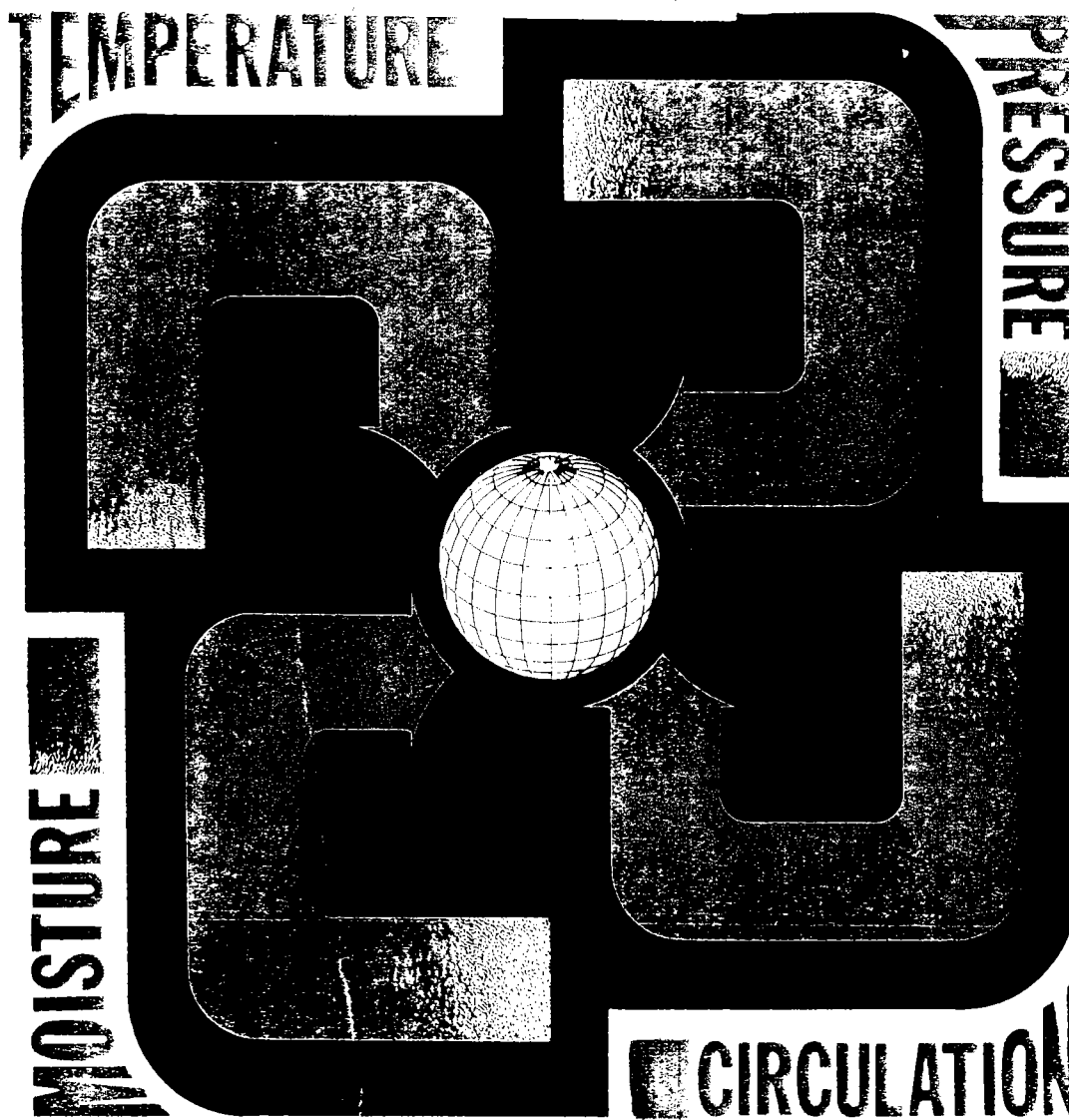


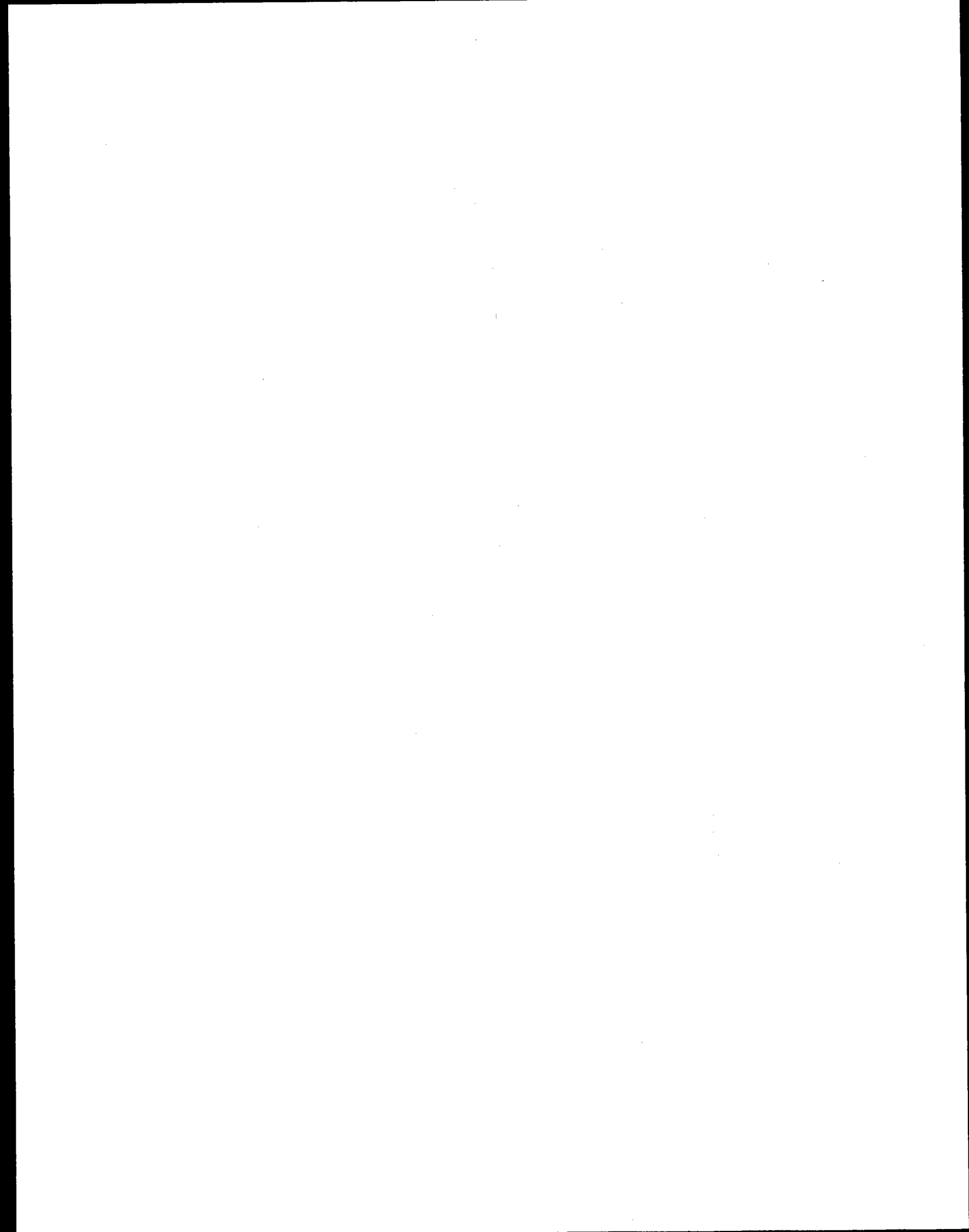
FM 1-230

# METEOROLOGY

## FOR ARMY AVIATORS



HEADQUARTERS, DEPARTMENT OF THE ARMY



**FIELD MANUAL  
NO. 1-230**

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**STATEMENT**

*When used in this publication, "he," "him," "his," and "men" represent both the masculine and feminine genders unless otherwise stated.*

**SECURITY**

"This publication has been reviewed for OPSEC considerations"

*Weather plays an important part in our lives, but it is of particular interest to Army aviators and other members of the crew because of its potential impact on the overall Army mission.*



# WEATHER PRINCIPLES AND THEORY

## CHAPTER 1

### INTRODUCTION

#### 1-1. PURPOSE AND SCOPE

a. This manual provides Army aviation personnel with the general principles of modern meteorology required to assist them in planning and conducting day-to-day flight operations. It will also be useful as a supplemental text and a ready reference.

b. It covers theoretical aspects of meteorological phenomena, the weather facilities available at airfields, severe weather warnings, types of forecasts, and information which will enable Army aviation personnel to interpret and evaluate weather conditions. Although the general information contained in this manual is required background information for weather forecasters, the manual does not include operational forecasting techniques.

c. Users 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 the change is recommended. To insure understanding and complete evaluation, reasons should be provided for each comment. Comments should be prepared using DA Form 2028 (Recommended Changes

to Publications and Blank Forms) and forwarded to the Commander, US Army Aviation Center, ATTN: ATZQ-TD-TL, Fort Rucker, AL 36362.

d. A list of pertinent references is contained in appendix A.

#### 1-2. GENERAL

Army aviators must be knowledgeable of existing and forecasted weather conditions prior to commencing a flight. The aviator must have a thorough knowledge of the meteorological conditions and factors which produce the weather. Although current navigational systems and flight techniques make flight into instrument meteorological conditions possible, flight into hazardous weather conditions, such as icing conditions that could exist in cloudless air, should be avoided whenever possible.

#### 1-3. METEOROLOGY IN THE HIGH THREAT ENVIRONMENT

a. Weather in the combat zone is a major factor in the decisions of the commander; and it can significantly influence the outcome of the battle. Army aviation units, as an essential part of the combined arms team, must be able to operate successfully in different

weather and terrain environments. The high threat posed by the enemy on the battlefield makes it necessary to conduct combat missions in the terrain flight mode to avoid detection by electronic means and destruction by highly sophisticated air defense weapons. Under these conditions, adverse weather can impair mission success and endanger aviation personnel and equipment.

b. It is essential that Army aviation units be able to provide—

- (1) Firepower.
- (2) Movement of troops.
- (3) Logistical support.
- (4) Aeromedical evacuation.
- (5) Surveillance and reconnaissance for the ground tactical elements.

c. Aircraft equipment enabling flight under instrument conditions that is not integrated with a thorough understanding of weather phenomenon is useless. Army aircraft can expect to operate on the battlefield with minimum navigational aids and minimum air traffic control facilities. Each aviator must depend on his proficiency and knowledge in interpreting weather phenomena to make critical decisions concerning the mission.

#### 1-4. MILITARY WEATHER SUPPORT FUNCTIONS

a. Military weather services are specialized services organized worldwide to satisfy unique military requirements. Mobility, responsiveness to combat readiness requirements, and flexibility to adapt to the new weapon systems and concepts are hallmarks of the military weather support services. General military user requirements include, but are not limited to,—

- (1) Meteorological information necessary to support particular weapon systems being deployed or employed.

- (2) Forecasts and analysis for command and control systems.

- (3) Specialized meteorological information for ballistic data, impact prediction, and test analysis assistance to research and development activities.

- (4) General meteorological support and information for training and deployment of military forces.

b. These services are obtained and provided by—

- (1) Forecasting and observation facilities.
- (2) Aerial reconnaissance.
- (3) Meteorological satellites.
- (4) Air-transportable units capable of deploying meteorological support equipment and personnel to support tactical operations.
- (5) Global communications network.

c. Atmospheric processes have a significant impact on Army operations. For this reason, the Army and Air Force are continually developing and improving meteorological techniques and equipment that will provide near real-time meteorological information as related to specific weapon systems and operations. Since Army operations are principally affected by local weather phenomena because of the relatively small area over which they are concentrated, the supporting meteorologists are concerned primarily with the detailed weather information in the lower atmosphere directly over the battlefield area.

- (1) Operational environment services for weather conditions are provided by a combination of Army and Air Force environmental service units. Operational weather forecasting is provided to the Army by the Air Force Air Weather Service (AWS). For example, the Army's artillery ballistic meteorological sections provide data, which is assimilated with other environmental data by AWS forecasters to make accurate weather forecasts.

(2) Specific meteorological support provided by Army units include such operations as:

- Meteorological observations and soundings in support of artillery weapon systems.

- Meteorological observations forward of the division command elements except for those provided by one AWS observing team available for support at each brigade.

- Specialized meteorological support to Army research and development activities.

(3) To support artillery weapon systems, one artillery ballistic meteorological section is assigned to each division/group/separate brigade artillery battalion. These sections generate five types of meteorological messages:

- Ballistic meteorological message.

- Computer meteorological message.

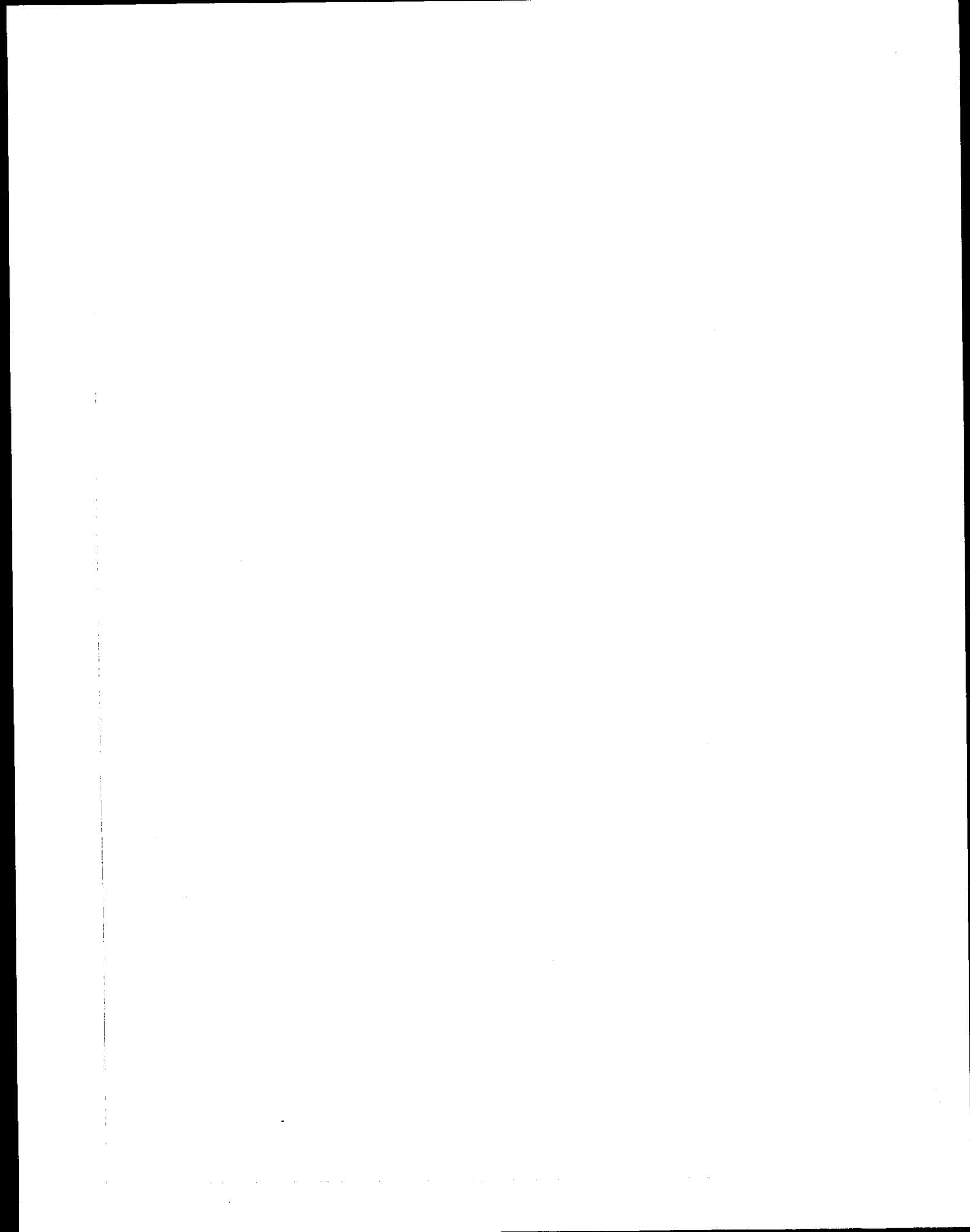
- Fallout meteorological message.

- Sound-ranging meteorological message.

- Air Weather Service (data exchange) message.

(4) The ballistic messages allow artillerymen to make corrections for wind, temperature, and atmospheric density—any of which can cause a projectile to miss its intended target. The fallout message allows the corps chemical officer to plot the areas of nuclear fallout, while the sound-ranging message allows enemy weapons to be located by the sound of their firing. The Air Weather Service message provides AWS forecasters with the upper air information needed for incorporation into technical weather products.

(5) For additional information on military weather support functions, refer to AR 115-10/AFR 105-3.





## CHAPTER 2

### THE ATMOSPHERE

#### 2-1. GENERAL

a. The atmosphere is the envelope of air which surrounds the earth. Approximately one half of the air, by weight, is within the lower 18,000 feet. The remainder of the air is spread over a vertical distance in excess of 1,000 miles. No definite outer atmospheric boundary exists. The air particles, however, become less numerous with increasing altitude until they gradually overcome the earth's gravitational force and escape into space.

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*. Although other factors influence circulation, it is created primarily by the imbalance of solar radiation between lower and higher altitudes. Circulation is also influenced by uneven heating of land and water areas by the sun.

c. The standard atmosphere covered in this field manual is in agreement with the accepted United States standard as adopted in NATO STANAG 4044 (Edition 2).

#### 2-2. COMPOSITION

a. *Gases.* A given volume of dry air contains about 78 percent nitrogen; 21 percent

oxygen; and 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 vapor it can hold.

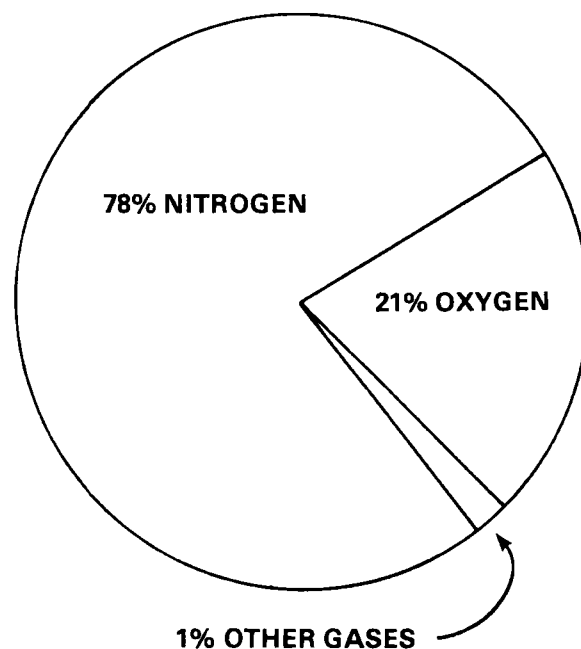


Figure 2-1. Composition of the atmosphere.

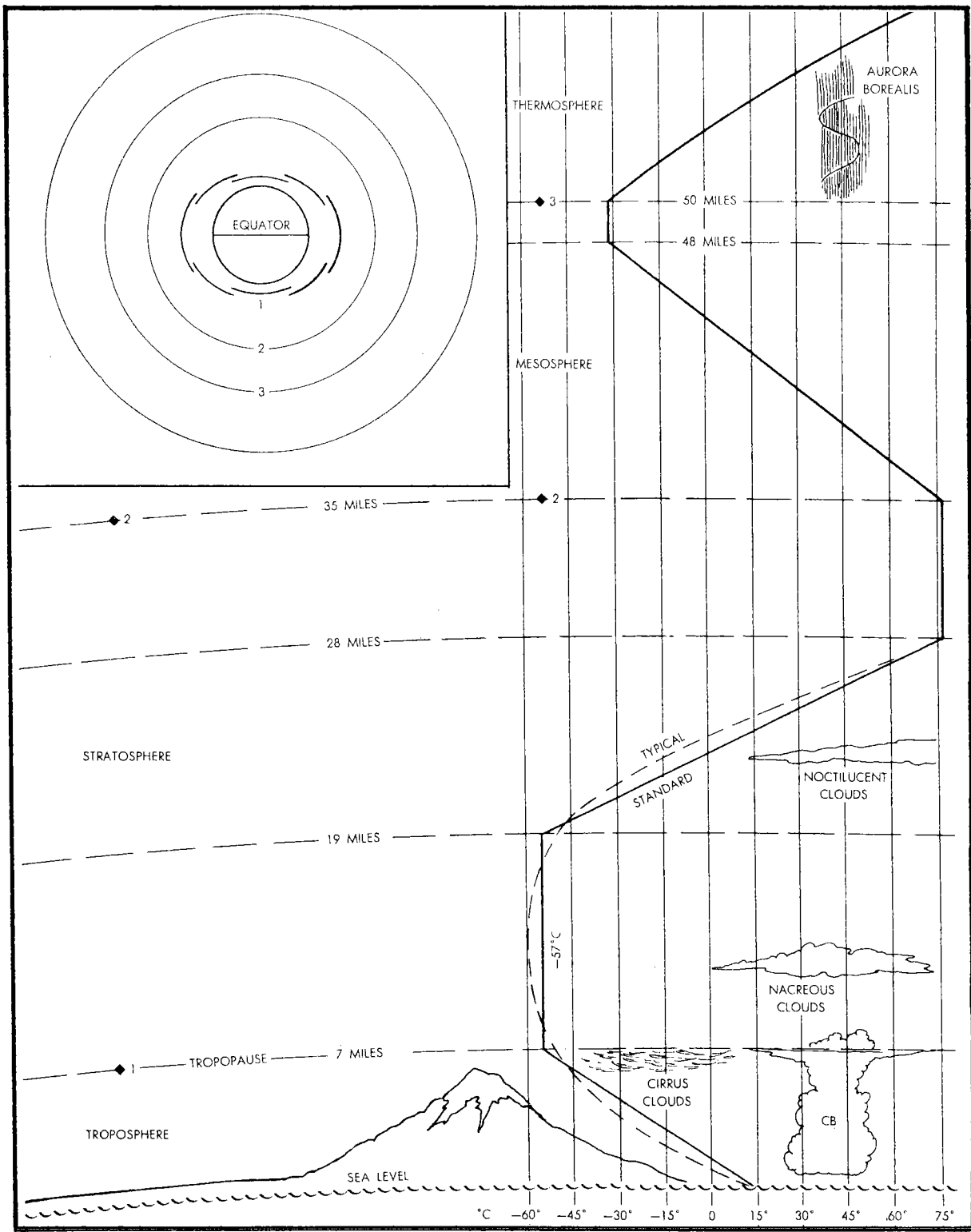


Figure 2-2. The earth's atmospheric layers.

*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 to water droplets or sublimation to ice crystals (these terms are covered in chapter 4). If the air did not have these impurities, there would be little condensation or sublimation.

## 2-3. STRUCTURE

*a. Weight.* Although extremely light, air does have weight. Because of its weight, the atmosphere exerts a pressure of approximately 14.7 pounds per square inch at sea level.

*b. Layers.* Figure 2-2 illustrates the division of the atmosphere. The troposphere is the layer closest to the earth where most of our weather phenomena occur (e.g., clouds, rain, hail). Next are the stratosphere, mesosphere, ionosphere, thermosphere, and exosphere. The troposphere varies in height from an average of 60,000 feet above sea level (ASL) over the Equator to 25,000 feet over the Poles and varies with seasons. It is higher in summer than in winter; for example, in temperate zones during the spring and fall seasons, it is about 35,000 feet ASL. The boundary zone between the troposphere and its neighbor, the stratosphere, is known as the tropopause.

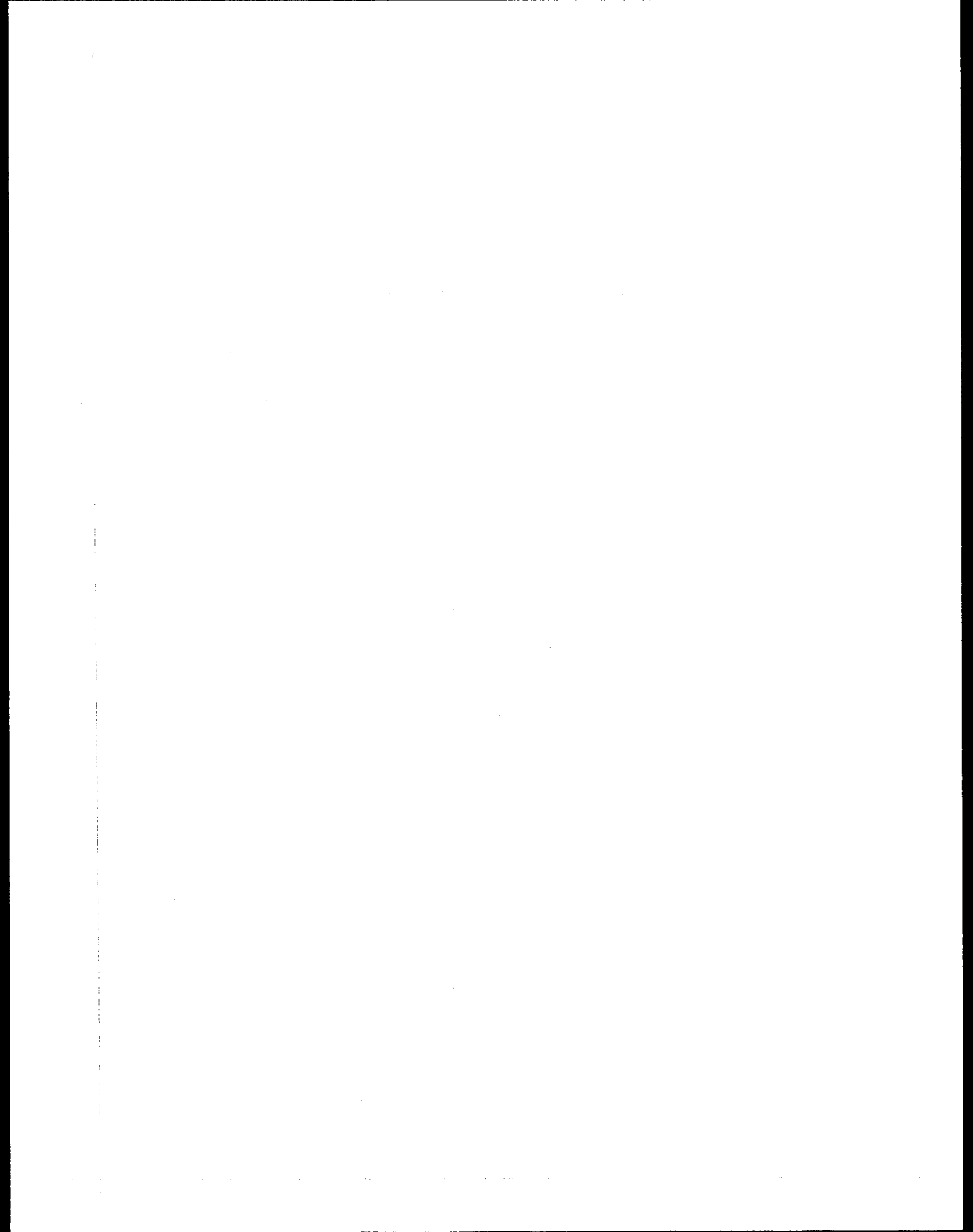
### *c. Weather Elements.*

(1) "Weather" is defined as the state of the atmosphere with respect to temperature, moisture content, turbulence, and cloudiness. These interact in various combinations to form the following six major meteorological elements:

- Air temperature.
- Humidity.
- Clouds.
- Precipitation.
- Atmospheric pressure.
- 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, and low ceilings) exist only where moisture is available, these conditions are primarily associated with processes occurring in the troposphere.



## CHAPTER 3

### 3-1. GENERAL

a. Temperature is a measurement of the amount of heat and expresses the degree of molecular activity. Since different substances have different molecular structures, equal amounts of heat applied to equal volumes of two different substances will result in unequal heating of each substance. Every substance has its own unique specific heat. For example, a land surface becomes hotter than a water surface when equal amounts of heat are added to each (fig 3-1). The degree of "hotness" or "coldness" of a substance is known as its temperature; and it is measured with a thermometer.

b. The earth's surface is heated during the day by the sun. Incoming solar radiation to the earth is called *insolation*. Heat radiated from the earth by outgoing radiation is called *terrestrial radiation*. The cooling that occurs at night is terrestrial radiation and insolation.

### 3-2. TEMPERATURE MEASUREMENT

a. Fahrenheit and Celsius (centigrade) are the temperature scales important to the aviator. On the Fahrenheit (F) scale, the freezing point is 32° and the boiling point is 212°—a difference of 180° (fig 3-2). On the Celsius (C) scale, the freezing point is at 0° and the boiling point is 100°—a difference of 100°. The ratio between degrees Fahrenheit and degrees Celsius is therefore 180 to 100, or 9 to 5. This means that a temperature difference of 9°F is equal to a temperature difference of 5°C. This ratio is used in converting from one scale to another as shown below and in figure 3-2.

$$^{\circ}\text{C} = \frac{5}{9} (^{\circ}\text{F} + 40) - 40$$

$$^{\circ}\text{F} = \frac{9}{5} (^{\circ}\text{C} + 40) - 40$$

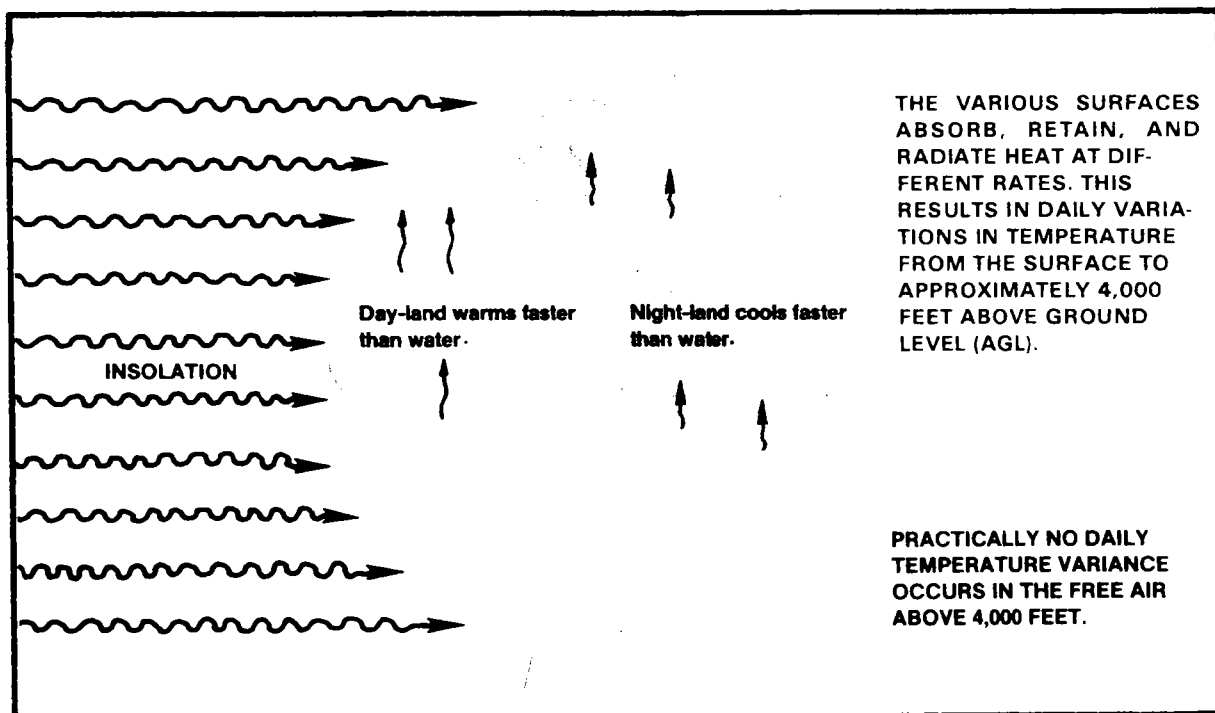


Figure 3-1. Land has greater temperature variance than water.

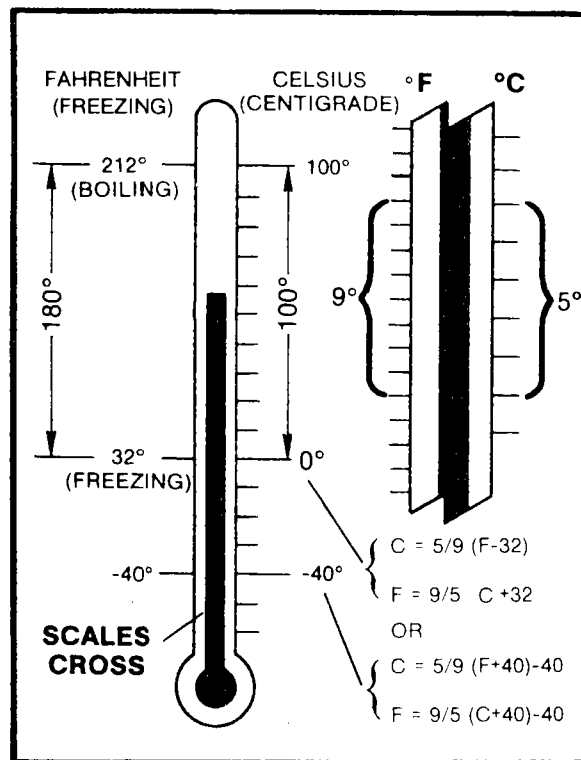


Figure 3-2. Temperature conversion methods.

Note that the only difference in the conversion from one scale to the other is the 9/5 and the 5/9. This conversion method should be easier to remember because it is less complex than earlier methods. Many air navigation computers are marked for direct conversion between Fahrenheit and Celsius.

b. The temperatures considered in aviation weather are those of the free air. The temperature-measuring elements are exposed in a manner that avoids direct sunlight and minimizes other effects that cause inaccuracies in the readings.

c. The measurement of outside air temperatures with the typical aircraft temperature gage is influenced by several factors (e.g., radiation, air compression, friction), which tend to decrease the accuracy of these observations. Such effects may cause the reading to differ from the true free-air temperature by 14°C or more, except where careful engineering has been provided.

3-2

3-3. DAILY RANGE OF TEMPERATURE

The range of temperature between night and day varies considerably with season and location. The daily variance is large near the surface of barren, high-level places and over sand, plowed fields, and rocks. It often ranges from 17°C to 28°C. The variance is much smaller over thick vegetation and deep water surfaces where it may be only about 1°C. Practically no change of temperature occurs between night and day in the stagnant free air 4,000 feet or more above the surface.

3-4. TEMPERATURE DISTRIBUTION

a. *Surfaces.* The temperature distribution over the surface of the earth depends first on the seasons and secondly on the composition and distribution of land and sea surfaces over the earth. Figure 3-3 shows the surface temperature distribution for January (A) and July (B) representing both hemispheres, winter and summer, respectively. It also clearly illustrates the influence of topography on the temperature.

The following information can be observed:

- (1) The ocean areas between latitudes 40 degrees north and 40 degrees south show very little temperature changes from summer to winter.
- (2) The land areas are warmer than the adjacent water areas at the same latitude during summer.
- (3) The water areas are warmer than the adjacent land areas during winter.
- (4) Both the warmest and coldest temperatures are found over the land areas.
- (5) The temperature and resultant density (density is the amount of mass per unit volume of any substance) at and near the surface greatly affect allowable gross weights for takeoff and landing. An aircraft, at the same location, taking off during night or early morning when the air is dense (due to

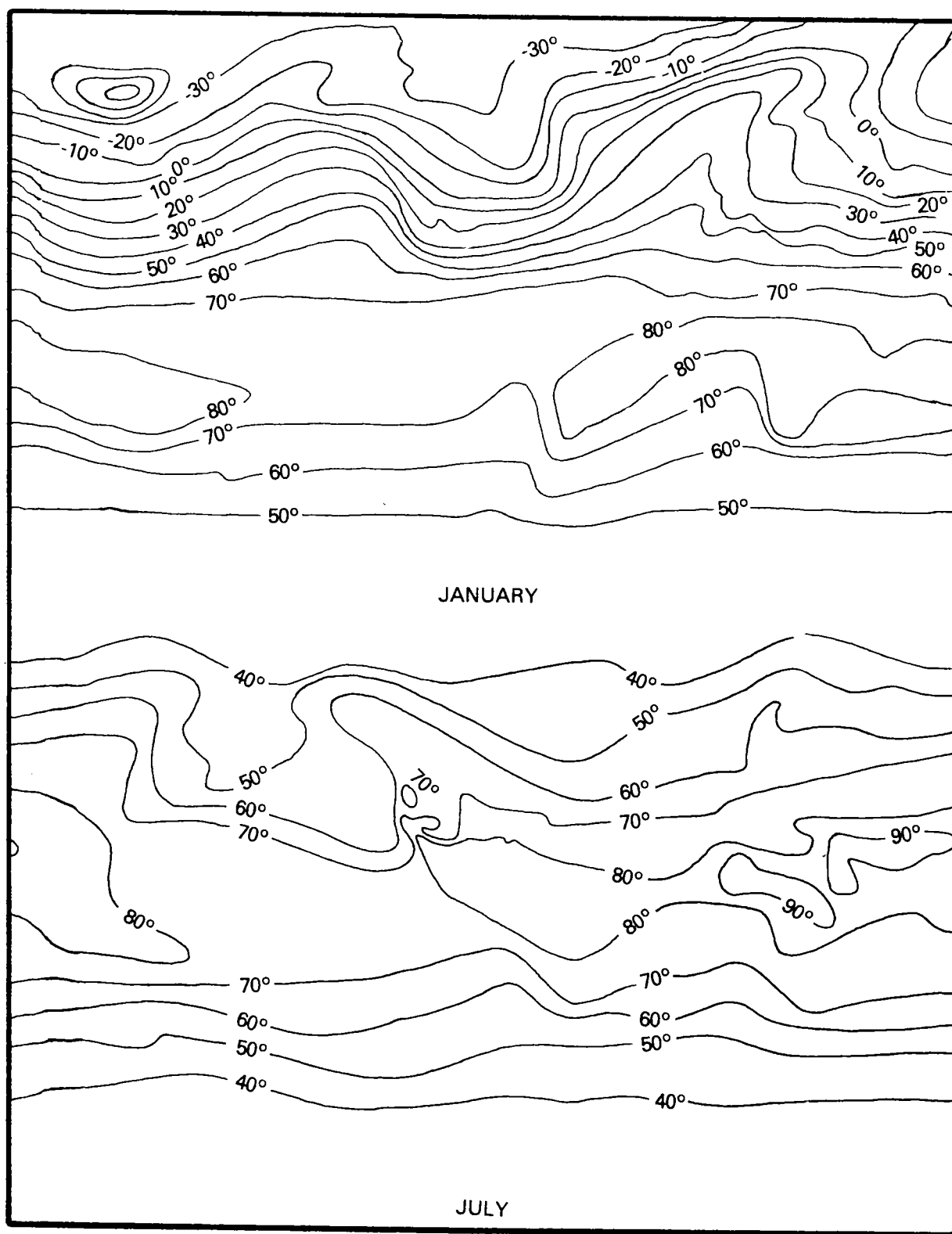


Figure 3-3. Surface temperature distribution for January-July.

nighttime cooling) generally has more allowable gross weight than it would have in the early afternoon when the air has warmed and become less dense.

*b. Aloft.* The aircrew is concerned with temperatures aloft in selecting flight altitudes and determining airspeeds and freezing levels.

### 3-5. HEAT TRANSFER

Heat can be transferred from one body to another in three ways—*radiation, conduction, and convection.*

*a. Radiation.* Radiation is the transfer of heat by electromagnetic waves. No medium of transfer is required between the radiator and the body being irradiated (receiving the radiation). Light waves are an example of this type of radiation. In the transport of light waves, certain materials are transparent and pass all light through. Most gases and clear glass are in this category. Some materials are opaque and will pass no light; others pass only some light. Of those that pass only some light, if they are selective and pass only certain wavelengths (colors), they are called *filters*. Heat waves can be filtered in much the same way by gases in the atmosphere, principally water, vapor, carbon dioxide, and ozone. Each of these gases will absorb certain wavelengths of heat waves and allow others through. When heat waves are absorbed, the energy is transferred to the absorber, raising its temperature. Heat waves can also be reflected. In meteorology, the principal reflectors are the earth's surface, water droplets, and particulate matter in the atmosphere. Clouds and snowfields are the most effective reflectors, since they can reflect between 50 percent and 80 percent of the sun's heat and light radiation back into space (fig 3-4).

*b. Conduction.* Conduction is the transfer of heat energy through a medium or between two substances in direct physical contact by passing from molecule to molecule. As with electricity, some materials are good conductors while others are poor conductors. The latter are considered to be insulators. Air is one of the poorest conductors of heat. If air

is compared to silver, one of the best conductors, it will be found that the silver will pass 20,000 times more heat than an equal mass of air across a similar temperature difference during a fixed period of time. Conduction in the atmosphere is considered to be a significant method of heat exchange only at the earth's surface, where the lowest few centimeters of the atmosphere are actually in contact with the ground or water.

*c. Convection.* Convection is the process whereby a heated substance such as a gas or a liquid moves from one place to another, carrying heat with it. This can be demonstrated very well by placing a container of cold water on a stove. When the water on the bottom is warmed, it expands, becomes less dense, and rises to the top, bringing heat with it. The cold water at the top, being more dense, sinks to the bottom where it will be heated before continuing its cycle (fig 3-5).

(1) The same type of heat transfer happens in the atmosphere when the ground is heated by the sun. The warm ground heats the air above it by radiation and conduction. The warm air rises and cooler air aloft, being more dense, moves in to take its place, subsequently to be heated.

(2) Heat can be transferred by convection in either a vertical or horizontal direction.

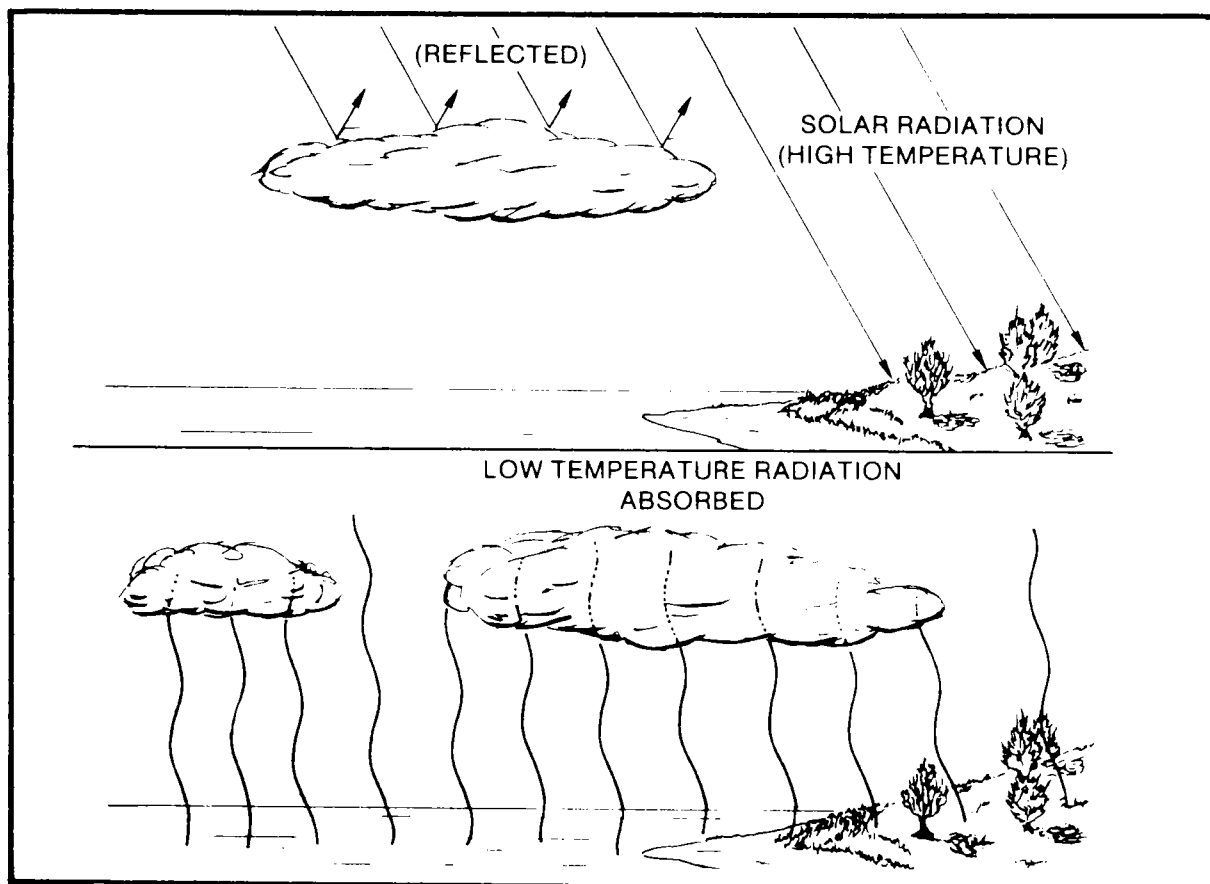
*d. Advection.* In meteorology, "advection" is the term used for the horizontal transport of heat by wind. It is important to differentiate between the vertical and horizontal paths of convection. In the atmosphere, the amount of heat transferred horizontally over the surface of the earth by *advection* is about one thousand times greater than that transferred vertically by *convection*.

### 3-6. ADIABATIC PROCESS

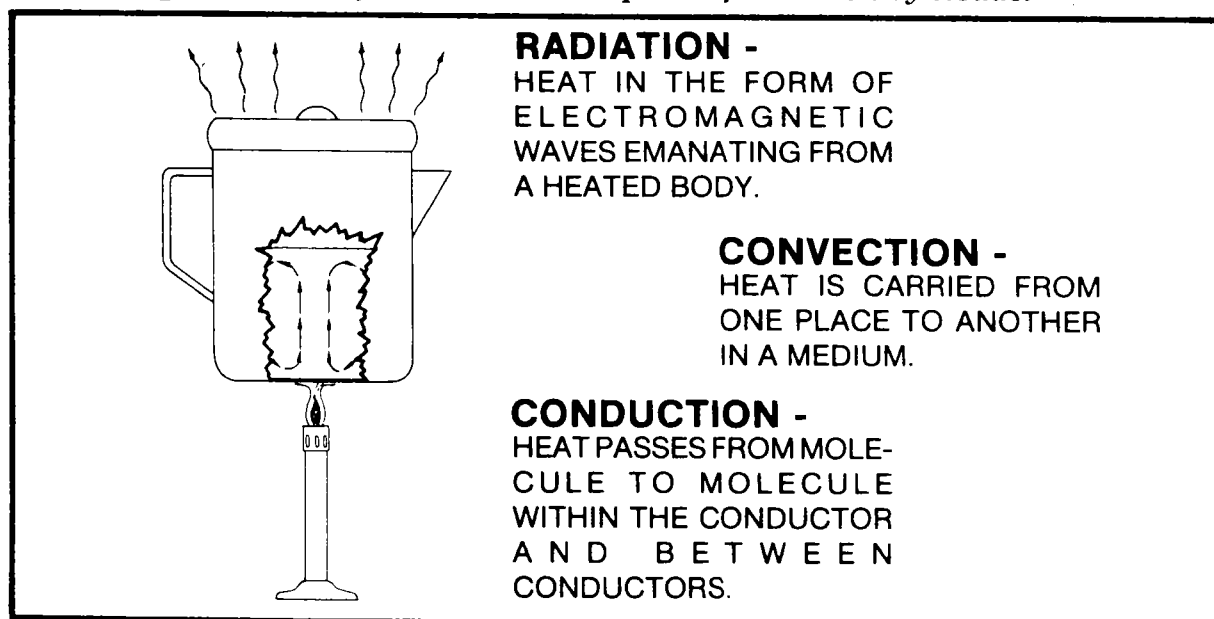
#### *a. General.*

(1) Air is made up of a mixture of gases that is subject to heating when it is compressed and cooling when it is expanded (fig 3-6). As a result, it will rise, seeking a level where the pressure of the body of the air is equal to the pressure of the air that surrounds





*Figure 3-4. Reflection and absorption of radiation by clouds.*



*Figure 3-5. Example of heat transfer.*

it. There are other ways air can be lifted (e.g., through a thunderstorm; mechanically, such as having colder, denser air move under it as it flows up over a mountain slope).

(2) Whatever the cause of the lifting, the air rises and the pressure becomes less, allowing the "parcel of air" to expand. This continues until it reaches an altitude similar in pressure and density to its own. As it expands, it cools through a process in which there is no heat added or withdrawn from the system in which it operates. This is known as the **adiabatic process** (fig 3-6). As air rises, it is cooled because it is expanding by moving to an altitude where pressure and density is less. This is called **adiabatic cooling**. When the process is reversed and air is forced downward, it is compressed, causing it to heat. This is called **adiabatic heating**.

b. **Dry Adiabatic Lapse Rate.** If the air which is rising is unsaturated (dry and relatively free of moisture content), the rate of decrease in temperature is about  $3^{\circ}\text{C}$  for each 1,000 feet of altitude. This is known as the **dry adiabatic lapse rate** (C, fig 3-7).

c. **Moist Adiabatic Lapse Rate.** If the air is saturated (relatively high in moisture content) the lapse rate (decrease) will be less, depending upon the existing temperature and amount of moisture in the air. This rate varies from  $1.1^{\circ}\text{C}$  to  $2.8^{\circ}\text{C}$  per 1,000-feet of altitude gain. Since air can hold more water vapor at high temperatures, a small decrease in the temperature of ascending saturated air causes a relatively large amount of moisture to condense as it cools. This condensation process releases the latent heat absorbed during the evaporation process (chap 4) and

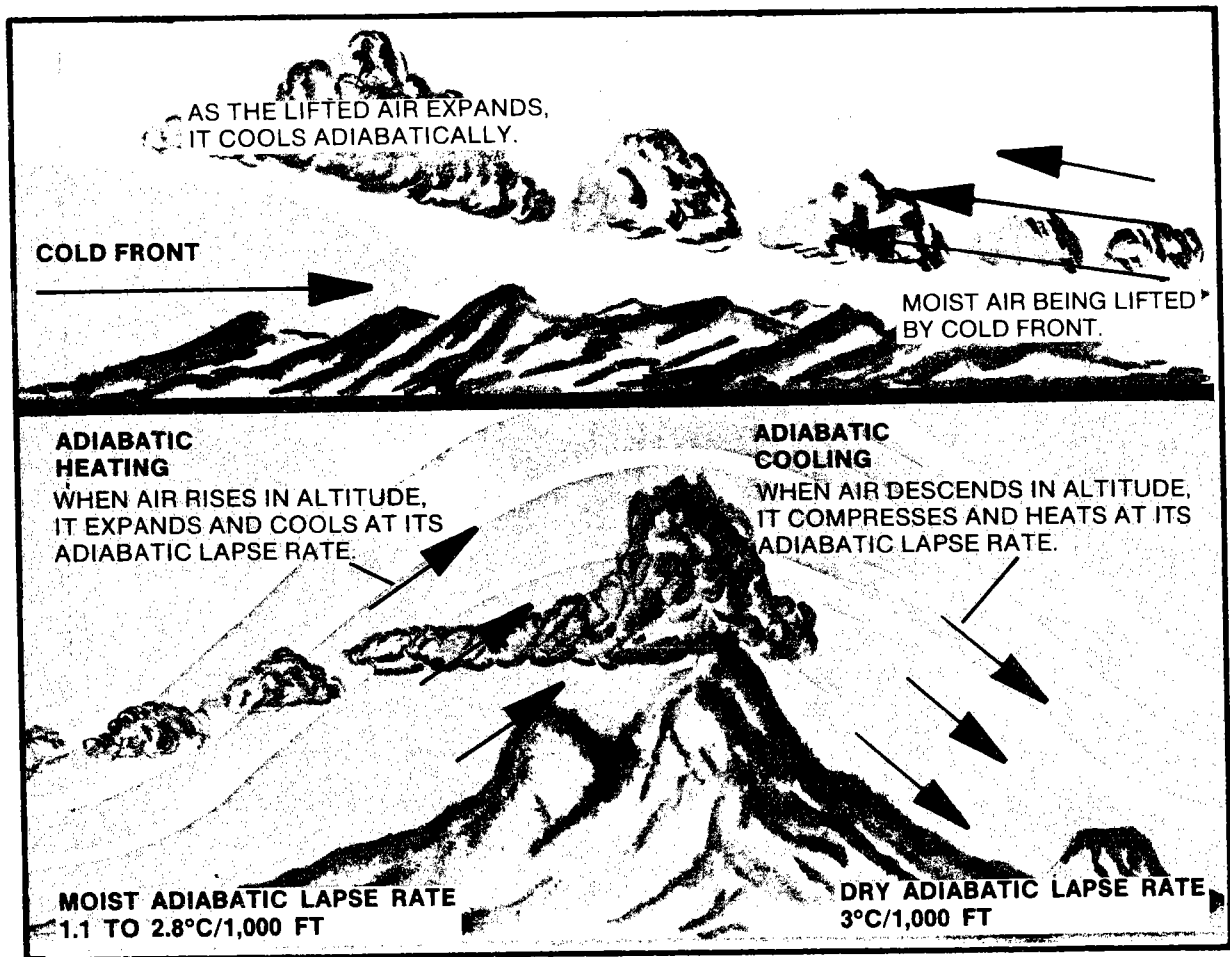


Figure 3-6. Adiabatic cooling and heating process.

heats the air, thus retarding the temperature decrease. This condensation process explains why the *moist adiabatic lapse rate* is not a fixed value (B, fig 3-7). "Latent heat" is defined as the amount of energy or heat required to cause water to go from a liquid to a gaseous state.

### 3-7. LAPSE RATE

There is another important free-air temperature which is the rate of temperature decrease with increase in altitude. Cold air decreases in temperature with altitude faster than warm air. Thus we see that as an object, such as an aircraft, moves through these different levels of pressure (altitudes), it will encounter different free-air temperatures. The

rate of temperature change with altitude is measured from the surface of the earth upward, usually at 1,000-foot intervals. The rate of decrease in temperature with altitude is called *lapse rate*.

a. *Standard Lapse Rate*. Because of the variance in lapse rates, it is necessary to establish a standard lapse rate as a basis for calibrating aircraft instruments and preparing performance charts (A, fig 3-9). By evaluating thousands of atmospheric soundings from various parts of the world it was determined that the average lapse rate was approximately  $2^{\circ}\text{C}$  per 1,000 feet of altitude gain. While the standard lapse rate is used in the United States and most of the world for calibrating aircraft instruments, there is no

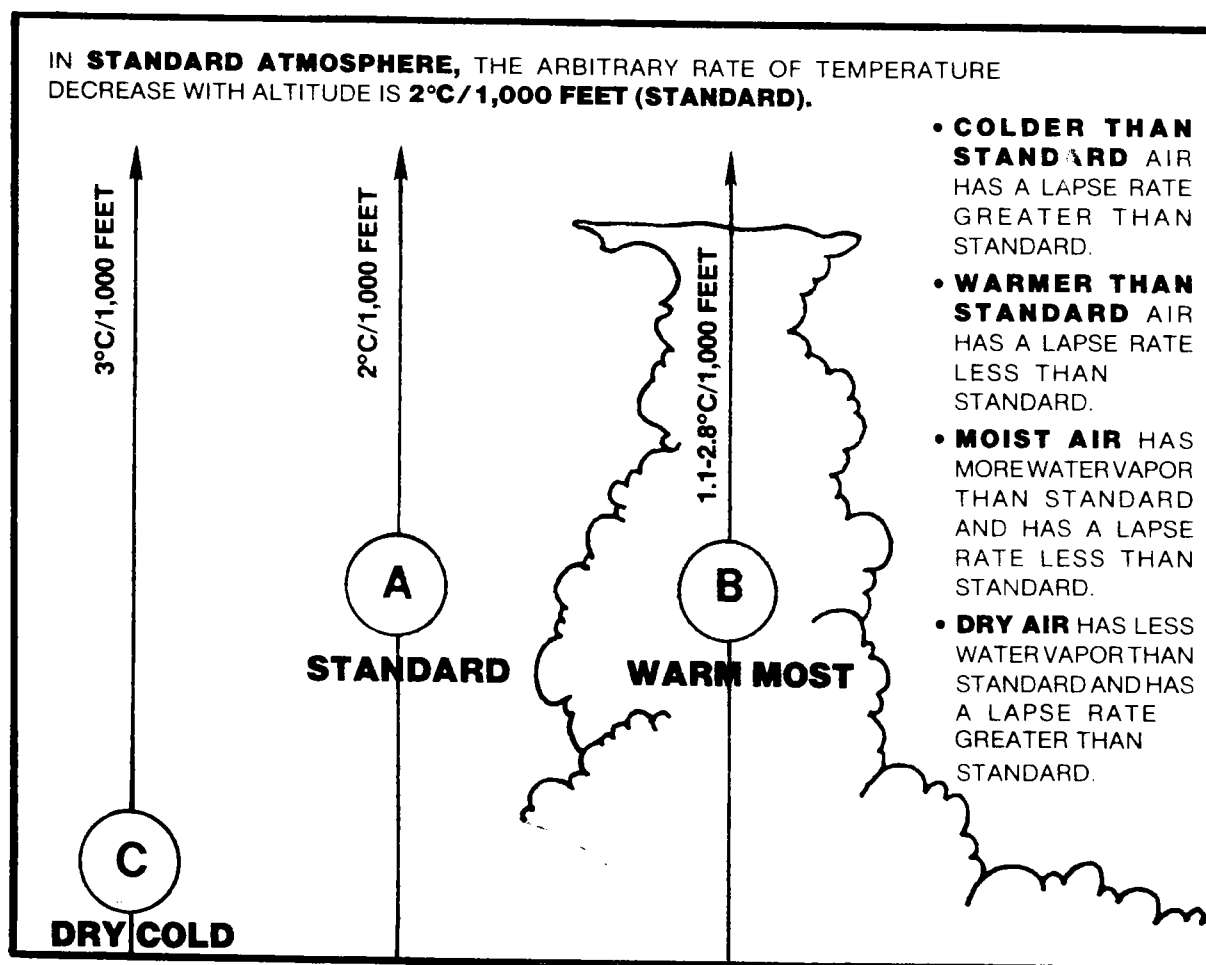


Figure 3-7. Adiabatic lapse rates.

connection with determining the stability of air on a day-to-day basis. Figure 3-8 shows nonstandard temperature effects on pressure and density. Variation in the lapse rate may change the altitude itself (fig 3-7). At a given time and place, for example, the temperature might decrease at a rate of 3°C per 1,000 feet from the ground to an altitude of 5,000 feet, at a rate of 1°C per 1,000 feet between 5,000 and 7,000 feet, and at 2°C per 1,000 feet above 7,000 feet until the tropopause is reached.

*b. Inversions.* Many times there is a layer within the troposphere that is characterized by an increase of temperature with altitude rather than a decrease. This situation occurs frequently, but is usually confined to a relatively shallow layer. It is called *an inversion*, because the usual decrease in temperature with altitude is inverted.

(1) The most frequent type of inversion to occur over land is produced immediately above the ground on a clear, relatively still night. The ground loses heat rapidly through terrestrial radiation, cooling the layer of air next to it. The amount of cooling decreases rapidly with altitude, and the temperature of the air a few hundred feet above the ground is affected very little or not at all. Thus terrestrial radiation causes the lowest layer of air to be colder than the air just above that layer.

(2) Inversions are also found in association with movement of colder air under warm air or the movement of warm air over cold air. Such inversions are often called *frontal inversions*. Their formation will be better understood after studying the chapter on "fronts."

(3) Another temperature inversion is produced by adiabatic warming of a layer of subsiding air. This inversion is enhanced by vertical mixing in the layer below the inversion; and it is associated with well-defined, large high-pressure systems.

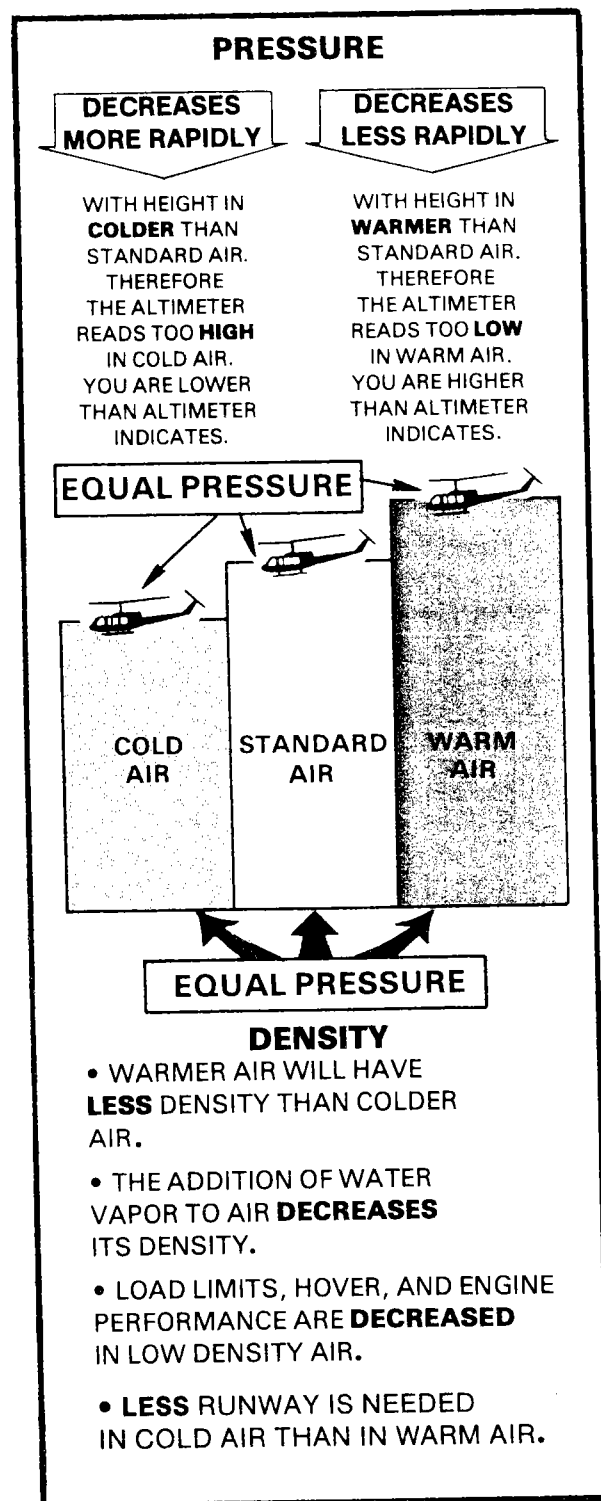


Figure 3-8. Effect of nonstandard temperature on pressure and density.

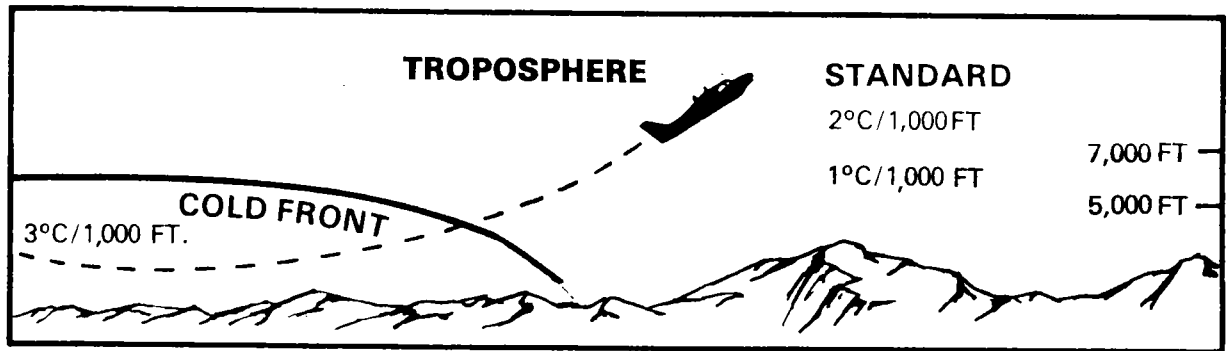


Figure 3-9. Lapse rates may vary from layer to layer.

(4) Figure 3-10 illustrates a ground (surface-based) inversion and an inversion aloft. Restrictions to vision, such as fog, haze, smoke, and low clouds, are often found in or below low inversions and in layers through

which there is only a small change in temperature. The air in these layers is usually very smooth; however, turbulence may be expected between the layers.

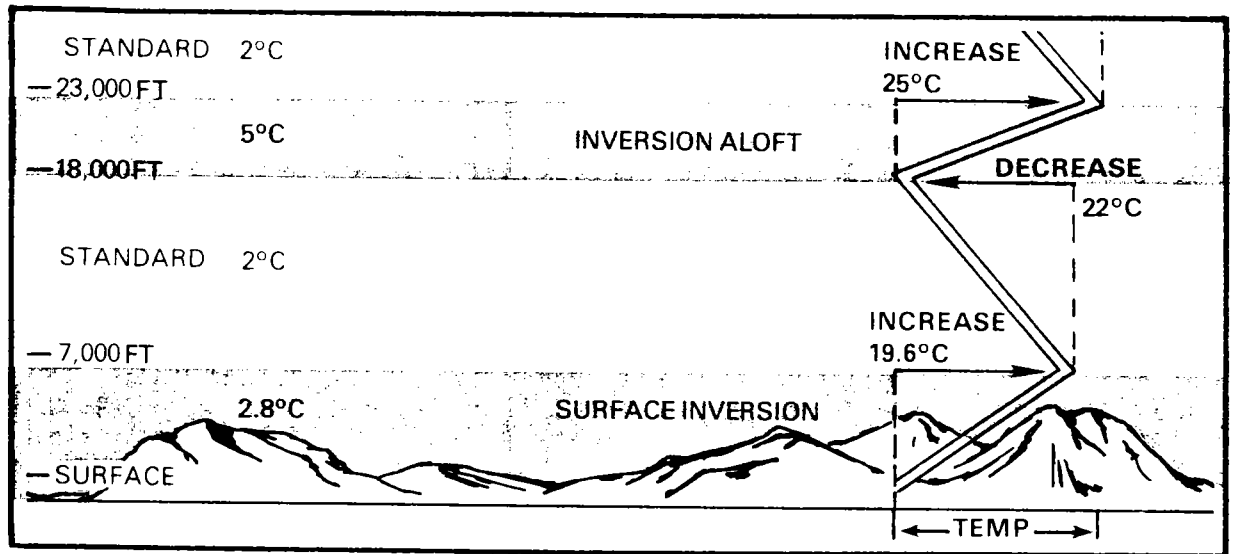
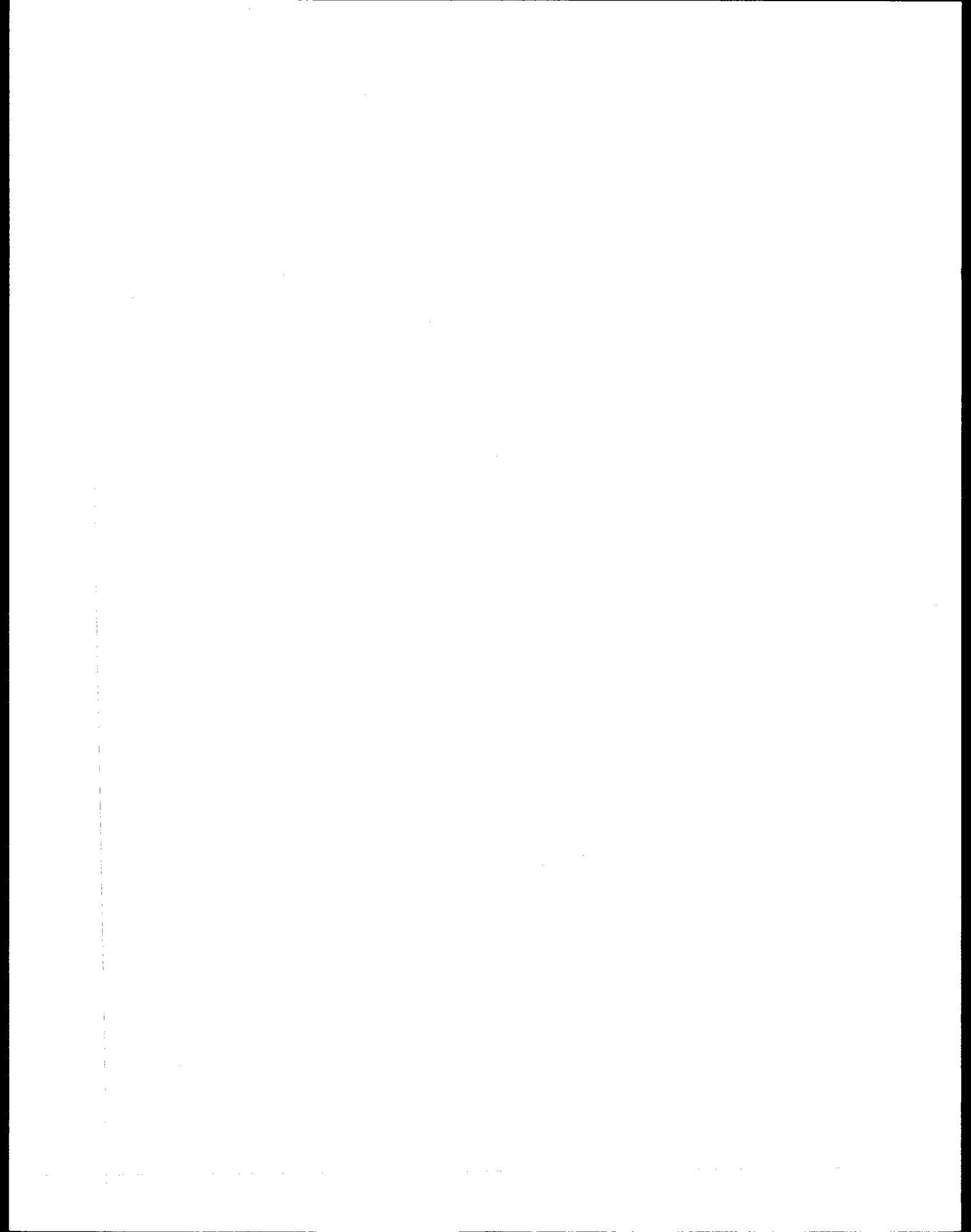


Figure 3-10. Lapse rate temperature reversals are called inversions.



## CHAPTER 4

### 4-1. GENERAL

a. More than two thirds of the earth's surface is covered with water. Water from this extensive source is continually evaporating into the atmosphere, cooling by various processes, condensing, and then falling to the earth again as various forms of precipitation. This never-ending process is referred to as the *hydrologic cycle* (fig 4-1). This

cycle keeps moisture in the atmosphere and causes temperature and pressure changes (fig 4-2).

#### NOTE

Almost all weather hazards that interfere with the operation of Army aircraft are associated with the effects of water.



Figure 4-1. Hydrologic cycle.

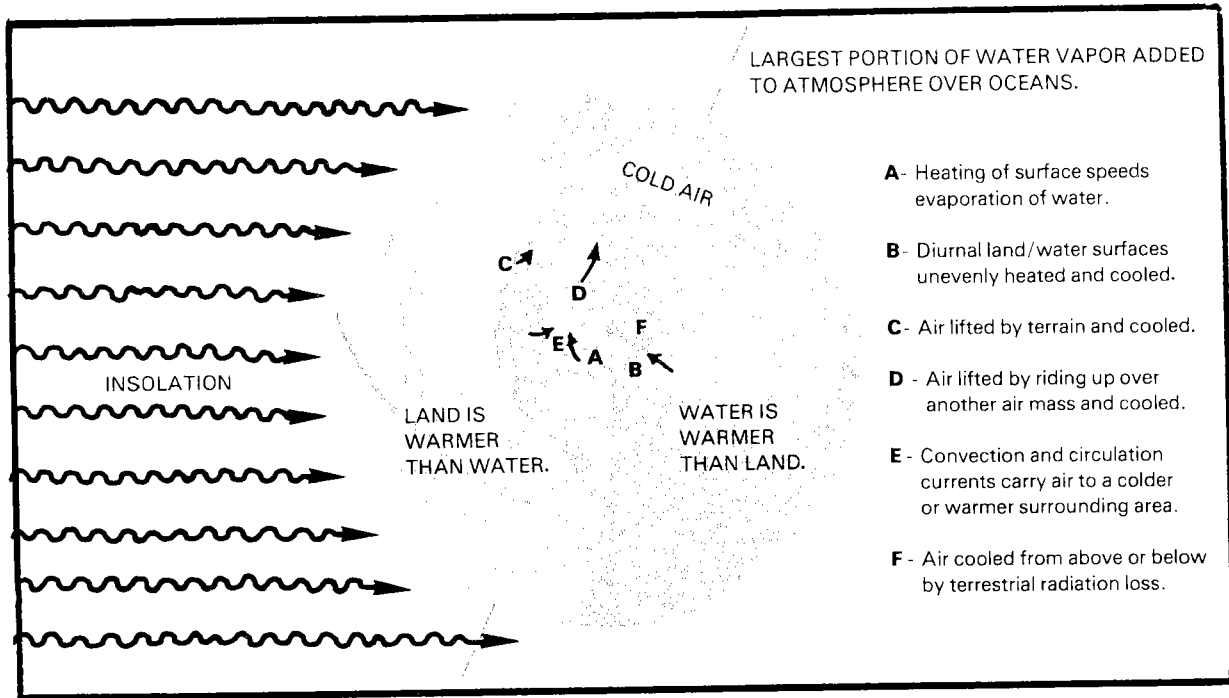


Figure 4-2. Factors affecting hydrologic cycle.

b. The remaining third of the earth's surface is composed of solid land with different terrain features. Knowledge of these terrain differences is important to the Army aviator in weather planning. The world terrain varies from large-scale mountain ranges to minor rolling hills and valleys to flat arid deserts. Each type of terrain significantly influences local wind flow, moisture availability, and the resulting weather.

## 4-2. MOISTURE CHANGES

### a. General.

(1) Water in the atmosphere is found in three states—**solid**, **liquid**, and **gaseous**. As a solid, it takes the form of snow, hail, ice pellets, frost, ice-crystal clouds, and ice-crystal fog. As a liquid, it is found as rain, drizzle, dew, and as the minute water droplets composing clouds and fog. In the gaseous state, water is an invisible vapor. Water vapor is the primary element in the production of clouds and precipitation. The availability of water vapor for the production of

precipitation largely determines the ability of a region to support life. However, it also creates problems—and sometimes hazards—for the Army aviator when it changes into the liquid or solid state.

(2) Most of the earth's moisture is concentrated in the lower troposphere. Rarely is it found in significant amounts above these altitudes.

(3) The oceans are the primary water source for the atmosphere. Other sources are—

- Lakes.
- Rivers.
- Swamps.
- Moist soil.
- Snow.
- Ice fields.
- Vegetation.

Moisture is introduced into the atmosphere in its gaseous state. It is then carried great



distances by the wind before it is discharged as liquid or solid precipitation.

**b. Heat Exchange.**

(1) The change from one state of moisture to another involves the exchange of heat energy. The moisture either absorbs it or releases it to its environment.

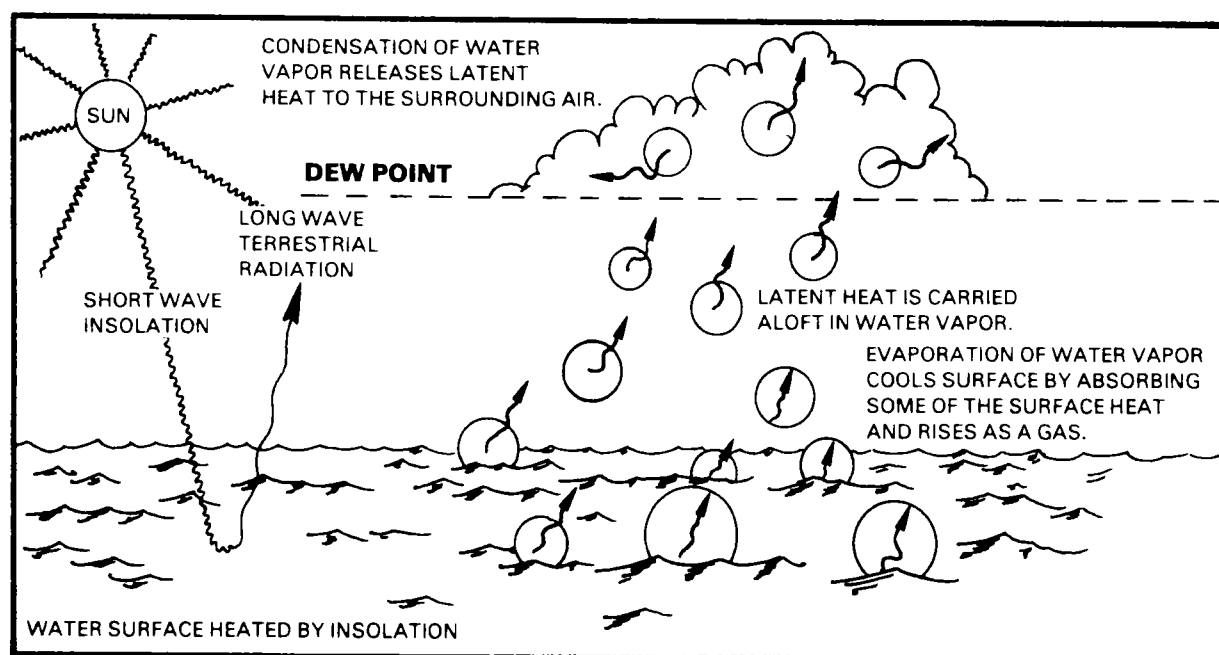
(2) The processes requiring heat to be added to the moisture are *melting*, *evaporation*, and *sublimation*.

**c. Melting.** Melting occurs when heat is applied to a solid until its molecules flow freely in the liquid state. Liquid water temperature increases  $1^{\circ}\text{C}$  for each calorie added per cubic centimeter of water.

**d. Evaporation.** Evaporation (fig 4-3) is a change in state from a liquid to a gas. During evaporation, the higher energy molecules escape, thereby reducing the overall energy or heat content of the liquid. This

results in a cooling of the liquid. The environment surrounding the liquid is subsequently cooled by conduction. At a temperature of  $0^{\circ}\text{C}$ , 577 calories of heat energy are lost from the liquid for every gram of water that evaporates. This is known as the latent heat of vaporization.

**e. Sublimation.** Sublimation is the direct change of state from solid to vapor and vice versa, without passing through the intermediate liquid state. This process takes place at temperatures below  $0^{\circ}\text{C}$ ; and is similar to evaporation (condensation) in that latent heat is liberated when solidification takes place and is absorbed when evaporation occurs. At temperatures below  $0^{\circ}\text{C}$ , ice or snow can sublime directly into the air as water vapor, absorbing 677 calories of heat energy per gram in the process. When the required nuclei are present, the water vapor can sublime directly into ice crystals, releasing 677 calories of heat energy in the process. The processes releasing heat are called *sublimation condensation*. Changes in the state of water are illustrated in figure 4-4.



**Figure 4-3. Evaporation and condensation.**

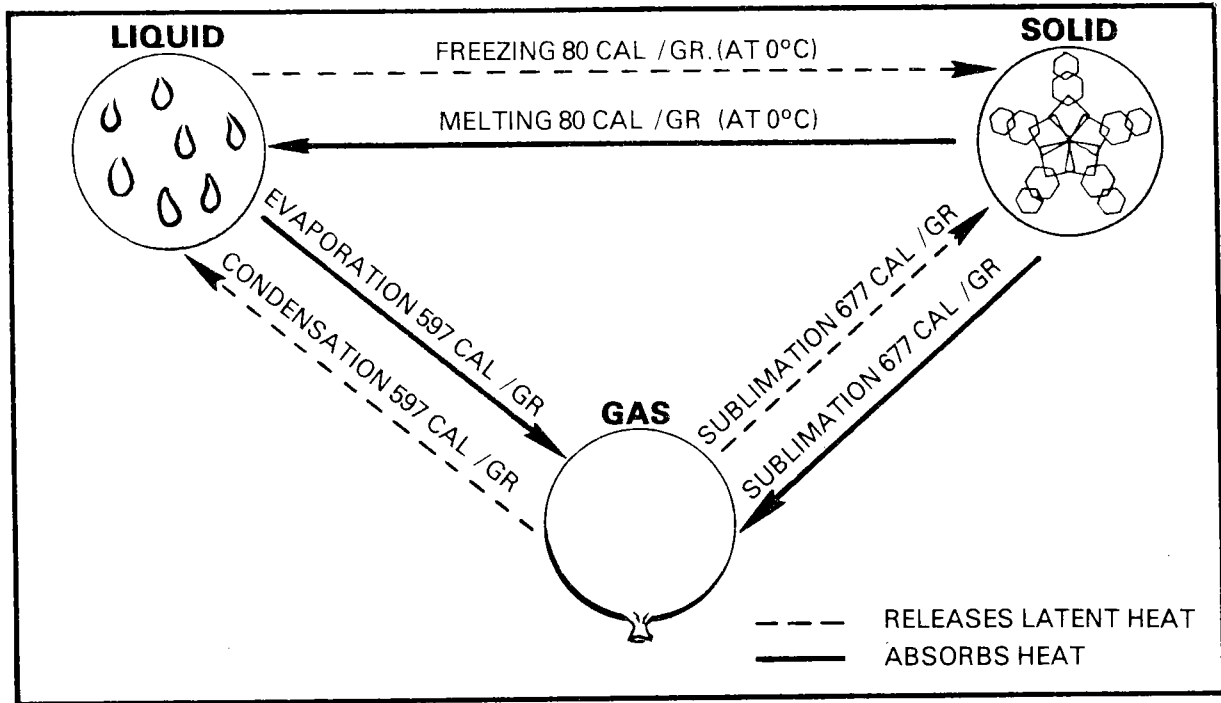


Figure 4-4. Changes in the state of water.

f. **Condensation.** Condensation (fig 4-3) is the change of state from a gas to a liquid. Water vapor at 0°C contains approximately 597 calories per gram more heat energy than a gram of liquid at the same temperature. 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. The latent heat energy released from the condensation in a single cloud may involve billions of calories. In addition to the heating effect, this released energy produces the force required to develop the extreme winds and turbulence in thunderstorms and hurricanes. Impurities must also be present in the atmosphere to act as a nucleus around which fog and cloud droplets can form. When the air is free of impurities, it can be cooled well below its normal capacity for maintaining its moisture in vapor state (supersaturation) without condensation or sublimation occurring. It is suspected that this phenomenon also occurs in certain

regions of the world's atmosphere where few impurities exist (e.g., high altitudes and polar regions).

g. **Fusion.** Freezing occurs as liquid water is cooled to 0°C. Each gram of water that changes to ice releases 80 calories of heat energy. This is the same 80 calories of heat it took to convert ice to water in the melting process.

### 4-3. MOISTURE CONTENT

a. There is a limit to the amount of water vapor that air, at a given temperature, can hold. When this limit is reached, the air is said to be **saturated**. The higher the air temperature, the more water vapor the air can hold before saturation is reached and condensation occurs (fig 4-5). Unsaturated air, containing a given amount of water vapor, will become saturated if its temperature decreases sufficiently. Further cooling forces some of the water vapor to condense as fog, cloud, or precipitation.

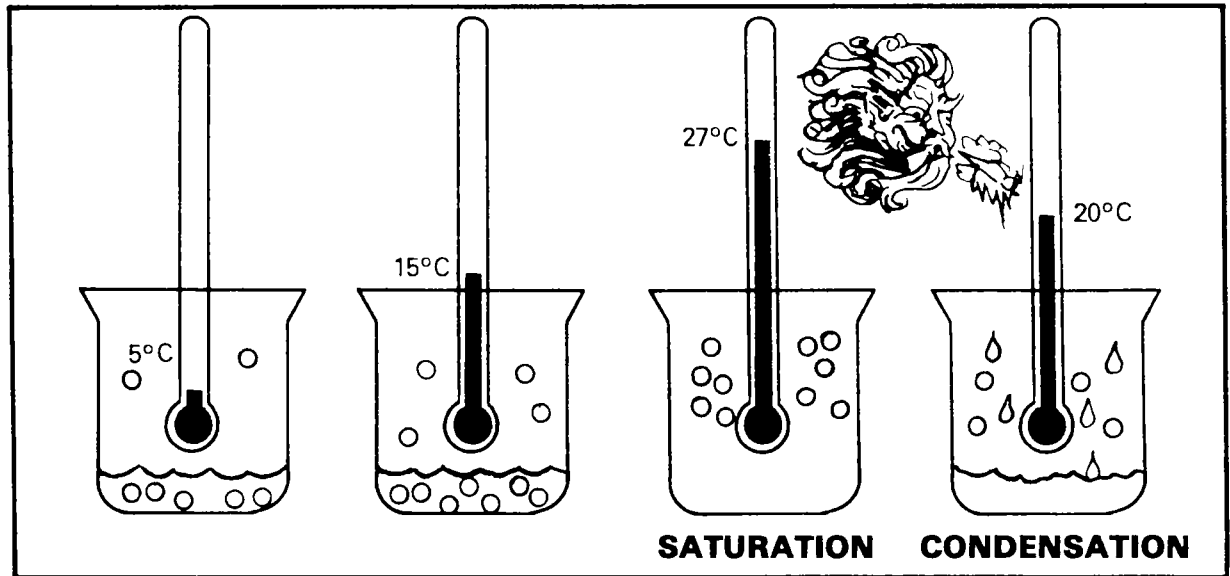


Figure 4-5. Saturation of air depends on its temperature.

b. "Relative humidity" is the ratio of the amount of water vapor in the air to the maximum amount the air can hold when saturated at that temperature. When the air contains all the water vapor it can hold at its

temperature, the relative humidity is 100 percent (fig 4-6). A relative humidity of 50 percent indicates that the air contains half of the water vapor that it is capable of holding at its temperature.

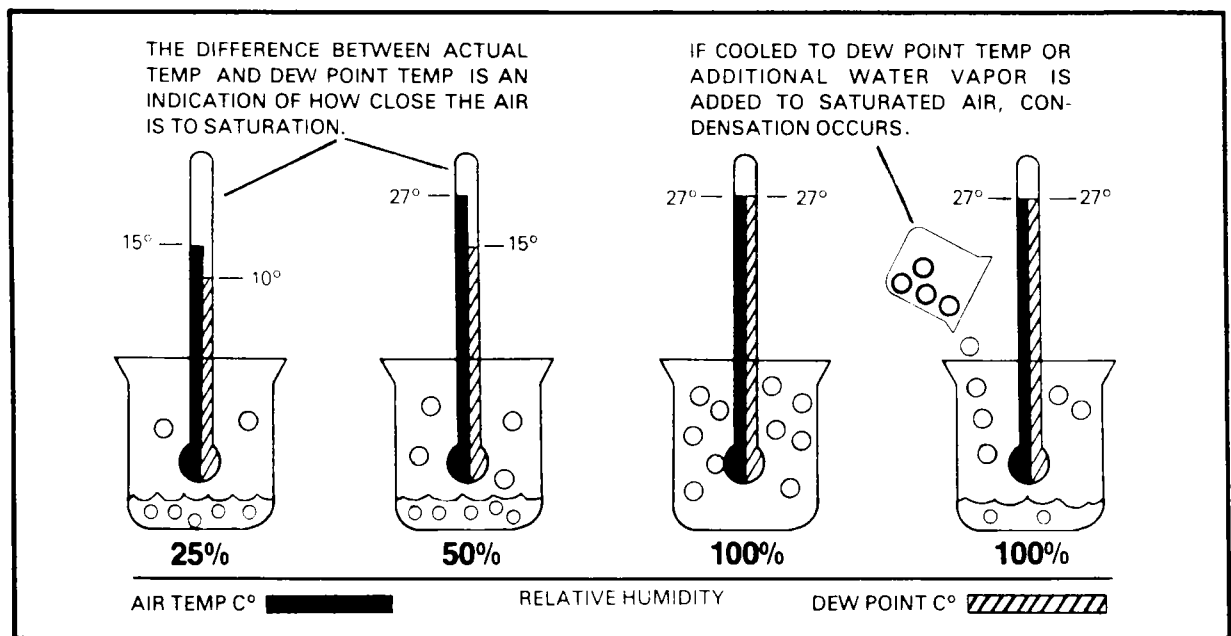


Figure 4-6. Relative humidity and dew point.

#### 4-4. DEW POINT

The dew point temperature is an indicator of the amount of moisture in the air. It is that temperature to which air would have to be cooled for saturation to occur. The dew point

is determined by weather observers during their hourly weather observations; and it is indicated in weather service reports. A narrow temperature-dew point spread of about 2°C indicates the possibility of the formation of fog or low clouds at a reporting station (fig 4-7).



Figure 4-7. Dew point and temperature spread.

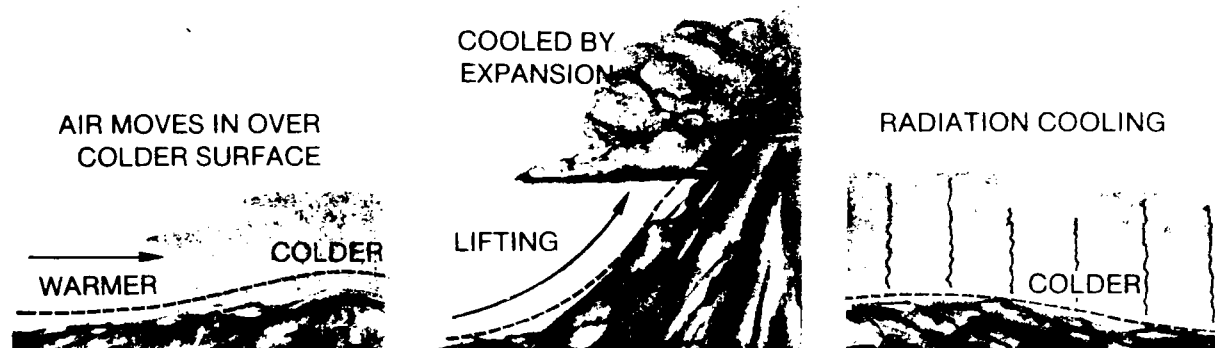


Figure 4-8. Cause of condensation.

#### 4-5. CONDENSATION AND SUBLIMATION PRODUCTS

**Condensation** occurs if moisture is added to the air after saturation has been reached, or if cooling of the air reduces the temperature below the saturation point. As shown in figure 4-8, the most frequent cause of condensation is cooling of the air. This often results when—

- Air moves over a colder surface.
- Air is lifted (cooled by expansion).
- Air near the ground is cooled at night as a result of terrestrial radiational cooling.

#### 4-6. CLOUDS AND FOG

*a.* The most common forms of condensation and sublimation products are clouds and fog. Except at temperatures well below freezing, clouds and fog are composed of small droplets of water. These collect on microscopic water-absorbent particles of solid matter in the air (e.g., salt from evaporating sea spray, dust, and products of combustion). The abundance of these particles on which the droplets form, called **condensation nuclei**, permits condensation to occur generally as soon as the air becomes saturated.

