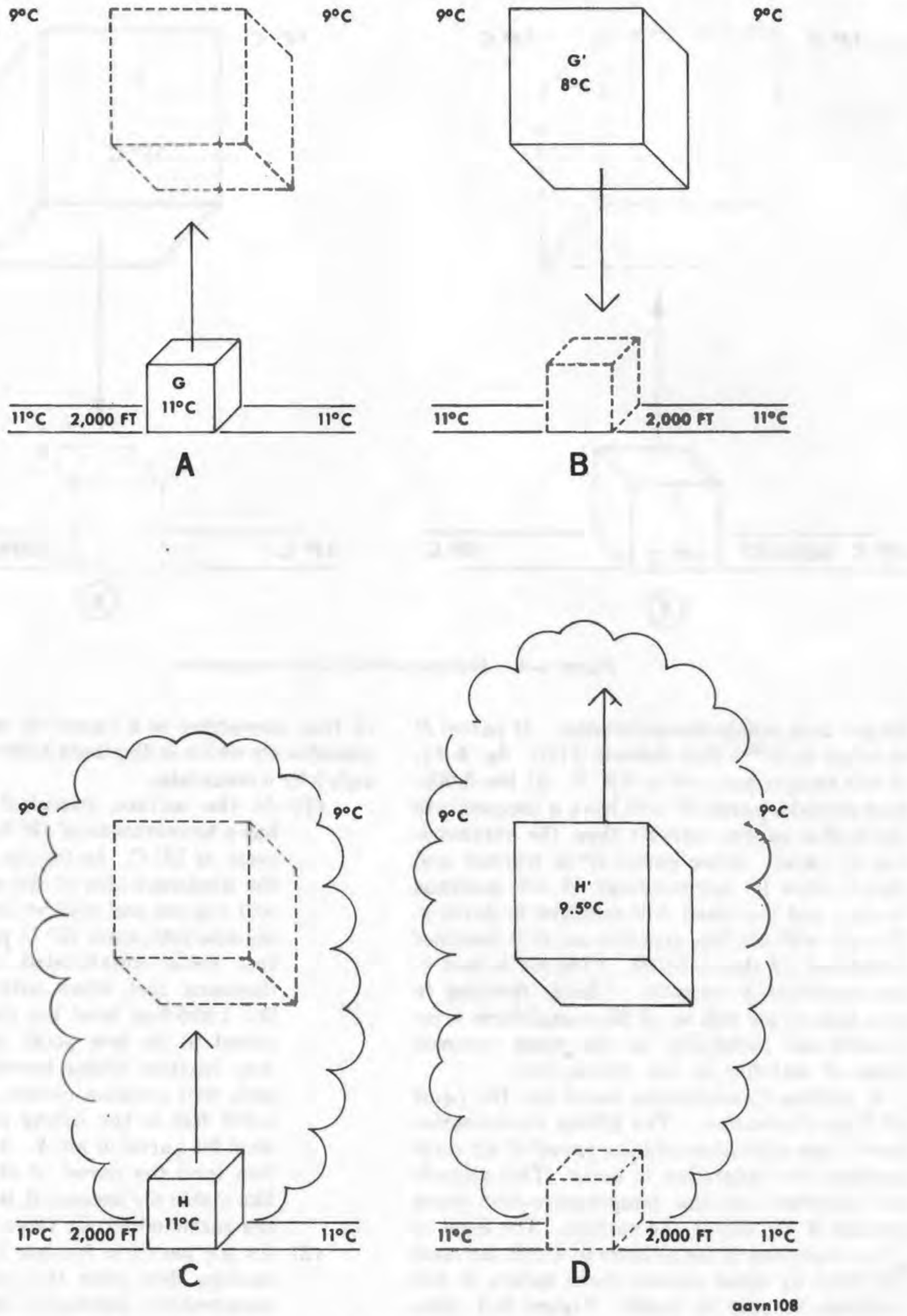


Figure 5-6. Conditional instability.

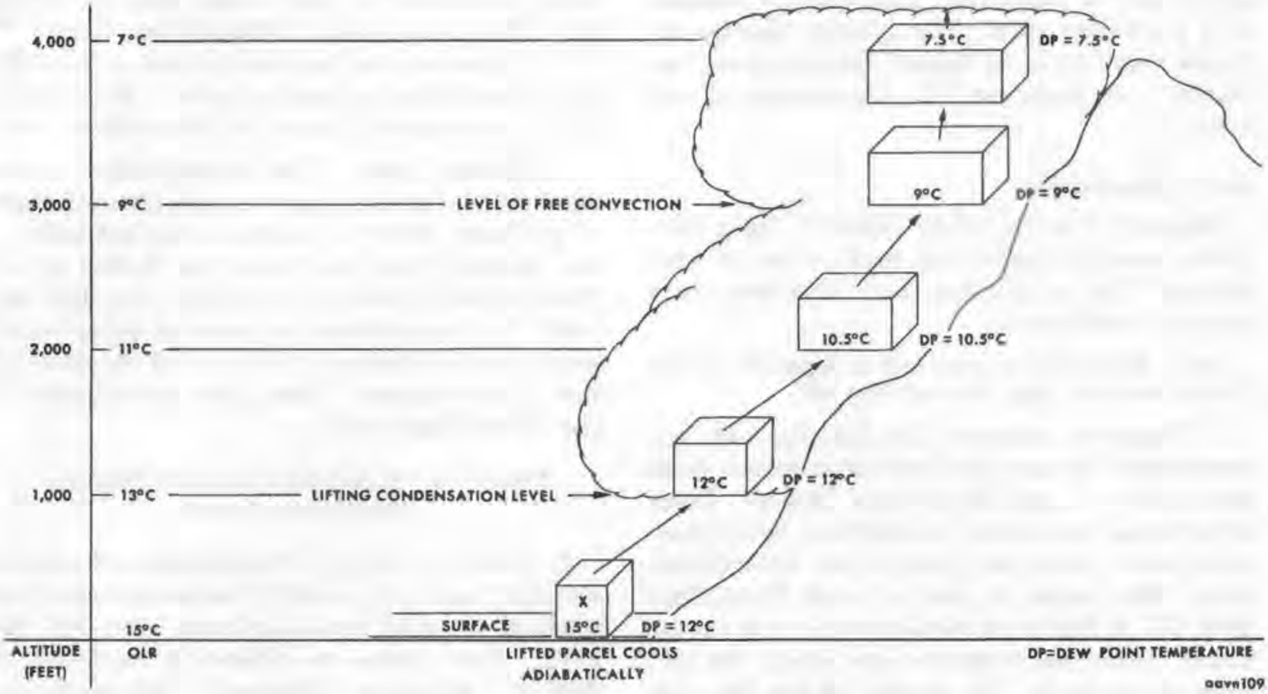


Figure 5-7. Conditionally unstable air being lifted.

layers. A state of equilibrium is reached at 3,000 feet. Any further lifting above 3,000 feet will cause the temperature of the lifted parcel to become warmer than the surrounding air. Therefore, 3,000 feet is the level of free convection in this parcel of air.

(3) By the time the air reaches the top of the mountain at 4,000 feet, the rising parcel is 0.5° C. warmer than the surrounding air layer, so it will continue to rise without further mechanical lifting. The air becomes unstable after it has been lifted beyond the level of free convection. The mass of air from which the parcel was displaced is conditionally unstable; the OLR is between the moist and dry adiabatic lapse rates. As clouds form in the displaced air (decreasing the water *vapor* content of the air), the dew point temperature decreases directly with the air temperature of the parcel.

5-6. Stability and Moisture Content

Warm air with a large amount of water vapor produces the most violent weather phenomena (hurricanes, thunderstorms, and tornadoes). As this air travels across the earth, sufficient lifting will release latent heat of condensation and produce unfavorable flying conditions. The temperature of the air, the degree of lifting, the observed lapse rate, and the moisture content determine the type and violence of the weather.

Section II. INTERPRETING THE ATMOSPHERIC SOUNDING DIAGRAM

5-7. The Radiosonde Observation

The atmospheric sounding diagram is a vertical-plot graph of pressure, temperature, and moisture data above a selected geographical location. The raw data is gathered by means of a radiosonde instrument carried aloft by balloon—pressure, temperature, and dew point are evaluated from the radiosonde transmissions. Transcribed to the atmospheric sounding diagram (Skew T, log p), the graphic picture represents the physical properties of the atmosphere over a particular geographical location at a particular time. The graphic display includes stability, cloud layers, freezing level, potential icing levels, and the temperature at any altitude.

5-8. Coordinates

Figure 5-8 is the USAF Skew T, log p Diagram inserted inside the back cover of this manual. Its coordinates and reference lines are explained below.

Note. Figure 5-8 is numbered as figure 86 on the foldout inside the back cover of this TM.

a. Pressure. Isobars (line AA, fig. 5-8) are represented by straight horizontal brown lines arranged on a logarithmic scale (log p). Pressure values are shown in brown at 50-millibar increments, from the 1,050- to the 100-millibar level. The height, in feet, of each 50-millibar level (U. S. Standard Atmosphere) is in parentheses under the pressure label along the left edge of the chart. The section of the diagram from 400 to 100 millibars can also be used for a range of 100 to 25 millibars by reference to the auxiliary pressure scale printed in brackets outside the left edge and inside the right edge of the chart.

b. Temperature. Isotherms (line BB,, fig. 5-8) are shown as straight brown lines sloping upward to the right (Skew T). Temperature is represented on a linear scale and the isotherms are equally spaced. They are labeled at 5° C. intervals in brown. Every other 10° C. increment is shaded green.

c. Dry Adiabats. The rate at which dry air cools or warms during adiabatic ascent or descent is depicted by curved brown lines, concave at the top, and sloping upward to the left (line CC, fig. 5-8). These lines cross the 1,000-millibar isobar at each 2° C. and are labeled at 10° C. intervals in brown within the chart, on the right and left edge, and on the top. The figures in parentheses are dry adiabatic values for using the chart between the altitudes of 100 to 25 millibars.

d. Moist Adiabats. Representations of the rate at which saturated air cools during ascent are called *moist adiabats.* These curved green lines (line DD, fig. 5-8) slope upward to the left. They cross the 1,000-millibar isobar at 2° C. intervals and are labeled along the 530- and 200-millibar isobars in green. Moist adiabats do not extend above the 200-millibar level.

e. Mixing Ratio. The mixing ratio is defined as the mass of water vapor per unit mass of perfectly dry air. Lines of constant saturation mixing ratio are shown as dashed green lines sloping upward to the right (line EE, fig. 5-8). They are labeled in grams of water vapor per thousand grams of dry air, at the base of the chart in green. These lines extend only to the 200-millibar level.

Figure 5-8. Atmospheric Sounding Diagram.
(Located in back of manual)

f. Thickness Scale. The thickness of several standard layers is shown by horizontal scales in black at the middle of each layer (line FF, fig. 5-8). These scales are labeled in hundreds of feet (i.e., 90 means 9,000 feet). Tick marks indicate increments of 10 feet.

Scales are included for the following layers:

Thickness layer (in millibars)	*Millibar level at which scale is printed*
1,000-700	838
1,000-500	708
700-500	592
500-300	388
300-200	245
200-150	172
150-100	122
100-50	71
50-25	33

g. Temperature-Pressure-Height Nomogram. To find the height of the 1,000-millibar level, a nomogram is printed in black with a pressure-height scale along the left edge and a temperature scale along the upper edge.

h. Standard Atmosphere Scale and Curve. An International Civil Aviation Organization (ICAO) standard atmosphere height scale, printed in black, is located along the right edge of the diagram. The height in kilometers is printed on the left side of the line and in thousands of feet on the right side.

i. Free Air Temperature Curve. The free air temperature curve of the ICAO standard atmosphere is represented by a heavy brown line curving from 17° C. at the 1,050-millibar level to −55° C. at the 233-millibar level. From the 233-millibar level, the curve parallels the −55° C. isotherm to the top of the chart (line CG, fig. 5–8, parallels a portion of the ICAO standard atmosphere line).

j. Wind Plotting Staffs. Just to the left of the standard atmosphere height scale, three vertical black lines are printed, with circles at the 1,000-, 850-, 700-, 500-, 400-, 300-, 250-, 200-, 150-, and 100-millibar levels. A dot is printed at the standard wind-reporting levels. These points are used for plotting wind velocities on the chart.

k. Fahrenheit Temperature Scale. Across the base of the chart, a horizontal line, graduated in degrees Fahrenheit, may be used for conversion of centigrade temperatures. The centigrade isotherm may be projected by placing a straightedge along the isotherm to intersect the Fahrenheit scale.

5–9. Analysis of Atmospheric Sounding for Aviators

a. Observed Temperature Lapse Rate. The observed temperature lapse rate, also referred to as the temperature *lapse curve* or *sounding curve*, represents the actual temperature lapse rate in the atmosphere, as determined from the radiosonde. The aviator can obtain the temperature for any desired flight level from the temperature lapse rate and altitude scale by (1) referring to the desired height on the altitude scale, (2) locating a point on the temperature sounding horizontal to the altitude, and (3) reading the temperature ordinates (isotherms). The temperature sounding curve is indicated by an unlettered solid black line (fig. 5–8).

b. Observed Dew Point Temperature Lapse Rate. The dew point temperature lapse rate, indicated by an unlettered black broken line (fig. 5–8) is determined from the radiosonde observation and is used in determining the moisture content for any desired level in the atmosphere. It is also used for determining cloud bases, cloud tops, cloud types, icing conditions, the type of potential icing, and the stability of the atmosphere.

c. Absolutely Stable Air. The observed lapse rate (line AB, fig. 5–9) shows a temperature of 14° C. at the 963-millibar level and −2° C. at the 525-millibar level. The difference in temperature between the two levels is 16° C. If unsaturated air having a temperature of 14° C. is lifted from the 965-millibar level, it will not cool according to this line, but according to the dry adiabatic rate. It will follow the dry adiabat until it becomes saturated (line AA_1, fig. 5–9). The saturated air at point A_1 then follows the moist adiabat to the 525-millibar level (A_2). By the time the air reaches the 525-millibar level, it will have cooled from 14° C. to a temperature of −22° C., and will be much cooler than the layer of air through which it is rising. Since it is cooler than the surrounding air, it will be heavier and will return to its former position when the lifting force is removed. This air is absolutely stable.

d. Absolutely Unstable Air. Line CD (fig. 5–9) indicates a temperature of 12° C. at the 960-millibar level and a −11° C. temperature at the 790-millibar level. The temperature difference between the two altitudes is 23° C. If a parcel of air is lifted between these two isobars, it will follow the dry adiabat until it reaches saturation (line C_1). From that point it will follow the moist adiabat. During this ascent (from C to C_2), the parcel will cool only 15° C. and will be warmer than the surrounding air; it will continue to rise. The air is absolutely unstable.

e. Conditional Instability. The difference in temperature represented by line EF (fig. 5–9), between points E and F, is 20° C. If a parcel of air is lifted from point E, it will follow the dry adiabat until it becomes saturated (point E_1). The air will then follow the moist adiabat. The lifted parcel will remain cooler than its surroundings, acting like stable air until it reaches point E_2. After passing E_2, the rising parcel will be warmer than the surrounding air and will become unstable. This air is conditionally unstable: it had to be lifted above the condensation level before it would continue to rise by itself.

f. Quick Analysis of Stability on the Atmospheric Sounding Diagram. When the slope of the sounding curve is to the right of the moist adiabat ((A), fig. 5–10), the air is absolutely stable. When the slope of the sounding curve

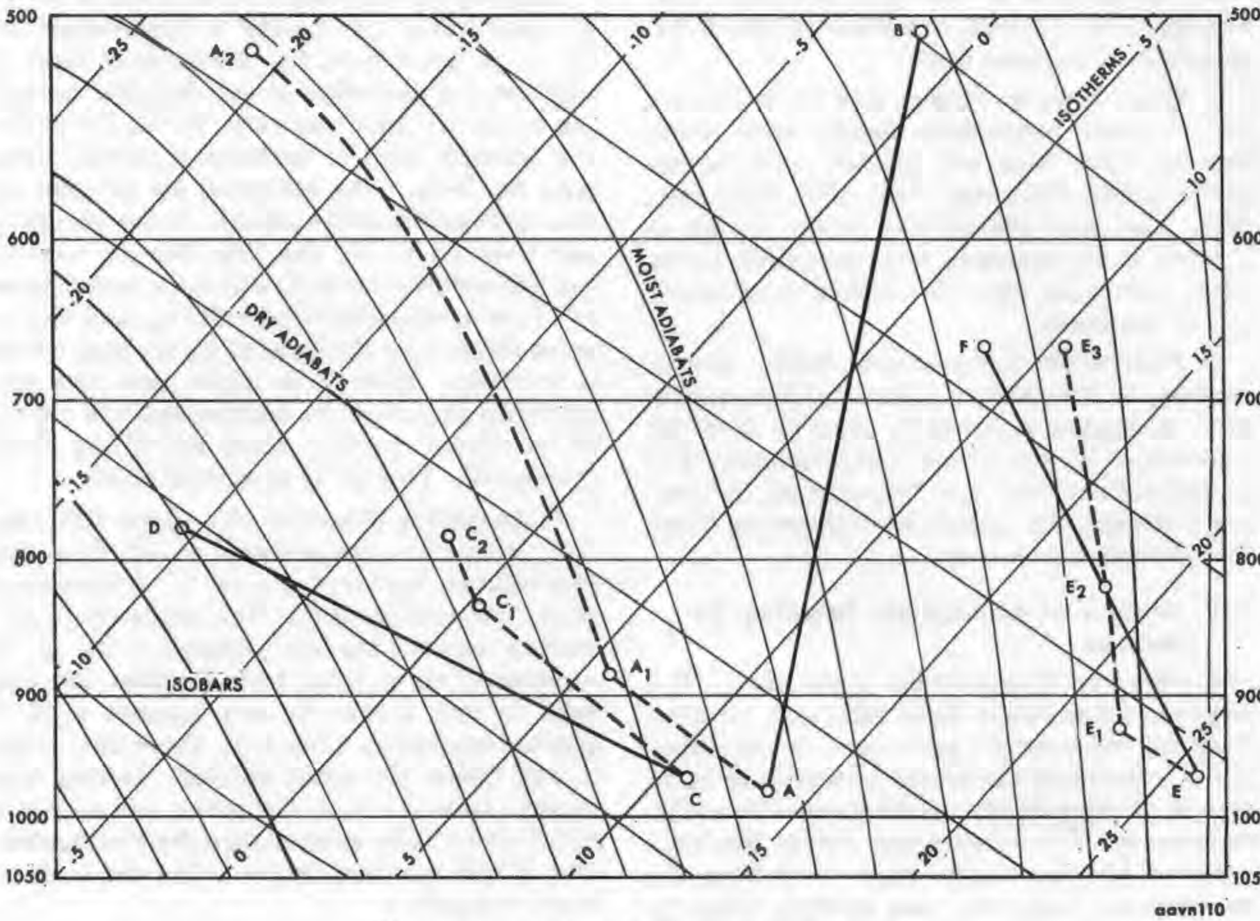


Figure 5–9. Analysis of atmospheric stability.

is to the left of the dry adiabat ((B), fig. 5–10), the air is absolutely unstable. When the slope of the sounding curve is between the moist and the dry adiabats ((C), fig. 5–10), the air is conditionally unstable. This same method can be used for determining stability on the USAF Skew T, log p diagram (fig. 5–8): the layer from the surface to the 900-millibar level is conditionally unstable, the layer from the 900-millibar level to the 800-millibar level is stable, and the layer from the 800-millibar level to the 715-millibar level is stable.

g. Cloud Levels.

(1) A radiosonde sounding for temperature and dew point is plotted on the atmospheric sounding diagram (fig. 5–8). Some selected approximate temperatures and dew point temperatures, from the sounding, are indicated below.

Millibar levels	*°C. Free air temperature (solid black line)*	*°C. Dew point temperature (dashed black line)*
975	5.0	1.0
900	−1.0	−2.5
800	−6.0	−6.5
780	−3.5	−3.5
715	+1.5	−4.0
600	−7.5	−12.5
520	−17.5	−20.5
450	−27.5	−28.5
400	−33.5	−34.5

(2) Clouds should be assumed to be present when the temperature-dew point spread is 2° C. or less (fig. 5–8),

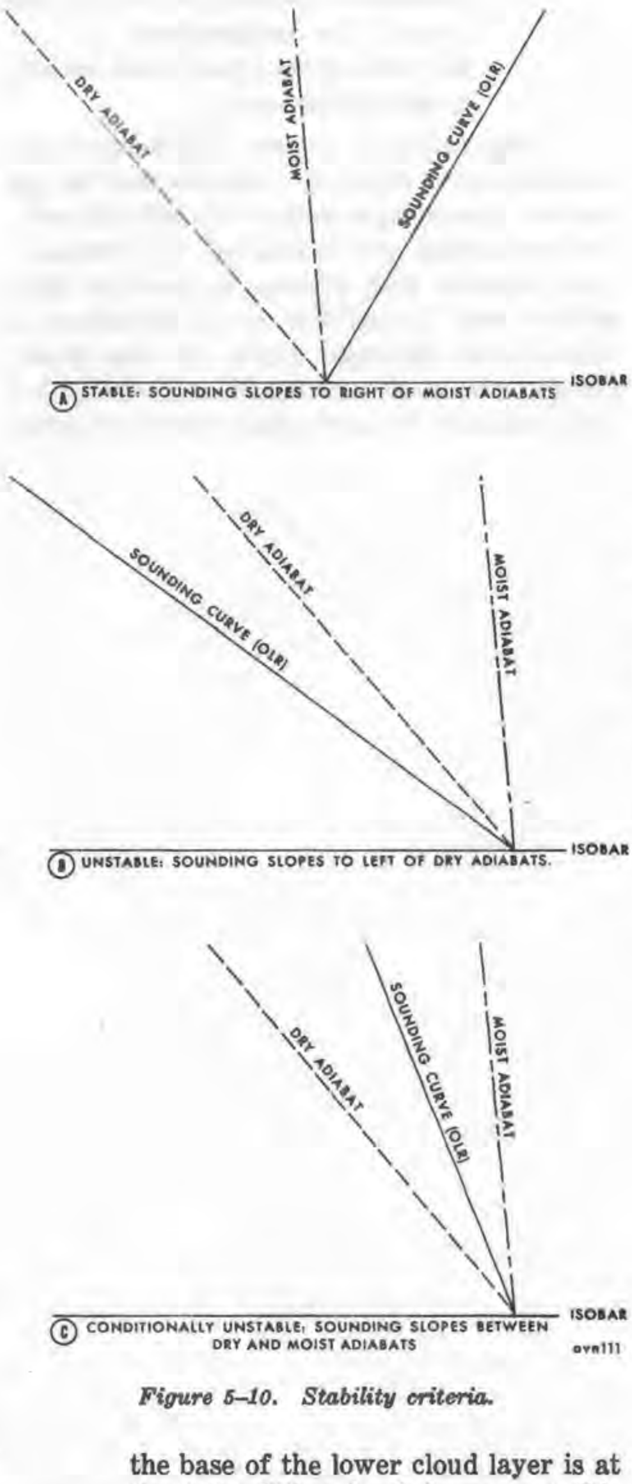


Figure 5-10. Stability criteria.

the base of the lower cloud layer is at the 910-millibar level, because at this point the temperature and the dew point are within 2° C. of each other. The top of the cloud layer is at the 755-millibar level, because this is the first point at which the temperature and dew point curve are more than 2° C. apart.

(3) Further analysis of the chart shows that between the 755-millibar and the 470-millibar level, the spread between free air temperature and dew point temperature is more than 2° C.—there are no clouds between these levels.

(4) At the 470-millibar level, the temperature and dew point again come within 2° C. of each other and clouds will exist at that altitude. These clouds extend up to the 400-millibar level.

h. Cloud Types. The general type of clouds can be determined by knowing the stability of the air at the level where clouds exist. Stratiform clouds are associated with stable air, and cumuliform clouds with unstable air. After determining the stability and referring the height of the base of the cloud to the altitude scale, the cloud can be placed in its general classification (high, middle, or low) and the type can then be determined (cumuliform or stratiform). The clouds represented in figure 5-8 are stratus (low layer) and cirrostratus (high layer).

i. Icing. (See also *Icing*, ch. 9.)

(1) *General.* Clear ice will form on the structure of an aircraft when clouds are present, the air temperature lies between 0° C. and —10° C., and the air is unstable. Rime ice will form in unstable cloud layers at temperatures between —10° C. and —20° C. because most of the larger water droplets will have been replaced by ice crystals. If an air layer is stable, rime ice will form in visible moisture at temperatures between 0° C. and —20° C.

(2) *Freezing and icing levels.*

(*a*) The free air temperature line (fig. 5-8) crosses the 0° C. temperature ordinate at approximately the 910-millibar level (the freezing level) and does not recross the 0° C. temperature ordinate until it reaches the 735-millibar level. Since visible moisture and freezing temperatures exist in this area, and the air is stable, rime ice will form on the structure of an aircraft passing through it.

(*b*) From the 735-millibar to the 690-millibar level temperatures are above freezing, but above the 690-millibar level temperatures are below freezing. Because no visible moisture is present within the layer, between 690 millibars and 470 millibars, no structural icing will form.

(*c*) Above the 470-millibar level, visible moisture is present, but due to extremely low temperatures it is in the form of ice crystals and serious icing will not occur.

j. Temperature Inversion. The temperature sounding curve (fig. 5–8) indicates that the air becomes increasingly colder with altitude until the 800-millibar level is reached. The temperature increases with altitude between the 800-millibar and 715-millibar levels; therefore, a temperature inversion exists in this layer. Clouds, haze, dust, and smoke layers often restrict visibility beneath such inversion layers.

CHAPTER 6

AIR MASSES

Section I. GENERAL

6–1. General

An *air mass* is a large body of air whose physical properties (mainly temperature and humidity) are relatively uniform horizontally. The various types of air masses are identified by the geographical area where they form. A periodic interchange between warm air masses and cold air masses characterizes the weather of the Temperate Zones. Warm air masses predominate in the summer and cold air masses in the winter, although either may exist almost anywhere in the Temperate Zone at any season.

Note. Wherever weather occurs, it is generally within an air mass or along the boundaries (fronts) between air masses (ch. 7).

6–2. Factors Which Determine the Characteristics of An Air Mass

The *characteristics* of an air mass include the stability, cloud types, sky coverage, visibility, precipitation, icing, and turbulence in addition to the basic properties of humidity and temperature. The terrain surface underlying the air mass is the primary factor in determining air mass characteristics.

a. The characteristics of an air mass are acquired in the source region. The *source region* is the surface area over which an 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.

b. Two secondary factors affecting air mass characteristics are—

(1) *The air mass trajectory.* The path over which an air mass travels after expanding and leaving the source region is called the *air mass trajectory.* Over a period of time, the trajectories of each specific air mass form a general pattern. Air masses often move over several different types of surfaces (mountains, plains, plateaus, barren land, water, snow-covered areas, etc.) along their trajectories, and each surface affects the moving air mass.

(2) *The age of the air mass.* The length of time the air mass has been away from the source region is called the *age* of the air mass. As an air mass moves along its trajectory, its characteristics are changed by the underlying surface; the air mass is *modifying.* The extent of modification depends upon (a) the temperature and moisture contrast between the air and the surface, (b) the terrain features, and (c) the time the air mass has been away from the source region. An "old" air mass may be modified to such an extent that its original characteristics disappear and the weather within the air mass completely changes.

6–3. Air Mass Classification

The standard classification of air masses and the nomenclature used to identify each air mass describes both the geographic and thermodynamic aspects of the air mass.

a. The geographic classification identifies the source region (temperature and moisture).

(1) *Temperature.* The latitude of the source region determines the relative air mass temperature. Therefore, capital-letter abbreviations which identify the latitude of the source region are used to indicate the air mass temperature; i.e., A—Arctic, P—Polar,

T—Tropical, and E—Equatorial. The two indicators most commonly used in Temperate Zone weather analysis are P—Polar and T—Tropical.

(2) *Moisture.* The relative moisture content is indicated by a small-letter abbreviation for the type of surface (land or water) over which the air mass originates. A land-source air mass is designated by the small letter "c" to indicate a continental air mass; a water-source air mass is designated by the small letter "m" to indicate a maritime air mass. These small-letter moisture designators precede the capital-letter temperature designators. For example, *mP* indicates a maritime polar or moist cold air mass; *cP* indicates a continental polar or dry cold air mass.

Note. Maritime air has a much higher moisture content than continental air; thus, precipitation and cloudiness will be more abundant in maritime than in continental air masses.

b. The thermodynamic classification indicates stability or instability. When the air is warmer than the surface over which it is moving, it is cooled by contact with the cold ground and becomes more stable; when the air mass is colder than the surface over which it is moving, it is heated from below and convective currents and instability result. A small letter "w" indicates that the air is warmer than the surface over which it is flowing and is, therefore, stable. A small letter "k" indicates that the air is colder than the surface over which it is flowing and is, therefore, unstable.

6-4. Air Mass Designation

The following designators identify air masses that frequently affect the northern Temperate Zone:

mPk (maritime polar cold) has its source region over an ocean north of 40° north latitude and is colder than the surface over which it is traveling.

mPw (maritime polar warm) has its source region over oceans north of 40° north latitude and is warmer than the surface over which it is traveling.

mTw (maritime tropical warm) has its source region over oceans between 10° and 30° north latitude and is warmer than the surface over which it is traveling.

mTk (maritime tropical cold) has its source region over oceans between 10° and 30° north latitude and is colder than the surface over which it is traveling.

cPk (continental polar cold) has its source region over land areas generally between 40° and 60° north latitude and is colder than the surface over which it is traveling.

cT (continental tropical) has its source region over a land area south of about 30° north latitude.

6-5. General Characteristics of Air Masses

The following weather conditions are typical of the air masses with which they are identified. Knowledge of these weather characteristics will aid an aviator in predicting, with considerable accuracy, the flying conditions likely to be found within any given air mass.

a. Cold (k type) Maritime Air Mass. General characteristics of a cold maritime air mass are—

(1) Cumulus- and cumulonimbus-type clouds.

(2) Generally good ceilings (except within precipitation areas).

(3) Excellent visibility (except within precipitation areas).

(4) Pronounced air instability (turbulence) in lower levels due to convective currents.

(5) Occasional local thunderstorms, heavy showers, hail, or snow flurries.

b. Warm (w type) Maritime Air Mass. General characteristics of a warm maritime air mass are—

(1) Stratus- and stratocumulus-type clouds and/or fog.

(2) Low ceilings (often below 1,000 feet).

(3) Poor visibility (since haze, smoke, and dust are held in lower levels).

(4) Smooth, stable air with little or no turbulence.

(5) Occasional light continuous drizzle or rain.

c. Continental Air Mass. Continental air masses are associated with good flying weather; i.e., clear skies or scattered high-based cumuliform clouds, unlimited ceilings and visibilities, and little or no precipitation. However, two exceptions are—

(1) Intense surface heating by day may produce strong convection (turbulence) with associated gusts and blowing dust or sand (par. 6–11).

(2) Movement of cold dry air over warm moist water surfaces may produce dense steam fog and/or low overcast skies with drizzle or snow. If the air continues its movement into mountainous terrain, heavy turbulence, icing, and showers may develop (par. 6–9*a*).

6–6. Source Regions and Trajectories

a. Source Regions. To understand the behavior of the weather within the various air masses, it is necessary to know the general characteristics of their source regions. The source regions of air masses in the Northern Hemisphere and their general characteristics are as follows:

(1) *Arctic air mass source region.* In the general circulation pattern, there is a permanent high pressure system surrounding the geographical pole. Within the high pressure area the air moves slowly around the arctic ice cap, forming an arctic air mass. Characteristically, arctic air in the source region is dry aloft and very cold and stable in the lower levels. (See also sec. I, app. III.)

(2) *Continental polar source region.* Polar air is not as cold as arctic air. The continental polar source regions consist of all the land areas dominated by the Canadian and Siberian high pressure cells. In the winter, these regions (generally between latitudes 45° north and 65° north) are completely covered with a layer of snow and ice. Even in the summer, much of the ice remains and the areas are still relatively cold. Because of the intense cold and the absence of water bodies, very little moisture evaporates into the air.

Note. The word *polar,* when applied to air mass designation, does *not* mean air around the poles. Air masses in the immediate polar region are designated as *arctic.*

(3) *Maritime polar source region.* The maritime polar source region consists of the open unfrozen polar sea region in the Atlantic and Pacific oceans. These water surfaces are a source of considerable moisture for polar air masses. Air masses forming over this polar sea region are moist in the lower layers, but the vapor content is limited by the cool air temperature.

(4) *Continental tropical source region.* A continental tropical source region can be any significant land area in the tropical regions, generally between latitudes 10° and 30° north and south. The large land masses in the tropical region are usually desert areas, such as the Sahara or Kalahari of Africa, the Arabian Desert, and the entire region of inland Australia. The air lying over these regions is hot, dry, and unstable.

(5) *Maritime tropical source region.* The maritime tropical source region is that vast zone of open tropical sea along the belt of subtropical anticyclones north of the Equator (Pacific and Bermuda highs). Semipermanent high pressure cells stagnate over the northern edge of the tropical source regions throughout most of the year. The air temperature is warm in these low latitudes, and the water vapor content of the air is very high.

(6) *Equatorial source region.* The equatorial source region is located in the vicinity of the thermal Equator (doldrums) from about 10° north latitude to 10° south latitude. It is essentially an oceanic belt, very warm, and very high in moisture content. Convergence of the trade winds from both hemispheres and intense insolation over this region cause voluminous lifting of the moist, unstable air to high levels. The weather is characterized by

considerable thunderstorm activity throughout the year.

b. Trajectories. As an air mass leaves its source region, it is modified by the different types of surfaces over which it moves, and by the nature and methods of heat transfer (par. 2-10) taking place within the air mass. For example—

(1) Cold dry air moving over a surface that is warm and moist will soon become warm and moist in the surface layer. The air mass is classified as *cP*, even though the surface layer has been modified by the trajectory over warm water. The upper air still retains its cold dry characteristics. However, when an air mass moves into a different source region, such as a *cP* air mass from Canada moving into an *mP* source region in the North Atlantic, the modification over several days may affect the mass to the extent that it can be reclassified from *cP* to *mP*.

(2) Warm moist air moving over hot dry continental areas will lose some of its moisture each day as surface heating causes clouds to form and precipitation to occur. The longer the air mass is out of its source region, the less it will have of its source region characteristics. An "old" air mass tends to take on the characteristics of the surface over which it is moving.

Section II. AIR MASSES AFFECTING THE UNITED STATES

6-7. General

The basic considerations in air mass analysis (sec. I) are applicable to a study of air mass weather throughout the world. However, local variables, such as the distribution and orientation of mountain ranges, the flow and temperature of ocean currents, prevailing pressure patterns, and the distribution of land and water surfaces, are too numerous to allow a detailed worldwide air mass analysis in the scope and space of this manual. These world air mass characteristics are discussed briefly and generally in appendix III. This section presents a more detailed analysis of the air masses affecting the weather of the continental United States (figs. 6-1 and 6-2).

6-8. Maritime Polar Air Masses

Maritime polar air masses which invade the United States arrive from two different source regions. One of these source regions is located in the North Pacific Ocean; the other in the northwestern portion of the North Atlantic Ocean. Those air masses originating over the Pacific Ocean dominate the weather conditions of the Pacific coast of the United States and western Canada. Those air masses originating over the North Atlantic Ocean frequently appear during the winter over the northeastern coast of the United States.

a. Winter.

(1) *Pacific coast.* Many of the maritime polar air masses which invade the Pacific coast originate in the interior of Siberia (par. 6-6*b*(1)). They have a long overwater trajectory and, during their trajectory over the Pacific Ocean, are unstable in the lower layers (fig. 6-3). As they invade the west coast, they are cooled from below by a cool ocean current and coastal area and become more stable. Along the Pacific coastal regions, stratus and stratocumulus clouds are common in these air masses. Maritime polar air masses cause heavy cumuliform cloud formation and extensive shower activity as they move eastward up the slopes of the mountains. East of the mountains, the air descends and is warmed adiabatically. This adiabatic warming results in decreased relative humidity, and the skies are generally clear (fig. 6-4).

(2) *Northeast section of United States.* In the northeastern section of the United States, maritime polar air moves into

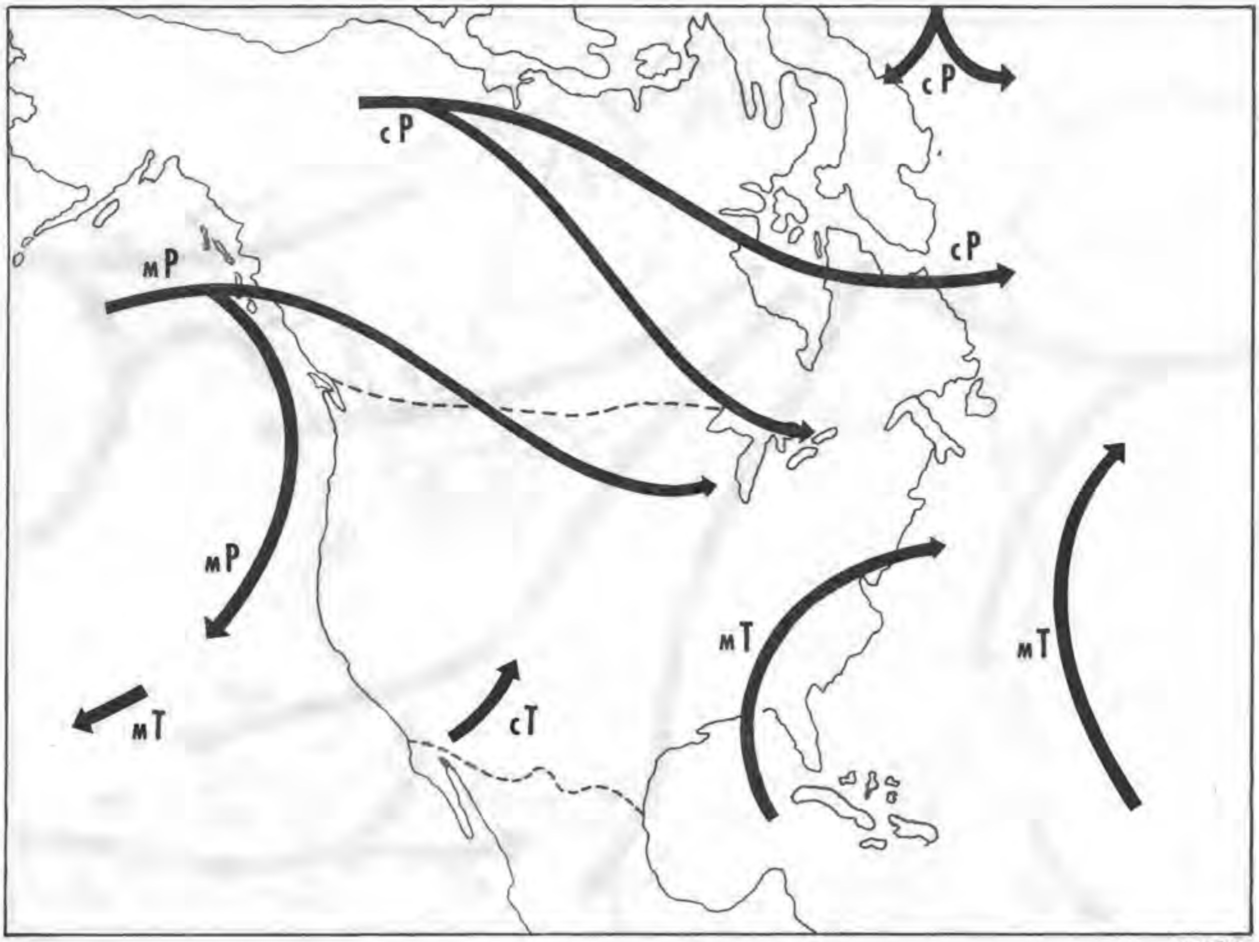


Figure 6–1. Air mass source regions and trajectories (July).

the New England States from the northeast. These air masses are usually colder and more stable than those entering the west coast from a northwest direction. Low stratiform clouds with light continuous precipitation and generally strong winds occur as these air masses move inland.

b. Summer. Since water temperatures are cooler than adjacent land temperatures in the summer, maritime polar air masses entering the Pacific coast become unstable because of the surface heating. In the afternoon, cumuliform cloud formations and widely scattered showers occur. At night, fog and low stratiform clouds are common on the coastal regions, especially along the coast of California. When the air masses cross the mountains, they lose a considerable amount of moisture on the western mountain slopes. The orographic lifting intensifies the development of cumuliform clouds on the windward slopes. These cloud buildups are accompanied by heavy showers with low ceilings and visibilities.

6–9. Continental Polar Air Masses

a. Winter. Continental polar air masses that invade the United States during winter originate over Canada and Alaska. They are stable in the source regions. As the air masses move southward into the United States, they are heated by the underlying surface. During daylight hours, the air is generally unstable near the surface and the sky is usually clear. At night, the air tends to become more stable. When these cold dry air masses move over the

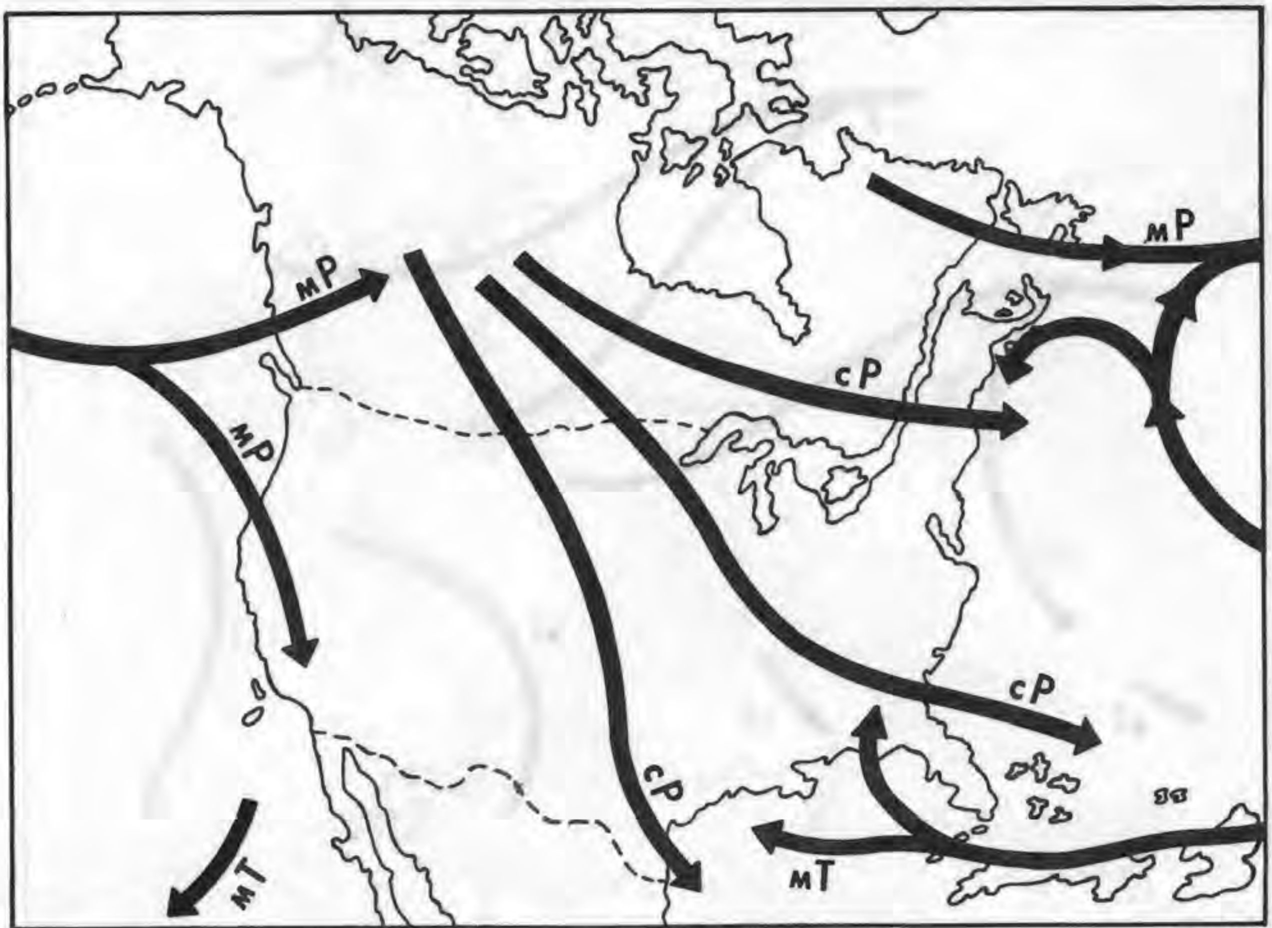


Figure 6-2. Air mass source regions and trajectories (January.)

warmer waters of the Great Lakes, they acquire heat and moisture and become unstable in the lower levels (fig. 6-5) ; cumuliform clouds form and produce snow flurries over the Great Lakes and on the leeward side of the Lakes. As the air masses move southeastward, the cumuliform clouds intensify along the Appalachian Mountains. Continental polar air masses between the Great Lakes and the peaks of the Appalachians contain some of the most unfavorable flying conditions (icing, turbulence, and below-minimum ceilings and visibilities) in the United States during the winter months. Clear skies or scattered clouds are normal east of the mountains.

b. Summer. Cold dry air masses have different characteristics and properties in the summer than in the winter. Since the thawed-out source regions are warmer and contain more moisture, the air is less stable in the surface layers. The air is therefore cool and contains slightly more moisture when it reaches the United States. Scattered cumuliform clouds form during the day in this unstable air, but dissipate at night when the air becomes more stable. When these air masses move over the colder water of the Great Lakes in the summer, they are cooled from below and become stable, resulting in good flying conditions.

6-10. Maritime Tropical Air Masses

Maritime tropical air masses originate over the Atlantic Ocean, the Gulf of Mexico, and the Caribbean Sea. They move into the United States from the Gulf of Mexico or Atlantic Ocean and are common along the Southeastern

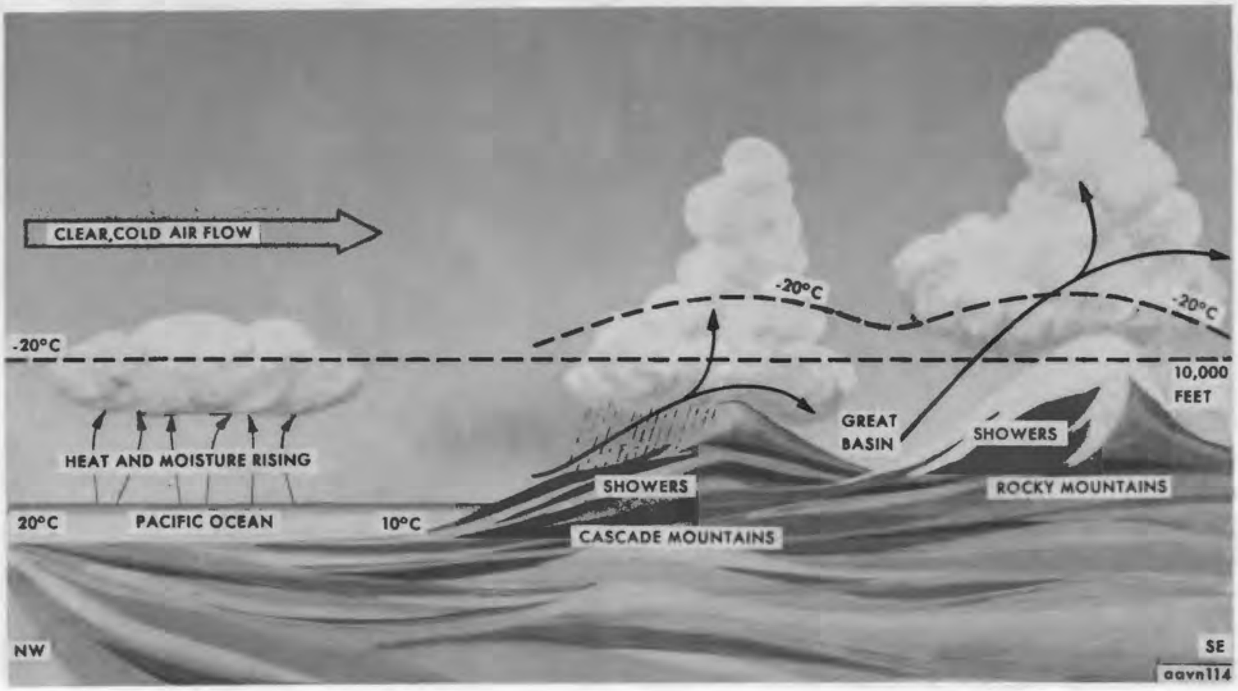


Figure 6–3. Winter movement of maritime polar air southeastward.

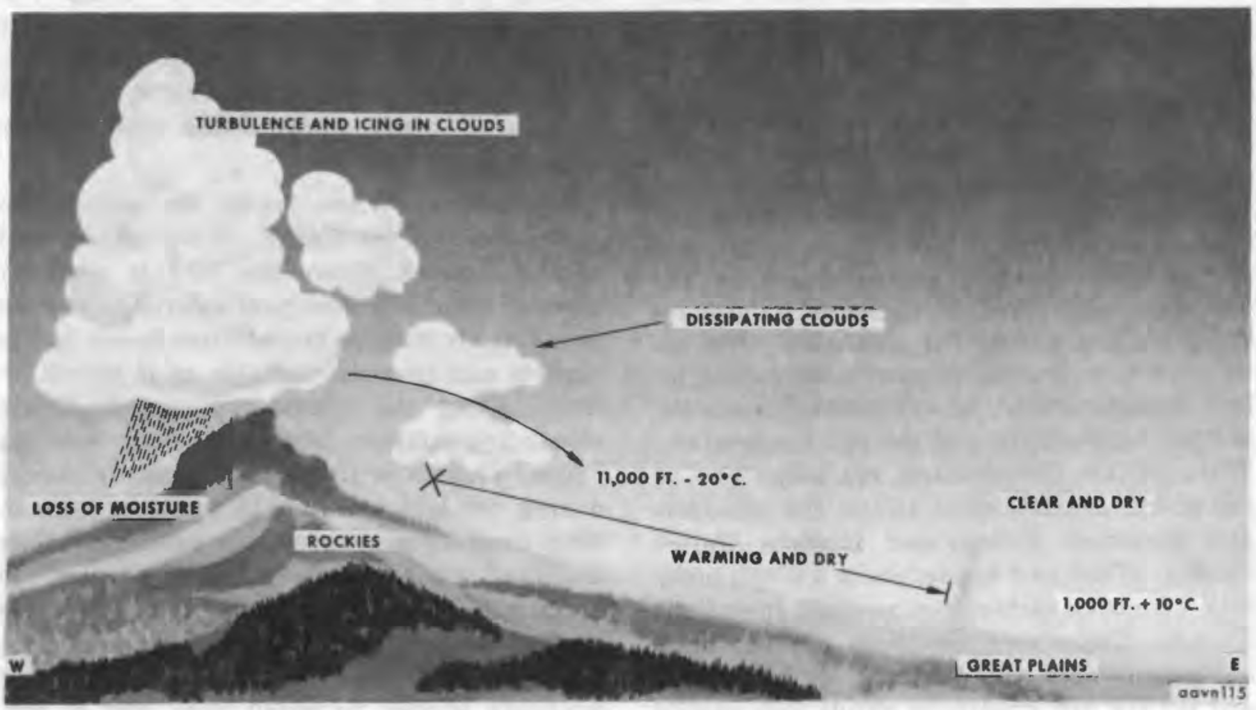


Figure 6–4. Maritime polar air after crossing the Rockies.

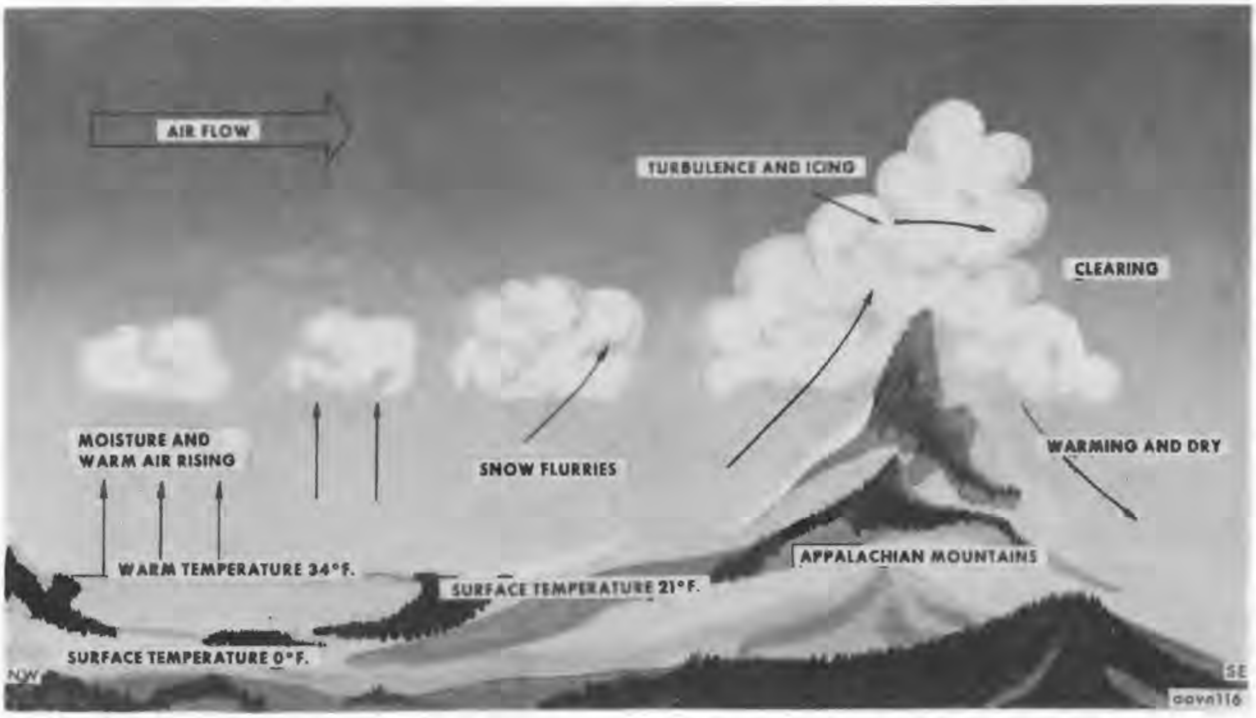


Figure 6–5. Continental polar air moving over the Great Lakes and Appalachians in winter.

and Gulf Coast States. Warm, moist stable air which originates over the Pacfic Ocean is rarely observed in Southwestern United States; the prevailing winds in the Southwest blow offshore.

a. Winter. Because in winter the land is colder than the water, warm moist air masses are cooled from below and become stable as they move inland over the South Atlantic and Gulf States. Fog and stratiform clouds form at night over the coastal regions (fig. 6–6). The fog and clouds tend to dissipate or become stratocumulus during the afternoon. The extent to which the cloudiness and fog spread inland is dependent on the difference between the surface temperature and the air temperature. When surface temperatures are cold, fog and stratiform clouds extend inland for considerable distances (throughout Eastern United States). When land temperatures are extremely cold, extensive surface temperature inversions devolop. Under such conditions, daytime heating usually does not eliminate the inversions, and the fog and stratiform clouds may persist for several days. In winter when the air moves over the Appalachian Mountains, the adiabatic cooling produced by orographic lifting (fig. 6–6) causes heavy cumuliform clouds to form on the windward side. Extremely low ceilings, poor visibility, moderate turbulence, and moderate icing typify winter flying conditions in the area.

b. Summer. Warm moist air covers the eastern half of the United States during most of the summer. Since the land is normally warmer than the water, particularly during the day, this air mass is heated from below by the surface and becomes unstable as it moves inland. Along the coastal regions, stratiform clouds are common during the early morning hours. These stratiform clouds usually change during the late morning to scattered cumuliform clouds. By late afternoon extensive widely scattered thunderstorms normally develop. In maritime tropical air masses, cumuliform clouds and thunderstorms are usually most numerous and intense on the windward side of mountain ranges, in squall lines, and in prefrontal activity.

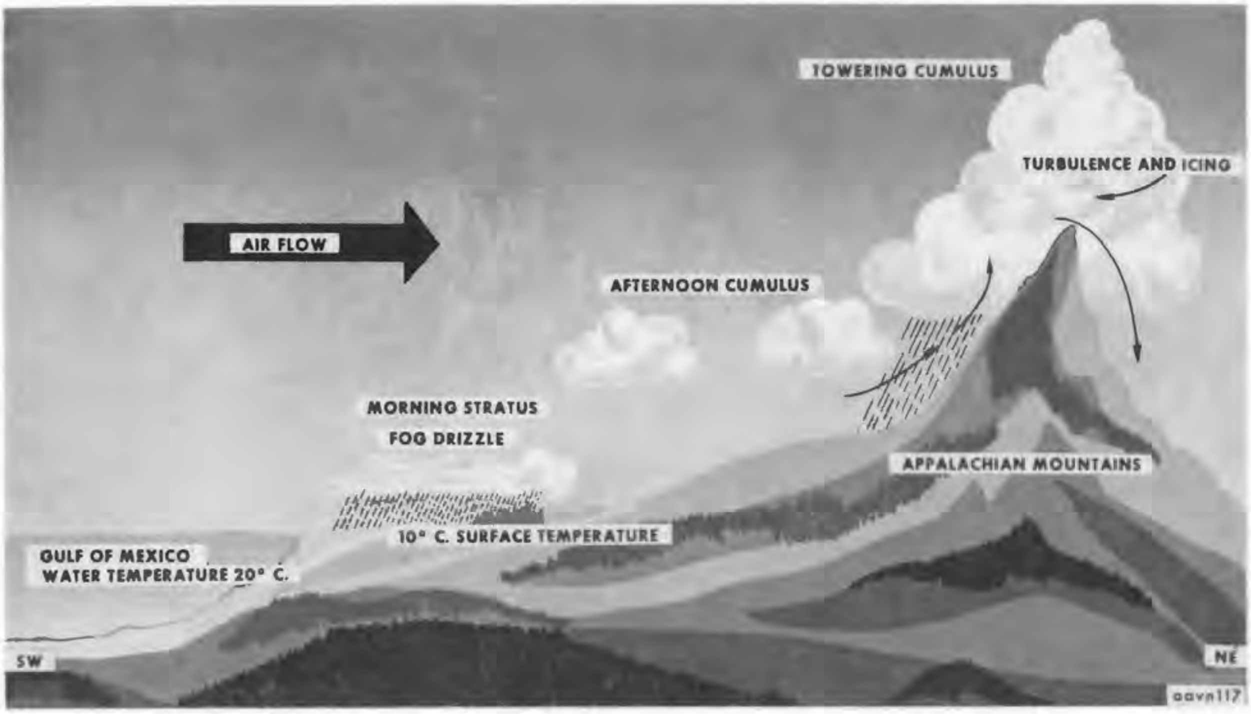


Figure 6–6. Maritime tropical air moving over the Appalachian Mountains in winter.

6–11. Continental Tropical Air Masses

Continental tropical air masses are observed primarily in the Mexico-Texas-Arizona-New Mexico area (their source region), and only in the summer. These air masses are characterized by high temperatures, low humidities, and extremely rare scattered cumuliform clouds. The bases of these cumuliform clouds are exceptionally high for this cloud type. Flying is often rough, especially during the daylight hours, because of the great vertical extent of the turbulence. Occasional dust storms present another significant flying hazard; the dust or sand may extend above 10,000 feet and reduce visibility for many hours.

CHAPTER 7

FRONTAL WEATHER

7–1. General

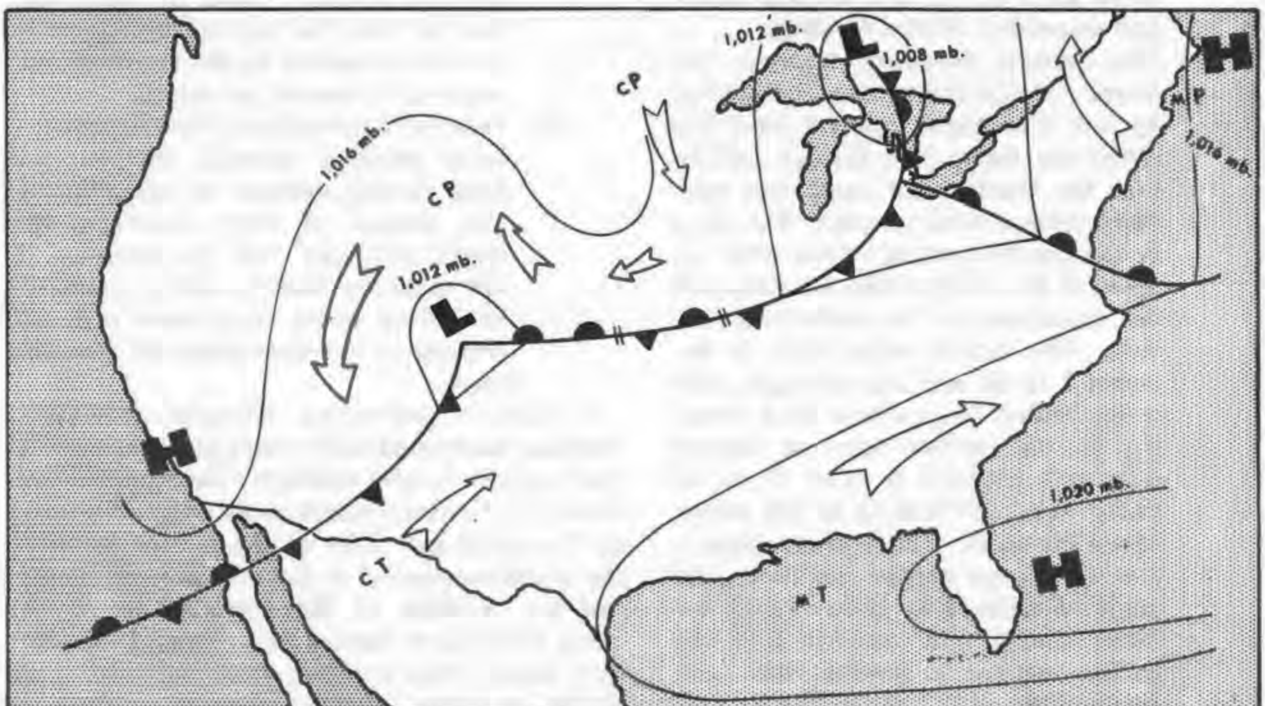
a. General. Fronts are transition zones (boundaries) between air masses that have different densities. The density of air is primarily controlled by the temperature of the air; therefore, fronts in Temperate Zones usually form between tropical and polar air masses. Fronts may also form outside of the Temperate Zone between tropical and equatorial air masses and between arctic and polar air masses. A typical surface weather map shows air mass boundary zones at ground level. Designs on the boundary lines indicate the type of front and its direction of movement. Figure 7–1 depicts polar air (P) over northern United States and tropical air (T) over southern United States. Between these air masses, the symbolized black lines indicate the presence of fronts. In local weather stations, fronts may also be indicated by colored lines (par. 12–6*a*).

b. Types. The four major fronts are the *cold front, warm front, stationary front,* and *occluded front.* The name of a front is determined from the movement of the air masses involved.

(1) A *cold front* (line with triangles, fig. 7–1) is the leading edge of an advancing mass of cold air.

(2) A *warm front* (line with semicircles, fig. 1–1) is the trailing edge of a retreating mass of cold air.

(3) When an air mass boundary is neither



aavn118

Figure 7–1. Frontal activity over the United States.

advancing nor retreating along the surface, the front is called a *stationary front* (line with alternate triangles and semicircles on opposite sides, fig. 7-1).

(4) An *occluded front* (line with alternate triangles and semicircles on the same side, fig. 7-1) occurs when a cold front overtakes a warm front at the surface and a temperature contrast exists between the advancing and retreating cold air masses.

c. Air Mass Boundaries. Special terms are used to differentiate between the horizontal extent of a front along the surface and the vertical extent of the front into the atmosphere.

(1) The air mass boundaries indicated on the surface weather map (fig. 7-1) are called *surface fronts*. A surface front is the position of a front at the earth's surface. The weather map, then, shows only the location of fronts on the ground. However, these fronts also have vertical extent; the colder, heavier air mass tends to flow under the warmer air mass. The underrunning mass produces the lifting action of warm air over cold air, causing clouds and associated frontal weather.

(2) The vertical boundary between the warm and cold air masses is a *frontal surface* and slopes upward over the colder air mass. The frontal surface lifts the warmer air mass and produces frontal cloud systems. The slope of the frontal surface varies with the speed of the moving cold air mass and the roughness of the underlying terrain. The typical slope ratio is between 1 to 50 and 1 to 300; i.e., 100 miles behind the surface cold front, the frontal surface may be located anywhere between 2 miles (1 to 50 ratio) and 1,760 feet (1 to 300 ratio) above the earth. The average slope is 1 to 80. Under normal conditions, the angle of inclination (slope ratio) between the frontal surface and the earth's surface is greater with cold fronts than with warm fronts (fig. 7-2). The approximate height of the frontal surface over any station is determined from the analysis of upper air observations; e.g., winds, aloft, radiosonde, and pilot reports.

d. Pressure Variation. As fronts move over a location on the surface, a typical change in pressure occurs. The fronts lie in a trough of low pressure in such a way that, at a given place on the surface, the pressure decreases as a front approaches and increases after it passes.

(1) Because fronts are located along the line of lowest barometric pressure (trough), the wind on the cold air side of a front may vary in direction as much as 180° from the wind on the warm air side.

(2) When an aircraft flies toward a region of lower pressure, it encounters a crosswind from the left (par. 4-10*c*(3)). Therefore, when an aircraft approaches a front, it will be drifting to the right or crabbing to the left to remain on course. Once the aircraft passes through the frontal surface, it has passed beyond the region of lowest pressure. (The trough extends from its surface position upward along the frontal surface.) Since the wind will then be from the right of the aircraft, a drift correction to the right will be required to remain on course.

(3) This drift correction principle applies when crossing through any well-defined frontal surface at any altitude. The amount of drift correction required will vary with the intensity of low pressure trough, but is normally least with warm fronts and with occlusions in the later stages of development.

e. Factors Affecting Frontal Weather. Weather associated with fronts and frontal lifting is called *frontal weather*. The type and intensity of frontal weather is determined largely by the speed and slope of the frontal surface, the moisture content of the displaced air mass, and the stability of the displaced air mass. Since these three factors vary, frontal weather may range from a minor wind shift with no clouds or other visible weather activity to severe thunderstorms accompanied by low

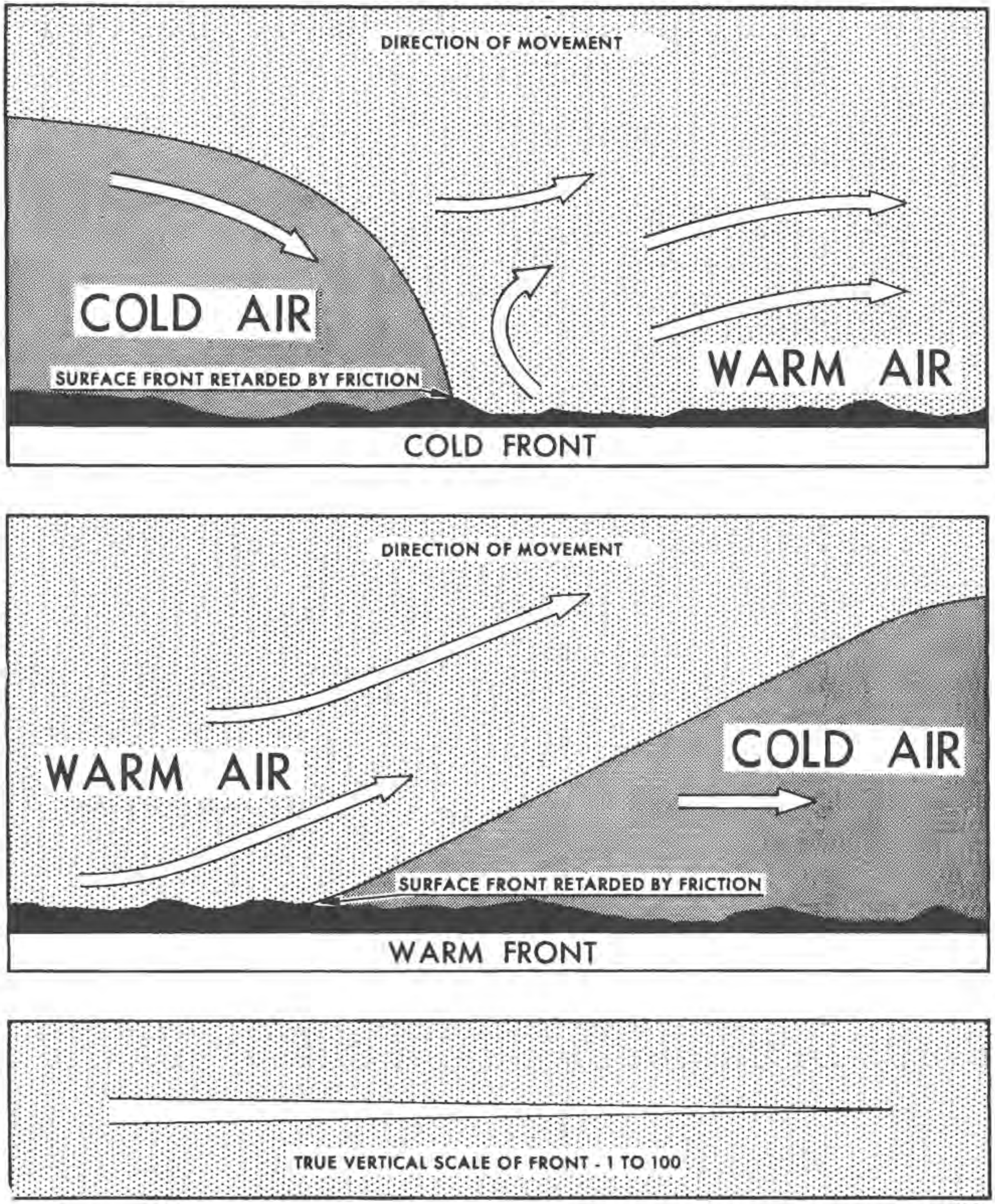


Figure 7-2. Vertical cross section showing frontal slopes.

clouds, poor visibility, hail, severe turbulence, and icing conditions. In addition, weather associated with one section of a front is frequently different from weather in other sections of the same front.

(1) *Speed and slope.* As the front moves over the ground, the amount of friction and the speed of the front regulate the slope of the frontal surface, which in turn affects the amount of turbulence in the frontal cloud system. For example—

(*a*) When a cold front moves rapidly, its leading edge steepens. This lifts the warm air ahead of the front abruptly, and adiabatic cooling condenses the moisture from the warm air. As the water vapor condenses in the form of clouds, large amounts of energy are released in a relatively narrow band along the leading edge of the front. This concentration of energy causes the turbulence and violent weather associated with the rapidly moving cold front.

(*b*) When a cold front moves slowly, terrain has less effect on the slope of the frontal surface and the slope is more gradual; the energy released by condensation is spread over a wide area. Turbulence is lessened and the weather is less violent.

(2) *Water vapor content.* The moisture content of the air mass being lifted by the frontal surface and the height to which the moist air is lifted determines whether clouds will form in the warm air. Clouds along all fronts are initially produced by expansional cooling as the warm air is lifted above the frontal surface. Clouds will form only when the air cools enough to lower the temperature to the dew point. In locations where the warm air has a continental source region, the lifting action may be insufficient to produce clouds ("dry" fronts).

(3) *Stability.* The stability of the displaced air also affects the degree of turbulence along a front. Unstable air will produce predominantly cumuliform clouds; stable air, stratiform clouds.

Note. Atmospheric stability is a function of the temperature lapse rate (par. 5-5).

7-2. Air Mass Discontinuities

A front is a boundary in the atmosphere along which certain physical properties between the air masses are discontinuous. These discontinuities between air masses are used to identify a front and to determine its location both in the atmosphere and at the surface.

a. Temperature. Temperature is one of the most obvious of frontal surface discontinuities. Typical fronts consist of warm air above the frontal surface and cold air below it. A radiosonde observation through a frontal surface will often indicate the relatively narrow layer where the normal decrease of temperature with height is reversed. This temperature inversion is called a *frontal inversion* (fig. 7-3), and its position indicates the height of the frontal surface 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. Active fronts tend to have shallow inversion layers; weak fronts tend to have deep inversion layers.

b. Wind. The discontinuity of wind across a frontal boundary is primarily a change of wind direction. A *wind shift* refers to a change in the direction *from* which the wind is blowing. If the wind ahead of a front is southwesterly, it normally shifts to northwesterly after the front passes. Easterly winds usually become westerly. The speed of the wind is not always discontinuous across a front; however, wind

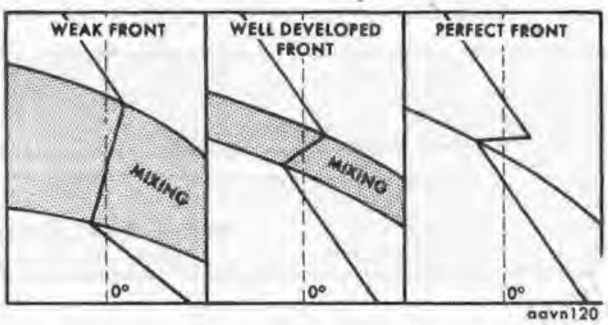


Figure 7-3. Temperature soundings through frontal surfaces.

speed frequently increases abruptly after the passage of a cold front, and decreases slightly after the passage of a warm front.

c. Pressure Tendency. Observing stations report pressure tendency (the rate at which surface pressure rises or falls) by *trend* (rising or falling) and by the *amount of change* during the 3 hours preceding the time of the report. Pressure tends to change regularly, in trend, with time; but when a frontal passage occurs, the change of pressure trend is abrupt and discontinuous. A falling pressure tendency gradually intensifies in amount with the approach of a front, then rises abruptly or becomes steady after frontal passage. Thus, a moving front is characterized by a discontinuous pressure tendency. Although a stationary front also lies in a trough of low pressure (pressure increases with distance perpendicular to the surface front), the pressure tendency is continuous across the front; i.e., stations on both sides of the front report similar pressure tendencies over a 3-hour period.

d. Dew Point. The dew point (par. 2–12*b*) can be used to determine the time of frontal passage at the surface or to locate the position of the frontal surface in the atmosphere. It may be a more reliable indicator than the free air temperature because the dew point is not directly affected by the daytime heating or nighttime cooling of the air. The dew point is relatively constant throughout the horizontal extent of an air mass, and therefore can be used to identify the arrival of a different air mass over a station.

7–3. Cold Fronts

a. Generation of a Cold Front. Frontal troughs normally extend from a closed area (center) of low pressure called a *cyclone* (fig. 7–1). The term *cyclone* should not be confused with the term *tornado.* A tornado is a funnel-shaped cloud, whereas the cyclone is an area of counterclockwise winds (clockwise in the Southern Hemisphere) that often covers thousands of square miles. In the Northern Hemisphere, as the cyclones move from west to east across the Temperate Zone, the counterclockwise rotation of wind about the low-pressure center causes the polar air to advance southward on the back (west) side of the cyclone. The cold front is the leading edge of this advancing mass of relatively cold air. Not all cyclones contain fronts; however, where a cold front does exist, it extends westward from the center of lowest pressure.

b. Characteristics of a Cold Front. The characteristics of a typical cold front (fig. 7–4) include—

(1) *Wind shift.* The wind in the warm sector ahead of the front is generally from the southwest quadrant of the compass rose, while the winds in the cold air mass behind the front are typically from the northwest quadrant of the compass rose.

(2) *Temperature distribution.* There is warm air ahead of the front in the southwesterly winds, and cold air behind the front in the northwesterly winds.

(3) *Cloud formations.* When the warm air ahead of the front is moist and unstable, the clouds are predominantly cumuliform. With typical cold fronts, a line of thunderstorms develops along the surface front and may extend for hundreds of miles. The typical weather band varies in width from 50 to 100 miles. The degree of instability, the moisture content of the warm air, and the speed and slope of the frontal surface determine the intensity and type of frontal clouds. The *typical cold front* in the United States has cumuli-

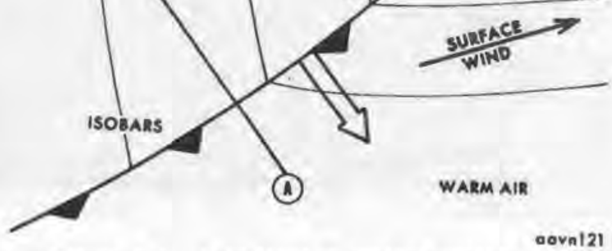


Figure 7–4. Cold front on surface weather map.

form clouds arranged as shown in figure 7-5. However, if the warm air ahead of the front is moist and stable and the slope of the frontal surface is shallow, a deck of stratiform clouds may persist many hours after frontal passage. When cold fronts move *rapidly* into moist unstable air, prefrontal squall lines (par. 10-3*c*) may form up to 300 miles ahead of the surface front.

(4) *Direction of movement and speed.* Cold fronts generally move from northwest to southeast at an average speed of 22 knots (fig. 7-4). This movement produces an average frontal surface slope ratio of 1 to 80 (fig. 7-5).

(5) *Dew point change.* The cold air behind a cold front may be a continental air mass with a low dew point whereas the warm air ahead of a cold front may be maritime with a high dew point. Even in exceptional temperature situations, a distinct dew point change should still occur across a front.

c. Cold Front Identification on the Weather Map. Cold fronts are identified by a solid blue line on colored weather maps or by a series of black triangles along a black line on the facsimile weather map. The cold front moves in the direction toward which the triangles are pointing (figs. 7-1 and 7-4).

d. Flight Procedures in Cold Front Weather. The chief hazards to aircraft flying in the vicinity of a cold front are caused by the solid line of cumuliform clouds along the front or a prefrontal squall line (par. 10-3*c*) several miles ahead of the front. These hazards include turbulence (which may be extreme), thunderstorms, lightning, heavy rain showers, tornadoes, hail, and clear (glaze) icing. An additional hazard, which has been a contributing factor in more Army aircraft accidents than any of the others, is the presence of strong, variable, gusty surface winds around and under the thunderstorms. The technique for flying in the vicinity of cold fronts is determined from the type of aircraft, aviator experience, intensity of frontal weather, and mission urgency. Flight procedures for Army aviators include the following:

(1) Because of the narrow weather band

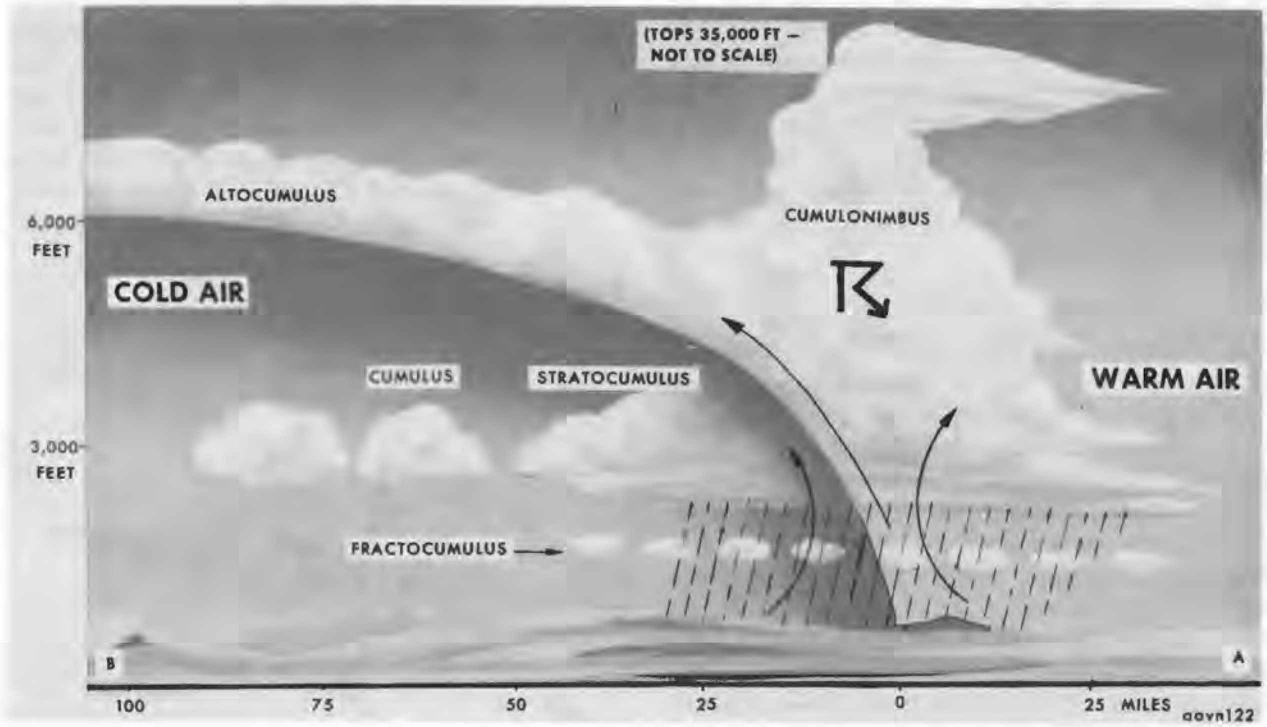


Figure 7-5. Typical cold front cloud formation.

associated with the average cold front, aviators can frequently land and wait for the squall line to pass.

(2) If penetration of the front is necessary, it should be made at a 90° angle to the front. This will provide passage through the weather band in the shortest possible time.

(3) En route weather facilities (radar approach control (RAPCON), airways route traffic control centers (ARTCC), or METRO (par. 15-7)) should be contacted to obtain latest information on the areas of least intensity in the squall line. The front should be penetrated at one of these "soft" points.

(4) Procedures for flight in turbulent air should be followed as established in the operator's manual (-10) for the particular aircraft. This *usually* states a reduced airspeed, a penetration altitude below 6,000 feet, and attitude instrument flying.

(5) Since no two fronts are exactly alike, each flight should be planned before takeoff to obtain maximum benefit from the weather briefing, including knowledge of the weather conditions of the particular front affecting the flight.

7-4. Warm Fronts

a. Generation of a Warm Front. Surface cool (polar) air retreats northward on the forward (east) side of cyclones in the Northern Hemisphere (fig. 7-1). The air mass boundary formed between the trailing edge of the retreating mass of cool air and the warm air mass moving in to replace it is a warm front. Warm fronts lie in troughs of low pressure and normally extend eastward from a center of low barometric pressure (fig. 7-6).

b. Characteristics of a Warm Front. The characteristics of a typical warm front include—

(1) *Wind shift.* The wind in the cool polar air ahead of the typical warm front is from the southeast quadrant of the compass rose, while the wind in the warm sector behind the front is from the southwest quadrant.

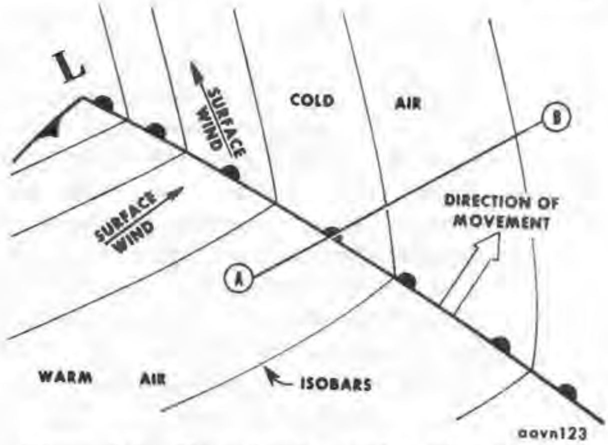


Figure 7-6. Warm front on surface weather map.

Note. The warm sector is the area of warm southerly winds between the cold front and the warm front at the surface. Therefore, the same wind pattern usually exists "ahead" of the cold front that exists "behind" the warm front; i.e., it is the same tropical air mass. "Behind" refers to conditions that will exist after the surface front has passed a location on the earth. "Ahead" refers to conditions that exist before a surface front arrives at a place on the earth. Northwest winds, decreasing temperatures and dew points, and rising pressure exist "behind" a typical cold front (fig. 7-4). Southwest winds, high temperatures and dew points, and rising or steady pressure exist "behind" a typical warm front (fig. 7-6).

(2) *Temperature change.* As a surface warm front passes a location, the temperature increases, but the amount of increase varies from a few degrees to more than 20° F.

(3) *Cloud formation.* As the warm southwesterly winds behind the front converge with the cool southeasterly winds ahead of the front, the lighter advancing warm air will glide up over the retreating wedge of cold air (fig. 7-2). If the warm air is lifted above the condensation level, clouds will form in the warm air above the frontal surface. When the warm air is moist and stable, the clouds will be stratiform, ranging from thick nimbostratus near the surface front to high cirrus as far as 1,000 miles ahead of the front. The typical cloud pattern is shown in figure 7-7. Normally an area of rain ex-

tends 300 miles ahead of the front. As the rain evaporates in the thin wedge of cold air, this air becomes saturated and produces an area of low stratus or fog about 100 miles wide ahead of the surface front. The pre-frontal fog may cover hundreds of square miles, with ceilings and visibilities below minimums. During the winter months, two distinct freezing levels exist in the typical warm front cloud and precipitation areas (fig. 7-8). During the summer when the warm moist air is conditionally unstable, the stratiform overcast above the frontal surface may become impregnated with scattered thunderstorms, with higher bases than cold front thunderstorms and not alined solidly as with a squall line. When cumuliform clouds occur in a warm front cloud pattern, possible heavy turbulence may be imbedded within the major cloud system. However, the *typical warm front* is characterized by a wide area of stratiform clouds with low ceilings and poor visibilities (fig. 7-7).

(4) *Direction of movement.* Warm fronts usually move from southwest to northeast at an average speed of 10 knots. This direction of motion is a combination of—

(*a*) The surface wind movement in the cool air mass, usually from southeast to northwest, and

(*b*) The movement of the entire pressure system from west to east.

(5) *Speed and slope.* The slow speed of a warm front is a result of opposing wind components—the surface winds in the cool polar air have an easterly (east to west) component, while the entire pressure system is moving from west to east. The cold front, by contrast, moves much more rapidly than the warm front because both the surface winds in the cold polar air and the movement of the entire cyclone have a west to east component. The average slope ratio of the warm frontal surface is 1 to 200 (fig. 7-7).

c. Warm Front Identification on the Weather Map. Warm fronts are identified by solid red lines on colored weather maps and by a series of black semicircles along a black line on the facsimile weather map. The warm front moves

Figure 7-7. Typical warm front cloud formation.

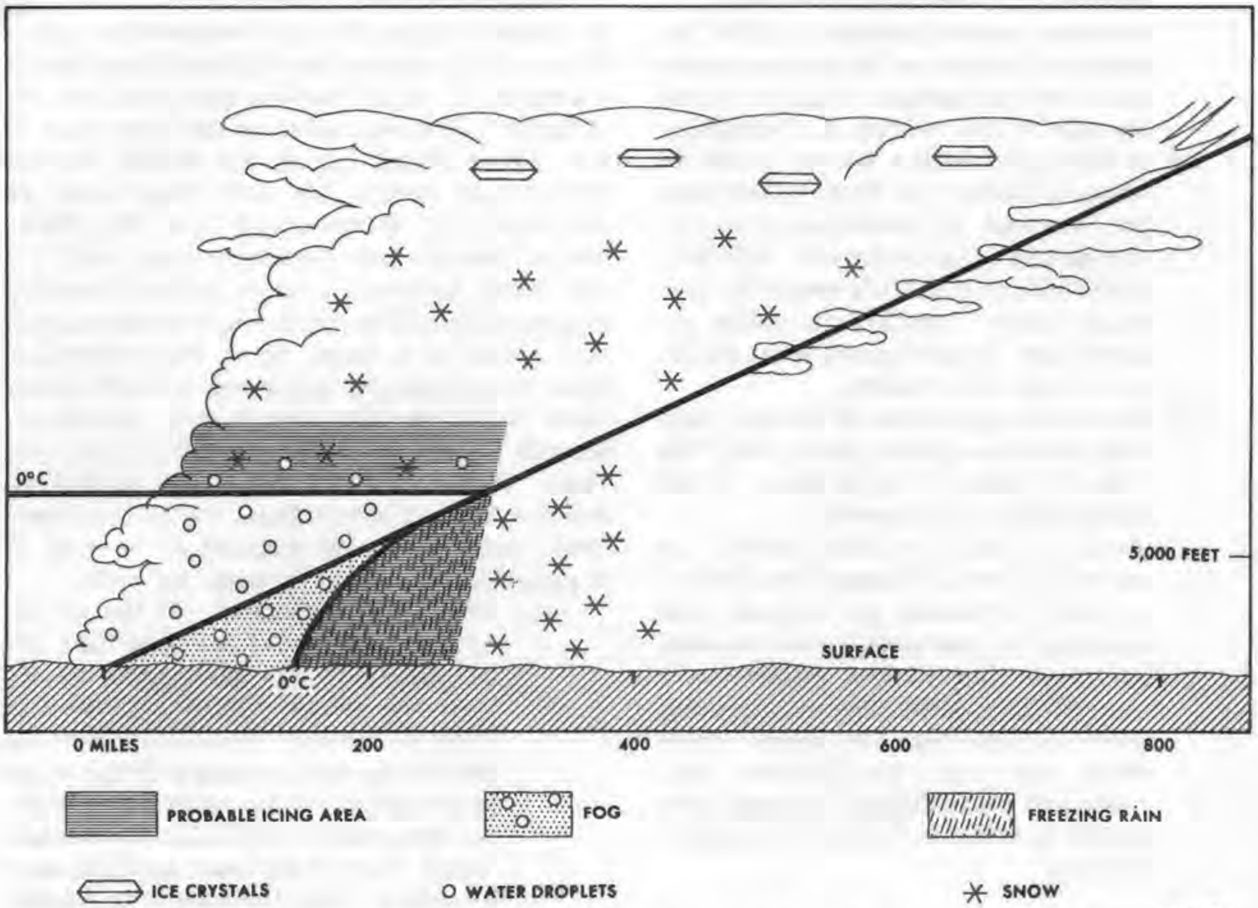


Figure 7–8. Probable icing zones in a warm front.

in the direction toward which the semicircles are pointing (figs. 7–1 and 7–6).

d. Flight Procedures in Warm Front Weather. The chief hazard to flight in *most* warm frontal areas is the wide overcast area with low ceilings and poor visibility ahead of the front. The first sign of an approaching warm front is the thickening of cirrostratus clouds in the west. When flying toward the front from the cold air side, the aviator will observe the base of the cirrostratus lowering to form a thicker altostratus overcast. Approximately 300 miles ahead of the surface front, rain falling from the thick altostratus clouds and evaporating in the wedge of cold air below the frontal surface saturates the cold air. An area of lower clouds (usually stratocumulus) begins to form in the saturated cold air mass. As the rain becomes heavier, the stratocumulus cloud deck becomes more solid. Gradually the upper and lower cloud decks merge and form a solid cloud layer which may be over 15,000 feet thick. Rain and fog may reduce ceiling and surface visibility to zero for 200 miles or more ahead of the front. As the warm front approaches a surface station, the cloud bases continue to lower, with increasing restriction to visibility. Thunderstorms during the warm months of the year or heavy icing during the winter are further hazards. The Army aviator should use the following procedures to combat warm frontal hazards:

(1) Warm frontal areas should be crossed either above the cloud tops or below the bases to avoid inadvertent entry into the turbulence of hidden thunderstorms which may exist at intermediate flight levels.

