Chapter 8

AIR MASSES AND FRONTS

The day-to-day fire weather in a given area depends, to a large extent, on either the character of the prevailing air mass, or the interaction of two or more air masses.

The weather within an air mass—whether cool or warm, humid or dry, clear or cloudy—depends on the temperature and humidity structure of the air mass. These elements will be altered by local conditions, to be sure, but they tend to remain overall characteristic of the air mass. As an air mass moves away from its source region, its characteristics will be modified, but these changes, and the resulting changes in fire weather, are gradual from day to day.

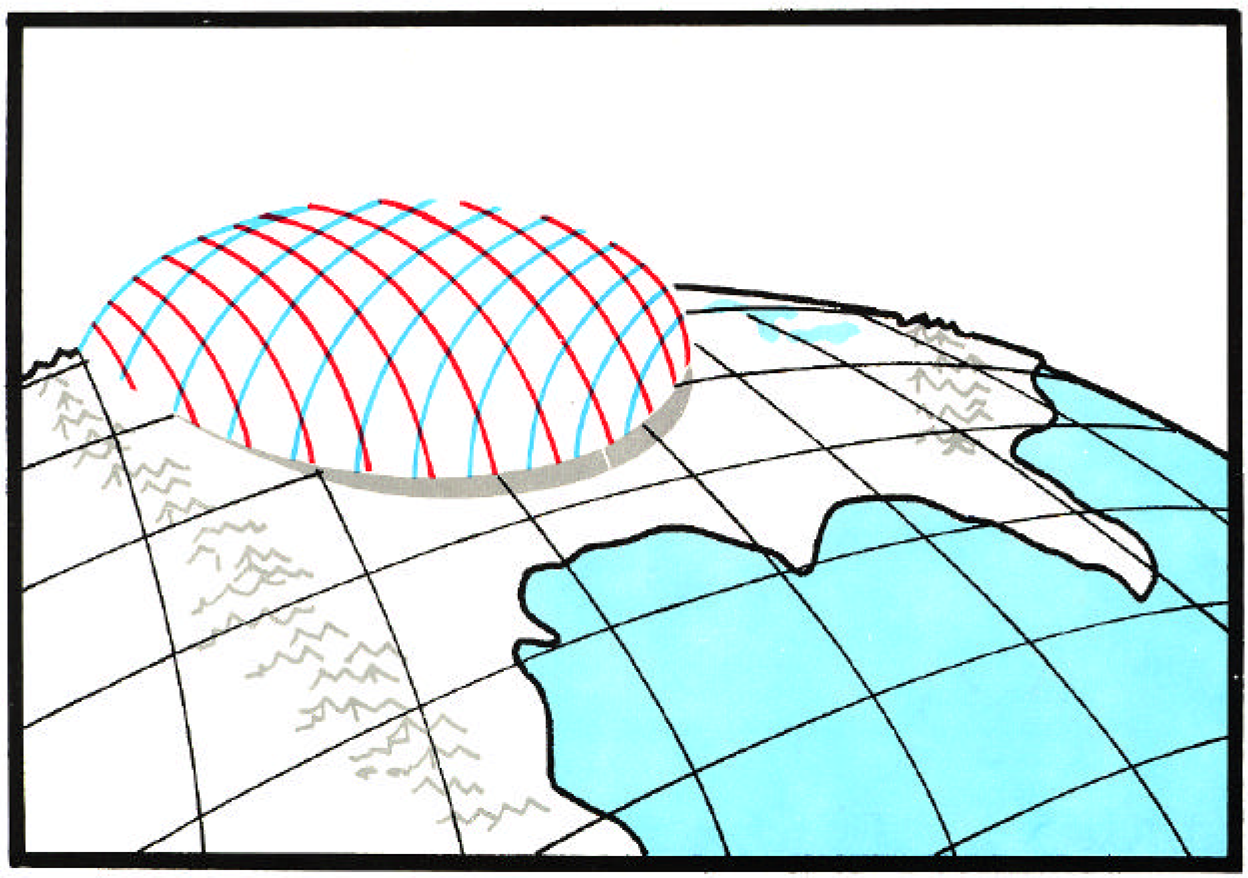
When one air mass gives way to another in a region, fire weather may change abruptly—sometimes with violent winds—as the front, or leading edge of the new air mass, passes. If the frontal passage is accompanied by precipitation, the fire weather may ease. But if it is dry, the fire weather may become critical, if only for a short time.

AIR MASSES AND FRONTS

In chapter 5 we learned that in the primary and secondary circulations there are regions where high-pressure cells tend to form and stagnate. Usually, these regions have uniform surface temperature and moisture characteristics. Air within these high-pressure cells, resting or moving slowly over land or sea areas that have uniform properties, tends to acquire corresponding characteristics—the coldness of polar regions, the heat of the tropics, the moisture of the oceans, or the dryness of the continents.

A body of air, usually 1,000 miles or more across, which has assumed uniform characteristics, is called an air mass. Within horizontal layers, the temperature and humidity properties of an air mass are fairly uniform. The depth of the region in which this horizontal uniformity exists may vary from a few thousand feet in cold, winter air masses to several miles in warm, tropical air masses.

Weather within an air mass will vary locally from day to day due to heating, cooling, precipitation, and other processes. These variations, however, usually follow a sequence that may be quite unlike the weather events in an adjacent air mass.



A body of air, usually 1,000 miles or more across, which has assumed uniform characteristics of temperature and moisture, is coiled an air mass.

Where two or more air masses come together, the boundary between them may be quite distinct; it is called a front. Frontal zones, where lighter air masses are forced over denser air masses, are regions of considerable weather activity.

In this chapter, we will consider first the different types of air masses and the weather associated with them, and then the different kinds of fronts and frontal weather.

FORMATION AND MODIFICATION OF AIR MASSES

The region where an air mass acquires its characteristic properties of temperature and moisture is called its source region. Ocean areas, snow- or ice-covered land areas, and wide desert areas are common source regions. Those areas producing air masses which enter the fire-occurrence regions of North America are:

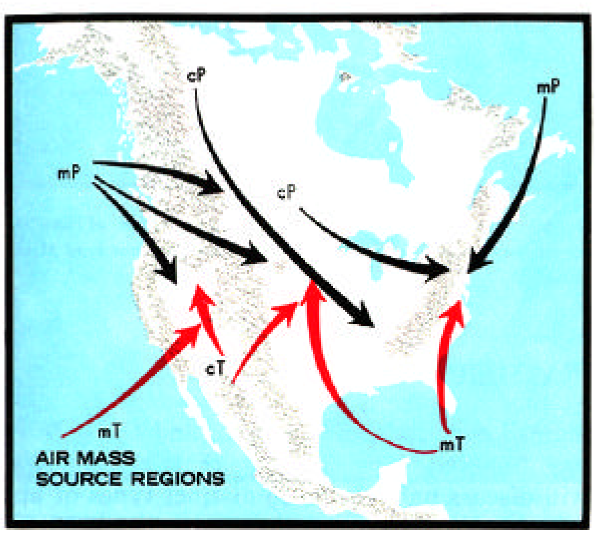
1. The tropical Atlantic, Caribbean, Gulf of Mexico, and the tropical Pacific, which are uniformly warm and moist.

2. The Northern Pacific and Northern Atlantic, which are uniformly cool and moist.

3. Interior Alaska, Northern Canada, and the Arctic, which are uniformly cold and dry during the winter months.

4. Northern Mexico and Southwestern United States, which are usually hot and dry during the summer months.

The time required for a body of air to come to approximate equilibrium with the surface over which it is resting may vary from a few days to 10 days or 2 weeks, depending largely on whether the body of air is initially colder or warmer than the temperature of its source region. If the air is colder, it is heated from below. Convective currents are produced, which carry the heat and moisture aloft and rapidly modify the air to a considerable height.



The oceans and the land are both important air-mass sources.

On the other hand, if the air is initially warmer than the surface, it is cooled from below. This cooling stabilizes the air and cuts off convection. Cooling of the air above the surface must take place by conduction and radiation, and these are slow processes. Thus, a longer time—up to 2 weeks—is required for the development of cold air masses, and even then these air masses are only a few thousand feet thick.