*b.* Clouds and fog which form at temperatures well below freezing ( $-15^{\circ}\text{C}$  or lower) are usually composed of small particles of ice known as ice crystals. These ice crystals form

directly from water vapor through the process of sublimation. However, liquid water droplets are frequently observed in the atmosphere at temperatures much lower than the freezing point. While rarely below  $-40^{\circ}\text{C}$ , water droplets have been known to exist in temperatures near  $-60^{\circ}\text{C}$  (under laboratory conditions). This is called **supercooling**; and it exists in clouds down to a temperature of about  $-15^{\circ}\text{C}$ . Aircraft penetrating supercooled clouds are likely to accumulate ice, because the impact of the aircraft may induce freezing of the droplets.

#### 4-7. PRECIPITATION

*a.* Precipitation is liquid or solid moisture that falls from the atmosphere in the form of rain, drizzle, ice pellets, snow, or combinations of these. As shown in figure 4-9, the form of precipitation is largely dependent upon the temperature and turbulence present. Although there can be no precipitation without clouds, most clouds do not precipitate.

*b.* Initial cloud particles are usually very small and remain suspended in the atmosphere. Precipitation occurs when the cloud particles grow sufficiently in size and weight or fall because of the gravitational pull of the earth. This growth can occur through a number of processes. The production of snow is an example. Snowflakes grow as water in the supercooled droplets evaporates and then sublimates on ice crystals. In clouds with above-freezing temperatures, collision of droplets of varying size is the most common process that produces precipitation. Vertical

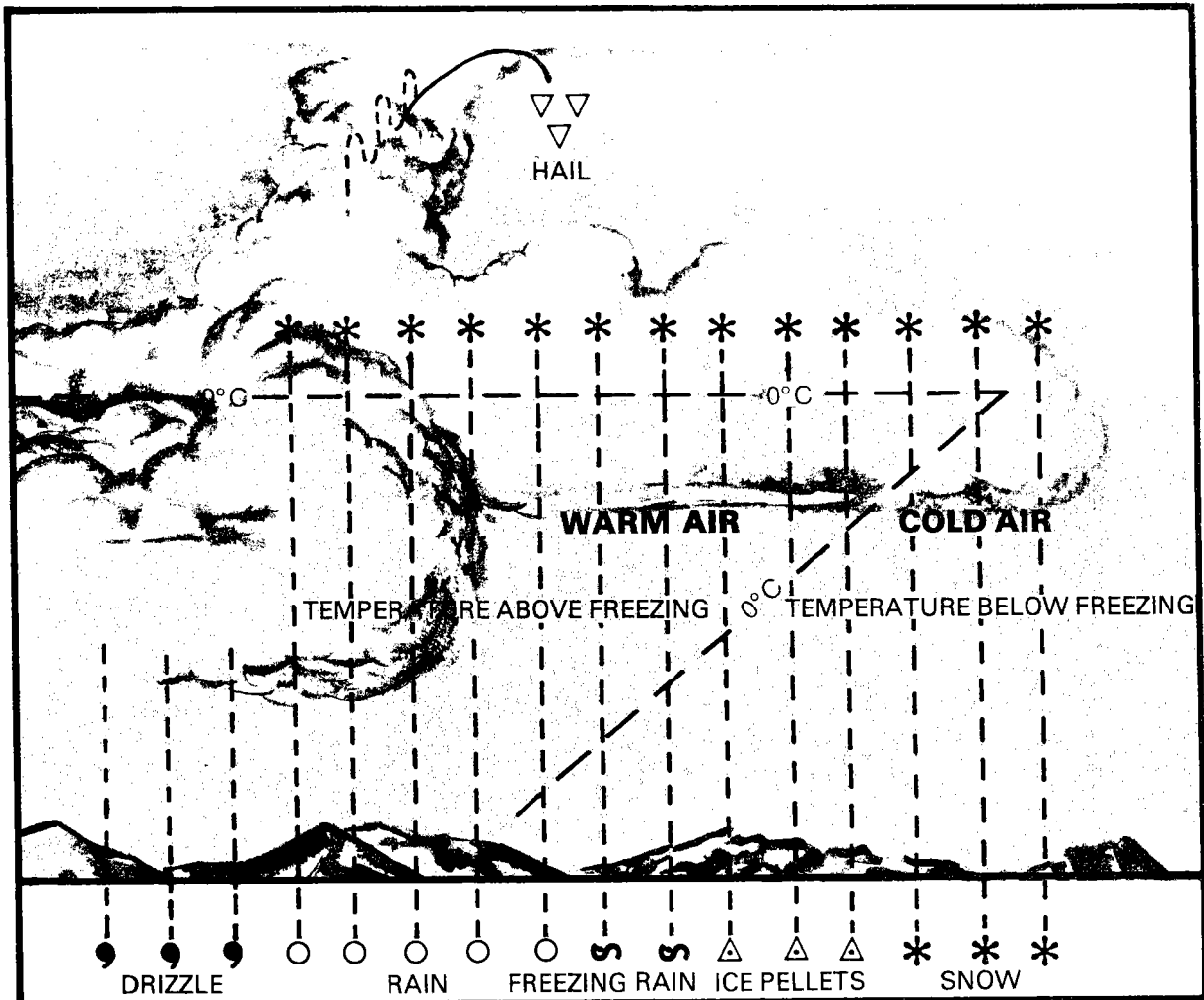


Figure 4-9. Precipitation products.

air currents cause the droplets to collide and assist in the growth of clouds by carrying droplets to higher altitudes (fig 4-10). Usually precipitation of other than light intensity requires the cloud to be more than 4,000 feet thick.

c. When the air is highly unstable, vertical currents in clouds are very strong and carry supercooled water droplets or ice particles to high altitudes. Since these droplets become large prior to falling, the resulting rain or snow is heavy.

d. Precipitation can change its state as the temperature of its environment changes.

For example, falling snow may melt in warmer layers of air at low altitudes to form rain, or rain may fall into cooler layers and freeze into ice pellets before reaching the ground.

e. Sometimes strong vertical currents carry the precipitation products up and down through repeated cycles of melting, sublimating, and/or freezing, leading to the formation of hail.

f. Precipitation does not necessarily reach the earth. Often it evaporates completely in dry air beneath the cloud base. This phenomenon, called *virga*, is a common occurrence in an arid climate.

**IN HIGHLY UNSTABLE AIR—**

- VERTICAL CURRENTS IN CLOUDS ARE STRONG.
- CURRENTS CARRY WATER DROPLETS OR ICE PARTICLES TO HIGHER ALTITUDES.
- DROPLETS RESULT IN HEAVY RAIN OR SNOW.

**PRECIPITATION—**

- CLOUD PARTICLES GROW IN SIZE AND WEIGHT AND FALL BECAUSE OF GRAVITATIONAL PULL OF THE EARTH.

**VERTICAL AIR CURRENTS—**

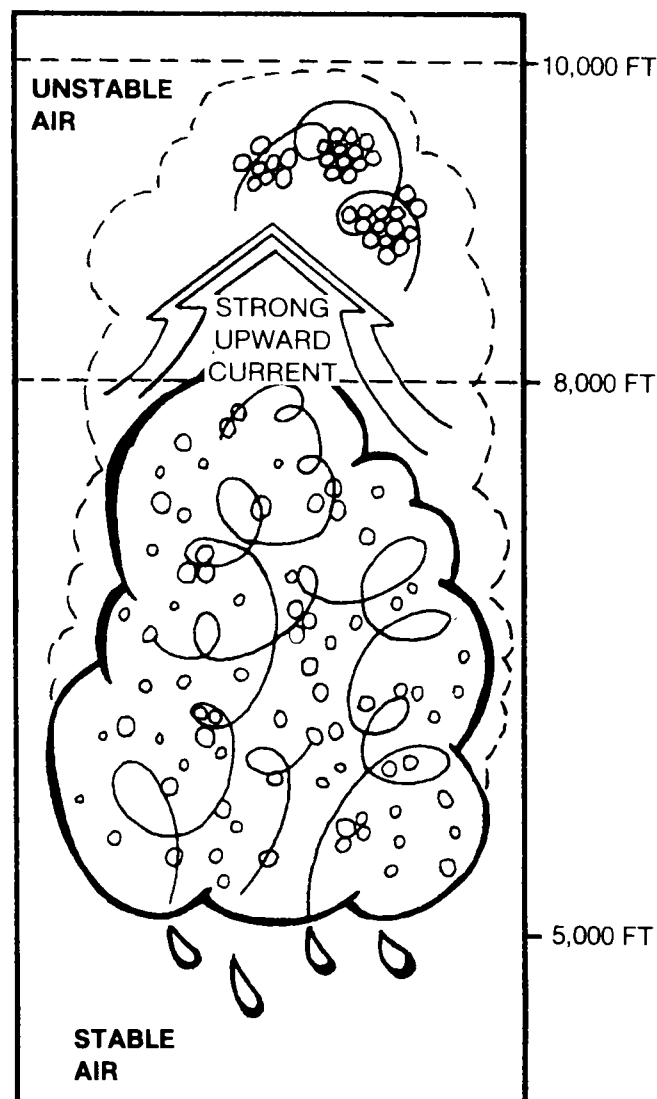
- CAUSE DROPLETS TO COLLIDE.
- ASSIST IN GROWTH OF CLOUDS BY CARRYING WATER VAPOR TO HIGHER ALTITUDES.

**LIGHT INTENSITY PRECIPITATION—**

- 4,000 FT THICK OR LESS

**MEDIUM TO HEAVY PRECIPITATION—**

- 4,000 FT THICK OR LESS



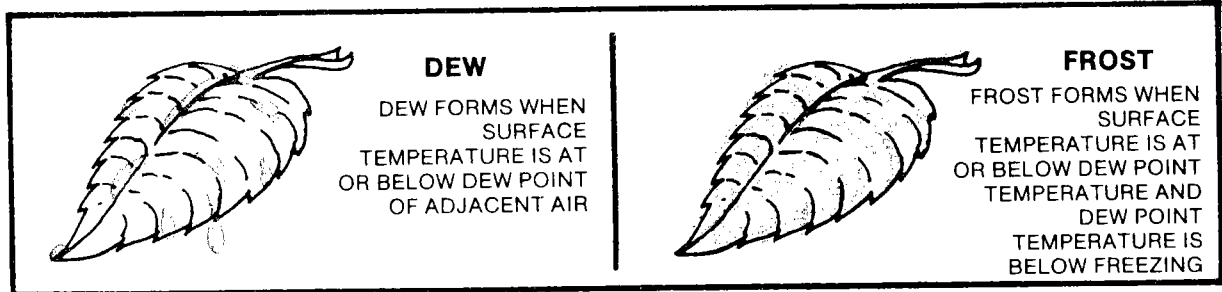
*Figure 4-10. Growth of raindrop by collision of cloud droplets.*

## 4-8. DEW AND FROST

*a.* During clear, still nights, vegetation often cools by radiation to a temperature at or below the dew point of the adjacent air. Moisture then collects on the leaves just as it does on a pitcher of ice water in a warm room. Heavy dew is often observed on grass and plants when there is none on the pavements or on large solid objects. These solid objects absorb so much heat during the day, or give up heat so slowly, that they may not cool

below the dew point of the surrounding air during the night (fig 4-11).

*b.* Dew does not fall; the moisture comes from the air in direct contact with the cool surface. When the temperature of the collecting surface is at or below the dew point of the adjacent air and the dew point of the adjacent air is below the freezing point, frost—a sublimation product—will form instead of dew. Sometimes dew forms and later freezes; but frozen dew is easily distinguishable from frost because it is transparent and frost is opaque.



*Figure 4-11. Dew or frost formation.*



## CHAPTER 5

# ATMOSPHERIC PRESSURE

### 5-1. GENERAL

Although the temperature is evenly spread over the earth's surface, differences in heating and cooling in the lower levels of the atmosphere cause density variations. These variations cause small horizontal pressure differences since they are only about one ten-thousandths of the magnitude of the normal change of pressure with altitude. However, they cause *all* atmospheric circulation and *most* weather phenomena.

**NOTE**

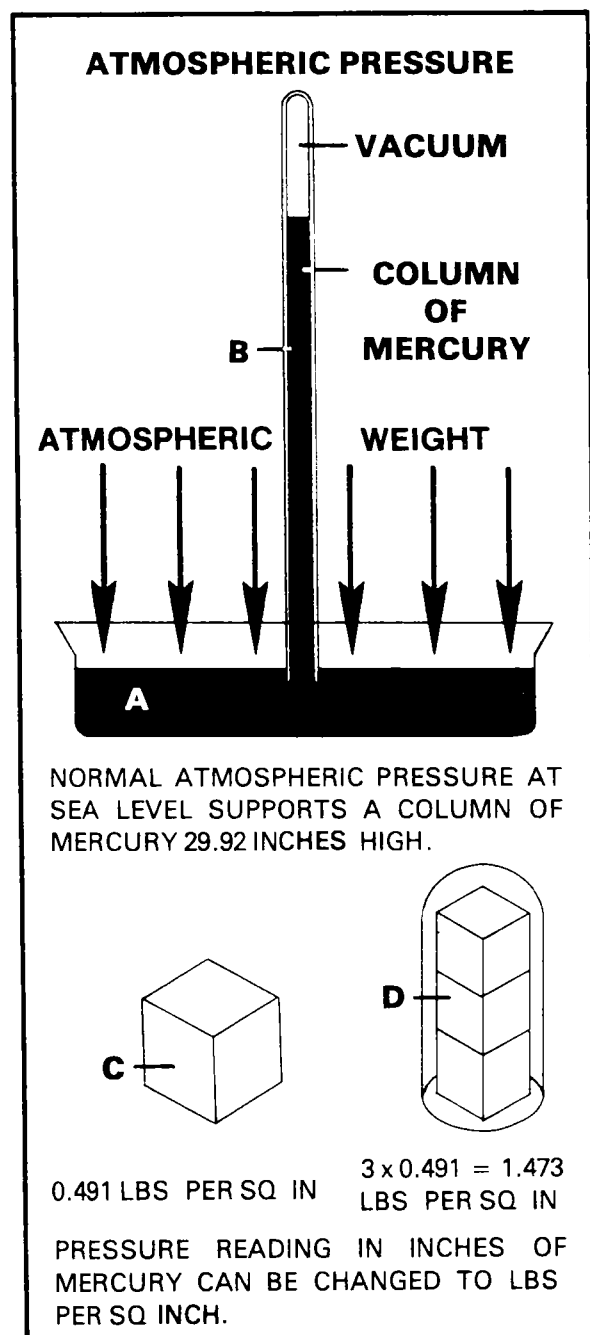
**Atmospheric pressure is the result of gravity acting on the mass of the earth's atmosphere.**

### 5-2. PRESSURE INSTRUMENTS

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

*a. Mercurial Barometer.* Figure 5-1 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 most of the air has been removed. The weight of the mercury column corresponds to the weight of the atmosphere. In the illustration (fig 5-1), the column of mercury (Hg) 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 5-1) weighs 0.491 pounds and exerts a pressure on



**Figure 5-1. Principles of the mercurial barometer.**

its bottom surface of 0.491 pounds per square inch.

(2) If three such cubes were placed in a container (D, fig 5-1), the bottom surface would be under a pressure of  $3 \times 0.491$ , or 1.473 pounds per square inch (psi).

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

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 to constitute the indicator mechanism (fig 5-2). Although not as accurate as the mercurial barometer, the aneroid barometer is useful because of its compactness.

c. **Barograph.** The barograph is an aneroid barometer which produces a continuous record of atmospheric pressure (fig 5-3).



Figure 5-2. Aneroid barometer.

### 5-3. UNITS OF PRESSURE MEASUREMENT

*Inches of mercury* and *millibars* (mb) are two pressure units every aviator must know. He uses these units during each flight and in each weather briefing by the forecaster.

*a. Inches of Mercury.* 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. Because 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 these units.

*b. Millibar.* In meteorology, it is more convenient to express the pressure directly as a force per unit area. This is done by using a unit called the *millibar*. Millibars divided by 33.86 equals inches of mercury.

(1) Many foreign nations use the millibar for altimeter settings. Aviators flying in these countries will need to refer to a conversion table (millibars to inches of mercury) found in the instrument flight rules (IFR) supplement.

(2) Standard atmospheric pressure at sea level is 1013.2 millibars, which is the equivalent of 29.92 inches of mercury.

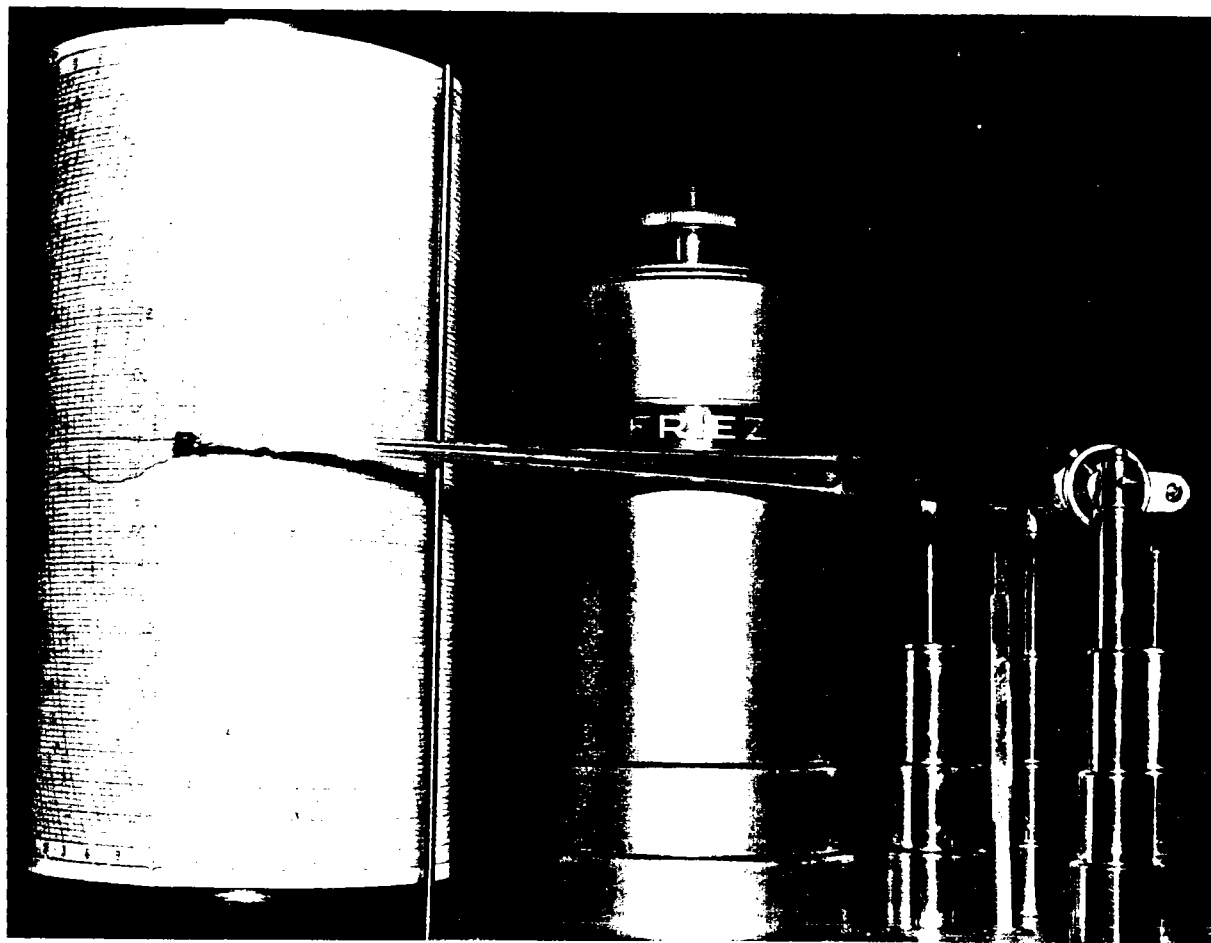


Figure 5-3. Barograph.

### 5-4. SEA LEVEL ATMOSPHERIC PRESSURE

a. When charting atmospheric pressures over various areas of the earth, the meteorologist is mainly interested in the pressure difference per unit distance—the pressure gradient.

b. In order to compensate for pressure variations because of different station elevations, all observations are mathematically corrected to mean sea level (MSL).

c. Altimeter settings are obtained by mathematically reducing station pressure to MSL. This enables the pilot to read MSL altitudes on his altimeter.

d. The standard or normal atmospheric pressure at sea level at a standard air temperature of 15°C is 1013.2 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 of the atmosphere vary from

as low as 950 millibars (about 28 Hg) to as high as 1050 millibars (about 31 Hg). Such variations in pressure indicate the dynamic nature of the atmosphere.

### 5-5. DETERMINING PRESSURE SYSTEMS

To eliminate pressure variations caused by stations being at different altitudes, the MSL pressure is plotted in millibars at each reporting station on a surface weather map. Lines (isobars) are drawn connecting equal values of reported MSL pressure. The isobars and appropriate labels in millibars 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, with intermediate 2-millibar spacing when needed. The isobaric pattern is never the same on any two weather maps. They, however, 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 5-4.

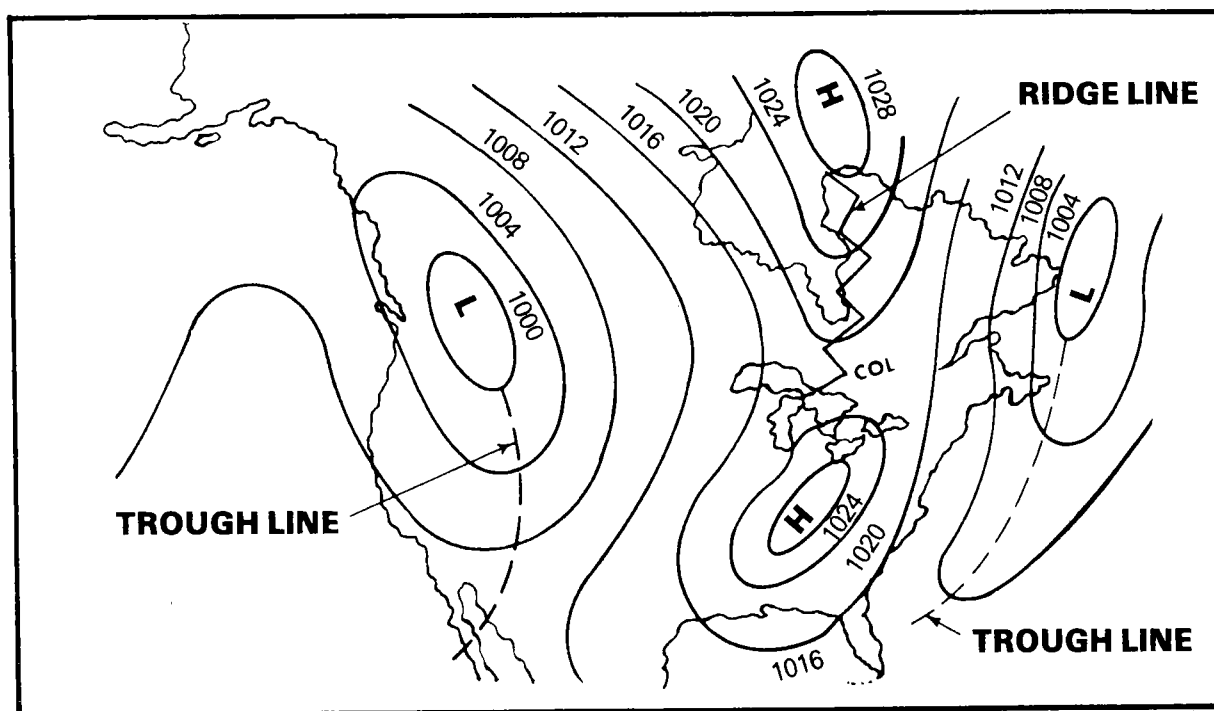


Figure 5-4. Pressure systems.

a. **Low.** A "low" is a pressure system in which the barometric pressure decreases toward the center and the wind flow around the system is counterclockwise in the Northern Hemisphere. The terms *low* and *cyclone* are interchangeable; whereas in referring to troughs, they are always called **low-pressure troughs**. Any pressure system in the Northern Hemisphere with a counterclockwise (cyclonic) wind flow is a cyclone. Hurricanes, typhoons, and tropical storms are all low-pressure systems, with tornadoes and waterspouts often associated with them. Tornadoes and waterspouts are also very intense low-pressure systems which are associated with severe thunderstorms. 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. 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 stationary and predominate over continental areas in the summer.

b. **High.** A "high" is a pressure system in which the barometric pressure increases toward the center and the wind flow around the system is clockwise in the Northern Hemisphere. Any pressure system in the Northern Hemisphere with a clockwise (anticyclonic) wind flow is an anticyclone. Flying conditions are generally more favorable in highs than in lows because of fewer clouds, light or calm winds, and less-concentrated turbulent areas. But in some situations, visibility may be reduced due to early morning fog, smog, or haze at flight level. 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 significant high pressure rarely exist south of 23 degrees north latitude in the Northern Hemisphere. 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 the winter season when the cyclones are most intense and the anticyclones extend farthest to the south.

c. **Col.** A "col" is a saddleback region between two highs.

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 along the ridge line. The weather in a ridge is generally favorable for flying.

## 5-6. PRESSURE GRADIENT

The rate of change in pressure in a direction perpendicular to the isobars is called **pressure gradient**. Pressure applied to a fluid is exerted equally in all 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 5-5) are close together. It is flat or weak when the isobars are far apart.

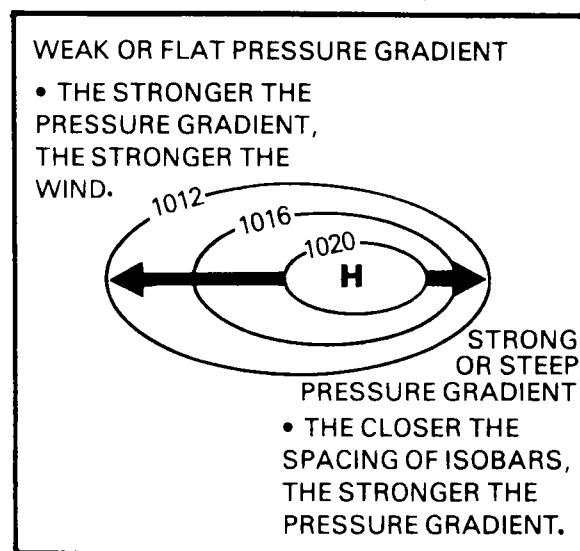


Figure 5-5. Principles of pressure gradient.

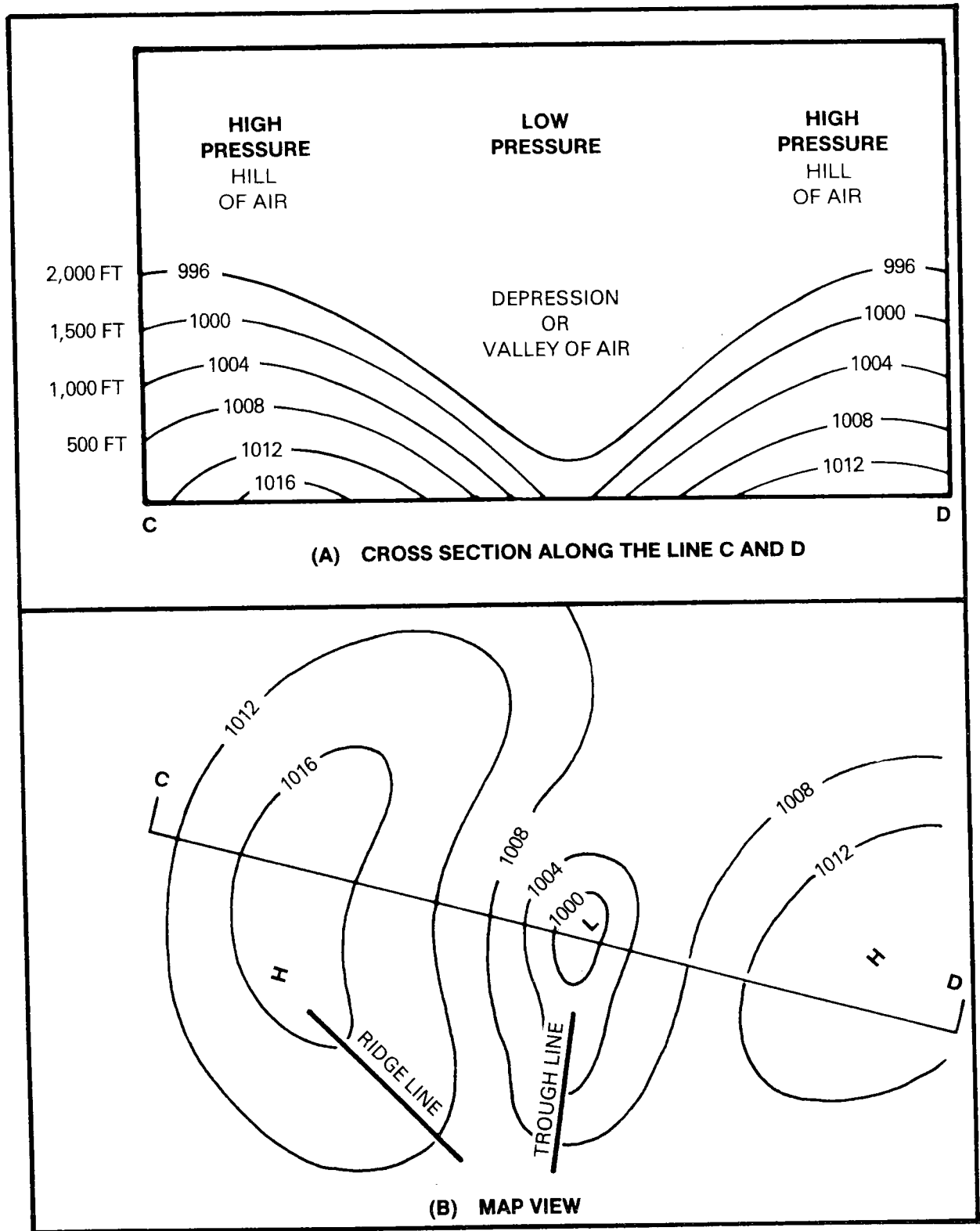


Figure 5-6. High- and low-pressure systems.

*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 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 a low (A, fig 5-6) depicts the vertical pressure gradient. A surface weather map view of the horizontal pressure gradient in the same high and low as illustrated by B of figure 5-6.

## 5-7. 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 adjustment to correct for nonstandard sea level pressure. 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. The atmospheric pressure frequently differs at the point of landing from that at takeoff. Therefore, an altimeter correctly set at takeoff may be in considerable 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 electronic navigation and/or communication

aids. 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. Figure 5-7 shows the pattern of isobars (or isobaric surfaces) in a cross section of the atmosphere from Miami, Florida, to New Orleans, Louisiana, which coincides with the direction of flight. The pressure at Miami is 1019 millibars and the pressure at New Orleans is 1009 millibars, a difference of 10 millibars. Assuming that an aircraft departs from Miami on a flight to New Orleans at an en route altitude of 500 feet, a decrease in MSL pressure of 10 millibars from Miami to New Orleans would cause the aircraft to gradually lose altitude. 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 and resetting the altimeter to agree with the destination adjustment. 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. If the air temperature at flight altitude is warmer than standard, the average pressure decrease per 1,000 feet between the aircraft and the surface is also less than standard (fig 5-8). Therefore, an aircraft flying in warmer than standard air will normally be higher than the altimeter indicates. Conversely, if the air temperature

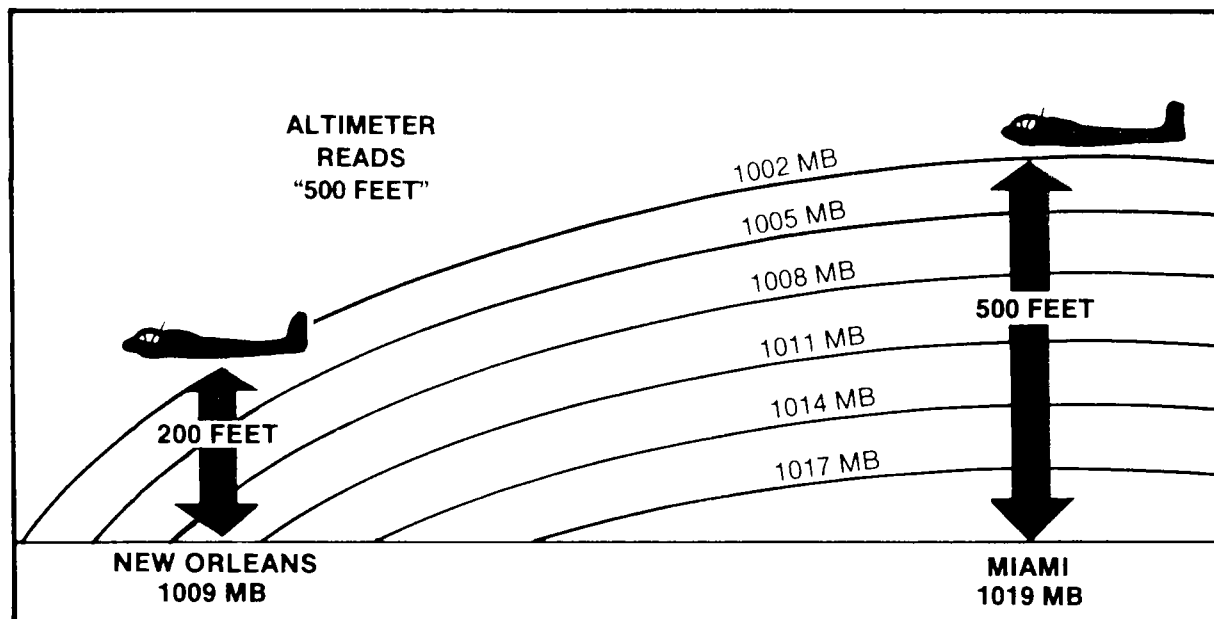


Figure 5-7. Altimeter errors due to change in surface pressure.

at flight altitude is colder than standard, pressure decrease with altitude is greater than standard. Therefore, an aircraft flying in colder than standard air will be normally lower than the altimeter indicates. Many accidents have occurred during instrument flight in cold weather because aviators did not understand nor consider this altimeter error. They failed to allow an adequate safety margin to clear mountainous terrain. The aviator does not attempt to correct his altimeter for nonstandard flight level temperatures. However, it is the aviator's responsibility to be aware of improper terrain clearance in temperatures much colder than standard. The amount of error caused by nonstandard temperatures can be obtained by use of the navigational computer. As a rule-of-thumb, the error is 2 percent of the altitude above the reporting station for each 5°C variation from standard temperature.

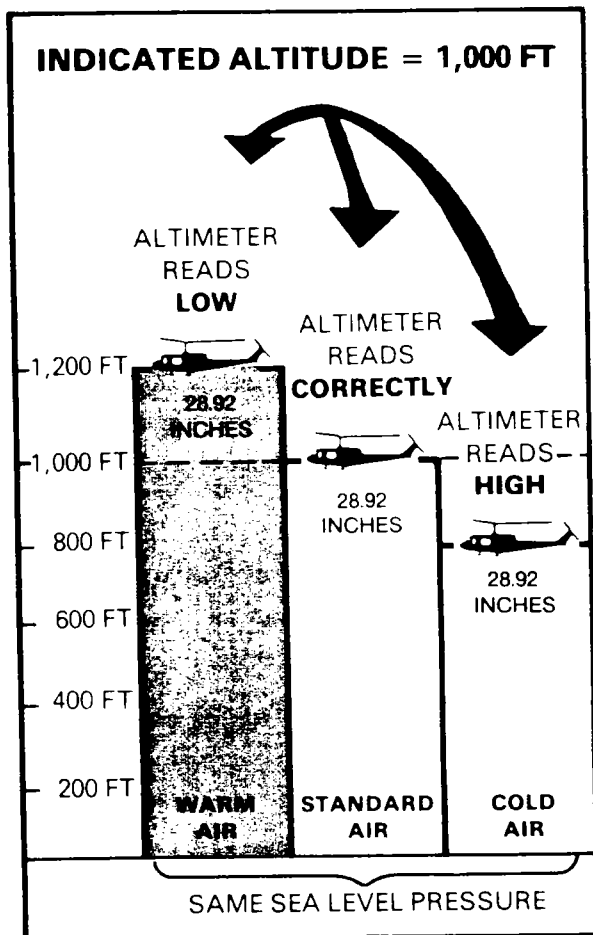
#### NOTE

Standard temperature is 15°C at sea level elevation with a lapse rate of 2°C per 1,000 feet.

## 5-8. DENSITY ALTITUDE

"Density altitude" is defined as the pressure altitude corrected for temperature deviations from the standard atmosphere. Density altitude bears the same relation to pressure altitude as true altitude does to indicated altitude. (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, temperature, and humidity. Changes in the water vapor content also affect the density of the air, but the amount is small. Therefore, it is not considered in density altitude computation. An airfield may have a density altitude that varies several thousand feet from the 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





**Figure 5-8. Density variation with temperature and altimeter errors due to nonstandard air temperature.**

feet (MSL) with a density altitude of 10,000 feet. Aircraft operating from this field would be in air of the same density that normally would be found in the standard atmosphere at 10,000 feet. The efficiency of the aircraft will be seriously affected in high density altitudes, and becomes critical when the aircraft is loaded at maximum weights. If the density altitude is lower (-) than normal for a given elevation, the efficiency of the aircraft can be increased. An aviator operating from a field at 5,000 feet with a density altitude of 1,000 feet will be in the same air density at field elevation that normally exists at 1,000 feet.

#### NOTE

The moisture content of the air (indicated by the dew point temperature) has less effect on the density altitude than the temperature and pressure. A dew point temperature of  $-7^{\circ}\text{C}$  would increase the density altitude approximately 50 feet ( $10^{\circ}\text{C}$ , 160 feet;  $21^{\circ}\text{C}$ , 320 feet;  $29^{\circ}\text{C}$ , 600 feet; and  $38^{\circ}\text{C}$ , 1,000 feet). Because dew point temperatures seldom exceed  $21^{\circ}\text{C}$ , moisture can be neglected in density altitude computations without causing any appreciable error.

*a. Effects on Aircraft Performance.* 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 for fixed-wing aircraft. A helicopter may be required to make a ground run to establish effective translational lift (ETL) for takeoff under such conditions. In areas of high density altitude, additional engine power to afford ETL 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 weight (payload or fuel) is required. Since high density altitudes reduce the service ceiling of aircraft, density altitude must be considered in computing maximum loads. The density altitude usually varies throughout the day with the movement of pressure systems, heating, and 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. Wind velocity creating translational lift while hovering will improve helicopter performance in areas of high density altitude.

b. **Computing Density Altitude.** 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:

**For pressure 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

**For pressure 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

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 is raised. Temperature variation is incorporated into a formula for obtaining density altitude from a known pressure altitude shown below:

$$DA = PA + (120 \times T_v)$$

Where DA = density altitude  
 PA = pressure altitude  
 120 = temperature constant

$T_v$  = variation of the actual air temperature from standard at the pressure altitude

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 variance is \_\_\_\_\_ +19°C

$$DA = 2,010 + 120 (30-11)$$

$$DA = 2,010 + 120 (19)$$

$$DA = 2,010 + 2,280$$

$$DA = 4,290 \text{ feet}$$

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

$$DA = 1,070 + 120 (+6 -13)$$

$$DA = 1,070 + 120 (-7)$$

$$DA = 1,070 + (-840)$$

$$DA = 1,070 - 840$$

$$DA = 230 \text{ feet}$$

Density altitude can also be determined by using computers. Density altitude charts are available in most -10s and at weather stations. 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 6

### Section I. GENERAL CIRCULATION

#### 6-1. GENERAL

a. The effects of atmospheric circulation or wind on aircraft is of primary concern to the Army aviator. Wind affects the aircraft in all phases of flight from takeoff and throughout the flight to the landing. Pilots must obtain wind information when considering—

- Flight headings.
- Total time en route.
- Time over reporting positions.
- Destinations and alternates.
- The degree of turbulence for flight safety.

b. The energy that sets the atmosphere into motion is obtained from the sun's radiation and the earth's rotation. Because of the angular relationship of the earth's axis 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 study of the atmospheric circulation as it actually exists.

#### 6-2. 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. This chapter, however, will be limited to the movement of air in the troposphere (fig 6-1).

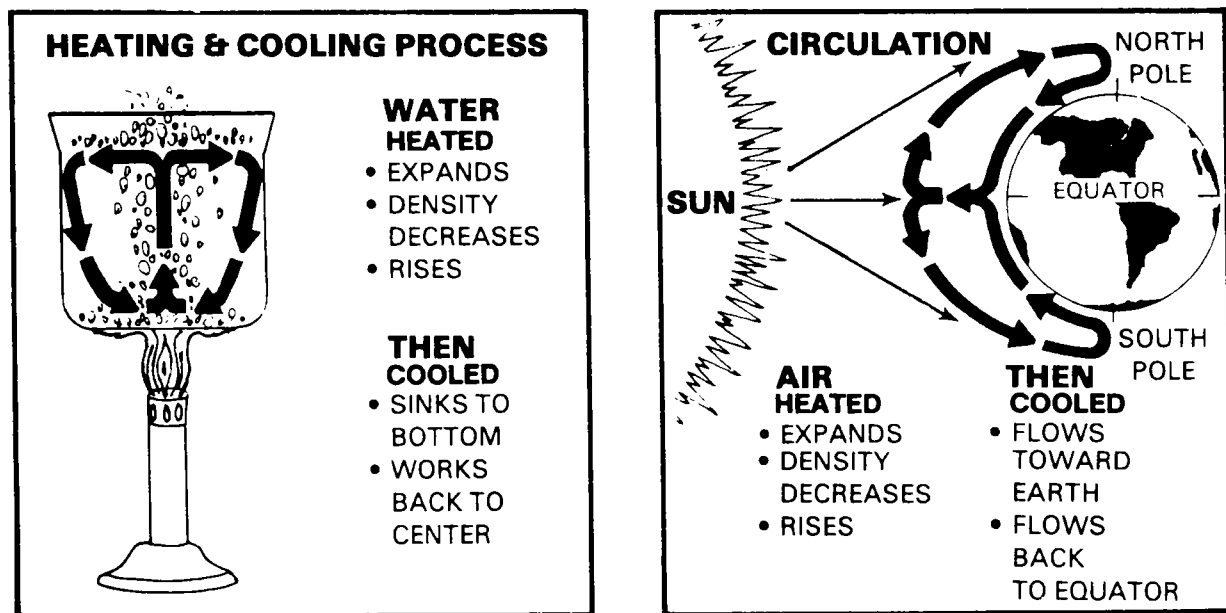


Figure 6-1. Simple circulation.

b. **Causes.** The air within the troposphere 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 that 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; sinks to the bottom; and eventually works 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 6-1).

**6-3. THEORETICAL ATMOSPHERIC CIRCULATION**

Simple circulation in the atmosphere would occur as described in paragraph 6-2 if it were not for the following considerations:

**6-2**

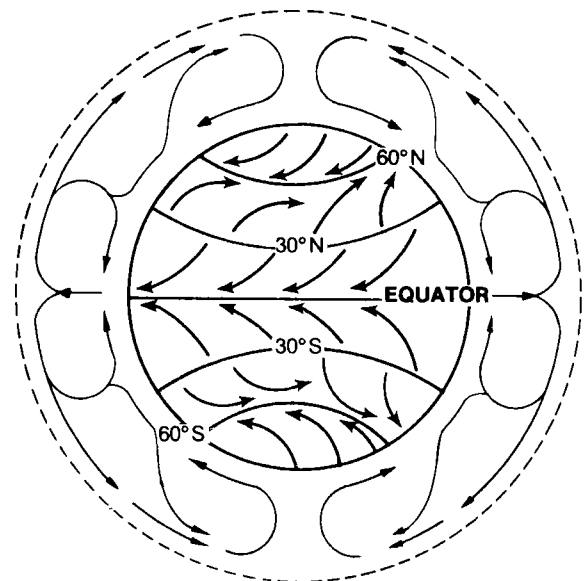
a. The earth is covered with an irregular surface of land and water areas.

b. The earth rotates, so that the area of the atmosphere being heated changes position constantly. **Coriolis deflection** (para 6-7b) 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.

**6-4. EFFECTS OF THE EARTH'S MOVEMENT**

a. **Rotation.** As the earth rotates, circulation is affected by the Coriolis force (para 6-8a(2)). 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 6-2).



**Figure 6-2. Prevailing wind belts with the three-cell circulation.**

*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 6-3) typifies the average position of differential heating areas and assumes a uniform surface of the earth in color, shape, and texture.

airflow. Another important factor is the difference in specific heats of land and water surfaces. These variations from the basic circulation pattern require consideration in any realistic view of the atmospheric circulation in the lower troposphere. The average surface pressure distribution for winter and summer is shown in figure 6-4. The corresponding winter wind patterns over the ocean are shown in figure 6-5.

### 6-5. SEMIPERMANENT PRESSURE AREAS

*a.* The 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 the great mountain ranges towering up to 5 miles into the atmosphere produces definite changes in the

*b.* Two high pressure cells form in the Northern Hemisphere near 30 degrees north latitude—one over the Pacific Ocean and one over the Atlantic Ocean (fig 6-4). The presence of high pressure over the oceans agrees 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), seasonal pressure changes occur.

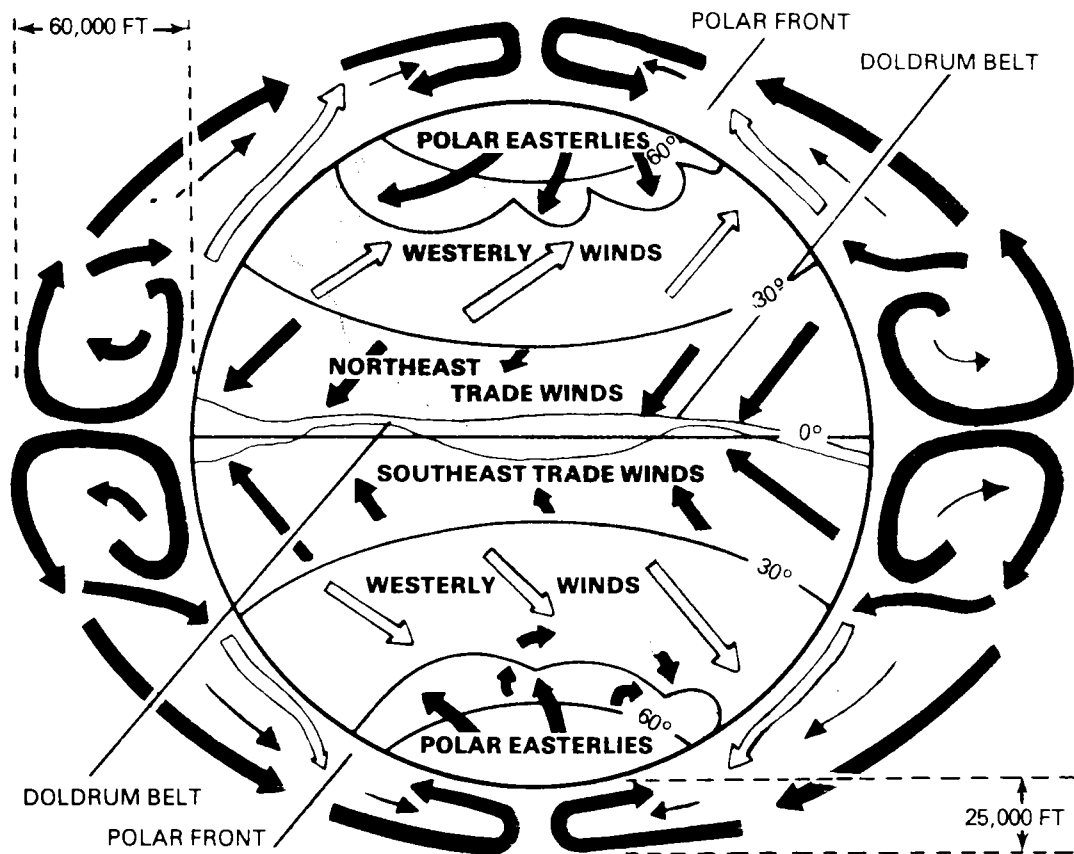


Figure 6-3. Idealized pattern of atmospheric circulation.

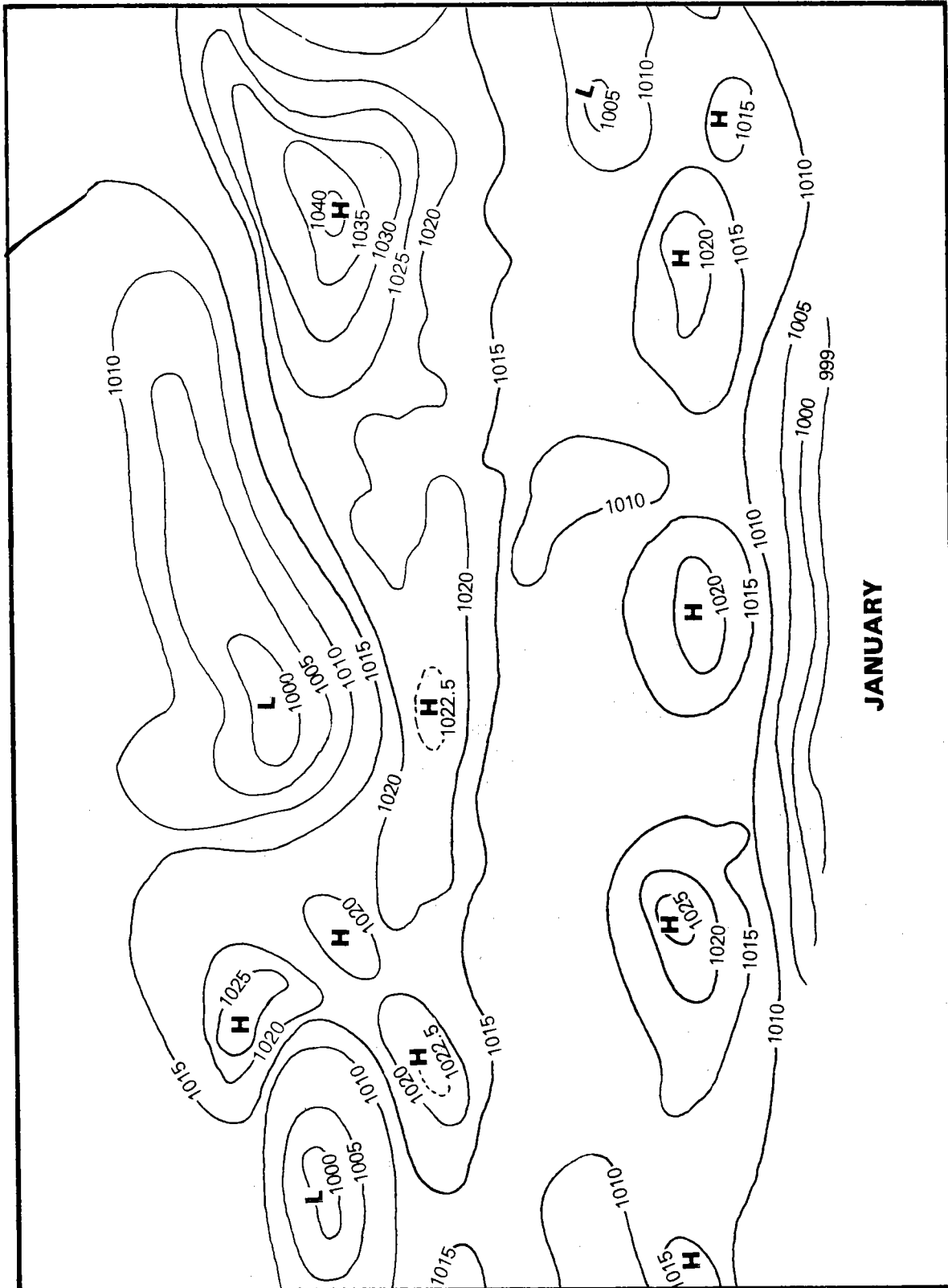


Figure 6-4. Prevailing world pressure systems.

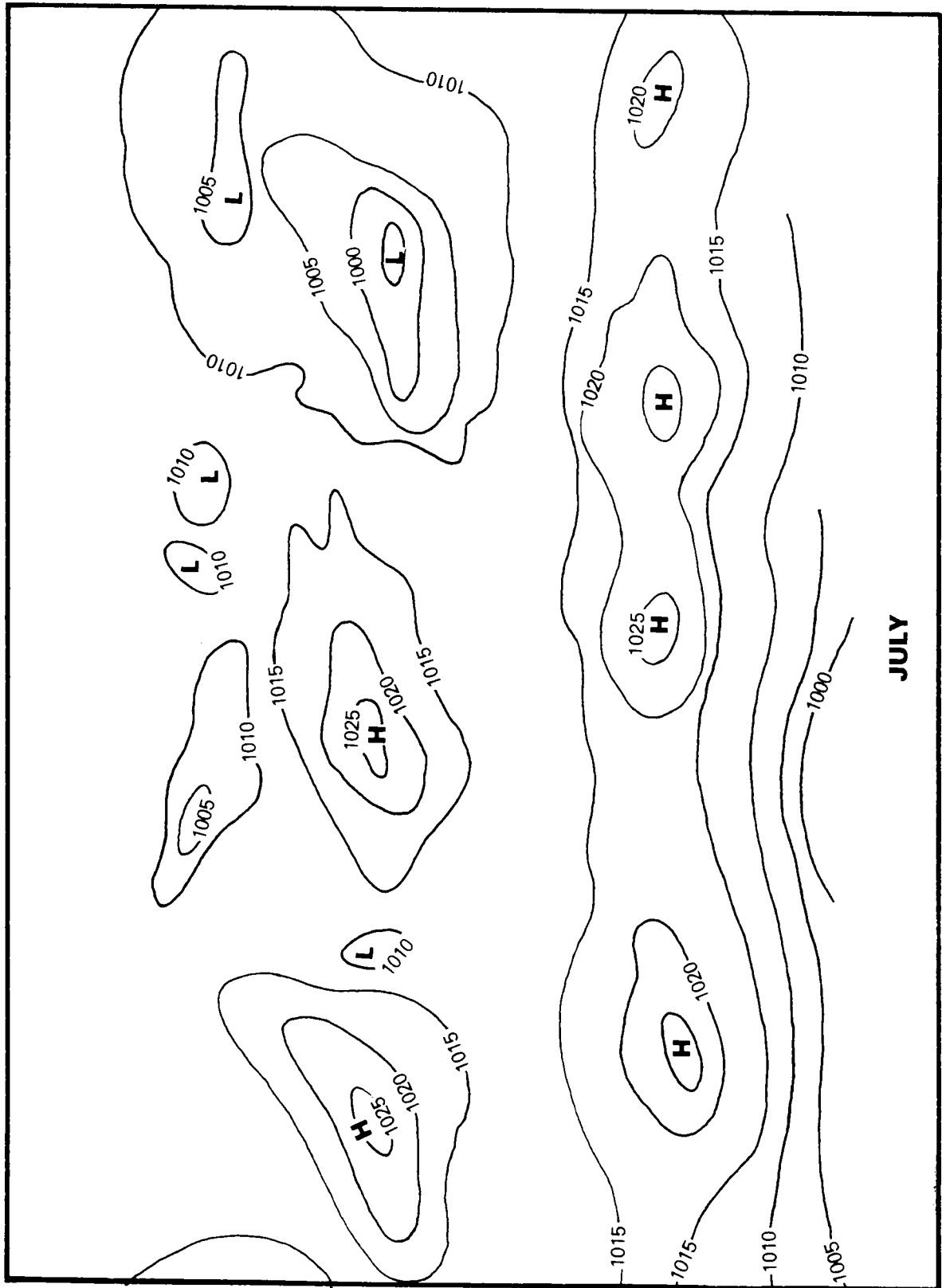


Figure 6-4. Prevailing world pressure systems—continued.

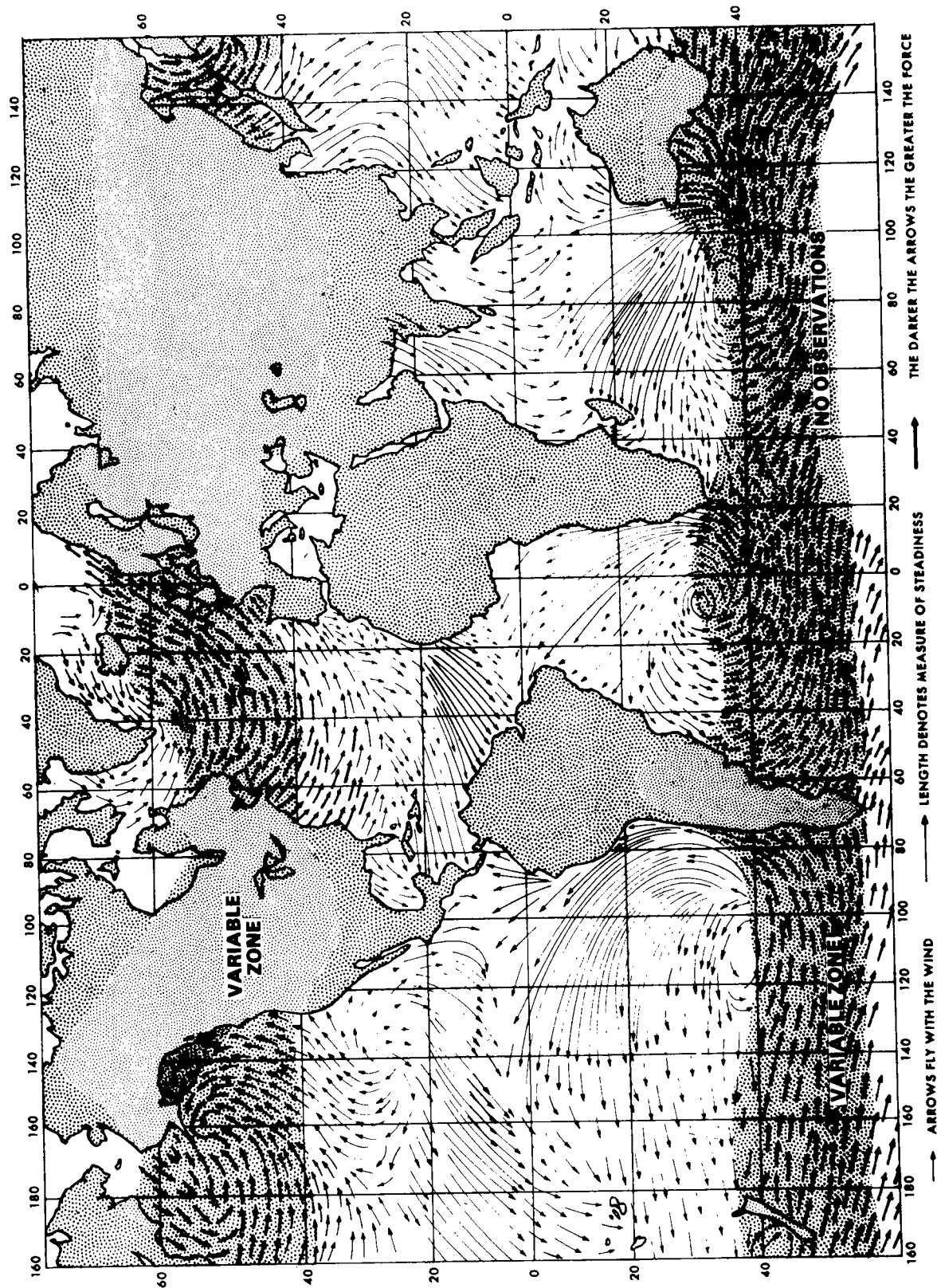


Figure 6-5. January and February world wind system over oceans.



c. Between the latitudes 45 degrees to 60 degrees, 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 north of the Equator, these high-pressure cells retreat to a more localized position near the Pole and become less intense.

d. The low-pressure cells (the Icelandic and Aleutian) form in the Northern Hemisphere over the ocean near the Aleutian

Islands. These lows are regions where dissipating storms moving along the polar front tend to stagnate. Consequently, they show up on charts of average pressure as low-pressure regions. These are regions where flying conditions are poor during a major percentage of the time.

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

## Section II. SECONDARY CIRCULATION

### 6-6. GENERAL

The secondary circulation consists of atmospheric disturbances and irregularities in the lower levels of the troposphere brought about by movement of high and low pressure systems and movement of air within these 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 generally move 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 at speeds of 90 miles per hour. The moving low-pressure systems generally have associated fronts, which produce adverse weather; whereas, high-pressure systems are relatively free of bad weather. The forces which affect the wind in the secondary circulation are discussed in this section.

### 6-7. FORCES AFFECTING AIR MOTION

a. *Pressure Gradient Force.* The intensity of the force acting toward low pressure

determines wind speed. It 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 gradient force, the stronger the wind will be. The pressure gradient force always acts directly across the isobars toward the lower pressure (fig 5-5).

b. *Coriolis Force.* If the pressure gradient force were the only force affecting wind flow, winds would always flow directly across the isobars from higher to lower pressure. However, the French mathematician, G.G. Coriolis, first demonstrated in 1836 that all nonsteered bodies would be deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The two aspects of this phenomenon will be explained in general terms and the explanation will be limited to the Northern Hemisphere.

(1) The earth rotates from west to east at a given speed in much the same way that a phonograph record turns on a turntable. Although the revolutions per minute (RPM) are the same, the outward rim of the phonograph record (which, in the case of the earth, is the Equator) has more distance to cover

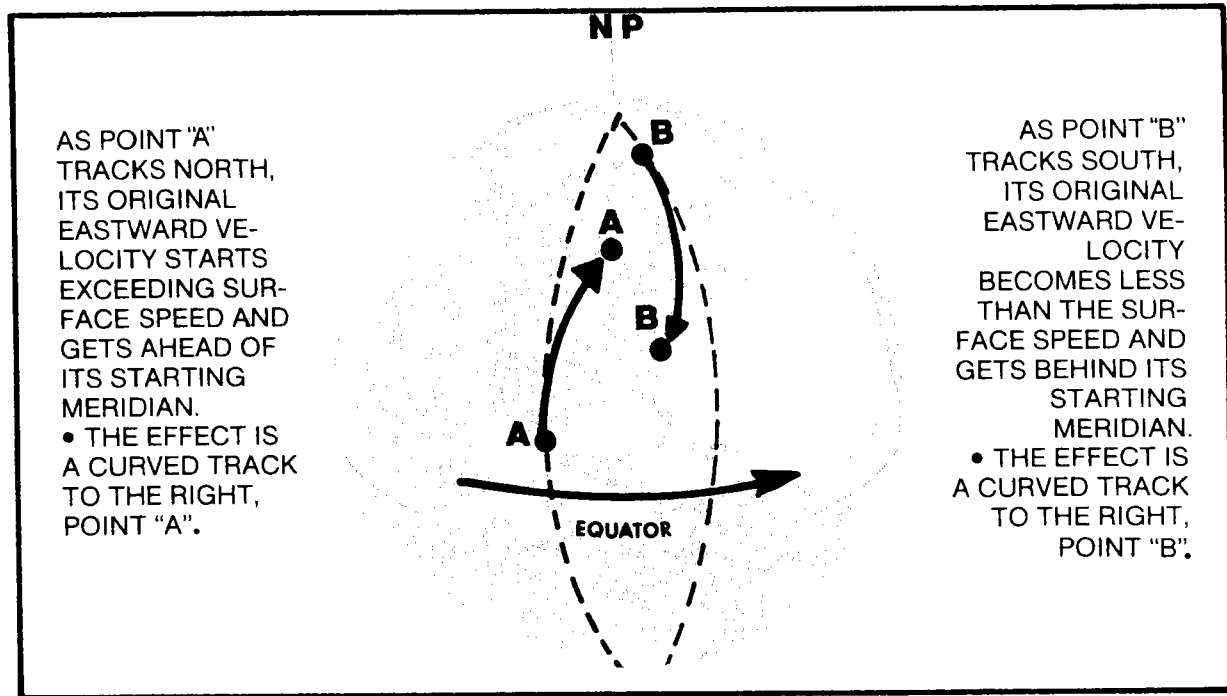


Figure 6-6. Coriolis force.

during one complete revolution than any of the inner points of the record (which would be comparable to the higher latitudes on earth) and therefore travels at a faster rate of speed. Our atmosphere is brought along by its gravitational attachment to earth at the same relative speed at each latitude. However, when a migrating pocket of air moves toward another latitude—either northward or southward—a phenomenon takes place known as the *Coriolis force* (fig 6-6). If the pocket of air moves northward, from a latitude with a greater circumference to a latitude with a lesser circumference, it will tend to move ahead (to the right) of the point directly north of its initial starting point because of its greater speed. To make up this difference, a free body—such as a pocket of air—must move along an *apparent* curved line ahead of the point immediately opposite its original longitude to obey the law of the conservation of angular momentum. Similarly, a pocket of air moving from north to south from an area with a smaller circumference to an area with a larger one would encounter a lag because it is entering a plane with a greater rim speed than the plane it left. Therefore, because of the lag, it too would encounter the effect of a

deflection to the right. Thus, a pocket of air moving either northward from the Equator or southward toward the Equator will be deflected toward the right.

(2) The other aspect of the Coriolis force affects the deflection of a parcel of air that is moving east or west. The rotation of the earth (which is greatest at the Equator) produces a centrifugal force which detracts from the true gravity of the earth. It also produces a tendency for the air to accelerate toward and bulge at the Equator. Another factor is that the gravitational attraction is greatest at the Poles. This is caused by the slightly flattened Poles being closer to the center of gravity and the absence of centrifugal force. Gravitational and centrifugal force tend to neutralize each other as long as the speed of the rotation of the earth is maintained. Without centrifugal force, free-moving bodies on the earth would be drawn toward the Poles. By the same reasoning, without gravity's poleward component, free-moving bodies on the earth would be drawn toward the Equator because of centrifugal force. A body moving from west to east would have an absolute speed equal to its speed plus the

rotational speed of the earth. This increased absolute speed of the body would result in an increase in centrifugal force. This would draw the body, in this case a pocket of air, toward the Equator (to the right in the Northern Hemisphere). A free-moving body moving in the opposite direction, from east to west, would have an absolute speed equal to the rotational speed of the earth minus its speed. This decreased absolute speed of the body would result in a decrease in centrifugal force. This would draw the body toward the Pole or to the right in the Northern Hemisphere.

(3) Combining the two explanations, the following conclusions can be summarized:

- The Coriolis deflection is perpendicular to the direction of the flow of air.
- The Coriolis force will deflect air to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.
- The Coriolis force is strongest at the Poles and decreases to zero at the Equator.
- The Coriolis force is zero with calm winds and increases in magnitude as wind speed increases.
- Coriolis force, in combination with other forces involved, will determine the different circulation patterns over the earth.

c. **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.

d. **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 degrees over the ocean to more than 45 degrees over rugged terrain. Frictional effects on the air are greatest near the ground, but the effects are also carried aloft by turbulence. Surface friction is effective in slowing the wind up 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.

## 6-8. WIND SYSTEMS

### a. *Winds Aloft*

(1) **Jet stream.** The jet stream is a relatively strong wind concentrated within a narrow stream in the atmosphere. This stream or band of maximum winds is imbedded in the mid-latitude westerlies and is concentrated in the upper troposphere.

(2) **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 6-7), 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

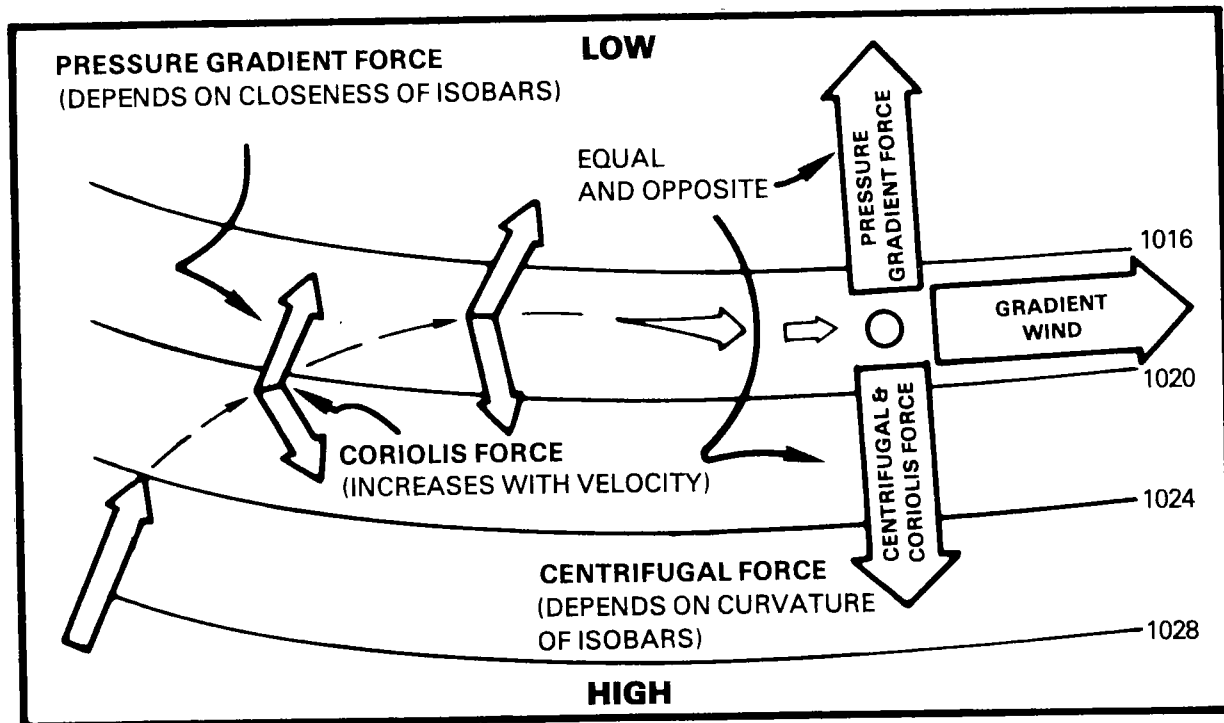


Figure 6-7. Gradient wind.

and the centrifugal force. The resultant wind is called the **gradient wind**.

(3) **Geostrophic wind.** Computations of wind velocity on the basis of pressure gradient and Coriolis force usually are 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**. 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 it will 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 wind flow will be somewhat toward the lower pressure.

(1) **The friction layer.** Surface wind is acted upon by pressure gradient force, Coriolis force, and centrifugal force. In practice, however, it tends to flow across the isobars from high toward low pressure (right-hand side of fig 6-8). 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-degree angle. The surface friction gradually decreases with altitude until the gradient or geostrophic level is reached.

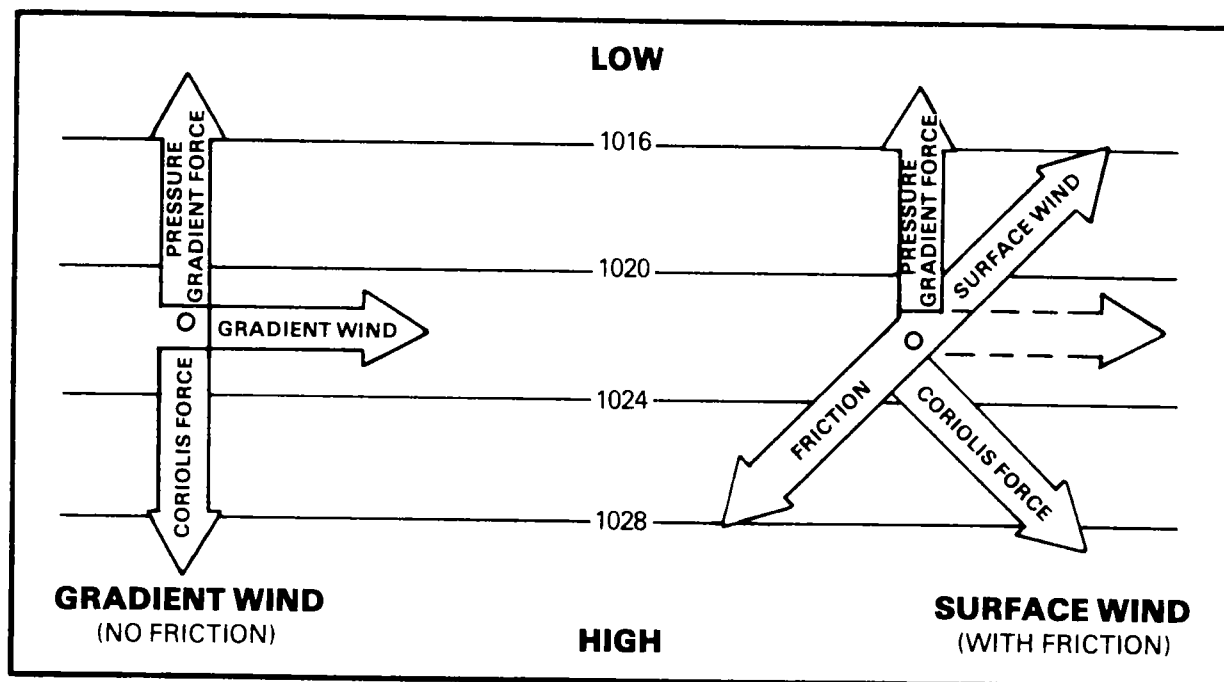


Figure 6-8. Comparison of gradient and surface winds.

(2) *Wind versus altitude.* Since the frictional force decreases with altitude, the wind speed will 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 6-9 and 6-10.

#### c. Winds and Pressure Systems.

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

(2) Surface winds (fig 6-11) in the Northern Hemisphere flow clockwise around and away from a center of high pressure and counterclockwise around and toward a center of low pressure.

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

with his back to the wind, is to the right of an area of low pressure (i.e., with a tail wind, 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.

d. *Convergence and Divergence.* "Convergence" is defined as the increase of mass within a given layer resulting from the net inflow of air. Low-pressure areas and fronts are forms of convergence. Convergence may also occur in areas where there are no lows or fronts. In some cases, thunderstorms may develop along lines of convergence. "Divergence" is defined as the decrease of mass within a given layer resulting from the net outflow of air. High-pressure areas and ridges are forms of divergence.

(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 (chap 3) decreases the relative humidity and produces generally good flying weather.

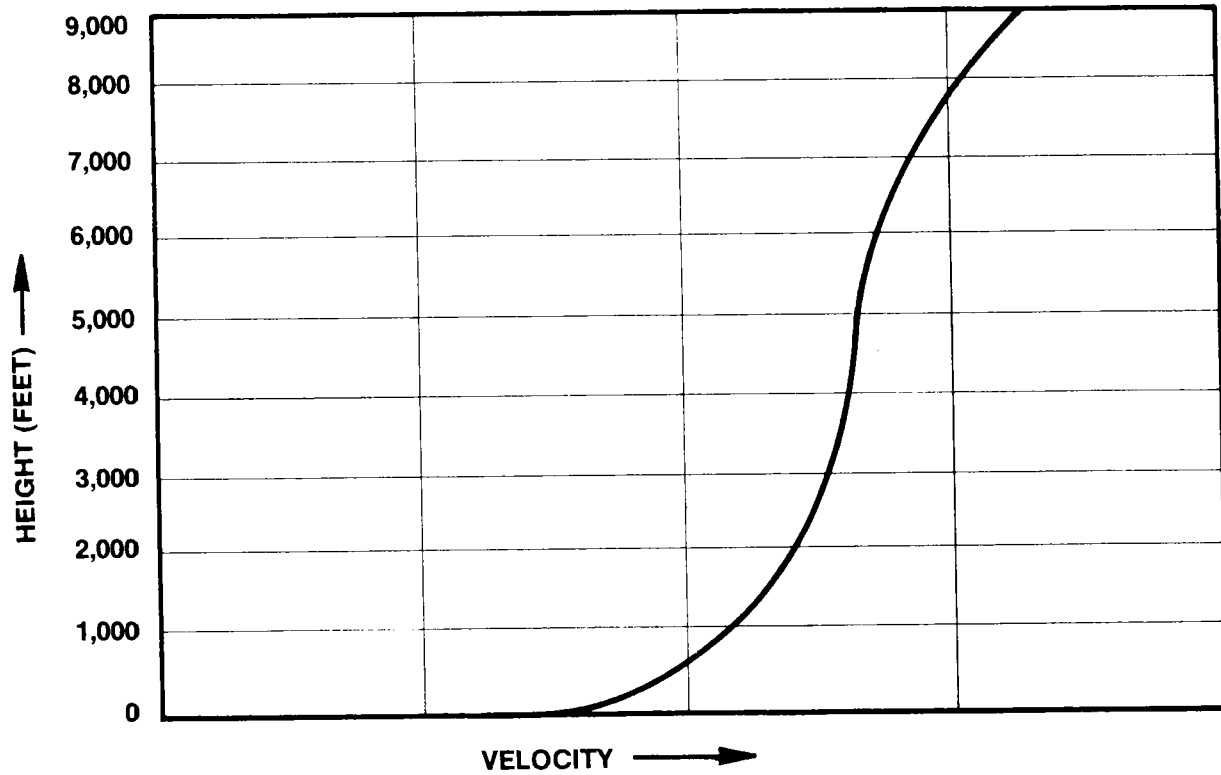


Figure 6-9. Approximate variation of wind velocity with height.

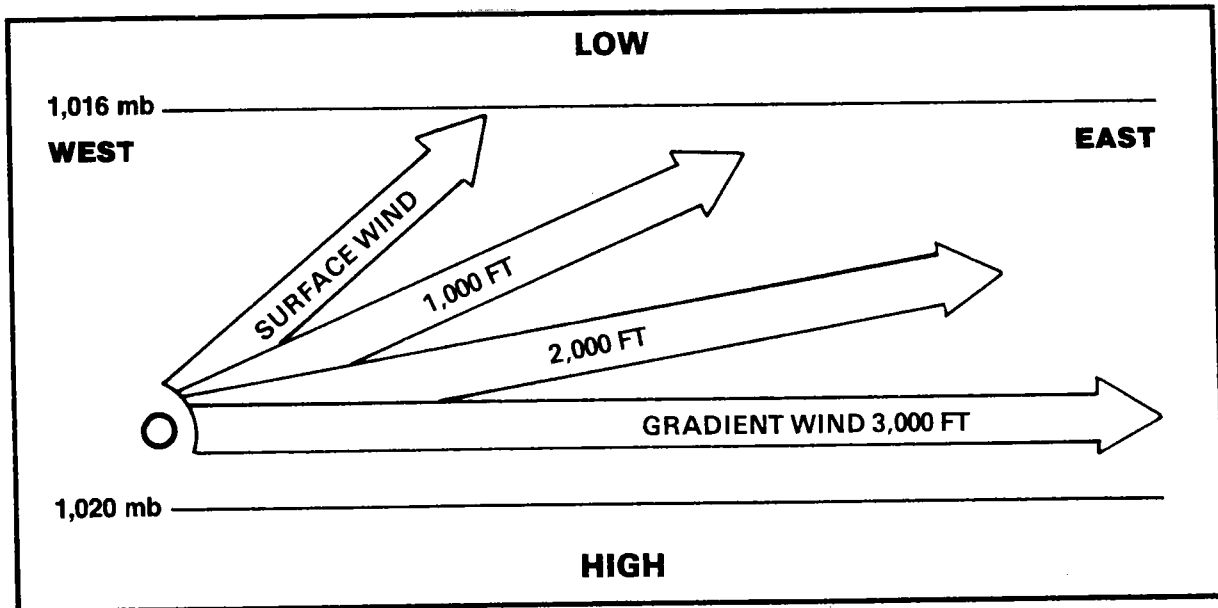


Figure 6-10. Approximate variation of wind direction with height.

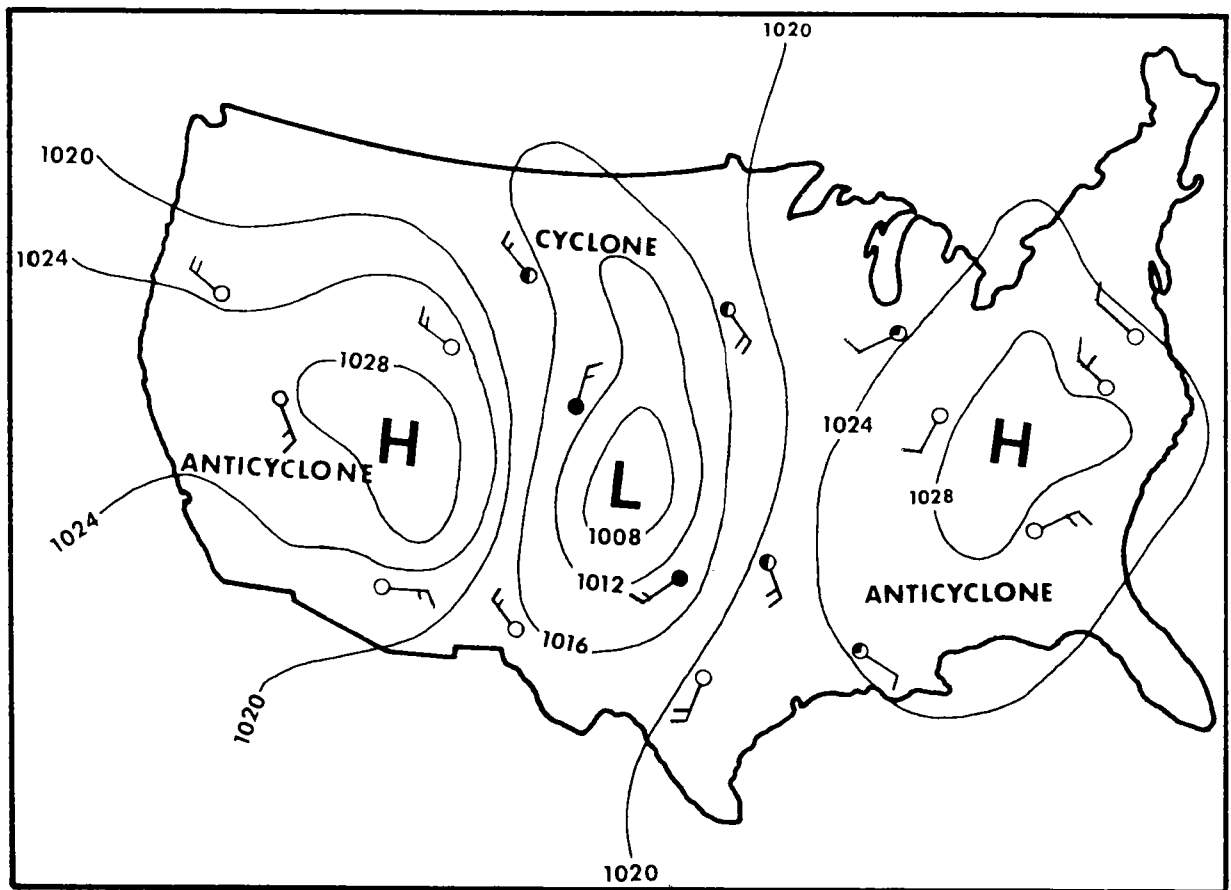


Figure 6-11. Surface wind flow in pressure systems.

(2) Convergence 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 flying weather.

## 6-9. SPECIAL AND LOCAL SECONDARY CIRCULATIONS

*a. Land and Sea Breezes.* During daytime, coastal lands generally become warmer than the adjacent water and a lower density will exist in the surface layer of air over the land than in the surface layer over the water (fig 6-12). 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.

*b. 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 mountainside during the day and flows down during the night. The daytime motion is a valley breeze; the nighttime motion is a mountain breeze.

*c. The Monsoon.*

(1) **General.** An important factor in the consideration of world weather phenomena is the monsoon and the mechanics of monsoonal circulation. "Monsoons" are names given for seasonal winds in certain parts of the world.

(2) **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 land areas (part of which lies near the border of the tropics and gets 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 landmass. Monsoonal circulation is extremely well developed in Southeast Asia. The southerly circulation in summer brings the warm moist air to the continent (fig 6-13). The winter pressure pattern causes a flow of very dry air from the north (fig 6-14). A similar monsoon circulation is found in North America, but it is not as well developed as the circulation found in Asia.

*d. The Mountain Wave.*

(1) Numerous aircraft accidents have occurred in mountainous areas in strong

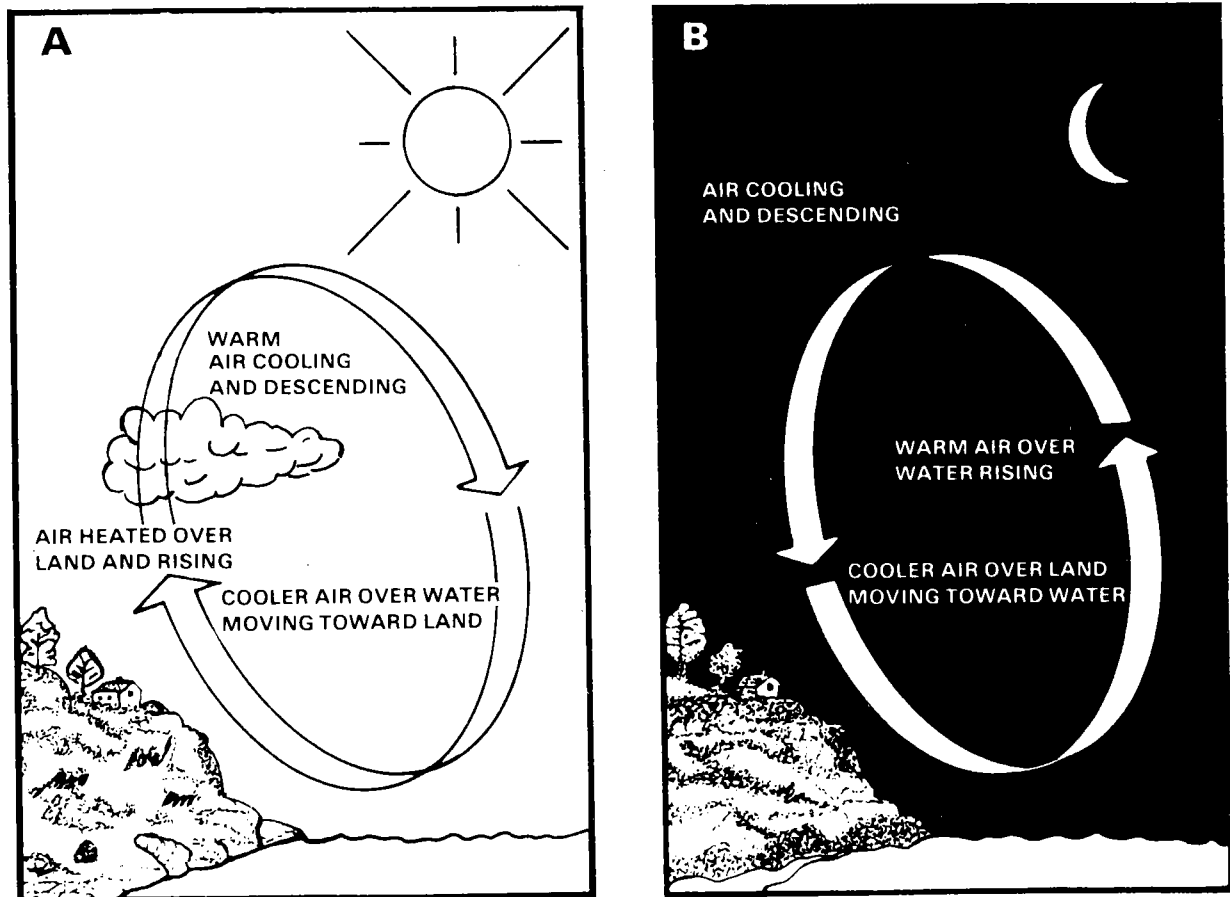
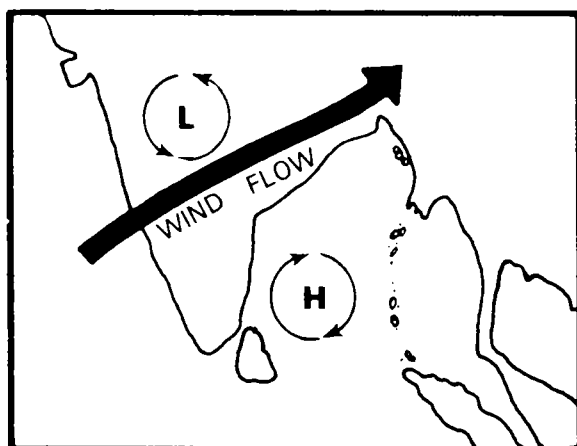
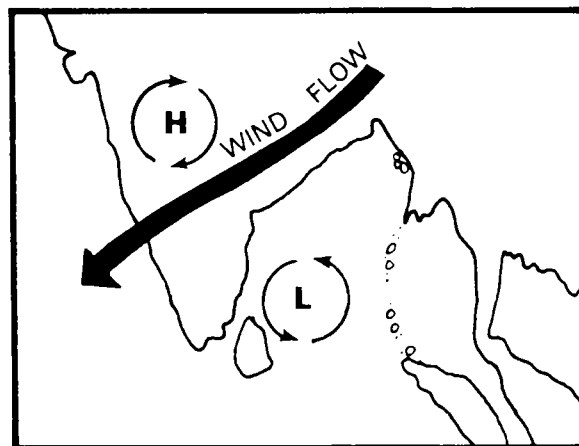


Figure 6-12. Land-sea effect.





*Figure 6-13. Summer monsoon.*



*Figure 6-14. Winter monsoon.*

wind situations, 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.

(2) 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. They had known that generally there is a descending flow on the lee side. During the 1930s, however, 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 1961, an altitude record of 46,267 feet was established in the United States during a period of strong mountain wave activity to the lee of the Sierra Nevada mountains near Mojave, California. 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.

(3) The characteristics of a typical mountain wave are represented in figures 6-15 and 6-16. Figure 6-15 shows the cloud formations normally found with wave development; figure 6-16 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.



*Figure 6-15. Typical cloud formations with mountain wave.*

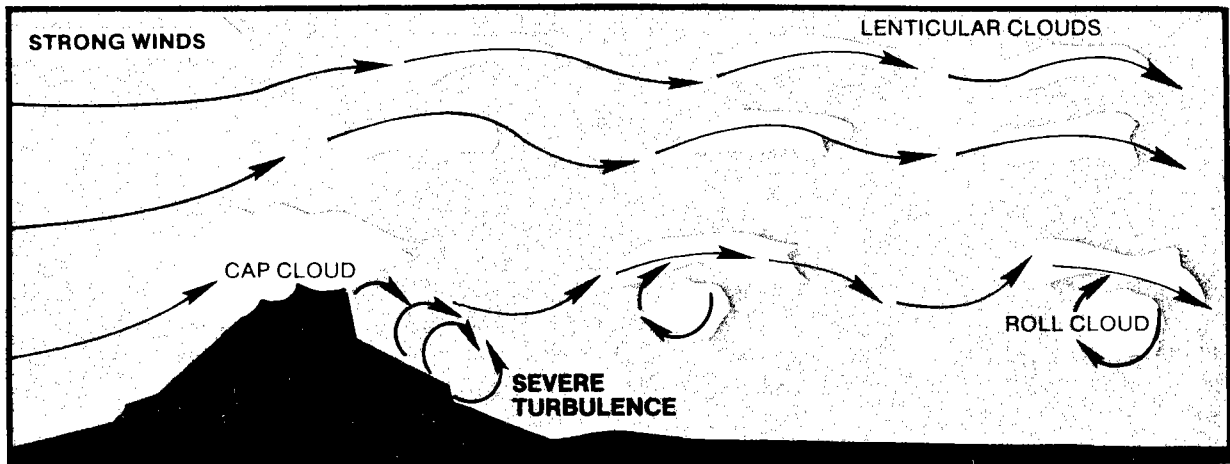


Figure 6-16. Multiple wave formation to the lee of a mountain range.