(2) If the flight destination is in an area

dominated by warm front weather, an alternate should be selected, either behind the front or as far as practicable ahead of the surface front, to avoid the area of low ceilings and visibility.

(3) A thorough weather briefing should be obtained before the flight to estimate the locations of turbulence, thunderstorms and icing conditions. METRO, RAPCON, or ARTCC's should be contacted (par. 7–3*d*(3)) to obtain inflight data. Severe hazard areas should be avoided ((5) below).

(4) Encountering an area of freezing rain that produces severe glaze icing, the aviator should immediately climb above the frontal inversion.

(5) Areas of icing in clouds should be avoided, either by climbing to a higher altitude containing ice crystals and snow, or by descending into warmer air nearer the surface. Since, however, it is possible for two freezing levels to occur with the winter warm front (fig. 7–8), freezing-level altitudes and flight altitude temperatures should be obtained during the weather briefing.

7–5. Occluded Fronts

a. Development of Occlusions. Successive stages in the development of an occluded wave are shown in (A), (B), (C), and (D) of figure 7–9. Figure 7–9(B) depicts an *open wave*—a cyclone which includes a warm and a cold front. A cold front moves eastward more rapidly than a warm front. The cold front first overtakes the warm front at the crest of the open wave, and the wave gradually closes like the hands of a clock. As this closing of the warm and cold fronts occurs, the air of the warm sector is lifted off the surface. This is called the *occlusion* process ((D) of figs. 7–9, and 7–10). The portion of the surface front, where the cold front has overtaken the warm front, is called a *surface occluded front* (fig. 7–10).

b. Relationship of Cold and Warm Front Occlusions. The type of occlusion, cold front or warm front, depends upon the temperature distribution of the colder (polar) air masses north of the fronts. In cyclones over land, generally the coldest air mass is *behind* a cold front, but in coastal regions the air temperature *ahead* of a warm front may be colder than that behind a cold front. If the cyclone illustrated in (C) of figure 7–9 were located on the west coast of the United States during the winter, the air temperature behind the cold front would be moderated by its trajectory over the Pacific Ocean. The air mass boundary would still be a cold front, however, because polar air moving southward would be displacing warmer tropical air. Ahead of a warm front, the continental polar air moving over the northern Rocky Mountains would be very cold during the winter, actually colder than the air behind the cold front. However, the trailing edge of this retreating mass of very cold air would be a warm front, since the warm tropical air moving in is replacing the retreating polar air mass.

(1) *Cold front occlusions.* If the air behind the cold front is colder than the air ahead of the warm front in the occlusion process (fig. 7–11), the cold front of the open wave will remain on the surface and displace both the warm sector air and the surface warm front. As the process continues, the surface warm front of the open wave becomes an *upper front* (no longer in contact with the surface). The upper warm front is so close to the surface occluded front that the symbol for the upper warm front is normally omitted from the surface weather map (figs. 7–1 and 7–12). The *cold front occlusion* is named from the cold front which remained at the surface. After a cold front occlusion passes a station, temperature will decrease and the wind will become more northerly (fig. 7–12).

(2) *Warm front occlusions.* If the air ahead of the warm front is colder than the air behind the cold front, the warm front of the open wave will remain on the surface and the occluding cold front will ride up over the warm frontal surface, becoming an *upper cold front* (*cold front aloft*) (fig. 7–13). The warm sector air will be displaced from the ground by both frontal surfaces. The upper cold front

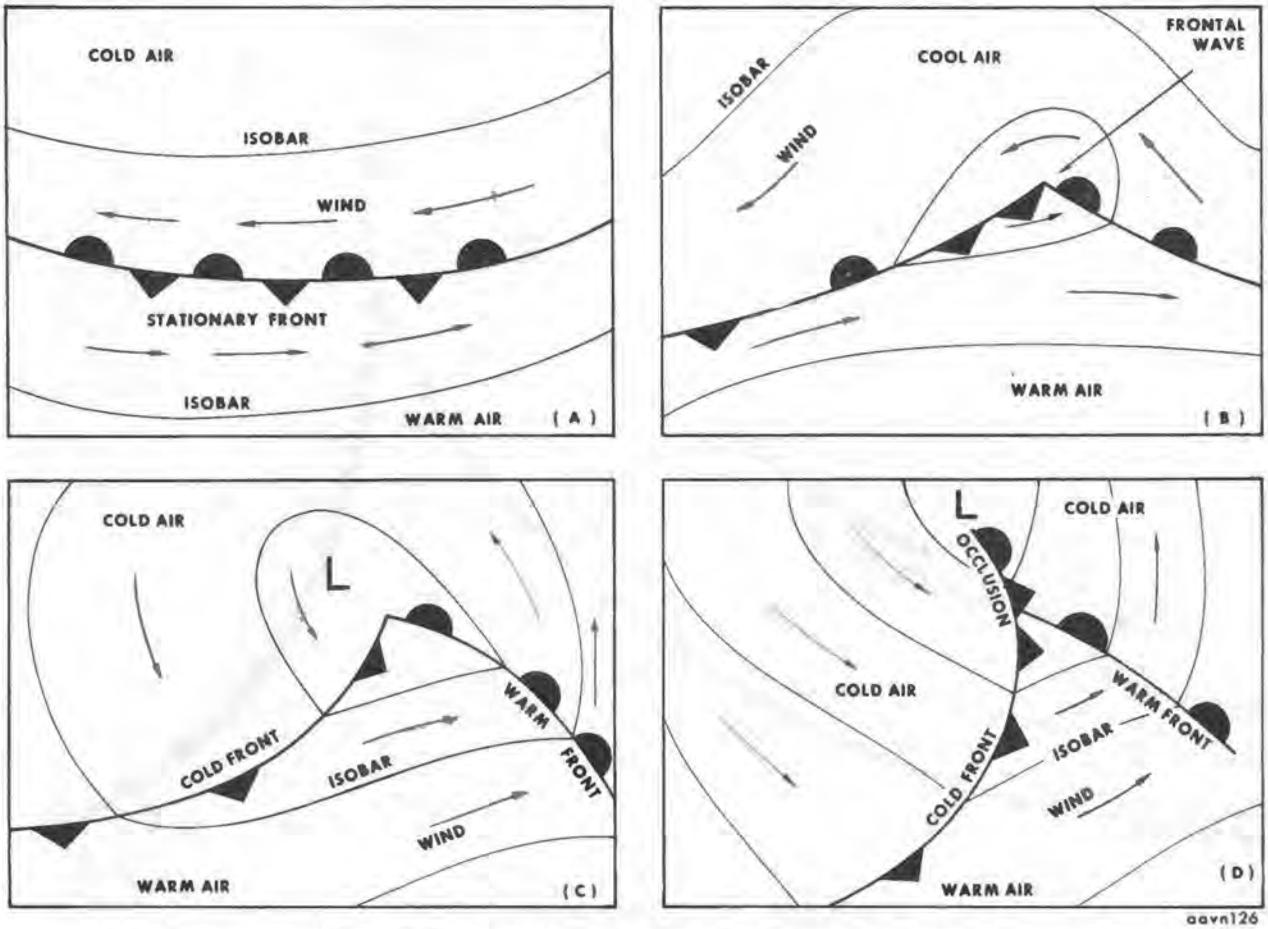


Figure 7–9. Stages in the development of the occluded wave.

is identified on the weather map by a series of open black triangles (fig. 7–14) or by a dashed blue line on a colored map. It frequently precedes the surface occluded front by 200 to 300 miles. The *warm front occlusion* is named from the warm front of the open wave which remained at the surface. After the warm front occlusion passes a station, the temperature will increase slightly and the wind will gradually become more northerly.

c. Weather Associated With Occlusions. Typical weather and cloud patterns associated with occlusions are shown in figures 7–14 and 7–15. Occlusions combine the weather of the warm and cold fronts into one extensive system. The line of thunderstorms typical of a cold front merges with the low ceilings and poor visibility of the warm front. However, the two significant differences between the weather of the two types of occlusions are—

(1) The cloud system of the warm front occlusion is characteristically wider than that of the cold front occlusion because the warm frontal surface extends under the upper cold front. This additional lifting surface between the upper cold front and the surface occluded front produces a region of nimbostratus or stratocumulus clouds not present with the cold front occlusion.

(2) Weather is most violent during the early stages of the occlusion along the upper front 50 to 100 miles north of the peak of the warm sector. The line of thunderstorms of the warm front occlusion is often imbedded within

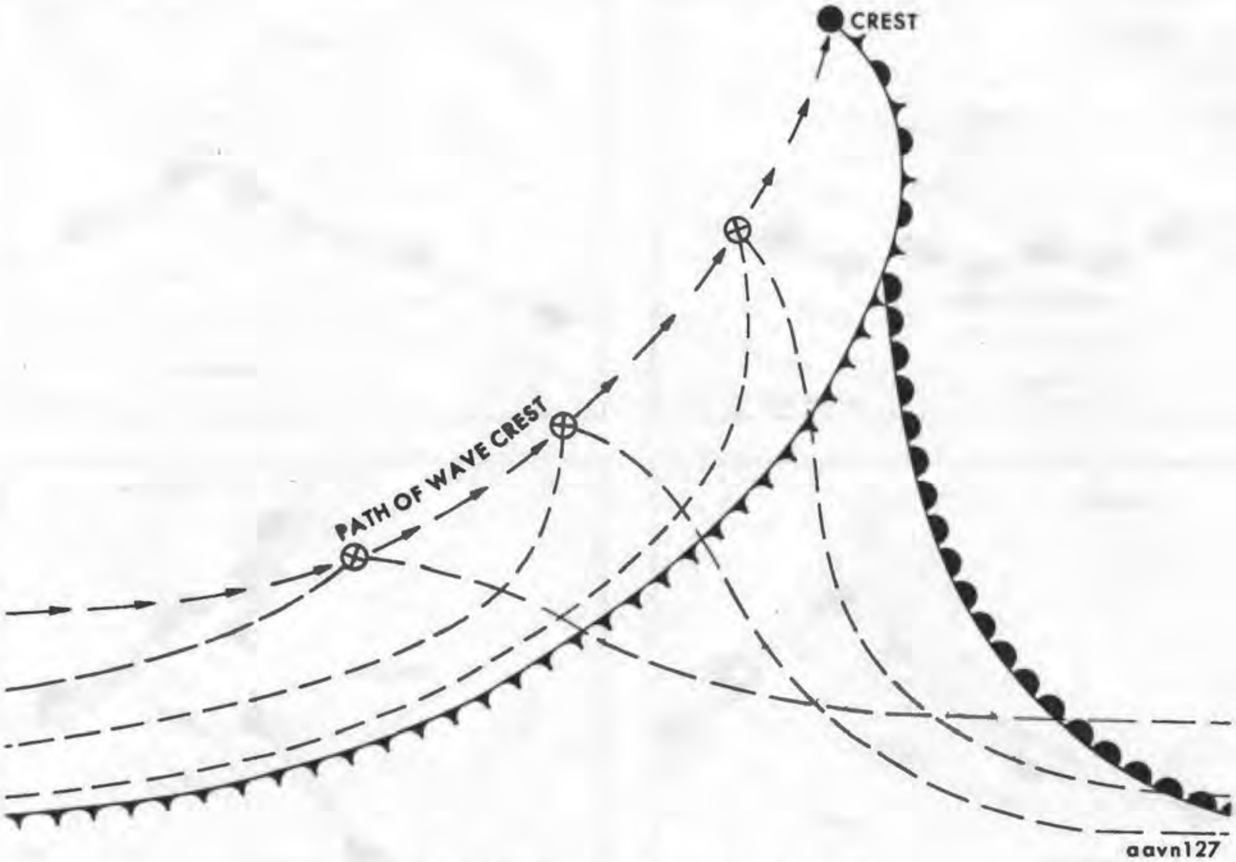


Figure 7-10. Wave development and occlusion.

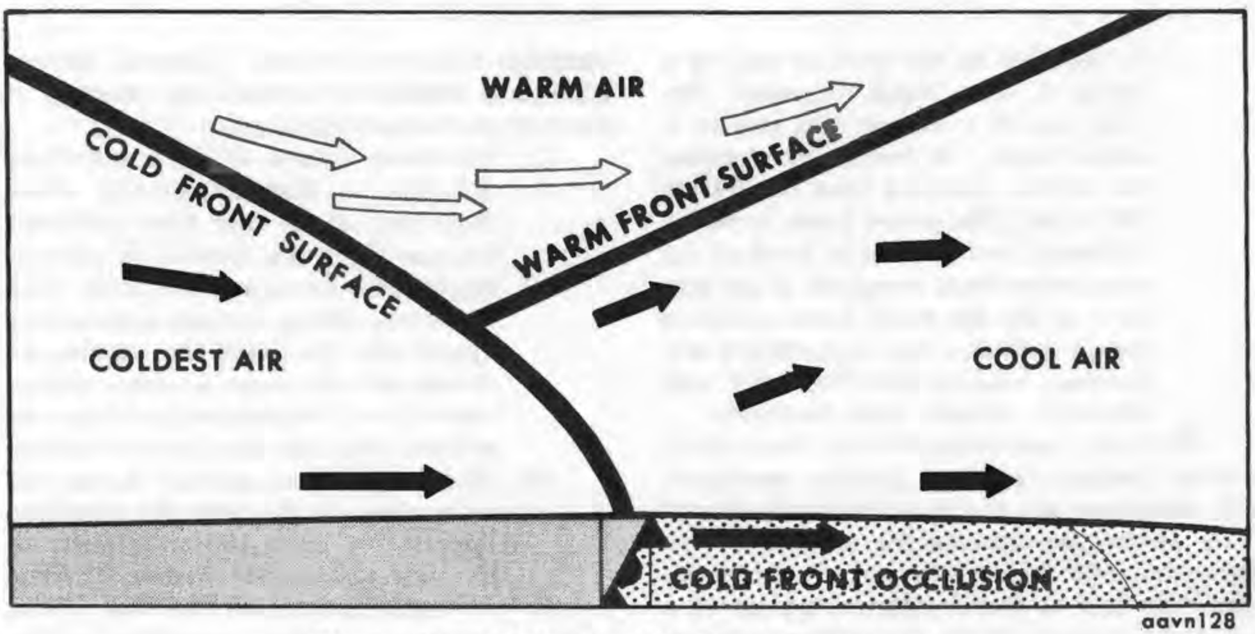


Figure 7-11. Cold front occlusion (vertical cross section).

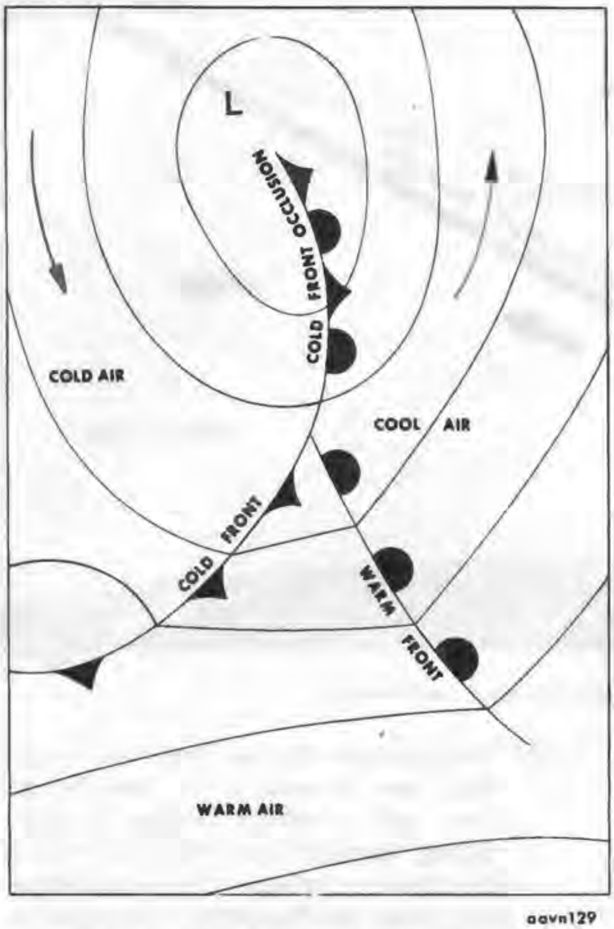


Figure 7–12. Cold front occlusion (surface map representation).

the overcast sky and may precede the surface occluded front by 200 to 300 miles. Thunderstorms of the cold front occlusion pass with the surface occluded front and may be visible from the air if approached from the west. Clearing skies often occur shortly after the passage of the surface cold front occlusion.

(3) Occluded frontal systems are more common in northern than in southern United States. Their greatest effect is felt during the winter months in both the northwest and northeast sections of the country.

d. Occluded Front Identification of the Weather Map. Map symbols are identical for the surface occluded fronts in both the warm and cold front occlusions. On the facsimile map, the symbol is an alternate triangle and semicircle on the same side of the black line. The symbols point in the direction of frontal movement. On the colored map, the surface occluded front is shown as a solid purple line; however, the weather map shows an upper cold front with the warm front type of occlusion (fig. 7–14). An upper warm front (dashed red line or open black semicircles) is seldom indicated on the map with a cold front occlusion.

e. Flight Procedures With Occluded Fronts. The weather within an occluded system combines flight problems of both the warm and the cold front. Special considerations include the following:

(1) The flight should be planned to avoid the area of severe weather extending 50 to 100 miles along the upper front north of the peak of the warm sector.

(2) Intermediate flight levels where hidden thunderstorms generally occur should be avoided. In Army aircraft, a low-level flight below 6,000 feet absolute altitude is generally recommended. While flying at low levels, the occurrence of heavy showers will indicate that stronger turbulence is present in the clouds above. Low-level flight under the clouds should be avoided where mountainous terrain is obscured by clouds, fog, or precipitation.

7–6. Stationary Fronts (Quasi-stationary Fronts)

Although there is no movement of the surface position of the true stationary front, an upglide of air can occur along the frontal slope. The angle of this flow of air in relation to the surface position of the front and the strength of the upgliding wind control the inclination of the frontal slope (fig. 7–16). Fronts moving less than 5 knots are called either *quasi-stationary* or *stationary*.

a. Warm Air. The warm air rising over the stationary frontal surface will cool adiabatically. If the air is lifted above the condensation level, clouds will form above the frontal surface.

(1) If the upgliding air is stable and sat-

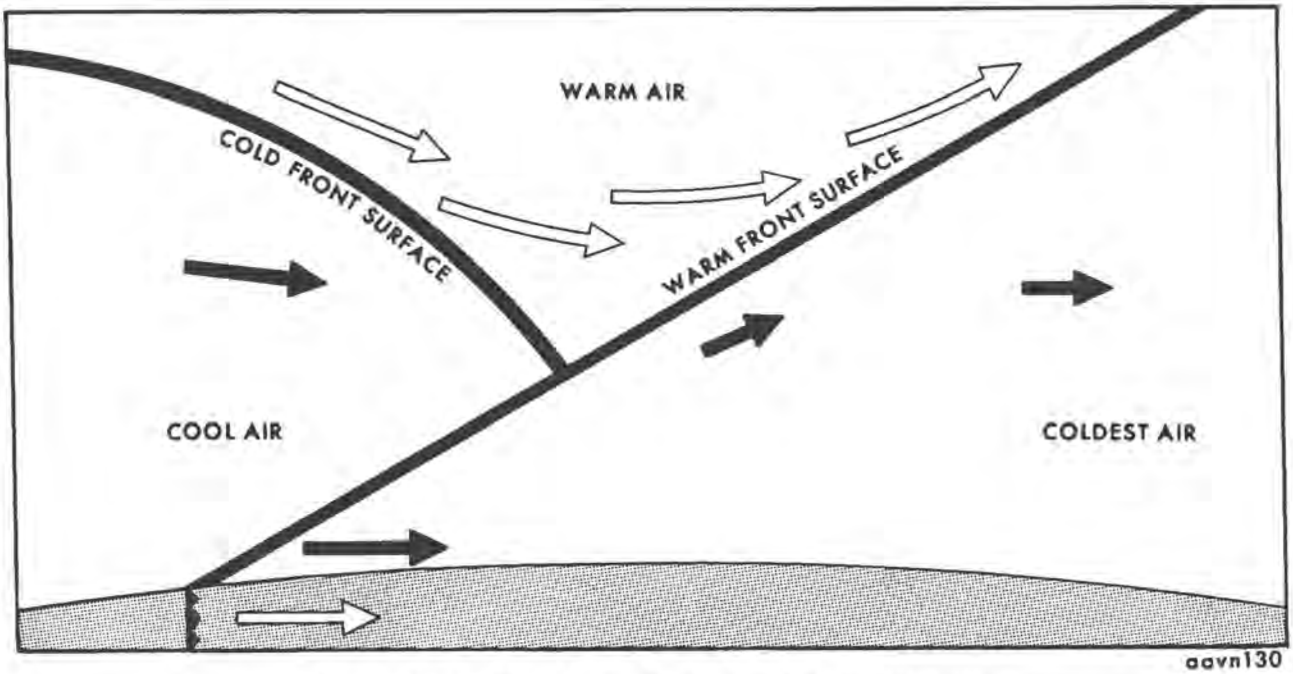


Figure 7-13. Warm front occlusion (vertical cross section).

uration occurs, stratiform clouds will form. Intermittent drizzle may occur and, if the air is lifted beyond the freezing level, icing conditions will exist. If the freezing level is fairly close to the ground, a mixture of drizzle, rain, and snow may appear over the area (fig. 7-17).

(2) If the upgliding air is conditionally unstable and saturation occurs, predominantly cumuliform clouds will form (fig. 7-18). The sky condition is often overcast, but the precipitation occurs as intermittent moderate to heavy showers with thunderstorm activity. Occasionally the thunderstorms may aline side by side to produce a line squall, but the typical cloud pattern is more similar to that of an unstable warm front.

b. Cold Air.

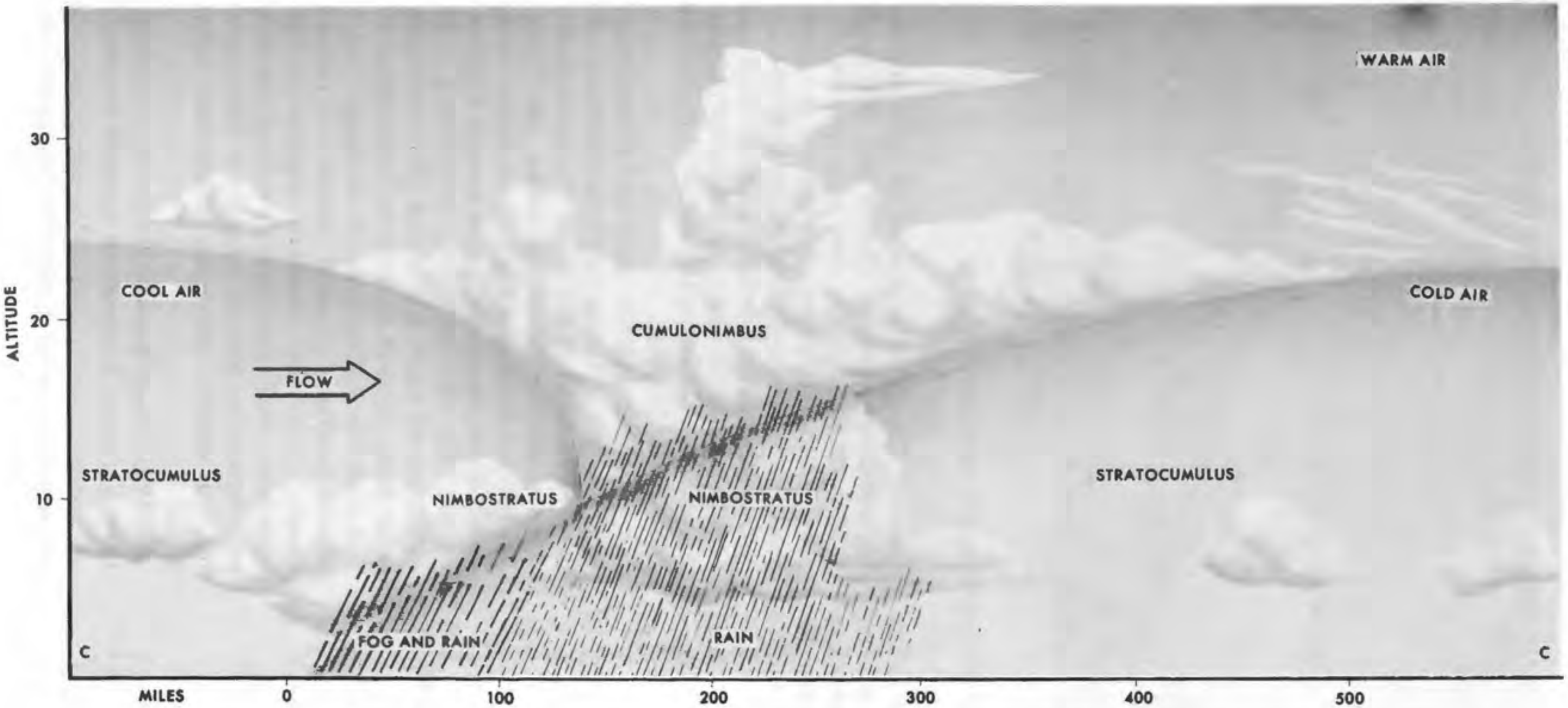
(1) Because of convergence of air across the isobars, the cold air below the frontal slope may also be rising near the surface position of the front. Cloudiness is less likely to form in the cold air since the humidity is usually low on this side of the front.

(2) Precipitation falling from the clouds that have formed above the frontal slope will partially evaporate while falling through the colder air below the frontal surface. The evaporation will cause the humidity to increase in the colder air. If saturation occurs at the surface, widespread frontal fog conditions will result. With strong winds, large frictional eddy currents near ground level will result in the formation of low-based clouds (figs. 7-17 and 7-18).

7-7. Cyclonic Wave Development

a. Fronts are air mass boundaries emanating from centers of low barometric pressure. To the meteorologist, any closed area of low barometric pressure is a *cyclone*. Not all cyclones have well-defined frontal waves. Those cyclones that do not contain fronts are relative lows, having their origin in the secondary circulation pattern; they are not caused by heating from the surface below them.

b. In the idealized general circulation pattern (par. 4-4), a large cap of cold, dense air accumulates around the polar regions. This cold air is characterized by high pressure. The outer



THE CROSS SECTION OF THE WARM FRONT OCCLUSION SHOWN ABOVE OCCURS AT LINE CC ON THE WEATHER MAP AT THE RIGHT.

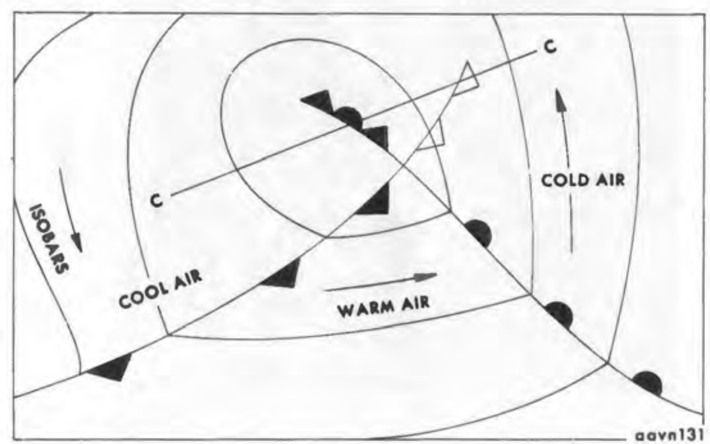


Figure 7–14. Warm front occlusion.

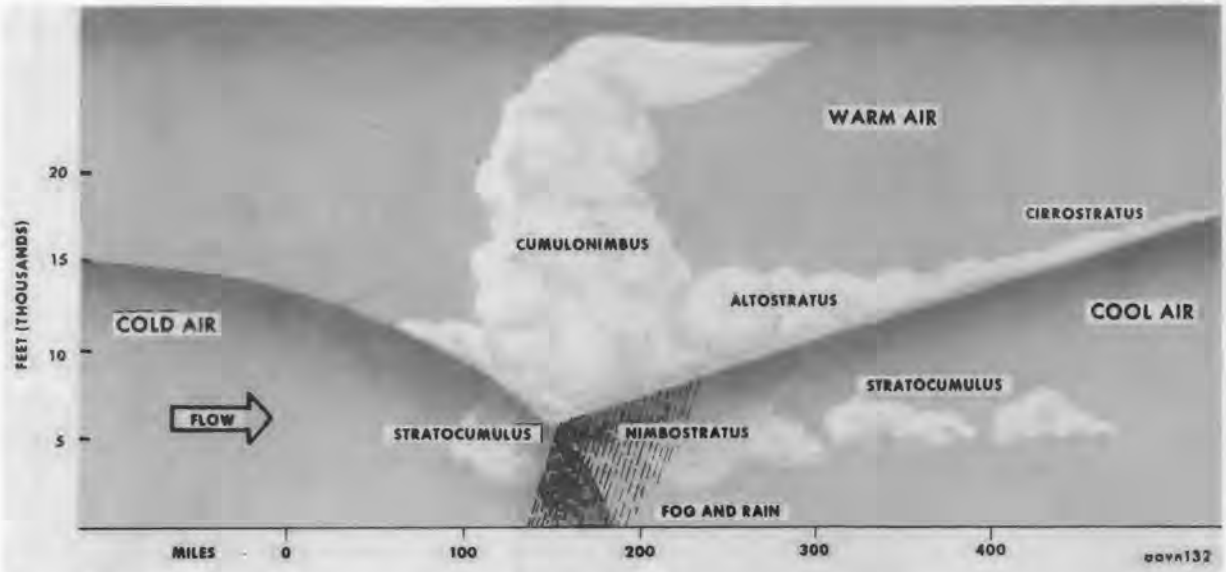


Figure 7-15. Cold front occlusion with associated weather.

boundary of this high-pressure area is in the vicinity of 60° north latitude. Another general circulation belt of high pressure is centered in the vicinity of 30° north latitude, with its strongest centers over the Atlantic and Pacific Oceans. The outer perimeter of these oceanic high-pressure areas is also in the 60° north latitude region. Thus, the area around 60° north latitude is a belt of relatively low pressure. It is also a frontal region between the cold polar easterly winds moving clockwise about the polar high and the warmer prevailing westerly winds coming out of the high-pressure areas in the Tropics.

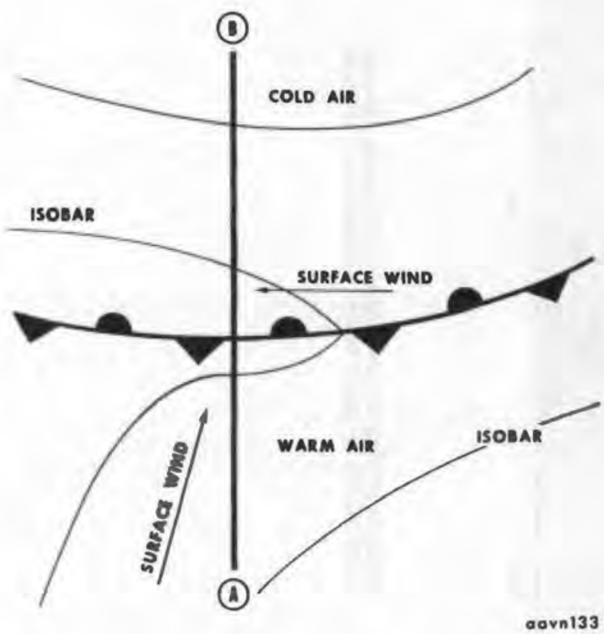


Figure 7-16. Stationary front as shown on a surface weather map.

c. Ideally, this polar front and polar trough would remain in the 60° north latitude zone. In fact, outbreaks of cold polar air move southward across the Temperate Zones (fig. 7-19). These *polar outbreaks* begin the cyclonic waves which move from west to east around the Temperate Zone (the secondary circulation). The outbreaks of polar air behind the outsurging polar front range in depth from a few thousand feet near the surface front to the upper troposphere hundreds of miles behind the surface front. Above this relatively shallow surface circulation, the west to east winds of the general circulation pattern continue to blow, moving the shallow secondary circulation below them.

d. Wind shear between the easterly winds of the cool air and the westerly winds of the warm air causes waves to form on the sloping surface of the polar front and make the front undulate.

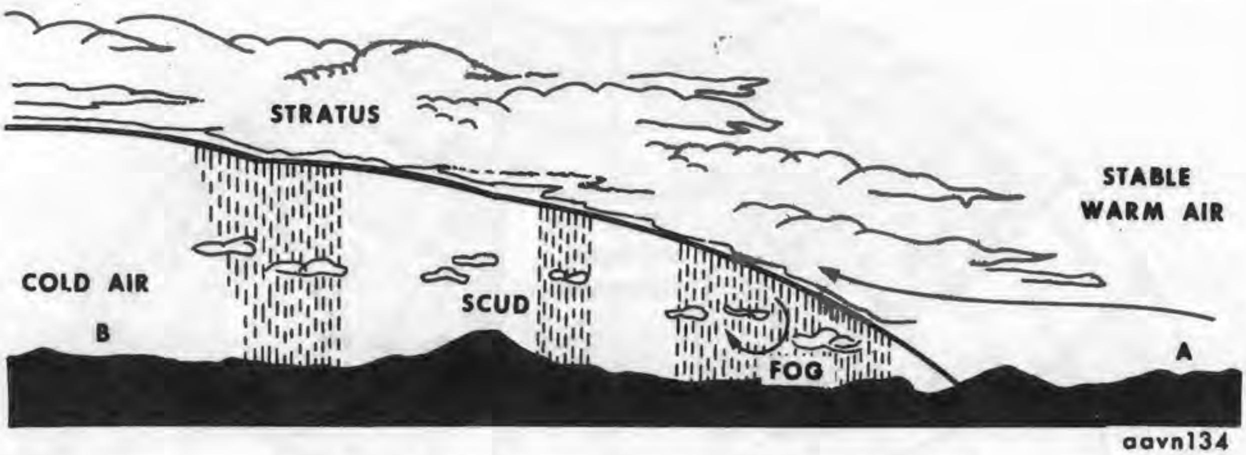


Figure 7-17. Stationary front with stable warm air.

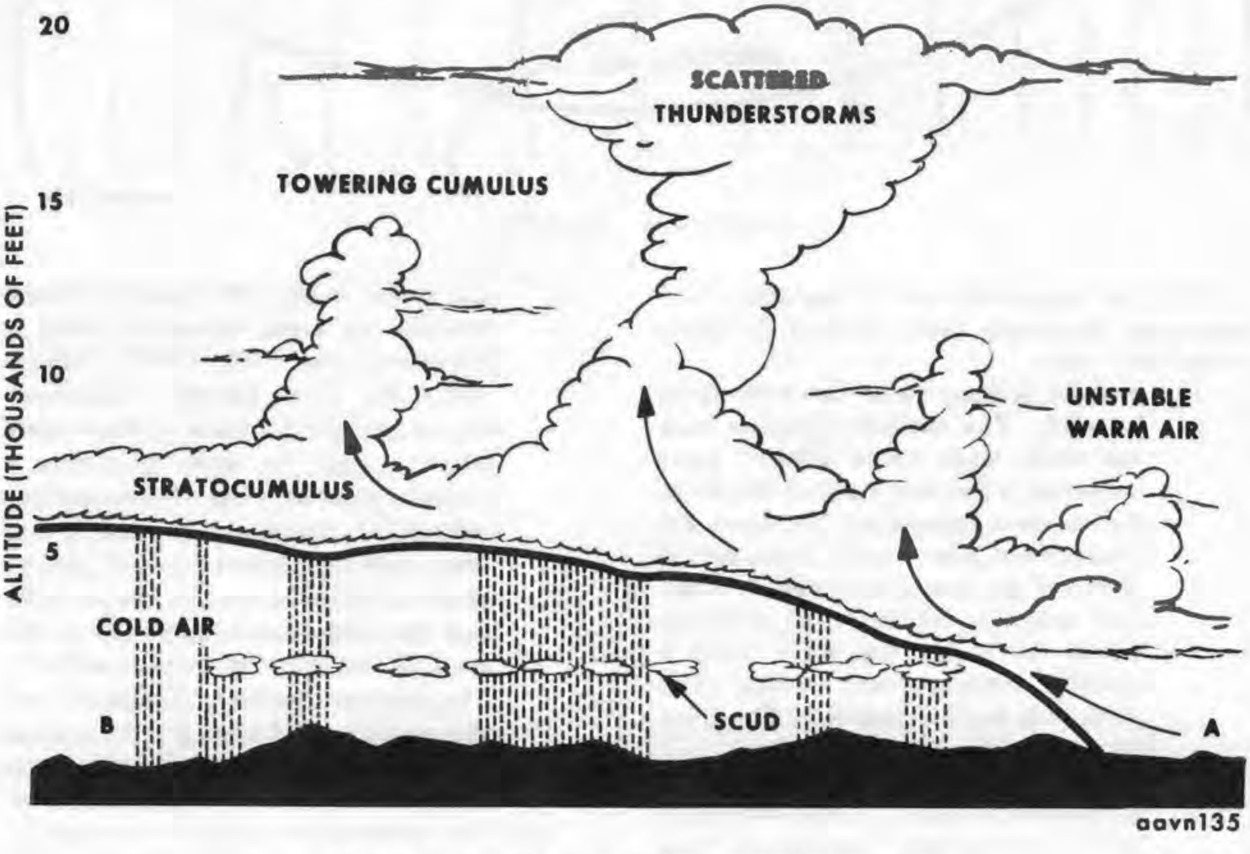


Figure 7-18. Stationary front with unstable warm air.

For example, if the front lies in an east-west direction, such a wave will cause one part of the frontal surface to bulge southward and another part northward. If the wind in the warm air is moving eastward, the bulges will move eastward as a wave. These waves are usually 200 to 1,500 miles from crest to crest (figs. 7-1 and 7-20).

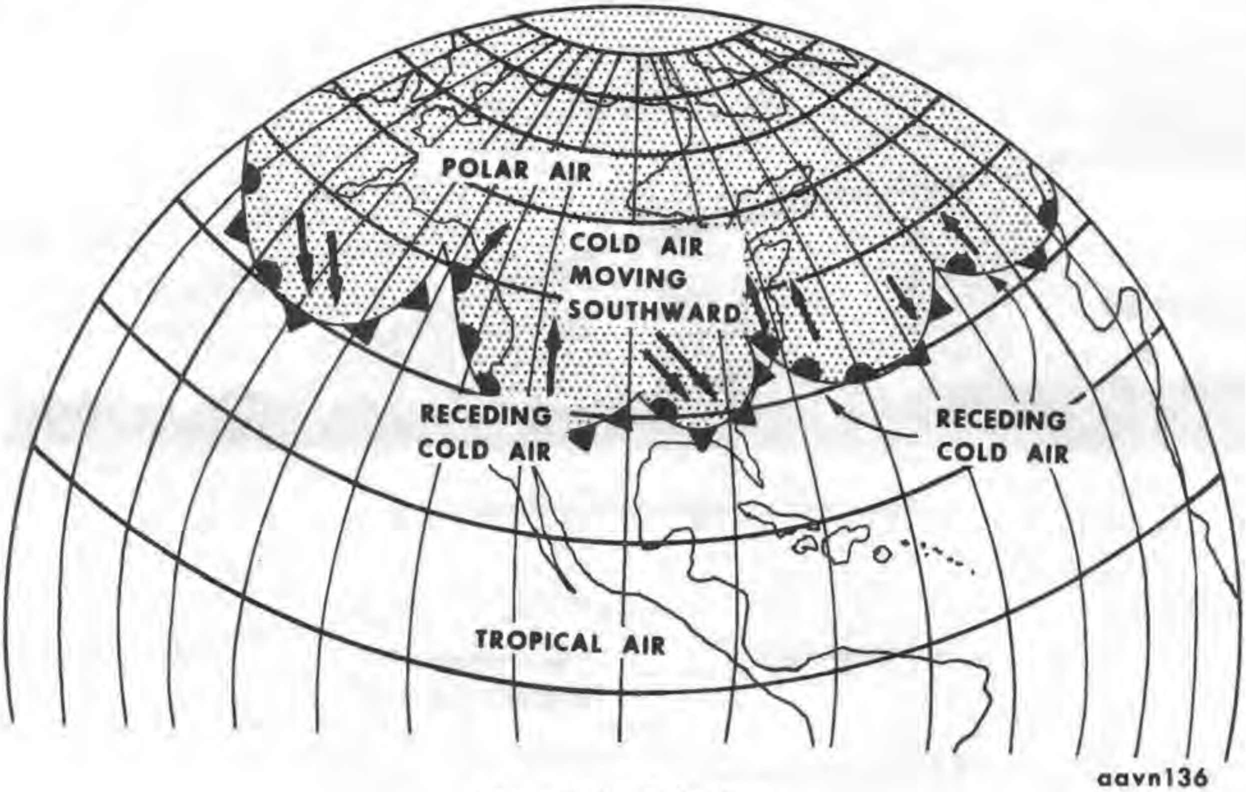


Figure 7–19. Polar front.

e. Cyclone formation can be understood by comparing stationary front activity to ocean waves (fig. 7–20).

(1) A wave in deep water far from shore is stable. The surface oscillates back and forth many times without great variation in the amplitude of the wave. As the wave approaches the shore, the distance becomes shorter from crest to crest and greater from trough to crest. The shorter the interval between crests, the higher the wave, until it becomes topheavy and breaks. The wave was made unstable by the great increase in amplitude.

(2) Atmospheric waves become unstable in the same manner. Long stationary fronts become wavy because of wind shear and pressure variation across the atmospheric boundary. Thus, the stationary front may change into a series of alternate cold and warm fronts, with wave crests (apexes) being the dividing points between cold and warm fronts. The interconnecting troughs are areas where the front is stationary (fig. 7–1). If the pressure about the apex becomes sufficiently low, a circular pressure pattern takes shape around the apex, producing a counterclockwise wind. A considerable amount of condensation occurs, and when sufficient latent heat of condensation is added to the air, the air rises and the atmospheric pressure at the crest of the wave is further reduced. The pressure gradient strengthens and the counterclockwise wind becomes stronger. The apex and its counterclockwise wind area is called a *cyclone.*

(3) The sideways movement of waves on a front is seldom stable. Once started, they tend to increase in amplitude (fig. 7–6). Instead of many waves following each other in orderly series, each wave continues to grow and the apex becomes deeper, so that the front never

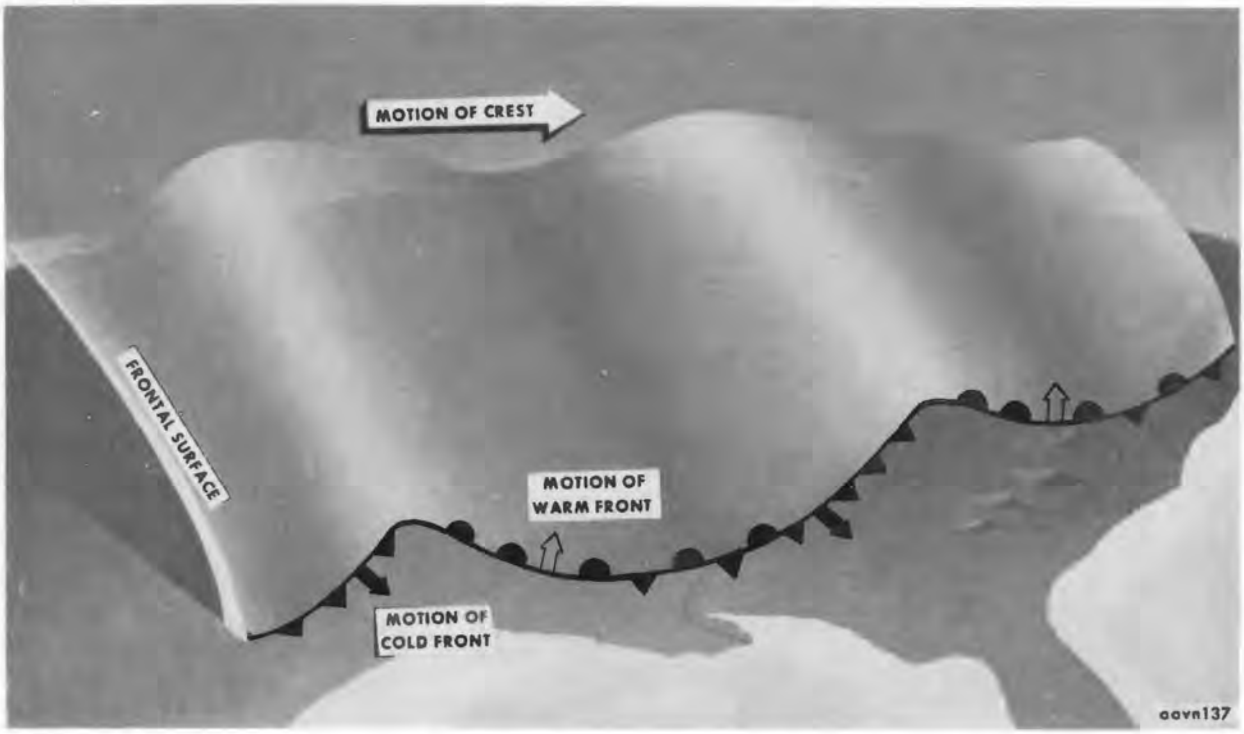


Figure 7-20. Horizontal waves on a front.

settles back to its original position (fig. 7-7). The frontal wave breaks down in a manner similar to the breaking of surf; a large atmospheric whirlpool is created north of the frontal area. The fronts then dissipate due to equal temperatures and dew points across their boundary lines, or become stationary again in a new position south of their original location. If the frontal system does not dissipate, a new wave may form on the stationary front and go through a similar life cycle (*cyclogenesis*).

CHAPTER 8

FOG

8–1. General

Fog is defined as minute droplets of water or ice crystals suspended in the atmosphere with no visible downward motion. It is similar to stratus clouds; however, the base of fog is at the earth's surface, whereas the base of a cloud is at least 50 feet above the surface. Fog may be distinguished from haze by its dampness and gray color. It is a serious hazard during take-offs and landings because it restricts surface visibility. However, unlike other weather hazards, fog is of little concern during the en route portion of a flight. A knowledge of fog types and of fog formation and dissipation processes will enable the Army aviator to plan his flights more accurately.

8–2. Fog Formation

a. High Relative Humidity. A high relative humidity is of prime importance in the formation of fog since neither condensation nor sublimation will occur unless the relative humidity is near 100 percent. Thus, the natural conditions which bring about a high relative humidity (saturation) are also fog-producing processes (i.e., the evaporation of additional moisture into the air or cooling of the air to its dew point temperature). A high relative humidity can be estimated from hourly sequence reports by determining the spread (difference in degrees) between the temperature and dew point. Fog is rare when the spread is more than 4° F.; it is most frequent when the spread is less than 2° F.

b. Light Wind. A light wind is generally favorable for fog formation. It causes a gentle mixing action (par. 4–32), which spreads surface cooling through a deeper layer of air and increases the thickness of the fog. If calm winds exist when other factors are favorable for fog formation, only dew, frost (freezing surface temperatures), or a shallow layer of fog will form.

c. Condensation Nuclei. Condensation nuclei, such as smoke and salt particles, suspended in the air provide a base around which moisture condenses. Although most regions of the earth have sufficient nuclei to permit fog formation, the amount of smoke particles and sulphur compounds in the vicinity of industrial areas is pronounced. In these regions, persistent fog may occur with above average temperature-dew point spreads.

8–3. Fog Dissipation

Fog tends to dissipate when the relative humidity decreases. During this decrease, the water droplets evaporate or ice crystals sublimate and the moisture is no longer visible. Either strong winds or heating processes may cause the decrease in relative humidity.

a. Strong winds cause large eddies in an inversion layer and mix the warm, dry air from aloft with the cool, saturated air at the surface. The mixing widens the temperature-dew point spread, and the fog evaporates near the surface. (Stratus clouds may still exist above the air currents.)

b. Air heated by daytime solar radiation or by the adiabatic process as the air flows downslope increases the air temperature, and the fog evaporates. Therefore, most fogs dissipate shortly after sunrise, and fog is rare on the lee sides of hills and mountains.

8–4. Fog Types and Characteristics

a. Radiation Fog. Radiation fog (fig. 8–1) forms after the earth has reradiated back to space the heat gained during daylight hours. By early morning the temperature at the surface may drop more than 20° F. Since the dew point temperature (moisture content) of the air normally changes only a few degrees during the night, the temperature-dew point spread will decrease as the air is cooled by contact with the cold surface. If the radiational cooling is great enough, and other conditions are favorable, radiation fog will form. Radiation fog is most likely when the—

(1) Sky is clear (maximum radiational cooling).

(2) Moisture content is high (narrow temperature-dew point spread).

(3) Wind is light (less than 7 knots).

Note. These conditions are common over land areas in high pressure cells. The resulting fog often occurs in patches of varying density and size.

b. Advection Fog.

(1) The cause of advection fog formation is the movement of warm, moist air over a colder surface. Advection fog (fig. 8-2) is common along coastal regions where the temperature of the land surface and the water surface contrasts. The southeastern area of the United States provides ideal conditions for advection fog formation during the winter months. If air flows (advection) from the Gulf of Mexico or the Atlantic Ocean over the colder continent, this warm air is cooled by contact with the cold ground. If the temperature of the air is lowered to the dew point temperature, fog will form. Advection fog forming under these conditions may extend over the entire eastern two-thirds of the Nation from the Rockies to Maine. It may persist both day and night until replaced by a drier air mass.

(2) If advection fog forms over water and is carried onshore by the wind, it is often referred to as *sea fog*. Cold ocean currents, such as those off the coast of California, may cool and saturate moist air coming from the warmer areas of the open sea. Sea fog is often very dense both offshore and onshore.

(3) As advection fog moves inland during the winter, the colder land surface often causes sufficient contact cooling to keep the air saturated. The fog may then persist during the day or with a wind speed of 10 to 15 knots.

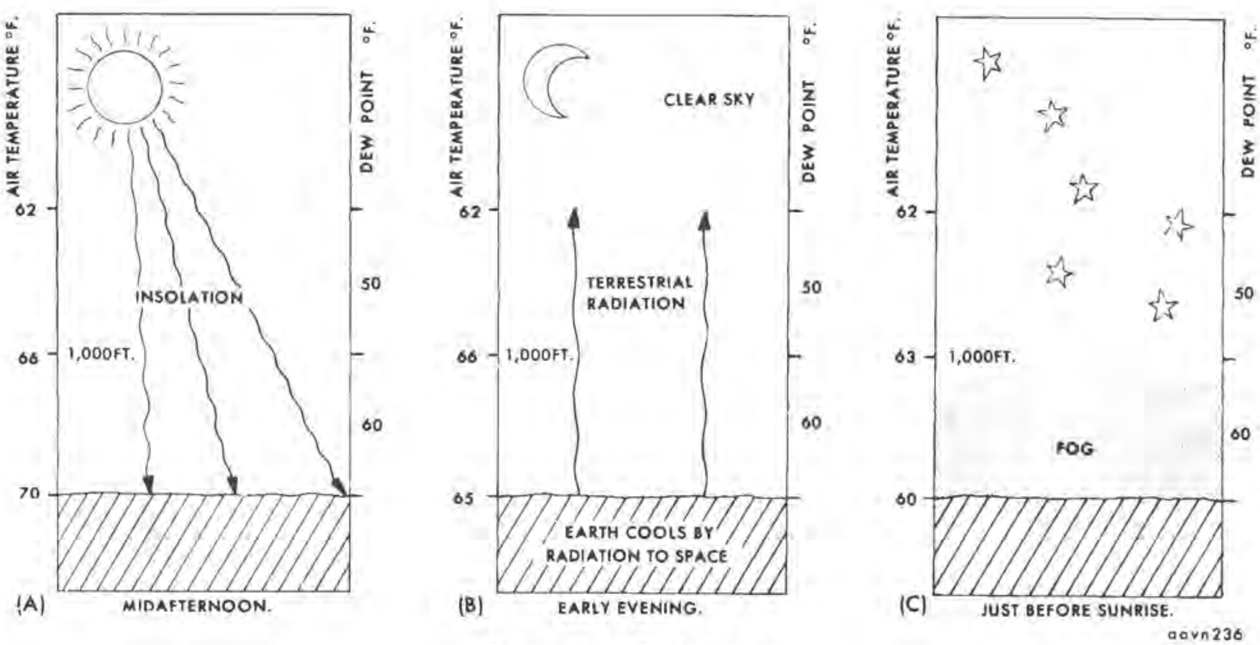


Figure 8-1. Radiation fog.

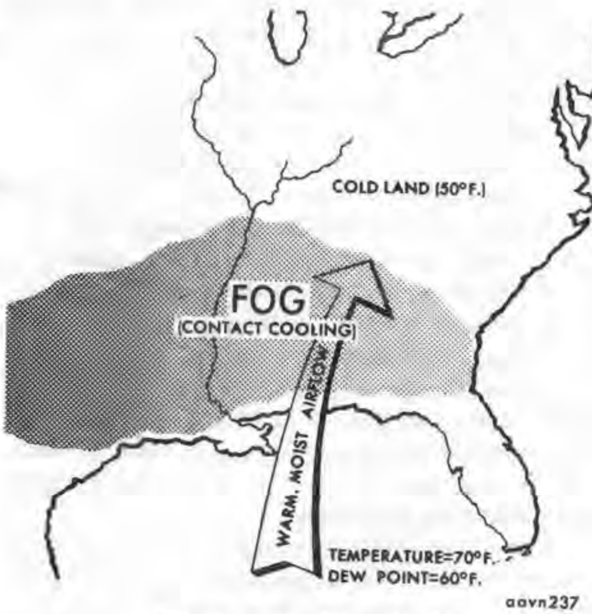


Figure 8-2. Advection fog.

c. Upslope Fog. Upslope fog forms when moist, stable air flows up a sloping land surface. When the air rises, it cools by expansion (adiabatic cooling) as the atmospheric pressure decreases. When the expansional cooling is sufficient to lower the temperature of the air to the dew point temperature, upslope fog may form. The windspeed (pressure gradient) must be adequate to support continued upslope motion; however, if the wind is too strong, the fog may be lifted from the surface, resulting in an overcast of low stratus clouds. Upslope fog is common on the eastern slope of the Rockies as air flows westward from the Missouri Valley or the Gulf of Mexico.

d. Valley Fog. During the evening hours, cold, dense air will drain from areas of higher elevation into low areas or valleys. As the cool air accumulates in the valleys, the air temperature may decrease to the dew point temperature, causing a dense formation of *valley fog.* While higher elevations may often remain clear throughout the night, the ceiling and visibility become restricted in the valley.

e. Ice Fog. When air near the surface becomes saturated in extremely cold regions, fog will form as ice crystals rather than water droplets. At temperatures well below 0° C., water vapor sublimates into ice crystals without passing through a liquid state. The resulting ice crystals are very small and usually persist in an area for many hours as *ice fog.* Atmospheric conditions favoring ice fog formation are common during the winter in north central United States and Canada. On many occasions, however, the air in these cold regions is so free of impurities that sublimation nuclei are insufficient to permit ice fog formations; the air may then become supersaturated. With supersaturated conditions, routine runup of an aircraft engine can supply enough exhaust impurities and moisture to cause sublimation. The resulting ice fog may be serious enough to halt aviation operations at the airfield for hours.

f. Evaporation Fog. Fog formed by the addition of moisture to the air is called *evaporation fog.* Two important types are *frontal fog* and *steam fog.*

(1) *Frontal fog.* Frontal fog is normally associated with slow-moving winter frontal systems (ch. 7). Frontal fog forms when liquid precipitation, falling from the maritime tropical air above the frontal surface, evaporates in the polar air below the frontal surface. Evaporation from the falling drops may add sufficient water vapor to the cold air to raise the dew point temperature to the temperature of the air. The cold air will then be saturated, and frontal fog will form. Frontal fog is common with active warm fronts during all seasons. It occurs ahead of the surface front in an area approximately 100 miles wide, and is frequently mixed with intermittent rain or drizzle. When fog forms ahead of the warm front, it is called *prefrontal fog.* A similar fog formation may occur in the polar air along a stationary front. Occasionally a slow-moving winter cold front with light wind may generate fog. This fog forms in the polar air behind the surface front and is known as *postfrontal fog.*

(2) *Steam fog.* Steam fog forms when cold, stable air flows over a water surface which is several degrees warmer than the air. The intense evaporation of moisture into the cold air saturates

the air and produces fog. Conditions favorable for steam fog are common over lakes and rivers in the fall and over the ocean in the winter when an offshore wind is blowing.

8-5. Flight Planning

a. An aviator should consider the possibility of fog formation at his destination and at alternates during flight planning, especially when the field is on or near the coast or large bodies of water. If a destination is near the water with an onshore wind, an alternate should be selected inland, preferably behind a hill or ridge. A ridge or range of mountains will act as a barrier and prevent fog from moving inland.

b. A check of the facilities in the weather station can help the aviator anticipate areas and times of fog formation. The teletype sequence reports (ch. 11) show the tendency of the temperature-dew point spread; this tendency may be projected to the time when the spread will become critical. Terminal forecasts indicate the expected ceiling and visibility at the forecast time of fog formation and/or dissipation. Surface weather maps and sequence reports, used together, indicate frontal precipitation areas where fog is likely to form. These two facilities also indicate the direction and velocity of the wind in relation to topography. This relationship is beneficial in predicting areas of advection or upslope fog formation.

c. Fog is sometimes difficult to forecast and may be an unexpected landing hazard. If an aviator, upon reaching a destination, finds that fog has formed and the ceiling and visibility are below minimums, he should immediately proceed to the alternate field.

d. The aviator should consult the forecaster about all probable fog areas since slight changes in temperature, moisture, and wind direction or speed can cause fog to form or to dissipate.

CHAPTER 9

ICING

9–1. General

The formation of ice on aircraft wings (fixed or rotary) will disrupt the smooth flow of air over the wings and cause decreased lift, increased drag, and increased aircraft stalling speed. Under ordinary circumstances, the danger of added weight is not too great. If, however, too much lift and thrust are lost simultaneously, weight also becomes an important factor, especially when the aircraft is critically loaded. The formation of ice on some structural parts of an aircraft may cause vibration and place added stress on those parts. For example, vibration caused by a very small amount of ice unevenly distributed on the delicately balanced propeller can place dangerous stress on the propeller and the engine mounts.

9–2. Factors Necessary for Structural Ice Formation

Factors necessary to produce structural icing on aircraft in flight are free air temperature at or below freezing and either the presence of visible liquid moisture (supercooled) or the abundance of sublimation nuclei in areas of high relative humidity.

a. Free Air Temperature. When saturated air flows over a stationary object, ice may form on the object when the free air temperature is as high as 4° C. The surface temperature of the object is cooled by evaporation and by pressure changes in the moving air current. When an object is moving through saturated air, the surface of the object is heated by friction and the impact of waterdrops. On an aircraft in flight, these cooling and heating effects tend to balance; therefore, structural ice may form when the free air temperature is at or below 0° C. The most severe icing occurs with temperatures between 0° and −10° C.; however, under some circumstances, dangerous icing conditions may be encountered with temperatures below −10° C. The accuracy of the aircraft free air thermometer may also be significant in determining potential icing areas. Even when a record is kept of the instrument error or the instrument has been calibrated correctly, other influences (par. 2–7) may cause the temperature reading to be at least 5° F. warmer or colder than the true free air temperature.

b. Visible Liquid Moisture.

(1) Clouds are the most common form of visible liquid moisture; however, not all clouds with temperatures below freezing produce serious ice formation. Although serious icing is rare in temperatures below −20° C., the aviator must recognize that icing is *possible* in any cloud where the temperature is below 0° C.

(2) Freezing rain, which occurs in the cold air below a frontal inversion (par. 7–2), is another form of visible liquid moisture that causes icing. Raindrops falling into a layer of cold air become supercooled when the air temperature is freezing or below. When these subfreezing liquid waterdrops strike an object (such as an aircraft), they turn to ice on the object. Freezing rain is probably the most dangerous icing condition; it can build hazardous proportions of ice in a few minutes. This ice is extremely difficult to break loose.

c. Sublimation Nuclei. Minute particles of such materials as dust and sea salt may act as nuclei for either condensation or sublimation (par. 2–11*c*) of moisture in the atmosphere. Large quantities of sublimation nuclei apparently intensify the sublimation process. An aircraft flying through an air layer with an abundance of nuclei and a high relative humidity may trigger the sublimation process and quickly accumulate a hazardous buildup of ice. Any air layer with a small temperature-dew point spread at altitudes above the freezing level is a potential icing zone. Air layers with temperatures below —40° C. are inferior icing areas because at these low temperatures water vapor tends to crystallize spontaneously. Reports of aircraft icing at temperatures below —40° C. are extremely rare and may have been the result of inaccurate free air temperature readings.

9-3. Types of Aircraft Structural Ice

Aircraft structural icing may be *clear*, *rime*, a combination of clear and rime, or *frost*. The type of ice that forms on a moving structure normally depends on four factors—(1) the free air temperature, (2) the surface temperature of the structure, (3) the surface characteristics of the structure (configuration, roughness, etc.), and (4) the size of the waterdrops.

a. Clear Ice (Glaze). Clear ice, also called *glaze*, is the most serious form of structural ice. It is normally caused by the large supercooled waterdrops in cumuliform clouds where the temperature is between 0° C. and —10° C. or by areas of freezing rain associated with warm frontal systems (fig. 9-1). A typical clear ice formation is transparent or translucent, with a glassy smooth or rippled surface (fig. 9-2). Transparent glaze resembles ordinary ice and is identical to the glaze which forms on trees and other objects as freezing rain strikes the earth. When mixed with snow, sleet, or small hail, the glaze may be rough, irregular, and whitish. Large supercooled waterdrops tend to spread out on a surface before they freeze. The resulting glaze adheres firmly to the surface and is difficult to remove. Glaze formation on the leading edges of wings, antennas, and propellers often takes a blunt-nose shape tapering toward the rear. When deposited as a result of the freezing of supercooled raindrops or very large clouddrops, the glaze deposit may become especially blunt-nosed with heavy protuberances which build outward perpendicular to the leading edge of an airfoil.

b. Rime Ice. Rime ice is normally encountered in regions of small supercooled water droplets, either in stratiform clouds where the temperature ranges from 0° C. to —20° C. or in cumuliform clouds with temperatures from —10° C. to —20° C. It is a white or milky, opaque, granular deposit of ice which accumulates on the leading edges of wings and other structural parts of an aircraft (fig. 9-2). Rime ice has a granulated, crystalline or splintery structure with a rough surface. The interior is composed of very tiny, opaque ice pellets or grains, which may be intermixed with a frost formation of feathery crystalline structure. Some airspaces are present because the small water droplets do not spread out before they

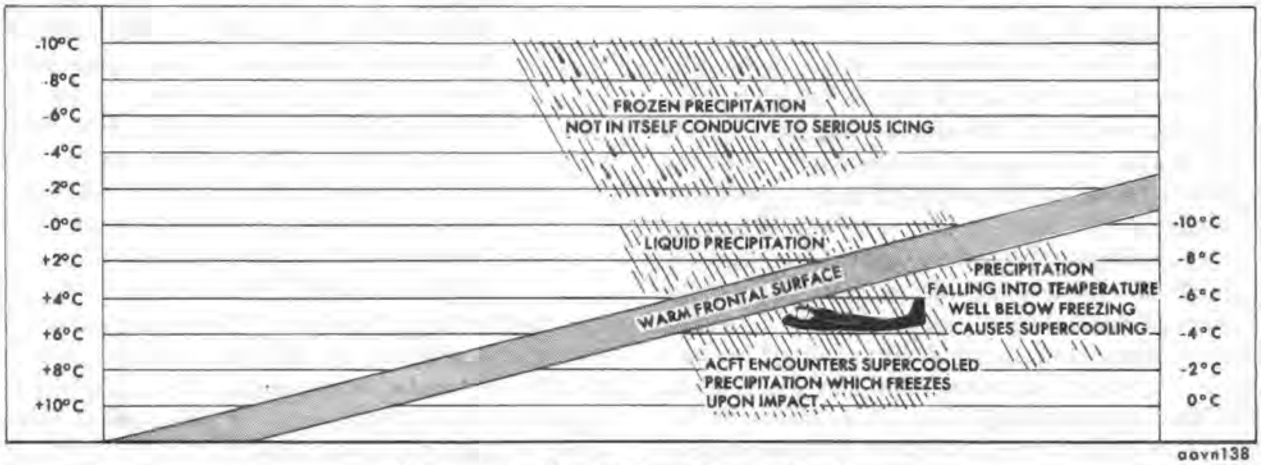


Figure 9-1. Typical freezing rain situation.

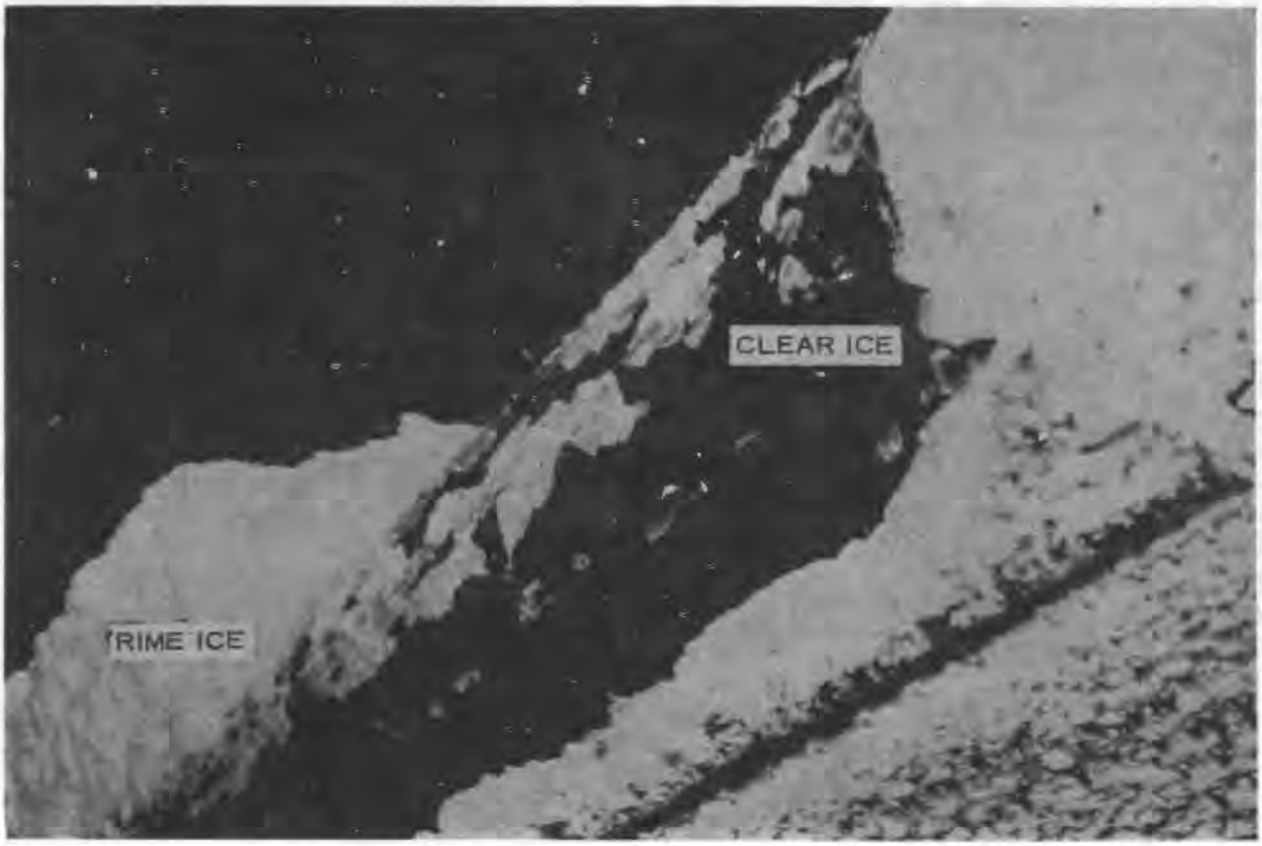


Figure 9–2. Formation of clear (glaze) and rime ice on aircraft wing.

freeze. Rime ice is less compact than glaze and does not adhere tenaciously to exposed objects. Rime often accumulates on the leading edges of exposed parts and projects forward, sharp-nosed, into the airstream. Except for a limited region near the center of the leading edge, rime generally shows little or no tendency to adhere to the contour of an airfoil. When supercooled water droplets strike surface projections of the aircraft, the ice deposit acquires the form of a bulge which may cling rather firmly to the projecting part of the aircraft structure. The protruding bulges may then grow into rough, irregular formations.

c. Frost.

(1) Frost is composed of ice crystals and is formed by sublimation when water vapor contacts a cold surface. On the ground, it may form during a clear night on subfreezing surfaces. (The temperature of the air over the surface may be above freezing.) Frost may also form in flight during descent into warmer moist air or when the aircraft passes from a subfreezing air mass into a slightly warmer moist air mass at the same altitude.

(2) Aviators tend to underestimate the flight hazards of frost formations. Frost increases drag and is particularly hazardous at low airspeeds during takeoff and landing. If frost is left on the aircraft during takeoff, the small ice crystals act as sublimation nuclei and may grow to serious proportions during the takeoff run and climbout. Frost on the windshield may cause restriction to or total loss of visibility.

9–4. Factors Influencing the Rate of Ice Formation

a. Amount of Liquid Water. Ice formation is more rapid in dense than in diffuse clouds. The rate of ice formation increases as the amount of supercooled liquid water in the air increases.

b. Drop Size. Water droplets in the air tend to move with the deflected airstream—the smaller the waterdrops, the greater their tendency to follow the airstream; the larger the drops, the more they resist the deflecting influence (fig. 9-3). Therefore, the large drops (small deflection) collect on a wing more easily than the small drops (large deflection).

c. Airspeed. The rate of ice formation is increased by an increase in airspeed. At very high speeds, such as those attained by jet aircraft, the situation is reversed because skin friction provides enough heat to melt structural ice. At true airspeeds above 575 knots, structural ice is seldom a problem. The critical airspeed at which frictional heating will prevent ice formation varies with the aircraft (type, configuration, surface characteristics, etc.) and the free air temperature.

d. Smoothness of Airfoil. The smoothness of the airfoil surface also affects the rate of icing. After the initial accumulation, the airfoil is aerodynamically unclean and presents a larger surface area to collect the freezing droplets.

9-5. Icing on Fixed Wing Aircraft

a. Wing and Tail Surfaces. Structural ice on wing and tail surfaces, disrupting the flow of air around the airfoil, causes a loss of lift and an increase in drag, and results in a higher-than-normal stall speed (figs. 9-1, 9-4, and 9-5).

b. Propeller. The accumulation of structural ice on propeller hubs and blades causes an unbalance which may produce severe vibration. Ice on the propeller blades spoils the aerodynamic properties of the airfoil and results in a loss of thrust (fig. 9-6). Increased throttle or power settings may then fail to produce sufficient thrust to maintain flying speed.

c. Pitot Tube. Ice in a pitot tube will reduce

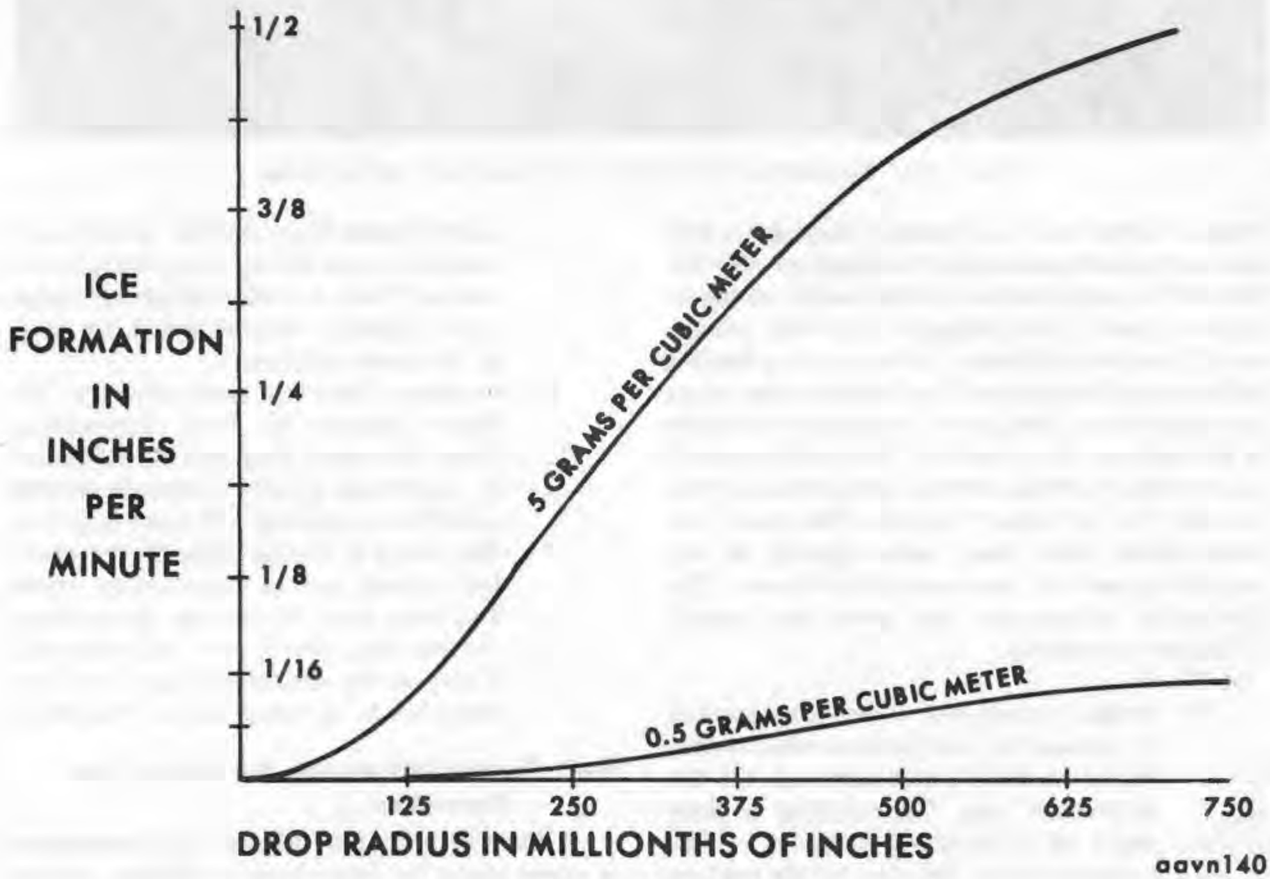


Figure 9-3. Rates of ice formation.

Figure 9-4. Clear ice on unheated wingtip.

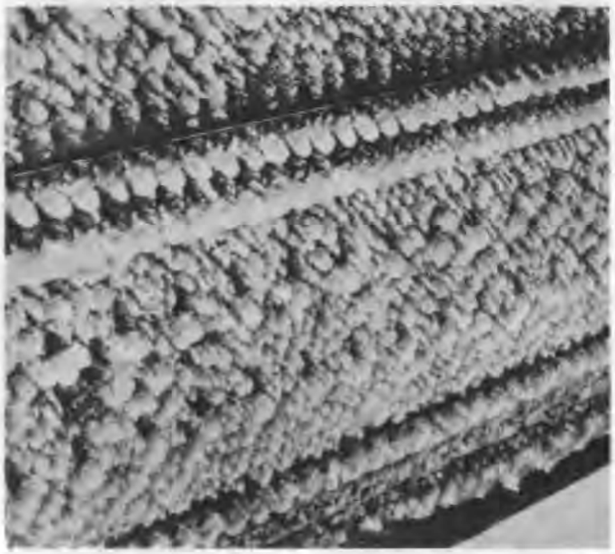


Figure 9-5. Undersurface of wing aerodynamically unclean because of ice formation.

the size of the opening and change the flow of air in and around it. As a result, the flight instruments which are part of the pitot static system (i.e., airspeed indicator, rate of climb indicator, turn indicator, etc.) will become unreliable (figs. 9-7 and 9-8).

d. Windshield. The formation of ice or frost on windshields of aircraft is most frequent during takeoffs and landings. Insignificant frost particles on the windshield prior to takeoff may act as sublimation nuclei during takeoff and reduce visibility to zero before the aircraft leaves the runway. Ice accumulation on the windshield during letdown may prevent visual contact with the runway (figs. 9-9 and 9-10).

e. Control Surfaces. Icing on aircraft control surfaces (ailerons, elevators, rudder, etc.) disrupts their aerodynamic characteristics and/or restricts their movement. A restriction to movement occurs when ice accumulates around protruding hinges.

Figure 9-6. Propeller icing.

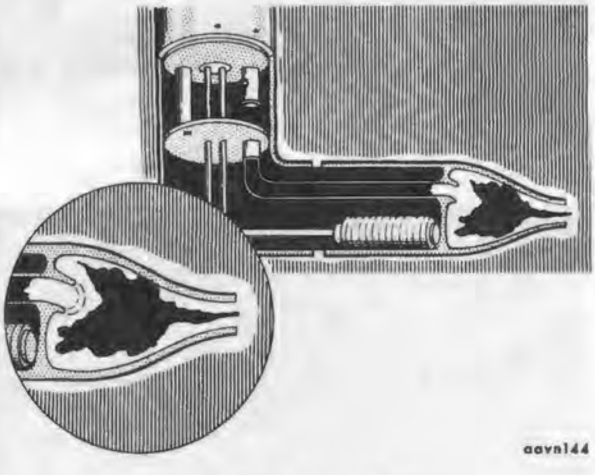


Figure 9-7. Pitot tube ice.

f. Fuel Vent. Heavy ice accretion on aircraft surfaces (fig. 9-11) may block fuel vents. A blocked vent produces a vacuum within the fuel tank which may prevent the flow of fuel to the engine or cause the fuel tank to collapse.

Figure 9–8. Pitot icing.

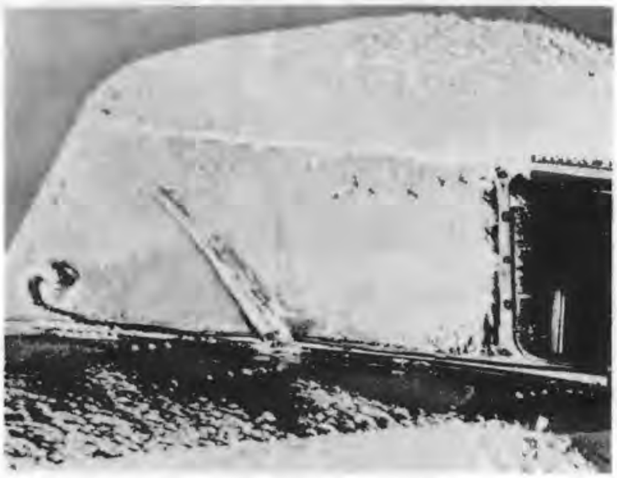


Figure 9–9. Windshield ice.

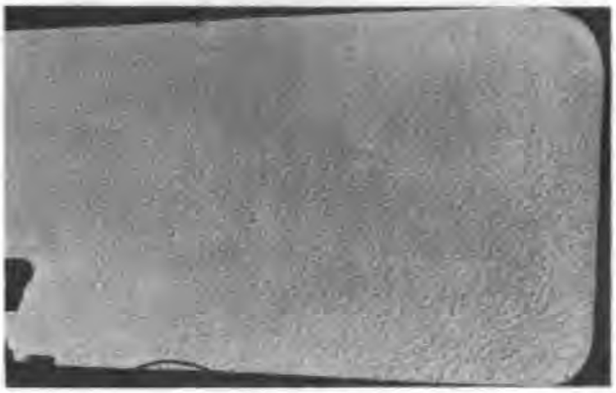


Figure 9–10. Frost and ice on windshield of aircraft.

Figure 9–11. Heavy ice formation on aircraft.

g. *Induction System Icing.*

(1) *Formation and indication.* Induction system ice (figs. 9–12 and 9–13) may form in such places as the airscoop, in curves of the induction system, at the discharge nozzle, in the venturi, or in the throttle (butterfly) valve. One of the best indications of induction system icing is an otherwise unexplained loss of manifold pressure.

(2) *Carburetor ice.* Carburetor ice results from a freezing process quite different from that which forms structural ice. It may form under conditions in which it is impossible for structural ice to form—if the humidity of the free air is high, carburetor ice may occur in clear air when the temperature is as high as 25° C., and is most serious when temperatures and dewpoints approach 20° C. Carburetor ice is the

Figure 9–12. Airscoop icing.

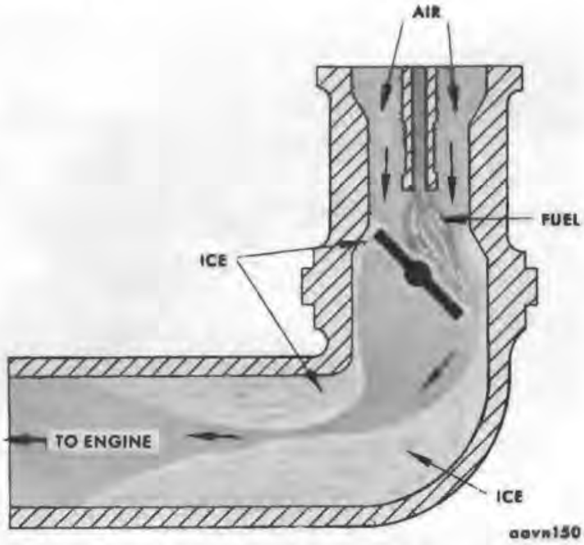


Figure 9-13. Induction system icing.

result of two separate cooling processes during carburetion—

(*a*) Vaporization of gasoline.

(*b*) Decrease of pressure in the venturi tube.

Note. The greatest temperature drop is caused by vaporization of gasoline.

9-6. Icing on Rotary Wing Aircraft

Helicopter structural icing studies by military and civilian research agencies between 1958 and 1960 revealed the following:

a. Rotor Systems. Ice formation on the helicopter main rotor system or antitorque rotor system may produce critical vibration and loss of efficiency or control. Although the slow forward speed of the helicopter reduces ice accretion on the fuselage, the rotational speed of main and tail rotor blades produces a rapid accretion rate on certain surface areas.

(1) *Main rotor head assembly.* Ice accumulation on the swashplates, push-pull rods, bell cranks, hinges, scissors assemblies, and other mechanisms of the main rotor head assembly (fig. 9-14) interferes with collective pitch and cyclic control.

(2) *Main rotor blades.* Several factors tend to reduce ice accretion on the main rotor blades; i.e., the centrifugal force of rotation, the bending and flapping of the blades during rotation, the slow rotational speed of the blades near the rotor head, and the fast rotational speed near the blade tips. However, at a hover a 3/16-inch coating of ice is sufficient to prevent some helicopters from maintaining flight. A critical icing hazard can therefore form rapidly on the center two-thirds of the main rotor blades (figs. 9-15—9-18). The uneven accretion or shedding of this ice formation may also produce severe rotor vibration.

(3) *Tail rotor.* Ice accumulation on either the antitorque rotor head assembly or blades produces the same hazards as those associated with the main rotor. The centrifugal force of rotation and the blade angle of incidence relative to the clouds help to reduce ice accretion on the tail rotor blades, but the shedding of ice from the blades may damage the fuselage or the main rotor (fig. 9-19).

b. Air Intake Screens. Ice accretion on the engine and transmission air intake screens is more rapid than accretion on the rotor systems. This results in inadequate cooling of the engine and transmission. On some helicopters, a loss

Figure 9-14. Main rotor head icing.

Figure 9-15. Main rotor icing.

Figure 9-16. Irregular rotor-blade icing pattern.

Figure 9-17. Smooth rotor-blade icing pattern.

of manifold pressure concurrently with air intake screen icing may force the immediate landing of the aircraft. Freezing water passing through the screens also coats control cables and may produce limited throttle movement and similar control problems (figs. 9-20 and 9-21).

Figure 9-18. Cross section of rotor-blade icing.

Figure 9-19. Tail rotor icing.

c. Other Icing Areas. Induction system icing, windshield icing, and pitot tube icing as presented in paragraph 9-5 is equally applicable to rotary wing aircraft.

Figure 9-20. Engine air intake screen icing.

9-7. Icing in Turbojet Engines

Between 1946 and 1958, 22 percent of the aircraft accidents in which icing was a contributing factor were in turbojet aircraft. Of these, 76 percent of the accidents were caused by airframe icing and 24 percent by induction system icing.

a. Turbojet engines with axial flow compressors are seriously affected by the same atmospheric conditions which cause wing icing. Ice over the inlet guide vanes restricts airflow, thereby producing less thrust, excessive turbine temperatures, and probable turbine failure. Severity of the internal icing conditions is indicated by the turbine tailpipe temperature. The rate of ice accretion is in proportion to the intensity of the icing condition (par. 9-12) and the flow of air through the engine (rpm).

b. Although jet engine icing occurs under the same conditions as wing icing, the rate of accretion is different. The amount of engine icing depends upon the concentration of water and is almost independent of the size of the waterdrops. For a given concentration of water in the atmosphere and for a given airspeed and engine rpm, the engine icing rate will be constant, but wing icing accretion will be lighter with small drops (par. 9-4*b*). Objects which protrude into the airstream with a small radius of curvature (tail surfaces, antennas, and pitot tube braces (fig. 9-22)) provide the most reliable visual indication of the rate of engine icing.

c. A low airspeed will reduce the rate of ice formation both in the engine and on the structural surfaces. However, the aviator should maintain a close watch on turbine tailpipe temperature whenever internal icing is suspected.

9-8. Weather Areas Conducive to Icing

a. Frontal Inversions. When warm air is forced to rise over a colder air mass, a frontal inversion is present (fig. 9-1). Below the inversion, structural icing areas are common in winter.

(1) Warm moist air displaced by the frontal surface cools by expansion and produces thick clouds and precipitation. The raindrops falling from the warmer air through the wedge of cold air may be cooled below 0° C., but the drops will remain liquid if their round shape is not disturbed. When the supercooled waterdrops strike an aircraft, their shape changes and they freeze on the aircraft. The large precipitation drops (freezing rain or freezing drizzle) produce a rapid accretion of glaze in a short period of time. Often the freezing precipitation is mixed with sleet (frozen waterdrops) or snow (ice crystals) as it falls through the cold air to the surface.

(2) An aviator should escape from an area of freezing precipitation by climbing to the warmer air above the frontal inversion. Prior to flight into the frontal area, the altitude of the inversion can be obtained from the Skew T, log p Diagram, from upper air charts, or from teletype weather reports. The inversion layer is indicated by a temperature increase and a distinct wind shift through a relatively narrow atmospheric layer (500 to 1,000 feet). Descending to avoid the freezing pre-

Figure 9-21. Transmission air intake screen icing.

Figure 9-22. Antenna icing.

cipitation may not resolve the icing problem because freezing rain or drizzle may extend to the surface, covering power lines, trees, and runways with a solid coating of ice. Reversing course in flight will prolong the flying time in the serious icing area and increase the ice accumulation.

***Warning:* An aviator should not descend to avoid freezing precipitation unless he knows the temperature at the surface is above freezing.**

b. Suspended Supercooled Water Droplets (Clouds).

(1) *Stratiform clouds.* Stratiform clouds indicate stable air in which either

minute water droplets or ice crystals are suspended. The ice crystals present no icing problem since they do not stick to the aircraft upon impact. The small supercooled water droplets, however, will freeze into rime upon contact with the aircraft. Glaze may form in the rain zones of stratiform clouds, and often a combination of rime and glaze will form in some areas of the clouds. Where icing zones occur in stratiform clouds, aircraft should either be flown *under* the icing zones where the temperature is above freezing or *above* the zones where only ice crystals are present.

(2) *Cumuliform clouds.* Cumuliform clouds indicate unstable air in which strong vertical currents can support supercooled liquid drops. Upon impact with aircraft, these large drops spread out before turning to ice. The resulting glaze adheres tenaciously to the aircraft. Since large waterdrops accumulate rapidly in areas of high liquid concentration, icing quickly becomes a serious hazard in icing zones of cumuliform clouds. Figure 9–3 shows the relation between the rate of ice formation and the drop size when the cloud contains a large amount of liquid water (5 grams per cubic meter) as contrasted to a smaller amount (0.5 grams per cubic meter).

c. Mountainous Terrain. The lifting of conditionally unstable moist air over mountain ranges during the winter is one of the major ice-producing processes in the United States. When *mT* air moves over the Appalachian Mountains, it is often cooled to subzero temperatures. An icing hazard exists for all flights through this air. Similarly, *mP* air approaching the west coast of the United States contains considerable moisture in its lower levels. As the air is forced aloft by the successive mountain ranges encountered in its eastward movement, severe icing zones develop. Figure 9–23 shows typical icing regions along parallel ridges. The most severe icing will take place above the crests of the mountains and to the windward side of the ridges. Usually the icing zone extends about 4,000 feet above the tops of the mountains. In unstable air, the icing may extend to higher altitudes. The movement of a front across a mountain combines two weather areas in which serious icing may occur. A study of icing in the Western United States has shown that almost all the icing conditions occurred where the air was blowing over a mountain slope, or up a frontal surface or a combination of both.

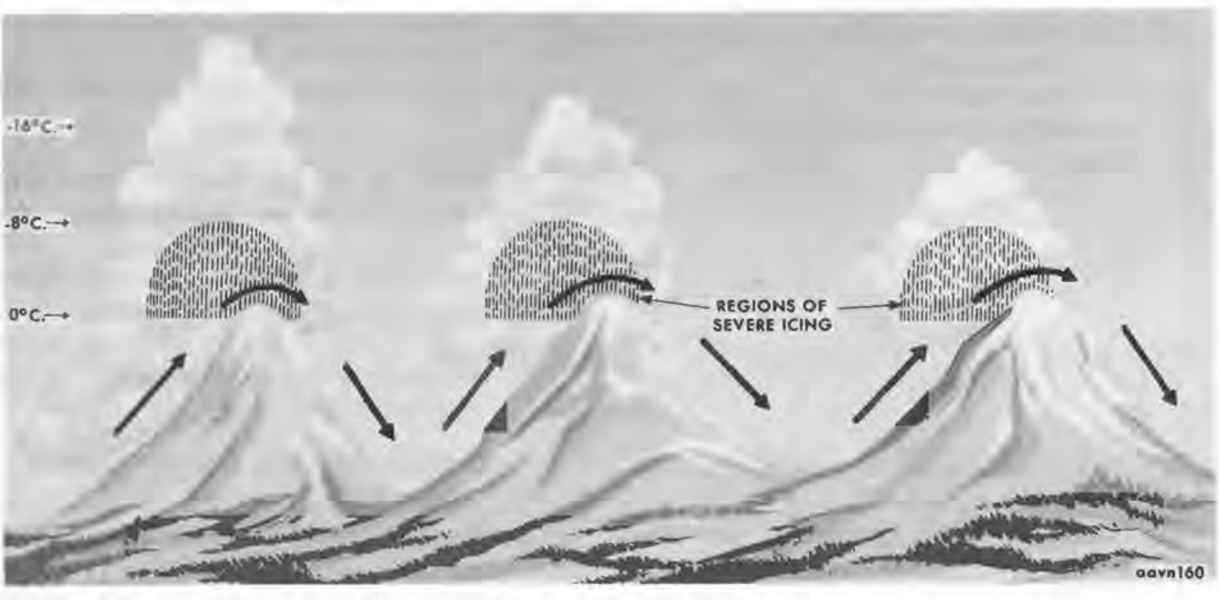


Figure 9–23. Icing over mountains.

