# CHAPTER 4

# AIR MASSES AND FRONTS

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

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

## AIR MASSES

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

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

### CONDITIONS NECESSARY FOR AIR MASS FORMATION

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

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

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

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

### EFFECTS OF CIRCULATION ON ALL AIR MASS FORMATION

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

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

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

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

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

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

## AIR MASS SOURCE REGIONS

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

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

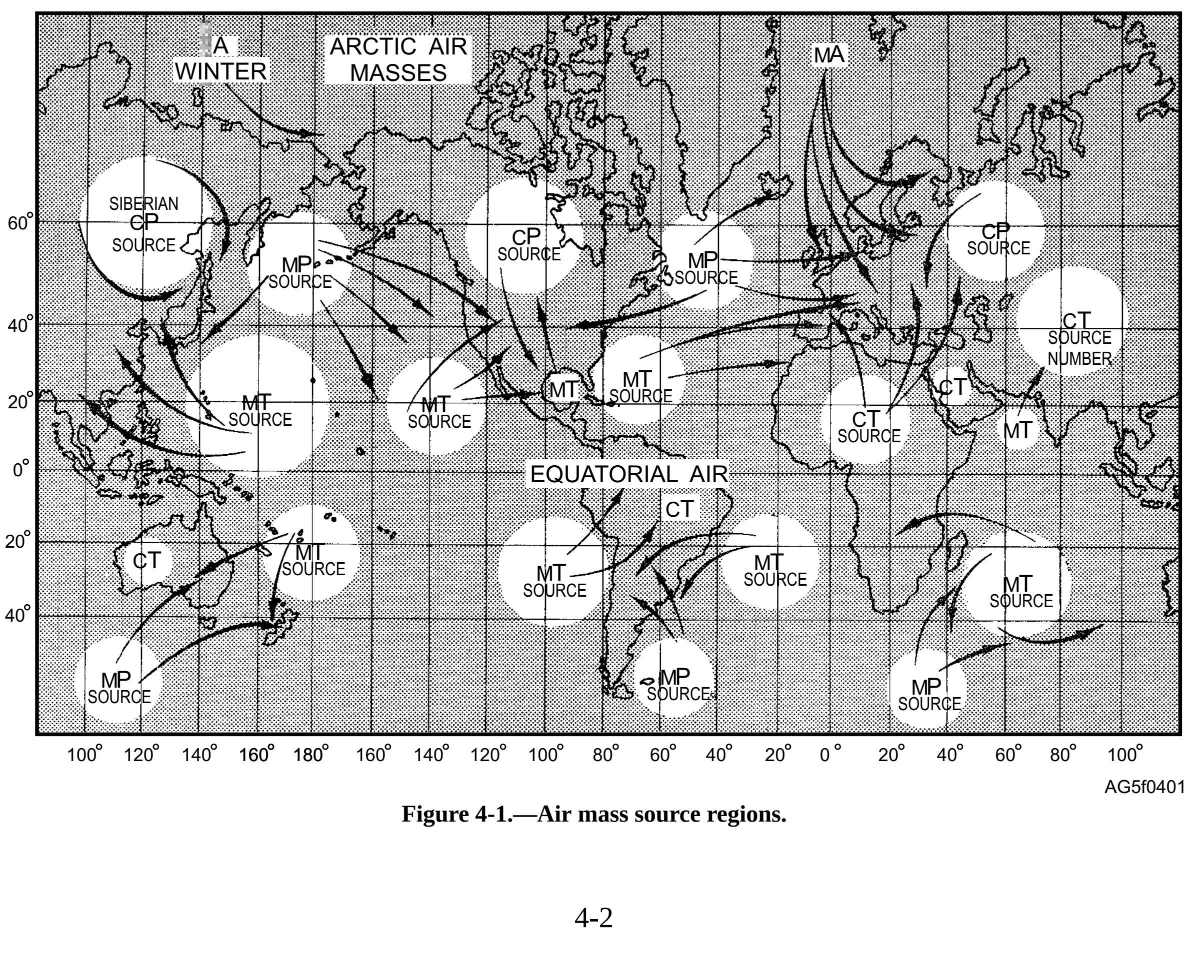


**Figure 4-1.—Air mass source regions.**

### Characteristics of Air Masses

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

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

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

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

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

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

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

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

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

### Southern Hemisphere Air Masses

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

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

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

## AIR MASS CLASSIFICATION

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

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

### Geographic Origin

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

### Moisture Content

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

### Thermodynamic Process

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

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

**Table 4-1.—Classification of Air Masses**

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

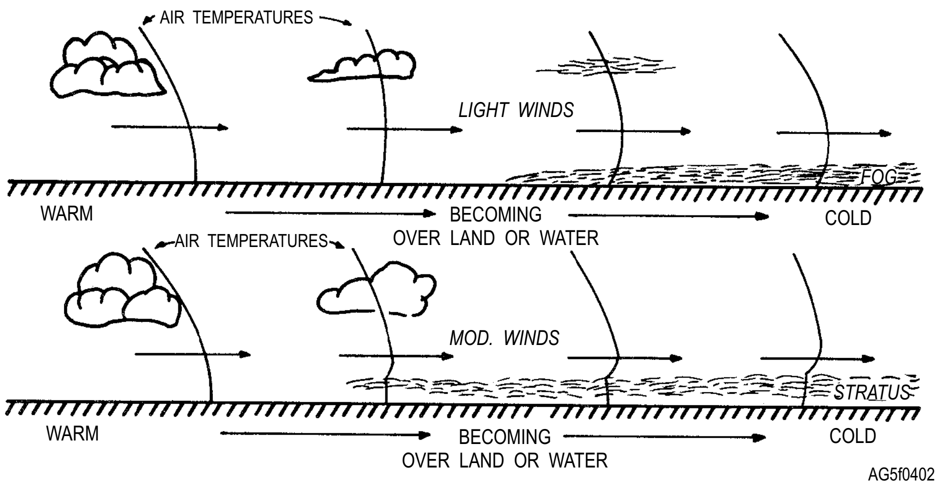


**Figure 4-2.—Passage of warm air over colder surfaces.**

## AIR MASS MODIFICATION

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

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

### Surface Temperature

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

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

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

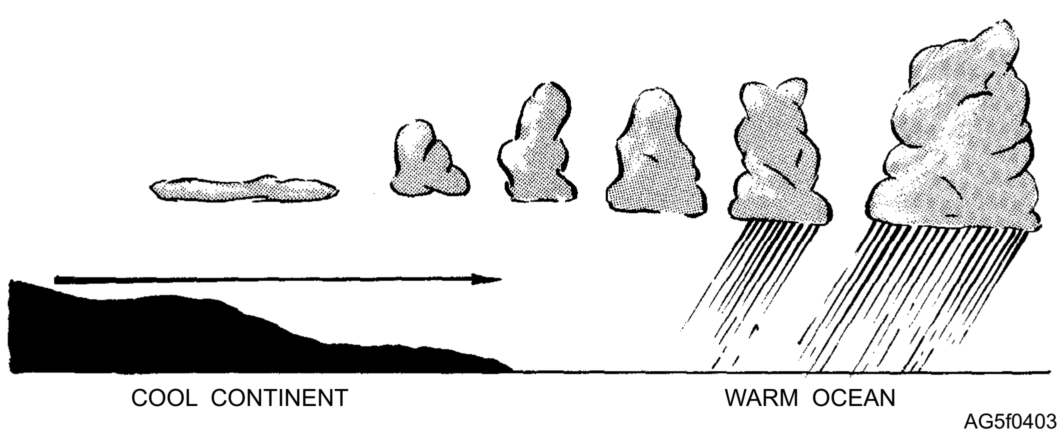


**Figure 4-3.—Continental polar air moving from cool continent to warm ocean (winter).**

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

### Surface Moisture

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

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

### Topography of Surface

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

### Trajectory

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

### Age

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

### Modifying Influences on Air Mass Stability

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

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

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

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

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

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

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

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**Figure 4-4.—Air mass changes.**