- 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 (FPM).

- Turbulence in varying degrees can be expected (fig 6-16), with particularly severe turbulence in the lower levels.

- Proceeding downwind 5 to 10 miles 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 6-16. 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 (wavelength) usually ranges from 2 to 10 miles, depending on the existing wind speed and atmospheric stability, although waves up to 20 miles apart have been reported.

(5) 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.

- The lenticular (lens-shaped) clouds in the upper right of figure 6-15 are smooth in contour. These clouds may occur alone or in layers at heights above 20,000 feet mean sea level, 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. It can be seen extending across the center of figure 6-15. The cap cloud, shown partially covering the mountain slope on the left in figure 6-15, 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.

- The cloud forms are generally a good guide to the degree of turbulence. That is, smooth airflow occurs in and near smooth clouds; but in some cases this may not be true, as in mountain regions and in the vicinity of fronts. Smoother conditions exist at the lenticular level than near the roll clouds (fig 6-15). However, proximity of smooth and turbulent areas is a characteristic of the mountain wave. Smooth flight conditions at the entry of wave is no assurance of continued smooth conditions. *Wave action also may*

*occur when the air is too dry to form clouds.* Thus, the aviator may fly into a wave area unexpectedly when clouds are not present to indicate the location of wave activity.

(6) There are several indications of wave development and intensity.

- Wind flow of about 25 knots or more perpendicular to the mountain range. Wave action rapidly decreases as the winds shift from this direction.

- An increase in wind speed with altitude up to and above the mountaintop height. Within limits, wave action becomes more intense with stronger winds. However, strong winds (over 100 knots in the free air above the ridge) may eliminate smooth wave-flow patterns entirely and cause severe turbulence.

- 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.

(7) If practicable, flight should be avoided in the wave area. Suggested *safe-guards* for flight into an area of suspected wave conditions are to—

- Avoid ragged and irregular-shaped lenticular and roll clouds.

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

- Avoid flight into a cloud deck lying on the mountain ridge (*cap cloud which may appear smooth*), since it can be

expected to contain strong downdrafts, turbulence, and the hazards of instrument flight near mountain level.

- Fly clear of the roll cloud to avoid its heavy turbulence and downdrafts.

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

- 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. However, you should be extremely careful in the vicinity of these clouds because extreme turbulence could be present. Since apparent updraft areas can be misleading, care should be used in employing this procedure.

*e. 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 approximately 3°C per 1,000 feet* until its temperature has dropped to the dew point. 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 approximately 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 approximately 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, strong wind. For example, if a mass of air with a temperature of 20°C 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 30°C. The foehn wind may greatly modify cold winter weather with its almost magical power to melt snow and ice.

*f. 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.

*g. Tornado and Waterspout.*

(1) *Tornado.* The tornado (fig 6-17) is the most violent of all storms. It is a whirlpool of air with a varying diameter averaging 250 yards. Generally it is associated with severe

squall-line conditions (lines of thunderstorms). And most frequently it is 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.

(2) *Waterspout.* The waterspout is a tornado that occurs over the water. 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 6-18 is a rare phenomenon composed of two funnels merged near the ocean.

*h. 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

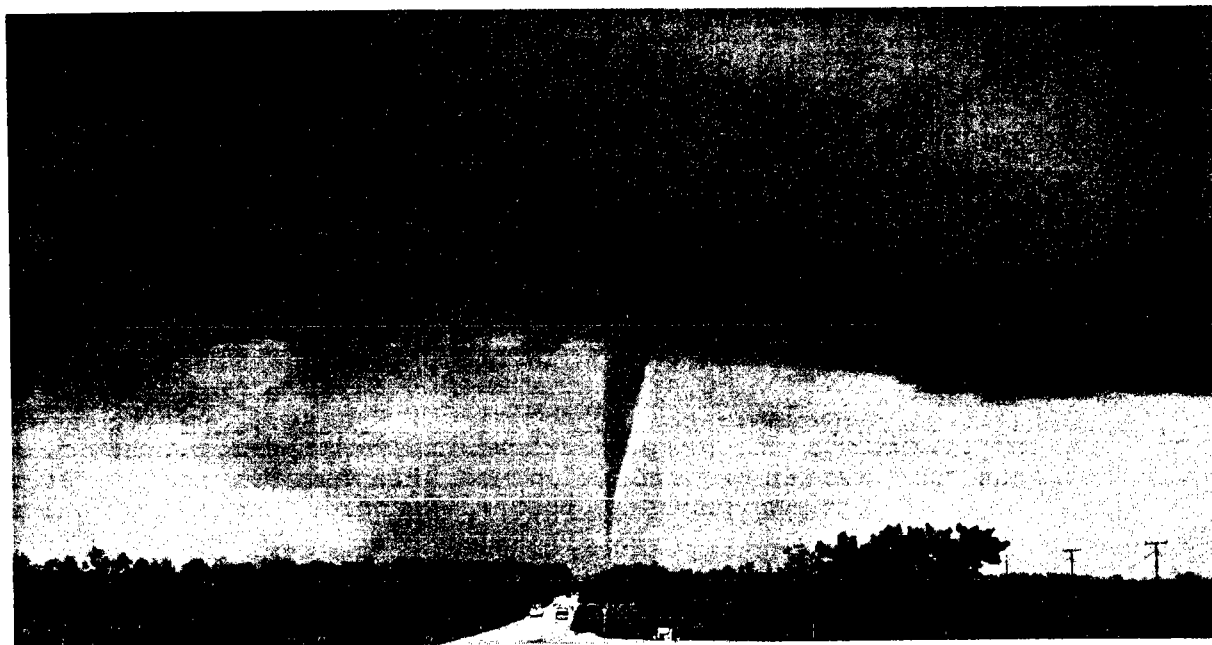


Figure 6-17. Funnel of tornado.



Figure 6-18. Waterspout.

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.

(1) 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.

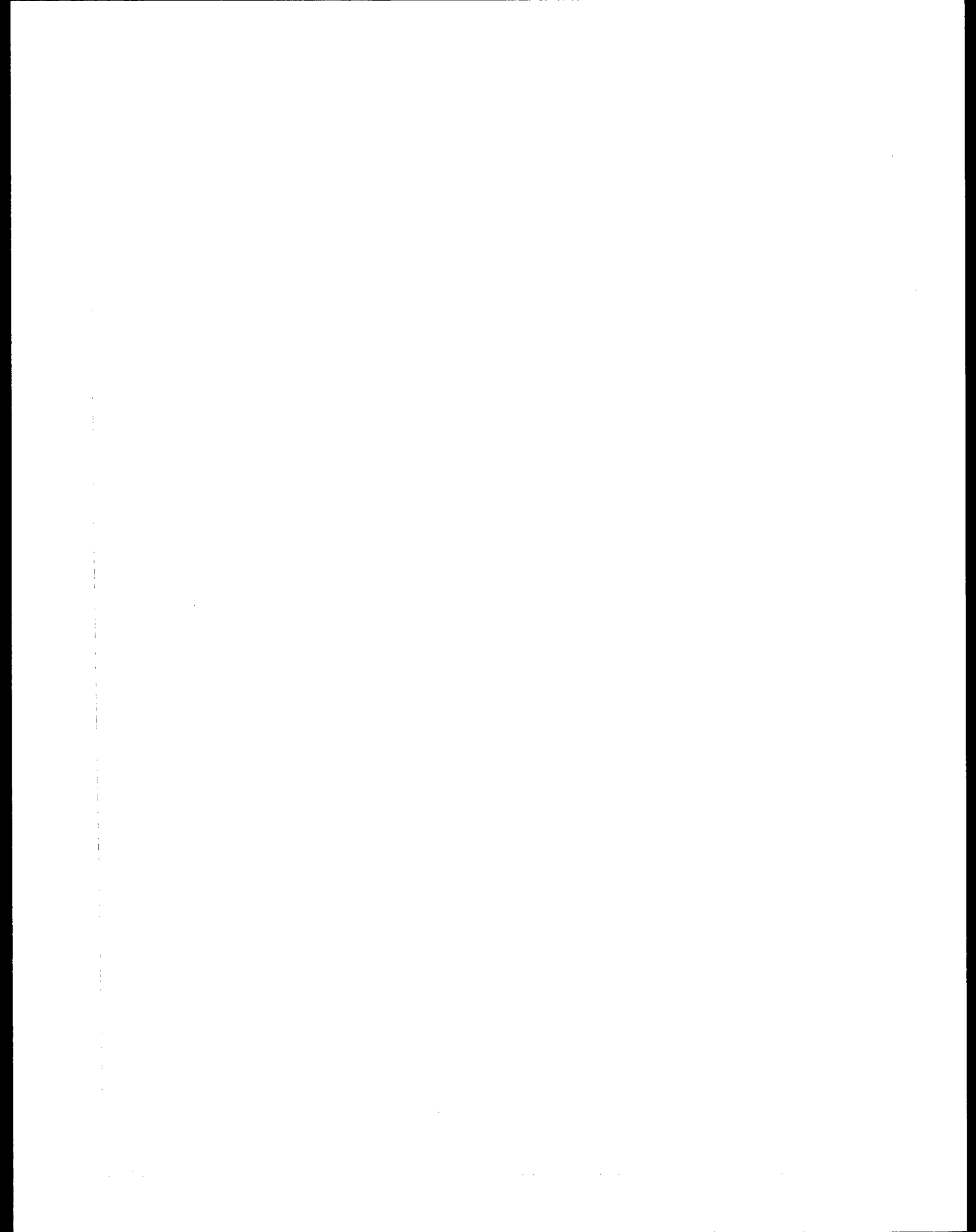
(2) The amount and extent of currents are affected by the roughness of the terrain. Over smooth water surfaces, only a few minor air currents form. In mountainous areas, even though the wind is light, many currents form. Large obstructions to airflow tend to produce more extensive air currents than small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

(3) 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.

(4) 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.

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

*i. Dust Devil.* A dust devil is a rotating column of air—normally 100 to 300 feet in height—carrying dust, straw, leaves, and other light material. It has no relationship to tornadoes. It is best developed in desert regions on hot afternoons with clear skies. Intense surface heating causes a steep lapse rate near the surface, producing a rising column of air. Surrounding air produces a circulation as it rushes in toward the rising column. While normally only an annoyance, dust devils can be a hazard to low flying aircraft and to aircraft on the ground.



## CHAPTER 7

## STABILITY AND INSTABILITY

## 7-1. GENERAL

a. The stability of the aircraft is a vital concern to the aviator. A stable aircraft if disturbed by the movement of the controls or by an external force will tend to return to a balanced, steady flight condition. An unstable aircraft, however, will continue to move away from the normal flight attitude.

b. This is also true with the atmosphere. The normal flow of air tends to be horizontal. If this flow is disturbed, a stable atmosphere will resist any upward or downward displacement. It will tend to return quickly to normal horizontal flow. An unstable atmosphere, on the other hand, will allow these upward and downward disturbances to grow, resulting in

rough (turbulent) air. An example is the towering thunderstorm which grows as a result of large and intensive vertical movement of air. It climaxes in lightning, thunder, and heavy precipitation, sometimes including hail.

c. Atmospheric resistance to vertical motion, called *stability*, depends upon the vertical distribution of the air's weight at a particular time. The weight varies with air temperature and moisture content. As shown in figure 7-1A, in comparing two parcels of air, hotter air is lighter than colder air and moist air is lighter than dry air. As shown in figure 7-1B, if air is relatively warmer or more moist than its surroundings, it is forced to rise and would be unstable. If the air is colder or dryer than its surroundings, it will sink

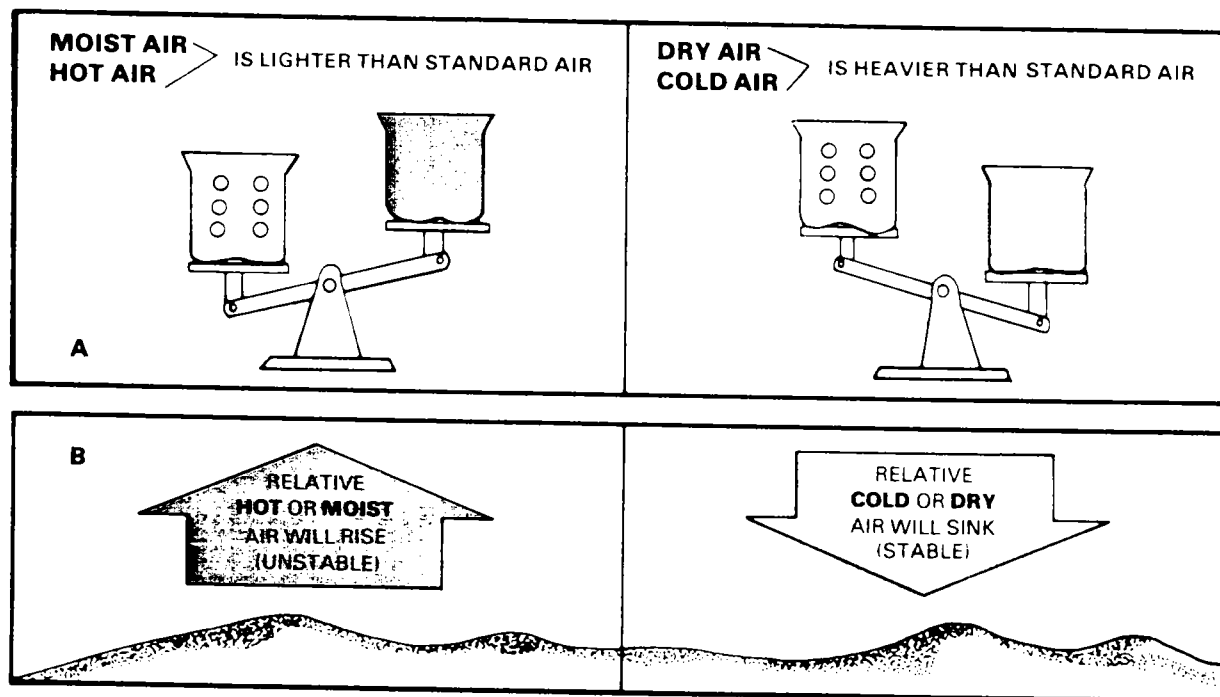


Figure 7-1. Moisture content and temperature determines weight of air.

until it reaches its equilibrium and would be stable. The atmosphere can only be at equilibrium when light air is above heavier air—just as oil poured into water will rise to the top to obtain equilibrium.

## 7-2. TEMPERATURE EFFECT

a. The air which is heated near the earth's surface on a hot summer day will rise. The speed and vertical extent of its travel depends on the temperature distribution of the atmosphere. Vertical air currents, resulting from the rise of air, can vary from the severe updrafts and compensating downdrafts associated with thunderstorms to the closely spaced upward and downward bumps that are felt on warm days when flying at low levels.

b. Since the temperature of air is an indication of its density, a comparison of temperatures from one level to another can approximate the degree of the atmosphere's stability; that is, how much it will tend to resist vertical motion.

## 7-3. LAPSE RATES

a. In chapter 3, it was shown that temperature usually decreases with altitude and that the rate at which it decreases is called the *lapse rate*. The lapse rate, commonly expressed in degrees per 1,000 feet, gives a direct measurement of the atmosphere's resistance to vertical motion. The degree of stability of the atmosphere may vary from layer to layer as indicated by changes of lapse rate with height.

b. When unsaturated air rises, its temperature decreases at the dry adiabatic lapse rate of 3°C per 1,000 feet. This occurs whether the air is forced upward, as a result of being heated from below (fig 7-2A), or through forced ascension, such as up a mountain slope (fig 7-2B). Visualizing the rising air as a bundle or parcel which is separate from the general atmosphere, the parcel in figure 7-2C is shown getting larger with height because, in its attempt to equalize pressure, the air expands, causing it to cool. Figure 7-2D shows the reverse process in which descending air is heated by compression.

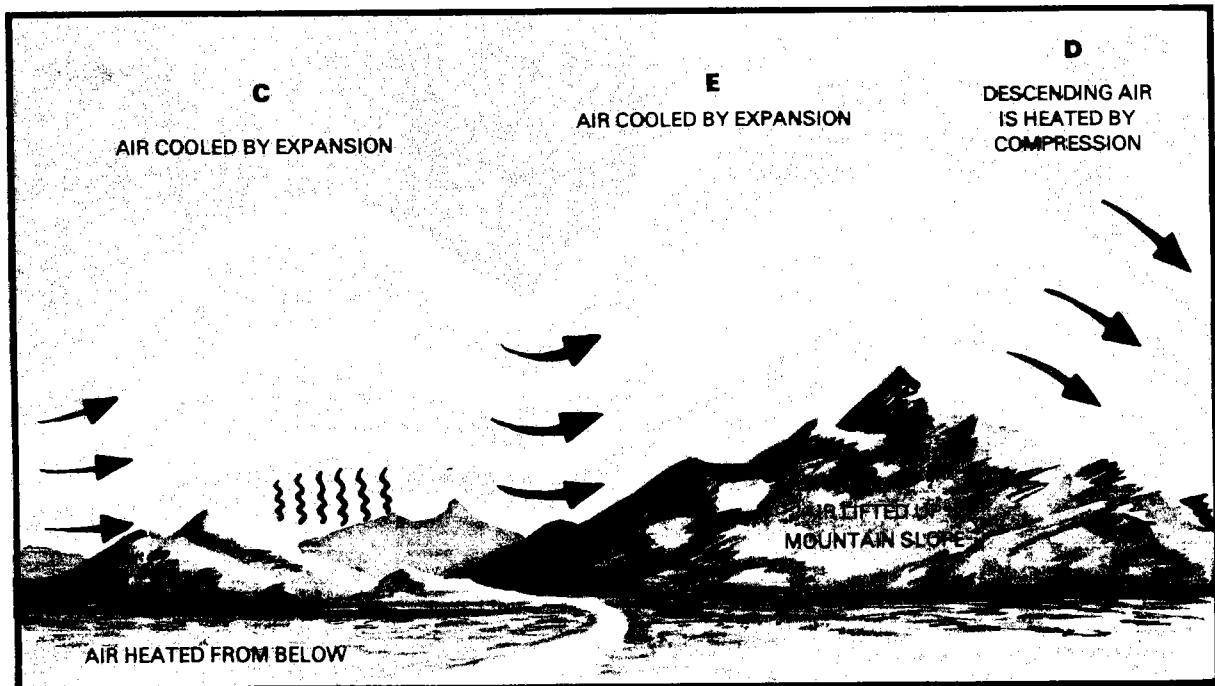


Figure 7-2. Effect of lifting dry air.



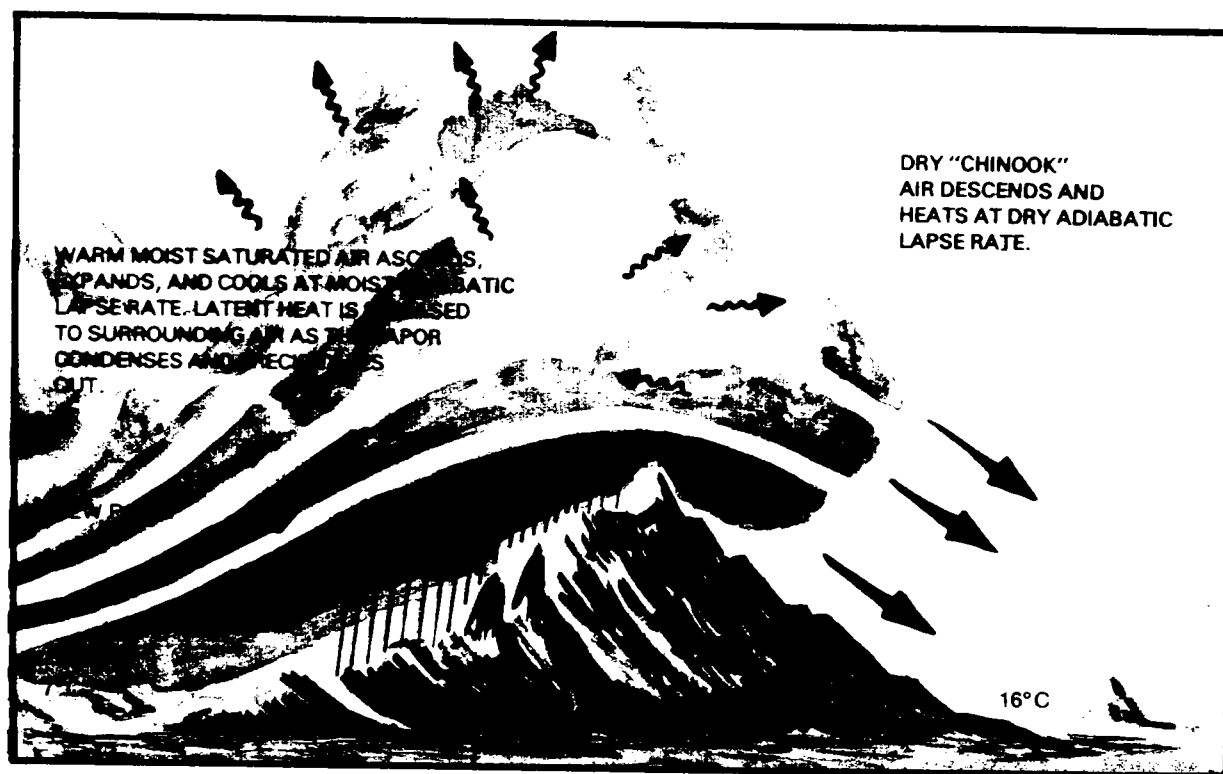


Figure 7-3. Effect of lifting moist air.

c. When saturated air rises or is forced to ascend, condensation occurs. Latent heat used during the evaporation process is released and tends to warm the air. Consequently, rising moist air does not cool as much as rising dry air. This causes the air to cool at a slower rate (depending on the moisture content of that air) than that of unsaturated air. It was pointed out in chapter 3 that the moist adiabatic lapse rate ranges from  $1.1^{\circ}$  to  $2.8^{\circ}\text{C}$ .

d. In winter, moist air from the Pacific Ocean is occasionally forced over the mountains by a strong wind flow. Assume that at 5,000 feet on the western slope the air is saturated and has a temperature of  $7^{\circ}\text{C}$ . Blowing over the mountains, the air is lifted to 12,000 feet (fig 7-3). Because it is saturated, the air cools at the moist adiabatic rate, with condensation occurring throughout the 7,000 feet of rise (from dew point at 5,000 feet through the 12,000-foot mountaintops). At 12,000 feet its temperature is  $-5.6^{\circ}\text{C}$ , having

cooled at an average rate of  $1.8^{\circ}\text{C}$  per 1,000 feet. Descending the eastern slope of the mountains, the air warms at the dry adiabatic lapse rate. As soon as the air starts to descend, its temperature increases due to compression (contraction); and it is no longer saturated. Thus the descending air, warming at  $3^{\circ}\text{C}$ , per 1,000 feet, arrives at 5,000 feet on the east side of the mountains with a temperature of  $15.4^{\circ}\text{C}$ . In doing so, its temperature has increased  $8.4^{\circ}\text{C}$  and its relative humidity has decreased considerably. This explains the formation of deserts on the lee side of some mountain ranges.

e. The standard lapse rate of  $2^{\circ}\text{C}$  is used as a basis for calibrating aircraft altimeters and has no connection with determining the stability of the air.

f. The general conclusion is that air at moderate and high temperatures is normally either stable or unstable, depending upon the amount of moisture it contains.

## 7-4. TYPES OF STABILITY

a. **General.** There are five types of stability. These include—

- (1) Absolute stability.
- (2) Neutral stability.
- (3) Absolute instability.
- (4) Conditional instability.
- (5) Convective instability.

To get a general idea of what these terms mean, study figure 7-4, which shows a surface, part of which is level and part of which has a ridge and a valley. The following effects will result if the marble is placed at:

- Location S: Will resist movement if displaced in either direction and will return to its original position at location S. It is **absolutely stable**.

- Location N: On this level surface, the marble will remain at rest in any position. It is **neutrally stable**.

- Location I: Will immediately fall down the slope without any outside force being applied to displace it. It is **absolutely unstable**.

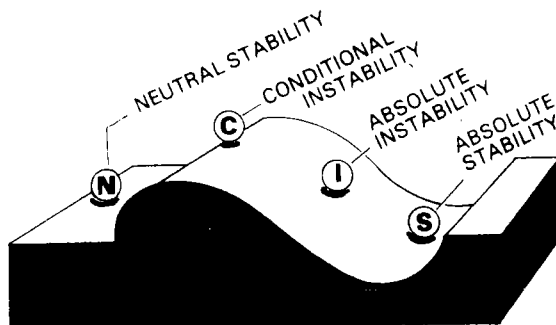


Figure 7-4. Types of atmospheric stability.

- Location C: The marble can be balanced atop the ridge; and so long as it is undisturbed, it will remain at rest. Once displaced, it will continue to fall until reaching equilibrium at some other location. It is **conditionally unstable**—that is, unstable on the condition that it receives an initial displacement.

The term **convective instability** refers to a condition within a layer which becomes unstable after lifting. It does not lend itself readily to illustration here, but it would be best represented by location C (conditionally unstable).

Now let's see what effect each of these types of stability has on our atmosphere.

b. **Absolute Stability.** When the actual lapse rate in a layer of air is less than the moist adiabatic lapse rate, that air is absolutely stable regardless of the amount of moisture it contains (fig 7-5). A parcel of absolutely stable air which is lifted becomes cooler than the surrounding air and sinks back to its original position as soon as the lifting force is removed. Similarly, if forced to descend, it becomes warmer than the surrounding air; and, like a cork in water, it rises to its original position upon removal of the outside force.

c. **Neutral Stability.** Neutrally stable air is air with the same temperature; therefore, there is no parcel to rise or descend.

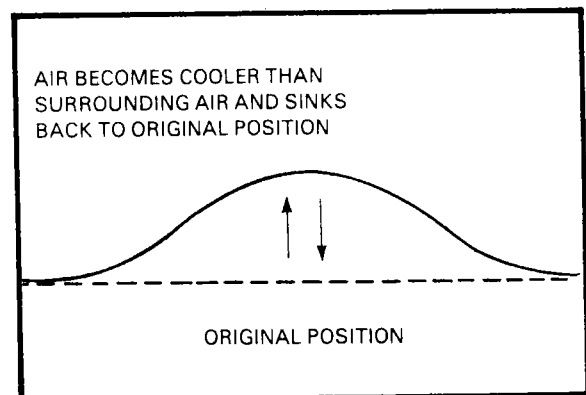


Figure 7-5. Absolute stability.

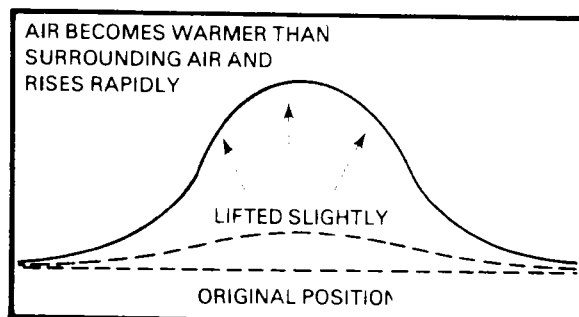


Figure 7-6. Absolute instability.

Typical of such a case would be where the surface area in contact with that air is of the same temperature.

*d. Absolute Instability.* When the actual lapse rate in a layer of air is greater than the dry adiabatic lapse rate, that air is absolutely unstable regardless of the amount of moisture it contains (fig 7-6). A parcel of air lifted even slightly will at once be warmer than its surroundings; and, like a hot air balloon, it will be forced to rise rapidly.

*e. Conditional Stability.* When the actual lapse rate lies between the dry and moist adiabatic lapse rates, the air is conditionally stable. If the air is saturated, it will be unstable; if unsaturated, it will be stable. In other words, whether the air is stable or unstable depends upon the amount of moisture it contains. The standard lapse rate lies also

between the dry and moist adiabatic lapse rates, indicating that—on the average—air is conditionally stable.

## 7-5. EFFECTS OF STABILITY AND INSTABILITY

*a.* The degree of stability of the atmosphere helps to determine the type of clouds if any form. For example, figure 7-7A shows that if very stable air is forced to ascend a mountain slope, clouds will be layerlike with little vertical development and little or no turbulence. Unstable air, if forced to ascend the slope, would cause considerable vertical development and turbulence in the cumulus-type clouds (fig 7-7B).

*b.* If air is subsiding (sinking), the heat of compression frequently causes an inversion of temperature which increases the stability of the subsiding air (fig 7-8). Sometimes when this occurs, as in wintertime high-pressure systems, a surface inversion formed by radiational cooling is already present. The subsidence-produced inversion, in this case, will intensify the surface inversion, placing a strong "lid" above smoke and haze. Poor visibility in the lower levels of the atmosphere results, especially near industrial areas. Such conditions frequently persist for days, notably in the Great Basin region of the Western United States.

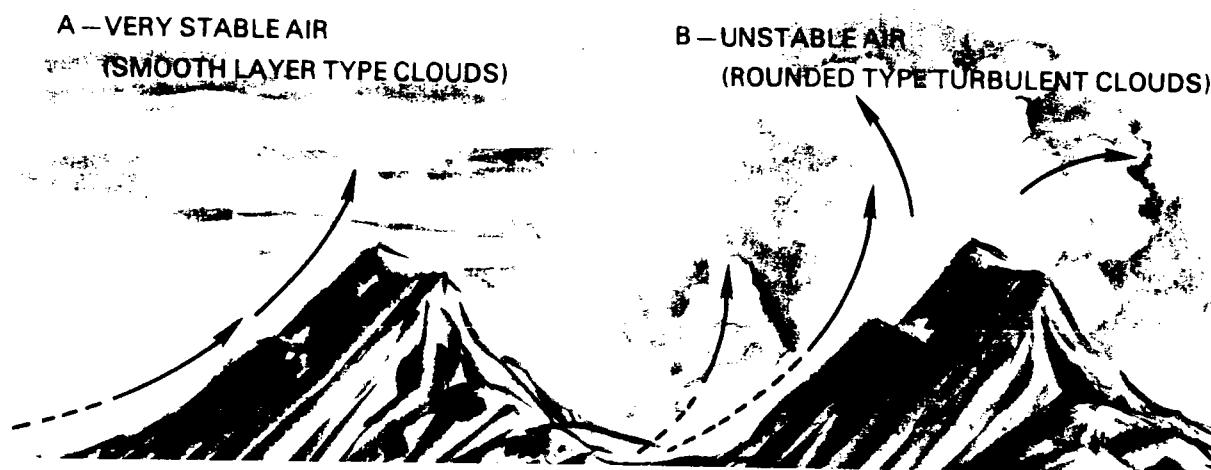
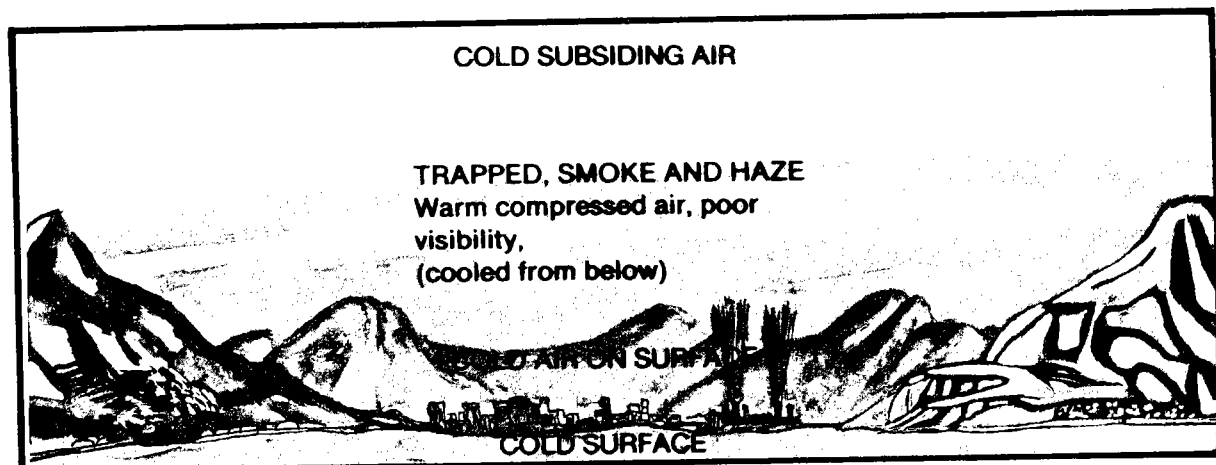


Figure 7-7. Stability of air affects type of cloud formation.



*Figure 7-8. Surface inversion (temperatures increase with altitude).*

## CHAPTER 8

# CLOUDS

### Section I. GENERAL

#### 8-1. CLOUD FORMATIONS AND DEFINITION

##### *a. General.*

(1) Clouds are weather signposts in the sky. They provide the aviator with visible evidence of the atmospheric motions, water content, and degree of stability. In this sense, clouds are a friend to the Army aviator. However, when they become too numerous or widespread, form at low levels, or show extensive vertical development, they present weather hazards to aviation.

(2) Cloud formations are the direct result of saturation-producing processes which take place in the atmosphere. The Army aviator must be able to identify cloud formations which are associated with weather hazards. Knowledge of cloud types will also assist the Army aviator in interpreting weather conditions from weather reports and existing weather. Table 8-1 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 supported and transported by air movements as shown as one-tenth of a mile per hour.

#### 8-2. INTERNATIONAL CLASSIFICATION OF CLOUDS

*a. General.* The international cloud classification (table 8-1) 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 (fig 8-1) are—

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

TABLE 8-1. International Cloud Classification, Abbreviations, and Weather Map Symbols.			
BASE ALTITUDE	CLOUD TYPE	ABBREVIATION	SYMBOL
BASES OF HIGH CLOUDS USUALLY ABOVE 18,000 FEET	CIRRUS	Ci	—
	CIRROCUMULUS	Cc	☁
	CIRROSTRATUS	Cs	☁
18,000 FT			
BASES OF MIDDLE CLOUDS RANGE FROM 6,500 FEET TO 18,000 FEET	ALTOCUMULUS	Ac	☁
	ALTOSTRATUS	As	☁
6,500 FT			
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.			

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 vertical development clouds are characterized by their lumpy or billowy appearance and are designated **cumuliform** type clouds, meaning “accumulation” or “heap.” Turbulent flying conditions usually exist in, below, around, and above cumuliform clouds.

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

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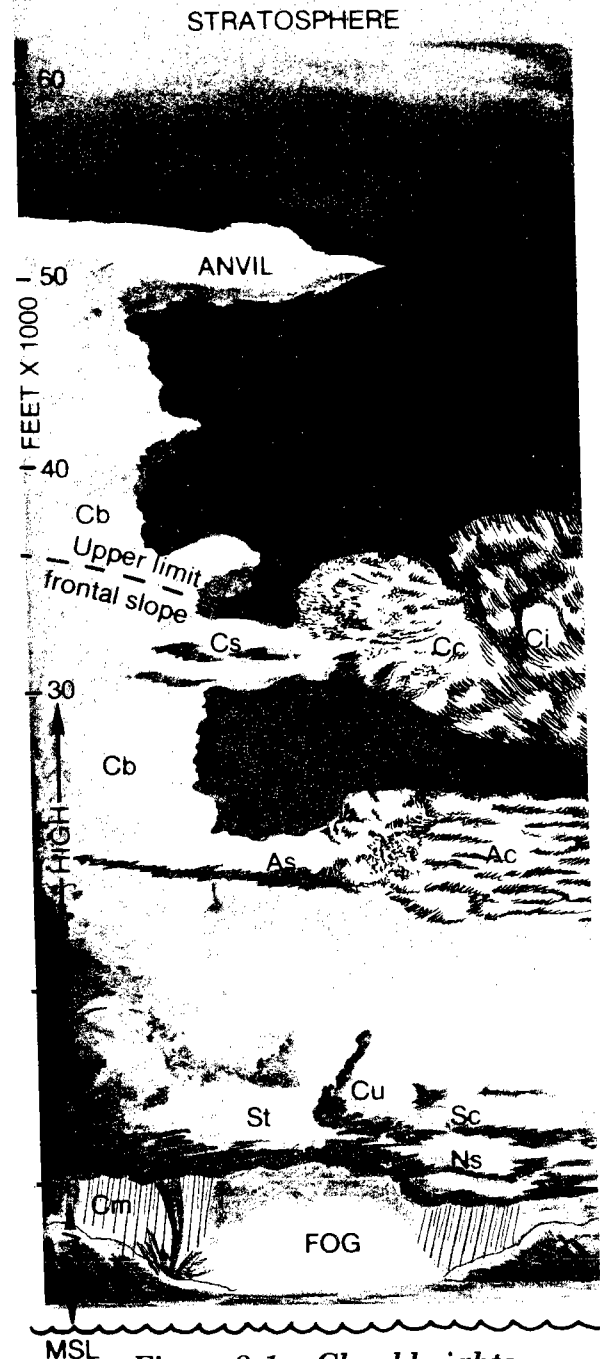


Figure 8-1. Cloud heights.

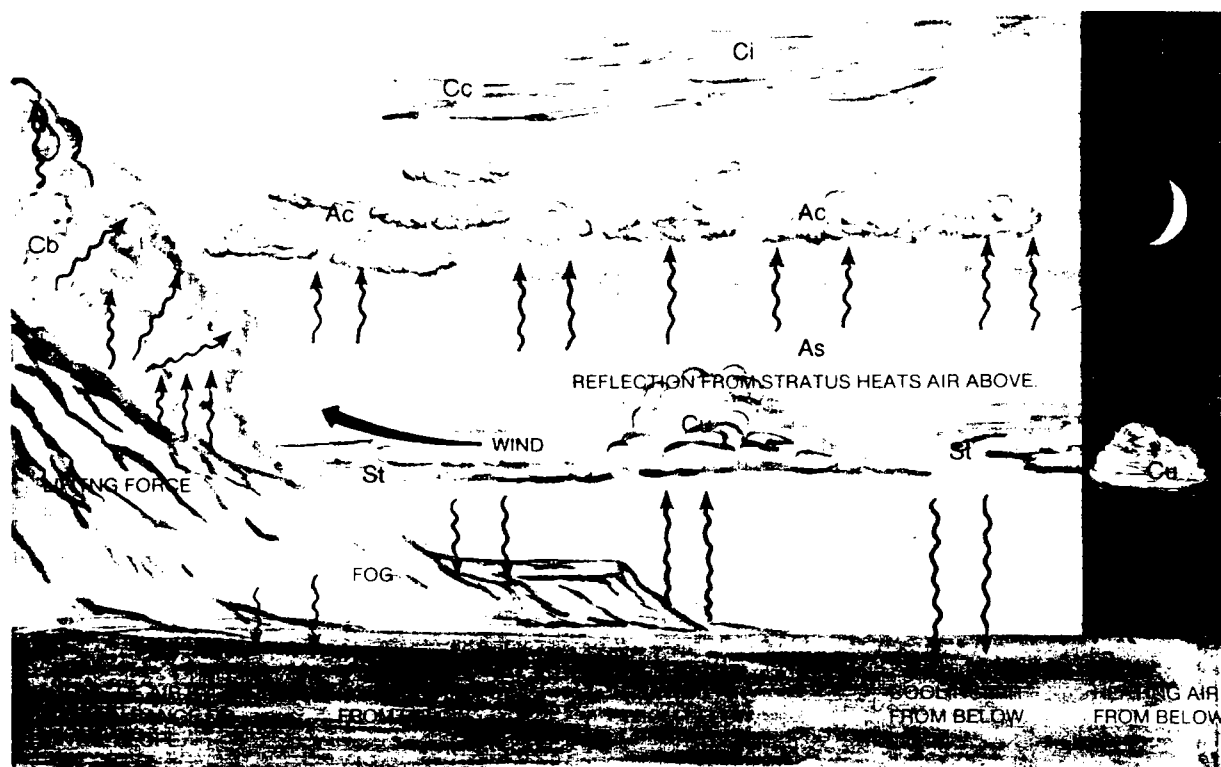


Figure 8-2. Various factors affecting cloud types.

#### WARNING

Cumuliform clouds may sometimes be imbedded within stratiform clouds.

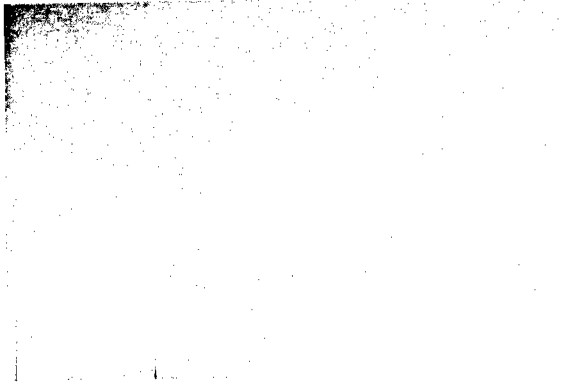
*c. Rain Clouds and Fragmentary Clouds.* In addition to the two main subdivisions discussed in "b" above, is the word *nimbus*, meaning "rain cloud." These clouds normally produce heavy precipitation, either liquid or solid. For example, a stratiform cloud producing precipitation is referred to as *nimbostratus*, and a heavy, swelling cumulus cloud that has grown into a thunderstorm is referred to as *cumulonimbus*.

## Section II. TYPES OF CLOUDS

A knowledge of principal cloud types and the factors that affect them (fig 8-2) helps the Army aviator to visualize expected weather conditions and to recognize potential weather hazards.

### 8-3. HIGH CLOUDS

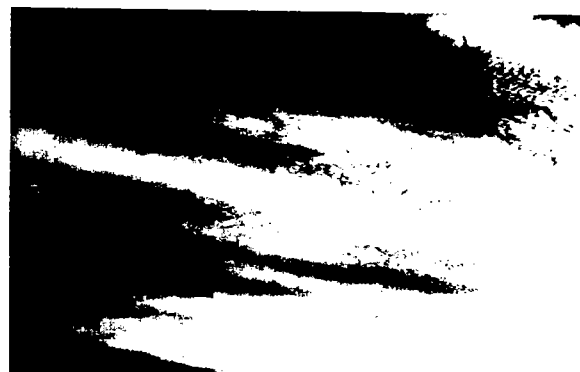
The high cloud group consists of *cirrus*, *cirrocumulus*, and *cirrostratus* clouds (figs 8-3, 8-4, 8-5). The mean base level of these three cloud types starts at 18,000 feet or higher above terrain. Cirrus clouds may give indications of approaching changes in weather. Cirriform clouds are composed of ice crystals, but normally 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 or corona effect.



*Figure 8-3. 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.)





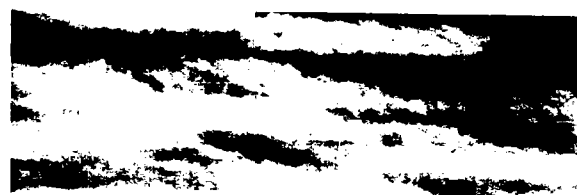
**Figure 8-4. Cirrocumulus clouds.**

(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.)



**Figure 8-5. Cirrostratus clouds.**

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





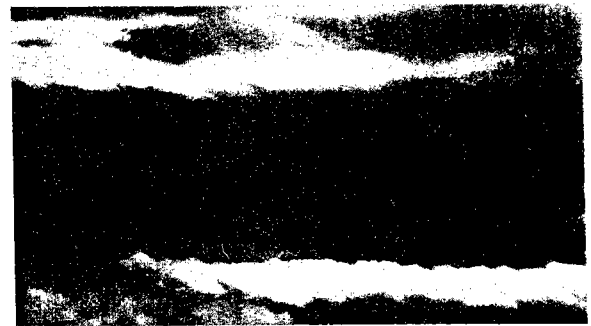
**Figure 8-6. Altocumulus clouds.**

(Description: White and/or gray clouds, 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 be merged.)

8-6

#### 8-4. MIDDLE CLOUDS

The middle cloud group consists of *altocumulus*, *altostratus*, and *nimbostratus* clouds (figs 8-6, 8-7, 8-8). 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 start as low as 6,500 feet and tops can range as high as 20,000 feet above the terrain. These clouds may be composed of ice crystals or water droplets (which may be supercooled); and they may contain icing conditions hazardous to aircraft. Altocumulus rarely produces precipitation, but altostratus usually indicates the proximity of unfavorable flying weather and precipitation.



**Figure 8-7. 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.)



**Figure 8-8. 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.)

### 8-5. LOW CLOUDS

This group of clouds consists of *stratus* and *stratocumulus* clouds (figs 8-9, 8-10). The bases of these clouds can start near the surface with the top extending to 6,500 feet or more above terrain. Low clouds are of great importance to the aviator, since they create low ceilings and poor visibility. The heights of the cloud bases may change rapidly. If low clouds form below 50 feet, they are classified as fog 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 particular threat because of the probability of icing. When flying near or through these clouds, the Army aviator must be constantly alert to changes in cloud formation, ceiling, and visibility. He must be prepared to fly to an alternate field if the ceiling or visibility drops below minimums at his destination. (Instrument flying publications issued to Army aviators contain specific airport ceiling or visibility minimums.)



**Figure 8-9. Stratus clouds.**

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



**Figure 8-10. Stratocumulus clouds.**

(Description: Gray and/or 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.)

## 8-6. CLOUDS WITH VERTICAL DEVELOPMENT

a. *Types.* Clouds with vertical development include the towering *cumulus* and *cumulonimbus* clouds (figs 8-11, 8-12). These clouds generally have their bases below 6,500 feet above the terrain and tops sometimes extend above 60,000 feet. Clouds with vertical development are caused by lifting action, such as convective currents, 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. (See Chapter 12, "Thunderstorms," and Chapter 13, "Airborne Weather Radar.")

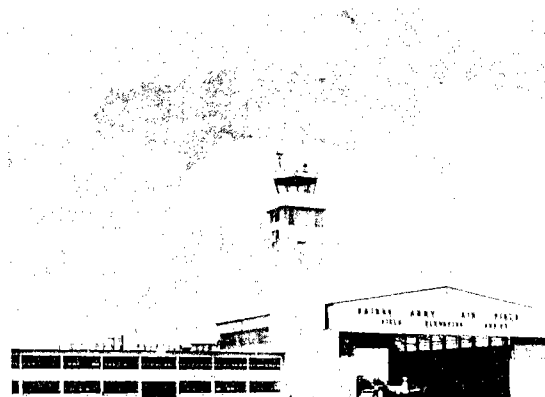
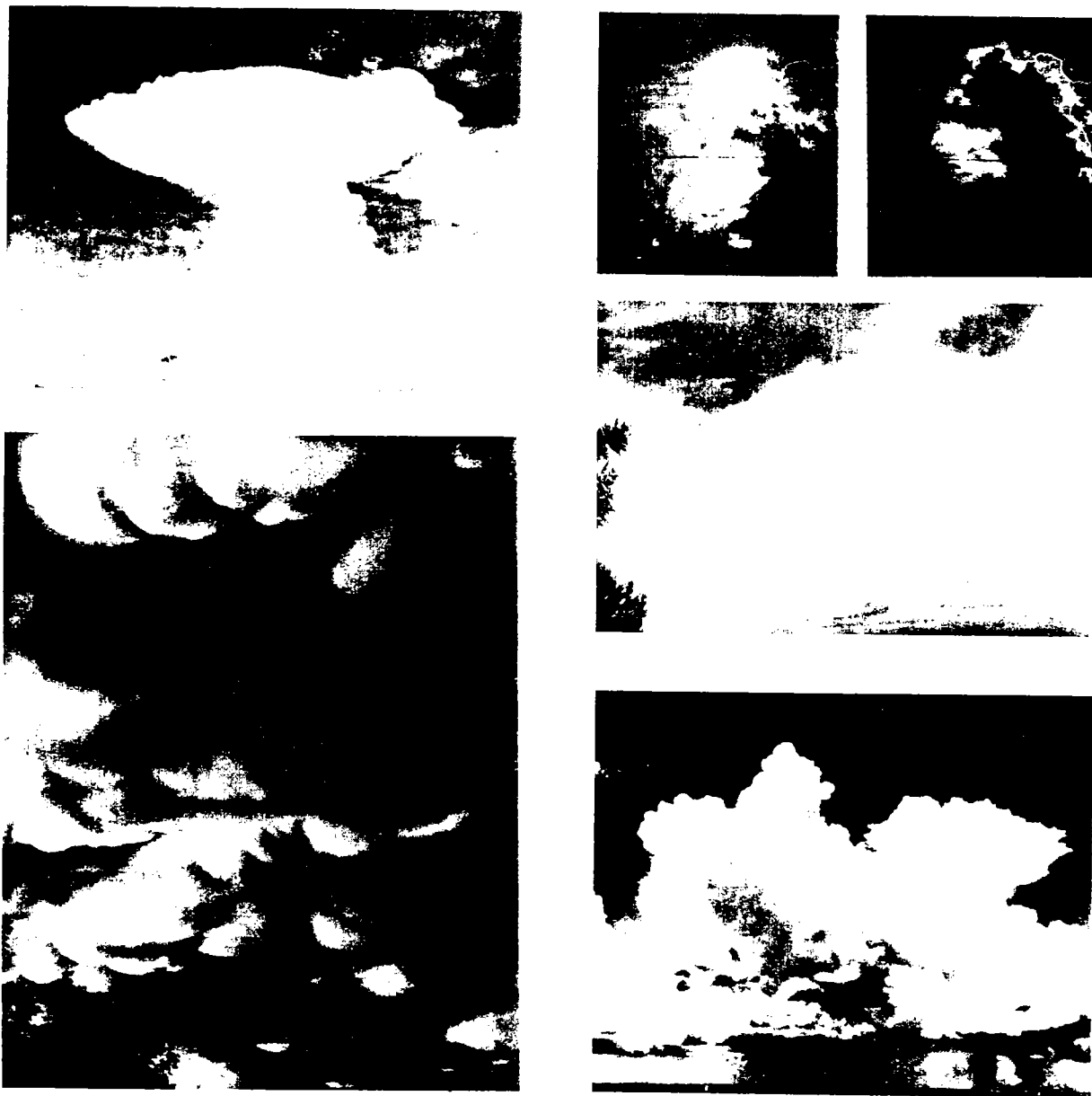


Figure 8-11. *Cumulus clouds.*

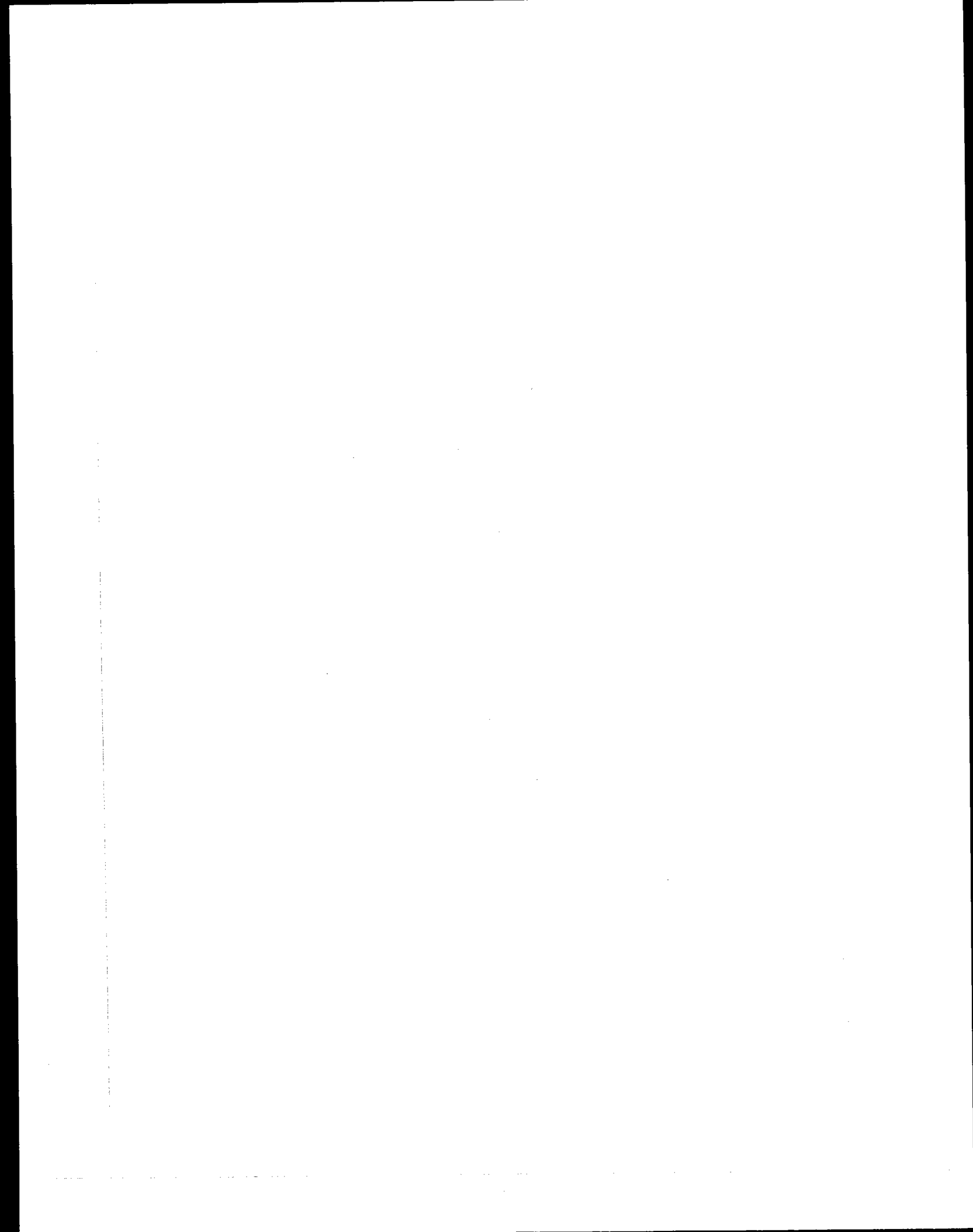
(Description: Detached clouds that are generally dense and with distinct outlines, developing vertically in the form of rising mounds, domes, or towers, of which the bulging upper part often resembles a cauliflower. The sunlit parts of these clouds are mostly brilliant white, with their bases relatively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



**Figure 8-12.** *Cumulonimbus (thunderstorm) clouds.*

(Description: Heavy, dense clouds with considerable vertical form like mountains or huge towers. They may be isolated, may appear in groups, may appear in lines extending hundreds of miles, or may be embedded in stratoform clouds. 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 merged. Precipitation varies from light showers to very heavy rain or hail. (Cumulonimbus produces lightning and gusty winds.) A cumulonimbus is a thunderstorm without the thunder; however, it contains all the hazards of a thunderstorm. Clouds in lower left are known as mammatus. It is part of the cumulonimbus (Cb), but is not a Cb. This cloud denotes strong turbulence.



## CHAPTER 9

### AIR MASSES

#### Section I. GENERAL

##### 9-1. GENERAL

An air mass is a large body of air (usually 1,700 kilometers or more across) whose physical properties (temperature and humidity) are horizontally uniform. An understanding of the characteristics of an air mass is essential to any comprehensive study of weather phenomena in the temperate regions. The weather in these regions is a direct result of the continuous alternation of the influences of warm and cold air masses. *Warm air masses* predominate in the summer and *cold air masses* predominate in the winter. However, both cold and warm air, alternately, may prevail almost anywhere in the temperate zone at any season. The basic characteristics of any air mass are temperature and humidity. These properties are relatively uniform throughout the extent of the air mass, and it is by measurement of these properties that the various types of air masses are determined.

##### 9-2. CHARACTERISTICS OF AN AIR MASS

The *characteristics* of an air mass consist of the basic properties of moisture and temperature which include the—

- Stability.
- Cloud types.
- Sky coverage.
- Visibility.
- Precipitation.
- Icing.
- Turbulence.

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* which is the surface area over which it 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*. The air masses are affected by the different types of surfaces (mountains, plains, plateaus, deserts, water, snow-covered areas, etc.) along their trajectories.

(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 the—

- Temperature and moisture contrast between the air and the surface.
- Terrain features.
- 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.

### 9-3. AIR MASS CLASSIFICATION

The standard classification of air masses describes 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; that is, A—Arctic, P—Polar, and T—Tropical. 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. Conversely, 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.

### 9-4. AIR MASS DESIGNATION

The following designators identify air masses that frequently affect the northern temperate zone:

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

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

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

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

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

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

### 9-5. 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. The following describes air mass types in Europe.

*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.

*c. Continental Air Mass.* Continental air masses are associated with good flying weather; that is, 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 (para 9-11).

(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 (para 9-9a).

## 9-6. SOURCE REGIONS AND TRAJECTORIES

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

(1) *Arctic air source region.* In the general circulation pattern, a permanent high-pressure system surrounds the geographic 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.

(2) *Continental polar source region.* Polar air is not as cold as arctic air. The continental polar source regions consist of the land areas dominated by the Canadian and Siberian high-pressure cells. In the winter, these regions (generally between latitudes 45 degrees north and 65 degrees 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, 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. Water surfaces

there 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 degrees and 30 degrees 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, in some cases. However, hot moist and unstable air also exists in these areas, as in the case of central Africa and South America.

(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.

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 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

### 9-7. GENERAL

The basic considerations in air mass analysis (paras 9-1 through 9-6) are applicable to a study of air mass weather throughout the world. However, local variables, such as the following are too numerous to allow a detailed worldwide air mass analysis in the scope and space of this manual:

- Distribution and orientation of mountain ranges.
- Flow and temperature of ocean currents.
- Prevailing pressure patterns.

- Distribution of land and water surfaces.

Therefore, this section will be limited to a detailed analysis of the air masses affecting the weather of the continental United States (figs 9-1, 9-2).

### 9-8. MARITIME POLAR AIR MASSES

Maritime polar air masses that invade the United States arrive from two different source regions. The main source is the North Pacific

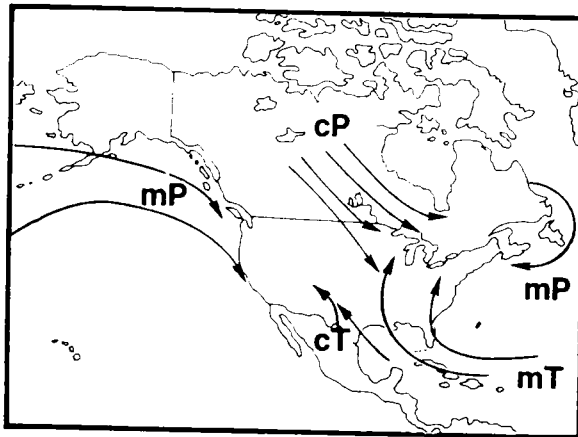


Figure 9-1. Air mass source regions and trajectories (July).

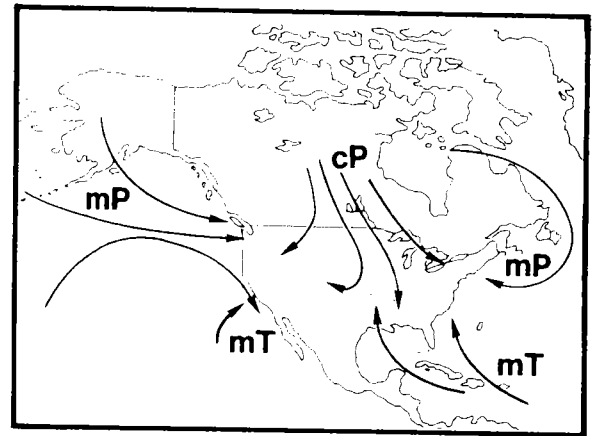


Figure 9-2. Air mass source regions and trajectories (January).

Ocean; the other is 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 that invade the Pacific Coast originate in the interior of Siberia (para 9-6b(1)). They have a long over-water trajectory and, during their trajectory over the Pacific Ocean, are unstable in the lower layers (fig 9-3). As they invade the West

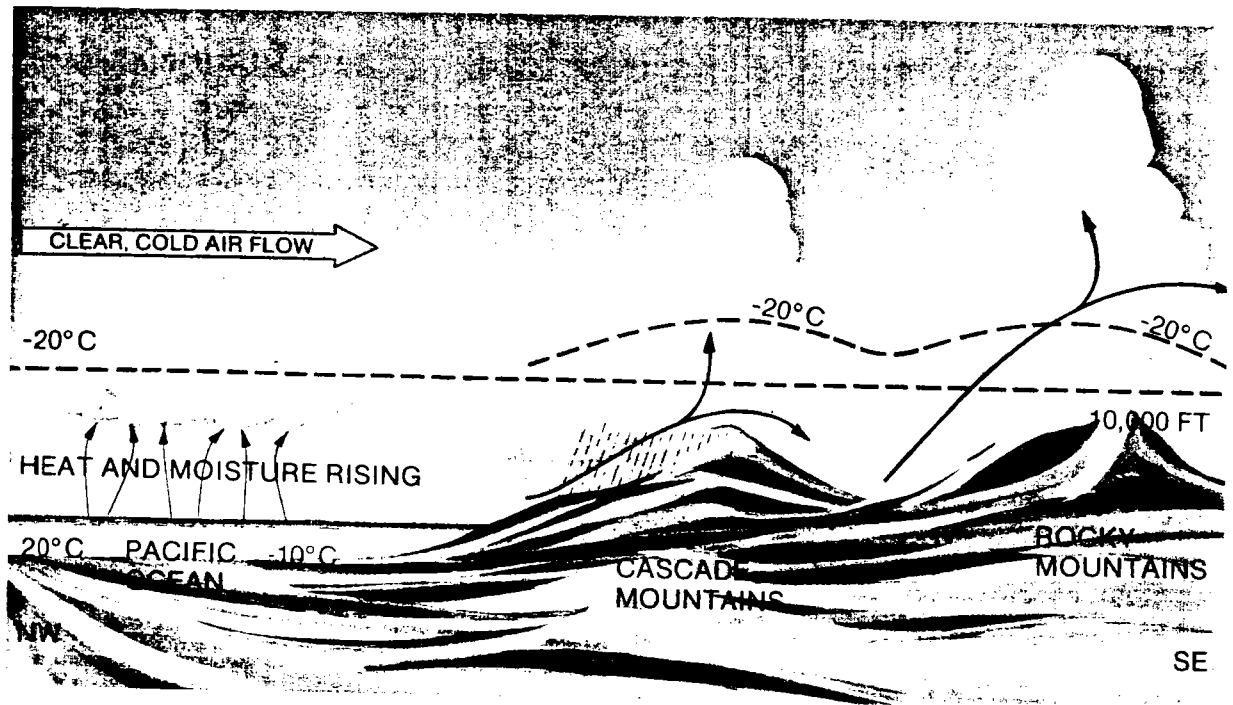


Figure 9-3. Winter movement of maritime polar air southeastward.

Coast, they are cooled from below by a cool ocean current and the 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. This warming results in decreased relative humidity, and the skies are generally clear (fig 9-4).

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

### 9-9. CONTINENTAL POLAR AIR MASSES

a. *Winter.* Continental polar air masses that invade the United States during winter

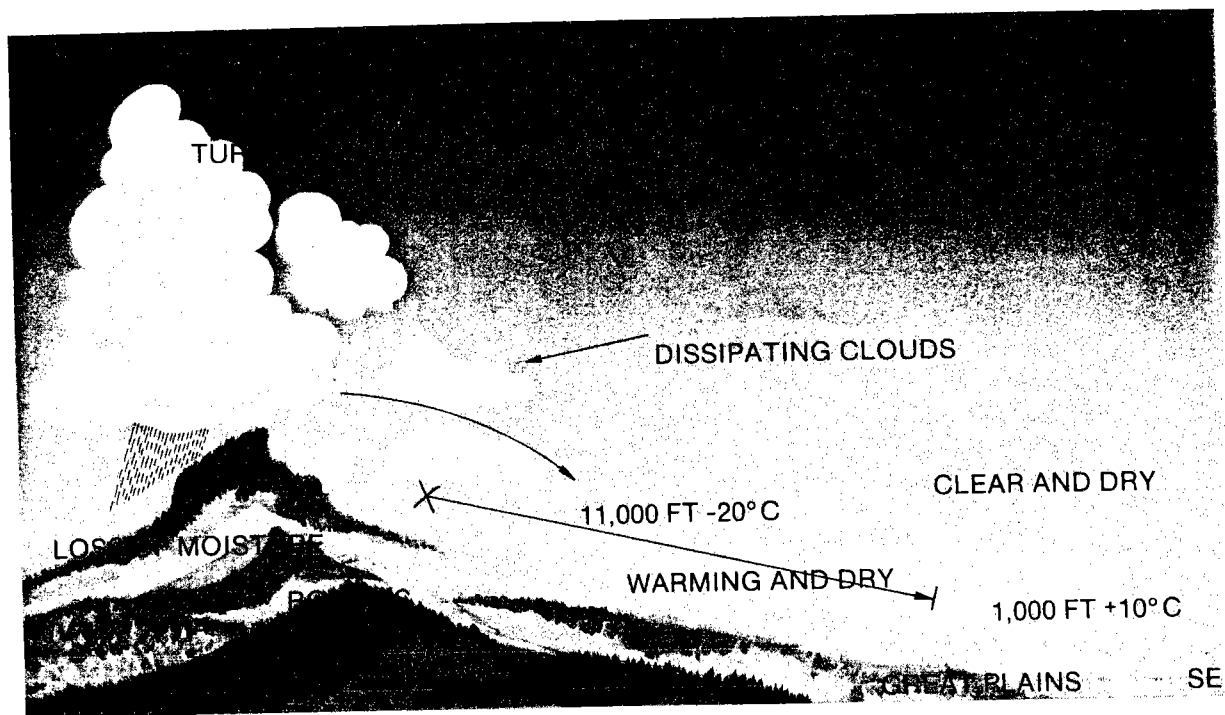


Figure 9-4. Maritime polar air after crossing the Rockies.

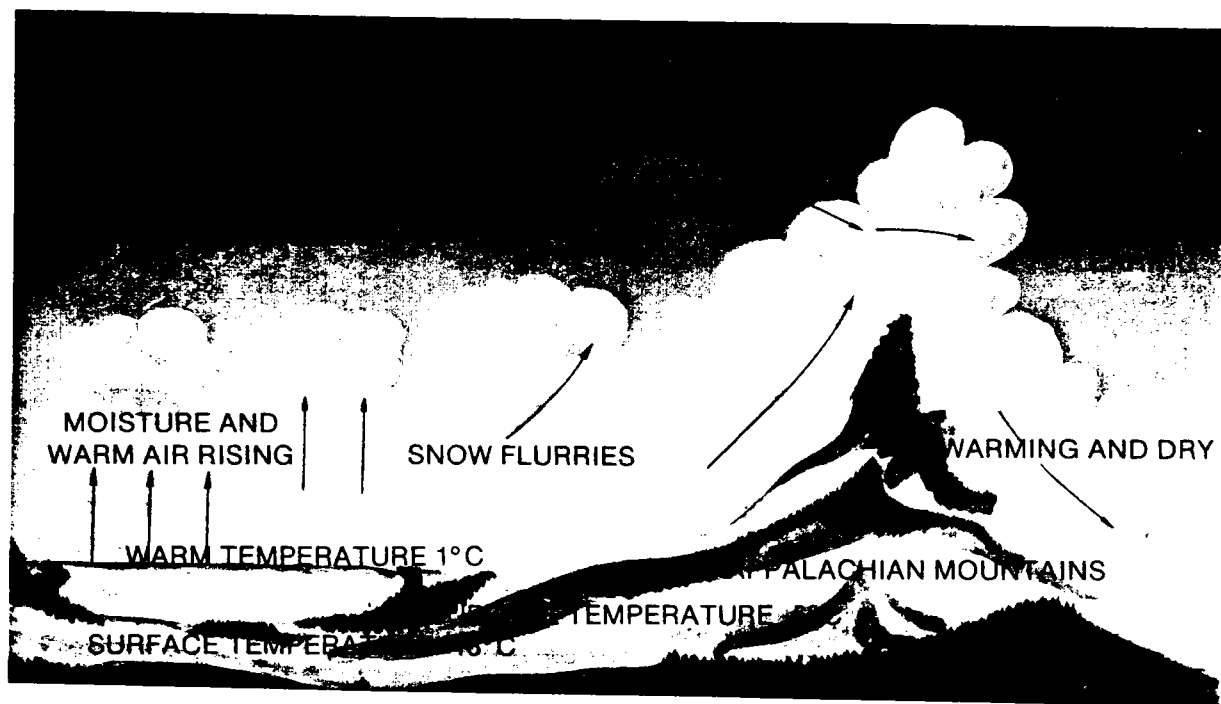
originate over Canada and Alaska. They are stable in the source regions. As the air masses move southward into the United States, they are heated by the underlying surface. During daylight hours, the air is generally unstable near the surface and the sky is usually clear. At night the air tends to become more stable. When these cold dry air masses move over the warmer waters of the Great Lakes, they acquire heat and moisture and become unstable in the lower levels (fig 9-5); 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, therefore, is 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 they become stable. As a result, flying conditions are good.

## 9-10. 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 the Atlantic Ocean; and they are common along the Southeastern and Gulf Coast States. Warm, moist stable air which originates over the Pacific



**Figure 9-5.** Continental polar air moving over the Great Lakes and Appalachians in winter.

Ocean is rarely observed in the 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 9-6). 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 the Eastern United States). When land temperatures are extremely cold, extensive surface temperature inversions develop. 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 cooling produced by orographic lifting (fig 9-6) 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 areas of widely scattered thunderstorms normally develop. In maritime tropical air masses, cumuliform clouds and thunderstorms are usually more numerous and intense on the windward side of mountain ranges, in squall lines, and in prefrontal activity.

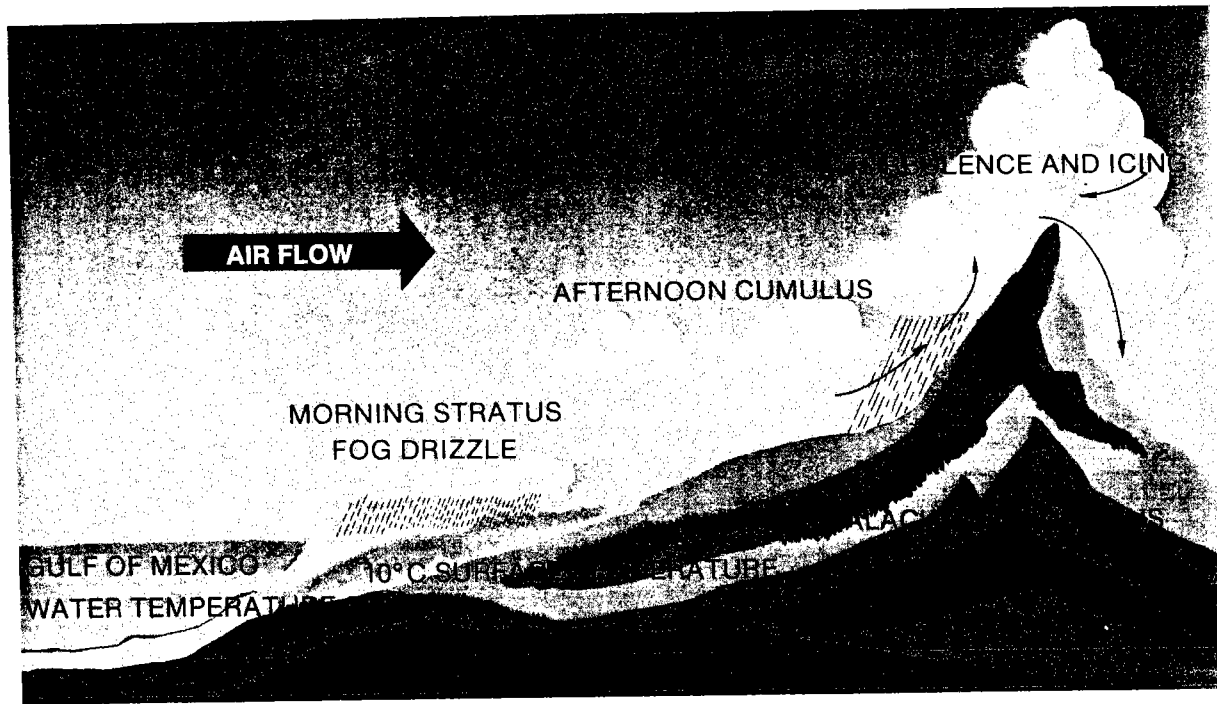
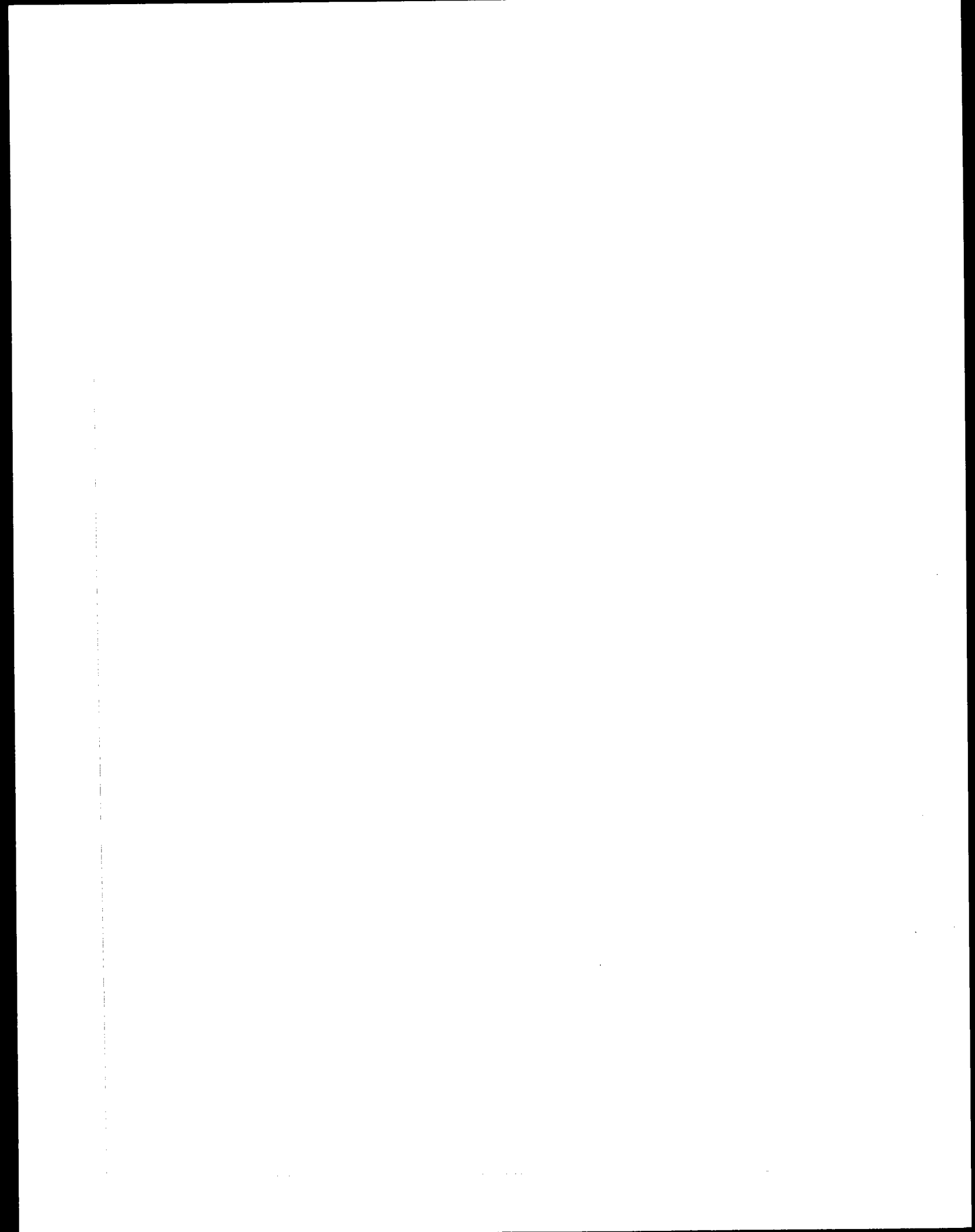


Figure 9-6. Maritime tropical air moving over the Appalachian Mountains in winter.

## 9-11. 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, although

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 10

## 10-1. GENERAL

## a. Introduction

(1) 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. However, they may also form 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 10-1 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.

(2) Fronts are especially important to pilots because many weather hazards to aviation may accompany them.

b. **Types.** The four major fronts are the—

- Cold front.
- Warm front.
- Stationary front.
- Occluded front.

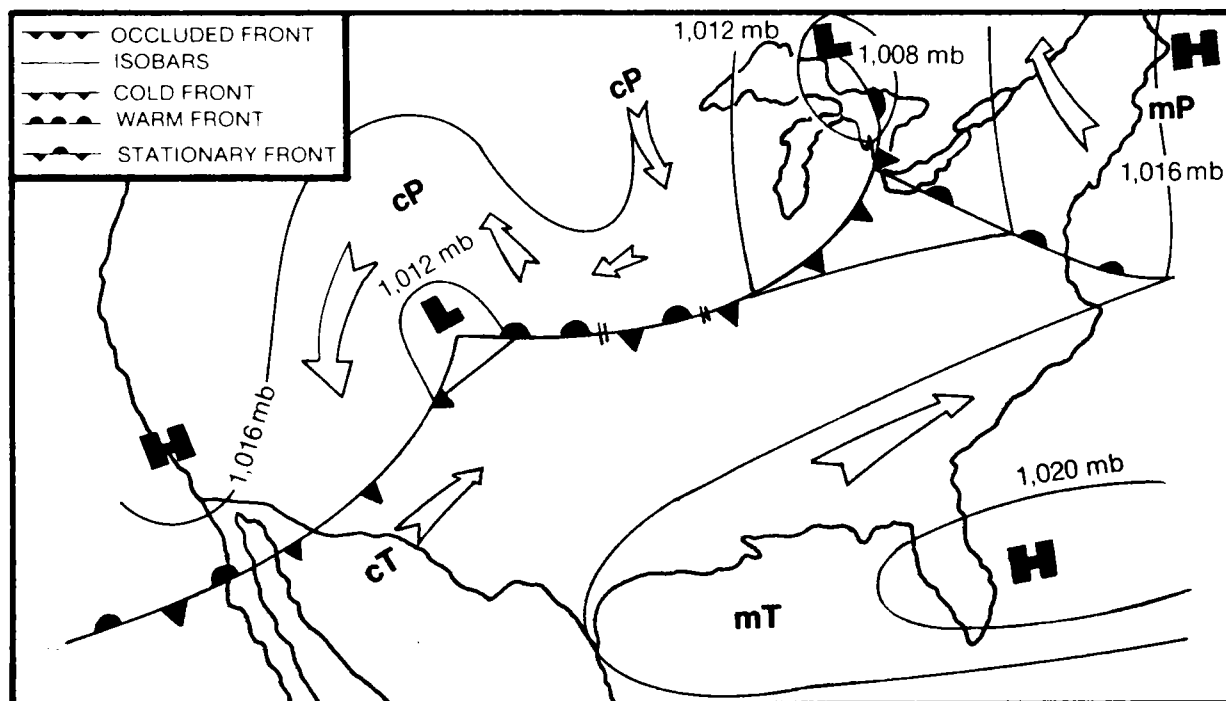


Figure 10-1. The polar front in North America.

The name of a front is determined from the movement of the air masses involved.

(1) A **cold front** (line with triangles, fig 10-1) is the leading edge of an advancing mass of cold air.

(2) A **warm front** (line with semi-circles, fig 10-1) is the trailing edge of a retreating mass of cold air.

(3) When an air mass boundary is neither advancing nor retreating along the surface, the front is called a **stationary front** (line with alternate triangles and semi-circles on opposite sides, fig 10-1).

(4) An **occluded front** (line with alternate triangles and semicircles on the same side, fig 10-1) 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. This process is referred to as a **cold occlusion**. A **warm occlusion** occurs when warm air overtakes cold air and the same process occurs as in cold occlusion.

**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 10-1) are called **surface fronts**. A surface front is the position of a front at the earth's surface. The weather map shows only the location of fronts on the surface. However, these fronts also have vertical extent. For example, 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

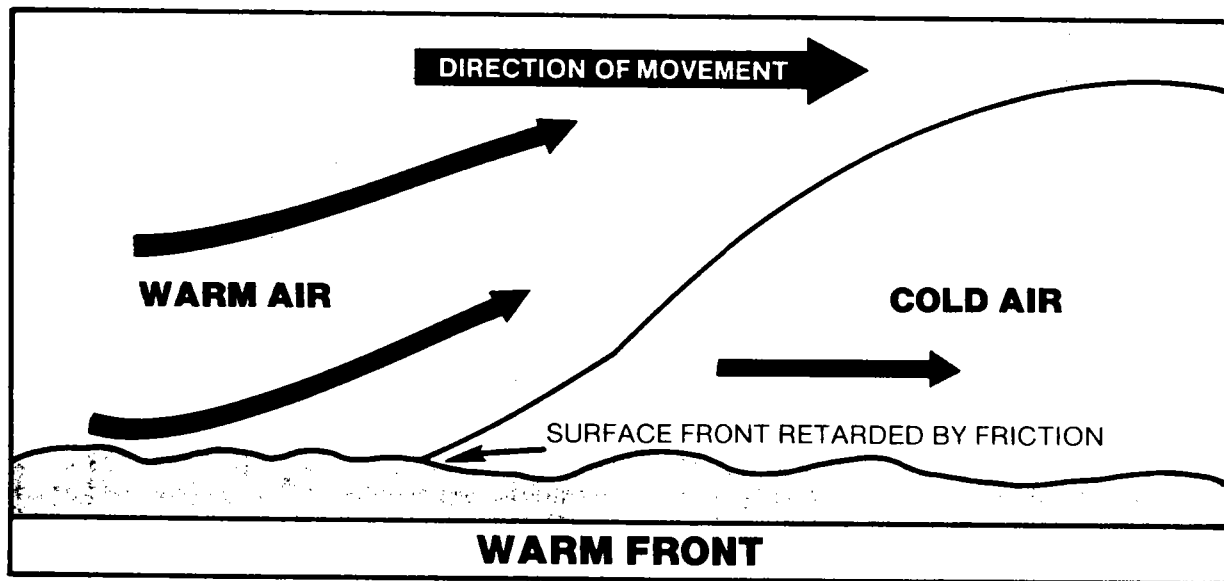
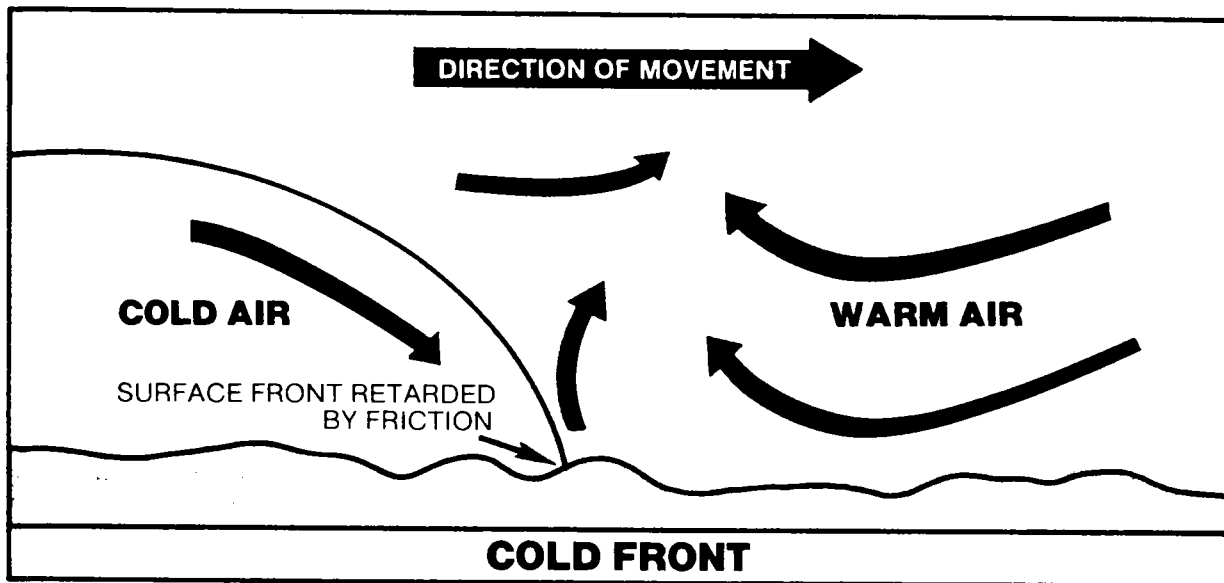
air mass. The frontal surface lifts the warmer air mass and produces frontal cloud systems. The slope of the frontal surface varies with the speed of the moving cold air mass and the roughness of the underlying terrain. Under normal conditions, the angle of inclination (slope ratio) between the frontal surface and the earth's surface is greater with cold fronts than with warm fronts (fig 10-2). The approximate height of the frontal surface over any station is determined from the analysis of upper air observations; for example, 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 degrees 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. 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 the low-pressure trough. But it is normally least with warm fronts and with occlusions in the later stages of development.



TRUE VERTICAL SCALE OF FRONT - 1 TO 50

Figure 10-2. Vertical cross section showing frontal slopes.

*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.
- 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 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—

- When a cold front moves rapidly, its leading edge steepens. This lifts the warm air ahead of the front abruptly and accelerates the cooling and condensation process. 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.
- When a cold front moves slowly, terrain has less effect on the slope of the frontal surface and the slope is more gradual. Therefore, the energy released by condensation is spread over a wide area. Also 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 determine whether or not 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.

## 10-2. 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 in the atmosphere and at the surface.

*a. Temperature.* Temperature is one of the frontal surface discontinuities. Typical fronts consist of warm air above the frontal surface and cold air below it (fig 10-3). 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*. 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

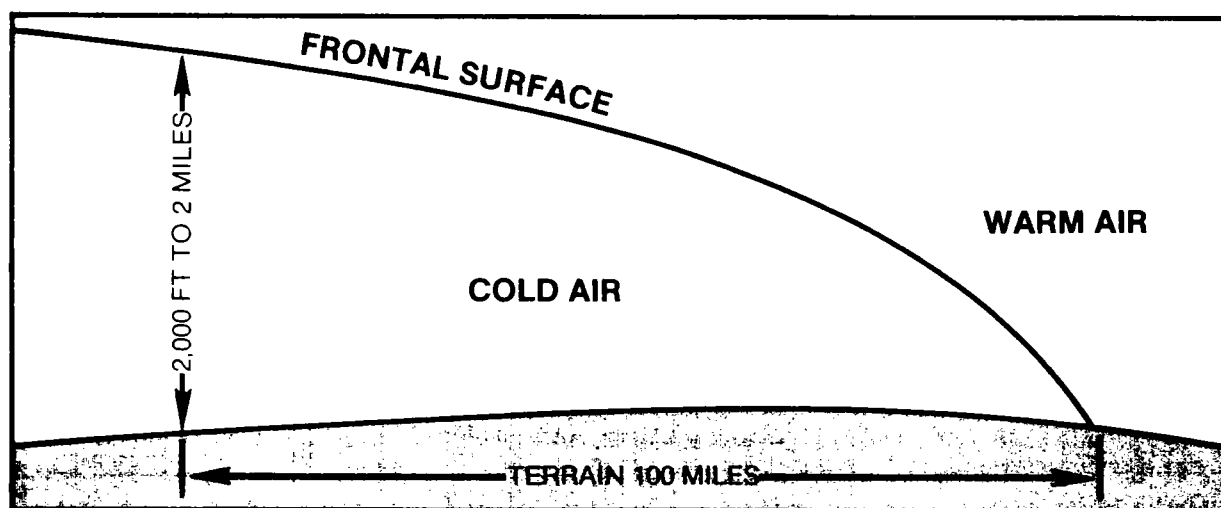


Figure 10-3. Cross section of a front.

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 speed frequently increases abruptly after the passage of a cold front; and it 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 with the approach of a front. It 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. That is, stations on both sides of the front report similar pressure tendencies over a 3-hour period.

d. **Dew Point.** The dew point 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. It therefore can be used to identify the arrival of a different air mass over a station.

### 10-3. COLD FRONTS

a. **Generation of a Cold Front.** Frontal troughs normally extend from a closed area (center) of low pressure called a *cyclone* (fig 10-1). 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 normally extends south to west from the center of lowest pressure.

b. **Characteristics of a Cold Front.** The characteristics of a typical cold front (fig 10-4) 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 cumuliiform. With typical cold fronts, a line of thunderstorms develops along the surface front; and it may extend for hundreds of miles along the front. 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 type of frontal clouds. The **typical cold front** in the United States has cumuliiform clouds arranged as shown in figure 10-5. 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 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 10-4). This movement produces an average frontal surface slope ratio of 1 to 80 (fig 10-5).

(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.

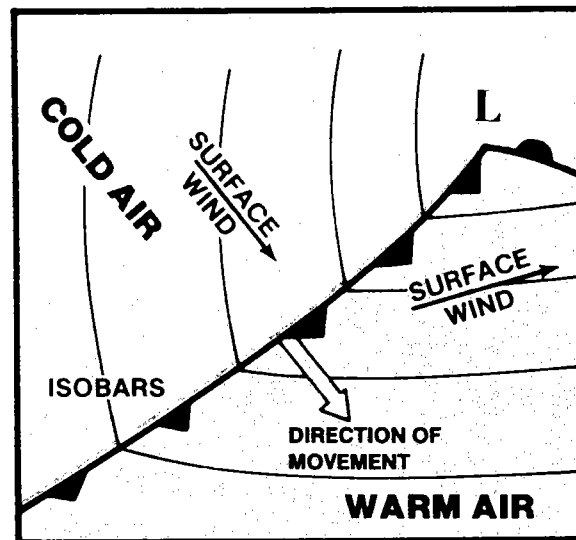


Figure 10-4. Cold front on surface weather map.

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 (fig 10-4).

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 cumuliiform clouds along the front or a prefrontal squall line 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 associated with the average cold front, aviators can frequently land and wait for the

squall line to pass. This is especially true when helicopters are engaged in terrain flight. When operating closer to the ground, the gusty shifting winds associated with a frontal passage can cause the helicopter to collide with obstacles or the ground.

(2) If penetration of the front is necessary, it should be made at a 90-degree 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 center (RAPCON), air route traffic control centers (ARTCC), or (METRO)) 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 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 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.

#### 10-4. 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 10-1). 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 10-6).