9–9. Polar Icing Reports

a. A summary of 14,843 pilot reports compiled during World War II indicates the following icing facts concerning flight operations north of 60° north latitude. (The temperatures used below are free air temperatures as reported by standard aircraft instruments. The reported flight altitudes ranged from 7,000 feet to 12,000 feet, and the reports were for the Alaskan Region.)

(1) Only 1,409 of the total 14,843 pilot reports mentioned icing of any type.

(2) The month of maximum occurrence of severe icing was February.

(3) The month of maximum *icing reports* of all types was February.

(4) The month of least occurrence of icing was September.

(5) Of all types of icing reported, rime, especially moderate rime, was the predominant type found at low temperatures in all seasons.

(6) One case of severe rime was reported at a temperature of −40° C. (Since this summary was made, cases of severe icing have been reported at temperatures as low as −55° C.)

(7) Severe ice in summer was reported at temperatures from 0° C. to −8° C.

(8) Severe ice in the winter was normally reported at temperatures from 2° C. to −8° C.

(9) When observations of icing conditions were possible, icing appeared least at a temperature of −11° C.

b. Light icing was classified as an accretion of a mere trace to 0.2 inch in 5 minutes; *moderate icing,* as a buildup of from 0.2 to 1.5 inches of ice in 5 minutes. *Severe icing* was reported where the rate of accretion was greater than 1.5 inches in 5 minutes.

9–10. Condensed Icing Facts (Structural Ice)

a. General.

(1) Icing conditions should be expected in cloud layers where the air temperature ranges from 0° C. to −20° C.

(2) Icing hazards above the clouds are not great.

(3) Severe icing should be expected in rain or drizzle below a cloud where the air temperature is less than 0° C.

(4) Ice crystals will not adhere to an aircraft.

(5) Icing is severe in winter frontal zones.

(6) Icing is severe in upslope moist air movement over mountains during the winter.

(7) Most structural ice formations are a combination of rime and clear.

b. Clear Ice.

(1) Clear ice is predominant in cumuliform clouds where temperatures range from 0° C. to −10° C.

(2) Clear ice is found in freezing precipitation below clouds.

(3) Clear ice is more hazardous than rime ice.

c. Rime Ice.

(1) Rime is predominant in stratiform clouds where temperatures range from 0° C. to −20° C.

(2) Rime ice is common in cumuliform clouds where temperatures range from −10° C. to −20° C. and the supercooled droplets are less numerous and smaller in size.

9–11. Checklist for Cold Weather Operations

Following is a winter checklist that will help reduce hazards of cold weather flying:

a. Check weather carefully; ask the aviator who just came through.

b. Check NOTAMS.

c. Remove frost and snow before takeoff.

d. Check controls for restriction of movement.

e. Taxi slowly. Use brakes with caution.

f. After runup in fog or rain, check wing and empennage for ice in propeller wash area.

g. Wear sunglasses if glare is bad.

h. Avoid taking off in slush or wet snow, if possible.

i. Be alert for snowbanks during takeoff and landing.

j. Use pitot heater when flying in rain, snow, clouds, or known icing zones.

k. When flying in freezing rain conditions, climb into the clouds where the temperatures will be above freezing (unless the temperature at a lower altitude is *known* to be high enough to prevent ice).

l. Report all in-flight weather hazards.

m. If icing can't be avoided, choose the altitude of least icing. (Glaze ice is common in cumulus clouds; rime ice is common in stratiform clouds.)

n. Use carburetor preheat to prevent ice formation; do not wait until an icing condition exists. Watch the carburetor air temperature, especially between $-5°$ C. and $+10°$ C. Use full carburetor heat to clear it of ice.

o. Watch airspeed. Stalling speed increases with airframe icing.

p. Check wing deicers; use them properly. Do not land with deicers on since they act as airflow spoilers.

q. Avoid making steep turns if the aircraft is heavily coated with ice.

r. Avoid making three-point landings when "iced up." Fly in with power. Before starting a landing approach, slowly move throttle back and forth to make sure the carburetor butterfly valve is free of ice.

s. Maintain carburetor heat whenever carburetor icing is likely.

t. Before takeoff, insure that anti-icing and deicing equipment is in operating condition.

Note. When ice forms on the aircraft, more fuel will be required to reach a destination. Increased drag and ice-preventive measures take workpower away from the aircraft and reduce its cruise range. Therefore, if icing conditions are anticipated, a more conservative cruise control also must be anticipated.

9–12. Icing Intensity

The aviator is responsible for reporting the intensity of icing encountered in flight, either upon completion of the flight or as a pilot report (PIREP, para 11–14*b*) during the flight. The standard criteria for judging the intensity of structural icing follows:

a. Trace of Icing. Ice accumulates on a small probe (projection from the airframe) at a rate of one-half inch per 80 air miles flown. Icing on the airframe is perceptible, but the rate of accretion is nearly balanced by the rate of sublimation. The use of deicing equipment is unnecessary except when icing continues for an extended period of time.

b. Light Icing. Ice accumulates on a small probe at a rate of one-half inch per 40 air miles. Prolonged flight in light icing is hazardous and diversionary action may be necessary. Occasional use of deicing equipment may be required.

c. Moderate Icing. Ice accumulates on a small probe at a rate of one-half inch per 20 air miles. This excessive rate of accretion on the airframe makes even short encounters hazardous. Immediate diversionary action is necessary or the use of deicing equipment is mandatory.

d. Heavy Icing. Ice accumulates at a rate of one-half inch per 10 air miles, or less. Deicing equipment fails to effectively reduce or control this hazardous accretion. Diversionary action is mandatory.

9–13. Deicing and Anti-icing Methods

Deicing and anti-icing methods include the following:

a. Mechanical Boots. The leading edges of wing and tail surfaces may be equipped with rubber skins or boots that fit the contour of the airfoil. During icing situations, compressed air is cycled through ducts in the rubber boots, causing the boots to swell and change shape. The stress produced by the pulsating boots causes the ice to crack so that the airstream can then peel the ice fragments from the boots.

b. Anti-icing Fluids. Anti-icing fluids are used on rotaing surfaces, such as propellers and rotor blades, where the centrifugal force produced by the rotating surface spreads the fluid evenly over the entire surface. Such fluids are effective anti-icing agents because the fluid helps prevent ice from adhering to the coated surface, and the ever-present centrifugal force throws the ice from the surface. Anti-icing fluids will not remove ice which has already formed.

c. Heat. The application of heat to a surface being iced is another method of removing structural ice. Since the leading edges of wings and the tail surfaces are conducive to the most serious icing, these areas may be heated by electrical means or by hot air which is piped from the manifold of the engine. The process of supplying hot air from the manifold gave rise to the name "hot wing" aircraft. However, practical considerations of weight, heat exchange between engine and manifold, temperature effects on the structure of the aircraft, and electrical insulation limit the use of thermal deicing equipment.

CHAPTER 10

THUNDERSTORMS

10-1. General

a. Since an average of 44,000 thunderstorms occur daily over the surface of the earth, it may be necessary for the Army aviator to fly through a thunderstorm or a thunderstorm area to complete a mission. He must be cognizant of the hazards and flight problems presented by thunderstorms to be able to plan and conduct a flight through an area of turbulence and associated phenomena with the same knowledge and confidence that he would have in any other weather situation.

b. When thunderstorms are in the flight area, it is sometimes possible to fly around them. Where flight must be made through thunderstorms, the danger of penetrating them will be reduced considerably if proper techniques are used. Fear will detract from the efficiency of the aviator's responses to the thunderstorm conditions (fig. 10-1) and hinder him in the proper use of penetration technique.

c. The aviator should remain on visual flight rules (VFR) through any known or suspected thunderstorm area, since these cumulonimbus clouds are often concealed by surrounding cloud

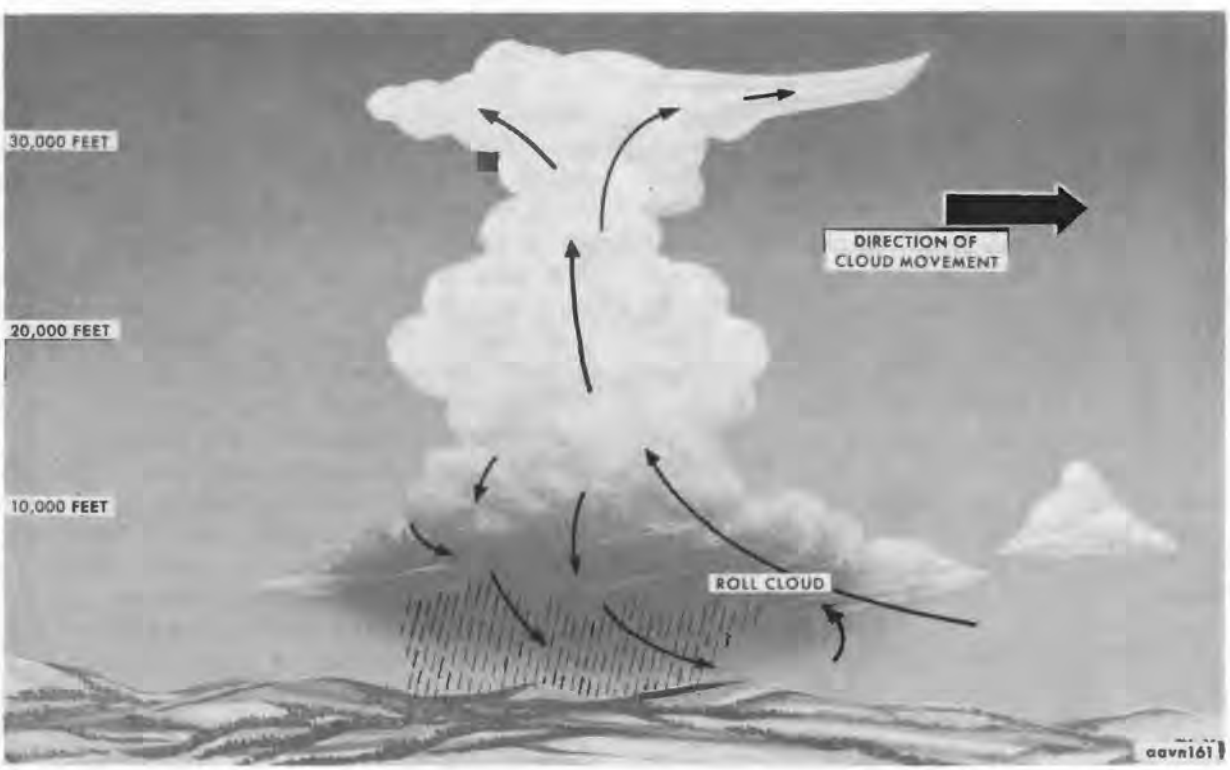


Figure 10-1. Thunderstorm (cumulonimbus) cloud.

layers. This practice eliminates the possibility of unintentional thunderstorm penetration.

d. All thunderstorms are similar in physical makeup, but for purposes of identification they are divided into two general groups—*frontal* and *air mass*. This division gives the aviator an indication of the method by which the storms are formed and the distribution of the clouds over the area. The specific nomenclature of these thunderstorms depends upon the manner in which the lifting action occurs as explained in paragraphs 10-3 and 10-4 below.

10-2. Factors Necessary for Thunderstorm Formation

The minimum factors essential to the formation of a thunderstorm are conditionally unstable air with relatively high moisture content and some type of lifting action.

a. Conditional Instability. Conditional instability exists when the temperature lapse rate of the air involved lies between the moist and dry adiabatic rates of cooling. Before the displaced air actually becomes unstable, it must be lifted to a point where it is warmer than the surrounding air. When this point has been reached, the relatively warmer air continues to rise freely until, at some higher altitude, its temperature has cooled to the temperature of the surrounding air. In the instability process, numerous variables tend to modify the air. One of the most important of these variables is the process called *entrainment*. In this process, air adjacent to the cumulus or mature thunderstorm is drawn into the cloud, primarily by strong updrafts within the cloud. The entrained air modifies the temperature of the air within the cloud as the two become mixed.

b. Lifting Action. Some type of external lifting action is necessary to bring the warm surface air to the point where it will continue to rise freely (the level of free convection). For example, an air mass may be lifted by thermal convection, terrain, fronts, or convergence.

c. Moisture. Warm air lifted upslope may not cause free convection. Air may be lifted to a point where the moisture condenses and forms clouds, but these cloud layers will be stable if the level of free convection has not been reached by the lifting. Conversely, it is possible for dry heated air to rise convectively without the formation of clouds; in this condition, turbulence might be experienced in perfectly clear weather. Cumulonimbus cloud formations require a combination of conditionally unstable air, some type of lifting action, and high moisture content. Once a cloud has formed, the latent heat of condensation released by the change of state from vapor to liquid tends to make the air more unstable.

Note. Stable or dry air at intermediate altitudes may prevent cumulus or towering cumulus clouds from building upward into the thunderstorm stage. Therefore, ideal conditions in the surface air being lifted are no assurance that thunderstorms will develop.

10-3. Frontal Thunderstorms

Thunderstorms may occur within the cloud system of any front—*warm, cold, stationary,* or *occluded.* Frontal thunderstorms are caused by the lifting of warm, moist, conditionally unstable air over a frontal surface. Thunderstorms may also occur many miles ahead of a rapidly moving cold front. The direct cause of these *prefrontal* thunderstorms is uncertain, but they are associated with frontal weather and weaken the thunderstorm activity along the cold frontal surface.

a. Warm Front Thunderstorms. These thunderstorms are caused when warm, moist, conditionally unstable air is forced aloft over a colder, more dense shelf of retreating air. Because the frontal surface is very shallow, the air is lifted gradually. The lifting condensation level is normally reached long before the level of free convection, thus producing stratiform clouds. The level of free convection will normally be reached in isolated areas along the frontal surface where the greatest amounts of water vapor are present in the warm air being lifted. Therefore, warm-front storms are generally scattered. Once the level of free convection is reached, warm-front thunderstorms may form. These storms are extremely difficult to identify because they are obscured by the surrounding stratiform clouds. The aviator, however, may be warned of such a condition by crash static in his earphones with his receiver on a low or medium frequency. A study of the Skew T, log p. Diagram for stations along the proposed flight route often aids the aviator by warning him of the existence of a conditionally unstable lapse rate through the layers of atmosphere in which clouds are forming (figs. 10-2 and 10-3). By referring to the radar summary charts, the aviator can determine the presence and nature of buildups (par. 15-6).

b. Cold-Front Thunderstorms. The forward motion of a wedge of cold air under a mass of warm, moist, conditionally unstable air causes thunderstorms to develop along a cold front. The slope of a typical cold frontal surface is relatively steep (fig. 10-4), so the lifting condensation level and the level of free convection are usually near the same altitude. Cold-front thunderstorms are typically positioned along the frontal surface in what appears to be a continuous line. These storms are easily recognized from the air because they are partly visible from the front and rear of the storm line. However, if the slope of the frontal surface is shallow (fig. 10-5), the lifting action is not sufficient to produce thunderstorms in lines (line squalls). With a shallow front, the thunderstorms form behind the surface front and are widely scattered. Such storms may be concealed by the surrounding cloud layers.

c. Prefrontal Squall-Line Thunderstorms. With rapidly moving cold fronts, the warm, moist, unstable air ahead of the surface front may be displaced by an outflow of cold air ahead of the front for a distance of 75 to 300 miles. The exact origin of the cold air outflow is controversial—the cold air may be a high-altitude outflow from above the frontal surface or a surface outflow from the downdrafts along the cold front. Whatever the cause, a continuous line of thunderstorms, known as a *prefrontal squall line,* frequently forms parallel to the cold front. Prefrontal squall-line thunderstorms are usually more violent than cold front thunderstorms and are most active between noon and midnight. The cold front cloud system usually weakens during the period of the greatest prefrontal squall-line activity, because the warm air displaced by the frontal surface has lost its moisture and energy in the prefrontal thunderstorms. In the United States, tornadoes are

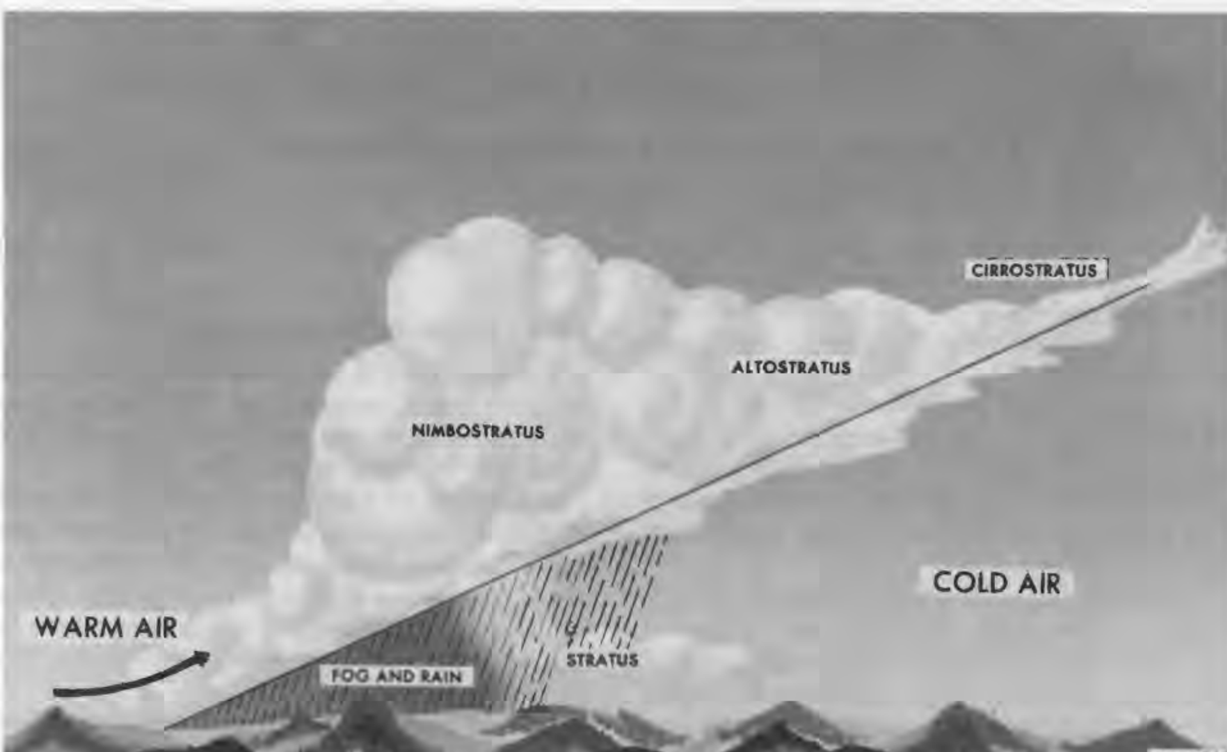


Figure 10-2. Warm front (stable warm air).

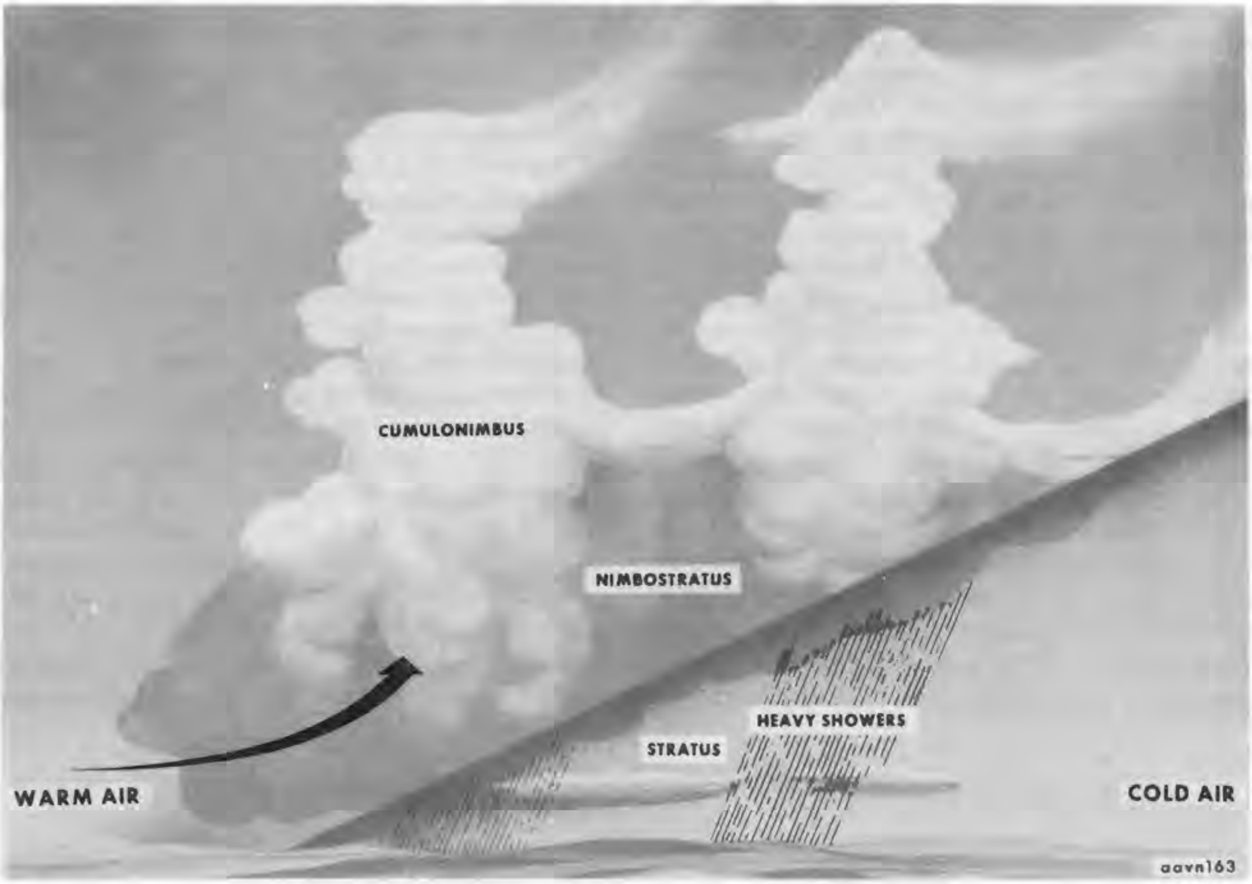


Figure 10-3. Warm front (conditionally unstable warm air).

frequently associated with strong prefrontal squall lines. Prefrontal squall-line thunderstorms are indicated on the surface weather map by an alternate dash-dot-dot line (figs. 10-6 and 10-7).

d. Stationary-Front Thunderstorms. The distribution of these thunderstorms is controlled by the slope of the frontal surface. Abrupt stationary fronts tend to have lines of storms, whereas shallow stationary fronts tend to have the storms widely scattered.

e. Occluded-Front Thunderstorms. Thunderstorms associated with the two types of occluded fronts (warm front and cold front occlusions) are usually cold-front thunderstorms that have been moved into the area of warm frontal weather by the occlusion process (par. 7-5*a*, *c*). They are found along the upper front and are normally strongest for a distance of 50 to 100 miles north of the peak of the warm sector.

10-4. Air Mass Thunderstorms

The two types of air mass thunderstorms are *convective* and *orographic*. Both types form within air masses and are typically scattered or isolated over a large region (fig. 10-8).

a. Convective Thunderstorms. Convective thunderstorms are often caused by solar heating of the land which, in turn, provides heat to the air, resulting in thermal convection. Relatively cool air flowing over a warmer water surface may also produce sufficient convection to cause thunderstorms.

(1) The land-type convective thunderstorms normally form during the afternoon hours after the earth has gained maximum heating from the sun. If

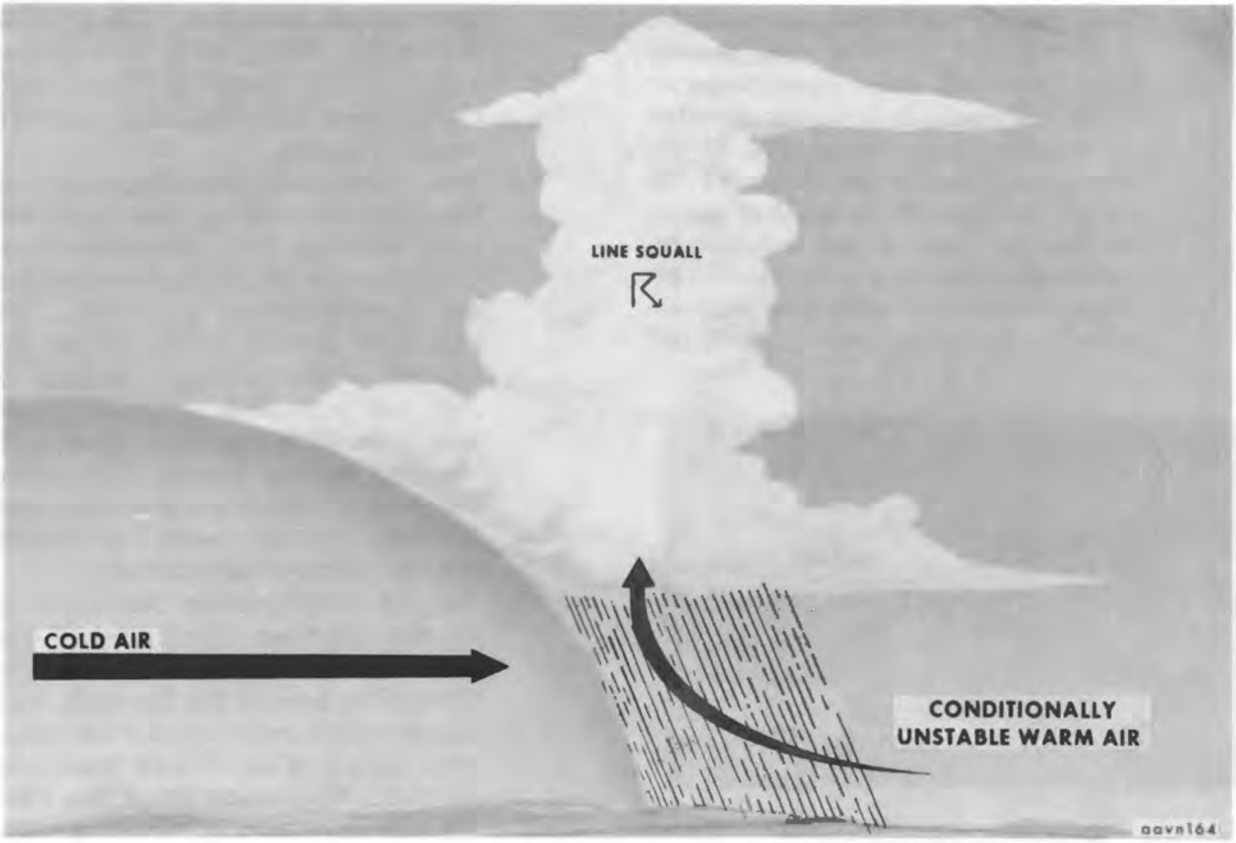


Figure 10-4. Abrupt cold front (conditionally unstable warm air).

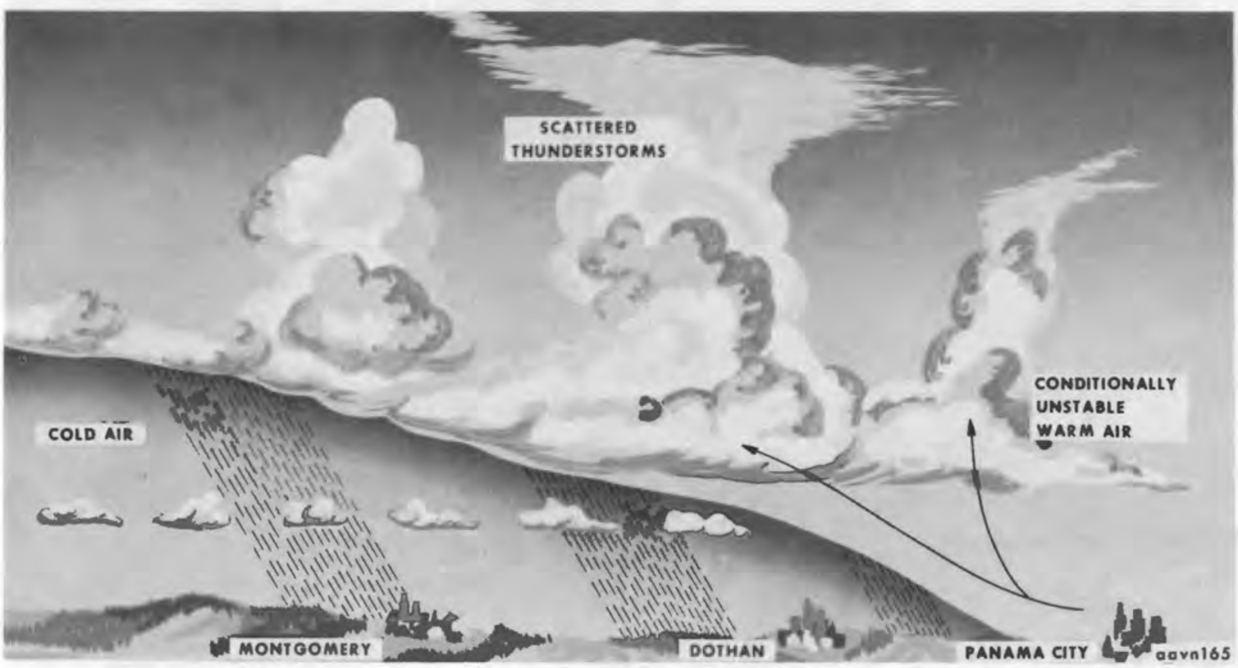


Figure 10-5. Shallow cold front (conditionally unstable warm air).

cool, moist, conditionally unstable air is passing over this land area, heating from below will cause convective currents and result in towering cumulus or thunderstorm activity (fig. 10-9). Dissipation usually occurs during the early evening hours as the land begins to lose its heat to the atmosphere. Although convective thunderstorms form as individual cells, they may become so numerous over a particular geographical area that VFR flight is impossible. These areas of congested cumulus and cumulonimbus clouds should break and dissipate in approximately 2 hours.

(2) Thunderstorms over the ocean are most common during the night and early morning. They frequently occur offshore when the land and sea breezes are blowing toward the water. The cool land breeze is heated by the warmer water surface, resulting in sufficient convection to produce thunderstorms. After sunrise, heating of the land surface reverses the airflow (sea breeze). The thunderstorms then dissipate over the water but re-form over the warmer land surface.

(3) The air mass weather that exists in Florida combines both types of convective thunderstorms (fig. 10-10). Circulation around the Bermuda high carries moist ocean air over the warm land surface of the Florida peninsula. At night, thunderstorms off the Florida coast are caused by the warm water

Figure 10-6. Squall line cloud.

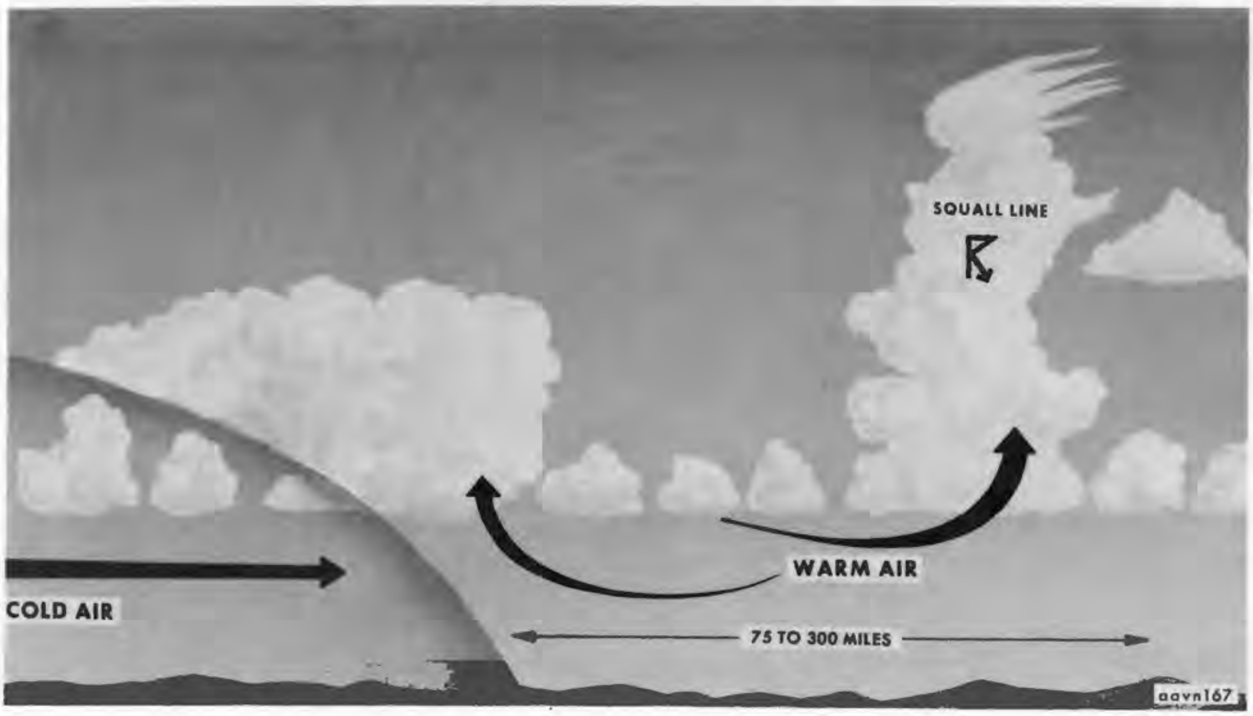


Figure 10-7. Prefrontal squall line.

Figure 10-8. Air mass thunderstorms.

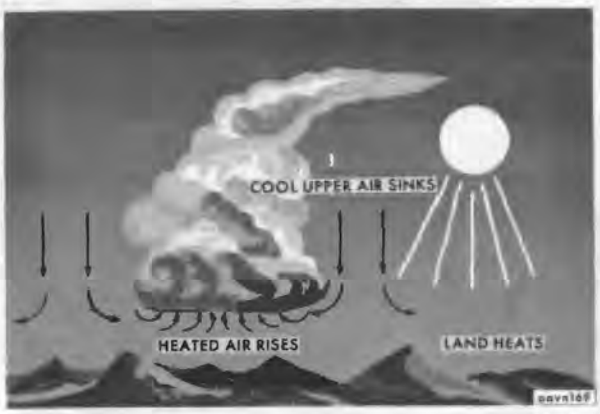


Figure 10-9. Convective thunderstorms.

of the Gulf Stream heating the surface air while the upper air is cooling by radiation to space. This heating from below produces thermal convection over the water. When the sun rises, the heat balance necessary to maintain storm formation over the water is destroyed. By day, the storms appear to move inward over the land areas, but actually dissipate off the coast and reform over the hot land. The heated land surface sets up an unstable lapse rate over the peninsula and causes storm development to continue until nocturnal cooling occurs. Usually, convective type storms are scattered and easily recognized. The visibility in the areas surrounding the clouds is generally excellent (fig. 10-10).

b. Orographic Thunderstorms. Thunderstorms will form on the windward side of a mountain if conditionally unstable air is lifted above the level of free convection. The storm activity is usually scattered along the individual peaks of the mountains, but occasionally it may form a long unbroken line of storms similar to a line squall. The storms persist as long as the circulation causes upslope motion. From the windward side of the mountains, identification of orographic storms may sometimes be difficult because the storm clouds are obscured by other clouds (usually stratiform) below the

Figure 10-10. Convective thunderstorms of Florida.

level of free convection. Almost without exception, orographic thunderstorms enshroud mountain peaks or hills. No attempt should be made to fly under this type of storm unless the opposite side of the area is clearly visible to the aviator and considerable altitude is available between the terrain and the cloud bases (fig. 10-11).

10-5. Structure of Thunderstorms

a. Convective Cells. The fundamental structural element of the thunderstorm is the unit of convective circulation known as a *convective cell.* A mature thunderstorm contains one or more of these cells in different stages of development, each varying in diameter from 1 to 5 miles. By radar analysis and measurement of drafts, it has been determined that each cell is generally independent of surrounding cells in the same storm. Each thunderstorm progresses through a life cycle of from 1 to 3 hours, depending upon the number of cells contained and their stage of development. In the initial stage (cumulus), the cloud consists of a single cell; as the development progresses, new cells may form as older cells dissipate.

b. Stages in Cell Development. The life cycle of each thunderstorm cell consists of three distinct stages: *cumulus, mature,* and *dissipating* or *anvil.*

(1) *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 the cumulus or building stage is an updraft which prevails throughout the entire cell (fig. 10-12). This updraft may vary from a few feet per second to as much as 100 feet per second (65 knots) in mature cells. As an updraft continues through the vertical extent of

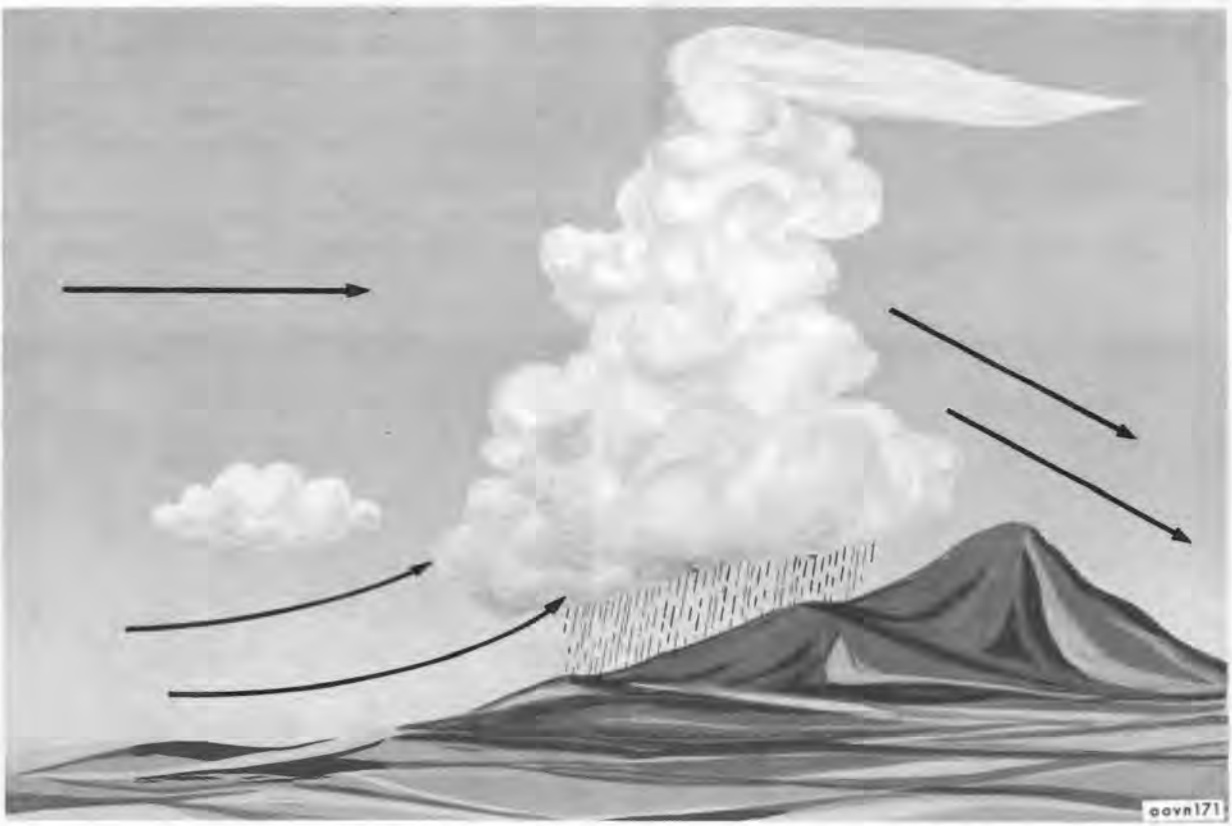


Figure 10-11. Orographic thunderstorm.

the cell, water droplets coalesce, and raindrops are formed.

(2) *Mature stage.* The beginning of surface rain and adjacent updrafts and downdrafts initiates the mature stage (fig. 10-13). By this time, the average cell has attained a height of 25,000 feet. As the drops begin to fall, the surrounding air begins a downward motion. Being unstable, this air becomes colder than its surroundings and its rate of downward motion is accelerated, forming the *downdraft.* The downdraft reaches maximum speed a short time after rain begins to fall in the cloud. Maximum downdrafts occur at all levels within the storm and their speed ranges from a few feet per second to about 40 feet per second (25 knots). Significant downdrafts never extend to the top of the cell because moisture is not sufficient in the upper levels for raindrops to form. At these high levels only ice crystals and snowflakes are present, and their rate of fall is insufficient to cause appreciable downdrafts. The mature cell generally extends far above 25,000 feet—in rare instances up to 70,000 feet. In the middle levels around 14,000 feet, strong updrafts and downdrafts are adjacent to each other. Their friction causes a shear action between the drafts and produces strong and frequent gusts. These gusts may easily flip the aircraft into unusual attitudes and overstress its structure especially during middle-altitude penetrations.

(3) *Dissipating or anvil stage.* Throughout the life span of the mature cell, more and more air aloft is entrained by the falling raindrops. Consequently, the downdraft spreads out to take the place of the weakening updrafts. As this process progresses, the entire lower portion of the cell becomes an area of downdraft. Since updrafts are necessary to produce condensation and latent heat energy, the entire structure begins to dissipate. The strong winds aloft carry the upper section of the cloud into the familiar anvil form

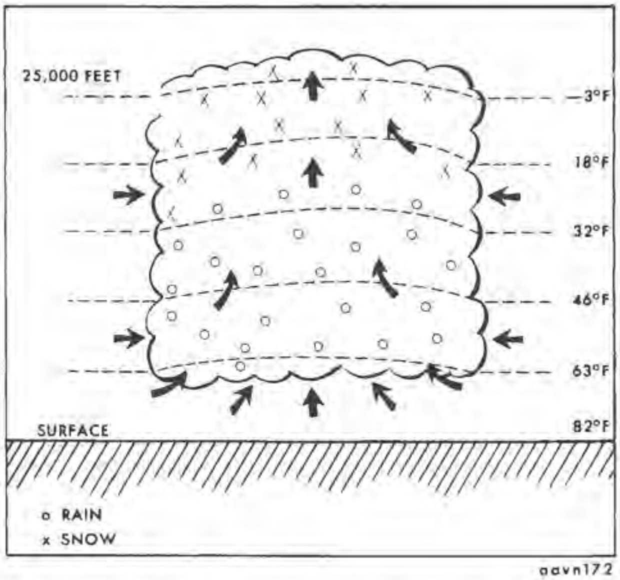


Figure 10-12. Thunderstorm cell, cumulus stage.

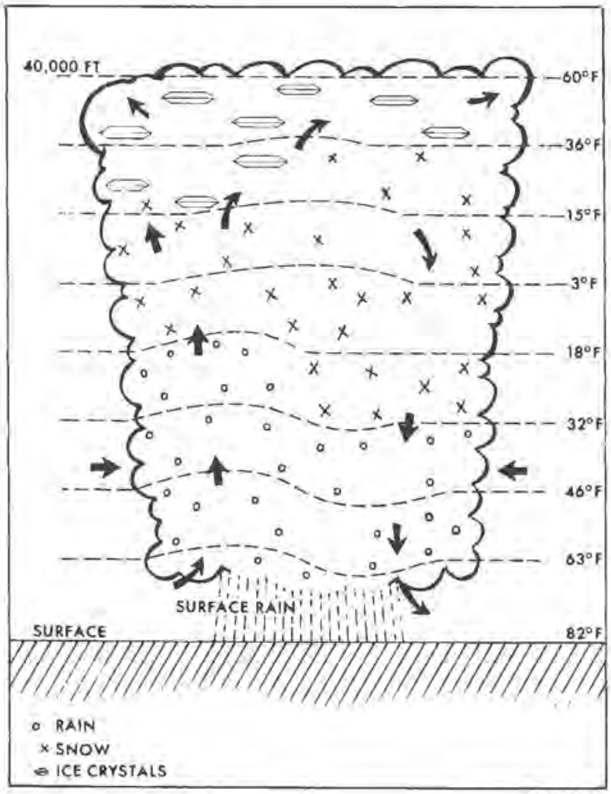


Figure 10-13. Thunderstorm cell, mature stage.

(cumulonimbus cloud), indicating that the storm cell is gradually dissipating (fig. 10-14).

10-6. Vertical Development

The height of storms is of great concern to the aviator determining an optimum flight altitude. Prior to the advent of radar analysis, accurate estimates of cumuliform cloud tops were difficult because of stratified cloud shelves at lower levels.

a. Measurements. Measurements of the vertical extent of thunderstorm activity were made in the Thunderstorm Project by use of radar equipment with a range-height indicator. The closest correspondence between the radar-measured top and the actual top was found to occur during the cumulus stage. Height, distribution, and frequency observations (table II) indicate that most of the storms measured (fig. 10-15) had heights between 25,000 and 29,000 feet. The average of all heights measured in the Thunderstorm Project was 37,000 feet, and the maximum height observed was 56,000 feet. Thunderstorms have been accurately measured, however, as high as 67,000 feet, and severe storms attain heights greater than this.

Note. The Thunderstorm Project was a joint Weather Bureau-Air Force-Navy-N.A.C.A. project conducted from 1946 through 1949. During the project, over 1,300 thunderstorm penetrations were accomplished with specially equipped F-61 aircraft stressed for +7 g's.

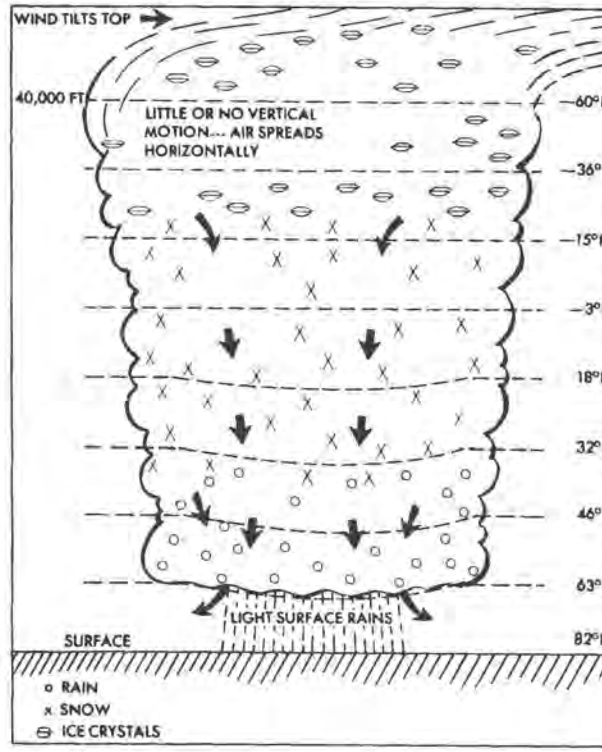


Figure 10-14. Thunderstorm cell, dissipating stage.

Table II. Height, Distribution, and Frequency Observations

Type of storm	Height (thousands of feet)							Average height (thousands of feet)	Number of storms
	25.0-29.9	30.0-34.9	35.0-39.9	40.0-44.9	45.0-49.9	50.0-54.9	55.0-59.9		
Air mass	22	26	19	17	14	11	2	37.2	111
Squall line	16	7	15	13	11	8	0	37.7	70
Frontal	1	1	0	0	2	0	0	37.8	4
Total	69	34	34	30	27	19	2		185

b. Drafts and Gusts Defined. Rising and descending drafts of air form the structural basis of the thunderstorm cell. A *draft* is a large vertical current which is continuous over many thousands of feet of altitude. Speeds of such drafts may either be constant or gradually varying from one altitude to the next. *Gusts* are smaller currents generally caused by a shearing action between the drafts. Individual gusts have a very short horizontal and vertical extent, but these gusts actually cause the severe bumpiness in flight. A draft may be compared to a

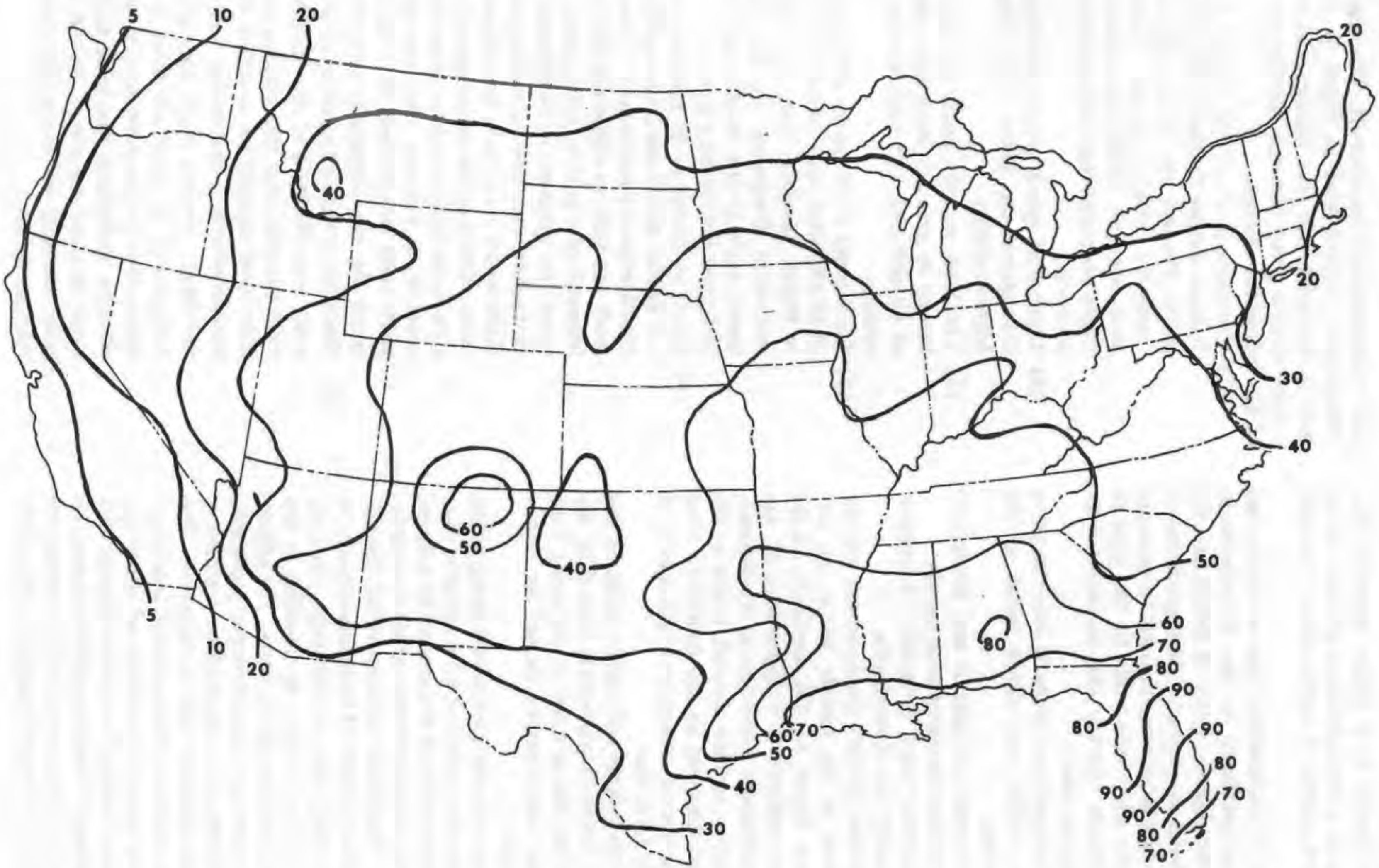


Figure 10–15. Average number of thunderstorms each year.

large 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.

c. Drafts. Considerable data on drafts was collected and tabulated in the Thunderstorm Project concerning the speed of drafts and the effects of drafts on aircraft. Measurements of drafts were computed from changes in pressure altitudes. No effort was made by the pilot to maintain altitude during the measurements. Results are given below.

(1) The maximum updrafts were found in the middle and upper levels of the storms.

(2) The mean of updraft and downdraft velocities increased with height.

(3) Updrafts were generally of greater velocity than downdrafts.

(4) Greater aircraft displacement was observed at the middle levels. An airplane flying at 130 knots at 14,000 feet suffered a displacement of approximately 6,000 feet in 70 seconds, whereas similar aircraft flying at the same airspeed at the 6,000-foot level experienced maximum displacement of only 1,600 feet.

(5) In the middle and upper levels of the cell, mean displacement caused by updrafts was greater in all cases than mean displacement caused by downdrafts.

(6) In no case was an aircraft flying at the 5,000- to 6,000-foot level brought dangerously close to the ground by a downdraft (uneven terrain areas excepted).

d. Gusts. Turbulent motions within the cellular circulation pattern of thunderstorms have considerable effect upon an aircraft. In fact, the severity of a storm may be classified by the intensity and frequency of its gusts. The eddies, which are typical of thunderstorm gustiness, vary in size from only a few inches to whirling masses several hundred feet in diameter. The characteristic reaction of an aircraft intercepting a series of gusts is a number of sharp accelerations or "bumps" without significant change in altitude. These accelerations may be accompanied by pitch, yaw, or roll movements and are caused by abrupt changes in the wind field encountered by the aircraft. The degree of "bumpiness" experienced in flight is related both to the number of such abrupt changes encountered in a given distance and the strength of the individual changes.

(1) Comparison of aviator reports of turbulence during flights in the Thunderstorm Project has shown that gusts occurring with a greater frequency than six per 3,000-foot interval of flight are associated with extreme turbulence.

(2) Light gust speeds were more frequent throughout the storm than those of higher velocity.

(3) The high velocity gusts (24 feet per second or greater) were also observed at all altitudes, but with far less frequency.

(4) Since gusts of all speeds are prevalent at all altitudes, they cannot be avoided in flight; however, there is a definite maximum frequency of the higher speed gusts in the vicinity of 15,000 feet, near the freezing level.

(5) Gusts as strong as 43 feet per second (27 knots) have been measured during thunderstorm penetrations. Most aircraft are built to withstand the stress imposed by a gust of this nature, provided the airspeed is sufficiently low at the time such gusts are encountered. High-speed gusts have been known to cause structural deformation and even structural failure, but in most of these cases it is believed that the strong gusts were encountered at a high airspeed for the particular aircraft.

(6) Since the greatest frequency of strong gusts was observed at the 15,000-foot level (usually near the freezing level), this level should be avoided when thunderstorm penetration becomes necessary. Strong gusts may also be encountered at other altitudes in the storm, and in a few cases severe and/or extreme turbulence has been encountered in clear air above, or out to 5 miles laterally of, developing mature thunderstorms.

10–7. Weather Within the Storm

a. Rain. Upon entering a thunderstorm, the aviator can expect to encounter considerable quantities of liquid water. This moisture is not necessarily falling to the ground as rain. It may be suspended in, or moving with, the updrafts. Rain is encountered below the freezing level in most penetrations of fully developed thunderstorms. Above the freezing level, there is a sharp decline in the frequency of rain. Clouds causing intense precipitation also have strong turbulence within them.

b. Hail.

(1) During the Thunderstorm Project (par. 10–6*a*), hail was encountered at a maximum of 10 percent of the traverses at a given altitude. It was seldom found at more than two levels in the same storm. When it was observed its duration was very short. All intensities of hail reached maximum occurrence at the middle altitudes.

(2) Hail has also been encountered outside the storm cloud. The hailstones may be thrown upward and outward from the cloud under the anvil for as much as 4 miles. Many severe storm clouds contain hail which may never reach the surface.

c. Icing. Clear icing in cumulus clouds and thunderstorms is usually limited in extent because of the cellular structure of the clouds, but may occasionally be very severe. The heaviest icing conditions usually occur just above the freezing level where the greatest concentration of supercooled water droplets exists. Within the cloud, severe icing may occur at any point above the freezing level. Since the freezing level is also the zone where heavy turbulence and rainfall most frequently occur, this particular altitude appears to be the most hazardous.

d. Snow. During Thunderstorm Project research, the maximum frequency of moderate and heavy snow occurred at the 20,000- and 21,000-foot levels. In many cases, a mixture of snow with supercooled raindrops was encountered at all altitudes above the freezing level. A unique icing problem was created by the accumulation of wet snow on leading edges of the aircraft and the resultant rapid accumulation of rime icing.

e. Electricity.

(1) *Lightning.* Observations of the atmosphere during periods of fair weather show that the earth normally has a negative electrical charge with respect to the air above it. With the development of a thunderstorm, the electrical charge in the atmosphere is redistributed in such a manner as to make the upper portion of the thunderstorm cloud positive and the lower portion negative. This in turn induces a positive charge on the ground, reversing the fair weather electric field in the lower levels and producing the distribution of electrical charges shown in figure 10–16.

(*a*) The center of the negative charge is generally located between the freezing level and the −10° C. level, while the positive charge center is located

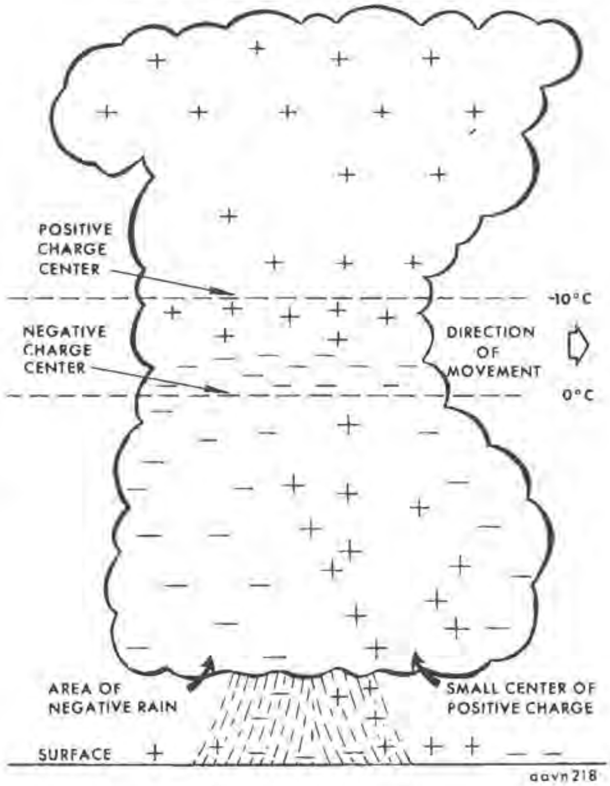


Figure 10–16. Location of electrical charges inside a typical thunderstorm cell.

near the $-10°$ C. level. As the thunderstorm progresses through the mature stage, a small region of positive charge also develops in the downdraft associated with the heaviest rain.

(*b*) Lightning develops in the region between the upper positive charge center and the negative charge center, sometimes called the "lightning hearth region." The lightning is apparently associated with the existence of both liquid water and crystals of ice and snow at the same level—the exact physical origin of lightning is very complex and beyond the scope of this manual.

(*c*) Lightning is most frequently encountered as discharges from a cloud to cloud or within a cloud, but it may also occur from cloud to ground or ground to cloud. The estimated total potential required to produce a lightning stroke 10,000 feet long is 20 to 30 million volts. Its current may vary from 60,000 to 100,000 amperes. The frequency of lightning is greatest at the time the thunderstorm cell reaches its maximum height, just prior to the time of maximum rainfall at the surface.

(*d*) Since lightning may damage an aircraft, the aviator should avoid thunderstorm areas where lightning is most frequent. Lightning strikes are least frequent at the lowest flight levels.

(*e*) Lightning discharges cause loud bursts of static (called *crash static*) on low- and medium-frequency radio receivers. Crash static affects radio communication throughout a distance of many miles from its thunderstorm source.

(2) *Precipitation static.* Static electricity is encountered more frequently by aircraft in thunderstorms than are lightning strikes. Two safeguards the aviator can provide against precipitation static are to reduce speed or change altitude.

(*a*) The *brush* or *corona discharge* is produced when an aircraft in flight accumulates pronounced static charges through contact with ice crystals and dust. The accumulation discharges to the surroundings and causes precipitation static in the aircraft radio receiver. Low- and medium-frequency radio reception may become impossible under such circumstances.

(*b*) On other occasions, an induced charge on the aircraft fuselage tends to strengthen the effect of the electric field in the cloud, and the resulting lightning discharge may use the airplane as a part of the conducting path. External electric fields strong enough to induce localized charges in the aircraft are usually associated with areas of strong updrafts and downdrafts in the thunderstorm. The greater the turbulence, the larger the associated external fields are likely to be.

(*c*) Strong external fields also exist in cloud regions where supercooled water droplets and ice crystals coexist. The production of negative charges is very common near the freezing level within the storm, and in the tops of the clouds where ice crystals are forming.

(*d*) External fields are also found in precipitation areas below the clouds and are generally strong in areas of heavy precipitation.

f. First Gusts. Another significant thunderstorm hazard is the rapid change in wind direction and speed immediately prior to storm passage at the surface. These strong winds are the result of the horizontal spreading out of the storm's downdraft currents as they approach the surface of the 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 of the storm are far greater than those at the trailing edge. This initial wind surge, as observed at the surface, is known as a *first gust*. The speed of this first gust may exceed 75 knots and vary 180°

in direction from the previously prevailing surface winds. First-gust speeds average about 15 knots over prevailing velocities, and average about 40° change in direction of the wind. First gusts usually precede the heavy precipitation and strong gusts may continue for approximately 5 to 10 minutes with each thunderstorm cell (fig. 10–17).

g. Pressure Variations. During the passage of a thunderstorm, rapid and marked surface pressure variations generally occur. These variations usually occur in a particular sequence characterized by—(1) an abrupt fall in pressure as the storm approaches, (2) an abrupt rise in pressure associated with rain showers as the storm moves overhead, and (3) a gradual return to normal pressure as the storm moves on and the rain ceases. Such pressure changes may result in significant altimeter errors on landing if the altimeter setting is not corrected. During the Thunderstorm Project, for each of the days on which one or more thunderstorms occurred, the maximum pressure rise and fall were converted to the equivalent altimeter error and tabulated. In 22 percent of the cases an altimeter setting 10 to 15 minutes old would have resulted in an error of 60 feet or more in the altimeter indication. If an aviator used an altimeter setting obtained during the time of maximum pressure and landed after the pressure had fallen, on 26 percent of the days his altimeter would have read 60 feet or more above the true altitude after he was on the ground. On two occasions, the altimeter would have read over 140 feet above the true altitude when he landed.

h. Ceiling and Visibility. Ceiling and visibility in the precipitation areas under the thunderstorms are normally poor. Because of the heavy precipitation, the ceiling reported is at best an estimate of where the aviator may break out into visual contact with the surface. The weather observer determines the vertical visibility into the precipitation, and this may be significantly different from the slant-range visibility of the aviator. With normal altimeter error and a gusty surface wind condition, the restrictions to visibility and low ceiling associated with the thunderstorm present a further hazard to the landing of aircraft.

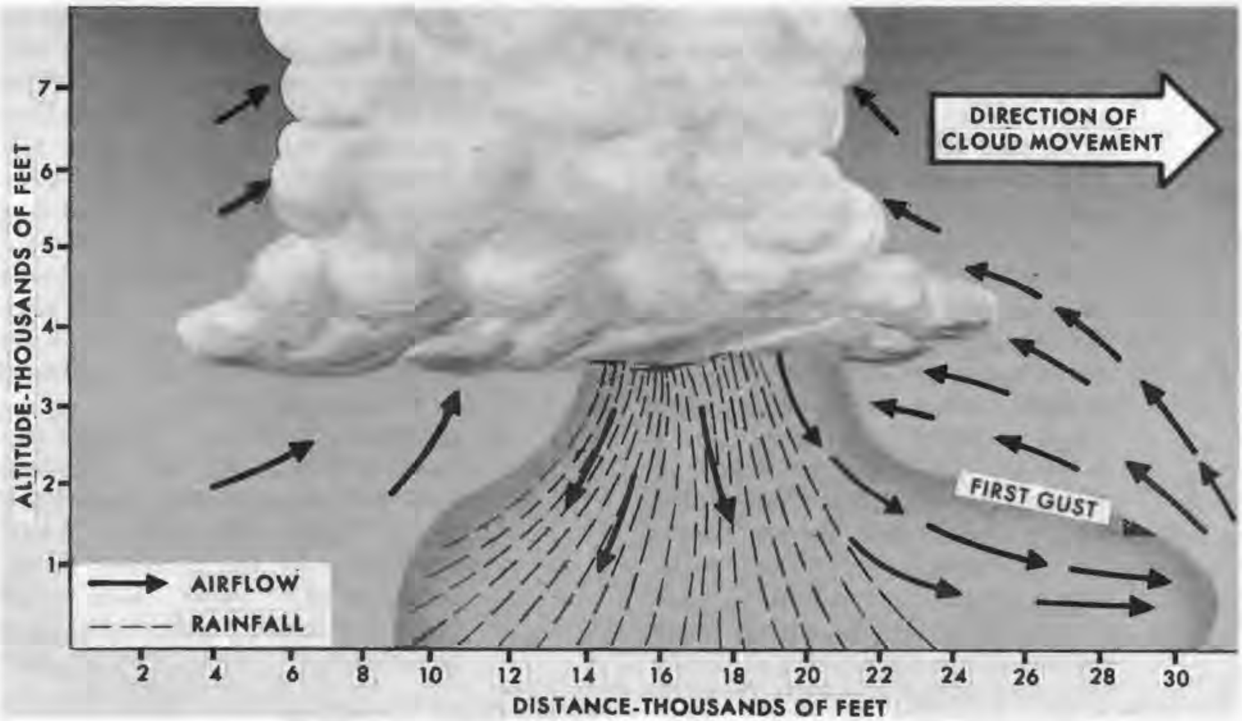


Figure 10–17. Air movement beneath a thunderstorm cell in the mature stage.

i. Turbulence.

(1) *Empirical classification.* Turbulence is the effect of updrafts, downdrafts, and gusts on aircraft in flight. The degree or intensity of turbulence in the atmosphere is classified into four categories.

(*a*) *Light turbulence.* Light turbulence may occur at any altitude and usually covers an extensive area. It is typically encountered during flights through small afternoon cumulus clouds; low-level flights over rough terrain when the surface wind speeds are less than 25 knots; and low-level flights over unequally heated land areas during the period of maximum heating or over warm water surfaces at night.

(*b*) *Moderate turbulence.* Moderate turbulence is typically encountered in the mountain wave up to 150 miles on the lee side of the mountains when the wind is perpendicular to the mountain range at speeds from 25 to 50 knots at ridge level, and on low-level flights when the surface winds exceed 25 knots. It is frequently encountered around and above thunderstorms or in the cirrus tops of cumulonimbus clouds; 5,000 feet above or below the jet stream core, or in areas of jet stream cirrus clouds; in towering cumulus clouds; and in unstable air which is too dry to produce cumuliform clouds of great vertical extent. Moderate turbulence may also occur with upper troughs, cold-core low pressure systems, fronts aloft, or in areas where the wind shear is at least 6 knots per 1,000 feet vertically or 10 knots per 100 miles horizontally.

(*c*) *Severe turbulence.* Severe turbulence is usually encountered in the mountain wave as much as 50 miles to the lee of the mountains when the winds are perpendicular to the mountain range at speeds from 20 to 50 knots at ridge level, and within mature thunderstorms. It may occasionally be encountered in jet streams or towering cumulus clouds.

(*d*) *Extreme turbulence.* Extreme turbulence is the strongest form of convection. It is typically encountered in the roll cloud of the mountain wave when winds are perpendicular to the mountain range at speeds exceeding 50 knots at ridge level, and with standing wave action or strong wind shear. It is frequently associated with growing thunderstorm cells where hail, heavy rainshowers, or heavy thunder is reported.

(2) *In-flight classification.* Another method of classifying turbulence is with regard to its effect on the aircraft in flight. This classification may be useful to the aviator in reporting turbulence and its effect on his particular aircraft.

(*a*) *Light turbulence.* Light turbulence *may* require the use of seat belts. It produces a variation in airspeed from 5 to 15 knots. Loose objects in the aircraft remain at rest during flight.

(*b*) *Moderate turbulence.* Moderate turbulence *requires* the use of seat belts. Airspeed is affected, varying from 15 to 25 knots. Objects loose in the aircraft tend to slide or roll.

(*c*) *Severe turbulence.* Severe turbulence causes the aviator to lose control of the aircraft momentarily. The occupants are thrown violently against seat belts and the seat. Loose objects are tossed about the aircraft, and the airspeed is affected in excess of 25 knots.

(*d*) *Extreme turbulence.* Extreme turbulence is relatively rare. The aircraft will be tossed about and control is practically impossible. Rapid fluctuation of the airspeed occurs in excess of 25 knots. Such turbulence may cause structural damage to aircraft.

10-8. Flight Techniques

In planning a flight into existing or expected thunderstorm areas, the aviator should try to determine whether the thunderstorms will be sufficiently scattered to permit circumnavigation, or will be sufficiently numerous to require flight through them. Radar weather reports are helpful in locating thunderstorm areas and in determining how numerous the storms are. The aviator should also check SIGMETS, PIREPS, **AIRMET's** , and SCAN reports (chs. 11 and 16), for the latest information available on storm areas along his route. In consulting with the meteorologist, the aviator should learn the height of the freezing level as an aid in selecting the proper flight altitude to avoid maximum lightning and icing areas. When a radar scope is available at the weather station, the aviator should check the radar picture to orient to the location and intensity of the storms in the immediate area. The aviator must then decide if it is possible to circumnavigate the storms or to avoid them by over-the-top or under-the-base flight. If all routes to avoid the storm are closed, he must decide if the mission is important enough to warrant penetrating the storm clouds.

a. Avoiding the Storm.

(1) *Circumnavigation.* Circumnavigation presents no special flight problems. When circumnavigation is possible (as in isolated air-mass storms), the aviator alters his course to go around the storm. Since most thunderstorms are less than 25 miles across, a slight detour to one side or the other adds negligible time and distance to the flight route. With a line of thunderstorms, circumnavigation by flying through "thin spots" between storm centers may be possible. Since another thunderstorm may lie at the end of the "thin spot," however, the aviator should contact METRO on 344.6 megacycles (par. 15-7) for guidance in selecting the proper "thin spots" for penetration.

(2) *Over-the-top flight.* Over-the-top flight is normally impossible in present Army aircraft because of altitude and oxygen limitation.

(3) *Flying under the base.* When circumnavigation is impossible, flight may be possible under the base of the storm if it lies over the sea or over flat open country. Flights should never be conducted under the storm in mountainous areas unless there is a definite ceiling with good visibility underneath. Storms in mountains customarily have their bases below and often around peaks. When flying underneath storms, choose an altitude one-third of the distance between the ground and the base of the clouds and circumnavigate the heavy rain shower areas. Since the bases of storms usually average about 3,000 feet (except in mountainous regions), this altitude will provide adequate terrain clearance and avoid the worst turbulence of the storm region.

b. Penetration of Storm. When it is not possible to avoid the storm, the aviator must decide if his mission is urgent enough to require penetration. Since directional changes place additional stress on the aircraft structure, the aviator should not attempt to turn back once the penetration is begun. The lower in the storm the penetration, the less the chance of encountering severe turbulence, hail, and structural icing; also, the less the chance of being struck by lightning. Adequate terrain clearance should be considered in the selection of a penetration level. The minimum penetration altitude should be 4,000 feet above the highest terrain in the area. The pressure altimeter in the aircraft indicates the approximate altitude above sea level. A rule of thumb for the selection of a penetration level is—minimum 4,000 feet of terrain clearance and indicated free air temperature of at least +5° centigrade. It should be remembered that free air temperature gages are often 1° to 3° in error. Most aircraft operator's manuals recommend a penetration altitude of 6,000 feet above the terrain. Thunderstorm Project results show the best penetration altitude is 4,000 feet to 6,000 feet above the terrain.

(1) *Preparing for penetration.* Since both direction and attitude of the flight are to be maintained by reference to the gyro instruments, they should be checked carefully before entering the storm. To guard against

temporary blindness from bright flashes of lightning, dark glasses should be worn and the cockpit lights should be turned on full. The aviator should turn off all radio equipment rendered useless by static, and use VHF or UHF frequencies which are not significantly affected by static. The carburetor mixture should be set FULL RICH.

(2) *Speed of flight.* The faster a plane is flying when it strikes an updraft or downdraft, the greater the shock will be. The operator's manual for the particular aircraft gives the correct range of speed for penetration. If hail is encountered, the aviator should slow the aircraft to the minimum speed recommended for flights in severe turbulence.

(3) *Icing.* Since ice formation in the pitot tube and carburetor is probable, heat should be applied to both.

c. Flight Through Thunderstorm.

Warning: Because of the potential hazards of thunderstorm flying, unnecessary penetration of thunderstorms will be avoided. The experience of airline pilots and others operating large aircraft has shown that it is possible to fly thunderstorms in reasonable safety IF crews are experienced in thunderstorm flying, IF suitable aircraft are used, and IF the proper flight techniques are used. Much study has gone into developing techniques for thunderstorm flying, but not all aviators experienced in thunderstorm flying are in full agreement as to the best techniques. The rules that are generally accepted by experienced aviators and which appear to be substantiated by the Thunderstorm Project are—

(1) Accomplish thunderstorm penetration at 4,000 to 6,000 feet above the terrain since this is the softest altitude in most storms.

(2) Fly at the airspeed or power setting recommended in the operator's manual.

(3) Establish airspeed and power settings before entering the storm.

(4) Fly at constant attitude and power setting as far as possible. Erratic reading of airspeed result from vertical drafts past the pitot tube and the clogging effects of rain and ice.

(5) Avoid all unnecessary maneuvering—to prevent adding maneuver loads to the loads already being imposed by the turbulence.

(6) Avoid use of the autopilot. A constant altitude device, the autopilot will dive the aircraft to compensate for an updraft and climb it in a downdraft. In updrafts excessive airspeeds may be built up, and in downdrafts the airspeed may approach the stalling speed.

(7) Hold a reasonably constant heading through the storm. Wandering will only prolong the flight and increase the dangers.

PART TWO

WEATHER FACILITIES AND THEIR APPLICATIONS

CHAPTER 11

TELETYPE SEQUENCE REPORTS

11-1. General

Teletype circuits provide the most rapid means of collecting and relaying existing weather condition data over a wide area. They are also useful for checking weather trends, for amending and verifying forecasts, and for supplementing other more infrequently reported data. The frequency of teletype sequence reports makes them valuable tools for the aviator and the forecaster.

11-2. Reporting Agencies

When an aviator is planning a flight, weather reports normally will be available from Weather Bureau stations, Flight Service stations, and all military installations with aircraft operations. The U.S. Weather Bureau is responsible for making weather observations. The Federal Aviation Agency (FAA) is responsible for transmitting these reports from civilian stations. The Air Weather Service (Air Force) is responsible for weather observations taken and transmitted by Air Force and Army installations. The Naval Weather Service satisfies the weather requirements at naval air stations. To obtain complete weather coverage, the various weather agencies in the Zone of Interior always exchange their reports and, during peacetime, this exchange of weather data is international in scope.

11-3. Teletype Circuits for Sequence Reports

a. General. Teletype aviation weather sequences are transmitted from hundreds of observation points and relayed to other weather stations over a network of numbered teletype circuits (called teletype *service A*). These circuits are established on a geographical basis and are used to collect the weather reports for designated geographical areas. There are approximately 23 circuits in the United States with an average of 25 stations in each circuit area. The FAA operates the majority of the circuits. The FAA and Weather Bureau transmit and receive reports on the FAA circuits. The military services use the remaining circuits for transmitting and receiving the Air Force, Army, and Navy reports. FAA and military circuits are frequently housed in the same weather station; the teletypewriters operate at approximately 100 words per minute and only a few minutes are required to collect all the reports from any one circuit (*the primary collection*). When a station transmits a report, all other stations on the circuit receive the information simultaneously. Each FAA circuit has a monitoring station which has teletype communications with other circuits and special forecast centers. When the local circuit has completed its scheduled primary collection, the monitoring station then relays reports from other circuits (FAA and military) through the local network to provide the local station with all the reports necessary for its operation.

b. Circuit Headings. The circuit headings enable the aviator to locate the reports needed for a particular flight.

(1) *SAUS 8 KWRF 150300Z.* The *SAUS* is a heading used for military reports. The *8* is the circuit number. A map of the United States showing the location of each circuit ((A), fig. 11-1) is on display in each weather station.

The reports are collected for each circuit and displayed on individual clipboards numbered to correspond to the circuit areas. The *KWRF* is the identifier for the consolidated weather relay center at Tinker AFB, Oklahoma. This center programs the Air Force, Army, and Navy reports into appropriate circuits for transmission throughout the United States. The *150300* is the date-time group. The first two digits (15) indicate the day of the month, and the next four digits (0300) indicate the time on the 24-hour clock. The *Z* indicates the date-time group is in *Z*ulu (GCT) time. (See fig. 11–2 for an example of sequences extracted from the military primary collection.)

Note. Convert Zulu (Greenwich) time to local standard time by subtracting 5 hours for eastern standard time (Z − 5 = EST), 6 hours for central standard time (Z − 6 = CST), 7 hours for mountain standard time (Z − 7 = MST), and 8 hours for pacific standard time (Z − 8 = PST).

(2) *028 SA28142000*. The *028* is the circuit number identifying the geographical area from which the subsequent sequence reports were transmitted ((B) fig. 11–1). The *SA* is a heading used by Weather Bureau and Flight Service (FAA) stations. The *28* is a repeat of the circuit number, and the *142000* is the date-time (Zulu) group (fig. 11–3).

11–4. Types of Reports

The aviator should be familiar with the two normal types of teletype sequence reports.

a. Record (Hourly). Record reports are transmitted under the headings of *SAUS* and *SA* every hour on the hour and are frequently referred to as *hourly reports*. All of the weather elements and specified remarks are transmitted in the record reports (figs. 11–2 and 11–3) as required by Circular N, Manual of Surface Observations.

b. Significant Changes and Notices to Airmen (SCAN). Between the scheduled hourly reports (*a* above), the FAA monitoring stations and the Air Force weather relay center (KWRF) scan the reporting stations on the various circuits to obtain reports of significant weather changes and notices to airmen (NOTAM's, para 11–14*e*).

(1) Assuming that 10 percent of the stations on a circuit have a significant change to report, the KWRF scanning net is able to complete a scanning cycle in less than 3 minutes. Each station on the eight military circuits thereby has an opportunity to report significant weather changes every 3 minutes. The FAA variable scanning system requires approximately 5 minutes to complete a scanning cycle. Scans are scheduled for transmission at 15, 30, and 45 minutes past each hour. Thus the SCAN's provide the aviator with the most current weather information available for flight planning.

(2) The SCAN reports (figs. 11–4 and 11–5) include the time of observation, sky condition, visibility, present weather, obstructions to vision, wind, and appropriate remarks. The altimeter setting is often reported after the wind speed value.

(3) The criteria for judging a *significant* weather change are contained in Circular N, Manual of Surface Observations. Some illustrations of these criteria follow.

(*a*) Ceiling decreases or increases by specified values.

(*b*) Clouds not previously reported form with bases below 1,000 feet, or below the highest instrument minimum for the particular airfield.

(*c*) Visibility values decrease or increase to specified distances.

(*d*) A tornado is observed or disappears.

(*e*) A thunderstorm begins, increases in intensity, or decreases.

(*f*) Hazardous precipitation begins or ends.

(*g*) Precipitation, other than very light, begins.

(*h*) Wind shifts or increases abruptly to exceed 26 knots.

(*i*) Any meteorological situation occurs that the observer believes is important to the safety or efficiency of aircraft operations.

(4) Many of the SCAN reports and some of the hourly reports are logged in the weather stations as "special" observations. When these specials are transmitted the Weather Bureau station identifier in the report may be followed by an *S*.

11–5. Station Identifiers

At the prescribed time for reporting, the monitoring station transmits the circuit heading and the stations report in a uniform sequence under the heading. Each station in the United States and in Mexico is identified by three letters; in Canada, by two letters. The identifiers for any station are available in the weather station (usually on clipboards). They are the same as the identifiers used in navigation publications.

11–6. Sky Condition and Ceiling

a. Sky Condition. The sky condition is transmitted after the station identifier. Standardized symbols (fig. 11–6) indicate the amount of sky covered by clouds or the amount obscured by surface-based phenomena.

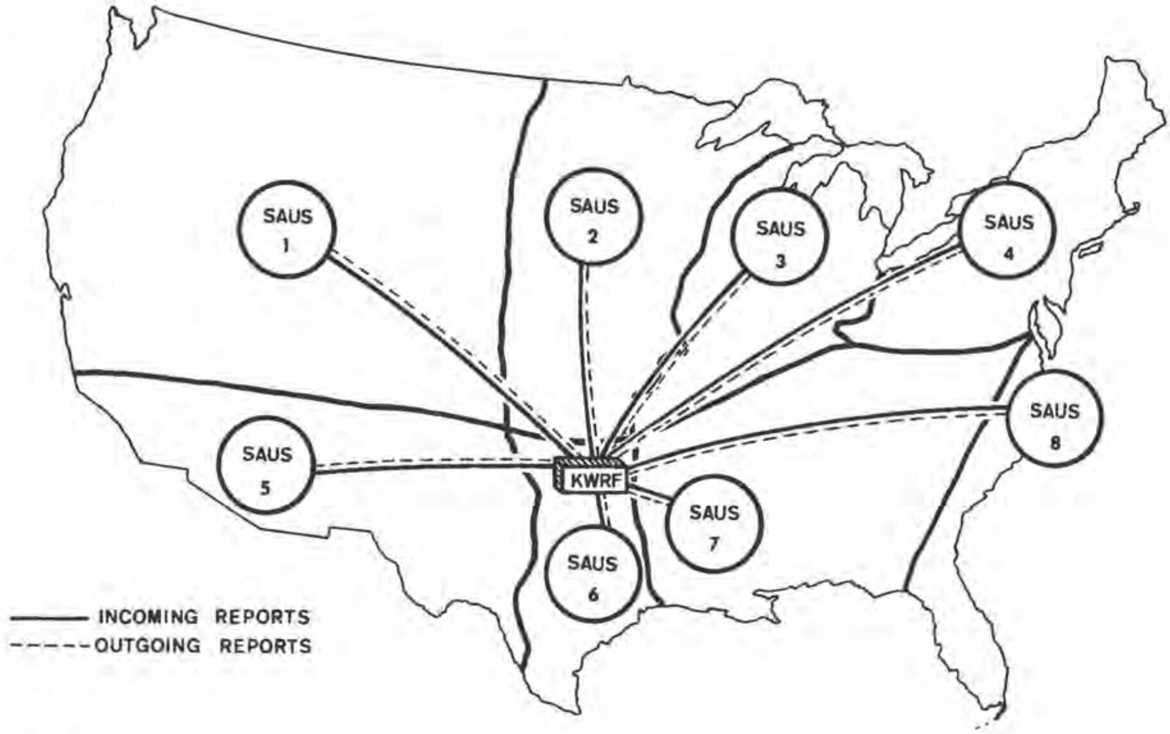
(1) *Heights with symbols.* Sequence reports contain the height of the base of each cloud layer that is indicated by a sky condition symbol. The cloud layers are encoded in ascending order. When the bases of the cloud layers are below 20,000 feet, the base height of each layer is reported in hundreds of feet above the surface. The base height precedes the appropriate sky condition symbol. Cirriform cloud heights are reported if the cloud base has been determined accurately. If no accurate measurement of the cloud base has been made, there are two methods for indicating the presence of high clouds—First, when the high clouds do not constitute a ceiling, the sky condition symbol is preceded by a slash (/); second, when the high clouds constitute a ceiling, the sky condition symbol is preceded by a *U*. Various encoded sky conditions and interpretations are shown in figure 11–7.

(2) *Amount of sky cover.* The sky coverage is accumulative in the sequence reports; i.e., each sky coverage symbol (fig. 11–6) represents the total coverage at and below the reported cloud deck. (Only those clouds visible from the surface can be reported.) The amount of sky cover designated by successive symbols at a station will either remain the same or show an increase in ascending layers. The amount of sky coverage will never decrease vertically; i.e., a report may appear as 12⦶25⦶55–⦷/–⊕, but *never* as 12–⊕25⦷55⦶.

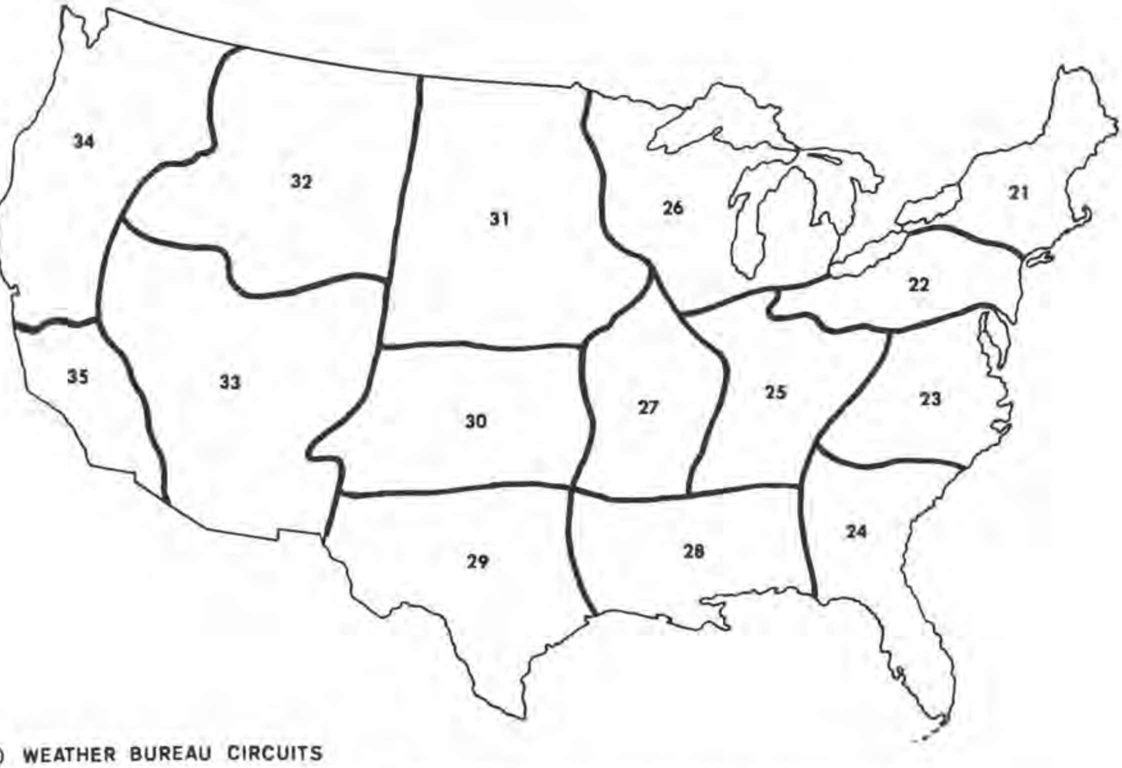
(3) *Obscuration (X) and partial obscuration (–X).* When obscuring phenomena such as fog, haze, smoke, dust, and the several forms of precipitation exist at the surface, the sky may be either totally or partially obscured.

(*a*) An obscuration (X) is reported when more than 9/10 of the sky is hidden by surface-based obscuring weather phenomena. In this situation, the limit of the observer's vertical visibility over the point of observation is reported as the ceiling height. The obscuration may be reported as 0X, 2X, 10X, etc. (interpreted as ceiling zero, sky obscured; ceiling 200 feet, sky obscured; ceiling 1,000 feet, sky obscured). Thus the altitude indicated with an obscuration is the *vertical visibility* into the obscuration, *not* the height to the base of the obscuration.