## WORLD AIR MASSES

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

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

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

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

#### cPk and cAk Air in Winter

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

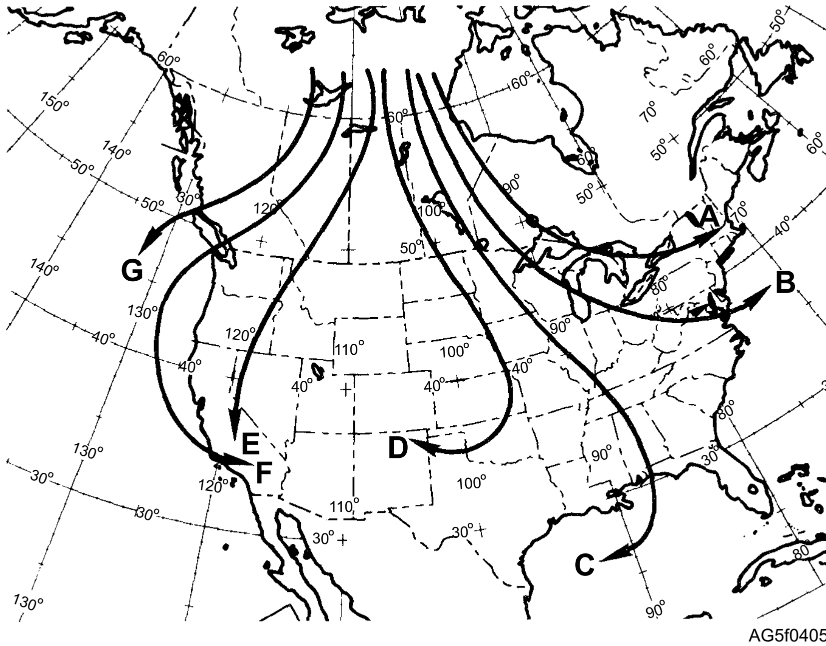


**Figure 4-5.—Trajectories of cP and cA air in winter.**

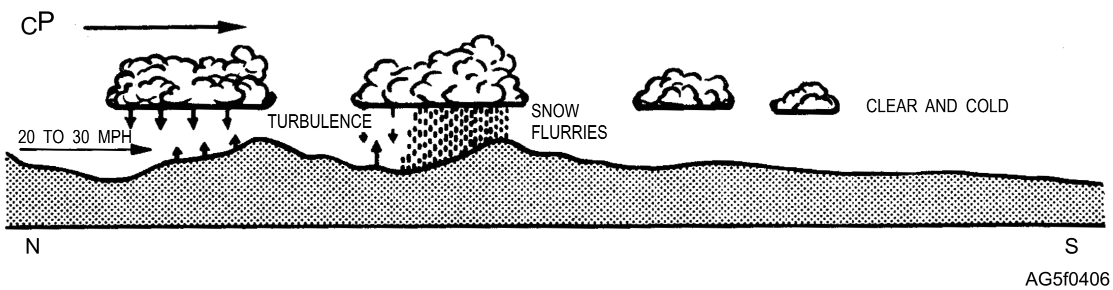


**Figure 4-6.—cP air moving southward.**

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

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

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

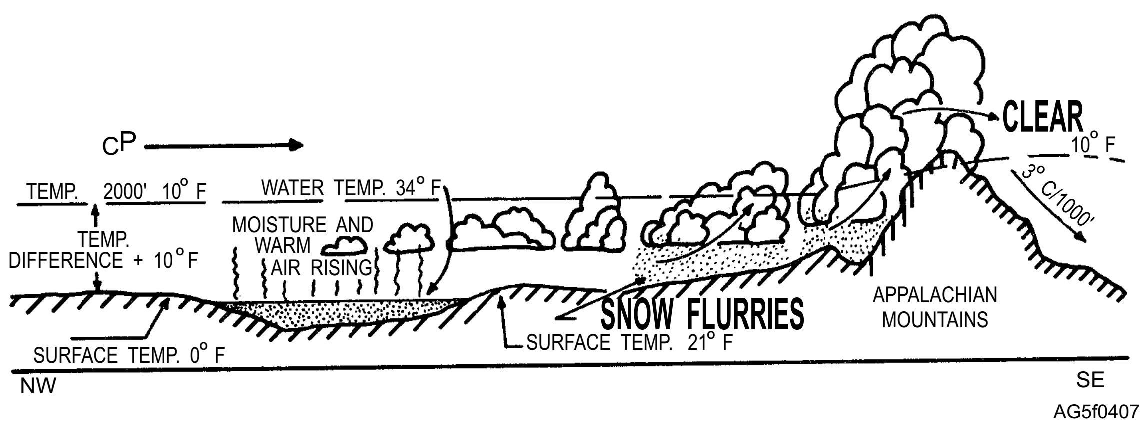


**Figure 4-7.—cP air moving over the Great Lakes (winter).**

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

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

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

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

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

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

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

### Maritime Polar (mP) Air Pacific in Winter

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

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

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

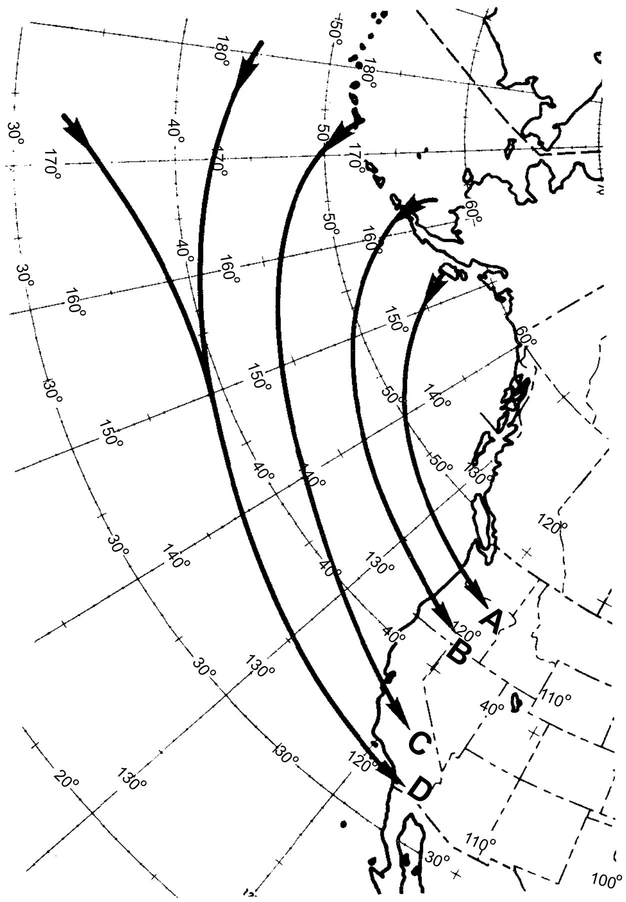


**Figure 4-8.—Trajectories of mP air over the Pacific Coast in winter.**

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

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

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

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

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

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

### Maritime Tropical (mT) Air Pacific in Winter

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

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

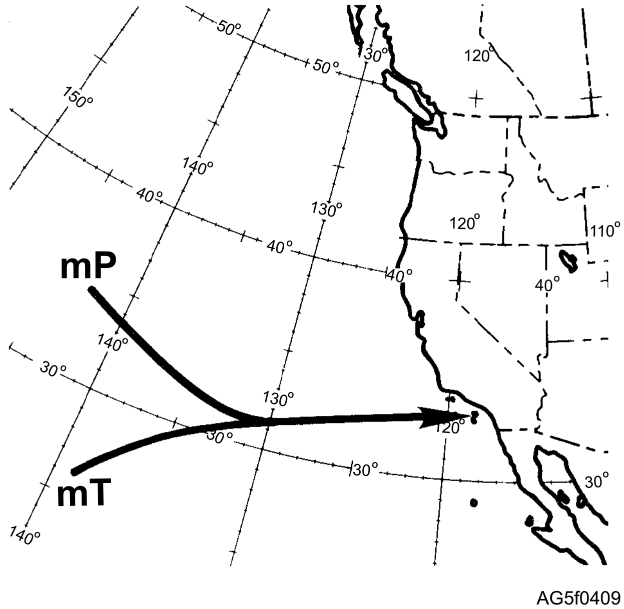


**Figure 4-9.—Trajectory of mT air over the Pacific in winter.**

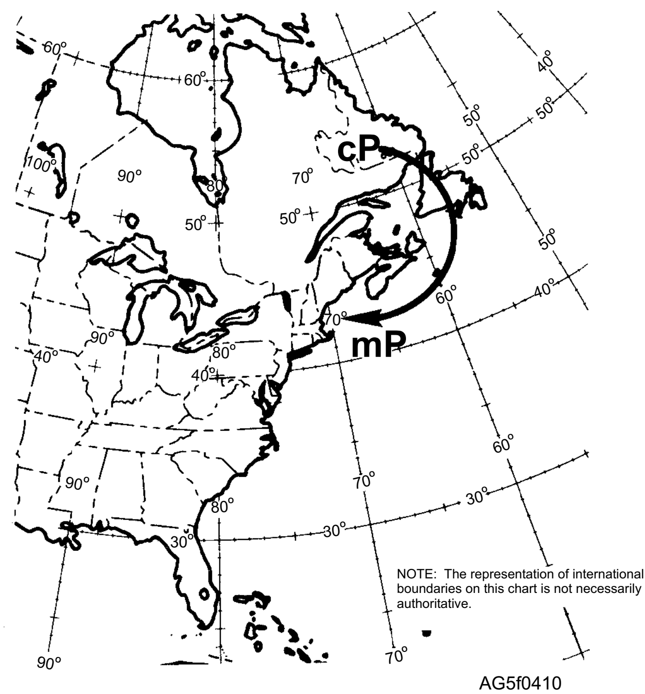


**Figure 4-10.—Trajectory of mP air over the Atlantic in winter.**

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

### Maritime Polar (mP) Air Atlantic in Winter

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

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

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

### Maritime Tropical (mT) Air Atlantic in Winter

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

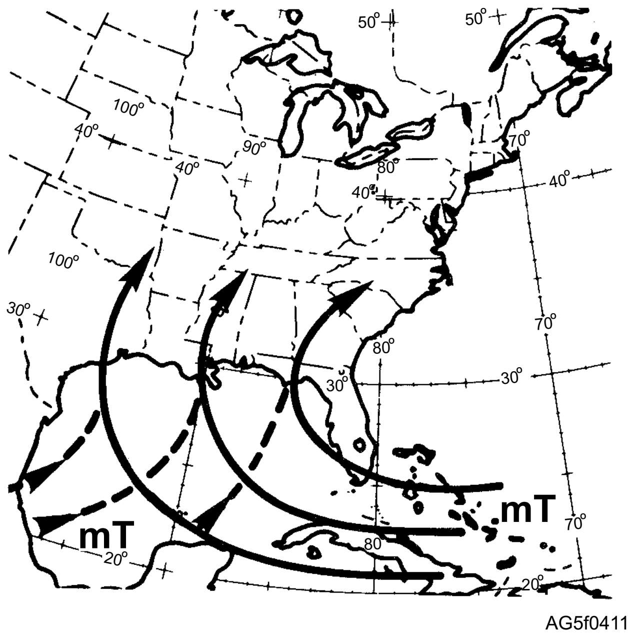


**Figure 4-11.—Trajectories of mT air over the Atlantic in winter.**

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

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

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

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

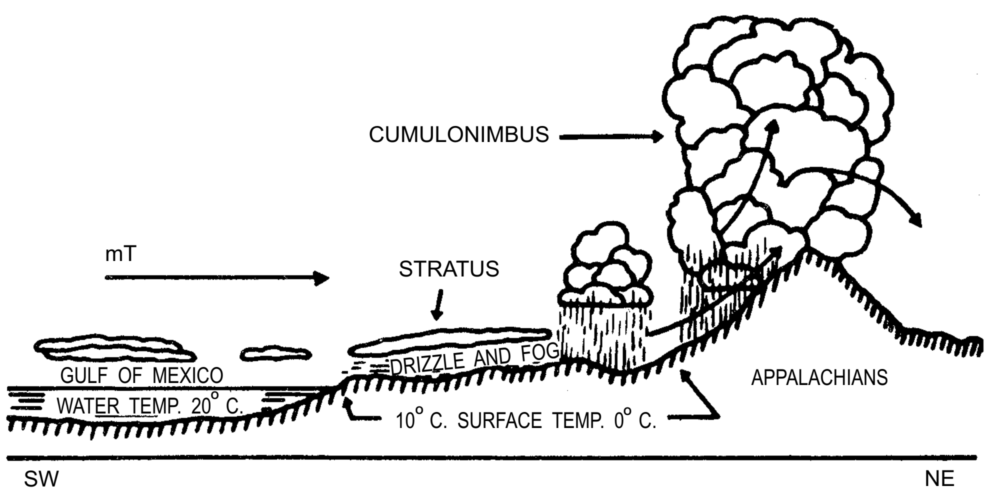


**Figure 4-12.—mT air moving northeastward.**

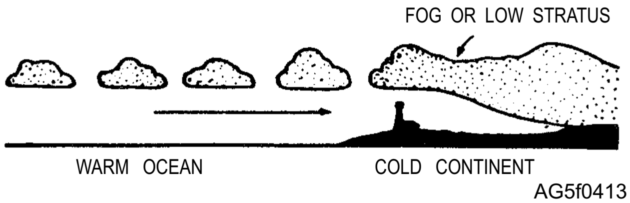


**Figure 4-13.—mT (Gulf of Mexico or Atlantic) air of winter moving northward over cold continent.**

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

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

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

### Continental Polar (cP) Air in Summer

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

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

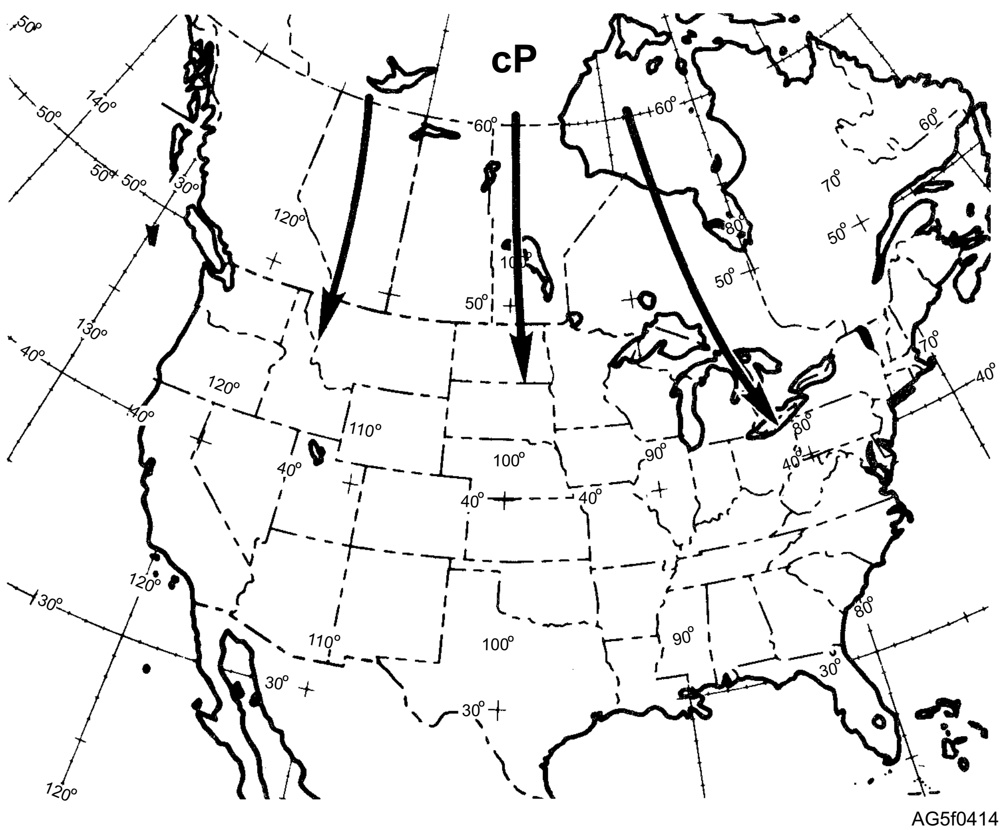


**Figure 4-14.—Continental polar (cP) air in summer.**

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

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

### Maritime Polar (mP) Air Pacific in Summer

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

### Maritime Polar (mP) Air Atlantic in Summer

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

### Maritime Tropical (mT) Air Pacific in Summer

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

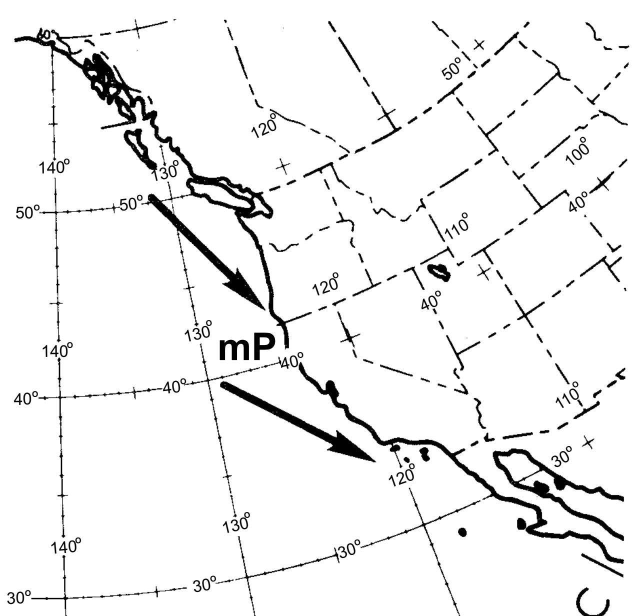

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**Figure 4-15.—Trajectories of mP air over the Pacific in summer.**

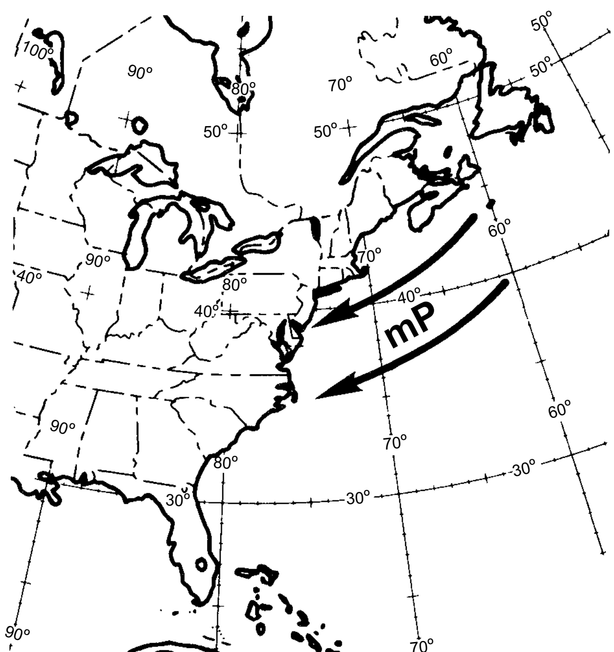

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**Figure 4-16.—Trajectories of mP air over the Atlantic in summer.**

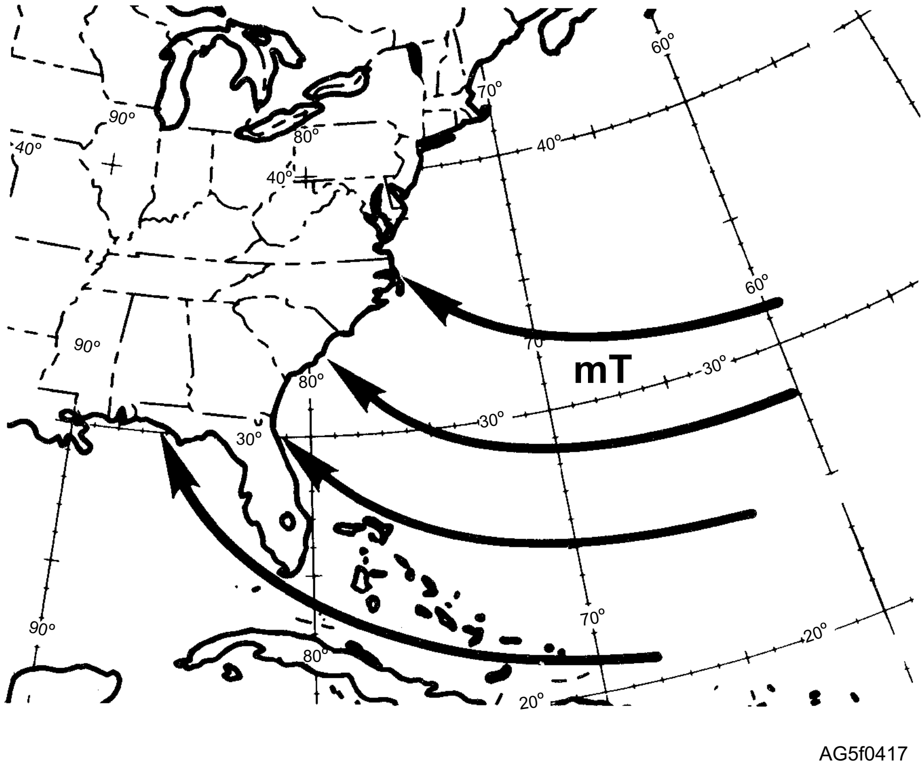


**Figure 4-17.—Maritime tropical (mT) air, Atlantic, in summer.**

**Maritime Tropical (mT) Air Atlantic in Summer**

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

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

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

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

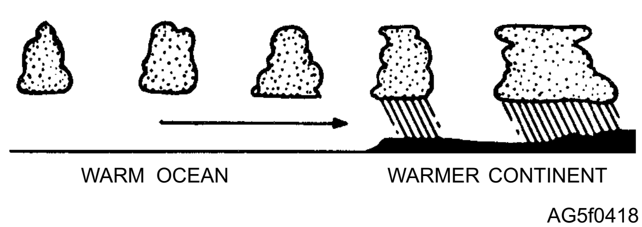


**Figure 4-18.—mT (Gulf of Mexico or Atlantic) air in summer moving northward over a warm continental surface.**

### Continental Tropical (cT) Air in Summer

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

### Superior (S) Air in Summer

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

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

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

## AIR MASSES OVER ASIA

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

### Continental Polar (cP) Air

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

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

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

### Maritime Tropical (mT) Air

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

### Equatorial (E) Air

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

A

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

B

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

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

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

## AIR MASSES OVER EUROPE

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

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

### Maritime Arctic (mA) Air in Winter

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

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

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

### Maritime Arctic (mA) Air in Summer

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

### Maritime Polar (mP) Air in Winter

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

### Maritime Polar (mP) Air in Summer

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

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

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

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

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

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

### Maritime Tropical (mT) Air in Winter

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

### Maritime Tropical (mT) Air in Summer

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

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

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

### Continental Tropical (cT) Air in Winter

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

### Continental Tropical (cT) Air in Summer

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

## AIR MASSES IN THE SOUTHERN HEMISPHERE

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

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

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

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

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

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

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

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

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

## REVIEW QUESTIONS

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

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

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

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

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

## FRONTS

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

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

## DEFINITIONS AND CLASSIFICATIONS

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

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

### Cold Front

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

### Warm Front

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

### Quasi-Stationary Front

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

### Occluded Front

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

## RELATION OF FRONTS TO AIR MASSES AND CYCLONES

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

### RELATION OF FRONTS TO AIR MASSES

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

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

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

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

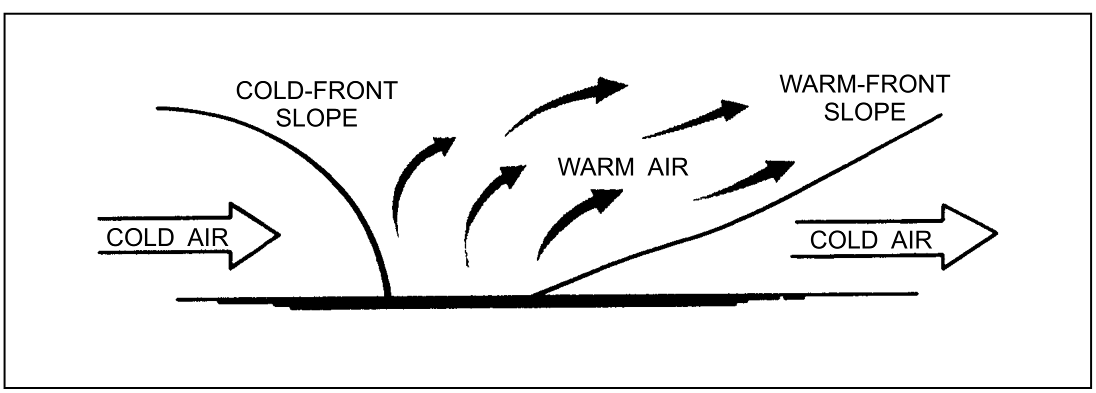


**Figure 4-20.—Vertical view of a frontal system (clouds not shown).**

## RELATION OF FRONTS TO CYCLONES

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

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

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

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

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

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

### Stable Waves

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

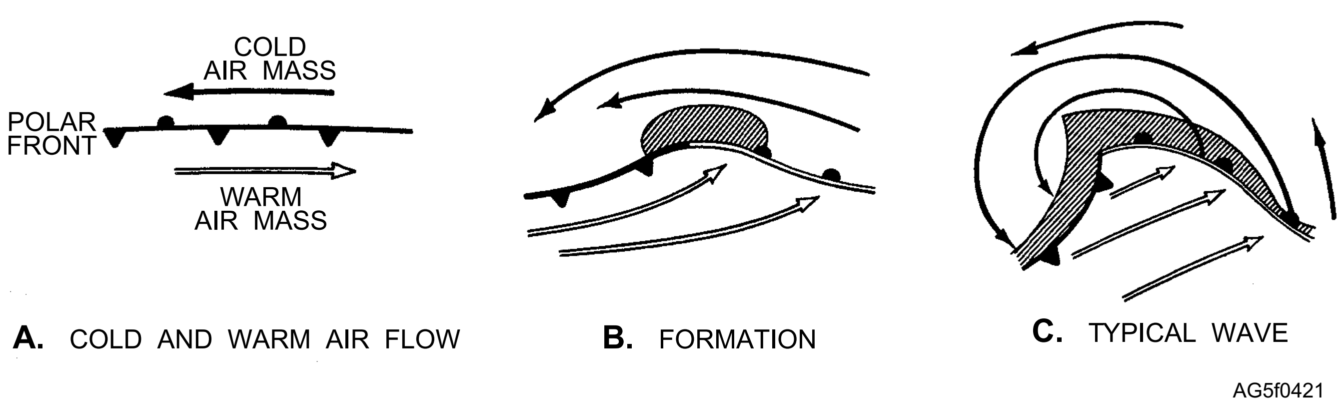


**Figure 4-21.—Life cycle of a stable wave cyclone.**

## Unstable Waves

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

In its initial stage of development, the polar front separates the polar easterlies from the mid-latitude westerlies (view A); the small disturbance caused by the steady state of the wind is often not obvious on the weather map. Uneven local heating, irregular terrain, or wind shear between the opposing air currents may start a wavelike perturbation on the front (view B); if this tendency persists and the wave increases in amplitude, a counterclockwise (cyclonic) circulation is set up. One section of the front begins to move as a warm front while the adjacent sections begin to move as a cold front (view C). This deformation is called a frontal wave.

The pressure at the peak of the frontal wave falls, and a low-pressure center is formed. The cyclonic circulation becomes stronger; the wind components are now strong enough to move the fronts; the westerlies turn to southwest winds and push the eastern part of the front northward as a warm front; and the easterlies on the western side turn to northerly winds and push the western part southward as a cold front. The cold front is moving faster than the warm front (view D). When the

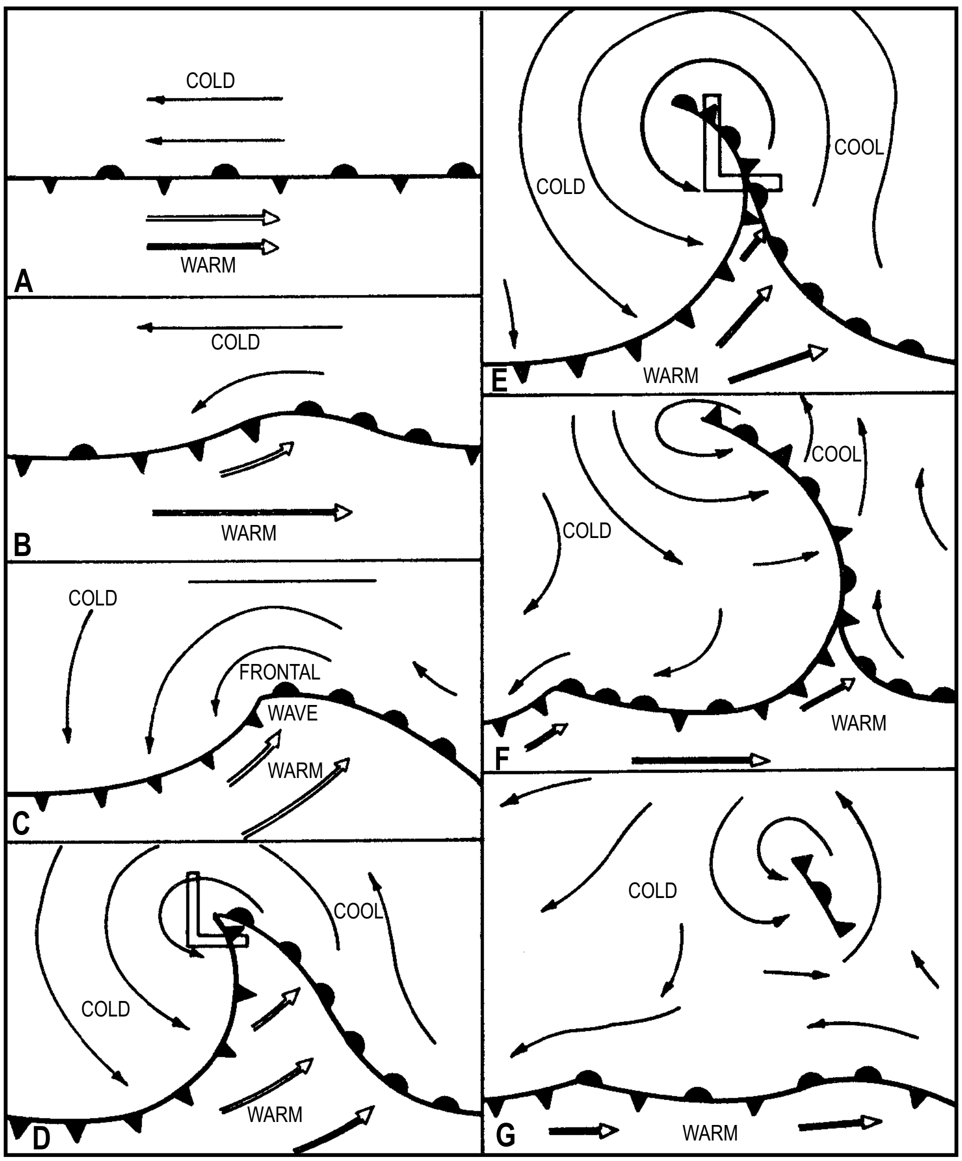


**Figure 4-22.—Life cycle of an unstable frontal wave.**

**Table 4-2.—Numerical Characteristics of the Life Cycle of an Unstable Wave Cyclone**

| | Wave Cyclone | Occlusion | Mature Occlusion | Cyclolysis |
|---|---|---|---|---|
| Time (hours) | 0 | 12-24 | 24-36 | 36-72 |
| Central Pressure (mb) | 1,012-1,000 | 1000-988 | 984-968 | 998-1,004 |
| Direction of Movement (toward) | NE to SE or (quad) | NNE to N (arc) | N to NNW (arc) |  |
| Speed of Movement (knots) | 30-35 | 20-25 | 10-15 | 0-5 |

The  symbol indicates that the filling center drifts slowly in a counterclockwise direction along an approximately circular path about a fixed point.

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cold front overtakes the warm front and closes the warm sector, an occlusion is formed (view E). This is the time of maximum intensity of the wave cyclone.

As the occlusion continues to extend outward, the cyclonic circulation diminishes in intensity (the low-pressure area weakens), and the frontal movement slows down (view F). Sometimes a new frontal wave may begin to form on the westward trailing portion of the cold front. In the final stage, the two fronts become a single stationary front again. The low center with its remnant of the occlusion has disappeared (view G). Table 4-2 shows the numerical average life cycle of a typical unstable wave cyclone from initial development to cyclolysis. It is only intended to be used as a guide in areas where reports are sparse.