Air masses that form over a source region vary in temperature and moisture from season to season, as does the source region. This is particularly true of continental source regions. High-latitude continental source regions are much colder and drier in the winter than in the summer, and tropical continental source regions are much hotter and drier in summer than in winter.

Air masses are classified according to their source region. Several systems of classification have been proposed, but we will consider only the simplest. Air masses originating in high latitudes are called polar (P), and those originating in tropical regions are called tropical (T). Air masses are further classified according to the underlying surface in the source region as maritime for water and continental for land. The "m" for maritime or "c" for continental precedes the P or T. Thus, the four basic types of air masses are designated as:
mP, mT, cP, and cT, according to their source region. It is natural that air stagnating for some time in a polar region will become cold, or in a tropical region will become warm. And air spending sometime over water becomes

moist, at least in the lower layers, while air over land becomes dry.

For convenience, the four basic air mass types are often referred to as moist cold, moist warm, dry cold, and dry warm.

As an air mass leaves its source region in response to broadscale atmospheric motions, it may be colder or warmer than the surface it passes over. It is then further classified by the addition of **k for colder** or **w for warmer** to its classification symbol. The k-type air mass will be warmed from below and will become unstable in the lower layers. A w-type air mass will be cooled from below, will become stable, and will be modified slowly, and only in the lower few thousand feet.

Air-mass properties begin changing as soon as the air mass leaves its source region. The amount of modification depends upon the speed with which the air mass travels, the type of surface over which it moves, and the temperature difference between the air mass and the underlying surface.

Air masses are modified in several ways. For the most part, these are processes which we have already considered in detail. Several of the processes usually take place concurrently:

1. An air mass is heated from below if it passes over a warmer surface (previously warmed by the sun) or if the surface beneath a slow-moving air mass is being currently warmed by the sun. Such modification is rapid because of the resulting instability and convection.

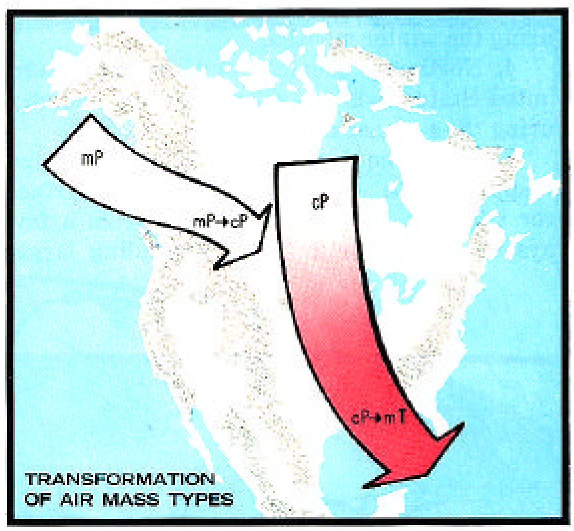
2. An air mass is cooled from below if it passes over a colder surface, or if the surface is cooled by radiation. This increases the stability of the lower layers, and further modification becomes a slow process.

3. Moisture may be added to an air mass by: (a) Evaporation from water surfaces, moist ground, and falling rain; (b) sublimation from ice or snow surfaces and falling snow or hail; and (c) transpiration from vegetation. Of these, sublimation is a relatively slow process by comparison.

4. Moisture may be removed from an air mass by condensation and precipitation.

5. Finally, air-mass properties may be changed by turbulent mixing, by sinking, or by lifting.

After moving a considerable distance from its source region, particularly after entering a source region of another type, an air mass may lose its original distinctive characteristics entirely and acquire those of another air-mass type. Thus, a continental polar all- mass moving out over the Gulf of Mexico takes on the characteristics of a maritime tropical air mass. Or a maritime polar air mass, after crossing the Rocky Mountains, may assume the characteristics of a continental polar air mass.



An air mass which moves into the source region of another air-mass type, and stagnates, is transformed into that type of air mass.

AIR-MASS WEATHER

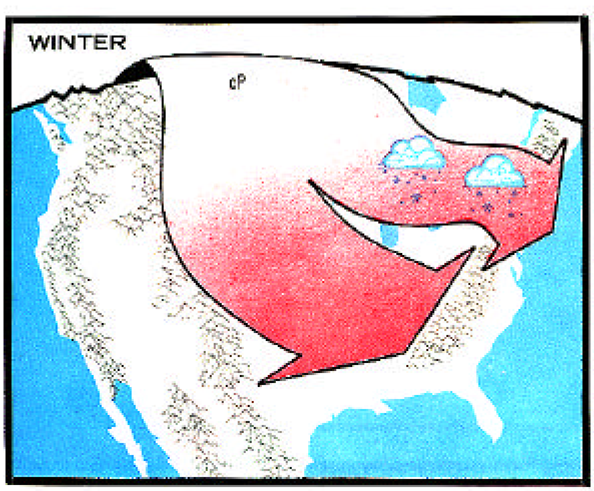
There are many differences in air masses and in the weather associated with them. Even within one air-mass type, there will be considerable variation, depending on the season, the length of time that an air mass has remained over its source region, and the path it has followed after leaving that region. We will discuss only the more distinct types of air masses and consider their most common characteristics.

Continental Polar—Winter

Continental polar air masses originate in the snow-covered interior of Canada, Alaska, and the Arctic in the colder months. Lower layers of the air become quite cold, dry, and stable. Much moisture from the air is condensed onto the snow surface. These air masses are high-pressure areas, and there is little cloudiness due to the lack of moisture and to the stability of the air mass.

These are the coldest wintertime air masses, and cause severe cold waves when moving southward through Canada and into the United States. Upon moving southward or southeastward over warmer surfaces, cP air masses change to cPk. The lower layers become unstable and turbulent. If a part of the air mass moves over the Great Lakes, it picks up moisture as well as heat and may produce cloudiness and snow flurries or rain showers on the lee side of the Lakes, and again on the windward side of the Appalachian Mountains. Once across the Appalachians, the air mass is generally clear and slightly warmer.

If a cP air mass moves southward into the Mississippi Valley and then into the Southeast, it will gradually warm up but remain dry. Modification is slow until the air mass passes beyond the snow-covered areas; then it becomes more rapid. When cP air moves out over the Gulf of Mexico, it is rapidly changed to an mT air mass. The generally clear skies and relatively low humidities associated with **cP air masses are responsible for much of the hazardous fire weather in the South and Southeast during the cool months.**



Continental polar air masses in winter cause severe cold waves when they move southward through Canada and into the Central and Eastern United States.

The Rocky Mountains effectively prevent most cP air masses from moving into the Far West. But occasionally, a portion of a deep cP air mass does move southward west of the Rockies, and in so doing brings this area its coldest weather. At times the air is cold enough for snow to fall as far south as southern California.

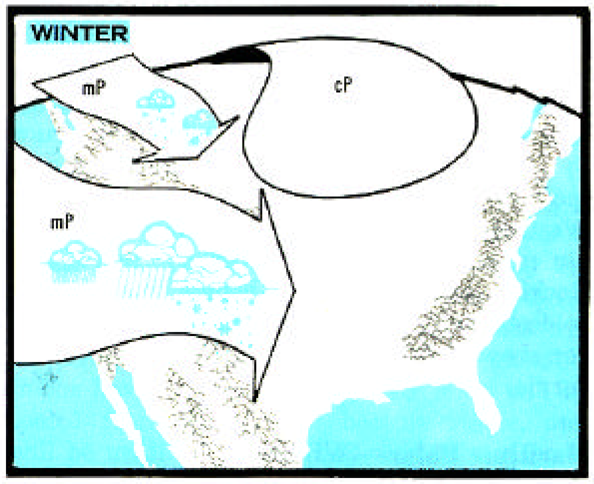
Maritime Polar—Winter

The North Pacific is the common source region for maritime polar air masses. While in its source region, the air mass is cold and has a lapse rate nearly the same as the moist-adiabatic rate. If the air mass moves into the snow-covered regions of Canada, it gradually changes to a cP air mass. Maritime polar air taking that trajectory usually has had a comparatively short stay over the water. It is quite cold and has high relative humidity, but moisture content in terms of absolute humidity is rather low. However, rain or snow showers usually result as the air is lifted over the coastal mountains.