(*b*) When the sky is only partially obscured by surface-based weather phenomena (0.1 to 0.9 of the sky obscured), a partial obscuration (–X) is reported. Since partial

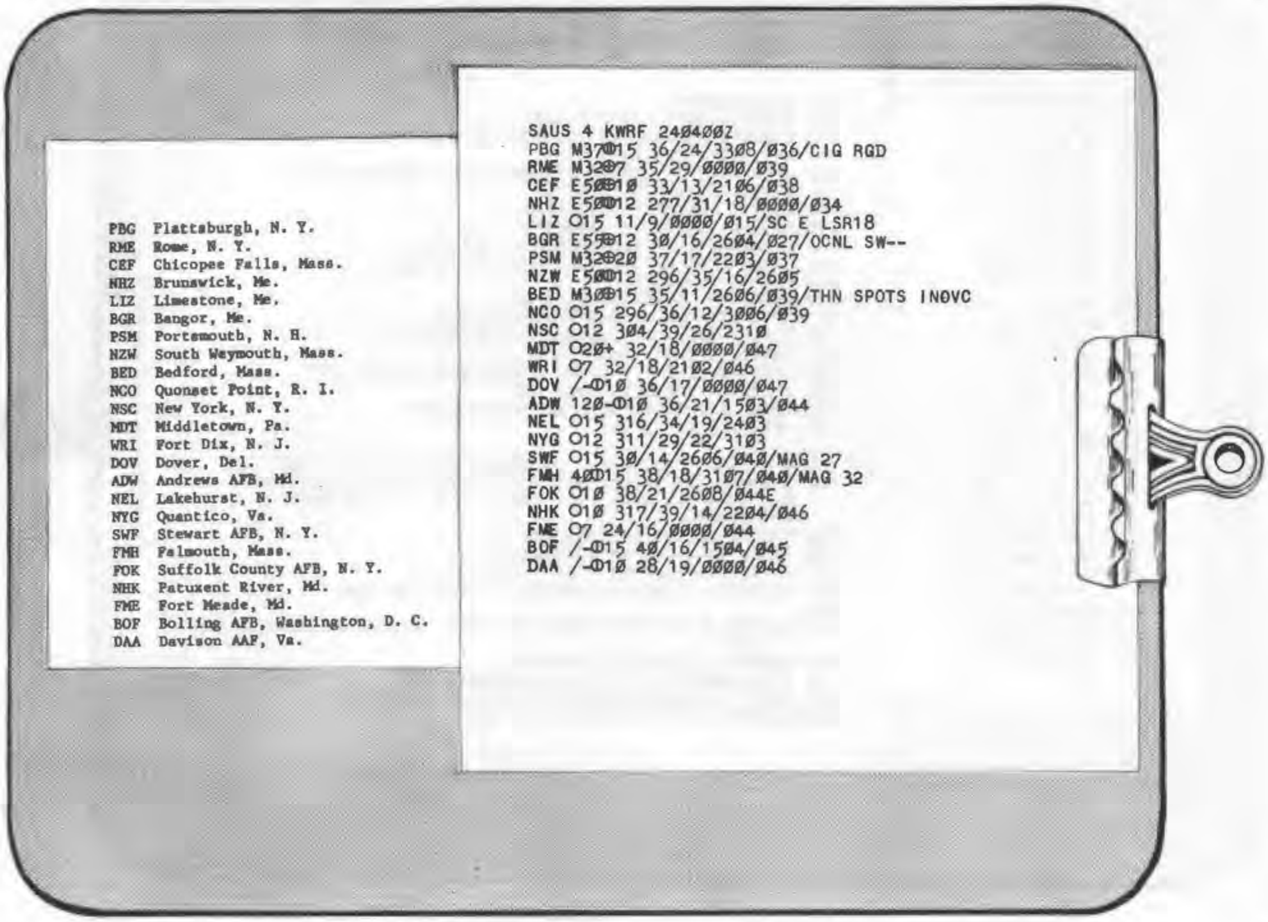


(A) 50,000 MILE ARMY, NAVY, AND AIR FORCE NETWORK



(B) WEATHER BUREAU CIRCUITS

Figure 11-1. (Superseded) *Military and civilian teletype circuit areas.*



PBG	Plattsburgh, N. Y.
RME	Rome, N. Y.
CEF	Chicopee Falls, Mass.
NHZ	Brunswick, Me.
LIZ	Limestone, Me.
BGR	Bangor, Me.
PSM	Portsmouth, N. H.
NZW	South Weymouth, Mass.
BED	Bedford, Mass.
NCO	Quonset Point, R. I.
NSC	New York, N. Y.
MDT	Middletown, Pa.
WRI	Fort Dix, N. J.
DOV	Dover, Del.
ADW	Andrews AFB, Md.
NEL	Lakehurst, N. J.
NYG	Quantico, Va.
SWF	Stewart AFB, N. Y.
FMH	Falmouth, Mass.
FOK	Suffolk County AFB, N. Y.
NHK	Patuxent River, Md.
FME	Fort Meade, Md.
BOF	Bolling AFB, Washington, D. C.
DAA	Davison AAF, Va.

```
SAUS 4 KWRF 24Ø4ØØZ
PBG M37⦷15 36/24/33Ø8/Ø36/CIG RGD
RME M32⊕7 35/29/ØØØØ/Ø39
CEF E5Ø⊕1Ø 33/13/21Ø6/Ø38
NHZ E5Ø⦷12 277/31/18/ØØØØ/Ø34
LIZ O15 11/9/ØØØØ/Ø15/SC E LSR18
BGR E55⊕12 3Ø/16/26Ø4/Ø27/OCNL SW--
PSM M32⊕2Ø 37/17/22Ø3/Ø37
NZW E5Ø⦷12 296/35/16/26Ø5
BED M3Ø⊕15 35/11/26Ø6/Ø39/THN SPOTS INOVC
NCO O15 296/36/12/3ØØ6/Ø39
NSC O12 3Ø4/39/26/231Ø
MDT O2Ø+ 32/18/ØØØØ/Ø47
WRI O7 32/18/21Ø2/Ø46
DOV /-⦶1Ø 36/17/ØØØØ/Ø47
ADW 12Ø-⦶1Ø 36/21/15Ø3/Ø44
NEL O15 316/34/19/24Ø3
NYG O12 311/29/22/31Ø3
SWF O15 3Ø/14/26Ø6/Ø4Ø/MAG 27
FMH 4Ø⦶15 38/18/31Ø7/Ø4Ø/MAG 32
FOK O1Ø 38/21/26Ø8/Ø44E
NHK O1Ø 317/39/14/22Ø4/Ø46
FME O7 24/16/ØØØØ/Ø44
BOF /-⦶15 4Ø/16/15Ø4/Ø45
DAA /-⦶1Ø 28/19/ØØØØ/Ø46
```

Figure 11-2. Military hourly sequences.

obscurations do not restrict the vertical visibility over the point of observation, any cloud layers observed above the partial obscuration are reported after the —X. The heights of the cloud bases and ceiling, if any, are reported, but the —X is not preceded by an altitude figure.

(*c*) Weather conditions producing partial and total obscurations are based on the surface and restrict the horizontal visibility, whereas cloud layers (⦶, ⦷, and ⊕) have definite bases above 50 feet and do not directly affect the horizontal surface visibility.

b. Ceiling. The ceiling is the lowest condition reported as ⦷, ⊕, or *X* that is not prefixed by a minus (—). A thin cloud layer or a partial obscuration is never a ceiling. When a ceiling is reported in sequence reports, the method by which the ceiling was determined or classified *must* precede the height of the symbol (⦷, ⊕, X) which appears as the ceiling layer. The letters used as ceiling classifiers are shown in figure 11-8.

11-7. Visibility

The visibility is reported in statute miles after the sky condition (no space separation). The visibility denotes the greatest horizontal distance that an object of specified characteristics can be seen and identified. When restricted or irregular, the visibility may be reported by one or more of the following refinements.

a. Prevailing Visibility. The prevailing visi-

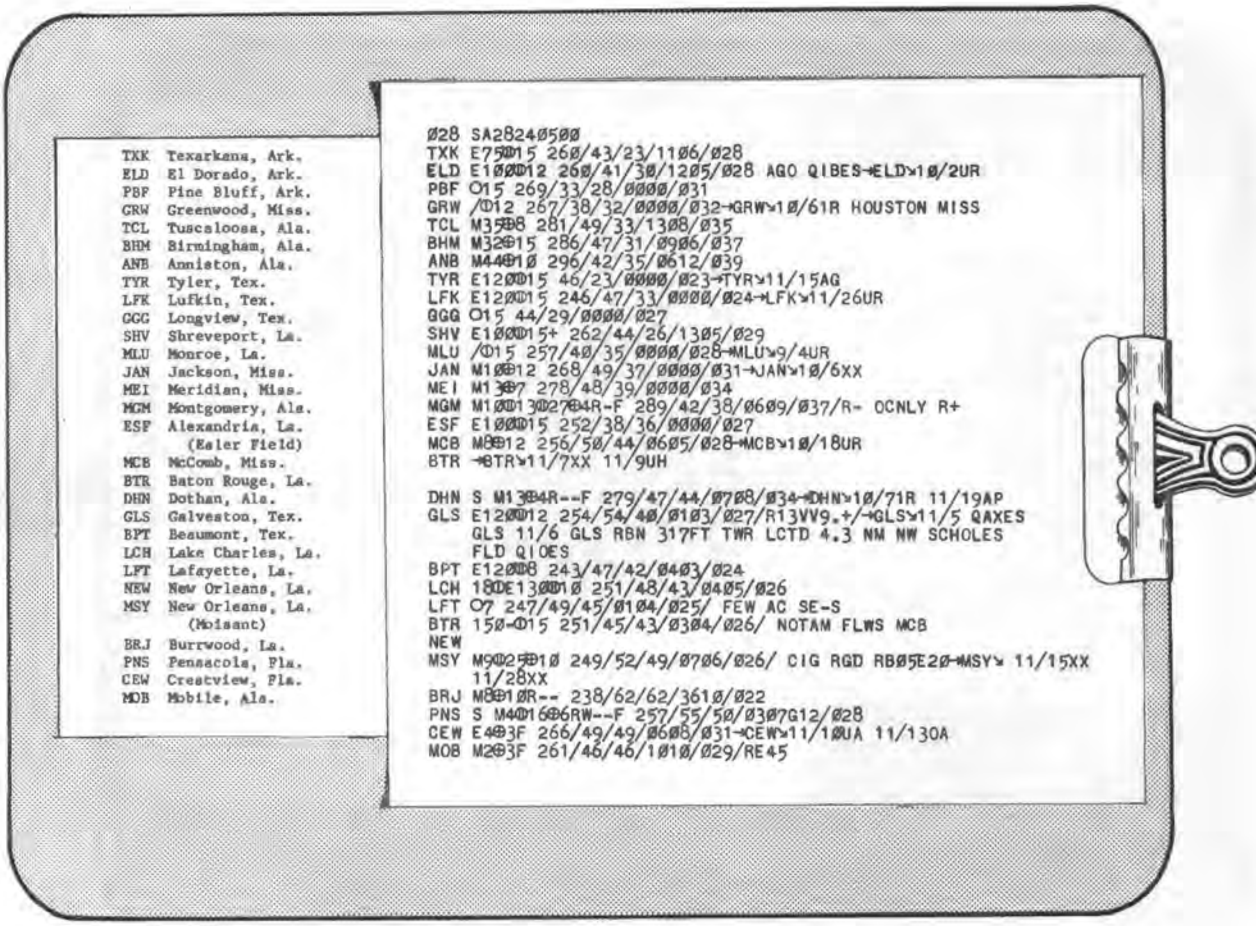


Figure 11-3. Weather Bureau and FAA hourly sequences.

bility is the greatest visibility that exists over half or more than half of the horizon. When the visibility varies in different quadrants from the point of observation, the prevailing visibility is reported. Variations from the reported prevailing visibility value are included at the end of the report (remarks section). The visibility may be variable at a station; if the prevailing visibility is varying between reportable values (*b* below) and less than 3 miles, the reported visibility value is followed by the letter V.

b. Reportable Values. When the visibility is less than 3 miles, it is reported in miles and fractions of a mile. When the visibility is between 3 and 15 miles, it is reported to the nearest mile. When the visibility is in excess of 15 miles, it is reported to the nearest 5 miles. At most stations, there are no visibility checkpoints beyond 15 miles. These stations report "15+" when the visibility markers at 15 miles are markedly clear, indicating that the visibility is greater than 15 miles.

c. Runway Visual Range (RVR) and Runway Visibility (RVV). Although the visibility or prevailing visibility will normally determine the type of flight plan to file, an aviator landing at a terminal under instrument conditions will find the *runway visual range* (RVR) to be the most reliable guide to visibility along the selected runway. RVR is the horizontal distance an aviator will see down the runway from the approach end. It is based upon the sighting of high intensity runway lights or upon the visual contrast of other sighting targets—whichever yields the greater visual range. The runway

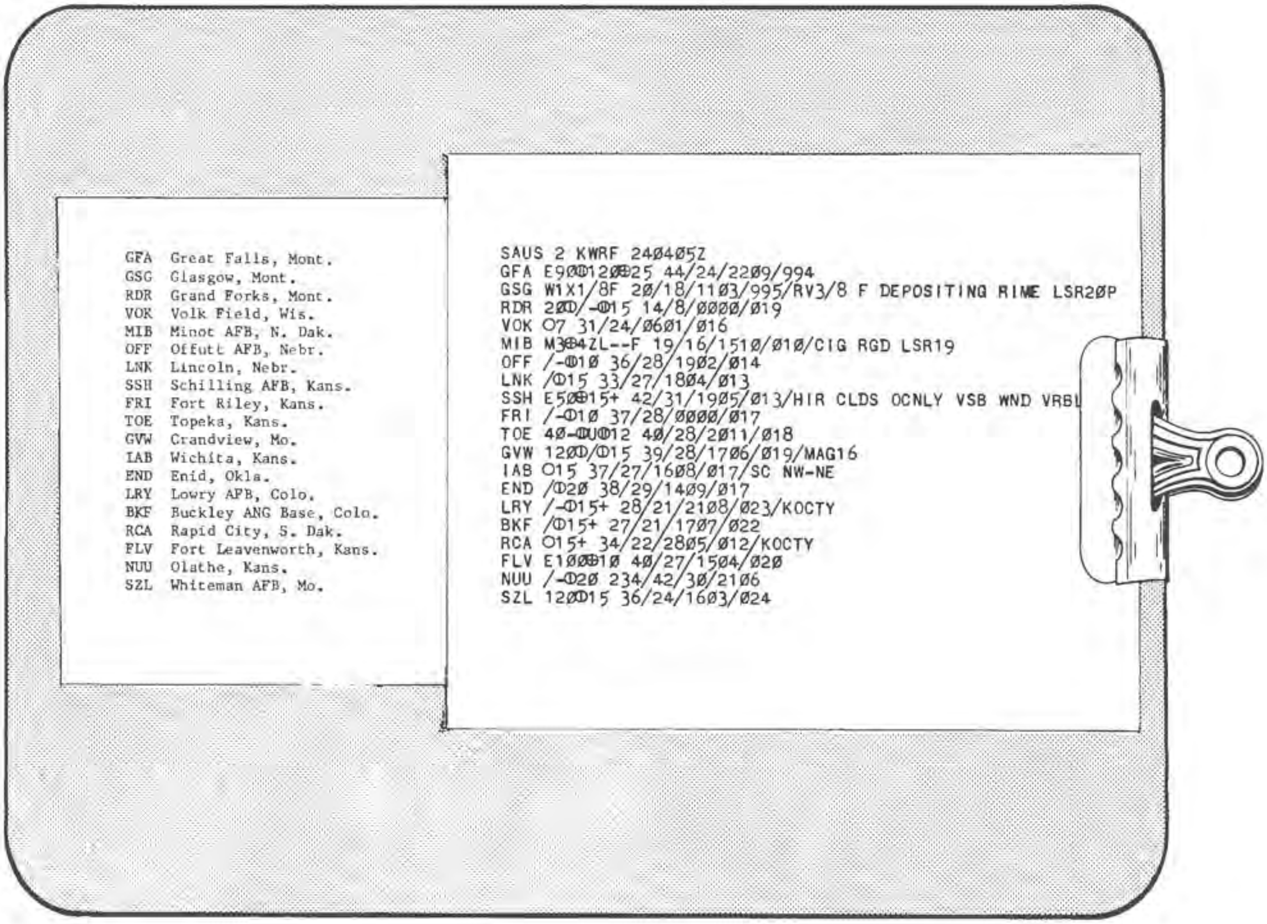


Figure 11–4. Military scanning.

visual range is determined by an instrument called the transmissometer. The transmissometer is mounted beside the instrumented runway near the touchdown point. *Runway visibility* (RVV) is closely related to the RVR; however, the high-intensity runway lights are not used in RVV. The RVR has a slight advantage over the RVV in that the high-intensity lights can often be seen on the approach path even though the actual runway is not visible. Under IFR conditions, the RVR provides an improved visibility condition along the runway for aircraft with proper instrumentation. The RVR and RVV systems are planned for all fully instrumented runways in the United States. The RVR and RVV are reported in the remarks section of the report when the RVR is 6,000 feet or less, or the RVV is 2 miles or less. The RVR is given in hundreds of feet, while the RVV is given in fractions of a mile. Generally, only RVV is available from instrumented Army airfields.

(1) *Examples of reporting RVR.* *R28VR38* indicates that on runway 28 the visual range is 3,800 feet. *R23VR30V* indicates that on runway 23 the visual range is 3,000 feet and variable.

(2) *Examples of reporting RVV.* *R06VV7/8* indicates that the runway visibility on 06 is seven-eighths of a mile. *R36VV5/8V1* indicates that the runway visibility on 36 is varying be-

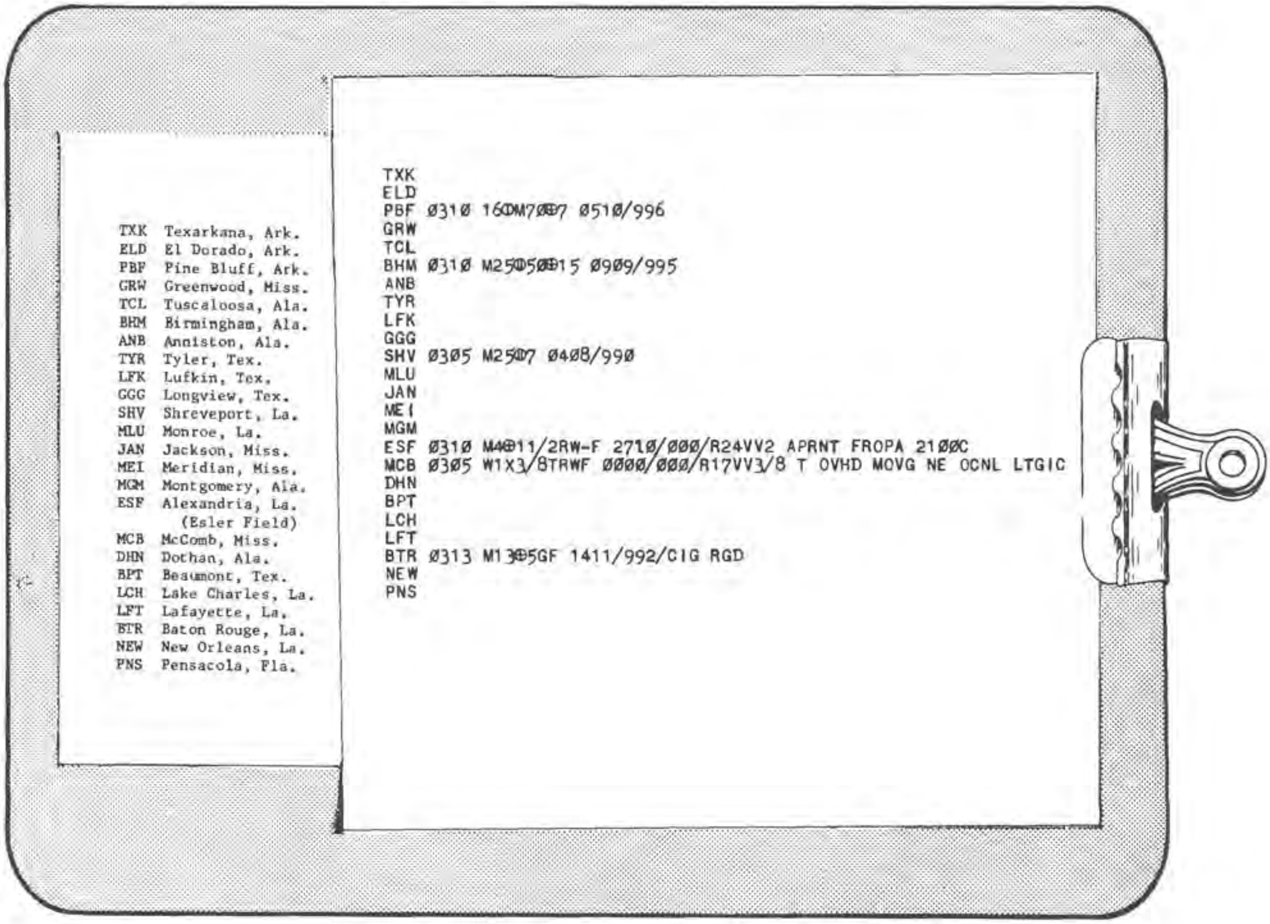


Figure 11-5. Weather Bureau scanning.

tween five-eighths of a mile and 1 mile.

11-8. Weather and Obstructions to Vision

Weather phenomena and obstructions to vision are reported by the use of letter symbols after the reported visibility.

a. Weather Elements. Atmospheric phenomena considered as weather elements in a report are tornadoes, waterspouts, funnel clouds, thunderstorms, and precipitation in any form. The letters used for reporting weather elements are shown in figure 11-9. These letters are used whenever the phenomena are occurring at observation time, regardless of their affect on visibility and ceiling.

b. Obstructions to Vision. Obstructions to vision are not reported when the visibility is more than 6 miles. When the visibility is reported as 6 miles or less, weather phenomena or obstructions to vision (or both) must be reported to explain the restricted visibility. The letters used for reporting obstructions to vision are given in figure 11-10.

11-9. Sea Level Pressure in Millibars

Sea level pressure is reported in three figures representing tens, units, and tenths of millibars. To interpret the value, one decimal place is pointed off and the reported figures are preceded with 9 or 10, whichever will make the complete figure read nearer 1013.2 millibars. Examples: 012=1001.2 mbs; 201=1020.1 mbs; 906=990.6 mbs; and 999=999.9 mbs. The SAUS circuits transmit the pressure in millibars every 3 hours beginning at 0000Z. The

SYMBOL	NAME	AMOUNT COVERED OR OBSCURED	
O	CLEAR	LESS THAN 1/10 COVERED	
⦶	SCATTERED	1/10 TO 5/10 COVERED	
⦷	BROKEN	6/10 TO 9/10 COVERED	
⊕	OVERCAST	OVER 9/10 COVERED	
-X	PARTIAL OBSCURATION	1/10 TO 9/10 OBSCURED	SURFACE BASED
X	OBSCURED	OVER 9/10 OBSCURED	

A MINUS (-) SIGN PRECEDING A SYMBOL (⦶, ⦷, OR ⊕) INDICATES THE LAYER IS THIN. A PLUS (+) SIGN INDICATES THE LAYER IS UNUSUALLY DARK.

Figure 11–6. Sky condition symbols.

REPORTED AS	INTERPRETED
2Ø⦶	TWO THOUSAND SCATTERED
5-⦷	FIVE HUNDRED THIN BROKEN
12Ø-⊕	ONE TWO THOUSAND THIN OVERCAST
-X1Ø-⦷	SKY PARTIALLY OBSCURED, ONE THOUSAND THIN BROKEN
5Ø⦶/⦶	FIVE THOUSAND SCATTERED, SCATTERED CIRRIFORM

Figure 11–7. (Superseded) *Encoded sky conditions and interpretations.*

CEILING CLASSIFIERS

A AIRCRAFT (PILOT REPORT)

B BALLOON (WITH KNOWN RATE OF ASCENT)

E ESTIMATED (NOT USED FOR CIRRIFORM LAYERS)

M MEASURED (NORMALLY WITH A CEILOMETER)

W INDEFINITE (USED WITH OBSCURED CONDITIONS)

R RADAR OR RADIOSONDE

D ESTIMATED (USED WITH PERSISTENT CIRRIFORM LAYERS ONLY, AND MUST HAVE BEEN ACCURATELY MEASURED WITHIN THE PAST SIX HOURS)

U UNKNOWN CEILING HEIGHT USED WITH CIRRIFORM LAYERS

CODE FORM	INTERPRETATION
2ØØ⦶M5Ø⦷	TWO THOUSAND SCATTERED, MEASURED CEILING FIVE THOUSAND BROKEN
-XA8⊕	SKY PARTIALLY OBSCURED, PILOT REPORTS CEILING EIGHT HUNDRED OVERCAST
W5X	INDEFINITE CEILING FIVE HUNDRED, SKY OBSCURED
28⦶5Ø-⦷A25Ø⦷	TWO THOUSAND EIGHT HUNDRED SCATTERED, FIVE THOUSAND THIN BROKEN, PILOT REPORTS TWO FIVE THOUSAND BROKEN
4Ø⦶1ØØ⦶/-⦷	FOUR THOUSAND SCATTERED, ONE ZERO THOUSAND SCATTERED, THIN BROKEN CIRRIFORM (NO CEILING)

Figure 11-8. (Superseded) *Ceiling classifiers and examples of their use.*

SA circuits include pressure data in each hourly transmission.

11-10. Temperature

The United States weather services report the surface temperature in sequence reports to the nearest whole Fahrenheit degree. Most other countries report the temperature in degrees centigrade. A minus sign preceding the temperature figure indicates that the temperature is below zero.

11-11. Dew Point Temperature

The dew point temperature is reported in degrees Fahrenheit. The teletype sequence reports contain the latest data available for determining the temperature-dew point spread and the tendency for the spread to decrease or increase. The rate at which the temperature-dew point spread will change is affected by the sky condition, precipitation, wind speed, advection of moist air (source and trajectory of wind), diurnal heating, nocturnal cooling. The

A	HAIL	S	SNOW
AP	SMALL HAIL	SG	SNOW GRAINS
E	SLEET	SP	SNOW PELLETS
EW	SLEET SHOWERS	SW	SNOW SHOWER
IC	ICE CRYSTALS	T	THUNDERSTORM
L	DRIZZLE	T+	HEAVY THUNDERSTORM
R	RAIN	T-	NEVER REPORTED
RW	RAIN SHOWERS	ZL	FREEZING DRIZZLE
ZR	FREEZING RAIN		

INTENSITIES INDICATED AS FOLLOWS(EXCEPT T, A, AND AP):

-- VERY LIGHT NO SIGN IS USED WITH MODERATE

\- LIGHT + HEAVY

INTENSITIES ARE NOT USED WITH TORNADO, WATERSPOUT, OR FUNNEL CLOUD. THESE ARE WRITTEN OUT IN FULL.

Figure 11–9. Symbols for weather elements.

spread tendency during the past few hours can be interpreted from preceding reports (para 2–12*b*).

11–12. Wind

The surface wind velocity (direction and speed) is reported in degrees and knots by four numerals. The first two numerals indicate the direction (to the nearest 10°) with reference to true north (36); the second two numerals indicate the wind speed to the nearest knot. For example, 0405 indicates a surface wind from 040° (northeast) at 5 knots; 0915 indicates 090° at 15 knots; 1803 indicates 180° at 3 knots, etc. Table VII in appendix II shows the relationship between degrees and the 16 compass points.

a. Calm winds are reported as 0000.

b. Gusts are sudden, intermittent increases in wind speed. If gusty conditions are re-

F	FOG	IF	ICE FOG
GF	GROUND FOG	H	HAZE
BS	BLOWING SNOW	K	SMOKE
BN	BLOWING SAND	D	DUST
BD	BLOWING DUST	BY	BLOWING SPRAY
INTENSITIES (+ OR -) ARE NOT INDICATED WITH OBSTRUCTIONS TO VISIBILITY			

Figure 11-10. Symbols for obstructions to vision.

ported, a G follows the average wind speed, with the peak speed recorded following the G. For example, 15G25 indicates that the 1-minute average wind speed is 15 knots with gusts to a peak speed of 25 knots as of the time of the observation.

c. Squalls are strong winds that increase abruptly in speed, maintain a specified peak speed over a period of 2 or more minutes, **then** decrease in speed. In reporting squalls, Q is used instead of G. For example, 20Q36.

d. Wind shifts are reported in the remarks section of the sequence report, with the local time of the shift; i.e., WSHFT 1200C.

11-13. Altimeter Setting

The altimeter setting is derived from the station pressure reduced (corrected) to sea level. It is represented (reported) by a three-digit group, without a decimal point, for units, tenths, and hundredths of inches of mercury. For example, 003=30.03 inches Hg; 987=29.87 inches Hg. A complete discussion of the altimeter setting system is contained in TM 1-215.

11-14. Remarks

a. General. The remarks section of the report is transmitted after the altimeter setting (at manned stations). The remarks are appended to the report to give the aviator and meterologist detailed information for flight planning. Some of the remarks are reported in code, while others are reported in standardized contractions of words and phrases. In some cases, the remarks are more valuable than the body of the report. Selected remarks in common usage are shown in figure 11-11.

b. Pilot Reports (PIREPS). Army aviators are encouraged to report in-flight weather conditions that will assist other aviators in planning their flights. The reports are especially significant when the aviator encounters hazardous conditions or weather that has not been forecast. They help to fill the distance gap between the weather stations, and enable the forecaster to brief aviators on actual, observed flight conditions. The aviator reporting meteorological phenomena should give the *time* of the observation, *location* of the aircraft with reference to a well-known point, *extent* (intensity) of the reported phenomena at the time of the observation, and the *altitude* of the reported phenomena (if applicable). When reporting icing or turbulence intensities, the type aircraft should also be reported. PIREPS may appear in the remarks section of teletype sequence reports or on a separate transmission (fig. 11-12).

c. NOTAM's (Notices to Airmen). NOTAM's present information about runway conditions, radio or navigation facilities, or other important terminal facilities. The NOTAM's may be in the remarks section of the sequence report or may be transmitted separately. The NOTAM's processed through flight control programmers (computers) are preceded by coded arrows. A standard international code is generally used; however, the NOTAM's are often supplemented by words or contractions. The NOTAM code consists of five letters, the first of which is a Q identifier. The second and third letters identify the subject of NOTAM, and the fourth and fifth letters give the information concerning the subject. The code key is available in navigation publications, airfield operations offices, and weather stations. Typical NOTAM's are shown in figure 11-13.

11-15. Automatic Meteorological Observing Station (AMOS)

Several automatic meteorological observing stations are in operation, and others are expected to be operational in the future. The data transmitted from these stations is the same as that from manned stations; however, the format for transmitting the data is different. The AMOS stations transmit in the teletype reporting sequence in their proper position. The formats for the reports from AMOS stations are shown in figure 11-14 (manned stations only) and figure 11-15 (manned full- or part-time stations).

1. T OVR STN MOVG E (THUNDERSTORM OVER STATION MOVING EAST)
2. RB18 (RAIN BEGAN AT 18 MINUTES PAST THE HOUR PRIOR TO THE TIME INDICATED IN THE CIRCUIT HEADING)
3. ZRE56 (FREEZING RAIN ENDED 56 MINUTES PAST THE PREVIOUS HOUR)
4. IR (ICE ON RUNWAY, FOLLOWED BY DECELEROMETER VALUE)
5. WR (WET RUNWAY, FOLLOWED BY DECELEROMETER VALUE)
6. BINOVC (BREAKS IN THE OVERCAST)
7. SC W (LESS THAN 1/10 STRATOCUMULUS WEST OF STATION)
8. CB ALQDS (CUMULONIMBUS ALL QUADRANTS)
9. FROPA (FRONTAL PASSAGE)
10. CIG RGD (CEILING RAGGED)
11. LN SC N-E HRZN (LINE OF STRATOCUMULUS ON THE HORIZON NORTH THROUGH EAST)
12. PRESFR (PRESSURE FALLING RAPIDLY)
13. PRESRR (PRESSURE RISING RAPIDLY)
14. THN SPOTS IN OVC (THIN SPOTS IN OVERCAST)
15. R13VR4ØV (RUNWAY 13 VISUAL RANGE 4,000 FEET, VARIABLE)
16. SHLW GF ALQDS (SHALLOW GROUND FOG ALL QUADRANTS)
17. MTN TOPS OBSCD (MOUNTAIN TOPS OBSCURED)
18. CIG 3V5 (CEILING 300 FEET VARIABLE TO 500 FEET)
19. OCNL L-- (OCCASIONAL VERY LIGHT DRIZZLE)
20. F INCR (FOG INCREASING)
21. ⊕V⦶ (OVERCAST VARIABLE TO BROKEN)
22. VSBY S-W 3/4 (VISIBILITY SOUTH THROUGH WEST THREE-FOURTHS OF A MILE)
23. R32VV3/8 (RUNWAY VISIBILITY ON RUNWAY 32 IS THREE-EIGHTHS OF A MILE)
24. LTGIC (LIGHTNING IN CLOUD)
25. LTGICCG (LIGHTNING IN CLOUD AND CLOUD TO GROUND)
26. DRK W (DARK TO THE WEST - DENSE CLOUDS)
27. RVRNO (RUNWAY VISUAL RANGE NOT OPERATING)
28. WND LGT VRBL (WIND LIGHT AND VARIABLE)
29. F3 (FOG OBSCURING 3/10 OF THE SKY)
30. DRFTG S NW (DRIFTING SNOW TO THE NORTHWEST)
31. 55⊕65 (PILOT REPORTS BASE OF OVERCAST AT 5,500 FEET WITH TOP OF OVERCAST AT 6,500 FEET)
32. T OVHD (THUNDER OVERHEAD)
33. TCU NE-SE-S RWU S (TOWERING CUMULUS NORTHEAST, SOUTHEAST, AND SOUTH; RAINSHOWERS OF UNKNOWN INTENSITY SOUTH OF THE STATION)
34. DSNT LTNG NE-SE (DISTANT LIGHTNING NORTHEAST THROUGH SOUTHEAST)
35. LGT TO MDT CAT (LIGHT TO MODERATE CLEAR AIR TURBULENCE)
36. BRAM15 (BRAKING ACTION MODERATE - DECELEROMETER VALUE 15. DECELEROMETER VALUES RANGE FROM IDEAL (Ø) TO POOR (3Ø))
37. BRAP28 (BRAKING ACTION POOR - DECELEROMETER VALUE 28)

Figure 11-11. Remarks.

1. BIF PIREP 142300Z ABI-BIF 350 WND 260/172K LGT TURBC T-33.
   PILOT REPORTED TO BIGGS AFB (BIF) ON THE 14TH DAY OF THE MONTH AT 2300Z THE WIND AT 35,000 FEET WAS 260° AT 172 KNOTS BETWEEN BIGGS AND ABILENE (ABI). LIGHT TURBULENCE WAS ALSO ENCOUNTERED. THE PILOT WAS FLYING A T-33 AIRCRAFT.
2. PIA PIREP 150138Z PIA-SBN MDT ICG RAIN AND SNW STICKING 40-50 LGT ICG 70 DC3.
   PILOT REPORTED TO PEORIA (PIA) AT 0138Z ON THE 15TH DAY OF THE MONTH THAT HE WAS ENCOUNTERING MODERATE ICING IN RAIN AND STICKING SNOW BETWEEN 4,000 AND 5,000 FEET WITH LIGHT ICING AT 7,000 FEET ON A FLIGHT BETWEEN PEORIA AND SOUTH BEND (SBN). TYPE OF AIRCRAFT, DC-3.
3. BWG PIREP 150225Z BNA-BWG XTREM TURBC 30 C182.
   PILOT REPORTED TO BOWLING GREEN (BWG) THAT EXTREME TURBULENCE WAS ENCOUNTERED AT 3,000 FEET BETWEEN NASHVILLE (BNA) AND BOWLING GREEN. TYPE OF AIRCRAFT, C-182.
4. BGS PIREP 141522Z 45 NW BGS 70-150 MDT-SVR TURBC T38.
   T-38 PILOT REPORTS MODERATE TO SEVERE TURBULENCE BETWEEN 7,000 AND 15,000 FEET 45 MILES NORTHWEST OF BIG SPRINGS.
5. RND PIREP 141524Z ON TKOF RND 15⊕46 CIG RGD.
   PILOT REPORTED AFTER TAKEOFF AT RANDOLPH (RND) THE BASE OF THE OVERCAST WAS 1,500 FEET AND THE TOP OF THE OVERCAST WAS AT 4,600 FEET; CEILING RAGGED.
6. HAR PIREP 141240Z OVR HAR TMP -2C NEG TURBC IN CLR FLT ALT 45 L20.
   AVIATOR IN L-20 REPORTED TEMPERATURE -2°C, WITH NEGATIVE TURBULENCE AND CLEAR AIR AT 4,500 FEET OVER HARRISBURG (HAR).
7. ATL PIREP 141430Z 60 ATL FLT LVL 330 NEG TURBC UNDERCAST TOPS UNK ACFT CLASSIFIED.
   PILOT REPORTED TO ATLANTA 60 MILES EAST OF ATLANTA AT 33,000 FEET THE TURBULENCE WAS NEGATIVE; UNDERCAST BELOW THE AIRCRAFT WITH HEIGHT OF TOPS UNKNOWN. TYPE OF AIRCRAFT CLASSIFIED.
8. STATIONS FREQUENTLY TRANSMIT A COLLECTION OF PIREP SUMMARIES AS FOLLOWS:

   ACF UA 141520
   PIREP SMRY
   OVR OKC LGT RIME ICG 120 C97. 40SSW OKC LGT-MDT TURBC 80 C47.
   31 WSW TUL LGT RIME ICG 70-100 C47. 44 WSW TUL ⊕95 CLR ABV.
   OVR IFI LGT RIME ICG LGT TURBC 70 C47. LIT-TXK 65KT HEADWIND 60.
   OVR LFK 01 MDT TURBC BNZA. 25 S LFK IN-OUT TOPS 90.
   OFF TUL ⊕50 ⊕60 IN-OUT 70 ⊕E90 B185

   ELP UA 142025
   PIREP SMRY
   35NE TUS MDT TURBC ⦶ CLDS 105 PA24.
   OVR FST LGT-MDT CAT 420 F106. OVR SFL TOPS CLDS E140 CLDS TPG MTNS.
   70 SE SAT MDT TO SVR CAT 420 F106.
   ROW-LBB 45⦶ LGT TURBC 45 C182.
   62SE ABQ ⦶125 FRONT MOVG S 20KTS MTNS OBSCD W.

Figure 11-12. Pilot reports.

```
RIC
FLE NOTAM QUNAZ 1513ØØ 15163Ø PERSONNEL DROP AT FLE DROP ZONE SFC
TO 85ØØ FT 14233Ø.

STL NOTAM RNWY 12-3Ø OPEN. MIDDLE 5ØØØ FT SANDED, FIRST 25ØØ FT
BOTH ENDS OF RNWY 1/4 IN MELTING SNW AND ICE. MIDDLE 5ØØØ FT 1/2
IN MELTING SNW AND ICE AND UP TO 2 IN IN SOME RIDGES. BRAKING
ACTION POOR BY M4Ø4 142353 + SEE NOTAM JAN 1422Ø1

SHV M14⦶2Ø⊕12 Ø97/62/61/1614/981/QAVOG 23ØKC QANES QENES DME
MLU E18⊕1Ø 132/61/54/131Ø/991/DRK W-N QANES QENES DME

PHX
ZPX NOTAM RARAD SVC AVBL FOR CIVIL JET ACFT J6V FM PHX 31Ø RAD TO
PRC VOR J1ØV PGS 14Ø RAD TO GJT 165 RAD J24V PRC 12Ø RAD TO TCS 3Ø5
RAD J58V PGS TO Ø2Ø RAD TO GJT 165 RAD J64V PRC 32Ø RAD TO GJT 165 RAD
J78V PGS 14Ø RAD TO FMN 19Ø RAD J92V RCE Ø4Ø RAD TO RCE Ø7Ø RAD 14214Ø

MIA 3Ø⦶E12Ø⦶12 217/76/66/Ø915/Ø16/5Ø7 123Ø QANES. SEE NOTAM BIRDS.
```

Figure 11-13. NOTAM's.

Format for teletypewriter transmission:

Manually Observed Data[1] — Automatically Observed Data

iii $h_m$hhh $C_tC_sh_m$hhh $C_tC_s$vvvvWWWWWW PPP/TTT/$T_dT_dT_d$/ddff/$P_aP_aP_a$/RRR/RnnVRnnn/

Manually Observed Data

Remarks and scheduled additional data whenever appropriate. 1, 2, 3, 6

Example of transmitted report:

DCA M 10 ⦷ 220 ⊕ 11/2TRW-GF 293/ 64/ 64/3011/039/001/R36VR60 / VSBY 1V2
T W MOVG SE FQT LTGCG SW TB51

	Data Reported and Explanatory Notes	Symbolic Form	Coded Data	Decoded Data
	Station Designator.	iii	DCA	Washington National Airport, D. C.
MANUALLY OBSERVED	Ceiling designator (prefix to known heights of ceiling layer). A "U" in this column indicates that the layer is a cirriform ceiling layer—height unknown.	h_m (See Footnote 4)	M	Height of layer measured as:
	Height of first layer reported, hundreds of feet.	hhh (See Footnote 4)	10	1000 feet.
	Thickness indicator, i.e., "-" identifies a layer aloft as "thin" or surface-based obscuring phenomena (X) as partial. A "/" in this column indicates that the layer is a cirriform non-ceiling layer—height unknown.	C_t (See Footnote 4)	(blank)	
	Sky cover amount, lowest layer (0.1 −0.5 = ⦶, 0.6 −0.9, = ⦷, 10/10 = ⊕, X = surface-based obscuring phenomena).	C_s (See Footnote 4)	⦷	Broken sky cover (0.6 to 0.9 of sky covered by cloud and hidden by obscuring phenomena at and below preceding height).
	Ceiling designator (prefix to known heights of ceiling layer). A "U" in this column indicates that the layer is a cirriform ceiling layer—height unknown.	h_m (See Footnote 5)	(blank)	
	Height of second layer reported, hundreds of feet.	hhh (See Footnote 5)	220	Sky-cover height 22,000 feet.
	Thickness indicator, i.e., a "-" identifies layer as "thin". A "/" in this column indicates that the layer is a cirriform non-ceiling layer—height unknown	C_t (See Footnote 5)	(blank)	
	Sky cover amount, second layer (0.1 −0.5 = ⦶, 0.6 −0.9 = ⦷, 10/10 = ⊕); or clear sky (zero tenths of sky cover = ○).	C_s (See Footnote 5)	⊕	Overcast sky cover (100% of sky covered by cloud or hidden by obscuring phenomena at and below preceding height).
	Prevailing visibility (statute miles).	vvvv	1½	1½ statute miles.
	Weather and obstructions to vision.	WWWWWW	TRW-GF	Thunderstorm (T), light rain showers (RW-), ground fog (GF).
AUTOMATICALLY OBSERVED	Sea-level pressure, tens, units, and tenths mb.	PPP	293	1029.3 millibars.
	Temperature, hundreds, tens, and units °F[2].	TTT	64	+64°F.
	Dew point temperature, hundreds, tens, & units °F[2].	$T_dT_dT_d$	64	+64°F.
	Wind direction and speed.	ddff	3011	300°, 11 knots.
	Altimeter setting, units, tenths, & hundredths inches of mercury.	$P_aP_aP_a$	039	30.39 inches of mercury.
	Cumulative precipitation (units, tenths, & hundredths inches) for six-hour periods beginning 0000, 0600, 1200 and 1800 GMT.	RRR	001	0.01 inch or precipitation (liquid measure).
	Instrument runway number.	Rnn	R36	Runway number 36.
	Runway visual range in hundreds of feet; "60+" is coded for visual ranges exceeding 6000 ft., & "19-" for ranges of less than 2000 feet, or runway visibility in miles and tenths (where a transmissometer is available but runway visual range is not applicable), e.g.,VVn.n, coded as VV1.3, as in MEA example on page 4 to report runway visibility 1.3 miles.	VRnnn	60	6,000 feet.

Miscellaneous

Manually Observed

Remarks added by observer in standard format and using standard weather symbols given in WBAN Manual of Surface Observations, Circular N, and authorized teletypewriter contractions, as given by FAA in "Contractions Manual".[3] In the DCA example above the remarks portion, (VSBY 1V2 T W MOVG SE FQT LTGCG SW TB51) reports the following supplementary information:

VSBY 1V2 = Prevailing visibility is variable from one to two statute miles.
T W MOVG SE = Thunderstorm (other than "heavy") to west of station, moving toward the southeast.

FQT LTGCG SW = Frequent lightning between clouds and ground to southwest of station.

TB51 = Thunderstorm began 51 minutes after the preceding hour.

[1] Manually observed data groups "drop out" at stations having limited hours of operation to leave blank spaces in columnized format during hours when personnel are not on duty.

[2] Normally, the first column of each of the 3-column code groups TTT and $T_dT_dT_d$ is reserved for use of the figure "1" when temperatures exceed "99", or for "−" when temperatures are less than 0°F. A zero (0) appears in the second column when temperatures range from +9°F to −9°F. Otherwise, at some stations, sub-zero temperatures appear as the algebraic sum of 100 and the temperature (e.g., −8°F would be reported as 92, i.e., the sum of 100 & −8); for temperatures above 99°F, the hundreds figure is omitted (e.g., 102°F is reported as 02).

[3] Scheduled coded data (in 3- to 5-figure code groups) are appended at selected stations, following remarks, in accordance with Circular N, Chapter 10. These code groups are not of direct concern for aircraft operations.

[4] The lowest of the following layers (a) the lowest cloud layer coverage 0.1 or more of the sky, or (b) the lowest layer of obscuring phenomena (aloft or on the surface) hiding 0.1 or more of the sky.

[5] The ceiling layer, if any, whenever it is not reported by the first sky cover group; otherwise, an operationally significant group. When more than two layers are present additional layers are reported as remarks.

[6] See Page 1 for explanation of selected standard weather symbols. Further information is contained in the Manual of Surface Observations (WBAN), Circular N.

Figure 11–14. Program 1 AMOS (manned stations only).

	Automatic Data	Manual Data
A. iii AMOS	PPP/TTT/TdTdTd/ddff/Pd Pd Pd/RRR/RnnVVn. n//hmhhhCtCs···	hmhhhCtCs vv·· vvWW ..WW//Remarks
B iii AMOS	/TTT/TdTdTd/ddff/PdPdPd/RRR/RnnVVn. n//hmhhhCtCs···	hmhhhCtCs vv·· vvWW··WW PPP//Remarks

EXAMPLES

A. HVR AMOS 293/ 64/ 64/3011/039/001/R27VV2.1//10⦷M25⊕3K VSBY N2W21/2//320 1001 25074

B. MEA AMOS / 74/ 66/3602/996/012/RO4VV1.3//M10⦷220⊕11/2TRW-GF 293//T W MOVG SE FQT LTGGG SW TB51

	Data Reported and Explanatory Notes[3]	Symbolic Form	Coded Data	Decoded Data
Automatic Data	Station designator	iii	MEA	Meacham, Ore.
	Type designator		AMOS	Automatic Meteorological Observing System followed by 19 spaces (or 22 spaces where sea-level pressure is not reported automatically).
	Sea-level pressure (if automatic).	PPP	(Blank)	Not automatic at Meacham.
	Dry-bulb temperature (hundreds, or space or minus, [4]tens and units).	TTT	74	Seventy-four degrees F.
	Dew-point temperature (space or minus, [4]tens & units).	TdTdTd	66	Sixty-six degrees F.
	Wind direction (degrees) and speed (knots).	ddff	3602	Wind from 360° at two knots.
	Altimeter setting, units, tenths and hundredths in. Hg.	PdPdPd	996	29.96 inches of mercury.
	Cumulative precipitation (units, tenths and hundredths of inches liquid state) for 6-hr. period beginning 0000, 0600, 1200 and 1800 GMT.	RRR	012	0.12 inch of precipitation (melted amount if catch is solid state).
	Instrument runway number, when appropriate.[5]	Rnn	R 04	Runway number 04 (Visibility follows).
	Runway visibility for foregoing runway, or directional vsby,[5] in statute miles and tenths.	VVn.n	VV1.3	Visibility on runway 36 is 1.3 statute miles.
Manually Determined Data	Ceiling designator, prefixed to ht. (if known) and to amount symbol for layer to which designator applies.	hm (See Footnotes 1 & 2)	M	Measured ceiling (height and/or character and amount follows).
	Height of first[2] layer at or above surface (in hundreds of feet), followed by "V" when rapidly variable.	hhh (See Footnotes 1 & 2)	10	1000 feet (character and amount follows).
	Thickness indicator, when appropriate, i.e., " – " identifies "thin" layers aloft or "partial" obscuration at surface; otherwise it is omitted.	Ct (See Footnotes 1 & 2)	(Omitted)	Layer not evaluated as "thin."
	Sky-cover amount (0.1 – 0.5 = ⦶, 0.6 – 0.9 = ⦷, 10/10 = ⊕ "X" = 10/10 surface-based obscuring phenomena, –"X" = less than 10/10 surface-based obscuring phenomena.	Cs (See Footnotes 1 & 2)	⦷	Broken sky cover aloft (0.6 to 0.9) of sky covered by sky-cover aloft and hidden by surface-based obscuring phenomena at and below level reported.
	Prevailing visibility, in statute miles & fractions, followed by "V" when rapidly variable.	vv·· vv	1½	1½ statute miles.
	Weather and obstructions to vision.	WW·· WW	TRW-GF	Thunderstorm "T," light rain showers "RW-," ground fog "GF."
	Sea-level pressure, (tens, units & tenths of millibars), where not determined automatically.	PPP	293	1029.3 millibars.
	Remarks preceded by two slants (plain language & authorized contractions, as appropriate).		T W MOVG SE FQT LTGCG SW TB51	Thunderstorm west, moving southeast, frequent cloud to ground lightning southwest, thunderstorm began 51 minutes after preceding hour.

[1]"hmhhh" is reported by "U" when ht. of cirriform ceiling layer is unknown; as "/" when ht. of cirriform nonceiling layer is unknown.
[2]The "hmhhhCtCs" group is repeated for other layers present, in ascending order of height.
[3]More detailed information is contained in the Manual of Surface Observations (WBAN), Circular N, and on Page 1.
[4]Reports of below zero temperatures may appear either as "minus" temperatures or as the algebraic sum of 100 and the temperature, e.g., a dew-point temperature of –10°F would be reported as –10 from some stations, but as 90 (i.e., 100 –10) from others. Temperatures above 99°F are reported either as three figures (e.g., 102° is reported as 102) or by omitting the hundreds figure (e.g., 102° is reported as 02).
[5]Where directional visibility is not associated with a runway "Rnn" is coded as RNO in lieu of a runway number.

Figure 11–15. Program 2 AMOS (manned full- or part-time stations).

CHAPTER 12

THE SURFACE WEATHER MAP

12-1. General

The surface weather map (surface synoptic chart) presents an analysis of surface weather information for a specific time and a given area. The analysis is based on surface-observed data recorded at a specified time by weather stations in the area covered by the map. These maps are also called *facsimile maps* after the name of the equipment used for their transmission. The surface weather map is just one of the many facsimile maps transmitted each day by the National Meteorological Center (NMC). The facsimile form of the map for North America presents the surface weather analysis for the United States and parts of Canada, Alaska, and for the North Atlantic and North Pacific Oceans (fig. 12-1). It is available in most weather stations in the United States and in selected stations outside the Zone of Interior.

12-2. National Meteorological Center

Approximately 350,000 reports of existing weather conditions are received each day at the NMC just outside of Washington, D. C. The Center prepares surface and upper air analysis maps, surface and upper air prognostic maps, winds aloft maps, and composite maps (containing additional required information) and transmits the maps over the facsimile circuit. Some of these maps include the entire Northern Hemisphere. A portion of the data necessary for the NMC mission is supplied by the following sources (figures are approximations): 900 airways surface reports every hour, 2,000 international land station reports every 6 hours, 200 ship reports every 6 hours, 500 aircraft in-flight reports each day, 300 aircraft reconnaissance reports each day, 500 winds aloft reports every 6 hours, and 300 radiosonde reports every 12 hours. From these reports, the necessary maps are prepared and transmitted by facsimile machine to Weather Bureau, Air Force, and Navy weather stations. The same data that is printed in black and white by the facsimile receiver is also transmitted in coded form by teletype circuits. Maps can be drawn by local weather station personnel using the coded data if some malfunction occurs in the facsimile equipment or if facsimile receivers are not available at the station.

Note. Some facsimile receivers print the facsimile maps in brown and white.

12.3 Construction

The surface weather map provides a picture of the weather as it exists at the time of the observation. This picture includes the atmospheric pressure patterns at sea level (pressure systems), fronts, and individual reporting station data. The two types of surface weather maps commonly displayed in the United States are the *facsimile* (black and white) map, and the *sectional* (colored) map.

a. Facsimile Map. Facsimile synoptic maps are drawn at the NMC eight times each day (fig. 12-1). The observations for these maps are taken at 0000Z, 0300Z, 0600Z, 0900Z, 1200Z, 1500Z, 1800Z, and 2100Z. The time of the observation appears in the lower left corner of the map. These observations are encoded and transmitted to the NMC by radio, telephone, and teletype. At the NMC this data is decoded, and the master map is drawn for facsimile transmission to the using agencies. The transmission of the facsimile surface maps is usually completed 1½ to 2 hours after the time of observation. The data on the facsimile surface map is, therefore, generally between 2 and 6 hours old when used by the aviator in the weather station. However, this facility shows the most complete picture of weather conditions over the entire United States. (The teletype sequence report is designed to provide up-to-the-minute individual station weather information.) The 0000Z,

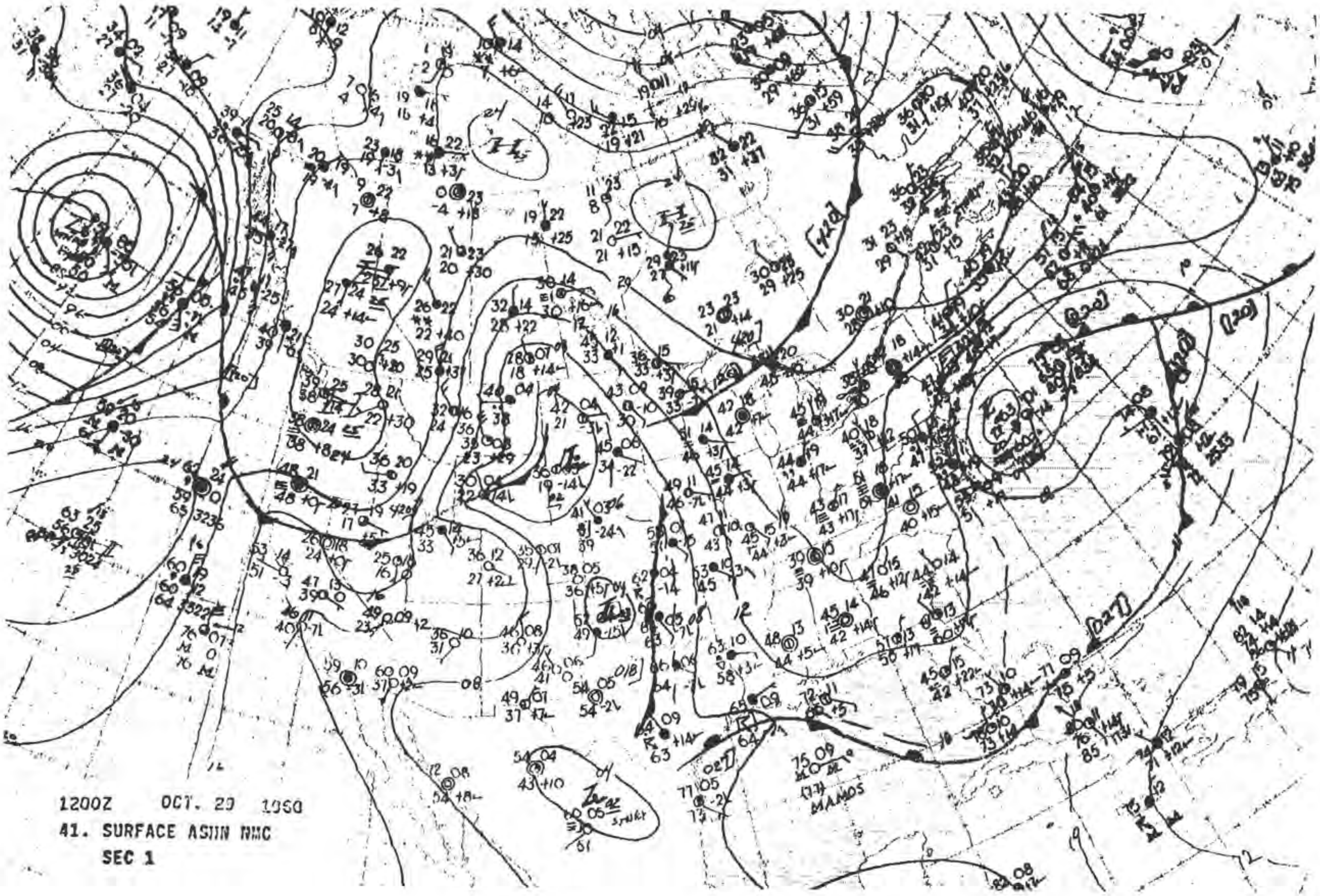


Figure 12–1. Typical facsimile surface weather map.

0600Z, 1200Z, and 1800Z maps are drawn to a 1 : 20,000,000 scale and depict a few stations over a large area. The remainder of the maps are drawn to a 1 : 10,000,000 scale and show a greater number of stations, but a smaller area is covered by each map. All of the symbols appearing on these maps are black when transmitted since the facsimile machine cannot reproduce color transmissions. At most weather stations, the major features of these maps are colored by the weather personnel on duty. A sequence of three or four maps is displayed in the weather office to indicate trends in the development of fronts, pressure systems, and weather phenomena.

b. Sectional Map. Sectional maps are large, brown, standard forms which normally show only the section of the United States in which the station is located—hence the name *sectional* map. The weather data is plotted and drawn on the sectional map by personnel in the weather station, using information received by teletype machine (fig. 12-2). This data may be obtained from the surface synoptic code or from regular teletype sequences. The weather symbols on the sectional map are in color. The map is easy to read and the data presented is usually more complete than that on the facsimile map, although the method of plotting the data is subject to minor local variations. The station model code is not always the same as that used on the facsimile map, but the arrangement of information around the station center is in the same pattern. If the station is equipped with facsimile service, only one or two sectional charts are drawn each day for local use.

12-4. Station Model

Data observed by individual stations are plotted in the form of standard symbols on the surface weather map. These symbols are grouped around a printed circle called the *station circle,* which indicates the geographical location of the station on the chart (fig. 12-3). This grouping of data is the *station model.* The arrangement of plotted data around the station model is standard in weather stations throughout the world. On NMC facsimile maps, the abbreviated station model includes only the sky cover, surface wind, present weather, temperature, dew point, pressure, and pressure tendency. The sectional map generally includes additional data on cloud types, ceiling, cloud bases, and visibility. The sky coverage symbols on the sectional chart resemble the symbols in the teletype sequence report rather than the international synoptic code symbol.

a. Wind. The direction from which the wind is blowing is indicated on the surface weather map by a shaft. The shaft on the station models in figure 12-3 indicates wind from the northwest. Wind speed is indicated by the barb and pennant system—a full barb is valued at 10 knots, a half-barb at 5 knots, and a pennant at 50 knots. To avoid confusion in length with a single full barb, the half-barb appears part way down the shaft when 5-knot winds exist. The wind speed is a summation of the number of barbs and pennants appearing on the shaft. For a calm wind, a circle is drawn around the station center. The wind direction is determined by reference to true north (a *true wind*), and the speed is rounded to the nearest 5 knots (app. II).

b. Sky Coverage. Two types of symbols on surface weather maps indicate the *total* sky coverage over the station.

(1) *Facsimile symbols.* The amount of black in the facsimile station circle is an indication of the total amount of sky coverage by all cloud layers over the station (figs. 12-3 and 12-4). These symbols are part of the international surface synoptic code.

(2) *Sectional map symbols.* The individual preparing the colored sectional map may use either the facsimile symbols for sky coverage or the regular teletype sequence report symbols for scattered or broken sky coverage.

c. Pressure. The mean sea level pressure is indicated either in tenths of millibars (three digits) or in tens of millibars (two digits). The facsimile map model uses two digits. If the reported pressure begins with a digit from 0 through 5, the figure is preceded with a 10; i.e., 091 means 1009.1 millibars, and 33 means 1033 millibars. When the reported pressure begins with a digit from 6 through 9, the figure is preceded with a 9; i.e., 991 means 999.1 millibars, and 65 means 965 millibars. These pressure values are corrected to mean sea level to eliminate pressure variations caused by varying field elevations.

d. Temperature and Dew Point. On surface weather maps, prepared by United States weather services, the temperatures and dew points are given

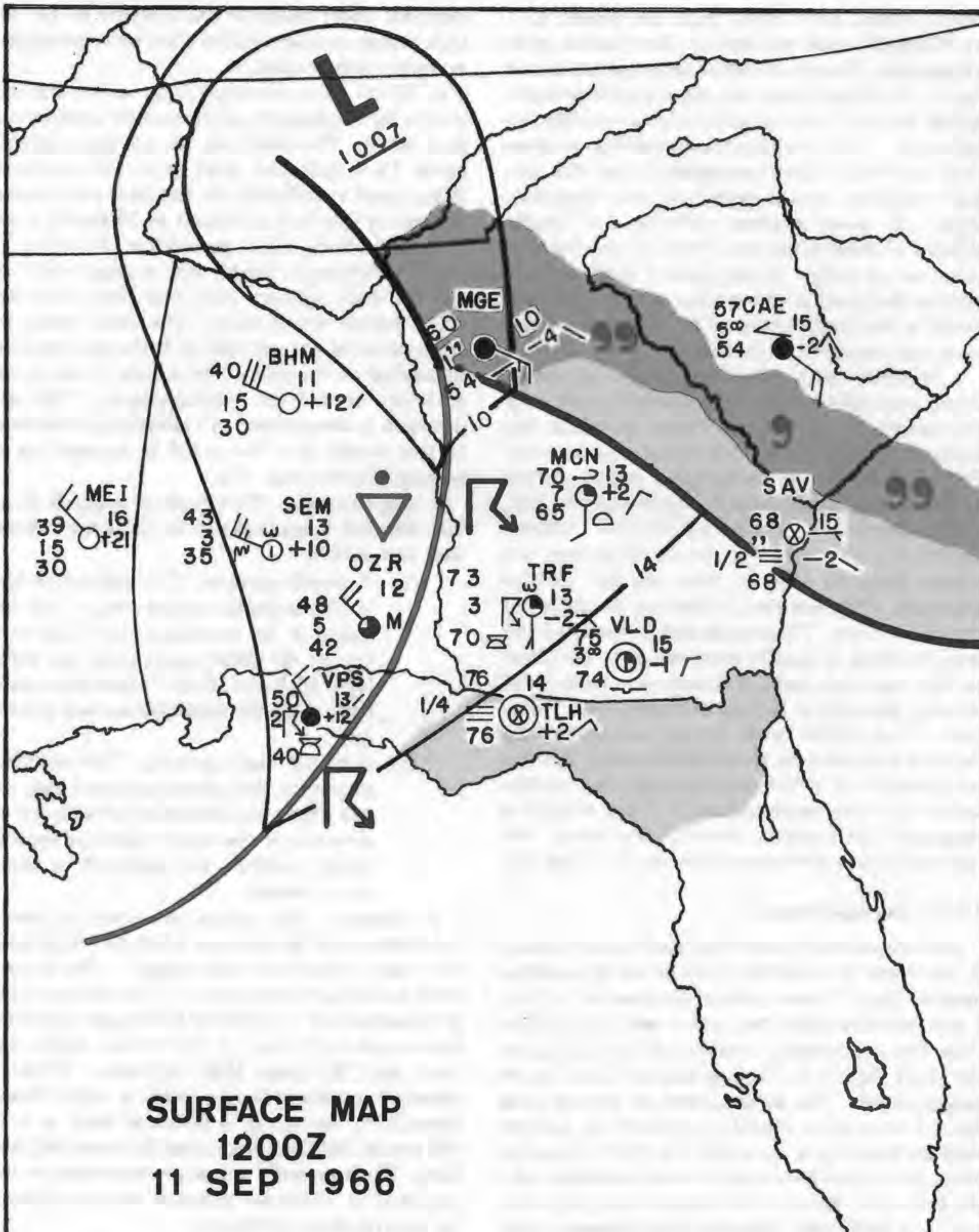
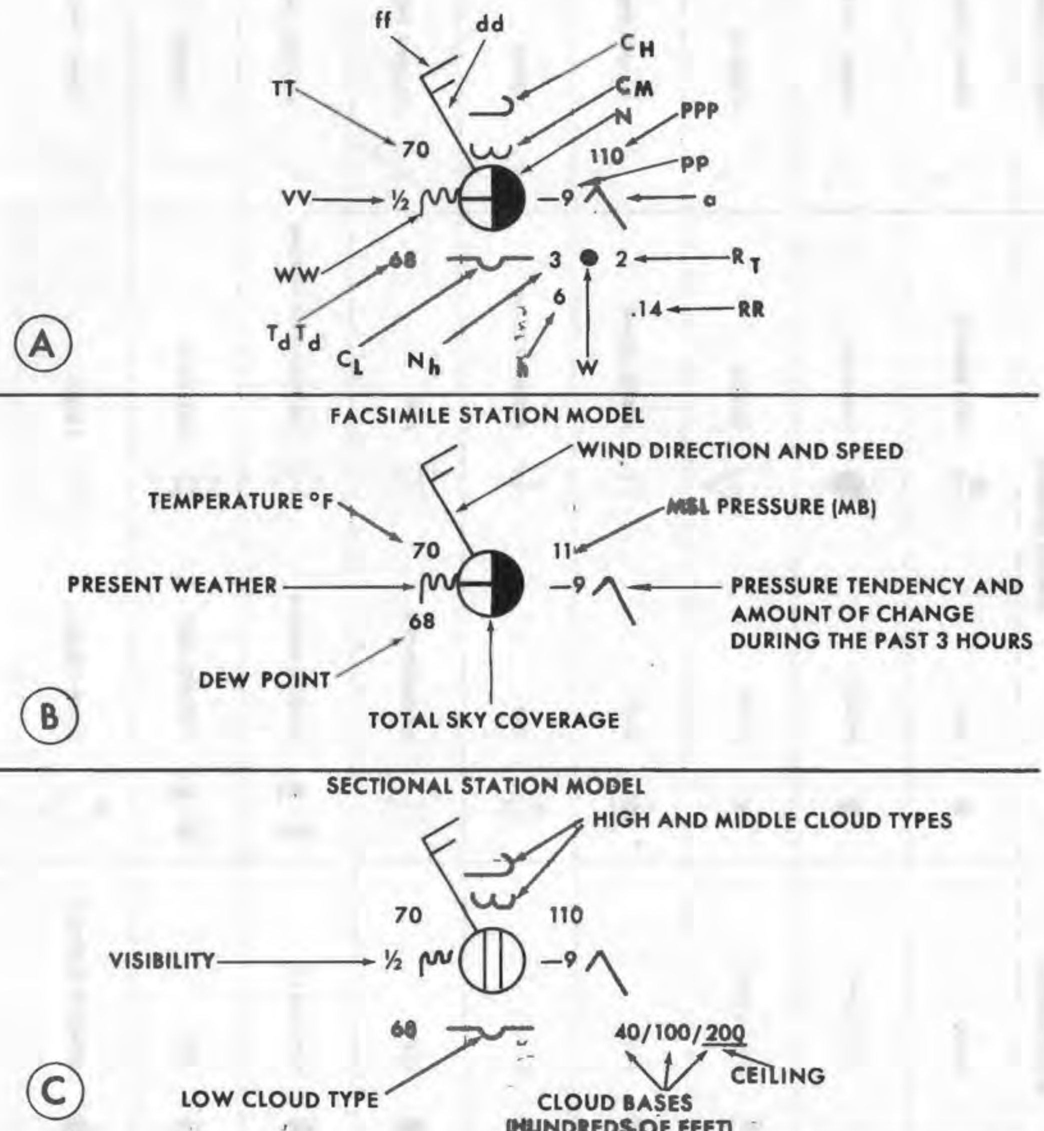


Figure 12-2. (Superseded) *Typical area and entries for a sectional surface weather map.*

INTERNATIONAL STATION MODEL

- C_M -MIDDLE CLOUD TYPE
- C_H -HIGH CLOUD TYPE
- T_dT_d-DEW POINT
- a * -PRESSURE TENDENCY*
- pp -CHANGE IN PRESSURE*
- RR -AMOUNT OF PRECIPITATION (PAST 6 HOURS)
- R_T -TIME PRECIPITATION BEGAN OR ENDED
- N -TOTAL SKY COVERAGE
- dd -WIND DIRECTION
- ff -WIND SPEED
- VV -VISIBILITY
- ww -PRESENT WEATHER
- W -PAST WEATHER (3 TO 6 HOURS)
- PPP-MSL PRESSURE
- TT -TEMPERATURE
- N_h -SKY COVERAGE OF "h"
- C_L -LOW CLOUD TYPE
- h -HEIGHT OF LOW CLOUDS

* TENDENCY OR CHANGE OVER THE PAST 3 HOURS



aavn221

Figure 12–3. Surface weather map station models.

SKY CONDITION	PRESENT WEATHER		PRESSURE TENDENCY	CLOUDS
CLEAR	RAIN	RAIN SHOWER	RISING, THEN FALLING (+)	St
1/10 OR LESS	DRIZZLE	HURRICANE	RISING AND STEADY (+)	Sc
2/10 TO 3/10	SNOW	SQUALL	RISING (+)	Ns
4/10	SLEET	FUNNEL CLOUD	FALLING, THEN RISING (+)	Cu
5/10	HAIL	BLOWING SNOW	STEADY	Cb
6/10	THUNDERSTORM	FOG	FALLING, THEN RISING (-)	Ac
7/10 TO 8/10	FREEZING DRIZZLE	BLOWING DUST OR SAND	FALLING, THEN STEADY (-)	As (THIN)
9/10	FREEZING RAIN	DUST DEVIL	FALLING (-)	Ci
COMPLETE OVERCAST	SNOW SHOWER	SMOKE	RISING, THEN FALLING (-)	Cc
OBSCURATION	THUNDERSTORM AND RAIN	HAZE	(+) HIGHER THAN 3 HOURS AGO (-) LOWER THAN 3 HOURS AGO	Cs

davn176

Figure 12–4. (Superseded) *Major station model symbols.*

in degrees Fahrenheit. However, weather maps produced in most other major countries give the temperatures and dew points in the centrigrade scale.

e. Present Weather. The symbols used for present weather (figs. 12–4 and 12–5) represent forms of precipitation or obstructions to vision, or both. Although there are over 100 possible combinations and types of weather symbols (fig. 12–5), the aviator needs to recognize only the major types (fig. 12–4).

f. Visibility. Visibility in statute miles is normally plotted only on the sectional map. Both whole and fractional parts of miles are shown, as applicable.

g. Pressure Tendency. Pressure tendency changes over the past 3 hours are indicated as follows: a plus or minus indicates whether the net change in pressure has resulted in an increase or a decrease; the amount of change is indicated in tenths of millibars; and the pattern of change is indicated by the coded symbol (fig. 12–4).

h. Cloud Types. Although there are 27 cloud types symbolized in the international code, a knowledge of the 10 basic types (fig. 12–4) will provide the aviator with a practical understanding of those symbols used on the sectional map. The same symbol (plotted above the station circle) is used for either nimbostratus or thick altostratus clouds. These two cloud types are similar in that both may obscure the sun and produce continuous precipitation at the surface. Cloud types are generally plotted for all stations on sectional maps but only for selected stations on the facsimile map.

i. Past Weather. The past weather normally does not appear on either the facsimile or sectional maps. It is indicated only on an international station model. The data is available to the aviator, however, in the form of teletype code transmission. All data plotted for the international station model is transmitted in an *international synoptic code* by teletype circuit to supplement the facsimile maps.

j. Amount of Precipitation. The total precipitation during the past 6 hours and the time that the precipitation began or ended is available only on teletype circuit transmission (international surface synoptic code).

k. Height and Amount of Lower Clouds. The height to the base of of each cloud deck over the station is normally plotted on sectional maps in hundreds of feet above the ground. The ceiling height is underlined on this type of station model. If no ceiling exists, none of the cloud heights are underlined. The height and amount of lower clouds are not plotted on facsimile maps, but the data may be obtained from the international synoptic code.

12–5. Weather Map Analysis

Station models are used by the NMC and local weather station personnel to analyze the surface weather map. The meteorologist draws the pressure patterns by using the wind data and sea level pressure. Isobars show the general pressure pattern and low-level circulation (below approximately 3,000 feet). The location of fronts is determined by using the dew point, temperature, wind, pressure tendencies, clouds, and present weather.

a. Isobars. Isobars are drawn at 4-millibar intervals on facsimile and sectional maps of North America. This interval places the isobars close enough to show the pressure pattern, but leaves enough space to plot additional data legibly. The isobars are labeled in tens of millibars by multiples of four, i.e., the labels *92*, *96*, *00*, *04*, and *08* would be interpreted as 992 millibars, 996 millibars, 1,000 millibars, 1,004 millibars, and 1,008 millibars. The 1,016-millibar line is the *normal* boundary between cyclones and anticyclones.

b. Isobaric Patterns. The pattern formed by the isobars shows the flow of the gradient wind above the affect of surface friction. At approximately 2,000 feet (the gradient level), winds flow parallel to the isobars; below the gradient level, winds tend to flow toward the lower pressure area. The average angle at which the surface winds cross the isobars is approximately 30° over a normal land surface: the angle is less over water and greater over irregular surfaces. The actual wind direction below 2,000 feet should be obtained from the station models. On surface weather maps of the United States, the windflow is counterclockwise around cyclones and clockwise around anticyclones. Cyclones are typically areas of overcast sky, turbulence, and generally unfavorable flying conditions. Cyclonic centers are characterized by gusty, strong, erratic winds, as opposed to anticyclone centers of calm or light and variable winds. A high typically represents an area of clear sky, smooth air at flight level, and generally good weather. Centers of high and low pressure are labeled with a blue *H* or a red *L* on display maps.

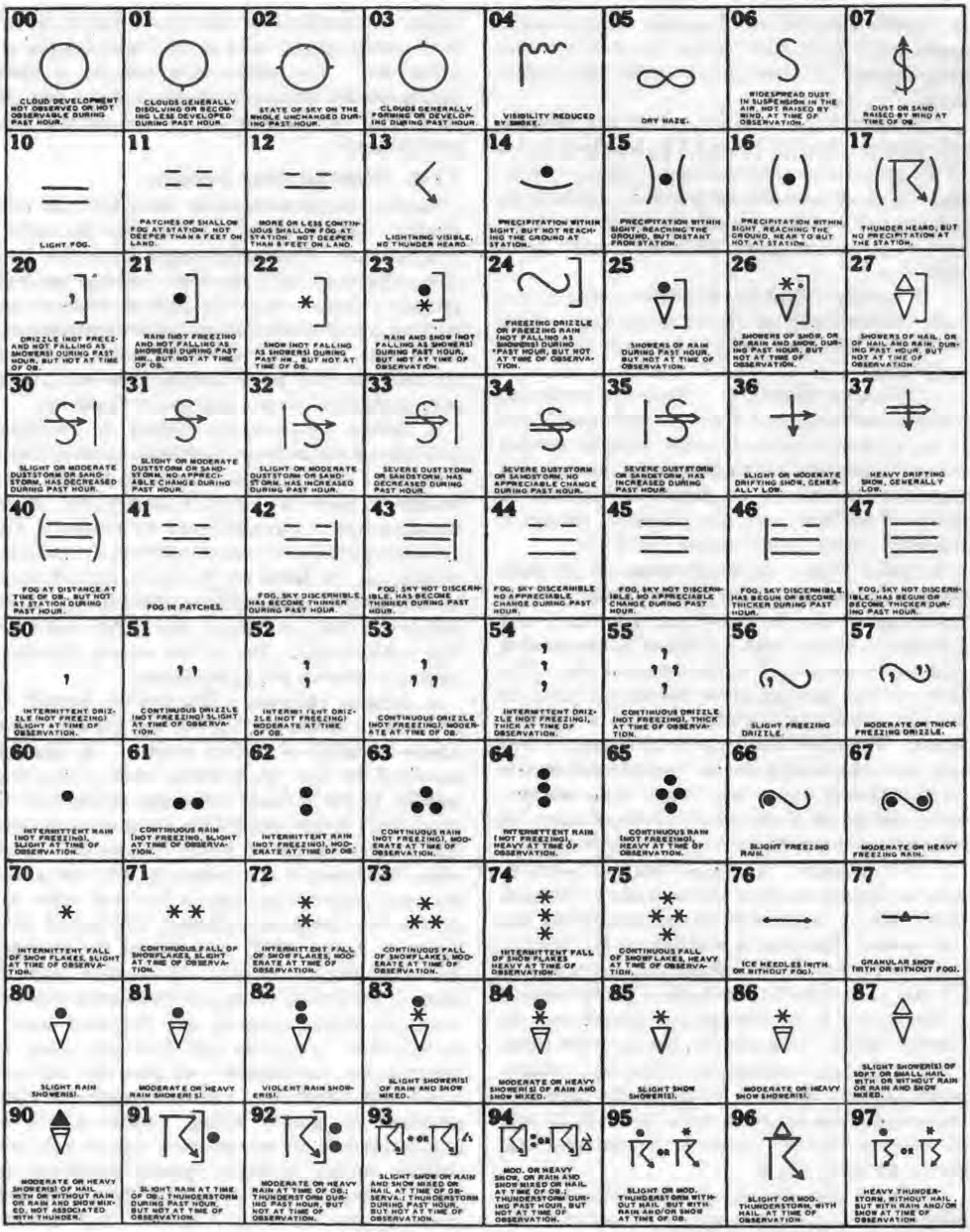


Figure 12–5. Symbols used on weather maps.

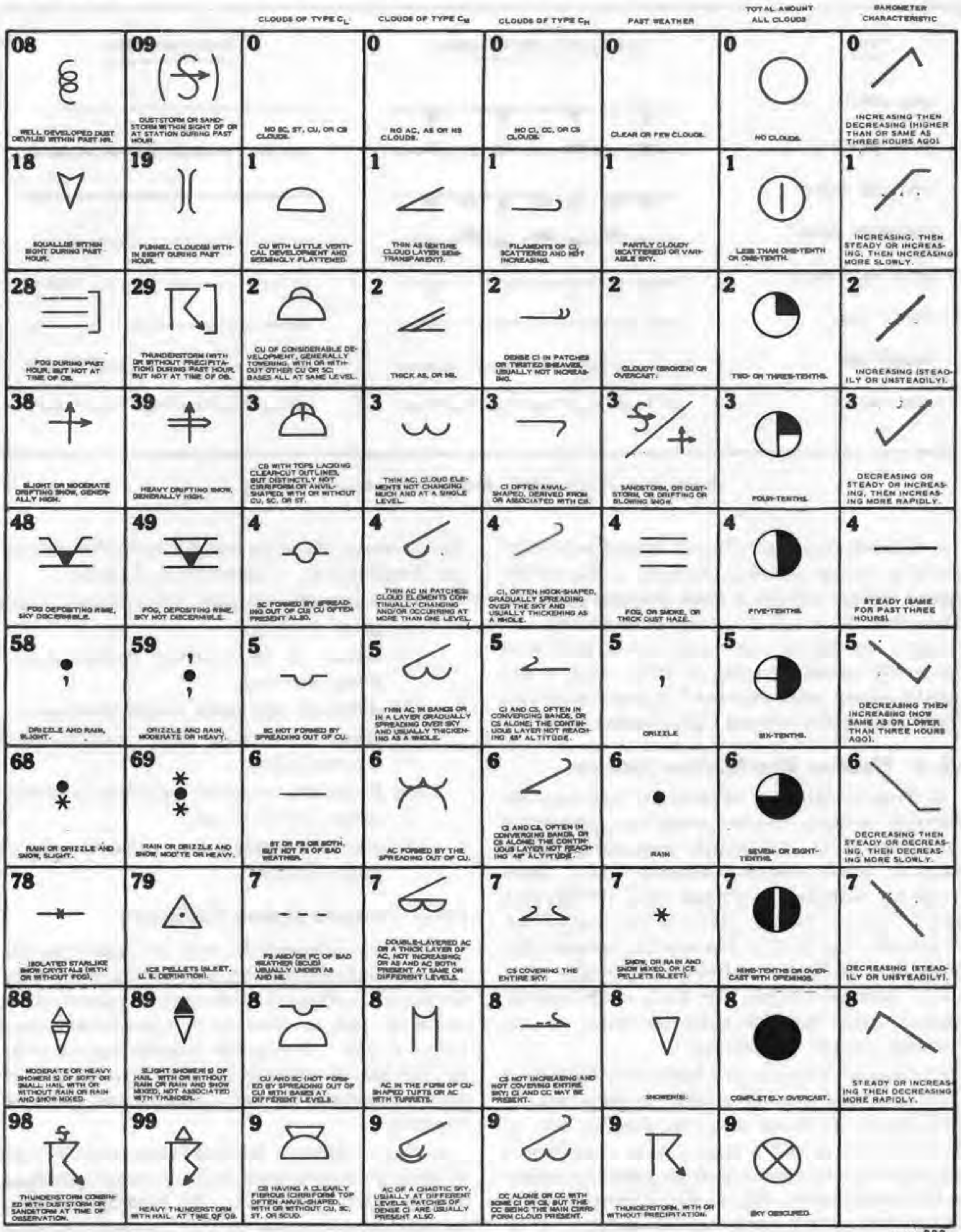


Figure 12-5—Continued.

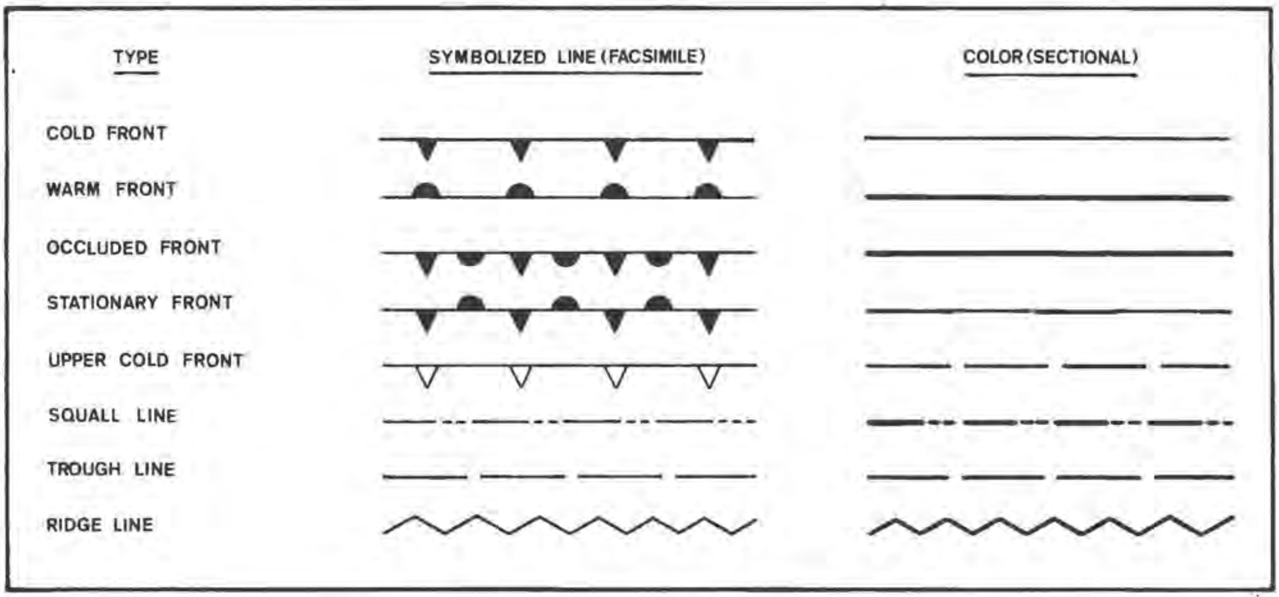


Figure 12–6. (Superseded) *Weather map analysis symbols.*

c. Isobaric Spacing. Closely spaced isobars indicate a strong pressure gradient, while widely spaced isobars indicate a weak pressure gradient. Therefore, the winds along the same latitude are strong where isobars are closely spaced and weak where the isobaric spacing is wide. Isobars are usually closely spaced around low-pressure centers and widely spaced around high-pressure centers.

12–6. Weather Map Analysis Symbols

a. Frontal Symbols. Fronts are indicated on facsimile surface weather maps by symbolized lines (fig. 12–6). On locally prepared sectional maps or locally colored facsimile maps, these fronts are indicated by colored lines. Prefrontal squall lines and trough lines are also symbolized or colored (fig. 12–6). The spacing between the symbols on the lines is subject to considerable variation. A coded analysis (fig. 12–7) of the front is plotted within brackets along the front on the facsimile surface weather map.

b. Areas of Weather and Restricted Visibility. When a certain type of weather or restriction to visibility is indicated at given stations over a rather large area on the map, a large symbol corresponding to the symbol used for present weather on the station model (fig. 12–4) is drawn in color on the map at the local weather station. If a large area of precipitation or restriction to visibility is present, the entire area is colored for immediate identification. Colors are as follows:

(1) Areas of continuous precipitation—solid green shading.

(2) Areas of intermittent precipitation—green hatching.

(3) Areas of fog—solid yellow shading.

(4) Areas of blowing dust or sand—solid brown shading.

(5) Hazardous weather—appropriate station model symbol in red.

(6) Showers—appropriate symbol over a green triangle.

12–7. Pressure System Movement

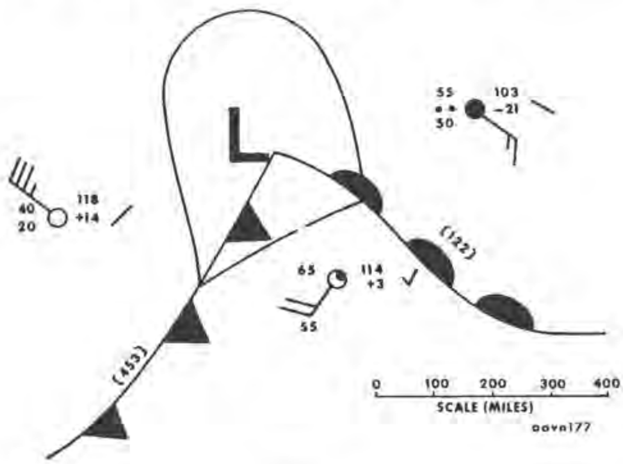
The most dependable way to determine the movement of pressure systems (and the fronts they contain) is to obtain the information from the forecaster on duty or from surface prognostic maps (para. 16–10). Two quick methods that the aviator can use to estimate the future movement of pressure systems are *extrapolation* and *pressure tendency*.

a. Extrapolation. Extrapolation is the process of using past movement of the pressure system to predict future movement. By locating the position of a pressure center on the three earlier surface weather maps, the movement (speed and direction) for the past 9 hours can be seen. This trend can then be projected into the future movement of the system for short periods of time (fig. 12-8). The same system can be used for predicting the movement of fronts on the surface weather map. Actual pressure system and frontal movements during an 18-hour period are depicted in figures 12-12 through 12-15 at the end of this chapter.

b. Pressure Tendency. Low-pressure systems tend to move toward the area of rapidly falling pressure, and high-pressure systems move toward the area of rapidly rising pressure. An estimate of the amount and direction of movement of a pressure center is obtained by a combination of the direction and speed of past movement and the path parallel to a line joining the rapidly rising and falling pressure.

(1) Because low-pressure convergence areas contain the greatest flight hazards, the future movement of lows is important to aviators. In using pressure tendencies for predicting a low-pressure movement, the highest negative and highest positive-pressure tendency within 600 to 700 miles of the low-pressure center are located. A straight line is drawn between these points. The future movement of the center moves parallel to this line, with the low moving toward the negative end of the line.

(2) To determine the speed of motion, a second line is drawn parallel to the first line and passing through the center of the low. The speed of movement can be estimated by adding the tendencies at each end of the line (disregarding the signs) and dividing the sum by four (fig. 12-9).



CODE

1st Digit—Frontal Type

0—Stationary front
1—Warm front
2—Warm occlusion
3—Upper warm front
4—Cold front
5—Cold occlusion
6—Upper cold front
7—Squall line
8—Intertropical front
9—Occlusion

2d Digit—Frontal Intensity

0—No specification
1—Weak, decreasing (incl. frontolysis)
2—Weak, little or no change
3—Weak, increasing (incl. frontogenesis)
4—Moderate, decreasing
5—Moderate, little or no change
6—Moderate, increasing
7—Strong, decreasing
8—Strong, little or no change
9—Strong, increasing

3d Digit—Frontal Characteristic

0—No specification
1—Frontal activity area, decreasing
2—Frontal activity area, little change
3—Frontal activity area, increasing
4—Intertropical
5—Forming or existence suspected
6—Stationary
7—With waves
8—Diffuse
9—Position doubtful

INTERPRETATION

[453] 4—Cold front
5—Moderate, little or no change
3—Frontal activity area, increasing

[122] 1—Warm front
2—Weak, little or no change
2—Frontal activity area, little change

Figure 12-7. Frontal analysis code.

12-8. Weather Maps in Flight Planning

Although the data plotted on surface weather maps is 2 to 6 hours old when used by the aviator, it presents the best overall picture of surface weather along his proposed flight route (fig. 12-10). It also may be used as a guide in obtaining other data in the weather station. The first course of action for planning a flight is to look at the latest surface weather map and proceed as follows:

a. Analyze trends in temperature and dew point, by comparing the two latest maps, in order to estimate possible fog areas along the flight route.

b. Determine position and movement of any low pressure center within 500 miles of the proposed flight track.

c. Read the station model cloud symbols, bases of clouds, and present weather symbols along and to both sides of the proposed line of flight. Compare these readings with current teletype sequence reports to determine whether sky condition and visibility is improving or deteriorating.

d. Become familiar with hazardous areas along the proposed route and obtain a thorough briefing from the forecaster on these areas.

e. Check the upwind weather conditions for the effects of advection on the flight area, such as temperature, clouds, fog, haze, and other phenomena that move with the wind.

f. Where frontal inversions appear to slope over the proposed route, check the latest winds aloft reports for the location of the wind shift and temperature inversion at flight level.

g. Ask the personnel on duty at the weather station to clarify any weather data which is not thoroughly understood.

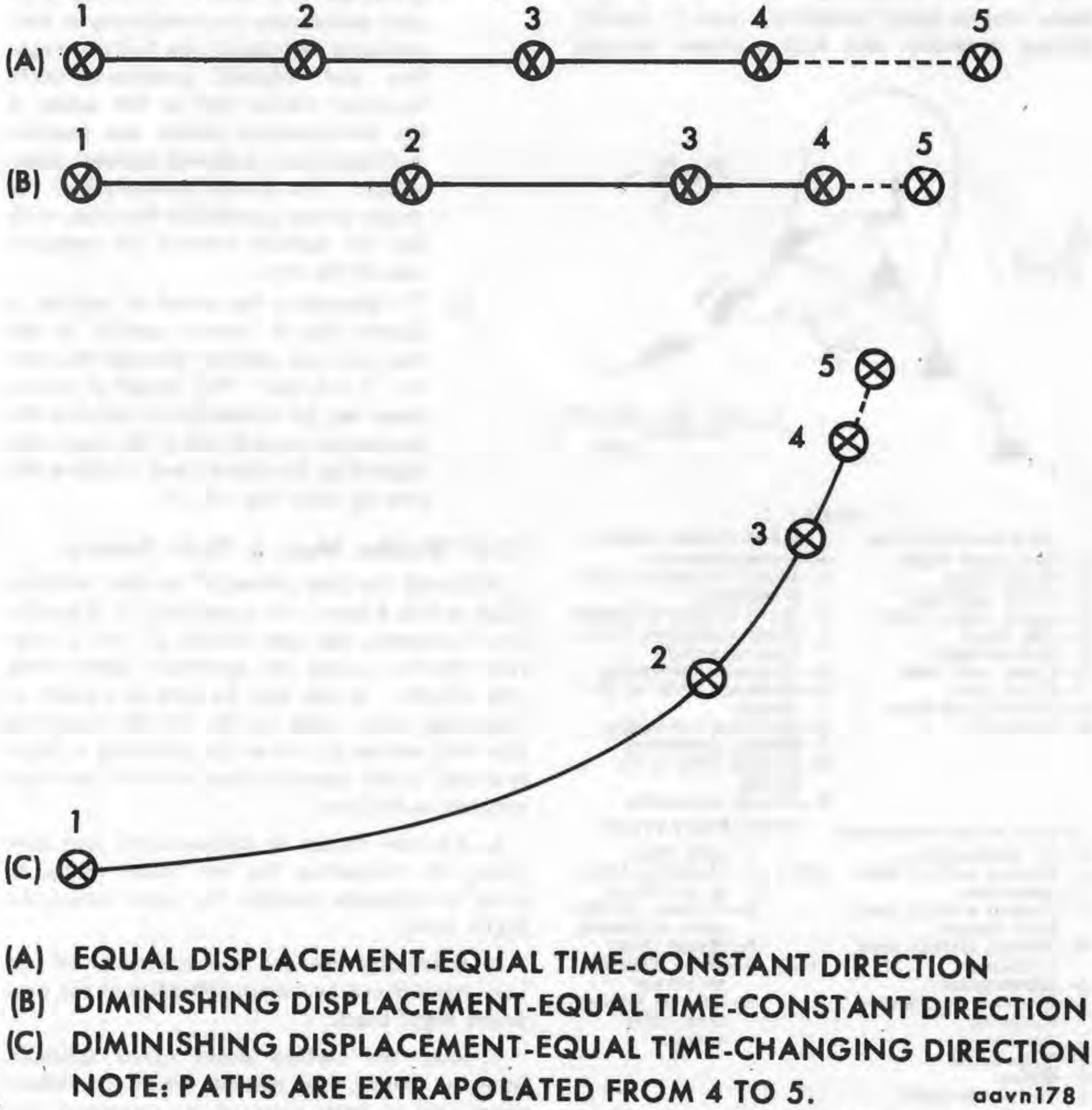


Figure 12-8. Forecasting movement of pressure systems by extrapolation.