## FRONTOGENESIS AND FRONTOLYSIS

**LEARNING OBJECTIVE**: Describe the conditions necessary for frontogenesis and frontolysis, and identify the world fronto-genetical zones.

### CONDITIONS NECESSARY FOR FRONTOGENESIS

Frontogenesis is the formation of a new front or the regeneration of an old one. Frontogenesis takes place only when two conditions are met. First, two air masses of different densities must exist adjacent to one another; and second, a prevailing wind field must exist to bring them together. There are three basic situations, which are conducive to frontogenesis and satisfy the two basic requirements.

The windflow is cross isothermal and flowing from cold air to warmer air. The flow must be cross isothermal, resulting in a concentration of isotherms (increased temperature gradient). The flow does not have to be perpendicular; however, the more perpendicular the cross isothermal flow, the greater the intensity of frontogenesis.

The winds of opposite air masses move toward the same point or line in that cross-isothermal flow. A classic example of this situation is the polar front where cold polar air moves southward toward warmer

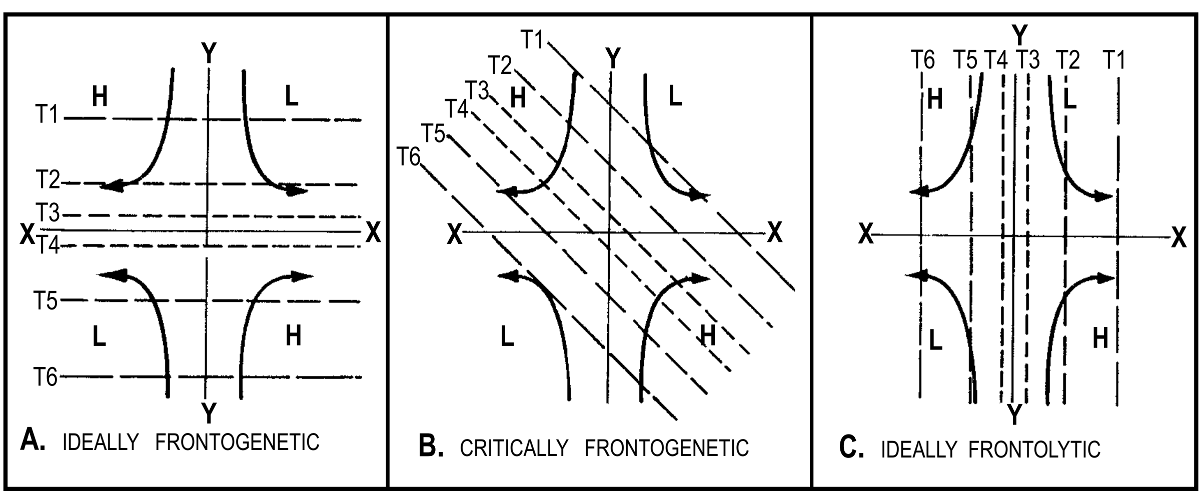


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**Figure 4-23.—Perpendicular deformation field.**

temperatures and warm tropical air moves northward toward colder temperatures.

The wind flow has formed a deformation field. A deformation field consists basically of an area of flat pressure between two opposing highs and two opposing lows (also called a COL or saddle). It has two axes that have their origin at a neutral point in the COL (view A in fig. 4-23). The y axis, or axis of contraction, lies between the high and low that bring the air particles toward the neutral point. (Note the flow arrows in fig. 4-23.) The x axis lies between the high and low that take air particles away from the neutral point and is known as the axis of dilation.

The distribution and concentration of isotherms T1 through T6 in this deformation field determine whether frontogenesis results. If the isotherms form a large angle with the axis of contraction, frontogenesis results. If a small angle exists, frontolysis (the dissipation of a front) results. It has been shown that in a perpendicular deformation field, isotherms must form an angle of 450 or less with the axis of dilation for frontogenesis to occur as shown in views A and B of the figure. In a deformation field not perpendicular, the critical angle changes correspondingly as illustrated in views A and B of figure 4-24. In most cases, frontogenesis occurs along the axis of dilation. Frontogenesis occurs where there is a concentration of isotherms with the circulation to sustain that concentration.

## CONDITIONS NECESSARY FOR FRONTOLYSIS

Frontolysis, or the dissipation of a front, occurs when either the temperature difference between the two air masses disappears or the wind carries the air particles of the air mass away from each other. Frontolytical processes are more common in the atmosphere than are frontogenetical processes. This comes about because there is no known property of the air, which is conservative with respect to all the physical or dynamical processes of the atmosphere.

Frontolytical processes are most effective in the lower layers of the atmosphere since surface heating and turbulent mixing are the most intense of the nonconservative influences on temperature.

For frontolysis to occur, only one of the two conditions stated above need be met. The simultaneous happening of both conditions results in more rapid frontolysis than if only one factor were operative. The shape and curvature of the isobars also give valuable indications of frontolysis and frontogenesis, and, therefore, possible cyclolysis or cyclogenesis.

On a cold front, anticyclonically curved isobars behind the front indicate that the FRONT is slow moving and therefore exposed to frontogenesis.

Cyclonically curved isobars in the cold air behind the cold front indicate that the front is fast moving and exposed to frontolysis. On the warm fronts the converse is true.

Anticyclonically curved isobars in advance of the warm front indicate the front is fast moving and exposed to frontolysis.

With cyclonically curved isobars the warm front is retarded and exposed to frontogenesis.

## WORLD FRONTOGENETICAL ZONES

Certain regions of the world exhibit a high frequency of frontogenesis. These regions are

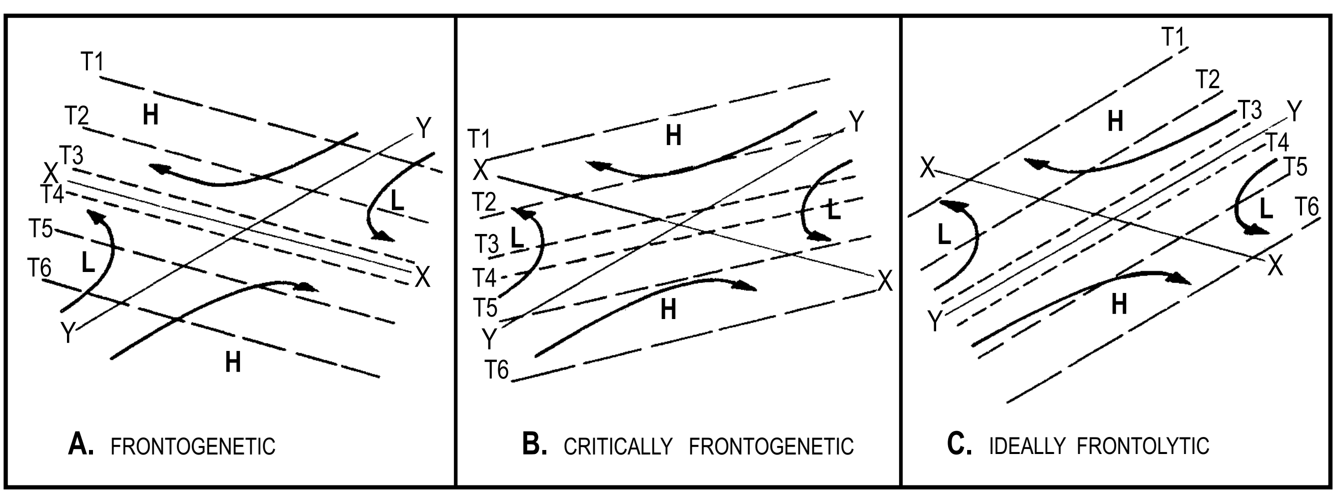


**Figure 4-24.—Nonperpendicular deformation field.**

coincident with the greatest temperature contrasts. Two of the most important frontal zones are those over the north Pacific and north Atlantic Oceans. In winter, the arctic front, a boundary between polar and arctic air, forms in high latitudes over northwest North America, the north Pacific, and near the Arctic Circle north of Europe (fig. 4-25). In summer, the arctic front mainly disappears, except north of Europe. (See fig. 4-26.)

The polar front, on the other hand, is present the year round, although it is not as intense in the summer as in the winter because of a lessening temperature contrast between the opposing air masses. The polar front forms wherever the wind flow and temperature contrast is favorable. Usually this is the boundary between tropical and polar air, but it may form between maritime polar and continental polar air. It also may exist between modified polar air and a fresh outbreak of polar air. The polar front is common over North America in the continental regions in winter in the vicinity of 50°N latitude.

The polar front in winter is found most frequently off the eastern coasts of continents in areas of 30° to 60° latitude. It is also found over land; but since the temperature contrasts are greater between the continent and the oceans, especially in winter, the coastal areas are more favorable for formation and intensification of the polar front.

The intertropical convergence zone (ITCZ), though not truly a front but a field of convergence between the opposing trades, forms a third semipermanent frontal type. This region shows a seasonal variation just as do the trade winds.

## FRONTAL CHARACTERISTICS

**LEARNING OBJECTIVE**: Describe the frontal elements and general characteristics of fronts.

### FRONTAL ELEMENTS

From our previous discussion and definitions of fronts, it was implied that a certain geometrical and meteorological consistency must exist between fronts

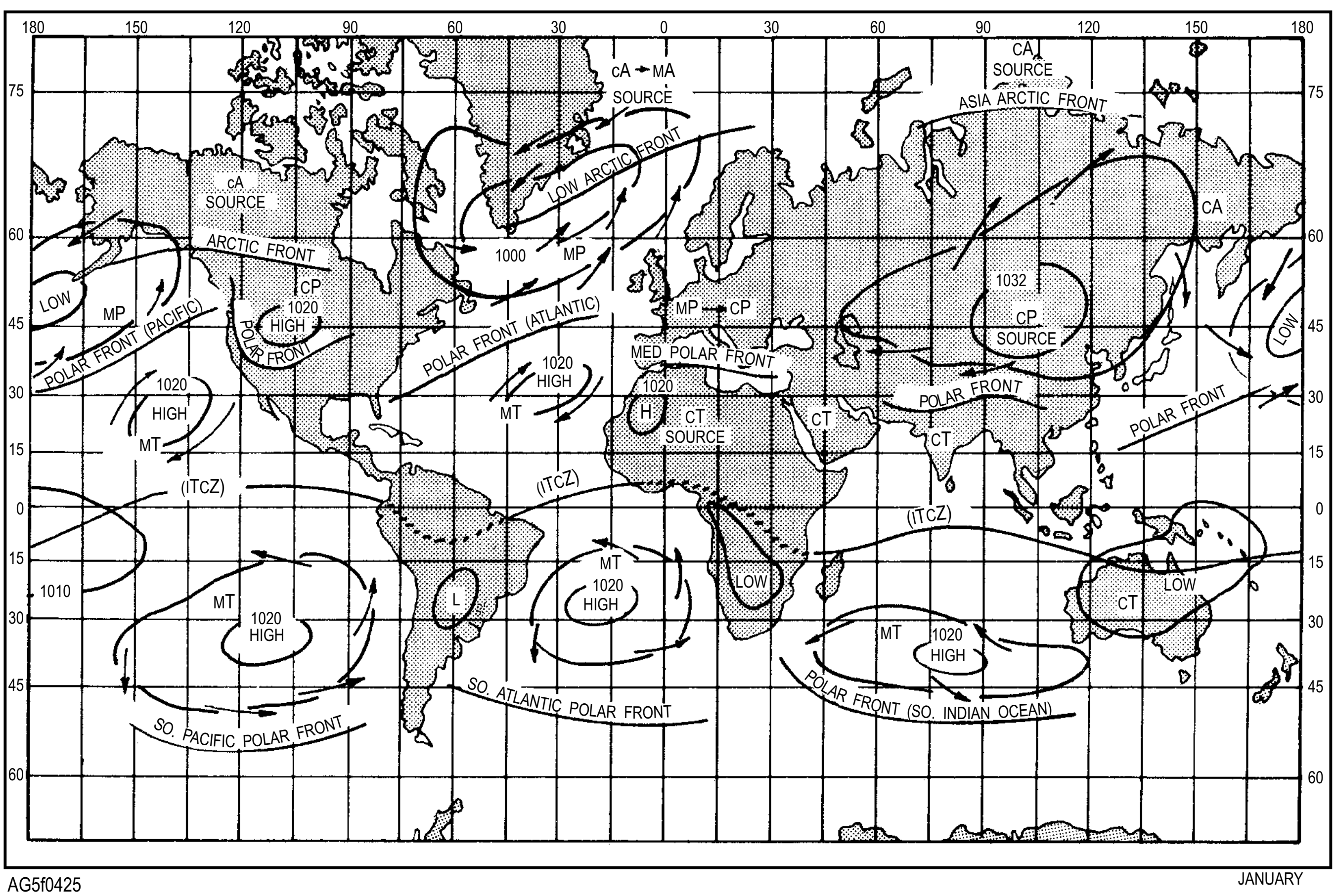


**Figure 4-25.—Chart showing world air masses, fronts and centers of major pressure systems in January.**

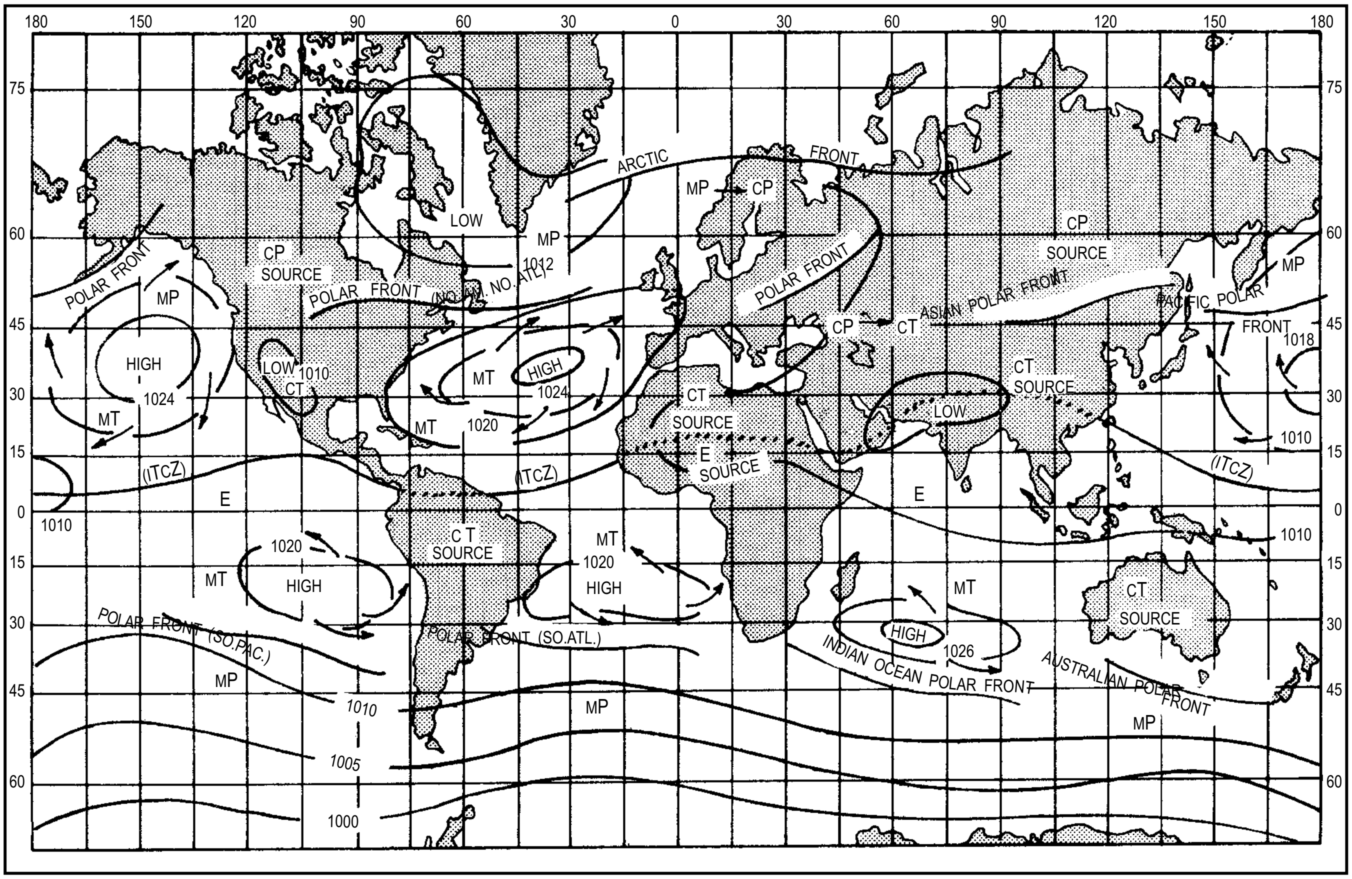


**Figure 4-26.—Chart showing world air masses, fronts and centers of major pressure systems in July.**

at adjoining levels. It can also be inferred that the data at no one particular level is sufficient to locate a front with certainty in every case. We must consider the horizontal and vertical distribution of three weather elements (temperature, wind, and pressure) in a frontal zone.

### Temperature

Typical fronts always consist of warm air above cold air. A radiosonde observation taken through a frontal surface often indicates a relatively narrow layer where the normal decrease of temperature with height is reversed. This temperature inversion is called a frontal inversion; its position indicates the height of the frontal surface and the thickness of the frontal zone over the particular station. The temperature increase within the inversion layer and the thickness of the layer can be used as a rough indication of the intensity of a front. Strong fronts tend to have a distinct inversion; moderate fronts have isothermal frontal zones; and weak fronts have a decrease in temperature through the frontal zone.

Frontal zones are often difficult to locate on a sounding because air masses become modified after leaving their source region and because of turbulent mixing and falling precipitation through the frontal zone. Normally, however, some indication does exist. The degree to which a frontal zone appears pronounced is proportional to the temperature difference between two air masses.

The primary indication of a frontal zone on a Skew T diagram is a decrease in the lapse rate somewhere in the sounding below 400 mb. The decrease in lapse rate may be a slightly less steep lapse rate for a stratum in a weak frontal zone to a very sharp inversion in strong fronts. In addition to a decrease in the lapse rate, there is usually an increase in moisture (a concurrent dew-point inversion) at the frontal zone. This is especially true when the front is strong and abundant cloudiness and

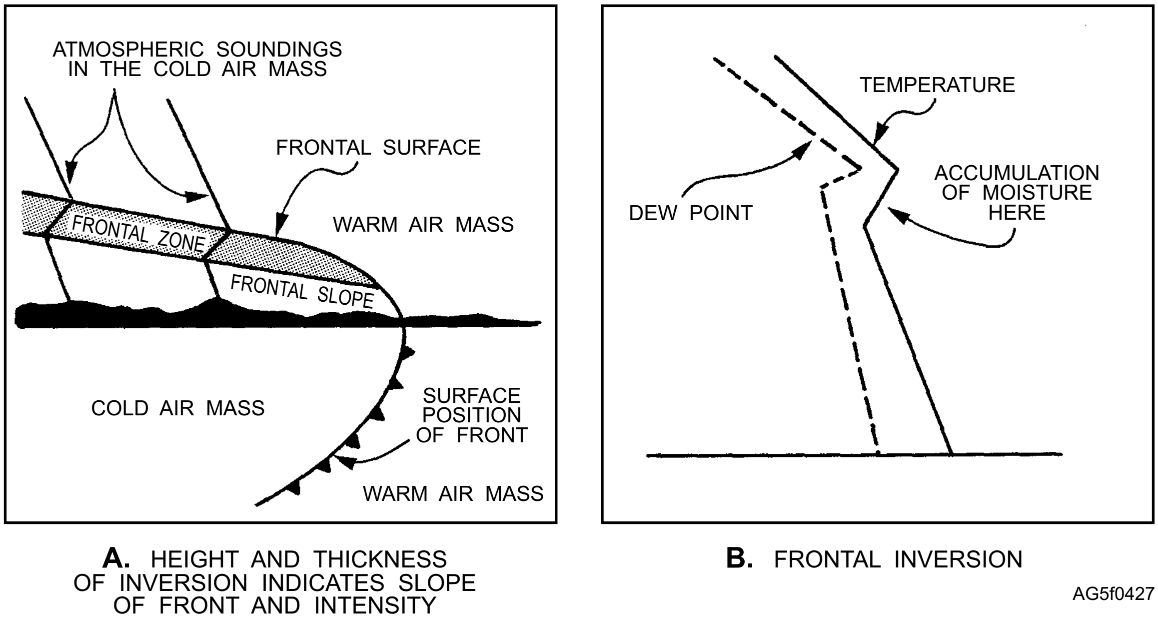


**Figure 4-27.—Inversions.**

precipitation accompany it. View A of figure 4-27 shows the height of the inversion in two different parts of a frontal zone, and view B of figure 4-27 shows a strong frontal inversion with a consequent dew-point inversion.