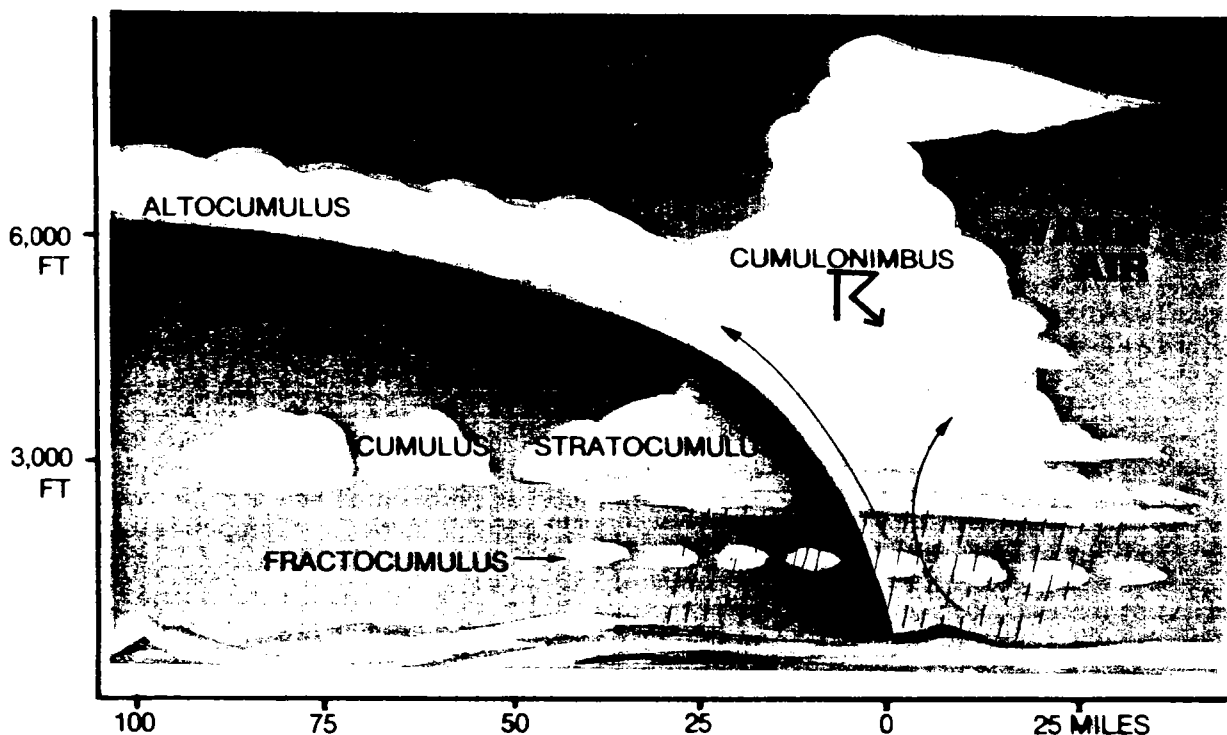


Figure 10-5. Typical cold front cloud formation.

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.

#### 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. That is, 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 10-4). Southwest winds, higher temperatures and dew points, and rising or steady pressure exist "behind" a typical warm front (fig 10-6).

(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 11°C.

(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 over the retreating wedge of cold air (fig 10-2). 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. They will range 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 10-7. An area of rain can extend as far as 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

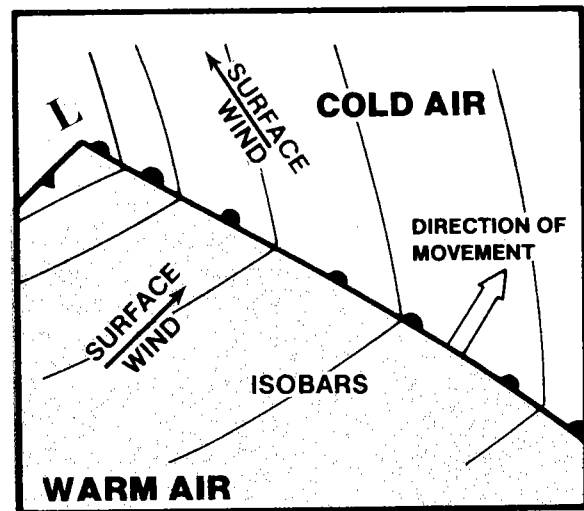


Figure 10-6. Warm front on surface weather map.

of low stratus or fog about 100 miles wide ahead of the surface front. The prefrontal 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 10-8). During 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 aligned 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 visibility (fig 10-7).

(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—

- The surface wind movement in the cool air mass, usually from southeast to northwest.
- The movement of the entire pressure system from west to east.



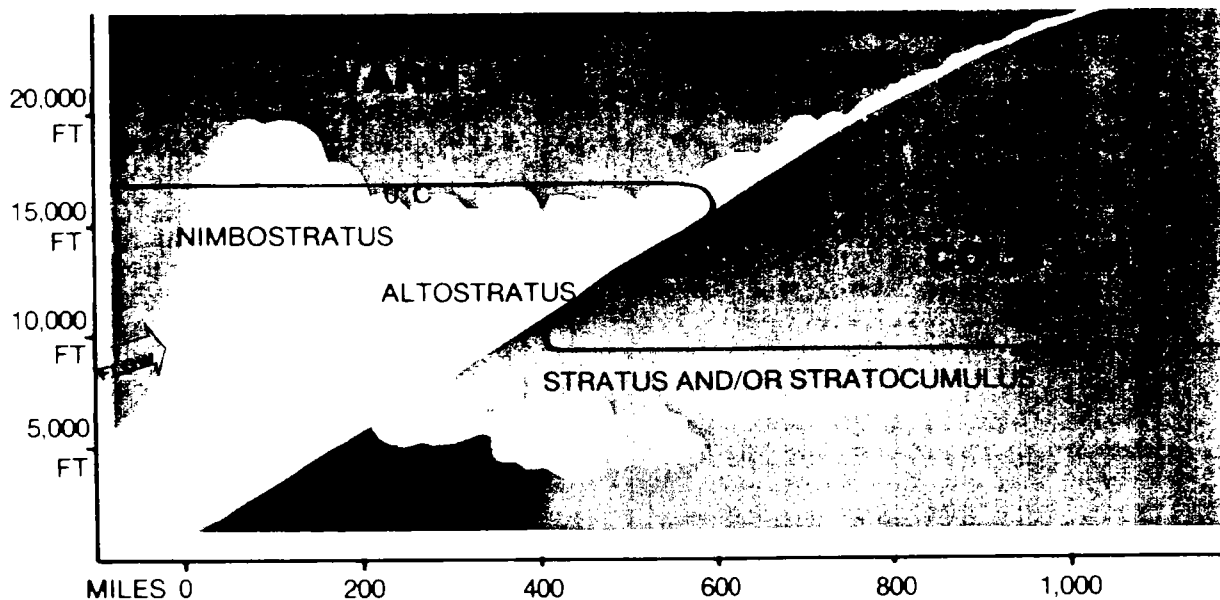


Figure 10-7. Typical warm front cloud formation.

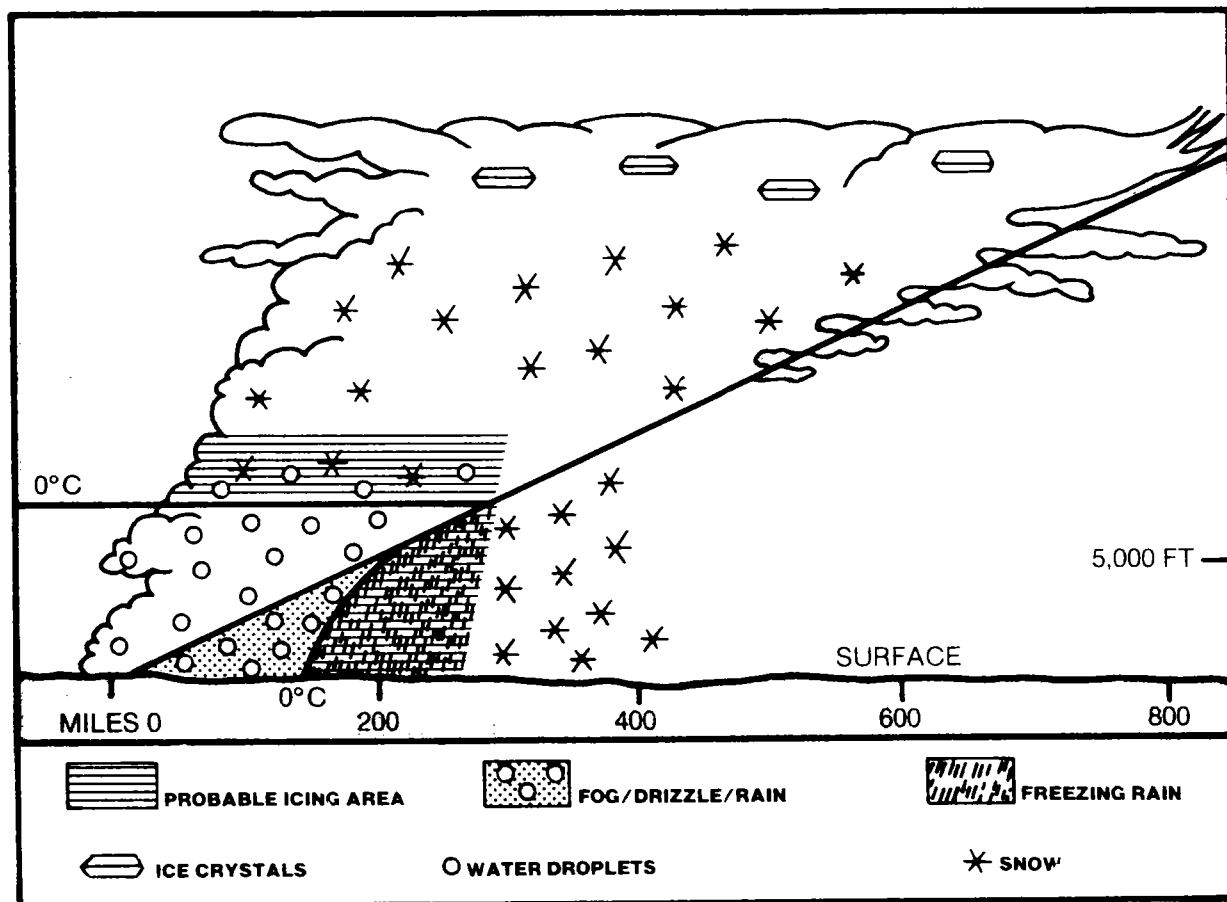


Figure 10-8. Probable icing zones in a warm front.

(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 10-7).

**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 in the direction toward which the semicircles are pointing (fig 10-6).

**d. Flight Procedures in Warm Front Weather.** The chief hazard to flight in **most** 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 generally to 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 to 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. This increases restriction to visibility. Embedded thunderstorms during the warm months of the year and severe 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 cloud bases to avoid inadvertent entry into the turbulence of hidden thunderstorms that 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 to avoid the area of low ceilings and poor visibility. This alternate may be behind the front or as far as practicable ahead of the surface front.

(3) A weather briefing should be obtained before the flight to estimate the locations of turbulence, thunderstorms, and icing conditions. METRO, RAPCON, or ARTCCs should be contacted (para 10-3d(3)) to obtain in-flight data. Severe hazard areas should be avoided as discussed below.

(4) Upon 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 by climbing to a higher altitude containing ice crystals and snow or by descending into warmer air near the surface. Since it is possible for two freezing levels to occur with the winter warm front (fig 10-8), freezing-level altitudes and flight altitude temperatures should be obtained during the weather briefing.

(6) Tactical flying using nap-of-the-earth (NOE) techniques may be necessary to complete essential missions.

(7) Wind shear in the vicinity of a warm front can start as much as 6 hours before passage of the front. With low flying aircraft, wind shear can be a major problem.

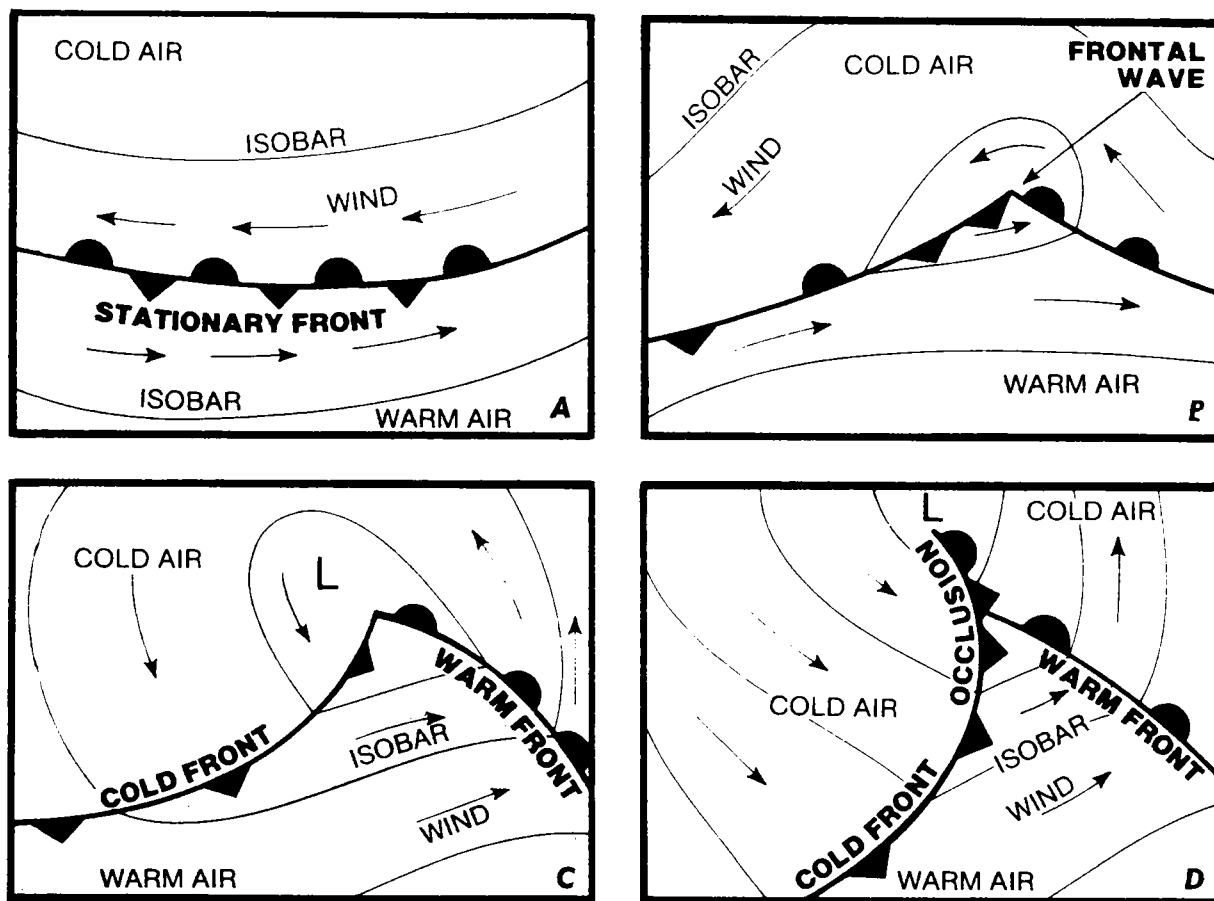


Figure 10-9. Stages in the development of the occluded wave.

### 10-5. OCCLUDED FRONTS

a. *Development of an Occlusion.* Successive stages in the development of an occluded wave are shown in (A), (B), (C), and (D) of figure 10-9. (B) of figure 10-9 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 in a counterclockwise direction. 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 fig 10-9 and fig 10-10). The portion of the surface front where the cold front has overtaken the warm front is called a **surface occluded front** (fig 10-10).

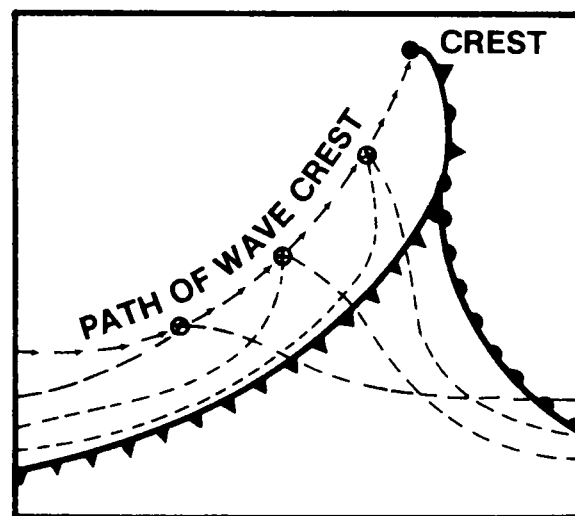


Figure 10-10. Wave development and occlusion.

*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. However, 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 10-9 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, 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, it would be colder than the air behind the cold front. The trailing edge of this retreating mass of very cold air would be a warm front because the warm tropical air would be 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 10-11), the cold front of the open wave will remain on the surface and displace 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 normally is omitted from the surface weather map (figs 10-1 and 10-7). 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 10-12).

(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 10-13). The warm sector air will be displaced from the ground by both frontal surfaces. The upper cold front is identified on the weather map by a series of open black triangles (fig 10-14) or by a dashed blue line on a

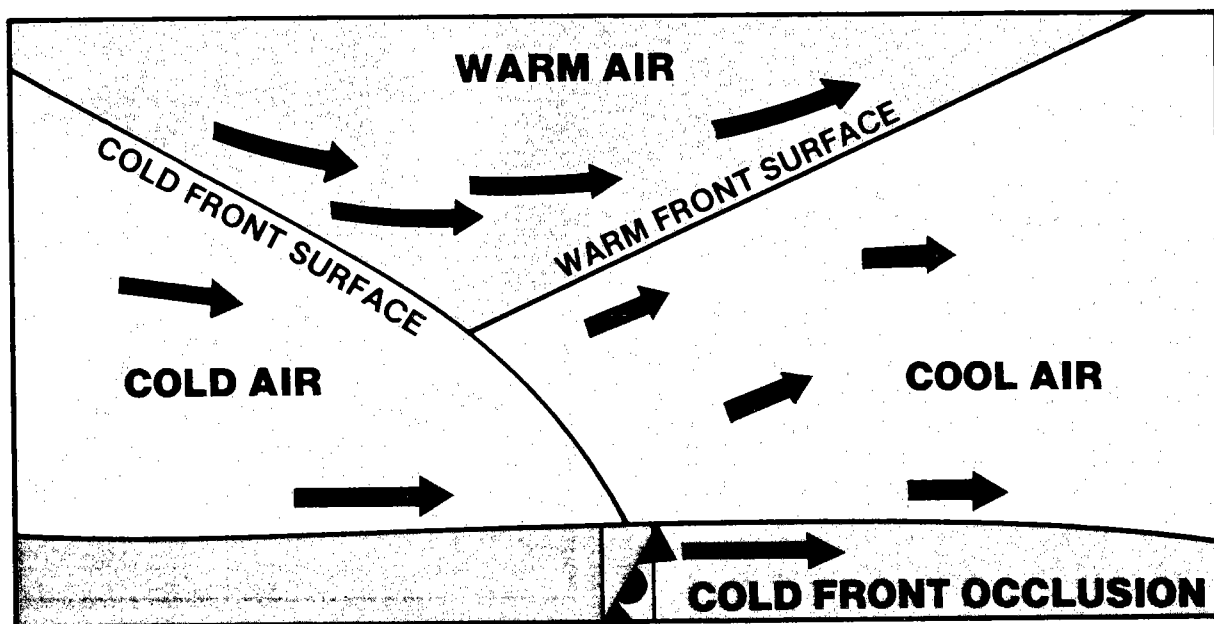


Figure 10-11. Cold front occlusion (vertical cross section).

colored map, but is seldom shown; only the surface front is shown. 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 10-14 and 10-15. 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

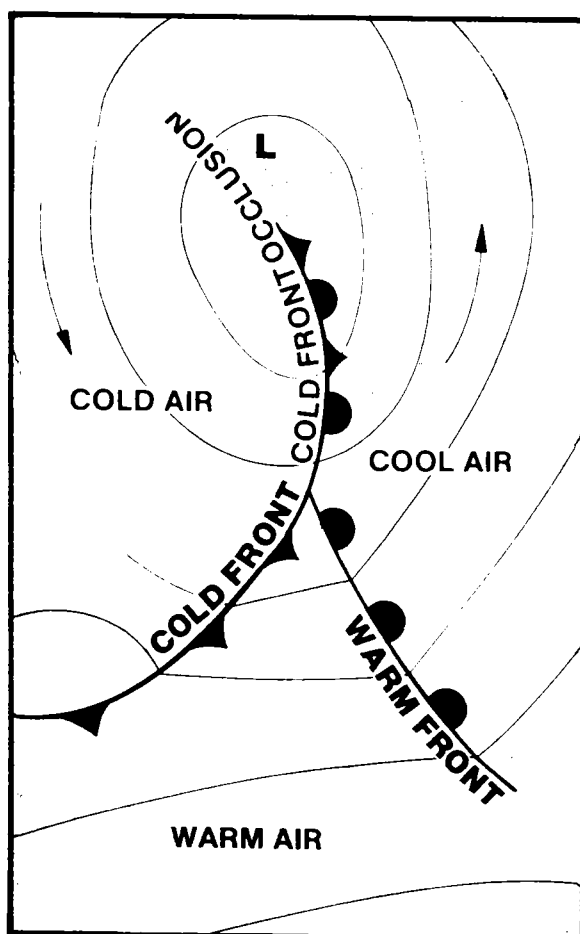


Figure 10-12. Cold front occlusion (surface map representation).

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 the overcast sky. And it may precede the surface occluded front by 200 to 300 miles. Thunderstorms of the cold front occlusion pass with the surface occluded front, and they 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 from the northwest to the northeast sections of the country.

d. **Occluded Front Identification on the Weather Map.** Map symbols are identical for the surface occluded fronts in the warm and the 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 (fig 10-14).

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

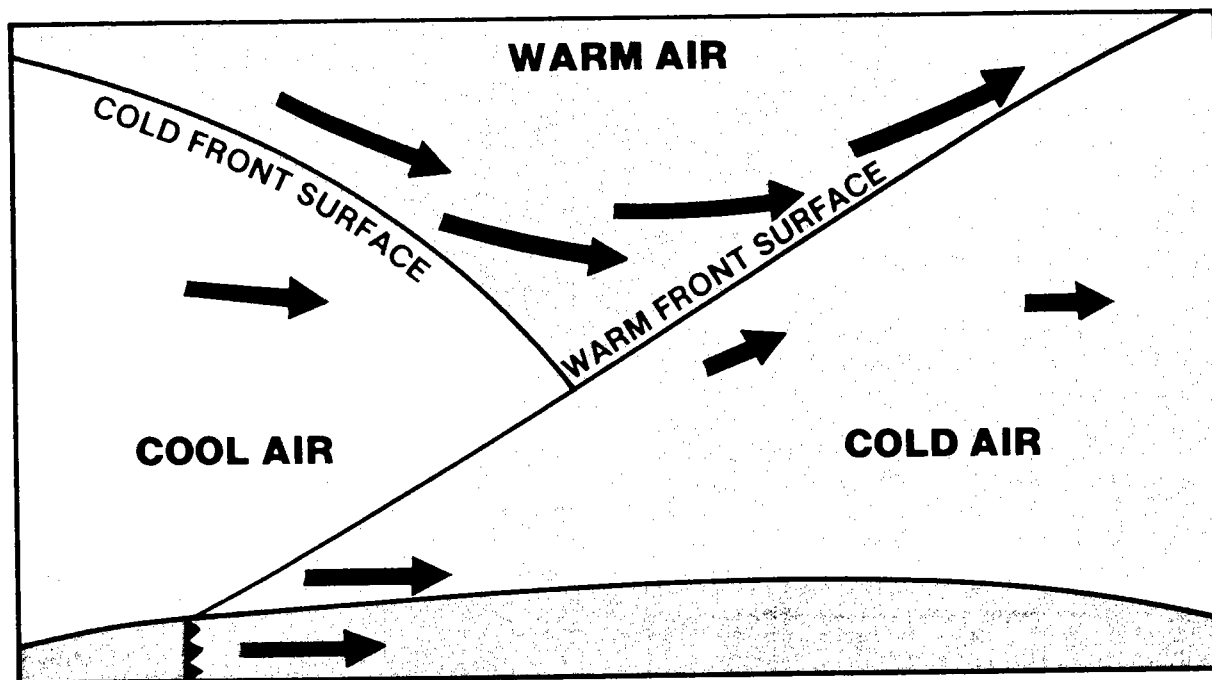


Figure 10-13. Warm front occlusion (vertical cross section).

(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.

## 10-6. STATIONARY FRONTS (QUASI-STATIONARY FRONTS)

Although there is no movement of the surface position of the true stationary front, an up-glide 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 up-gliding wind control the inclination of the frontal scope (fig 10-16).

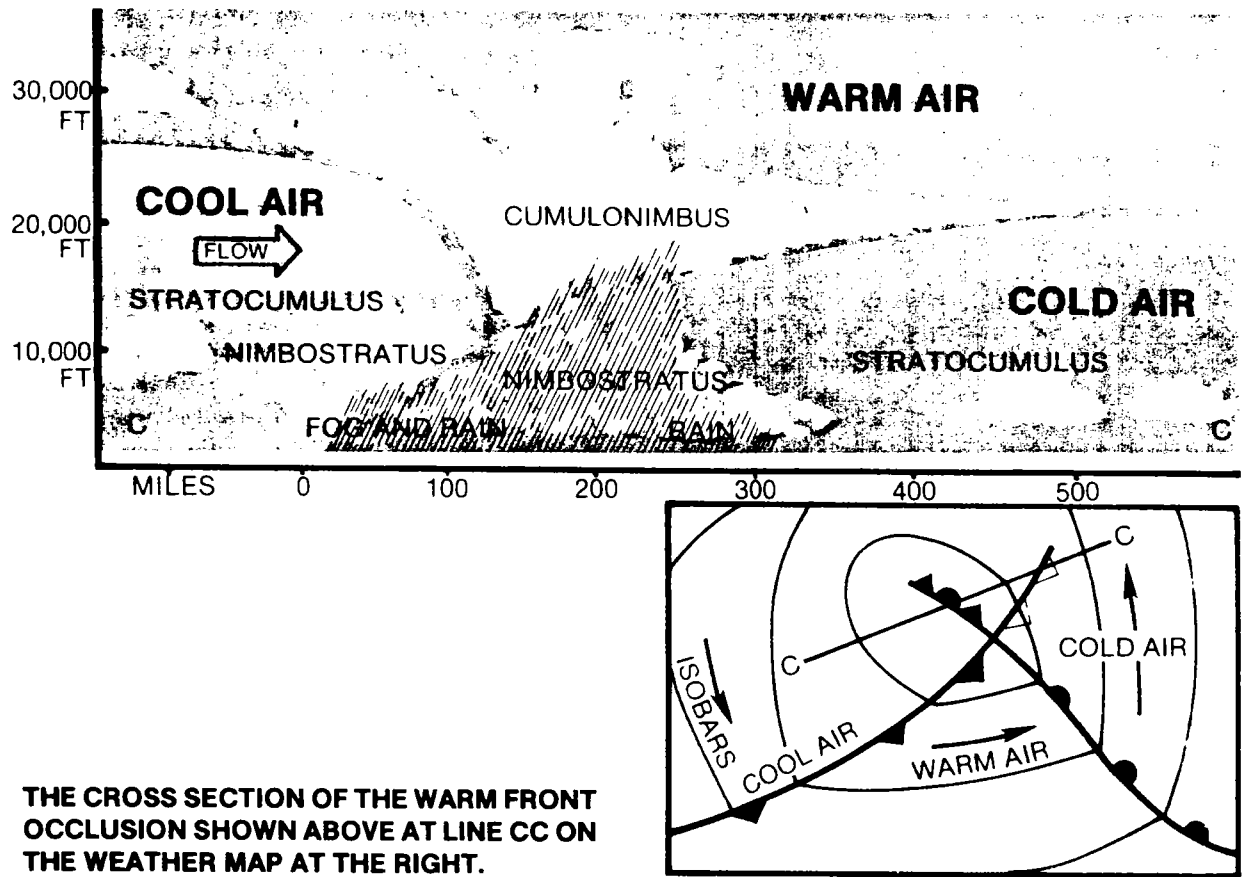
10-14

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 up-gliding air is stable and saturation 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 10-17).

(2) If the up-gliding air is conditionally unstable and saturation occurs, predominantly cumuliform clouds will form (fig 10-18). The sky condition is often overcast, but the precipitation occurs as intermittent moderate to heavy showers with thunderstorm activity. Occasionally the thunderstorms may align side by side to produce a line squall, but the typical cloud pattern is more similar to that of an unstable warm front.



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

Figure 10-14. Warm front occlusion.

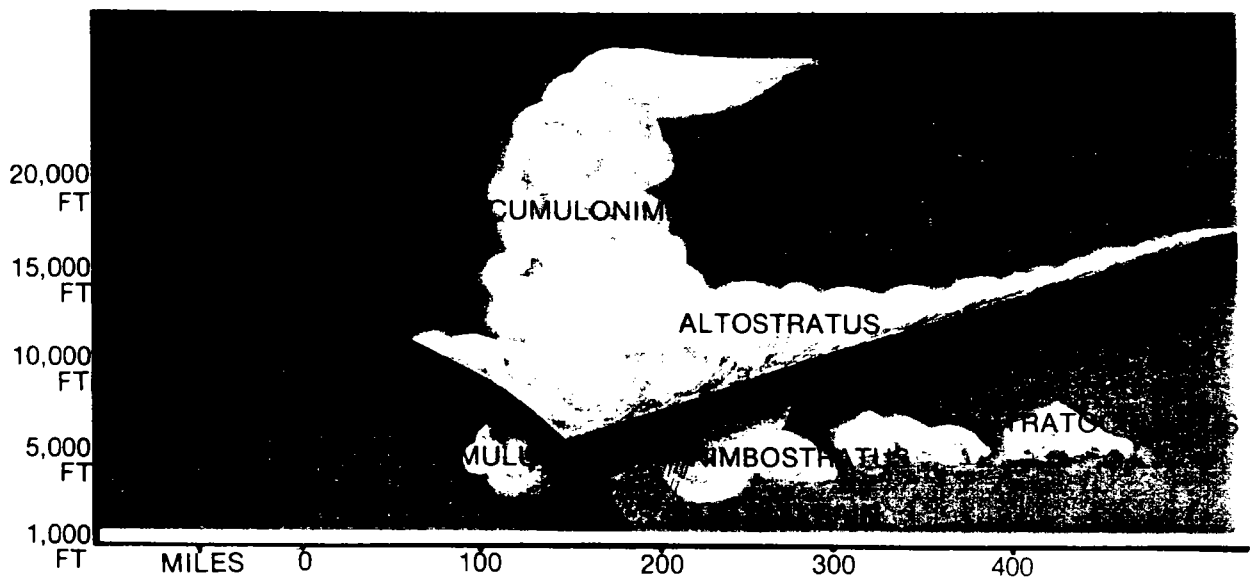


Figure 10-15. Cold front occlusion with associated weather.

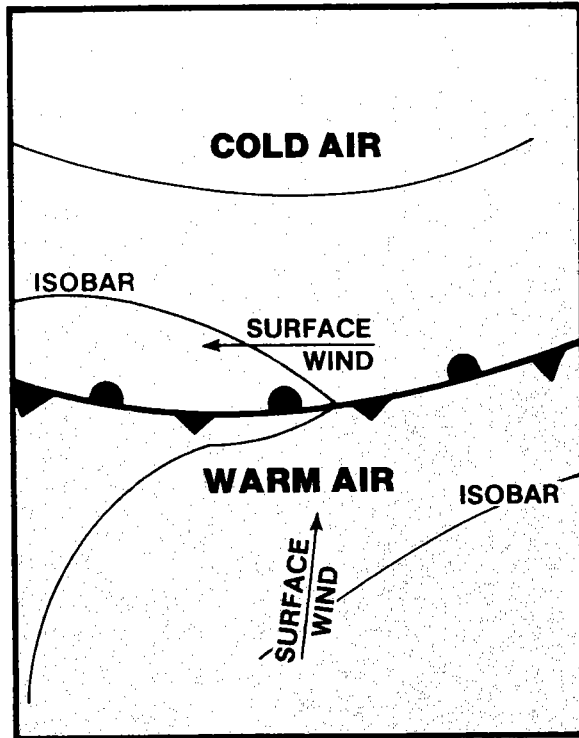


Figure 10-16. Stationary front as shown on a surface weather map.

b. Cold Air.

(1) Because of convergence of air across the isobars, the old 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 10-17, 10-18).

### 10-7. 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 "low." Not all lows 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. These systems may sometimes be as strong as lows associated with fronts.

b. In the idealized general circulation pattern, a large cap of cold dense air accumulates around the polar regions. This cold air is

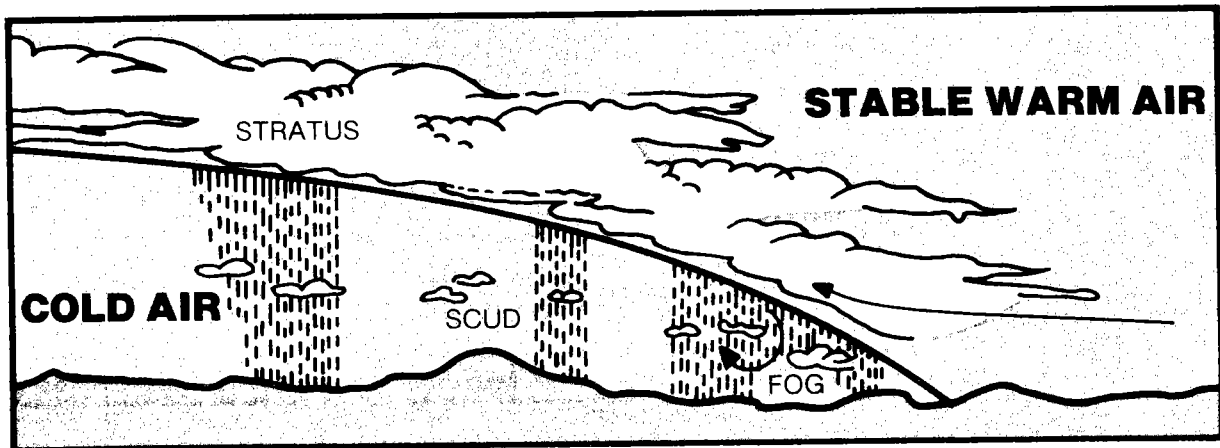


Figure 10-17. Stationary front with stable warm air.



characterized by high pressure. The outer boundary of this high-pressure area is in the vicinity of 60 degrees north latitude. Another general circulation belt of high pressure is centered in the vicinity of 30 degrees 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-degree north latitude region. Thus, the area around 60 degrees 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.

c. Ideally, this polar front and polar trough would remain in the 60-degree north latitude zone. In fact, outbreaks of cold polar air move southward across the temperate

zones (fig 10-19). 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, making the front undulate. For example, if the front lies in an eastward direction, such a wave will cause one part of the frontal surface to bulge southward and another part northward. If the

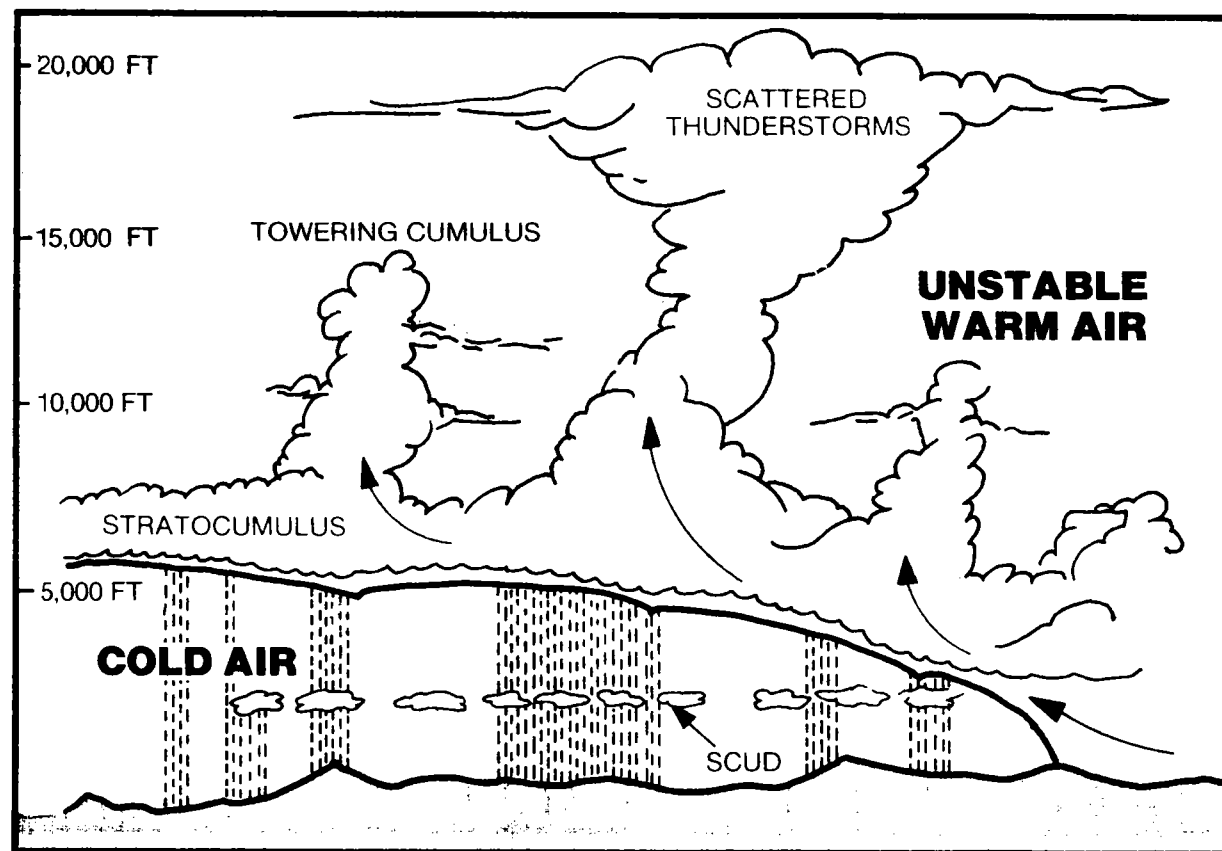


Figure 10-18. Stationary front with unstable warm air.

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 (fig 10-1).

e. Cyclone formation can be understood by comparing stationary front activity to ocean waves.

(1) A wave in deep water far from shore is stable. The surface oscillates 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 top-heavy 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. 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 10-9). Instead of many waves following each other in orderly series, each wave continues to grow and the apex becomes deeper. Therefore, the front never settles back to its original position (fig 10-10). 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 they 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*).

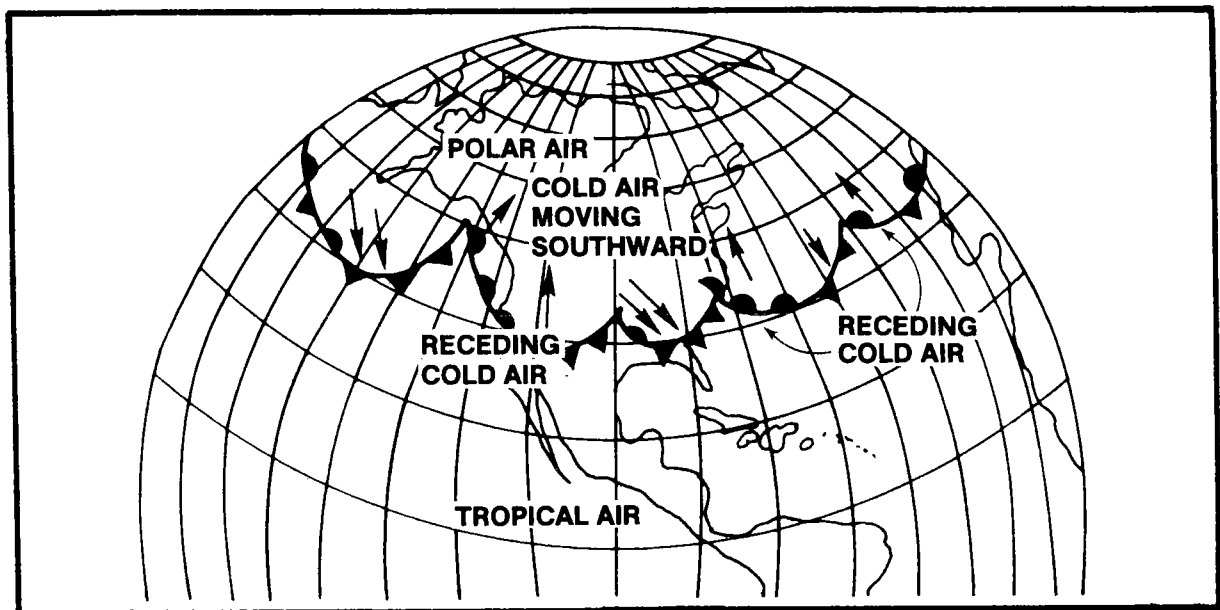


Figure 10-19. Polar front.

*Weather hazards affect the safety of all flights. Adverse weather is a contributing factor in many accidents. Weather may cause the pilot to become disoriented and unable to fly. Weather may cause loss of control, structural damage, or failure of the aircraft. This part of the manual discusses various weather hazards encountered by the aircrew.*

## WEATHER HAZARDS

### CHAPTER 11

#### 11-1. GENERAL

Turbulence affecting Army aircraft may range from mild bumps to severe jolts capable of producing structural damage. Since turbulence is associated with many different weather situations, a knowledge of its causes and the behavior or irregular air movements will help in avoiding or minimizing the effects of this disturbed air.

#### 11-2. CAUSES OF TURBULENCE

*a.* Atmospheric turbulence is caused by random fluctuations of airflow which are instantaneous and irregular, so much so that to accurately describe the random fluctuations by other than statistical analysis is almost impossible. Since aircraft operate in the atmosphere, the effects of turbulence on aircraft operations warrant consideration.

*b.* In general, turbulence can be approached from the standpoint of causative factors and described by a subjective scale of degrees of intensity of turbulence. The four degrees of turbulence are—

- Light.
- Moderate.
- Severe.
- Extreme.

*c.* For the purpose of this discussion, turbulence will be divided according to the following causes:

(1) *Thermal*—caused by localized vertical convective currents due to surface heating or unstable lapse rates and cold air moving over warmer ground or water.

(2) *Mechanical*—resulting from wind flowing over irregular terrain or obstructions.

(3) *Frontal*—resulting from the local lifting of warm air by cold air masses, or the abrupt wind shift (shear) associated with most cold fronts.

(4) *Large scale wind shear*—marked gradient in wind speed and/or direction due to general variations in the temperature and pressure fields aloft.

Two or more of the above causative factors often work together. In addition, turbulence is produced by man-made phenomena, such as in the wake of aircraft.

### 11-3. THERMAL CAUSES

a. Vertical air movements or convective currents develop in air which is heated by contact with a warm surface. This heating from below occurs when either cold air is advected (moved horizontally) over a warmer surface or the ground is strongly heated by solar radiation.

b. The strength of convective currents depends in part on the extent to which the earth's surface below has been heated; and this depends upon the nature of the surface (fig 11-1). Notice in the illustration that barren surfaces, such as sandy or rocky wasteland and plowed fields, are heated more rapidly than surfaces covered with grass or other vegetation. Thus, barren surfaces generally cause stronger convection currents. In comparison, water surfaces are heated more slowly. This difference in surface heating between land and water masses is responsible for the turbulence experienced by aircrews

when crossing shorelines on hot summer days.

c. When air is very dry, convective currents may be present although convective-type clouds (cumulus) are absent. Figure 11-2 shows how pilots can avoid convective (thermal) turbulence by flying above the levels reached by convective currents. The general upper limits of the convective currents are often marked by the tops of cumulus clouds, which form in them when the air is moist, or by haze lines. However, turbulence may extend beyond this boundary. Varying types of surfaces can affect an aircraft on final approach to a considerable extent.

d. If the atmosphere is already unstable in an area where convective currents have been initiated by thermal effects, the convective currents will be sustained—or even accelerated—by the atmosphere. Instability can also be achieved by the advection of cold air into an area, which may result in forming a layer of instability at the surface or aloft. Convective currents may then be inaugurated by this unstable situation. The replacing of warm air aloft by colder air may result in the formation of a layer in which the lapse rate is more unstable, thereby causing turbulence.

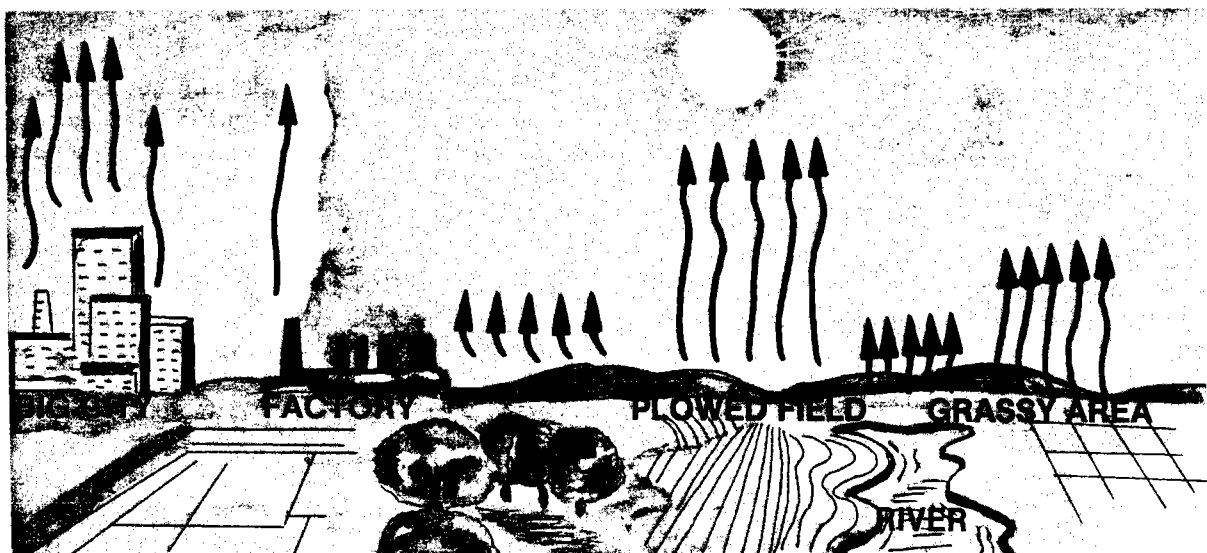
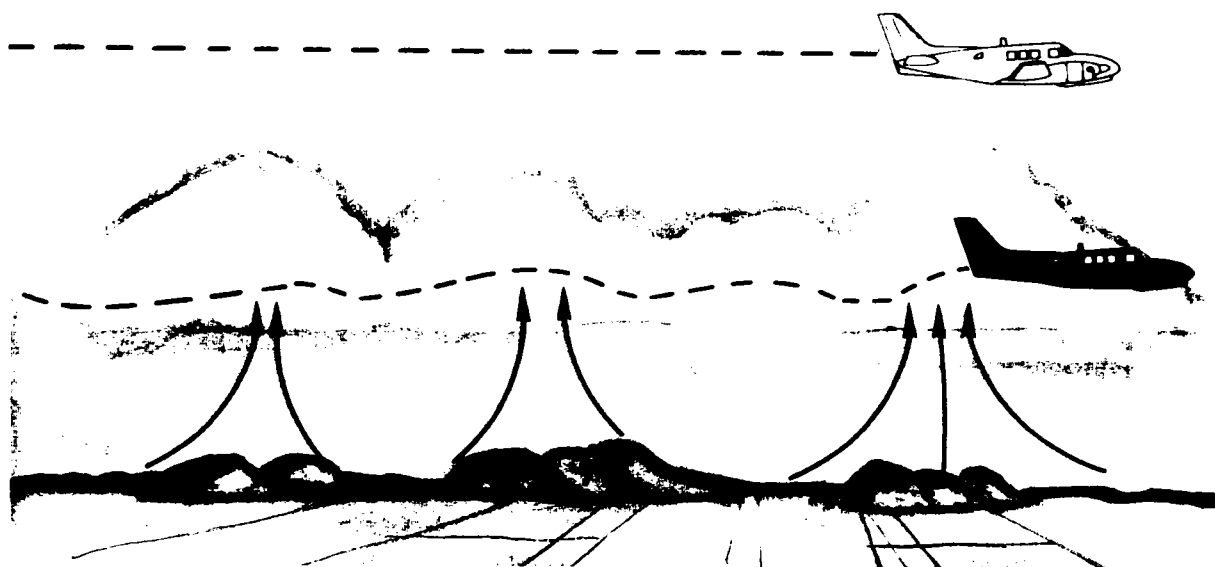


Figure 11-1. Strength of convective currents vary according to ground conditions.

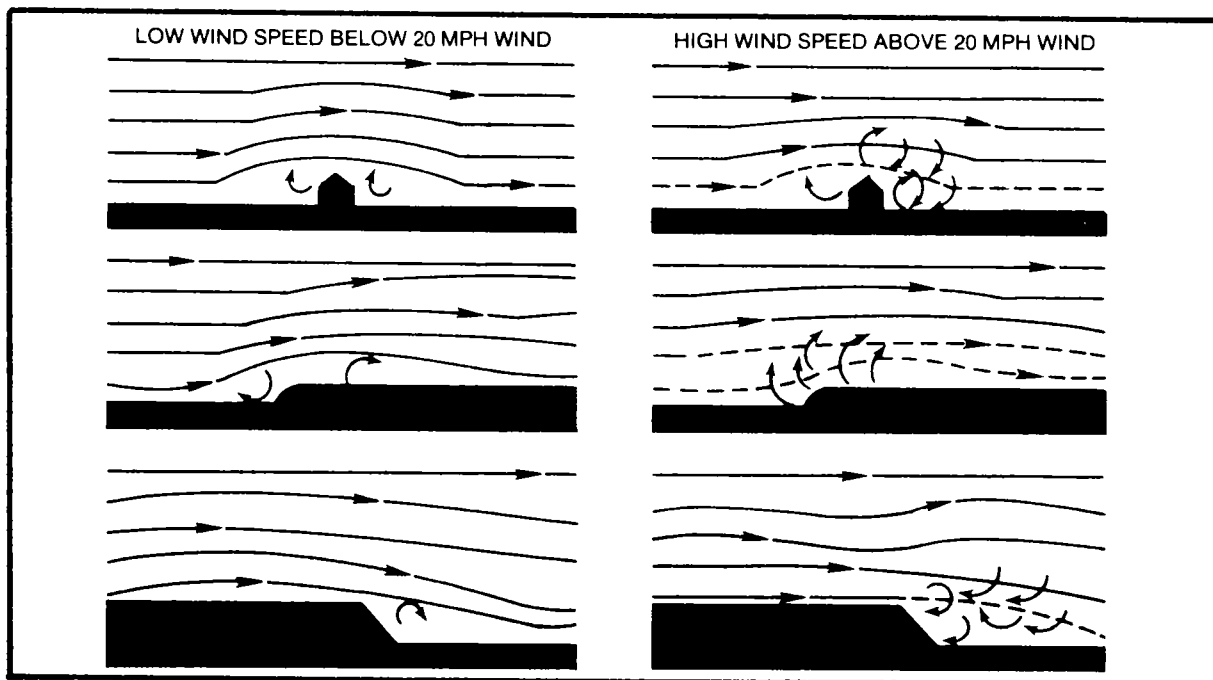


*Figure 11-2. Avoiding convective turbulence by flying above cumulus clouds.*

**11-4. MECHANICAL CAUSES**

a. When the air near the surface of the earth flows over obstructions, such as irregular terrain (bluffs, hills, mountains) and buildings, the normal horizontal wind flow is

disturbed. As a result, it is transformed into a complicated pattern of eddies and other irregular air movements (fig 11-3). Note from the illustration how the buildings or other obstructions near an airfield can cause turbulence.



*Figure 11-3. Surface obstructions cause eddies and other irregular air movements.*

b. The strength and magnitude of mechanical turbulence depend upon—

- (1) The speed of the wind.
- (2) The nature of the obstruction.
- (3) The stability of the air.
- (4) The angle at which the wind moves over the obstacle.

Stability seems to be the most important factor in determining the strength and vertical extent of the mechanical turbulence.

c. Mechanical turbulence has only minor significance when a light wind blows over irregular terrain. In such cases, the turbulence is usually only a few hundred feet thick. When the wind blows faster and/or the obstructions are larger, the turbulence increases and extends to higher levels.

d. When strong winds blow approximately perpendicular to a mountain range, the resulting turbulence may increase in intensity. Associated areas of steady updraft and downdraft may extend to heights from 2 to 20 times the height of the mountain peaks. Under these conditions when the air is stable, large waves tend to form on the lee side of the

mountains and extend up to the lower stratosphere for a distance up to 100 miles or more downwind. These are referred to as *standing waves* or *mountain waves*, and may or may not be accompanied by turbulence. Pilots, especially glider pilots, have reported that the flow in these waves is often remarkably smooth. However, there have been reports of severe turbulence.

Note in figure 11-4 that the mountains are at the right and the wind flow is from right to left. The cap cloud is shown on the mountain range crest to the right of the illustration. The roll clouds are shown in the lower left-center portion of the sketch. The pile of lenticular (lens-shaped) clouds, one above the other, fan out above and slope a little windward toward the mountain range. Turbulence is most likely in the lee area up to the height of the mountains and again near the tropopause.

e. The airflow is fairly smooth and has a lifting component as it moves up the windward side of the mountain range. The wind speed gradually increases, reaching a maximum near the peak of the mountain. On passing the peak, the flow breaks down into a much more complicated pattern with downdrafts predominating. Downwind, perhaps 5 to 10 miles from the peak, the airflow begins to ascend as part of a definite wave pattern

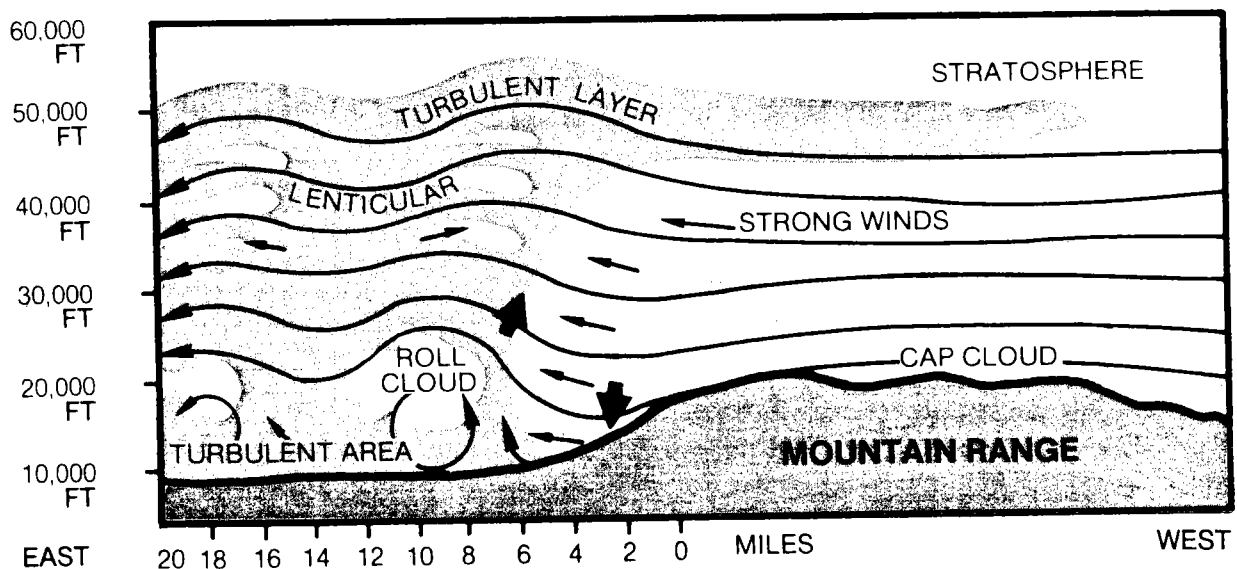


Figure 11-4. Mountain wave turbulence.

which has been induced into the general flow of the mountain range. Additional waves, generally less intense than the primary wave, may form farther downwind.

*f.* The pilot is primarily concerned with the first wave, because of its more intense action and proximity to the high mountain terrain. Severe turbulence frequently can be found out to 150 miles downwind when the winds are greater than 50 knots at mountain-top level. Moderate turbulence often can be experienced out to 300 miles under the previously stated conditions. When the winds are less than 50 knots at mountain peak level, a lesser degree of turbulence may be experienced. (See definitions of degrees of turbulence in paragraph 11-8.) Wave formation with roll clouds seems to require a certain degree of stability and a sufficient increase of wind speed with height in the middle troposphere.

*g.* Characteristic cloud forms, peculiar to wave action, provide the best means of visual identification. Although the lenticular clouds in figure 11-4 are smooth in contour, they may be quite ragged when the airflow in that level is quite turbulent. These clouds may occur singularly or in layers, at heights usually above 20,000 feet. The roll cloud forms at a lower level, generally about the height of the mountain ridge. The cap cloud usually obscures both sides of the mountain peak. The lenticular clouds, like the roll and cap clouds, are stationary in position. The cloud formations themselves are a useful guide to the location of turbulence.

*h.* Some of the most dangerous features of the mountain wave are the turbulence in and below the roll clouds and the downdrafts just to the lee side of the mountain peaks and to the lee side of the roll clouds. The cap cloud must always be avoided in flight because of turbulence and concealed mountain peaks.

*i.* While clouds are generally present to forewarn the presence of mountain-wave activity, it is possible for wave action to take place when the air is too dry to form clouds. This increases the likelihood of flying into a wave unexpectedly.

## 11-5. TIPS ON FLYING THE MOUNTAIN WAVE

When flying mountain ranges where waves exist, the Army aviator should consider the six rules listed below:

*a.* If possible, fly around the area when wave conditions exist. If this is not feasible, fly at a level which is at least 50 percent higher than the height of the mountain range. Be cautious to attain or maintain the minimum safe altitude (terrain elevation plus 50 percent) during climb-out to cruising altitude and descents for landings.

*b.* Avoid the roll clouds, since they are the areas with the most intense turbulence of the mountain wave.

*c.* Avoid the strong downdrafts on the lee side of mountains.

*d.* Avoid high lenticular clouds, particularly if their edges are ragged.

*e.* Do not place too much confidence in pressure altimeter readings near mountain peaks. They may indicate altitudes which are more than 1,000 feet higher than the actual altitude.

*f.* Penetrate turbulent areas at airspeeds recommended for your aircraft.

## 11-6. FRONTAL CAUSES

*a.* Frontal turbulence is caused by the lifting of warm air by a frontal surface, leading to instability and/or the mixing or shear between the warm and cold air masses. The vertical currents in the warm air are strongest when the warm air is moist and unstable. The most severe cases of frontal turbulence are generally associated with fast-moving cold fronts. In these cases, mixing between the two air masses as well as the differences in wind speed and/or direction add to the intensity of the turbulence.

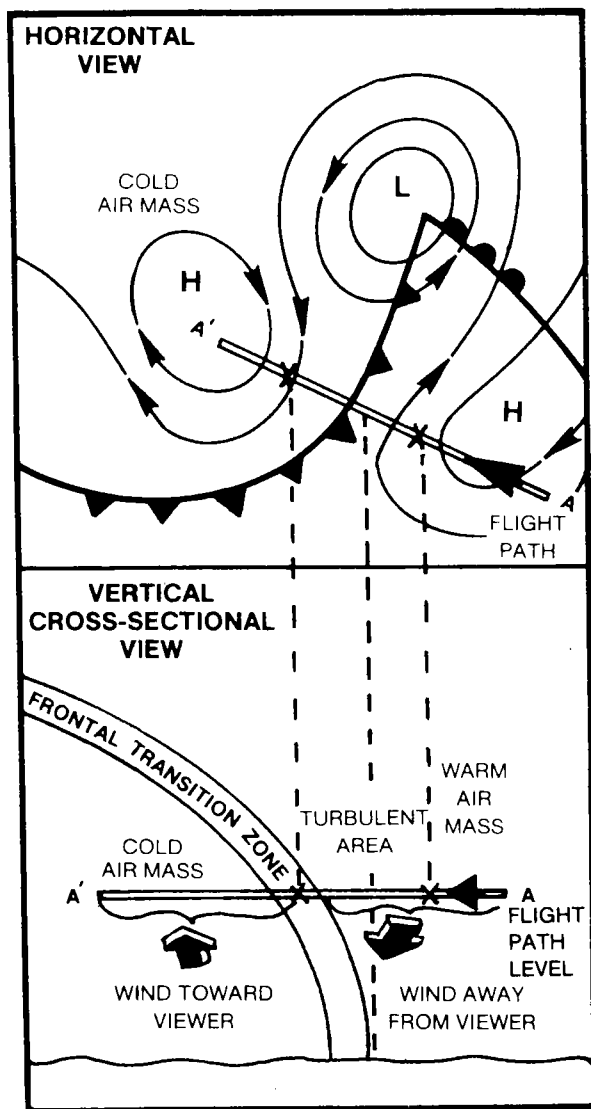


Figure 11-5. Turbulence across a typical cold front.

b. Excluding the turbulence that would be encountered in any thunderstorm along the front, figure 11-5 illustrates the wind shift that contributes to the formation of turbulence across a typical cold front. As a general rule, the wind speed is greater in the colder air mass.

## 11-7. WIND SHEAR CAUSES

a. Wind shear is a relatively steep gradient in wind velocity along a given line of direction (either vertical or horizontal) and

produces churning motions (eddies) which result in turbulence. The greater the change of wind speed and/or direction in the given direction, the greater the shear and associated turbulence. Turbulent flight conditions are frequently encountered in the vicinity of the jet stream. These conditions occur where large horizontal and vertical shears are often found. Since this type of turbulence may occur in clear air without any visual warning in the form of clouds, it is often referred to as *clear-air* turbulence (CAT). Clear-air turbulence is not necessarily limited to the vicinity of the jet stream. It may occur in isolated regions of the atmosphere during various situations. For example, the turbulence in a mountain wave can also be classified as clear-air turbulence, because the identifying clouds in the wave do not necessarily have to occur for the turbulence to be present.

b. A narrow zone of wind shear, with its accompanying turbulence, will sometimes be encountered by aircraft during a climb or descent at the top of the temperature inversion. These inversions occur anywhere from just above the surface to the tropopause.

c. An extreme form of wind shear that is important to the pilot while landing and taking off is that which is associated with strong inversions near the ground. As an example, a pocket of calm, cold air has formed in the valley as a result of nighttime cooling, but the warmer air moving over it had not been affected appreciably. Due to the difference in velocity between the two bodies of air, a narrow layer of very turbulent air is formed. An aircraft climbing or descending through this zone will encounter considerable turbulence as well as changes in lift.

d. Greater turbulence may be encountered momentarily when passing through the wake of another aircraft. On landing and departing, the wake of aircraft produces turbulence in the approach path to and along runways. The turbulence in the wake of heavy aircraft is usually of concern to pilots of lighter aircraft. Pilots should adjust their departure or approach flight paths so they will not encounter the turbulent wake of the heavy aircraft.



## 11-8. DEGREES OF TURBULENCE DEFINED

Classification of turbulence intensities is difficult for the pilot reporting an encounter and also for the forecaster predicting it. If two or more pilots flying separate but identical aircraft encounter the same degree of turbulence, their individual evaluations of its intensity are likely to vary. Experience has shown that individual crewmembers of the same aircraft often do not agree on the degree of turbulence which they encountered. Each pilot judges the severity of the turbulence on the basis of his training, experience, and individual mental reaction.

*a. Light Turbulence.* Light turbulence is subjectively defined as a condition of turbulence existing over extensive areas and altitudes. The more intense turbulence in this class is experienced in small cumuliform clouds. It is also found at low levels over rough terrain with surface wind speed less than 25 knots, at low levels over unequally heated land areas during the period of maximum heating, and at night over warm water areas.

*b. Moderate Turbulence.* Moderate turbulence is subjectively defined in relation to—

(1) The mountain wave when the strongest winds at mountaintop level perpendicular to the ridge line are 20 to 50 knots or more. Moderate turbulence is frequently found from the surface to 10,000 feet above the tropopause and as much as 300 miles leeward of mountains, or within cirrus clouds associated with the wave.

(2) The mountain wave when the strongest winds at mountaintop level perpendicular to the ridge line are 25 to 50 knots. Moderate turbulence is frequently found between the surface and the tropopause from the ridge line of mountains to 150 miles leeward, or within cirrus clouds associated with the wave.

(3) The jet stream, and is frequently found within a layer between the height of

the jet core and 5,000 feet below the core of the jet; and from the core to 250 miles toward the cyclonic (cold) side of the core, or within cirrus clouds associated with the jet.

(4) Cumuliform clouds, and is usually found within thick or towering cumulus.

(5) Strong surface winds, and is usually found near the ground when surface winds exceed 25 knots.

(6) Upper trough, cold low, or front aloft, and is frequently found where vertical wind shear exceeds 6 knots per 1,000 feet or horizontal wind shear exceeds 40 knots per 150 miles.

(7) Unstable atmosphere, and is frequently found at low levels where the atmosphere is unstable, but moisture is insufficient for thunderstorms or towering cumulus to form.

*c. Severe Turbulence.* Severe turbulence is subjectively defined in relation to—

(1) The mountain wave when the strongest winds at mountaintop level perpendicular to the ridge line are 50 knots or more. Severe turbulence is usually found from the surface to the tropopause, and from the ridge line to 150 miles leeward.

(2) The mountain wave when the strongest winds at mountaintop level perpendicular to the ridge line are 20 to 50 knots. Severe turbulence will usually be found leeward of mountains up to 50 miles downstream.

(3) Thunderstorms, and is usually found in and around mature thunderstorms.

(4) The jet stream, and is infrequently found within a layer between the height of the jet core and 5,000 feet below the core, and approximately 50 to 150 miles toward the cyclonic (cold) side of the jet core.

(5) Cumuliform clouds, and is infrequently found in towering cumulus.

d. **Extreme Turbulence.** Extreme turbulence is subjectively defined in relation to—

(1) The mountain wave when the strongest winds at mountaintop level perpendicular to the ridge line are 50 knots or more. Extreme turbulence is usually found at low levels, leeward of the mountains in or near the roll cloud, if present.

(2) The mountain wave when the strongest winds at mountaintop level perpendicular to the ridge line are 20 to 50 knots. Extreme turbulence is infrequently found at low levels, leeward of mountains.

(3) Thunderstorms, and is frequently found within a growing cell (indicated by

hail, heavy rain, strong radar echo gradients, or almost continuous lightning).

(4) Strongest forms of convection, wind shear, or standing wave action, and is usual.

The derived gust velocity criteria found in table 11-1 appears to provide the most suitable bridge, now available, between aircraft design characteristics and atmospheric turbulence as related to flight operations. This table has been adopted as standard by weather agencies and should be used for making in-flight reports of significant turbulence.

**Table 11-1. Turbulence Reporting Criteria Table.**

INTENSITY	AIRCRAFT REACTION	REACTION INSIDE AIRCRAFT
Light	<p>Turbulence that momentarily causes slight, erratic changes in altitude and/or attitude (pitch, roll, yaw). Report as light turbulence.*</p> <p style="text-align: center;">or</p> <p>Turbulence that causes slight, rapid, and somewhat rhythmic bumpiness without appreciable changes in altitude or attitude. Report as light chop.</p>	<p>Occupants may feel a slight strain against seat belts or shoulder straps. Unsecured objects may be displaced slightly. Food service may be conducted and little or no difficulty is encountered in walking.</p>
Moderate	<p>Turbulence that is similar to light turbulence but of greater intensity. Changes in altitude and/or attitude occur, but the aircraft remains in positive control at all times. It usually causes variations in indicated airspeed. Report as moderate turbulence.*</p> <p style="text-align: center;">or</p> <p>Turbulence that is similar to light chop but of greater intensity. It causes rapid bumps or jolts without appreciable changes in aircraft altitude and/or attitude. Report as moderate chop.</p>	<p>Occupants feel definite strains against seat belts or shoulder straps. Unsecured objects are dislodged. Food services and walking are difficult.</p>

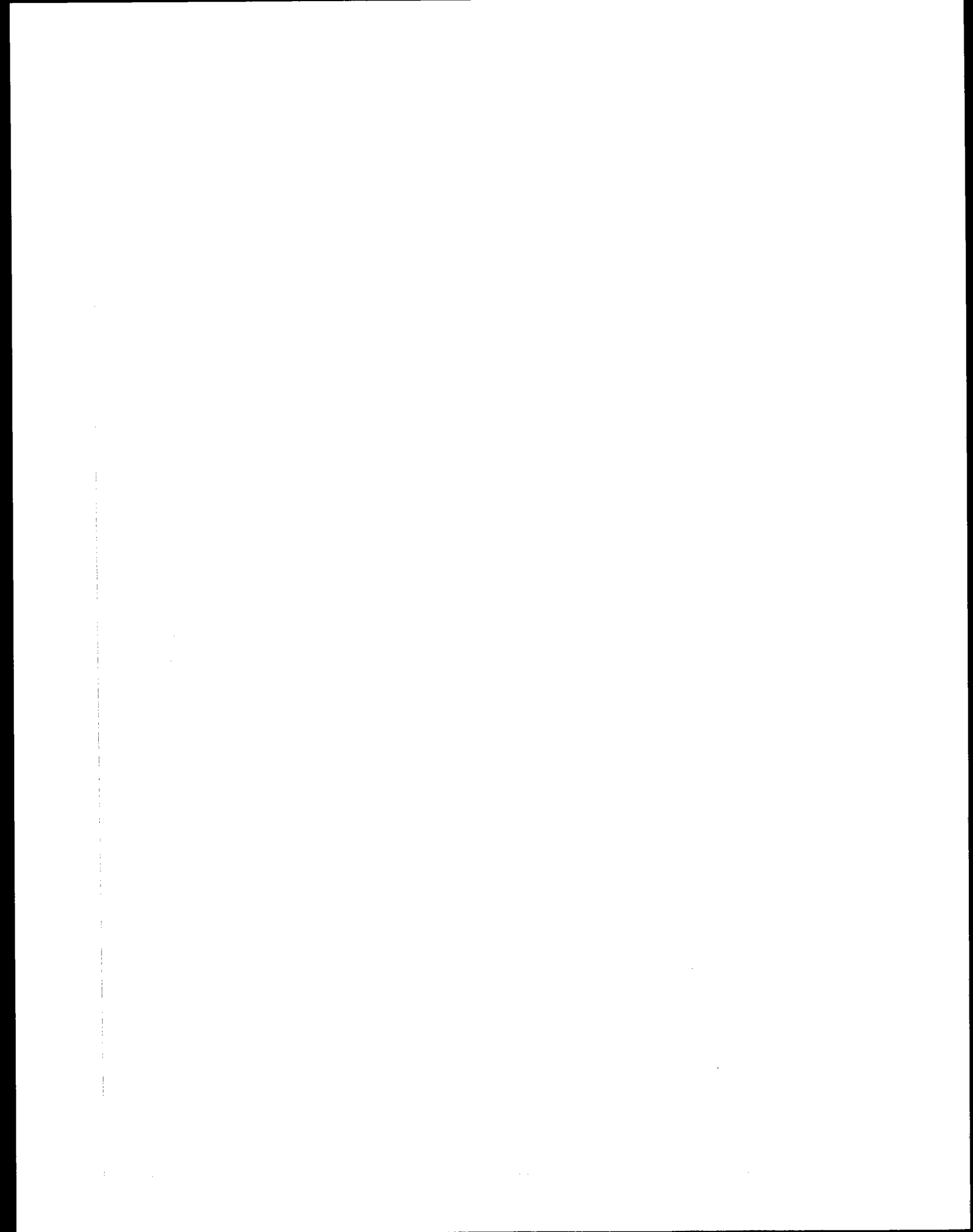
See footnotes at end of table.

**TABLE 11-1. Continued.**

<p><b>Severe</b></p>	<p>Turbulence that causes large, abrupt changes in altitude and/or attitude. It usually causes large variations in indicated airspeed. Aircraft may be momentarily out of control. Report as severe turbulence.*</p>	<p>Occupants are forced violently against seat belts or shoulder straps. Unsecured objects are tossed about. Food service and walking are impossible.</p>
<p><b>Extreme</b></p>	<p>Turbulence in which the aircraft is violently tossed about and is practically impossible to control. It may cause structural damage. Report as extreme turbulence.</p>	

\*High level turbulence (normally above 15,000 feet mean sea level) not associated with cumiform cloudiness including thunderstorms, should be reported as clear-air turbulence preceded by the appropriate intensity, or light or moderate chop.

NOTE	
Reporting Term	Definition
Occasional	Less than 1/3 of the time
Intermittent	1/3 to 2/3 of the time
Continuous	More than 2/3 of the time



## CHAPTER 12

### THUNDERSTORMS

#### 12-1. GENERAL

Thunderstorms and cumulonimbus (Cb) clouds contain many of the most severe atmospheric hazards for the Army aviator. They are almost always accompanied by strong gusts of wind, severe turbulence, heavy rain showers, lightning, and mixed icing conditions. During thunderstorms, hail is not uncommon and tornadoes are possible.

a. Because an average of 44,000 thunderstorms occur daily over the surface of the earth, it may be necessary to fly through thunderstorm areas to complete a mission. As an Army aviator, you must be aware of the hazards and flight problems caused by thunderstorms to plan and conduct a safe flight through areas of turbulence and associated phenomena.

b. When thunderstorms (fig 12-1) are in the flight area, it is sometimes possible to fly around them. You should remain clear of clouds through any known or suspected thunderstorm area, since cumulonimbus (thunderstorm) clouds are often concealed by surrounding cloud layers. This practice eliminates the possibility of unintentional thunderstorm penetration.

c. *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 you 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 12-3 and 12-4.

#### NOTE

**This chapter does not advocate flying into thunderstorms. It is merely intended to provide a general knowledge of this weather phenomena. Plan your flights to preclude inadvertent penetration; and before deliberate penetration is deemed necessary, an in-depth evaluation of the mission should be addressed. Based on experience and research, flight through thunderstorms and mission accomplishment are not compatible.**

#### 12-2. 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.

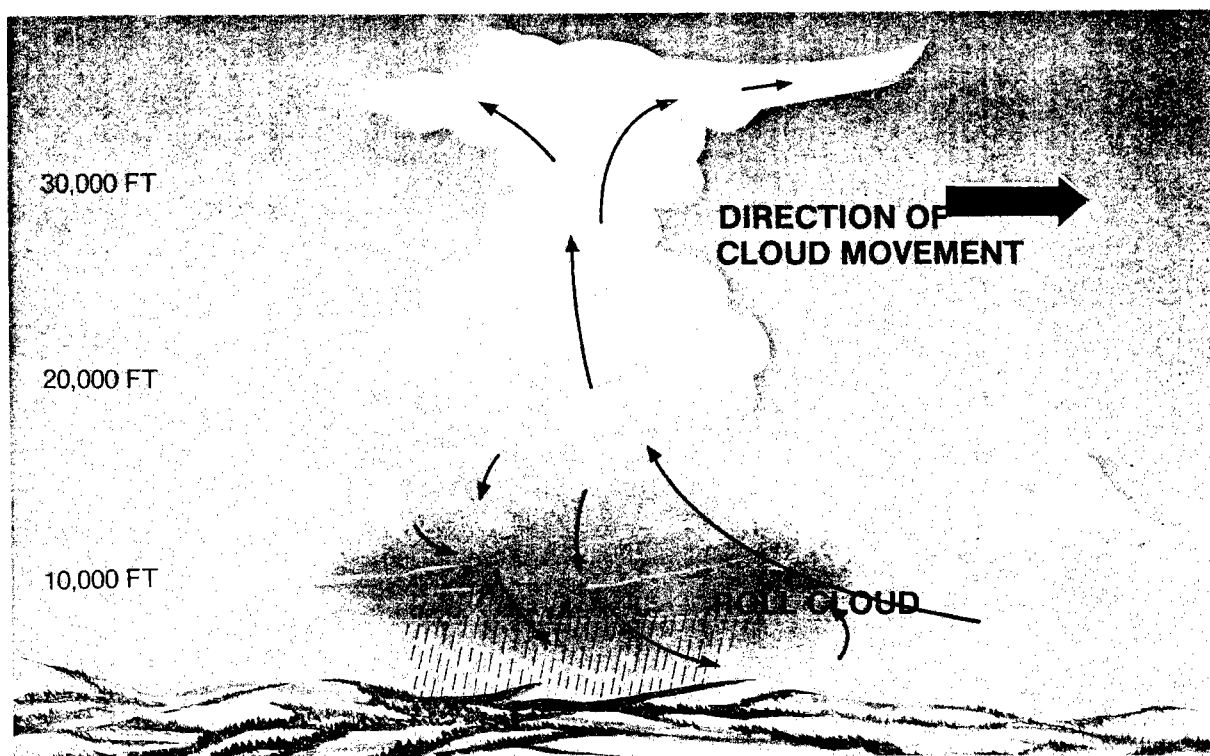


Figure 12-1. Thunderstorm (cumulonimbus) cloud.

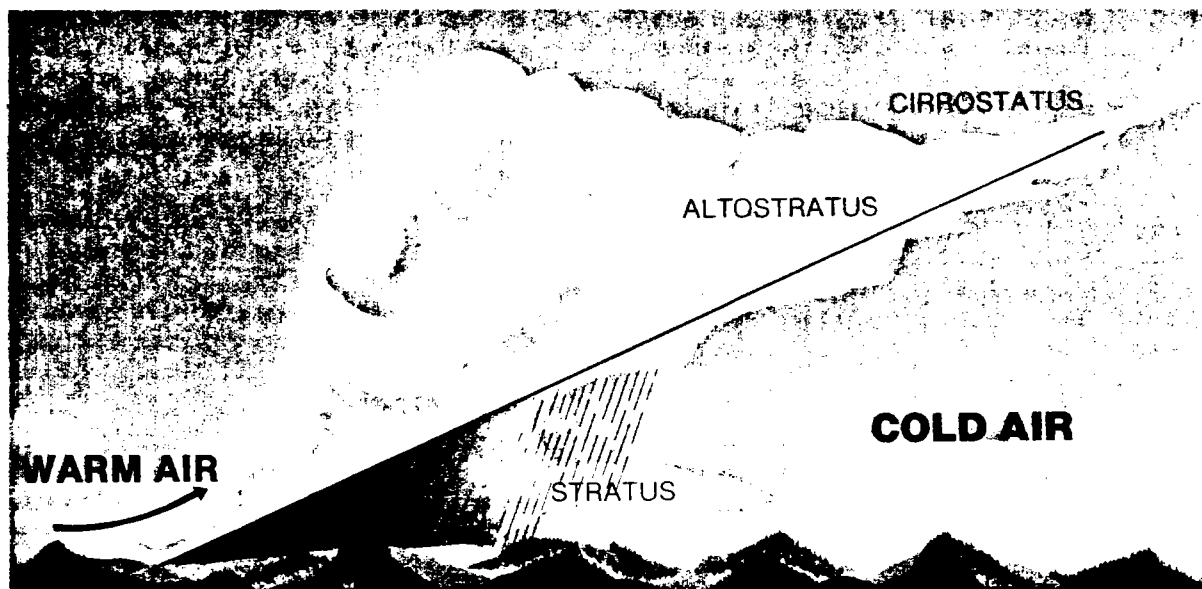
**b. Lifting Action.** Some type of external lifting action is necessary to bring the warm surface air to the point where it will continue to rise freely (the level of free convection). For example, an air mass may be lifted by thermal convection, terrain, fronts, or convergence.

**c. Moisture.** Lifting of warm air will not necessarily cause free convection. The air may be lifted to a point where the moisture condenses and clouds form. These cloud layers, however, 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.

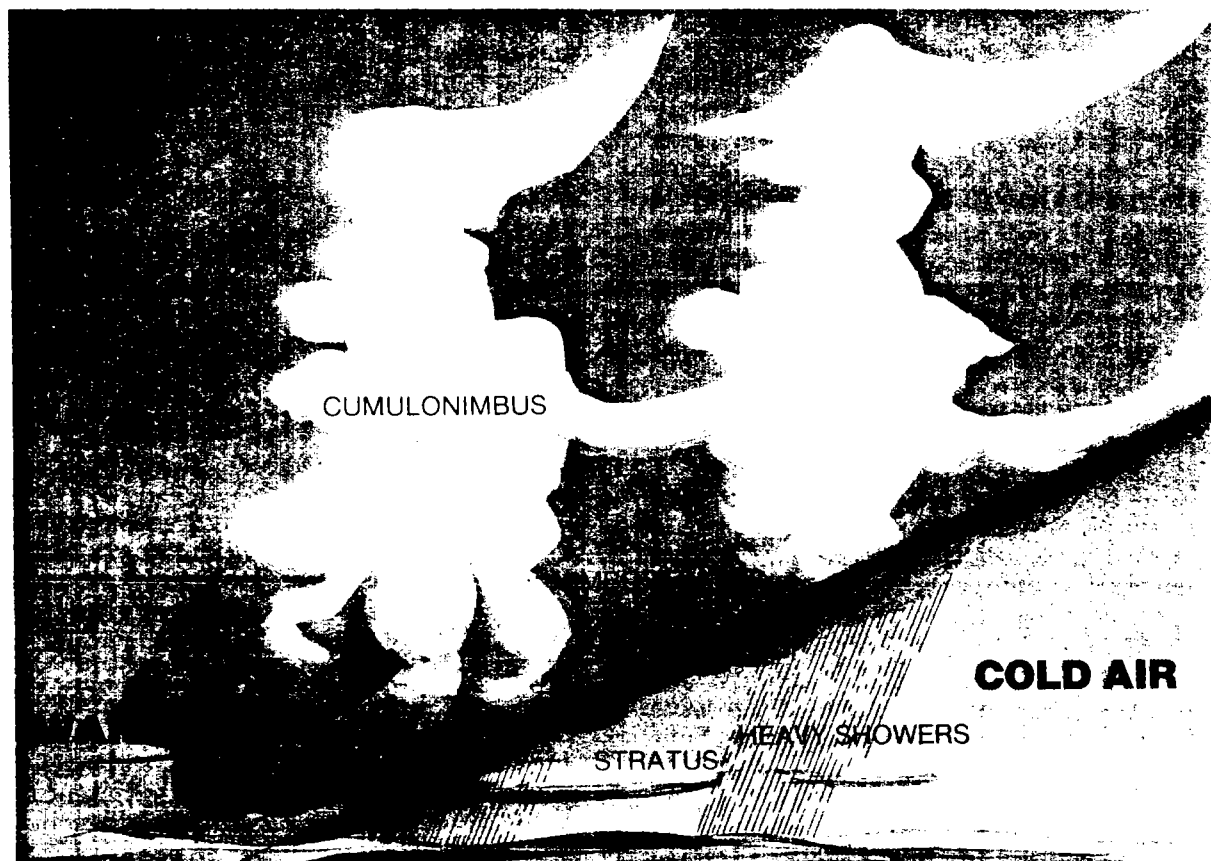
### 12-3. FRONTAL THUNDERSTORMS

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 and are called *prefrontal* or *squall line* thunderstorms.

**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 shallow, the air is lifted gradually. The lifting condensation level normally is reached long before the level of free convection, thus producing stratiform clouds (fig 12-2). The level of free convection normally will be reached in isolated areas along the frontal surface. This is the area where the greatest amount of water vapor is present in the warm air being



*Figure 12-2. Warm front (stable warm air).*



*Figure 12-3. Warm front (conditionally unstable warm air).*

lifted. Therefore, warm-front storms are generally scattered. Once the level of free convection is reached, warm-front thunderstorms may form (fig 12-3). Without airborne weather radar (chap 13) these storms are extremely difficult to detect, because they are obscured by the surrounding stratiform clouds. However, you may be warned of such a condition by loud crashes of static in your earphones (paras 12-7e(1),(2)) when using your low-frequency or medium-frequency receiver.

**b. Cold-Front Thunderstorms.** The forward motion of a wedge of cold air under a mass of warm, moist, conditionally unstable air (cold front) increases the possibility for thunderstorms to develop. The slope of a typical cold frontal surface is relatively steep (fig 12-4), 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 12-5), 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.** Frequently, with a rapidly moving cold front, lines of thunderstorms may develop ahead of the cold front. These are known as **prefrontal squall lines**, and frequently form parallel to the cold front (figs 12-6 and 12-7). Prefrontal squall-line thunderstorms usually are more violent than cold-front thunderstorms. They 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 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 (display).

**d. Stationary-Front Thunderstorms.** The distribution of these thunderstorms is controlled by the slope of the frontal surface. Steeply sloped 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 (paras 10-5a and 10-5b). They are found along the upper front; and they normally are strongest for a distance of 50 to 100 miles north of the peak of the warm sector.

## 12-4. AIR MASS THUNDERSTORMS

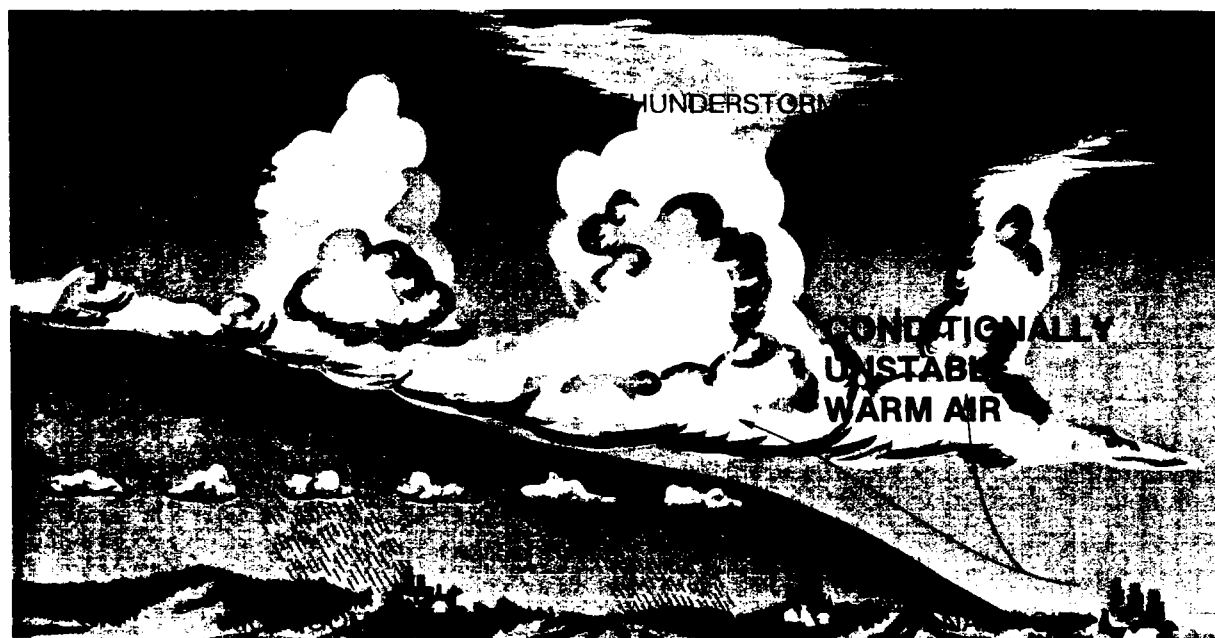
The two types of air mass thunderstorms are locally **convective** and **orographic**. Both types form within air masses and are randomly distributed throughout the air mass (fig 12-8).