12–9. Other Facsimile Maps Showing Cloudiness And/Or Visibility

In addition to the surface synoptic map, the NMC prepares two other facsimile charts which will aid the aviator in flight planning—the *radar summary chart* and the *weather depiction map.*

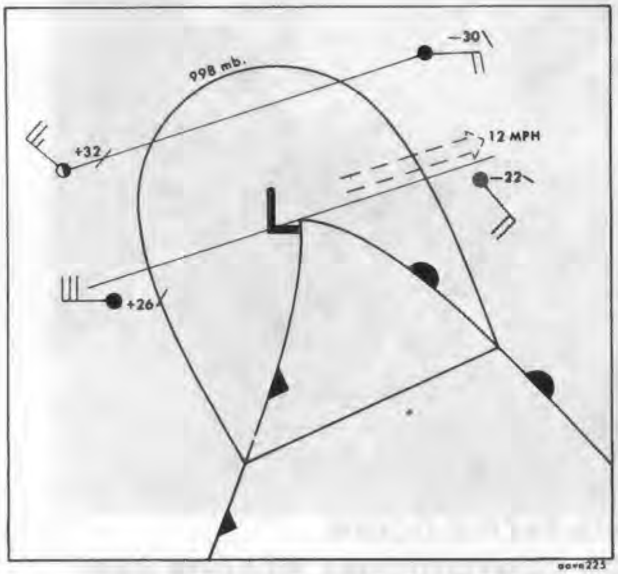
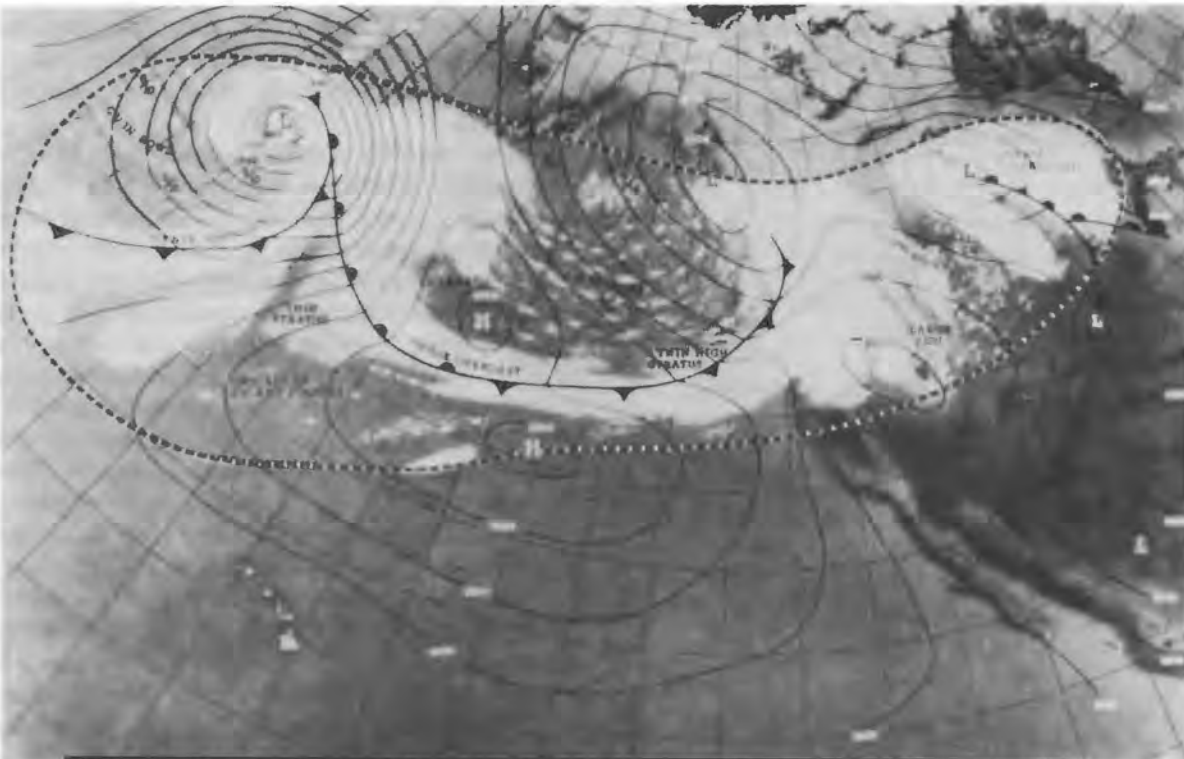


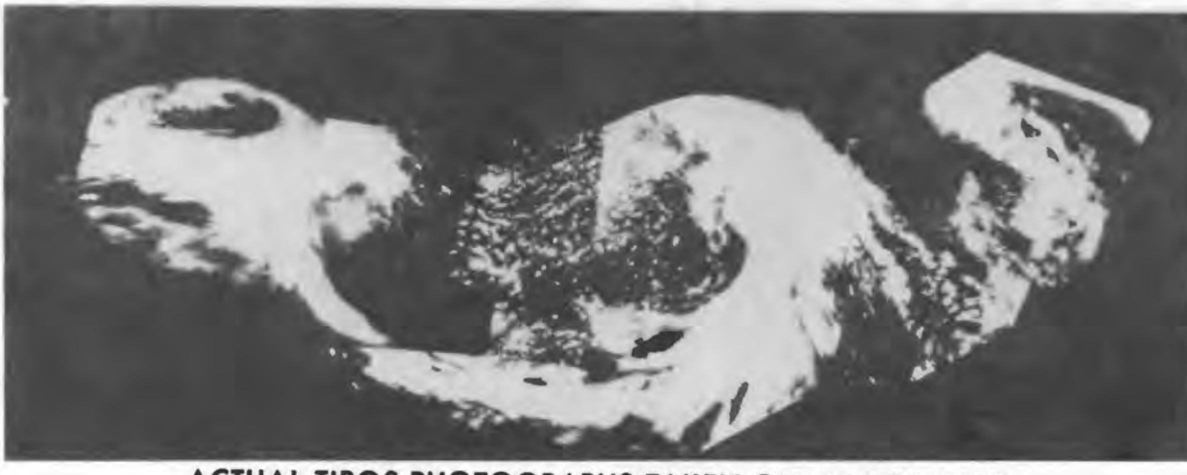
Figure 12–9. Tracing the future movement of a low.

a. The radar summary chart is discussed in chapter 15.

b. The weather depiction map (fig. 12–11) is transmitted eight times a day, beginning at 0100Z and every 3 hours thereafter. It is designed primarily as a supplement to the surface synoptic map for pilot weather briefing. Drawn from the same teletype data used to construct the surface synoptic map, it shows visibility and cloud conditions for selected stations across the United States. The station model is constructed as follows: The total sky coverage is plotted in the station circle; when restricted to 6 miles or less, the visibility is recorded to the left of the station circle; the height of the cloud base is plotted below the station circle in hundreds of feet. Areas where the visibility is less than 3 miles and/or the ceiling is less than 1,000 feet are colored red by the local weather station personnel. Areas in which the ceiling is between 1,000 and 5,000 feet are colored green or blue. Areas of IFR conditions are immediately apparent on this map. Comparison with the surface synoptic map, as a further step in weather analysis, will show the cause of the cloud formations and/or restrictions to visibility.



STORM FAMILY OVER THE NORTH PACIFIC OCEAN
(TIROS CLOUD PICTURES SUPERIMPOSED ON CONVENTIONAL WEATHER MAP)



ACTUAL TIROS PHOTOGRAPHS TAKEN ON MAY 20, 1960

aavn179

Figure 12–10. Weather map and actual weather conditions as photographed by TIROS I observation satellite.

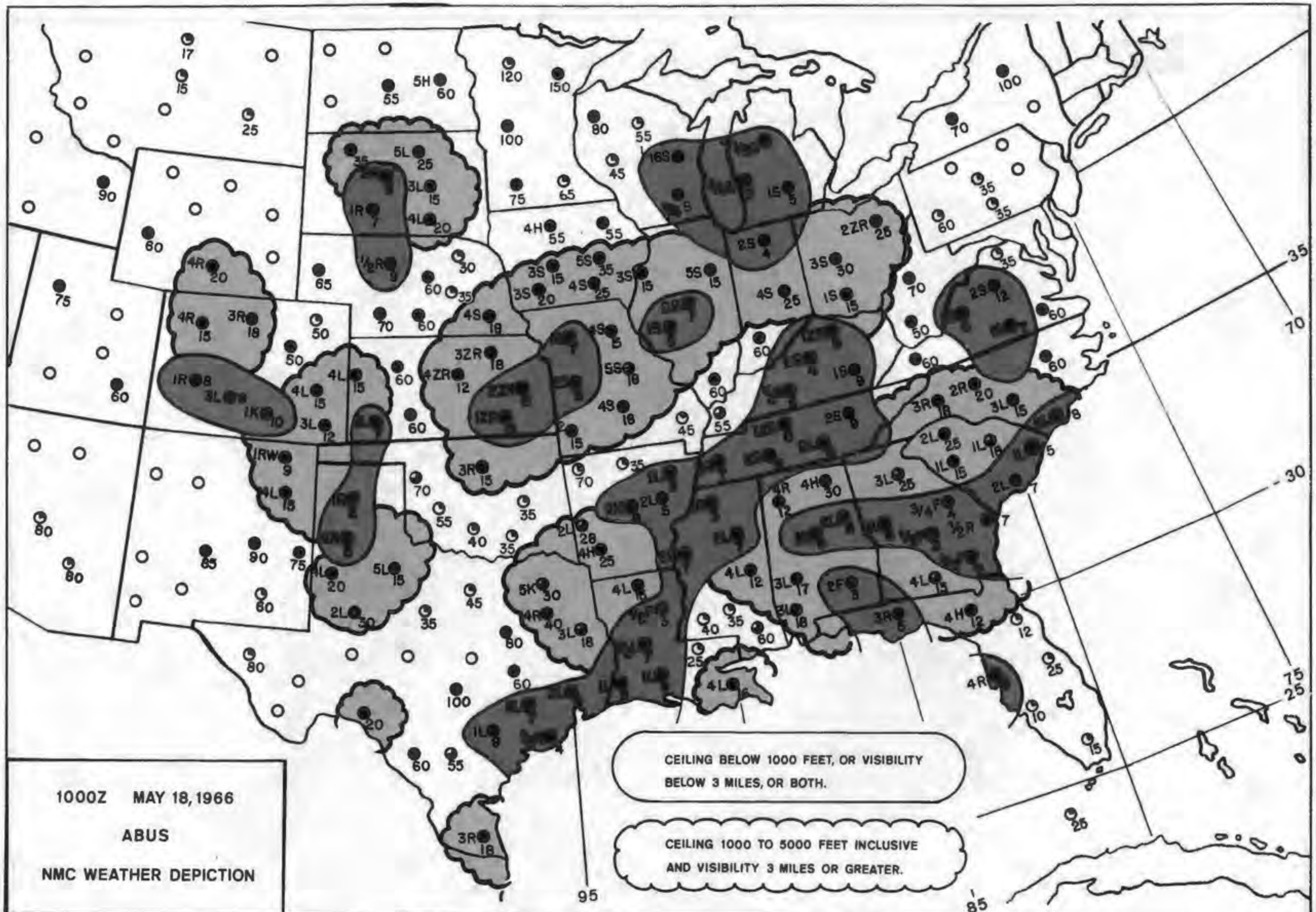


Figure 12–11. (Superseded) *Weather depiction map.*

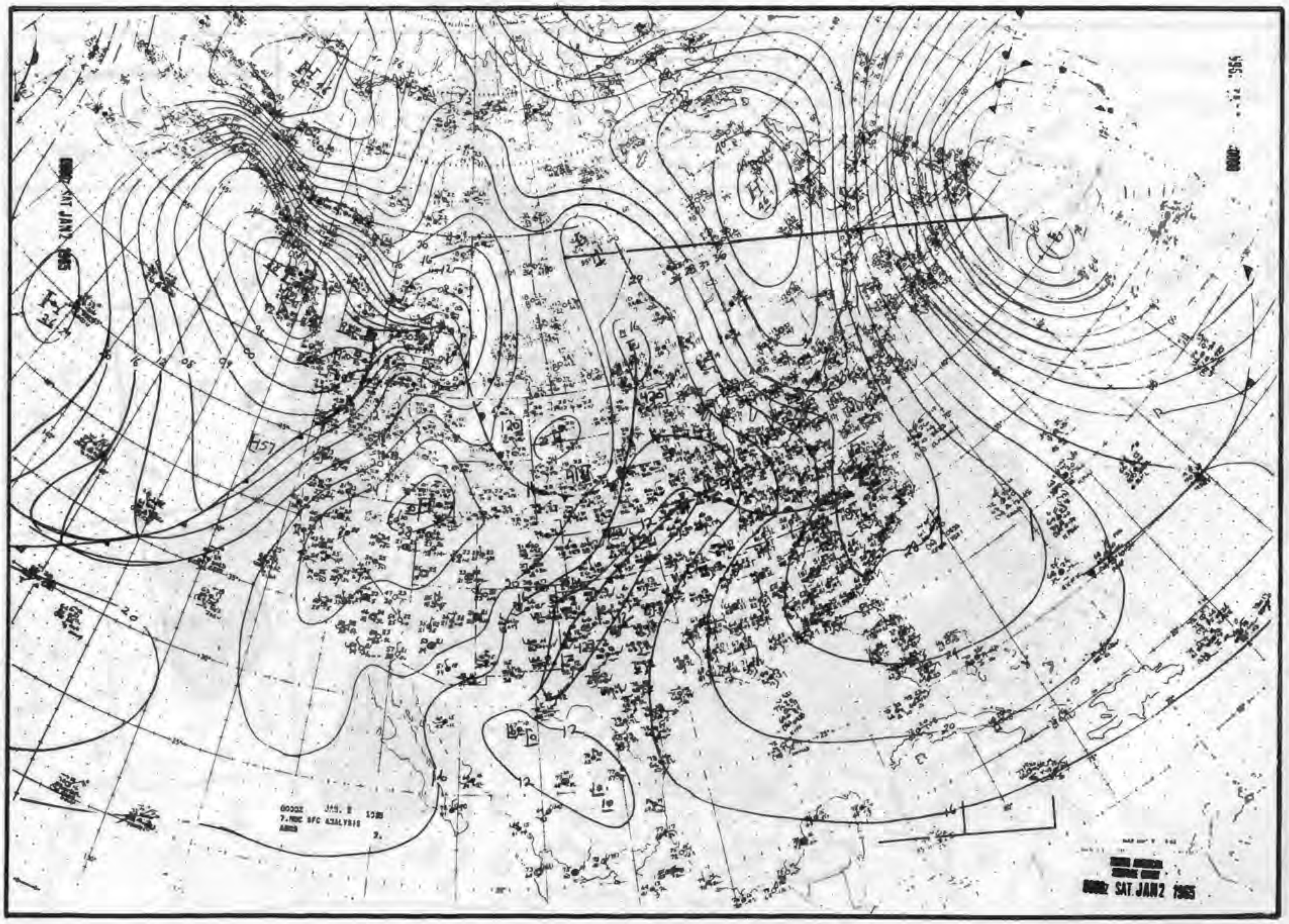


Figure 12–12. Surface weather map, 0000Z, 2 January 1965.

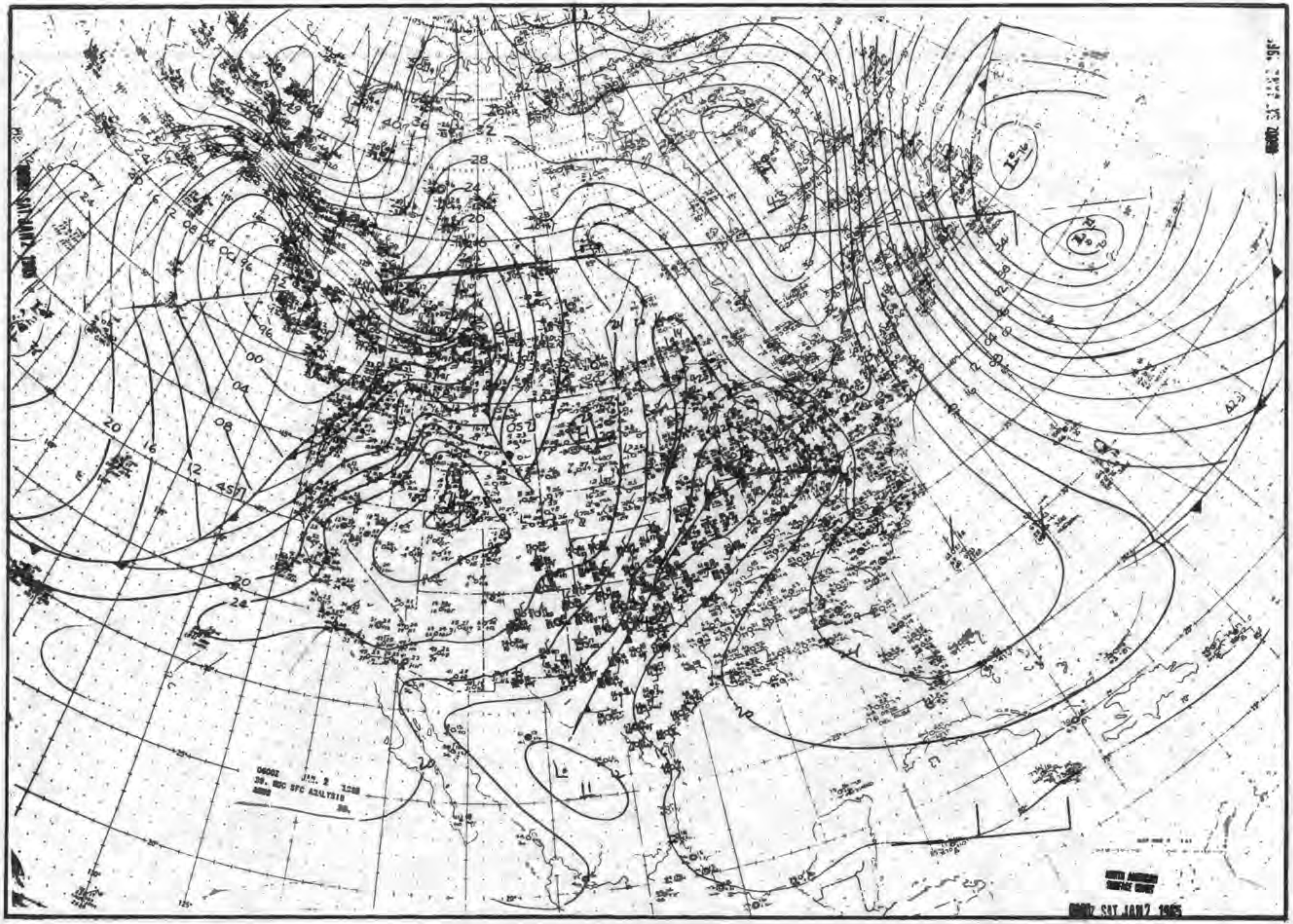


Figure 12-13. Surface weather map, 0600Z, 2 January 1965.

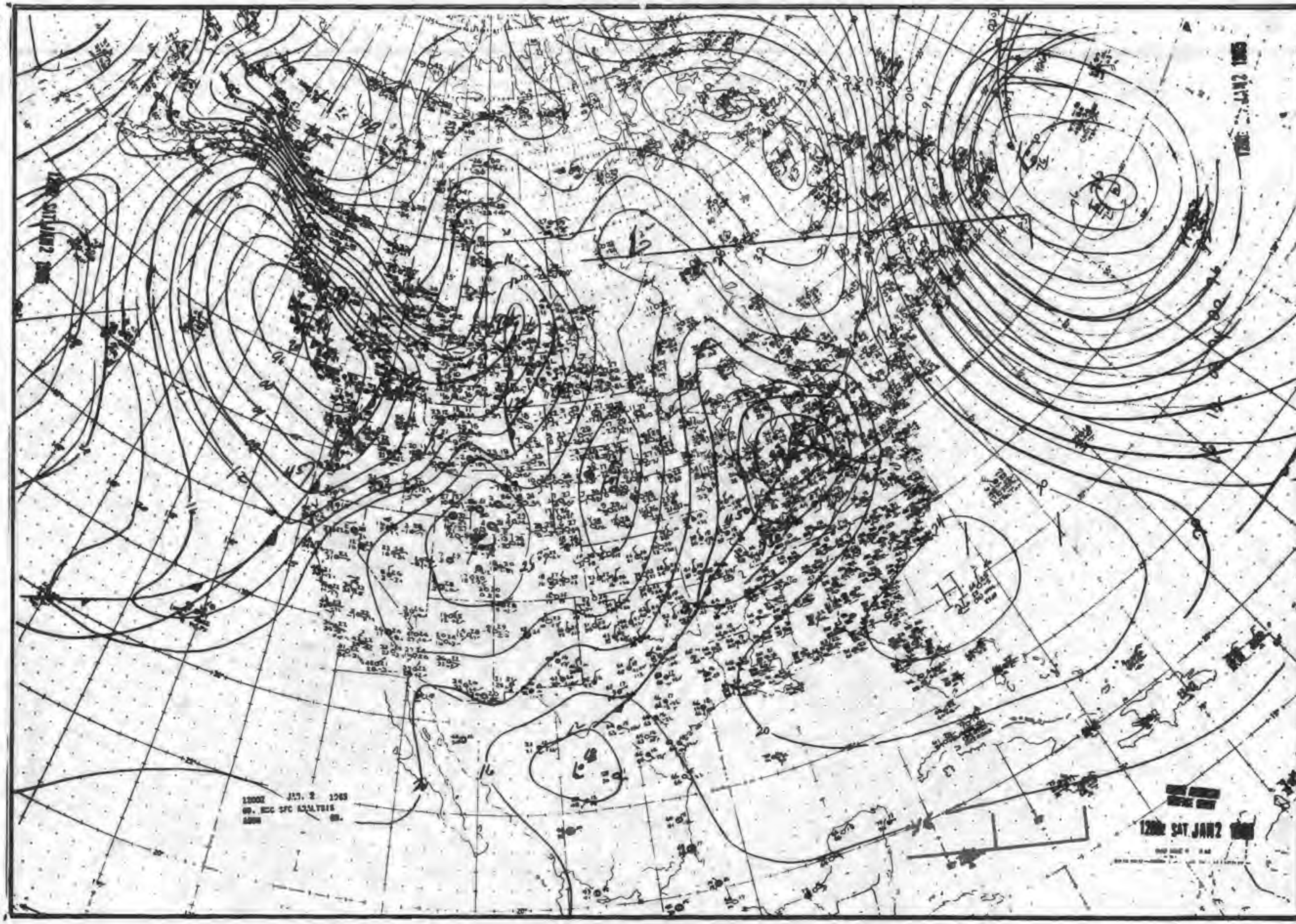


Figure 12-14. Surface weather map, 1200Z, 2 January 1965.

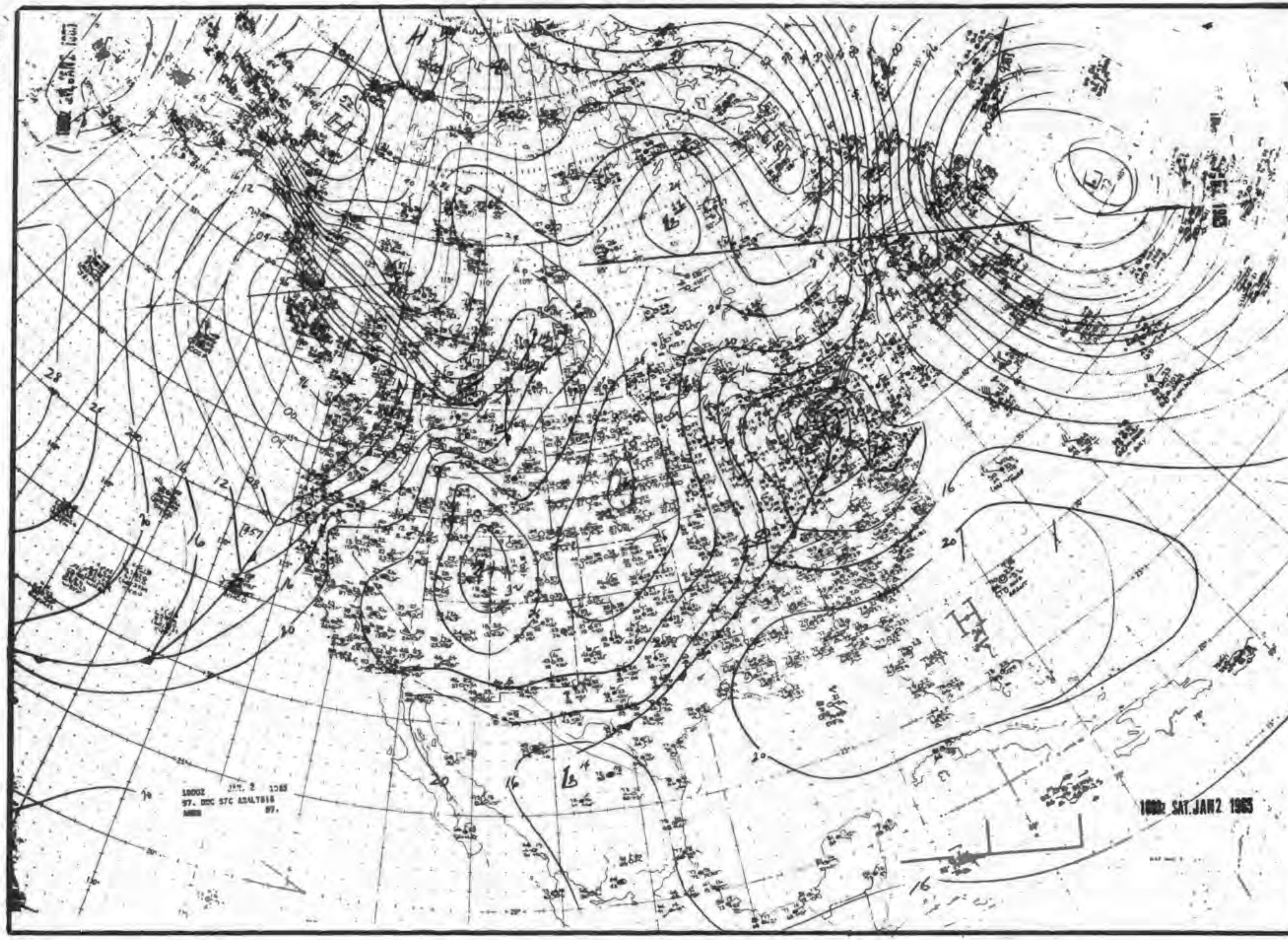


Figure 12–15. Surface weather map, 1800Z, 2 January 1965.

CHAPTER 13

WINDS ALOFT

13-1. General

The wind at flight altitude is an important factor in air navigation. The aviator should take full advantage of winds aloft information, both current and forecast, to compute correct headings; determine the best altitudes for flight; compute range, groundspeed, and estimated time of arrival; and be prepared for wind velocity changes along the flight route.

13-2. Methods of Observation

Winds aloft are determined by pilot balloon (PIBAL) and rawinsonde (RAWIN) observations.

a. PIBAL. Helium- or hydrogen-filled balloons of standard lift are released daily at 0000Z, 0600Z, 1200Z, and 1800Z. Each balloon rises at a known rate and its height is charted for a specified time interval. As the balloon rises and drifts with the wind, its movement is followed with a theodolite. With known height, vertical angle, and azimuth angle, the movement of the balloon is plotted and the wind velocity calculated. At night, a small battery-powered light is attached to the balloon to make it visible. The PIBAL observation is simple, economical, and requires a minimum of trained personnel. Disadvantages of this type observation are that—

(1) Dense clouds, precipitation, and other restrictions to visibility may conceal the balloon and cause an early termination of the observation.

(2) Strong winds may carry the balloon too far from the tracking equipment. When this occurs, accurate changes in direction and speed of the balloon may be impossible to measure from the ground.

b. RAWIN. Rawinsonde observations are obtained by attaching a radiosonde instrument to a balloon that rises at a computed rate and tracking the balloon with radio direction finding equipment. As the balloon rises, the radiosonde equipment transmits electrical signals which are computed as temperature, relative humidity, and pressure data. Wind velocity data is obtained by tracking the signal with the radio direction finding equipment. All of this data is evaluated and plotted on the atmospheric sounding diagram (ch. 5). The data concerning wind velocity is also used for the preparation of winds aloft reports and upper-air charts. Rawinsonde observations are usually taken twice daily (0000Z and 1200Z) as a significant supplement to PIBAL observations. Clouds, precipitation, and other restrictions to visibility have negligible affect on wind velocity measurement by rawinsonde. Wind data can be obtained to heights above 75,000 feet.

13-3. Winds Aloft Reports

Winds aloft are observed at approximately 180 weather stations in the United States and the reports are transmitted four times a day by teletype circuits. Winds aloft reports (fig. 13-1) are transmitted in numerical code, which states altitude, direction, and speed of the winds aloft as follows:

a. The station identifier is followed by a five-digit group of figures for the time of observation, the type of observation, and the direction and speed of the surface wind. This five-digit group is called the *surface group.*

b. After the surface group, the report shows the winds aloft direction and speed for each consecutive thousand-foot level above MSL, up to 10,000 feet. After the 10,000-foot level, each even thousand-foot level is reported between 10,000 and 20,000 feet followed by the 23,000-foot level. Next the winds at the 25,000-foot

foot intervals, to the highest point of the observation (fig. 13-1).

SAMPLE WINDS ALOFT REPORT AS RECEIVED ON TELETYPE

TLH 00411 0808 21011 1215 41418 1620 61825 1831 81932
2035 02138 22040 42139 62240 82039 02040 32241 52358 02582 57510 07865 53213 00200 03325 00200

REPORT DECODED

TLH	Tallahassee, point of observation.
00411	Surface data:
	00 0000Z, time of observation
	4 PIBAL observation (RAWIN is indicated by a 9).
	1 Wind from NE (eight points of the compass are represented by the figures 1 through 8) "0" indicates a calm, and 9 indicates an unknown direction.
	1 Wind 10 knots (the first figure to the nearest 10 knots is used. For example, a wind of 20 knots would be indicated as 2).
0808	1,000 feet level,[1] 80 degrees, 8 knots.[2]
21011	2,000 feet level, 100 degrees, 11 knots.
1215	3,000 feet level, 120 degrees, 15 knots.
41418	4,000 feet level, 140 degrees, 18 knots.
1620	5,000 feet level, 160 degrees, 20 knots.
61825	6,000 feet level, 180 degrees, 25 knots.
1831	7,000 feet level, 180 degrees, 31 knots.
81932	8,000 feet level, 190 degrees, 32 knots.
2035	9,000 feet level, 200 degrees, 35 knots.
02138	10,000 feet level, 210 degrees, 38 knots.
22040	12,000 feet level, 200 degrees, 40 knots.
42139	14,000 feet level, 210 degrees, 39 knots.
62240	16,000 feet level, 220 degrees, 40 knots.
82039	18,000 feet level, 200 degrees, 39 knots.
02040	20,000 feet level, 200 degrees, 40 knots.
32241	23,000 feet level, 220 degrees, 41 knots.
52358	25,000 feet level, 230 degrees, 58 knots.
02582	30,000 feet level, 250 degrees, 82 knots.
57510	35,000 feet level, 250 degrees, 110 knots.[3]
07865	40,000 feet level, 280 degrees, 165 knots.
53213	45,000 feet level, 320 degrees, 213 knots.[4]
00200	
03325	50,000 feet level, 330 degrees, 225 knots.
00200	

[1] Odd thousand-foot levels contain 4 digits. Even thousand-foot levels contain 5 digits, the first of which indicates the height.

[2] Teletype reports are given for 1,000-foot intervals from the surface to 10,000 feet; 2,000-foot intervals from 12,000 feet; 5,000-foot intervals above 20,000 feet; an interim report for 23,000 feet; and 10,000-foot intervals above 50,000 feet.

[3] When wind speed exceeds 100 knots, the wind direction digits will exceed 36 in which case the person reading the report must subtract 50 from the wind direction digits and add 100 knots to the wind speed digits.

[4] When a report is followed by 00200, the direction should be read as indicated by the wind direction digits and the person reading the report should add 200 to the wind speed digits.

Figure 13-1. Key to winds aloft report.

13-4. Interpretation of Winds Aloft Reports

a. Altitude Reading. The winds aloft report (fig. 13-1) consists of a series of four- and five-digit groups. The first group of digits after the surface group indicates the direction and speed of the wind at the lowest thousand-foot MSL altitude above the station. For example, if a station were 2,358 feet above MSL, the first group of digits would consist of four numbers and would be for the 3,000-foot altitude. If the station were 3,115 feet above MSL, the first winds aloft group would consist of five digits, and would indicate the winds at 4,000 feet. The first digit of any five-digit group indicates the altitude level of the report. The altitude of the wind is not indicated in the four-digit groups—these four-digit groups are used to report odd thousand-foot levels from 1,000 feet to 9,000 feet (MSL). The aviator can determine the altitude of the odd thousand-foot levels by comparison with the even thousand-foot levels on either side. Since only one digit is used to indicate altitude, the altitude readings above 10,000 feet can only be determined by their position in the sequence of five-digit groups.

b. **Wind** *Direction.* **Wind** direction (true north) is shown in the second and third digit of a five-digit group, or the first and second digit of a four-digit group. **Wind** direction is given to the nearest 10°: therefore, the final *0*, in all **wind** directions, is omitted —e.g., a north wind is coded as *36*; with a calm condition the direction is encoded *00*.

c. Wind Speed. The last two digits of the four- or five-digit groups indicate the wind speed in knots. If a calm wind exists, the report will read *00* for the last two digits. If the windspeed is between 100 and 200 knots, the coded wind *direction* digits are increased by 50 (as shown at the 35,000- and 40,000-foot levels in fig. 13-1. To decode this group, subtract 50 from the coded wind direction digits and add 100 knots to the coded wind speed. If the wind is over 200 knots, the direction in degrees and the speed in tens and units of knots is given, followed by *00200*. To decode wind speeds 200 knots or more, add 200 knots to the speed of the wind in the group preceding the

00200 group (as shown at the 45,000- and 50-000-foot levels in fig. 13-1).

13-5. Winds Aloft Charts

a. Method of Plotting. The National Meteorological Center prepares winds aloft charts from the winds aloft reports. These charts are transmitted four times daily, approximately 2 hours after the standard PIBAL observation times. The observed winds for appropriate levels are plotted on these charts, using the barb and pennant system (fig. 13-2). The wind direction to the nearest 10° is represented by an arrow flowing with the wind and a numeral near the tail of the arrow. A full barb length on the wind arrow represents 10 knots, a half barb 5 knots, and a pennant 50 knots. The wind represented in figure 13-2 is from 280° (W) at 65 knots.

b. Levels Plotted. Winds aloft charts are transmitted over facsimile circuits within the United States. There are two winds aloft facsimile charts of special interest to the aviator—

(1) The lower level chart containing plotted winds for the second standard level above the surface (approximately 2,000 feet above the ground), 5,000-, 8,000-, and 10,000-foot altitudes above mean sea level (fig. 13-3).

(2) The intermediate level chart containing winds for the 14,000-, 20,000-, 25,000-, and 30,000-foot altitudes above mean sea level (fig. 13-4).

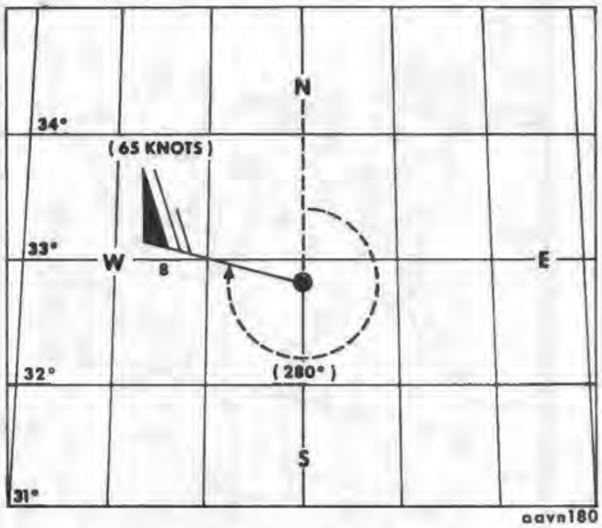


Figure 13-2. Winds aloft chart station model.

Note. Winds aloft are also transmitted in chart form for levels above 30,000 feet. Supplementary high altitude wind data may be obtained from the coded teletype winds aloft reports and from constant pressure charts (ch. 14).

c. Using the Charts. Winds aloft charts are useful in representing the windflow pattern that existed at the time of the PIBAL or RAWIN observation. However, the charts are based on observed data several hours old and may not represent the wind that will be encountered on a flight subsequent to the observation time. For this reason, the aviator should also refer to the forecast winds aloft reports (ch. 16) when planning his flight.

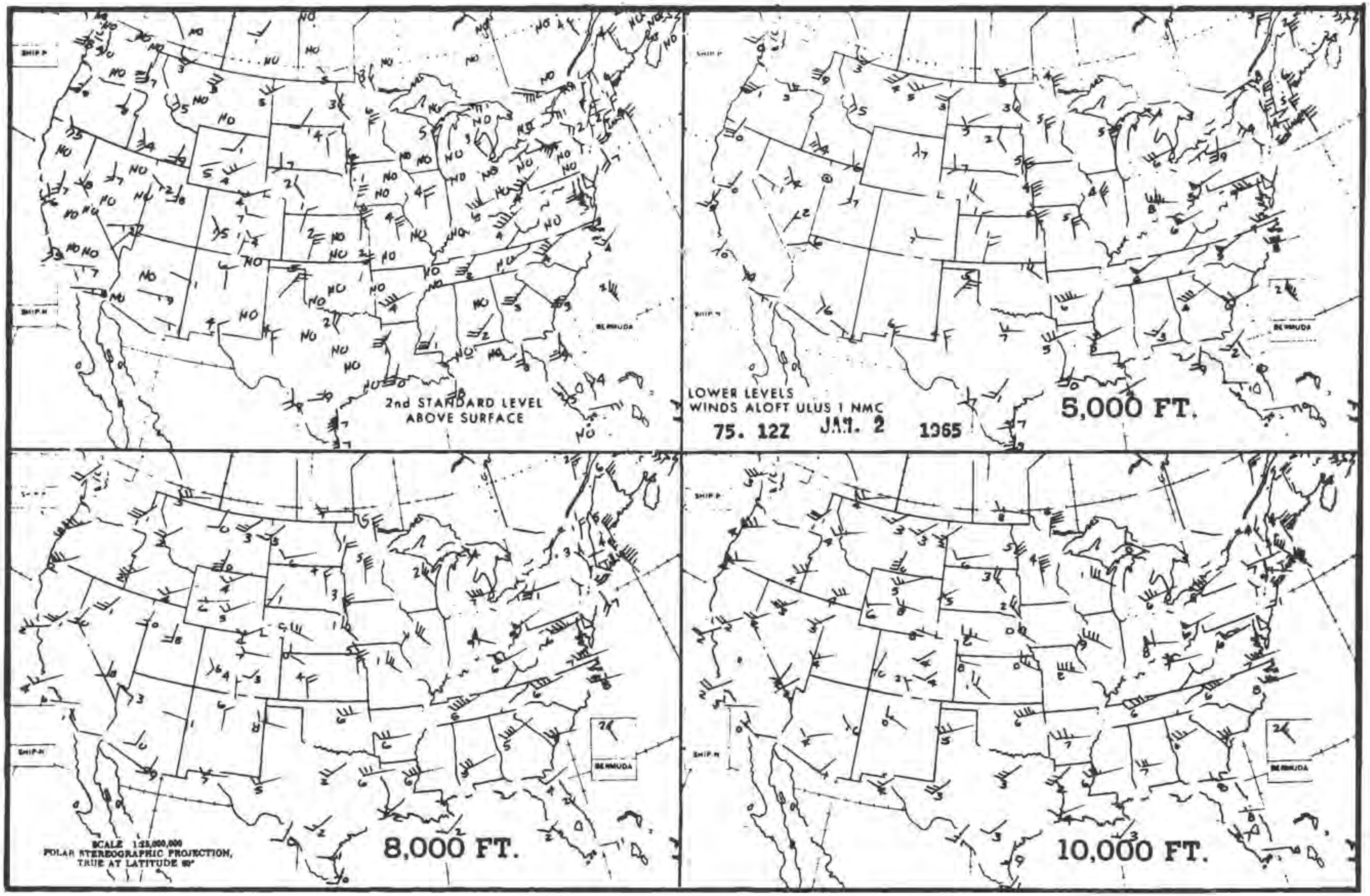


Figure 13–3. Lower level winds aloft chart.

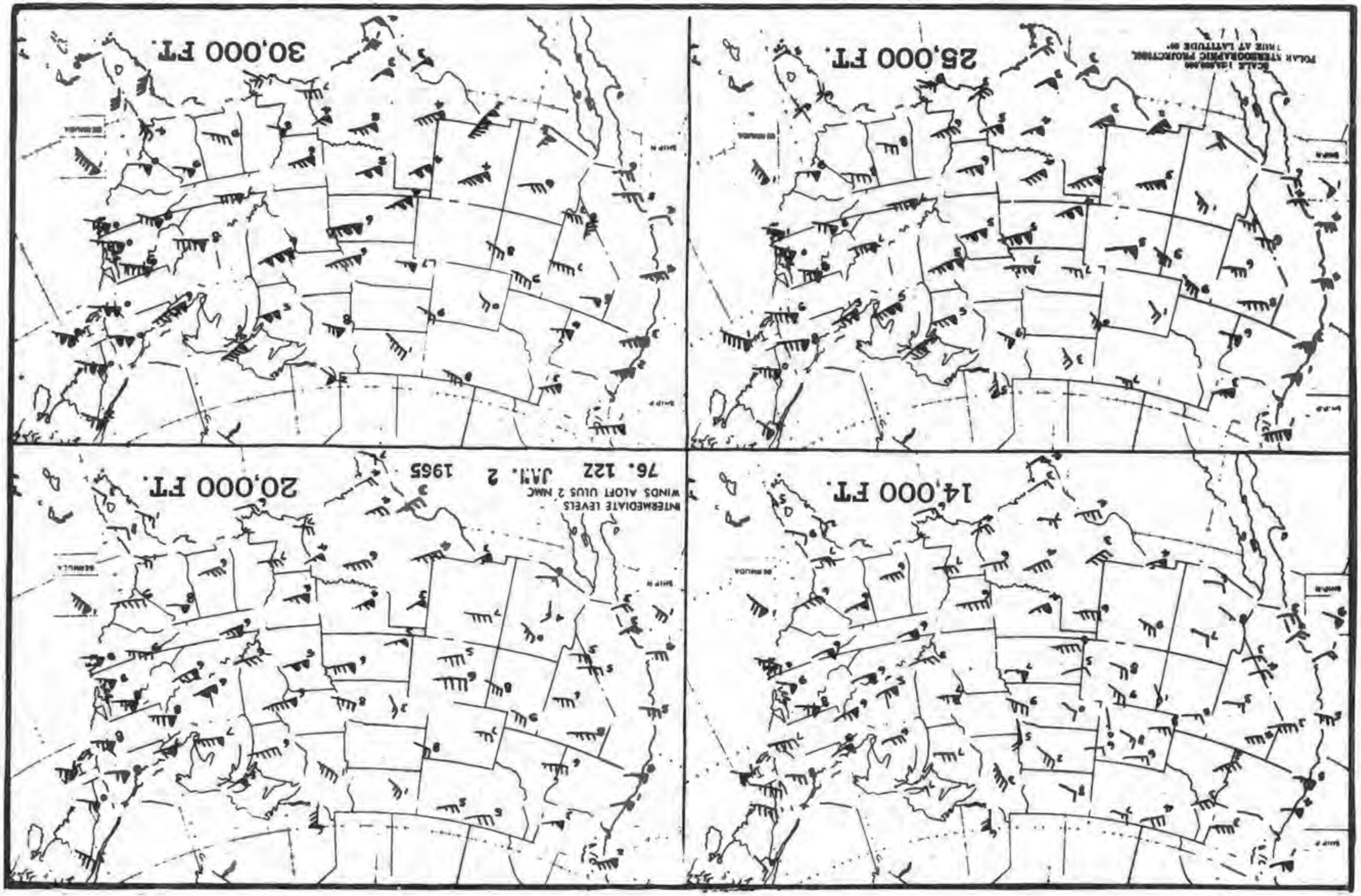


Figure 13-4. Intermediate level winds aloft chart.

CHAPTER 14

CONSTANT PRESSURE CHARTS AND HIGH ALTITUDE WEATHER

14–1. General

The surface weather map is effective in presenting pictorially the atmospheric conditions from the surface to approximately 5,000 feet. At altitudes above 5,000 feet, the pressure patterns and frontal positions begin to change shape and location as the surface secondary circulation of migratory cyclones and anticyclones merges gradually into the more constant primary circulation of the upper atmosphere. *Constant pressure charts* (fig. 14–1) are weather maps designed for flights at and above 5,000 feet. Constant-pressure charts depict the weather along a specific pressure level, whereas surface weather maps depict the pressure changes at a constant altitude (MSL). Furthermore, many weather phenomena occur at high altitudes which are unique to these levels and do not appear on surface weather maps. When flight missions are to be conducted near the middle and upper portions of the troposphere, it will be necessary for the aviator to use weather charts for upper levels, in addition to the surface weather map. The *constant-pressure charts* correlate several weather facilities in the weather station; i.e., the surface weather map, winds aloft charts, and the Skew T, log p Diagram. The constant-pressure charts for each pressure level are drawn twice each day from observations made at 0000Z and 1200Z.

14–2. Levels of Constant Pressure Charts

The rate in change of pressure with altitude is controlled by the rate in change of temperature with altitude. For example, if the temperature of the air decreases faster than it should, the pressure level of 850 millibars, which would be approximately 5,000 feet in standard atmosphere, may be at 4,600 feet or lower in the cold air. When the temperature lapse rate is less than standard, the 850-millibar level may be 5,400 feet or higher in the warmer than standard air. The heights of a pressure level are also influenced by the variation in sea level pressure. A constant pressure chart for the 850-millibar level depicts the amount of altitude variation of the 850-millibar constant pressure level in the atmosphere. Wherever the pressure level varies 60 meters (approximately 200 feet), a new contour line is drawn (fig. 14–1). The same type of chart can be drawn for any pressure level desired. However, the standard levels with which the aviator is concerned are—

a. 850-Millibar Chart. In the standard atmosphere the 850-millibar level is 1,457 meters (4,781 feet). For planning flights at approximately 5,000 feet, this chart is the most useful (fig. 14–1).

b. 700-Millibar Chart. In the standard atmosphere the 700-millibar level is 3,012 meters (9,882 feet). This chart is used for planning flights near the 10,000-foot level.

c. 500-Millibar Chart. In the standard atmosphere the 500-millibar level is 5,574 meters (18,289 feet). This chart is used for flight planning near the 18,000-foot level. At this altitude, the atmospheric pressure decreases to approximately one-half the mean sea level pressure value.

d. 300-Millibar Chart. In the standard atmosphere the 300-millibar level is 9,164 meters (30,065 feet). Although few flights in Army aircraft are performed at this height, the 300-millibar chart is significant in that the strong winds of the jet stream, the associated wind shear and clear air turbulence, and the tops of thunderstorms will frequently appear at this level. It is also used for the interpolation of temperatures and winds for flights between the 18,000- and 30,000-foot levels.

14-3. Source of Data

Data for plotting constant pressure charts is obtained from radiosonde and pilot balloon observation.

a. Radiosonde Observations. The radiosonde is a balloon-borne instrument which contains (1) a plastic strip coated with a moisture-sensitive film used to measure the moisture content of the air, (2) a thermistor to measure the temperature of the air at mandatory pressure levels, (3) an aneroid wafer which closes electrical relays as it expands to transmit data at specific intervals as the pressure changes, and (4) an electrical transmitter which radios the data to a surface receiver. The distance between the pressure levels at which the radiosonde transmits data is computed by using the average air density (temperature) through the distance; the speed and direction of the wind is determined by radio ground-tracking instruments (RAWIN observation). This same data is used in the construction of the Skew T, log p Diagram and winds aloft reports. Radiosonde observations are made twice a day at 0000Z and 1200Z at approximately 80 stations in the United States.

b. Pilot Balloon Observations (PIBAL). PIBAL observations involve no electrical instrumentation. The observer tracks a constant-rate-of-rise balloon through a theodolite (an instrument similar to a surveyor's transit) and obtains the elevation and azimuth angles, which are necessary for computing the wind direction and speed. Data recorded from the PIBAL observations are for altitudes rather than constant-pressure levels, and the data does not contain any information about temperature or dew point. At night a small battery-powered light is attached to the balloon for ground tracking. PIBAL observations are made four times a day at 0000Z, 0600Z, 1200Z, and 1800Z. The winds determined by this method at 0000Z and 1200Z may be plotted on constant-pressure charts as supplemental data.

14-4. Methods of Plotting

The station model on the constant pressure chart (fig. 14-2) includes the wind direction and speed, the altitude of the constant-pressure level, the temperature in degrees centigrade, and the dew point in degrees centigrade.

a. Wind.

(1) *PIBAL.* The wind arrow plotted from the data obtained by PIBAL observation shows the direction from which the wind is blowing ((A), fig. 14-2). The number appearing at the rear of the shaft indicates the wind direction in tens of degrees. A "4" with wind from the southeast quadrant of the compass indicates *140°*. A "4" with wind from the northeast quadrant indicates the direction as *040°*. The speed of the wind is shown by the barb and pennant system. A full barb represents 10 knots wind speed, a half barb 5 knots, and a pennant (flag) 50 knots. When used, the half barb is placed part way down the shaft to prevent confusion with a whole barb. No other data for plotting can be obtained by PIBAL equipment.

(2) *RAWIN.* The wind plotted from a radiosonde observation ((B), fig. 14-2) shows the direction and speed in the same manner as the PIBAL observation ((1) above).

b. Altitude. At stations where the observation has been made with radiosonde equipment, the altitude of the pressure level above MSL is shown ((B), fig. 14-2). On the 850- and 700-millibar charts this altitude is plotted in whole meters with the first digit missing; e.g., 483 represents 1,483 meters on the 850-millibar chart and 3,483 meters on the 700-millibar chart. On the 500- and 300-millibar charts the altitude of the pressure level is indicated in tens of meters; e.g., 534 represents 5,340 meters and 948 represents 9,480 meters. When working with the 850- and 700-millibar charts, the aviator must check the chart pressure level in the lower left-hand corner of the chart to read the altitude properly. A plotted value of 380 would logically be 1,380 meters at the 850-millibar level and 3,380 meters at the 700-millibar level.

c. Temperature and Dew Point. The tem-

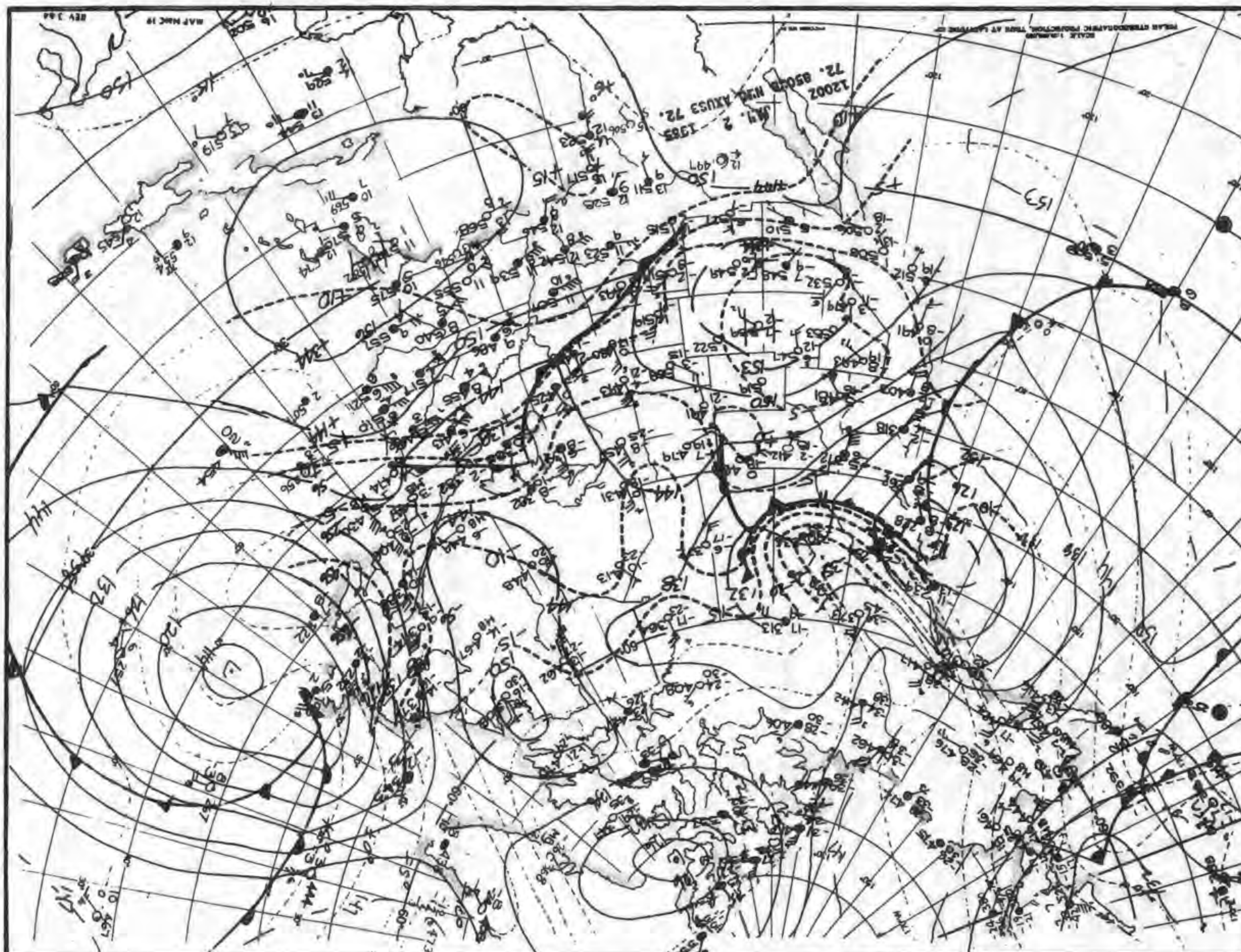


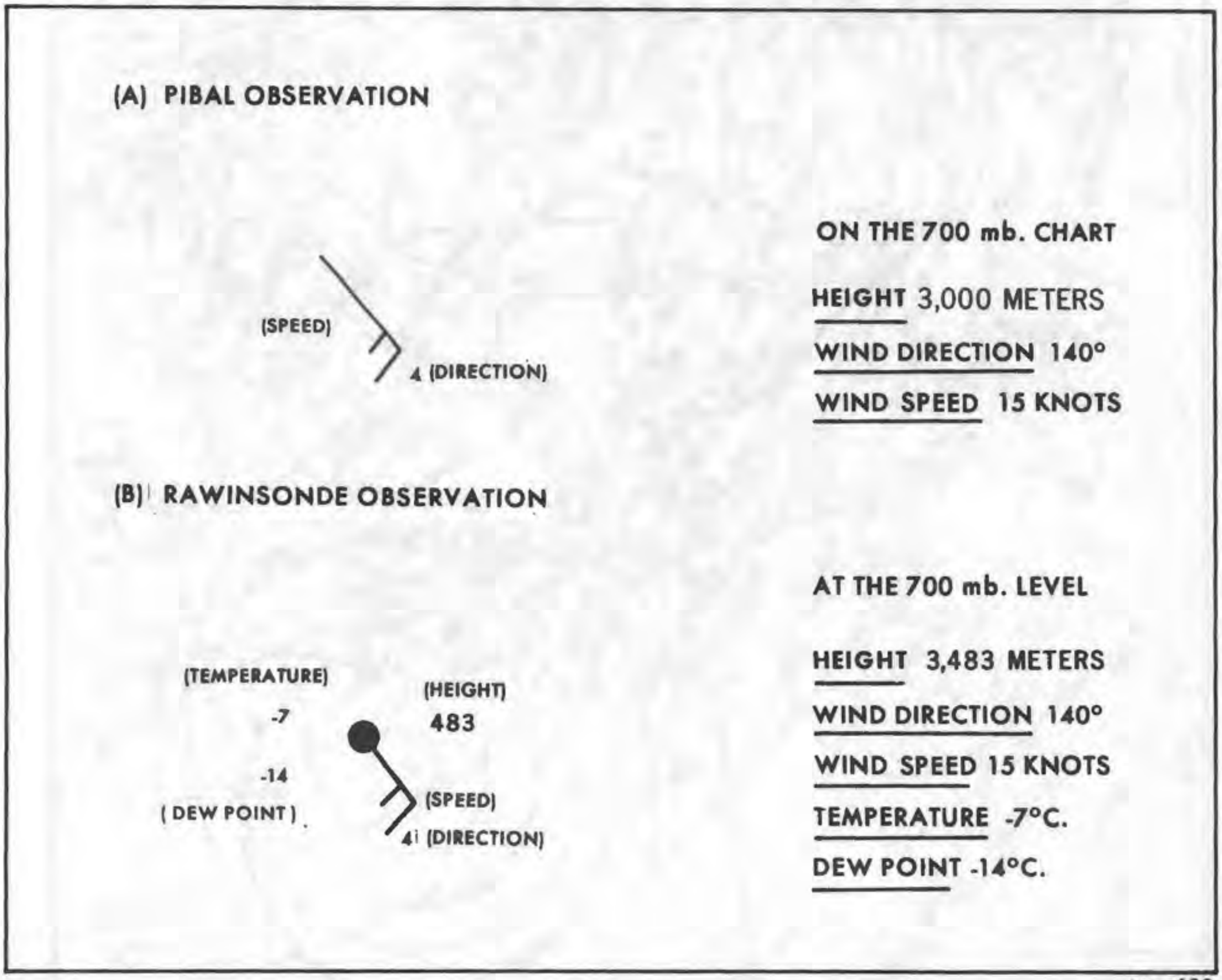
Figure 14–1. An 850-millibar constant pressure chart.

perature and dew point are plotted to the left of the station model ((B), fig. 14–2). Upper-air temperatures and dew points are always in degrees centigrade. When the temperature is within 2° C. of the dew point, clouds often exist at that level. An "M" indicates missing data: "MB" indicates that the quantity of water vapor in the air is so low that the instrument could not measure it. Dew point temperatures are not plotted below –40° C.

14–5. Isoline Analysis

a. Contour Lines (Isohypses). Contour lines are solid black lines joining points of equal elevation (fig. 14–1). The contour lines are labeled in tens of meters; i.e., 138 means 1,380 meters, 294 means 2,940 meters, 546 means 5,460 meters, and 936 means 9,360 meters. An interval of 60 meters between contour lines is used on the 850-, 700-, and 500-millibar charts. A 120-millibar interval is used on charts at and above the 300-millibar level.

(1) Wind speed and direction can be interpreted from the contour lines in the same manner as from isobars on the surface weather map, even though the principle of their construction is reversed. The windflow in the Northern Hemisphere is parallel to the contour lines clockwise around areas of high



aavn182

Figure 14–2. Station model on a constant pressure chart.

elevation and counterclockwise around areas of low elevation. The closer the isohypse spacing, the faster the speed of the wind.

(2) Closed areas labeled with an *H* or *L* are not interpreted as regions of High or Low pressure, but are areas of High or Low elevation, respectively. A region of high elevation on a constant-pressure chart may be directly over a region of low pressure at the surface.

(3) Steering levels for the surface pressure systems may be obtained from these charts. For example, if closed contour lines are present up to the 500-millibar level, but open contour lines appear on the 300-millibar chart over the same area, the surface pressure system will tend to move in the direction of windflow on the 300-millibar chart. Shallow surface pressure systems usually move at the greatest speed. Most of the winds on the charts at 10,000 feet and higher over the United States have a west-to-east component typical of the primary circulation.

b. Isotherms. Isotherms are dashed lines joining points of equal temperature at 5° C. intervals (fig. 14-1). Weather station personnel may color these lines red when time permits. When the temperatures across a front on the constant-pressure charts change as much as 5° C. in a distance of 200 miles or less, the front is usually active. Where isotherms cross the contour lines at a sharp angle, warm or cold air advection is occurring at that altitude. Cold air advection aloft (fig. 14-3) tends to fill a Low or intensify a High at the surface. Warm-air advection aloft tends to deepen a Low or weaken a High at the surface (fig. 14-4).

c. Isotachs. Isotachs are dotted lines joining points of equal wind speed and are drawn on the 300-millibar level constant-pressure chart where strong wind speeds generally exist. Occasionally isotachs appear on the 500-millibar chart if the strong winds dip down to the 18,000-foot level. Isotachs indicate wind speed but not the direction of windflow. Areas of strongest wind with close isotach spacing indicate that the wind speed is changing rapidly in a short distance. This abrupt change in wind speed causes a shear action which may cause clear air turbulence. The greatest wind shear is associated with maximum isotach centers. The isotachs are drawn for intervals of 25 knots and the values are circled for ease of identification (fig. 14-5).

14-6. Jet Stream

a. Definition. The jet stream is a strong meandering current of air near the tropopause over the Temperate Zone that changes altitude and latitude with the seasons. The windflow has a west-to-east component with speeds in

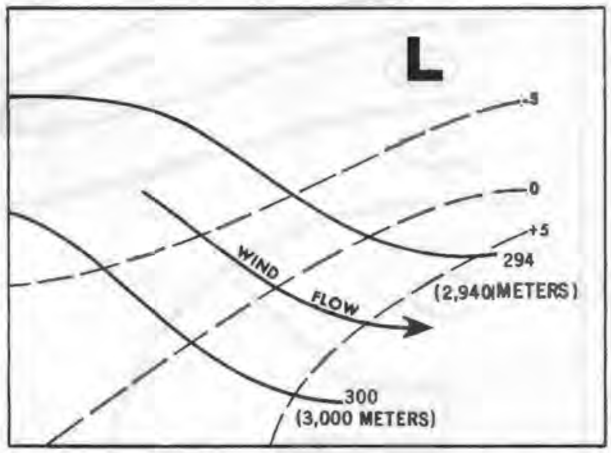


Figure 14-3. Cold air advection.

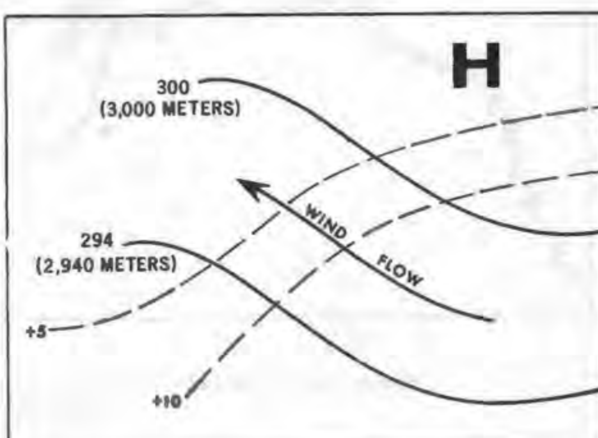


Figure 14-4. Warm air advection.

excess of 50 knots. At times the jet stream takes the form of a continuous river of air encircling the Northern Hemisphere. More frequently it is found in segments from 1,000 to 3,000 miles in length, 100 to 400 miles in width, and 3,000 to 7,000 feet in thickness (fig. 14-6). There are normally two jet stream axes in the Northern Hemisphere—one between the arctic and polar air masses, and one between the polar and tropical air masses. The location of a jet stream is indicated on constant pressure charts by solid black arrows (fig. 14-5).

b. Altitude. Jet stream winds are found where breaks appear in the tropopause. The average height of the tropopause (*d* below) over the United States is 35,000 feet. This is the ideal altitude for maximum winds of the jet stream core, although jet streams have been recorded as low as 15,000 feet and as high as 50,000 feet. The altitude of the jet stream

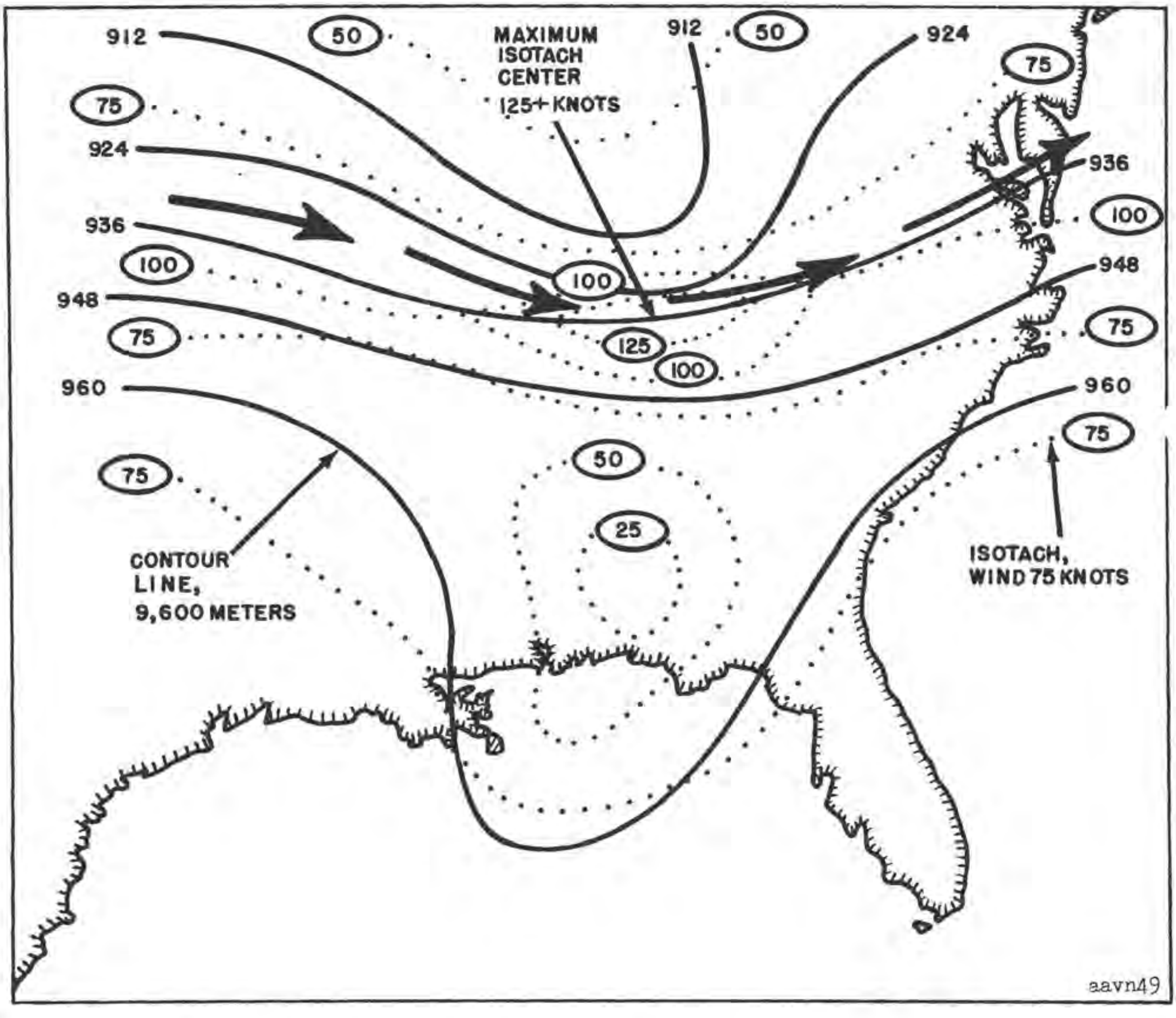


Figure 14-5. Isotachs, contour lines, and jet stream as depicted on a 300-millibar constant pressure chart.

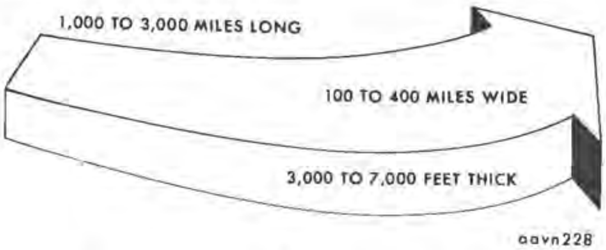


Figure 14–6. Size of a jet stream segment.

varies along its course, and the height of the complete segment may change slightly from day to day.

c. Latitude. Jet streams are found between 20° and 60° north latitude with equal frequency in summer and winter. The polar jet migrates with the outbreaks of cold polar air from the north. During the winter season, the cold air may push as far south as Cuba, with the jet stream axis as far south as Florida. During the summer season, the cold-air outbreaks are weakened and the jet stream is typically located near the Canadian border. Daily variation in latitude of the jet stream is slight.

d. Tropopause. The tropopause is the boundary between the troposphere and the stratosphere. It is not a layer but a plane of transition marking the upper limit of the temperature decrease with height, vertical air currents, and moisture content. The tropopause is not a continuous boundary; it has large distinct breaks above air masses of different density (fig. 14–7). There is a significant temperature change with latitude across these breaks at high altitudes. The air south of the break in the tropopause is colder than the air north of the break because the temperature lapse rate extends through a deeper layer of the atmosphere to the south. (At the base of the stratosphere, temperatures are colder over the Equator than they are over the poles.) This thermal gradient sets the air into horizontal motion at great speeds, and Coriolis force deflects it sharply to the east. Thus, a strong flow of westerly winds forms at the break in the tropopause; this flow is the *jet stream* (fig. 14–8). The jet stream can frequently be located by following a cold frontal surface from the ground to the point where the frontal boundary intersects the 500-millibar level. The jet stream is usually above this point at an average altitude of 30,000 feet (fig. 14–7).

e. Wind Speed. When jet streams move southward, the wind speed tends to increase—if two jet streams exist over the United States, the more southerly one usually contains the stronger wind velocities. Wind speeds up to 291 knots have been observed in the jet core, but the average speed is approximately 150 knots. The high-velocity winds of the jet stream extend for a great distance along the length of the stream, but decrease rather rapidly above, below, and on either side of the central core of maximum winds (maximum isotach centers) (fig. 14–9).

f. Wind Shear. The wind speed of a jet stream decreases rapidly to the north (polar air mass side) and more slowly to the south (tropical air mass side). The horizontal wind shear (change in wind speed in the horizontal plane) outward from the jet stream core may be as much as 100 knots in 100 miles north of the stream and as little as 25 knots in 100 miles south of the stream. The vertical shear (change in wind speed with height) may be 3 to 4 knots per thousand feet above and below the maximum wind core. If the aviator encounters an adverse jet stream, a descent or climb toward the polar side of the stream will effect the most abrupt decrease in headwind velocity.

g. Clear Air Turbulence. Extreme wind-shear areas (8 knots per 1,000 feet) may cause *clear air turbulence,* which denotes the bumpiness sometimes experienced while flying in cloudless skies at high altitudes. This bumpiness may be of sufficient intensity to cause serious stresses on the aircraft and physical discomfort to the aviator. Clear air turbulence is generally associated with changing wind velocities with height (vertical-wind shear) in and near the maximum wind speed centers of the jet stream. The length of the turbulent area varies from 50 to 100 miles, the width from 5 to 20 miles; the thickness averages 2,000 feet. If the aviator encounters significant clear air turbulence, he should change altitude to avoid the strong wind shear and follow procedures established in the specific operator's manual for flight in turbulent air.

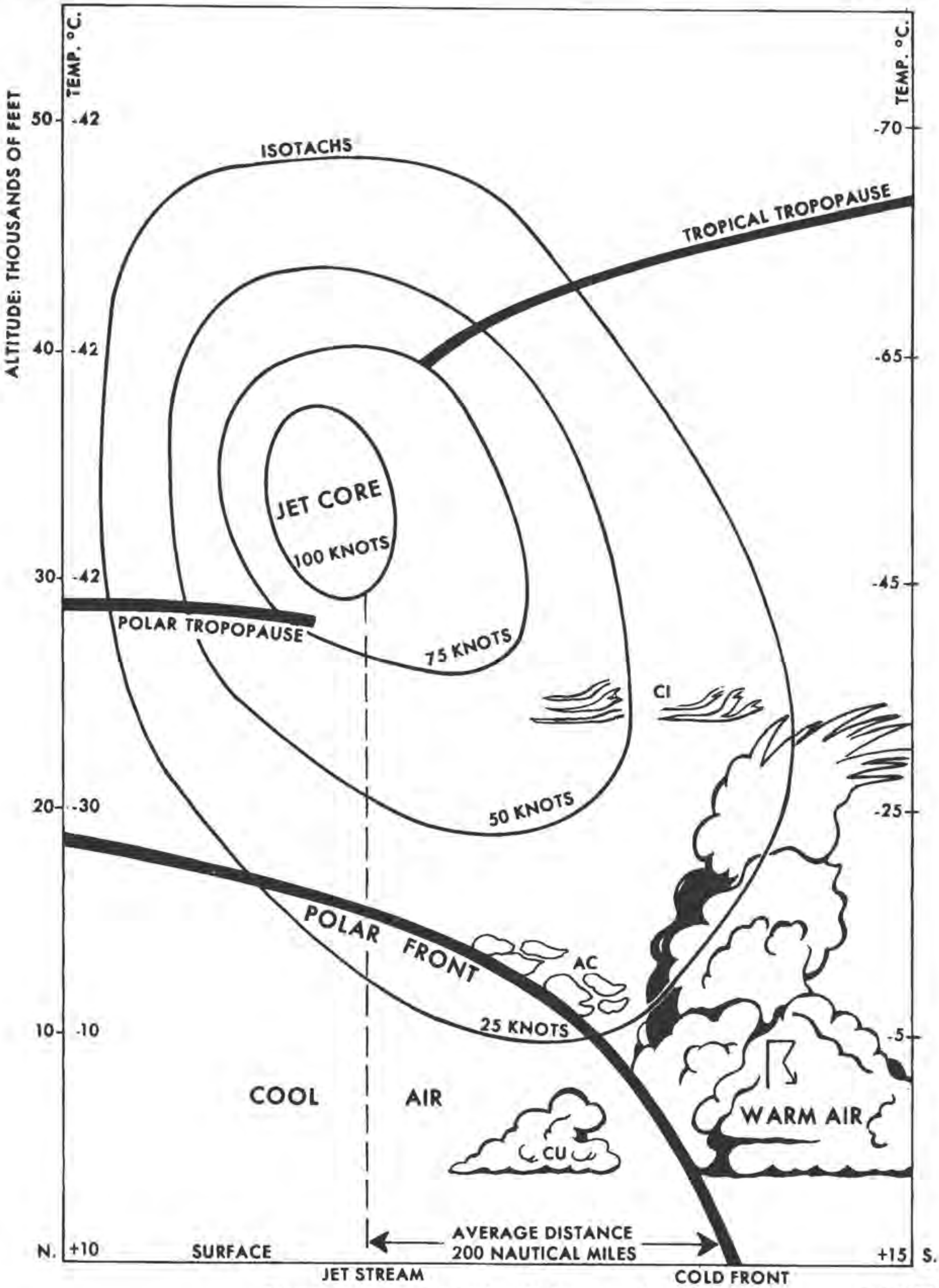


Figure 14-7. Jet stream (vertical cross section).

aavn186

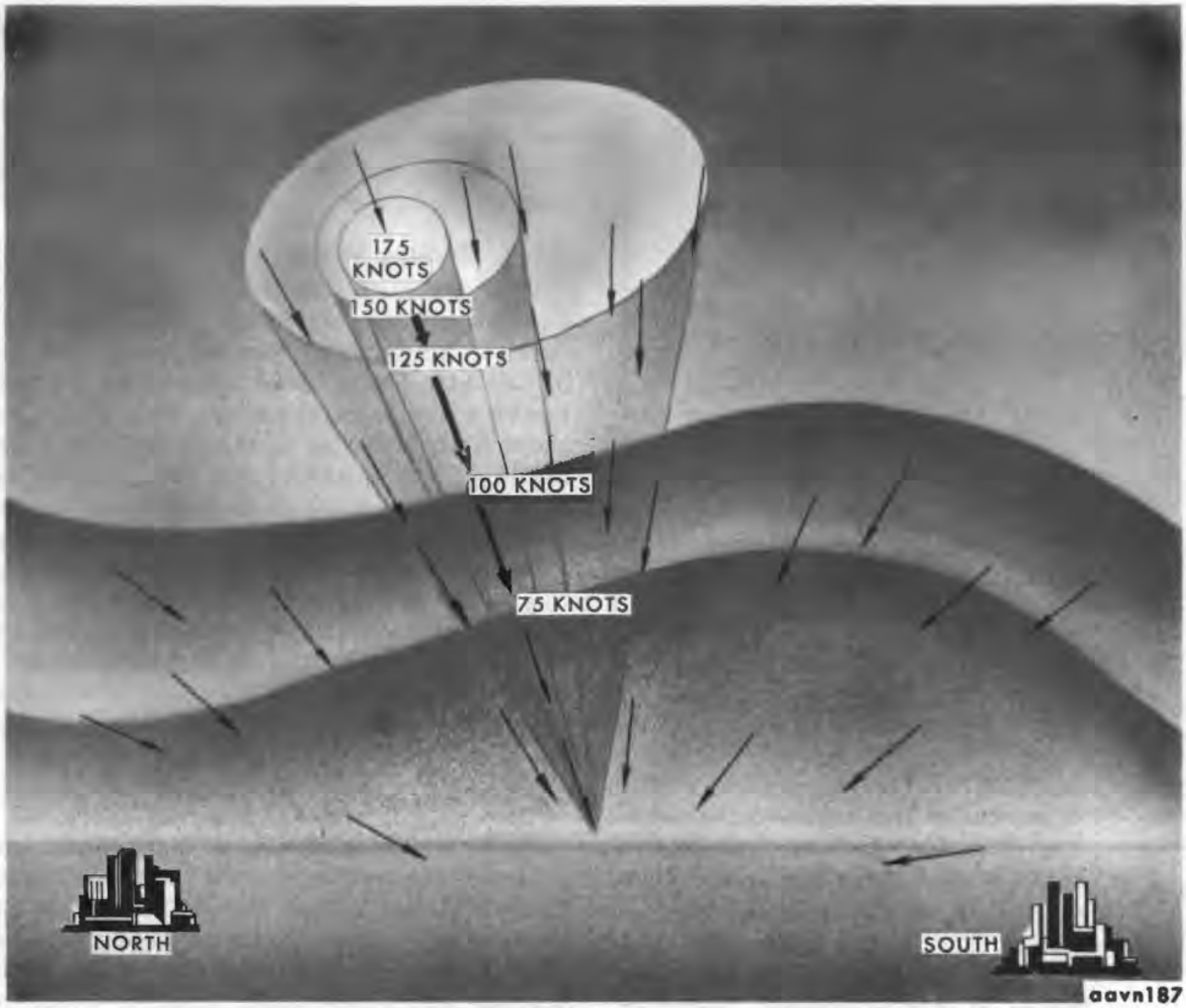


Figure 14–8. Windflow in a jet stream.

14–7. Contrails

a. General. The formation of condensation trails, commonly called *contrails*, presents serious problems to aircraft operating against an enemy. Contrails hamper operations by revealing the location, number, course, and type of aircraft. Even if enemy radar units are jammed, the aircraft can be visually spotted. The cirrus clouds formed by the contrails may interfere with formation flights in rendezvous areas for several hours. The two types of contrails are *aerodynamic* and *engine exhaust.*

(1) *Aerodynamic Contrails.* Aerodynamic contrails are caused by the reduction of pressure when air flows at high speed past an airfoil. They form at the tips of wings and propellers during performance of extreme flight maneuvers, such as sharp pullouts and high-speed diving turns. They occur at altitudes where the atmosphere is near saturation. These trails are of short duration; a small change in altitude or reduction in speed may stop their formation.

(2) *Engine Exhaust Contrails.* Exhaust contrails from aircraft engines form when the water vapor in the exhaust gas mixes with and saturates the air through which the aircraft is flying.

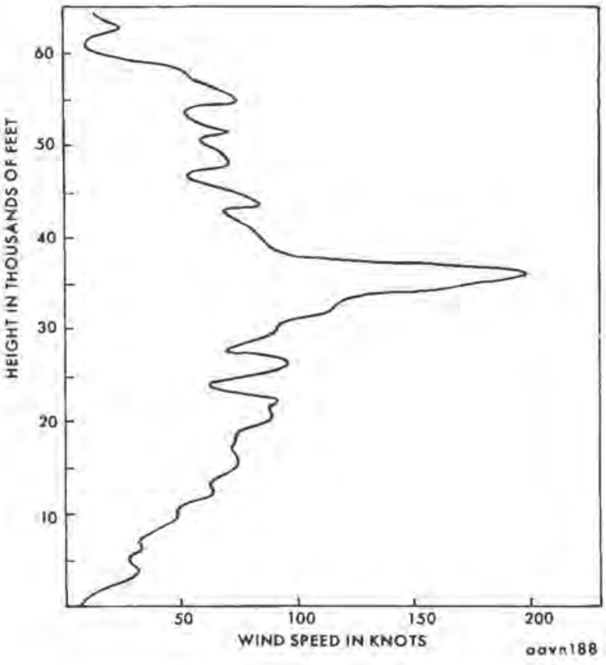


Figure 14-9. Vertical wind speed variation in a jet stream.

Aircraft fuel is a hydrocarbon which, upon combustion, results in the addition of water vapor and sublimation nuclei to the wake of the aircraft. The amount of exhaust contrail formation is a function of relative humidity, pressure, and temperature. The maximum period of exhaust contrail formation is in the winter season. In very cold arctic air, these contrails may even form at the surface. A change in altitude or power setting may eliminate exhaust contrails.

b. Relation of Contrails to Cirrus Clouds. A band of cirrus clouds approximately 100 miles wide extends from horizon to horizon below and to the south of a typical jet stream. Contrails forming near this cirrus band are difficult to distinguish from the original cloud layer.

14-8. Haze Layers

Haze layers invisible to ground observers are frequently encountered in the upper troposphere. The base of the haze layers is a gradual transition from clear sky to thick haze, but the tops have a more definite boundary. Although the horizontal visibility above the haze is excellent, air-to-ground visibility is sometimes reduced to zero, especially when the rays of the sun intersect the layer at an angle. Generally, high-altitude haze layers form in stagnant air masses.

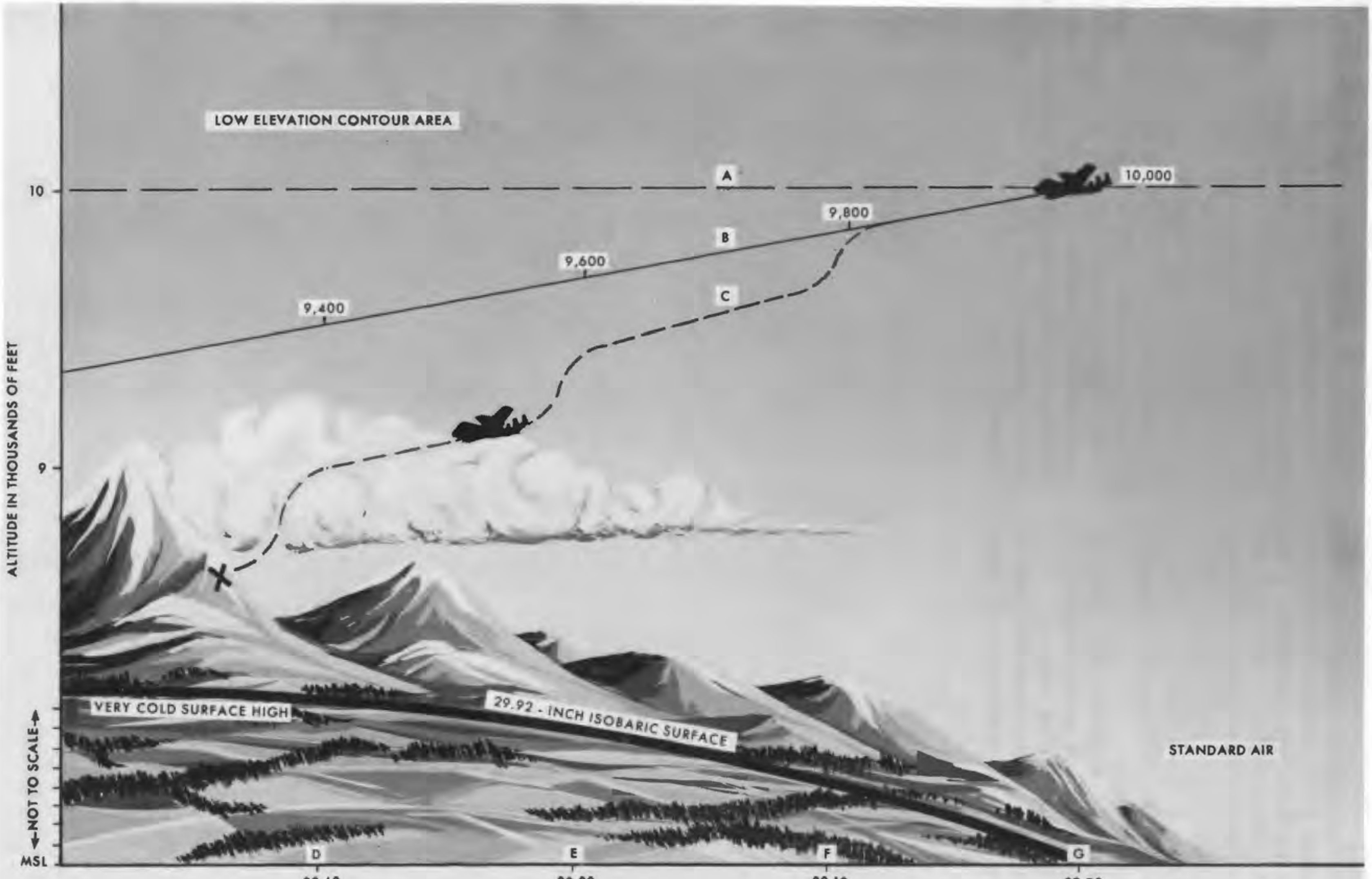
14-9. Canopy Static

Canopy static is similar to precipitation static encountered at lower levels. When solid particles of ice crystals in cirrus clouds, dust, or of dry haze layers brush against the aircraft canopy and structural surface, they build up a static electric charge on the surface. The discharge of this electricity into the air or within the aircraft produces static in the radio equipment and is disconcerting to the aviator. The discharges can occur in rapid succession and can be observed visually within the aircraft as a continuous electrical disturbance. A change of altitude to remove the aircraft from the frictional contacts and/or a reduction in airspeed to reduce the skin friction should eliminate the canopy static.

14-10. Altimeter Error

Under certain conditions of temperature and pressure, the combined error in the altimeter reading at flights near 18,000 feet may be as much as 2,000 feet. Figure 14-10 illustrates a flight from an area of standard atmospheric pressure and temperature (Station G) to an area of surface high pressure with cold air (Station D). Although altimeter settings are received at regular intervals along the route and inflight corrections are made accordingly, a disastrous loss of altitude occurs along the route.

a. The 700-millibar constant-pressure chart indicates that the pressure level is at 10,000 feet over the point of departure (G) and decreases in altitude to 9,400 feet over the mountains (D). At flight level the aircraft is flying into a region of low pressure-elevation aloft. Following the 700-millibar pressure level without changing the altimeter setting will result in an indicated altitude of 10,000 feet while the aircraft is actually descending to 9,400 feet. The altimeter would read 600 feet higher than the true altitude of the aircraft.



A PROPOSED FLIGHT PATH OF 10,000 FEET MSL.
B ACTUAL HEIGHT OF 700-mb PRESSURE LEVEL ON CONSTANT PRESSURE CHART.
C FLIGHT PATH USING ALTIMETER SETTINGS FROM SURFACE STATIONS.

aavn189

Figure 14–10. Combined altimeter error aloft.

b. Resetting the altimeter over Station F will add 180 feet to the indicated altitude; i.e., the difference between 30.10 and 29.92 is eighteen-hundredths of an inch—the equivalent of 180 feet of altitude where 1 inch is equal to 1,000 feet of altitude. The aviator will *descend* 180 feet to remain at the indicated 10,000-foot altitude.

c. Over Station E the aviator will descend another 200 feet after resetting his altimeter for the surface pressure.

d. Over Station D, resetting the altimeter will cause him to descend another 300 feet to remain at an indicated 10,000 feet.

e. The total error in the indicated altitude due to surface altimeter settings is 680 feet; i.e., the altimeter would read 680 feet higher than the true altitude of the aircraft. When this error is added to the 600-foot error caused by the lowering of the 700-millibar pressure level aloft, as determined from the constant-pressure chart, the total combined error is 1,280 feet. The aircraft is actually 8,720 feet from MSL while indicating 10,000 feet of altitude. By realizing this before takeoff, the aviator will recognize that the minimum acceptable flight altitude for traversing the 9,000-foot mountain ranges around Station D will be 11,000 feet. With proper flight planning and use of weather station facilities, this type of error can be avoided.

CHAPTER 15

RADAR AND WEATHER

15-1. General

Radar engineering developments in the past few years have produced weather observing capabilities that offer a unique service for the meteorologist and the aviator. Radar is now an integral part of the science of meteorology and an effective aid in all-weather flying. Weather radar is now standard equipment on most large aircraft and is also installed on many smaller aircraft.

15-2. Basic Principles of Radar Set Operation

Radar equipment consists essentially of a very-short-wave-directional radio transmitter and receiver. The transmitter emits brief pulses of energy which are radiated from the antenna in a directed beam. By electronic timing of the interval (microseconds) between the emission of the transmitted signal and the reception of the reflected signal (echo), it is possible to determine the distance to a reflecting object. A good weather radar set at weather stations has an average range of 150 to 200 miles, although under some atmospheric conditions the range is much greater. The distances and bearings of detected objects are electronically computed and automatically depicted on the radar scope. By continuous scanning, the operator maintains a representation of the reflecting objects on the radar scope.