A cold front generally shows a stronger inversion than a warm front, and the inversion appears at successively higher levels as the front moves past a station. The reverse is true of warm fronts. Occluded fronts generally show a double inversion. However, as the occlusion process continues, mixing of the air masses takes place, and the inversions are wiped out or fuse into one inversion.

It is very important in raob analysis not to confuse the subsidence inversion of polar and arctic air masses with frontal inversions. Extremely cold continental arctic air, for instance, has a strong inversion that extends to the 700-mb level. Sometimes it is difficult to find an inversion on a particular sounding, though it is known that a front intersects the column of air over a given station. This may be because of adiabatic warming of the descending cold air just under the frontal surface or excessive local vertical mixing in the vicinity of the frontal zone. Under conditions of subsidence of the cold air beneath the frontal surface, the subsidence inversion within the cold air may be more marked than the frontal zone itself.

Sometimes fronts on a raob sounding, which might show a strong inversion, often are accompanied by little weather activity. This is because of subsidence in the warm air, which strengthens the inversion. The weather activity at a front increases only when there is a net upward vertical motion of the warm air mass.

### Wind

Since winds near Earth's surface flow mainly along the isobars with a slight drift toward lower pressure, it follows that the wind direction in the vicinity of a front must conform with the isobars. The arrows in figure 4-28 indicate the winds that correspond to the pressure distribution.

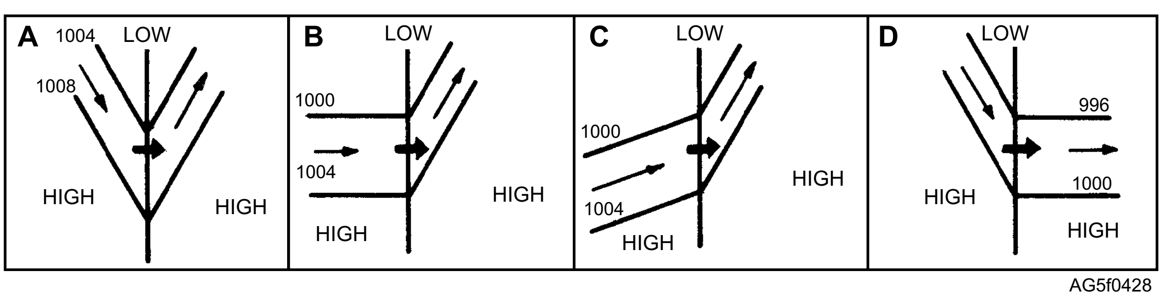


**Figure 4-28.—Types of isobars associated with fronts.**

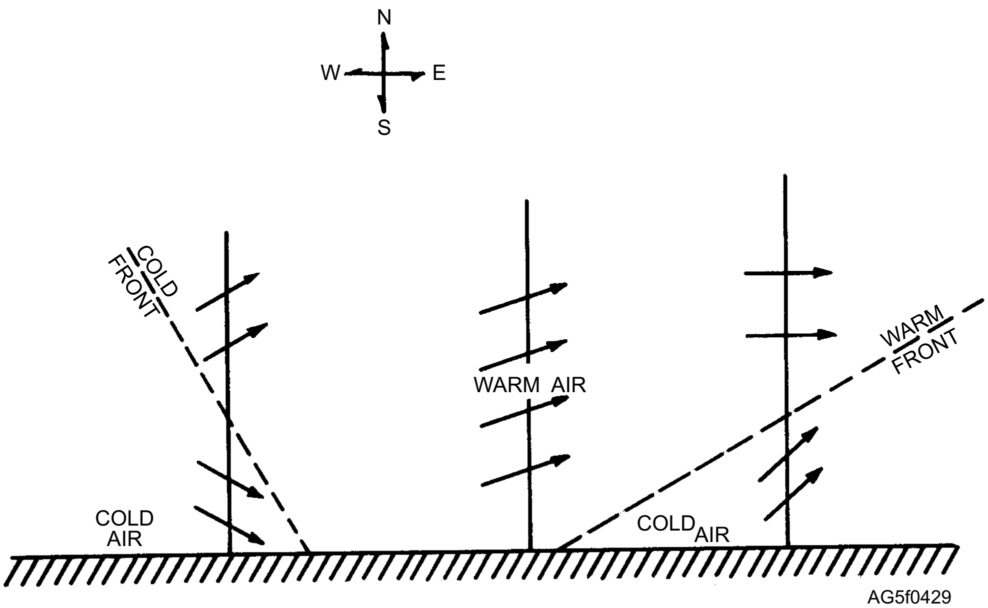


**Figure 4-29.—Vertical distribution of wind direction in the vicinity of frontal surfaces.**

From this it can be seen that a front is a wind shift line and that wind shifts in a cyclonic direction. Therefore, we can evolve the following rule: *if you stand with your back against the wind in advance of the front, the wind will shift clockwise as the front passes.* This is true with the passage of all frontal types. Refer back to figure 4-22.

**NOTE**: The wind flow associated with the well-developed frontal system is shown in figure 4-22, view E. Try to visualize yourself standing ahead of each type of front depicted as they move from west to east. The terms *backing* and *veering* are often used when discussing the winds associated with frontal systems.

**BACKING**.—Backing is a change in wind direction—counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. The opposite of backing is veering.

**VEERING**.—Veering is a change in wind direction—clockwise in the Northern Hemisphere, counterclockwise in the Southern Hemisphere. The opposite of veering is backing.

The speed of the wind depends upon the pressure gradient. Look at figure 4-28. In view A, the speed is about the same in both air masses; in views B and C, a relatively strong *wind* is followed by a weaker wind; and in view D, a weak wind is followed by a strong wind. An essential characteristic of a frontal zone is a wind discontinuity through the zone. The wind normally increases or decreases in speed with height through a frontal discontinuity. Backing usually occurs with height through a cold front and veering through a warm front. The sharpness of the wind discontinuity is proportional to the temperature contrast across the front and the pressure field in the vicinity of the front (the degree of convergence between the two air streams). With the pressure field constant, the sharpness of the frontal zone is proportional to the temperature discontinuity (no temperature discontinuity—no front; thus, no wind discontinuity). The classical picture of the variation in wind along the vertical through a frontal zone is shown in figure 4-29. An example of a frontal zone and the winds through the frontal zone is shown in figure 4-30.

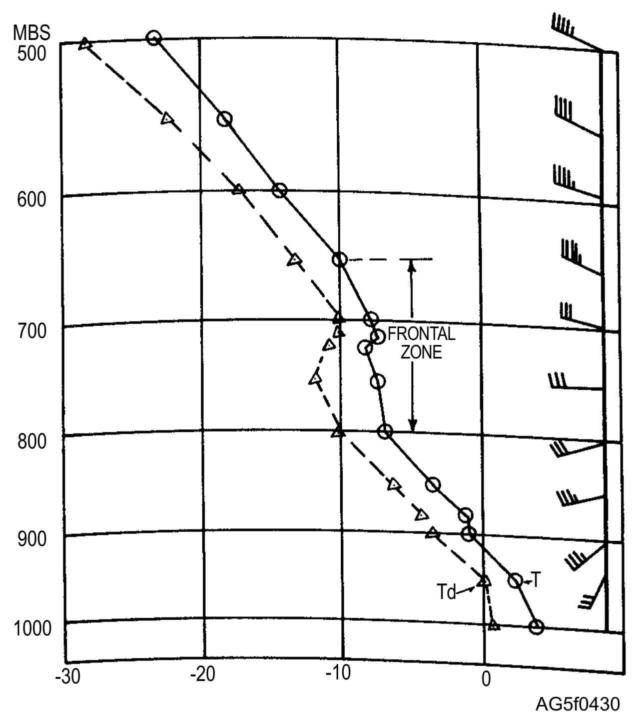


**Figure 4-30.—Distribution of wind and temperature through a warm frontal zone.**

On this sounding the upper winds that show the greatest variation above the surface layer are those between the 800- to 650-mb layers. This indication coincides closely with the frontal indications of the temperature (T) and dew point (T*d*) curves (see fig. 4-30). Since the wind veers with height through the layer, the front would be warm. The vertical wind shift through a frontal zone depends on the direction of the slope. In cold fronts the wind backs with height, while in warm fronts the wind veers with height. At the surface the wind always veers across the front, and the isobars have a sharp cyclonic bend or trough that points toward higher pressure. Sometimes the associated pressure trough is not coincident with the front; in such cases there may not be an appreciable wind shift across the front—only a speed discontinuity.

### Pressure

One of the important characteristics of all fronts is that on both sides of a front the pressure is higher than at the front. This is true even though one of the air masses is relatively warm and the other is relatively cold. Fronts are associated with troughs of low pressure. (A trough is an elongated area of relatively low pressure.) A trough may have U-shaped or V-shaped isobars. How the pressure changes with the passage of a front is of prime importance when you are determining frontal passage and future movement.

Friction causes the air (wind) near the ground to drift across the isobars toward lower pressure. This causes a drift of air toward the front from both sides. Since the air cannot disappear into the ground, it must move upward. Hence, there is always a net movement of air upward in the region of a front. This is an important characteristic of fronts, since the lifting of the air causes condensation, clouds, and weather.

## GENERAL CHARACTERISTICS OF FRONTS

All fronts have certain characteristics that are common and usually predictable for that type of front. Cold frontal weather differs from warm frontal weather, and not every cold front has the same weather associated with it. The weather, intensity of the weather, and the movement of fronts are, to a large degree, associated with the slope of the front.

### Frontal Slope

When we speak of the slope of a front, we are speaking basically of the steepness of the frontal surface, using a vertical dimension and a horizontal dimension. The vertical dimension used is normally 1 mile. A slope of 1:50 (1 mile vertically for every 50 miles horizontally) would be considered a steep slope, and a slope of 1:300 a gradual slope. Factors favoring a steep slope are a large wind velocity difference between air masses, small temperature difference, and high latitude.

The frontal slope therefore depends on the latitude of the front, the wind speed, and the temperature difference between the air masses. Because cold air tends to under run warm air, the steeper the slope, the more intense the lifting and vertical motion of the warm air and, therefore the more intense the weather.

### Clouds and Weather

Cloud decks are usually in the warm air mass because of the upward vertical movement of the *warm air. Clouds forming* in a cold *air mass* are caused by the evaporation of moisture from precipitation from the overlying warm air mass and/or by vertical lifting. Convergence at the front results in a lifting of both types of air. The stability of air masses determines the cloud and weather structure at the fronts as well as the weather in advance of the fronts.

### Frontal Intensity

No completely acceptable set of criteria is in existence as to the determination of frontal intensity, as it depends upon a number of variables. Some of the criteria that may be helpful in delineating frontal intensity are discussed in the following paragraphs.

**TURBULENCE**.—Except when turbulence or gustiness may result, weather phenomena are not taken into account when specifying frontal intensity, because a front is not defined in terms of weather. A front may be intense in terms of discontinuity of density across it, but may be accompanied by no weather phenomena other than strong winds and a drop in temperature. A front that would otherwise be classified as weak is considered moderate if turbulence and gustiness are prevalent along it, and an otherwise moderate front is classified as strong if sufficient turbulence and gustiness exist. The term *gustiness* for this purpose includes convective phenomena such as thunderstorms and strong winds.

**TEMPERATURE GRADIENT**.—Temperature gradient, rather than true difference of temperature across the frontal surface, is used in defining the frontal intensity. Temperature gradient, when determining frontal intensity, is defined as the difference between the representative warm air immediately adjacent to the front and the representative surface temperature 100 miles from the front on the cold air side.

A suggested set of criteria based on the horizontal temperature gradient has been devised. A weak front is one where the temperature gradient is less than 100F per 100 miles; a moderate front is where the temperature gradient is 10 0F to 20 0F per 100 miles; and a strong front is where the gradient is over 20 0F per 100 miles.

The 850-mb level temperatures may be used in lieu of the surface temperatures if representative surface temperatures are not available and the terrain elevation is not over 3,000 feet. Over much of the western section of the United States, the 700-mb level temperatures can be used in lieu of the surface temperatures.

### Speed

The speed of the movement of frontal systems is an important determining factor of weather conditions. Rapidly moving fronts usually cause more severe weather than slower moving fronts. For example, fast-moving cold fronts often cause severe prefrontal squall lines that are extremely hazardous to flying. The fast-moving front does have the advantage of moving across the area rapidly, permitting the particular locality to enjoy a quick return of good weather. Slow-moving fronts, on the other hand, may cause extended periods of unfavorable weather. A stationary front that may bring bad weather can disrupt flight operations for several days in succession. The specific characteristics of each of the types of fronts is discussed in lessons 3 through 6.

### Wind Component

The speed of a front is controlled by a resultant component of wind behind a front. The wind component normal to a front is determined by the angle at which the geostrophic winds blow toward the front, resulting in a perpendicular force applied to the back of the front. For example, the component of the wind normal to a front that has a geostrophic wind with a perpendicular flow of 30 knots behind the front has a 30-knot component. However, a 30-knot geostrophic wind blowing at a 450 angle to the front has only a 15-knot component that is normal to or perpendicular to the front. The greater the angle of the wind to the front, the greater the wind component normal to that front. The smaller the angle, the less the wind component normal to the front.

## REVIEW QUESTIONS

*Q4-6. What is the definition of a frontal surface?*

*Q4-7. Where is the frontal zone located?*

*Q4-8. What is the difference between a stable wave and an unstable wave?*

*Q4-9. Where does frontogenesis occur?*

*Q4-10. Where is the polar front normally found during the winter?*

## THE COLD FRONT

**LEARNING OBJECTIVE**: Describe slow-moving cold fronts, fast-moving cold fronts, secondary cold fronts, and cold fronts aloft.

A cold front is the leading edge of a wedge of cold air that is under running warm air. Cold fronts usually move faster and have a steeper slope than other types of fronts. Cold fronts that move very rapidly have very steep slopes in the lower levels and narrow bands of clouds that are predominant along or just ahead of the front. Slower moving cold fronts have less steep slopes, and their cloud systems may extend far to the rear of the surface position of the fronts. Both fast-moving and slow-moving cold fronts may be associated with either stability or instability and either moist or dry air masses.

Certain weather characteristics and conditions are typical of cold fronts. In general, the temperature and humidity decrease, the pressure rises, and in the Northern Hemisphere the wind shifts (usually from southwest to northwest) with the passage of a cold front. The distribution and type of cloudiness and the intensity and distribution of precipitation depend primarily on the vertical motion within the warm air mass. This vertical motion is in part dependent upon the speed of that cold front.

### SLOW-MOVING COLD FRONTS (ACTIVE COLD FRONT)

With the slow-moving cold front, there is a general upward motion of warm air along the entire frontal surface and pronounced lifting along the lower portion of the front. The average slope of the front is approximately 1:100 miles. Near the ground, the slope is often much steeper because of surface friction.

Figure 4-31 illustrates the typical characteristics in the vertical structure of a slow-moving cold front. The lower half shows the typical upper airflow behind the front, and the upper half shows the accompanying surface weather. This is only one typical case. Many variations to this model can and do occur in nature. The slow-moving cold front is an active front because it has widespread frontal cloudiness and precipitation at and behind the front caused by actual frontal lifting.

### Surface Characteristics

The pressure tendency associated with this type of frontal passage is indicated by either an unsteady or steady fall prior to frontal passage and then weak rises behind. Temperature and dew point drop sharply with the passage of a slow-moving cold front. The wind veers with the cold frontal passage and reaches its highest speed at the time of frontal passage. Isobars are usually curved anticyclonically in the cold air. This type of front usually moves at an average speed between 10 and 15 knots. Slow-moving cold fronts move with 100% of the wind component normal to the front.

### Weather

The type of weather experienced with a slow-moving cold front is dependent upon the stability of the warm air mass. When the warm air mass is stable,

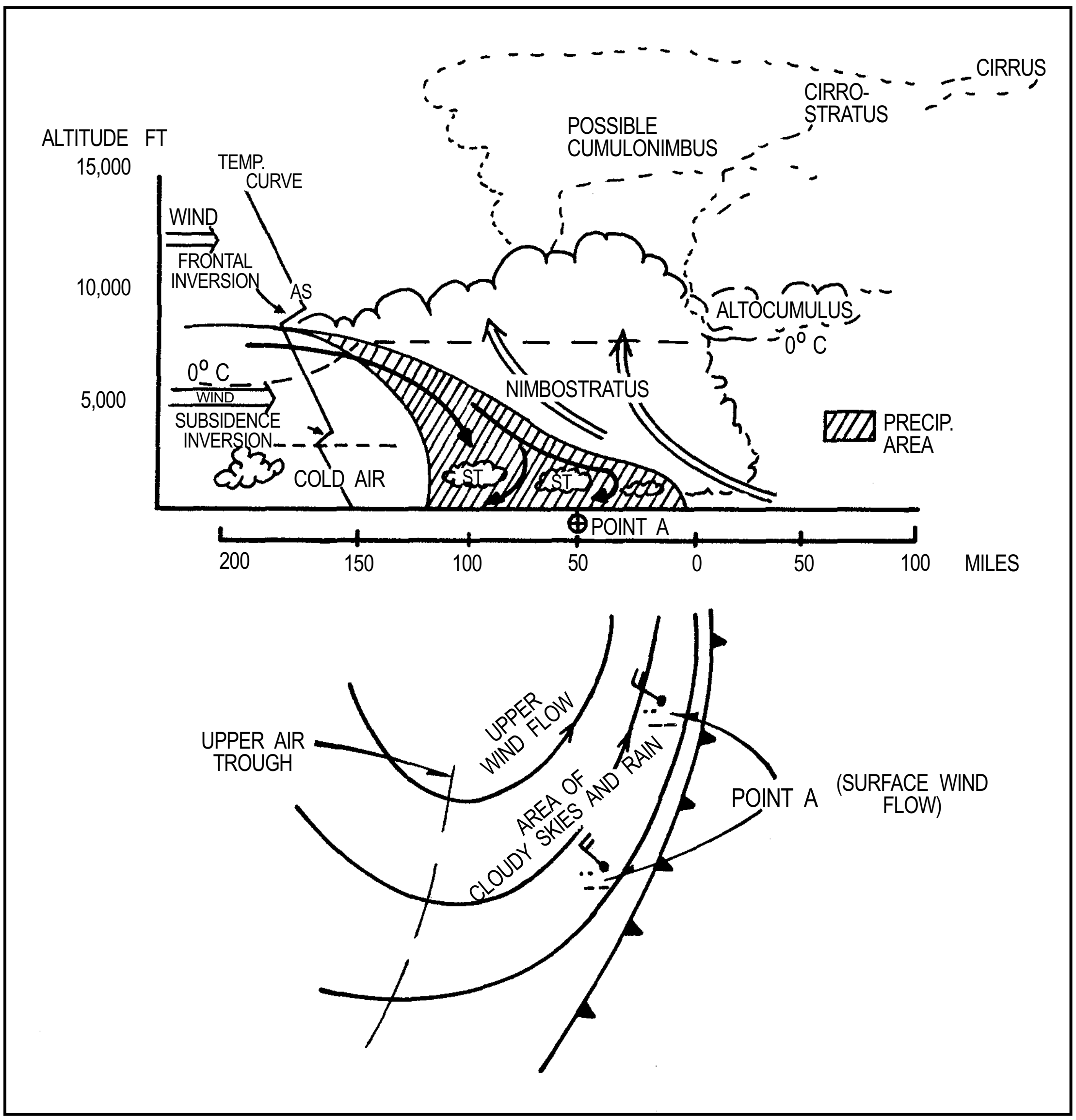


**Figure 4-31.—Typical vertical structure of a slow-moving cold front with upper windflow in back of the front.**

a rather broad zone of altostratus and nimbostratus clouds accompany the front and extend several hundred miles behind the front. If the warm air is unstable (or conditionally unstable), thunderstorms and cumulonimbus clouds may develop within the cloud bank and may stretch for some 50 miles behind the surface front. These cumulonimbus clouds form within the warm air mass. In the cold air there may be some stratus or nimbostratus clouds formed by the evaporation of falling rain; but, generally, outside of the rain areas, there are relatively few low clouds. This is because of the descending motion of the cold air that sometimes produces a subsidence inversion some distance behind the front.