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

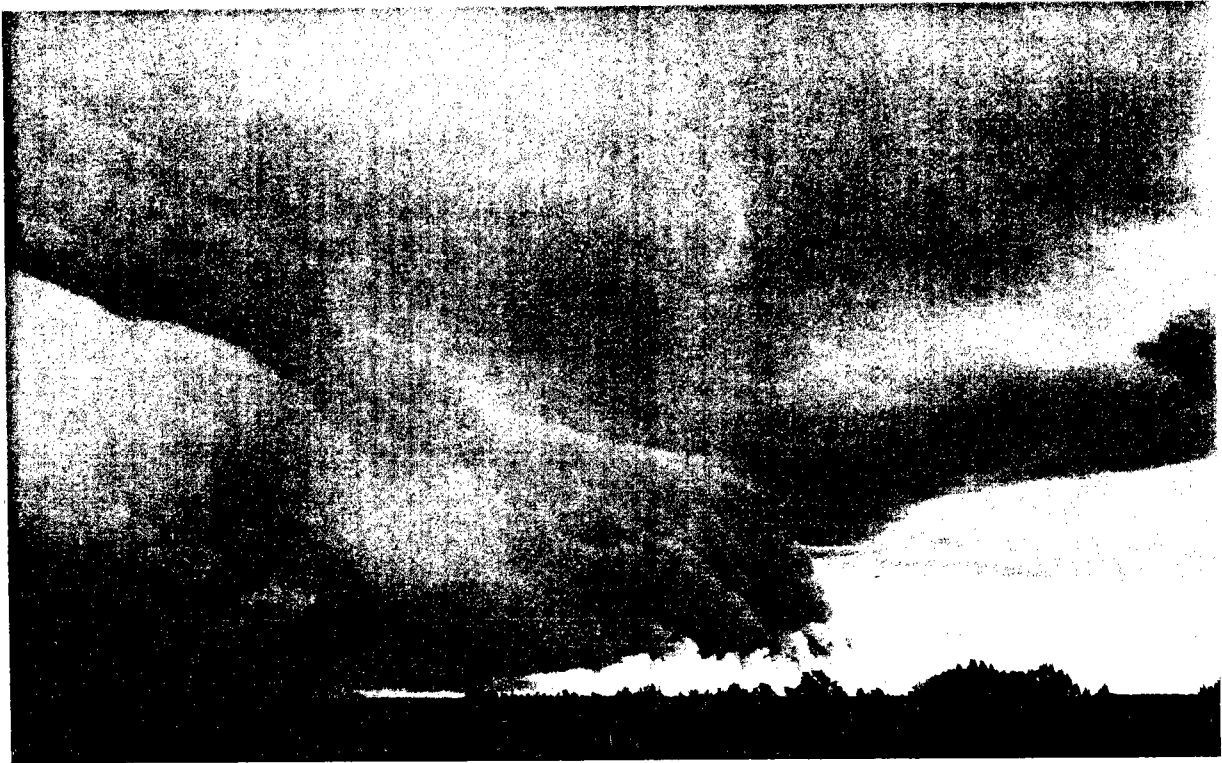




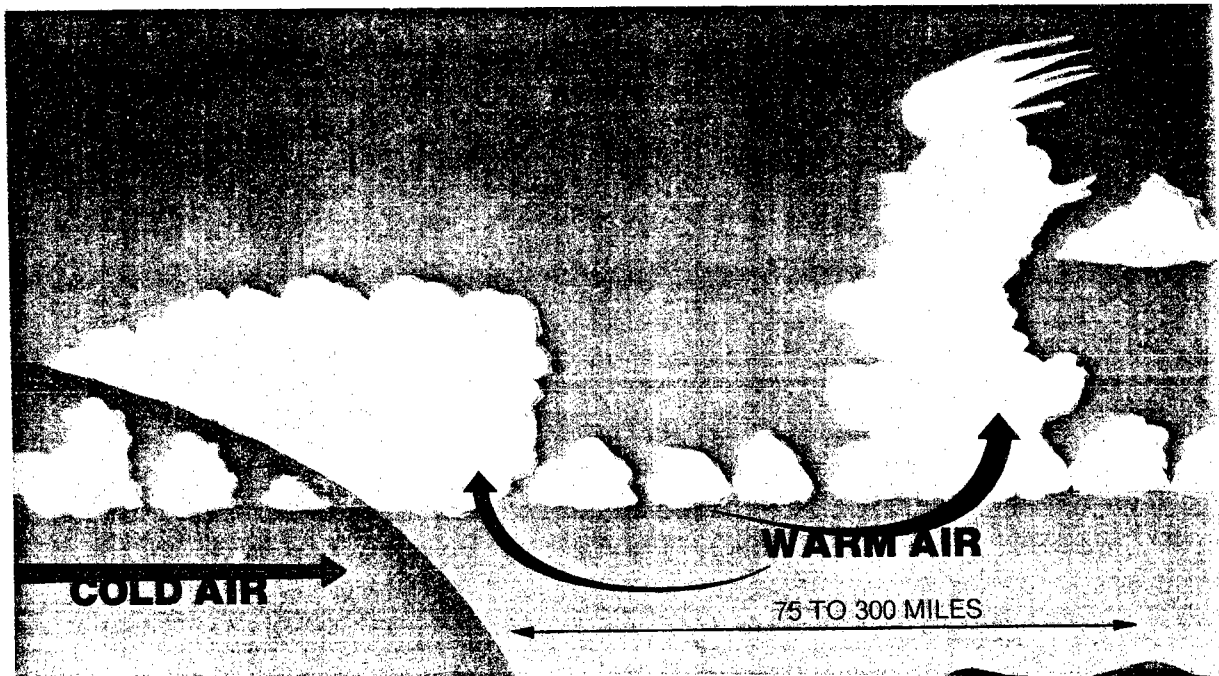
*Figure 12-4. Abrupt cold front (conditionally unstable warm air).*



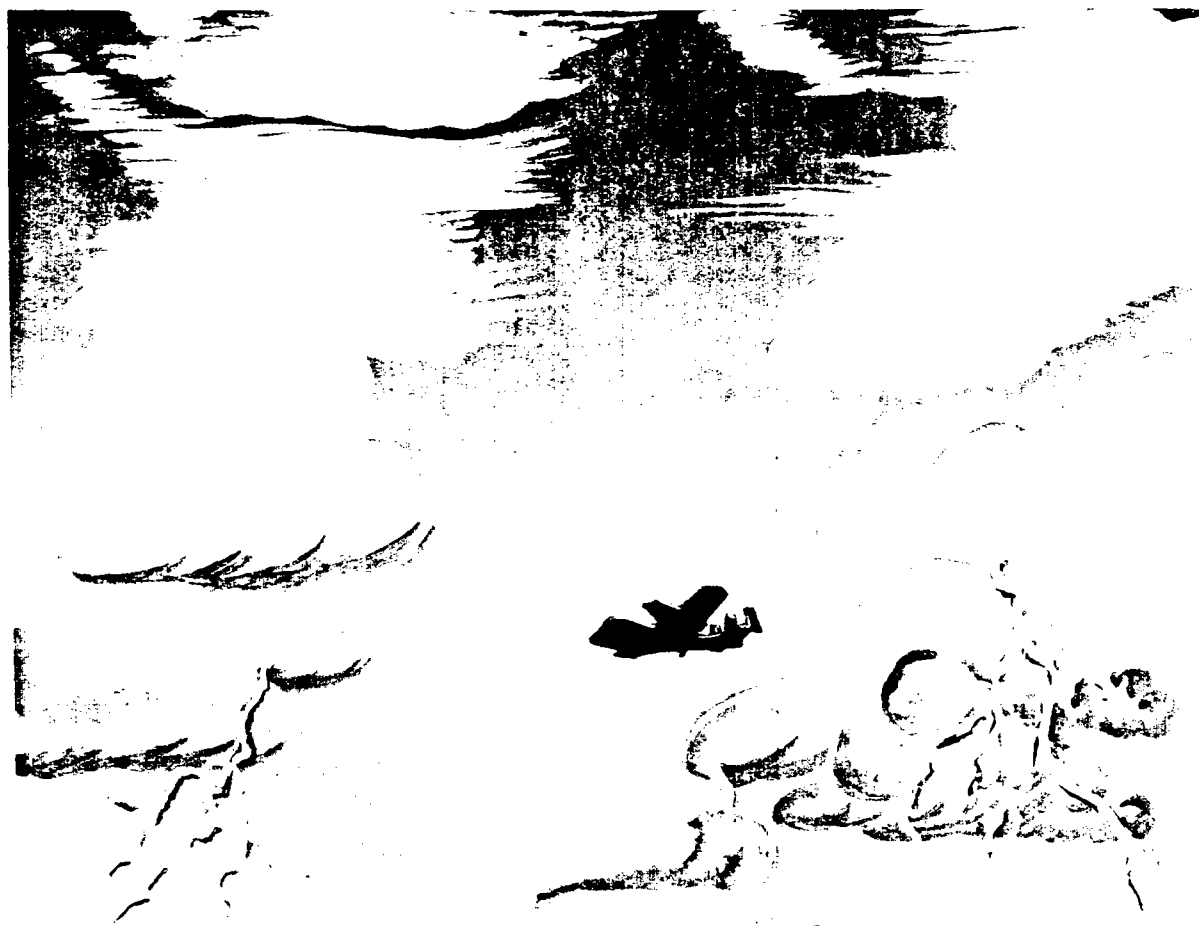
*Figure 12-5. Shallow cold front (conditionally unstable warm air).*



*Figure 12-6. Squall-line clouds.*



*Figure 12-7. Prefrontal squall line.*

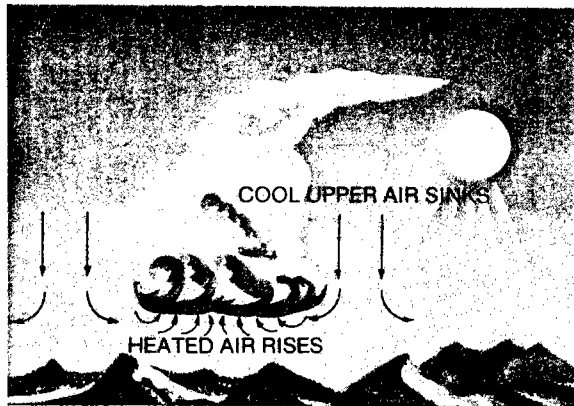


*Figure 12-8. Air mass thunderstorms.*

(1) The land-type convective thunderstorms normally form during the afternoon hours, after the earth has gained maximum heating from the sun. If cool, moist, conditionally unstable air is passing over this land area, heating from below will cause convective currents, thereby resulting in towering cumulus or thunderstorm activity (fig 12-9). 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 visual meteorological conditions (VMC) cannot be maintained.

(2) Thunderstorms over the ocean are most common during the night and early morning. They frequently occur offshore when a land breeze is blowing toward the water. The cool land breeze is heated by the warmer water surface, which results 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 they may re-form over the warmer land surface.

(3) The air mass weather that exists in Florida combines both types of convective thunderstorms (fig 12-10). Circulation



*Figure 12-9. Locally convective thunderstorms.*

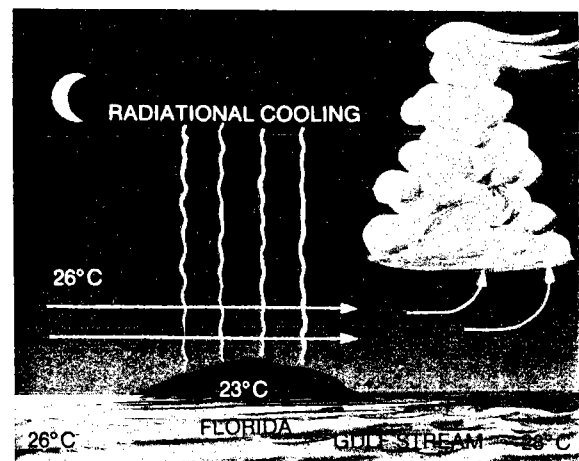
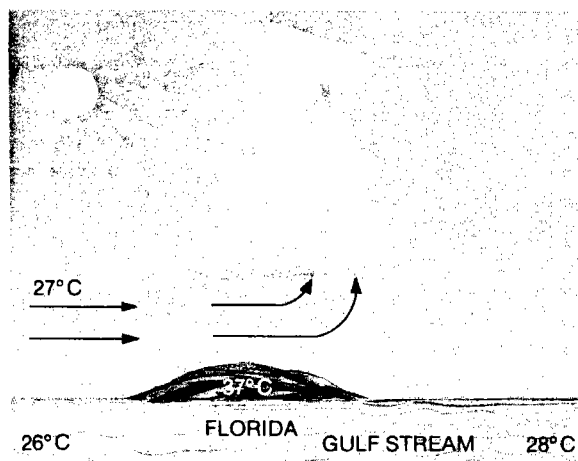
around a semipermanent high-pressure system off the southeastern United States (Bermuda high) carries moist ocean air over the warm land surface of the Florida Peninsula. At night, thunderstorms off the Florida Coast are caused by the warm water of the Gulf stream heating the surface air while the upper 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 re-form over the hot landmass. 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 randomly distributed and easily recognized. The visibility in the areas surrounding the clouds is generally excellent (fig 12-10).

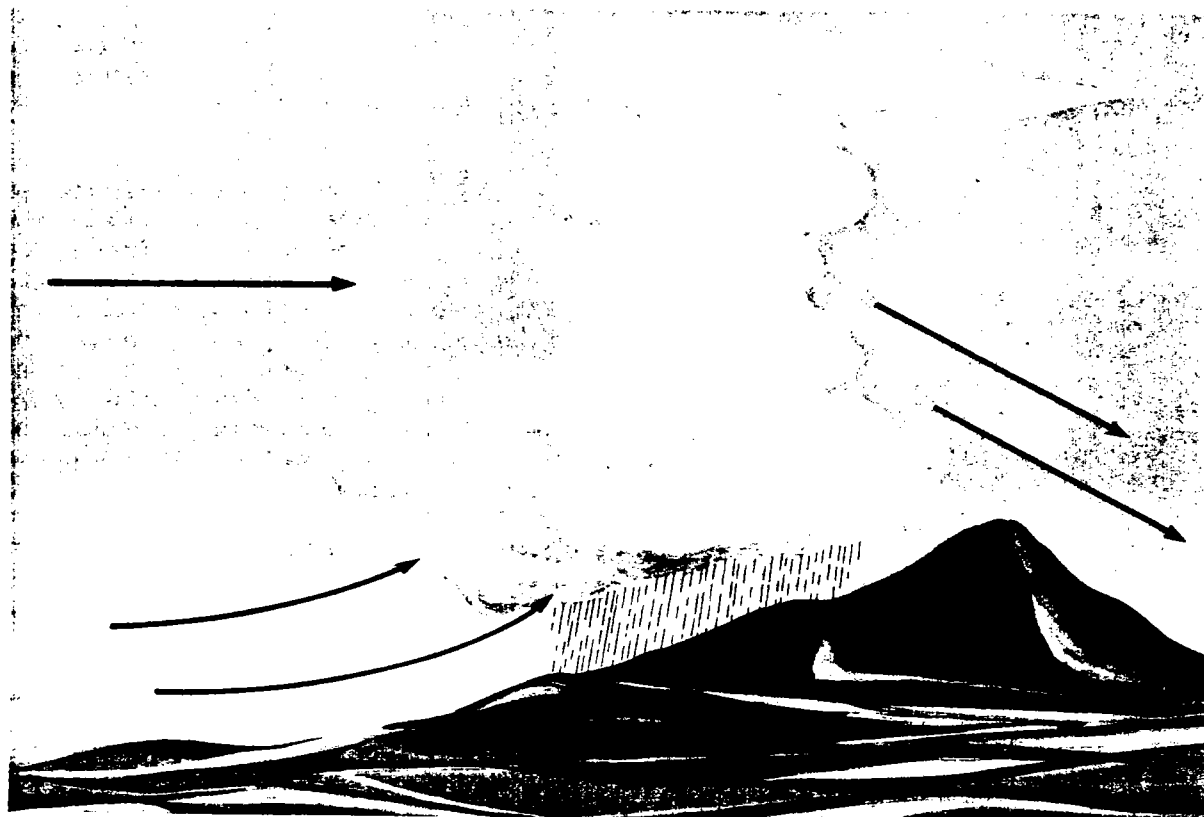
*b. Orographic Thunderstorms.* These thunderstorms will form on the windward side of a mountain if conditionally unstable air is lifted above the level of free convection. The storm activity is usually scattered along the individual peaks of the mountains. Occasionally, however, this activity may form a long unbroken line of storms similar to a squall line. 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). Almost without exception, orographic thunderstorms enshroud mountain peaks or hills. No attempt should be made to fly under this type of storm (fig 12-11).

## 12-5. STRUCTURE OF THUNDERSTORMS

*a. Convective Cells.* The fundamental structural element of the thunderstorm is the unit of convective circulation known as a



*Figure 12-10. Daily variations of coastal thunderstorms.*



*Figure 12-11. Orographic (upslope) thunderstorm.*

**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, however, 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.
- 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 that prevails throughout the entire cell (fig 12-12). This updraft may vary from a few feet per second to as much as 6,000 feet per minute (65 knots) in mature cells. As an updraft continues through the vertical extent of the cell, water droplets grow in size (coalesce), and raindrops are formed.

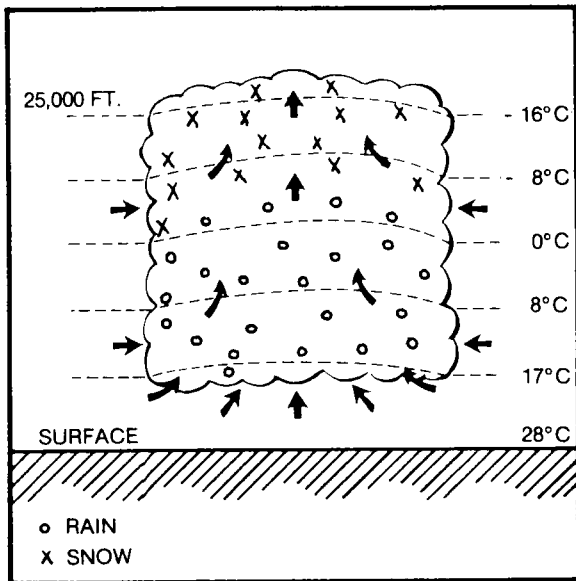


Figure 12-12. Thunderstorm cell, cumulus stage.

(2) **Mature stage.** The beginning of surface rain and adjacent updrafts and downdrafts initiates the mature stage (fig 12-13). 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 because of frictional drag. This descending air will be 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. Downdrafts occur at all levels within the storm and their speed ranges from a few feet per minute to about 2,500 feet per minute (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, snowflakes, and supercooled water are present. Therefore, 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. A shear action exists between these drafts and produces strong and frequent gusts. The gusts may easily flip the aircraft

into unusual attitudes and overstress its structure, especially during middle-altitude penetrations. However, thunderstorm penetration is not advised at any level.

(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 release 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 (cumulonimbus cloud), (fig 12-14). However, the appearance of the anvil does not always indicate the thunderstorm is dissipating.

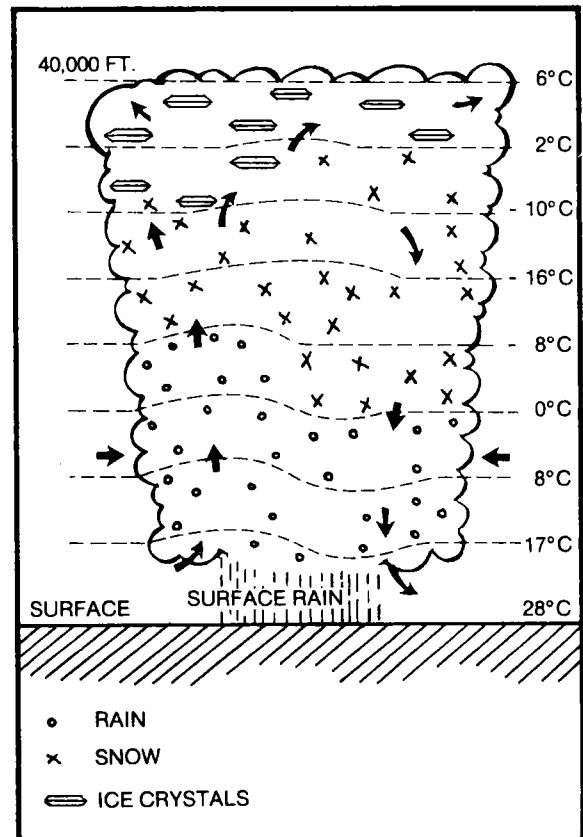


Figure 12-13. Thunderstorm cell, mature stage.

## 12-6. VERTICAL DEVELOPMENT

The height of storms is of great concern to the aviator who is determining an optimum flight altitude. Before 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 have been made in various projects by use of radar. The average height measured was 37,000 feet and the maximum height observed was 56,000 feet. Severe storms attain heights greater than this. The average annual number of thunderstorms over the conterminous United States is shown in figure 12-15.

*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 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 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 various studies concerning the speed of drafts and the effects of drafts on aircraft. Measurements of drafts were computed from changes in pressure altitudes. However, no effort was made by the pilot to maintain altitude during the measurements. Results are given below.

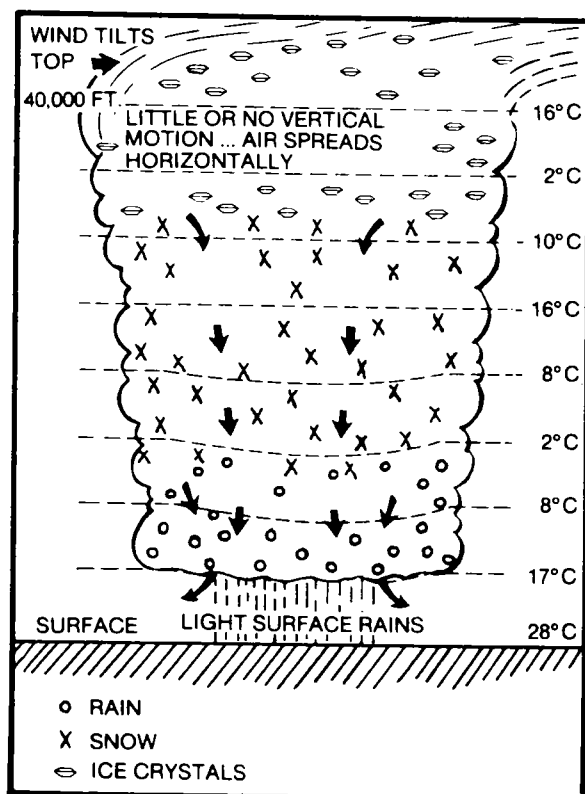


Figure 12-14. Thunderstorm cell, dissipating stage.

(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. For instance, an aircraft 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 no case was an aircraft flying at the 5,000-foot to 6,000-foot level brought dangerously close to the ground by a downdraft (uneven terrain areas excepted).

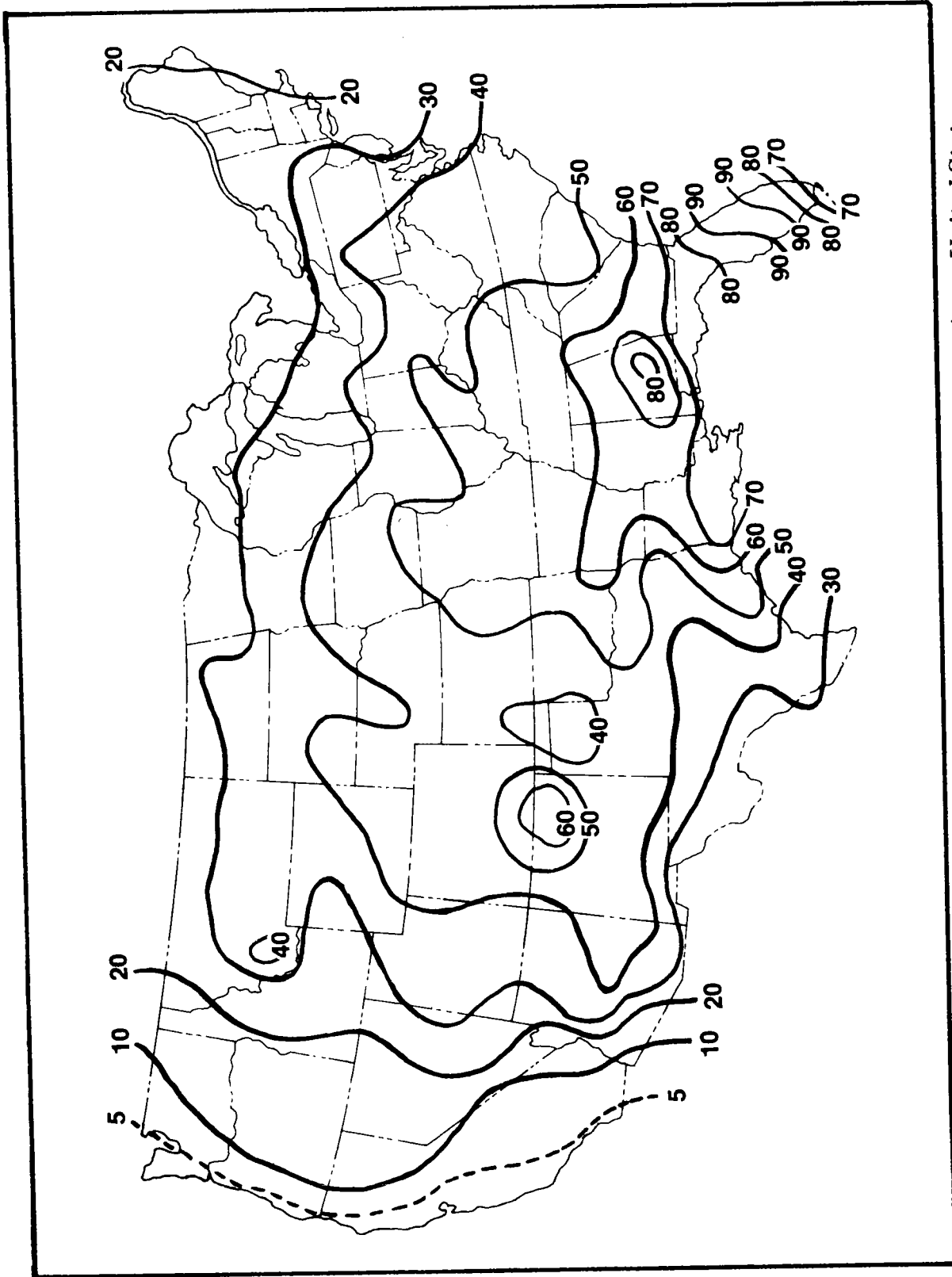


Figure 12-15. Average number of thunderstorms each year over the conterminous United States.



*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 are caused by abrupt changes in the air currents encountered by the aircraft and may be accompanied by pitch, yaw, or roll movement. 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 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 (1,500 feet per minute or greater) (15 knots) were also observed at all altitudes, but with far less frequency.

(4) Since gusts of all speeds are prevalent at all altitudes, you cannot avoid them in flight. However, there is a definite maximum frequency of the higher speed gusts in the vicinity of 15,000 feet, usually near the freezing level.

(5) Gusts as strong as 2,500 feet per minute (25 knots) have been measured during thunderstorm penetrations. High-speed gusts have caused structural deformation and even structural failure. In most of these cases, however, it is believed that the strong gusts were encountered at an incorrect air-speed 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 if thunderstorm penetration becomes necessary. Avoiding the entire storm, however, is still the best procedure. Strong gusts may also be encountered at other altitudes in the storm. In a few cases, severe and/or extreme turbulence has been encountered in clear air above, or out to 5 miles laterally from, developing and mature thunderstorms.

## 12-7. WEATHER WITHIN THE STORM

*a. Rain.* If a thunderstorm is penetrated, you can expect to encounter considerable quantities of water droplets. 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) Hail competes with turbulence as the greatest hazard to aircraft produced by the thunderstorm. Most thunderstorms have hail in the interior of the cumulonimbus cloud at some stage during their existence. In most cases, the hail melts before reaching the ground. But this does not lessen its danger to the aviator who encounters it aloft.

(2) A single unit of hail, called a *hailstone*, is found in the form of a ball or an irregular lump of ice, ranging from the size of a pea to the size of a grapefruit. Large hailstones usually have alternating layers of clear and cloudy ice.

(3) Large hail is most commonly found in thunderstorms which have—

- Strong updrafts.
- Large liquid water content.
- Large-size cloud droplets.
- Great vertical height.

(4) Hail usually is produced during the mature stage of the thunderstorm's life span. It is most frequently encountered at levels between 10,000 and 30,000 feet, but the frequency of large hail decreases quite markedly above 35,000 feet. Hailstones with diameters up to 5 inches have been reported at 29,500 feet. Hail may be found at any level within a thunderstorm. Occasionally, it is encountered in clear air outside of the storm cloud. Hailstones may be thrown upward and outward from the cloud for as much as 5 miles under an innocent-appearing anvil of cirrus clouds. Hailstones larger than one-half to three-quarters of an inch can cause significant aircraft damage in a few seconds.

(5) While there is risk of an encounter with hail in any thunderstorm, subtropical and tropical thunderstorms contain less hail than those in more northern latitudes. Hail seldom reaches the ground in the subtropics and tropics.

c. *Icing*. Clear icing in cumulus clouds and thunderstorms is usually limited in extent because of the cellular structure of the clouds. However, it may occasionally be very severe. The severest 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 various projects, the maximum frequency of moderate and heavy snow occurred at the 20,000-foot 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 ice.

#### 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 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 12-16.

- The center of the negative charge is generally located between the freezing level and the  $-10^{\circ}\text{C}$  level, while the positive charge center is located near the  $-10^{\circ}\text{C}$  level. As the thunderstorm progresses through the mature stage, a small region of positive charge also develops in the down-draft associated with the heaviest rain.

- 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 water droplets 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.

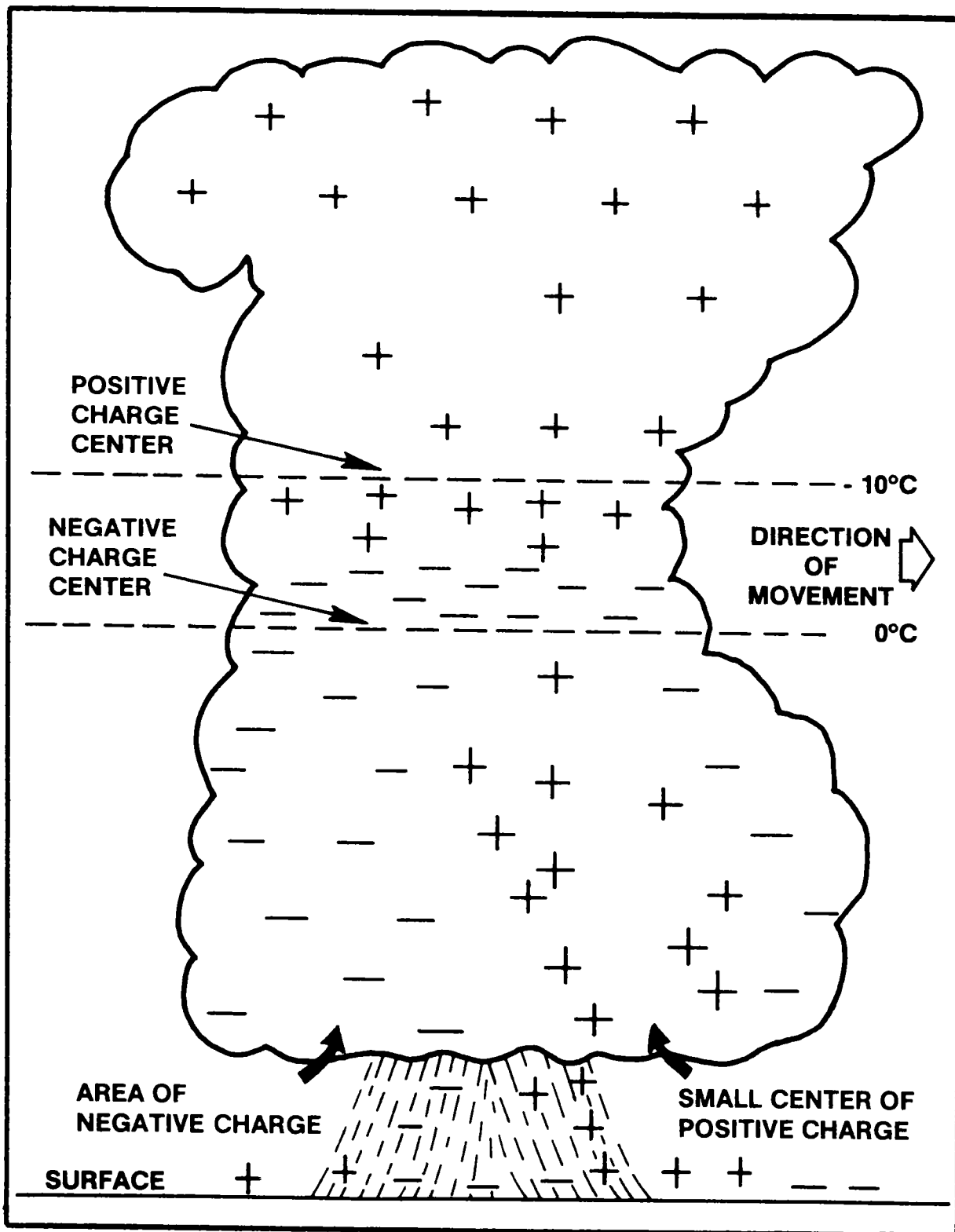


Figure 12-16. Location of electrical charges inside a typical thunderstorm cell.

- Lightning is most frequently encountered as discharges from 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.

- Since lightning may damage aircraft, the aviator should avoid thunderstorm areas where lightning is most frequent. Lightning strikes are least frequent at the lowest flight levels.

- Lightning discharges cause loud crashes of static on low-frequency and medium-frequency radio receivers. This static affects radio communication from 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.

- 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-frequency and medium-frequency radio reception may become impossible under such circumstances.

- 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 aircraft 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.

- 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.

- External fields are also found in precipitation areas below the clouds. Generally, they are strong in areas of heavy precipitation.

f. **First Gusts.** Another significant thunderstorm hazard is the rapid change in wind direction and wind speed immediately prior to storm passage at the surface. These strong winds are the result of the horizontal spreading of the storm's downdraft current as they approach the surface of the earth. 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 degrees in direction from the previously prevailing surface winds. First-gust speeds average about 15 knots over prevailing velocities; and they average about a 40-degree 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 12-17). First gusts are not limited to the area ahead of the storm's movement. They may be found in all sectors including the area back of the storm's movement.

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—

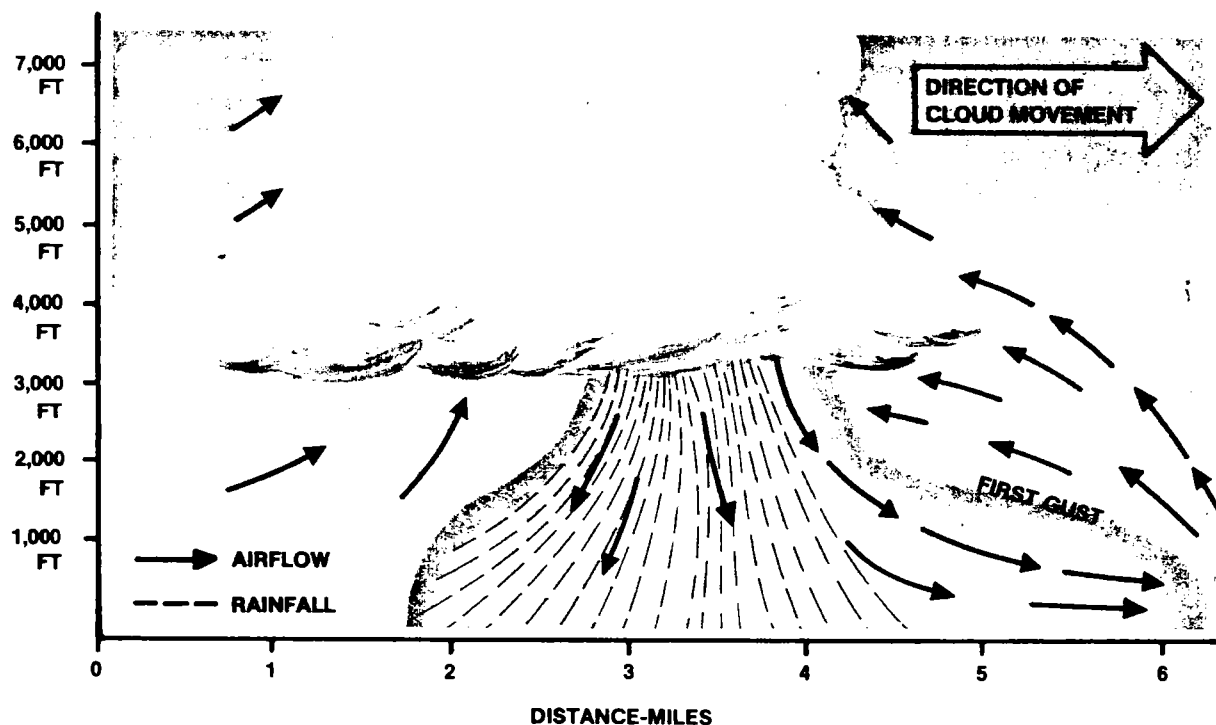


Figure 12-17. Air movement beneath a thunderstorm cell in a mature stage.

- An abrupt fall in pressure as the storm approaches.

- An abrupt rise in pressure associated with rain showers as the storm moves on and the rain ceases.

Such pressure changes may result in significant altimeter errors if the altimeter setting is not corrected. When landing during thunderstorm activity (even when one has passed or is in the area), check your altimeter setting for possible major fluctuations.

**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,

which 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.

**i. Turbulence.** Refer to Chapter 11, "Turbulence," for turbulence classifications.

(1) **Inside the cloud.** Potentially hazardous turbulence is present in all thunderstorms. A severe thunderstorm may contain turbulence capable of destroying an aircraft. The strongest turbulence occurs with the shear between updrafts and downdrafts during the mature stage of the thunderstorm. While studies show little variation of turbulence with altitude, there is some evidence that maximum turbulence can be expected near the freezing level. Severe turbulence is also found in the anvil clouds 15 to 20 miles downwind from severe storm cores.

(2) **Outside the cloud.** Severe turbulence may also be found in clear air on the inflow side of a severe storm. At the edge of the cloud, the mixing of cloudy and clear air often produces strong temperature gradients associated with rapid variations of vertical velocities and resultant turbulence.

(3) **Atop the cloud.** Flight data shows a relationship between turbulence above storm tops and the speed of the upper tropospheric winds. When the winds at storm top exceed 100 knots, there are times when significant turbulence may be experienced as much as 10,000 feet above the cloud top. This value may be decreased 1,000 feet for each 10-knot reduction of wind speed. This is especially important for clouds exceeding the height of the tropopause. Consideration of flight above these storms in Army aircraft is primarily academic, since the storms usually extend to 40,000 feet or higher.

(4) **Beneath the cloud.** The rapidly changing wind velocities associated with the first gust beneath a thunderstorm can generate extreme turbulence 10 to 15 miles in advance of the storm core.

*j. Low-level wind shear.*

(1) **Definition.** "Low-level wind shear" can be described as a change in low-altitude wind speed or wind direction in a short distance in the atmosphere. There have been recorded observations within 200 feet of the ground of wind direction changes of 180 degrees and speed changes of 50 knots or more. This is not a usual occurrence; however, its rarity compounds the problem of coping with such an encounter.

(2) **Causes.** Because of the complexity of winds around a thunderstorm, wind shear can be expected on all sides of a storm cell. The strongest shear is associated with the first gust of an approaching cell. It can exist in clear air 10 to 15 miles ahead of the storm core (fig 12-18). **Note.** *Low-level wind shear may also be present in the vicinity of fronts because of the differing wind speeds and direction within the adjacent air masses.* Depending on the movement and frontal slope, this shear may exist just after a cold frontal passage for a period of a few minutes to a few hours. The most critical period for a warm front is the

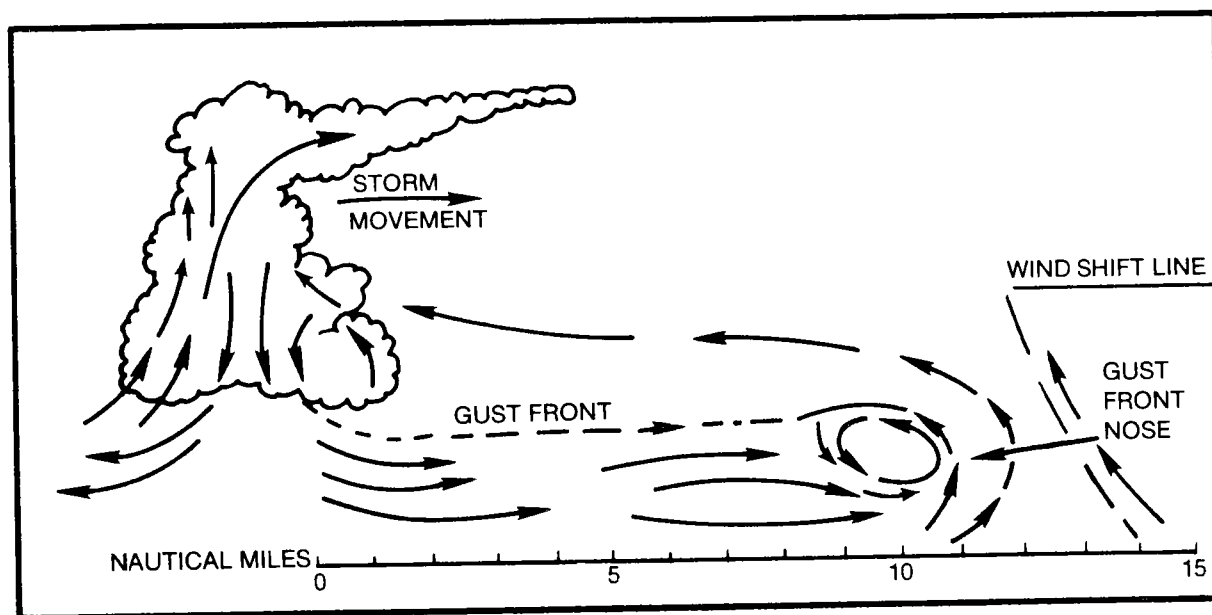


Figure 12-18. Low-level wind shear hazards.

last few hours prior to frontal passage. Data compiled on wind shear indicates that the amount of shear in warm fronts is much greater than that found in cold fronts.

(3) *Effects on airspeed.* Aviators have been taught that wind does not affect the airspeed of an aircraft after it has become airborne—only drift and ground speed would be affected. This is not true, however, if the wind changes faster than the mass of the aircraft can be accelerated or decelerated. A shear from a tail wind to a calm or head wind will initially cause an increase in airspeed. Conversely, a change from a head wind to a calm or tail wind condition will initially cause a decrease in airspeed. These sudden changes in airspeed, depending upon aircraft type, will produce radical deviations from the stabilized conditions prior to experiencing the wind shear. These deviations become especially hazardous during low-level operations such as terrain flight and takeoffs and landings.

## 12-8. FLIGHT TECHNIQUES

*a. General.* In planning a flight into existing or expected thunderstorm areas, you should try to determine whether the thunderstorms will be sufficiently isolated to permit circumnavigation or will be sufficiently scattered to require flight between them. Radar weather reports are helpful in locating thunderstorm areas and in determining how numerous the storms are. You should also check significant meteorological information (SIGMET), pilot reports (PIREP), airmen's meteorological information (AIRMET), and significant changes and notices to airmen (SCAN) reports for the latest information available on storm areas along your route. In consulting with the meteorologist, you 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 radarscope is available at the weather station, check the radar picture to correlate the location and intensity of the storms in the immediate area. Then decide if it is possible to circumnavigate the storms or fly between them. Over-the-top flight is normally impossible in current Army aircraft because of

altitude and oxygen limitations. If all routes to avoid the storm are closed, you must decide if the mission is important enough to warrant flying through the area.

### *b. Do's and Don'ts of Thunderstorm Flying.*

(1) As an Army aviator, never regard any thunderstorm lightly, even when radar observers report the echoes are of light intensity, because they may intensify rapidly. Avoiding thunderstorms is the best policy. Following are some *do's* and *don'ts* of thunderstorm avoidance.

- Do avoid—by at least 20 miles—any thunderstorm identified as severe or giving an intense radar echo. This is especially true under the anvil or a large cumulonimbus. (See Chapter 13, "Airborne Weather Radar," for detailed weather radar procedures.)

- Do remember that vivid and frequent lightning indicates the probability of a severe thunderstorm.

- Do regard as extremely hazardous any thunderstorm with tops 35,000 feet or higher, whether the top is visually sighted or determined by radar.

- Don't land or take off in the face of an approaching thunderstorm. A sudden gust front of low-level turbulence could cause loss of control.

- Don't attempt to fly under a thunderstorm even if you can see through it. Turbulence, wind shear, and forming tornadoes under the storm could be disastrous.

- Don't fly without airborne radar into a cloud mass containing embedded thunderstorms. Thunderstorms not embedded usually can be visually circumnavigated.

- Don't trust the visual appearance to be a reliable indicator of the turbulence inside a thunderstorm.

(2) If you cannot avoid the possibility of penetrating a thunderstorm, the following are some *do's before* entering the storm:

- Contact pilot-to-metro service or Army radar approach control for weather guidance.
- Tighten your safety belt and shoulder harness and secure all loose objects.
- Plan and hold your course to take you through the storm in minimum time.
- To avoid the most critical icing, establish a penetration altitude below the freezing level or above the level of  $-15^{\circ}\text{C}$ .

**NOTE**

**Although rare, severe updrafts may cause freezing-rain-type icing in upper storm levels at  $-15^{\circ}\text{C}$  or lower.**

- Verify that pitot heat is on and turn on carburetor heat or jet engine anti-ice. Icing can be rapid at any altitude; and it can cause almost instantaneous power failure and/or loss of airspeed indication.
- Establish power settings for turbulence penetration airspeed recommended in your aircraft operator's manual.
- Turn up cockpit lights to highest intensity to lessen temporary blindness from lightning.

- If using automatic pilot, disengage altitude hold mode and speed hold mode. The automatic altitude and speed controls will increase maneuvers of the aircraft, thus increasing structural stress.

- If using airborne radar, tilt the antenna up and down occasionally. This will permit you to detect other thunderstorm activity at altitudes other than the one being flown.

(3) Following are some *do's* and *don'ts* during the thunderstorm penetration:

- Do keep your eyes on your instruments. Looking outside the cockpit can increase danger of temporary blindness from lightning.

- Do try to maintain a level flight *attitude*; let the aircraft "ride the waves." Maneuvers in trying to maintain constant altitude increase stress on the aircraft.

- Do pass a pilot report to the nearest weather facility after penetration.

- Don't change power settings; maintain settings for the recommended turbulence penetration airspeed.

- Don't turn back once you are in the thunderstorm. A straight course through the storm is most likely to get you out of the hazards more quickly. In addition, turning maneuvers increase stress on the aircraft.



## CHAPTER 13

### AIRBORNE WEATHER RADAR

#### 13-1. GENERAL

a. Airborne weather radar, when properly used, is an invaluable aid to the Army aviator in avoiding thunderstorms and other precipitation-related hazards. Correct analysis of radar displays permits the aviator to—

- Locate areas of precipitation.
- Estimate the relative amount of associated turbulence.
- Detect areas of possible hailshafts and tornadoes.
- Select a flight path that will avoid or minimize weather hazards in the affected areas.

#### NOTE

**Airborne weather radar is a thunderstorm avoidance tool.**

b. The following cannot only negate the usefulness of the device, but can create a false sense of security when flight hazards actually exist or cause needless detours when flight hazards do not exist:

- Improper operation of the radar set.
- Incorrect interpretation of radar displays.
- Failure to employ correct avoidance procedures.

c. The purpose of this chapter is to acquaint the aviator with the—

- Principles and operation of weather radar sets.

- Interpretation of radar displays.

- Recommended methods of avoiding hazardous weather areas.

#### 13-2. BACKGROUND

a. *Radar* is an acronym for *radio detecting and ranging*. It was developed just prior to World War II. Initially, it was used for the detection of aircraft and surface ships and the positioning of anti-aircraft and naval weapons. Radar users later found it could be used for ground mapping, bombing, and detection of precipitation.

b. The use of airborne weather radar for weather detection was initially a by-product of sets designed for navigation and bombing. Nonsurface returns on the radar indicator were found to be areas of precipitation and frequently associated with moderate to severe turbulence. Radar operators learned through trial and error to identify the turbulence-associated displays and developed detour techniques to avoid them. In most cases, however, the effectiveness of the radar was dependent upon the experience and skill of the individual operator in interpreting indicator displays.

c. Modern airborne radars are now available that have been designed specifically for use in weather avoidance. Computer-generated imagery (in some cases using color enhancement) assists the operator in interpreting the display.

#### NOTE

**Airborne weather radar is *not* a thunderstorm penetration tool—it is an avoidance tool.**

### 13-3. PRINCIPLES OF OPERATION

a. Radar is an electronic version of the echo principle shown in figure 13-1A. With the knowledge that sound travels *about* 1,100 feet per second and using a stopwatch, the distance to the adjacent mountain can be determined. Similarly, knowing that radar energy travels at the speed of light (161,770 nautical miles per second) and using an extremely accurate timing device, the distance from the radar antenna in figure 13-1B,

to the rain cloud can also be determined. A *radar set* can be defined as a device that—

- Generates pulses of electromagnetic energy.
- Directs those pulses toward a reflecting body.
- Receives the reflected energy.
- Translates the time between the transmission and reception of the energy to distance from the antenna.
- Displays the results on an indicator.

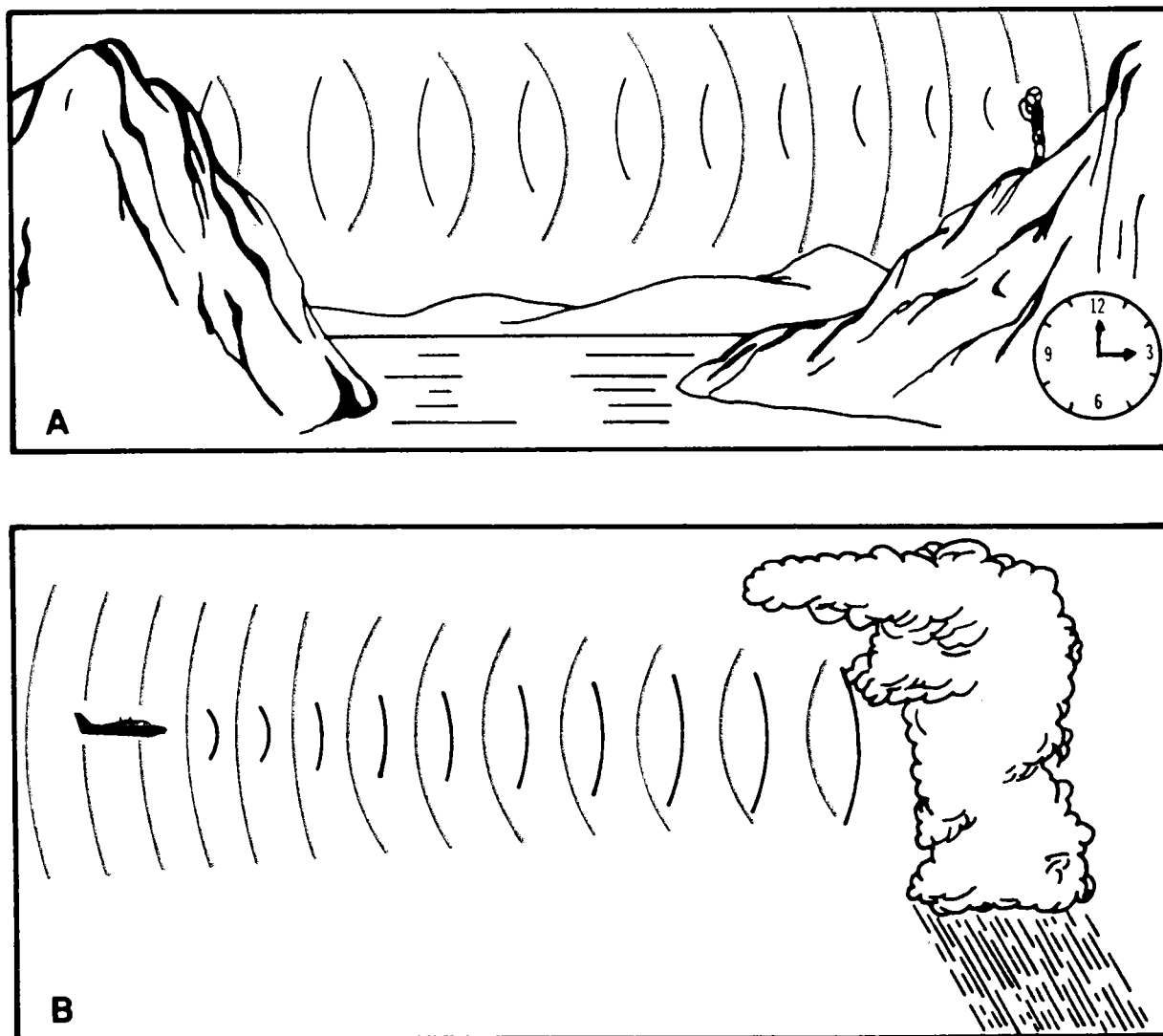


Figure 13-1. Echo principle.

b. A simplified radar set is shown in figure 13-2, and consists of a timer or synchronizer, transmitter, transmit/receive switch, receiver, and indicator. It illustrates, in very general terms, the operation of the various components of a radar set.

(1) **Timer or synchronizer.** This component is the stopwatch of a radar set. It determines the pulse repetition frequency (PRF) of the set and synchronizes the indicator with the pulse transmission such that energy returns are accurately displayed. In this set, the PRF is 400 hertz (Hz). The transmitter and receiver are turned on and off 400 times per second. The transmitter transmits for only 2 microseconds while the receiver is activated for 2,500 microseconds—awaiting the return of the reflected energy. These transmission and reception times affect the range and resolution capabilities of the set.

(2) **Transmitter.** This component is controlled by the timer and generates the high frequency—high-power electromagnetic energy used in the detection

process. Depending upon the requirements of a particular set, the generated pulse of energy may exceed 10,000 watts of power. The transmitted energy is in the microwave spectrum with the actual band (frequency) being determined by a combination of factors such as—

- Power requirements.
- Associated antenna size.
- Target penetration ability.
- Ability to isolate closely spaced targets (resolution).

Listed below are various radar bands with their associated frequency, wavelength, and general use:

- L-band radar has an approximate frequency of 1,300 megahertz (MHz) and a wavelength of 23 centimeters. Its excellent penetrating ability makes it ideal for the detection of aircraft through rain. However, this characteristic, together with its low resolution, makes it unsuitable for weather radar.

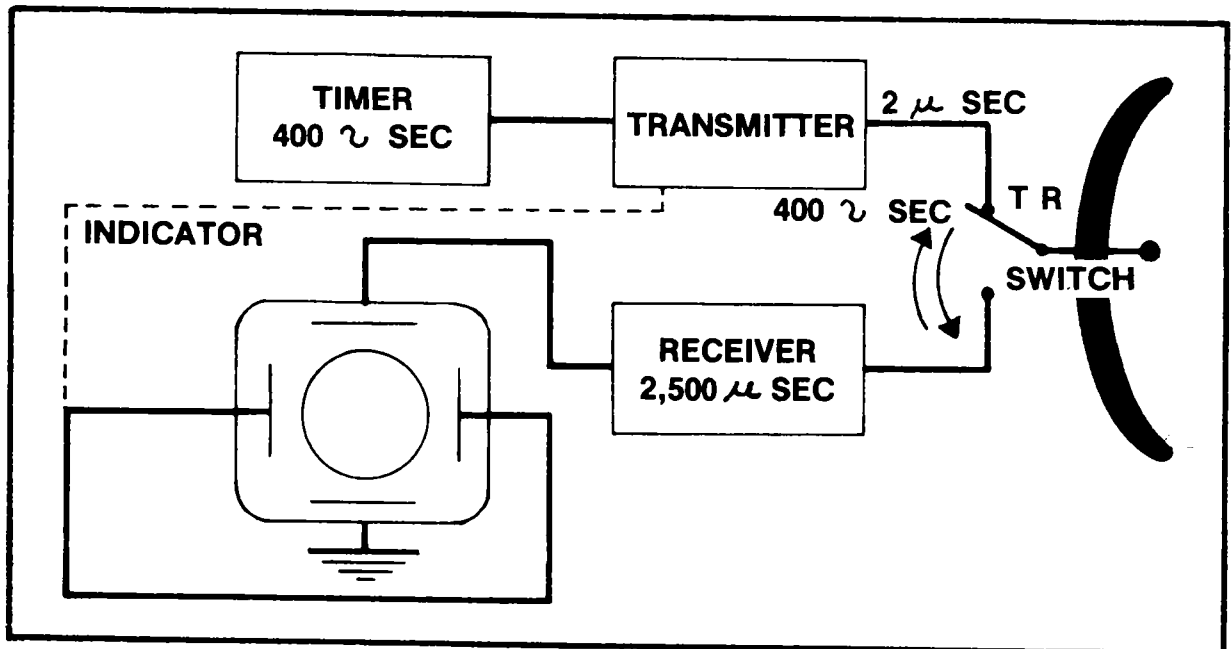


Figure 13-2. Simplified weather radar system.

- S-band radar has an approximate frequency of 3,000 MHz and a wavelength of 10 centimeters. This weather radar has good penetrating capability and is used by the National Weather Service ground radar, but it requires a 12- to 30-foot antenna to obtain acceptable resolution.

- C-band radar has an approximate frequency of 5,500 MHz and a wavelength of 5.5 centimeters. It has good penetration ability, and acceptable resolution can be achieved with a 25-inch, or larger, antenna. This band is sometimes used on radars in large aircraft.

- X-band radar has an approximate frequency of 10,000 MHz and a wavelength of 3.2 centimeters. It has acceptable penetration and provides good resolution when used with a 10-inch, or larger, antenna and requires relatively lower power. The X-band radar is used for airborne weather radars in Army aircraft.

- K-band radar has an approximate frequency of 167,000 MHz and a wavelength of 1.8 centimeters. This band is not suitable for airborne weather radar because

its wavelength is too short for acceptable penetration. Its superior resolution makes it ideal for the detection of aircraft and vehicular movement on an airport surface.

(3) **Transmit/receive (TR) switch.**

This component allows the set to use a single antenna for both transmission and reception. During the time of transmission, the receiver is electronically isolated from the antenna, thus preventing damage to the set. After transmission has ended, the receiver is activated and the transmitter is isolated to prevent leakage of the received energy.

(4) **Antenna.**

- This component directs the energy from the transmitter toward a reflecting surface (target) and receives the reflected energy (echo) and passes it to the receiver. Antennas in most Army aircraft employ a 120-degree sector scan, have an up-and-down tilt capability of 15 degrees, and are gyro-stabilized in respect to pitch and bank.

- The usable energy radiated from the antenna has a cone-shaped pattern (fig 13-3) much like that of a flashlight. The

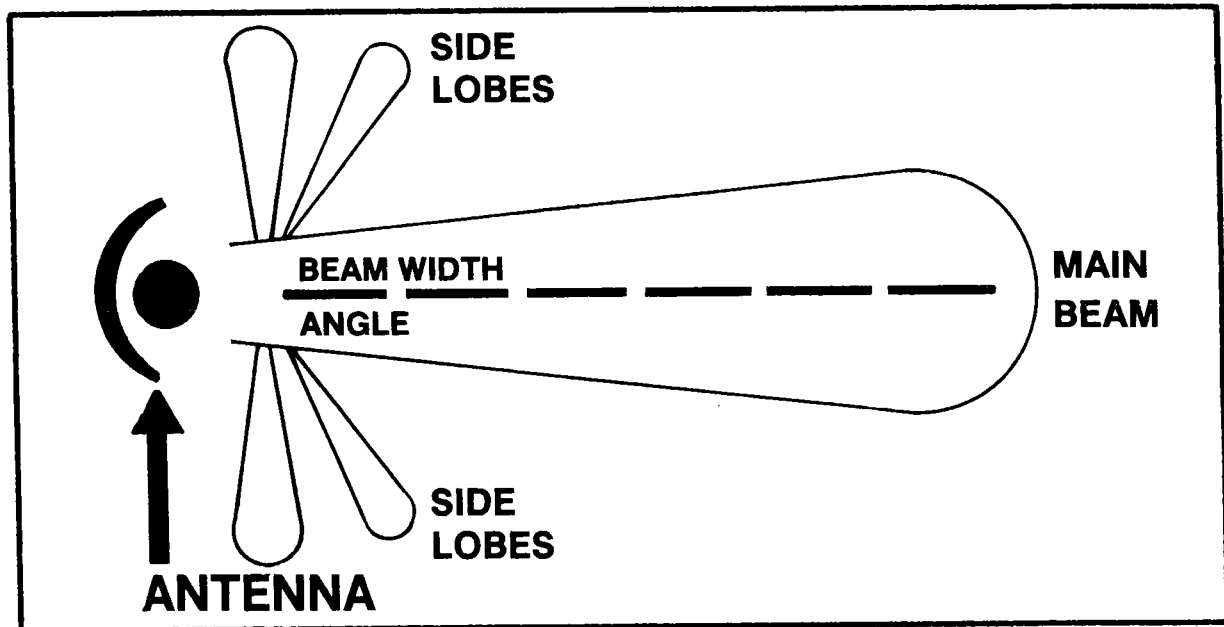


Figure 13-3. Radar energy beam.

angle formed by the cone is known as the **beam width**. For a given band, it is primarily controlled by the size of the antenna. For a close approximation of X-band radars, a 12-inch antenna will produce an 8-degree beam, while an 18-inch antenna will produce a 5-degree beam. Therefore, when the antenna is larger, the beam will be more narrow and the energy more concentrated.

- Some older type radars use a parabolic antenna as shown in figure 13-4A. This type antenna produces side lobes of energy in addition to the main conical lobe (fig 13-4B). Some of these side lobes will be directed toward the surface of the earth. Their echoes will produce a clutter on the indicator known as an altitude ring. The size of this ring is controlled by the height of the aircraft (fig 13-5). Later developed radars employ a flat plate array antenna (fig 13-6A), which produces fewer and smaller side lobes.

As a result, more energy is concentrated in the main lobe (fig 13-6B). Altitude rings will not be present when this type antenna is used.

- The antenna tilt control will move the center of the beam up or down 15 degrees. Operational tilt adjustments should be made slowly because it does not take many degrees of tilt to move the beam a considerable distance. For example, moving the antenna tilt 1 degree will shift the beam centerline 6,367 feet at a range of 60 nautical miles from the set (fig 13-7).

(5) **Receiver**. This component receives the weak echoes of reflected radio frequency (RF) energy from the antenna, amplifies them, and transforms them to video signals which are fed to the indicator for presentation. Some special features of radar receivers are also discussed.

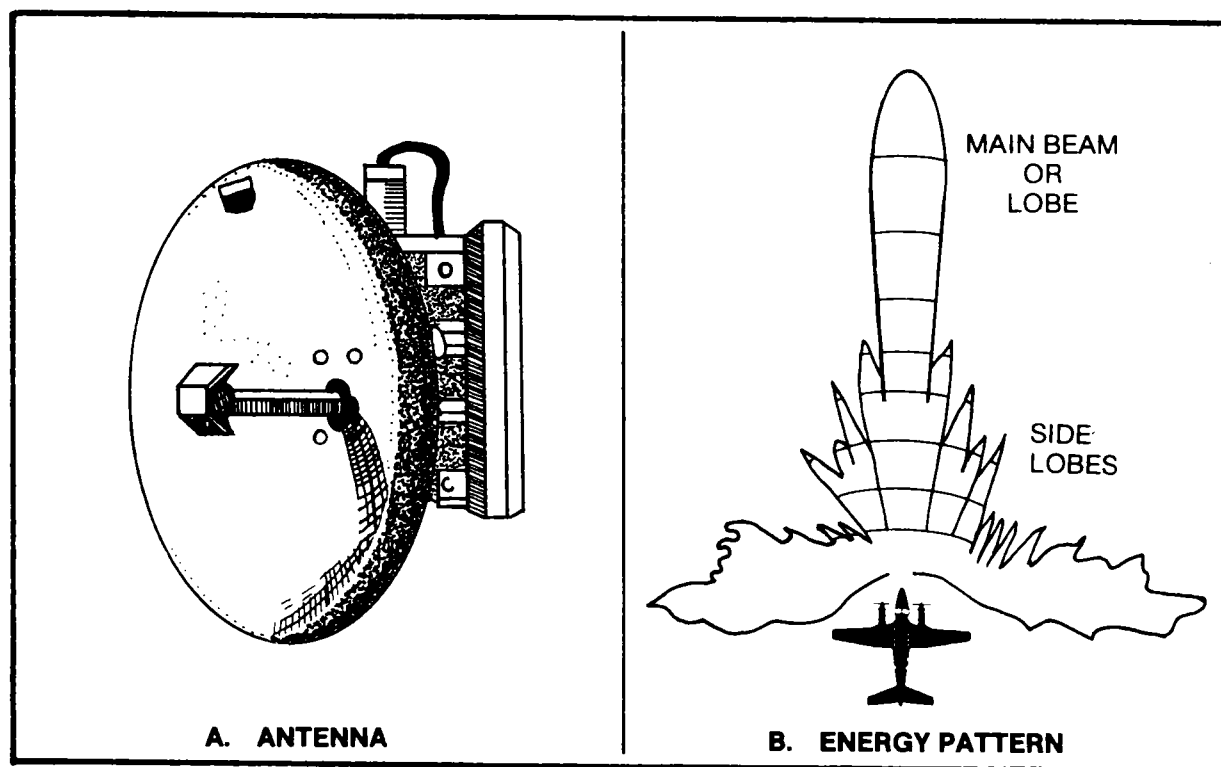


Figure 13-4. Parabolic antenna and typical energy pattern.

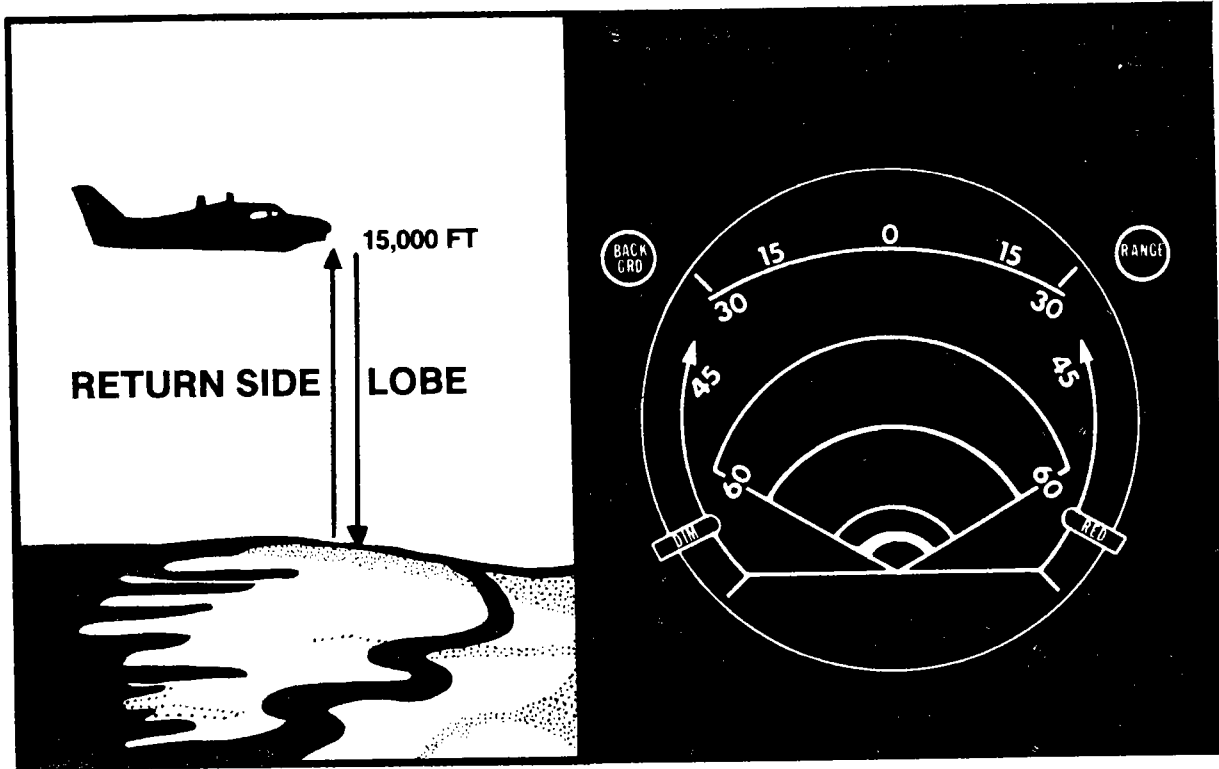


Figure 13-5. Side lobes and altitude ring.

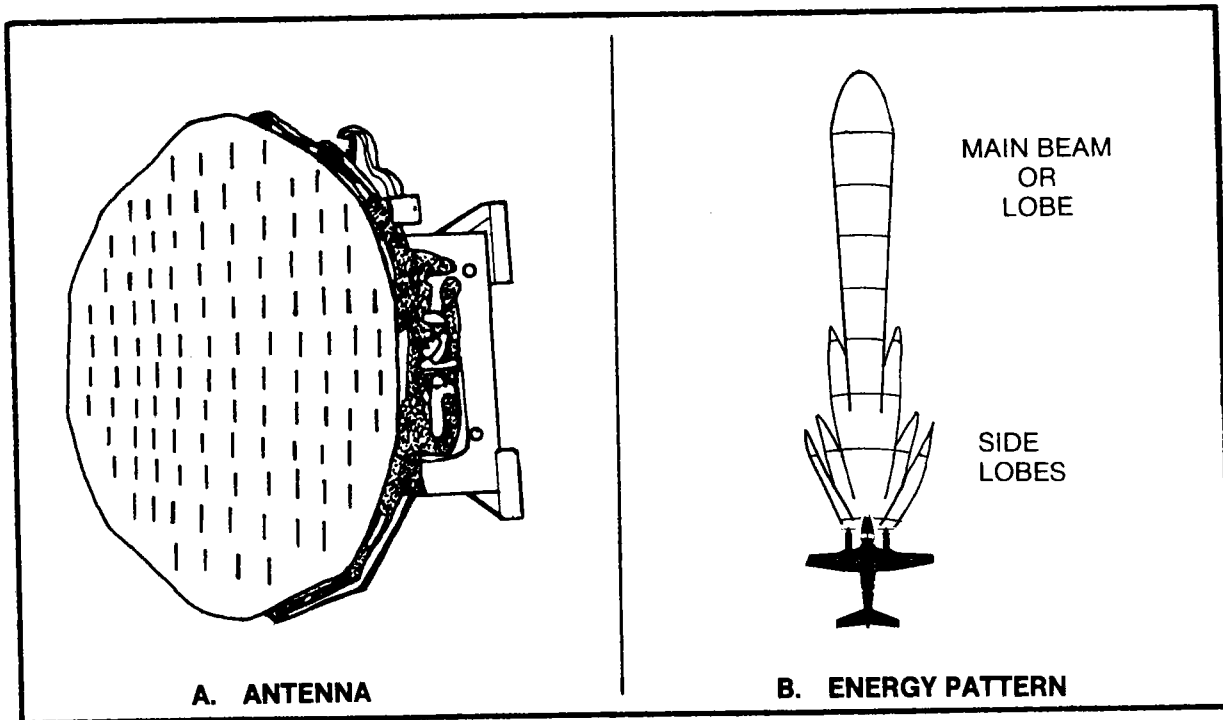


Figure 13-6. Flat plate array antenna and typical energy pattern.

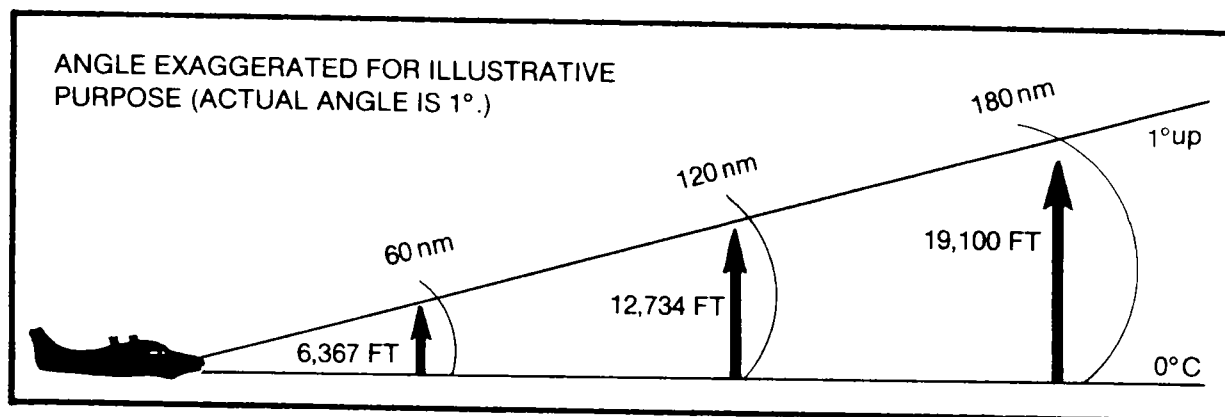


Figure 13-7. Antenna tilt beam shift (feet per degree) versus distance.

- **Gain control.** Initially all radar receivers incorporated a variable RF gain control. This varies the amplitude of video signals much like the volume control on a radio set varies the amplitude of audio signals. The practice of using different gain settings for varying weather situations, however, left the operator no basis for comparing the indicator displays from situation to situation. To correct this weakness, most sets now use a fixed gain when operating in the weather mapping mode. When using sets that have a variable-gain control, it is recommended that the control be positioned to full gain (in most sets, full clockwise) during all weather mapping operations.

- **Sensitivity time control (STC) circuit.** The echo returns from close weather targets will be much stronger than those from more distant targets and will produce a brighter and larger display on the indicator. Thus, as an aircraft approaches a weather target, it will appear to grow in intensity and size. This could be misleading to a pilot trying to analyze the display for weather avoidance purposes. To prevent this, most sets incorporate an STC circuit which automatically activates when the weather target gets within a predetermined distance of the set. This distance varies with different sets, but is usually within 20 to 40 nautical miles of the set. Its function is to reduce the sensitivity of the receiver so as to compensate for increasing echo strength due to the decreasing distance. If a weather echo becomes more intense or grows in size on the indicator,

within the STC range, it is doing so because the weather target is intensifying or growing and not because the target is getting closer to the set.

- **Contour circuit.** To be able to correctly analyze a displayed weather target, the operator must be able to determine the intensity of the echo. This was accomplished in early weather radars by varying the gain control and observing the decay or build of the display. This method, at best, was very subjective. It required a highly skilled operator to obtain acceptable results. To correct for this deficiency, some radar sets have incorporated a circuit whereby an incoming signal above a certain prescribed value is eliminated from the display. This results in a "hole" appearing in the area of greatest return (fig 13-8). This feature is called a **contour circuit** and is activated by a control switch generally marked "CTR" or "CONT" as opposed to "NORMAL" or "NOR" for noncontoured operation. Most radars used in Army aircraft will contour echoes from targets with a rainfall rate of 12 millimeters (mm) per hour or greater. A detailed discussion on the use of this feature is found later in this chapter.

(6) **Indicator.** This component converts the video signals produced by the receiver to visual images on a cathode ray tube (CRT). A scan line that sweeps back and forth across the screen of the CRT paints the target echoes as it moves. The scan is synchronized to the antenna sweep so that echoes

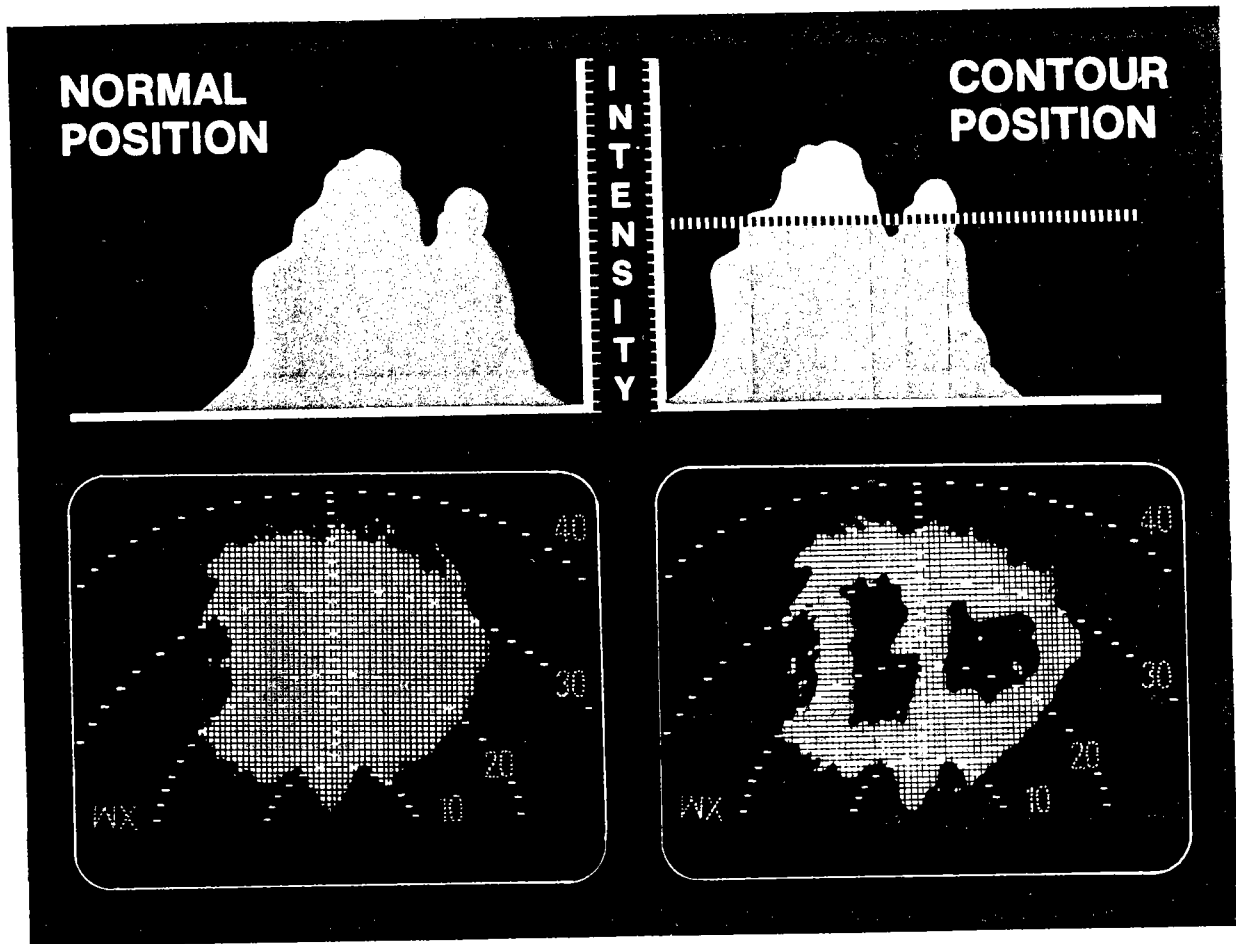


Figure 13-8. Contour circuit.

detected by the antenna in a certain position are displayed in the same relative position. Internally generated range marks and azimuth lines allow the operator to locate weather targets according to distance from the aircraft and direction relative to the nose (fig 13-9). Most sets incorporate three or more range selections with varying distances between range marks. Depending upon the type radar installed, the aviator may find one of three different types of displays. Each type is briefly discussed below.

• *Display storage tube (DST).*

This is the type display which was used by first-generation weather radars. The inside of the tube is coated with a phosphor which glows (and has a slow decay) when struck by a stream of fast-moving electrons (fig 13-9).

Advantages of the DST include—

- The brightness of the display being proportional to the intensity of the echo.
- Ground clutter is easily distinguished from weather echoes.
- The visual displays are fairly true representations of actual targets.

Disadvantages of the DST include—

- The fading of the display after sweep passage.
- Its low visibility in a high light environment.
- Its inability to accept and project alphanumeric features onto the screen.



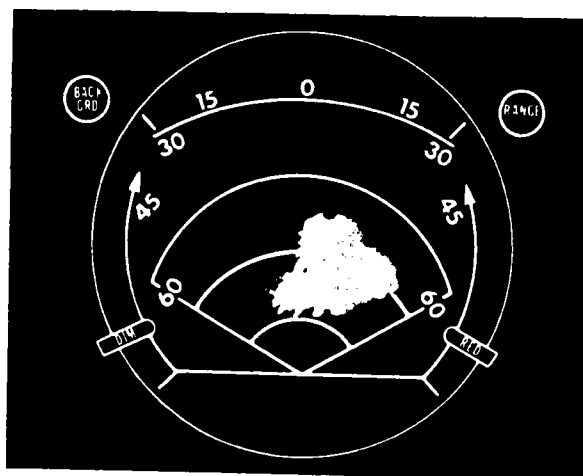


Figure 13-9. Display storage tube (DST) indicator.

• **Monochromatic digital display.** This system employs a TV tube and a digital computer. The screen raster (frame) is formed by an electron gun, which scans the screen from left to right starting at the upper left portion of the screen. The scanning continues downward until all lines of the frame have been completed. The electron gun(s) is turned on (off) at any instant in the scan to produce a video display. Depending upon the type radar set, there may be as many as 256 lines per frame. The frames are repeated approximately 50 times per second, which produces a continuous visual display of information. The video display is controlled by the data stored in memory. Using a 256-line screen, there are 256 single items (bits) of data in memory for each line of the screen, resulting in a total of 256 x 256 or 65,536 bits that can be displayed (fig 13-10). Video information from the receiver is processed and stored in the appropriate memory bit. This allows the total weather display to be stored continuously in memory. The data stored in memory is changed at update time only if the data from the radar receiver is different. As the screen is scanned, the memory is addressed at each point on each line. The data stored at the address is applied to circuits which turns the electron gun on or off. Memory bits not used for weather returns can be programed to project any desired alphanumeric presentation. Most sets will have dual memory banks with identical bits in

each memory; one storing the most significant data and one the least significant data. When addressed during the scan, the two bits will form a data word controlling the intensity of the displayed video from light to medium to high. The following video intensities are representative of weather targets with different rainfall rates.

RAINFALL RATE	SCREEN INTENSITY
1 mm/hr or less	no indication
1-4 mm/hr	light intensity
4-12 mm/hr	medium intensity
12 mm/hr or more	high intensity

Some advantages of this type display include—

- A constant display of information.
- Good visibility in a high light environment.
- The ability to accept and project alphanumeric presentations such as range setting, distance between range marks, movable cursors, etc.

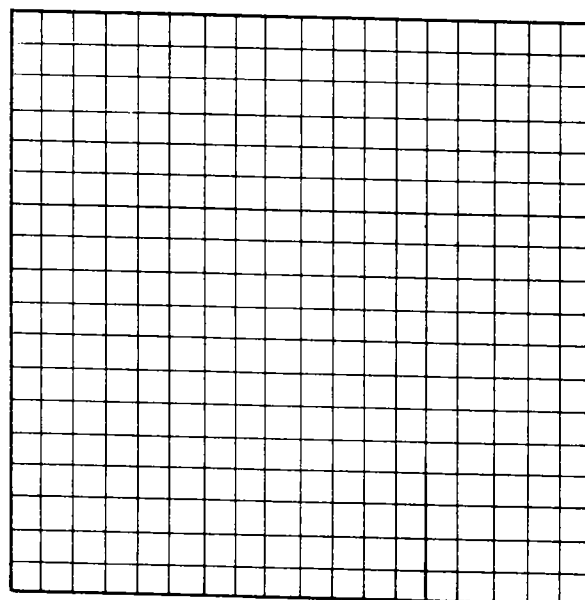


Figure 13-10. Digitized radar matrix (frame).

Some disadvantages include—

- A sawtooth appearance of echoes (fig 13-11).
- Difficulty in distinguishing between ground clutter and weather echoes.
- A limited number of echo intensity levels that can be displayed.

As the number of memory bits is increased, the sawtooth appearance of echoes becomes less noticeable (e.g., a 256 x 256 bit presentation would have much less sawtooth distortion than a 178 x 178 bit presentation). Figure 13-12 depicts a monochromatic digital display screen with typical thunderstorm echoes.

• **Color-enhanced digital display.** Except for color, this display is almost identical to the monochromatic digital display using dual memory banks. When addressed during the scan, the data bits from the two memories will form a data word that turns the appropriate color guns on or off. The following color presentations are used by the AN/APN-215(V) to denote weather targets with different rainfall rates.

RAINFALL RATE	SCREEN INDICATION
1 mm/hr or less	dark
1-4 mm/hr	green
4-12 mm/hr	yellow
12 mm/hr or more	red

The advantages and disadvantages of this type display are the same as those for the monochromatic digital display except for the added ease of identifying different rainfall levels due to color contrast. Figure 13-13 depicts a color-enhanced set with typical thunderstorm echoes.

13-10

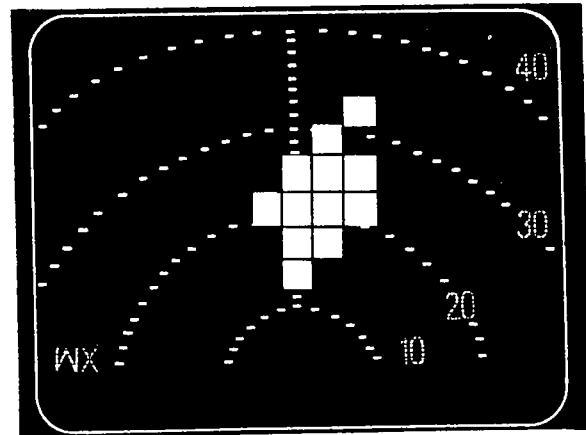


Figure 13-11. Exaggerated sawtooth or checkerboard display on digitized indicator.

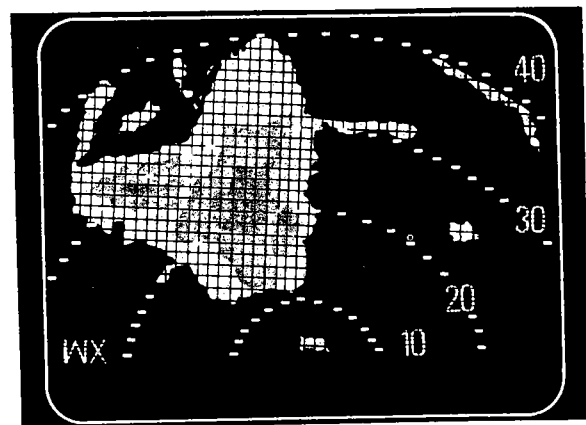


Figure 13-12. Monochromatic digital display screen.

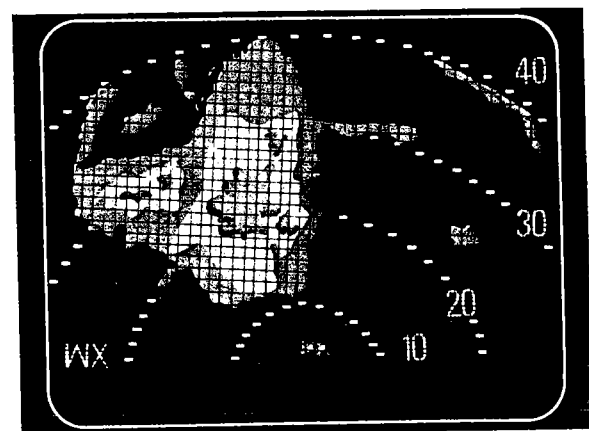


Figure 13-13. Color-enhanced radar screen.

## 13-4. RADAR TARGETS

*a. General.* A radar target is any mass that will reflect or re-radiate the electromagnetic energy emitted by the radar antenna. In this chapter, radar targets are referred to as either *weather targets* or *ground targets*.

### *b. Weather Targets.*

(1) *Rain.* Raindrops produce excellent radar returns. The intensity of the return is determined primarily by the rain density (number of drops per unit volume) and the size of the drops, with the latter being much more decisive. For example, if the drop size was kept constant and the density doubled, the return would be twice as intense. If the rain density was kept constant, however, and the diameter of the raindrops doubled, the intensity of the return would increase by two to the sixth power ( $2 \times 2 \times 2 \times 2 \times 2 \times 2 = 64$  times). This is the reason thunderstorms with large raindrops produce such vivid weather echoes on the screen.

(2) *Hail.* Wet hail (hail coated with liquid water) produces strong returns; dry hail produces a much less intense return.

(3) *Snow.* Wet snow produces some returns which can be identified by a sandy or grainy appearance on the CRT. Dry snow is generally not detectable.

(4) *Clouds.* Because of the small size of cloud particles (1 million or more to a drop of rain), they cannot be detected by X-band radar.

### NOTE

**Weather radar detects rain—not clouds.**

*c. Ground Targets.* The following type surfaces/objects produce strong radar returns:

- (1) Mountains.
- (2) Metal bridges.

(3) Metal or reinforced concrete buildings.

(4) Uneven terrain.

(5) Rough water—smooth water produces a shadow on the indicator.

## 13-5. LIMITATIONS OF AIRBORNE WEATHER RADAR

*a. Beam-Width Distortion.* This limitation makes strong targets appear larger laterally on the screen than they actually are. In figure 13-14, a 6-degree beam is rotating clockwise. The leading edge at position A moves to position A<sub>1</sub>. A strong target is in the path of the beam. As the leading edge of the beam just hits the target, the radar will indicate as if the target were in the center of the beam. This elongates the echo as shown by the hatched area in figure 13-10. The echo will continue to appear on the screen until the trailing edge of the beam (position B<sub>1</sub>) leaves the target. The echo will then be elongated on its other side as indicated by the hatched area. **The result will appear on the display as an arc-shaped echo. Terrain is a strong target, so terrain will show as arc-shaped echoes with the arc paralleling the range marks.** This knowledge will greatly aid the operator in distinguishing between weather echoes and ground clutter. This same distortion will occur with strong thunderstorms, but generally is less noticeable.

*b. Pulse-Length Distortion.* Regardless of the length of time a pulse of energy is transmitted, each pulse will have a finite length determined by the speed of light and the duration of the pulse. In figure 13-15, a 2-microsecond pulse of energy is shown as being about 2,000 feet long. Normally, airborne weather radars generate pulses of 0.5 to 3.5 microseconds duration. This means that the length of the energy train will vary from 500 to 3,500 feet. The different pulses are used for different purposes, with longer pulses being used for long-distance detection and short pulses used for ground mapping. Radars with long pulse lengths have less

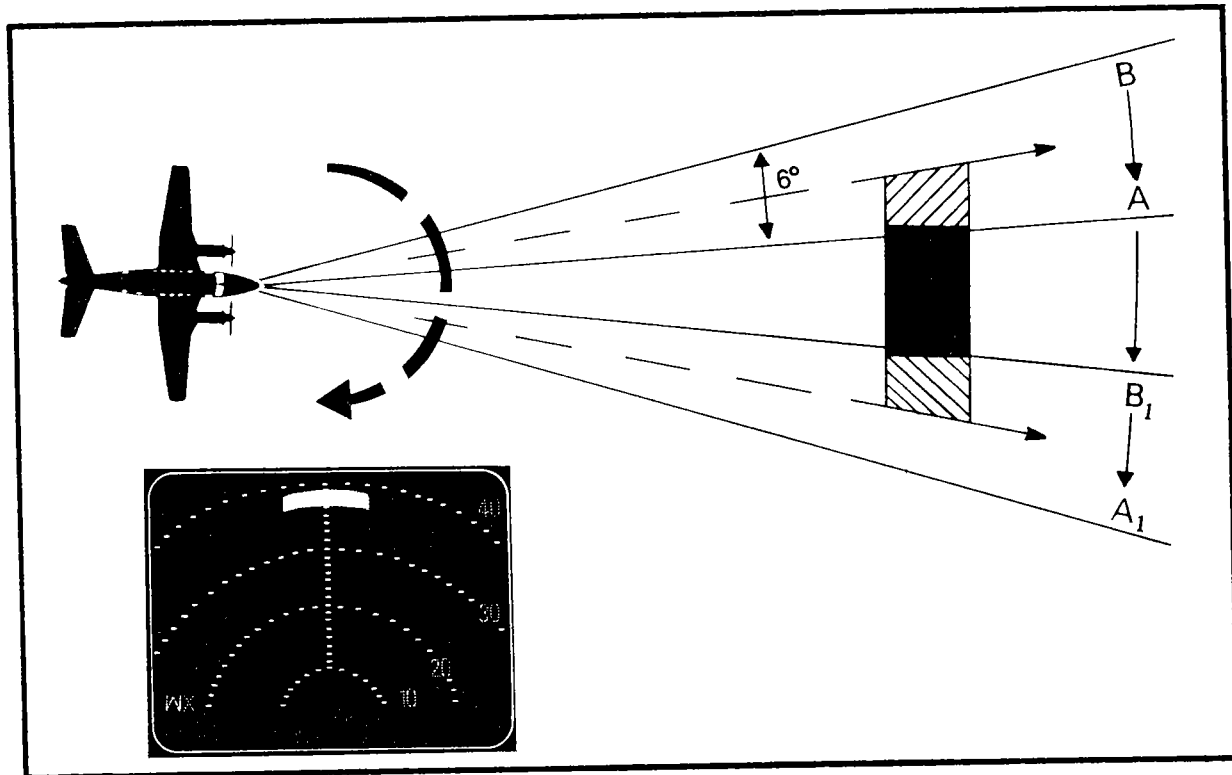


Figure 13-14. Beam-width distortion.

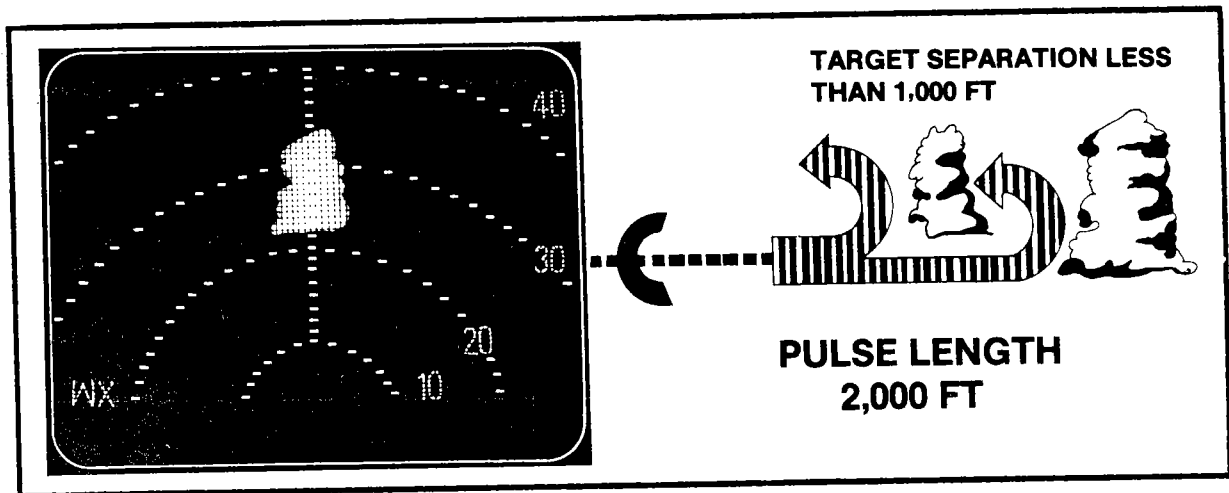


Figure 13-15. Pulse-length distortion.

resolution capabilities than those with short pulse lengths. For example, the 2,000-foot-long train of energy in figure 13-15 has a resolution of 1,000 feet. That is, it cannot resolve targets closer than 1,000 feet apart. The resolution distance is one half the pulse

length. Therefore, it makes the rear of a target appear farther away than it actually is by a distance equal to one half the length of the energy train. The echoes in figure 13-16 show the combined effects of beam-width and pulse-length distortions.