Maritime polar air masses originating farther south and entering Western United States or Southwestern Canada have had a longer overwater trajectory, are not quite so cold, and have a higher moisture content. On being forced over the Coast Ranges and the Rocky Mountains, an mP air mass loses much of its moisture through precipitation. As the air mass descends on the eastern slopes of the Rocky Mountains, it becomes relatively warm and dry with generally clear skies. If, however, it cannot descend on the lee side of the mountains, and instead continues eastward over a dome of cold cP air, snow may occur.

East of the Rockies, mP air at the surface in winter is comparatively warm and dry, having lost much of its moisture in passing over the mountains. Skies are relatively clear. If this air mass reaches the Gulf of Mexico, it is eventually changed into an mT air mass.

Maritime polar air sometimes stagnates in the Great Basin region of the Western United



Maritime polar air masses in winter vary according to the length of time they spend in the source region. Those entering the continent farther north usually have spent only a short time over the water and are cool and quite dry, but showers may occur in the mountains. Those entering the west coast farther south ore more moist and produce much rain and snow, particularly in the mountains.

States in association with a Great Basin High. The outflow from the Great Basin High may give rise to strong, dry foehn winds in a number of the surrounding States.

At times during the winter, mP air is trapped in Pacific coast valleys and may persist for a week or more. Low stratus clouds and fog are produced, making these valleys some of the foggiest places on the continent during the winter.

Although mP air forms over the North Atlantic Ocean, as well as the North Pacific, the trajectory of Atlantic mP air is limited to the northeastern seaboard.

Maritime Tropical - Winter

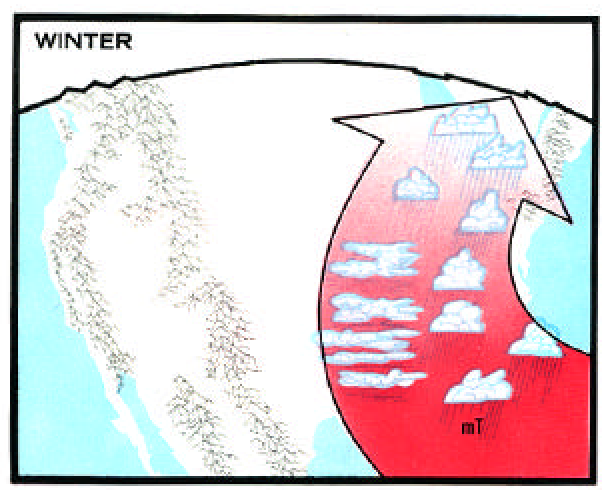
Most of the maritime tropical air masses affecting temperate North America originate over the Gulf of Mexico or Caribbean Sea. They are warm, have a high moisture content, and a conditionally unstable lapse rate. Maritime tropical air is brought into the southeastern and central portions of the country by the circulation around the western end of the Bermuda High. In moving inland during the winter, mT air is cooled from below by contact with the cooler continent and becomes stabilized in the lower levels. Fog and low stratus clouds usually occur at night and dissipate during the day as this air mass invades the Mississippi Valley and the Great Plains. If mT air is lifted over a cP air mass, or if it moves northeastward and is lifted on the western slopes of the Appalachians, the conditional instability is released and large cumulus clouds, heavy showers, and frequent thunderstorms result.

Maritime tropical air seldom reaches as far as the Canadian border or the New England States at the surface in winter. Nevertheless, it occasionally causes heavy rain or snow in these areas, when mT air encounters a colder cP or mP air mass and is forced to rise up over the denser air. More will be said about this process in the section on fronts.

The tropical Pacific is also a source region for mT air, but Pacific mT seldom enters the continent. When it does, it is usually brought in with a low-pressure system in Northern Mexico or California, where the Pacific mT air can cause heavy rainfall when rapidly forced aloft by the mountains.

Continental Polar-Summer

In summer, even though the source region for cP air masses is farther north than in winter—over Northern Canada and the polar regions—the warmer surface temperatures result in little surface cooling and frequently in



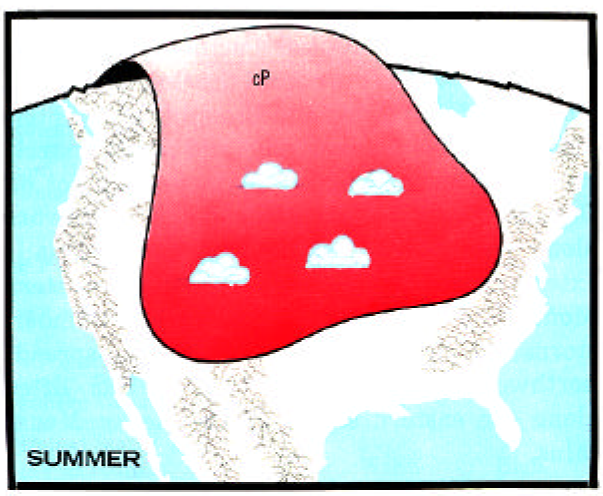
Maritime tropical air in winter produces nighttime cloudiness and fog in the Mississippi Valley and Great Plains and showers or snow over the Appalachians and in areas where it overruns a cooler air mass.

actual heating of the air near the ground. The air mass, therefore, may be relatively unstable in the lower layers in contrast to its extreme stability during the winter. Since the air is quite dry from the surface to high levels, the relative instability rarely produces cloudiness or precipitation.

The general atmospheric circulation is weaker during the summer, and polar outbreaks move more slowly than in winter. As a result, cP air undergoes tremendous changes in passing slowly from its source region to Southern United States. During its southward and southeastward travel, cP air is warmed from below and becomes more unstable.

Continental areas, over which cP air travels, are relatively moist in summer, being largely covered with crops, grass, forests, and other vegetation. Transpiration from these plants and evaporation from water bodies and moist soil increase the moisture content of cP air rather rapidly. As the moisture content increases, cloudiness also increases.

The weather associated with cP air as it passes through Canada and enters the United States is generally fair and dry. **Frequent intrusions of this air give rise to much of the fire weather in the north-central and northeastern regions from spring, through summer, and into fall.**



Continental polar air in summer brings generally fair and dry weather to the central and eastern portions of the continent. The air mass warms rather rapidly and becomes unstable as it moves southward. It may pick up enough moisture to produce some clouds.

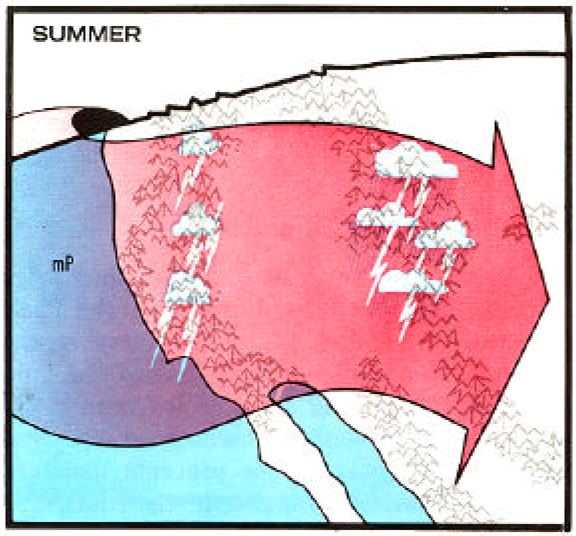
Occasionally, cP air stagnates in the Southeastern United States and accumulates sufficient moisture to produce showers and isolated thunderstorms, particularly over mountainous areas.