The ceiling is generally low with the frontal passage, and gradual lifting is observed after passage. Visibility is poor in precipitation and may continue to be reduced for many hours after frontal passage as long as the precipitation occurs. When the cold air behind the front is moist and stable, a deck of stratus clouds and/or fog may persist for a number of hours after frontal passage. The type of precipitation observed is also dependent upon the stability and moisture conditions of the air masses.

### Upper Air Characteristics

Upper air contours show a cyclonic flow and are usually parallel to the front as are the isotherms. The weather usually extends as far in back of the front as these features are parallel to it. When the orientation changes, this usually indicates the position of the associated upper air trough. (A trough is an elongated area of relatively low pressure.)

The temperature inversion on this type of front is usually well marked. In the precipitation area the relative humidity is high in both air masses. Farther behind the front, subsidence may occur, giving a second inversion closer to the ground.

The wind usually backs rapidly with height (on the order of some 60 to 70 degrees between 950 and 400 mb), and at 500 mb the wind direction is inclined at about 15 degrees to the front. The wind component normal to the front decreases slightly with height, and the component parallel to the front increases rapidly.

On upper air charts, slow-moving cold fronts are characterized by a packing (concentration) of isotherms behind them. The more closely packed the isotherms and the more nearly they parallel the fronts, the stronger the front.

## FAST-MOVING COLD FRONTS (INACTIVE COLD FRONT)

The fast-moving cold front is a very steep front that has warm air near the surface being forced vigorously upward. At high levels, the warm air is descending downward along the frontal surface. This front has a slope of 1:40 to 1:80 miles and usually moves rapidly; 25 to 30 knots may be considered an average speed of movement. They move with 80 to 90 percent of the wind component normal to the front. As a result of these factors, there is a relatively narrow but often violent band of weather.

Figure 4-32 shows a vertical cross section of a fast-moving cold front with resultant weather. Also indicated in the lower half of the diagram is the surface weather in advance of the front and the upper airflow above the front.

If the warm air is moist and unstable, a line of thunderstorms frequently develops along this front. Sometimes, under these conditions, a line of strong convective activity is projected 50 to 200 miles ahead of the front and parallel to it. This may develop into a line of thunderstorms called a squall line. On the other hand, when the warm air is stable, an overcast layer of altostratus clouds and rain may extend over a large area ahead of the front. If the warm air is very dry, little or no cloudiness is associated with the front. The front depicted is a typical front with typical characteristics.

The fast-moving cold front is considered an inactive front because lifting occurs only at and ahead of the front. The lifting is caused by descending air ahead of the front and only in part by the frontal surface.

### Surface Characteristics

Pressure tendencies fall ahead of the front with sudden and strong rises after frontal passage. If a squall line lies some distance ahead of the front, there may be a strong rise associated with its passage and a shift in the wind. However, after the influence of the squall line has passed, winds back to southerly and pressures level off. The temperature falls in the warm air just ahead of the front. This is caused by the evaporation of falling precipitation. Rapid clearing and adiabatic warming just behind the front tend to keep the cold air temperature near that of the warm air. An abrupt temperature change usually occurs far behind the front near the center of the high-pressure center associated with the cold air mass. The dew point and wind

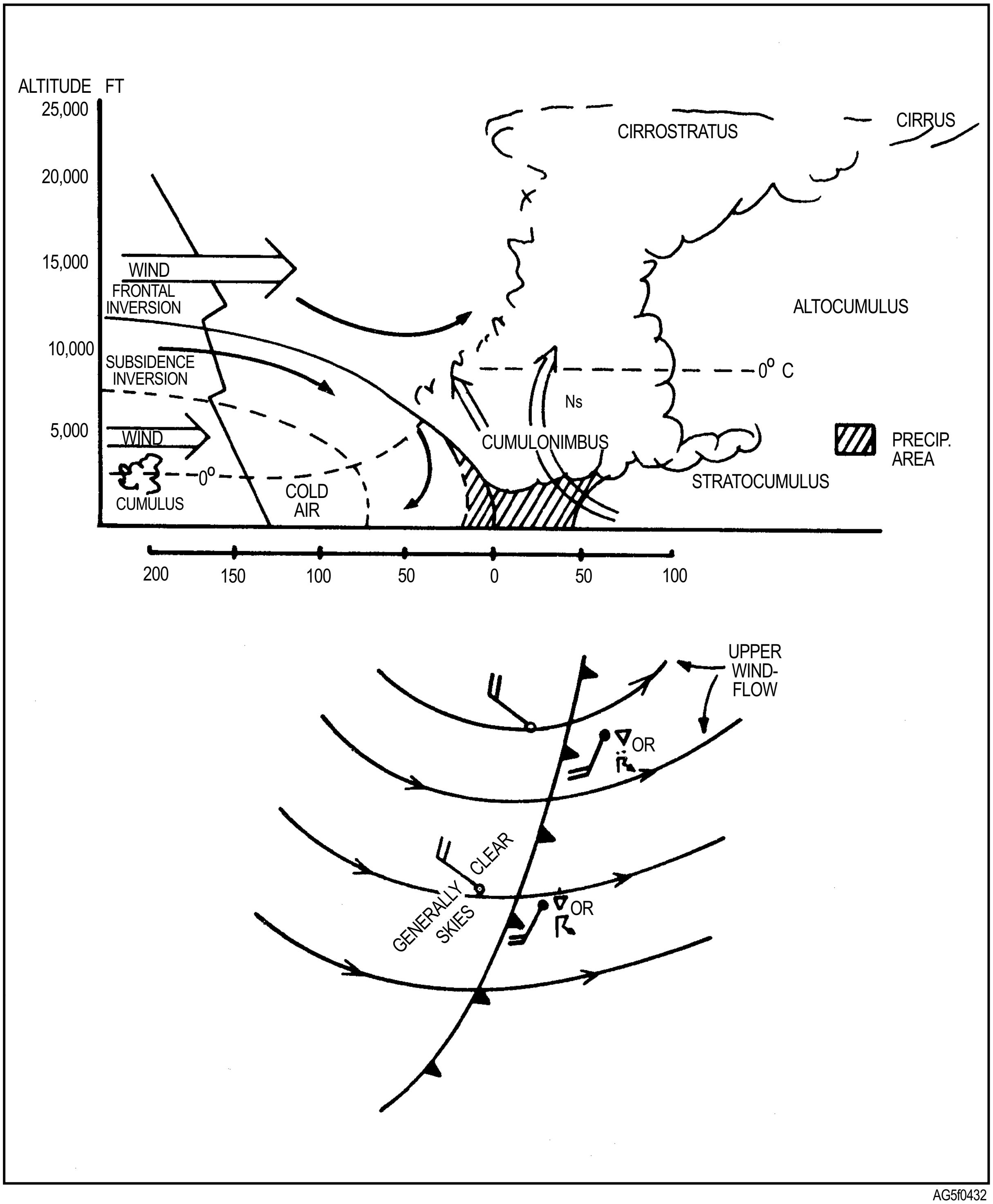


**Figure 4-32.—Typical vertical structure of a fast-moving cold front with upper windflow across the front.**

directions are a good indication of the passage of a fast-moving cold front. The wind veers with frontal passage and is strong, gusty, and turbulent for a considerable period of time after passage. The dew point decreases sharply after frontal passage.

**Weather**

Cumulonimbus clouds are observed along and just ahead of the surface front. Stratus, nimbostratus, and altostratus may extend ahead of the front in advance of the cumulonimbus and may extend as much as 150 miles ahead of the front. These clouds are all found in the warm air. Generally, unless the cold air is unstable and descending currents are weak, there are few clouds in the cold air behind the front. Showers and thunderstorms occur along and just ahead of the front. The ceiling is low only in the vicinity of the front. Visibility is poor during precipitation but improves rapidly after the frontal passage.

### Upper Air Characteristics

Because of the sinking motion of the cold air behind the front and the resultant adiabatic warming, the temperature change across the front is often destroyed or may even be reversed. A sounding taken in the cold air immediately behind the surface front indicates only one inversion and an increase in moisture through the inversion. Farther back of the front, a double inversion structure is evident. The lower inversion is caused by the subsidence effects in the cold air. This is sometimes confusing to the analyst because the subsidence inversion is usually more marked than the frontal inversion and may be mistaken for the frontal inversion.

In contrast to the slow-moving cold front, the wind above the fast-moving cold front exhibits only a slight backing with height of about 20 degrees between 950 and 400 mb; the wind direction is inclined toward the front at an average angle of about 45 degrees. The wind components normal and parallel to the front increase with height; the wind component normal to the front exceeds the mean speed of the front at all levels above the lowest layers. On upper air charts, the isotherms are NOT parallel to the front. Instead they are at an angle of about 30 degrees to the front, usually crossing the cold front near its junction with the associated warm front.

## SECONDARY COLD FRONTS

Sometimes there is a tendency for a trough of low pressure to form to the rear of a cold front, and a secondary cold front may develop in this trough. Secondary cold fronts usually occur during outbreaks of very cold air behind the initial outbreak. Secondary cold fronts may follow in intervals of several hundred miles to the rear of the rapidly moving front. When a secondary cold front forms, the primary front usually tends to dissipate and the secondary front then becomes the primary front. Secondary fronts usually do not occur during the summer months because there is rarely enough temperature discontinuity.

## COLD FRONTS ALOFT

There are two types of upper cold fronts. One is the upper cold front associated with the warm occlusion that is discussed later in this unit. The other occurs frequently in the areas just east of mountains in winter. This cold front aloft is associated with mP air crossing the mountains behind a cold front or behind a cold trough aloft and a very cold layer of continental polar air lying next to the ground over the area east of the mountains. The area east of the Rocky Mountains is one such area in the United States. When warm maritime tropical air has moved northward from the Gulf of Mexico and has been forced aloft by the cold cP air, and cool mP air flows over the mountains, it forces its way under the warm mT air aloft. The resulting front then flows across the upper surface of the colder cP air just as if it were the surface of the ground. All frontal activity in this case takes place above the top of the cP layer. Figure 4-33 shows an example of this type of front and the synoptic structure. Weather from cold

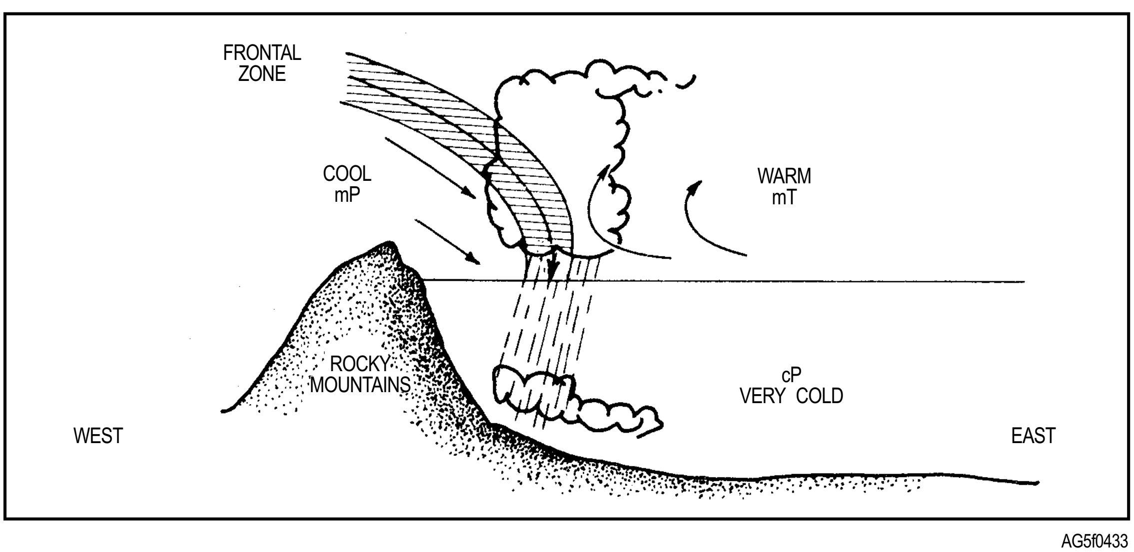


**Figure 4-33.—Cold front aloft.**

fronts aloft can produce extensive cloud decks and blizzard conditions for several hundred miles over the mid western plains.

## INSTABILITY AND SQUALL LINES

The terms instability line and squall line are synonymous with violent winds, heavy rain, lightning, thunder, hail, and tornadoes. The terms are often used interchangeably and are incorrectly applied to any severe weather phenomena that moves through a region. However, there is a difference between an instability line and a squall line.

### Instability Line

An instability line is any nonfrontal line or band of convective activity. This is a general term and includes the developing, mature, and dissipating stages of the line of convective activity. However, when the mature stage consists of a line of active thunderstorms, it is properly termed a squall line. Therefore, in practice, the instability line often refers only to the less active phases.

### Squall Line

A squall line is a nonfrontal line or band of active thunderstorms (with or without squalls). It is the mature, active stage of the instability line. From these definitions, instability and squall lines are air mass phenomenon because they are both nonfrontal occurrences. However, they are frequently associated with the fast-moving cold front.

**NOTE**: The term instability line is the more general term and includes the squall line as a special case.

### Prefrontal Squall Lines

A prefrontal squall line is a squall line located in the warm sector of a wave cyclone. They form about 50 to 300 miles in advance of fast-moving cold fronts and are usually oriented roughly parallel to the cold front. They move in about the same direction as the cold front; however, their speed is, at times, faster than the cold front. You can roughly compute the direction and speed by using the winds at the 500-mb level. Squall lines generally move in the direction of the 500-mb wind flow and at approximately 40% of the wind speed.

**FORMATION**.—There are several theories on the development of prefrontal squall lines. A generally accepted theory is that as thunderstorms develop along the fast-moving front, large quantities of cold air from aloft descend in downdrafts along the front and form a wedge of cold air ahead of the front. The wedge of cold air then serves as a lifting mechanism for the warm, moist, unstable air; and a line of thunderstorms develops several miles in advance of the front. Since the thunderstorms form within the air mass and not along the front, the squall line is considered as air mass weather (fig. 4-34). In the United States, squall lines form most often in spring and summer. They are normally restricted to the region east of the Rocky Mountains with a high frequency of occurrence in the southern states.

**WEATHER**.—Squall-line weather can be extremely hazardous. Its weather is usually more severe than the weather associated with the cold front behind it; this is because the moisture and energy of the warm air mass tends to be released at the squall line prior to the arrival of the trailing cold front. Showers and thunderstorms (sometimes tornadoes) occur along the squall line, and the wind shifts cyclonically with their passage (fig. 4-35). However, if the zone is narrow, the wind shift may not be noticeable on surface charts. There is generally a large drop in temperature because of the cooling of the air by precipitation. Pressure rises after the passage of the squall line, and, at times, a

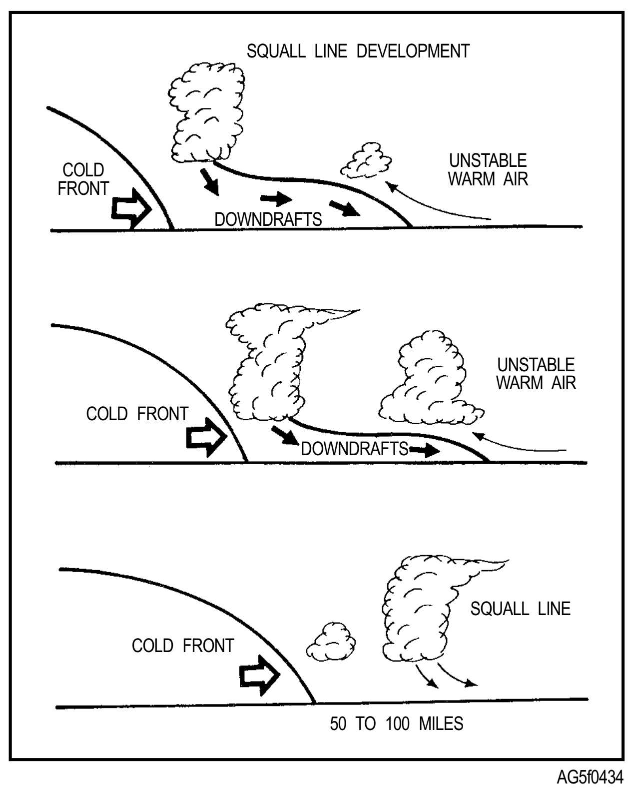


**Figure 4-34.—Prefrontal squall line development.**

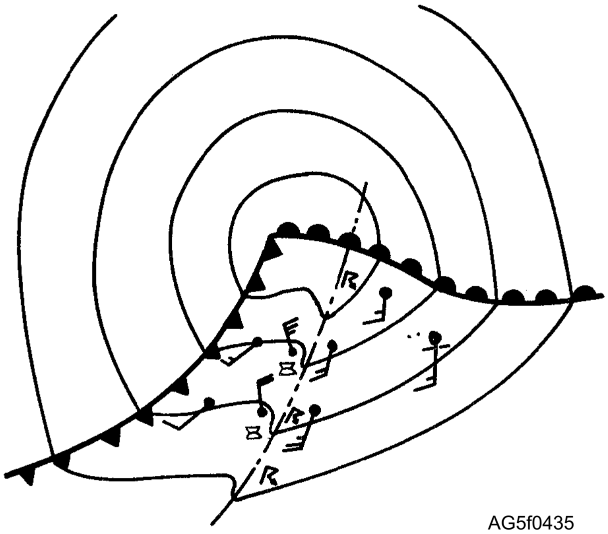


**Figure 4-35.—Typical isobaric pattern associated with a prefrontal squall line.**

micro-high (small high) may form behind it. After passage of the squall line, the wind backs to southerly before the cold frontal passage. When the squall line dissipates, severe weather may develop along the fast-moving cold front.

Turbulence is severe in the squall-line thunderstorms because of violent updrafts and downdrafts. Above the freezing level, icing may occur. Hail is another possibility in the squall-line thunderstorm and can do extensive structural damage to an aircraft. Under the squall line, ceiling and visibility may be reduced because of heavy rain showers. Fog is a rare occurrence because of the strong wind and gusts, but it may be found in isolated cases. Tornadoes frequently occur with squall lines when the warm air mass is extremely unstable.

### Great Plains Squall Lines

Not all instability lines that reach the mature or squall-line stage develops in advance of a fast-moving cold front. The Great Plains region of the United States has a high frequency of these squall lines. The Great Plains type of squall lines also develop in warm, moist, unstable air masses. The necessary lifting or trigger may be supplied by intense thermal heating, orographic lifting, or convergent winds associated with a low-pressure area.

**FORMATION**.—The Great Plains squall line forms when an extremely unstable condition develops—normally in spring and summer. Extremely unstable conditions exist when moist mP air cools in the upper levels because of the evaporation of falling precipitation. This cooler air aloft then moves over warm moist mT air (or even warm, moist, highly modified mP air) at the surface. If a sufficient trigger such as a steep lapse rate of a lifting mechanism exists, this extremely unstable situation rapidly develops into a squall line.

**WEATHER**.—The weather associated with the Great Plains squall line is the same as that found with the prefrontal squall line. Because of the extreme instability, tornadoes are a common occurrence.

## REVIEW QUESTIONS

*Q4-11. What is the pressure tendency with the passage of a slow moving cold front?*

*Q4-12. What is the normal slope of a fast moving cold front?*

*Q4-13. Where do prefrontal squall lines normally form?*

## THE WARM FRONT

**LEARNING OBJECTIVE**: Describe the characteristics and weather of warm fronts at the surface and aloft.

A warm front is the line of discontinuity where the forward edge of an advancing mass of relatively warm air is replacing a retreating relatively colder air mass. The slope of the warm front is usually between 1:100 and 1:300, with occasional fronts with lesser slopes. Therefore, warm fronts have characteristically shallow slopes caused by the effect of surface friction that retards the frontal movement near the ground.