15-3. Echoes

The intensity (brightness) of the reflection on the scope is a direct indication of the size and number of water droplets, ice particles, and/or precipitation in the atmosphere.

a. On a standard weather-detection radar scope, many or large raindrops or hail produce strong echoes; fewer or smaller liquid drops and snowflakes produce weaker echoes; and cloud particles are so small that they produce very weak echoes or none at all.

b. Radar shows only that portion of a storm which contains water droplets or ice crystals of sufficient size and/or number to produce the echoes on the scope.

c. Once a storm area has been detected, the movement and changes in size and intensity can readily be determined by making successive observations. To assist in issuing hurricane warnings and forecasts, several storm-detection radar sets have been installed along the coasts of southern and eastern United States where hurricanes are common.

15-4. Airborne Radar (Weather)

Airborne weather radar is of great value to aviators in locating and avoiding turbulent weather. That is, the intensity of precipitation is a primary indication of the amount of turbulence within a storm; strong drafts and gusts are necessary to support water drops of significant size and quantity. Thus, since the relative intensities of precipitation can be detected by radar, the aviator can select a *comparatively* safe and smooth flight path in thunderstorm *areas* by avoiding the localized areas of heavy precipitation indicated on the radar scope. A complete discussion of the APN-158 airborne weather radar set is contained in TM 1-225.

15-5. Radar Reports (RAREPS)

The surface weather radar sets now in operation are used to identify and track storms over most of the United States east of the Continental Divide. Every hour the stations which observe significant radar echoes transmit the information on the weather teletypewriter circuits. These transmissions are known as RAREPS. All stations, and especially those which are not equipped with radar sets, receive much valuable information from RAREPS. An example of a RAREP is as follows:

CNTRL GLF STATES
BRKN LN STG 20 WIDE 50 NE MSY 30 NW MGM TOPS 420 WITH VRY STG CELL 45 W MGM CELLS → → 40.

Properly interpreted, this RAREP is a report for the central Gulf States. It reports a broken storm line of strong intensity, 20 miles wide, from 50 miles northeast of New Orleans (MSY) to 30 miles northwest of Montgomery (MGM). The cloud tops extend to 42,000 feet (MSL). A very strong cell is located 45 miles west of MGM. The cells are moving east-north-east at 40 knots.

15–6. Radar Summaries

Every 3 hours, beginning at 0000Z, all RAREPS are plotted on charts (maps) and transmitted, over the facsimile circuit (para 12–1). These charts are prepared at the weather central in Kansas City by the Radar Analysis and Development Unit. If an aviation severe *w*eather *w*arning forecast (*WW*) is in effect for an area of the United States, the area will be outlined by dotted black lines on the chart. The identification number of the WW's and their valid times will be shown in the lower left corner of the chart (figs. 15–1 through 15–4).

a. Four consecutive radar summary charts are illustrated by figures 15–1 through 15–4. This series of charts depicts the development and movement of storm areas across the United States.

b. Figures 15–1 through 15–4 are interpreted by using a legend (fig. 15–5).

15–7. Metro (Pilot to Forecaster Service)

A pilot to forecaster service called *METRO* is available to aviators in flight on a standard frequency of 344.6 mc.

a. This service can be obtained by tuning the aircraft radio to the frequency of 344.6 mc. Contact should be established by monitoring the channel and giving the call sign of the receiving station, followed by the word METRO. For example, "Eglin, METRO, this is Army 12345. Over."

b. After contact with METRO is established, the aviator in flight has all the services that the forecaster is capable of providing, such as RAREPS, PIREPS, sequence reports, winds aloft reports, severe weather warnings, and forecasts.

c. The appropriate FAA facilities will be notified before tuning the radio to METRO, and upon return to the appropriate FAA frequency.

Note. This service is of special significance when the aircraft is not equipped with radar. The aviator is frequently able to obtain complete radar coverage of the flight area from the forecaster on the ground.

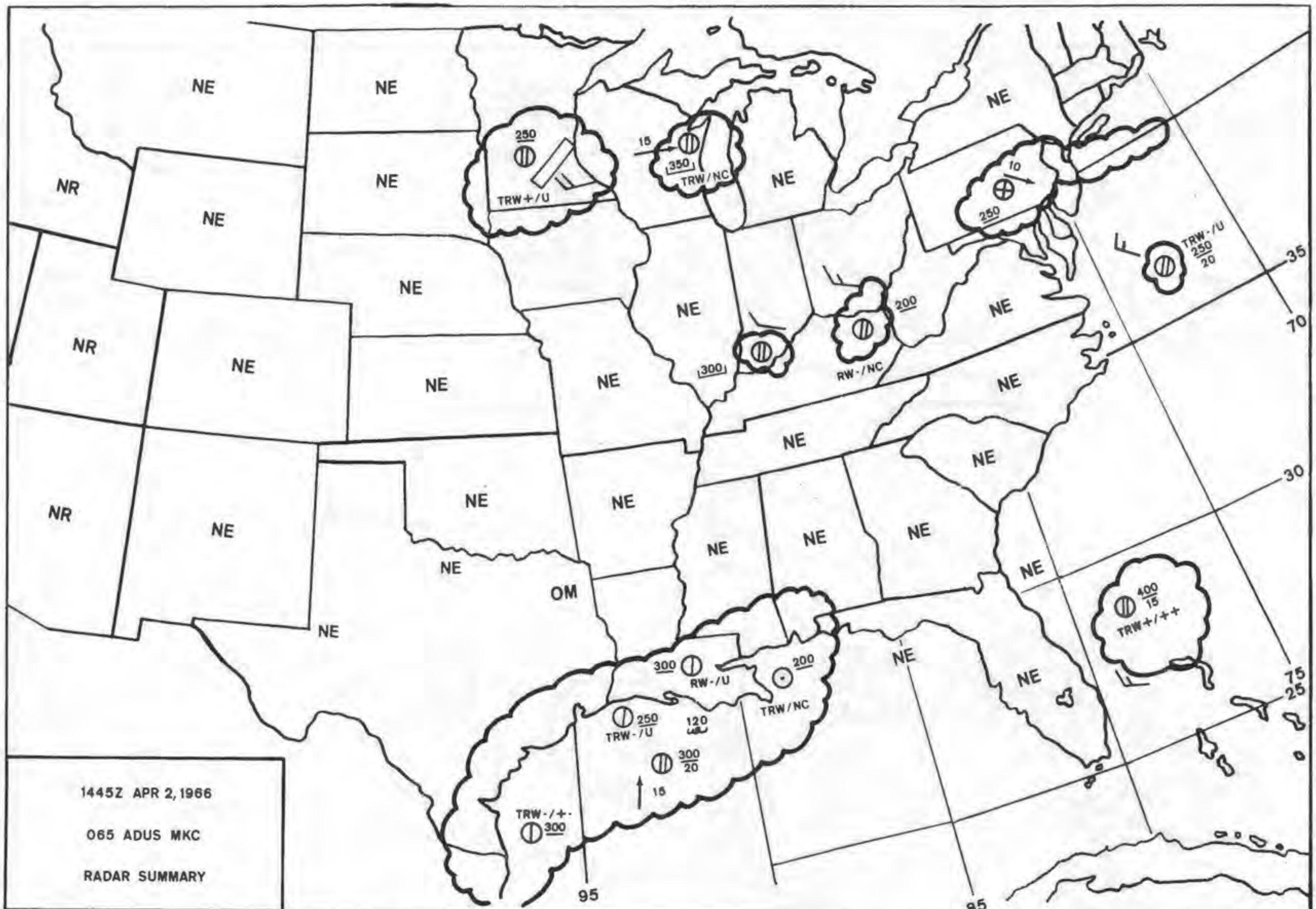


Figure 15–1. (Superseded) *Radar summary chart.*

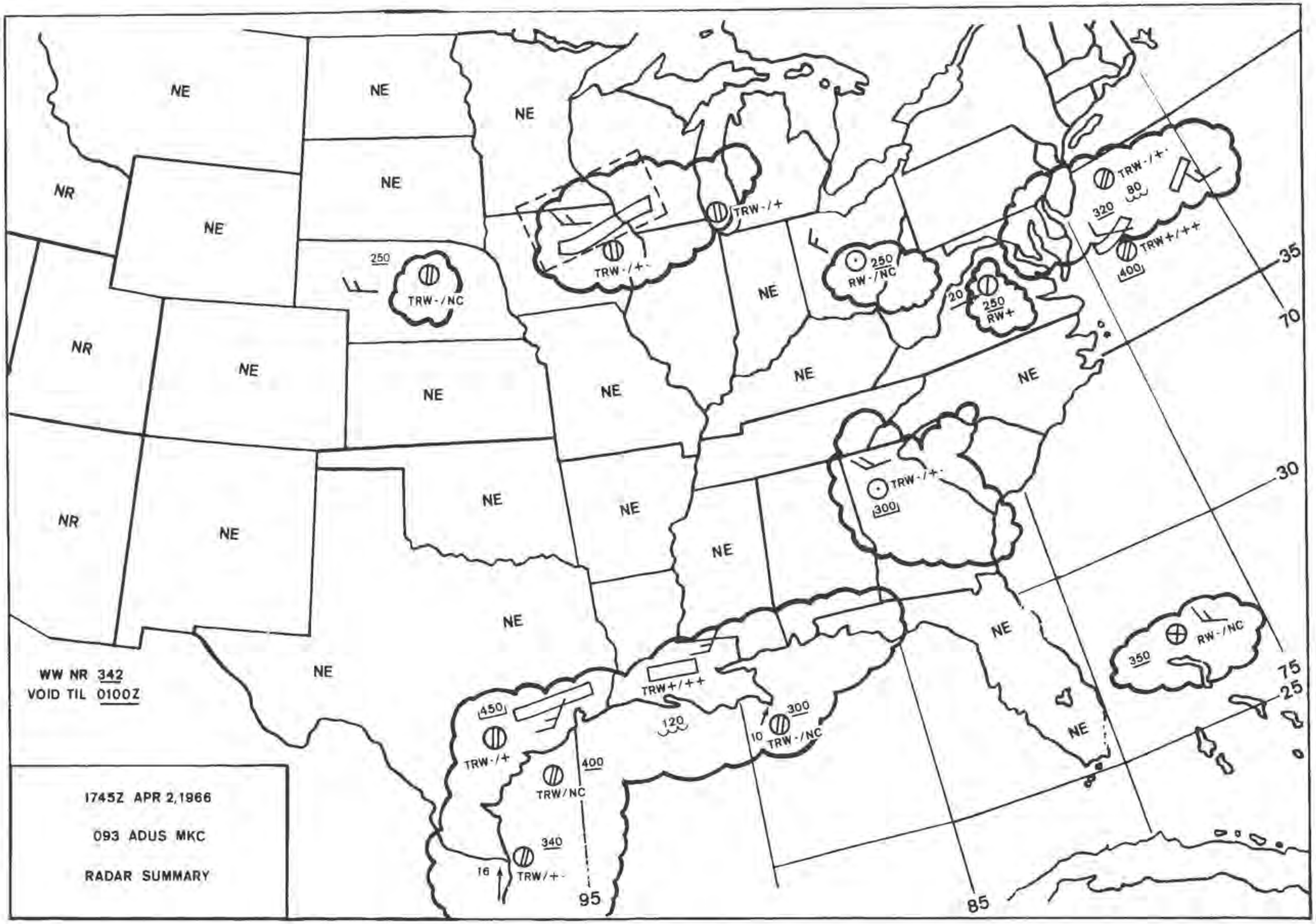


Figure 15–2. (Superseded) *Radar summary chart.*

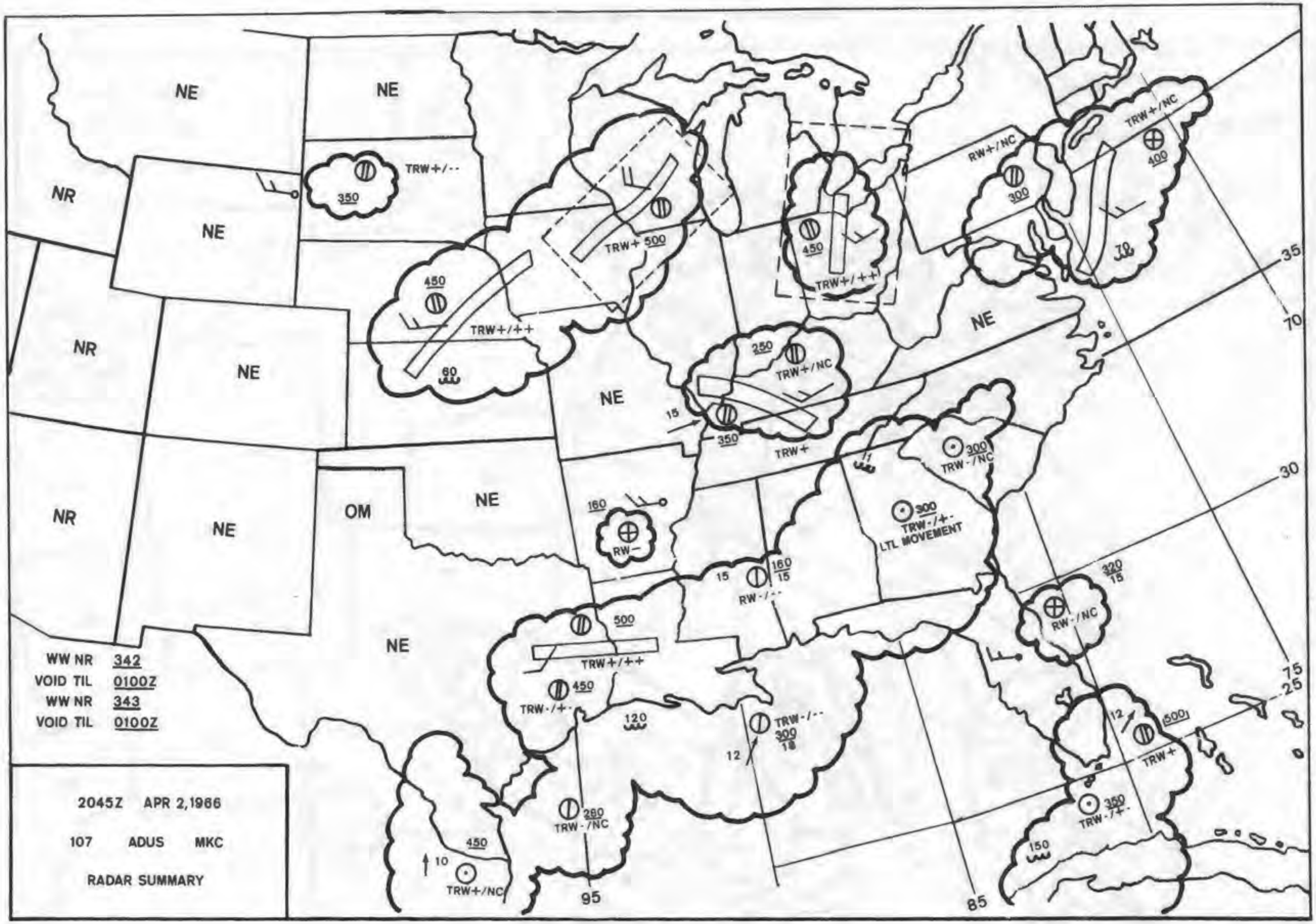


Figure 15-3. (Superseded) *Radar summary chart.*

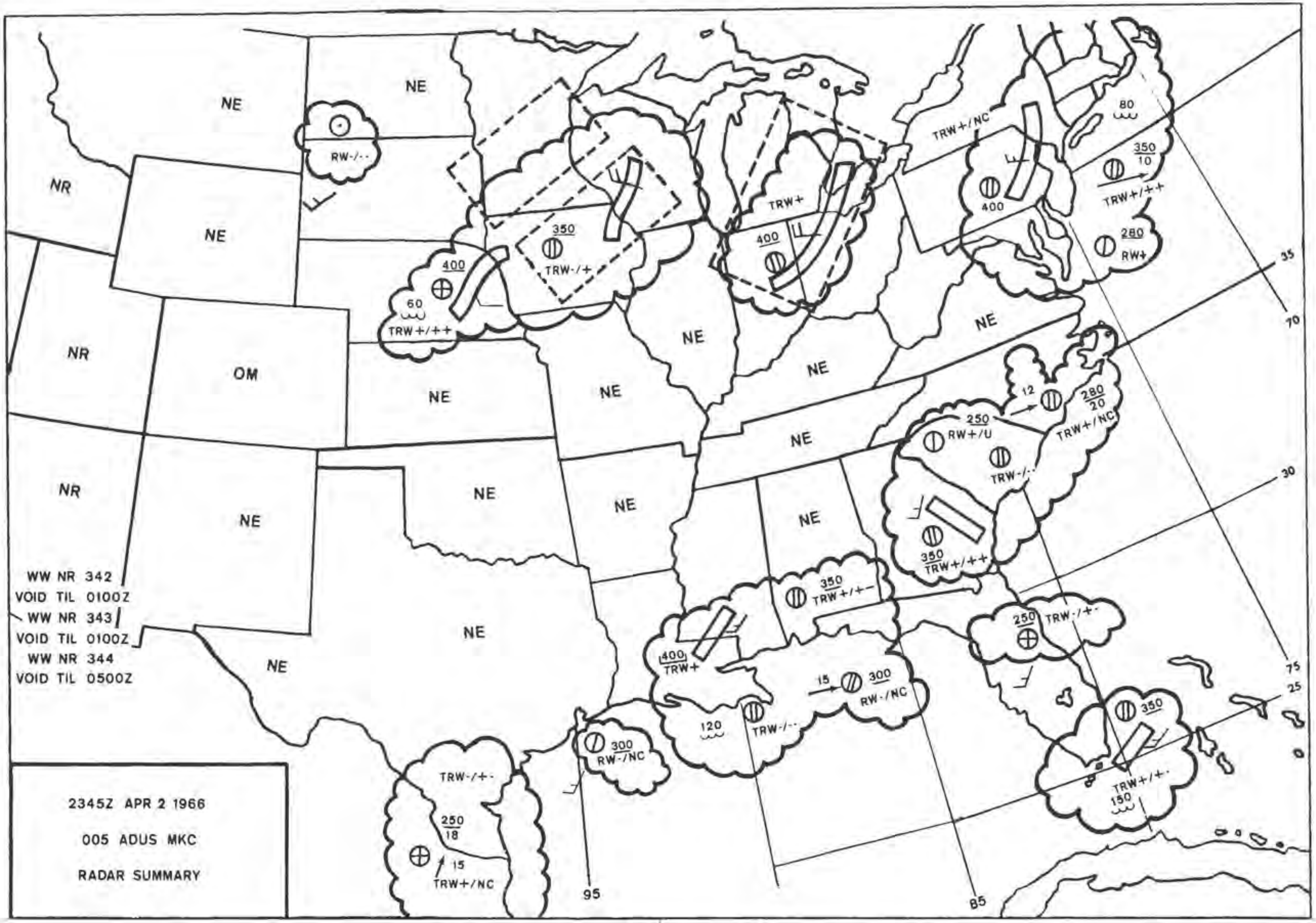


Figure 15-4. (Superseded) *Radar summary chart.*

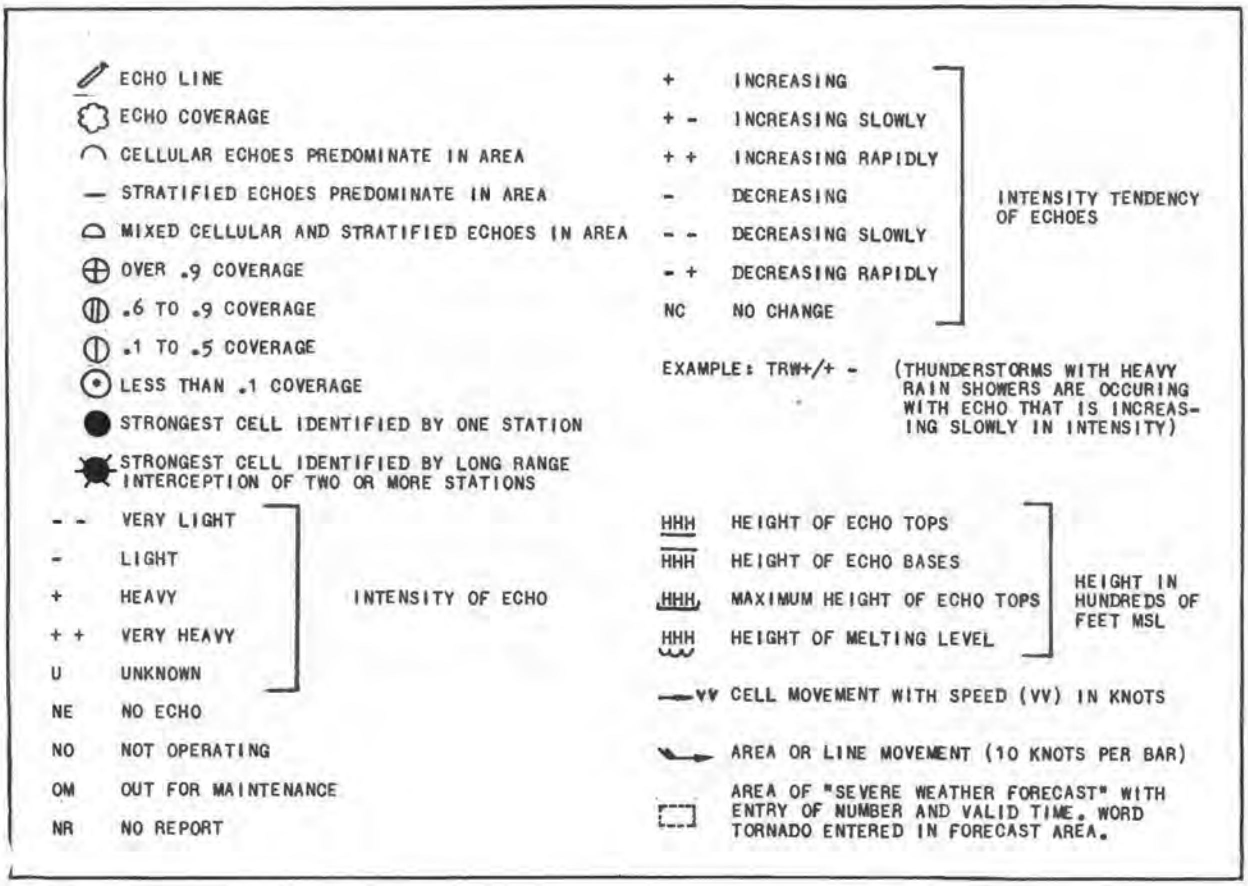


Figure 15-5. (Superseded) *Legend for radar summary charts.*

CHAPTER 16
FORECASTS

Section I. INTRODUCTION

16-1. General

The aviator planning a flight is concerned with observed and forecast weather conditions along his route. Teletype sequence reports, surface weather maps, winds aloft reports, and atmospheric diagrams are consulted for past and present weather information. Weather forecasts for a proposed flight are available from several types of weather facilities.

16-2. Types of Forecasts

Forecasts are available at the weather station in the form of teletype transmissions, locally prepared forecasts, and facsimile prognostic charts. The aviator may also be advised of the development of potentially hazardous weather by radio transmission during flight. Each of the many types of forecasts is designed to serve a specific function, so each varies to some extent in format and scope.

Section II. TELETYPE FORECASTS

16-3. (Rescinded) Regional Forecast

16-4. Area Forecast

a. General. Area forecasts (fig. 16-2), prepared daily for transmission over FAA teletype service A at approximately 0100Z, 0700Z, 1300Z, and 1900Z, present more specific flight conditions than regional forecasts. They give the expected conditions for a 12-hour period, with an outlook section for an additional 12 hours, and cover a smaller geographical area than the regional forecasts.

b. Interpretation of Area Forecast (fig. 16-2). In the circuit heading, *FA* is the area forecast identifier, and *MEM* is the station identifier (Memphis). This forecast was transmitted on the 27th day of the month at 1245 Zulu time. The forecast is valid from 0500C Friday until 1900C Friday for an area covering Arkansas, Tennessee, and the northern half of Mississippi.

(1) *Clouds and weather.* In western Arkansas the ceiling will be from 2,000 to 3,000 feet, with the sky coverage varying from broken to overcast. A dissipating squall line in the extreme western portion will produce ceilings of 1,000 feet, with overcast sky and 2-mile visibility locally in thunderstorms, and moderate rain showers in a few of the thunderstorms. Thunderstorms will dissipate by 0900C, but they will redevelop in the late morning and early afternoon, spreading eastward into central Arkansas by 1900C. Locally in the heavier thunderstorms, the ceiling will be 600 feet, sky overcast, and visibility of 1 mile in thunderstorms with heavy rain showers. Elsewhere over the area, the visibility will be 2 to 4 miles in a few patches of ground fog, until 0830C. Cumulus clouds developing with bases from 3,000 to 4,000 feet above ground level will produce a sky coverage varying from scattered to broken by 1100C. These clouds will dissipate over Tennessee and the northern half of Mississippi after 1700C. The tops of the thunderstorms will be up to 35,000 feet.

Figure 16-1—**Rescinded.**

```
FA MEM 271245
Ø7C FRI-19C FRI

ARK TENN N HLF MISS

CLDS AND WX. WRN ARK C2Ø-3Ø⦷V⊕ WITH DSIPT SQLN EXTRM W PTN
LCLY C1Ø⊕2TRW. TSTMS WL DSIPT BY Ø9C BUT REDVLP LATE MRNG
AND EARLY AFTN SPRDG EWD INTO CNTRL ARK BY 19C LCLY C6⊕1
TRW+ IN HVYR TSTMS. ELSW OVER AREA A FEW PATCHES GND FOG
LCLY 2-4GF TIL Ø83ØC. CU DVLP 3Ø-4Ø⦶V⦶ BY 11C AND WL DSIPT
OVR TENN N HLF MISS AFT 17C. TOPS TSTMS TO 35Ø.

ICG. MDT TO HVY MXD ICG IN CBS AND TSTMS ABV FRZG LVL. FRZG
LVL NEAR 1ØØ ERN TENN AND 12Ø OVR ARK.

TURBC. MDT TO SVR IN AND NEAR TSTMS.

OTLK. 19C FRI-Ø7C SAT. COLD FRONT WL MOV EWD ACRS WRN ARK
INTO ERN ARK BY Ø7C. SHWRS AND SCTD TSTMS OCNL IN LINES
ALG AND AHD OF FRONT LCLY C6⊕1TRW+ OTHERWISE C25-35⦷V⊕
7Ø-9Ø⦷V⊕ OVR ARK SPRDG EWD INTO WRN TENN AND N HLF MISS BY
Ø1C AND INTO CNTRL TENN BY Ø6C. W OF FRONT 3Ø-4Ø⦶ 7Ø-9Ø⦷.
```

Figure 16–2. (Superseded) *Area forecast.*

(2) *Icing.* Moderate to heavy mixed icing (rime and clear) will occur in the cumulonimbus and thunderstorms above the freezing level. The freezing level will slope from 10,000 feet in eastern Tennessee to 12,000 feet over Arkansas.

(3) *Turbulence.* There will be moderate to severe turbulence in and near the cumulonimbus and thunderstorms.

(4) *Outlook from 1900C Friday to 0700C Saturday.* The cold front will move eastward across western Arkansas into eastern Arkansas by 0700C. Showers and scattered thunderstorms will form occasionally in lines along and ahead of the front. Locally, the ceiling will be 600 feet with overcast sky and 1-mile visibility in thunderstorms and heavy rain showers. The ceiling will be 2,500 to 3,500 feet with the ceiling layer varying from broken to overcast. Other cloud layers will be present at 7,000 to 9,000 feet varying in coverage from broken to overcast. These clouds will develop over Arkansas and spread eastward into western Tennessee and the northern half of Mississippi by 0100C, and into central Tennessee by 0600C. West of the front, the sky condition will be scattered at 3,000 to 4,000 feet above ground level and broken at 7,000 to 9,000 feet above ground level.

16–5. Terminal Forecasts

a. General. Terminal forecasts (figs. 16–3 and 16–4) are prepared 4 times daily at approximately 500 civilian and military aviation terminals in the United States. Weather Bureau terminal forecasts are valid for either 12- or 24-hour periods and are prepared at approximately 0500Z, 1100Z, 1700Z, and 2300Z. They are transmitted on FAA teletype service A. Air Weather Service forecasts

```
FT1 271Ø45
11Z FRI- 23Z FRI

Ø7Ø
MSY 25⦶C15Ø⦷ 1818 OCNLY C25⦷ SCTD TRW OCNLY C5X1/2TRW+ Ø2ØØC
     C15⦷ 1412 WDLY SCTD TRW
LKC C1ØØ⦷45⊕5TRW 1415G2Ø SCTD C8⊕2TRW+. 2ØØØC C15⦷ 1818 SCTD TRW.
     Ø3ØØC C8⊕5F 1812 FEW TRW
SHV C3⊕1L-F SCTD C8⊕2TRW. 21ØØC C12⦷ 1615 OCNL TRW. Ø3ØØC C8⊕5F
     FEW TRW
```

Figure 16-3. Terminal forecast, Weather Bureau.

```
FTUS  7  Ø214ØØZ

OZR   -X5⊕3F  ØØØØ  QNH 299Ø
      15Z  8⦷3F  ØØØØ QNH 2989
      17Z  2Ø⦶12Ø⦶1Ø  161Ø QNH 2989
      22Z  25⦶12Ø⦶1Ø  161Ø QNH 2988
      INTER  3Ø⦷5TRW

LSF   12⦷15  2Ø12 QNH 2991
      15Z  2Ø⦷15 2Ø15G2Ø QNH 299Ø
      19Z  4Ø⦶12Ø⦶15  2Ø18G28 QNH 2987
      Ø3Z  12Ø⦶15  2Ø15 QNH 2986
```

Figure 16-4. (Superseded) *Terminal forecast, Air Weather Service.*

(called *PLATF*'s, a concentration of *p*lain *l*anguage *t*erminal *f*orecasts) are valid for 24-hour periods and are prepared every 6 hours beginning at 0300Z.

b. Interpretation of Terminal Forecast, Weather Bureau (fig. 16-3). Forecast ceilings are preceded by the letter C. Visibilities expected to exceed 8 miles are omitted, as are winds below 12 knots. When more than one layer of clouds is expected, the layers are indicated in ascending order of height from left to right. The times of expected significant changes are indicated in the body of the forecast.

(1) *Circuit heading.* In the circuit heading (fig. 16-3), the *FT* is the identifier for terminal forecasts, *1* identifies a 12-hour forecast and 271045(Z) is the date and time group. The forecast is valid from 1100Z Friday until 2300Z Friday for the area covered by the forecast. The *070* identifies the geographical section of the forecast area.

(2) *Forecast for Moisant, New Orleans, La. (MSY).* Scattered clouds are forecast at 2,500 feet, ceiling 15,000 feet with broken clouds, and wind from the south at 18 knots. Occasionally the ceiling will be 2,500 feet with broken clouds. Scattered thunderstorms and rain showers will occassionally produce ceilings of 500 feet, with the sky obscured, and visibility will be one-half mile in thunderstorms and heavy rain showers. By 0200C, the ceiling will be 1,500 feet with

broken clouds, wind will be from the southeast at 12 knots, and thunderstorms and rain showers will be widely scattered.

(3) *Forecast for Lake Charles, La. (LKC)*. Ceiling will be 1,000 feet with broken clouds, 4,500 feet overcast sky, visibility of 5 miles in thunderstorms and rain showers, wind from the southeast at 15 knots with gusts to 20 knots; in scattered areas the ceiling will be 800 feet, overcast, and a 2-mile visibility in thunderstorms and heavy rain showers. By 2000C the ceiling will be 1,500 feet with broken clouds, wind from the south at 18 knots, and there will be scattered thunderstorms and rain showers; by 0300C the ceiling will be 800 feet, overcast, visibility 5 miles in fog, wind from the south at 12 knots; there will be a few thunderstorms and rain showers.

(4) *Forecast for Shreveport, La. (SHV)*. Ceiling will be 300 feet with overcast sky, visibility 1 mile in very light drizzle and fog. Scattered sections with ceilings of 800 feet overcast and visibility 2 miles will occur in thunderstorms and rain showers. By 2100C, the ceiling will be 1,200 feet broken, with south-southeast wind at 15 knots, and occasional thunderstorms and rain showers. By 0300C, the ceiling will be 800 feet, overcast, visibility 5 miles in fog, and there will be a few thunderstorms and rain showers.

c. Interpretation of Terminal Forecast, Air Weather Service (PLATF) (fig. 16-4). The interpretation of the Air Weather Service terminal forecast is similar to that of the Weather Bureau forecast (*b* above). Some minor variations are—difference in selection and spelling of many of the plain language contractions, forecast of weather changes in Zulu time, and forecast of the minimum altimeter setting (which follows the identifier *QNH*). For example—

(1) In the circuit heading (fig. 16-4), 7 is the geographical circuit area number, ∅2 is the day of the current month, and 14∅∅Z is the time the forecast becomes valid.

(2) At 14∅∅Z, OZR (Cairns, AAF) forecasts a partial obscuration with a 500-foot overcast, 3-mile visibility in fog, and a calm wind. At 1500Z, the clouds will become broken at 800 feet with 3-mile visibility in fog and the wind will remain calm. At 1700Z, scattered clouds will exist at 2,000 feet and 12,000 feet; visibility will be 10 miles with a south-southwest wind at 10 knots. At 2200Z, the cloud layers will be scattered at 2,500 feet and 12,000 feet, 10-mile visibility, and south-southwest wind at 10 knots. Broken clouds with 5-mile visibility in thunderstorms and rain showers will also be in the vicinity. The minimum altimeter setting (QNH) is given for each forecast period.

(3) Other PLATF's are interpreted in a similar manner.

d. Terminal Forecasts in Full Form (TAFOR). Another type of terminal forecast is transmitted on the Air Weather Service teletype circuit along with the PLATF's. This forecast is called a *TAFOR* (Terminal Aviation Forecast); it contains more complete and detailed weather information than the PLATF. A complete TAFOR forecasts the following weather data: total amount of sky coverage (in eighths of the sky); wind direction, speed, and gustiness (QXT); visibility; weather phenomena, including forms of precipitation and restrictions to visibility; eighths of sky coverage by each cloud layer expected over the station, with base-height of the layer and the type of cloud; tops of individual cloud layers; height of the 0° C. isotherm; height and thickness of turbulent layers in the clouds; height and thickness of icing layers in the clouds; temperature and wind at specified altitudes; and pertinent clear language remarks. The encoding and decoding of TAFOR's is beyond the scope of this manual; however, the aviator should realize that the facility is available for use by the briefing forecaster at the weather station.

16-6. Winds Aloft Forecasts (Superseded)

a. General. Winds aloft forecasts (fig. 16-5) are made every 6 hours for 89 selected locations in the contiguous States and are transmitted on

FD JAX 27235Ø
ØØ-12Z SAT

LVL	3ØØØ	5ØØØ FT	1ØØØØFT	15ØØØFT	2ØØØØFT	25ØØØFT
AMG	2425	2325+13	2428+Ø4	2455-Ø2	248Ø-1Ø	2595-25
CHS	2425	2525+12	2432+Ø4	2445-Ø4	258Ø-14	2595-26
JAX	2121	2227+14	2335+Ø5	2447-Ø3	2556-15	2682-25

A MANUALLY PRODUCED

FD1 WBC Ø2Ø55Ø
Ø6-12Z FRI

LVL	3ØØØ	5ØØØ FT	1ØØØØFT	15ØØØFT	2ØØØØFT	25ØØØFT
BOS	2Ø15	2328+Ø6	2633-Ø1	2936-1Ø	3Ø43-15	3Ø48-2Ø

12-18Z FRI

LVL	3ØØØ	5ØØØ FT	1ØØØØFT	15ØØØFT	2ØØØØFT	25ØØØFT
BOS	2925	2833+ØØ	3Ø3Ø-Ø6	2828-13	3Ø35-17	314Ø-23

B COMPUTER PRODUCED

FD MEM 24235Ø
ØØ-12Z MON

LVL	3ØØØ	5ØØØ FT	1ØØØØFT	15ØØØFT	2ØØØØFT	25ØØØFT
HRO	243Ø	1945+11	214Ø+Ø1	2445-11	265Ø-16	2665-25
Ø4Z	3Ø35	285Ø+Ø5	274Ø-Ø1	2645-12		
Ø6Z	334Ø	314Ø-Ø1	3Ø45-Ø7	3Ø55-15		
DYR	2615	243Ø+Ø9	2325+Ø1	254Ø-12	2645-15	266Ø-25
1ØZ	3Ø35	285Ø+Ø5	274Ø-Ø1	2845-13	2945-16	297Ø-26

C MANUALLY PRODUCED CHANGES

Figure 16-5. (Superseded) *Winds aloft forecast.*

service A. Twice a day (0550Z and 1750Z) these forecasts are computer-produced by the National Meteorological Center, and twice a day (1150Z and 2350Z) they are manually produced by the Flight Advisory Weather Service. All four winds aloft forecasts issued daily are for a 12-hour period, but those which are computer-produced are in the form of two 6-hour forecasts. Each winds aloft forecast includes the expected wind direction and speed for 3,000 feet (for stations having a terrain elevation of 2,000 feet or lower), 5,000 feet (for stations having a terrain elevation of 4,000 feet or lower), 10,000 feet, 15,000 feet, 20,000 feet, and 25,000 feet. All heights are in thousands of feet above mean sea level. Temperature forecasts are appended to all wind forecasts above 3,000 feet, except no temperature forecasts are appended to the 5,000-foot wind forecast when this is the lowest level forecast.

b. Direction. The wind direction is in reference to true north and is reported in two digits, except as noted in *c* below. For example, 270° is reported as 27.

c. Speed. The windspeed is reported in knots. Speeds less than 10 knots are shown as Ø8, Ø6, etc. If the speed is expected to be less than 5 knots, the group "99ØØ" is inserted instead of the direction and speed. This group is spoken of as "light and variable." Forecast winds of 100 to 199 knots are indicated by subtracting 100 from the speed and adding 50 to the direction. *For example*, a forecast of 250°/145 knots would be reported as 7545.

d. Interpretation of Winds Aloft Forecast (A, fig. 16-5). In the circuit heading, FD (manually produced) or FD1 (computer-produced) is the identifier for winds aloft forecasts, JAX is the station identifier (Jacksonville, Fla.), and the forecast was transmitted on the 27th day of the current month at 2350 Zulu time. The forecast is valid from 0000Z Saturday until 1200Z Saturday.

(1) Alma, Ga. (AMG), forecasts the wind at 3,000 feet (MSL) to be from 240° at 25 knots; at 5,000 feet, the wind is forecast to be 230° at 25 knots and the temperature is forecast to be +13° C.

(2) Charleston, S.C. (CHS), and Jacksonville, Florida. (JAX), use the same format as Alma, Ga.

e. Computer-Produced Winds Aloft Forecast (B, fig. 16-5). The winds aloft forecasts produced by the National Meteorological Center cover the 12-hour period with two consecutive 6-hour forecasts.

f. Significant Changes in Wind Velocity or Temperature (C, fig. 16-5). When significant changes in wind direction, windspeed, or temperature are expected at any time during the 12-hour forecast period, the manually produced winds aloft forecasts issued by FAWS centers show the new values on a separate line with the expected time of the change. The following guidelines are used by FAWS in deciding whether or not a change in the forecast is necessary:

(1) The windspeed is 25 knots or less and the direction is expected to change by 45° or more.

(2) The windspeed is more than 25 knots and the direction is expected to change by 30° or more.

(3) The windspeed is 25 knots or less and is expected to change as much as 10 knots or more.

(4) The windspeed is more than 25 knots and is expected to change as much as 15 knots or more.

(5) An expected change in temperature of 5° C. or more at all altitudes, except a change of 3° C. or more at the 5,000-foot level.

Section III. LOCALLY PREPARED FORECASTS

16-7. Local Terminal Forecast

Local terminal forecasts (fig. 16-6) are prepared by the station duty forecaster, giving the expected weather conditions in the local flying area. Requirements of the agencies served by the weather station determine the intervals at which these forecasts are prepared. They usually cover an 18- to 24-hour period, and may be extended in the *further outlook section* at the bottom of the form.

16-8. Vertical Cross Section Forecast

Vertical cross section forecasts (also called *flight forecast cross section*) (fig. 16-7) are schematic diagrams prepared by the station duty forecaster, showing the weather conditions expected along, and 25 miles either side of, a proposed flight route. Cross sections are prepared for aviators upon request; however, at least 2 hours' advance notice is required for the forecaster to prepare the diagram. Cross sections are particularly valuable for proposed flights over unfamiliar terrain or large bodies of water and for extensive flights. The cross section weather information is easy to assimilate and understand because of its graphic form. Some of the major weather items indicated on the diagram are as follows:

a. Fronts—surface position, upper air position, and slope.

b. Clouds—types, amounts of coverage, and altitudes of bases and tops. Clouds below the freezing level are normally colored green; the portions of the clouds above the freezing level where icing may occur are normally shaded red.

c. Freezing level—solid green line labeled 0°C.

d. Intensity of turbulence and icing—appropriate symbol.

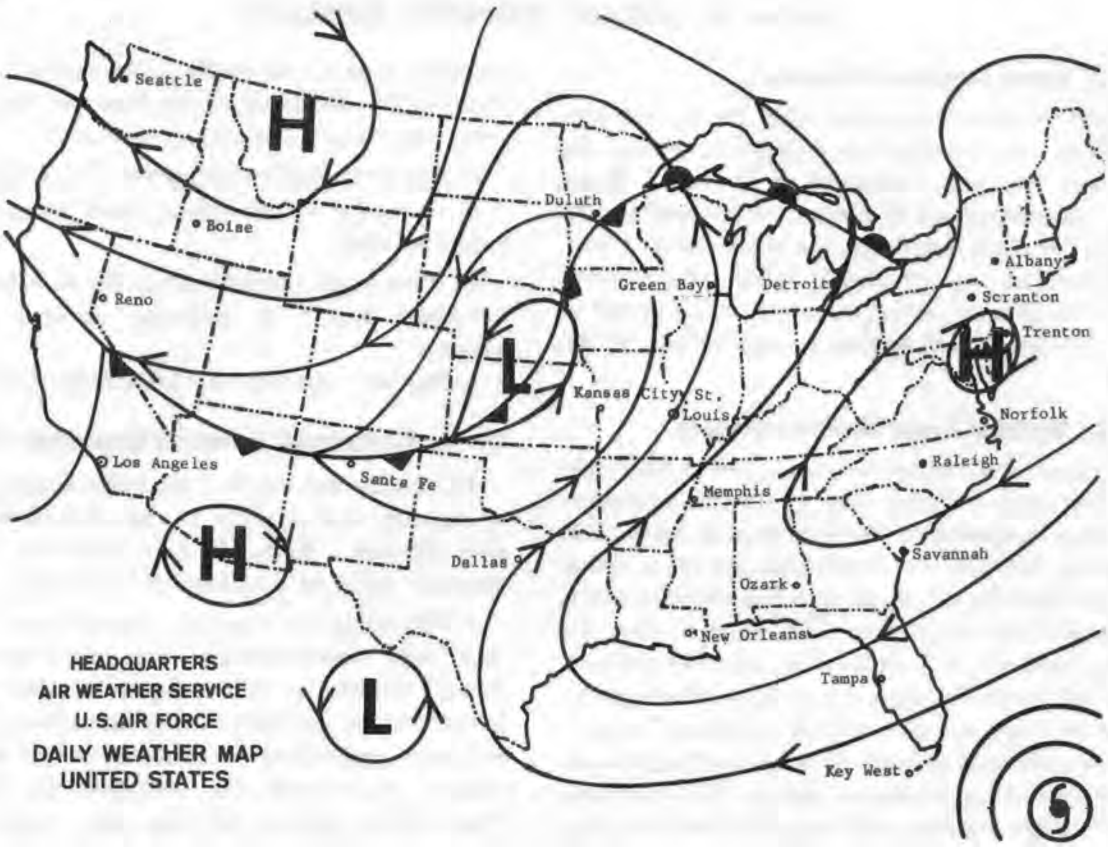
e. Winds and temperatures—for each leg of the proposed flight, at altitudes selected by the aviator.

f. Surface visibility and significant weather.

16-9. Horizontal Weather Depiction Chart

The horizontal weather depiction chart (fig. 16-8) may by used in place of the vertical cross section forecast. Normally this chart is a 12-hour forecast valid at midtime of the flight.

a. Hatching or shading depicts areas where significant clouds and/or weather are forecast to occur. Clouds in which flight hazards such as icing, hail, or turbulence may be encountered are indicated regardless of amount; otherwise, only broken or overcast sky coverages are depicted. Cloud data consists of—the sky coverage (in eighths), cloud type, and the height of bases and tops (in hundreds of feet above the surface). The height of the cloud top is entered above the base-height and the two height figures are separated by a horizontal line. When more than one significant cloud layer is forecast, the higher deck is entered directly above the lower.



NOT FOR DISSEMINATION TO
COMMERCIAL FACILITIES

THIS FORECAST IS FOR PLANNING PURPOSES ONLY AND WILL NOT BE AMENDED.

DATE: 11 SEP 66

GENERAL SITUATION: THE WEATHER DURING THE NEXT 24 HOURS FOR THE FORT RUCKER AREA WILL BE INFLUENCED PRIMARILY BY THE HIGH PRESSURE SYSTEM CENTERED OVER DEL.

FORECAST: VALID FROM: 11/Ø7C TO 12/Ø7C

SKY CONDITION; VISIBILITY; WEATHER; OBSTRUCTIONS TO VISION; AND SURFACE WINDS:

Ø7C 25⦶7 Ø4Ø7
Ø9C 2Ø⦶3ØØ⦶7 Ø41Ø 2Ø⦶V⦶
12C 25⦶3ØØ⦶9 Ø41Ø
2ØC 25⦶1Ø CLM

HAZARDS: NONE

WINDS AND TEMPERATURES ALOFT: 2ØØØ FT. Ø81Ø +15°C. 6ØØØ FT. 1318 +12°C.
4ØØØ FT. Ø912 +13°C. 8ØØØ FT. 142Ø +13°C.

FREEZING LEVEL: 15ØØØ FT. MAXIMUM DENSITY ALTITUDE: +1475 FT.

MAXIMUM TEMPERATURE: 74°F. MINIMUM TEMPERATURE: 6Ø°F.

SUNRISE TODAY: Ø538C TOMORROW: Ø538C SUNSET TODAY: 1726C TOMORROW: 1725C

FURTHER OUTLOOK: TUE & WED: FAIR TO PARTLY CLOUDY AND COOL. HURRICANE "MARTHA" WILL CONTINUE NORTHWEST MOVEMENT FOR THE NEXT 24 HOURS.

PREPARED BY: *Frosty Knight*
FROSTY KNIGHT, 1/LT. USAF
WEATHER OFFICER

AWS-WPC 2-20-1

Figure 16–6. (Superseded) *Local terminal forecast.*

AWS FLIGHT FORECAST CROSS SECTION

1. ISSUED 18 MAY 1966	2. BY WEATHER STATION AT OZR	3. FORECASTER FROSTY KNIGHT	4. AIRCRAFT IDENTIFICATION OV-1 0345	FOLDER NO. 12
6. ROUTE	7. TO FORT BRAGG	8. VIA ATL	9. TRACK	
10. VALID FOR DEPARTURE BETWEEN				

22 — TERMINAL AND ALTERNATE FORECASTS

STATION NAME	TIME OF PREPARATION GCT	PERIOD OF VALIDITY GCT	TIME OF LATEST SYNOPTIC CHART	SURFACE WIND DIRECTION VELOCITY AND GUSTINESS	SURFACE VISIBILITY	WEATHER AND OBSTRUCTION TO VISION	CLOUD AMOUNT, TYPE, HEIGHT OF BASES AND TOPS: LOWEST LAYER	HIGHER LAYERS	HIGHEST LAYER	ALTIMETER SETTING ETA (INS)	REMARKS (SIGNIFICANT CHANGES DURING VALID PERIOD, ETC.)
PENSACOLA	1100Z	1730Z	0900Z	220/12	15 MILES	NONE	8/10 CU 2500	—	—	—	CHECK WITH PNS FORECASTER
FT BRAGG	1100Z	1730Z	0900Z	190/10	15 MILES	NONE	4/10 CU 8000	8/10 AS 11,000	—	29.85	ON WEATHER CONDITIONS IN
											WARM FRONT.

12. ZONE

13. MILEAGE

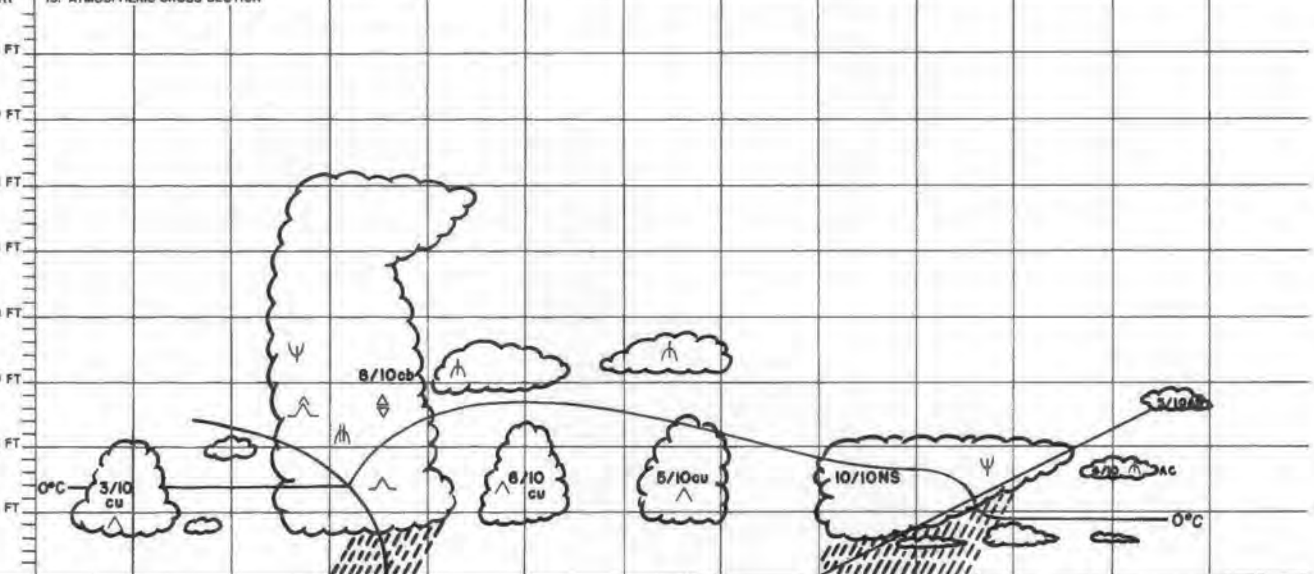
23. SYMBOLS

- RAIN
- SNOW
- FOG
- HAIL
- THUNDERSTORMS
- BLOWING SAND OR DUST
- BLOWING (DRIFTING) SNOW
- ICE PELLETS (SLEET)
- FREEZING RAIN
- RAIN AND SNOW (MIXED)
- SQUALL
- LITE RIME ICING
- MOD RIME ICING
- SEV RIME ICING
- LITE CLEAR ICING
- MOD CLEAR ICING
- SEV CLEAR ICING
- LITE TURBULENCE
- MOD TURBULENCE
- SEV TURBULENCE

SOLID LINES

GREEN	0°C ISOTHERM
BLUE	— COLD FRONT
RED	— WARM FRONT
PURPLE	— OCCLUDED FRONT
RED AND BLUE	— STATIONARY FRONT

14. HEIGHT — 15. ATMOSPHERIC CROSS SECTION



	MWL	LCH	MSY	PNS	ATL	FTB
16. IDENTIFICATION POINT	MWL	LCH	MSY	PNS	ATL	FTB
17. SIGNIFICANT WEATHER					99	
18. BASE OF LOW CLOUDS	2500	2000	3000	3000	1500	8000
19. VISIBILITY	15 MILES	1 MILE	10 MILES	10 MILES	1/2 MILE	15 MILES
20. REMARKS		HAIL ALOFT				
21. WINDS AND TEMPERATURES — SURFACE	290/15					
10,000 FT MSL	280/25 - 7°C	→ ←	250/30 + 6°	→	←	220/30 - 10°
20,000 FT MSL	260/35 - 25°C	→ ←	230/35 - 15°	→	←	220/35 - 24°
30,000 FT MSL	260/50 - 30°C	→ ←	230/45 - 25°	→	←	230/45 - 35°

AWS FORM 29A 1 NOV 64 PREVIOUS EDITIONS OF THIS FORM MAY BE USED.

Figure 16–7. (Superseded) *Vertical cross section forecast.*

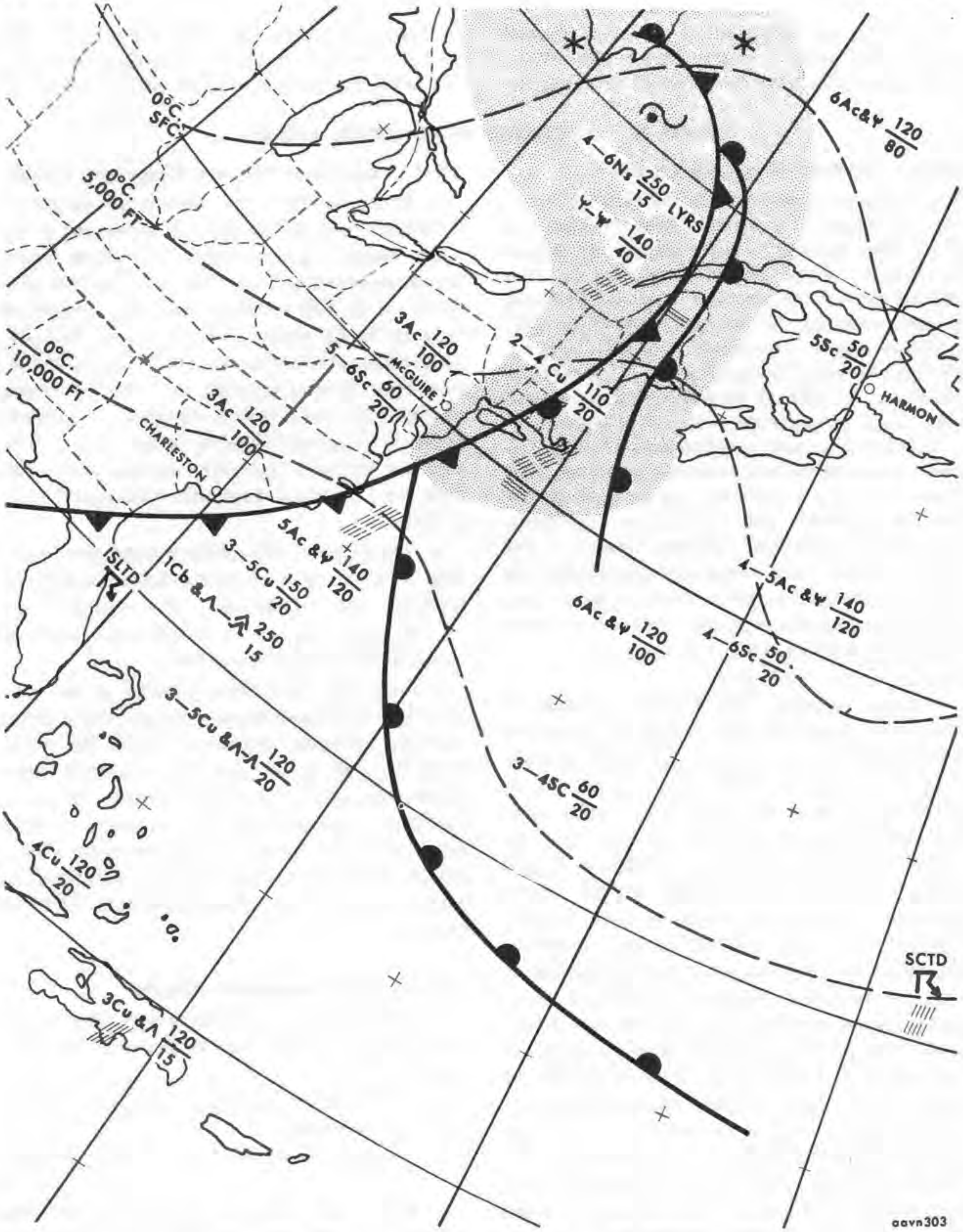


Figure 16–8. Typical horizontal weather depiction chart (forecast).

b. Fronts are indicated by the same symbols used on the surface weather map (fig. 12-6). The symbols for weather elements are identical to those illustrated on AWS Form 29A (fig. 16-7). The 0° C. isotherm is shown as a dashed line with the isotherm height clearly indicated.

Section IV. FACSIMILE PROGNOSTIC CHARTS

16-10. Surface Prognostic Charts

a. A major function of the National Meteorological Center is to provide field weather stations with forecasts (prognoses) of surface conditions. These forecasts are used as forecasting aids at local weather stations. The local forecast remains the responsibility of the individual issuing it. The objective of NMC prognosis is to forecast the major anticipated weather changes. Individual weather stations should make local refinements to NMC prognoses.

b. NMC forecasts are transmitted over facsimile circuits to local weather stations. Surface facsimile prognostic charts show the expected position and orientation of fronts, pressure systems, and isobars. Many of the forecast charts are *composite,* containing the forecast position of 500-millibar contour lines in addition to surface isobars. Composite charts indicate isobars as solid black lines and contour lines as dashed black lines.

c. Approximately seven forecast surface and composite charts are transmitted by facsimile process each day. One such chart is the 36-hour surface prognostic chart (fig. 16-9) transmitted twice daily for the United States area. Isobars are drawn at 4-millibar intervals and labeled in multiples of four. Standard frontal symbols (par. 12-6*a*) are used, and the fronts are coded as to type and intensity (par. 12-6*a*). The centers of high (H) and low (L) pressure are identified, with central pressures labeled in tens and units of millibars. The forecast direction of movement of the pressure centers is normally indicated by an arrow, with the speed of movement shown in knots. The cross-hatched areas on the chart indicate regions where an overcast cloud cover or an overcast with a few breaks will occur at the verifying time (*VT*) of the prognosis. Stippled areas indicate where precipitation is expected. Areas of overcast and precipitation are usually colored at the local weather station.

16-11. Constant-Pressure Prognostic Charts

a. Facsimile forecast charts of upper-air conditions are called *constant-pressure prognostic charts.* Approximately 20 of these charts are transmitted by the NMC each day for altitudes up to **300** millibars and for periods of time up to 72 hours. Charts drawn for altitudes below 300 millibars usually consist of contour lines, frontal symbols, and labeled centers of high (H) and low (L) elevation. Constant-pressure prognostic charts at and above 300-millibar altitudes normally include additional data for jet stream axes and wind speed (isotachs).

b. The 36-hour 700-millibar prognostic chart (fig. 16-10) is convenient for flight planning at altitudes near 10,000 feet. The contour lines on this chart are drawn at 200-foot intervals and labeled in hundreds of feet.

c. Since the wind flows parallel to the contour lines at a speed directly proportional to the distance between contours, values for wind direction and speed may be computed from constant-pressure prognostic charts. Weather conditions on the charts depict the conditions expected at the specified verifying time (VT), rather than the average weather conditions expected between transmission time and verifying time.

16-12. Other Prognostic Charts

Other commonly available prognostic charts of surface and upper-air weather conditions include—

a. Twenty-four- and thirty-six-hour vertical velocity prognoses.

b. Five-day forecast charts for the surface.

c. Thirty-day outlook charts covering the 700-millibar contours, regional surface temperatures, and precipitation areas.

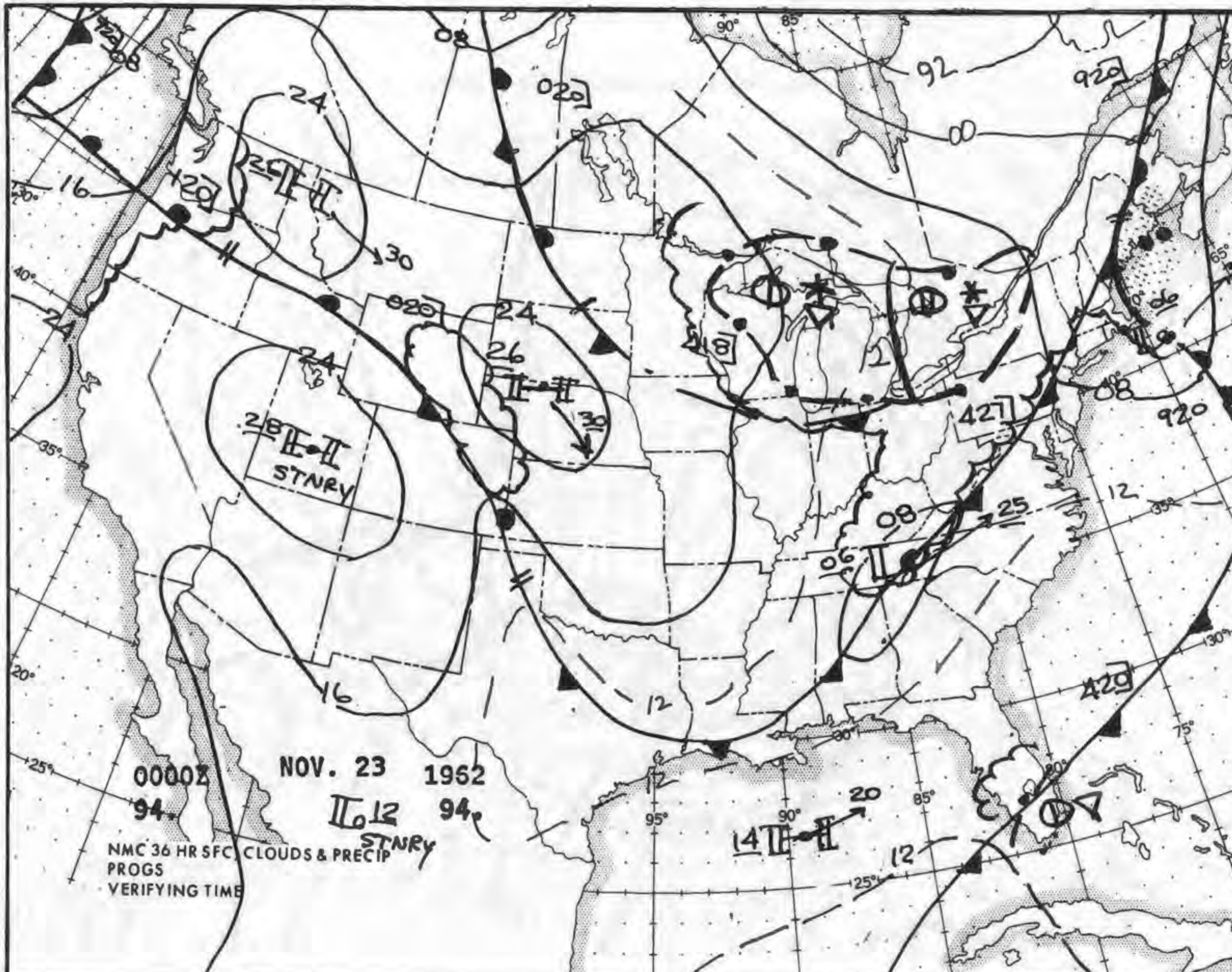


Figure 16–9. A 36-hour surface prognostic chart.

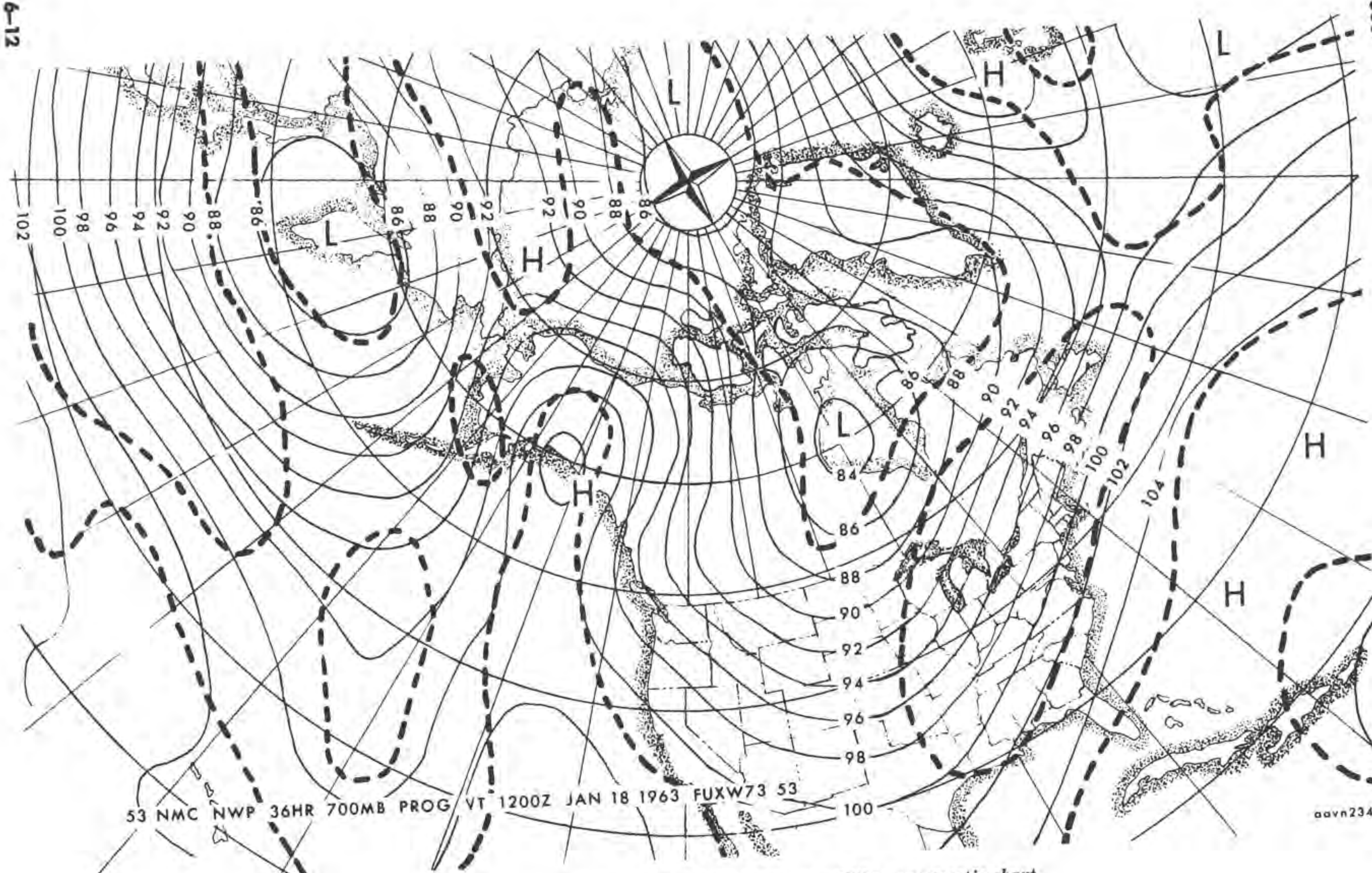


Figure 16–10. A 36-hour 700-millibar prognostic chart.

Section V. IN-FLIGHT FORECASTS

16-13. Weather Broadcasts

All flight service stations that have voice facilities on continuously operated navigational aids broadcast weather reports and other airway information at 15- and 45-minute intervals past each hour.

a. The broadcast at 15 minutes past the hour consists of weather reports from stations within approximately 150 miles of the broadcasting station.

b. The broadcast at 45 minutes past the hour consists of weather reports from important terminals located on airways within approximately 400 miles of the broadcasting station.

c. Continuous transcribed weather broadcasts are made over a countrywide network of selected low and medium frequency range stations. These broadcasts contain a synopsis of current weather and forecasts of conditions for an area within a 250-mile radius of the station, as well as latest hourly reports from selected stations, pertinent pilot reports, and in-flight advisories for aircraft. Stations providing this service are listed in the flight information manual.

16-14. Weather Advisories

Special weather developments and NOTAM's are broadcast, upon receipt, by flight service stations having voice facilities on continuously operated navigational aids. Two special weather advisories, called *SIGMET*'s and *AIRMET*'s, provide immediate information about weather that may endanger aircraft in flight. The aviator receiving such advisories must use his experience, judgment, and weather knowledge to decide his course of action. He should continue to monitor the appropriate navigational aid frequency after an advisory has been issued within his area of flight.

a. SIGMET. A SIGMET (fig. 16-11) is an in-flight advisory report concerning *sig*nificant *met*eorological developments of such intensity as to be potentially hazardous to *all* aircraft in flight, e.g.; tornadoes, squall lines, hail (three-fourths of an inch and larger), severe turbulence, heavy icing, and widespread duststorms or sandstorms that reduce visibility to less than 2 miles. SIGMET advisories are broadcast upon receipt and at 15-minute intervals thereafter, beginning on the hour, throughout the valid period.

b. AIRMET's. An *AIRMET* (fig. 16-12) is a report concerning weather of an intensity potentially hazardous to aircraft weighing 12,500 pounds or less. These broadcasts may include conditions involving moderate icing, moderate turbulence, weather that produces extensive areas where visibility is less than 2 miles or ceilings less than 1,000 feet, and wind of 40 knots or greater which are located within 2,000 feet of the surface. This advisory is broadcast upon receipt by the station, then becomes a part of the routine 15- and 45-minute past-the-hour broadcast through the valid period.

```
FL DEN Ø9Ø23Ø

SIGMET BRAVO 1.  ROCKY MTN AREAS COLO AND SRN WYO.  STANDING
WVS E OF RDGS CAUSING EXTNSV AREAS OF STG UP AND DOWN DRAFTS
AND LCLY SVR TURBC TO 18Ø MSL.  CONDS CONTG PAST MIDN.
```

Figure 16-11. (Superseded) *SIGMET.*

```
FL DCA Ø5Ø815

AIRMET ALFA 1. RAIN AND FOG WITH CIGS LWRG TO BLO 1 THSD FT
AND VSBYS BLO 2 MI OVER CAROLINAS EAST OF MTNS BY Ø4ØØE SPRDG
OVER VA SOUTH OF RICHMOND ROANOKE LINE BY Ø7ØØE.
```

Figure 16–12. (Superseded) *Advisory for light aircraft.*

CHAPTER 17

WEATHER FLIGHT PLANNING

17-1. General

a. Effective weather flight planning on the ground requires an understanding of the weather facilities available at the weather station, the ability to use the available weather information properly, and a knowledge of the services provided by the Weather Services.

b. In the air, weather flight planning continues as the aviator relates his visualization of weather conditions obtained during the ground briefing to the existing en route weather conditions. His knowledge of cloud forms, pressure pattern, airflow, etc., will enable him to analyze the validity of the briefing and the forecast. His decisions in flight will also reflect his knowledge and understanding of hazard-producing phenomena and related flight procedures.

17-2. Aviator's Analysis

Weather stations are maintained at all major airfields for the collection, analysis, and dissemination of weather information. Trained observers and forecasters are available at most weather stations to assist the aviator in his flight planning. Before consulting the forecaster, the aviator should make his own weather analysis. If he accepts a forecast or analysis that he does not understand, he is negligent in the performance of his duties.

a. The objective of the aviator's analysis of weather is to obtain a complete picture of the weather conditions that will affect his flight. With a mental picture and understanding of the weather, he is prepared to discuss the weather briefing with the forecaster.

b. The steps in conducting the weather phase of a typical flight plan are to—

(1) Determine whether the flight will be conducted under instrument or visual flight rules (IFR or VFR).

(2) Obtain the ceiling and visibility values and nature of weather phenomena affecting them at destination and alternate airfields. Conditions below acceptable flight minimums will delay flight.

(3) Determine the height of the freezing level and note areas to be avoided where structural ice might be encountered.

(4) Obtain the wind velocity at optimum flight levels to determine fuel requirements and flight time to destination and alternate airfields.

(5) Locate probable or known areas of turbulence, hail, low visibility, and other flight hazards.

(6) Visualize the complete weather picture along the route.

c. After the aviator is in the air, he will rely primarily on his own knowledge of weather, his flying experience, and his weather briefing. If the aviator encounters conditions in flight which necessitate additional information, a pilot-to-forecaster service is available on a radio frequency of 344.6 megacycles (METRO).

17-3. Use of Weather Facilities

a. Weather Map. Weather flight planning normally begins with a study of the surface weather map. This map presents a picture of the main atmospheric features that determine the weather. The air masses, fronts, and pressure systems shown control the weather throughout the forecast period. Current weather reports will enable the aviator to follow the movements of the weather systems subsequent to the time of the map observation. Local weather changes are difficult to analyze and explain without a knowledge of the synoptic situation shown by the weather map.

b. Constant Pressure Charts. Constant-pressure charts are synoptic charts for the upper atmosphere. They are designed to show conditions of temperature, moisture, winds, and the height of a specific pressure level at a definite time. These charts are important tools for planning a flight. For example, an aviator planning a flight from Cairns AAF to Fort Bragg, N. C., may analyze the 850-millibar chart (5,000 feet) and find that he will have adverse headwinds for the entire flight. However, a check of the 700-millibar chart (10,000 feet) may indicate a wind from the west and favorable weather for the entire flight. Also, the height of the pressure level will indicate the relationship between the indicated altitude and the true altitude.

c. Skew T, Log P Diagram. With the types and movements of pressure systems and fronts well in mind, the aviator should inspect the Skew T, log p Diagram. One or more diagrams for stations centrally located in the area of cloudiness and near the route to be flown are preferable. The aviator should determine the flight-level temperature, cloud thickness, altitudes of icing conditions, and the stability of the air. If conditions are unfavorable at the proposed flight altitude, it may be necessary to select another altitude by correlating information on the Skew T, log p Diagram with other facilities.

d. Sequence Weather Reports.

(1) *Teletype sequence reports* should be analyzed to determine the current weather along the proposed flight path, at the destination, and at the alternate airfield. These reports provide the aviator with the most current weather data.

(2) *Notices to airmen,* concerning items such as radio facilities and field and runway conditions, are added at the end of aviation weather observations. These are coded in the International NOTAM Code, available for reference in all weather stations.

e. Winds Aloft Data. After selecting an altitude with favorable weather conditions, the aviator should check the winds aloft code to determine wind velocities between the place of departure and the destination airfield. An aviator on instrument flight in a controlled area may be unable to obtain clearance for the best altitude; therefore, he should make a written notation of the expected wind at all probable flight altitudes. When the winds aloft chart does not provide the necessary wind velocity information, the constant-pressure charts should be used.

f. Pilot Reports (PIREPS). Pilot reports are a valuable source of current information for flight conditions, especially in areas remote from weather observing stations. To obtain maximum benefit from these reports, an aviator should carefully check the—

(1) Time of the pilot's observation.

(2) Location of the aircraft.

(3) Type and extent of the reported phenomena.

(4) Altitude of the reported phenomena.

g. Forecasts. The last and most important item to check is the current forecast. After an aviator has made his own analysis of the weather and obtained the forecaster's analysis, he is in a position to discuss any differences intelligently. The aviator should never leave a weather office until he is fully aware of the weather conditions along his route.

17-4. Weather Trends and Flight Planning

Figures 17-1 through 17-4 depict weather conditions as they existed at 0000Z, 2 January 1965 from the surface to 18,000 feet. Figures 17-5 through 17-8 indicate the changes in the weather pattern that had developed 12 hours later (1200Z). The ability to use and interpret these and other weather station facilities will enable the aviator to anticipate future weather trends and apply his weather knowledge to a meaningful flight plan.

17-5. Aviator Briefing

The briefing forecaster is better equipped to serve the aviator when the aviator requests specific information. The forecaster should be informed of the aircraft type, the estimated time of departure, the proposed route and altitude, estimated time en route, and other information that will enable him to visualize the flight.

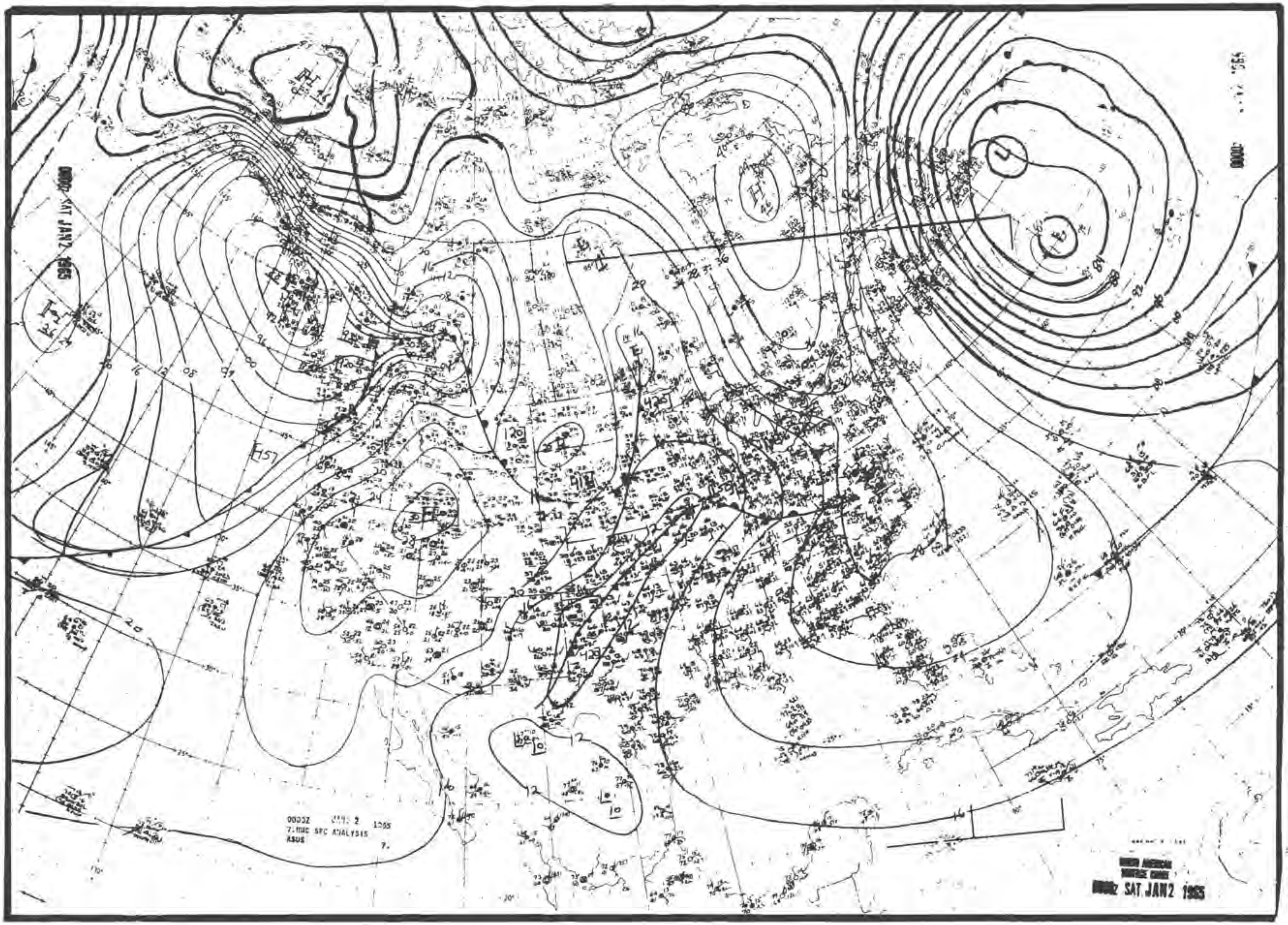


Figure 17-1. Surface weather map, 0000Z.

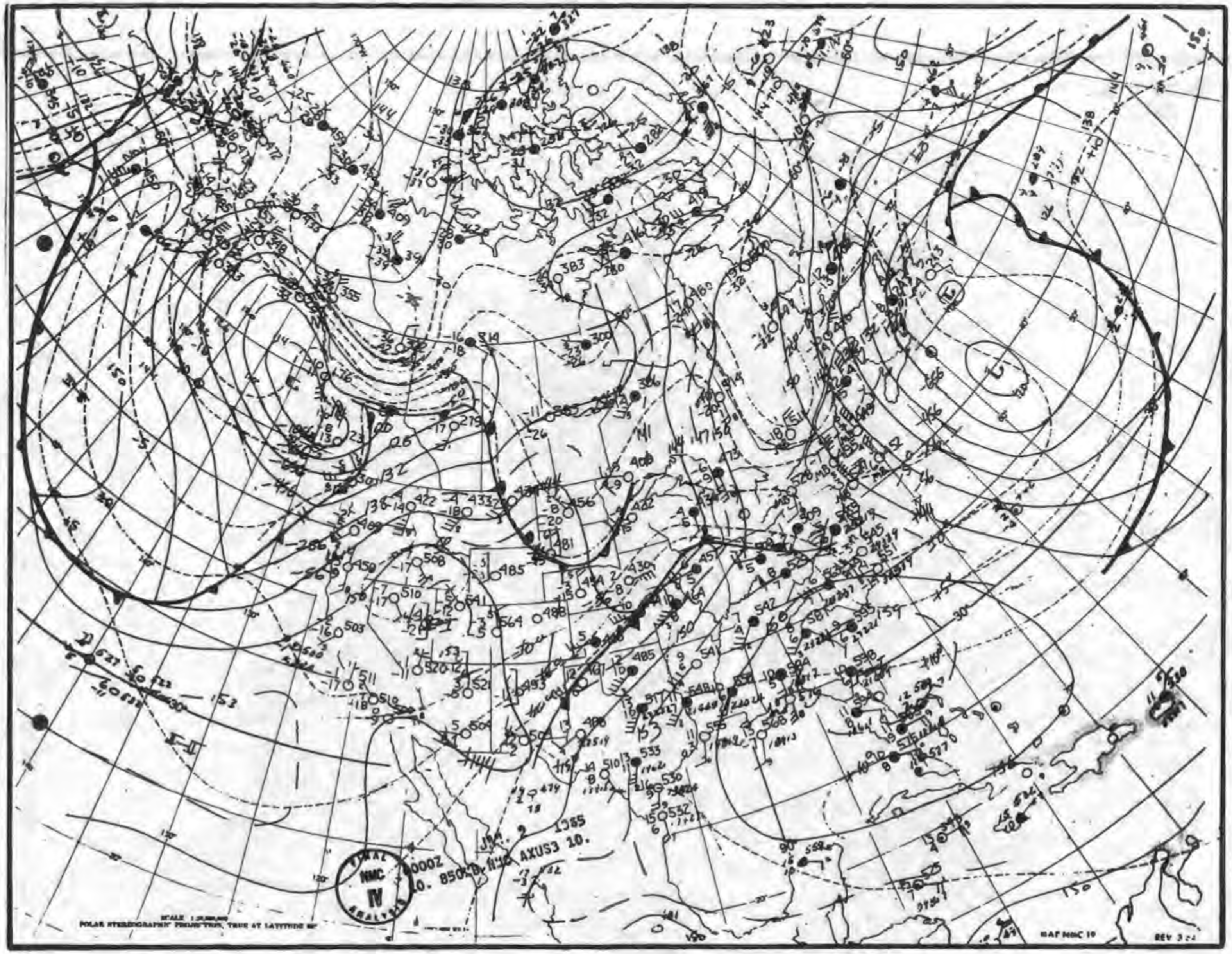


Figure 17-2. 850-millibar constant pressure chart, 0000Z.

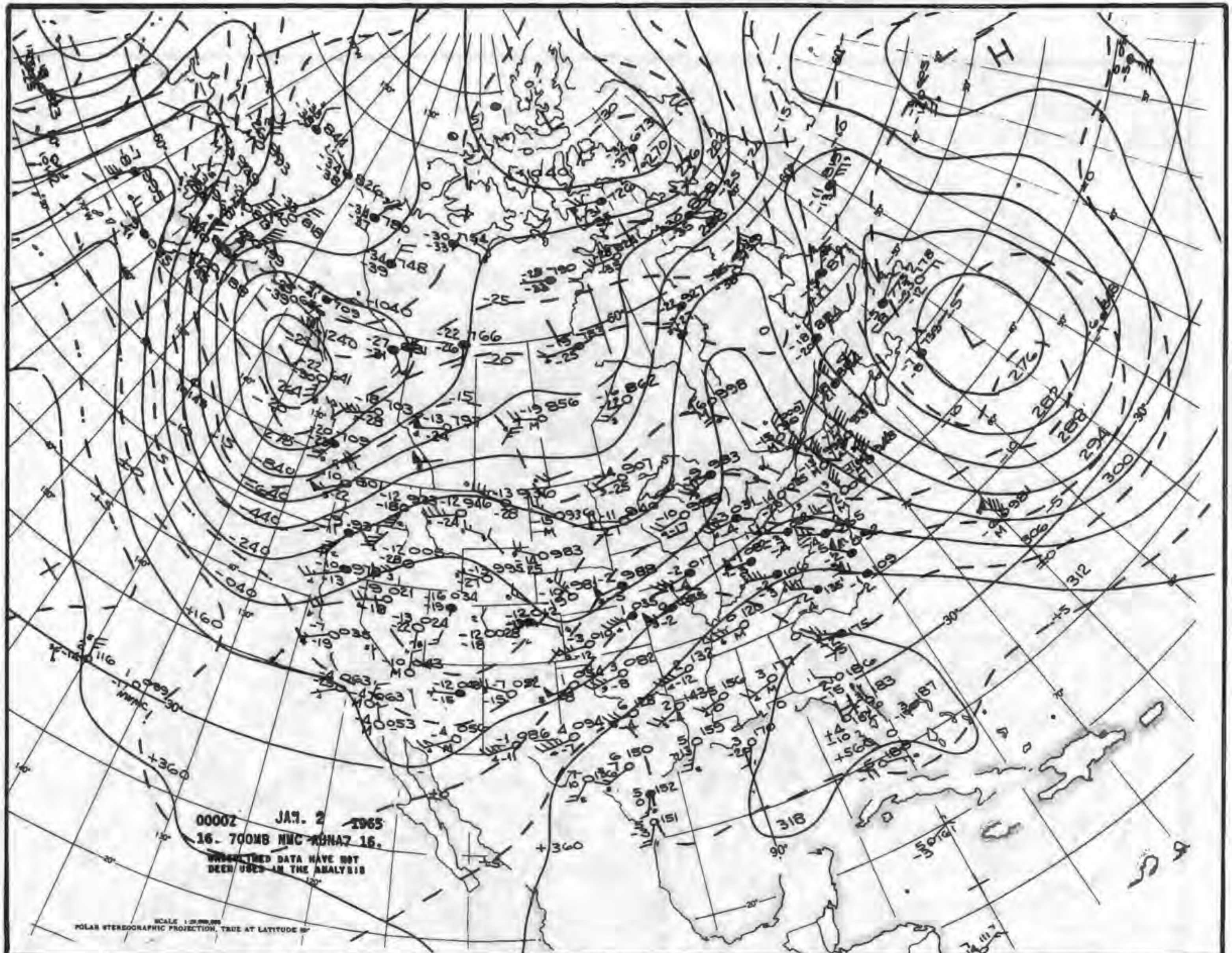


Figure 17-3. 700-millibar constant pressure chart, 0000Z.

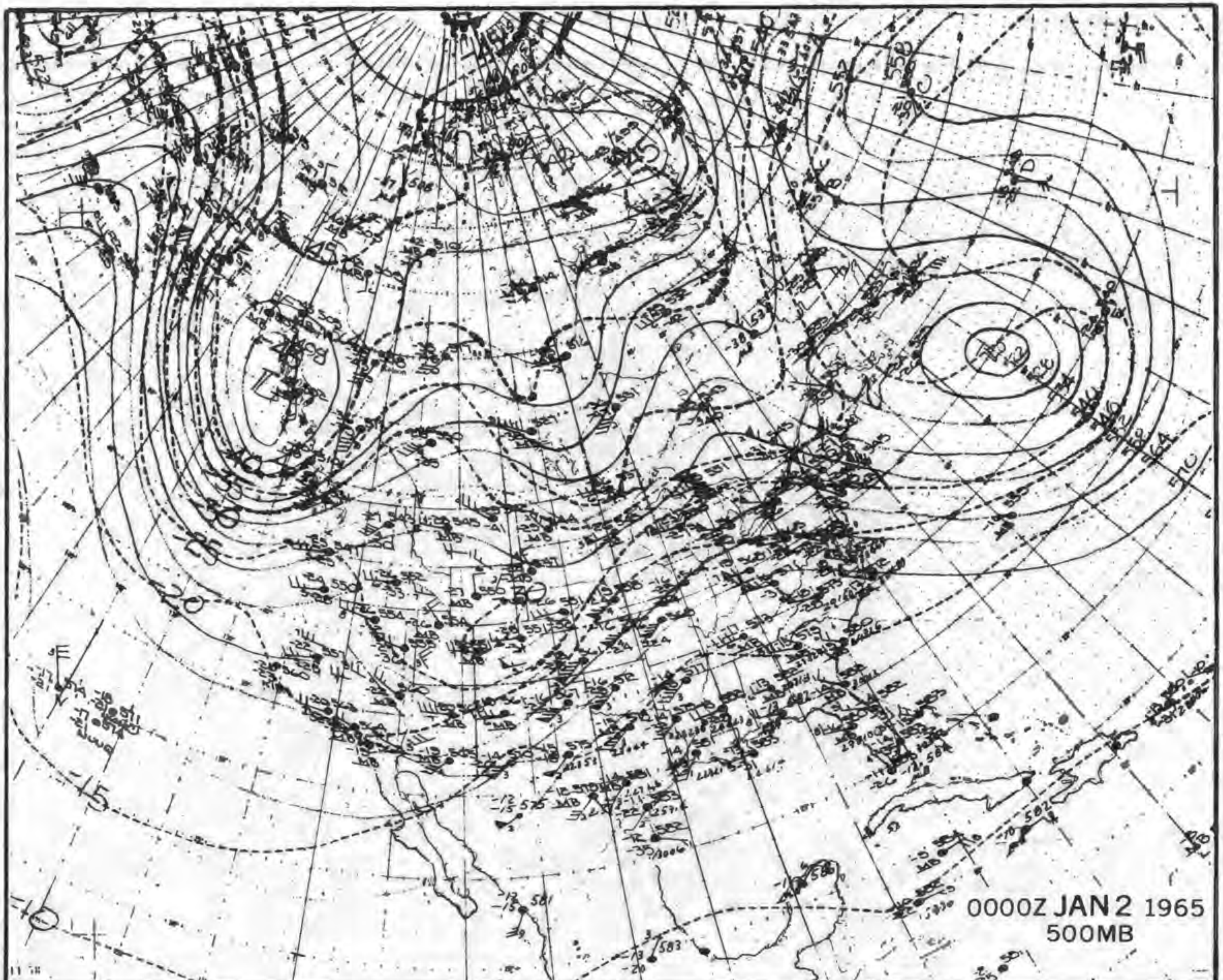


Figure 17-4. 500-millibar constant pressure chart, 0000Z.