Maritime Polar—Summer

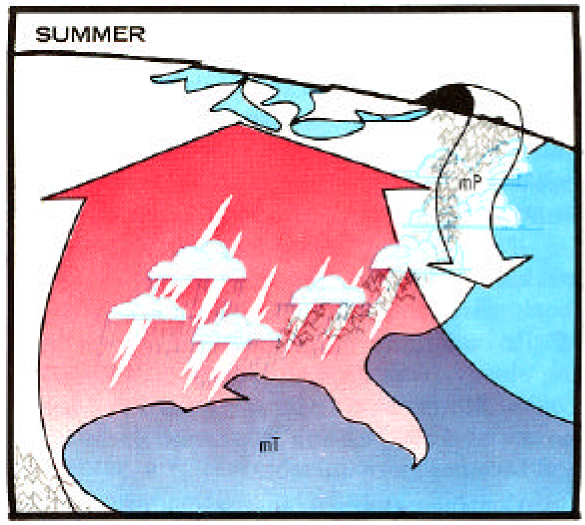
Maritime polar air masses in summer originate in the same general area over the Pacific Ocean as in winter. In summer, however, the ocean is relatively cool compared to the land surfaces. Summer mP air is cooled from below in its source region and becomes stable. Stability in the lower layers prevents moisture from being carried to higher levels. Aloft, this air mass remains very dry, usually even drier than summer cP, and becomes quite warm through the subsidence which takes place in the Pacific High.

As mP air approaches the Pacific coast, the cold, upwelling waters along the shore cause further cooling, increasing relative humidity, and stimulating the formation of considerable fog or low stratus clouds. Thus, along the Pacific coast, summer mP is characterized by a cool, humid marine layer from 1,000-2,000 feet thick, often with fog or low stratus clouds, a strong inversion capping the marine layer, and warm, dry, subsiding air above.

As mP air moves inland from the west coast, the strong daytime heating in interior California, Oregon, Washington, and portions of British Columbia warms the surface layers and lowers the relative humidity. The intense heating and the lifting as mP air crosses the mountains may result in cumulus cloud formation and occasional scattered showers and thunderstorms at high elevations. In descending the eastern slopes of the Rockies, summer mP is heated adiabatically as in winter, and the relative humidity may become quite low at times. When it arrives in the Plains and the Mississippi Valley, it is hardly distinguishable from cP air in the area and results in clear, dry weather. Continuing eastward, it becomes warmer and more unstable, and picks up moisture from the earth and plants. By the time it reaches the Appalachians, it has become unstable and moist enough so that lifting can again produce showers or thunderstorms.



Stratus clouds and fog along the Pacific coast are characteristic of mP air in summer. Heating and lifting of the air are likely to produce clouds in the Sierras and showers or thunderstorms in the Rockies if sufficient moisture is present.



Maritime tropical air moving onto the continent is conditionally unstable. Daytime heating and orographic lifting produce showers and thunderstorms in this warm, humid air mass.

Maritime polar air formed over the colder waters of the North Atlantic in summer occasionally moves southward bringing cool weather and cloudiness to the Atlantic coastal areas.

Maritime Tropical—Summer

Maritime tropical air in its source region over the Gulf of Mexico and the Caribbean in summer has properties similar to those in winter, except that it is conditionally unstable to higher levels, slightly warmer, and more moist. In summer, mT air invades central and eastern North America very frequently, sometimes penetrating as far north as Southern Canada, bringing with it the typical heat and oppressive humidity of those tropical source regions.

Daytime heating of the air as it moves inland produces widespread showers and thunderstorms, particularly, during the afternoon and evening. At night, there may be sufficient cooling of the earth's surface to bring the temperature of the air near the ground to the dew point and produce fog or stratus clouds. This is dissipated in the early morning by surface heating.

When mT air is lifted, either by crossing mountains or by being forced to rise over cooler mP or cP air, widespread clouds, numerous showers, and intense thunderstorms are produced.

Although some of the summer thunderstorm activity in Northern Mexico and the Southwestern United States is the result of mT air from the tropical Pacific, most of it is associated with mT air from the Gulf of Mexico. This moist air is usually brought in at intermediate levels by easterly and southeasterly flow. Heating and lifting by mountains set off thunderstorms as the air spreads northward along the Sierra-Cascade range, occasionally extending as far as northern Idaho, western Montana, and Southern Canada. Some thunderstorm activity develops as mT air spreads northwestward from the Gulf and is lifted along the eastern slopes of the Rocky Mountains.

On rare occasions, mT air originating in the tropical Pacific spreads northward over Northwestern Mexico and California with thunderstorm activity. Usually this is residual mT air from a dying tropical storm.

Continental Tropical—Summer

The only source regions for continental tropical air in North America are Mexico and the Southwestern United States. This air mass is hot, dry, and unstable, and causes droughts and heat waves when it persists for any length of time. It is similar to the upper-level, subsiding air in the Pacific High, and may actually be produced by subsidence from aloft.

In summer, cT air sometimes spreads eastward and northward to cover portions of the Central or Western United States. Because of its heat and dryness, it has a desiccating effect on wildland fuels, setting the stage for serious fire-weather conditions.

Characteristics of winter and summer air masses are summarized in the following tables.

Characteristics of Winter Air Masses

Air mass	Lapse rate	Temperature	Surface RH	Visibility	Clouds	Precipitation
cP at source region	Stable	Cold	High	Excellent	None	None
cP over mid-continent, Southeastern Canada and Eastern United States	Variable	do.	Low	Good, except in industrial areas and in snow flurries	Stratocumulus in hilly regions, stratocumulus or cumulus along lee shores of Great Lakes	Snow flurries in hilly areas and along lee shores of Great Lakes
mP at source region	Unstable	Moderately cool	High	Good	Cumulus	Showers
mP over west coast	do.	Cool	do.	do.	do.	do.
mP over Rockies	do.	do.	do.	Good, except in mountains and during precipitation	do.	Showers or snow
mP over midcontinent, Southeastern Canada, and Eastern United States	Stable	Mild	Low	Good, except near industrial areas	None, except in mountains	None
mT at source region	Unstable	Warm	High	Good	Cumulus	Showers
mT over Southern United States	Stable in lower layers	do.	do.	Fair in afternoon, poor with fog in early morning	Stratus and stratocumulus	Rain or drizzle

Characteristics of Summer Air Masses

Air mass	Lapse rate	Temperature	Surface RH	Visibility	Clouds	Precipitation
cP at source region	Unstable	Cool	Low	Good	None or few cumulus	None
cP over midcontinent, Southeastern Canada, and Eastern United States	do.	Moderately cool	do.	Excellent	Variable cumulus	None
mP at source region	Stable	Cool	High	Fair	Stratus, if any	None
mP over west coast	do.	do.	do.	Good, except poor in areas of fog	Fog or stratus	None
mP over Rockies	Unstable	Moderately cool	Moderate	Good	Cumulus	Showers at high elevations
mP over midcontinent, Southeastern Canada, and Eastern United States	do.	Warm	Low	do.	Few cumulus	Showers windward side of Appalachians
mT at source region	do.	Warm	High	do.	Cumulus, if any	Showers
mT central and eastern continent	do.	Hot	Moderate	Good during day except in showers; poor with fog in early morning	Fog in morning, cumulus or cumulonimbus in afternoon	Showers or thunderstorms
	Unstable	Hot	Low	Good except in dust storms	None	None

VARIATIONS IN AIR-MASS WEATHER

We have considered the usual characteristics of the principal air masses in winter and in summer. We must realize, however, that there are many variations in individual air masses— variations from day to night, and seasonal variations other than just in winter and summer. We will consider a few general principles to help us understand these variations.