### SURFACE CHARACTERISTICS

Warm fronts move slower than cold fronts. Their average speed is usually between 10 and 20 knots. They move with a speed of 60 to 80 percent of the component of the wind normal to the front in the warm air mass.

The troughs associated with warm fronts are not as pronounced as those with cold fronts and sometimes make location difficult on the surface chart. The pressure tendency ahead of the front is usually a rapid or unsteady fall with a leveling off after frontal passage. A marked decrease in isallobaric gradient is noticed in the warm sector except when rapid deepening is taking place. The wind increases in velocity in advance of warm fronts because of an increase in pressure gradient and reaches a maximum just prior to frontal passage. The wind veers with frontal passage, usually from a southeasterly direction to a southwesterly direction behind the front. This shift is not as pronounced as with the cold front.

Temperature generally is constant or slowly rising in advance of the front until the surface front passes, at which time there is a marked rise. This rise is dependent upon the contrast between the air masses. Dew point usually increases slowly with the approach of the front with a rapid increase in precipitation and fog areas. If the warm sector air is maritime tropical, the dew point shows a further increase.

## WEATHER

A characteristic phenomenon of a typical warm front is the sequence of cloud formations (fig. 4-36). They are noticeable in the following order: cirrus, cirrostratus, altostratus, nimbostratus, and stratus. The cirrus clouds may appear 700 to 1,000 miles or more ahead of the surface front, followed by cirrostratus clouds about 600 miles ahead of the surface front and altostratus about 500 miles ahead of the surface front.

Precipitation in the form of continuous or intermittent rain, snow, or drizzle is frequent as far as 300 miles in advance of the surface front. Surface precipitation is associated with the nimbostratus in the warm air above the frontal surface and with stratus in the cold air. However, when the warm air is convectively unstable, showers and thunderstorms may occur in addition to the steady precipitation. This is especially true with a cyclonic flow aloft over the warm front. Fog is common in the cold air ahead of a warm front.

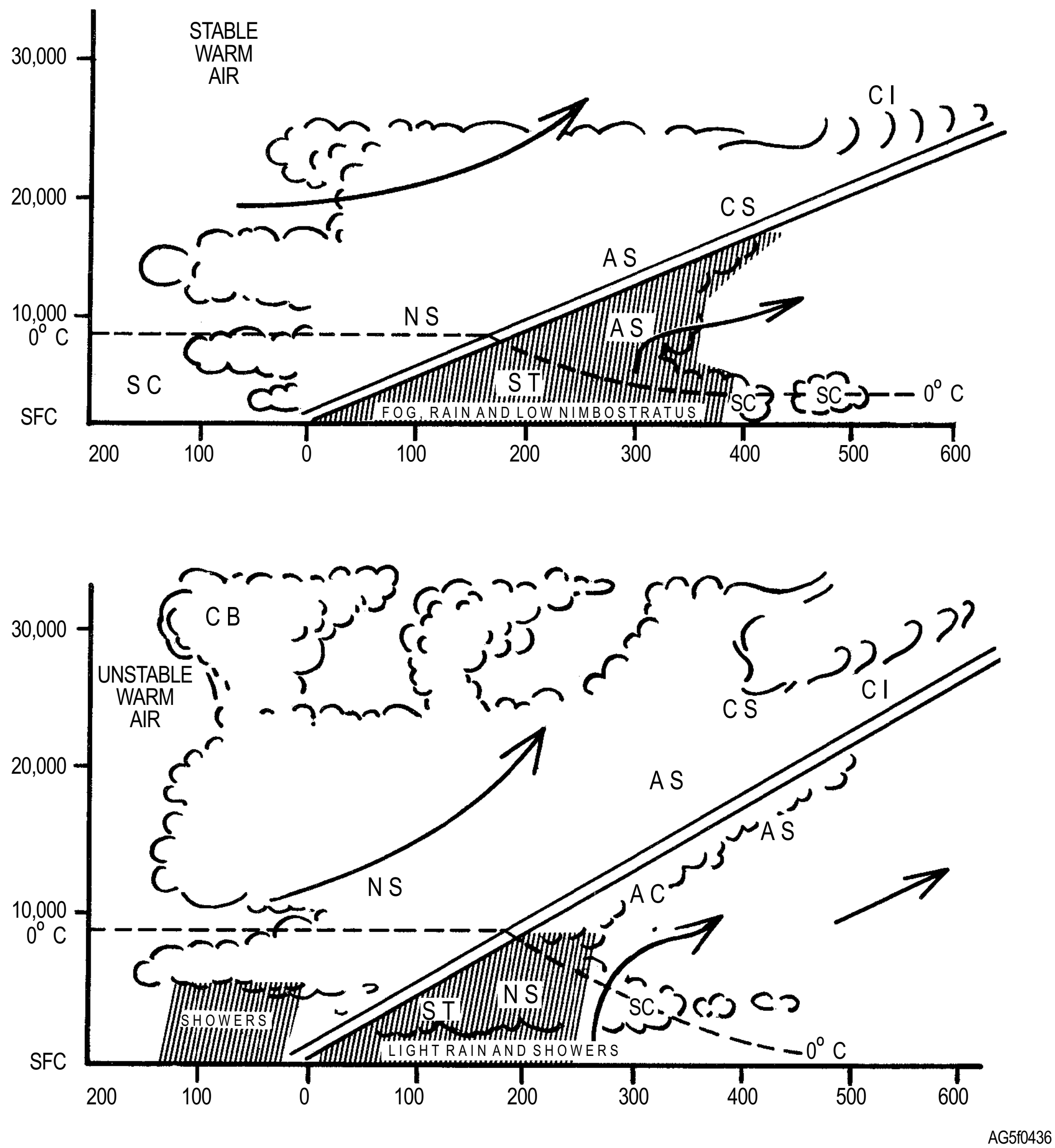


**Figure 4-36.—Vertical cross section of a warm front with stable and unstable air.**

Clearing usually occurs after the passage of a warm front, but under some conditions drizzle and fog may occur within the warm sector. Warm fronts usually move in the direction of the isobars of the warm sector; in the Northern Hemisphere this is usually east to northeast.

The amount and type of clouds and precipitation vary with the characteristics of the air masses involved and depending on whether the front is active or inactive. Generally, with warm fronts, an increase of the wind component with height perpendicular to the front gives an active front. This produces strong overrunning and pronounced prefrontal clouds and precipitation. Inactive fronts, characterized by broken cirrus and altocumulus, are produced by a decrease with height of the wind component perpendicular to the front.

When the overrunning warm air is moist and stable, nimbostratus clouds with continuous light to moderate precipitation are found approximately 300 miles ahead of the front. The bases of the clouds lower rapidly as additional clouds form in the cold air under the frontal surface. These clouds are caused by evaporation of the falling rain. These clouds are stratiform when the cold mass is stable and stratocumulus when the cold air is unstable.

When the overrunning air is moist and unstable, cumulus and cumulonimbus clouds are frequently imbedded in the nimbostratus and altostratus clouds. In such cases, thunderstorms occur along with continuous precipitation. When the overrunning warm air is dry, it must ascend to relatively high altitudes before condensation can occur. In these cases only high and middle clouds are observed. Visibility is usually good under the cirrus and altostratus clouds. It decreases rapidly in the precipitation area. When the cold air is stable and extensive, fog areas may develop ahead of the front, and visibility is extremely reduced in this area.

## UPPER AIR CHARACTERISTICS

Warm fronts are usually not as well defined as cold fronts on upper air soundings. When the front is strong and little mixing has occurred, the front may show a well-marked inversion aloft. However, mixing usually occurs and the front may appear as a rather broad zone with only a slight change in temperature. Quite frequently there may be two inversions—one caused by the front and the other caused by turbulence. Isotherms are parallel to the front and show some form of packing ahead of the front. The stronger the packing, the more active the front. The packing is not as pronounced as with the cold front.

## WARM FRONTS ALOFT

Warm fronts aloft seldom occur, but generally follow the same principles as cold fronts aloft. One case when they do occur is when the very cold air underneath a warm front is resistant to displacement and may force the warm air to move over a thinning wedge with a wave forming on the upper surface. This gives the effect of secondary upper warm fronts and may cause parallel bands of precipitation at unusual distances ahead of the surface warm front. Warm air advection is more rapid and precipitation is heaviest where the steeper slope is encountered. Pressure falls rapidly in advance of the upper warm front and levels off underneath the horizontal portion of the front. When a warm front crosses a mountain range, colder air may occur to the east and may move along as a warm front aloft above the layer of cold air. This is common when a warm front crosses the Appalachian Mountains in winter.

## REVIEW QUESTIONS

*Q4-14. What is the average speed of a warm front?*

*Q4-15. What cloud types, and in what order usually form in advance of a warm front?*

## THE OCCLUDED FRONTS

**LEARNING OBJECTIVE**: Describe the formation, structure, and characteristics of cold and warm air occluded fronts.

An occluded front is a composite of two fronts. They form when a cold front overtakes a warm front and one of these two fronts is lifted aloft. As a result, the warm air between the cold and warm front is shut off. An occluded front is often referred to simply as an occlusion. Occlusions may be either of the cold type or warm type. The type of occlusion is determined by the temperature difference between the cold air in advance of the warm front and the cold air behind the cold front.

A cold occlusion forms when the cold air in advance of a warm front is warmer than the cold air to the rear of the cold front. The overtaking cold air undercuts the cool air in advance of the warm front. This results in a section of the warm front being forced aloft. A warm occlusion forms when the air in advance of the warm front is colder than the air to the rear of the cold front. When the cold air of the cold front overtakes

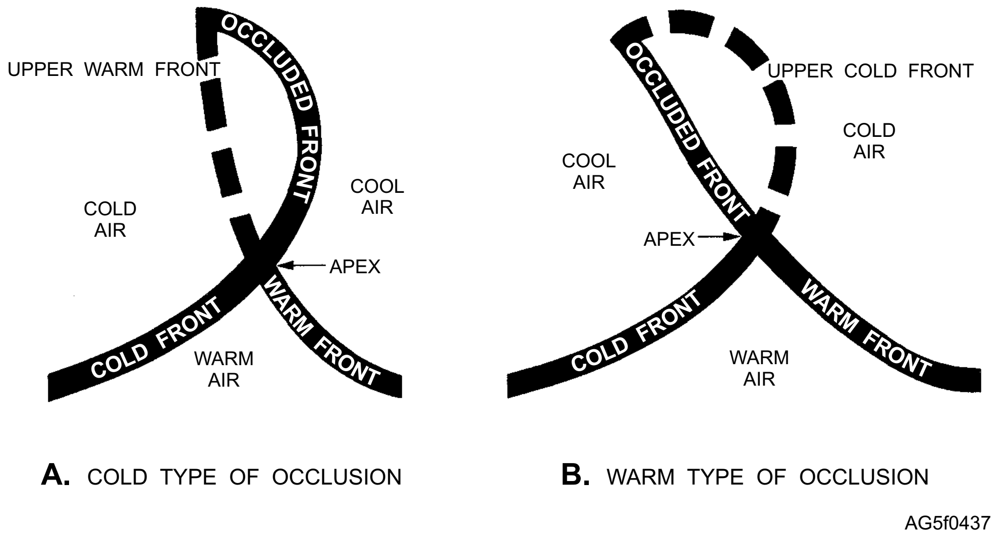

**Figure 4-37.—Sketch of occlusions (in the horizontal) and associated upper fronts.**

the warm front, it moves up over this colder air in the form of an upper cold front.

The primary difference between a warm and a cold type of occlusion is the location of the associated upper front in relation to the surface front (fig. 4-37). In a warm type of occlusion, the upper cold front precedes the surface-occluded front by as much as 200 miles. In the cold type of occlusion the upper warm front follows the surface-occluded front by 20 to 50 miles.

Since the occluded front is a combination of a cold front and a warm front, the resulting weather is that of the cold front's narrow band of violent weather and the warm front's widespread area of cloudiness and precipitation occurring in combination along the occluded front. The most violent weather occurs at the apex or tip of the occlusion. The apex is the point on the wave where the cold front and warm front meet to start the occlusion process.

## COLD OCCLUSIONS

A cold occlusion is the occlusion that forms when a cold front lifts the warm front and the air mass preceding the front (fig. 4-38). The vertical and horizontal depiction of the cold occlusion is shown in figure 4-39. Cold occlusions are more frequent than warm occlusions. The lifting of the warm front as it is underrun by the cold front implies existence of an upper warm front to the rear of the cold occlusion; actually such a warm front aloft is rarely discernible and is seldom delineated on a surface chart.

Most fronts approaching the Pacific coast of North America from the west are cold occlusions. In winter these fronts usually encounter a shallow layer of surface air near the coastline (from about Oregon northward) that is colder than the leading edge of cold air to the rear of the occlusion. As the occluded front nears this wedge of cold air, the occlusion is forced aloft and soon is no longer discernible on a surface chart. The usual practice in these cases is to continue to designate the cold occlusion as though it were a surface front because of the shallowness of the layer over which it rides. As the occlusion crosses over the mountains, it eventually shows up again on a surface analysis.

The passage of the cold type of occlusion over the coastal layer of colder air presents a difficult problem of analysis in that no surface wind shift ordinarily occurs at the exact time of passage. However, a line of stations

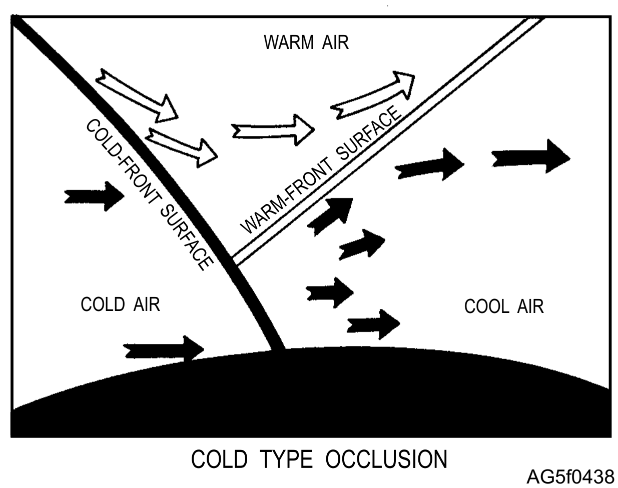

**Figure 4-38.—Vertical cross section of a cold type of occlusion.**

reporting surface-pressure rises is the best criterion of its passage. This should be verified by reference to plotted raob soundings where available. When a Pacific cold occlusion moves farther inland, it sometimes encounters colder air of appreciable depth over the Plateau or Western Plains areas; in this case, it should be redesignated as an upper cold front.

**Surface Characteristics**

The occlusion lies in a low-pressure area; and in the latter stages, a separate low center may form at the tip of the occlusion, leaving another low-pressure cell near the end of the occlusion. The pressure tendency across the cold occluded front follows closely with those outlined for cold fronts; that is, they level off, or more often, rapid rises occur after the passage of the occluded front.

**Weather**

In the occlusion's initial stages of development, the weather and cloud sequence ahead of the occlusion is quite similar to that associated with warm fronts; however, the cloud and weather sequence near the surface position of the front is similar to that associated with cold fronts. As the occlusion develops and the warm air is lifted to higher and higher altitudes, the warm front and prefrontal cloud systems disappear. The weather and cloud systems are similar to those of a cold front. View A of figure 4-39 shows the typical cloud and weather pattern associated with the cold occlusion. Most of the precipitation occurs just ahead of the occlusion. Clearing behind the occlusion is usually rapid, especially if the occlusion is in the advanced stage. Otherwise, clearing may not occur until after the passage of the warm front aloft.

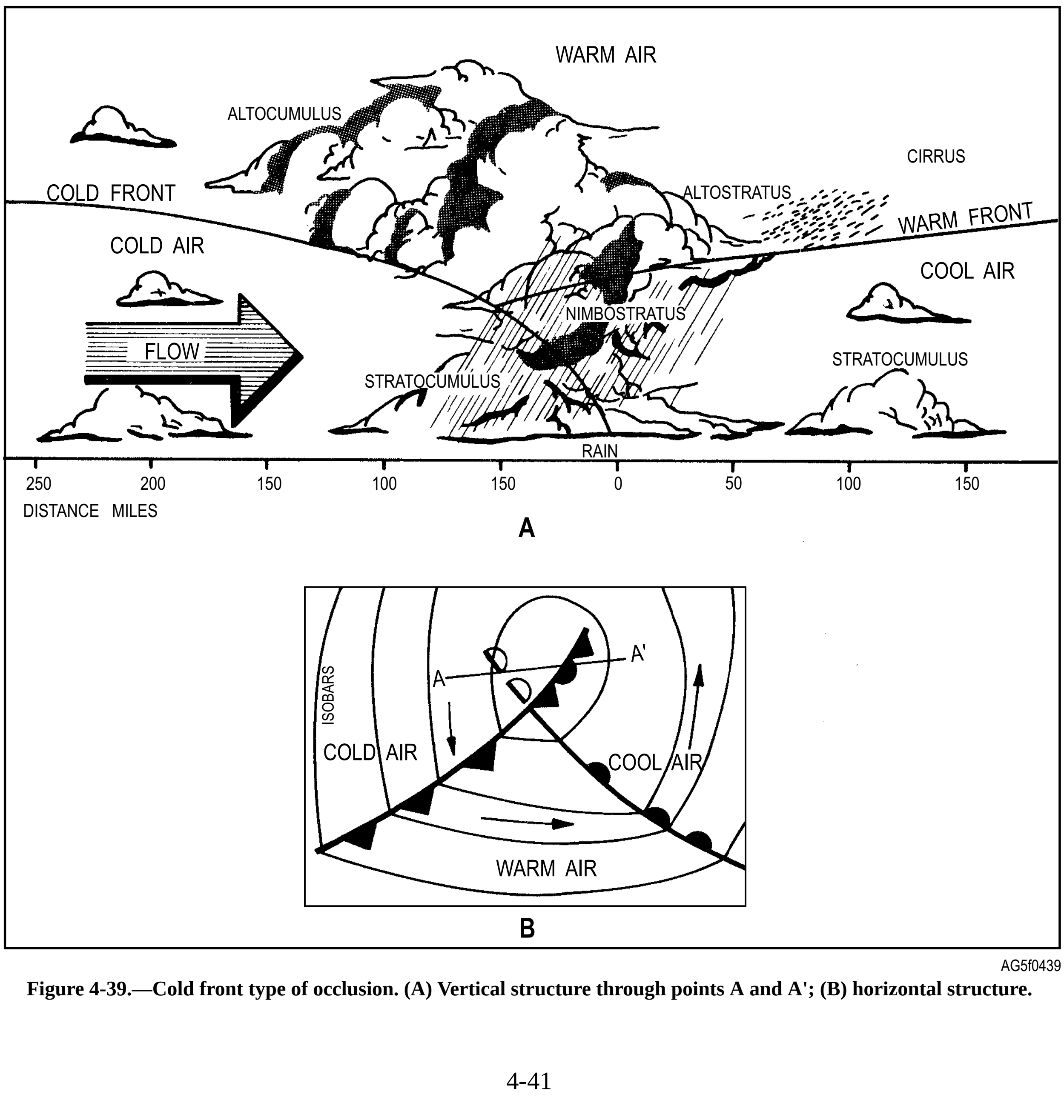


**Figure 4-39.—Cold front type of occlusion. (A) Vertical structure through points A and A'; (B) horizontal structure.**

### Upper Air Characteristics

If only one upper air sounding were taken so that it intersected either the cold or warm front, the sounding would appear as a typical warm or cold front sounding. However, if the sounding were taken so that it intersected both the cold and warm air, it would show two inversions.

The occlusion may appear on some upper air charts. It usually appears on the 850-mb chart, but rarely on the 700-mb chart. As the two air masses are brought closer together and as the occlusion process brings about gradual disappearance of the warm sector, the isotherm gradient associated with the surface front weakens. The degree of weakening depends on the horizontal temperature differences between the cold air to the rear of the cold front and that ahead of the warm front. The angle at which the isotherms cross the surface position of the occluded fronts becomes greater as the temperature contrast between the two cold air lasses decreases. A typical illustration of the isotherms shows a packing of isotherms in the cold mass behind the cold front and less packing in the cool mass in advance of the warm front. A warm isotherm ridge precedes the occlusion aloft.