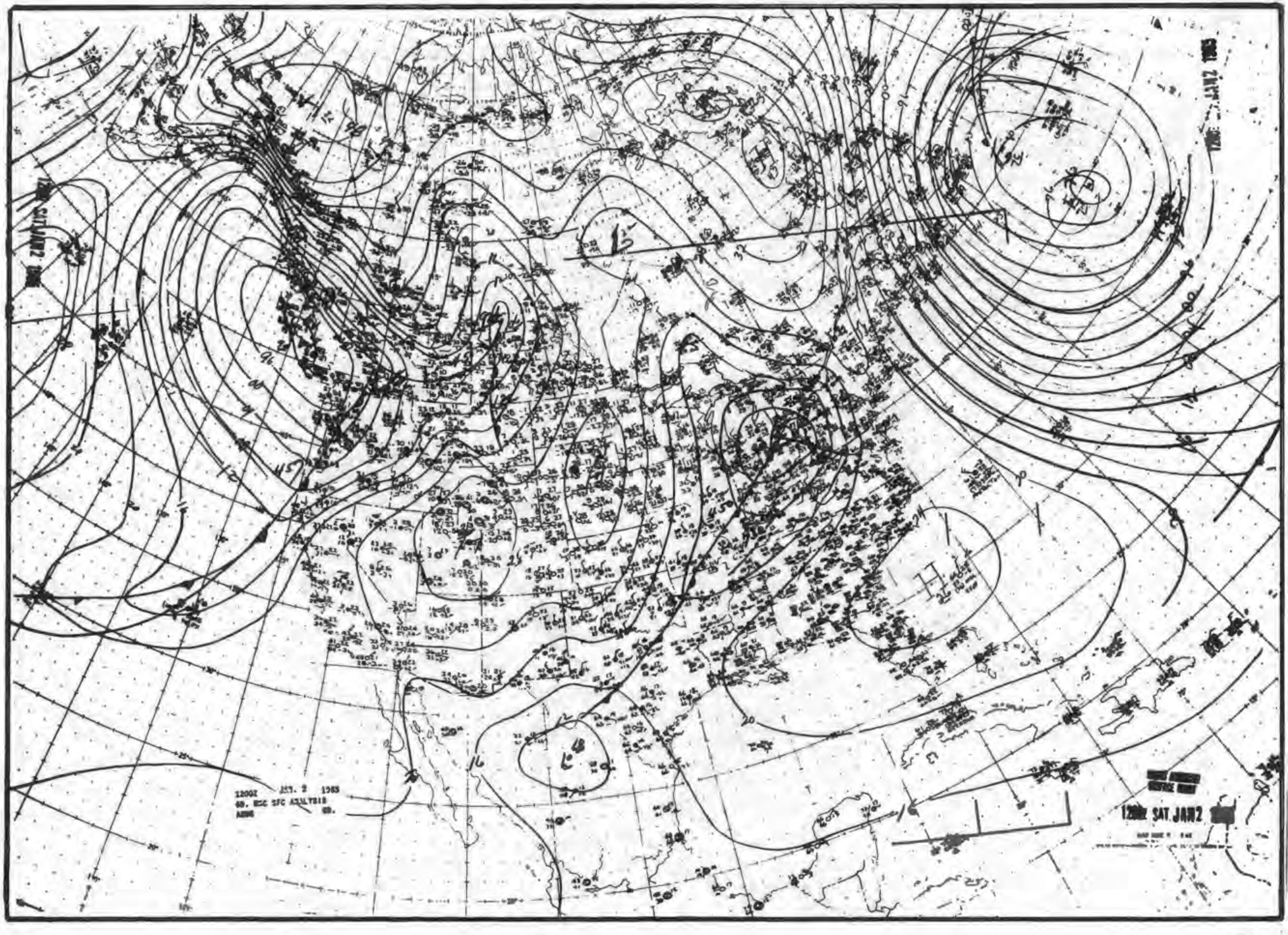


Figure 17-5. Surface weather map, 1200Z.

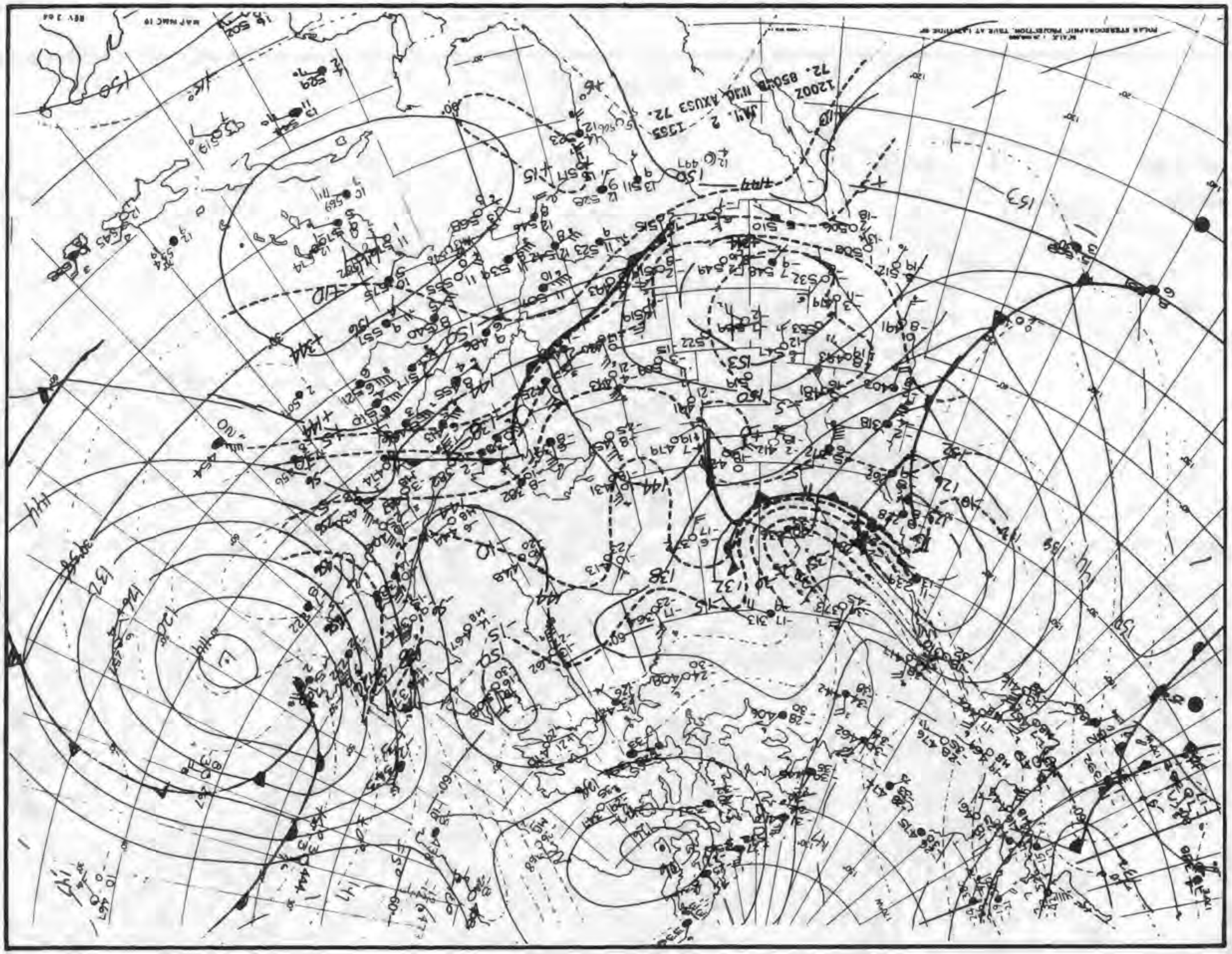


Figure 17-6. 850-millibar constant pressure chart, 1200Z.

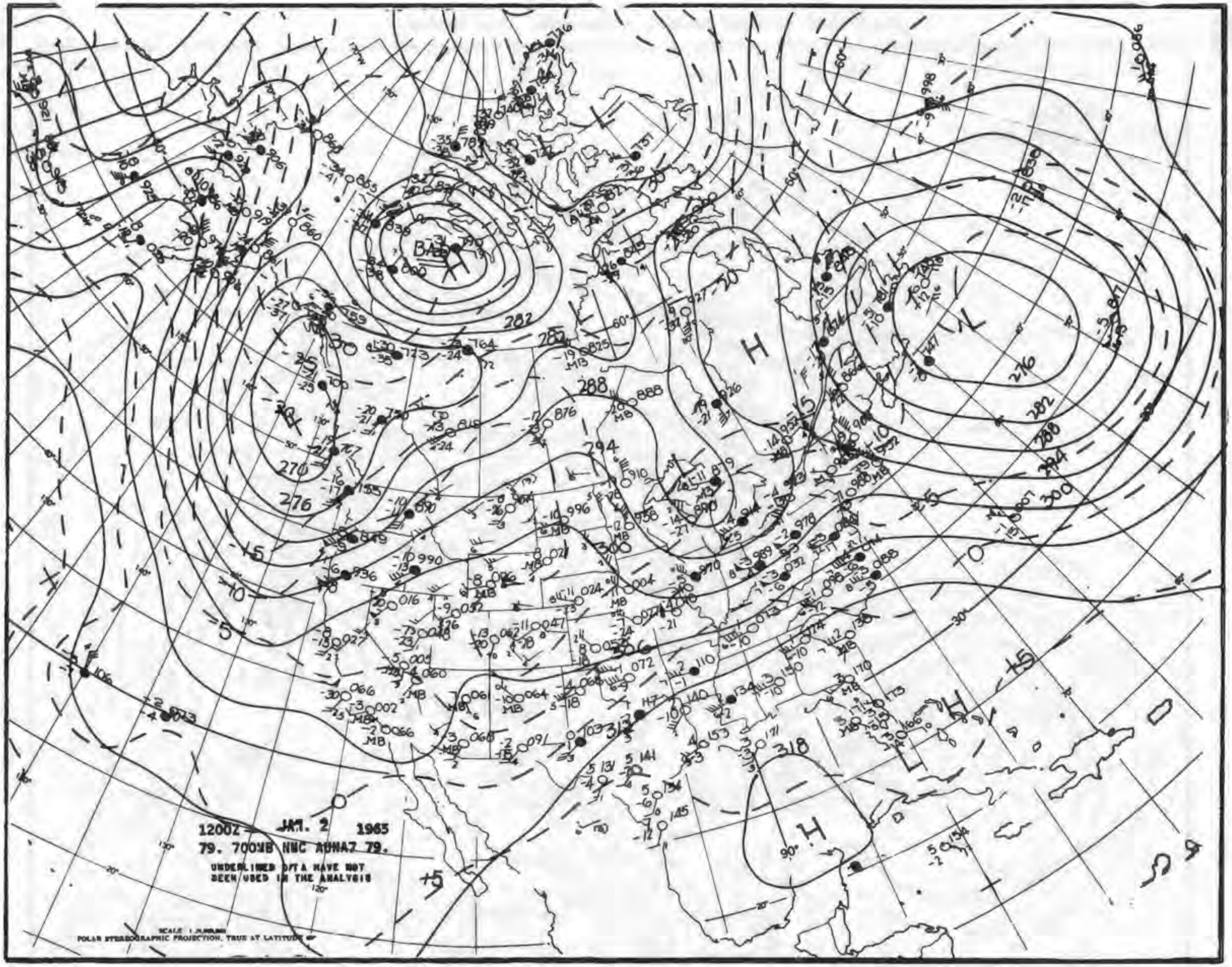


Figure 17–7. 700-millibar constant pressure chart, 1200Z.

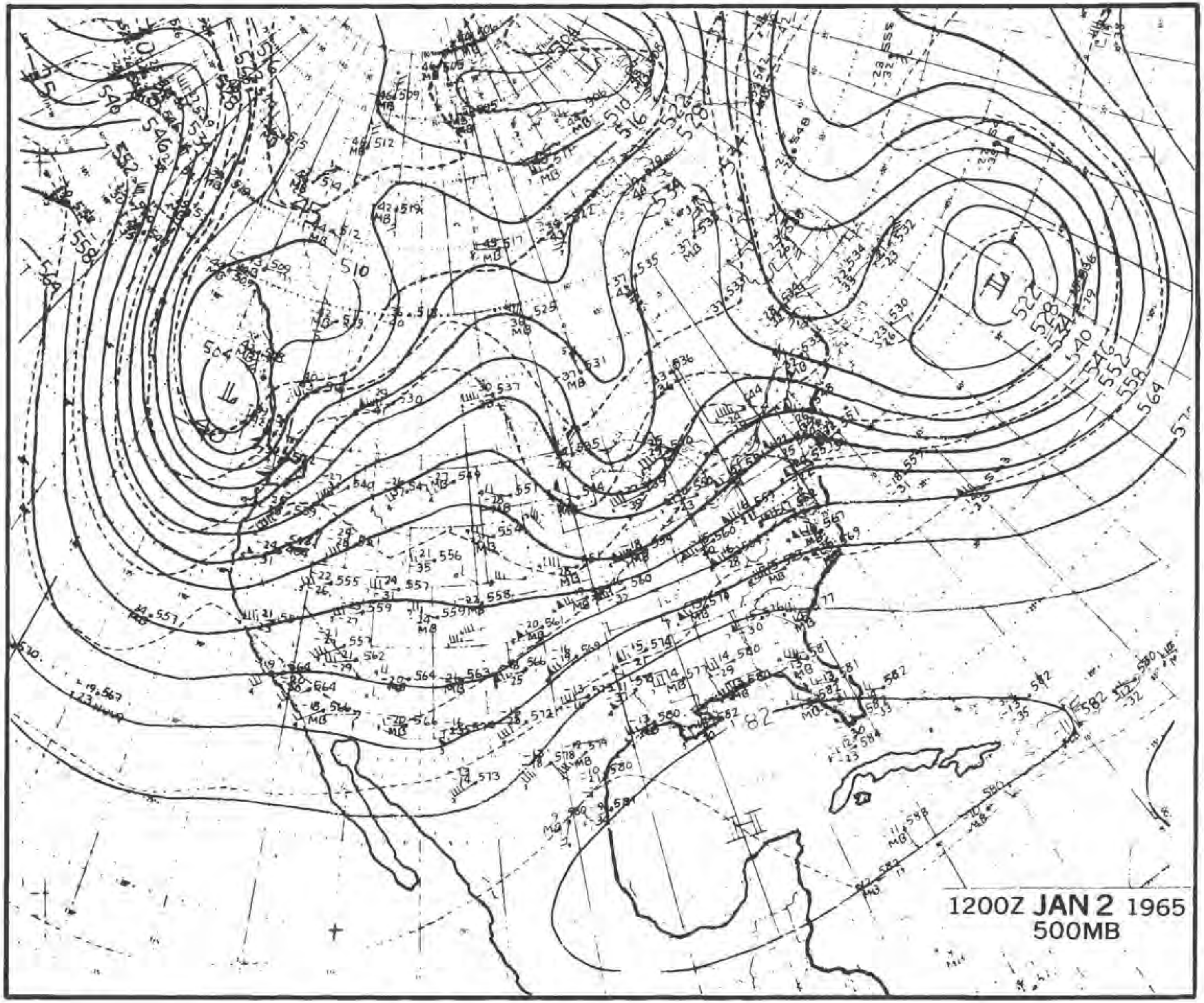


Figure 17–8. 500-millibar constant pressure chart, 1200Z.

a. Specific Weather Conditions. Specific questions, when applicable, should then be asked by the aviator to determine—

(1) *Weather at takeoff.*

(*a*) Bases and tops of cloud layers.

(*b*) Visibility and obstructions to vision.

(*c*) Type and intensity of precipitation.

(*d*) Freezing level.

(*e*) Temperature and winds up to flight altitude.

(*f*) Runway temperature and density altitude.

(*g*) Condition of runways, if affected by weather.

(2) *Weather en route.*

(*a*) Bases, tops, types, and amount of each cloud layer.

(*b*) Visibility at the surface and aloft.

(*c*) Type, location, intensity, and direction and speed of fronts.

(*d*) Freezing level.

(*e*) Temperature and winds at various flight altitudes.

(*f*) Areas of severe weather (thunderstorms, hail, icing, and turbulence).

(3) *Weather at destination and alternates.*

(*a*) Bases, tops, types, and amount of each cloud layer.

(*b*) Visibility and obstructions to vision.

(*c*) Type and intensity of precipitation.

(*d*) Freezing level.

(*e*) Surface wind velocity.

(*f*) Condition of runways, if affected by weather.

b. Other Weather Considerations.

(1) The weather at the point of takeoff is often neglected in flight planning. Knowledge of this weather will be the deciding factor if an immediate decision must be made because of an emergency soon after takeoff.

(2) Temperatures and winds up to the flight altitudes must be known to compute the distance flown and the fuel consumed during the climb to altitude.

(3) A complete picture of the ceilings, visibilities, and clouds en route will prove valuable if the aircraft malfunctions or some other emergency forces him to land.

(4) A knowledge of the type and intensity of precipitation at the destination will assist the aviator in estimating the runway braking action.

(5) Obtaining all the pertinent briefing information available (fig. 17-9) is a necessity in proper flight planning. A few extra minutes spent in the weather office in forming a complete mental picture of the weather conditions will be an important factor in executing a successful mission.

Note. The decision to make a flight in adverse weather conditions is not a responsibility of the forecaster; this is a decision for the aviator and/or appropriate clearing authority.

17-6. Weather Vision

Some airfields are equipped with closed-circuit television to transmit weather information to auxiliary fields or other nearby airfields which lack fully staffed and equipped weather stations. This televised weather service is called *weather vision.* An illustration of the types of weather data received on weather vision equipment is shown in figure 17-10.

Figure 17-9. Typical weather briefing situation.

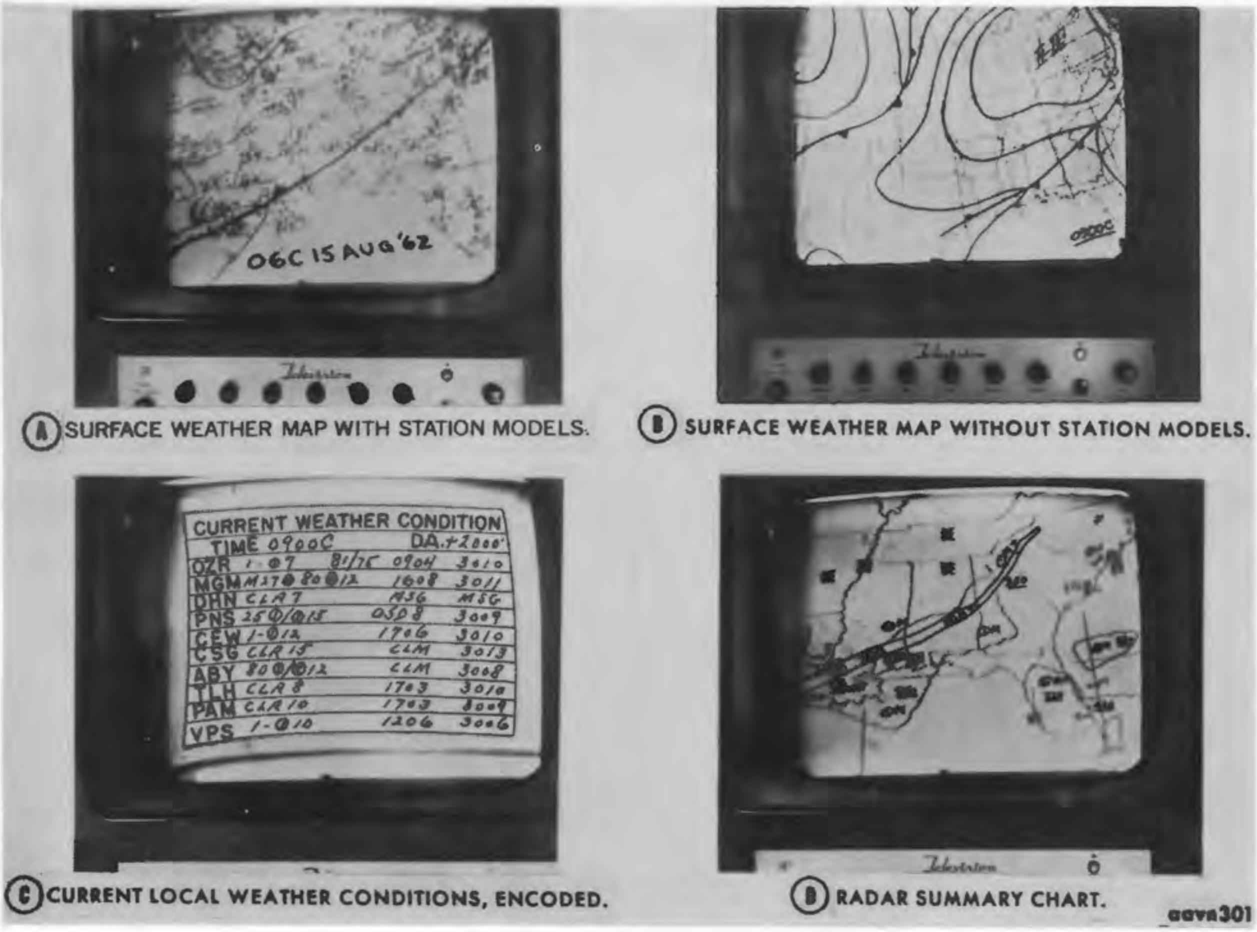


Figure 17–10. Typical weather vision transmissions.

APPENDIX I

REFERENCES

TM 1–215	Attitude Instrument Flying.
TM 1–225	Navigation for Army Aviation.
FM 6–15	Artillery Meteorology.
CAA TM 104 (ROTCM 145–1–4)	Pilot's Weather Handbook.
Circular N	*Manual of Surface Observations (WBAN)* (Washington, D.C.: Government Printing Office, 7th edition revised, November, 1961).
Circular S	*Manual of Cloud Forms and Codes of the Sky* (Washington, D.C.: Government Printing Office, May, 1956).
Glossary	*Glossary of Meteorology* (Huschke, Ralph E. (editor); sponsored by U.S. Weather Bureau, U.S. Air Force, U.S. Army, and U.S. Navy, American Meteorological Society, 1959).
Handbook	*Handbook of Meteorology* (Berry, F. A., Jr.; Bollay, E.; and Beers, Norman R. (editors); New York: McGraw-Hill Book Company, Inc., (1945)).
NAVAER 00–80U–24	*Meteorology for Naval Aviators* (Office of the Chief of Naval Operations, Aviation Training Division, 1958).
AFM 105–5	*Weather for Aircrews* (Department of the Air Force, Air Training Command, September 1962).
Project Report	*The Thunderstorm* (Joint Project of the Air Force, Navy, NACA, and Weather Bureau; Washington, D.C.: Government Printing Office, June, 1949).

APPENDIX II

UNITS OF MEASUREMENT FOR METEOROLOGICAL ELEMENTS

Table III. Conversion From Inches of Mercury to Millibars

In Hg	0	.1	.2	.3	.4	.5	.6	.7	.8	.9
28	948	952	955	958	962	965	968	972	975	979
29	982	985	989	992	996	999	1,002	1,006	1,009	1,013
30	1,016	1,019	1,023	1,026	1,030	1,033	1,036	1,040	1,043	1,046
31	1,050	1,053	1,057	1,060	1,063	1,067	1,070	1,074	1,077	1,080

Table IV. Dew Point and Moisture Content at 1,000-Millibar Pressure

Dew Point °F.	Water vapor in g/kg (approximate)	Dew Point °F.	Water vapor in g/kg (approximate)
90	31	40	5.4
80	22	30	3.6
70	16	20	2.3
60	11	10	1.5
50	7.7		

Explanation: Any parcel of air with a dew point temperature of 70° F. contains approximately 16 grams of water vapor per 1,000 grams of air (atmosphere pressure at 1,000 millibars); or, any parcel of air containing 11 grams of water vapor per 1,000 grams of air would have a dew point of approximately 60° F., etc.

Table V. The Standard Atmosphere

	Metric units	Dynamic units	English units
Standard temperature	15° C		59° F.
Standard pressure	760 mm of mercury or 10,332.276 kg/m²	1,013,250 dynes/cm² 1,013.25 mb	29.92 in. of mercury 14.696 lb/in²
Standard gravity (45° lat)	980.63 cm/sec²		32.1740 ft/sec²
Standard air density	1.2255 kg/m³		0.7651 lb/ft³
Standard vertical temperature gradient (lapse rate).	0.0065° C/m (2° C/1,000 ft)		0.003566° F/ft 3.6° F/1,000 ft
Standard isothermal temperature	−55° C. (tropopause)		−67° F.

Table VI. Miscellaneous Constants and Units

Density of water at 15° C.[1]	0.9991286 g/ml
Latent heat of fusion of ice	79.7 g-cal/g
Latent heat of vaporization of water	594.9 g-cal/g at 0° C. 539.1 g-cal/g at 100° C.
1 meter	39.37 in
1 kilogram	2.2046 lb
1 statute mile	5,280 ft
1 nautical mile	6,080 ft (1.15 statute miles)
1 kilometer[2]	3,281 ft
1 inch	2.54 cm
1 inch Hg	33.86395 millibars
1 millibar[2]	0.0295299 in Hg
1 m/sec	2.2369 mph
1 m/sec	1.943 knots
1 mph	0.8684 knots
1 nautical mile	1.15 statute miles
Solar constant	1.932 cal/cm²/min at the mean solar distance
Angular velocity of earth's rotation (ω)	7.29×10^{-5} radian/sec

[1]For temperature conversion between F. and C. scales, use the scale on figure 5-8 (Skew T, log p Diagram).
[2]For pressure-altitude relationship in the standard atmosphere, use ICAO sounding on figure 5-8 (Skew T, log p Diagram).

Table VII. Wind Direction—Degrees to Compass Points

Degrees	Compass point
349-011	N
012-033	NNE
034-056	NE
057-078	ENE
079-101	E
102-123	ESE
124-146	SE
147-168	SSE
169-191	S
192-213	SSW
214-236	SW
237-258	WSW
259-281	W
282-303	WNW
304-326	NW
327-348	NNW

Table VIII. Surface Wind Character

Wind speed in knots	Character of wind
0	Calm
1-3	Light air
4-6	Light breeze
7-10	Gentle breeze
11-16	Moderate breeze
17-21	Fresh breeze
22-27	Strong breeze
28-33	Moderate gale
34-40	Fresh gale
41-47	Strong gale
48-55	Whole gale
56-63	Storm
64+	Hurricane

Table IX. Force of the Wind Against a Stationary Object at Sea Level in Standard Atmosphere

Wind speed (knots)	Force (pounds per square foot)
10	0.26
20	1.02
30	2.30
40	4.09
50	6.39
60	9.21
70	12.53
80	16.36
90	20.71
100	25.57

Table X. Approximate Density Altitude Computations to the Nearest 100 Feet

Pressure Altitude (feet)	Air Temperature										
	°F 97	90	82	75	68	61	54	47	39	32	25
	°C 36	32	28	24	20	16	12	8	4	0	−4
Sea level	2,500	2,100	1,600	1,100	600	100	−400	−900	−1,400	−1,900	−2,300
500	3,100	2,700	2,200	1,800	1,300	800	300	−200	−700	−1,200	−1,600
1,000	3,700	3,200	2,800	2,400	1,900	1,400	900	500	−100	−600	−1,100
1,500	4,300	3,900	3,400	3,000	2,500	2,000	1,500	1,100	600	100	−500
2,000	4,900	4,500	4,000	3,600	3,100	2,600	2,200	1,700	1,200	700	200
2,500	5,500	5,100	4,600	4,200	3,700	3,200	2,800	2,300	1,800	1,300	800
3,000	6,300	5,700	5,200	4,800	4,300	3,800	3,400	2,900	2,500	2,000	1,500
3,500	6,800	6,300	5,900	5,400	4,900	4,400	4,000	3,500	3,100	2,600	2,100
4,000	7,500	7,000	6,600	5,900	5,500	5,000	4,600	4,100	3,700	3,200	2,700
4,500	8,000	7,500	7,100	6,500	6,000	5,500	5,100	4,600	4,200	3,600	3,200
5,000	8,500	8,000	7,600	7,100	6,500	6,100	5,600	5,200	4,700	4,200	3,700
5,500	9,100	8,600	8,200	7,700	7,100	6,700	6,200	5,800	5,300	4,700	4,300
6,000	9,700	9,200	8,800	8,300	7,800	7,300	6,900	6,400	5,900	5,300	4,900
6,500	10,300	9,800	9,400	8,800	8,400	7,800	7,400	7,000	6,400	6,000	5,600
7,000	10,800	10,400	10,000	9,500	9,000	8,500	8,100	7,600	7,100	6,700	6,200
7,500	11,400	11,000	10,600	10,200	9,700	9,200	8,700	8,300	7,800	7,300	6,800
8,000	12,100	11,600	11,200	10,800	10,300	9,800	9,200	8,800	8,400	7,900	7,500

APPENDIX III

WEATHER OUTSIDE THE TEMPERATE ZONE

Section I. POLAR AND SUBPOLAR REGIONS

1. General

a. Flights in polar and subpolar regions present special problems for the aviator. Most of the weather phenomena of special significance in these regions occur at low altitudes or at the surface. Terminal weather conditions are serious hazards in polar flight operations. Obstructions to visibility and depth perception make landings and takeoffs difficult. Iced runway conditions require special flight techniques during takeoff. Mechanical turbulence (par. 4–32) is frequent during periods of strong surface wind. In flight the aviator has to check carburetor air temperatures constantly to maintain safe engine operation or an ice-free carburetor when temperature-moisture conditions are ideal for induction system icing.

b. Although extremely cold air is typical of the polar and subpolar regions, the characteristic flight problems of cold air are not limited to these geographical areas. Flight hazards discussed in this chapter are applicable to areas of cold temperature wherever found.

2. Climatic Boundaries

a. Polar Region. The polar region is that part of the earth where the mean annual temperature is 32° F. or less and where the mean temperature for the warmest month is less than 50° F. In North America this region includes the northern coast of Alaska and Canada, the Canadian Arctic Archipelago, most of Labrador, Greenland, the Svalbard Archipelago, and the southern end of the Aleutian Island chain. The southern boundary of the polar region roughly follows the 60th parallel.

b. Subpolar Region. The subpolar region is more difficult to delineate than the polar region. In North America it includes the area between the southern limit of the polar region and the 40° F. isotherm of average annual temperature. Across the United States the boundary roughly follows the 48th parallel, but it then swings northward to include most of the inhabited sections of Alaska and the Aleutian Island chain.

3. Weather

a. Weather phenomena in the polar region are confined to a relatively shallow atmospheric layer near the surface because of the lack of convective activity to carry the moisture to higher levels. High-altitude flight is comparatively weather-free, but poor air-to-ground visibility, coupled with the mountains' refractive effect on radio waves, may complicate navigation at high altitudes.

b. The proportion of clear days to overcast days at Alaskan stations, for example, is often less than 1:3 (fig. III–1). In the course of a year, only those stations in interior Alaska average more clear days than cloudy days. The best flying conditions in the Aleutians, along the southeast Alaskan coast, and over the Seward Peninsula occur during the winter. The Alaskan gulf coast and interior regions present optimum flying conditions during the summer. The poorest (annual) flying conditions of Alaska exist in the Aleutians and the coastal section of the mainland. Although in the interior and Anchorage area ceilings and visibilities are below 2,000 feet and 6 miles for more than 10 percent of the time, these conditions exist more than 50 percent of the time in the Aleutians and along the southwest coast bordering the Alaskan gulf.

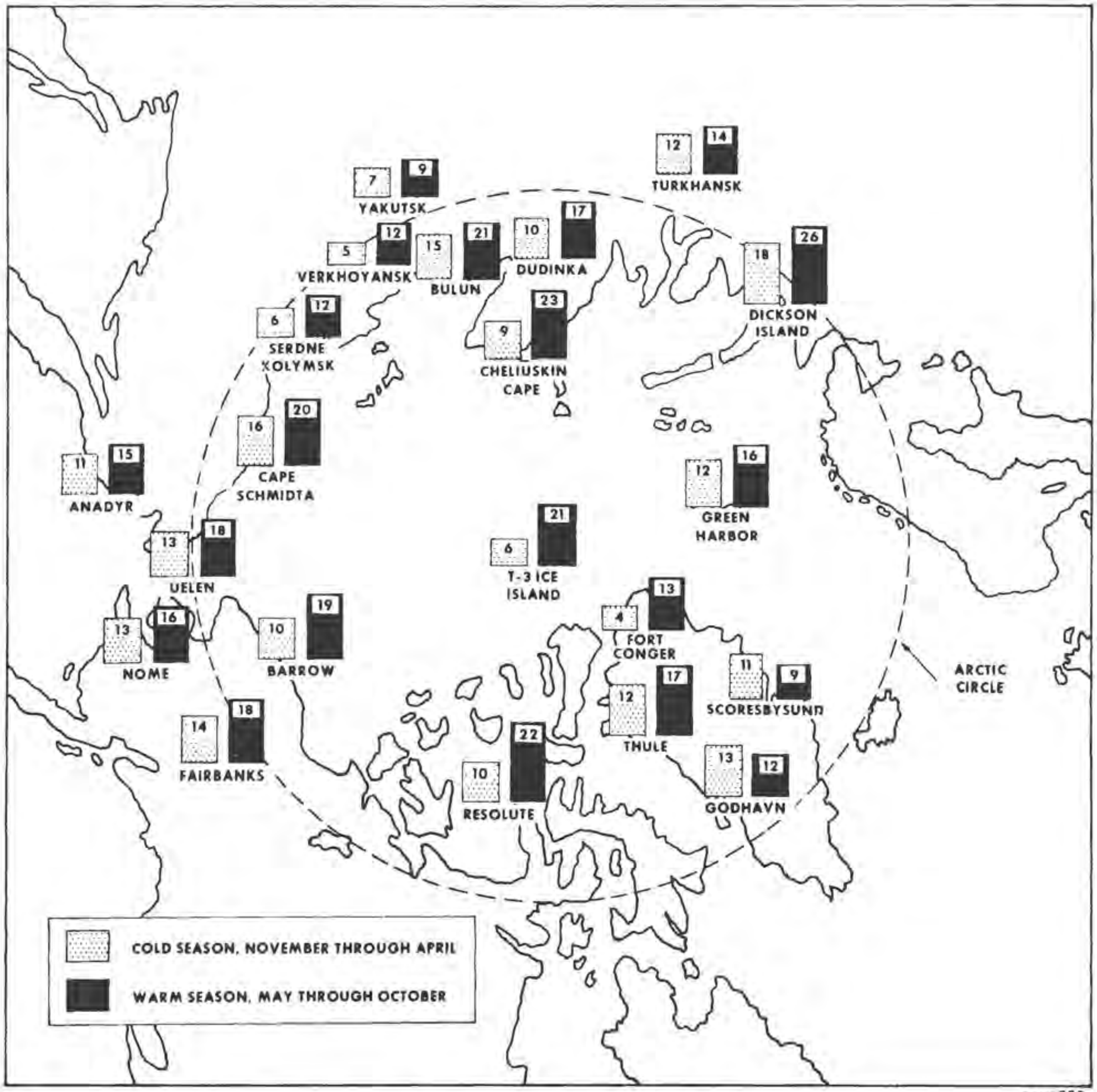


Figure III–1. Average number of overcast days per month.

4. Terminal Hazards

a. Depth Perception. The effect of polar sunlight and weather phenomena on depth perception is the worst flight hazard encountered. Over newly formed snow on a dull overcast day, shadows are not visible; the effect is similar to that of glassy water, so that depth perception is extremely difficult after takeoff. This atmospheric condition is called a *whiteout*.

b. Fog.

(1) Advection fog and low stratus clouds generally prevail in coastal polar regions (fig. III–2). They are caused by a combination of orographic lifting of moist air and contact of the relatively warm air from the sea with the

cold land surface. Usually they are found on the windward side of islands, since adiabatic heating or turbulence normally reduces the formation of fog on the lee sides of mountains and islands. The fog and stratus quickly diminish inland because of the extreme coldness of the snow-covered land mass.

(2) Steam fogs occur when the cold, dry air passes from the land areas over the relatively warm ocean. The rate of evaporation from the warm water surface is high, but the cold air cannot support moisture in the vapor state. Condensation takes place just above the water surface and is visible as "steam" rising from the ocean.

(3) Polar ice fog in the interior land regions occurs most frequently when the ground temperature is near or below —20° C. Ice fog results from sublimation of water vapor in the atmosphere during periods of relatively clear weather. The small crystals of ice fog remain suspended in the atmosphere

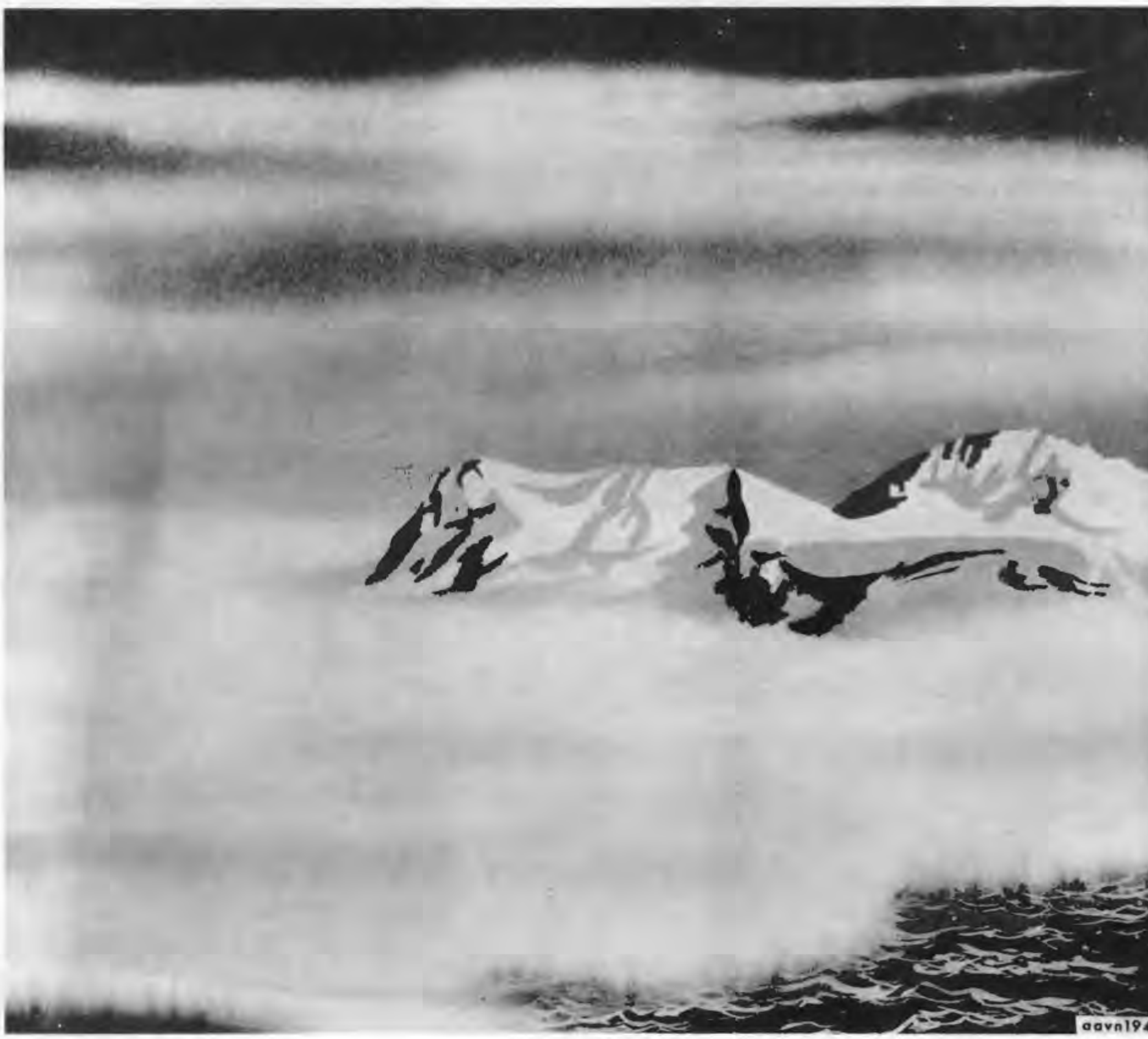


Figure III–2. Fog and stratus clouds over polar coastal areas.

for long periods of time. Ice fog produces neither rime nor glaze on exposed surfaces contacted; however, it may produce scintillating effects in sunlight or other light beams, halos, luminous vertical columns over lights, and light diffusion. Over snow-covered surfaces, ice fog is invisible from the air.

(4) Ice crystals, as a form of precipitation, produce the same effects on vision as ice fog, and have the same relation to ice fog that drizzle has to liquid fog. The rate of fall with ice crystal precipitation is very gradual and almost negligible. Ice crystals may fall from either cloudy or cloudless skies.

c. Drifting and Blowing Snow. Winds of 12 knots lift the surface snow a few feet off the ground, hiding objects such as rocks and runway markers. This *drifting* snow does not restrict surface visibility above 6 feet. Winds of 15 knots pick up dry, powdery snow and lift it high enough to obscure buildings when the surface is irregular (fig. III-3). The strong fall winds (par. 4-30) and the winds in arctic blizzards may lift this *blowing* snow to heights above 1,000 feet and produce surface drifts over 300 feet deep. Although surface drifting of snow may occur without restricting vertical visibility, the drifts can still obstruct horizontal visibility during takeoff and landing. All objects protruding into the wind stream during drifting or blowing snow create drifts to their lee.

5. Flight Problems in Polar Regions

a. Takeoff.

(1) *Windshield icing.* Even when precautions are taken prior to flight to prevent structural ice accumulation during takeoff, windshield ice or frost may still form if ground haze is present. Thus, when haze is present, the aviator should be prepared to go on instruments at any time during the takeoff run.

(2) *Carburetor icing.* Carburetor icing is

Figure III-3. Blowing snow.

likely along coastal regions and around islands when the moisture content of the air is high and the temperature is warm as the air moves onshore. If the air is cold and dry, there is no danger of carburetor icing; however, under extreme low-temperature conditions in interior polar areas, the application of carburetor heat will aid fuel vaporization and improve engine operation.

b. Inflight.

(1) *Structural ice.* After takeoff from a snow-covered field, the landing gear, flaps, and other movable structural parts of the aircraft should be cycled to loosen ice or packed snow and to prevent parts from freezing in an "up" position.

(2) *Moist air indicators.* The aviator should remain alert to the visible signs of high atmospheric moisture content. In cold air with low moisture content, snowflakes form as hard, dry, small grains. In moist, warmer air, the snow may appear as large flakes or pellets. In regions of supercooled water droplets, the greater the moisture content the more rapidly ice gathers on exterior parts of the aircraft (i.e., propeller hub, windshield, antenna, and wings). These parts should be observed frequently while flying in clouds and fog. A high water vapor content with proper air temperatures is conducive to the formation of carburetor ice. This icing condition is most frequently indicated by a drop in manifold pressure. (When the application of carburetor heat improves the operation of the engine and causes the manifold pressure to increase, it shows that ice was forming in the carburetor.)

(3) *Radio contact.* In areas of precipitation and ice crystal formation, static electricity may seriously interfere with radio transmission and reception. A change of altitude, airspeed, or propeller rpm may help to correct the problem of radio contact. The effects of mountainous terrain, snow-covered surfaces, and dense air layers also result in a bending of the radio waves, which further complicates radio communication and radio navigation under instrument conditions.

(4) *Altimeter error.* In polar regions, strong winds and colder than standard air cause serious altimeter errors. The aviator should allow for an ample safety margin in selecting flight altitudes over mountainous terrain.

c. Landing.

(1) *Engine temperatures.* The operator's manual for each aircraft specifies cold-weather flight procedures and explains the proper use of special cold-weather equipment. The engine may require preheating before starting. Because of strong surface inversions, the aviator may also have difficulty maintaining engine and carburetor temperature when landing. Surface temperatures in polar areas are frequently 15° F. to 30° F. colder than the temperatures at flight level.

(2) *Mechanical turbulence.* Katabatic (fall) winds are common in polar regions and may blow continuously for days. As these cold winds drain from high plateau or mountain areas down to lower elevations, their speed increases abruptly and may exceed 100 knots. Arctic fronts and blizzards also cause frequent, strong winds. As the wind moves near the surface over obstructions such as ridges, cliffs, bluffs, buildings, and jagged ice or stone peaks, strong gusts develop in eddies and may move with the wind across the airfield. For positive control of the aircraft, the aviator should land (with power on) as far from the lee sides of these obstructions as possible.

(3) *Runway icing.* Aircraft exhaust may freeze and settle onto the runway. When landing in trail formation, the last aircraft to land may thus encounter an iced-over runway. The frozen exhaust moisture also may remain suspended in the air as ice crystals or ice fog and limit visibility over the runway.

6. Arctic and Polar Air Masses

a. The classification of arctic and polar air masses is based on the geographical region in which they form. Arctic air masses originate over the Arctic ice cap or in the great polar high over the Greenland ice cap. These air masses generally form north of the Arctic Circle (66½° north latitude). The source regions of polar air masses are generally between 40° and 66½° north latitudes. As cold air accumulates in these source regions, the increasing density causes it to drain southward—to move out of its source region. Arctic and polar air masses may move as far south as Cuba and Mexico during the winter months. As these air masses move, they bring in clear skies, stable air, and low temperatures.

b. Frontal activity is common between the arctic and polar air masses. The cyclones and their associated fronts cause some strong wind conditions, but the clouds and precipitation forming in the cool, dry polar air are not extensive. Arctic cold fronts frequently increase the temperature at the surface for a short time after passage. The mechanical turbulence produced by the strong frontal winds may upset the surface inversion layer, with the warmer air from aloft descending to the surface. The invasion of arctic air masses into midwestern United States brings in the coldest weather of the winter over large areas of the country.

Section II. TROPICAL WEATHER

7. General

a. The Tropics include the vast region lying between the Tropic of Cancer and the Tropic of Capricorn (23½° north latitude and 23½° south latitude respectively). Tropical weather may also occur more than 45° from the Equator, especially on the east coast of continents.

b. The predominant pressure field in the Tropics is low and the pressure gradient is weak. The presence of low pressure throughout the year is a result of the following two pressure systems:

(1) *The equatorial trough*. This trough contains the intertropical convergence zone—a zone which migrates north and south of the Equator, and is present all year.

(2) *The thermal lows*. These lows are formed by the intense heating of the continents by perpendicular or near-perpendicular solar radiation during all seasons.

c. Most weather in the Tropics is *air mass* and can be classified as *oceanic tropical weather* and *continental tropical weather*. Along coastal regions and over islands, a transitional effect takes place between ocean and land.

8. Oceanic (Maritime) Tropical Weather

Weather over open seas in the Tropics is characterized by cumuliform clouds. About one-half of the sky is covered with cumulus clouds with bases averaging 2,000 feet and tops averaging 8,000 feet. Frequently these clouds produce scattered rain showers, but visibility is good outside of the shower areas. The surface air and upper air temperatures are quite uniform over the open ocean. The temperature variation of the air seldom exceeds 2° C. daily or annually. The freezing level is approximately 16,500 feet throughout the year. Surface pressure patterns change very little (except in tropical storms) and the pressure gradient is weak.

9. Island and Coastal Tropical Weather

a. Daily pressure and temperature variations are fairly constant along coastal areas and over islands. The daily land and sea breezes control the air movement. During the day, moist ocean air moves on-shore and is lifted and heated by the land surface. The lifting produces an increase in the number and intensity of cumuliform clouds and in the amount of precipitation. Towering cumulus clouds are often the aviator's first indication that he is approaching an island (under the blanket of small ocean cumulus) below the aircraft.

b. Where high mountains parallel the continental shorelines or where the continental area forms a high plateau, the moisture from the maritime air is condensed by orographic lifting and adiabatic cooling. The windward slopes may receive rainfall exceeding 400 inches a year at some stations where the prevailing surface airflow is from a semipermanent high pressure cell over the sea toward a thermal low over the continent (e.g., Cherripunji, India).

10. Continental Tropical Weather

The weather over interior continental areas within the Tropics is subject to extreme climatic variation. Factors which control the climate are the—pressure pattern and windflow; orientation, height, and extent of coastal mountain ranges; altitude of the continental area; and rate of evaporation from the surrounding ocean surface. Various combinations of these factors produce tropical weather ranging from the hot humid climate of the lower Congo River to the arid Libyan Desert and the snowcapped mountains of Kenya and South America. However, the two *major* climatic groups of the tropical continental areas are the arid (or semiarid) climates, and the humid (jungle or rain forest) climates.

a. Arid Tropical Weather. The climate for land areas to the lee of mountain ranges or on high plateaus is characterized by hot, dry, unstable continental air (e.g., the desert regions of South America and Africa). The afternoon temperature may be in excess of 100° F. in these areas, but the night temperature may drop below freezing. Strong convection is present during the day, but the relative humidity is so low at the surface that the cumuliform cloud bases are above 10,000 feet. Precipitation falling from high-based thunderstorm clouds often evaporates completely before reaching the surface. The "dry" thunderstorms, however, produce squall winds and may cause severe dust or sandstorms. These storms are a hazard to aircraft because of the severe turbulence aloft and the restricted ceiling and visibility, accompanied by gusts and squalls, at the surface. The blowing sand may cause extensive damage to inadequately protected aircraft on the ground.

b. Humid Tropical Weather. Where no mountains or high terrain are present to obstruct the flow of maritime air onshore, the warm moist oceanic air influences wide continental areas of the Tropics. Cloudiness and precipitation are at a maximum over these regions of jungle and tropical rain forests.

(1) In humid tropical climates, the daily variation of wind direction and speed determines the daily variation in cloudiness, temperature, and precipitation. Slight shifts in the wind direction may cause the air to lose its moisture over hills or to come from a different marine source region with less moisture. Slight increases in wind speed may reduce local contact heating and result in fewer convective currents and clouds.

(2) Clouds are predominantly cumuliform with afternoon cumulonimbus, but thick early-morning steam fog often forms in the jungles. The average daytime cloud coverage is approximately 60 percent of the sky throughout the year, with maximum cloud coverage during the day and minimum near sunset. The high moisture content and extensive cloud coverage reduce summer heating and winter cooling.

(3) The annual range in temperature for jungle stations may be less than 2° F., but the daily range is often 30° F. or more. When afternoon showers occur, the descending cold air currents may produce nights with temperatures in the 60° F. range. These rain showers are very heavy and produce low clouds that may reduce ceiling and visibility to near zero.

11. Other Tropical Phenomena

The principal types of special weather phenomena observed in the Tropics are tropical cyclones (pars. 4–11 through 4–24), monsoons (par. 4–27), easterly waves, the trade inversion, and the intertropical convergence zone.

a. Trade Inversion. Water surfaces cover most of the area in the Tropics. Convective mixing in the lower levels carries the moisture from the warm ocean surface up to approximately 8,000 feet. The actual height of the moist layer varies considerably, depending on the particular local synoptic weather situation. Above the moist layer is a very dry air layer caused by subsidence in the subtropical oceanic anticyclones. The two layers are separated by a well-defined temperature inversion known as a *trade inversion* (fig. III–4). The actual height of the trade inversion is a qualitative indication of whether convergence or divergence is occurring in the lower levels (moist air layers). The moist layer will be considerably higher than average if the air is converging at or near the surface. The inversion will be lower than average if the air is diverging (has sinking air currents) at the surface. Flight above the trade inversion avoids the roughness and cloudiness of the moist air layer.

b. Intertropical Convergence Zone. The subtropical high pressure areas of both hemispheres are separated in the region of the heat equator by a trough of low pressure in which hot tropical air is converging and rising. This is called the *intertropical convergence zone (ITC)*. The ITC is not a true front because the discontinuity of the air density is not significant. The convergence zone has the appearance of a front, however, because the rising warm, moist air produces a line of towering cumulus clouds and thunderstorm activity, with tops of the clouds above 60,000 feet. The ITC moves considerably northward in the summer and somewhat southward in the winter as a result of the migration of the direct rays of solar radiation with the seasons (fig. III-5).

c. Easterly Waves. Easterly waves are lines of definite wind shift and barometer depression (fig. III-6) originating near the southeastern perimeter of the subtropical high pressure cells in the Northern Hemisphere. The top of the moist layer of air (trade inversion) is low (5,000 to 8,000 feet) and the sky condition is either clear or scattered, with cumulus clouds west of the wave. The moist air layer frequently extends to 15,000 feet, or more, eastward of the surface position of the wave. In this area, thunderstorms, low ceilings, rain, and bad weather predominate. The bad weather forms a line, normally oriented north-south, and

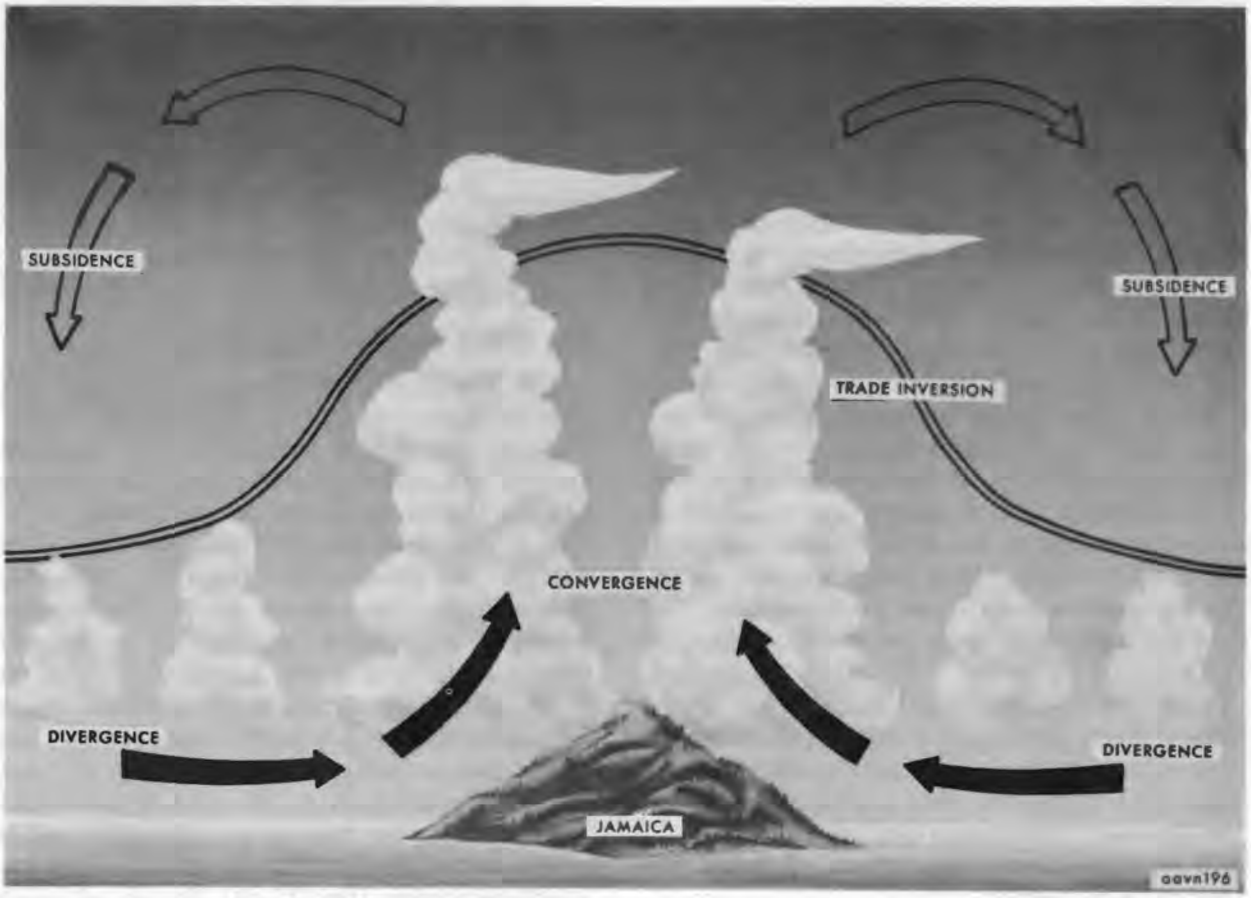


Figure III-4. Variation in height of trade inversion.

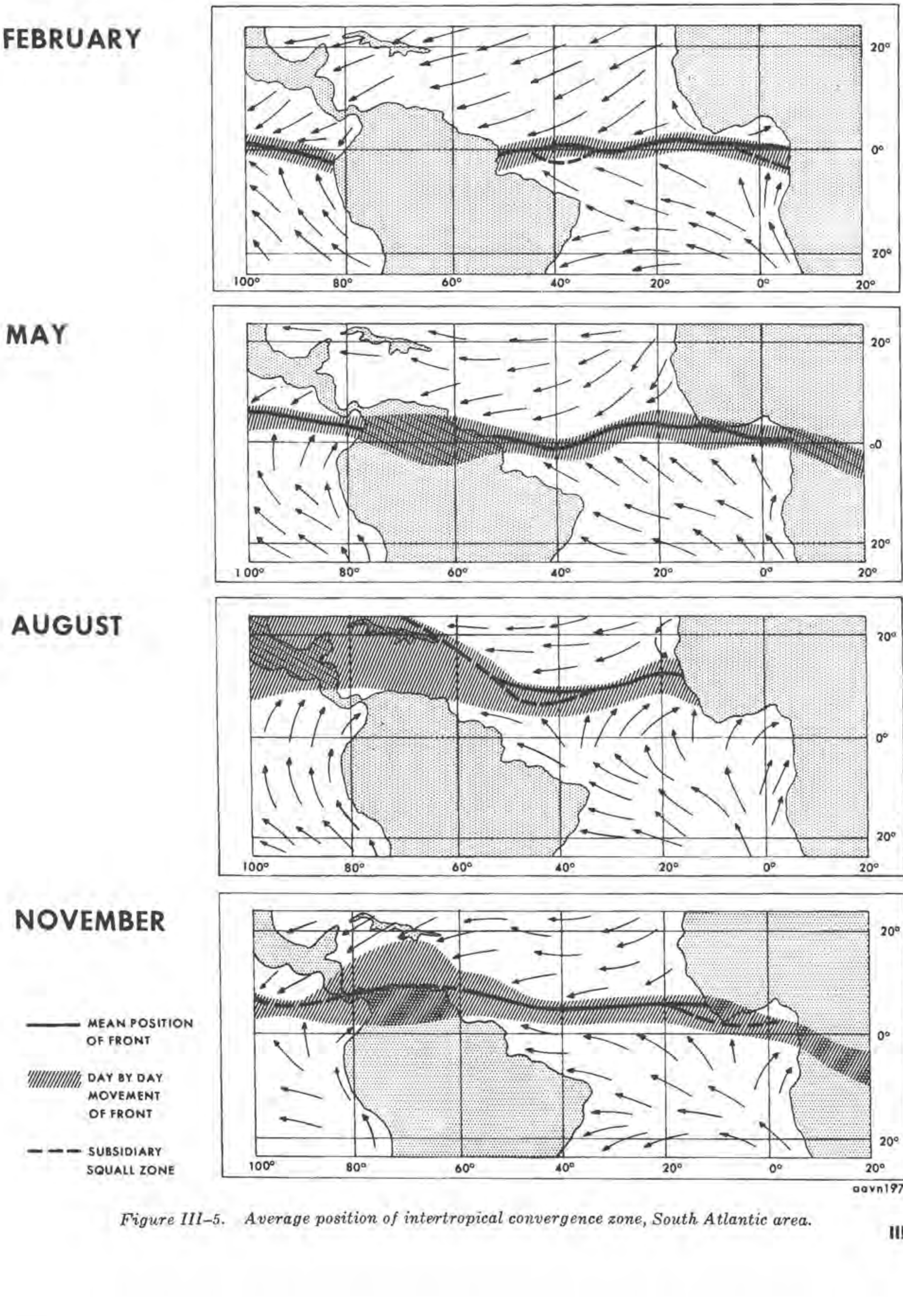


Figure III–5. Average position of intertropical convergence zone, South Atlantic area.

resembles the cold frontal weather of the middle latitudes. Easterly waves travel around the southern periphery of the subtropical highs from east to west, with the prevailing easterly circulation typical of the Tropics in the Northern Hemisphere. These atmospheric waves are common in all seasons of the year but are strongest in the summer and early fall. Occasionally the effects of easterly waves are felt along the Gulf coast section of the United States. Waves which are originally weak and hardly discernible on the weather map may deepen rapidly in 24 hours and become the spawning ground of tropical cyclones and hurricanes.

d. Other Bad Weather Zones. There are several less frequent atmospheric discontinuities

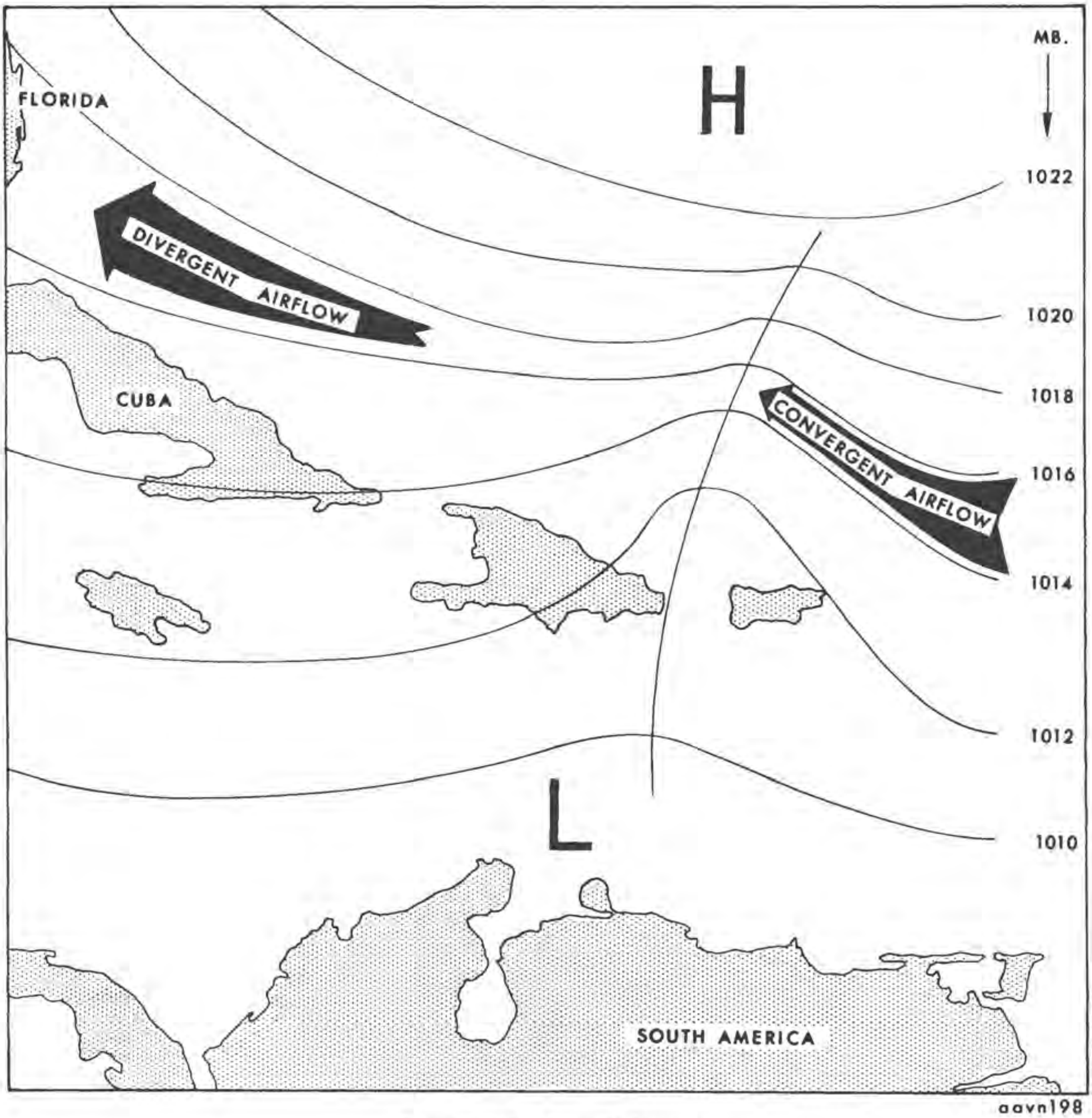


Figure III-6. An easterly wave.

which develop in the tropical airstreams. These often appear in synoptic charts as weak *polar troughs* extending from middle latitude frontal systems. The weather along a polar trough (fig. III–7) is similar to that found along an easterly wave, but its movement is from west to east and it is accompanied by a considerable temperature reduction. The cloud system tends to weaken as the trough moves eastward, whereas the easterly wave is very likely to intensify as it moves westward. *Shear lines* (fig. III–8) also form in the Tropics when the leading edge of a continental polar air mass advances southward and displaces the semipermanent oceanic high. Mixing in the southern latitudes causes the density discontinuities across the front to disappear, leaving only a wind shift across the diffuse front. Convergence and cumuliform activity may still be found along this wind shift line. As the anticyclone behind the shear line advances, the high pressure area ahead of the shear line tends to weaken and the two highs gradually merge. The narrow band of bad weather is then replaced by a freshening of the trade winds.

12. Flight Problems Within the Tropics

In tropical regions over the ocean, weather observation and reporting stations are few and far between. The aviator must often use his knowledge of the normal height of the moist layer and cloud tops to detect his approach to a zone of bad weather.

a. Flight in the **ITCZ**. The density and vertical extent of the cumulus clouds in the **ITCZ** vary considerably. Most of the time a scattered row of cumulonimbus, accompanied by considerable middle and high clouds, typifies the **ITCZ**. These clouds occasionally become so congested it is impossible to circumnavigate them. The technique for crossing the **ITCZ** is determined from the performance capabilities of the aircraft. With aircraft service ceilings of 16,000 feet or more, the aviator rarely has difficulty in climbing over saddlebacks between cloud tops. Clouds whose tops are less than 14,000 feet normally do not contain serious hazards because the tops are still below the freezing level. The principal danger during low-level flight under the clouds (where the precipitation is light), or during actual cloud penetration, lies in entering the cumulonimbus clouds whose tops extend well above the freezing level. In these thunderstorms strong turbulence, gusts, hail, lightning, and heavy precipitation are present. When approaching the **ITCZ**, it is dangerous to fly into clouds when the actual heights of the tops are unknown. The aviator should not attempt a low-level flight under thunderstorms and large buildups unless good ceilings and visibilities exist.

b. Flight in Other Bad Weather Areas. Flight through any of the special tropical weather phenomena presents problems of turbulence and moisture similar to the **ITCZ**. Most of these zones offer a favorable spawning area for tropical cyclones, with the storm intensities varying greatly in short periods of time. Where these storm areas are located over warm tropical oceans, the turbulence is stronger during the evening hours.

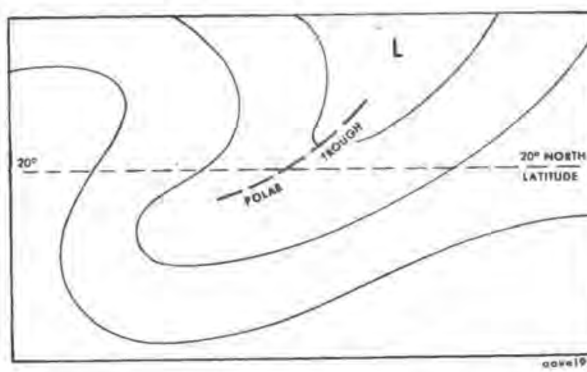


Figure III–7. The polar trough in the Tropics.

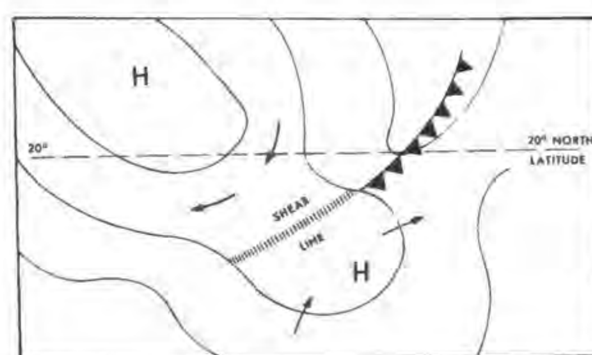


Figure III–8. Shear line in the Tropics.

APPENDIX IV

CLIMATOLOGY

Section I. INTRODUCTION

1. Terminology

Both meteorology and climatology deal with the atmosphere and the processes that take place within the atmosphere. *Meteorology* is the study of current conditions of the atmosphere, whereas *climatology* is the study of all of the meteorological elements that characterize the average and extreme conditions of the atmosphere over a specified period of time at any one place or region of the earth's surface. Special meanings for several terms of climatology must be understood for the subject to be of significant value.

a. Mean. The term "mean" normally refers to the arithmetic mean, which is obtained in the same manner as the arithmetic average. However, meteorologists have found that a modified method of computing the mean is satisfactory for climatological data. The mean is obtained by averaging the maximum and minimum values for the pertinent meteorological element. For example, if the maximum temperature for the day is 75° F. and the minimum is 57° F., the mean temperature for the day is 66° F. In most cases, the difference in the mean obtained by averaging extremes and by averaging the temperature for each hour during the day is slight. In analyzing weather data, the terms "average" and "mean" are often used interchangeably.

b. Absolute. The term "absolute" usually is applied in climatology to the extreme value for any given meteorological element recorded at the place of observation. If the highest temperature ever recorded at a particular station has been 106° F. and the lowest recorded temperature has been —15° F., these values are the *absolute maximum and absolute minimum* for that station. The *absolute recorded* range of temperature at the station has been 121° F.

c. Extreme. The term "extreme" is applied to the highest or lowest values for a particular meteorological element which have occurred over a period of time (usually months, seasons, years, or a number of years). At times it is also applied to the average of the highest and lowest values over a month or year, such as mean monthly extremes or mean annual extremes.

d. Normal. The term "normal" is applied to the average value which any meteorological element has during a specific period of time (i.e., a day, a year, or a period of years). The normal serves as a standard for comparison with values occurring over a subsequent or specified period of time.

2. Classification of Climate

a. The climate of a given region or locality is determined by a combination of several meteorological elements such as cloudiness, dew, humidity, ice, rain, pressure, temperature, wind force, and wind direction—not by any one element alone. No two locations have exactly the same climate. They may have similar temperature climates but very different precipitation climates. Their climatic difference becomes apparent only if more than one climatic factor is considered. However, it is possible to place similar areas into a grouping known as a *climatic zone.*

b. Climatic zones are often classified into five broad belts based on astronomical and mathematical considerations. The five basic regions are the Torrid or Tropical Zone, the two Temperate Zones, and the two Polar Zones:

(1) The Tropical Zone is limited on the north by the Tropic of Cancer and on

the south by the Tropic of Capricorn, located at latitudes 23½° north and south respectively.

(2) 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 latitude 66½° north.

(3) 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 latitude 66½° south.

(4) The Polar Zones are bounded by the Arctic and Antarctic Circles. (For a map of the world showing meridians and parallels, see fig. IV-2).

c. Climatic zones may also be arbitrarily designated in terms of isotherms. Isotherms normally do not coincide with latitude lines (fig. IV-1). The astronomical (light) zones differ from the zones of heat (isotherms) because of the differential in heating between oceans and continents, the circulation of ocean currents, and the polar outbreaks in the secondary circulation. One method of classifying climatic zones by isotherms is by limiting the Hot Belt by the two mean annual isotherms of 68° F. The asymmetrical distribution of land in the lower latitudes of both hemispheres results in an asymmetrical position of the Hot Belt with reference to the Equator. The belt extends farther north than south and increases in width over the continents (fig. IV-1). The boundary between the Temperate and Polar Zones is the isotherm of 50° F. for the warmest month of the year.

d. Any classification of climate depends on the purpose of the classification. A classification for the purpose of establishing airfields would differ considerably from one for establishing the limits of areas that are favorable for the growing of crops. The classifications established by Koeppen and Thornthwaite are based on growth of vegetation. Koeppen used values of temperature, precipitation amount, and season of maximum precipitation; Thornthwaite placed emphasis on the effectiveness of precipitation (i.e., the relationship between precipitation and evaporation in a certain locality).

3. Climatic Controls

The variation of climatic elements from place to place and season to season is caused by several factors called *climatic controls*. These controls acting in different combinations and with varying intensities, affect temperature, precipitation, humidity, air pressure, and winds to produce the many types of weather and climate.

a. Latitude. The position of the earth relative to the sun is the most important climatic control. The more directly the sun shines overhead, the more heating occurs on the surface. Cloudiness and surface composition vary the daily heat distribution to a slight extent, but during any significant period of time the low latitudes receive much more heating from the sun than the high latitudes. This uneven heating on the earth's surface is responsible for the formation of pressure and wind systems throughout the world (fig. IV-2).

(1) In the hot humid climates of equatorial Africa and South America, there is no time throughout the year when the sun is low in the heavens at noon. Very little difference exists between the mean temperature for the coldest month and the warmest month. Except near the outer limits and at high elevations, this belt is free of frost.

(2) In the polar regions, the sun is either below the horizon or slightly above the horizon throughout the year. The sun's rays intersect the earth's surface at such a small angle that the energy received per unit area is extremely small. The effectiveness of the sun is lost, even though it may shine continuously for months. Most surfaces in polar regions are covered with perpetual snow and ice.

(3) Between the equatorial belt and the two polar regions are the great temperate belts. These areas have a wide climatic variation because of the following: Frontal activity between the polar and tropical air masses, the uneven distribution of large continental and maritime surfaces, and the migratory nature of the cyclones and anticyclones of the secondary circulation.

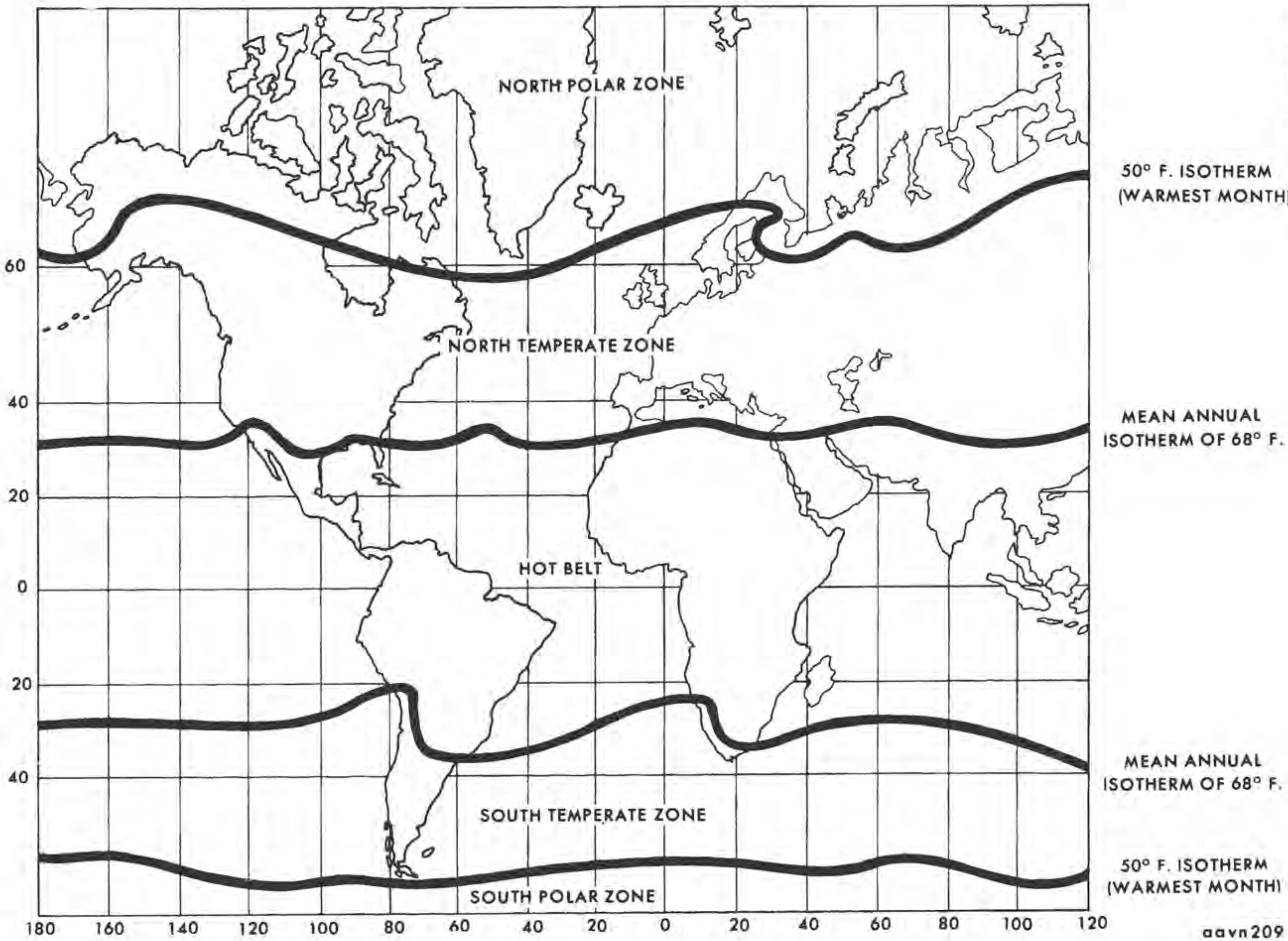


Figure IV–1. Temperature zones.

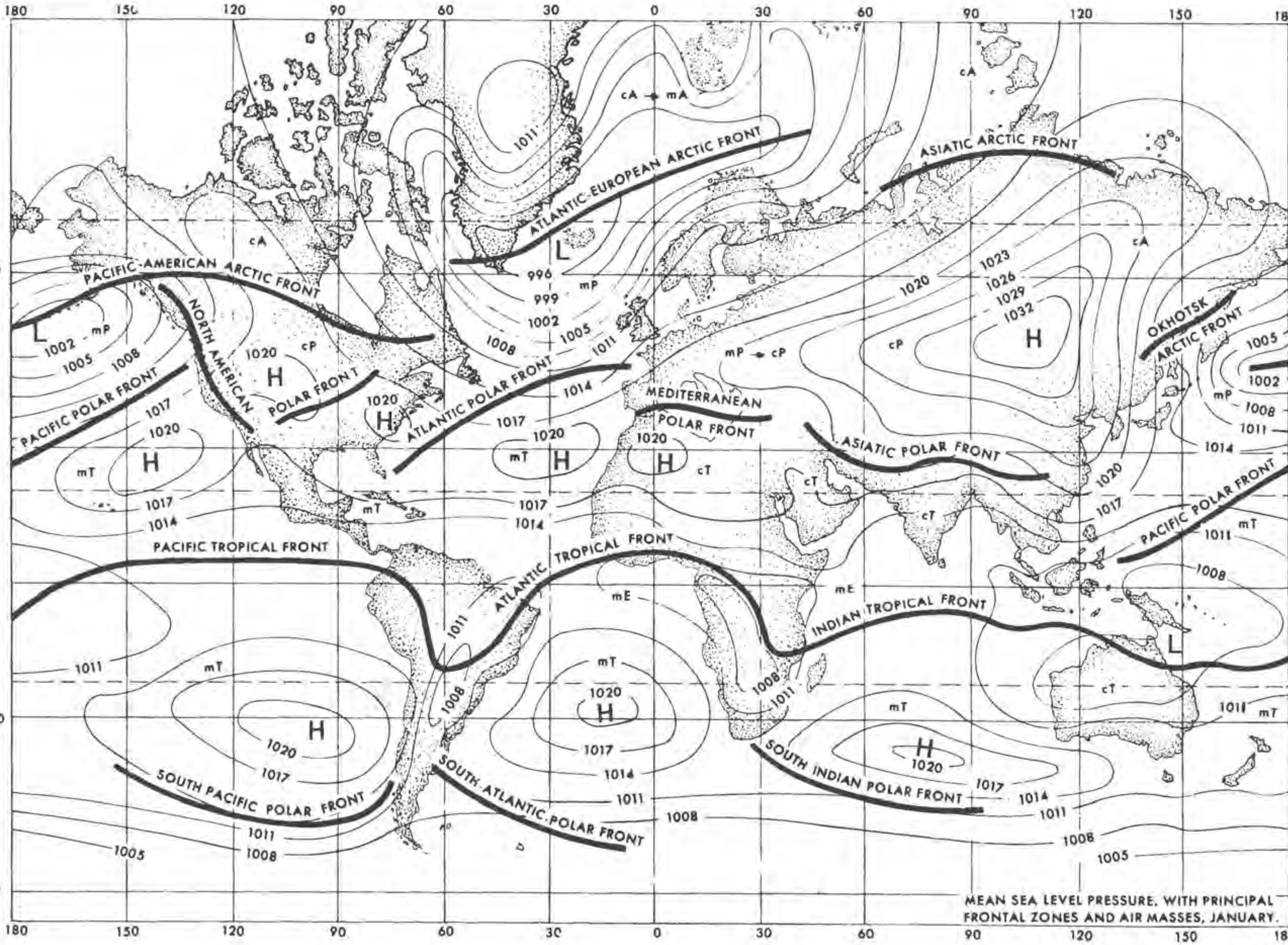


Figure IV-2. Generalized pattern of primary air masses and fronts, January and February.

Still, the climatic variation of the Temperate Zone is an end-product of latitudinal heat variation (par. 4–2).

b. Continental and Marine Influences. Many stations located at the same latitude vary greatly in climate because of maritime and continental influences. Stations located far inland will normally have colder winters and warmer summers than those located near the ocean. Stations affected by marine influences tend to have cool breezes during the summer and warm air advection during the winter, a large percentage of sky coverage throughout the year to reduce daytime heating and nightime cooling, and large amounts of precipitation throughout the year.

c. Winds. Prevailing wind belts of the Primary Circulation have a strong influence on climate.

(1) The prevailing westerly winds which blow over the United States carry with them the cyclonic and anticyclonic systems that provide a variety of weather conditions in the Temperate Zones. The northwestern coastal region of the United States is under the influence of the air masses that move inland from the Pacific, and therefore has a marine climate. The east coast of the United States is affected climatically by the modifications that the air masses undergo as they cross the great expanse of land to the west. The climate is predominantly continental, with occasional invasions by air masses from the Atlantic Ocean. The temperatures are generally milder on the west coast than on the east coast.

(2) Normally, the climate on the windward sides of the mountains is much wetter than that on the leeward sides. The heaviest rainfall of the United States is on the western slopes of the coastal mountains in the State of Washington. The eastern slopes are considerably drier where the prevailing westerlies cause the air to descend and warm adiabatically.

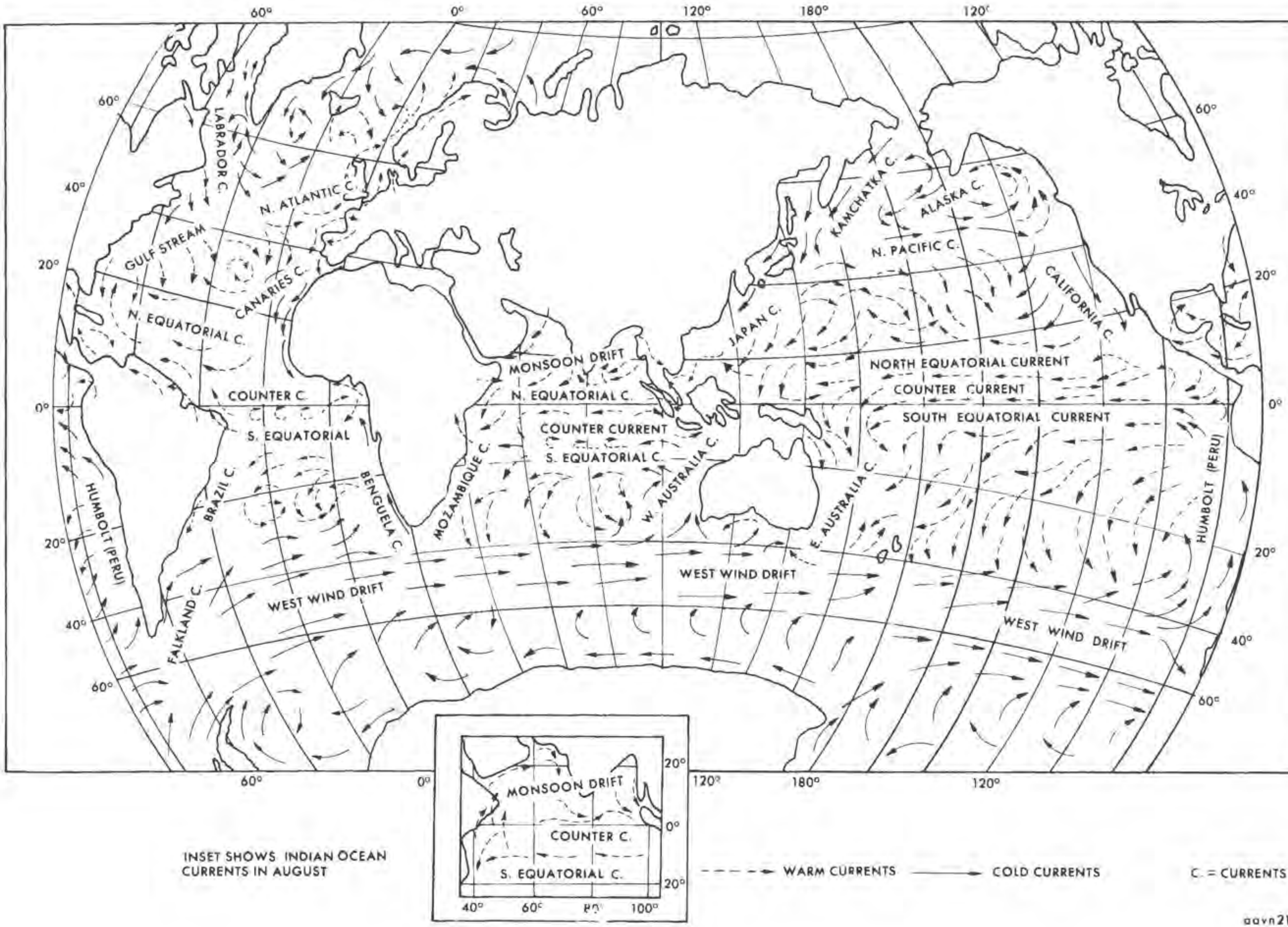
(3) In the Northern Hemisphere, where the land areas are extremely large, the annual heating and cooling cause a seasonal monsoon effect. The winds blow from sea to land in the summer and from land to sea in winter. In India, the rainy season from June to September is directly attributable to the humid air being brought from the ocean over the mountainous land area by the prevailing surface wind.

d. Pressure. Although pressure itself is not a climatological element, the pressure gradient, which is a result of the temperature differences between various parts of the earth, produces the wind. The movement of the air brings about the temperature, humidity, and precipitation which make up climate.

e. Ocean Currents. Although the coast of Norway is north of 60° latitude, the climate is mild enough to permit ocean transportation into ports on the Atlantic throughout most of the long winter. The moderation of the Norwegian climate is the effect of the warm ocean current which sweeps across the Atlantic Ocean from the equatorial region. The cold ocean current off the coast of California is a decisive factor in producing cool temperatures in cities such as San Francisco in the summer. Ocean currents (fig. IV–3) and wind systems work together as climatic controls.

f. Cyclonic Activity. Frontal systems, accompanied by stormy weather and low pressure, are associated with the cyclonic systems of the Temperate Zones. The anticyclonic systems usually bring better weather conditions for a time. These systems move across the country from west to east, and give a great deal of variety to the weather of the Temperate Zones.

g. Altitude. The height of an area above sea level exerts a considerable influence on the air temperature and the amount of precipitation. Air which is lifted to a higher altitude expands and cools adiabatically, tending to produce cooler temperatures at stations of high elevation. Air at high altitudes is low in density and frequently free of impurities or moisture. As a result of the clear pure air, the terrestrial radiation from the surface is not absorbed in large quantities: the clear air remains relatively cooler than the impure air at lower elevations. Moisture moving with the wind from maritime areas onto continents is usually condensed from the air on the windward slopes so that the air



aavn212

Figure IV–3. Ocean currents, February.

reaching the higher altitudes is quite dry and free of precipitation.

h. Mountain Barriers. Long chains of mountains deflect the tracks of cyclones and block the passage of air masses in the lower levels. If the pressure gradients are strong enough to force the air masses over the mountains, the forced ascent and descent will modify the air masses to a great extent, thus changing the weather conditions between the windward and leeward sides.

(1) The Himalayas and Alps, with an east-west orientation, prevent fresh polar air masses from advancing southward. Therefore, the climates of India and Italy are warmer in winter than other locations of the same latitude that do not have a mountain barrier on their northern borders. The coastal mountain ranges in western North America run in a north-south line and prevent the passage of unmodified maritime air masses to the lee side. Precipitation amounts are much higher on the windward side than on the lee side where desert areas predominate.

(2) In regions where a westerly circulation prevails, precipitation increases uniformly up to the tops of the mountains (to elevations of about 10,000 feet). In the Trade Wind zone, such as the Hawaiian Islands, precipitation increases to a maximum at about 3,000 feet and then decreases gradually, but more rain occurs at 6,000 feet than at sea level.

4. Climatological Characteristics of Air Masses

The climatological characteristics of air masses depend upon the surface properties of air mass source regions and the areas over which the air masses travel. The classification of world air masses (fig. IV-2) is based on the geographical location of the source regions, which is an indication of the temperature of the surface over which they form. The designation of air masses as *Equatorial, Tropical, Polar,* or *Arctic* indicates the location of the source region in a particular latitude belt. Equatorial air is warm and humid. Tropical air masses may originate over either ocean or land areas. Those originating over land areas are hot and dry; those originating over ocean areas are hot and humid, the humidity being especially high in the lower layers. Polar air masses originate in high latitudes over either ocean or land areas. These air masses may be cold and dry or cold and humid, depending upon the place of origin. Arctic air masses are extremely cold and dry because of the snow and ice surfaces over which they stagnate. For a complete discussion of the modifications in air masses as they move from their source region, see paragraphs 6-1 through 6-6.

Section II. CLIMATOLOGICAL RECORDS

5. Climatological Data

Climatological records are based on meteorological observations taken at a particular locality. This data may be presented as follows:

a. Temperature. Temperature records include the following values: daily maximums and minimums by month, the extremes, the average by year and month, the mean monthly and annual readings, and the mean monthly maximum and minimum. The number of *degree-days* by month and year may also be included. A degree-day is the departure of the mean temperature from a daily average temperature of 65° F. If the mean temperature for a particular date was 50° F., the number of degree-days for that date would be 15. The range between the mean temperature of the warmest month and the coldest month also has climatic significance.

b. Precipitation. In addition to hourly and daily precipitation amounts, precipitation records also include the mean annual and monthly totals. The range between the highest and the lowest annual rainfall for a locality may be important as an indication of the dependability of the precipitation. The records often include the absolute maximum rainfall and snowfall for a 24-hour period by month, as well as the maximum and minimum precipitation for each month.

c. Wind. Wind data includes the mean hourly speed and prevailing wind direction by month, as well as the speed and direction of the strongest wind for each of the 12 months and for the year.

d. Other Data. Data on cloudiness, humidity, thunderstorms, and fog are often recorded. Other helpful data includes the frequency and distribution of cyclones and anticyclones, passage of fronts, the proportion of rainfall and snowfall received from cyclonic and air mass storms, and climatological data on upper air conditions.