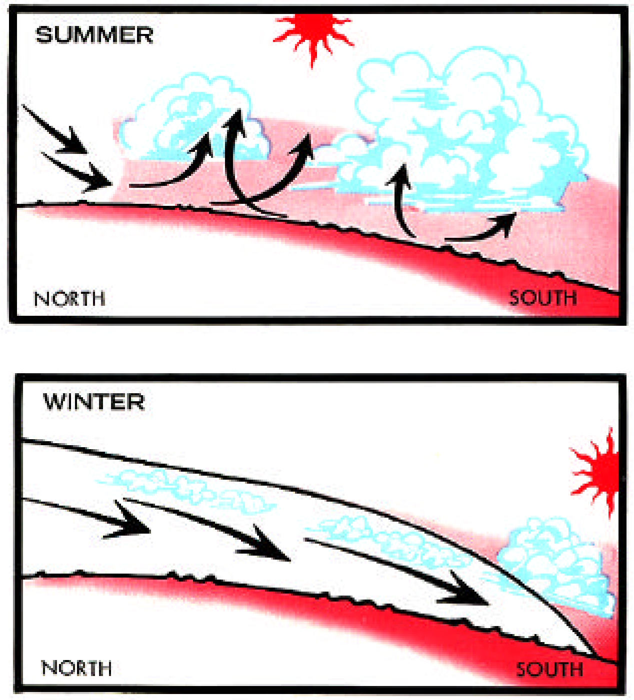
1. If the surface over which an air mass is located is warmer than the air mass, the lower layers will be heated. This results in increased instability, convective mixing and turbulence, and a lowering of surface relative humidity. If sufficient moisture is present, cumulus clouds and possible showers may be formed. The increased mixing generally results in good visibility.

2. If the surface is colder than the air mass, the lower layers are gradually cooled. This increases the stability and retards convective mixing and turbulence. Water vapor and atmospheric impurities tend to be concentrated in the lower layers, and visibility is decreased. With sufficient moisture, fog and low stratus clouds will form,

3. As a rule, air masses over land and away from their source region tend to be cooler than the surface during the day, and warmer than the surface at night. Thus, the weather characteristics change accordingly from day to night.

4. In the spring, land surfaces away from source regions warm faster than the water or snow-covered surfaces at source regions. This leads to increased instability in the lower layers as air masses leave their source region, and causes considerable thunderstorm activity, hail, and, sometimes, tornadoes.

5. During the summer, there is the least temperature difference between polar and tropical regions. The general circulation is weaker so that air masses move more slowly, and spending more time in transit, are thus more subject to modification. The belt of westerlies is farther north than in winter. As a result, tropical air masses penetrate far to the north, but polar air masses are



In summer, because of the weaker general circulation, air masses move more slowly and are subject to greater modification. In winter, when the general circulation is stronger, cold polar air masses move rapidly away from their source region and penetrate far southward with little modification.

blocked at high latitudes and do not penetrate far southward.

6. As the earth's surface begins to cool in the fall, air masses tend to be more stable in the lower layers, and thunderstorm activity is reduced. As fall progresses and winter approaches, stable cold air near the surface becomes deeper and more persistent, encouraging the formation of fog or low stratus clouds.

7. During the winter, cold polar air masses move at a faster rate and penetrate far southward. The temperature contrast between polar and tropical regions increases, as does the speed of the general circulation.

FRONTS

We have seen that polar air masses have time ocean origin are different from those of properties very different from those of tropical

continental origin. Because the various types of air masses, and that air masses having a man- air masses move into the middle latitudes, it is inevitable that they meet somewhere and interact. Since air masses have different densities, they tend not to mix when they come together. Instead, a discontinuity surface, or front, is found between them (see page 129).

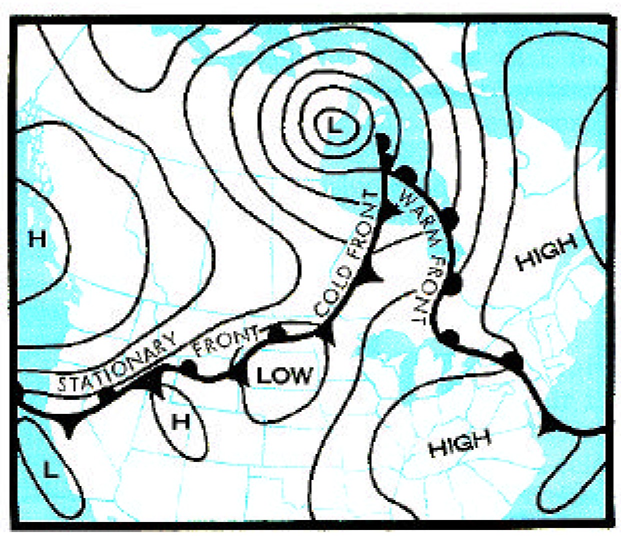
Some of the weather conditions most adverse to fire control, such as strong, gusty winds, turbulence, and lightning storms, occur in frontal zones. Sometimes there is insufficient moisture in the warm air mass, or inadequate lifting of this mass, so that no precipitation occurs with the front. Strong, gusty, and shifting winds are typical of a dry frontal zone, adding greatly to the difficulty of fire control.

In a frontal zone, the warmer air mass, being lighter, will be forced over the colder air mass. The rotation of the earth deflects the movement of both the cold and the warm air masses as one tries to overrun or underride the other, and prevents the formation of a horizontal discontinuity surface. Instead, the frontal surface **slopes up** over the colder air. The slope varies from about 1/50 to 1/300, A 1/50 slope means that for every 50 miles horizontally, the front is 1 mile higher in the vertical. The amount of slope is dependent upon the temperature contrast between the two air masses, the difference in wind speed across the front, and the relative movements of the air masses involved; that is, whether cold air is replacing warm air at the surface or warm air is replacing cold air. On a surface weather map, only the intersection of the frontal surface with the earth is indicated. The contrast between the air masses is strongest near the earth's surface, and decreases upward in the atmosphere.

The central portions of air masses are usually associated with areas of high pressure, but fronts are formed in troughs of low pressure. From a position on a front, we find that the pressure rises both toward the warmer air and toward the colder air. Because the gradient wind in the Northern Hemisphere always blows with high pressure on the right, as one faces downstream, this means that the wind blows in one direction in the cold air and a different direction in the warm air. At a given location, shown in chapter 6, the wind shifts in a clockwise direction as a front passes—for example, from southeast to southwest or from southwest to northwest.

The wind-shift line and pressure trough line provide good clues to the weatherman for the location of fronts, but there are other indications to consider. A temperature discontinuity exists across a front. As a rule, the greater and more abrupt the temperature contrast, the more intense the front. Weak fronts are characterized by gradual and minor changes in temperature. The moisture contrast between air masses on different sides of a front may be indicated by the dew-point temperatures. Usually the cold air mass will be drier than the warm air mass. Other indications of front location are cloud types, pressure changes, and visibility changes.

Types of fronts are distinguished by the way they move relative to the air masses involved. If a front is moving so that cold air is replacing warm air, it is a cold front**.** If the warm air is advancing and replacing cold air ahead, the front is a warm front**.** If a front is not moving, it is a stationary front. Cold fronts are indicated on weather maps by pointed cusps, and warm fronts by semicircles, on the side toward which they are moving. A stationary front is indicated by a combination of both. (See sketch.)



Fronts ore classified by the way they move relative to the air masses involved. At a cold front, cold air is replacing warm air. At a warm front, warm air is replacing cold air. A stationary front, as the name implies, is temporarily stalled.

Cold Fronts

The leading edge of an advancing cold air mass is a cold front. It forms a wedge which pushes under a warm air mass forcing the warm air to rise. Because of surface friction, the lowest layers of the cold air are slowed down. This increases the steepness of the frontal surface and causes a cold front to have a blunted appearance when viewed in cross-section. The slopes of cold fronts usually vary between 1/50 to 1/150.