## WARM OCCLUSIONS

A warm occlusion is the occlusion that forms when the overtaking cold front is lifted by overrunning the colder retreating air associated with the warm front. This is shown in figure 4-40. The warm occlusion usually develops in the Northern Hemisphere when conditions north and of ahead of the warm front are such that low pa temperatures exist north of the warm front. This usually occurs along the west coasts of continents when a relatively cool maritime cold front overtakes a warm front associated with a very cold continental air mass of high pressure situated over the western portion of the continent. The cold front then continues as an upper cold front above the warm front surface. The occlusion is represented as a continuation of the warm front. The cold front aloft is usually represented on all surface charts. Figure 4-41 depicts a typical warm type of occlusion in both the vertical and horizontal.

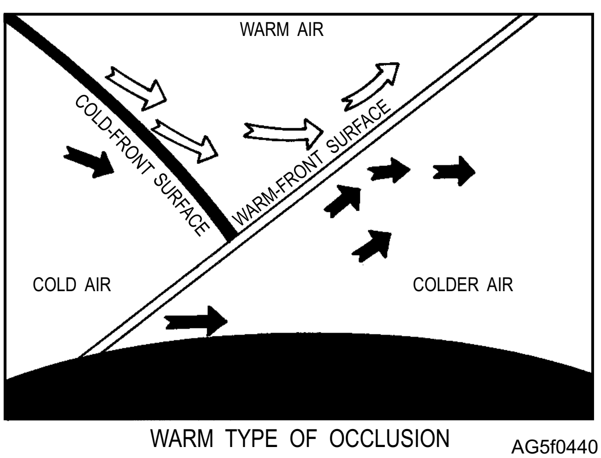


**Figure 4-40.—Vertical cross-section of a warm type of occlusion.**

### Surface Characteristics

The warm type of occlusion has the same type of pressure pattern as the cold type of occlusion. The most reliable identifying characteristics of the upper front are a line of marked cold frontal precipitation and clouds ahead of the occluded front, a slight but distinct pressure trough and a line of pressure-tendency discontinuities.

**NOTE**: The pressure tendency shows a steady fall ahead of the upper cold front and, with passage, a leveling off for a short period of time. Another slight fall is evident with the approach of the surface position of the occlusion. After passage the pressure shows a steady rise.

The pressure trough is often more distinct with the upper front than with the surface front.

### Weather

The weather associated with warm front occlusions has the characteristics of both warm and cold fronts. The sequence of clouds ahead of the occlusion is similar to the sequence of clouds ahead of a warm front; the cold front weather occurs near the upper cold front. If either the warm or cool air that is lifted is moist and unstable, showers and sometimes thunderstorms may develop. The intensity of the weather along the upper front decreases with distance from the apex. Weather conditions change rapidly in occlusions and are usually most severe during the initial stages. However, when the warm air is lifted to higher and higher altitudes, the weather activity diminishes. When showers and thunderstorms occur, they are found just ahead and with the upper cold front. Normally, there is clearing weather after passage of the upper front, but this is not always the case.

### Upper Air Characteristics

Upper air soundings taken through either front show typical cold or warm front soundings. Those

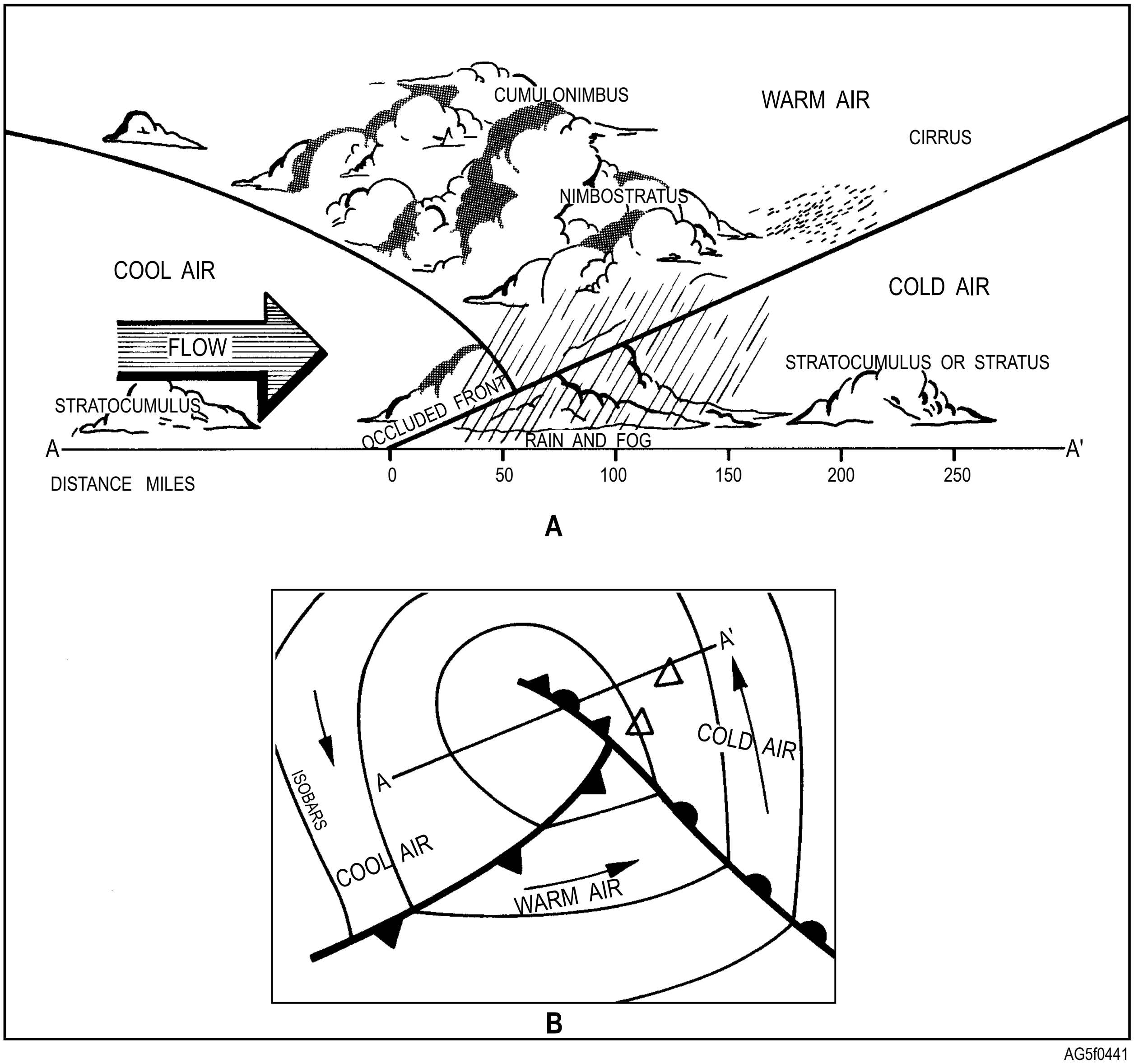


**Figure 4-41.—Illustration of warm type of occlusion. (A) Vertical structure through points A and A'; (B) Horizontal structure.**

taken that intersect both fronts show two inversions. The warm type of occlusion (like the cold type) appears on upper air charts at approximately the same pressure level. However, one distinct difference does appear in the location of the warm isotherm ridge associated with occlusions. The warm isotherm ridge lies just to the rear of the occlusion at the peak of its development.

### REVIEW QUESTIONS

*Q4-16. What is the difference between warm and cold occlusions?*

*Q4-17. Where does the most violent weather occur with the occlusion?*

### THE QUASI-STATIONARY FRONT

**LEARNING OBJECTIVE**: Describe the characteristics of stable and unstable quasi-stationary fronts.

A quasi-stationary front, or stationary front as it is often called, is a front along which one air mass is not appreciably replacing another air mass. A stationary front may develop from the slowing down or stopping of a warm or a cold front. When this front forms, the slope of the warm or cold front is initially very shallow. The dense cold air stays on the ground, and the warm air is displaced slowly upward. The front slows or stops moving because the winds behind and ahead of the front become parallel to the stationary front. It is quite unusual for two masses of different properties to be side by side without some movement, so the term stationary is a misnomer. Actually the front, or dividing line between the air masses, is most likely made up of small waves undulating back and forth; hence the term quasi-stationary. The important thing is that the front is not making any appreciable headway in any one direction. A front moving less than 5 knots is usually classified as a stationary front.

## CHARACTERISTICS

When a front is stationary, the whole cold air mass does not move either toward or away from the front. In terms of wind direction, this means that the wind above the friction layer blows neither toward nor away from the front, but parallel to it. The wind shift across the front is usually near 180 degrees. It follows that the isobars, too, are nearly parallel to a stationary front. This characteristic makes it easy to recognize a stationary front on a weather map.

## STABLE STATIONARY FRONT

There is frictional inflow of warm air toward a stationary front causing a slow upglide of air on the frontal surface. As the air is lifted to and beyond saturation, clouds form in the warm air above the front. If the warm air in a stationary front is stable and the slope is shallow, the clouds are stratiform. Drizzle may then fall; and as the air is lifted beyond the freezing level, icing conditions develop and light rain or snow may fall. At very high levels above the front, ice clouds are present. (See fig. 4-42).

If, however, the slope is steep and significant warm air is being advected up the frontal slope, stratiform clouds with embedded showers result (view B of fig. 4-42). Slight undulation or movement of the quasi-stationary front toward the warm air mass adds to the amount of weather and shower activity associated with the front.

## UNSTABLE STATIONARY FRONT

If the warm air is conditionally unstable, the slope is shallow, and sufficient lifting occurs, the clouds are then cumuliform or stratiform with embedded towering cumulus. If the energy release is great (warm, moist, unstable air), thunderstorms result. Within the cold air mass, extensive fog and low ceiling may result if the cold air is saturated by warm rain or drizzle falling

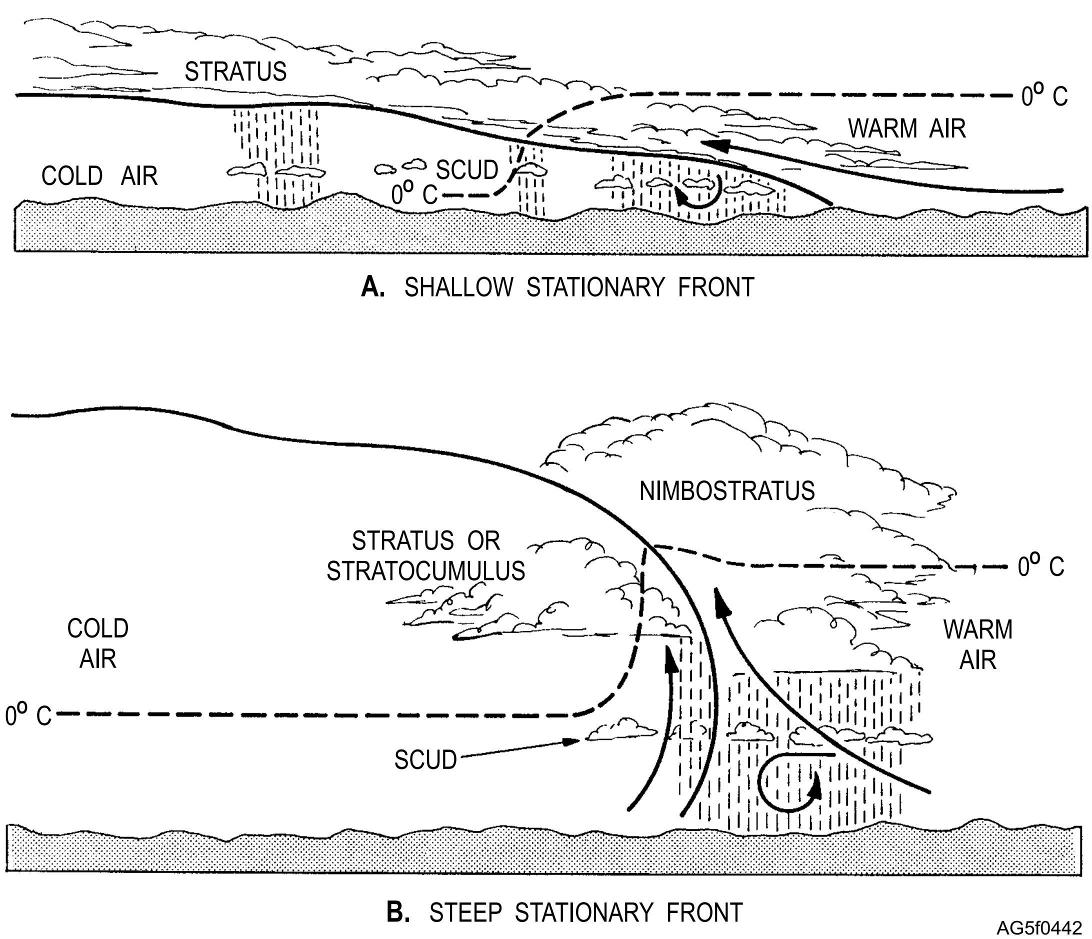


**Figure 4-42.—Types of stable stationary fronts.**

through it from the warm air mass above. If the temperature is below 0°C, icing may occur; but generally it is light (view A of fig. 4-43). The shallow slope of an unstable stationary front results in a very broad and extensive area of showers, fog, and reduced visibility.

If the slope of an unstable stationary front is steep and sufficient warm air is advected up the slope or the front moves slowly toward the warm air mass, violent weather can result (view B of fig. 4-43). Heavy rain, severe thunderstorms, strong winds, and tornadoes are often associated with this front. The width of the band of precipitation and low ceilings vary from 50 miles to about 200 miles, depending upon the slope of the front and the temperatures of the air masses. One of the most annoying characteristics of a stationary front is that it may greatly hamper and delay air operations by persisting in the area for several days.

## REVIEW QUESTIONS

*Q4-18. When a quasi-stationary front moves, if it does, what is the normal speed?*

*Q4-19. What type of weather is normally associated with an unstable stationary front?*

## MODIFICATIONS OF FRONTS

**LEARNING OBJECTIVE**: Describe how fronts are modified by their movement, orographic features, and underlying surfaces.

The typical fronts we have just covered can and do undergo modifications that strengthen or weaken them. Such things as frontal movement, orographic effects, and the type of surface the fronts encounter contribute to the modification of fronts.

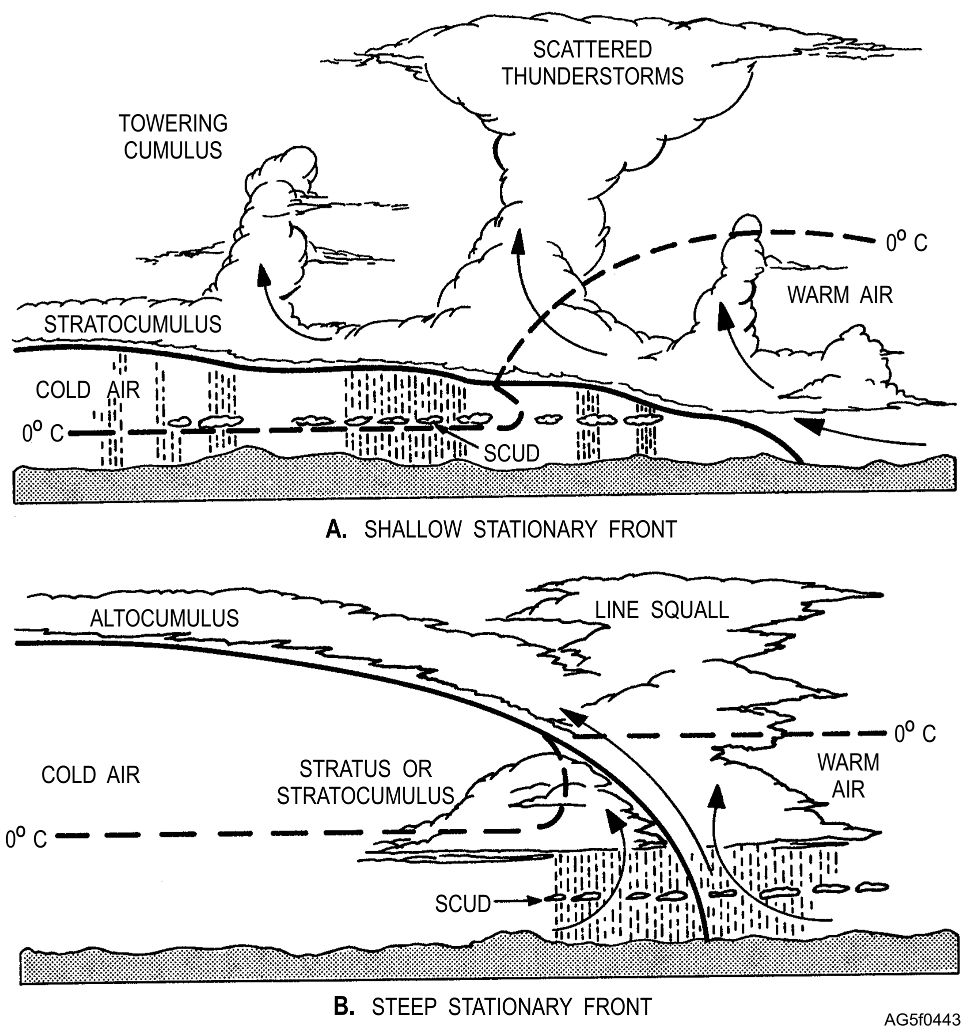


**Figure 4-43.—Types of unstable stationary fronts.**

## EFFECTS CAUSED BY MOVEMENT

The weather is greatly affected by the movement of frontal systems. From the time the front develops until it passes out of the weather picture, it is watched closely. The speed of the movement of frontal systems is an important determining factor of weather conditions. Rapidly moving fronts usually cause more severe weather than slower moving fronts. Fast-moving cold fronts often cause severe prefrontal squall lines that are extremely hazardous to flying. The fast-moving front does have the advantage of moving across the area rapidly, permitting the particular locality to enjoy a quick return of good weather. Slow-moving fronts, on the other hand, may cause extended periods of unfavorable weather. A stationary front may bring bad weather and can disrupt flight operations for several days if the frontal weather is sitting over your station.

Knowledge of the speed of the frontal system is necessary for accurate forecasting. If the front has a somewhat constant speed, it makes your job and the forecaster's job comparatively easy. However, if the speed is erratic or unpredictable, you may err as far as time and severity are concerned. If a front was ultimately forecast to pass through your station and instead becomes stationary or dissipates, the station forecast will be a total bust.

## OROGRAPHIC EFFECTS

Mountain ranges affect the speed, slope, and weather associated with a front. The height and horizontal distance of the mountain range along with the angle of the front along the mountain range are the influencing factors. Mountain ranges can affect cold fronts, warm fronts, and occluded fronts differently.