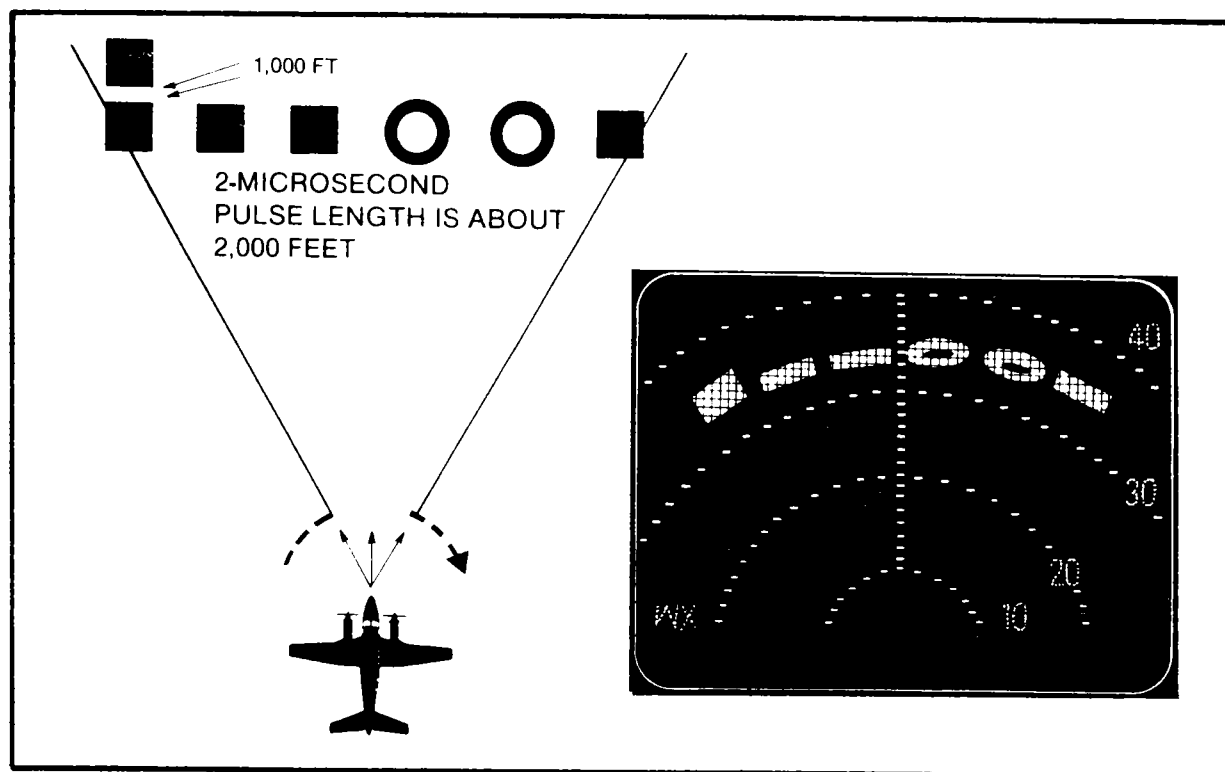


Figure 13-16. Combined effects of beam-width and pulse-length distortions.

**c. Interference From Other Radars.**

This type of interference is shown in figure 13-17. The small curved train of echoes is caused by energy trains of other radars operating in the same band. They are observed more frequently on DST displays than on digital displays.

**d. Attenuation.** Attenuation, or loss of electromagnetic energy, must be considered when interpreting radar displays. The energy, in dry air, attenuates according to the square of the distance traveled. Because energy must reach a target and then return to the antenna, the total attenuation is a function of the square of twice the distance to the target. The sketch in figure 13-18A shows two identical thunderstorms with one seven times more distant from the antenna than the other. The energy attenuation during the round trip to the storm at 140 nautical miles would be  $7^2$  ( $7 \times 7$ ) or 49 times greater than the attenuation during the round trip to the storm at 20 nautical miles. An approximation of the size of the two echo sizes is shown in the depicted display. It should be noted that this distortion would not exist within the

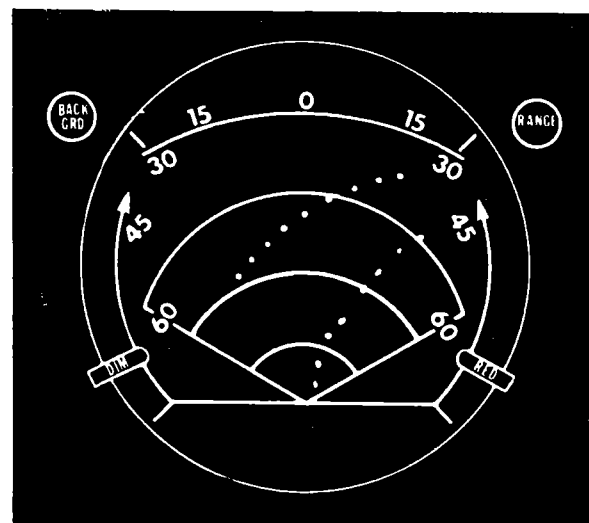


Figure 13-17. Interference from other radars.

range of the STC circuit as explained in paragraph 13-3b(5). The effects of attenuation in areas of precipitation is even more pronounced. The energy reflected or re-radiated by the precipitation greatly reduces the ability of the radar beam to detect what is

happening deep within or back of a cell. A pilot observing the radar screen in figure 13-18B would see a large area of heavy precipitation echoes with pronounced contour holes directly ahead of the aircraft. The echoes are about 10 nautical miles in depth with smaller echoes on the left and right back of the display. This could have been the actual situation. In this case, however, the energy was attenuated by the first area of precipitation which left the even larger back area undetected. Figure 13-18C depicts a large area of heavy precipitation from nimbostratus clouds with a thunderstorm embedded in the rear of the area. The thunderstorm, in this instance, did not contour out because of heavy attenuation in the front portion of the storm. *As has been noted, weather radar will not always portray the actual weather situation. The aviator must supplement the displayed information with his knowledge of the overall weather picture.*

**NOTE**

Always assume that radar is not showing the full extent of precipitation even if the display appears to paint the back side of a cell.

**13-6. CONTROLS**

a. **General.** All airborne weather radars will have some or all of the following controls. This is not intended to be a complete list. The aviator should consult the operator's manual for the particular set installed in his aircraft. Each of the following controls will be discussed briefly:

- (1) ON/OFF.
- (2) Range Setting.
- (3) Range-Mark Brightness.
- (4) Intensity or Brightness.
- (5) Gain Control.
- (6) Normal/Contour.
- (7) Background.
- (8) Antenna Tilt.
- (9) Hold/Freeze.

b. **"ON/OFF"**. As the name implies, this control turns the set on and off. Many sets have a standby position incorporated in this

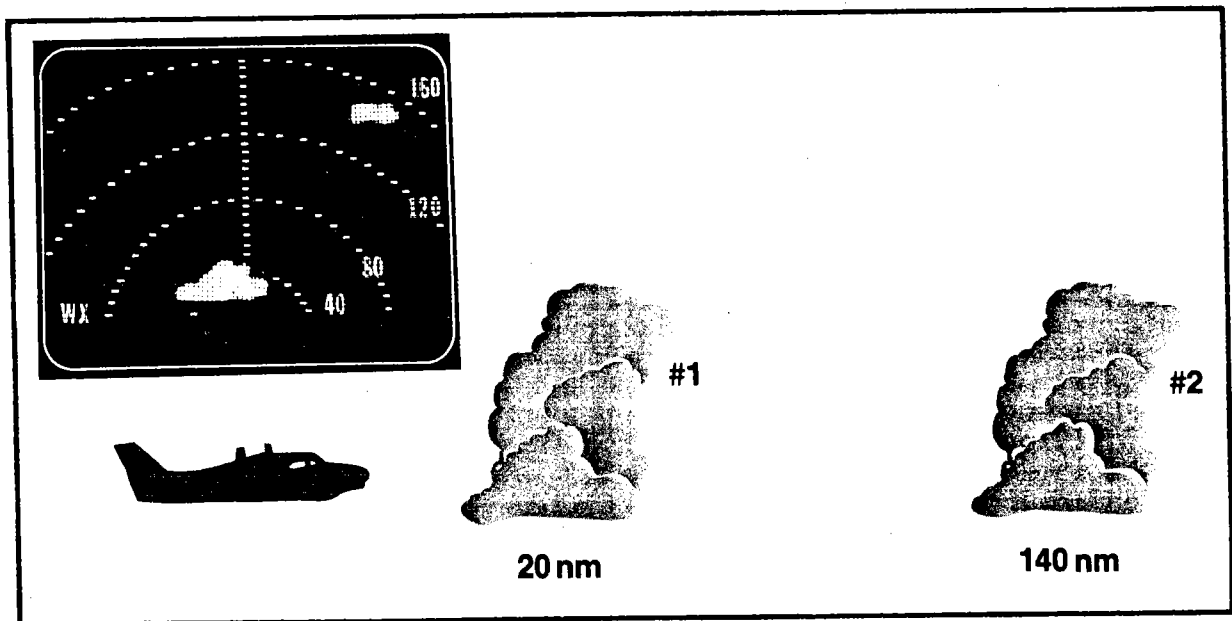


Figure 13-18A. Effects of attenuation.

switch. In "standby," warm-up power is applied to the set, but the transmitter and receiver are not activated. If the operator fails to allow the set to warm up the required amount of time (approximately 4 minutes) before going to the operate position, a safety relay will delay operation until the warm-up is completed.

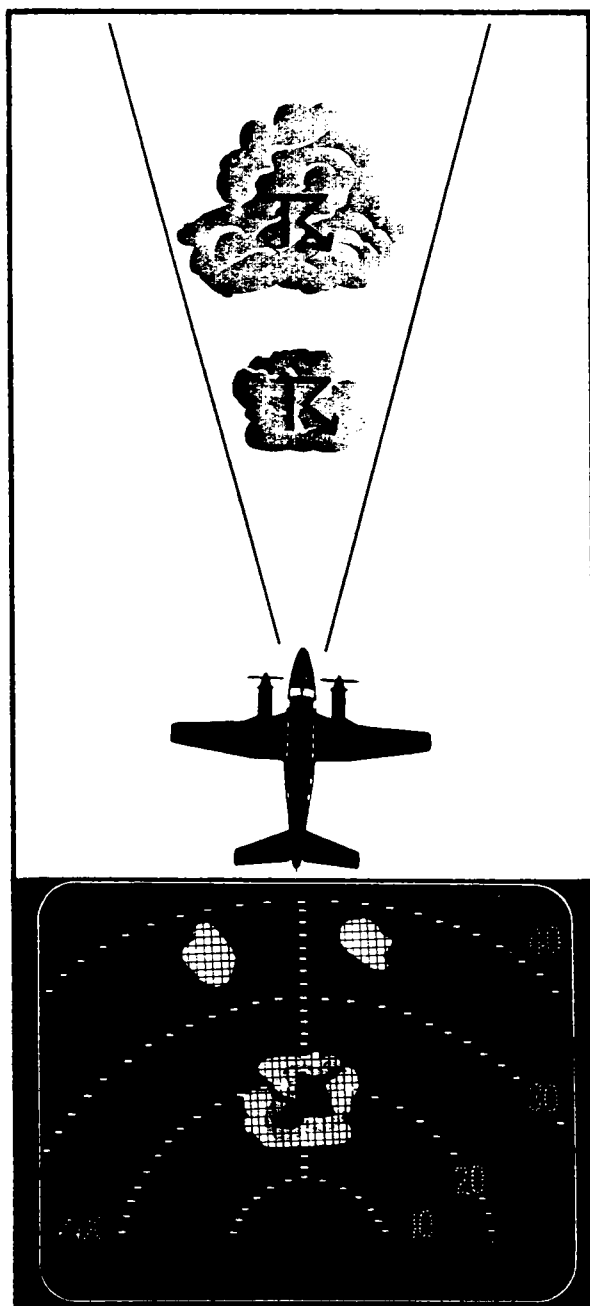


Figure 13-18B. Effects of attenuation.

c. **Range Setting.** This allows the operator to select an appropriate range for his immediate needs. Normally, long-range settings are used for exploratory views of distant weather, medium ranges for continuous operation, and short ranges for close viewing and aircraft maneuvering.

**CAUTION**

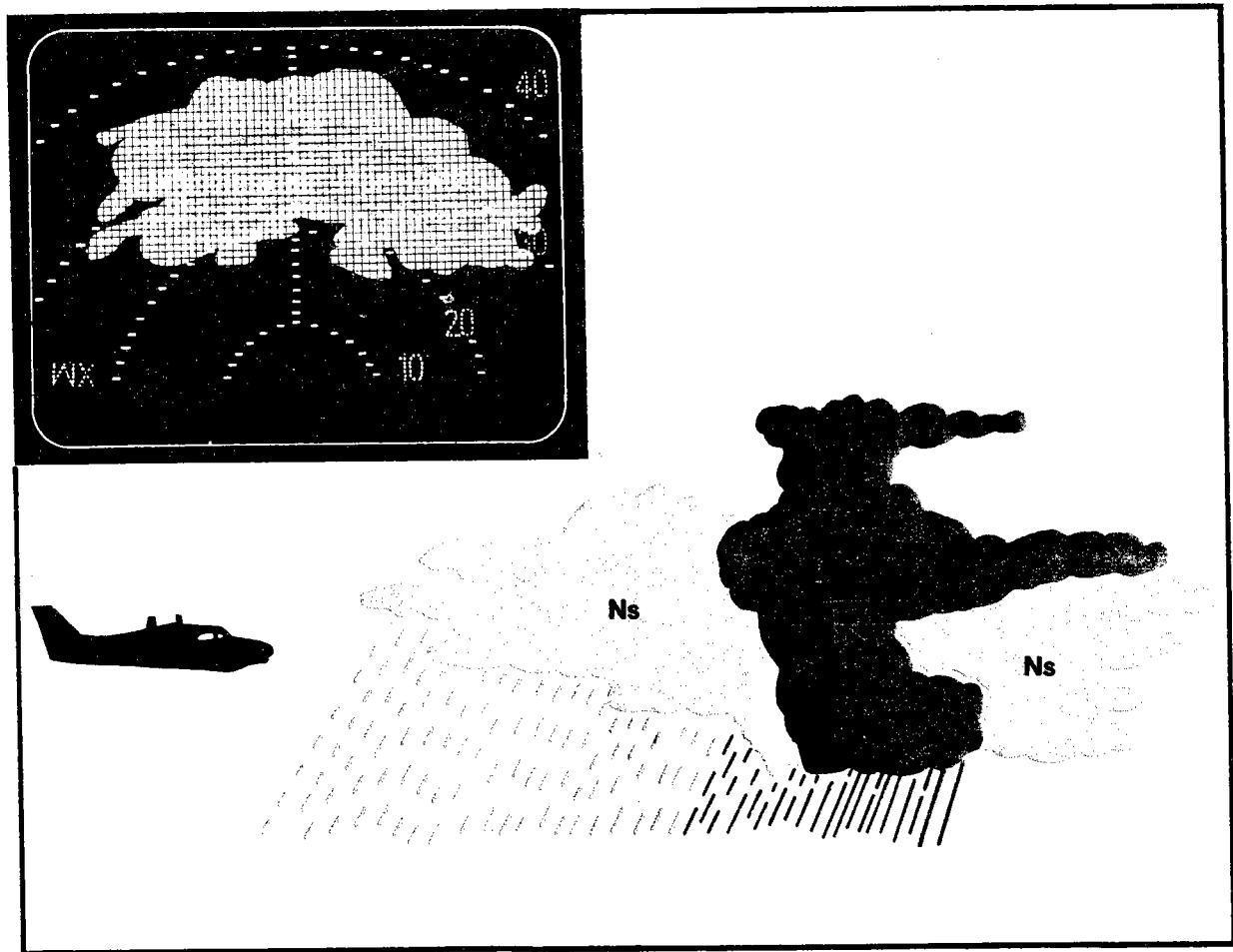
Do not continuously leave the radar in its short-range setting. You may fly into a blind weather alley.

d. **Range-Mark Brightness.** This control should be adjusted so that the range marks are comfortably visible. Too bright a display may obscure small, faint echoes.

e. **Intensity of Brightness.** This control changes the intensity of the electron beam. On nondigitized screens, too high a setting will cause the screen to "bloom," becoming almost unreadable. On digitized screens, too high a setting can cause the presentations to become overly bright and disrupt intensity level indications of the screen.

f. **Gain Control.** This controls the receiver sensitivity. *It is probably the most important control on the set,* if the set is so equipped. Most of the newer radars have a preset detented gain control position for weather use. If so, it should ALWAYS be used when weather mapping. Any other setting can give erroneous weather information. The gain control, on sets which do not have a special weather setting, should be turned to the maximum position during weather mapping operations. On some sets, the gain is internally preset and has no usable pilot gain control.

g. **Normal/Contour.** As discussed earlier, when a radar set is operating in the contour mode, the electron gun is cut off at preset incoming energy levels. This produces a "hole" in the display indicating the areas of heaviest precipitation. Generally, the radar set is operated in the normal mode with frequent checks made in the contour mode. Some sets will contour only when a button is pushed and others alternate between contour



**Figure 13-18C. Effects of attenuation.**

and normal. On sets having color-enhanced displays, echoes displayed in red approximate the contour "holes" of monochromatic displays.

*h. Background.* This control is found in some sets in lieu of a brightness control. It should be adjusted for the best display of echoes. On the same sets, this also controls the brightness of the range marks. The best setting normally is that point where the radar beam scan just becomes visible.

*i. Antenna Tilt.* This control moves the antenna up or down. The limits of tilt vary with different sets, but generally is 15 degrees. Some up-tilt (approximately one-half

the beam width) will generally be required at low altitudes to get rid of excessive ground clutter. Because of the earth's curvature, some down-tilt at high altitudes will be required to detect distant targets. The exact amount of tilt for these operations can only be determined by experience. When using the radar for weather avoidance at short ranges, the antenna tilt should be near zero in order to depict the weather directly ahead of the aircraft. Proper use of the tilt will also allow the aviator to approximate the vertical extent of the target. For example, if a small up-tilt or down-tilt will cause an echo to disappear, the target has small vertical extent; but if large amounts of tilt are required to erase the echo, the vertical extent is great.



**CAUTION**

When displaying the set in the freeze position, the aircraft will show the echo for 10 minutes after the set is placed in the freeze position. The radar will not show the echo for 60 seconds after the set is placed in the freeze position.

j. **Hold/Freeze.** When this control is activated, the screen display will remain constant until the control is deactivated. This allows the aviator to make a detailed examination of an unchanging display. Another use of this feature is to freeze the display for a few minutes, then switch back to normal operation and note the changes in position, size, and intensity of echoes.

**CAUTION**

Do not leave the set in the freeze position for any extended period of time. You may fly into "what is" while looking at "what was".

### 13-7. INTERPRETATION OF DISPLAYS

a. **General.** As stressed earlier, X-band radar can only detect precipitation. Therefore the radar screen depicts only areas of precipitation according to intensity. A knowledge of weather is required for the aviator to make inferences concerning these displays. For example, if a line of echoes is observed with pronounced contour holes (red displays on color-enhanced sets) (fig 13-19), the aviator interprets the display as a line of thunderstorms containing the flight hazards associated with thunderstorms. The following paragraphs will discuss some other inferences which can be made from differing type displays.

b. **Turbulence.** X-band radar cannot detect turbulence—it can only detect areas of precipitation according to intensity. Neither the area nor the intensity of rainfall alone is meaningful with regard to shear or turbulence. Research, however, has shown a definite correlation between turbulence and the variation of rainfall per unit distance

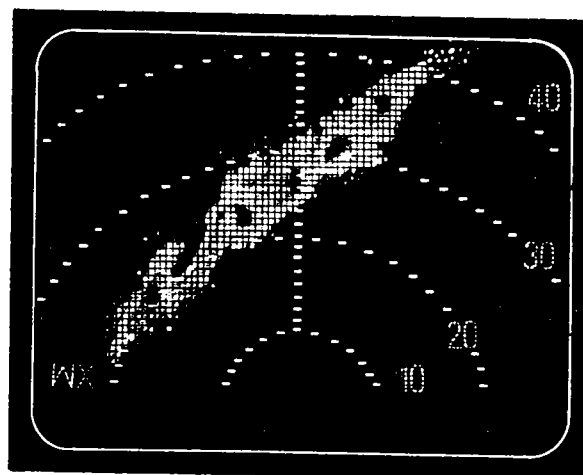


Figure 13-19. DST display showing a line of echoes with contour holes.

(rainfall gradient). A steep gradient is shown at figure 13-20A, where the rainfall changes from no rain to heavy rain in a very short distance. The changes in air drafts associated with the rain create a sharp wind shear which results in turbulence. Figure 13-20B depicts a condition when the change in rainfall is gradual over a long distance. This is representative of a shallow gradient, small shear, and little turbulence.

**NOTE**

The steeper the rainfall gradient—the greater the turbulence.

The black hole in monochromatic sets and the red display in color-enhanced sets allow the aviator to easily determine the rainfall gradient. The distance from the edge of an echo to the edge of the contour hole is called an *echo wall*. It is a visual indicator of the rain gradient—the thinner the wall, the steeper the gradient. *A rain gradient is considered steep when the distance from the edge of the echo to the edge of the contour hole (or red display) is 3 nautical miles or less.* It is from the rain gradient that turbulence is inferred. The thinner the wall—the greater the turbulence. With this in mind, the aviator might be tempted to leave the set in the contour position continuously. This, however, should be

avoided because an extremely sharp, intense echo might contour out completely, leaving no visible indication. Additionally, what may appear to be a contour hole could be an area of no precipitation. To recapitulate, moderate or greater turbulence is probable when a steep rain gradient is indicated on a weather echo. A steep rain gradient is depicted on the screen when distance from the edge of the echo to the edge of the contour is 3 nautical miles or less. Figure 13-21 depicts a DST screen, in contour mode, with echoes showing thin walls (steep gradient). Figure 13-22 depicts echoes with thick walls (shallow gradient).

c. **Hail.** The presence of hail has been associated with echo intensity, echo shapes, and echo changes. The echo shapes include narrow fingers (fig 13-23), U-shapes (fig 13-24), and scalloped edges (fig 13-25). Hail has also been associated with a sudden change in the shape or intensity of an echo; for example, a protrusion forming on a well-defined echo or a sudden increase in the intensity of an echo. Hail is not always found when these indicators are observed, but the aviator should always be aware of the possibility and thus avoid the area.

d. **Tornadoes.** Tornadoes have been associated with hooks as depicted in figure 13-26, and figure 6 type echoes as depicted in figure 13-27. Tornadoes have also occurred when no hooks, figure 6s, or any of the formations in subparagraph "c" were present. The aviator should remain aware that a tornado is a possibility in any thunderstorm.

**NOTE**  
**The thinner the contour wall—the steeper the gradient, and the more severe the turbulence.**

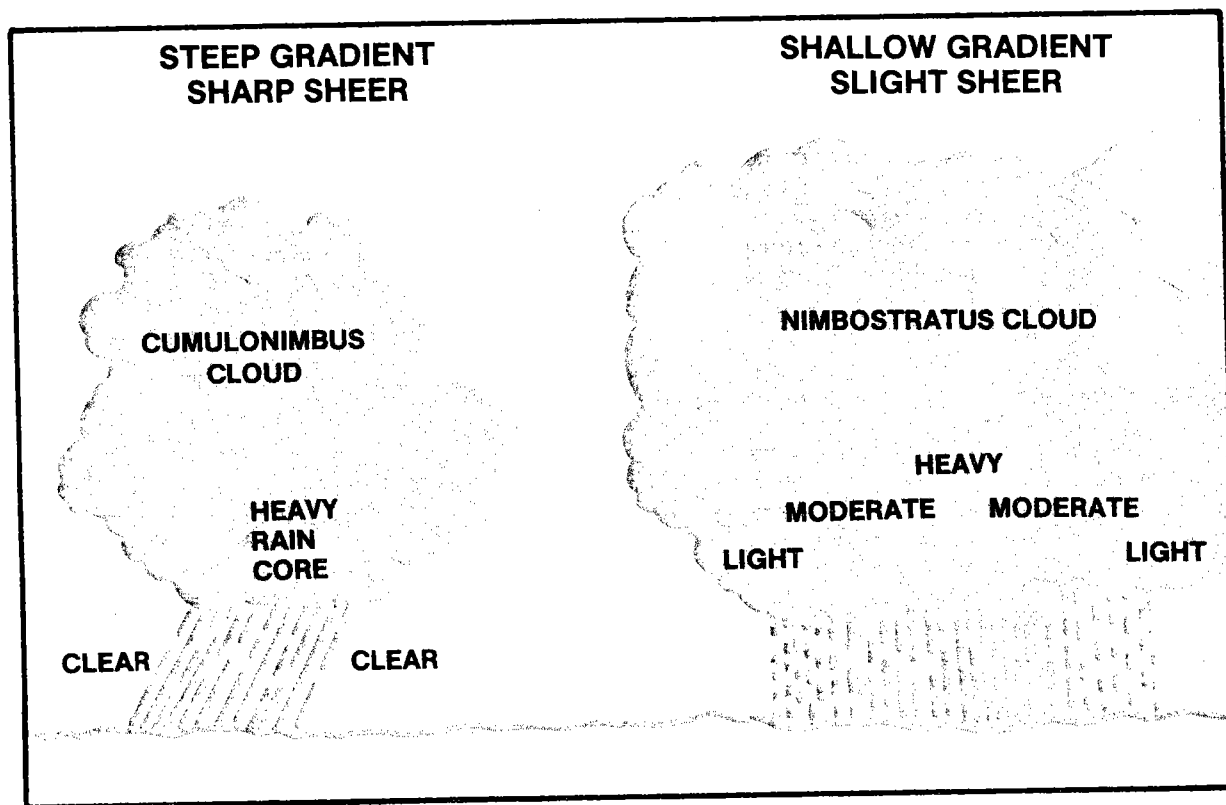
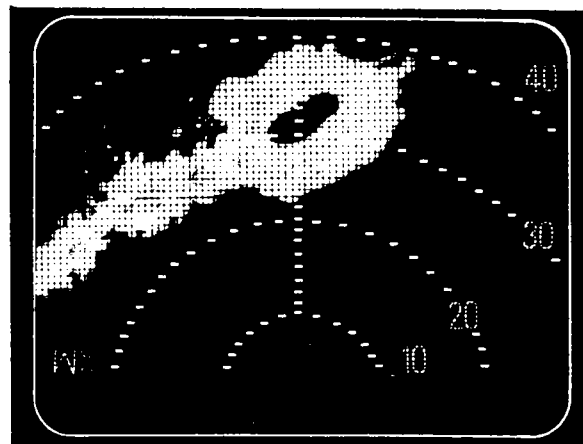


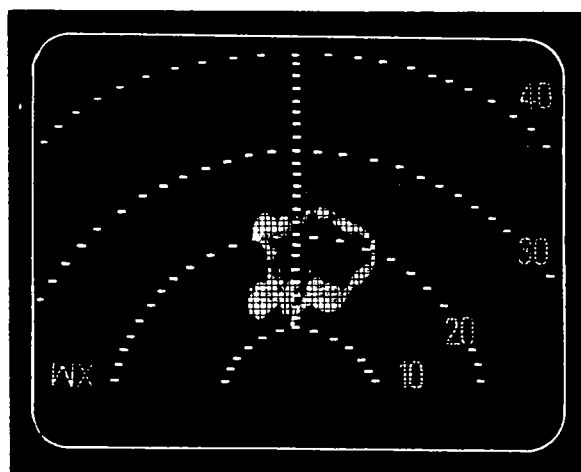
Figure 13-20. Rainfall gradient.

*e. Freezing Rain.* Supercooled rain or drizzle does not produce echoes significantly different from the same type precipitation at temperatures above freezing. Icing, however, can be anticipated when flying into precipitation at temperatures below 0°C. Cloud icing, in the absence of precipitation, cannot be detected by X-band radar.

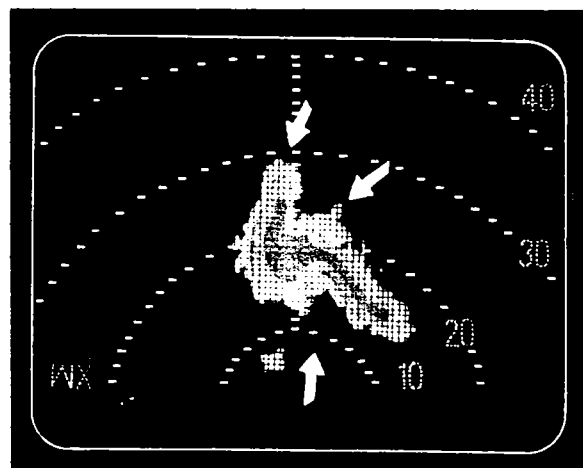
*f. Ground Clutter.* Sometimes it is necessary for ground clutter to be present when weather-mapping, for example, low-altitude operations over hilly terrain and at high altitudes when the antenna has been tilted down to search for distant weather targets.



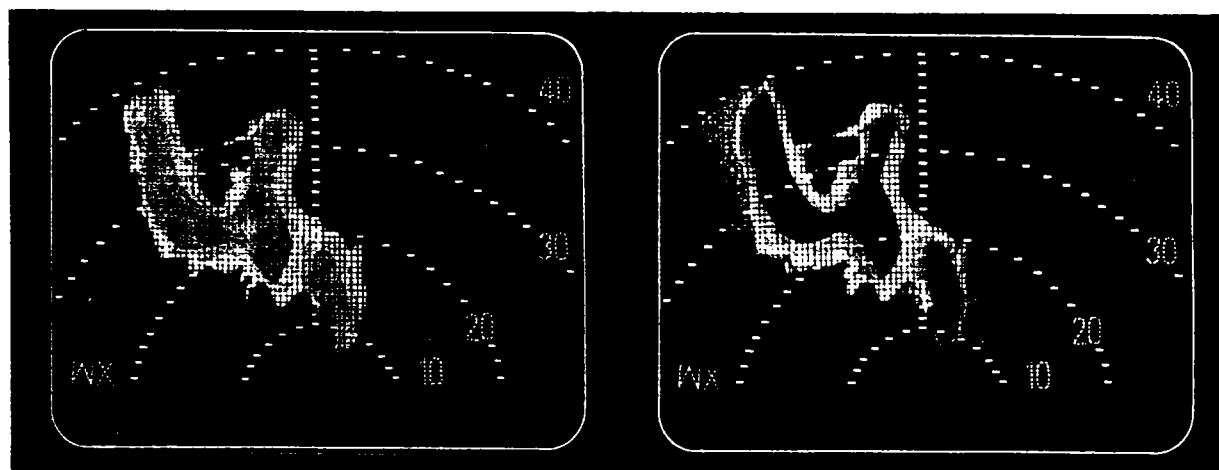
*Figure 13-22. Thick contour wall—shallow rainfall gradient.*



*Figure 13-21. Thin contour wall—steep rainfall gradient.*



*Figure 13-23. Finger echoes.*



*Figure 13-24. U-shaped echoes.*

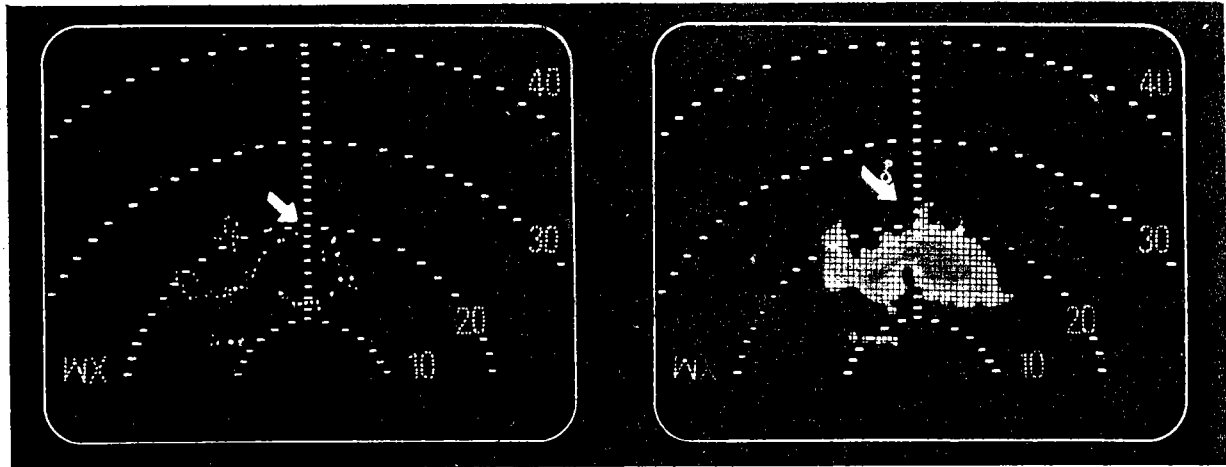


Figure 13-25. Scalloped-edged echoes.

In these cases, the operator must distinguish between ground clutter and weather echoes in order to obtain any valid weather information. Terrain normally gives a stronger radar return than precipitation, thus giving one cue for discrimination between the two. A second cue is the arc-shaped returns, parallel to the range marks, that are associated with terrain. A third cue could be obtained by slowly increasing the antenna tilt upward to see if the returns fade. Normally, ground returns would fade quicker than weather returns. The operator will often need to use all of the above cues for accurate identification. Figure 13-28 shows weather echoes, snow echoes, and ground clutter.

g. **Shadows.** Shadows, or areas of no radar returns, can provide significant information to an aviator if properly interpreted. Listed below are some probable implications of shadows.

(1) **Shadows behind intense weather echoes.** There is a strong possibility that other weather targets may be behind the displayed echoes with the radar energy having been attenuated by the nearer targets.

(2) **Shadows behind intense arcs of ground clutter.** The terrain is higher than the beam scan—possibly higher than the aircraft.

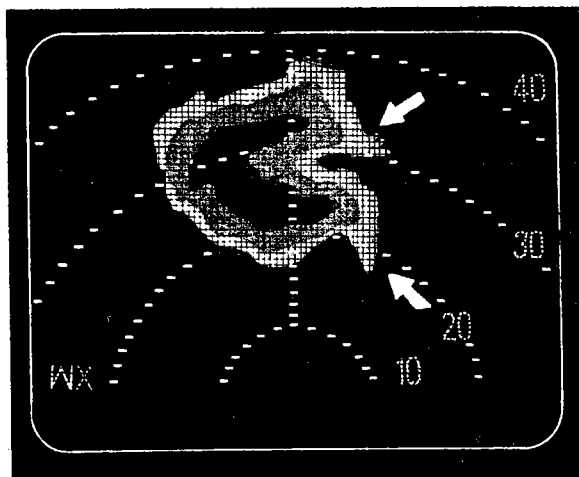


Figure 13-26. Hook-shaped echoes.

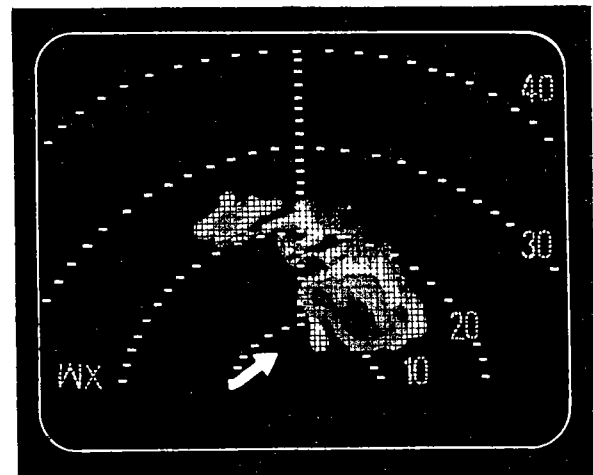


Figure 13-27. Pendant or figure 6 echo.

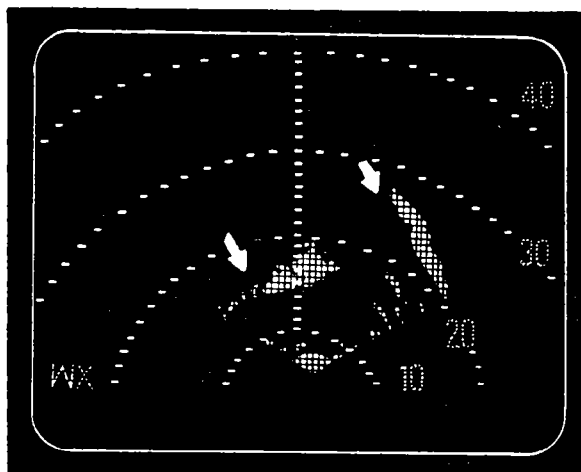


Figure 13-28. Snow and ground clutter.

(3) **Shadows beside, or embedded within, ground returns during ground mapping operations.** Smooth water bodies are reflecting the energy away from the antenna rather than back. Land-water contrast provides excellent ground mapping cues (fig 13-29).

**NOTE**

**Radar displays precipitation areas; aviators interpret precipitation areas.**

### 13-8. OPERATIONAL RECOMMENDATIONS

*a. Ground Precautions.* The following are general precautions to be followed during ground operations. (The aircraft or equipment operator's manual should be consulted for specific actions or procedures.)

(1) Do not operate the set in a hangar or other inclosed area.

(2) Do not point the nose of the aircraft toward a close metal building with the radar on.

(3) Do not operate the set near munitions or during fueling operations.

*b. Departure Procedures.* Scan the departure route; some up-tilt may be necessary. Do not take off if your departure route will

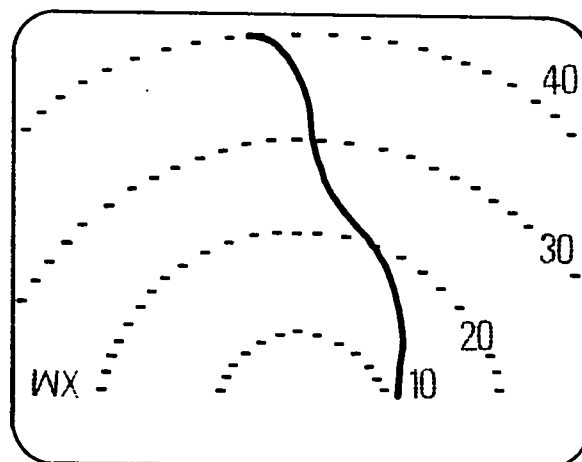
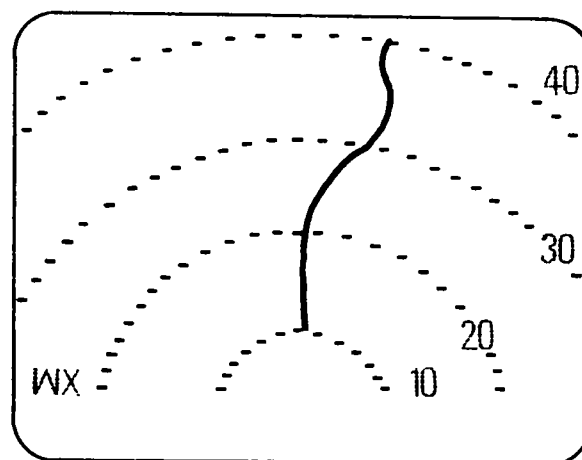
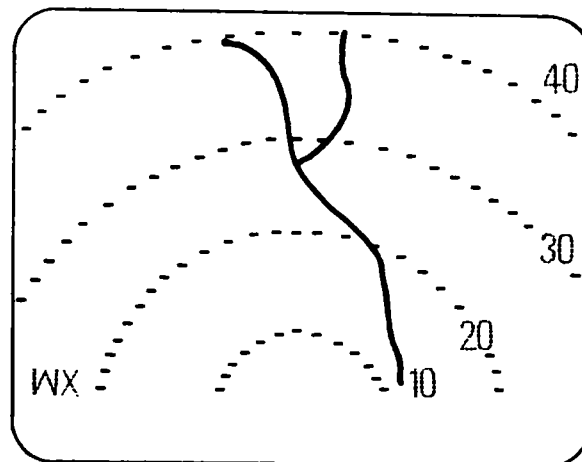


Figure 13-29. Land-water contrast.

necessitate flying through or beneath a thunderstorm.

c. *En Route Procedures.*

(1) After leveloff and periodically thereafter, select the longest range and search for distant echoes—some down-tilt will probably be required to see the distant echoes because of the curvature of the earth .

(2) Use an intermediate range during cruise flight. Too short a range could result in having to make drastic detours if severe weather is suddenly encountered.

(3) When using monochromatic displays, use the normal mode of operation and periodically check the status of echoes with the contour mode.

(4) Do not operate the set in the freeze/hold position for prolonged periods.

(5) When thunderstorm conditions are detected, determine an early evasive action. If detected early enough, a few degrees heading change may clear the storm area.

(6) When early evasive actions are not possible or practical, the following guidelines are recommended:

- When using the shorter range settings to circumnavigate echoes, frequently monitor the longer ranges to determine the extent of the area and to watch for additional developments.

- Selected navigable corridors between echoes should be relatively straight.

- Avoid flying under a cumulonimbus overhang if possible. If it is not possible, use upward antenna tilt to avoid possible encounters with hail.

- Above 23,000 feet, avoid *all echoes* by 20 nautical miles.

- Below 23,000 feet, the following avoidance criteria is recommended.

- Avoid echoes having steep rainfall gradients (3 nautical miles contour wall or less) by at least 5 nautical miles or more when the outside air temperature is 0°C or warmer.

- Avoid echoes having steep rainfall gradients by 10 nautical miles or more when the outside air temperature is less than 0°C.

- Increase the distances indicated above by 5 nautical miles for echoes which are rapidly increasing in size or intensity, changing shape rapidly, exhibiting hooks, figure 6s, U-shapes, fingers, scalloped edges, or other forms of protrusions.

- Weak echoes may be flown through, or near, if avoidance is impossible or impractical.

d. *Terminal Procedures.* In addition to the recommendations above, do not accept an approach route which will position the aircraft near or beneath the base of a thunderstorm.

## CHAPTER 14

### ICING

#### 14-1. GENERAL

The formation of ice on lift-producing airfoils (airplane wings, propellers, helicopter rotors, and control surfaces) will disrupt the smooth flow of air over the airfoils. This will result in decreased lift, increased drag, increased stall speed of fixed-wing aircraft, and decreased retreating blade stall speed of rotary-wing aircraft. 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 small amount of ice unevenly distributed on a delicately balanced rotor or propeller can place dangerous stress on the system, transmission, and engine mounts.

#### 14-2. FACTORS NECESSARY FOR STRUCTURAL ICE FORMATION

Factors necessary to produce structural icing on aircraft in flight are free-air temperature (FAT) at or below freezing and presence of visible liquid moisture in the form of clouds or precipitation.

*a. Free-Air Temperature.* When saturated air flows over a stationary object, ice may form on the object when the FAT 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. Structural ice, therefore, may form when the outside air temperature is at or below 0°C. The most severe icing occurs with temperatures between 0°C and -10°C. Under some circumstances, however, dangerous icing conditions may be encountered with temperatures below -10°C. The accuracy of the aircraft FAT gage 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 may cause the temperature reading to be at least 3°C warmer or colder than the true outside temperature.

##### *b. Visible Liquid Moisture.*

(1) Clouds are the most common form of visible liquid moisture. Not all clouds with temperatures below freezing, however, 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, 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 the most dangerous icing condition outside of thunderstorms. It can build hazardous amounts of ice in a few minutes, which is extremely difficult to break loose.

### 14-3. CONDENSED ICING FACTS (STRUCTURAL ICE)

#### a. General.

(1) Icing conditions should be expected in cloud layers where the air temperature ranges from  $\pm 4^{\circ}\text{C}$  to  $-20^{\circ}\text{C}$ .

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

(3) Severe icing should be expected in rain or drizzle in or below a cloud where the air temperature is less than  $0^{\circ}\text{C}$ .

(4) Ice crystals will not generally 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 ice.

#### b. Clear Ice.

(1) Clear ice is predominant in cumuliiform clouds where temperatures range from  $0^{\circ}\text{C}$  to  $-10^{\circ}\text{C}$ .

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

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

#### c. Rime Ice.

(1) Rime ice is predominant in stratiform clouds where temperatures range from  $0^{\circ}\text{C}$  to  $-20^{\circ}\text{C}$ .

(2) Rime ice is common in stratiform clouds where temperatures range from  $-10^{\circ}\text{C}$  to  $-20^{\circ}\text{C}$  and where the supercooled droplets

are less numerous and smaller in size, such as in stratiform clouds.

### 14-4. 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 notice to airmen (NOTAM).

c. Remove all frost and snow before takeoff.

d. Check controls for restrictions of movement.

e. Hover or taxi slowly. Use brakes with caution.

f. After runup in fog or rain, check for ice in rotor or propeller wash areas.

g. Wear sunglasses if glare is bad.

h. In fixed-wing aircraft, avoid taking off in slush or wet snow and avoid snowbanks, if possible. Rotary-wing aircraft should maintain a high hover over such surfaces to reduce blow up onto the aircraft.

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

j. 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).

k. Report all in-flight weather hazards.

l. If icing cannot be avoided, choose the altitude of least icing. (Glaze ice is common in



cumulus clouds; rime ice is common in stratiform clouds.)

*m.* Watch airspeed. Airfoil stalling speed increases with the formation of ice. Higher revolutions per minute (RPM) is required for safe autorotation of the helicopter when blades are covered with ice. Maintain an appropriate amount of extra airspeed while landing fixed-wing aircraft.

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

*o.* Before takeoff, insure that anti-icing and deicing equipment is in operating condition. Use a shallower climb angle for fixed-wing aircraft as this presents less surface for ice accumulation.

*p.* On aircraft with reciprocating engines, use carburetor preheat to prevent ice formation. Do not wait until an icing condition exists. Watch the carburetor air temperature, especially between  $-5^{\circ}\text{C}$  and  $+10^{\circ}\text{C}$ . Use full carburetor heat to clear it of ice. Always maintain carburetor heat whenever carburetor icing is likely.

*q.* On fixed-wing aircraft, check wing deicers; use them properly. Do not land with deicers on, since they act as airflow spoilers. 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.

#### NOTE

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

## 14-5. 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) during the flight. If the flight is to be made through known or forecast moderate icing, the aircraft must be equipped with adequate deicing/anti-icing equipment. Army aircraft will not be flown into known or forecast severe icing conditions (AR 95-1). The standard criteria for judging the intensity of icing is shown in table 14-1.

#### NOTE

**Some aircraft are not certified for flying into any icing conditions.**

**Table 14-1. Airframe Icing Reporting Table.**

INTENSITY	ICE ACCUMULATION
TRACE	Ice becomes perceptible. Rate of accumulation slightly greater than rate of sublimation. It is not hazardous even though deicing equipment is not used, unless encountered for an extended period of time (over 1 hour).
LIGHT	The rate of accumulation may create a problem if flight is prolonged in this environment (over 1 hour). Occasional use of deicing/anti-icing equipment removes/prevents accumulation. It does not present a problem if the deicing/anti-icing equipment is used.
MODERATE	The rate of accumulation is such that even short encounters become potentially hazardous and use of deicing/anti-icing equipment or diversion is necessary.
SEVERE	The rate of accumulation is such that deicing/anti-icing equipment fails to reduce or control the hazard. Immediate diversion is necessary.

## 14-6. DEICING AND ANTI-ICING METHODS

Deicing and anti-icing methods include the mechanical boots, anti-icing fluids, and heat.

*a. Mechanical Boots.* On fixed-wing aircraft, 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. This causes the boots to swell and to 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 rotating 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 vulnerable to the most serious icing, these areas may be heated by electrical means or by hot air which is piped from the manifold or bleed air of the engine. The process of supplying hot air gave rise to the name "hot wing" aircraft. However, practical considerations of weight, heat exchange characteristics, temperature effects on the structure of the aircraft, and electrical insulation limit the use of thermal deicing equipment.

## 14-7. FORECASTING

Approximately one-fourth of the icing encounters are reported by pilots flying under visual flight rules (VFR) flights. In most of these reports, freezing levels were forecast,

but icing was not. On many occasions, icing conditions can be forecast for specific altitudes. The instrument flight rules (IFR) flight plan is assigned a presumably safe altitude free of icing conditions. Icing, however, may be encountered at the assigned altitude. Data indicates that the majority of all icing encounters occur during cruise flight at altitudes between 1,500 and 6,000 feet.

## 14-8. TYPES OF AIRCRAFT STRUCTURAL ICE

Aircraft structural icing may be *clear, rime, a combination of clear and rime (glime), or frost*. The type of ice that forms on a moving structure normally depends on the following four factors:

- The outside air temperature.
- The surface temperature of the structure.
- The surface characteristics of the structure (configuration, roughness, etc.).
- The size of the waterdrops.

*a. Clear Ice (Glaze).* Clear ice, also called *glaze*, is the most serious form of structural ice. It normally is caused by the large supercooled waterdrops found in cumuli-form clouds where the temperature is between 0°C and -10°C or in areas of freezing rain associated with warm frontal systems (fig 14-1). A typical clear ice formation is transparent or translucent, with a glassy smooth or rippled surface (fig 14-2). Transparent glaze resembles ordinary ice. It 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 or around movable surfaces before they freeze. The resulting glaze adheres firmly to the surface and is difficult to remove. Glaze formation on the leading edges of rotors, propellers, wings, and antennas often takes a blunt-nose shape,

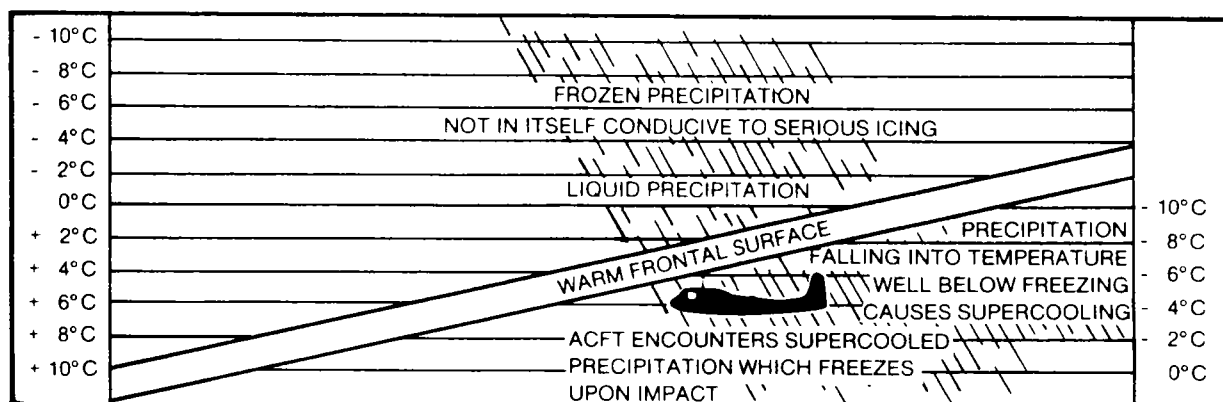


Figure 14-1. Typical freezing rain situation.

tapering toward the rear. When deposited as a result of the freezing of supercooled raindrops or very large cloud drops, the glaze deposit may become especially blunt-nosed with heavy bulges which build outward perpendicular to the leading edge of an airfoil.

b. *Rime Ice.* Rime ice normally is 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 airfoils and other structural parts of an aircraft

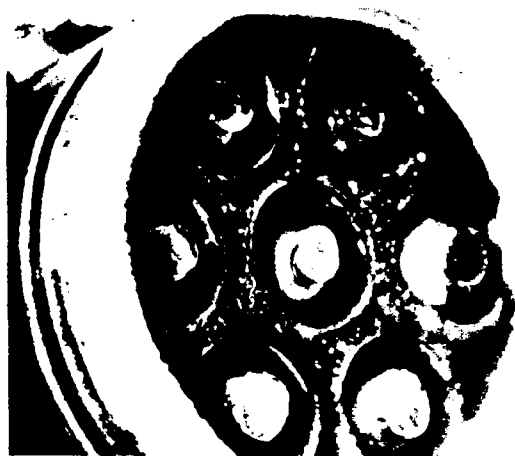


Figure 14-2. Formation of clear (glaze) and rime ice on aircraft armament.

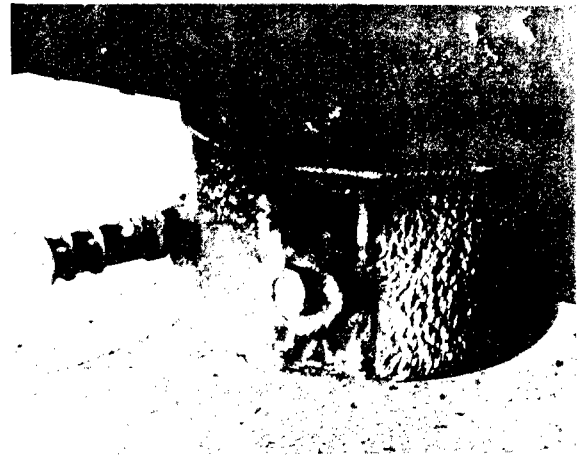
(figs 14-3, 14-4). Rime ice has a granulated, crystalline or splintery structure with a rough surface. The interior is composed of tiny opaque ice pellets or grains that may be intermixed with a frost formation of feathery crystalline structure. Some airspaces are present because the small water droplets do not spread out before they freeze. Rime ice is less compact than glaze and does not cling to exposed objects. Rime ice 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 ice 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 of 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.



*Figure 14-3. Rime ice formation on aircraft wing stores.*



*Figure 14-4. Rime ice on aircraft armament.*

(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. They may grow to serious proportions during the takeoff and climbout; and they may prevent takeoff. Frost on the windshield may cause restriction to, or total loss of, visibility.

#### 14-9. FACTORS INFLUENCING THE RATE OF ICE FORMATION

*a. Amount of Liquid Water.* Ice formation is more rapid in solid cloud conditions. The rate of ice formation increases as the amount of supercooled liquid water in 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 14-5). Therefore, the large drops

(small deflection) collect on an airfoil 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 airspeed at which frictional heating will prevent ice formation varies with the aircraft (type, configuration, surface characteristics, etc.) and the outside air temperature. For most Army helicopters at normal cruise speed and rotor RPM, the tip speed for the advancing blade and the main rotor equals to approximately 570 to 575 knots. Frictional heat, therefore, reduces or precludes ice buildup at the extreme outboard portion of the main rotor blades. The chance of ice buildup increases, however, as you progress inboard on the rotor disk.

*d. Smoothness.* The smoothness of the aircraft and airfoil surface also affects the rate of icing. Initial accumulation creates an aerodynamically unclean configuration and presents a larger surface area to collect the freezing droplets.

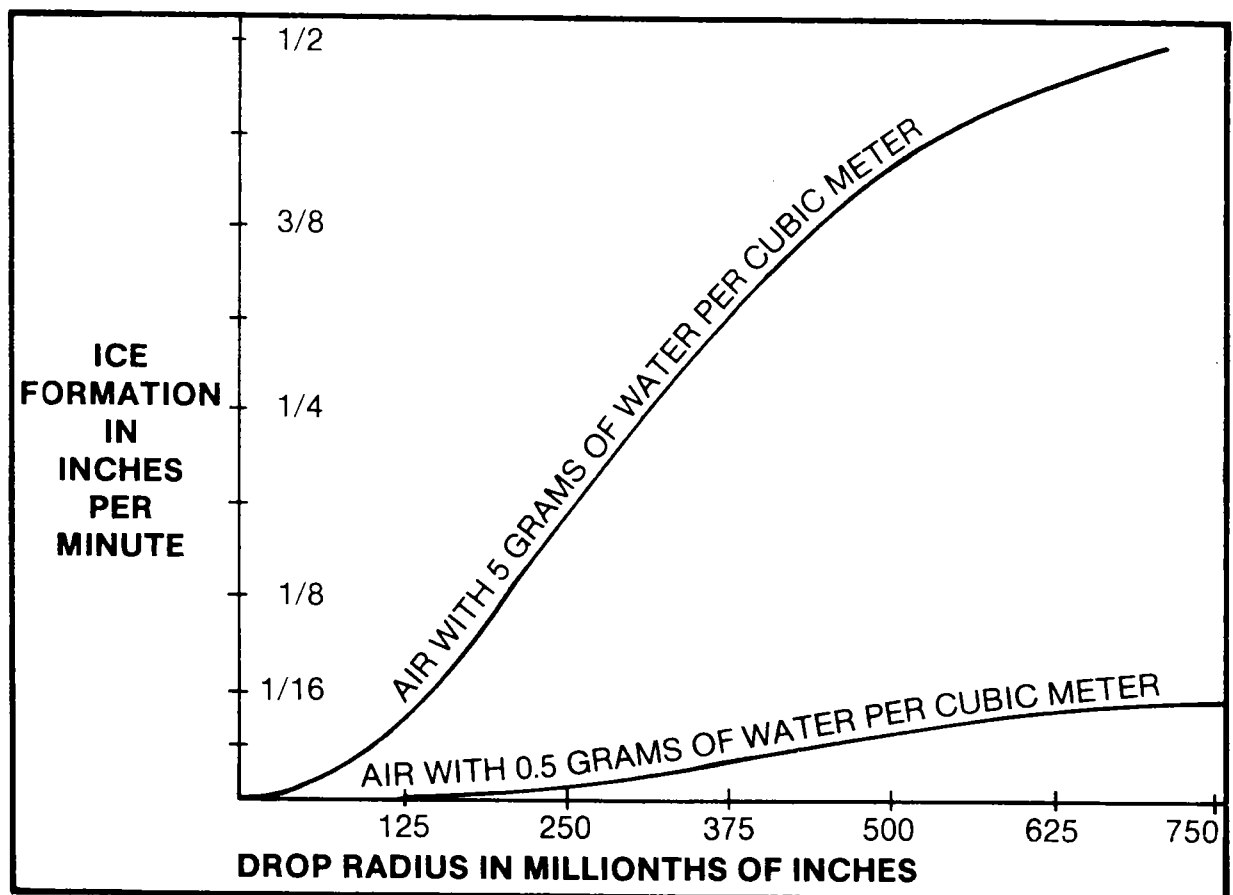


Figure 14-5. Rates of ice formation.

#### 14-10. EFFECTS OF ICING ON AIRCRAFT

Aircraft icing can have an adverse effect on the performance of an aircraft in at least four ways:

- Ice can cause a mechanical or visual obstruction.
- Ice can modify the profile of part of the aircraft, reducing its aerodynamic efficiency.
- Ice can alter the frequency of some parts of the aircraft, so that serious vibration may be induced.
- Ice that has formed can break off and cause serious mechanical damage or engine flameout or produce an asymmetric condition on a rotating mechanism (such as a helicopter rotor), which will give rise to serious vibration.

*a. Pitot Tube.* Ice in a pitot tube will reduce the size of the opening and change the flow of air in and around it. As a result, the flight instruments that are part of the pitot static system (e.g., airspeed indicator, vertical speed indicator, and altimeter) will become unreliable.

*b. Windshield.* The formation of ice or frost on windshields of aircraft is most hazardous during takeoffs and landings. Insignificant frost particles on the windshield prior to takeoff may act as sublimation nuclei during takeoff and reduce visibility to near zero before the aircraft leaves the runway. Ice accumulation on the windshield during let-down may prevent visual contact with the runway (figs 14-6, 14-7).

*c. Fuel Vent.* Heavy ice buildup on aircraft surfaces may block fuel vents. As fuel is

used, a blocked vent will prevent air replacing fuel being withdrawn from the tank. This causes a partial vacuum in the tank that may prevent the flow of fuel to the engine or may cause the fuel tank to collapse.

#### 14-11. ICING ON ROTARY-WING AIRCRAFT

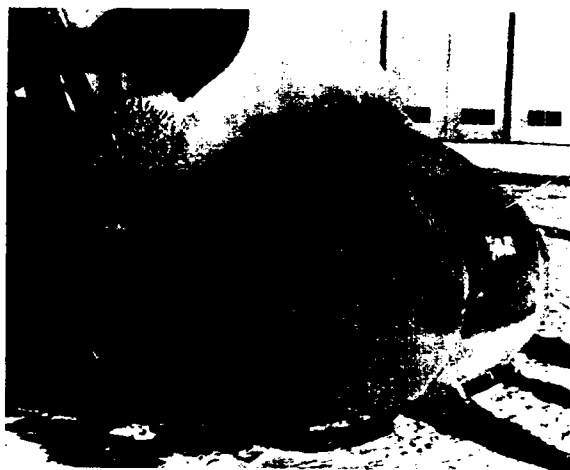
Future generation Army helicopters will be capable of performing missions under favorable weather conditions. A capability for helicopter flight in icing conditions will allow a vast majority of attack/airmobile operations to be performed under adverse weather conditions even without IFR, terrain avoidance, and target acquisition capability. The most pressing need is to enable the helicopter

to arrive safely and functional at its destination. Once there, mission completion depends on local conditions. Without a capability for flight in icing conditions, attack/airmobile operations will have to be canceled or delayed until en route weather conditions permit. In Europe, weather statistics indicate that during winter months, attack/airmobile operations cannot be conducted approximately 35 percent of the time because of icing conditions. From a strategic standpoint, this limitation is intolerable.

*a. Helicopter Icing Levels.* Studies by military and civilian research agencies reveal that, generally, when the windshield is obscured, the severity level of icing is assumed to be *moderate* to *severe*. If the



Figure 14-6. Windshield ice.



**Figure 14-7. Frost and ice on windshield.**

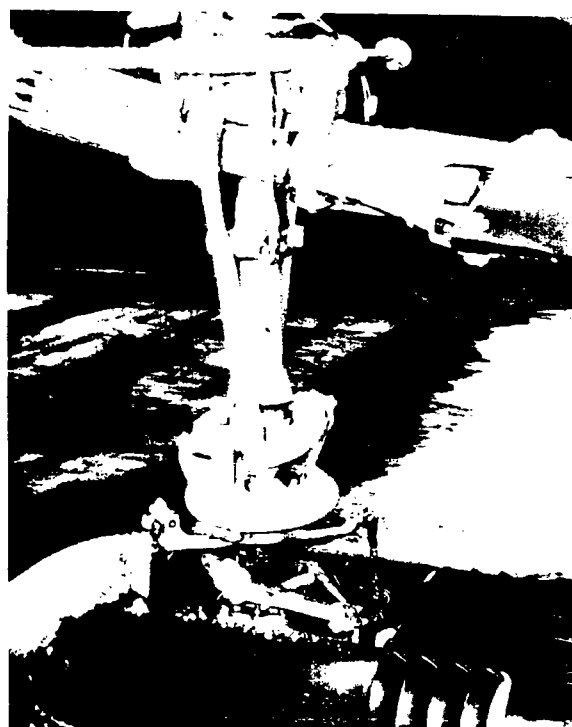
windshield wiper blades, door handles, and skids begin to accumulate ice, the level of icing generally ranges from a trace to moderate. In either of these cases, the main rotor blade may not be accumulating ice. If the pilot cannot see to land or has to make a sideslip approach to gain visibility, this could be considered a *serious or severe condition*. Usually, if torque increases or vibrations are observed by the pilot, this could be considered as a *moderate or severe icing condition*. Although the situation *may be critical*, this *does not* imply that the icing severity level falls into the severe category as outlined in Air Weather Service criteria.

**b. Rotor Systems.** Ice formation on the helicopter main rotor system or antitorque rotor system may produce critical vibrations and loss of efficiency or control. Although the slower forward speed of the helicopter reduces ice accumulation on the fuselage, the rotational speed of main and tail rotor blades produces a rapid growth rate on these surfaces.

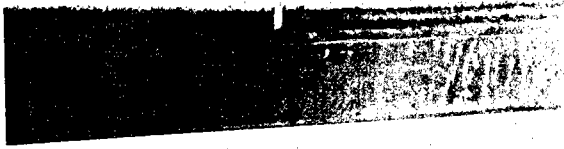
(1) **Main rotor head assembly.** The rotating parts of the flight control system, although subject to ice buildup, normally do not suffer any adverse effects because they are in continuous cyclic motion. Movement of other parts of the control system subject only

to random linear motion may be restricted due to the accumulation of ice (fig 14-8).

(2) **Main rotor blades.** An increase in the indicated torque accompanies ice accumulation on the main rotor and indicates ice buildup. With an excess ice accumulation on the inboard portions of the main rotor (which is indicated to the pilot by an increase in torque pressure), it may not be possible to maintain an autorotational rotor speed above the lower limit. The resulting low rotor speed provides insufficient rotor kinetic energy to insure a safe autorotational landing. Flights should not be continued when it is determined that ice accumulation on the main rotor degrades the autorotational capability. Deliberate control inputs may be induced to cause ice to shed from the blades. However, this procedure should not be used because ice may shed asymmetrically, resulting in severe rotor vibrations. A critical icing hazard can form rapidly on the inboard two-thirds of the main rotor blades (figs 14-9, 14-10, 14-11).



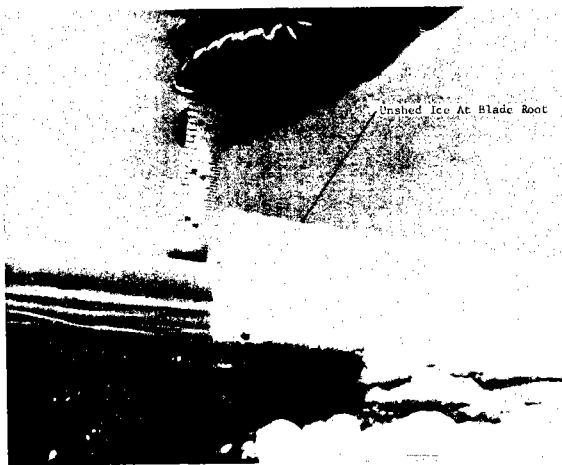
**Figure 14-8. Main rotor head icing.**



*Figure 14-9. Main rotor icing.*



*Figure 14-10. Irregular rotor blade icing pattern.*



*Figure 14-11. Cross section of rotor blade icing.*

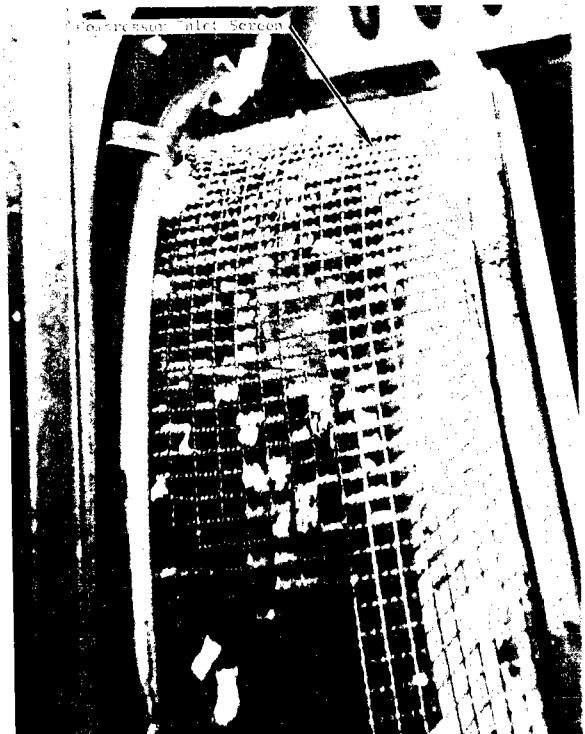
(3) *Tail rotor.* Ice accumulation on either the tail rotor hub assembly or blades produces the same hazards as those associated with the main rotor. However, icing tests have shown that ice accretion to the tail rotor and blades is minimized due to engine exhaust wash over the tail rotor area.

*c. Air Intake and Air Inlet Screens.*

(1) Ice accumulation on the engine and transmission air intake screens is more

rapid than accumulation on the rotor systems. This results in adequate cooling of the engine and transmission. It also inhibits the flow of air to the carburetor/air induction system. Freezing water passing through the screens may also coat controls and linkage, producing limited movement and similar control problems (figs 14-12, 14-13).

(2) Ice may form on air inlet screen, foreign object damage (FOD) screens, and particle separators. Some of the best indicators of air inlet icing is a loss in power, elevated exhaust gas temperatures (EGT) accompanied by compressor surges, and/or stalls. To accommodate an icing environment, some engine air inlets (rotary wing and fixed wing) are configured with deflectors and heated inlet cowls (electrically or bleed air).



*Figure 14-12. Engine air intake screen icing.*



*d. Airframe.* Ice deposited on the airframe is unlikely to present any problem from weight growth, as it is mainly limited to those parts which present a relatively small projected area to the airstream. The main problems arise from the buildup of ice on external struts, pipes, and other projections of small sections which have a high catchment rate. In these cases, the ice tends to build in a form which will eventually be shed by aerodynamic forces when it extends beyond a certain amount. Shedding also may be initiated if the aircraft, having encountered icing conditions, then descends through warmer air.

*e. Antennas.* Buildup and shedding of ice on antennas can cause severe oscillations and also may affect communications. Accumulation and shedding of ice on the frequency modulated (FM) whip antenna can cause large amplitude oscillations, causing the antenna to strike the tail rotor.



**Figure 14-13.** Engine air intake screen icing.

#### NOTE

Tests are currently being conducted by military agencies and civilian industrial firms to better determine the effects of icing on rotary-wing aircraft during powered and autorotative flight.

### 14-12. ICING ON FIXED-WING AIRCRAFT

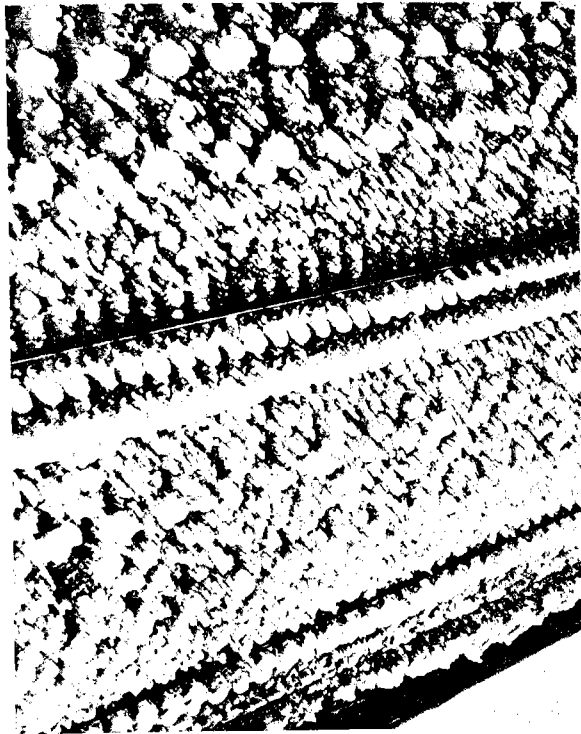
*a. Wing and Tail Surfaces.* Structural ice on wing and tail surfaces that disrupts the flow of air around the airfoil causes a loss of lift and an increase in drag. This condition, therefore, results in a higher-than-normal stall speed (fig 14-14).

*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. Increased throttle or power settings may then fail to produce sufficient thrust to maintain flying speed.

*c. 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.

### 14-13. WEATHER AREAS CONDUCTIVE TO ICING

*a. Frontal Inversions.* When warm air is forced to rise over a colder air mass, a frontal inversion is present (fig 14-1). Below the inversion, structural icing areas are common in winter.



*Figure 14-14. Undersurface of wing aerodynamically unclean because of ice formation.*

(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 may remain as 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 formation of glaze in a short period of time. Often the freezing precipitation is mixed with ice pellets (frozen raindrops) or snow (ice crystals) as it falls through 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 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 precipitation may not resolve the icing problem, because freezing rain or drizzle may extend to the surface.

**WARNING**

An aviator should not descend to avoid freezing precipitation unless he knows the temperature at his planned altitude near 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 and/or ice crystals are suspended. The ice crystals present no icing problem, since they do not stick to the aircraft upon impact unless they are accompanied by liquid water. The small supercooled water droplets, however, will freeze into rime ice upon contact with the aircraft. Glaze may form in the rain zones of stratiform clouds, and often a combination of rime ice 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 large supercooled liquid drops. Upon impact with aircraft, these large drops spread out before turning to ice. The resulting glaze has a tendency to stick 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 14-5 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 maritime tropical (mT) air moves over the Appalachian Mountains, it is often cooled to freezing temperatures. An icing hazard exists for all flights through this air. Similarly, maritime polar (P) 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 14-15 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.

#### 14-14. 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 degrees north latitude. (The temperatures used below are free-air temperatures as reported by standard 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.

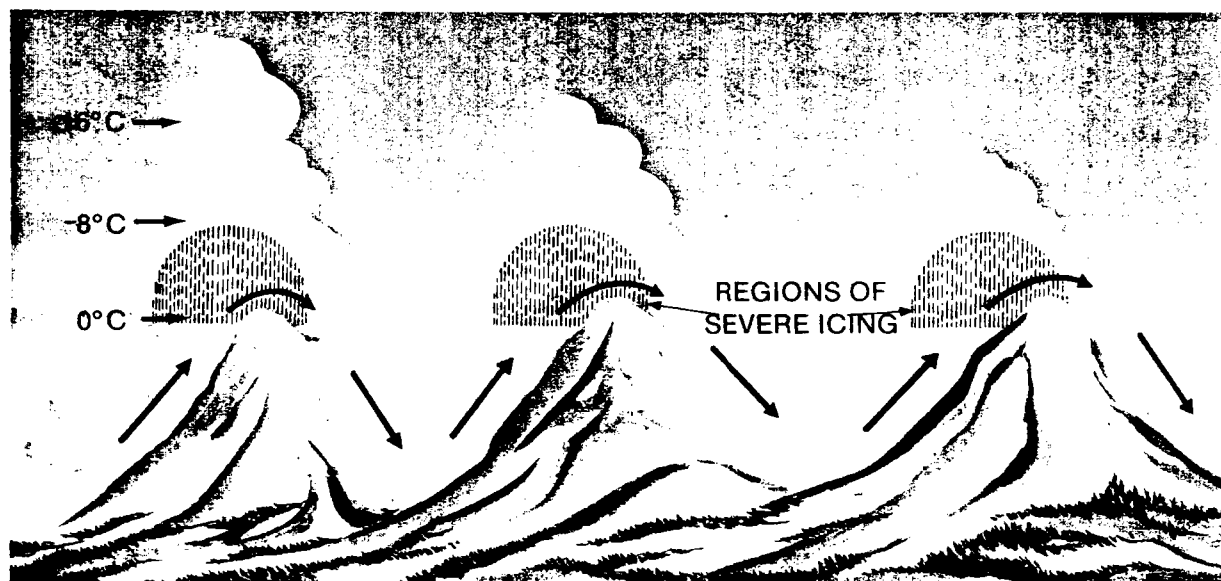


Figure 14-15. Icing over mountains.

(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 ice, especially moderate rime ice, was the predominate type found at low temperatures in all seasons.

(6) There have been isolated reports of icing at extremely cold temperatures.

(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. Icing was categorized as light, moderate, and severe as follows:

(1) Light icing was classified as a formation of a mere trace to 0.2 inch in 5 minutes.

(2) Moderate icing was classified as a buildup of 0.2 to 1.5 inches of ice in 5 minutes.

(3) Severe icing was reported where the rate of formation was greater than 1.5 inches in 5 minutes.

## CHAPTER 15

### FOG

#### 15.1 GENERAL

Fog is minute droplets of water or ice crystals suspended in the atmosphere with no visible downward motion. It is one of the most common and persistent weather hazards encountered by Army aviators. Fog 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 hazardous during takeoffs and landings because it restricts surface visibility. Unlike other weather hazards, however, fog may be insignificant 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.

#### 15-2. 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; for example, 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 rarely occurs when the spread is more than  $2.2^{\circ}\text{C}$ . It is most frequent when the spread is less than  $1.1^{\circ}\text{C}$ .

*b. Light Wind.* A light wind is generally favorable for fog formation. It causes a gentle mixing action, which spreads surface cooling through a deeper layer of air and increases the thickness of the fog.

*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.

#### 15-3. 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 which is heated as it flows down-slope or by daytime solar radiation evaporates fog. Most fog dissipates shortly after sunrise, and rarely is on the lee sides of hills and mountains.

### 15-4. FOG TYPES AND CHARACTERISTICS

*a. Radiation Fog.* Radiation fog (fig 15-1) forms after the earth has radiated back to the atmosphere the heat gained during daylight hours. By early morning, the temperature at the surface may drop more than 11° C. 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 sufficient, 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 15-2) 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 larger areas of the nation east of the Rockies. It may persist day and night until replaced by a drier air mass.

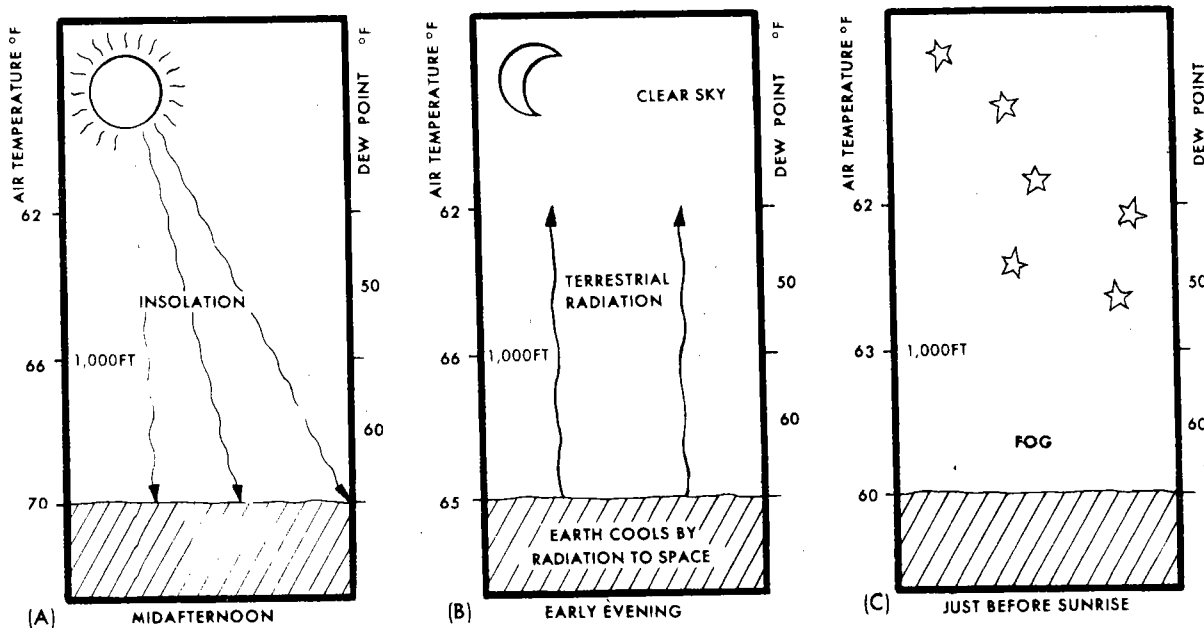
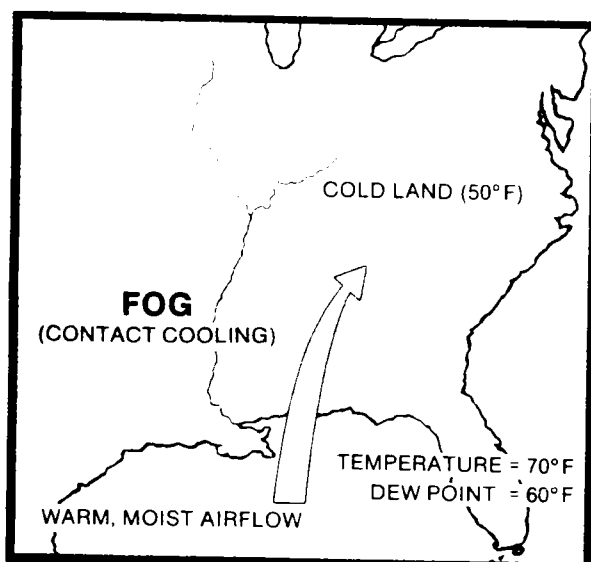


Figure 15-1. Radiation fog.



**Figure 15-2. Advection fog.**

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

**c. Upslope Fog.** Upslope fog forms when moist stable air flows up a sloping land surface. When the air rises, it cools by expansion 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 wind speed (pressure gradient) must be adequate to support continued upslope motion. If the wind, however, is too strong, the fog may be lifted from the surface. This results 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 of approximately  $-25^{\circ}\text{C}$  and below, water vapor sublimates into ice crystals without passing through a liquid state. The resulting ice crystals are small, and they usually persist in an area for many hours as *ice fog*. Atmospheric conditions favoring ice fog formation are common during the winter in the extreme north central United States and Canada. Many times, 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 run-up 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*. The major types are *frontal fog* and *steam fog*.

(1) **Frontal fog.** Frontal fog is normally associated with slow-moving winter frontal systems (chap 10). 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. It is, therefore, 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 nonfrozen water surface that 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.

## 15-5. 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 to 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 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 of 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. It, therefore, may be an unexpected landing hazard. An airfield can change from clear to solid fog in a matter of minutes. If an aviator, upon reaching a destination, finds that fog has formed and the ceiling and visibility are below minimums, a check should be made of the alternate airfield's weather before proceeding.

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.



*Part three of this manual provides aircrew members a basic understanding of weather conditions in areas outside of the mid-latitudes, such as the extremely cold arctic regions or the hot tropical regions. Each of these areas presents its own unique advantages and disadvantages as well as hazards.*

## **POLAR, SUBPOLAR, AND TROPICAL WEATHER**

### **CHAPTER 16**

#### **16-1. 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 hazardous to the pilot in polar flight operations. Obstructions to visibility and depth perception make landings and takeoffs difficult. Also, iced runway conditions require special flight techniques.

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 also apply to other areas with cold temperatures.

#### **16-2. CLIMATIC BOUNDARIES**

a. *Polar Region.* The polar region is that part of the earth where the mean annual

temperature is 0°C or less and where the mean temperature for the warmest month is less than 10°C. In North America, this region includes—

- The northern coast of Alaska and Canada.
- The Canadian Arctic Archipelago.
- Most of Labrador, Greenland, and the Svalbard Archipelago.
- The southern end of the Aleutian Island chain.

#### **NOTE**

**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 4°C isotherm of average annual temperature. Across the United States, the boundary roughly follows the 48th parallel; but it then swings northward to include part of Alaska and the Aleutian Island chain.

### 16-3. 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 wave, 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 16-1). 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 ceilings and visibilities in the interior and Anchorage area 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.

### 16-4. 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) Fog limits landing and takeoff operations in the Arctic more than any other visibility restriction.

(2) Ice fog presents the major restriction to aircraft operations in winter, because it occurs often and tends to persist. Rarely found outside the Arctic climate, ice fog is composed of tiny ice crystals (rather than water droplets as found in ordinary fog). It forms in moist air during extremely cold, calm conditions. When the sun shines on these suspended particles (called needles) very bright reflection results.

(3) Advection fog and low stratus clouds generally prevail in coastal polar regions (fig 16-2). 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 landmass.

(4) 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.

(5) Polar ice fog in the interior land regions occurs most frequently when the ground temperature is near or below -25°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 for long periods of time. Ice fog produces neither rime nor glaze on exposed surfaces contacted. It may, however, produce sparking effects in sunlight or other light

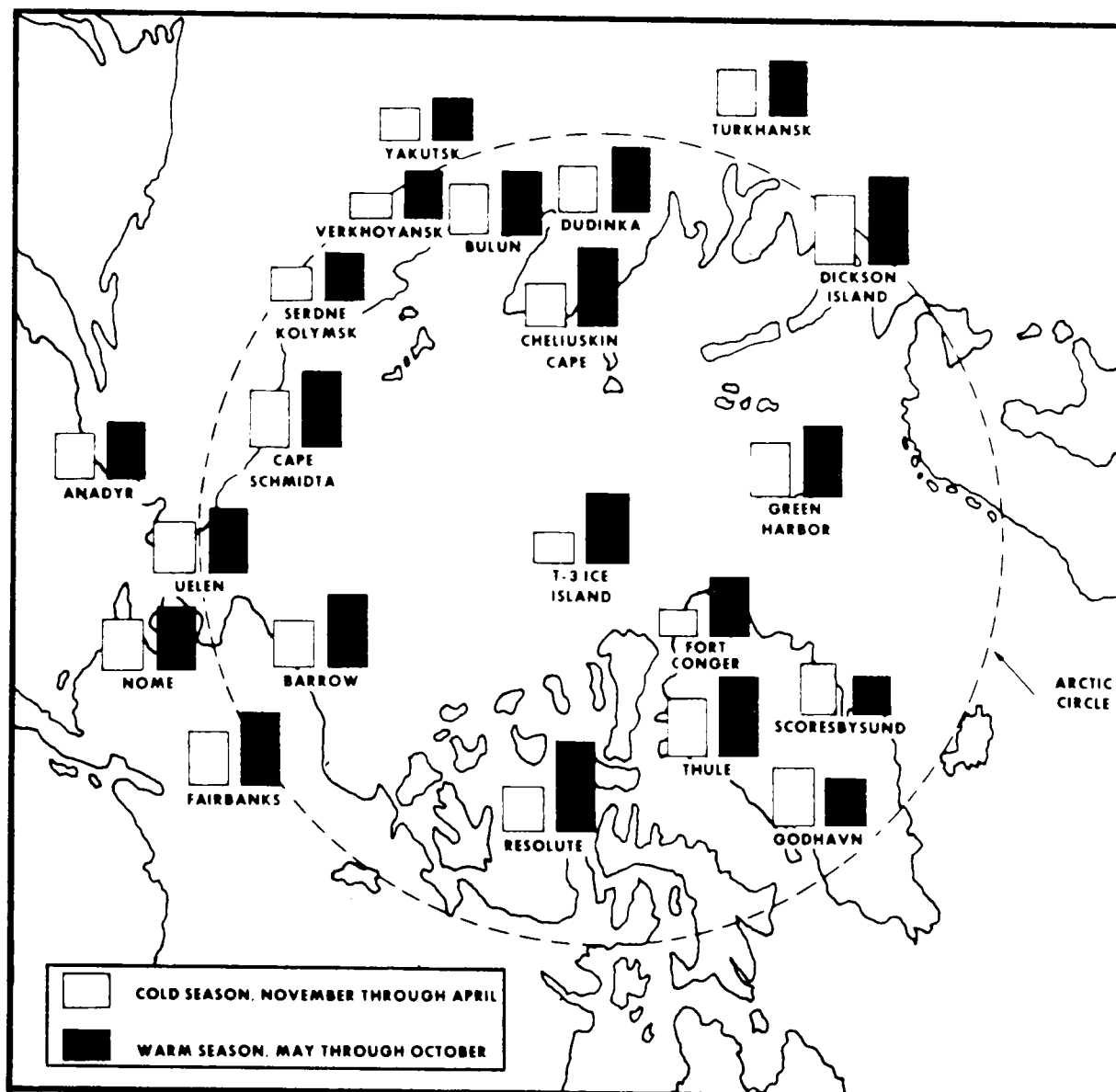


Figure 16-1. Average number of overcast days per month.

beams, halos, luminous vertical columns over lights, and light diffusion. Over snow-covered surfaces, ice fog is invisible from the air.

(6) Ice crystals, as a form of precipitation, produce the same effects on vision as ice fog. The rate of fall with ice crystal precipitation is very gradual and almost negligible. Ice crystals may fall from cloudy or cloudless skies.

a. **Drifting and Blowing Snow.** Winds of 12 knots lift the loose surface snow a few feet off the ground, hiding objects such as rocks and runway markers. This drifting snow, by deflection, does not restrict surface visibility above 6 feet. Winds of 15 knots pick up dry, powdery snow and lift it high enough to obscure large objects, such as buildings, when the surface is irregular (fig 16-3). The strong fall winds and the winds in arctic blizzards may lift snow to heights above 1,000 feet and produce surface drifts over



*Figure 16-2. Fog and stratus clouds over polar coastal areas.*

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 side.

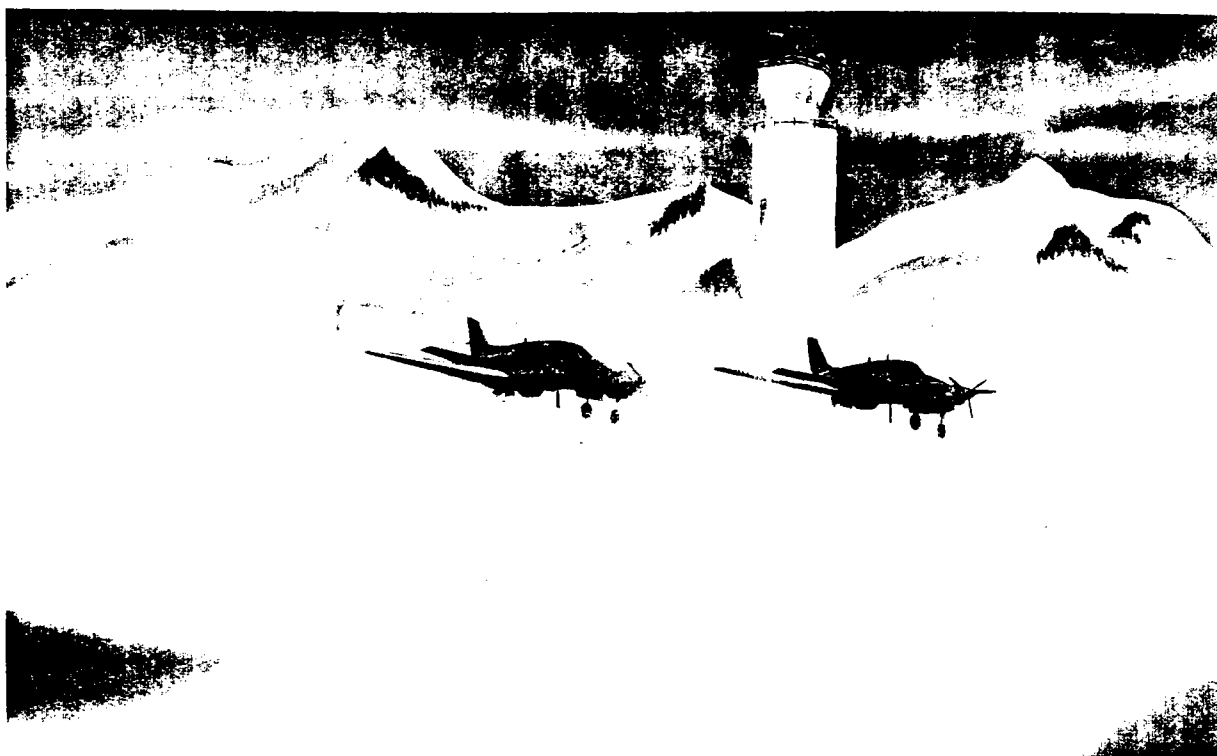
## 16-5. FLIGHT PROBLEMS IN POLAR REGIONS

### a. Takeoff.

(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. Reciprocating engines may require preheating before starting. Surface temperatures in polar areas frequently range from approximately 10°C colder to 1°C warmer than the temperature at flight level.

(2) **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. The aviator, therefore, should be prepared to go on instruments at any time during takeoff when haze is present.