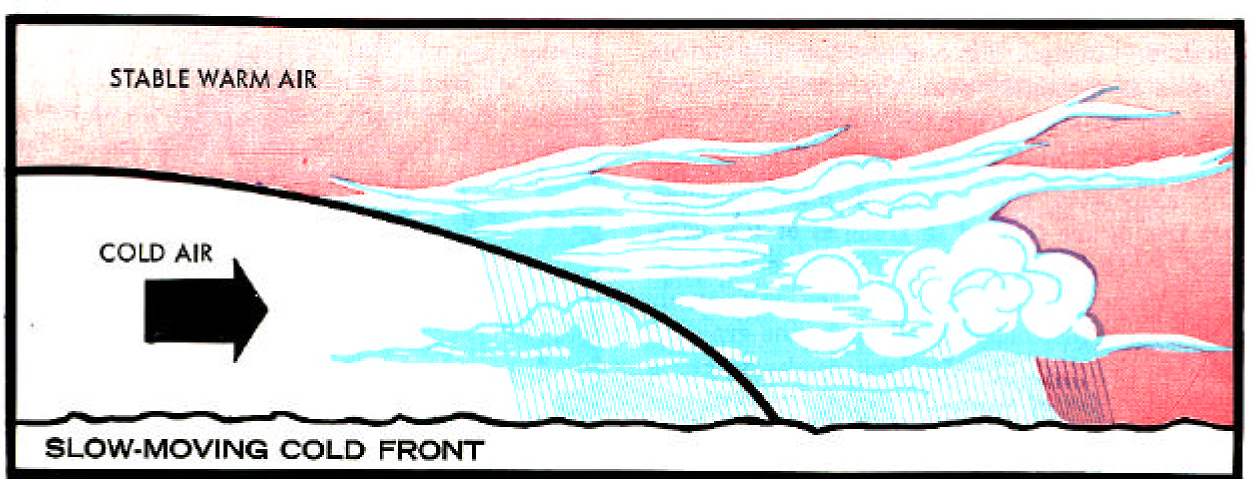
There are wide variations in the orientation and speed of cold fronts. Usually, they are oriented in a northeast-southwest direction, and they move to the east and southeast, at speeds varying from about 10 to 40 m.p.h. and faster in the winter.

As a cold front approaches, the southerly winds increase in the warm air ahead of the front. Clouds appear in the direction from which the front is approaching. The barometric pressure usually falls, reaches its lowest point as the front passes, then rises sharply. Winds become strong and gusty and shift sharply to westerly or northwesterly as the cold front passes. Temperature and dew point are lower after the cold front passes. In frontal zones with precipitation, the heaviest precipitation usually occurs with the passage of the front. Then it may end quickly and be followed by clearing weather.

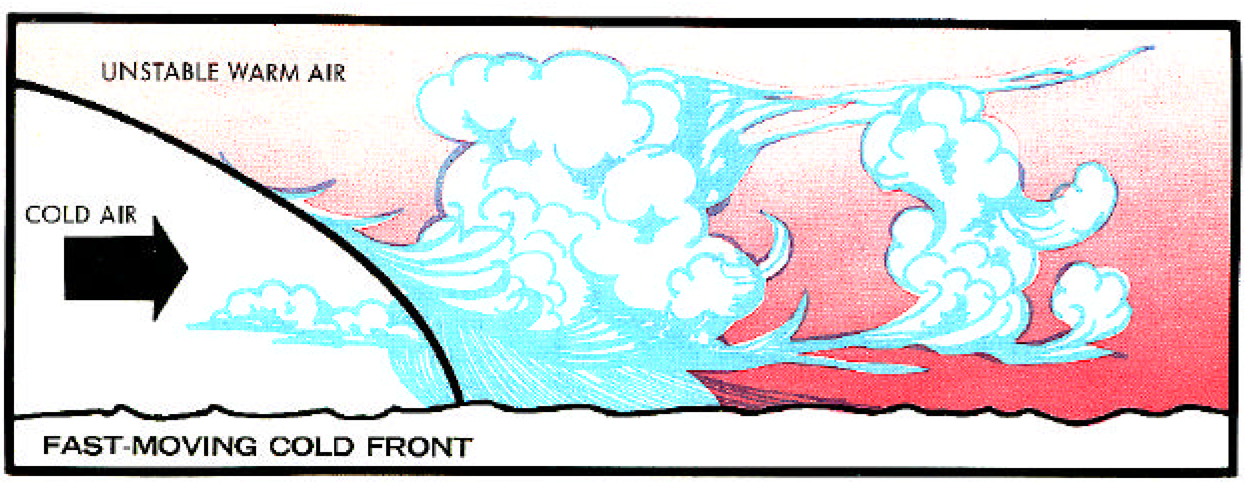
There are many exceptions to the foregoing general pattern of cold-front passages. The severity of the weather associated with cold fronts depends upon the moisture and stability of the warm air, the steepness of the front, and the speed of the front. Since cold fronts are usually steeper and move faster than warm fronts, the accompanying band of weather is narrower, more severe, and usually of shorter duration than with warm fronts.

With slow-moving cold fronts and stable warm air, rain clouds of the stratus type form in a wide band over the frontal surface and extend for some distance behind the front. If the warm air is moist and conditionally unstable, thunderstorms may form, with the heaviest rainfall near the frontal zone and immediately following. If the warm air is fairly dry and the temperature contrast across the front is small, there may be little or no precipitation and few or no clouds.

With rapidly moving cold fronts, the weather is more severe and occupies a narrower band. The disturbance is also of shorter duration than that caused by a slow-moving front. If the warm air is relatively stable, overcast skies and precipitation may occur for some distance ahead of the front, and the heaviest precipitation may occur ahead of the surface cold front. If the warm air is moist and conditionally unstable, scattered showers and thunderstorms form just ahead of the cold front.



Clouds and precipitation cover a wide bond and extend some distance behind slow-moving cold fronts. If the warm air is moist and stable, stratus-type clouds and steady rain occur, If the warm air is conditionally unstable, showers and thunderstorms are likely.



With rapidly moving cold fronts, the weather is mare severe and occupies a narrower band. If the warm air is moist and conditionally unstable, as in this case, scattered showers and thunderstorms form just ahead of the cold front.

The weather usually clears rapidly behind a fast-moving cold front, with colder temperatures and gusty, turbulent surface winds following the frontal passage.

Under some conditions, a line of showers and thunderstorms is formed from 50 to 300 miles ahead of, and roughly parallel to, a cold front. This is called a squall line. The weather associated with squall lines is often more severe than that associated with the subsequent cold front. After the passage of the squall line, the temperature, wind, and pressure usually revert to conditions similar to those present before the squall line approached. Occasionally, the showers and thunderstorms are scattered along the squall line so that some areas experience strong, gusty winds without any precipitation.

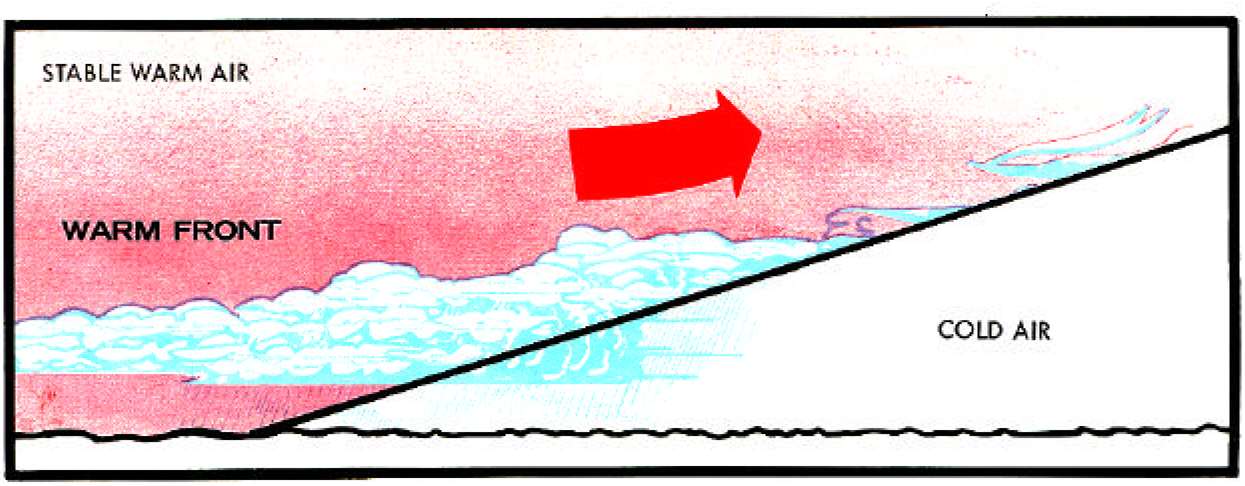
Dry cold fronts often cause very severe fire weather in many sections. Dry cold-front passages may occur in any region, but they are a major problem in the Southeast. Cold fronts tend to be drier farther away from the low-pressure center with which they are associated. Thus, a cold front associated with a Low passing eastward across Southern Canada or the Northern States may be very dry as it passes through the Southeast. In addition, the polar air mass following the cold front may become quite unstable because of surface heating by the time it reaches the Southeast.