### Cold Fronts

As a cold front approaches a mountain range, the surface portion of the front is retarded and the upper portion pushes up and over the mountain. On the windward side of the mountain, warm air is pushed up along the mountain slope because of the additional lift of a now steeper frontal slope and the mountain itself (view A of fig. 4-44). After the front passes the crest of the mountain, the air behind the front commences to

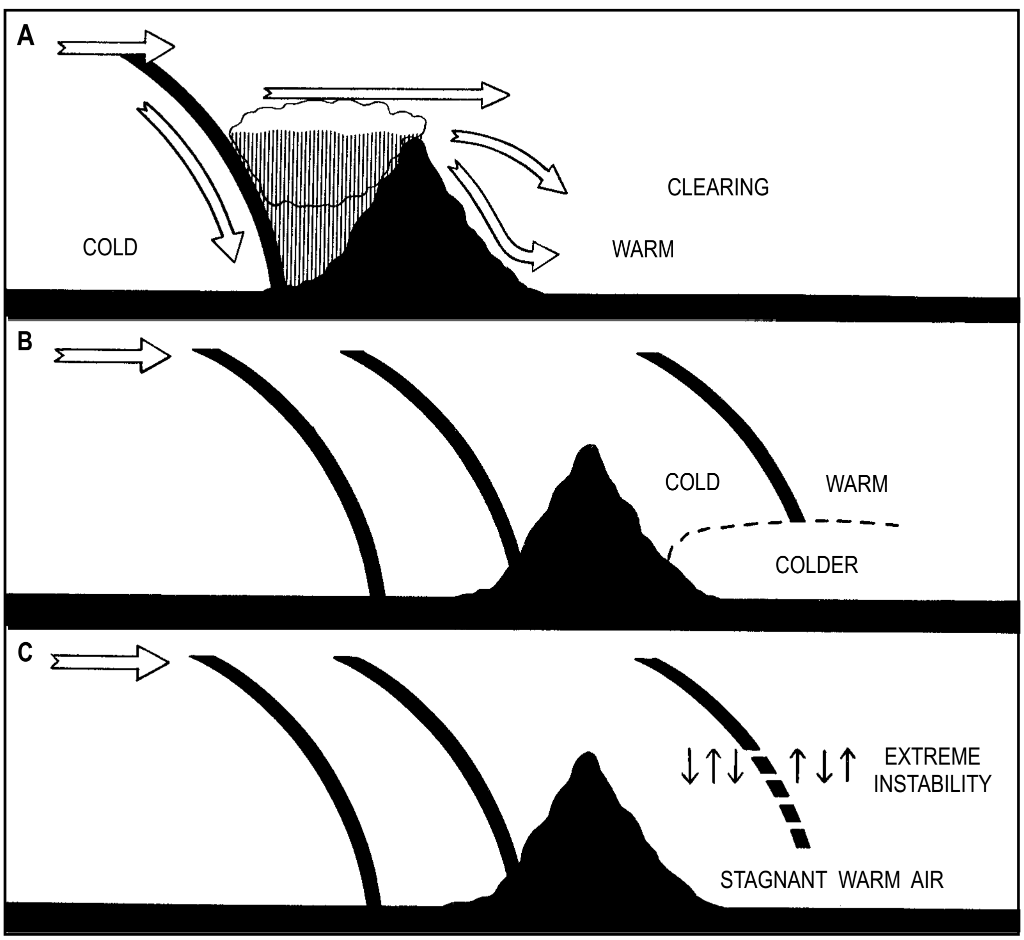


**Figure 4-44.—Orographic effects on a cold front.**

flow down the leeward side of the range. The warmer air on the leeward side of the mountain is displaced by the colder air mass. As this cold air descends the leeward side of the mountain, the air warms adiabatically (view A of fig. 4-44) and clearing occurs within it. However, since the cold air is displacing warm air, typical cold frontal clouds and precipitation may occur within the warm air if the warm air is sufficiently moist and conditionally unstable. In some cases maritime polar air that has crossed the Rockies is less dense than maritime tropical air from the Gulf of Mexico that may lie just east of the mountains. If the maritime polar air is moving with a strong westerly wind flow and the maritime tropical air is moving with a strong southerly wind flow, the maritime polar air may overrun the maritime tropical air. This results in extremely heavy showers, violent thunderstorms, and possible tornadoes.

If COLDER stagnant air lies to the leeward side of the mountain range, the cold front passing over the mountain range does not reach the surface but travels as an upper cold front (view B of fig. 4-44). Under this condition, frontal activity is at a minimum. This situation does not continue indefinitely; either the stagnant air below mixes with the air above or the upper cold front breaks through to the ground when the stagnant surface air has warmed sufficiently. Then the front returns to a normal classic front and begins to lift the now warm air. This ultimately results in the development of thunderstorms and squall lines (view C of fig. 4-45). In the summer, this occurs frequently in one form along the eastern United States. When a cold sea breeze occurs and a cold front crosses the Appalachian Mountains, the associated cold wedge of on-shore flow forces the warm air in advance of the cold front aloft, producing intense thunderstorm activity.

Generally, the area of precipitation is widened as a cold front approaches a mountain range. There is an increase in the intensity of the precipitation and cloud area on the windward side of the range and a decrease on the leeward side.

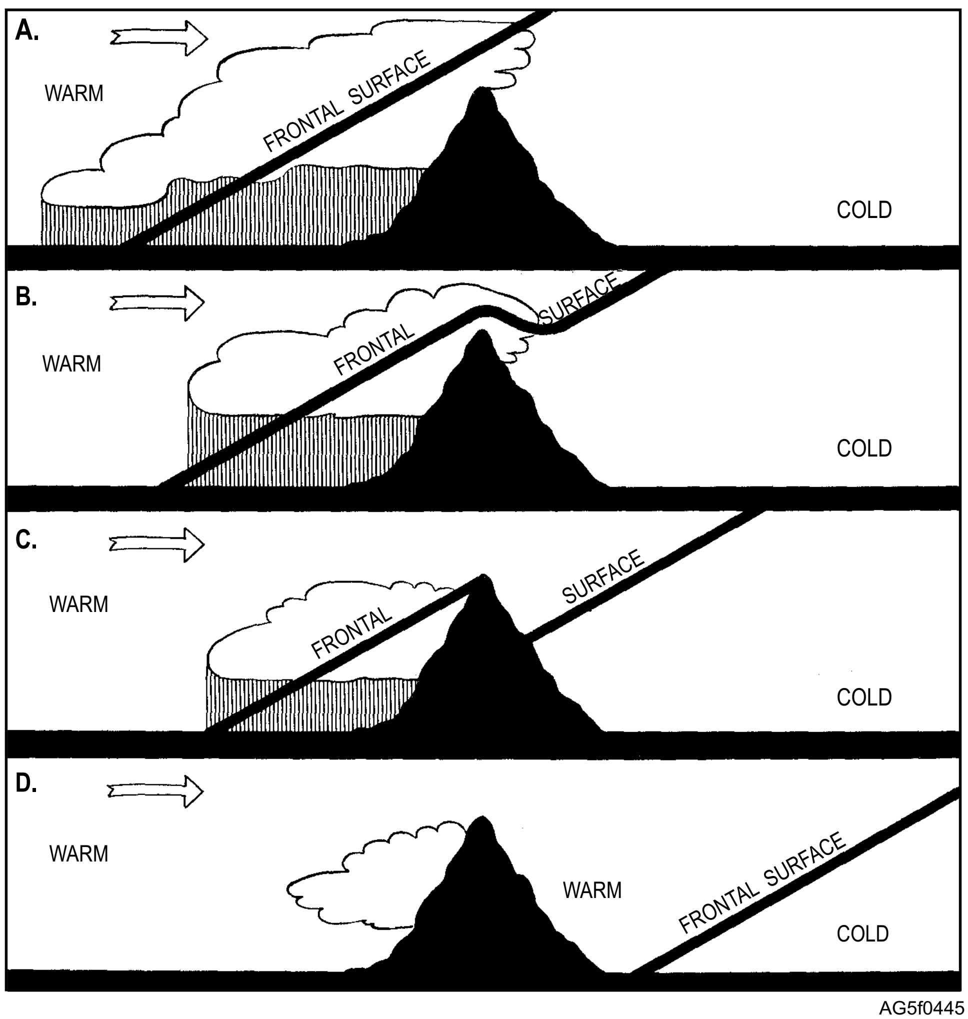


**Figure 4-45.—Orographic effects on a warm front.**

### Warm Fronts

When a warm front approaches a mountain range, the upper section of the frontal surface is above the effects of the mountain range and does not come under its influence (view A of fig. 4-45). As the lower portion of the frontal surface approaches the range, the underlying cold wedge is cut off, forming a more or less stationary front on the windward side of the range. The inclination of the frontal surface above the range decreases and becomes more horizontal near the mountain surfaces, but the frontal surface maintains its original slope at higher altitudes (view B of fig. 4-45). While the stationary front on the windward side of the range may be accompanied by prolonged precipitation, the absence of ascending air on the leeward side of the range causes little or no precipitation. The warm air descending the leeward side of the range causes the cloud system to dissipate and the warm front to travel as an upper front.

Frontogenesis (the formation of a new front or the regeneration of an old front) may occur in the pressure-trough area that accompanies the front. The frontal surface then gradually forms downward as the frontal system moves away from the mountain and extends to the earth's surface again (views C and D of fig. 4-45). The effect of the mountain range on a warm front is to widen and prolong the precipitation on the windward side of the range, while on the leeward side the precipitation band is narrowed and weakened, or is nonexistent.

### Occluded Fronts

Mountain ranges have much the same effect on occluded fronts as they do on warm and cold fronts. Cold type occlusions behave as cold fronts, and warm type occlusions behave as warm fronts. The occlusion process is accelerated when a frontal wave approaches a mountain range. The warm front is retarded; but the cold front continues at its normal movement, quickly overtaking the warm front (views A and B of fig. 4-46).

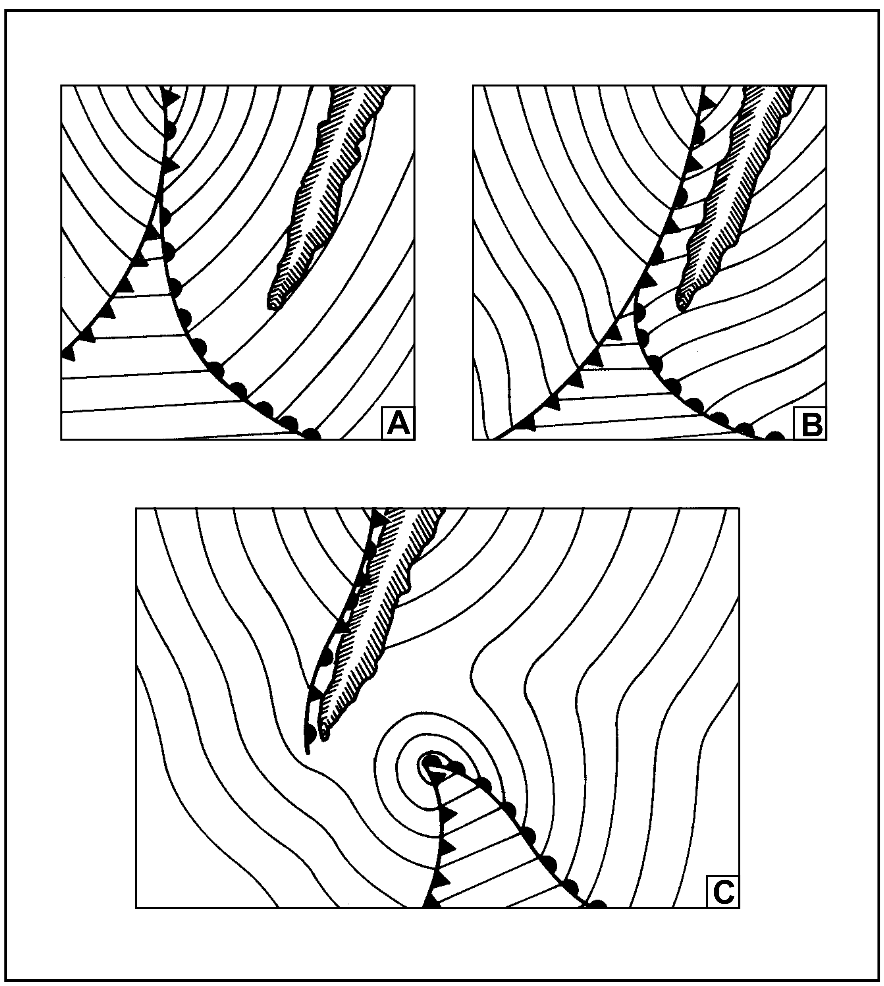


**Figure 4-46.—Acceleration of the occlusion process and development of a frontal wave cyclone.**

When a cold front associated with an occluded frontal system passes a mountain range, the cold front may develop a bulge or wave. In the case of an occlusion, a new and separate low may form at the peak of the warm sector as the occluded front is retarded by a mountain range (view C of fig. 4-46). The low develops on the peak of the wave because of induced low pressure that results when air descends on the leeward side of the mountain and warms adiabatically.

The development of a new low on a frontal wave and ultimate separation from its original cyclone is a fairly common occurrence. This can occur over open oceans but occurs more frequently along the west coast of mountainous continents and along the west coast of Japan. The typical stages of this type of frontal modification are shown in figure 4-47. Orographic features play a great role in certain preferred areas of this phenomena, but over the ocean some other factors must be operative. In some cases, a rapidly moving wave overtakes the slow moving occlusion and may be the triggering mechanism for this cyclogenesis.

Whatever the exact nature of its causes, this type of cyclogenesis proceeds with great rapidity. Initially, the old occlusion in view A of figure 4-47 either moves against a mountain range or is overtaken by another cyclone. The occlusion then undergoes frontolysis (view B of fig. 4-47). The new occlusion forms immediately and soon overshadows its predecessor in both area and intensity (view C of fig. 4-47). However, the cold occlusion, having greater vertical extension, exerts a certain control on the movement of the new center, which at first follows the periphery of the old center. Later, the two centers pivot cyclonically (view D of fig. 4-47) about a point somewhere on the axis joining them until the old center has filled and loses its separate identity.

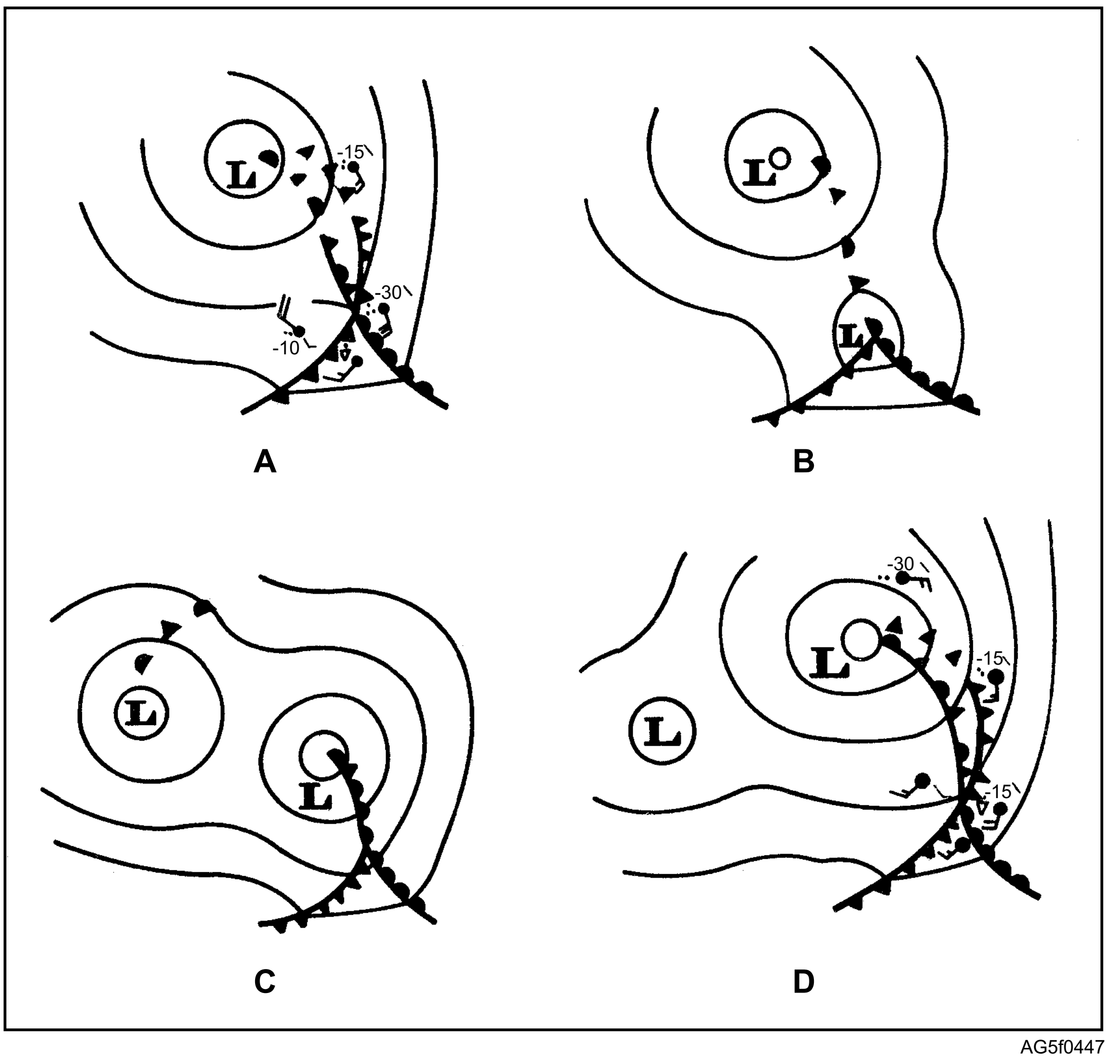


**Figure 4-47.—Stages in the development of a secondary wave cyclone.**

This can take place with either a warm or cold occlusion. If it occurs near a west coast in winter, there is a good chance the new occlusion is warm. This formation of a secondary wave cyclone, the dissipation of the original occluded front, and the rapid development of a new occlusion is sometimes called skagerraking, pressure jump, or bent-back occlusion.

## EFFECTS OF UNDERLYING SURFACES

The migration of a frontal system from one area and type of underlying surface to another often has a great modifying effect. It may cause the front to be regenerated in some instances or to dissipate in others. This transition affects cyclones, air masses, and fronts.

### Movement Over Land Surfaces

So far, we have established that frontal systems generally weaken when moving from water to land surfaces. Once these systems are over land, further modification can be expected. A front that has just crossed the mountains and has weakened remains weak or dissipates unless something occurs to strengthen the contrast between the air masses. If a cold front has just moved onshore in winter and encounters ice and snow cover over the western half of the United States, the maritime air behind the front quickly takes on colder continental properties. The cold underlying surface may totally destroy the cold front, especially if the associated air mass is moving slowly. On the other hand, if the front is moving quickly enough that it is not totally destroyed or modified by the colder surface, it may quickly regenerate as it approaches a warmer underlying surface and air mass. These normally exist over the eastern half of the United States. In this particular situation, the air behind the front is much colder than when it started. As the front arrives at the edge of the snow field, it probably will encounter warmer moist air from the gulf or the ocean. This situation quickly results in frontogenesis because of a sharp air mass contrast. Strong lifting by the wedge of approaching cold air results in severe thunderstorms and abundant precipitation along the frontal surface.

If the ice and snow field does not exist over the western half of the United States, then the weakened front gradually strengthens as it approaches the warmer eastern United States. The weather will not be as intense; however, the cold front will have a much wider band of clouds and precipitation. With this situation, air mass contrast is not strong. If the air masses behind and ahead of the front are weak, the front becomes stationary over the extreme southeast United States. The frontal systems are usually oriented in a northeast-southwest direction and occur mostly during the summer and autumn months. Frequently, stable waves develop and travel along this frontal system, causing unfavorable weather conditions. When these waves move out to sea and warmer moist air is brought into them, they become unstable waves and are regenerated as they move across the ocean.

As the cold fronts cross the Appalachian Mountains, they normally weaken once again because warm moist air is cut off. After passage over the mountains, warm Gulf Stream waters quickly resupply the frontal surface with the moisture and warm air needed for the front to strengthen.

### Land to Water Migration

Once a cold front moves offshore, most forecasters and analysts forget about them and concentrate on the next approaching weather. When a front moves into the Atlantic, the weather generally becomes more intense, especially during fall and winter. While your station may be relaxing to some degree and enjoying the clear skies after frontal passage, Bermuda and ships at sea are most likely bracing for gale force wind and severe thunderstorm activity.

In middle latitudes, ocean currents carry warm water away from the equator along the eastern coasts of continents and carry cold water toward the equator along the western coasts of continents. The most active frontal zones of the winter season are found where cold continental air moves over warm water off eastern coasts. This situation is noticeable off the eastern coast of the United States over the Atlantic Ocean. As a cold front moves off the coast and over the Gulf Stream, it intensifies, and frequently wave development occurs near the Cape Hatteras area. This gives the eastern coast of the United States much cloudiness and precipitation. This system and its newly intensified front eventually reaches Bermuda. A similar situation occurs off the eastern coast of Japan. That area in the Pacific generates more cyclones than any other area in the world.

## REVIEW QUESTIONS

*Q4-20. What two effects cause the modification of fronts?*

*Q4-21. What normally happens to a cold front that moves off the eastern coast of the United States in the winter?*