*Figure 16-3. Blowing snow.*

(3) **Carburetor icing.** Carburetor icing is 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. Under extreme low-temperature conditions in interior polar areas, however, the application of carburetor heat will aid fuel vaporization and improve engine operation.

*b. In Flight.*

(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.

(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 or airspeed 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 over rough terrain 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) *Mechanical turbulence.* Katabatic (fall) winds are common in polar regions, and they 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 as far from the lee sides of these obstructions as possible.

(2) *Runway icing.* Aircraft exhaust may freeze and settle onto the runway. The frozen exhaust moisture also may remain suspended in the air as ice crystals or ice fog and limit visibility over the runway.

## 16-6. 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 degrees north latitude). The source regions of polar air masses are generally between 40 degrees and 66½ degrees north latitude. 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 generally high. Arctic cold fronts frequently increase the temperatures 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 the midwestern United States brings in the coldest weather of the winter over large areas of the country.

## CHAPTER 17

## TROPICAL WEATHER

## 17-1. GENERAL

a. The tropics include the vast region lying between the Tropic of Cancer and the Tropic of Capricorn ( $23\frac{1}{2}$  degrees north latitude and  $23\frac{1}{2}$  degrees south latitude, respectively). Tropical weather may also occur more than 45 degrees 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 three 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 monsoon trough.* This trough oscillates from the Equator to 20 degrees north over the western Pacific.

(3) *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.

## 17-2. OCEANIC (MARITIME) TROPICAL WEATHER

Weather over open seas in the tropics is characterized by cumuliform clouds. Over extensive portions of the tropical ocean, the sky is clear. In fact, some areas are considered desert. 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 cumulus 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  $2^{\circ}\text{C}$  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.

## 17-3. 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 onshore 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. During oceanic flight, towering cumulus clouds are often the aviator's first indication that he is approaching an island.

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 semi-permanent high-pressure cell over the sea toward a thermal low over the continent (e.g., Cherripunji, India).

#### 17-4. 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 wind flow.
- Orientation, height, and extent of coastal mountain ranges.
- Altitude of the continental area.
- 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 38°C 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. (This is known as *virga* and is a type of cloud.) The “dry” thunderstorms, however, produce squall winds and may cause severe dust or sandstorms. These storms are a hazard to flight 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 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 monthly mean temperature for jungle stations may be less than 1°C, but the daily range is often 17°C or more. When afternoon showers occur, the descending cold air currents may produce nights with temperatures in the 15°C range. These rain showers are very heavy and produce low clouds that may reduce ceiling and visibility to near zero.



## 17-5. OTHER TROPICAL PHENOMENA

The principal types of special weather phenomena observed in the tropics are—

- Trade inversions.
- Intertropical convergence zone.
- Easterly waves.
- Monsoons.
- Tropical cyclones.
- Hurricanes.

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 weather situation. Above the moist layer is a very dry air layer caused by subsidence. The two layers are separated by a well-defined temperature inversion known as a *trade inversion* (fig 17-1). 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.

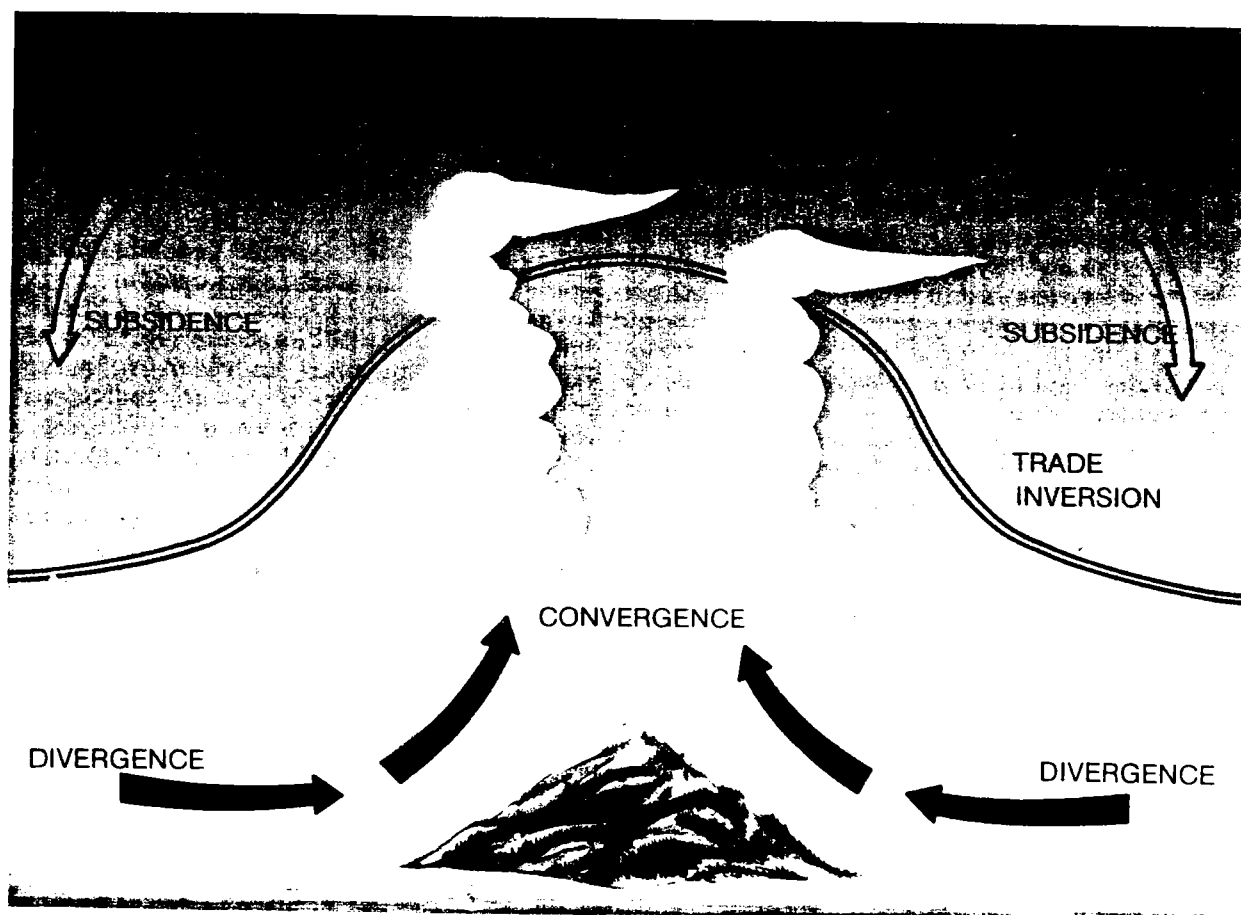


Figure 17-1. Variation in height of trade inversion.

*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* (ITCZ). The ITCZ is not a true front because the discontinuity of the air density is not significant. The convergence zone has the appearance of a front, 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 ITCZ moves northward in the summer and southward in the winter as a result of the migration of the direct rays of solar radiation with the seasons (fig 17-2).

*c. Easterly Waves.* Easterly waves (fig 17-3) are common wave-like disturbances of the tropical easterlies. They are waves within the broad easterly current and move from east to west. Generally, they move slower than the current in which they are embedded. Although best described in terms of their wave-like characteristics, they also consist of a weak trough of low pressure. In the west of the easterly wave over the ocean, there is generally found divergence, a shallow moist layer, and exceptionally fine weather. To the east of the trough line of the wave, the moist layers rise rapidly near this line. To the east of this line, there is heavy rain, much cloudiness, and strong convergence. Those 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 evident along the Gulf coast section of the United States. Waves which are initially weak and hardly discernible on the weather map may deepen rapidly in 24 hours to become the spawning ground for tropical cyclones and hurricanes.

*d. Monsoons.*

(1) The term *monsoon* is of Arabic origin and means "season." The monsoon wind is a seasonal wind that blows from continental interiors or large land areas to the ocean in winter and in the opposite direction during the summer. Monsoons occur over a number of world areas, but the degree of

influence on climatic conditions varies greatly. Southern and southeastern Asia are the continental areas most affected by this seasonal land and sea breeze. During the winter season, because of the large Siberian high, polar air flows southward across the Himalayan Mountain range toward the Equator (although the mountains interfere significantly with the flow and keep the coldest air from reaching India). This air is relatively dry and is warmed adiabatically as it flows down the southern slopes of the mountains. This is the dry or winter monsoon (fig 17-4).

(2) During the summer season, air from an equatorial source flows up over the mountains from the south. The lifting of moist air in this area produces extensive cloudiness and widespread rain. The summer monsoon is responsible for some of the heaviest rains on earth. Stations in India report more than 400 inches of rainfall in a year, with most falling between the months of June and October (fig 17-5).

*e. Tropical Cyclones.*

(1) Tropical cyclones occur in many localities throughout the world and are known by various names. In the Atlantic area and the eastern North Pacific, tropical cyclones are known as *hurricanes*. In the North Pacific they are known as *typhoons*. In Australia they are known as *willy-willies*, and in the Philippines they are called *baguios*. For tracking and statistical purposes, these storms are given names to help identify them. Any fully developed tropical cyclone usually means havoc and destruction.

(2) Every Army aviator, whether his job is to perform a combat mission or to safeguard government property, should be familiar with—

- The nature of these storms.
- The season of their occurrence.
- The areas in which they form.
- Their common tracks.

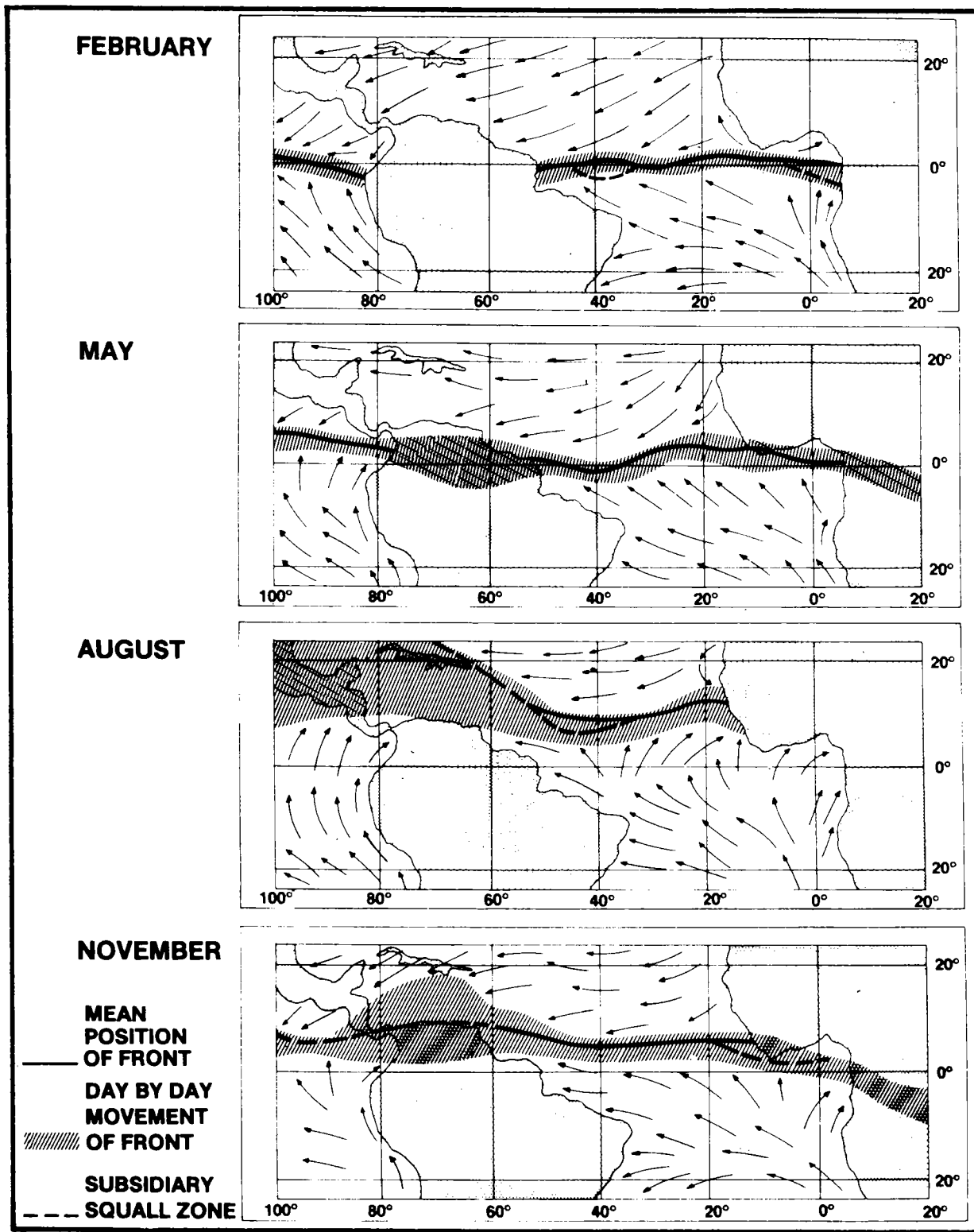


Figure 17-2. Average position of intertropical convergence zone (South Atlantic area).

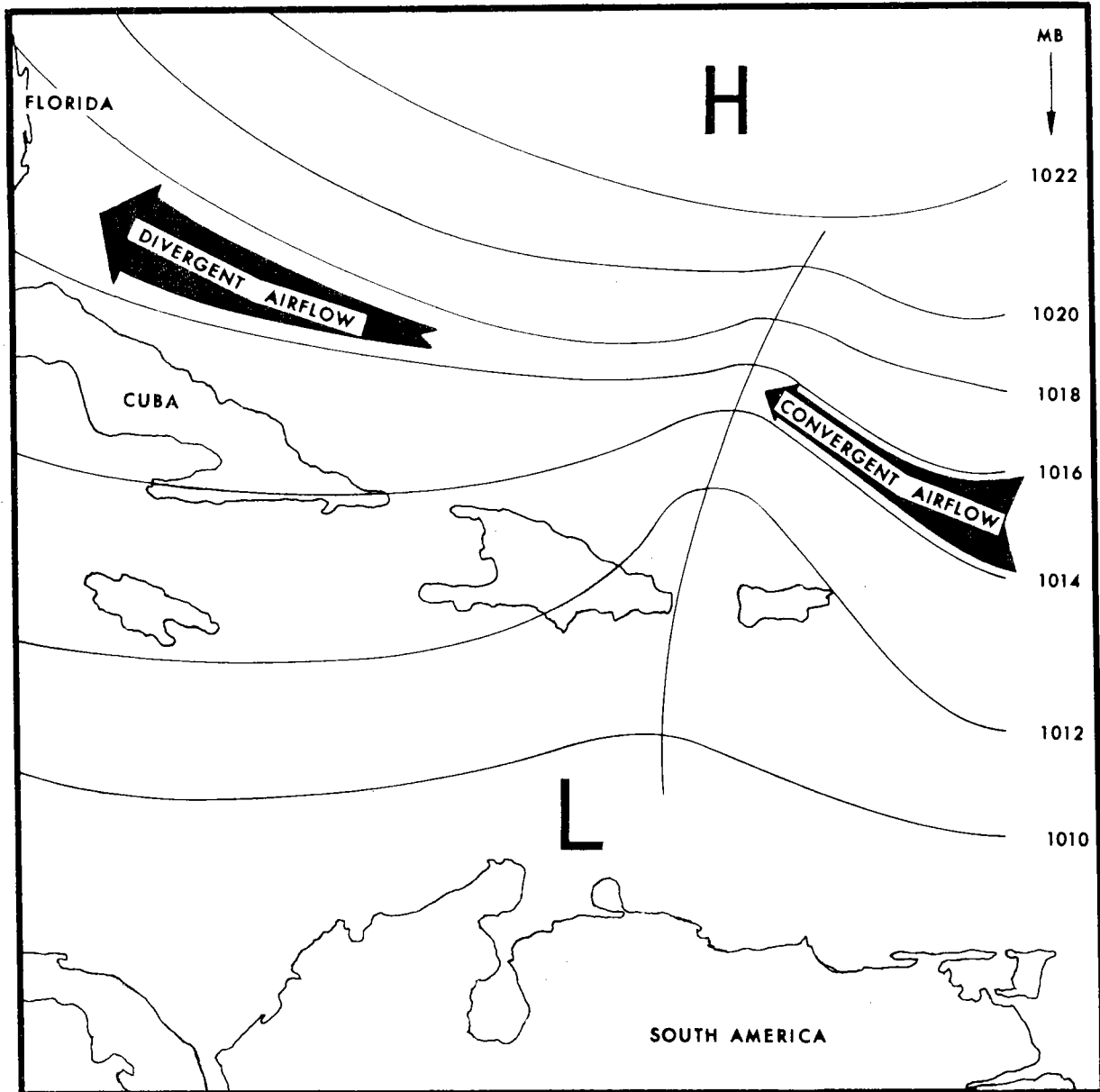


Figure 17-3. An easterly wave.

(3) Tropical cyclones come in all shapes and sizes. In the Pacific they can occur during any month of the year. They occur, however, most frequently in August and September. At times there will be more than one cyclone in a region and sometimes they are close enough together so they interact. Tropical cyclones, in addition to being individually as distinctive as fingerprints, can change shape, size, maximum wind veloc-

ity, and direction quickly. Once a tropical cyclone is in the area or detected by ship or station radar, its progress must be carefully monitored. Army aviators should try to avoid these dangerous cyclones.

(4) A *hurricane* is a tropical cyclone with winds of 64 knots per hour or greater. Hurricanes originate over the Atlantic Ocean, the Caribbean Sea, the Gulf of Mexico, the

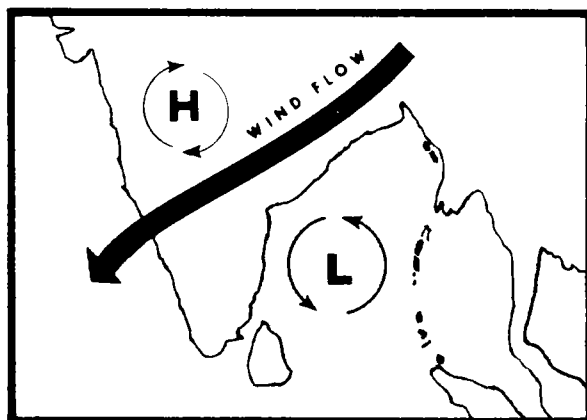


Figure 17-4. Winter monsoon.

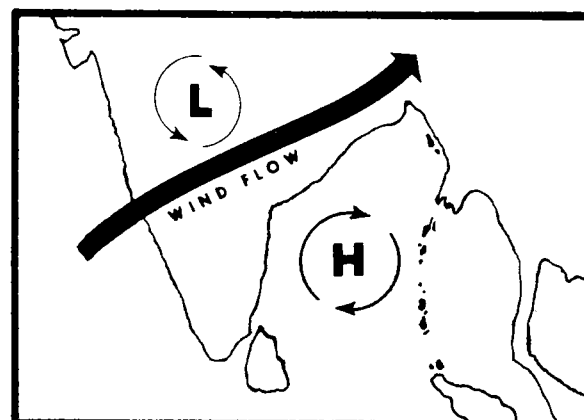


Figure 17-5. Summer monsoon.

eastern North Pacific, and along the coasts of Central America and Mexico. Generally, hurricanes 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 17-6.

associated. The term "hurricane," however, is properly applied only to tropical cyclones with winds equal to or greater than this speed. Tropical cyclones with winds less than 64 knots per hour are called **tropical storms** or **tropical disturbances**.

(5) Winds of 64 knots per hour or more are called **hurricane force winds**, regardless of the type storm with which they are

(6) Some of these cyclonic disturbances develop into violent storms within 24 to 36 hours; others reach intensity only after

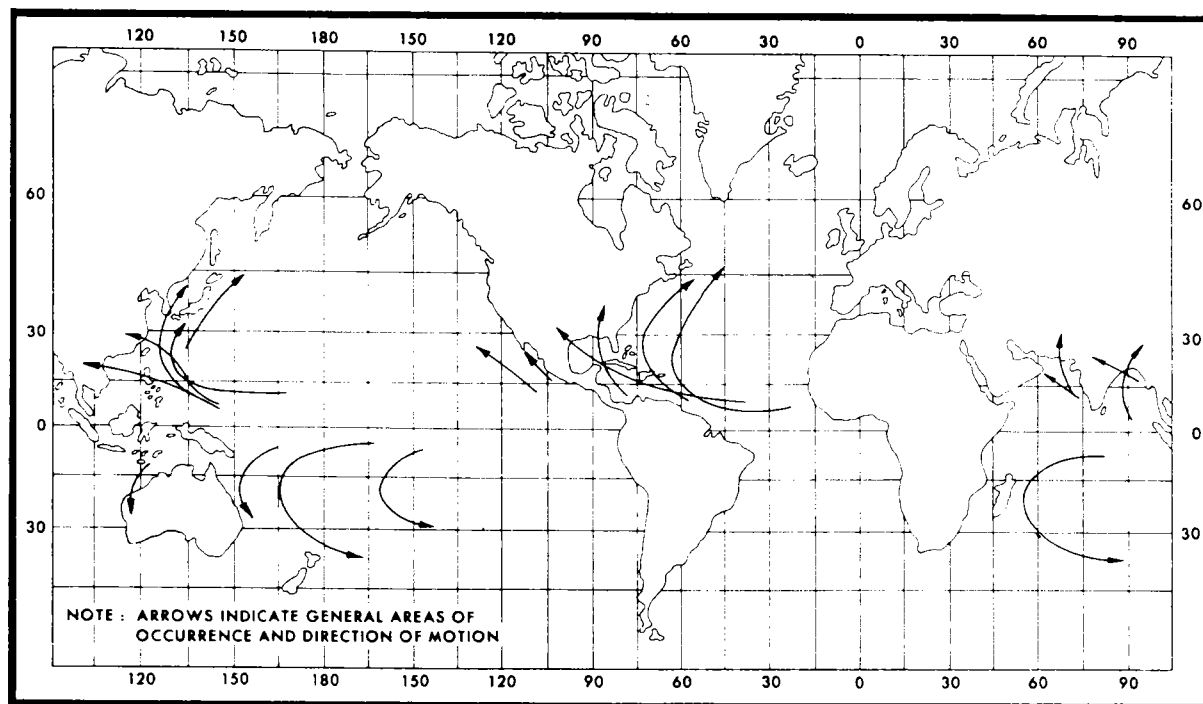


Figure 17-6. Principal world regions of tropical cyclones.

several days. By far the largest number, however, become no more than wild systems with unsettled weather.

*f. Other Hazardous Weather Zones.*

There are several atmospheric discontinuities 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 17-7) 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 17-8) also form in the tropics when the leading edge of a continental polar air mass advances southward and displaces the semipermanent oceanic high. These are very frequent in the Pacific Ocean. 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 cumuloform 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.

**17-6. FLIGHT HAZARDS OF THE TROPICAL STORM**

a. All pilots, except those specially trained to explore tropical storms and hurricanes, must avoid these dangerous storms. They contain heavy concentrations of thunderstorms with tops exceeding 40,000 feet. Winds near the center often reach or exceed 150 knots. Although the most severe turbulence is encountered near the "eye," other areas of turbulence exist within the spiral rain bands. Due to the large pressure changes in and near the storm center, altimeter errors can exceed 1,000 feet.

b. For low-level flights circumnavigating the storm, it is preferred to keep the storm to the left of the flight path to capitalize on the tail wind component. It should be noted that the most intense part of the storm is found in the right front quarter of the storm center relative to its direction of movement. **Most tornadoes which have occurred with hurricanes were located in this quadrant.** The weakest portion of the storm is usually the left rear quarter with respect to the path of movement.

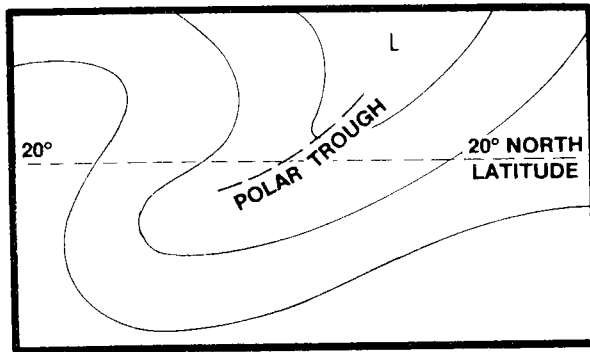


Figure 17-7. The polar trough in the tropics.

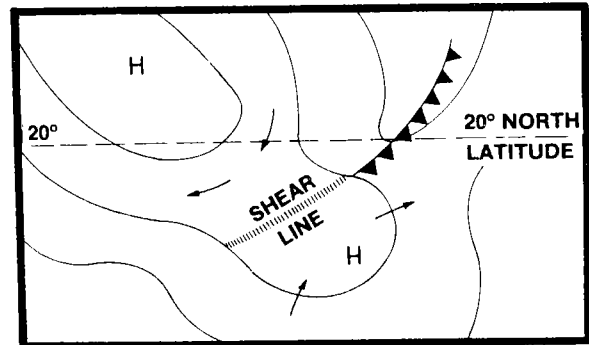


Figure 17-8. Shear line in the tropics.

*Effective weather flight planning requires that the aviator have sound knowledge of basic weather principles, a thorough understanding of the weather facilities available for his use, and the ability to use the available weather data in order to complete the mission safely.*

## **WEATHER FLIGHT PLANNING**

### **CHAPTER 18**

#### **18-1. GENERAL**

The amount of weather information that the aviator needs will vary with the conditions for the flight, the aircraft equipment, and aviator capabilities.

a. The aviator planning a flight under instrument flight rules (IFR) is primarily interested in the ceiling and visibility conditions at point of departure, destination, and possible alternates, and the type weather he will encounter en route as it pertains to icing, turbulence, and winds aloft. Since the aviator planning a flight under visual flight rules (VFR) must rely on visual references for navigation and be able to see other aircraft for separation purposes, he is more concerned with the height of cloud bases and visibility.

b. After takeoff, the aviator must continue with his weather flight planning. He must be aware of the actual weather conditions he encounters and, with the aid of in-flight

weather advisories and services available to him, keep abreast of conditions which will affect his flight. His knowledge of cloud formations, pressure patterns, airflow, and other weather phenomena will enable him to analyze the validity of the forecast presented him in the briefing. Always have an escape route planned.

c. The kinds and amounts of data and briefing support available will vary from complete support 24 hours a day at busy locations in the Continental United States (CONUS), to severely limited support in tactical combat situations overseas.

#### **18-2. STANDARD PILOT BRIEFING DISPLAY**

a. The information in this paragraph will acquaint the aviator with the standard pilot briefing display. You should become familiar with the weather charts normally displayed in the airfield weather station. You should learn how to read and use these charts.

b. Many Army airfield weather stations do not maintain a continuous forecaster service. Aircrews flying into and out of these locations must therefore call a station with a 24-hour weather briefing capability. These 24-hour stations are listed in the flight information publication (FLIP) en route supplement.

c. Many limited-duty base weather stations will maintain a standard pilot briefing display when aircrews must receive flight weather briefings via telephone. The standard pilot briefing display described in this chapter is found only in CONUS. Similar charts may be available at other locations. As an Army aviator, however, you may operate in areas where no weather chart displays are available.

d. In some exercise and actual combat field operations, telephone briefing support may be available. In such cases, familiarity with maps, normal weather patterns, and terminology will greatly aid the aviator. In other cases, even telephone briefings may not be available. In such situations, it is essential

that the Army aviator understand meteorology to accurately assess the weather situation visually and to read correctly aircraft instrument indications.

### 18-3. BRIEFING DISPLAY CHARTS

a. Prior to calling for a weather briefing, the aviator must become familiar with all the information on the charts posted on the standard pilot briefing display (fig 18-1). Read the latest aviation weather observations, radar observations, and pilot reports applicable to the planned route to provide a picture of the current weather situation. You should also study the terminal forecasts for destination and at least one alternate if conditions indicate one may be required.

b. The standard pilot briefing display consists of the following:

- (1) Surface analysis.
- (2) Horizontal weather depiction.

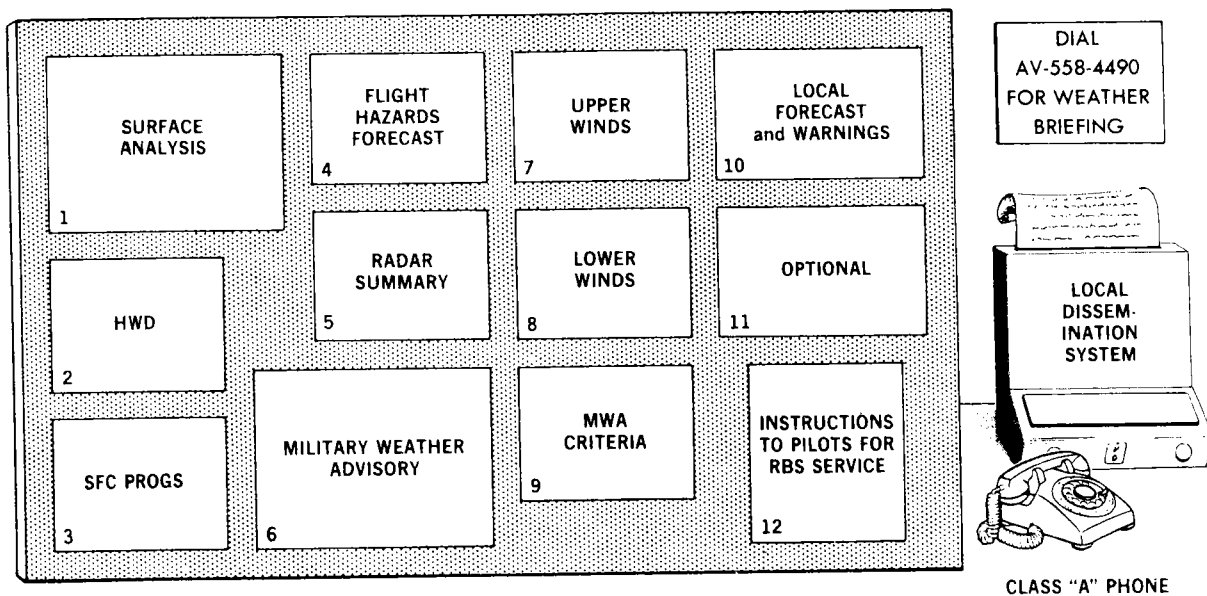


Figure 18-1. Standard pilot briefing display.



(3) Surface forecasts prognostic charts (surface progs).

(4) En route flight hazards forecast.

(5) Radar summary.

(6) Military weather advisory.

(7) Winds aloft charts (high-level wind panels).

(8) Winds aloft charts (low-level wind panels).

(9) Military weather advisory criteria.

(10) Local forecasts and weather warnings.

(11) Optional chart.

(12) Instructions to aircrews for regional briefing system service.

## 18-4. SURFACE ANALYSIS CHART—CHART 1

A surface analysis chart (fig 18-2) gives a view of weather conditions at a given time in the past. In the contiguous 48 states, a map covering these states and adjacent areas is transmitted every 3 hours. Other areas with facsimile receive surface weather maps appropriate to their areas at regularly scheduled

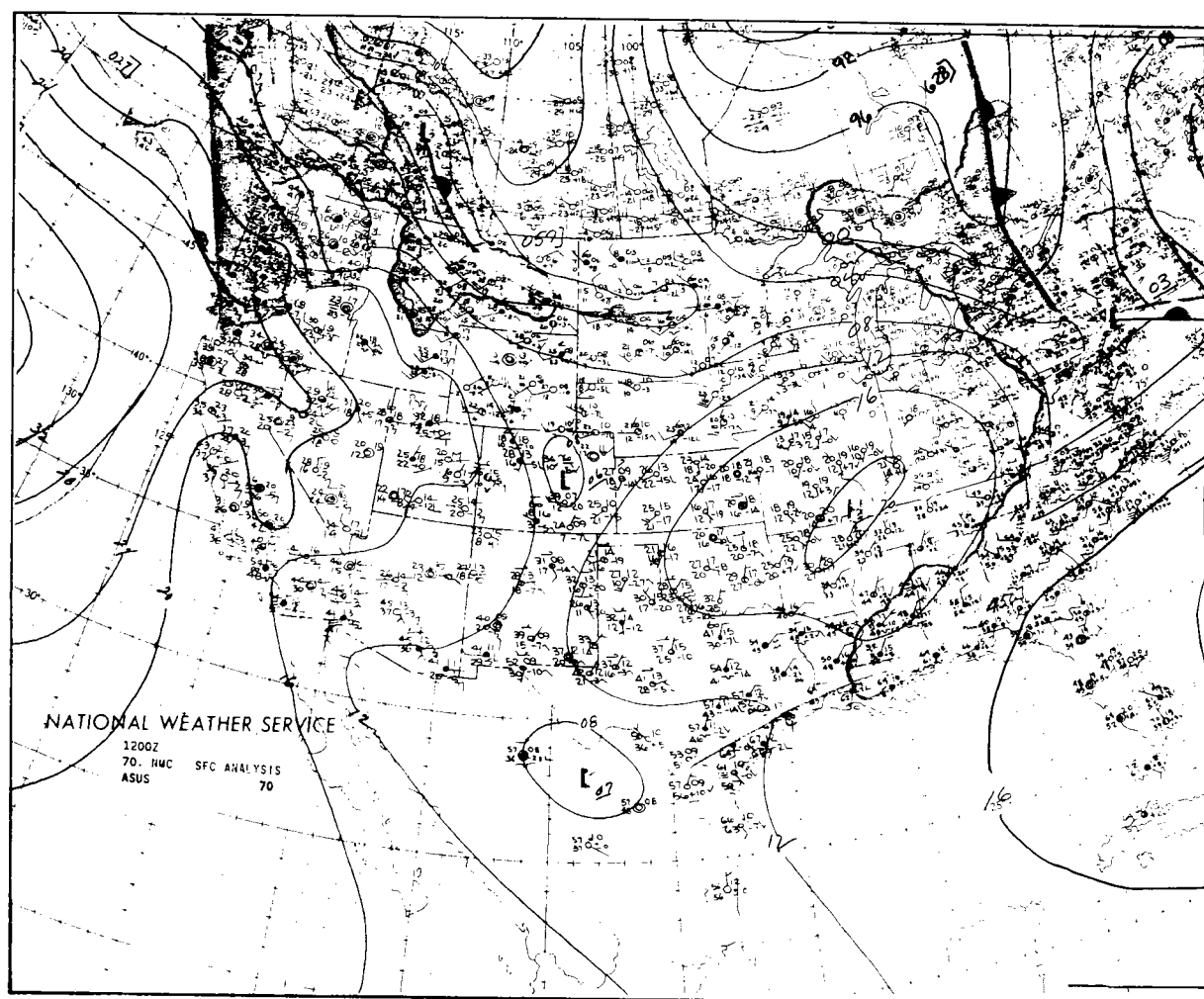


Figure 18-2. Surface analysis chart—chart 1.

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intervals. Most of the information plotted is for the forecaster. We will discuss only that portion of the plot valuable to the aircrew. The information pertinent to the aircrew is shown in the station model (fig 18-3).

*a. Analysis of Symbols.*

(1) Normally, isobars (lines connecting points of equal barometric pressure) are drawn at 4-millibar (mb) intervals. When the pressure gradient is weak, dashed isobars are sometimes inserted at 2-millibar intervals to more closely define the pressure pattern. Each isobar is labeled by two numbers representing the numerical value of that isobar. For example, 32 means 1032 mb; 00 is 1000 mb; and 92 is 992 mb.

(2) Pressure centers are designated by "L" for a low and an "H" for a high. The pressure at each center is indicated by a two-digit number which is interpreted the same as the isobar labels.

(3) Frontal analysis symbols are depicted in figure 18-4. There are some minor differences between the Air Weather Service and the National Weather Service color schemes and symbols. The "pips" on the frontal symbols indicate the type of front and point in the direction of frontal movement. Pips on both sides of a symbol of a stationary front suggest little or no movement. Weather personnel will color-code the fronts only as time permits.

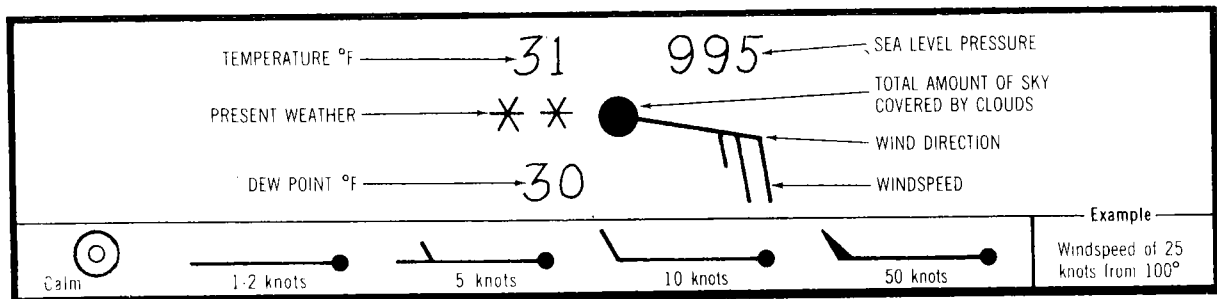
(4) Wind direction is plotted to the nearest 10 degrees relative to true north. The wind blows in a direction from the barb or pennant to the station circle.

(5) Basic weather symbols plotted on the chart appear in figure 18-5 and figure 18-6, table III.

*b. Using the Chart.* When using the surface analysis, concentrate on pressure patterns and fronts more than on plotted data. Keep in mind that weather systems move and conditions change. Since the chart is more than 2 hours old when received, use it as a guide to other briefing charts and teletype information. Use the surface analysis in conjunction with the weather depiction, radar summary, upper air, and prognostics (forecast charts) to obtain a more complete weather picture.

**18-5. HORIZONTAL WEATHER DEPICTION CHART—CHART 2**

The horizontal weather depiction chart (fig 18-7) is prepared from surface aviation observations and *is one of the most valuable graphic displays of weather*. This chart is a graphic presentation of visibility, total sky cover, cloud height or ceiling, and weather from the hourly weather reports. The plotting model (fig 18-8) is an abbreviated version of the station model given in figure 18-3.



**Figure 18-3. Station model.**

Type of Fronts	Color Scheme (If Used)	Symbolized Lines
Cold Front . . . .	Blue . . . . .	
Warm Front . . . .	Red . . . . .	
Occluded Front . . . .	Purple . . . . .	
Upper Cold Front . . . .	Blue . . . . .	
Upper Warm Front . . . .	Red . . . . .	
Stationary Front . . . .	Alternately Blue and Red . . . . .	
Trough Line . . . .	Black (AWS) . . . . .	
Ridge Line . . . .	Brown (NWS) . . . . .	
Squall Line . . . .	Black (AWS) . . . . .	
	Yellow (NWS) . . . . .	
	Black (AWS) . . . . .	
	Purple (NWS) . . . . .	

Figure 18-4. Symbols for indicating fronts.

a. **Total Sky Cover.** Total sky cover is shown by the station circle shaded as in figure 18-9.

b. **Cloud Height or Ceiling.** Cloud height is entered under the station circle in hundreds of feet. If total sky cover is scattered

or less, the height is the base of the lowest layer. If total sky cover is broken or greater, the height is the ceiling. Partly or totally obscured sky is shown by the same sky cover symbol. Partial obscuration is denoted by absence of a height entry. Total obscuration has a height entry denoting the indefinite ceiling (vertical visibility into the obscuration).

c. **Weather and Obstructions to Vision.** Weather and obstructions to vision are entered just to the left of the station circle using the same symbols as found on the surface analysis. Precipitation intensity is not entered. When several types of weather and/or obstructions are reported at a station, only the most significant one or two types are entered.

d. **Visibility.** When visibility is less than 7 miles, it is entered to the left of weather and obstructions to vision in statute miles and fractions. Figure 18-10 shows examples of plotted data.

TABLE I—TURBULENCE		TABLE III—WEATHER		
Symbol	Meaning	Symbol	Letter Designator	Meaning
	Light Turbulence		K	Smoke
	Moderate Turbulence		H	Haze
	Severe Turbulence		F	Fog
	Extreme Turbulence		L	Drizzle
TABLE II—ICING			R	Rain
Symbol	Meaning		S	Snow
	Light Clear Icing		RW	Rain Shower
	Moderate Clear Icing		SW	Snow Shower
	Severe Clear Icing		T	Thunderstorm
	Light Rime Icing		ZL	Freezing Drizzle
	Moderate Rime Icing		ZR	Freezing Rain
	Severe Rime Icing			Lightning
	Light Mixed Icing			Tropical Storm
	Moderate Mixed Icing			Hurricane (typhoon)
	Severe Mixed Icing			

NOTE: Character of precipitation is the manner in which it occurs. It may be intermittent or continuous. A single symbol denotes intermittent, a pair of symbols indicates continuous.

\* Intermittent      \*\* Continuous

Figure 18-5. Total amount of all clouds.

0		5	
	No clouds		Six-tenths
1		6	
	One-tenth or less, but not zero		Seven- or eight-tenths
2		7	
	Two- or three-tenths		Nine-tenths or more, but not ten-tenths
3		8	
	Four-tenths		Ten-tenths
4		9	
	Five-tenths		Sky obscured, or cloud amount cannot be estimated

Figure 18-6. Standard weather symbols.

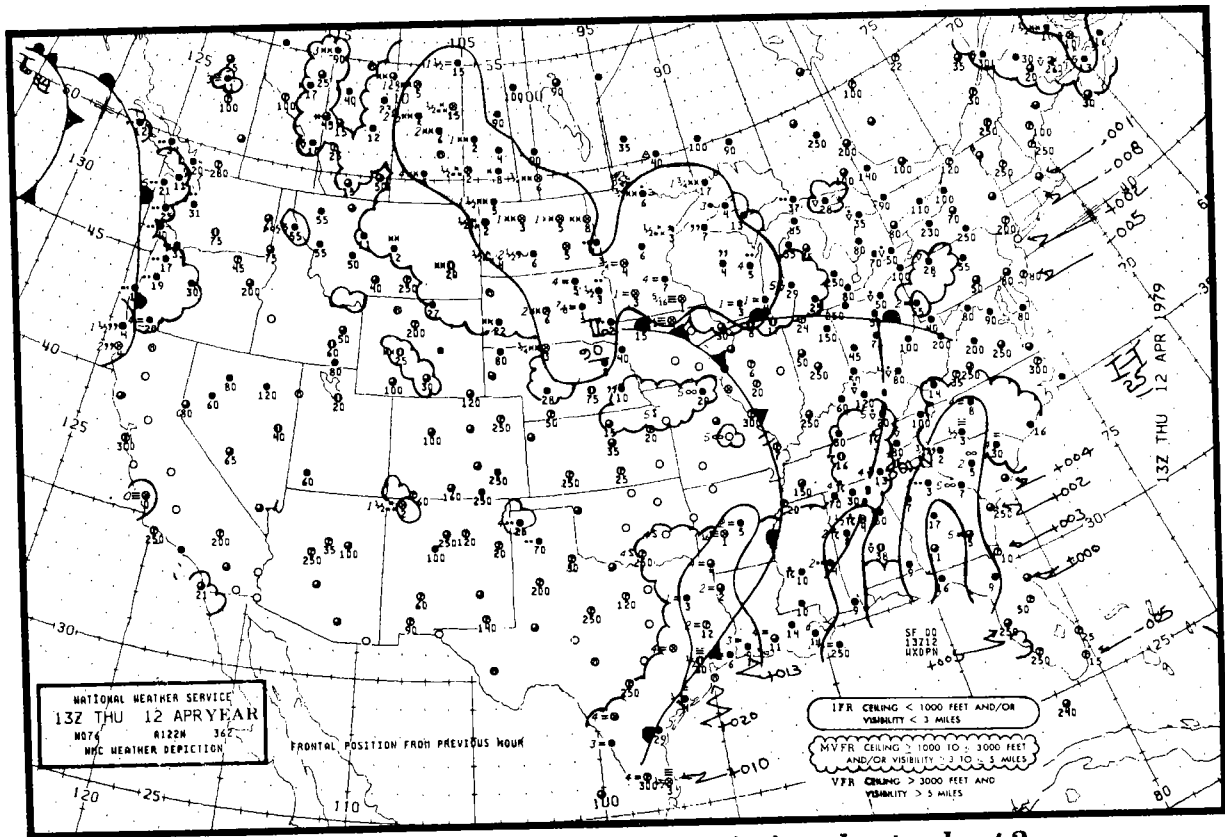


Figure 18-7. Horizontal weather depiction chart—chart 2.

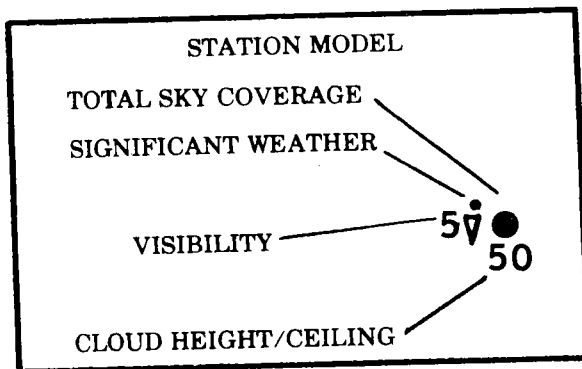


Figure 18-8. Plotting model.

e. Analysis of the Chart.

(1) Continuous lines (either solid or scalloped) outline areas where observed conditions at terminals have specified ceilings and/or visibility conditions. Isolated conditions over a small geographical area normally are not portrayed on this chart.

IFR—ceiling less than 1,000 feet and/or visibility less than 3 miles, outlined by a smooth line.

MVFR (marginal VFR)—ceiling 1,000 to 3,000 feet and/or visibility 3 to 5 miles inclusive, outlined by a scalloped line.

(2) Frontal positions from the preceding surface analysis chart will be depicted along with the major high- and low-pressure centers. These features are depicted the same as on the surface chart.

f. Using the Chart.

(1) The weather depiction chart gives information which directly affects flight plan decision-making. From it you can determine

Symbol	Meaning
○	Clear
⊕	Scattered
⊖	Broken
⦿	Overcast with breaks (BINOVC)
●	Overcast
⊗	Sky obscured or partially obscured

**Figure 18-9. Total sky cover.**

general weather conditions more readily than from any other source. It gives you a bird's-eye view at map time of areas of favorable and adverse weather, and pictures frontal and pressure systems associated with the weather. This chart does not eliminate the need for reading the selected hourly aviation weather reports, but does highlight the areas which need detailed study.

(2) This chart may not completely represent en route conditions because of variations in terrain and weather between stations. Furthermore, you should compare previous charts to obtain an idea of cloud changes and frontal movement. The area inclosed by the 1,000-foot and/or less than 3-mile smooth line may be helpful in determining bases below alternate minimums. After you initially evaluate the general picture, your final flight planning must consider forecasts, progs, and the latest pilot, radar, and surface weather reports.

## 18-6. LOW-LEVEL (SURFACE—400 MB) PROGNOSTIC—CHART 3

### a. General.

(1) The purpose of surface prognostic charts is to provide forecasts of significant weather at the surface and of cloud, turbulence, and precipitation through the lower layers. This layer normally extends up to 400 millibars (approximately 24,000 feet).

Plotted	Interpreted
⊕ <sub>8</sub>	Scattered clouds, base 800 feet, visibility more than 6 miles
⊖ <sub>12</sub>	Broken sky cover, ceiling 1,200 feet, rain shower, visibility more than 6 miles
2 ⊕	Sky clear, visibility 2 miles, fog
¼ ⊗ <sub>5</sub>	Sky obscured, ceiling 500 feet, visibility ¼ mile, snow
⊖ <sub>12</sub>	Overcast, ceiling 1,200 feet, thunderstorm, visibility 1 mile

**Figure 18-10. Examples of plotting on the horizontal weather depiction chart.**

(2) The US low-level prog is a four-panel chart as shown in figures 18-11, 18-12, and 18-13. The two lower panels are 12- and 24-hour surface progs. The two upper panels are 12- and 24-hour progs of significant weather from the surface to 400 millibars. The charts show conditions as they are forecast to be *at the valid time of the chart*.

### b. Analysis of the Chart.

(1) The two surface prog panels use standard symbols for fronts and pressure centers explained in the previous section. Isobars depicting forecast pressure patterns are included on some 24-hour surface progs.

(2) The surface prog outlines areas of forecast precipitation and/or thunderstorms. Smooth lines inclose areas of expected continuous or intermittent precipitation; dash-dot lines inclose areas of showers or thunderstorms. Symbols indicating precipitation type are the same as used on the surface analysis (fig 18-6, table III). If precipitation will affect half or more of an area, that area is shaded; absence of shading denotes less than half the area coverage.

(3) The upper panels of figure 18-11 depict ceiling, visibility, turbulence, and freezing level. Note the legend near the center of the chart which explains methods of depiction.

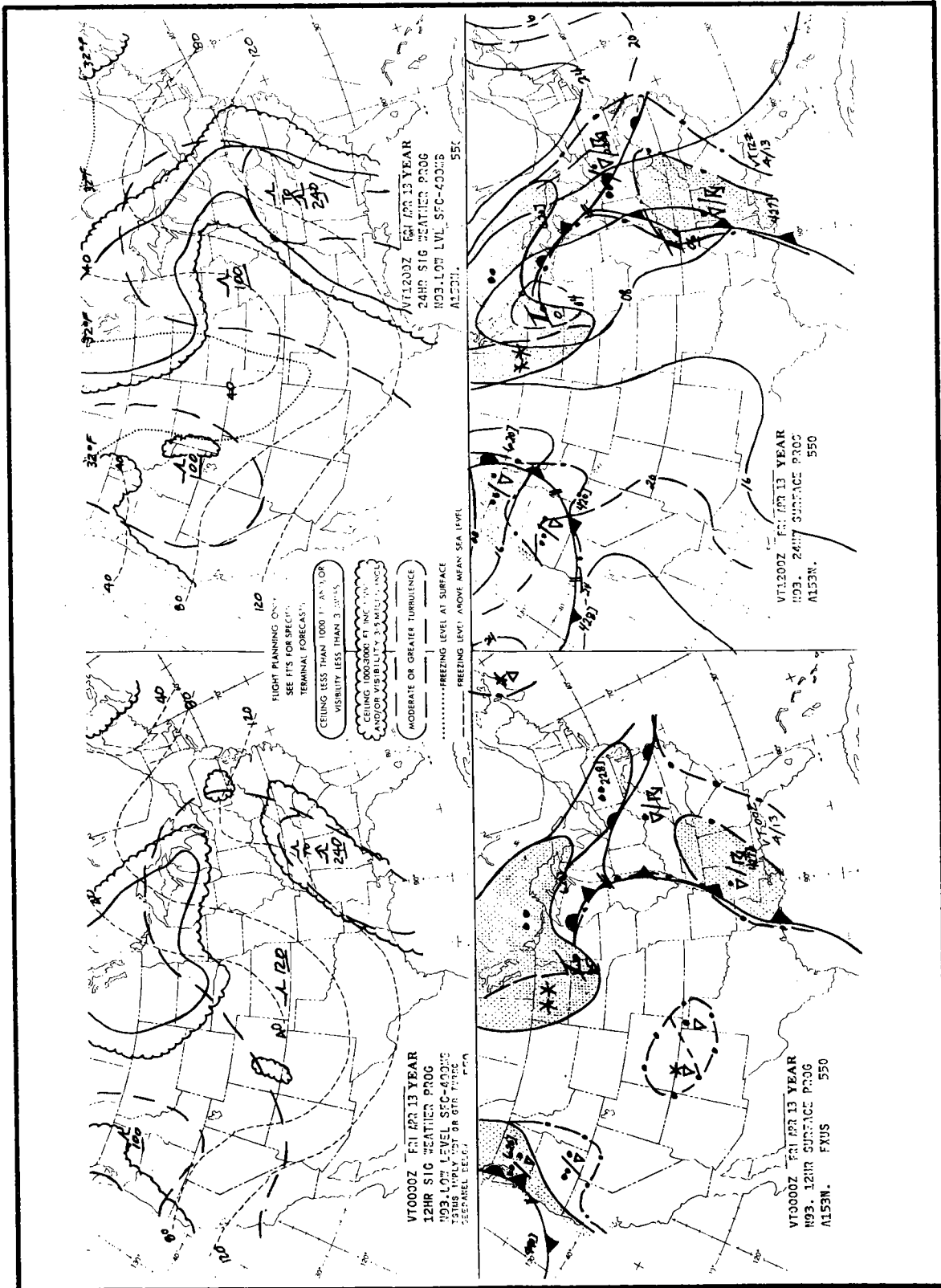


Figure 18-11. Low-level and surface prognostic chart— chart 3.

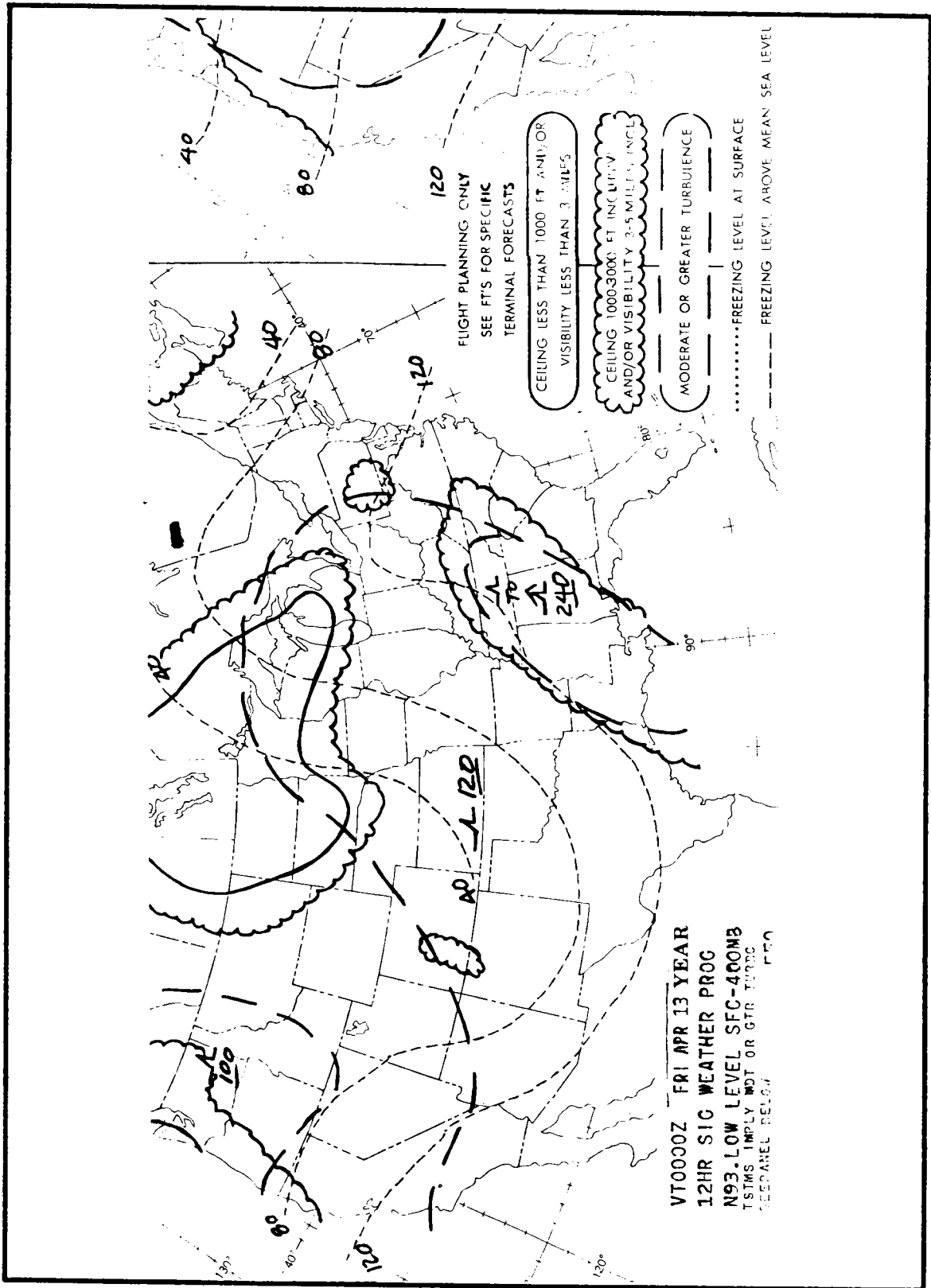


Figure 18-12. Upper panel chart— chart 3 continued.

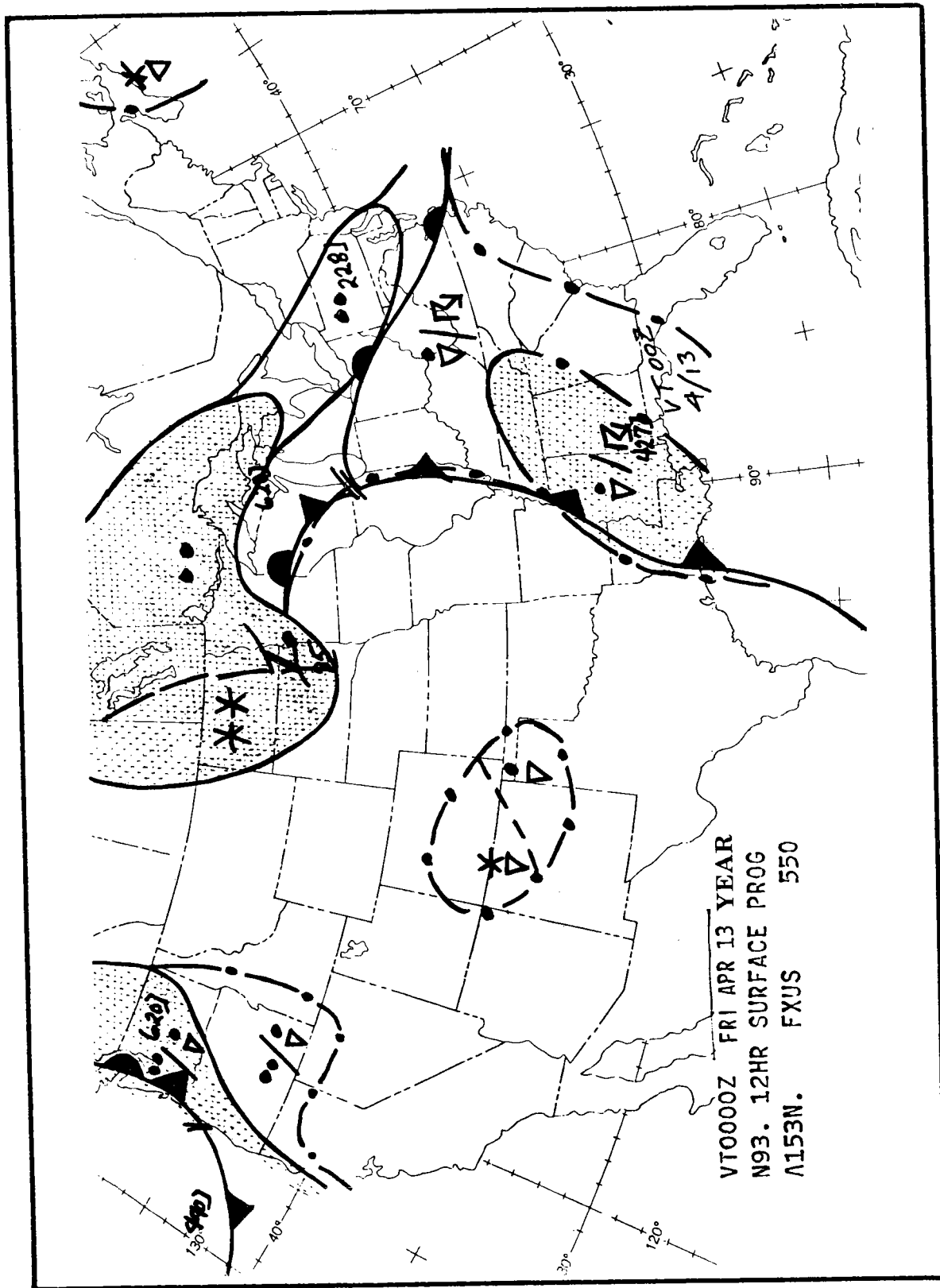


Figure 18-13. Lower panel chart—chart 3 continued.



(4) Smooth lines inclose areas of forecast IFR weather; scalloped lines inclose areas of marginal weather (MVFR); VFR areas are not outlined. Recall that this is the same manner of depiction used on the weather depiction chart to portray ceiling and visibility.

(5) Long dashed lines inclose general areas of forecast moderate or greater turbulence. Thunderstorms forecast on a surface prog, however, *always* imply moderate or greater turbulence in the storms even though a general area of turbulence may not be outlined on the associated significant weather panel.

(6) A symbol entered within a general area of forecast turbulence denotes intensity (fig 18-6, table I). Figures below and above a short line show expected base and top of the turbulent layer in hundreds of feet. Absence of a figure below the line indicates turbulence from the surface upward. In figure 18-12, for example, the annotation appearing over the Pacific Northwest denotes moderate turbulence from the surface to 10,000 feet.

(7) Freezing level height contours for the uppermost freezing level are drawn at 4,000-foot intervals beginning with 4,000 feet mean sea level (MSL). The 4,000-foot contour terminates at the 4,000-foot terrain level along the Rocky Mountains. Contours are labeled in hundreds of feet MSL. The freezing level line at the surface is labeled "32 degrees."

(8) The low-level significant weather prog does not specifically outline areas of icing. Icing, however, is always implied in clouds and precipitation above the freezing level.

#### c. Using the Chart.

(1) Low-level prog charts provide an overall forecast of weather conditions below

24,000 feet for fixed times. These charts do not replace forecasts for specific terminals, but supplement them by portraying general area forecast conditions. Specifics, such as ceiling and visibility, must be obtained from teletype/electrically transmitted station forecasts. By comparing progs with analyses, you can determine expected movement and changes in weather patterns.

(2) Significant weather progs for overseas locations normally cover a large geographical area. The symbols in figure 18-6 are used, but the legend may be somewhat different. It is best to consult a weather forecaster if you have any questions about the presentation of these details.

## 18-7. FLIGHT HAZARDS FORECAST—CHART 4

This display shows forecast areas of icing, clear air turbulence, and thunderstorms above 10,000 feet MSL (fig 18-14). The forecast areas of icing and clear air turbulence depict worst conditions (*not associated with thunderstorm activity*) expected within the period noted.

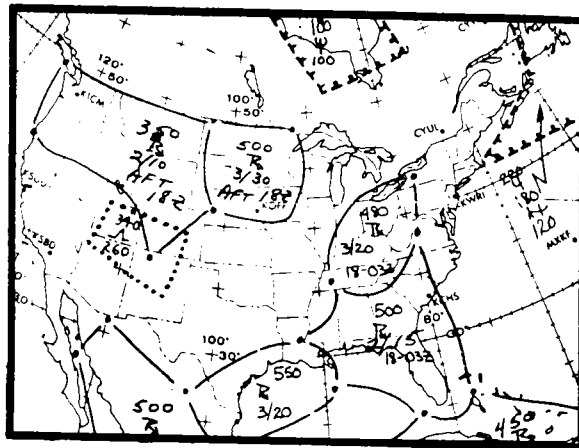



Figure 18-14. Flight hazards forecast—chart 4.

a. **Analysis of the Chart.** The flight hazards forecast chart contains the following information:

(1) **Icing:** Areas of forecast light or greater intensity icing.


(2) **Turbulence:** Areas of moderate or greater clear air turbulence. If mountain wave turbulence is forecast, it will be either spelled out or annotated as "MTN WV" on the chart.

(3) **Thunderstorms:** Areas of thunderstorms for which the maximum instantaneous coverage (MIC) is 2 percent or greater. Thunderstorms forecast on this chart will be more generalized than those forecast on the military weather advisory chart, the official severe weather guidance chart for the CONUS. Thunderstorm symbols will be displayed in the following format:

MAX TOPS  
  
 MIC/TAA  
 VALID PERIOD



(4) **MIC:** Percent of the area which will be covered by thunderstorms at the time of maximum activity; TAA is the percent of the area which will experience one or more thunderstorms during the applicable valid period.

Example:

<i><b>SYMBOL</b></i>	<i><b>MEANING</b></i>
480  3/20 18-03Z	Thunderstorms forecast from 18Z to 03Z. Maximum instantaneous coverage is 3 percent, while total area affected is 20 percent. Maximum thunderstorm tops are forecast to be 48,000 feet.

• Symbols for icing and turbulence are the same as found in figure 18-6, tables I and II.

Examples:

<i><b>SYMBOL</b></i>	<i><b>MEANING</b></i>
300  230	Moderate turbulence from 23,000 to 30,000 feet.
180  120	Severe mixed icing from 12,000 to 18,000 feet.

• Hazards associated with weather systems move with the system. Therefore, an area on the flight hazards forecast chart represents the movement, if any, of the hazard through the area during the time period. For example, in figure 18-14, the moderate turbulence area over the Southwest may mean that the turbulence is forecast over western Utah and Arizona at the beginning of the period and is expected to move to eastern Colorado and New Mexico by the end of the period.

b. **Using the Chart.**

(1) The flight hazards forecast chart is the official Air Force forecast of clear air turbulence and icing. It serves as the official forecast guidance for thunderstorms in the Pacific. Thunderstorms in the CONUS are normally covered in the Air Force global weather center (AFGWC) military weather advisory, while thunderstorms in Europe are covered in the AFGWC European military weather advisory.

(2) Use this significant weather prog in planning your flight to avoid areas and/or altitudes of probable significant icing and turbulence. This chart may also be used in conjunction with the AFGWC military weather advisory or weather warning advisory to plan your flight to remain clear of possible thunderstorms. By comparing progs with analyses, you can determine expected movement and changes in weather patterns.

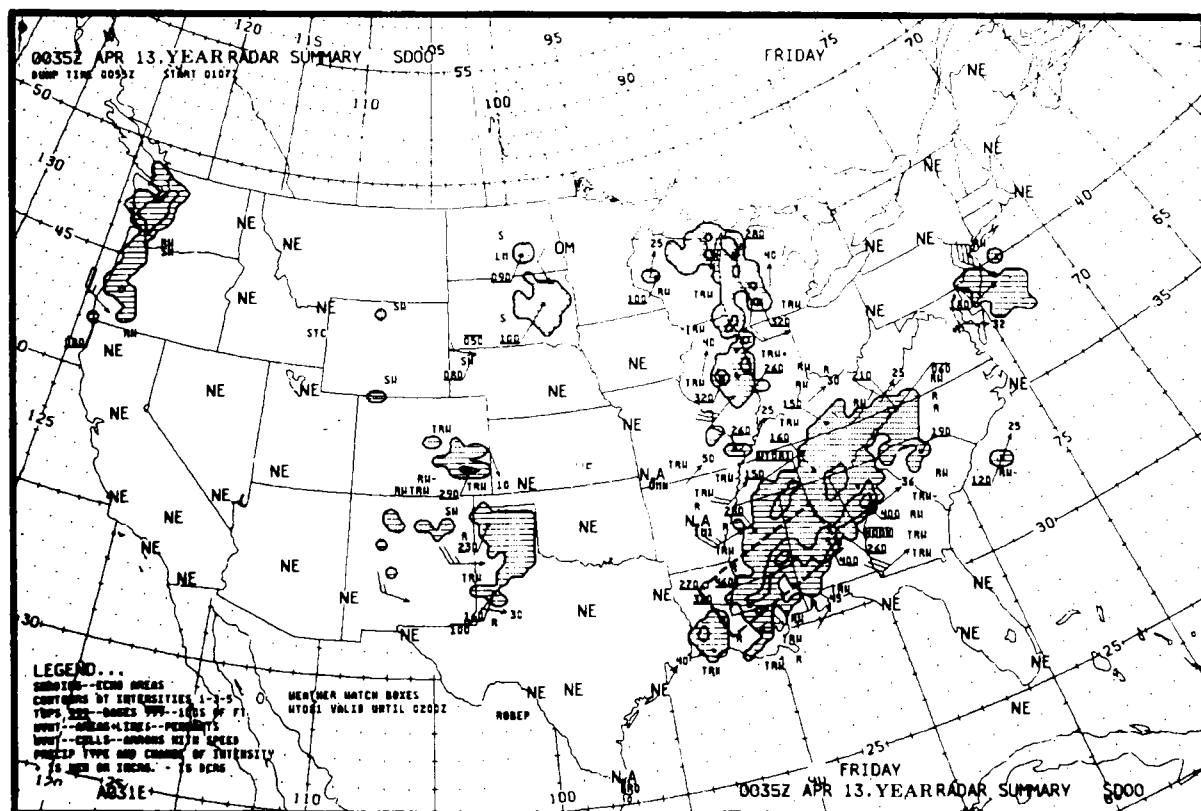


Figure 18-15. Radar summary chart.

### 18-8. RADAR SUMMARY CHART—CHART 5

The automated radar summary chart (fig 18-15) graphically displays a collection of radar weather reports. It is produced by computer, using coded surface radar observations. It shows precipitation echoes indicating their location, coverage, movement, and

tops, along with other pertinent information associated with the echoes. Also, note the time of this chart in particular. Convective activity changes rapidly, and often this chart is more than 2 hours old.

a. *Analysis of the Chart.* A legend appears in the lower left-hand corner of the automated radar summary chart (fig 18-16).

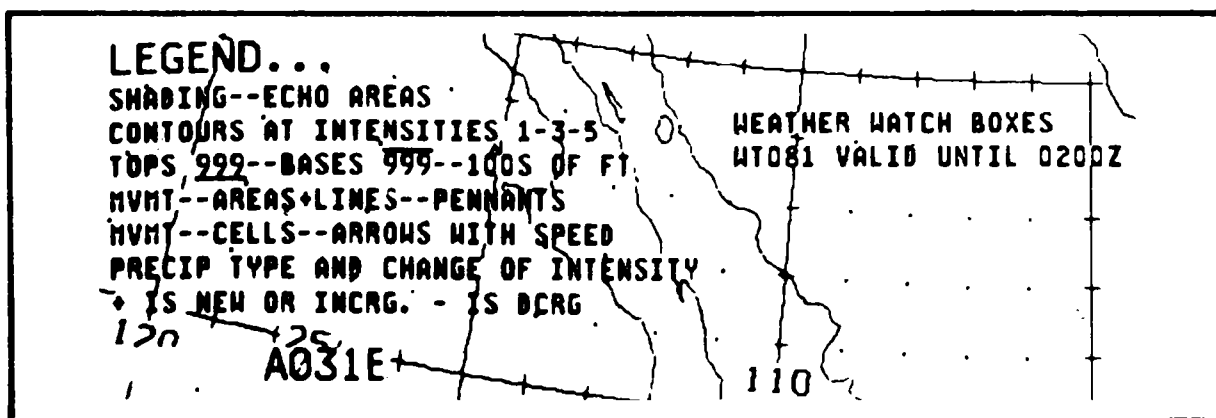
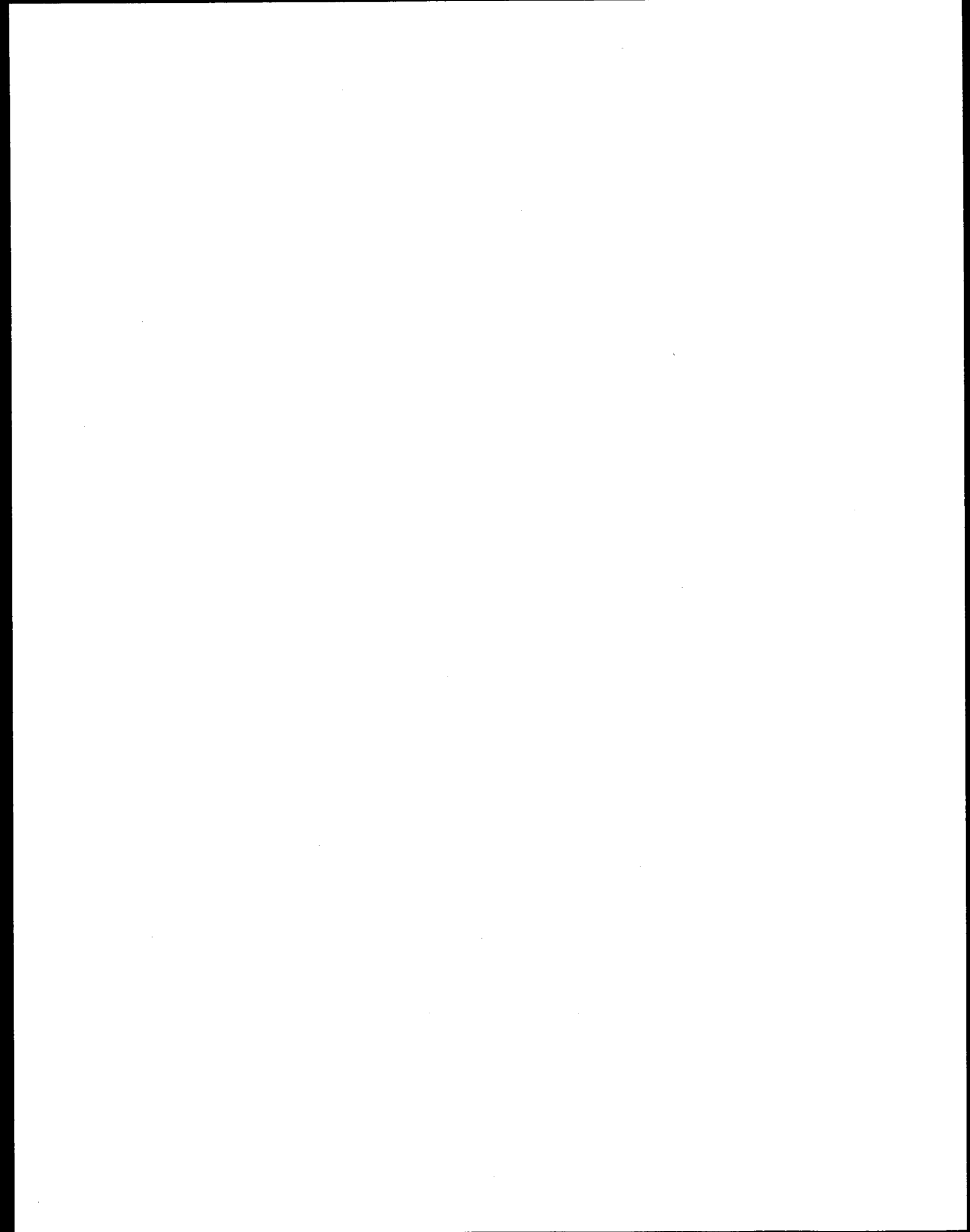
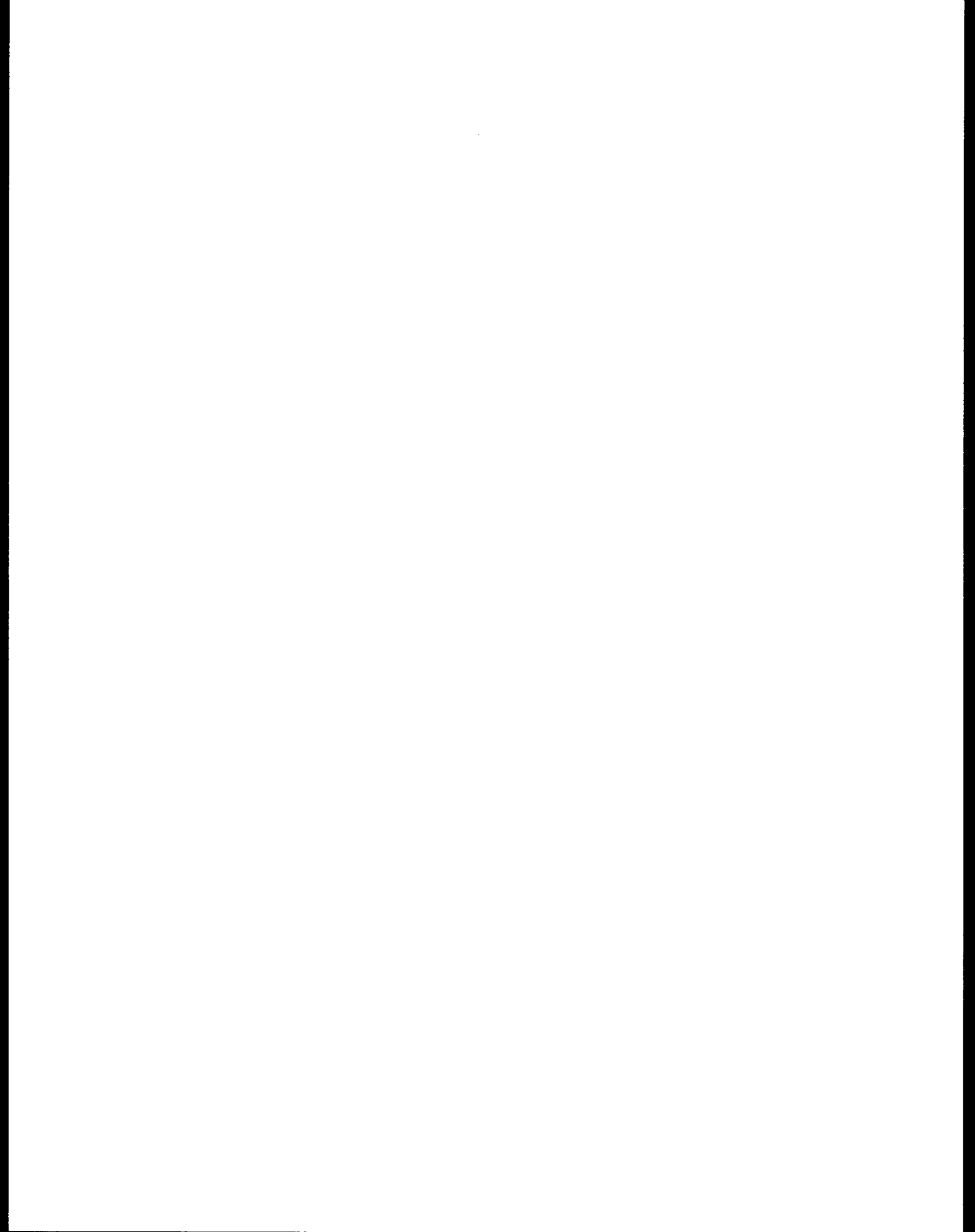


Figure 18-16. Radar summary legend.





Refer to it for explanation of weather echoes appearing on the chart. The legend does not include a discussion of the following symbols which may appear on the chart, but as an Army aviator, you should be familiar with them:

(1) *Precipitation-type symbols associated with echoes.*

<u>Symbol</u>	<u>Precipitation Type</u>
R	Rain
RW	Rain shower
TRW	Thundershower
ZR	Freezing rain
ZRW	Freezing rain shower
S	Snow
SW	Snow shower
L	Drizzle
ZL	Freezing drizzle
A	Hail

(2) *Change of intensity of radar return.*

<u>Symbol</u>	<u>Echo Intensity</u>
+	New or increasing
-	Decreasing

Contours are drawn on the chart indicating relative intensity with less intense echoes corresponding to level 1 and most intense echoes corresponding to level 5.

(3) *Severe weather watch boxes.* Severe weather watch areas are issued by the National Weather Service when the potential for tornadoes and/or severe thunderstorms exists over a specific area. These areas are shown on the radar chart as dashed lines inclosing the watch area. The watch number is also included. A labeled area at the bottom of the chart will indicate the watch number and the valid time the watch is in effect.

(4) *Status of radar equipment.*

<u>Symbol</u>	<u>Meaning</u>
NE	Equipment operating, but no echoes observed
NA	Observation not available
OM	Equipment out for maintenance

b. *Using the Chart.*

(1) The radar summary chart aids in preflight planning by identifying general areas and movement of precipitation and/or thunderstorms. Remember radar detects only water droplets or ice particles of precipitation size; it does not detect clouds and fog. The absence of echoes, however, does not guarantee clear weather. Furthermore, actual cloud tops may be higher than precipitation tops detected by radar. The chart gives general movement and intensity changes which will aid in deciding what may happen *later*. The chart must be used in conjunction with other charts, reports, and forecasts.

(2) Review both current and previous radar summary charts. Examine chart annotations carefully. Always determine location and movement of echoes. If echoes are forecast near your planned route, take special note of echo intensity and movement. Keep in mind that thunderstorms and rain showers shown on the chart may change intensity in a matter of minutes.

### 18-9. MILITARY WEATHER ADVISORY—CHART 6

AFGWC prepares and transmits a 12-hour military weather advisory which is a forecast of possible severe weather. Two versions are produced; one is a facsimile presentation (fig 18-17), while the other is a graphical teletype product.

*a. Analysis of the Chart.*

(1) *MWA codes (known as chart 6).*  
The forecast is coded as follows:

- Red—tornadoes, waterspouts, or funnel clouds.

- Blue—severe thunderstorms (maximum wind gusts of 50 knots or greater and/or hail, if any, three-fourths inch or greater in diameter) and locally damaging windstorms.

- Green—moderate thunderstorms (maximum wind gusts of 35 knots or greater, but less than 50 knots; and/or hail, if any, one-half inch or greater in diameter, but less than three-fourths inch in diameter).

- Orange—thunderstorms (maximum wind gusts less than 35 knots and/or hail, if any, less than one-half inch in diameter).

- Black—strong surface winds (35 knots or more and not associated with thunderstorms).

- Purple—heavy rain (2 inches or more in 12 hours or less).

- Hatched purple—heavy snow (2 or more inches in 12 hours or less).

- Brown—freezing precipitation.

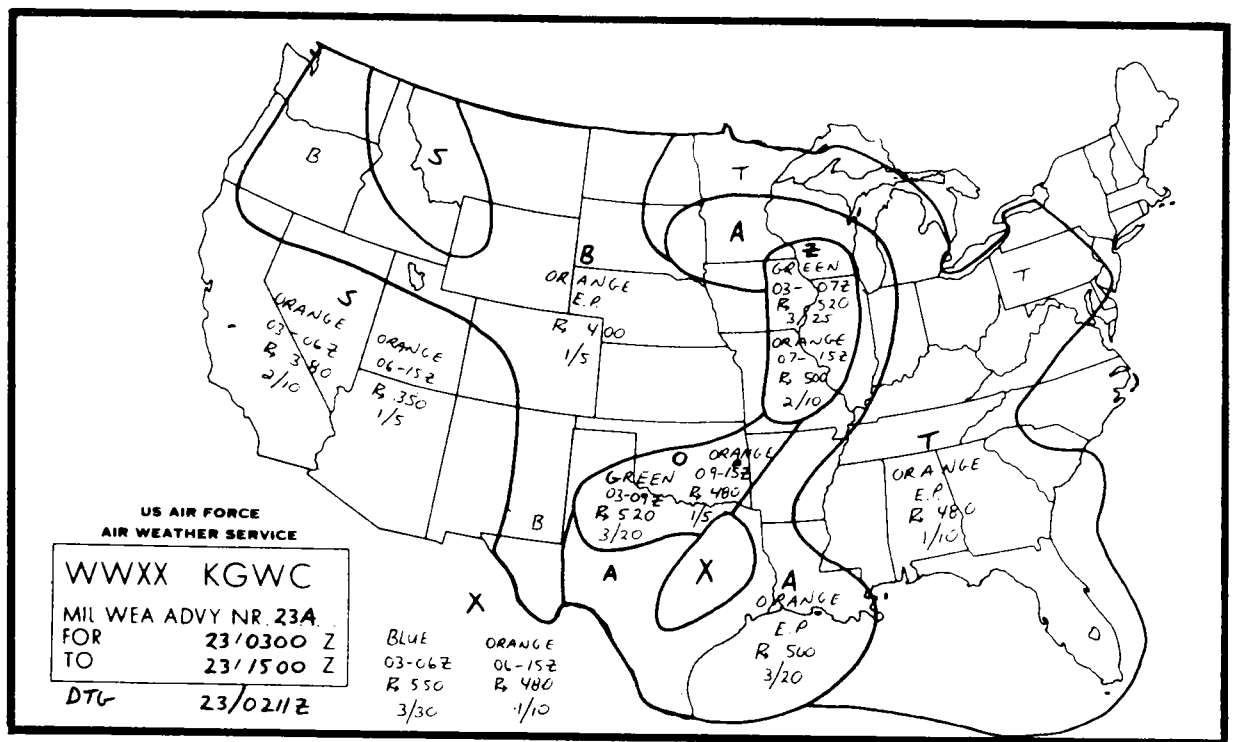


Figure 18-17. Military weather advisory—chart 6.

(2) *Other abbreviations.*

- MIC (maximum instantaneous coverage)—the percent of the area which will be covered by thunderstorm cells at time of maximum activity.

- TAA (total area affected)—the percent of the area which will experience one or more thunderstorms during the applicable valid period.

- EP (entire period)—used if the phenomena are expected for the entire period instead of a particular time period.

(3) *Maximum thunderstorm tops.*

The percentages of MIC and TAA will be entered in the thunderstorm areas as MIC/TAA (such as 3/25). The advisory areas will be inclosed by solid lines with a letter designator within the area. Forecast areas depict the worst conditions expected during period noted.

(4) *Teletype bulletin.* This bulletin contains information identical to the facsimile product. It also serves to amend and correct both the facsimile and teletype product.

*b. Using the Chart.* Use the contents of this advisory strictly as a preflight aid to help plan your route of flight to avoid possible severe weather. Compare the MWA forecast with the existing or latest weather in the available weather charts and teletype reports. Request clarification and update via the telephone briefing too.

## 18-10. WINDS ALOFT CHARTS—CHARTS 7 AND 8

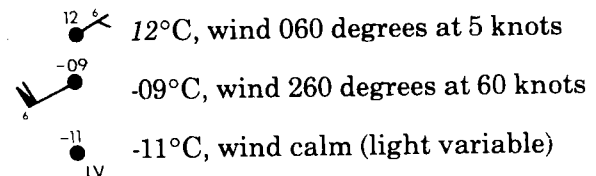
### *a. Forecast Winds and Temperatures Aloft.*

(1) Forecast winds and temperatures aloft charts are prepared for eight levels in eight separate panels. A legend on each panel shows the valid time and level of the chart.

Levels below 18,000 feet are true altitudes, while levels 18,000 feet and above are pressure altitudes or flight levels. Figures 18-18 and 18-19 are panels of a wind and temperature aloft forecast.

(2) Temperature in degrees Celsius ( $^{\circ}\text{C}$ ) for each forecast point is entered in one or two digits above the station circle. Arrows with pennants and barbs similar to those used on the surface map show true wind direction and speed. Wind direction is drawn to the nearest 10 degrees, and the second digit of the coded direction is entered at the outer end of the arrow. A calm or light variable wind is shown by "LV" entered in the lower right of the station circle. Following are examples of plotted temperatures and winds with their interpretations:

#### PLOTTED



*b. Observed Winds Aloft.* Charts of observed winds for selected levels are sent twice daily on a four-panel chart. Wind direction and speed at each observing station are shown by arrows the same as the forecast charts. Figure 18-20 is a panel of the observed wind aloft chart. Observed temperatures are included on the upper two panels (24,000 feet and 34,000 feet).

### *c. Using the Charts.*

(1) Use the winds aloft chart to determine winds at a proposed flight altitude or to select the best altitude for a proposed flight. The information can also be used to compute correct headings, ground speed, and temperature at altitude. To determine winds and temperatures at an altitude between charted levels, interpolate between the charted levels. Estimate flight level temperatures by using the latest prog for the level nearest your designed altitude. Adjust the temperature  $2^{\circ}\text{C}$  per 1,000 feet of altitude according to your planned flight level.



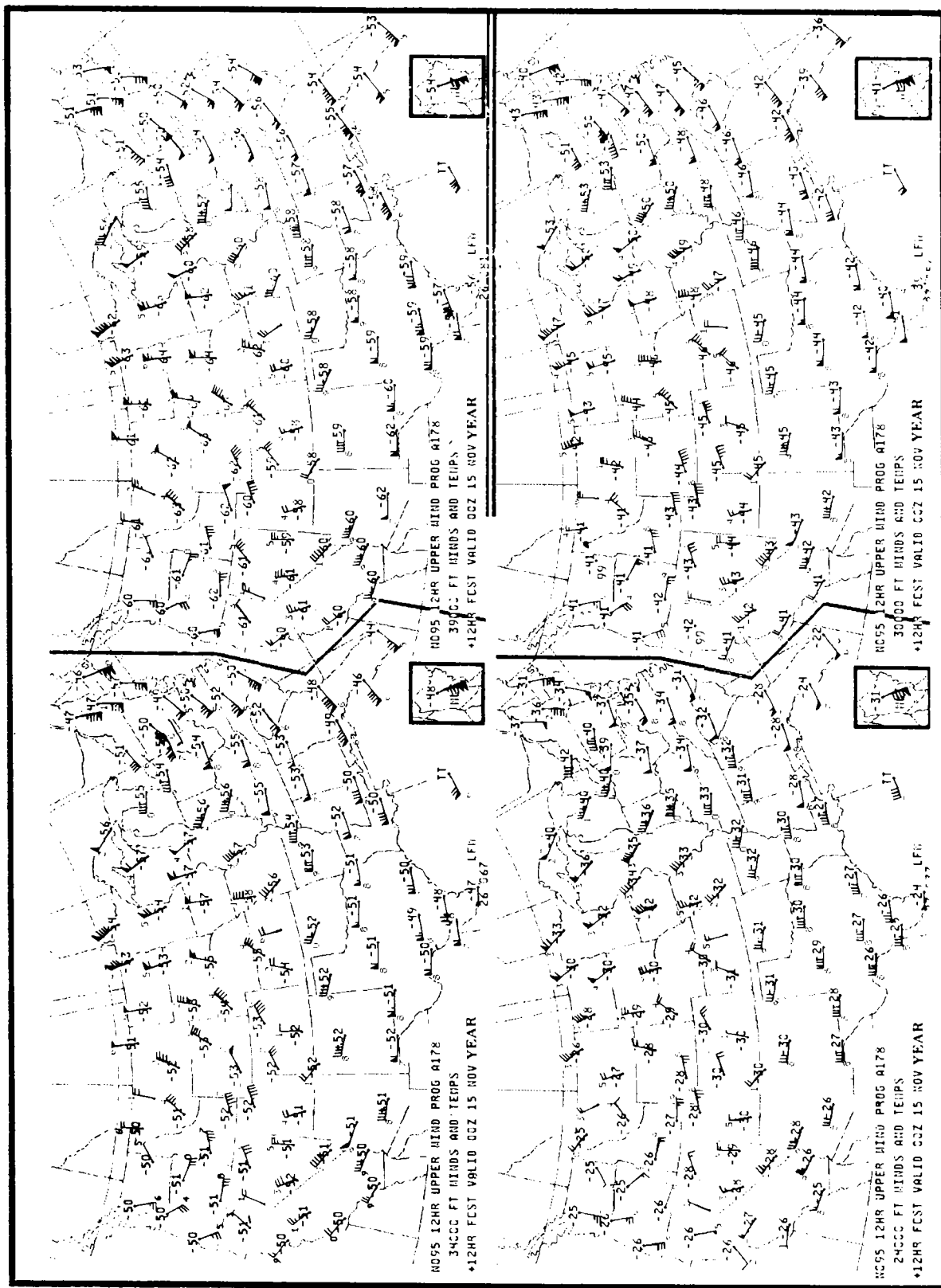


Figure 18-18. Upper-level forecast winds—chart 7.