The combination of strong, gusty winds and dry, unstable air creates serious fire weather. The second of two cold fronts passing through the Southeast in rapid succession also tends to be dry. The warm air mass ahead of the first cold front may be moist and produce precipitation, but the air mass between the first and second fronts usually will not have had time to acquire much moisture. Therefore, the second cold-front passage may be dry and will be the more serious from the fire-control standpoint.

The dry, trailing ends of cold fronts cause serious fire weather wherever they occur. Along the Pacific coast, the winds behind such cold fronts are, at times, from a northeasterly direction. This offshore direction means that the air flows from high elevations to low elevations and has foehn characteristics. The strong, shifting, gusty winds of the cold-front passage combine with the dry foehn wind to the rear of the front to produce a short-lived but extremely critical fire-weather condition.

Warm Fronts

The leading edge of an advancing warm air mass is called a warm front. The warm air is overtaking and replacing the cold air, but at the same time sliding up over the wedge of cold air. Warm fronts are flatter than cold fronts, having slopes ranging from 1/100 to 1/300. Because of this flatness, cloudiness and precipitation extend over a broad area ahead of the front, providing, of course, that there is sufficient moisture in the warm air.

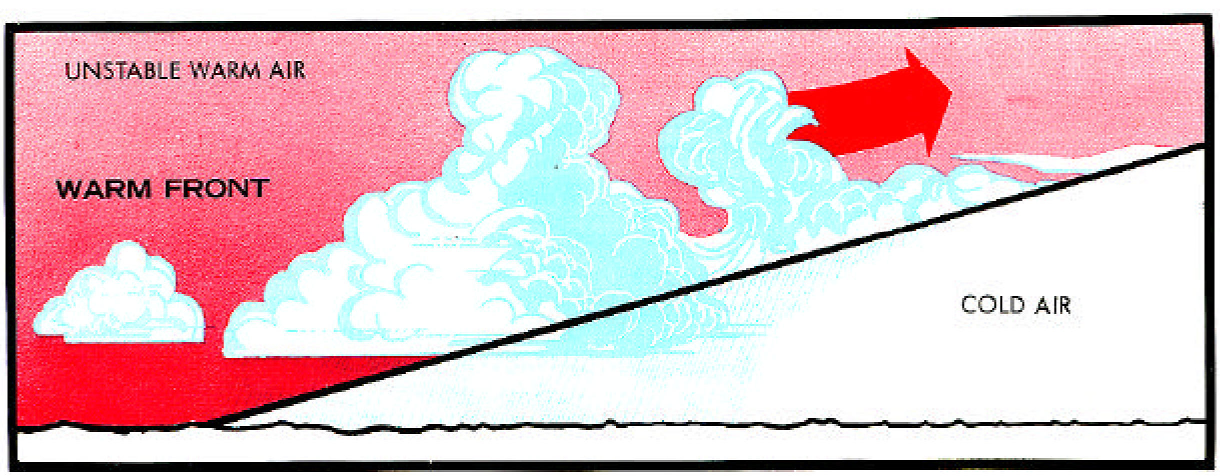


If the warm air above a warm front is moist and stable, clouds are of the stratus type. The sequence of cloud types is cirrus, cirrostratus, altostratus, and nimbostratus. Precipitation is steady and increases gradually with the approach of a front.

Warm fronts are less distinct than cold fronts and more difficult to locate on weather maps. This is particularly true in rough terrain where high-elevation areas may extend up into the warm air before the warm front has been felt at lower elevation stations.

The first indication of the approach of warm, moist air in the upper levels ahead of the surface warm front may be very high, thin, cirrostratus clouds which give the sky a milky appearance. These are followed by middle-level clouds which darken and thicken as precipitation begins. This sequence may be interrupted by short clearing periods, but the appearance of successively lower cloud types indicates the steady approach of the warm front. Rains may precede the arrival of the surface warm front by as much as 300 miles. Rain falling through the cold air raises the humidity to the saturation level and causes the formation of low stratus clouds.

If the warm air above the warm front is moist and stable, the clouds which form are of the stratus type. The sequence is cirrus, cirrostratus, altostratus, and nimbostratus. Precipitation is a steady type and increases gradually with the approach of the surface front.



If the warm air above a warm front is moist and conditionally unstable, altocumulus and cumulonimbus clouds form. Often, thunderstorms will be embedded in the cloud masses.

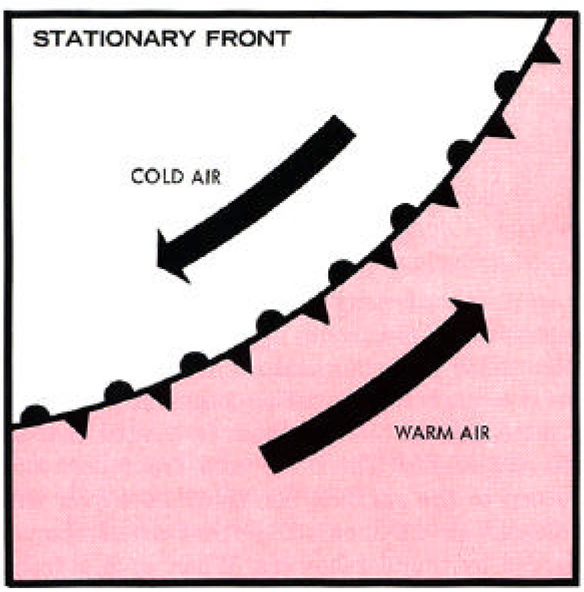
If the warm air is moist and conditionally unstable, altocumulus and cumulonimbus clouds form, and, frequently, thunderstorms will be embedded in the cloud masses that normally accompany a warm front.

The rate of movement of warm fronts is about half that of cold fronts. Winds are usually not as strong or gusty with the approach of warm fronts as with cold fronts. The shift in wind is generally from an easterly to a southerly direction as a warm front passes. After it passes, temperatures rise, precipitation usually stops, and clouds diminish or vanish completely.

From the standpoint of fire weather, warm fronts associated with moist air are a real benefit. The accompanying precipitation is widespread and long-lasting, and usually is sufficient to thoroughly moisten forest fuels, reducing the fire danger.

Stationary Fronts

When the forces acting on two adjacent air masses are such that the frontal zone shows little movement, the front is called a stationary front. Surface winds on either side of the front tend to blow parallel to the front, but in opposite directions. Weather conditions occurring with a stationary front are variable; usually they are similar to those found with a warm front, though less intense. If the air is dry, there may be little cloudiness or precipitation. If the air is moist, there may be continuous precipitation with stable, warm air, or showers and thunderstorms with conditionally unstable, warm air. The precipitation area is likely to be broader than that associated with a cold front, but not as extensive as with a warm front.



Surface winds on either side of a stationary front tend to blow parallel to the front, but in opposite directions. Stationary fronts are indicated on weather maps by alternate sharp cusps and semicircles on apposite sides of the front.

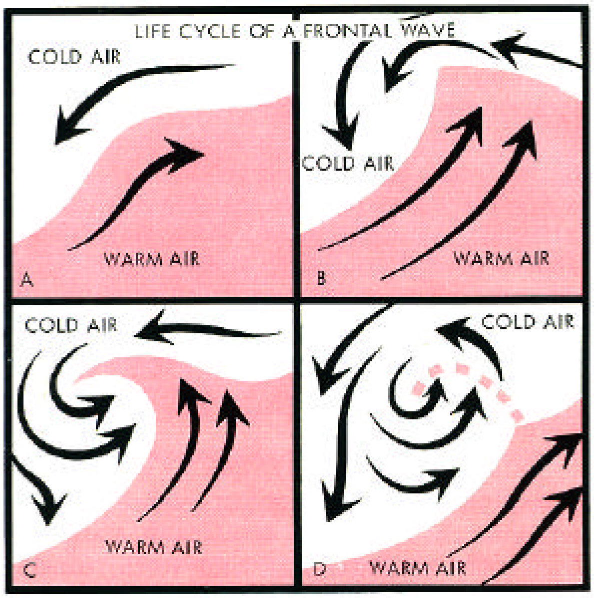
Stationary fronts may quickly change back to moving fronts as a slight imbalance of forces acting on the air masses develops. A stationary front may oscillate back and forth, causing changing winds and weather conditions at a given location. It may become a cold or warm front, or a frontal wave may develop, as we will see in the next section.