6. Methods of Presentation

Climatological information is presented in many different ways. Tables provide a means for summarizing statistical data in a small space. Graphs are especially helpful in presenting comparative data for two or more areas. Maps present climatic information in which geography is an important factor. Wind data is often shown by a *wind rose,* which indicates prevailing wind directions (fig. IV-4). Although each of these devices has a specific and useful purpose, most climatological data must be described in narrative form.

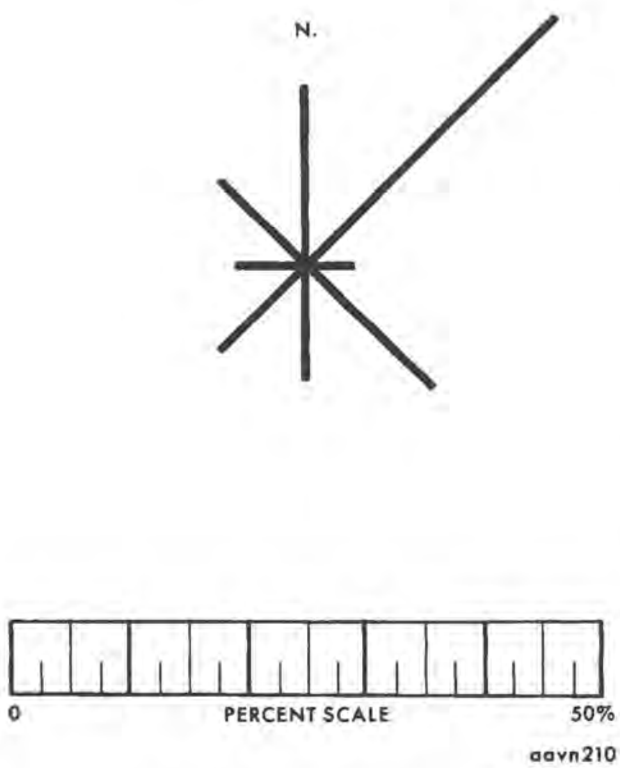


Figure IV-4. A wind rose.

7. Interpretation

a. Climatological records are almost worthless unless interpreted correctly. To properly interpret just one meteorological element requires the study of all the available data. From an isolated study of temperature alone, for example, it is possible to arrive at the false conclusion that Cairo, Egypt, and Galveston, Texas, have the same type of climate. Their yearly and monthly means and their annual temperature ranges are much the same. However, Galveston has about 40 times as much precipitation as Cairo, so weather conditions during the year are quite different.

b. The temperature of a particular locality must be studied from the standpoint of mean, extremes, and diurnal and annual ranges. The effectiveness of precipitation depends on the amount and distribution of the precipitation and the rate of evaporation from the surface. The mean precipitation for a particular month for a locality may be several inches, but in some years the precipitation for a particular month is less than 1 inch.

8. Availability and Uses of Climatological Data

Most weather stations have climatological records available for the local area and for such other areas as may be necessary to carry out their mission. Climatology is an essential supplement to meteorology, but it is not a substitute for the meteorological data which constitutes a current weather condition. Use of climatological data includes the following aviation applications and considerations:

a. In locating an airfield, fog probability is an important consideration. Ground fog tends to drain into an area that is located in a topographical depression. When ground fog occurs, a station located in this area would be the first to be fogged in, and the last to have the fog dissipate. Effects of advection fog in an area can be minimized by selecting an airfield site where the prevailing wind during such fogs has a downslope component, so that adiabatic heating will dissipate the fog.

b. The site of an airfield to be located in an industrial area should be to the windward side of the industrial area to minimize reduced visibility due to smoke and haze. Airfields should not be located near the lee side of high obstructions which could produce dangerous eddy currents.

c. A study of available climatological data at a location will reveal the frequency of low ceilings which would adversely affect flight operations.

d. Frontal passages bring about significant changes in flying conditions. The annual and monthly passage of frontal systems, the normal speed of the frontal movement, the seasonal variation in frequency and intensity of fronts, and the usual weather conditions that accompany the different types of frontal activity in the area are all-important climatic considerations at an airfield.

e. The distribution and frequency of thunderstorms are important to the location of an airfield because of the dangers of gusty winds, hail, lightning, and possible tornadoes that accompany many thunderstorms.

f. The prevailing winds of an area should be considered in airfield runway orientation. Data should be obtained as to the several wind directions that occur with greatest frequency, and the speed of the winds from these directions (fig. IV-4).

g. When studying climatological records, all the available elements and values should be considered. Heavy reliance on the normal values that are attached to certain weather elements is inadequate because one year or month may vary a great deal from the average, with a serious effect on the aviation mission.

h. Detailed studies of climate (including flight conditions) in all areas of the world are found in section 23 of the "National Intelligence Summaries." The content of these summaries is classified, but the data can be obtained by the Air Weather Service unit or the staff weather officer attached to each Army headquarters.

Section III. REGIONAL CLIMATOLOGY

9. North America

North America has many types of climates because of the latitudinal extent of the continent, its topography, and the atmospheric circulation patterns. However, the continent can be divided into regions which have some general characteristics in common.

a. Alaska. Alaska is a land of contrast. Its southern coast, including the Aleutians, is moderated by the relatively warm waters of the Aleutian Current and has a mild and humid climate. This portion of Alaska experiences a high frequency of cloudiness and fog, with the maximum amount of precipitation in the autumn and winter. The western and northern coasts of Alaska show a rapid transition in both temperature and precipitation from south to north; both decrease rapidly and the precipitation maximum in the north is during the summer. The interior of Alaska has a continental type of climate. The winters are extremely cold, but the summers are warm—the mean temperature for January at Fairbanks is −13° F., and the mean for July is 60° F.

b. Pacific Coast. Considerable seasonal variation in precipitation occurs along the northern and central Pacific coast because of seasonal changes in the atmospheric circulation (par. 4-6). Heavy precipitation occurs along the Canadian coast all year, with a maximum in autumn and winter, but the amount decreases sharply southward into California. Southern California receives only a trace of rain during June, July, and August, and receives 93 percent less rainfall annually than the Canadian Pacific coast. Fog is common along the Pacific coast in the summer and over the inland valleys during the winter. The fog in the valleys is a radiation fog caused by the stagnation of moist polar air in the valley and the radiational cooling of the ground. The coastal fog is an advection fog formed by the movement of maritime air over the cold coastal water. Low stratus clouds are common over the southern California coast throughout the year. The air temperature along the coast increases gradually from north to south, but is relatively uniform during all seasons at individual stations. Compared to inland temperatures at the same latitude, the coastal areas are warmer in the winter and cooler in the summer.

c. Plateau Region. The Plateau region includes the mountainous area from Alaska to Mexico. Precipitation is light, with a winter maximum. The amount of precipitation decreases from north to south to such an extent that desert regions exist in the southern part of the region. The temperature regime is characterized by cool summers, except in the south, and cold winters.

d. Great Plains. The Great Plains region is continental in its characteristics. The temperature varies latitudinally and has a large seasonal and diurnal range. Precipitation reaches a maximum in the summer. The amount increases slightly from north to south, but increases greatly from west to east.

e. Gulf States. Throughout the Gulf States the temperature is seasonably high all year. Moderate to heavy precipitation occurs all year; a maximum occurs in the summer, with regular afternoon thundershowers. Advection fog and low stratus are common during the winter.

f. Eastern North America. There is no pronounced season of maximum or minimum precipitation in eastern North America. Over the southeast, the precipitation is heavy, but it decreases northward. The temperature varies from cold during all seasons in part of Canada to warm during all seasons in southern Florida. Eastern United States north of 40° latitude is subject to periodic change from warm to cold and vice versa, caused by frontal passages in all seasons. Latitude for latitude, stations along the east coast show temperatures colder in winter than west coast stations at the same latitude, due to the prevailing westerly winds. The climate of the east coast has a much stronger continental influence than the west coast. For example, the mean temperature for January in Norfolk (latitude 37° N.) is 40° F. while the mean for January in San Francisco (latitude 38° N.) is 49° F. The temperature is cooler in summer at west coast stations than at east coast stations; the July mean for Norfolk is 78° F. and for San Francisco is 57° F.

10. Central America

a. Mexico.

(1) The east coast of Mexico has high temperatures in summer and fall. In winter, the temperatures range from cool in the north to warm in the south. Precipitation is heavy all year in the south, but decreases toward the north with a maximum in summer and fall.

(2) The plateau region of Mexico has cool temperatures for the latitude because of the high elevation; however, stations show extreme ranges in temperature from summer to winter, especially in the north. In general, the precipitation maximum occurs during the summer, but is light all year, decreasing from south to north.

(3) The west coast of Mexico south of 25° latitude experiences heavy summer precipitation and very dry winters. The temperature is high during all seasons.

(4) Northwestern Mexico has a desert climate with very slight precipitation in late summer. Summer temperatures are very warm, but low temperatures may occur during the winter.

(5) The northern part of Lower California has a winter precipitation maximum and dry summers. Temperatures are moderate in both seasons due to a marine influence.

b. Remainder of Central America. Temperatures are generally high over the remainder of Central America, but they decrease somewhat on the mountains. Precipitation is heavy, with the rainy season in summer and early fall. In winter and spring, precipitation is very light on the west coast and light to moderate on the east coast.

11. South America

The climate of South America is not subject to the temperature extremes that are prevalent in North America because most of the continent is located near the Equator. Also, the smaller part of the continent tapers very sharply toward the pole. Even the extremely cold temperatures of much of the Andes Mountains are somewhat higher than would be expected of such high elevations. Some desert areas exist, but they are not as extensive as in the Northern Hemisphere.

a. Andes Region. Due to its great height the Andes Mountain chain is an area of perpetual snow, even in the equatorial portions. The higher levels of the Andes receive precipitation during all seasons and at all latitudes because of the orographic lifting. The least precipitation in South America occurs on the western slopes of the Andes from about 30° south latitude to about 5° south latitude. Precipitation is slight because the wind at the lower levels is parallel to the coast without significant orographic lifting, and the air is stabilized by the cold water of the Peru Current. In the middle latitudes, on the eastern slope of the Andes, rainfall gradually increases toward the south where the mountain chain is lower, and permits some humid air to cross the mountains from the west to the east.

b. Central and Eastern Regions.

(1) The precipitation is slight between 40° south latitude and 50° south latitude, but the southern area receives slightly more than the northern area. Temperatures on the east coast are higher than on the west coast, but some winter invasions of cold air occur. North of 40° latitude the plains area has occasional summer and winter rain. Temperatures are very high in summer and usually low in winter. The coastal region in these altitudes has scattered precipitation in all seasons with moderate to high temperatures.

(2) From the Andes to the Brazilian highlands, precipitation is light with a summer maximum and a winter minimum. Temperatures are high with a small annual range. A desert region is located at approximately 20° south latitude and just to the east of the widest section of the Andes Mountains.

(3) The coastal region from the Tropic of Capricorn to 15° south latitude has rain in summer and fall, and is dry in winter and spring. Temperatures are moderate to high during all seasons.

(4) The east coast of Brazil north to 15° south latitude has rain in all seasons, with a winter maximum. The rainy season actually varies from south to north, with the southern region getting more summer rain and the northern region getting more fall rain. Temperatures are high throughout the year.

(5) The interior of northeast Brazil is comparatively dry. It receives occasional rain in the fall. Temperatures are high during all seasons, but the annual range is large for this tropical latitude.

c. Guianas and Lower Amazon. Near the mouth of the Amazon River, the maximum rainfall occurs in the fall. As spring approaches, the amount of precipitation diminishes and the dry season begins. Temperatures are high in all seasons. The Guiana region has two precipitation maximums and two precipitation minimums. The wet seasons are May and June, and December and January; the dry seasons are March and April, and September and October. Temperatures are always high, with the warmest periods during the dry seasons.

d. Upper Amazon. Rainfall in the upper Amazon is abundant throughout the year, with a maximum occurring in summer. Temperatures are high throughout the year. The daily variation in temperature exceeds the annual variation.

e. North of the Equator and West of 60° West Longitude. A regime of tropical rains with a summer maximum and a winter minimum dominates the climate of Venezuela. The temperature is high and the annual variation is small. Precipitation along the northwest coast depends upon the seasonal displacement of the doldrum belt. Near the Gulf of Panama, the rainy seasons are spring and fall; the dry seasons are summer and winter. South of this area distinct dry and rainy seasons extend as far south as 5° south latitude. The rainy season at the southern limit of the area occurs in February. Temperatures are moderate to high with the highest temperature occurring in the dry season, but the annual range is small.

12. Europe

The climate of Europe has two outstanding features—(1) the temperatures are more moderate than would be expected of a continent located in such a northerly latitude belt, and (2) no areas are classified as desert.

a. Northwest Europe. The climatic region of northwest Europe includes the British Isles and the coastal region of the continent from northern Spain to coastal Norway. The climate is humid and temperate. Precipitation occurs during all seasons, with a fall and early winter maximum. More precipitation occurs on the coasts than inland. Spring is the driest season. During winter this region has high mean temperatures for the latitude, due to the moderating influence of the Gulf Stream and the North Atlantic Current. Low-temperature invasions of the region are a result of cold air outbreaks from the east (fronts and cyclones). In summer, coastal temperatures are cooler than inland temperatures; autumn is warmer than spring in inland areas.

b. Central Europe. The climatic region of Central Europe consists of that portion of the continent west of Russia and north of the Alps, Yugoslavia, and Bulgaria. This region shows a transition from the mild, wet winters of the coastal areas to the very cold, dry winters of Russia. In the western section, the precipitation maximum occurs in early winter; in the east, it occurs in the summer. Sweden and Finland have much less precipitation than Norway, but in all three of these countries the maximum rainfall occurs in summer and fall. The longitudinal temperature variation is greater than the latitudinal variation. In summer, higher temperatures occur over the interior than in the coastal regions.

c. Mediterranean Region. The Mediterranean region has dry summers and wet falls and winters. The precipitation varies considerably due to topographic features and seasonal variation of the atmospheric circulation (amount of frontal activity). Two rainy periods occur along the northern Mediterranean—one in spring and one in fall. The southern portion has only one rainy period—in midwinter. Precipitation is heavier in the eastern part of this region than in the western part. Both summer and winter temperatures are mild; however, unusually cold outbreaks from the north may affect this region.

d. Alps Region. Due to the elevation, the Alps have a climate somewhat different from the surrounding plains. Large amounts of precipitation occur in all seasons of the year, with the largest amounts along the slopes. To the north, the maximum precipitation occurs in the summer; to the east and south, the maximum occurs in the fall; and in all regions, the minimum occurs during the winter. Mean temperatures are cooler in the mountains than over the adjacent plains.

13. Asia

a. Russia.

(1) The climates of European Russia and Asiatic Russia complete the transition from the humid temperate climate of western Europe to the cold continental climate of central and northern Siberia.

(2) Most of the precipitation Russia receives occurs during the summer, except in the region of the Black Sea and from the Caspian Sea to Lake Balkhash which has a winter maximum. East of the Caspian Sea, the precipitation is very light and results in a desert climate. The remainder of Russia (extending to the Pacific coast of Siberia) has a late summer precipitation maximum, although the amount is light in all seasons.

(3) The coldest temperatures of the world, with the possible exception of the continent of Antarctica, occur in the vicinity of Verkhoyansk, Siberia. In summer, however, temperatures are moderate in most regions, with the exception of the extremely hot area east of the Caspian Sea.

b. Southwest Asia. The area from Turkey and Arabia to Afghanistan and western Pakistan is a region of rapid weather changes in winter, because the air may come from the warm moist Mediterranean Sea or from cold dry central Asia. Maximum precipitation occurs in winter, with the greatest amount occurring along the coasts; summer is dry. Arabia has very little precipitation in any season, but the coast of the Pakistan region has considerable summer rainfall due to the monsoon winds. In winter, inland temperature changes are rapid and extreme. In summer, inland temperatures are hot and coastal temperatures are mild. However, sections of Afghanistan and Pakistan have mild summer temperatures because of their high elevation.

c. Central Asia. The climatic region of central Asia includes the Tibetan plateau and the basin area of China west of the Kingan Mountains. In general, this region is characterized by cold, dry winters and warm summers, with slight-to-moderate precipitation. In the western section, winter and summer precipitation are about equal, but both are slight. In the northern part of this region, there is very little precipitation in any season, which results in desert conditions. Eastern Tibet receives moderate precipitation in summer. Because of the high elevation, temperatures in Tibet are low in all seasons. The basin region of China has extremely warm summers and extremely cold winters. The temperature range, both diurnal and annual, is very large.

d. Burma, India, and Ceylon. The climate of this region is controlled by the Asiatic monsoon. January and February are cool and dry except for the northwest, which receives considerable precipitation from an onshore prevailing wind. The period from March to mid-June is very hot and dry, except for the milder coastal regions. The period from mid-June to mid-September has moderate-to-heavy rain and cooler temperatures. The period from mid-September to December has mild temperatures and clear skies. Additional precipitation occurs on the coast of Bengal from tropical storms.

e. Japan and the Maritime Provinces of China.

(1) Japan has no dry season. In winter, the heaviest precipitation is on the western slopes of the mountains; in summer, it is on the eastern slopes of the mountains. Winters in northern Japan are warmer than those in northern China. Winter temperatures vary from east to west, as well as from north to south.

(2) The climate of the maritime provinces of China is controlled primarily by the Asiatic monsoon. Winters are cold and dry and summers are warm and humid with moderate-to-heavy rain. North China has very cold dry winters, and maximum precipitation in the summer. Central China has a temperate climate with cold winters and hot summers. Precipitation occurs in all seasons, but the maximum is in summer. South China has a subtropical climate except for infrequent winter outbreaks of cold continental air.

f. (Superseded) *Southeast Asia.*

(1) *Physical characteristics.*

(*a*) *Republic of Vietnam.* The Republic of Vietnam is predominantly mountainous, except for the narrow coastal plains and the Mekong River Delta area. The Chaine Annamitique, a series of eroded plateaus extending southward along part of the western border, is the major geographical feature of the country. Much of the terrain is above 3,000 feet, with many peaks above 6,000 feet. The highest peak, 60 miles west of Quang Ngai, is near 10,500 feet. With the exception of the Mekong, rivers are short and flow east in deep-walled valleys. The Mekong River branches to form an extensive delta in the south.

(*b*) *North Vietnam.* The lowlands of North Vietnam are primarily confined to a 25- to 40-mile coastal strip, while in the Red River Delta the lowlands extend inland 75 miles. Mountains cover the western and northern portions of North Vietnam. The highest peak is about 15 miles southwest of Lao Kay and extends to 10,312 feet. The mountain ranges are oriented northwest-southeast. Rivers generally parallel the mountain ranges and in most cases flow in deep, narrow gorges.

(*c*) *Laos.* The northern half of Laos consists of mountains and high plateaus that are cut by deep river valleys. The highest peak, 9,242 feet, is about 60 miles northeast of Vientiane. The southern half, often called the "panhandle" of Laos, is a long narrow region consisting of the Chaine Annamitique in the east, the Alluvial plains and hills near the center, the Plateau des Bolovens in the extreme south, and the low-lying valley floor adjoining the Mekong River in the west. There are a number of deep, narrow mountain passes between North Vietnam and Laos; the best known is the Mu Gia Pass just south of 18° north latitude.

(*d*) *Cambodia.* Cambodia is a large plain, broken by ranges of low, densely forested mountains. Flatlands in the center form a basin for the Mekong River and a large lake, creating excellent conditions for rice growing. The countryside is dotted with sugar palms and small rural villages of straw huts raised on piles. Cambodia is bordered by Thailand, Laos, the Republic of Vietnam, and the Gulf of Siam.

(*e*) *Thailand.* Thailand has a mountainous northwest frontier with large tropical forests. The Chao Phraya River and its tributaries water the broad central plain where most of the people live and most of the country's large rice crop is grown. The great Mekong River which flows from China to southern Vietnam forms Thailand's border with Laos and Cambodia.

(2) *Southwest monsoon.*

(*a*) The southwest monsoon is strongest during July and August and is a result of the intertropical convergence zone (ITCZ), (fig. IV–5). The ITCZ is defined as the area or zone of converging winds near the latitudinal position of the sun. The air that comprises the southwest flow has passed over thousands of miles of tropical oceans as it moves out of Australia, over the southwestern Pacific and Indian Oceans, and finally across the Gulf of Siam. The air that arrives over the Republic of Vietnam is warm, moist, and unstable. Additional surface heating and lifting of the air by the mountains will trigger off cumulus clouds and frequent thunderstorms. Therefore, the southwest monsoon weather is characterized by frequent showers, high humidities, high temperatures, numerous thunderstorms, and extensive cloudiness in the southern lowlands and the interior highlands. The sequence of daily weather over most of southeast Asia normally takes the following patterns:

1. 0600 to 1000 LST—Patches of fog and dense stratus with frequent light rain or drizzle in the mountains. Patches of fog and low stratus will form along the rivers and marshlands.

2. 1000 to 1300 LST—Cumulus clouds begin to develop and gradually grow in size.

3. 1300 to 2300 LST—Cumulus clouds increase in height and amount with many showers and thunderstorms occurring throughout southeast Asia. Thunderstorms occur most frequently over the mountains but seldom form solid lines such as squall lines that are common in the Southeastern United States.

4. 2300 to 0200 LST—Thunderstorms normally dissipate and rain showers cease in many locations; however, thunderstorms frequently continue until after sunrise in the mountains.

5. 0200 to 0600 LST—Cumulus clouds will gradually dissipate until only a few middle and high clouds remain. Fog and stratus will begin to form late in the period.

(*b*) Continuous rain is infrequent during the southwest monsoon, even though most stations experience some rain nearly every day. Heavy rains, however, will fall continuously over the area for several hours when typhoons move inland or near the mainland. The number of days per month with precipitation is quite high during the southwest monsoon, averaging 10 days per month at all locations except along the northeastern coast of the Republic of Vietnam and the southeast coast of North Vietnam. Many locations in the highlands and along the southern coast of the Republic of Vietnam average 20 to 25 days with rain during this period.

(3) *Northeast monsoon.* The northeast monsoon begins in southeast Asia during October and predominates over the area until mid-March. This is the result of the southward migration of the intertropical convergence zone (fig. IV–6). During

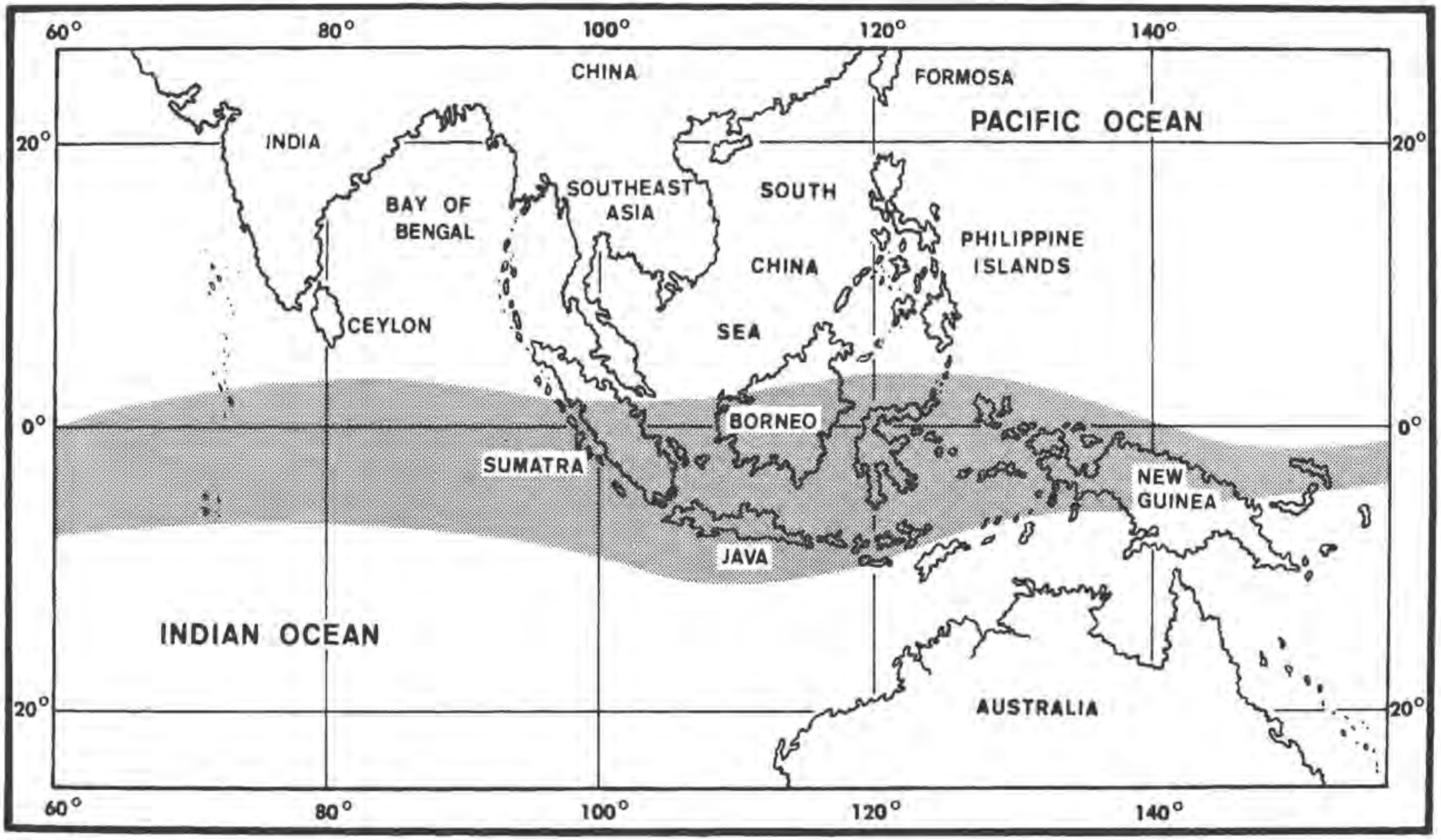


Figure IV-5. (Added) Mean position of intertropical convergence zone (December).

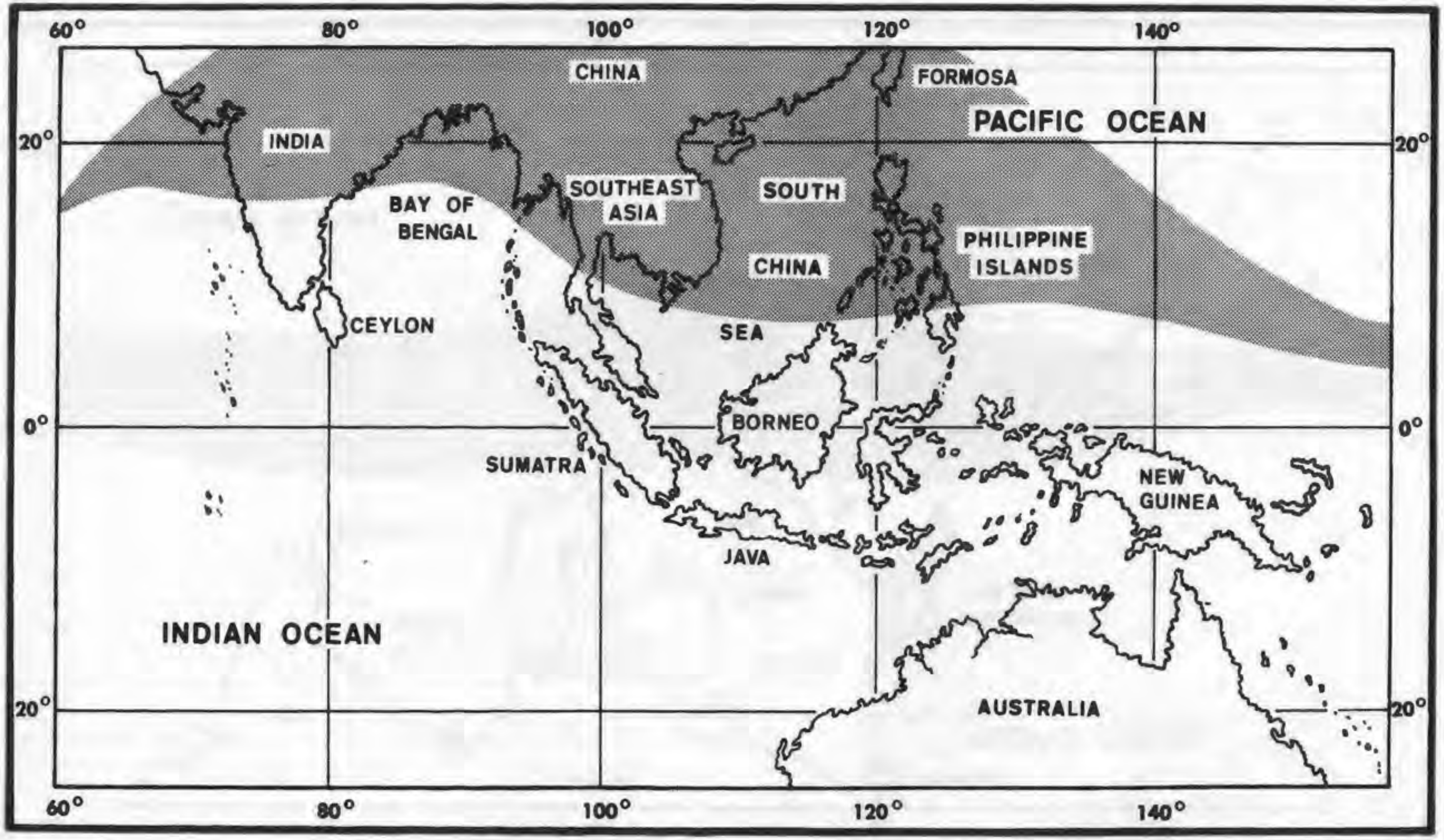


Figure IV–6. (Added) *Mean position of intertropical convergence zone (July).*

the northeast monsoon, the low-level winds up to 6,000 feet are persistently from the northeast. Except for the eastern coastlands, this is the dry season.

g. East Indian Islands. The East Indies have a tropical rainy climate. Temperatures are high, with very slight seasonal variation. Precipitation occurs in all seasons; but, due to the movement of the doldrums, the maximum rain occurs from June to October in regions north of 5° north latitude and from December to April in regions south of 5° south latitude. Around the Equator, precipitation is uniform throughout the year.

14. Africa

Because the continent of Africa extends for an almost equal distance on each side of the Equator, the various climates of the northern portion are roughly paralleled in the southern part. However, the desert region of southwestern Africa is not as extensive as that of the Sahara in the northwest. The continent is relatively high throughout, with few real lowland areas. For the most part, it is a hot continent, with a tropical or subtropical climate. It would be even hotter if it were not for the extensive plateaus and numerous mountains. However, it has no great mountain systems comparable to the Andes, Rockies, or Himalayas in other continents. Africa is not a source region for cold continental air masses, nor do such air masses invade the continent since it is surrounded by vast bodies of water to the south.

a. North Africa. This region includes the coastal areas from Morocco to Cairo, Egypt and the inland mountains of Morocco and Tunis. Precipitation is at a maximum in winter, with dry summers. Winters are mild and summers are cool for the latitude.

b. Sahara. The region of the Sahara extends from the coastal area (*a* above) in the north to 15° or 18° north latitude. Precipitation in this region is negligible. The northern part borders on the belt of coastal precipitation in the winter and the southern part borders on the region affected by the northward displacement of the doldrum belt. Some violent thunderstorms occur over the high mountains in the central regions. Temperatures show high daytime values and very large diurnal variation. Temperatures are cooler in the central part where the elevation is high.

c. Sudan and Guinea Coast. The climate between 15° north latitude and 15° south latitude is influenced by the doldrum belt moving northward or southward. Precipitation is characterized by a heavy summer maximum. Near the northern and southern boundaries of the region, one precipitation maximum occurs, with little or no precipitation during the dry season. Nearer the Equator, the rain occurs for a long period of time with two maximums and one real minimum during the period. Rain is plentiful during all seasons at the Equator. Coastal stations receive more precipitation than inland stations. On the equatorial coasts, temperatures are always high, but reach a maximum just before the rainy season. Inland, the winter season temperatures are lower and the summer season temperatures are higher than at the coastal stations. East of 10° east longitude and between 15° latitude north and south, the continental affect is present. Less precipitation and higher mean summer temperatures occur.

d. Cameroons to Southwest Africa. South of the Equator there is a transitional belt from equatorial rains to the desert conditions at 20° south latitude. Precipitation along the coast of this region is less than along the coast north of the Equator. Coastal precipitation in this area shows a definite trend: heavy rain from May to October in the Cameroons; rain from September to May, and a dry season from July to August near the Equator; and a gradual decrease in precipitation with increasing latitude to 20° south latitude where desert conditions begin. Precipitation inland is similar to that of the coast. The upper Congo has a maximum in July and August, equatorial regions have precipitation in all seasons, and the south Congo is very dry from May to September. Temperatures vary from uniformly high equatorial temperatures to high summer and low winter temperatures over the desert.

e. South Africa. South Africa has a varied climate, due to seasonal variation and topography. The Cape of Good Hope has winter (June–July) precipitation and summer (December–January) dryness. The west coast has slight winter precipitation, increasing from north to south. The east coast has precipitation in all seasons, with a maximum in summer. Inland regions have precipitation in spring and summer. The longitudinal temperature variation from a cool west coast to a warm east coast is greater than the latitudinal temperature variation. Only the inland valleys have warm humid conditions in the low latitudes.

f. East Africa. The climatic region of East Africa includes the east coast and east central portion from 20° south latitude to the Red Sea. The climate is extremely varied due to irregular topography and the seasonal circulation changes. The precipitation regime varies from south to north: south of 10° south latitude precipitation is heavy to moderate in summer, and slight in winter: in Kenya, Uganda, and Tanganyika precipitation varies from a single summer maximum in the south to a double maximum (spring and fall) in the north with heavier precipitation occurring inland than along the coast: Ethiopia, Eritrea, and Somaliland have a summer maximum of precipitation, with slight winter precipitation (again, coastal areas have less precipitation than inland areas): the northeast coast is dry, even in summer, but the coastal region bordering the Red Sea has slight winter rain. The highest temperatures occur at the end of the dry season and are lowest in the winter dry season. At all times, temperatures are moderate to high.

15. Australia

Tropical and subtropical climates dominate Australia. This is because the continent extends from 10° to 40° south latitude and has no extensive system of high mountains. The climatic regions are as follows:

a. Northern Coastal Region. Precipitation in this region is moderate to heavy in the summer. There is slight winter rainfall in the eastern section, but none in the western section. The northeast coast of Queensland has the heaviest precipitation. Temperatures are relatively high in all seasons, even in winter. The interior has a very high summer maximum temperature.

b. Eastern Queensland. The region north of 25° south latitude has a maximum of rainfall in summer, with only slight precipitation in winter. Heavy rain occurs along the coast, but inland regions are dry. Maximum summer temperatures are high; but winter temperatures, although still moderate, are lower than the winter temperatures farther north.

c. Southeast Australia. The climatic region of southeast Australia includes southeast Queensland, New South Wales, and Victoria. Precipitation is distributed uniformly in this region, except for the coastal areas which receive more precipitation than the inland areas. Toward the north, the heaviest rain occurs in summer; toward the south, the maximum occurs in the winter. Winter temperatures are cooler and summer temperatures are milder than farther north.

d. Southern Coast Region. Precipitation in the coastal region of the southern part of Australia is slight to moderate in winter and dry in summer. There is a pronounced decrease of rainfall along the Australian Bight as compared to the coastal regions to the east and west. This region has cool winter temperatures and moderate-to-high summer temperatures.

e. Interior and West. The region along the west coast from 28° south latitude to 18° south latitude and inland to 140° or 145° east longitude has almost no precipitation. Very slight amounts occur in both summer and winter. In summer, daytime temperatures are extremely high; in winter, the air is cool.

16. Arctic Climatic Regions

Climatic conditions in the Arctic area vary rapidly in short distances with changes in latitude, marine proximity, and topography. Three types of arctic climates based on temperature are maritime, coastal, and continental. The three climatic types and their general precipitation characteristics are as follows:

a. Maritime. In the Arctic Ocean, the temperature in June, July, and August deviates very slightly from the freezing point, thus producing a flat temperature curve in summer. In winter there is also a flatness to the temperature curve, but the winter temperature remains close to −30° F.

b. Coastal. The coastal climate closely resembles the maritime, with primarily a long, cold winter and a short, cool summer similar to fall or spring as experienced on the European continent. The annual temperature curve has the same flat winter characteristics as that of the Arctic Ocean, but there is a seasonal maximum in July. The mean temperature for summer, however, remains under 50° F.

c. Continental. The Arctic continental climate is characterized by very low winter temperatures, with a pronounced winter minimum and a relatively high summer maximum. The annual range of mean temperature may be as much as 80° F. or 100° F. The seasonal changes from summer to winter and winter to summer are rapid.

d. Precipitation Amount. The time of maximum precipitation varies with the prominence of marine or continental influence. The Arctic region has extremely light snowfall. Stations in continental areas have a maximum precipitation in late summer, which indicates that a large percentage of the yearly total precipitation falls as rain. The amount of precipitation decreases considerably toward the pole, especially in winter. Zonal variations in precipitation amounts are large; but snow may fall in every month, whereas rain falls only in June, July, August, and September. May has the greatest number of days with precipitation; midwinter months have the smallest. The contrast between conditions in summer and winter is greater over the pack ice than at the coast.

e. Precipitation Frequency. The frequency of precipitation varies, in general, with total precipitation. Most of the Arctic region of North America has fewer than 80 days per year of measurable amounts of precipitation. The number of days with precipitation in the North American Archipelago is particularly small in winter. A maximum frequency of precipitation occurs in the region between the east coast of Greenland and Novaya Zemlya in October and November, but on the Asiatic Russian north coast the maximum frequency appears in September, although the period of heaviest precipitation is usually July and August.

17. Antarctic Climatic Regions

In the Antarctic precipitation occurs during all seasons, with the maximum probably occurring in summer. The amount of precipitation decreases poleward from the coast. Temperatures are extremely cold all year. In winter, temperatures decrease from the coast to the pole, but there is some doubt that this is true in summer. The annual temperature variation is from approximately 30° F. in January to —50° F. in early September. A peculiar feature of Antarctic temperature variation is that the maximum temperature on clear days is shortly after midnight.

GLOSSARY

Terms defined in the text are not repeated in this glossary: the index should be used to locate word definitions contained in the text. The explanations and definitions contained in the glossary serve to—(1) clarify terms as used in the text; i.e., in their meteorological sense, (2) explain or define common meteorological terms not included in the text.

Absolute humidity. A ratio of the quantity of water vapor present per unit volume of air, usually expressed as grams per cubic meter or grains per cubic foot. This ratio is of limited value to the meteorologist because slight changes in atmospheric pressure or temperature alter the amount of air and vapor in a specific volume, thus changing the absolute humidity even though the amount of moisture in the air (grams per kilogram) has not changed.

Active front. A front which produces appreciable cloudiness and precipitation.

Advection. See *Convection.*

Air mass analysis technique. The two primary principles to be considered in a practical air mass analysis are—(a) heating from below promotes instability, and (b) cooling from below promotes stability. By applying these principles to a specific air mass of known moisture content, the aviator can analyze the air mass for—stability, cloud type and coverage, precipitation amount and intensity, visibility restrictions, icing type and intensity, and degree of turbulence.

Anemometer. An instrument for measuring the force or speed of the wind.

Anticyclogenesis. A term applied to the process which creates or intensifies an anticyclone.

Anvil cloud. The popular name of a heavy cumulus or cumulonimbus cloud having an anvil-like formation of cirrus clouds in its upper portions. If a thunderstorm is seen from the side, the anvil form of the cloud mass is usually noticeable.

Arctic front. The zone of discontinuity between the extremely cold air of the Arctic regions and the cool polar air of the northern Temperate Zone.

Aurora. A luminous phenomenon caused by electrical discharges in the atmosphere; probably confined to the tenuous air of high altitudes. It is most commonly seen in sub-Arctic and sub-Antarctic latitudes and is called *aurora borealis* or *aurora austrailis* respectively, according to the hemisphere in which it occurs. Observations with the spectroscope seem to indicate that a faint "permanent aurora" is a normal feature of the sky in all parts of the world.

Back. To change or shift in a counterclockwise direction (to the left of the moving mass) ; applied to the wind when it so changes, as, for example, from the north to northwest. Opposite to *veer*, which signifies a clockwise change. In scientific practice, this definition applies to both hemispheres.

Blizzard. A violent, intensely cold wind laden with snow.

Buildup. A cloud with considerable vertical development.

Buys-Ballot's Law. A law formulated by a Dutch meteorologist in 1857 stating—If you stand with your back to the wind, pressure is lower on your left than on your right in the Northern Hemisphere, and the reverse in the Southern Hemisphere.

Ceiling. The height ascribed to the lowest layer of clouds of obscuring phenomena reported as broken, overcast, or obscured and not classified as thin or partial.

Celsius scale. A centigrade temperature scale originally based on 0° for the boiling point of water and 100° as the freezing point of water; i.e., an inverted centigrade scale. It is now used interchangeably with the centigrade scale.

Cloud bank. A mass of clouds, usually of considerable vertical extent, stretching across the sky on the horizon but not extending overhead.

Cloudburst. A sudden and extremely heavy downpour of rain; frequent in mountainous regions where moist air encounters orographic lifting.

Cold wave. A rapid and marked fall of temperature during the cold season of the year. The U.S. Weather Bureau applies this term to a fall of temperature in 24 hours equaling or exceeding a specified number of degrees and reaching a specified minimum temperature or lower. Specifications vary for different parts of the country and for different periods of the year.

Conduction. Air is a poor conductor of heat; therefore, molecular heat transfer (conduction) during the course of a day or night affects only 2 or 3 feet of air directly. Wind and turbulence, however, continuously bring fresh air into contact with the surface and distribute the warmed or cooled air throughout the atmosphere.

Convection. Although frequently used in physics to denote a complete atmospheric current, in meteorology *convection* refers to vertical air motion. The horizontal air movement that completes an air current is called *advection.*

Cooling processes, major. Air temperature is decreased by all or any of the following processes:

(1) *Nocturnal cooling.* The earth continuously radiates its heat outward toward space. During the night (or at any time when outgoing radiation from the earth exceeds incoming solar radiation) the loss of radiant energy lowers the temperature of the earth's surface. The air temperature is thereafter reduced by conduction.

(2) *Advective cooling.*

a. When the windflow is such that cold air moves into an area previously occupied by warmer air, the temperature of the air over the area is decreased. With strong, cold wind prevailing, the advective cooling may be sufficient to cause a temperature decrease in an area even though the surface is absorbing solar radiation.

b. Warm air advection over a colder surface will result in conductive cooling of the lower air layers.

(3) *Evaporative cooling.* When rain or drizzle falls from clouds, the evaporation of the water drops cools the air through which these drops are falling. Similar evaporative cooling occurs whenever liquid water is changing to vapor, thereby taking latent heat energy from the environment.

(4) *Adiabatic cooling.* If air is forced upward in the atmosphere, the resulting decrease in atmospheric pressure surrounding the rising air allows the air to expand and cool adiabatically. Weather produced by lifting processes is the result of adiabatic cooling; e.g., frontal weather, convective and orographic thunderstorms, and upslope fog.

Coriolis force. This effect of the earth's rotation on wind direction was expressed as an acceleration by a French scientist, G. G. Coriolis, in 1844. The Coriolis acceleration becomes a force when applied to a moving mass of air, as expressed by the equation

$$\mathbf{C} = 2\,\Omega\,\mathbf{v}\sin\theta$$

where C is Coriolis acceleration, Ω is the angular velocity of the earth's rotation, v is the wind velocity, and θ is the latitude where the motion occurs. The acceleration changes the wind velocity (*q.v.*) with regard to direction only.

Cyclogenesis. The process which creates or intensifies a cyclone.

Deepening. The decreasing of pressure in the center of a low pressure system.

Density. The amount of mass per unit volume of any substance (pound per cubic foot, gram per cubic centimeter, kilogram per cubic meter, etc.). Heating causes a substance to expand, thereby reducing the number of molecules that can be contained by a fixed volume and decreasing density. Cooling increases the density of a substance. The density of a gaseous medium is particularly sensitive to changes in temperature (and pressure). The weight of a substance varies directly with its density.

Depression. A cyclonic (low pressure) area.

Dew point. This term may also be called the *dew point temperature, temperature of the dew point,* and *dew point.*

Discontinuity. The term applied in a special sense by meteorologists to a zone within which there is a comparatively rapid and abrupt transition of the meteorological elements from one value to another.

Diurnal. Actions completed within 24 hours.

Equinox. The moment, occurring twice each year, when the sun, in its apparent annual motion among the fixed stars, crosses the celestial equator; so called because then the night is equal to the day, each being 12 hours long over the whole earth. The *autumnal equinox* occurs on or about September 22, when the sun is traveling southward; the *vernal equinox* on or about March 21, when the sun is moving northward.

Filling. The increasing of pressure in the center of a low pressure system; the opposite of *deepening.*

Frontogenesis. The process which creates or recreates a front in areas where air mass discontinuities are intensifying.

Frontolysis. The process by which a front weakens or dissipates as the density of air masses change or the wind field changes.

Gradient. 1. The rate of increase or decrease in magnitude, such as a pressure or temperature *gradient.* When a horizontal pressure gradient exists, the direct force exerted by the area of higher pressure is called the *pressure gradient force.* 2. When used to describe a wind (*gradient* wind), gradient refers to winds above the influence of terrestrial friction—normally above 2,000 feet—where only pressure gradient force is affecting the speed of the wind.

Greenhouse effect. This term is derived from the affect of the glass roof on a greenhouse which transmits high-frequency insolation but blocks the passage of terrestrial radiation from within the glass enclosure. The greenhouse effect caused by clouds and impurities in the atmosphere is most noticeable at night when they reduce the nocturnal cooling of the earth.

Horse latitudes. The subtropical high pressure region at approximately 30° latitude, characterized by calm or light, variable winds.

Hot wave. A period of abnormally high temperatures, usually lasting 3 or more consecutive days during each of which the maximum temperature is 90° F. or over.

Humidity. A general term to denote the water vapor content of the air.

Inclination of the wind. The angle of the wind with respect to the isobar at the point of observation (usually between 20° and 30° at the surface).

Intertropical front. The boundary between the trade wind systems of the Northern and Southern Hemispheres. It appears near the Equator as a fairly broad zone of transition commonly known as the *doldrums.*

Lapse rate. A change in value expressed as a ratio, generally used with temperature changes vertically; i.e., 2° C. per 1,000 feet in the standard atmosphere.

Line squall. See *Squall line.*

Main sea level. In the United States, the average height of the surface of the sea for all stages of the tide during a 19-year period.

Mesometeorology. The study of atmospheric phenomena such as tornadoes and thunderstorms which occur between meteorological stations or beyond the range of normal observation from a single point; i.e., on a scale larger than that of *micrometeorology,* but smaller than the *cyclonic* (*synoptic*) scale.

Micrometeorology. The study of variations in meteorological conditions over very small areas, such as hillsides, forests, river basins, or individual cities.

Molecular theory. A scientific theory that all matter is composed of electrical energy organized into atoms and molecules. These molecules are in constant motion, and their collision produces temperature. The relative amount of heat energy in an object is measured by temperature scales. When radiant energy is absorbed by a molecule, the molecular energy content is increased—molecular activity speeds up and a higher temperature results. All substances which have a temperature above —273° C. also radiate energy continuously. If fresh radiant energy were not supplied by the sun, the temperature of the earth would become progressively colder.

Nacreous clouds. Luminous, iridescent "clouds" occurring near 75,000 feet and made visible by reflected and diffracted light approximately 25 minutes before sunrise or after sunset; also called *mother-of-pearl clouds.*

Natural air. Air as found in the atmosphere, containing water vapor and other impurities.

Noctilucent clouds. Silvery or bluish-white "clouds" which form approximately 55 miles above the earth and are made visible after sunset and before sunrise by reflected sunlight.

Nocturnal. Occurring during the hours between sunset and sunrise.

Operator's manual. TM 55-1510-( )-10 for fixed wing aircraft. TM 55-1520-( )-10 for rotary wing aircraft. The operator's manual is the title ascribed to the flight handbook under the former technical order numbering system (TO 1-1H-( )-1, TO 1-1L-( )-1, etc.) The operator's manual may also be referred to as the TM 55 aviation series -10, or simply the Dash Ten (-10).

Radiation. Electromagnetic waves traveling at 186,000 miles per second, many of which may be visible as light. Cosmic rays, gamma rays, X-rays, ultraviolet rays, visible light rays, infrared rays, and radio waves are some common types of radiation which vary in wave length from 0.0000000001 cm to 10,000,000,000 cm. Visible rays range from about 3.8 to 7.6 ten-millionths of a meter in wave length. The wave length emitted by an object decreases as the temperature of the object increases. A decrease in wave length signifies an increase in radiation frequency. Thus, a hot surface emits high frequency radiation. The rate at which an object emits radiation is controlled by the temperature contrast between the object and its environment. Radiation travels best through a vacuum, but the quantity absorbed by a substance is controlled by the wave frequency and the density of the absorbing medium. High frequency waves can penetrate dense media, whereas low frequency waves may be absorbed by low density media, especially by gaseous water (water vapor).

Rate of evaporation. The quantity of vapor which will escape from a liquid surface into the air is primarily governed by (1) the temperature of the liquid, (2) the amount of vapor already in the air (partial vapor pressure of the air), and (3) the speed of air movement over the liquid surface. Thus, much water will evaporate from the Great Lakes into the cold, dry winter air above it, even though the air cannot support the moisture in the vapor state. The resulting condensation forms a dense evaporation fog over the lakes.

Roll cloud. Part of the cloud base along the leading edge of a cumulonimbus cloud, formed by a rolling action in the wind shear region between cool downdrafts within the cloud and warm updrafts outside the cloud.

Saturated adiabatic lapse rate. A rate of temperature decrease with height, equal to the rate at which an ascending body of saturated air will cool during adiabatic expansion. It varies inversely with the air temperature. The average value generally used is 1.5° C. per 1,000 feet.

Secondary. A small area of low pressure on the border of a large (primary) area. The secondary may develop into a vigorous cyclone while the primary center disappears.

Secondary circulation. In this wind classification category, many authorities include *only* migratory anticyclones and cyclones. Such wind patterns as land and sea breezes, mountain and valley breezes, eddies, and Foehn winds are then classified as *local winds.*

Selective absorption. Substances are *selective* in the radiation frequencies which they will absorb and radiate. The gases and impurities of which air is composed absorb and radiate only a few of their incident radiation frequencies. For example, water vapor absorbs several of the lower frequency radiation waves of terrestrial radiation, but is transparent to the high frequency radiation from the sun.

Solstice. The time of year when the direct ray of the sun is farthest from the Equator. The approximate dates are—summer solstice, June 22, and winter solstice, December 22.

Spread. The difference between the temperature of the air and the dew point of the air, expressed in degrees. Although there is a definite relationship between spread and relative humidity, a spread of 5° F. between 90° F. and 85° F. produces a significantly different relative humidity from the same spread between 65° F. and 60°F.

Squall line. A line of thunderstorms, generally continuous across the horizon. Although *squall line* and *line squall* are interchangeable terms, the text refers to a line squall as the line of thunderstorms along a typical cold front, whereas *squall line* refers to prefrontal thunderstorm activity. Such distinction of terminology is purely arbitrary.

Subsidence inversion. An inversion layer which forms near a center of high pressure where the entire column of air is descending (subsiding) toward the surface. As the air layers descend, they are compressed by the inflow of fresh air aloft. Compression heats the subsiding air layer and often the layer becomes warmer at the base levels than at the upper levels. The resulting increase in temperature through the layer is a *subsidence inversion.* Haze layers often develop below these inversion layers.

Synoptic. That which presents a general view of the whole; as a *synoptic* weather map, or a *synoptic* weather situation, wherein the major weather phenomena over a large geographical area are depicted or discussed.

Temperature lag. 1. Although the sun is directly overhead at noon, incoming radiation continues to exceed re-radiation from the earth until after 1400 hours local standard time. Thus, the diurnal surface temperature increase reaches a maximum in the midafternoon. 2. Seasonally, the sun is highest in the northern hemisphere at the summer solstice (June 22), but the long hours of daylight and relatively direct incident radiation cause the summer temperatures to continue increasing into July and August.

Twilight. Twilight is the interval of incomplete darkness following sunset and preceding sunrise.

Veer. See *Back.*

Weather. In addition to its complete definition (par. 2–3*c*(1)), the term *weather* has several specialized meanings in meteorology. It may refer to (1) *only* the forms of precipitation in the atmosphere at the time of a meteorological observation, (2) *both* the forms of precipitation and the obstructions to vision (fog, haze, smoke, dust, etc.) present over a station at the time of a meteorological observation or, (3) all forms of atmospheric phenomena that affect an aircraft during takeoff, landing, and in flight.

Wind shear. The rate of change of wind velocity (speed and/or direction) with distance. Eddies and gusts form in areas of wind shear, thus producing turbulent flying conditions. Wind shear may occur in either the vertical or horizontal plane.

Wind velocity. The speed *and* direction of the wind.

INDEX

	Paragraph	Page
Adiabatic lapse rate (*see also* Lapse rates):		
Dry	5-4*a*, 5-8*c*	5-3, 5-8
Moist	5-4*b*, 5-8*d*	5-3, 5-8
Adiabatic process	5-4	5-3
Advection (transfer of heat)	2-6*a*, 2-10*d*, *e*, 14-5*b*	2-4, 2-11, 14-5
Advection fog	8-4*b*	8-2
Advisory for light aircraft	16-14*b*	16-13
Air mass:		
Analysis	6-7 (Glossary)	6-4, G-1
Characteristics	6-2, 6-5	6-1, 6-2
Classification	6-3, (6, app. III)	6-1, III-6
Continental polar	6-9	6-5
Continental tropical	6-11	6-8
Definition	6-1	6-1
Designation	6-4	6-2
Formation	6-2*a*	6-1
Maritime polar	6-8	6-4
Maritime tropical	6-10	6-6
Modification	6-2*b* (2)	6-1
Source regions	6-2*a*, 6-6	6-1, 6-3
Stability	6-3*b*	6-2
Thunderstorms	10-4	10-4
Trajectories	6-2*b* (1), 6-6*b*	6-1, 6-4
Altimeter:		
Adjustment for nonstandard pressure	2-18*b*(1), 2-22	2-19, 2-23
Combined errors	14-10	14-10
Effect of mountain wave	4-28*f*(5)	4-28
Effect of thunderstorm	10-7*g*	10-15
Error due to temperature	2-22*c*	2-25
Setting, as given on hourly sequence report	11-13, 14-10	11-10, 14-10
Altitude:		
Density (table X App. II)	2-23	2-27, II-3
Pressure	2-23	2-27
Aneroid barometer	2-17*b*	2-18
Anticyclones (*See* High pressure areas.)		

	Paragraph	Page
Area forecasts	16-4	16-2
Atmosphere:		
Composition	2-2	2-1
Definition	2-1	2-1
Divisions (layers)	2-3, 14-6*b*	2-1, 14-5
Standard (table V App. II)	2-3*a*, 2-19, 5-9*h*, *i*,	2-1, 2-20, 5-11, II-1
Atmospheric circulation (*See* Circulation.)		
Atmospheric sounding diagram (*See* Skew T, log p Diagram.)		
Atmospheric stability (*see also* Stability)	5-2, 5-5, 5-9*b*-*f*	5-1, 5-3, 5-9
Atmospheric waves	7-7	7-14
Barometer (*see also* Pressure):		
Aneroid	2-17*b*	2-18
Mercurial (mercury)	2-17*a*	2-18
Blowing snow	(5*c*, app. III)	III-5
Buys—Ballot's Law	4-10*c* (4), 4-21	4-12, 4-22
Canopy static	14-9	14-10
Carburetor ice (*See* Induction system icing.)		
Ceiling:		
Definition	10-6*b*, (Glossary)	10-10, G-1
In thunderstorms	10-7*h*	10-15
On surface weather maps	12-4*k*	12-7
On teletype sequence reports	11-6*b*	11-7
Centrifugal force, effect on circulation	4-9*b*	4-10
Changes of state	2-11	2-11
Charts (*see also* Maps, weather):		
Constant pressure (*See* Constant pressure charts.)		
Prognostic	16-10, 16-11 16-12	16-10
Radar summary	15-6	15-2
Weather depiction	12-9*b*, 16-9	12-13, 16-6
Winds aloft	13-5	13-3
Chinook (Foehn) wind	4-29	4-28

	Paragraph	Page
Circuits, teletype (*See* Reports, teletype sequence.)		
Circulation (*see also* Wind):		
Centers of action	4-6	4-5
Definition	4-2*a*	4-1
Effect:		
Centrifugal force	4-9*b*	4-10
Coriolis force	4-5*a*, 4-9*a*	4-4, 4-9
Friction	4-9*c*	4-10
Insolation	4-2*c*(2), 4-5*b*	4-1, 4-4
Land and sea	2-10*c*(1), 4-25, 10-4*a*(2), (3)	2-10, 4-25, 10-6
Land and sea breezes	4-25, 10-4*a* (2), (3)	4-25, 10-6
Mountain and valley breezes	4-26	4-25
Primary	4-4	4-3
Secondary	4-7, 7-7	4-9, 7-14
Semipermanent pressure areas	4-6	4-5
Three-Cell Theory	4-4	4-3
Transfer of heat energy	4-2*c*	4-1
Clear air turbulence	14-6*g*	14-7
Clear ice (glaze) (*See also* Icing: Structural)	9-3*a*	9-2
Clear language remarks	11-14	11-10
Climatology	(app. IV)	IV-1
Clouds:		
Ceiling	11-6*b*, (Glossary)	11-7 G-1
Classification, international (Table I)	3-2	3-1
Formation	3-1, 5-9*g*, 7-1*e*, 8-3*a*, 10-5	3-1, 5-10, 7-2, 8-1, 10-8
High	3-3	3-2
In mountain waves	4-28*d*	4-27
Levels	5-9*g*	5-10
Low	3-5	3-3
Middle	3-4	3-3
Rain and fragmentary:		
Cumulonimbus	3-2*c*, 10-5*b* (3), 10-6*a*	3-2, 10-9, 10-10
Fractocumulus	3-2*c*	3-2
Nimbostratus	3-2*c*	3-2
Sky condition	11-6	11-6
Subdivisions:		
Cumuliform	3-2*b*(1), 5-9*h*	3-1, 5-11
Stratiform	3-2*b*(2), 5-9*h*	3-1, 5-11
Types:		
Altocumulus	3-4	3-3
Altostratus	3-4	3-3
Cirrocumulus	3-3	3-2
Cirrostratus	3-3, 5-9*h*	3-2, 5-11
Cirrus	3-3	3-2
Cumulonimbus	3-6, 10-5*b* (3), 10-6*a*	3-5, 10-9, 10-10
Cumulus	3-6, 10-5*b* (1), (2)	3-5, 10-8, 10-9
Nimbostratus	3-5	3-3
Stratocumulus	3-5	3-3
Stratus	3-5, 5-9*h*, 8-3*a*	3-3, 5-11, 8-1
Vertical development	3-6, 10-5	3-5, 10-8
Coalescence	2-14*a*(3)	2-17
Col	2-20*c*	2-23
Cold air masses. (*See* Air mass: Classification.)		
Cold fronts (*See* Fronts.)		
Condensation	2-2*b*, 5-5*d*	2-1, 5-5
Condensation nuclei	8-2*c*	8-1
Conditional instability	5-5*c*, 5-9*e*, 10-2*a*	5-4, 5-9, 10-2
Conduction, transfer of heat	2-6*b*, 2-10*b*	2-5, 2-10
Constant pressure charts:		
Altimeter errors	14-10	14-10
Contour lines	14-5*a*	14-4
Isolines	14-5	14-3
Isotachs	14-5*c*	14-5
Isotherms	14-5*b*	14-5
Levels	14-2	14-1
Observations	14-3	14-1
Purpose	14-1	14-1
Station model	14-4	14-3
Weather phenomena:		
Canopy static	14-9	14-10
Clear air turbulence	14-6*g*	14-7
Contrails	14-7	14-10
Haze layers	14-8	14-10
Jet stream	14-6	14-5
Continental air masses (*See* Air mass.)		
Contour lines	14-5*a*	14-3
Contrails	14-7	14-9
Convection:		
Currents	2-10*c*, 4-2*c*, 5-3, 10-4*a*	2-10, 4-1, 5-2, 10-4
Level of free	5-5*d*, 10-2*b*	5-5, 10-2
Transfer of heat	2-10*c*, 10-2	2-10, 10-2
Types (*See* Thermal convection and Mechanical convection.)		
Convective thunderstorms	10-4*a*	9-3
Convergence	4-10*d*, 5-3*a*(3)	4-13, 5-2

	Paragraph	Page
Conversion:		
Formulas, temperature	2-4b	2-2
Tables, meteorological	(app. II)	II-1
Time	11-3b(1)	11-1
Cooling processes, major	2-10, (Glossary)	2-9, G-2
Coriolis force	4-5a, 4-9a	4-4, 4-9
Cumuliform clouds:		
Classification and identification	3-2b(1)	3-1
Description	3-2b(1)	3-1
Development	3-2b(1), 10-5	3-1, 10-8
Flight conditions with	3-2b(1), 3-6b, 9-8b(1)	3-1, 3-5, 9-10
Cyclones (*See* Low pressure areas.)		
Density altitude (Table X, app. II)	2-23,	2-27, II-3
Dew point (Table IV, app. II)	2-12b, 5-9b, 7-2d, 11-11	2-13, 5-9, 7-5, 11-9, II-1
Divergence (*See* Convergence.)		
Drafts	10-5b, 10-6b, c	10-8, 10-10, 10-12
Drizzle	2-14b(2)	2-17
Easterly waves	(11c, app. III)	III-8
Eddy winds	4-32, (5c(2), app. III)	4-30, III-5
Electricity, within thunderstorms	10-7e	10-13
Energy, transport of heat (*See* Heat transfer, methods.)		
Evaporation	2-11a	2-11
Evaporation fog	8-4f	8-3
Facsimile service (*see also* Maps)	12-1	12-1
Fall (katabatic) winds	4-30	
Flight conditions:		
In mountain waves	4-28d, e, f	4-27, 4-28
In polar regions	(5, app. III)	III-4
Through thunderstorms	10-7	10-13
Flight:		
Forecast	16-8, 16-9	16-6
Planning (*see also* Tables):		
Aviator weather analysis	17-2	17-1
Briefing technique, weather	17-5, 17-6	17-5, 17-13

	Paragraph	Page
Cold weather operations	9-11	9-12
Density altitude computation	2-23b	2-28
In specific weather areas:		
Clear air turbulence	14-6g	14-7
Cold fronts	7-3d	7-6
Fog	8-5	8-4
Freezing rain	7-4d(4)	7-10
Icing	9-10	9-12
Jet stream	14-6	14-7
Mountain wave	4-28d, e, f	4-27, 4-28
Occluded fronts	7-5e	7-12
Polar regions	(Sec I, app. III)	III-1
Thunderstorms	10-8	10-16
Tropical regions	(Sec II, app. III)	III-6
Warm fronts	7-4d	7-10
Using available facilities:		
Advisories	16-4	16-13
Constant pressure charts	14-1, 14-10a, 17-3b, 17-4	14-1, 14-10, 17-2
Forecasts	16-2, 7-3g	16-1, 17-2
Integration of facilities	17-3, 17-4	17-1, 17-2
Pilot reports (PIREPS)	17-3f	17-2
Pilot to forecaster service (METRO)	15-7	15-3
Radar summaries	15-6	15-2
Sequence weather reports	11-1, 17-3d	11-1, 17-2
Skew T, log p Diagram	5-9, 17-3c	5-9, 17-2
Surface weather map	12-8, 17-3a	12-11, 17-1
Winds aloft data	13-1, 13-5c, 17-3e	13-1, 13-3, 17-2
Foehn (chinook) winds	4-29	4-28
Fog:		
Advection	8-4b	8-2
Characteristics	8-1, 8-4	8-1
Dissipation	8-3	8-1
Evaporation	8-4f	8-3
Formation	8-2	8-1
Frontal	7-4b(3), 7-6b(2), 8-4f(1)	7-7, 7-14, 8-3
Hazards	8-5	8-4
Ice	8-4e, (4, app. III)	8-3, III-2
Radiation	8-4a, (4, app. III)	8-1, III-2

	Paragraph	Page
Fog—Continued		
Steam	8-4f(2)	8-3
Upslope	8-4c	8-3
Valley	8-4d	8-3
Force:		
Centrifugal	4-9b	4-10
Coriolis	4-5a, 4-9a	4-4, 4-9
Definition	2-16a	2-18
Frictional	4-9c	4-10
Of wind (Table IX, app. II)		II-2
Pressure gradient	2-21, 4-8	2-23, 4-9
Forecasts:		
Facsimile:		
Constant pressure prognostic charts	16-11	16-10
Other prognostic charts	16-12	16-10
Surface prognostic charts	16-10	16-10
In-flight:		
Weather advisories	16-14	16-13
Weather broadcasts	16-13	16-13
Locally prepared:		
Horizontal weather depiction chart	16-9	16-6
Terminal	16-7	16-6
Vertical cross section	16-8	16-6
Teletype:		
Area	16-4	16-2
Regional	16-3	16-1
Terminal	16-5	16-3
Winds aloft	16-6	16-5
Formulas, conversion (*See* Conversion: Tables and Formulas.)		
Free air temperature	2-7, 9-2a	2-6, 9-1
Freezing rain	2-14c(1), 7-4d(4), 9-2b(2)	2-17, 7-10, 9-1
Frictional force	4-9c	4-10
Frontal aspects:		
Fog	7-4b(3), 7-6b(2), 8-4f(1)	7-7, 7-14, 8-3
Inversions	7-2a, 9-8a	7-4, 9-9
Slope (*see also* Fronts: Slope)	7-1c(2)	7-2
Storms	7-3b(3), 10-3	7-5, 10-2
Waves and cyclones	7-7	7-14
Weather	7-1e, 9-8	7-2, 9-9
Fronts:		
Characteristics	7-3b, 7-4b, 7-5b, 7-6	7-5, 7-7, 7-10, 7-12

	Paragraph	Page
Cloud formations with	7-3b(3), 7-4b(3), 7-5c, 7-6, 10-3	7-5, 7-7, 7-11, 7-12, 10-2
Cold	7-1b(1), 7-3, 10-3b	7-1, 7-5, 10-3
Cyclonic waves	4-4a(3), 7-7	4-3, 714
Definitions	7-1	7-1
Discontinuities	7-1d, 7-2, 7-3b, 7-4b	7-2, 7-4, 7-5, 7-8
Flight procedures through	7-3d, 7-4d, 7-5e	7-6, 7-9, 7-12
Frontal surface	7-1c(2)	7-2
Identification on surface weather map	7-3c, 7-4c, 7-5d, 12-6	7-6, 7-8, 7-12, 12-10
Occluded	7-1b(4), 7-5	7-2, 7-10
Open wave	7-5	7-10
Polar	7-7c	7-16
Prefrontal squall line	7-3b(3), 10-3c	7-5, 10-3
Slope	7-1c(2)	7-2
Stationary	7-1b(3), 7-6	7-1, 7-12
Structure	7-3a, 7-4a, 7-5a, 7-6	7-5, 7-7, 7-10, 7-12
Surface	7-1c(1)	7-2
Upper (fronts aloft)	7-5b(1), (2)	7-10
Warm	7-1b(2), 7-4, 10-3a	7-1, 7-7, 10-2
Warm sector	7-4b	7-7
Weather factors affecting	7-1e	7-4
Frost	9-3c	9-3
Fusion, heat of	2-11d	2-12
Geostrophic wind	4-10a(2)	4-10
Glaze ice (*See* Clear ice.)		
Glossary		G-1
Gradient wind	4-10a(1), 12-4a	4-10, 12-3,
Greenhouse effect	2-10a(3)	2-10
Gusts (*see also* Thunderstorms: Gusts)	4-32, 10-7f	4-30, 10-14
Hail	2-14d(2), 10-7b	2-17, 10-13
Haze layers, high altitude	5-9j, 14-8	5-12, 14-10
Heat exchange	2-11d	2-12
Heat of fusion	2-11d	2-12
Heat of vaporization	2-11d	2-12
Heat transfer (*see also* Cooling processes, major)		
Advection	2-6a, 2-10d, e, 14-5b	2-4, 2-11, 14-5
Conduction	2-6b, 2-10b	2-5, 2-10
Convection	2-10c, 5-3a, 5-5d	2-10, 5-2, 5-3

	Paragraph	Page
Heat Transfer—Continued		
Methods of	2–10	2–9
Radiation	2–10*a*	2–9
Reradiation	2–6*b*	2–5
Heating, land vs. water	2–8*c*, 10–4*a*	2–8, 10–4
High pressure areas	2–20*b*, 4–6*b*, *c*, 4–10*c*, 8–4*a*	2–22, 4–5, 4–11, 8–2
Highs, semipermanent	4–6*b*, *c*	4–5
Horizontal weather depiction chart	16–9	16–6
Horse latitudes (subtropical high pressure belt)	4–4*a*(1)	4–3
Hourly sequence report	11–4*a*	11–2
Humidity (*See* Moisture.)		
Hurricane(s):		
Cause and formation	4–13	4–16
Definition	4–11	4–13
Pressure within	4–18	4–18
Storm tracks	4–12, 4–14, 4–15	4–14, 4–17
Tides	4–20	4–22
Warnings	4–24	4–23
Winds within	4–16, 4–17 4–21, –22	4–18, 4–22
Hydrologic cycle	2–15	4–17
Hygrometer	2–13*a*	2–16
Icing:		
Cold weather operations	9–10	9–12
Danger in mountains	9–8*c*	9–11
Danger in thunderstorms	9–8*b*(1), 10–7*c*	9–10, 10–13
Deicing and anti-icing	9–13	9–1, 9–3, 9–13
Deposit factors	9–2, 9–4, 9–12	
Effect on:		
Airfoil	9–1	9–1
Airspeed	9–1	9–1
Fixed wing aircraft	9–5	9–4
Rotary wing aircraft (helicopters)	9–6	9–7
Formation factors	9–8	9–9
Forms of	9–2	9–1
Intensity (classification)	9–12	9–13
Of aircraft structures	9–1, 9–5, 9–6	9–1, 9–4, 9–7
Of induction systems	9–5*g*, 9–6*b*, 9–7	9–6, 9–7, 9–9
Polar	9–9, (5, app. III)	9–12, III–4
Structural	9–2, 9–3	9–1, 9–2
Temperatures	9–2*a*	9–1
Turbojet	9–7	9–9
Induction system icing	9–5*g*, 9–6*b*, 9–7	9–6, 9–7, 9–9
Insolation:		
Definition	2–10*a*(1)	2–9
Effect on circulation	4–1*b*	4–1
Instability (*See* Stability.)		
Intertropical convergence zone (ITC)	(11*b*, app. III)	III–8
Intertropical front	(11*b*, app. III)	III–8
Inversion, temperature	2–6, 5–9*j*, 7–2*a*, 9–8*a*	2–4, 5–12, 7–4, 9–9
Inversion, trade	(11*a*, app. III)	III–7
Isobars and pressure systems	2–20, 12–5	2–21, 12–7
Isobars and wind	4–8, 4–9, 4–10*b*(1), 12–5*b*	4–9, 4–11, 12–7
Isotach	14–5*c*	14–5
Isotherm	2–10*e*, 14–5*b*	2–9, 14–5
Jet stream	14–6	14–5
Katabatic (fall) winds	4–30	4–29
Land and sea breezes	4–25, 10–4*a* (2), (3)	4–25, 10–6
Land-water effect on convection currents	2–10*c*(1), 4–25, 10–4*a* (2), (3)	2–10, 4–25, 10–6
Lapse rates:		
Pressure	2–21, 14–2, 14–10	2–23, 14–1 14–10
Temperature	2–5, 2–6, 5–4*a*, *b*, 5–5, 5–9*a*	2–2, 2–4, 5–3, 5–9
Latent heat	2–11*d*	2–12
Lifting and sinking processes	4–10*d*, 5–3, 10–2*b*	4–13, 5–2, 10–2
Lifting condensation level	5–5*d*, 5–9*e*	5–5, 5–9
Lightning	10–7*e*(1)	10–13
Line squalls (*See* Squall line, prefrontal.)	(Glossary)	G–5
Low pressure areas	2–20*a*, 4–6*d*, 4–10*c*, 7–7, 12–7	2–22, 4–9, 4–11, 7–14, 12–10
Lows, semipermanent	4–6*d*	4–9
Maps, weather (*see also* Charts):		
Analysis	12–2, 12–5	12–1, 12–7
Facsimile	12–3*a*, 12–9, 16–10, 16–11 16–12	12–1, 12–13, 16–10
Sectional	12–3*b*, 16–8	12–3, 16–6
Maritime air mass (*See* Air mass.)		

	Paragraph	Page
Masses, air (*See* Air mass.)		
Mean sea level (MSL)	2–19 11–9	2–20, 11–9
Mechanical convection	2–6*b*(2), 2–10*c*(2), 5–3*a*(2)	2–5, 2–10, 5–2
Mechanical turbulence	2–6*b*(1), 4–28, 4–32, 5–3*a*(2), 5*c*(2), app. III)	2–5, 4–25, 4–30, 5–2, III–5
Mercurial (mercury) barometer	2–17*a*	2–18
METRO	15–7	15–3
Millibar	2–18*b*	2–18
Mixing ratio	2–12*e*, 5–8*e*	2–15, 5–8
Moisture (humidity):		
Absolute humidity	2–12*c*	2–14
Condensation	2–11*b*, 5–5*d*	2–12, 5–5
Dew point (Table IV, app. II)	2–12*b*, 5–9*b*, 11–11	2–13, 5–9, 11–9, II–1
Distribution of water vapor	2–12*c*(2), 2–12*g*	2–14, 2–15
Evaporation	2–11*a*	2–11
Heat exchange	2–11*d*	2–12
Humidity instruments	2–13	2–16
Mixing ratio	2–12*e*, 5–8*e*	2–15, 5–8
Moisture-temperature relationship	2–12*a*(4)	2–13
Relative humidity	2–12*d*	2–14
Saturated mixing ratio	2–12*f*	2–15
Specific humidity	2–12*c*	2–12
Stability, affects	5–6, 10–2*c*	5–7, 10–2
Sublimation	2–11*c*	2–12
Subsidence	4–10*d*(1)	4–13
Supercooled water	2–14*c*, 9–2*b* (2), 9–8*a*, *b*	2–17, 9–1, 9–9, 9–10
Supersaturation	2–11*b*	2–12
Water vapor	2–11, 2–12	2–11, 2–13
Monsoon	4–27	4–25
Mountain and valley breezes	4–26	4–25
Mountain wave	4–28	4–25
Northeast Trades	4–4*a*(1)	4–3
NOTAMS	11–14*c*	11–10
Notices to Airmen (NOTAMS)	11–14*c*	11–10
Obscurations	11–6*a*(3)	11–7
Observed lapse rate (OLR)	5–5, 5–9*a*	5–3, 5–9
Observations, weather (*See also* Atmospheric sounding diagram):		
PIBAL	13–2*a*, 14–3*b*	13–1, 14–3
Radar	15–1 through 15–4	15–1
RAWIN	13–2*b*, 14–3*a*	13–1, 4–3
Synoptic	12–1	12–1
Winds aloft	13–2	13–1
Occluded fronts	7–1*b*(4), 7–5	7–2, 7–10
Orographic lifting	5–3*a*(2) (*a*), 8–4*c*, 10–4*b*	5–2, 8–3, 10–7
Orographic thunderstorms	10–4*b*	10–7
PIBAL wind observations	13–2*a*, 14–3*b*	13–1, 14–3
Pilot reports (PIREPS)	11–14*b*	11–10
Pilot to forecaster service (METRO)	15–7	15–3
Polar fog	8–4*e*, (4*b*, app. III)	8–3, III–2
Polar front	7–7*c*	7–16
Polar regions:		
Stratus clouds	4*b*, app III)	III–2
Temperature	(Sec. I, app. III)	III–1
Polar tropical trough	(11*d*, app. III)	III–10
Polar weather	(app. III)	III–1
Precipitation:		
Forms	2–14	2–16
Static	10–7*e*(2)	10–14
Symbols	11–8*a*, 12–4*e*, 12–6*b*	11–9, 12–7, 12–10
Prefrontal fog (*See* Fog: Frontal.)		
Prefrontal squall line	7–3*b*(3), 10–3*c*	7–5
Pressure:		
Altitude	2–23	2–27
Altitude relationships	2–21*b*, 14–2	2–23, 14–1
Aneroid barometer	2–17*b*	2–18
Constant pressure charts	14–1	14–1
Definition	2–16	2–18
Gradient	2–21, 4–8	2–23, 4–9
High pressure areas	2–20*b*, 4–6*b*, *c*, 4–10*c*, 8–4*a*	2–22, 4–5, 4–11, 8–1
Isobars and pressure systems	2–20	2–21
Lapse rates (gradient)	2–21	2–23
Low pressure area movement forecasts	12–7, 14–5*a*(3)	12–10, 14–4
Mean sea level	2–19, 11–9	2–20, 11–9
Measurement, units (Table III, app. II)	2–18	2–18, II–1
Measuring, instruments	2–17	2–18
Mercurial (mercury) barometer	2–17*a*	2–18
Systems	2–20	2–21
Tendency	7–1*d*, 7–2*c*	7–2, 7–5
World distribution	4–6*a*	4–5
Prevailing westerlies	4–4*a*(2)	4–3
Primary circulation	4–4	4–3

	Paragraph	Page
Prognostic charts (*See* Forecasts, Facsimile.)		
Psychrometer	2-13*b*	2-16
Quasi-permanent highs and lows	4-6	4-5
Radar:		
Reports (RAREPS)	15-5	15-1
Summary charts	15-6	15-2
Weather observations	15-1 through 15-4	15-1
Radiation, terrestrial	2-6*b*, 8-4*a*	2-5, 8-1
Radiation, transfer of heat	2-10*a*	2-9
Radio broadcasts, weather	16-13, 16-14	16-1, 16-13
Radiosonde observations (RAOB)	5-7, 13-2*b*, 14-3*a*	5-7, 13-1, 14-3
Rain	2-14*b*(1)	2-17
Rawinsonde observations (RAWIN)	13-2*b*, 14-3*a*	13-1, 14-3
References	(app. I)	I-1
Regional forecasts	16-3	16-1
Relative humidity	2-12*d*, 8-2	2-14, 8-1
Reports, teletype sequence:		
Agencies reporting	11-2, 11-15	11-1, 11-10
Ceiling	11-6*b*	11-7
Circuits:		
Civilian weather	11-3*b*(2)	11-2
General	11-3	11-1
Military weather	11-3*b*(1)	11-1
Code:		
Automatic meteorological observing stations	11-15	11-10
Obstructions to vision	11-8*b*	11-9
Sky condition and ceiling	11-6	11-6
Visibility	11-7	11-7
Weather elements	11-8*a*	11-9
Wind	11-12	11-9
Hourly sequence	11-4*a*	11-2
Notices to airmen (NOTAMS)	11-14*c*	11-10
Pilot reports (PIREPS)	11-14*b*	11-10
Record (hourly)	11-4*a*	11-2
Remarks	11-14	11-10
SCAN	11-4*b*	11-2
Service A	11-3*a*	11-1
Station identifiers	11-5	11-6
Reports, winds aloft	13-3	13-1
Reradiation, transfer of heat	2-6*b*	2-5
Ridge	2-20*e*	2-23
Rime ice (*see also* Icing: Structural)	9-3*b*	9-2
Rotor system icing	9-6*a*	9-7
Runway visibility (RVV)	11-7*c*	11-8
Runway visual range (RVR)	11-7*c*	11-8
Saturated mixing ratio	2-12*f*	2-15
Saturation	2-12*a*	2-13
Sea and land breezes	4-25	4-25
Secondary circulation	4-7, 7-7	4-9, 7-14
Sectional map	12-3*b*, 16-8	12-3, 16-6
Semipermanent highs and lows	4-6	4-5
Sequence weather reports (*See* Reports, teletype sequence.)		
Shear	10-6*b*, 14-5*c*, 14-6*f*, *g*	10-10, 14-5, 14-7
Shear line	(11*d*, app. III)	III-10
SIGMET	16-14*a*	16-13
Skew T, log p Diagram:		
Atmospheric stability	5-9*c* through *f*	5-9
Clouds	5-9*g*, *h*	5-10, 5-11
Icing	5-9*i*	5-11
Lapse rates	5-9*a*, *b*, *j*	5-9, 5-12
Plotting data	5-7, 5-8, 5-9	5-7, 5-8, 5-9
Sleet	2-14*d*(1)	2-17
Slope, frontal	7-1*c*(2)	7-2
Snow	2-14*d*(3), (5*c*, app. III)	2-17, III-5
Sounding diagram, atmospheric (*See* Skew T, log p Diagram.)		
Spread	2-12*b*, 5-9*g*(2), 8-2*a*, 11-11	2-13, 5-10, 8-1, 11-9
Squall lines, prefrontal	7-3*b*(3), 10-3*c*, (Glossary)	7-5, 10-3, G-5
Stability	2-6*b*(2), 5-1, 5-2, 5-5, 5-9*c* through *f*	2-5, 5-1, 5-3, 5-9
Standard atmosphere (*See* Atmosphere: Standard.)		
Station model:		
Constant pressure charts	14-4	14-3
Surface weather maps	12-4	12-3
Stationary fronts	7-6, 10-3*d*	7-12, 10-4
Storm tracks	4-12*a*, 4-14, 4-15	4-14, 4-17
Stratiform clouds (*see also* Clouds)	3-2*b*(2), 9-8*b*(1)	3-1, 9-10
Stratosphere	2-3, 14-6*d*	2-1, 14-7
Structural icing	9-2	9-1
Sublimation	2-11*c*, 9-2*c*	2-12, 9-1
Subsidence	2-6*b*(2), 4-10*d*(1), 5-3, 5-9*j*	2-5, 4-13, 5-2, 5-12

	Paragraph	Page
Supercooled water	2-14*c*, 9-8*a*, *b*	2-17, 9-9, 9-10
Surface weather map:		
Analysis	12-2, 12-5, 17-4	12-1, 12-7, 17-2
Ceiling on	12-4*k*	12-7
Construction	12-3	12-1
Facsimile map	12-3*a*	12-1
Identification of fronts	12-6	12-10
Observation time	12-3*a*	12-1
Sectional map	12-3*b*	12-3
Station model	12-4	12-7
Symbols	12-4, 12-6	12-7, 12-10
Time conversion	11-3*b*(1)	11-2
Use in forecasting	12-7	12-10
Wind Velocity	12-4*a*	12-3
Synoptic phenomena	12-1	12-1
Table I. International Cloud Classification, Abbreviations, and Weather Map Symbols		3-1
II. Height, Distribution, and Frequency Observations		10-10
III. Conversion from Inches of Mercury to Millibars		II-1
IV. Dew Point and Moisture Content at 1,000-Millibar Pressure		II-1
I V. The Standard Atmosphere		II-1
VI. Miscellaneous Constants and Units		II-2
VII. Wind Direction: Degrees to Compass Points		II-2
VIII. Surface Wind Character		II-2
IX. Force of the Wind Against a Stationary Object at Sea Level in Standard Atmosphere		II-2
X. Approximate Density Altitude Computations to the Nearest 100 feet		II-3
Teletype circuits	11-3	11-1

	Paragraph	Page
Teletype reports (*See* Reports, teletype sequence.)		
Temperature:		
Altimeter error due	2-22*c*	2-25
Conversion of scales	2-4*b*, 5-8*k*	2-2, 5-9
Definition	2-4	2-2
Free air	2-7, 9-2*a*	2-6, 9-1
Icing	9-2*a*	9-1
In air mass classification	6-3*a*(1), 6-3*b*	6-1, 6-2
In polar regions	(Sec. I, app. III)	III-1
In tropical regions	(Sec. II, app. III)	III-6
Inversion	2-6, 5-9*j*, 7-2*a*	2-4, 5-12, 7-4
Lapse rates	2-5, 5-4, 5-5, 5-9*a*, *b*	2-2, 5-3, 5-3
Moisture relationship	2-12*a*(1), (4), 2-12*d*	2-13, 2-14
Seasonal variations	2-8	2-6
Shown in hourly sequence	11-10	11-9
World distribution	2-8	2-6
Terminal forecasts	16-5, 16-7	16-3, 16-6
Thermal convection	2-10*c*(1), 5-8*a*(1), 10-4*a*	2-10, 5-2, 10-4
Three-Cell Theory	4-4	4-3
Thunderstorm(s):		
Air mass	10-4	10-4
Cell development	3-6, 10-5*a*	3-5, 10-8
Convective	10-4	10-4
Drafts	10-5*b*, 10-6*b*, *c*	10-9, 10-10, 10-12
Effect on airplanes in flight	10-6*b* through *d*, 10-7	10-12, 10-13
Electricity within	10-7*e*	10-14
Flight conditions	10-7	10-13
Flight planning through	10-1, 10-8	10-1, 10-16
Formation factors	10-2	10-2
Frontal	7-3*b*(3), 7-4*b*(3), 7-5*c*, 7-6*a*(2), 10-3	7-5, 7-7, 7-11, 7-14, 10-2
Gusts	10-6*b*, *d*, 10-7*f*	10-10, 10-12, 10-14
Hail	10-7*b*	10-13
Icing	10-7*c*	10-13
Lightning	10-7*e*(1)	10-14
Orographic	10-4	10-4
Prefrontal squall line	7-3*b*(3), 10-3*c* (Glossary)	7-5, 10-3, G-5

	Paragraph	Page
Thunderstorms—Continued		
Stages	10–5*b*	10–8
Turbulence associated with	5–6, 10–7*i*	5–7, 10–16
Time conversion	11–3*b*(1)	11–1
Tornado	4–31	4–29
Tracks, storm	4–12*a*, 4–14, 4–15	4–14, 4–17
Trade inversion	11*a*, app. III)	III–7
Trade winds, northeast	4–4*a*(1)	4–3
Transfer of heat (*See* Heat transfer.)		
Tropical cyclone (*See* Hurricane(s).)		
Tropical weather	(7, app. III)	III–6
Tropopause	2–3, 14–6*b*	2–1, 14–5
Troposphere	2–3*b*, 14–6*b*	2–1, 14–5
Trough	2–20*d*	2–22
Turbulence:		
Cause	4–28*c*, 4–32, 5–3*a*, 10–7*b-d*, *f*	4–26, 4–30, 5–2, 10–13, 10–14
Intensity classification	10–7*i*	10–16
Mechanical	2–6*b*(1), 4–28, 4–32, 5–3*a*(2), (5*c*(2), app. III)	2–5, 4–25, 4–30, 5–2 III–5
Thermal convection	2–10*c*(1), 5–3*a*(1), 10–4*a*	2–10, 5–2, 10–14
Units, meteorological	(app. II)	II–1
Upper air analysis	14–1	14–1
Upslope fog	8–4*c*	8–3
Valley and mountain breezes	4–26	4–25
Vaporization, heat of	2–11*d*	2–12
Vapor pressure	2–12*a*(1)	2–13
Vertical cross section forecast	16–8	16–6
Visibility	11–7	11–7
Vision, weather	17–6	17–13
Warm air Mass (*See* Air mass: Classification.)		
Warm front (*see also* Fronts)	7–4, 10–3*a*	7–7, 10–2
Water (*see also* Moisture (humidity))	2–8*c*, 2–11	2–8, 2–11
Water vapor	2–11, 2–12	2–11, 2–13
Waves:		
Atmospheric	7–7	7–14
Easterly	(11*c*, app. III)	III–8
Weather:		
Advisories	16–14	15–1
Arctic	(1, 6, app. III)	III–1, III–6,
Aviator analysis	17–2	17–1
Broadcasts	16–13	16–13
Definition	2–3*c*(1), (Glossary)	2–2, G–5
Depiction	12–9*b*	12–13
Facilities, aviation (*see also* Surface weather map; and Reports, teletype sequence)	17–3, 17–4	17–1, 17–2
Forecasts (*See* Forecasts.)		
Frontal	7–1*e*, 9–8	7–4, 9–9
High altitude (*See* Constant pressure charts: Weather phenomena.)		
Map analysis	12–2, 12–5	12–1, 12–7
Map, surface (*See* Surface weather map.)		
Maps (*See* Maps, weather.)		
Observations (*See* Observations, weather.)		
Polar	(1, 6, app. III)	III–1, III–6
Reports (*See* Reports, teletype sequence.)		
Symbols	11–8, 12–4, 12–6	11–8, 12–3, 12–10
Tropical	(7, app. III)	III–6
Vision	17–6	17–13
World	(app. IV)	IV–1
Westerlies, prevailing	4–4*a*(2)	4–3
Wind:		
And fog	8–2*b*, 8–3*a*	8–1
Eddy	4–32, (5*c*(2), app. III)	4–30, III–5
Fall (katabatic)	4–30	6–1
Foehn (chinook)	4–29	4–28
Geostrophic	4–10*a*(2)	4–10
Gradient	4–10*a*(1), 12–4*a*	4–10 12–3
Hurricane	4–11, 4–16, 4–17, 4–21, 4–22	4–13, 4–18, 4–22
Jet stream	14–6	14–5
Land and sea breezes	4–25, 10–4*a*(2), (3)	4–25 10–6
Monsoon	4–27	4–25
Mountain wave	4–28	4–25
Relation to pressure systems	4–10*c*, 12–4*a*	4–11, 12–3

	Paragraph	Page
Wind—Continued		
Shear	10–6*b*, 14–5*c*, 14–6*f*, *g*	10–10, 14–5, 14–7
Shift	7–2*b*, 11–12*c*	7–4, 11–10
Speed	4–8, 4–9*c*, 11–12*b*, 14–5*c*	4–9, 4–10, 11–10, 14–5
Surface	4–9*c*, 4–10*b*, 12–4*a*	4–10, 4–11, 12–3
Tornado	4–31	4–29
Trade	4–4*a*(1)	4–3
Valley and mountain breezes	4–26	4–25
Velocity (Tables VII, VIII, IX, app. II)	11–12, 12–4*a*, (Glossary)	11–9, 12–3, II–2, G–5
Winds aloft:		
Charts	13–5	13–3
Classification	4–10*a*	4–10
Forecasts	16–6	16–5
Interpretation of charts	13–5*c*	13–3
Interpretation of reports	13–4	13–2
Observation	13–2	13–1
PIBAL	13–2*a*	13–1
RAWIN	13–2*b*	13–1
Reports	13–3	13–1
World:		
Air masses	(app. IV)	IV–1
Climate	(app. IV)	IV–1
Pressures	4–6	4–5
Temperatures	(app. IV)	IV–1
Weather	(app. IV)	IV–1

By Order of the Secretary of the Army:

EARLE G. WHEELER,
General, United States Army,
Chief of Staff.

Official:

J. C. LAMBERT,
Major General, United States Army,
The Adjutant General.

Distribution:

To be distributed in accordance with DA Form 12–31 requirements for Instructional and General Literature, Other General.

★ U. S. GOVERNMENT PRINTING OFFICE: 1963 O - 691-312