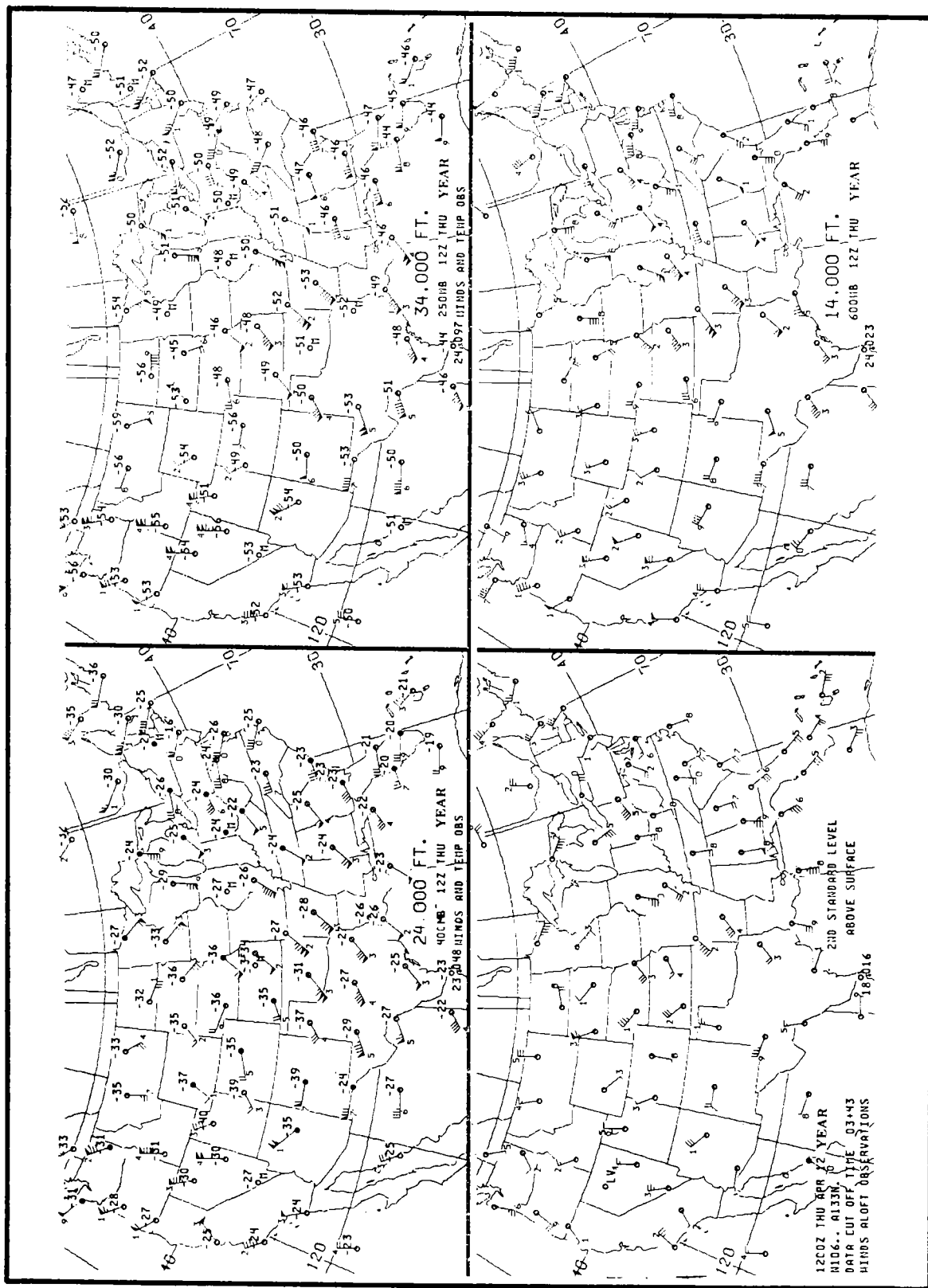


Figure 18-20. Observed winds aloft chart.

(2) Remember, forecast winds are generally preferable to observed winds since they are more relevant to flight time. Observed winds are 5 to 8 hours old when received by facsimile, and their reliability diminishes with time.

**18-11. MILITARY WEATHER ADVISORY CRITERIA—CHART 9**

Chart 9 in the standard pilot briefing display is a permanent display of the color codes and discussion of MIC and TAA found on the military weather advisory—chart 6.

**18-12. LOCAL SCHEDULED FORECASTS AND POINT WARNINGS—CHART 10**

Local forecasts and weather warnings will be written in this space as required.

**18-13. OPTIONAL CHART—CHART 11**

a. *General.* Some examples of optional charts you may see include—

- (1) Constant pressure chart.
- (2) Satellite imagery.
- (3) Freezing level chart.
- (4) Astronomical/climatological tables.
- (5) Regional briefing system/pilot-to-metro service facilities.
- (6) Low-level bombing route forecasts.
- (7) Primary and alternate forecasts.
- (8) Range and drop zone forecasts.

b. *Constant Pressure Charts.* Constant pressure charts with surface weather charts are used by the forecaster to find what past conditions existed in the atmosphere. Constant pressure charts, together with surface weather charts and other charts and

diagrams, present a three-dimensional picture of the atmosphere. The standard pressure surfaces for which these charts are prepared and transmitted by facsimile are listed below with their corresponding approximate altitudes.

STANDARD PRESSURE SURFACE	APPROXIMATE HEIGHT ABOVE MEAN SEA LEVEL	
<i>Millibars</i>	<i>Meters</i>	<i>Feet</i>
1,000	120	400
850	1,500	5,000
700	3,000	10,000
500	5,500	18,000
300	9,000	30,000
250	10,000	34,000
200	12,000	39,000

**18-14. SATELLITE CHARTS**

a. *General.* Satellite imagery allows us to see weather systems and prominent land features in near real time from a vantage point high above the earth. This ability has led to a tremendous increase in confidence in the forecast for the aircrew member and forecaster alike. Ironically, it has also led to a special trap called *nowcasting*. It is very tempting for a person to look at a satellite photo that is 30 minutes old and believe that nothing will change during the period of the proposed flight.

b. *Using the Chart.*

(1) Satellite imagery should be used exactly the same way as any other weather chart. Compare the satellite chart to the horizontal weather depiction chart for a broad area observation. Then, refer to the low-level prog chart to see how systems are expected to move or change in intensity.

(2) Aircrew members must remember that satellite pictures should not be used to forecast. They give an overall view of *past* cloud patterns. Satellite imagery should be interpreted only by qualified weather forecasters.

## CHAPTER 19

## 19-1. MONITORING THE WEATHER

There are seldom enough observations to fully describe the weather for all portions of the route. The science of forecasting does not provide for total accuracy in its prediction. The aviator must continue to analyze the weather en route and update his weather forecast using any means available. The present system provides many ways to keep abreast of current conditions, significant changes, and updated forecast conditions.

*a. Weather Broadcasts.* Selected FAA flight service stations (FSS) continuously broadcast transcribed weather data over the voice feature of the low-frequency navigational aids and VHF-omnidirectional range (VOR) facilities.

*b. Weather Advisories.* Special weather developments and notices to airmen are broadcast upon receipt by flight service stations. Two special weather advisories, significant

meteorological information (SIGMET) and airman's meteorological information (AIRMET), provide immediate weather information that may endanger aircraft in flight.

(1) **SIGMET (fig 19-1).** This advisory is issued when the weather phenomena are potentially hazardous to single-engine and light aircraft and, in some cases, to all aircraft. This would include the following:

- Tornadoes.
- Severe lines of thunderstorms (squall lines).
- Embedded thunderstorms.
- Hail three-fourths of an inch or greater.
- Severe turbulence.
- Severe icing.
- Widespread dust storms/sandstorms, lowering visibility to less than 2 miles.

```

WBC UWS 060645
SIGMET INDIA 1 060645061045
OH
FM 25S DET TO CMH TO CVG TO 40NE FWA
CCNL MDT TO SVR RIME ICGICIP EXPCD SPCLY BTWN 50120 DUE TO OVRNG
MXD PCPN. FRZLVL NR SFC. CONDS CONTG BYD 1045Z AND SPRDG. OVR SERN
OH INTO SWRN WV.
JTF

```

Figure 19-1. Typical SIGMET.

```

MKC WA 061015
AIRMET WHISKEY 1 061015061615
ND SD NE
FM 06N ISN TO 07N GFK TO OMA TO LBF TO 03SW RAP
CONL MDT MXD ICGICIP ABV FRZLVL EXPCD DUE TO CLDS AND SCT PCPN. FRZLVL
SFC030. CONDS CONTG BYD 1615Z AND SPRDG OVR SERN QTR NE AND NERN QTR
BY 16Z.
WEISS
    
```

*Figure 19-2. Typical AIRMET.*

(2) **AIRMET (fig 19-2).** This advisory is issued when the weather phenomena are potentially hazardous to single-engine and light aircraft and, in some cases, to all aircraft. This would include the following:

- Moderate icing.
- Moderate turbulence.
- Sustained winds of 30 knots or more at, or within, 2,000 feet of the surface.
- Extensive areas where visibility is less than 3 miles and/or ceilings are less than 1,000 feet, including mountain ridges and passes.

(3) **Identification of SIGMET and AIRMET.** SIGMET and AIRMET are issued by the weather service forecast officer (WSFO) for their area, and are classified by letter and number for identification. The letter identifies the area and the number is used to update. The first SIGMET issued after 0000Z would be ALFA 1 with any revisions labeled as ALFA 2, etc. If a different area of the WSFO region is concerned, it would be listed as BRAVO 1, etc. FAA flight service stations broadcast SIGMET and AIRMET during their valid period as follows:

- **SIGMET** advisories are transmitted at 15-minute intervals during the first hour at H + 00, H + 15, H + 30, and H + 45.
- **AIRMET** advisories are transmitted at 30-minute intervals during the first hour at H + 15 and H + 45. After the first hour, an alert notice is forecast at 15 and

45 minutes past each hour, advising pilots which SIGMETs or AIRMETs are valid. The aviator receiving these notices should contact the nearest flight service station for information on these advisories to determine if his flight may be affected.

*c. Pilot to Weather Briefer/Forecaster.*

(1) **FAA flight service station.** Direct pilot weather briefing service is available by radio contact to any FAA flight service station. This would provide the aviator with available in-flight weather data much like that offered during a preflight briefing.

(2) **Pilot-to-metro service (PMSV).** The PMSV can provide an update to weather forecast for the in-flight phase. The advantage of this service over that provided by FAA flight service is that a forecaster is available rather than a briefer. Locations of pilot-to-metro facilities and operating times may be found in the flight information publication (FLIP) en route supplement.

*d. En Route Flight Advisory Service.* This is a civil advisory service which parallels the military PMSV described above. This service is designed to provide timely weather information pertinent to the type of flight, route, and altitude along prominent airways. It is provided by selected FAA flight service stations using the station name followed by the phrase "FLIGHT WATCH."

**NOTE**

**En route FLIGHT WATCH is not intended to be used for flight plan filing, routine position reporting, or to obtain a complete briefing in lieu of contacting an FSS or National Weather Service office prior to the flight.**

**19-2. WEATHER RADAR**

Many times a mission requires a flight under conditions of hazardous weather in the form of heavy precipitation areas, thunderstorms, and possible tornadoes. If further flight cannot be conducted under visual flight rules (VFR), then a proper instrument flight rules (IFR) flight plan should be filed.

*a. Ground-Based Systems.* Ground-based radar facilities offer the aviator a means for identifying potentially dangerous areas of weather with the additional capability of vectoring the aircraft to avoid them.

(1) *Air traffic control (ATC) radar.* Air traffic control radar can detect weather, but it is limited in capability when compared to true weather radars. Some of the shortcomings of ATC radar are—

- Frequency and wavelength are not best suited for weather detection.
- Lack antenna tilt capability.
- Have no iso-echo (contour) capability for best weather interpretation.
- When aircraft targets are obscured by weather, they must adjust equipment to eliminate weather interference.
- ATC radar is primarily for traffic control—not for weather advisories.

The use of ATC radar to advise pilots of isolated storm cells and the vectoring around

them is a very good service. However, the aviator should be aware that they do not have a real weather vectoring capability in extensive storm areas or in lines of thunderstorms.

(2) *Weather radar facilities.* Many of the pilot-to-metro facilities have weather radar equipment (see FLIP supplement) and can provide radar storm advisory service to en route aircraft. These radar units operate at a frequency and wavelength best suited to weather detection. They also have antenna tilt and calibrated gain control circuits or contour circuitry for good interpretation of storm cell echoes. The weather personnel using this type equipment can advise pilots as to—

- The horizontal extent and top of squall lines.
- Individual thunderstorms.
- Thunderstorm complexes.
- Other phenomena.

The weather personnel can determine—

- Which cells may represent severe weather.
- Where it appears easiest to penetrate a line of thunderstorms.
- Whether an echo system is too high to overfly.
- The most open route by which a terminal can be approached.
- Other needed information.

All of this is usually available through a simple radio call to weather personnel through the PMSV frequency. *However, USAF weather forecasters are prohibited from vectoring aircraft around weather echoes.*

**NOTE**

**When using PMSV/WX radar information for avoiding severe storm areas, the aviator must coordinate with the appropriate ATC controller before deviating from his assigned route of flight.**

*b. Airborne Weather Radar.* (See chapter 13.)

**19-3. PILOT REPORTS (PIREP)**

Pilot reports provide the forecaster with timely and accurate observations of conditions aloft which cannot be observed from the ground. Such conditions observed between weather reporting stations are often the first indication of the beginning of hazardous flying weather, especially turbulence and icing conditions.

*a. Requirement to Report.* The Federal Aviation Regulations (FAR) or IFR flights require a mandatory report of any significant weather conditions. AR 95-1 requires that in-flight and postflight weather reports will be made to requesting agencies. Any unforecast weather conditions will also be reported without request to appropriate agencies. Refer to DOD FLIP for procedures. The FAA stations are required to solicit and collect PIREPs which describe conditions aloft whenever ceilings are at or below 5,000 feet, visibilities are at or below 5 miles, or thunderstorms are reported or forecast. The pilot should realize the importance of his contribution to the system and volunteer reports of cloud tops, upper cloud layers, thunderstorms, ice, turbulence, strong winds, and other significant flight condition information.

*b. Making the Report.* The main criteria for reporting is when unforecast or hazardous weather conditions are encountered which have not been forecast. PIREP should be given to the FAA ground facility with which the aviator is communicating; that is, air route traffic control, approach control, or FSS. In addition to complete PIREPs, pilots can materially help round out the in-flight

weather picture by adding to routine position reports, both VFR and IFR, the type aircraft and the following phrases as appropriate:

**ON TOP**

**BELOW OVERCAST**

**WEATHER CLEAR**

**MODERATE (or HEAVY) ICING**

**LIGHT, MODERATE, SEVERE, OR EXTREME TURBULENCE**

**FREEZING RAIN (or DRIZZLE)**

**THUNDERSTORMS (location)**

**BETWEEN LAYERS**

**ON INSTRUMENTS**

**ON AND OFF INSTRUMENTS**

If pilots are unable to make PIREPs by radio, they may be made to the FSS or weather services officer upon landing.

*c. Body of the Report.* The actual report should consist of the following:

- (1) Location.
- (2) Time (Greenwich mean time).
- (3) Phenomena reported.

- Any hazardous weather (with explanatory remarks such as direction of movement of storms, frequency of lightning, and/or hail).

- Bases and/or tops of cloud layers and coverage if known.

- Smoke, haze, or dust layer with top of layer and the horizontal visibility in the layer.

- Marked wind changes.

- All turbulence with intensity, duration, and proximity to clouds.



- All airframe icing with intensity and type.

(4) Altitude of phenomena.

(5) Type of aircraft.

Airframe icing and turbulence should be elevated according to criteria listed in current navigation publications (FLIP supplements). The following terms should be used to indicate the duration of the reported phenomena.

**Reporting Term    Definition**

Occasional	less than one-third of the time
Intermittent	one-third to two-thirds of the time
Continuous	more than two-thirds of the time

d. **Uses of PIREPs.** The various uses of pilot reports are as follows:

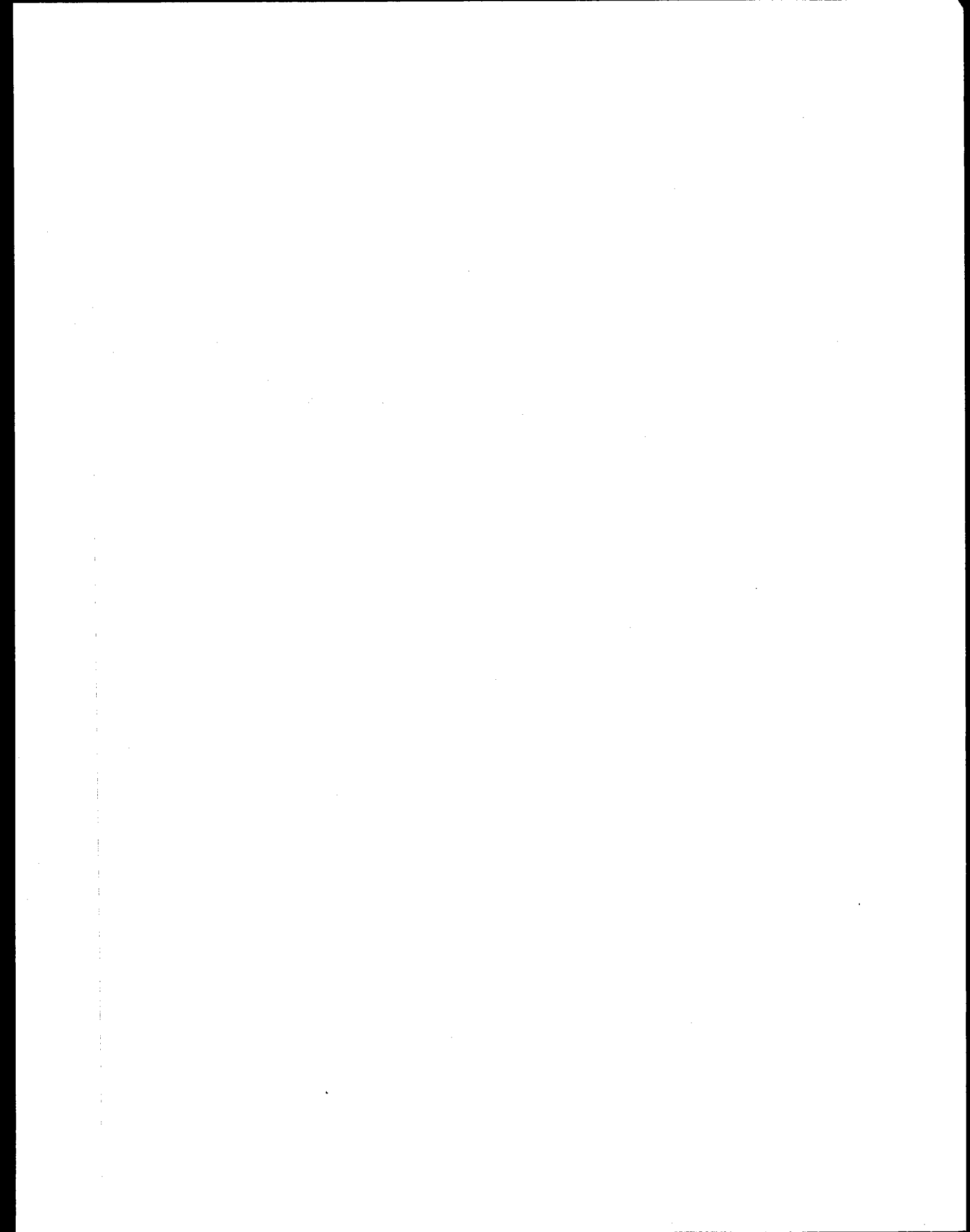
(1) Control towers use the reports to expedite the flow of traffic and forward reports to other interested offices.

(2) The flight service station uses the reports to brief other pilots.

(3) Weather services offices use them for briefing and to aid in forecasting.

(4) Air route traffic control centers use them to help flow their traffic with regard to both route and altitude.

(5) Weather service forecast offices use the data for issuing advisories of hazardous weather conditions, pilot briefings, and forecasting.



## APPENDIX A

### REFERENCES

Department of the Army pamphlet 310-1 should be consulted frequently for latest changes or revisions of references listed and for new publications on subjects covered in the manual.

#### ARMY REGULATIONS (AR)

- 95-series (Aviation Regulations)
- 115-10 Meteorological Support for the US Army (AFR 105-3)
- 310-25 Dictionary of United States Army Terms (Short Title: AD)
- 310-50 Catalog of Abbreviations and Brevity Codes  
(Available in 48x microfiche only)

#### DEPARTMENT OF THE ARMY PAMPHLETS (DA PAM)

- 108-1 Index of Army Motion Pictures and Related Audio-Visual Aids
- 310-1 Consolidated Index of Army Publications and Blank Forms

#### FIELD MANUALS (FM)

- 1-5 Instrument Flying and Navigation for Army Aviators
- 1-202 Environmental Flight (under preparation)
- 1-203 Fundamentals of Flight (under preparation)
- 1-400 Aviator's Handbook (under preparation)

#### US AIR FORCE PUBLICATION (USAF PUB)

- AFM 51-12 Weather for Aircrews (Available from USAF Distribution Center, Baltimore, MD 21220)

#### US NAVY PUBLICATION (USN PUB)

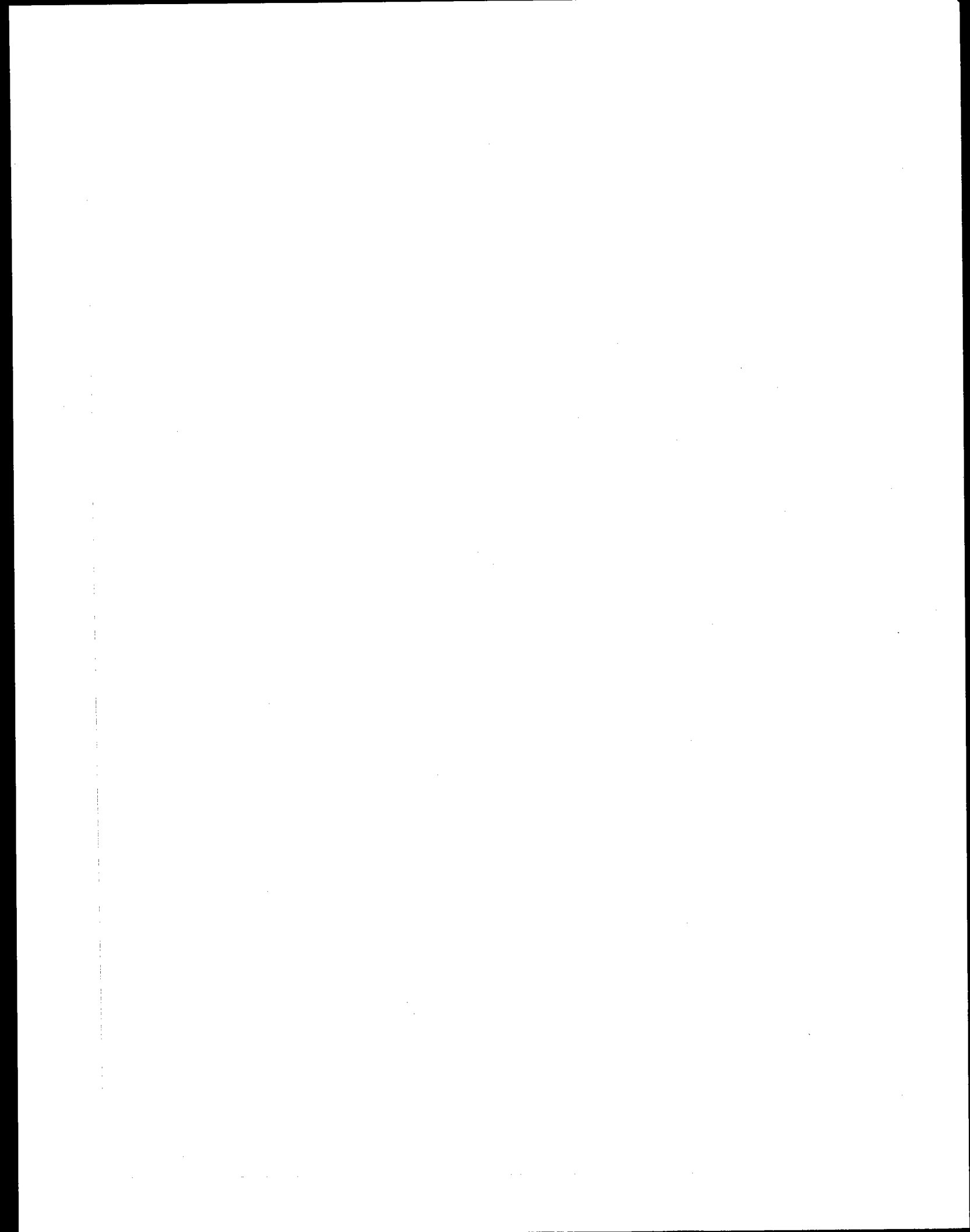
- NAVAIR 00-80V-24-1 Meteorology for Navy Aviators (Available from Superintendent of Documents, Government Printing Office, Washington, D.C. 20402)

#### FEDERAL AVIATION ADMINISTRATION (FAA PUB)

- FAR 91 General Operating Flight Rules (Available from Superintendent of Documents, Government Printing Office, Washington, D.C. 20402)
- 7110.100 Flight Services Handbook (Available from Superintendent of Documents, Government Printing Office, Washington, D.C. 20402)
- AC 006A Aviation Weather (Available from Superintendent of Documents, Government Printing Office, Washington, D.C. 20402)
- AC 0045 Aviation Weather Services Advisory Circular (Available from Superintendent of Documents, Government Printing Office, Washington, D.C. 20402)

#### STANDARDIZATION AGREEMENT (STANAG)

- STANAG 4044 Adoption of a Standard Atmosphere, Edition 2



## APPENDIX B

# TELETYPE INFORMATION

### B-1. GENERAL

The amount of teletype information available to assist the aviator is voluminous. This volume has been reduced in Continental United States (CONUS) and Hawaii by the use of CONUS Meteorological Data System (COMEDS), a computer system featuring the video display of alphanumeric weather data. Since many aviators fly into locations with limited forecaster service or fly overseas, they must be familiar with teletype data necessary to supplement the charts they will use. This data includes observations and forecasts.

### B-2. OBSERVATIONS

Weather is observed and reported in a number of ways. The three most important to the aircrew member are as follows:

a. *The Aviation Weather Report*. This report indicates the current weather at a specific geographic location.

b. *The Radar Report (RAREP)*. This gives radar information from individual radar reporting stations.

c. *The Pilot Report (PIREP)*. This is reported via teletype and describes the weather other aircrews actually encounter. PIREPs assist your understanding of the total weather picture. Examples are given later in this appendix.

### B-3. AVIATION WEATHER REPORT

Because of the aviator's need for up-to-date weather information, surface weather observations are made routinely. These reports are disseminated on the hour. They are *record observations* (SA)—more commonly referred to as *hourly observations*. In addition, special (SP) and local (L) observations are taken and distributed as required to report significant changes in weather conditions between hourly observations. Hourly and special observations are distributed on long-line teletype. Local observations, however, reflect changing conditions significant to airfield operations. They are, therefore, passed only to local agencies.

### B-4. SURFACE OBSERVATION CODES

Depending upon the geographical locations of the weather station, current aviation weather observations are encoded and reported in either the airways code or METAR code (aviation routine weather report in

international MET figure code, discussed later in this appendix). The airways code, used mainly in North America, Hawaii, and Guam, is shown in figure B-1. It is explained in reference to general observation procedures and their relation to the aircrew member.

*a. Sky Cover and Ceiling.*

(1) The weather observer estimates the amount (in tenths or eighths) in METAR code of the total sky which is covered by clouds or by obscuring phenomena (either surface-based or aloft). In figure B-2, examples A and B show two different conditions in which the observer would report the sky cover as scattered; that is, half-covered by clouds. Six-tenths, or more of the sky must be covered for the cloud layer to be classified as broken (or overcast).

(2) Cumuliform clouds tend to produce a "packing effect" when their sides and tops are visible, and they appear more numerous toward the horizon. The observer estimates the cloud cover based upon *the amount of sky actually covered*. In part C of figure B-2, the base and sides of the clouds cover the entire sky. This condition would be reported as overcast at 2,000 feet despite the fact there are "clear" areas between the clouds.

(3) When two or more cloud layers are present, the summation principle is applied (fig B-3, A and B). It is especially important for aircrews to understand that a report of broken or overcast clouds at a particular height above the ground does not necessarily mean that the cloud layer *at that altitude* actually covers more than half of the sky. The surface-based observer often does not see the actual extent of higher cloud layers because lower clouds block the view. The observer uses the summation principle to report the amount of sky covered by clouds at each level. This involves adding the amount covered at lower levels to the apparent amount of sky cover at higher levels. Thus, an upper layer, which by itself would be considered scattered, will be reported as broken (or overcast) if the total summation of clouds at and below that level is six-tenths or more.

(4) The cumulative amount of sky cover reported determines whether a layer is described as scattered, broken, overcast, partly obscured, or totally obscured sky (table 3 of fig B-1). The ceiling will be the lowest layer that is reported as broken, overcast, or totally obscured and *not classified as thin, or partly obscured*. If the sky is totally obscured, the ceiling is the vertical visibility from the ground upward into the obscuration. A ceiling designator from table 2 of figure B-1 describes how the ceiling was determined.

*b. Visibility.* Meteorological visibility is the greatest horizontal distance at which selected objects are seen and identified. This distance is not always the same in all directions. For this reason, the "prevailing" value is included in aviation weather reports. Reportable values for airways code will be the increments of 1/16ths up to 1/2-mile, increments of 1/8ths from 1/2-mile through 2 miles, in increments of 1/4-mile from 2 miles through 3 miles, in increments of 1 mile from 3 to 15 miles, and in increments of 5 miles

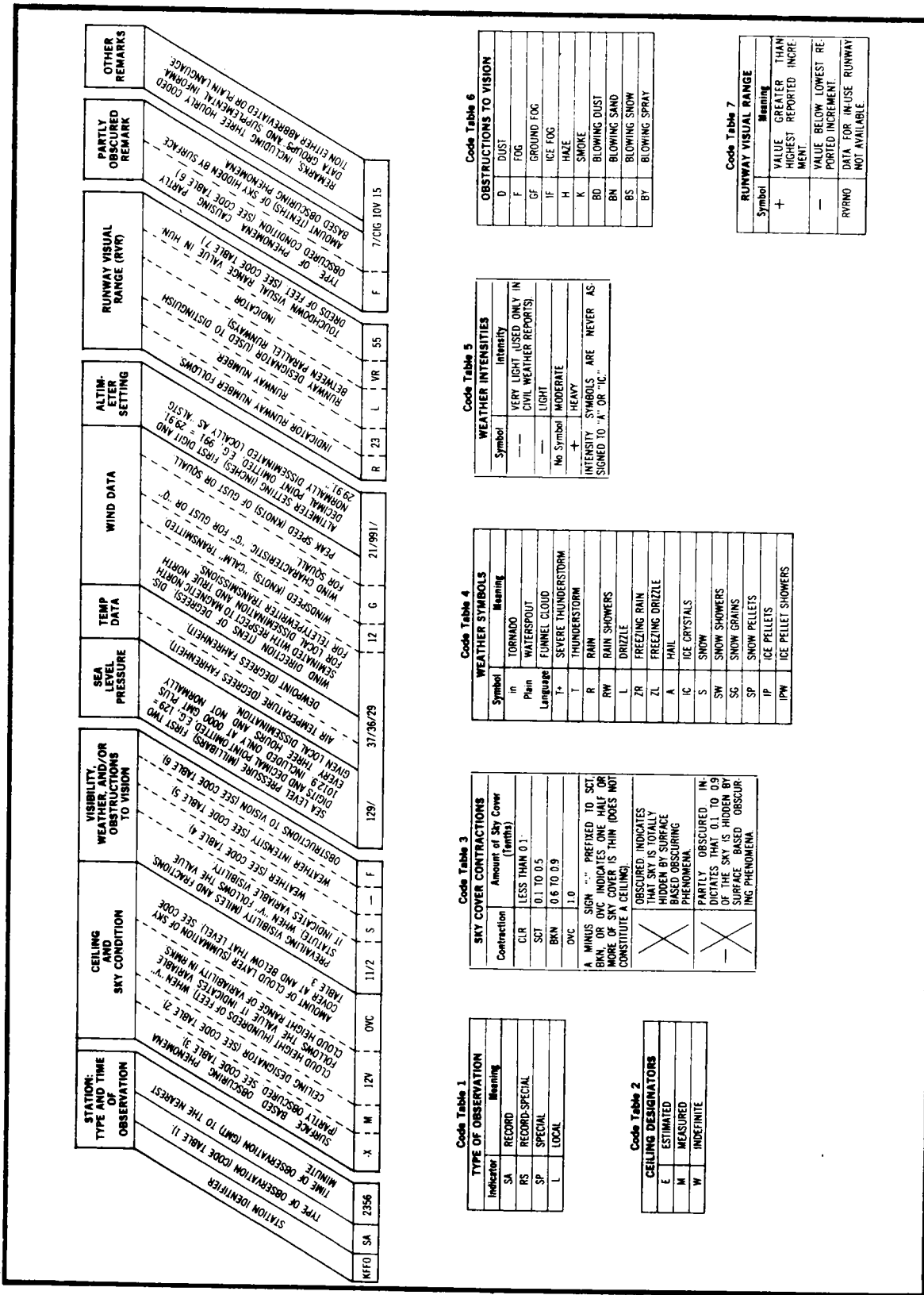


Figure B-1. Airways code.

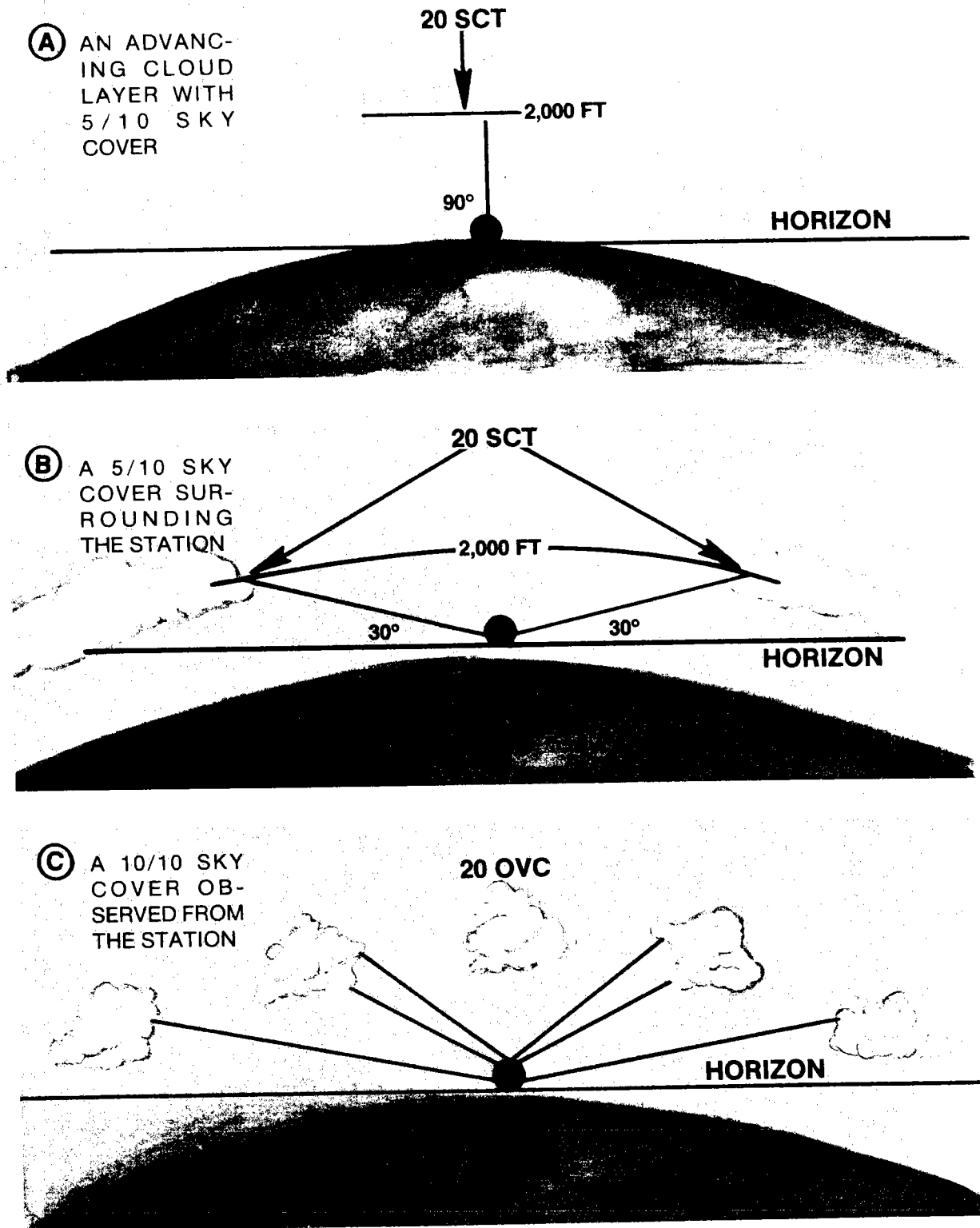


Figure B-2. Sky cover determination (single-cloud cover).



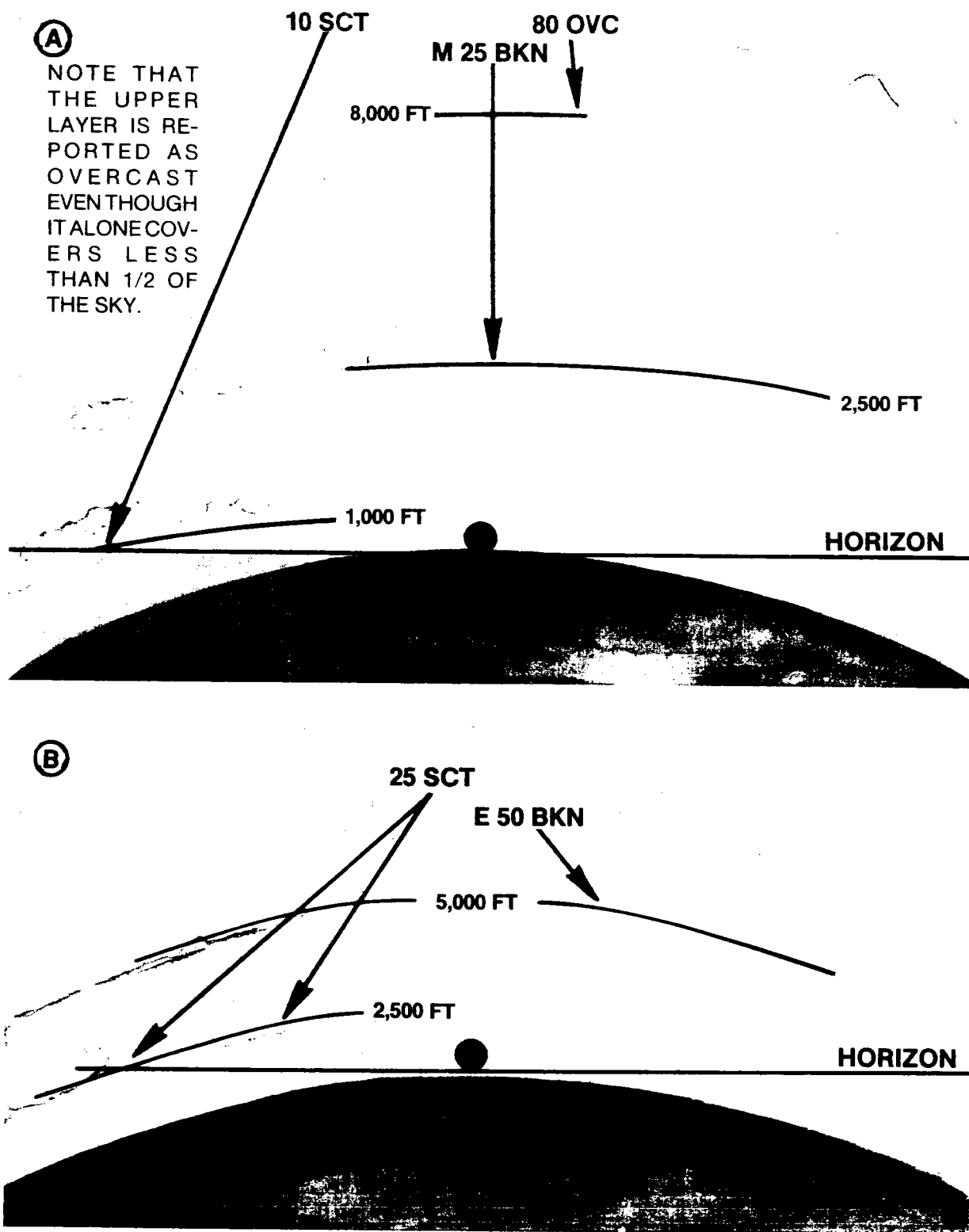


Figure B-3. Summation of cloud cover.

from 15 miles on. The reportable values for visibility in METAR are in meters. They start with 0000 meters and progress in 100-meter increments through 4,800 meters; then in 1,000-meter increments after 5,000 meters.

c. **Prevailing Visibility.** Prevailing visibility is defined as the greatest horizontal visibility observed throughout at least half of the horizon circle. The segments making up this half of the horizon circle need not be adjacent to one another. Figure B-4 shows how prevailing visibility is determined. Figure B-5 shows how prevailing visibility varies at different levels and how it would be explained in the remarks section of the weather report.

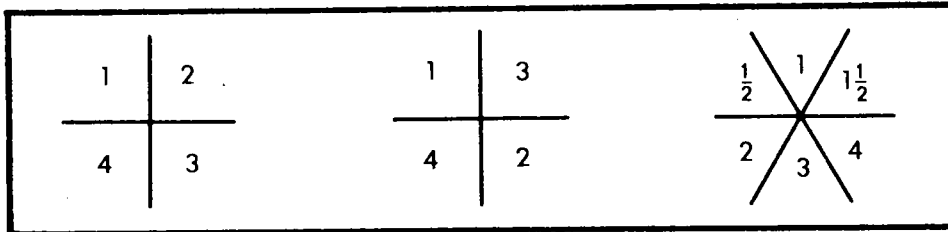


Figure B-4. Determination of prevailing visibility.

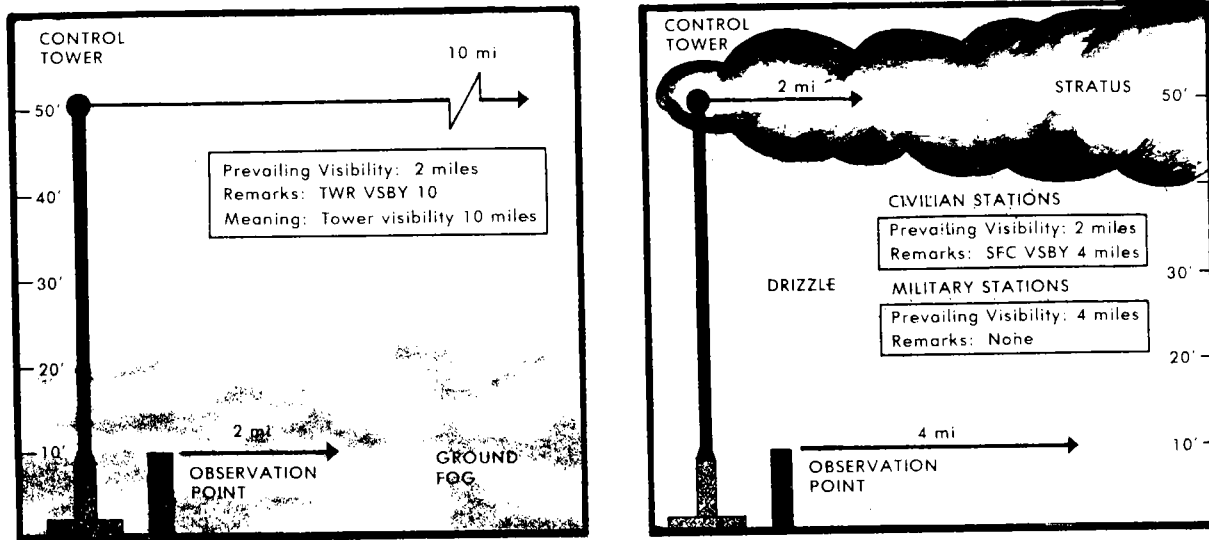


Figure B-5. Visibility at different levels.

d. **Precipitation and Obstructions to Vision.**

(1) Types of precipitation are determined visually. Precipitation types are classified mainly according to size and state (table 4, fig B-1). The intensity of precipitation is determined either on the basis of rate-of-fall, or according to its effect on the prevailing visibility at the time (table 5, fig B-1).

(2) The type of visual obstruction (table 6, fig B-1) is determined by eye. Sometimes it is difficult to distinguish one form of obstruction from another. For example, haze and smoke often look very much alike.

Therefore, the observers must use their knowledge of local effects in making this determination. In addition, the type of visual obstruction will be reported only if it restricts prevailing visibility to 6 statute miles (10 km) or less.

*e. Atmospheric Pressure and Altimeter Settings.* The atmospheric pressure reported in an aviation weather report is the pressure at the observing station reduced to mean sea level (MSL). Sea level pressure will be computed, recorded, and transmitted by observers every hour at Army airfields. Army aviators are more interested in the altimeter setting than in the pressure at sea level.

*f. Temperature and Dew Point.* Temperature and moisture content (dew point) directly determine the density of the atmosphere. These two factors greatly influence the length of runway required for aircraft takeoff and landing roll, as well as power settings for helicopter operations. Temperatures and dew points are reported in degrees Fahrenheit in airways code and in degrees Celsius (C) in METAR code.

*g. Wind.*

(1) Wind direction, speed, character (gusts or squalls), and shifts are measured at most weather stations. At stations without instrumentation, or where wind instrumentation is temporarily inoperative, the elements of the wind report must be estimated. In these uncommon situations, the aviation weather report signifies that the wind direction and speed are estimated and the direction is prefixed by an "E."

(2) Gustiness is characterized by sudden, brief increases in wind speed. It is not reported unless the variation between peaks and lulls is at least 10 knots. For example, in airways, "20G30" means that the average wind speed is 20 knots, and the peak speeds in gusts are 30 knots; whereas, in METAR code this would be written "20/30." A *squall* condition is reported if the wind speed suddenly increases by at least 15 knots, maintains a peak speed of 20 knots or more for 1 or more minutes, and then decreases. A wind of 15 knots with peak gusts to 30 knots in squalls would appear in the appropriate position in the aviation weather reports as "15Q30." The occurrence of gusts or squalls indicates the air near the surface is turbulent.

**NOTE**

The difference between the average and the peak wind speed does not represent the true speed. Gust spread represents the range of wind speed from minimum to maximum during the gust cycle. This value is not normally reported due to the difficulty in observing. For application of gust spread to aircraft limitations (e.g., starting and stopping of helicopter rotor systems), the aviator should ask the tower for the specific minimum and maximum wind velocities.

(3) The reported wind direction is that direction in reference to *true north* from which the wind is blowing. Normally, it is the prevalent direction over a 1-minute interval. For METAR observations, however, it is the prevalent direction over the 10-minute interval immediately preceding the time of observation.

(4) An aviator preparing to take off or land needs to know the wind direction in reference to magnetic north because runways are oriented on this basis. The *magnetic* north wind direction at the local airport is given in air-ground conversations between pilots and airport traffic control personnel. Wind directions for other locations are given in reference to true north. Therefore, all local surface winds are given to *magnetic north* and all teletype, forecast, and en route winds are given in reference to *true north*.

*h. Remarks.*

(1) The remarks portion of an aviation weather report often contains information which is of considerable importance to the aircrew. Remarks are added at the end to cover unusual aspects of the weather, as well as pertinent information for pilots, air traffic control personnel, and weather forecasters. Many remarks are mandatory, while others are added if considered operationally significant by the observer. The observer will report any additional known information of importance to flight operations in the remarks section of the hourly observation, or if the conditions warrant it, in special observations.

(2) As the information is available, data are appended to the remarks section of aviation weather reports in the following order:

- *Runway visual range (RVR).* The RVR readings along the runway are made by direct measuring devices or visual observations. At airfields where minima are published in feet, RVR is reported in hundreds of feet during periods in which the prevailing visibility is 1 mile or less or the RVR is 6,000 feet or less. RVR is transmitted as a remark on long-line weather communications circuits. In local observations, however, RVR immediately follows the prevailing visibility in the body of the aviation observation.

- *Surface-based obscuring phenomena.* For example, in airways, "F4" would be translated as "fog obscuring 4/10 of the sky," but in METAR code, it would read "4FG///."

- *Remarks to code elements.* Remarks pertaining to coded elements which have been reported in preceding sections, such as extremes of variability of ceiling, visibility or wind, beginning or end of a thunderstorm or rain, and peak winds.

- *Runway conditions.* This information is transmitted on long-line weather circuits as provided by the base operations officer or airfield manager as follows:

<i>Conditions Reported</i>	<i>Encoded</i>
Wet runway	WR
Slush on runway	SLR
Loose snow on runway	LSR
Packed snow on runway	PSR
Ice on runway	IR

(3) Runway condition reading (RCR) is a two-digit decelerometer number from 02 to 25 (or “//” when a reading is not available). When applicable, “P” (patchy) and “SANDED” are appended. In addition, when conditions are “patchy,” the appropriate term “WET” or “DRY” is reported following the encoded runway condition.

(4) An RCR value is not transmitted in weather reports when base operations is closed or data is not available, and when the runway is not completely dry. During such periods, the remark “RCRNR” (no report) will be appended to hourly weather observations. However, this remark may be omitted if the runway is known to be completely dry.

**Examples:**

PSR15 (packed snow on the runway, decelerometer reading 15).

IRQ8P DRY (ice on runway, decelerometer reading 08, patchy; remainder of runway is dry).

WR// (wet runway, decelerometer reading not determined).

IR05 SANDED (ice on runway, decelerometer reading 5, runway has been sanded).

RCRNR (base operations closed, runway is not completely dry).

## **B-5. SPECIAL OBSERVATIONS**

*a.* Major changes in weather conditions which are significant to aviation safety and efficiency require the prompt distribution of special observations. These special reports usually contain the elements of sky and ceiling, visibility, weather, obstructions to vision, wind, and appropriate remarks.

*b.* As ceiling and visibility deteriorate and begin to restrict aircraft operations, only slight changes in these elements may require the transmission of special reports. Tornadoes, thunderstorms, hail, freezing precipitation, ice pellets, and sudden wind changes also require special observations.

## B-6. METAR WEATHER REPORTS

a. Army aviators flying in overseas areas must be familiar with the METAR report (fig B-6). This code is issued by all Air Weather Service (AWS) units outside North America, Hawaii, and Guam. Figure B-7 includes tables which explain each of the METAR code groups.

b. The METAR code is similar to the standard format approved by the World Meteorological Organization and has two formats. The first is for long-line teletype dissemination of weather observations to other bases. The second format is for local dissemination and is relayed to pilots by controlling agencies.

## B-7. RADAR REPORT (RAREP)

a. A network composed of National Weather Service and Air Weather Service radars is designed to observe precipitation patterns and to provide area coverage, height, intensity, and precipitation movement information. Radar observations are made normally at 35 minutes past each hour. Storm detection (SD) is the radar report identifier. The radar code is made up of two major sections—the SD section and a digital section. The SD section gives radar data in an azimuth-range format (*relative to true north*) that can easily be interpreted by the aircrew. The digital section is used as coded input to the automated radar summary and will not be discussed. The RAREP is explained in figure B-8.

b. As mentioned earlier, these observations are used in preparing the radar summary chart. They should also be used to update these charts. It is wise never to rely entirely on the chart, especially if your route of flight is planned through an area of bad weather. Remember convective cells can change their character and intensity very rapidly.

## B-8. PILOT WEATHER REPORT

a. Weather observations made from the ground contain precise information that is valuable for takeoffs, landings, approaches, and departures. They do not, however, fully meet the need for information on weather conditions at flight altitude. An aviator has a distinct advantage over ground observers in making weather observations. Not only does the aviator usually have a broader horizon, but if he is flying above a cloud layer, he may see higher clouds or other phenomena which probably are unseen by the ground observer. Heights of upper cloud layers, turbulence, and icing frequently are evident only to airborne pilots; and their reports of these conditions are valuable to other aircrews, controllers, and weather forecasters.

b. Air traffic control facilities (towers and centers) make wide use of PIREPs to expedite the flow of air traffic in the terminal and in en route areas. For example, pilot weather reports of turbulence would be considered when assigning a departure route or flight altitude. Weather forecasters use pilot weather reports to provide preflight briefings and in-flight services to

LOCAL IDENTIFIER	TYPE REPORT	TIME	WIND DATA	PREVAILING VISIBILITY	RUNWAY VISUAL RANGE (RVR)—LOCAL	RUNWAY VISUAL RANGE (RVR)—LONGLINE	PRESENT WEATHER	SKY CONDITION	CAVOK	TEMP DATA (IN HOURLY REPORTS ONLY)	ALTIMETER SETTING	CEILING HEIGHT	REMARKS
EDMH	METAR	75010 20	0600	R 0550	48FC	7 SI 005	01 M01	01 M01	2984 INK	01 MOOS			LONGLINE TELETYPEWRITER LOCAL DISSEMINATION
EDMH	SA	75010 20	3/8	R 1 22 L VR 1 18	TC	7 SI 005	01 MOOS	01 MO1	ALSTG 2984				

LOCAL IDENTIFIER	TYPE REPORT	TIME	WIND DATA	PREVAILING VISIBILITY	RUNWAY VISUAL RANGE (RVR)—LOCAL	RUNWAY VISUAL RANGE (RVR)—LONGLINE	PRESENT WEATHER	SKY CONDITION	CAVOK	TEMP DATA (IN HOURLY REPORTS ONLY)	ALTIMETER SETTING	CEILING HEIGHT	REMARKS
EDMH	METAR	75010 20	0600	R 1 22 L VR 1 18	48FC	7 SI 005	01 M01	01 M01	2984 INK	01 MOOS			LONGLINE TELETYPEWRITER LOCAL DISSEMINATION
EDMH	SA	75010 20	3/8	R 1 22 L VR 1 18	TC	7 SI 005	01 MOOS	01 MO1	ALSTG 2984				

LOCAL IDENTIFIER	TYPE REPORT	TIME	WIND DATA	PREVAILING VISIBILITY	RUNWAY VISUAL RANGE (RVR)—LOCAL	RUNWAY VISUAL RANGE (RVR)—LONGLINE	PRESENT WEATHER	SKY CONDITION	CAVOK	TEMP DATA (IN HOURLY REPORTS ONLY)	ALTIMETER SETTING	CEILING HEIGHT	REMARKS
EDMH	METAR	75010 20	0600	R 1 22 L VR 1 18	48FC	7 SI 005	01 M01	01 M01	2984 INK	01 MOOS			LONGLINE TELETYPEWRITER LOCAL DISSEMINATION
EDMH	SA	75010 20	3/8	R 1 22 L VR 1 18	TC	7 SI 005	01 MOOS	01 MO1	ALSTG 2984				

LOCAL IDENTIFIER	TYPE REPORT	TIME	WIND DATA	PREVAILING VISIBILITY	RUNWAY VISUAL RANGE (RVR)—LOCAL	RUNWAY VISUAL RANGE (RVR)—LONGLINE	PRESENT WEATHER	SKY CONDITION	CAVOK	TEMP DATA (IN HOURLY REPORTS ONLY)	ALTIMETER SETTING	CEILING HEIGHT	REMARKS
EDMH	METAR	75010 20	0600	R 1 22 L VR 1 18	48FC	7 SI 005	01 M01	01 M01	2984 INK	01 MOOS			LONGLINE TELETYPEWRITER LOCAL DISSEMINATION
EDMH	SA	75010 20	3/8	R 1 22 L VR 1 18	TC	7 SI 005	01 MOOS	01 MO1	ALSTG 2984				

Figure B-6. Key to METAR and terminal aerodrome forecast codes.

TABLE 1 w' w' SIGNIFICANT PRESENT AND FORECAST WEATHER				METAR AND TAF CODE TABLES						TABLE 4	
Code	Decode	Code	Decode	TABLE 3 $hh\text{h}hh - h\text{h}h\text{h} - h\text{h}h\text{h}h - h\text{h}h\text{h}h - h\text{h}h\text{h}h - h\text{h}h\text{h}h$						B-TURBULENCE	
04 FU	Smoke	56 FZDZ	Light freezing drizzle	Code Figure	Meters	Feet	Code Figure	Meters	Feet	Code	Decode
05 HZ	Haze	57 XZDZ	Moderate or heavy freezing drizzle	000	30	100	045	1350	4500	0	None
06 HZ	Dust	58 RA	Light drizzle and rain	001	30	100	046	1380	4600	1	Light turbulence
07 SA	Blowing dust or sand	59 RA	Moderate drizzle and rain	002	60	200	047	1410	4700	2	Light OCNI, moderate turbulence in clear air
08 PD	Dust debris	60 RA	Light rain	003	90	300	048	1440	4800	3	Moderate turbulence in clear air
10 BR	Mist (fog)	61 RA	Moderate rain	004	120	400	049	1470	4900	4	Moderate turbulence in cloud
11 MFG	Shallow fog or ice fog	62 RA	Heavy rain	005	150	500	050	1500	5000	5	Light OCNI, severe turbulence in clear air
12 MFG	Thunderstorm (no precipitation)	63 RA	Light freezing rain	006	180	600	060	1800	6000	6	Light OCNI, severe turbulence in cloud
17 TS	Thunderstorm (no precipitation)	64 XRA	Moderate or heavy rain and snow	007	210	700	070	2100	7000	7	Severe turbulence in cloud
18 SO	Squall	65 XRA	Light snow	008	240	800	080	2400	8000	8	Severe turbulence in clear air
19 FC	Tornado activity	66 XRA	Moderate or heavy freezing rain	009	270	900	090	2700	9000	9	Severe turbulence in cloud
20 RZDZ	Recent drizzle	67 XRFRA	Light rain and snow	010	300	1000	100	3000	10000		
21 RERA	Recent rain	68 RASH	Moderate or heavy rain and snow	011	330	1100	110	3300	11000		
22 RESN	Recent snow	69 XRASH	Light snow	012	360	1200	120	3600	12000		
23 REASN	Recent rain and snow	70 SH	Moderate snow	013	390	1300	130	3900	13000		
24 RAFZRA	Recent freezing rain	71 SH	Heavy snow	014	420	1400	140	4200	14000		
25 RESH	Recent showers	72 SH	Ice crystals	015	450	1500	150	4500	15000		
26 RESNSH	Recent snow showers	73 SH	Snow grains	016	480	1600	160	4800	16000		
27 REGR	Recent hail*	74 XSN	Ice pellets	017	510	1700	170	5100	17000		
29 RETS	Recent thunderstorms	75 XSN	Light rainshowers	018	540	1800	180	5400	18000		
30 SA	Duststorm or sandstorm	76 IC	Moderate rainshowers	019	570	1900	190	5700	19000		
31 SA	Duststorm or sandstorm	77 SC	Heavy rainshowers	020	600	2000	200	6000	20000		
32 SA	Duststorm or sandstorm	79 PE	Light rain and snow showers	021	630	2100	210	6300	21000		
33 XXSA	Heavy duststorm or sandstorm	80 RASH	Moderate or heavy rain and snow showers	022	660	2200	220	6600	22000		
34 XXSA	Heavy duststorm or sandstorm	81 XSNH	Light snowshowers	023	690	2300	230	6900	23000		
35 XXSA	Heavy duststorm or sandstorm	82 XSNH	Moderate or heavy snowshowers	024	720	2400	240	7200	24000		
36 DRSN	Drifting snow	83 RASH	Light ice or snow pellet showers	025	750	2500	250	7500	25000		
37 DRSN	Drifting snow	84 XRASH	Moderate or heavy ice or snow pellet showers	026	780	2600	260	7800	26000		
38 BLSN	Blowing snow	85 SHSH	Hail	027	810	2700	270	8100	27000		
39 BLSN	Blowing snow	86 XXSNH	Rain	028	840	2800	280	8400	28000		
40 BCFG	Fog patches	87 GR	Heavy rain	029	870	2900	290	8700	29000		
41 BCFG	Fog patches	88 GR	With recent thunderstorms	030	900	3000	300	9000	30000		
42 FG	Fog or ice fog	89 GR	Hail*	031	930	3100	350	10500	35000		
43 FG	Fog or ice fog	90 XGR	Thunderstorm with rain/snow	032	960	3200	400	12000	40000		
44 FG	Fog or ice fog	91 RA	Thunderstorm with rain/snow	033	990	3300	450	13500	45000		
45 FG	Fog or ice fog	92 XRA	Thunderstorm with hail*	034	1020	3400	500	15000	50000		
46 FG	Fog or ice fog	93 GR	Severe thunderstorm with rain/snow	035	1050	3500	550	16500	55000		
47 FG	Fog or ice fog	94 XGR	Thunderstorm with duststorm or sandstorm	036	1080	3600	600	18000	60000		
48 FZFG	Freezing fog	95 TS	Severe thunderstorm with hail*	037	1110	3700	650	19500	65000		
49 FZFG	Freezing fog	96 TSGR	Thunderstorm with duststorm or sandstorm	038	1140	3800	700	21000	70000		
50 DZ	Light drizzle	97 XZTS	Severe thunderstorm with hail*	039	1170	3900	(etc)	(etc)	(etc)		
51 DZ	Light drizzle	98 TSSA	Thunderstorm with duststorm or sandstorm	040	1200	4000	990	29700	99000		
52 DZ	Moderate drizzle	99 XZTGR	Severe thunderstorm with hail*	041	1230	4100	999	30000	100000		
53 DZ	Moderate drizzle			042	1260	4200	or more	or more	or more		
54 XZDZ	Heavy drizzle			043	1290	4300					
55 XZDZ	Heavy drizzle			044	1320	4400					

TABLE 2 CC-CLOUD TYPE			
Code	Decode	Code	Decode
CI	Cirrus	NS	Nimbostratus
CC	Cirrocumulus	SC	Stratocumulus
CS	Cirrostratus	ST	Stratus
AC	Altostratus	CU	Cumulus
AS	Altostratus	CB	Cumulonimbus

TABLE 4	
Code	Decode
0	None
1	Light turbulence
2	Light OCNI, moderate turbulence in clear air
3	Moderate turbulence in clear air
4	Light OCNI, moderate in cloud
5	Moderate turbulence in cloud
6	Light OCNI, severe turbulence in clear air
7	Severe turbulence in clear air
8	Light OCNI, severe turbulence in cloud
9	Severe turbulence in cloud

TABLE 5	
Code	Decode
0	None or trace
1	Light icing (light mixed)
2	Light icing in cloud (light rime)
3	Light icing in precipitation (light clear)
4	Moderate icing (moderate mixed)
5	Moderate icing in cloud (moderate rime)
6	Moderate icing in precipitation (moderate clear)
7	Severe icing (severe mixed)
8	Severe icing in cloud (severe rime)
9	Severe icing in precipitation (severe clear)

TABLE 6	
FORECAST CHANGE GROUPS	
The form GRADU GGG <sub>1</sub> G <sub>2</sub> is used if changes are expected to take place at an approximately constant rate throughout the period beginning at GG and ending at G <sub>1</sub> G <sub>2</sub> . e.g., "GRADU 0203" indicates a gradual change between 0200 and 0300 GMT. RAMPD is used instead of GRADU when the changes are expected to take place during a period lasting less than half an hour.	
The form INTER GGG <sub>1</sub> G <sub>2</sub> is used if the changes are expected to occur frequently for short periods and fluctuate almost constantly throughout the period beginning at GG and ending at G <sub>1</sub> G <sub>2</sub> . e.g., "INTER 0317" indicates intermittent changes between 0300 and 1300 GMT. The intermittent condition will not cover in the aggregate more than one half of the forecast period, or more than 30 minutes of any hour (45 minutes for thunderstorms).	

Figure B-7. METAR and terminal aerodrome forecasts (TAF) code tables.

aircrews, and as a forecasting aid. The reports are broadcast regularly over selected navigational aids for the benefit of listening aircrews. Also, they are transmitted on teletype circuits for the benefit of other facilities.

c. Pilot reports are required by paragraph 3-10, AR 95-1. The Department of Defense flight information publication (DOD FLIP) should be consulted for procedures and requirements for making PIREPs.

### B-9. PIREP—UNITED STATES DOMESTIC CODE AND OVERSEAS CODE

a. **US Domestic Code.** The domestic PIREP format includes a "message type" (UUA, severe; UA, regular) and a series of "text element indicators" that precede each element of the PIREP and tell the computer that certain data follow. Each "indicator" consists of a slash (/), two letters, and a space.

(1) Indicator "/OV" indicates aircraft position, time of observation, and altitude follows. Aircraft position is encoded relative to an omnirange





Examples:

• OZR UA/OV OZR 315045 2224 FL LINK/TP U21/RM OKN LNTSTMSN-S OCNLLTGCCCG 030 LINK 112. A pilot in a U-21 reports a broken line of thunderstorms 40 miles NW of Cairns AAF, aligned N-S at 2224Z. Bases are at 3,000 feet, tops at 11,200 feet. There is occasional cloud-to-cloud and cloud-to-ground lightning.

• LSF UA/OV LSF 050040 2312 FL 120/TP C-47/TB MDT CAT 850-120. A pilot in a CH-47 reports to Lawson AAF encountering moderate clear air turbulence between 8,500 and 12,000 feet 20 miles NE of Columbus at 2312Z.

b. **Overseas Code.** This code is used by AWS units outside continental North America, Hawaii, and Guam. Distances are encoded in nautical miles (nm) and heights are shown in hundreds of feet above MSL; for example, 2,000 is encoded as 020. If a height is reported above ground level (AGL) and an MSL equivalent cannot be determined, AGL will be appended to the height. Authorized word or phrase abbreviations and international cloud abbreviations (Cu, Ac, As, Cb) are used except for temperature. In this case, "OAT" is used rather than "T" or "TEMP." When type of aircraft is unknown, "ACFT UNK" is reported.

- (1) Station identification International Civil Aviation Organization ((ICAO) identifier).
- (2) Message identifier (PIREP).
- (3) Location and/or extent (location and/or extent of phenomenon relative to ICAO four-letter identifier. Location in whole degrees latitude and longitude will be reported on overwater flights).
- (4) Time (time phenomenon observed in GMT).
- (5) Phenomenon.
- (6) Altitude of phenomenon (reported above MSL unless AGL appended).
- (7) Type of aircraft (required in reports of electrical discharge, contrails, turbulence, and icing).

Examples:

• LIYW PIREP OVR LIRA 1700 MOD CAT 050-080 U21. The Aviano BWS received a report at 1700 GMT of a U-21 encountering moderate clear air turbulence between 5,000 and 8,000 feet over Rome.

• EDIE PIREP 5-20N EDOC 1500 MOD RIME ICG 080 UH-1. The pilot of a UH-1 reports to Heidelberg AAF that at 1500 GMT the aircraft encountered moderate rime icing 5 to 20 miles north of Stuttgart at 8,000 feet.

## B-11. AVIATION WEATHER FORECASTS

### a. *General.*

(1) The aviator planning a flight is also concerned with the forecast surface weather conditions along the proposed route and at the destination and alternate. These forecasts advise the aircrew of the development of potentially hazardous weather, and they are used to determine the fuel requirements to complete the mission.

(2) Teletype forecasts are given in two formats—terminal aerodrome forecasts and US terminal forecast code or plain language terminal forecast (PLATF) code or forecast terminal (FT). The AWS and international terminal aerodrome forecast codes are virtually the same.

b. *Terminal Aerodrome Forecast (fig B-6).* The TAF code, in the same format as the METAR observation code (figs B-6, B-7), is a forecast for a particular terminal covering a period of time up to 24 hours for the following weather data:

(1) *Wind direction, speed, and maximum wind expected.*

(2) *Prevailing visibility in meters.* 9999 indicates visibility is 10 kilometers (km) (7 statute miles) or more.

(3) *Weather phenomena to include forms of precipitation and restrictions to visibility.* Forecast weather is encoded in both the numbers and alphabetical designator from table 1 of figure B-7. For example, 61RA would indicate light rain is forecast.

(4) *Eighths of sky coverage of each cloud layer expected over the station, with base height of the layer AGL and type of cloud.* When no clouds are forecast, "SKC" for clear sky will be entered. When clouds at or below a layer will cover *more than* four-eighths of the sky, that layer will be the ceiling. The ceiling will be identified in the remarks section as "CIG" with height expected; for example, CIG050. No ceiling will be reported as "CIGNO." The format 9//h<sub>s</sub>h<sub>s</sub>h<sub>s</sub> means the sky is forecast obscured where h<sub>s</sub>h<sub>s</sub>h<sub>s</sub> is the vertical visibility in hundreds of feet; for example, 9//002.

(5) *"CAVOK."* The code word "CAVOK" (normally not used by AWS) is used in place of visibility, weather, and cloud layers when the following conditions are forecast at the same time:

- Visibility 10 km or more.
- No clouds below 5,000 feet and no Cb.
- No precipitation, thunderstorm, shallow fog.

(6) *Height and thickness of icing and turbulence layers (not associated with thunderstorms).* These entries are omitted when no icing or turbulence is forecast.

(7) *Minimum altimeter setting expected.*

(8) *Change group identifier.*

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TAF CODE CONTRACTIONS AND MEANINGS

GRADU Used if the change is expected to take place at an approximately constant rate throughout the period of the GRADU (gradual) times.

RAPID Indicates fast-changing weather expected to take place over a period of less than half an hour.

INTER Intermittent conditions will occur for less than 30 minutes (45 minutes for thunderstorms) of any hour, and less than one half of the period for which the conditions are forecast.

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INTERNATIONAL TERMINAL AERODROME FORECAST CODE  
CONTRACTIONS

TEMPO Indicates temporary change expected to occur for a period of less than 1 hour.

FRONT Frontal passage indicator. "FRONT" is followed by four digits giving hours and minutes of passing.

PROB Term used to indicate probability in percent of conditions occurring; that is, "PROB20" means a 20-percent probability of conditions occurring.

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NWS FORECASTERS ABBREVIATED REMARKS

OCNL or VRBL These are used interchangeably to forecast brief but frequent changes from the predominant forecast condition.

BRF This indicates that changes are expected to last for less than 1 hour and, in the aggregate, for less than half the forecast period. This remark implies a probability for occurrence greater than 50 percent.

- CHC Used to indicate a change from the predominant forecast condition, with a probability for occurrence of 30 to 40 percent. "SLT CHC" indicates a probability of 10 to 20 percent.
- PSBL or RISK Either term indicates a change from the predominant forecast condition, but usually with a less than 10 percent chance of occurrence.
- CFP, WFP, or OFP These stand for cold frontal passage, warm frontal passage, or occluded frontal passage. The letters follow a two-digit or four-digit time group to indicate time of passage.

c. *US Terminal Forecast.*

(1) Terminal forecasts in the US FT code (sometimes called *domestic* code) are valid for a 24-hour period. The FT format is essentially the same as for airways code; most of the same symbols, abbreviations, and reportable values are used. Coded elements include terminal identification, date-time group, height and amount of sky cover, visibility, weather and obstruction to vision, surface wind, remarks, and a 6-hour categorical outlook.

(2) Following is an example of FT, with explanation:

STL 251010 C5 X 1/2S-BS 3325G35 OCNL CO X OS+BS 16Z C30  
BKN 3BS 3320 BRF SW-. 22Z 30 SCT 3315. 00Z CLR. 04Z VFR WIND.

- *Station identifier "STL."* Forecast is for St. Louis, Missouri.
- *Date-time group "251010."* Forecast valid on the 25th day of the month at 1000Z until 1000Z the following day.
- *Sky and ceiling.* "C5 X" means ceiling 500 feet, sky obscured.
- *Visibility.* "1/2" means visibility 1/2 statute mile. Absence of a visibility entry specifically implies visibility more than 6 miles.
- *Weather and obstructions to visibility.* "S-BS" means light snow and blowing snow. These elements are in symbols identical to those used in airways reports (fig B-1, tables 4 and 6).
- *Wind.* "3325G35" means wind from 330 degrees true at 25 knots gusting to 35 knots. Omission of a wind entry specifically implies wind less than 10 knots.
- *Remarks.* "OCNL CO X OS+BS" means occasional ceiling zero, sky obscured, visibility zero, heavy snow, and blowing snow.

• **Expected changes.** When changes are expected, preceding conditions are followed by a period and the time and conditions of the expected change. For example, "16Z C30 BKN 3BS 3320 BRF SW-. 22Z 30 SCT 3315. 00Z CLR." means by 1600Z, ceiling 3,000 feet broken, visibility 3 miles blowing snow, wind 330 degrees at 20 knots, brief light snow showers. By 2200Z, 3,000 scattered, visibility more than 6 (implied), wind 330 degrees at 15 knots. By 0000Z sky clear, visibility more than 6 miles, wind less than 10 knots (implied).

• **Six-hour categorical outlook.** The last 6 hours of the forecast is a categorical outlook using the following code:

LIFR (low IFR) Ceiling 500 ft and/or visibility  
< 1 mile.

IFR Ceiling 500 ft to < 1,000 ft and/or  
visibility 1 to < 3 miles.

MVFR (marginal VFR) Ceiling 1,000 to 3,000 ft and/or visi-  
bility 3 to 5 miles, inclusively.

VFR Ceiling > 3,000 ft and visibility  
> 5 miles (includes sky clear).

• "04Z VFR WIND.." means that from 0400Z until 1000Z—the end of the forecast period—weather will be ceiling more than 3,000 feet and visibility greater than 5 miles (VFR); the word "WIND" indicates the wind or gusts will be 25 knots or greater for the outlook period. The double period (..) signifies the end of the FT.

## APPENDIX C

### USE OF DD FORM 175-1 (FLIGHT WEATHER BRIEFING)

#### C-1. GENERAL

Army aviators are required to obtain adequate weather information prior to flight. They are encouraged to acquire this data with minimum cost to the government. Use of AUTOVON/toll free calls should be made if possible. Government-collect, long-distance calls, however, may be made if necessary. Proper flight planning includes obtaining all the pertinent weather information available. Extra time spent in the weather station forming a mental picture of the weather conditions could be an important factor in completing a mission.

#### C-2. ENTRIES ON DD FORM 175-1

a. During the preflight weather briefing, a DD Form 175-1 is normally issued to insure a complete briefing (fig C-1). The DD Form 175-1 will indicate the forecast departure, en route, and arrival weather conditions. During closed-circuit television weather briefings, the forecaster may show completed portions of the form.

b. Flight weather briefing folders made up of pictorial weather data, such as wind and temperature, horizontal weather depiction, cross-sectional charts, and/or computer flight plans, may be issued as a supplement to, or in lieu of, DD Form 175-1. The forecaster may also provide a "verbal brief" instead of the DD Form 175-1 at some locations. When issued in lieu of DD Form 175-1, the flight weather briefing folder or the verbal brief should contain the data included in the DD Form 175-1, in a format acceptable to the major air command supported.

c. As an aircrew member, you may have to take a telephone weather briefing and complete a DD Form 175-1. The following paragraph discusses how to fill out this form.

#### C-3. GENERAL INSTRUCTIONS FOR COMPLETING DD FORM 175-1

Entries in individual blocks are based on aircrew requirements and the weather situations. Make all time entries "Z." Enter all heights (except minimum ceiling en route) in *hundreds of feet*. Enter all winds in tens of degrees, speed in knots.

a. *Section I, "Mission Takeoff Data."*

- (1) *Date*. Enter GMT departure date.
- (2) *Acft Type/No*. Enter aircraft type (UH-1, T-42) and radio call, mission number, or last three digits of tail number.
- (3) *Dep Pt/ETD*. Enter departure airfield call letters and estimated time of takeoff.
- (4) *Runway Temp, Dewpoint, Temp Dev*. Enter in degrees Celsius unless requested in Fahrenheit. Enter "temp dev" as the difference between the forecast temperature for climb and the standard atmosphere temperature.
- (5) *Pressure Alt, Density Alt*. Enter in feet with algebraic sign.
- (6) *Sfc Wind*. Enter *magnetic* direction. True directions will be given by the forecaster during telephone briefings. In either case, the forecaster will specify "magnetic" or "true" during the briefing, and suffix *magnetic* entries with "M."
- (7) *Climb Winds*. Enter *true* direction.
- (8) *Local Wea Wrng/Met Watch Adv*. Enter weather warning or meteorological watch advisories valid for ETD  $\pm$  1 hour.
- (9) *RCR*. Enter latest reported runway condition for departure airfield, if available.
- (10) *Remarks/Takeoff Altn Fcst*. Enter remarks on weather that will affect takeoff and climb. Enter a terminal forecast for the takeoff alternate, if required.

b. *Section II, "En Route Data."* Enter data for the entire route, exclusive of climb and descent.

- (1) *Flt Level*. Enter planned flight level in hundreds of feet, in three digits; for example, "280" for 28,000 feet, "080" for 8,000 feet.
- (2) *Flt Level Winds/Temp*. Enter *true* wind direction at flight level in tens of degrees, speed to the nearest 5 knots. Enter temperature in degrees Celsius. If there are significant differences, enter winds and temperatures in legs; for example, "STL-ORD 2745-45." If one wind and temperature is representative of the entire route, identifiers are not necessary; for example, "3240-38."
- (3) *Clouds at Flt Level*. Check appropriate block. "In and out" implies flight in clouds between 1 percent and 45 percent of the time.



FLIGHT WEATHER BRIEFING													
I. MISSION/TAKEOFF DATA													
DATE	ACFT TYPE/NO.	DEP PT/ETD	RUNWAY TEMP	DEWPOINT	TEMP DEV	PRESSURE ALT	DENSITY ALT						
3 FEB 8	UH-1/689	OZR/1200	+15 °F/C	+13 °F/C	-5 °C	+50 FT	—	FT					
SFC WIND	CLIMB WINDS	LOCAL WEA WRNG/MET WATCH ADV			RCR								
3410	SFC-040 3510	NONE			—								
REMARKS/TAKEOFF ALTN FCST													
II. ENROUTE DATA													
FLY LEVEL		FLY LEVEL WINDS/TEMP											
060		3615 + 5											
CLOUDS AT FLY LEVEL				MINIMUM VISIBILITY AT FLY LEVEL OUTSIDE CLOUDS 5 MILES DUE TO									
<input type="checkbox"/> YES <input type="checkbox"/> NO <input checked="" type="checkbox"/> IN AND OUT				<input checked="" type="checkbox"/> SMOKE <input type="checkbox"/> DUST <input type="checkbox"/> HAZE <input type="checkbox"/> FOG <input type="checkbox"/> PRECIPITATION <input type="checkbox"/> NO OBSTRUCTION									
MINIMUM CEILING		LOCATION		MAXIMUM CLOUDS TOPS		LOCATION		MINIMUM FREEZING LEVEL					
FT AGL				FT MSL				FT MSL					
THUNDERSTORMS			TURBULENCE			ICING			PRECIPITATION				
MRA/WW NO. 03B			CAT ADVISORY —			NONE X			NONE X				
<input checked="" type="checkbox"/> NONE	<input type="checkbox"/> AREA	<input type="checkbox"/> LINE	<input type="checkbox"/> NONE	<input type="checkbox"/> IN CLEAR	<input type="checkbox"/> IN CLOUD	<input type="checkbox"/> NONE	<input type="checkbox"/> RIME	<input type="checkbox"/> MIXED	<input type="checkbox"/> CLEAR	<input type="checkbox"/> DRIZ	<input type="checkbox"/> RAIN	<input type="checkbox"/> SNOW	<input type="checkbox"/> SLEET
ISOLATED 1-2%			LIGHT			TRACE			LT				
FEW 3-18%			MOD			LIGHT			MOD				
SCATTERED 18-48%			SVR			MOD			HVV				
NUMEROUS-MORE THAN 48%			EXTREME			SVR			SHWRS				
MAIL, SVR, TURB, SEVERE, ICING, PRECIPITATION AND LIGHTNING EXPECTED IN AND NEAR TSTMS.			LEVELS			LEVELS			FRZG				
SFC-060													
LOCATION			LOCATION			LOCATION			LOCATION				
III. TERMINAL FORECASTS													
AIRDROME	CLOUD LAYERS				VSBY/WEA	SFC WIND	ALTIMETER	VALID TIME					
DEST/ALTN													
MGM	15 SCT 30 BKN 250 OVC				7	3510 620	2998 INS	1200 Z TO 1400 Z					
DEST/ALTN													
BHM	30 SCT 250 BKN				7	3610	3002 INS	1400 Z TO 1600 Z					
DEST/ALTN													
CSG	15 BKN 30 OVC				4 FH	3408	2995 INS	1600 Z TO 1800 Z					
DEST/ALTN													
OZR	15 OVC				6 FH	3510	2990 INS	1800 Z TO 2000 Z					
DEST/ALTN													
DEST/ALTN							INS	Z TO Z					
DEST/ALTN							INS	Z TO Z					
DEST/ALTN							INS	Z TO Z					
DEST/ALTN							INS	Z TO Z					
IV. COMMENTS/REMARKS													
BRIEFED ON LATEST RCR FOR DESTN AND ALTN <input type="checkbox"/> YES <input checked="" type="checkbox"/> NOT AVAILABLE							REQUEST PIREP AT SIG WX						
V. BRIEFING RECORD													
WEA BRIEFED		FLIMSY BRIEFING NO.			FORECASTER'S SIGNATURE OR INITIALS								
1059		Z			CB								
VOID TIME		EXTENDED TO		WEA REBRIEFED AT		FORECASTER'S INIT		NAME OF PERSON RECEIVING BRIEFING					
1229		Z		Z		Z		BARRON CW2					

DD FORM 175-1 1 SEP 77 PREVIOUS EDITION IS OBSOLETE

Figure C-1. A sample DD Form 175-1.

(4) **Minimum Visibility at Flt Level Outside Clouds.** Enter minimum horizontal visibility en route *outside of clouds*; check appropriate blocks to indicate obstruction(s) to vision.

(5) **Minimum Ceiling and Location.** Enter minimum ceiling en route above ground level (AGL) and the geographical location; for example, "6,000 ft STL-PIA." If the minimum ceiling is over hilly or mountainous terrain, or in thunderstorms, so indicate; for example, "1,000 ft BOSTON MTS," or "2,000 ft SW KY TSTMS."

(6) **Maximum Cloud Tops and Locations.** Enter maximum tops of cloud layers (exclusive of thunderstorm tops) with more than four-eighth coverage in hundreds of feet mean sea level (MSL), and the geographical location.

(7) **Minimum Freezing Level and Location.** Enter height of lowest freezing level en route in hundreds of feet MSL and the geographical location. If lowest freezing level is at the surface, enter "SFC" and geographical location.

(8) **Thunderstorms.** Enter applicable military weather advisory number or date/time of product used and check applicable blocks. Enter geographical location and maximum tops of thunderstorms that may affect the flight.

(9) **Turbulence.** Enter date/time group of the turbulence forecast used (significant meteorological information (SIGMET), airman's meteorological information (AIRMET)). If forecast is based on SIGMETs or AIRMETs, strike out "CAT" and substitute "SIGMET" or "AIRMET," as appropriate. Check applicable blocks. Enter levels and locations of turbulence that may affect the flight.

**NOTE**

**Whenever a 175-1 weather briefing is given and the block under thunderstorms is checked, aviators should be aware that severe turbulence is forecast.**

(10) **Icing.** Check applicable blocks and enter levels and geographical location of icing that may affect the flight.

(11) **Precipitation.** Check applicable blocks and enter geographical location of precipitation areas that may affect the flight.

c. **Section III, "Terminal Forecasts."** Enter a forecast for first stop and alternate, if an alternate is required. Enter forecasts for subsequent stops and alternates, if desired; but you must update these forecasts when able.

(1) **Dest/Altn.** Line out inappropriate designator and enter station identifier. For Army multi-stop missions, enter A/S (for all stops) where the terminal forecast for all stops is similar.

(2) **Cloud Layers, Vsby/Wea.** Enter the lowest prevailing condition expected during the valid period. Enter conditions described by a change group (such as "INTER") on the next line, preceded by the change group. Enter visibility in units that will be used at destination; for example, nautical miles for European destinations, statute miles for CONUS.

(3) **Sfc Wind.** Enter *true* direction if the destination is an airfield other than your own. If the flight is a "round-robin" that will terminate at your own airfield with no intermediate stops, enter the direction *magnetic*. In either case, specify "magnetic" or "true" during the briefing and suffix *magnetic* entries with "M."

(4) **Altimeter.** Enter the lowest setting expected during the valid period in all cases except those in which it is impossible to obtain or determine one.

(5) **Valid Time.** Enter valid time as  $ETA \pm 1$  hour. For flights of less than 1 hour, make the first entry same as ETD.

*d. Section IV, "Comments/Remarks."*

(1) **Briefed on latest RCR for Destn and Altn.** Check appropriate block.

(2) **Request PIREP at specific location or significant weather encountered.** If pilot reports (PIREP) are requested for specific areas, enter the areas.

(3) **Remarks.** Enter any other significant data; for example:

- Data for which there was insufficient space in other blocks.
- Comments and remarks on terminal forecasts.
- Icing and turbulence on letdown to destination (enter location, type, intensity, and level).
- Specialized remarks, such as for low-level mission areas, air refueling, or gunnery/bombing ranges.

*e. Section V, "Briefing Record."*

(1) **Wea Briefed.** Enter time the briefing was completed.

(2) **Flimsy/Briefing No.** If a flight weather briefing folder, flimsy, or computer flight plan (CFP) was prepared for this mission, enter the folder, flimsy, or CFP identification. (For USAF use only.)

(3) **Forecaster's Signature or Initials.** Enter the name or initials of the forecaster providing the briefing.

(4) **Wea Rebriefed At.** If weather is rebriefed, make changes to original weather entries and enter the time the rebriefing was completed.

(5) *Forecaster's Init.* Enter initials of the forecaster providing the rebriefing, or update.

(6) *Name of Person Receiving Briefing.* Enter your name and grade.

## GLOSSARY

### Section I. TERMS AND DEFINITIONS

**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) had 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 an abbreviated air mass analysis are (1) heating from below promotes instability, and (2) cooling from below promotes stability. By applying these principles in conjunction with other guidelines 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 subarctic and subantarctic latitudes and is called *aurora borealis* or *aurora australis*, 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; for example, the wind backs from the north to northwest. Opposite of 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."

**CALORIES**—the amount of heat required to raise the temperature of 1 gram of water 1 degree Celsius.

**CEILING**—the height above the earth's surface of the lowest layer of clouds of obscuration phenomena that is 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; that is, an inverted centigrade scale. It is now used interchangeably with the centigrade scale, with 0° freezing and 100° boiling temperatures.

**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 National Weather Service 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**—the transfer of heat by contact. 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 wind flow 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 a 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.** The process by which air cools due to decrease in pressure. 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; for example, frontal weather, convective, and orographic thunderstorms, and up-slope 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

$$C = 2\omega v \sin \theta$$

where C is Coriolis acceleration,  $\omega$  is angular velocity, and  $\theta$  is the latitude where the motion occurs. The acceleration changes the wind velocity 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.

**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, or pertaining to daytime.

**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 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 or 3,000 feet—where only pressure gradient force is affecting the speed of the wind.

**GUST**—rapid fluctuations in wind speed with a variation of 10 knots or more between peaks and lulls.

**GREENHOUSE EFFECT**—This term is derived from the effect of the glass roof on a greenhouse which transmits high-frequency insolation, but blocks the passage of terrestrial radiation from within the glass inclosure. 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 degrees latitude characterized by calms and 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 72°C 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 degrees 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; that is, 2°C per 1,000 feet in the standard atmosphere.

**LINE SQUALL**—See **SQUALL LINE**.

**MEAN 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; that is, 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 256 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.

**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 0.000000001 centimeter to 10,000,000,000 centimeters. 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 measured time for the changing state of a substance from a liquid to a gas. 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 celestial 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 -15°C between 32°C and 29°C produces a significantly different relative humidity from the same spread between 18°C and 16°C.



**SQUALL**—a sudden increase in wind speed of at least 15 knots and sustained at 20 knots or more for at least 1 minute.

**SQUALL LINE**—a line of thunderstorms, generally continuous across the horizon. The squall line is associated with prefrontal activity.

**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 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 reradiation 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**—the interval of incomplete darkness following sunset and preceding sunrise.

**VEER**—See **BACK**.

**WEATHER**—In addition to its complete definition (para 2-3c), 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.

## Section II. ABBREVIATIONS AND BREVITY CODES

**A**—arctic

**AFGWC**—Air Force global weather service

**AIRMET**—airmen's meteorological information

**ARTCC**—air route traffic control centers

**ASL**—above sea level

**ATC**—air traffic control

**AWS**—Air Weather Service

**B**

**C**—Celsius

**CAT**—clear-air temperature

**Cb**—cumulonimbus

**CFP**—complete flight plan

**CIG**—ceiling

**CIGNO**—no ceiling

**COMEDS**—CONUS Meteorological Data System

**CONUS**—Continental United States

**cPk**—continental polar cold

**CRT**—cathode ray tube

**cT**—continental tropical

**DST**—display storage tube

**DURGC**—during climb

**DURGD**—during descent

**EGT**—exhaust gas temperature  
**EP**—entire period  
**ETL**—effective translational lift  
**F**—Fahrenheit  
**FAA**—Federal Aviation Administration  
**FAR**—Federal Aviation Regulation  
**FAT**—free-air temperature  
**FLIP**—flight information publication(s)  
**FM**—frequency-modulated  
**FOD**—foreign object damage  
**FPM**—feet per minute  
**FSS**—flight service station  
**GMT**—Greenwich mean time  
**Hg**—inches of mercury  
**Hz**—Hertz  
**ICAO**—International Civil Aviation Organization  
**IFR**—instrument flight rules  
**ITCZ**—intertropical convergence zone  
**J**  
**K**  
**LV**—light variable  
**mb**—millibar  
**METAR**—aviation routine weather report (in international MET figure code)  
**METRO**—pilot-to-metro voice call  
**MHz**—megahertz  
**MIC**—maximum instantaneous coverage  
**mPw**—maritime polar warm  
**mTk**—maritime tropical cold  
**nm**—nautical miles  
**NOTAM**—notice to airmen  
**OAT**—outside air temperature  
**P**—Polar

Glossary-6

**PIREP**—pilot report(s)  
**PMSV**—pilot-to-metro service  
**PRF**—pulse repetition frequency  
**psi**—pounds per square inch  
**Q**  
**radar**—radio detecting and ranging  
**RAREP**—radar report  
**RCR**—runway condition reading  
**RCRNR**—runway condition reading no report  
**RF**—radio frequency  
**RPM**—revolutions per minute  
**RVR**—runway visual range  
**SCAN**—significant changes and notices to airmen  
**sfc**—surface  
**SIGMET**—significant meteorological information  
**STC**—sensitivity time control  
**T**—Tropical  
**TACAN**—tactical air navigation  
**U**  
**VFR**—visual flight rules  
**VMC**—visual meteorological conditions  
**VOR**—VHF omnidirectional range  
**VORTAC**—collocated VOR and TACAN navigation aids  
**WX**—weather  
**X**  
**Y**  
**Z**—Zulu (time)

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By Order of the Secretary of the Army:

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