Frontal Waves and Occlusions

A frontal surface is similar to a water surface. A disturbance such as wind can cause the formation of waves on the water. If the wave moves toward the shoreline, it grows until it becomes topheavy and breaks. Similarly, along frontal surfaces in the atmosphere a disturbance may form a wave. This disturbance may be a topographic irregularity, the influence of an upper-level trough, or a change in the wind field cause by local convection. Waves usually form on stationary fronts or slow-moving cold fronts, where winds on the two sides of the front are blowing parallel to the front with a strong shearing motion.

When a section of a front is disturbed, the warm air begins to flow up over and displace some of the cold air. Cold air to the rear of the disturbance displaces some of the warm air. Thus, one section of the front begins to act like a warm front, and the adjacent section like a cold front. This deformation is called a frontal wave.

The pressure at the peak of the frontal wave falls, and a low-pressure center with



The life cycle of a frontal wave includes the following steps: A. A disturbed section of a front. *B.* Cold air begins to displace warm air to the rear of the disturbance, and warm air ahead tends to override the cold air. The front ahead of the disturbance becomes a warm front, and the portion to the rear becomes a cold front. C. A cyclonic circulation is established and pressure falls at the crest of the wave. D. After the cold front overtakes the worm front, an *occlusion* is formed and the system enters its dying phases.

a counterclockwise (cyclonic) circulation is formed. If the pressure continues to fall, the wave may develop into a major cyclonic system. The Low and its frontal wave generally move in the direction of the wind flow in the warm air, which is usually toward the east or northeast.

As the system moves, the cold front moves faster than the warm front and eventually overtakes the warm front. The warm air is forced aloft between the cold air behind the cold front and the retreating cold air ahead of the warm front. The resulting combined front is called an occlusion or occluded front. This is the time of maximum intensity of the wave cyclone. The pressure becomes quite low in the occluded system with strong winds around the Low Usually the system is accompanied by widespread cloudiness and precipitation. The heaviest precipitation occurs to the north of the low-pressure center.

As the occlusion continues to grow in length, the cyclonic circulation diminishes in intensity, the low-pressure center begins to fill, and the frontal movement slows down.

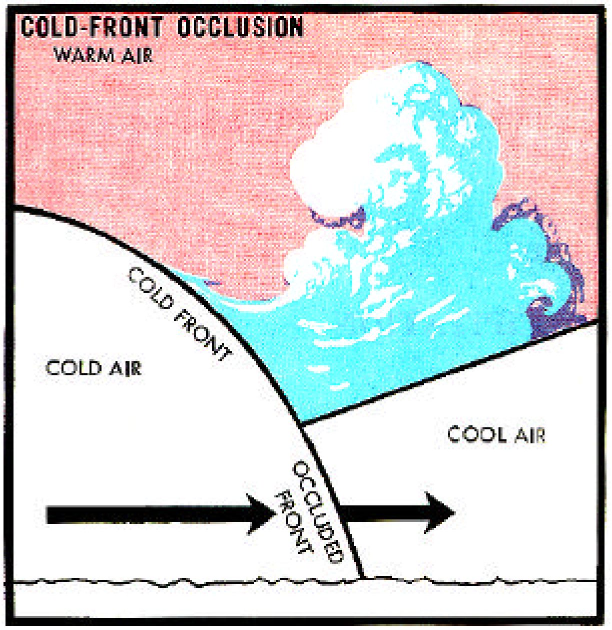
There are two types of occluded fronts— a warm-front type and a cold-front type—depending on whether the surface air ahead of the occlusion is warmer or colder than the air to the rear.

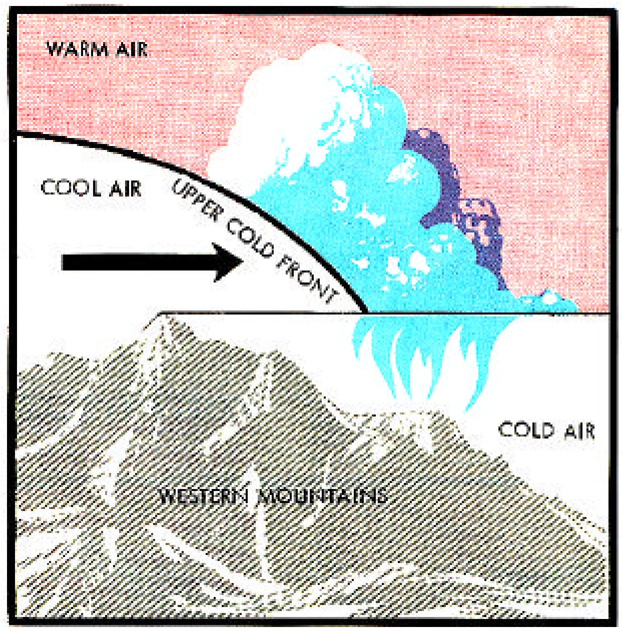
The cold-front type is predominant over most of the continent, especially the central and eastern regions. The weather and winds with the passage of a cold-front occlusion are similar to those with a cold front. Ahead of the occlusion, the weather and cloud sequence is much like that associated with warm fronts.

Most warm-front occlusions are found along the west coast. The air mass to the rear is warmer than the air mass ahead. Therefore, when the cold front overtakes the warm front, it rides up the warm-front surface and becomes an **upper cold front.**

The weather associated with a warm-front occlusion has characteristics of both warm-front and cold-front weather. The sequence of clouds and weather ahead of the occlusion is similar to that of a warm front. Cold-front weather occurs near the upper cold front. With moist and conditionally unstable air, thunderstorms may occur. At the surface, the passage of a warm-front occlusion is much like that of a warm front. The rainy season in the Pacific Northwest, British Columbia, and southeastern Alaska is dominated by a succession of warm-front occlusions that move in from the Pacific.

Another type of upper cold front should be mentioned. Cold fronts approaching the Rocky Mountains from the west are forced to rise and cross over the mountains. Quite frequently in winter, a very cold air mass is located east of the mountains. Then, the cold front does not return to the surface, but rides aloft over the cold air as an upper cold front often accompanied by thundershowers. When such a front meets an mT air mass, and underrides it, a very unstable condition is produced that will result in numerous thunderstorms and, occasionally, tornadoes.





A cross section through a cold-front occlusion shows the warm air having been lifted above the two colder air masses. At the surface, cold air is displacing cool air. The weather and winds associated with the frontal passage are similar to those with a cold front.

Cold fronts crossing the Rocky Mountains from the west are forced to rise over the mountains. Quite frequently in winter, a very cold air moss is located east of the mountains. The cold front then does not return to the surface, but rides aloft ever the cold air as an upper cold front. The frontal activity takes place above the cold air.

SUMMARY

When air stagnates in a region where surface characteristics are uniform, it acquires those characteristics and becomes an air mass. Warm, moist air masses are formed over tropical waters; cold, moist air masses over the northern oceans; cold, dry air masses over the northern continent; and warm, dry air masses over arid regions.

Air masses have characteristic weather in their source regions. But, as air masses leave their source regions, they are modified according to the surface over which they travel, and the air-mass weather changes.

In frontal zones, where differing air masses meet, considerable weather is concentrated. Cloudiness, precipitation, and strong and shifting winds are characteristic of frontal passages; but, occasionally, frontal passages are dry and adversely affect fire behavior.

In discussing many of the topics so far, it has been necessary to mention different types of clouds from time to time. Different cloud types are associated with stability and instability, and certain cloud sequences are characteristic of different frontal systems. In the following chapter, we will discuss types of clouds more fully and examine the precipitation processes that develop in clouds.