3 Clouds and Fronts

Clouds, specifically cloud types, tell a great deal about the state of the atmosphere. Clouds are a product of their environment. It should be no surprise that cloud types are closely related to moisture, vertical motion, and stability—the weather equation.

Clouds form from cooling through the process of condensation. Cooling processes are adiabatic or diabatic. The adiabatic process cools the air as it rises. The diabatic process cools the air through a loss of heat. The loss of heat may occur through conduction, such as terrestrial radiation—which may result in fog or low clouds. The diabatic process may be associated with the movement—advection—of air across a colder surface. Cooling may occur through mixing with colder air. Should the mixing results in a temperature below the dewpoint clouds may form. Moisture can be added through the process of evaporation.

The boundary between air masses results in fronts. In mid-latitudes the interaction of air masses at the polar front boundary significantly affects the weather. Fronts fall into four categories:

- cold fronts,
- warm fronts,
- occluded fronts, and
- stationary fronts.

The Earth's atmosphere moves cold air down from the arctic and warm air up from the tropics. Typically, in the northern hemisphere the cold air pushes down from the northwest, lifts, and replaces warmer air—a cold front. To accomplish this, at some point, warm air must replace retreating cooler air. This typically takes place ahead of the cold front as warm air, moving from the south, overrides and replaces the retreating, cooler air—a warm front. Cold fronts move faster than warm fronts. When a cold front overtakes a warm front an occlusion takes place—an occluded front. When frontal speed decreases to five knots or less it becomes a stationary front.

Expect to see the terms surface and aloft. They often appear in the text local National Weather Service Office Area Forecast Discussions (AFD), the Convective Outlook (AC) and Severe Weather bulletins. We live and fly in a three-dimensional atmosphere. “Surface” or “low-level” refers to phenomena occurring from the surface up to about 500 mb (18,000 ft). “Aloft” refers to phenomena occurring at or above the 500 mb level.

pyrocumulus—A cloud that develops from the rising hot air of a wildfire or volcanic eruption. Water vapor condenses on the ash forming cloud drops. Under the right conditions thunderstorms can form.

Table 3-1 contains oversimplified, generalizations. There are many qualifications to these statements.

Signposts in the Sky

Stratiform describes clouds with extensive horizontal development—associated with a stable air mass. Stratiform clouds consist of small water droplets. Cumuliform describes clouds characterized by vertical development in the form of rising mounds, domes, or towers—associated with an unstable air mass. Because of upward moving currents, cumuliform clouds can support large water droplets. Although not a true general classification, a third generic cloud type describes the group of high clouds—cirriform. Clouds are further divided into three main types using their Latin names: cirrus (curly), stratus (spread out), and cumulus (heaped up).

Table 3-1 describes the generic characteristics of the two general cloud classifications.

Table 3-1. *Characteristics of Cloud Types*

Stratiform	Cumuliform
stable lapse rate	unstable lapse rate
poor visibility	good visibility
smooth	turbulent
widespread cloud mass	more localized cloud mass
steady precipitation	showery precipitation
rime icing	clear icing

Cloud types can also be categorized by the height of their bases: *low* (bases near the surface to about 6500 ft), *middle* (bases from 6500 ft to 20,000 ft), *high* (based at or above 20,000 ft), and those with vertical development (based near the surface, tops above 20,000 ft). Two additional prefixes/suffixes may be added: alto (high) and nimbus (rain). Table 3-2 list lists cloud types.

Table 3-2. *Cloud Types*

Low	Middle	High	Vertical Development
Stratus	Altostratus	Cirrus	Cumulus
Stratocumulus	Altocumulus	Cirrostratus	Cumulonimbus
Nimbostratus		Cirrocumulus	

Stratus fractus and *cumulus fractus* (shreds of small, detached clouds moving rapidly below a solid deck or higher clouds—scud) are normally associated with poor weather. Pilots may see, or think they see, a hole or clear spot in the weather only to realize—usually too late—it was only a fantasy (*sucker hole*). Pilots who fly in these conditions are colloquially known as scud runners. This practice fits the axiom: "There are old pilots and there are bold pilots, but there are no old, bold pilots." All too often, scud runners have a rather limited life expectancy.

Case Study

> An unfortunate pilot attempted to negotiate Oakland, California's east bay hills under scud conditions—callout. Unfortunately, the pilot took his two grandchildren with him. As John Hyde, an excellent pilot and ex-Army Aviator frequently laments: "Cowardice is the better part of valor."

Throughout the subsequent material we'll expand on cloud types and their significance to aviation weather.

Fronts

Norwegian meteorologist Vilhelm Bjerknes and his son Jakob developed the polar front theory at the beginning of the 20th century. World War I had begun, and it was popular to use the language of the conflict. Thus, weather was described using words like *fronts*, *advances*, and *retreats*. The weather did resemble a war between air masses.

Fronts run the spectrum from a complete lack of weather to benign clouds that can be conquered by the novice instrument pilot, to fronts that spawn lines of severe thunderstorms that no pilot or aircraft can negotiate. Each front—or weather system for that matter—must be evaluated separately and a flight decision made based on the latest

There are a number of methods of cloud classification. It was not until 1803 that Luke Howard, an Englishman, first classified cloud forms categories using Latin names.

Stratus fractus—Scud

weather reports and forecast, and the pilot's and aircraft's capabilities and limitations. (We'll address this in greater detail in Part Two: Risk Assessment and Management.

Fronts produce vertical motion from the surface to about the middle troposphere—about 20,000 ft. Fronts have sloping boundaries—which are much shallower than illustrated in this chapter, with an average slope between 1 in 50 and 1 in 300. That is, for every mile a front extends above the ground, the slope extends 50 to 300 miles horizontally. Frontal boundaries lose their identity above about 20,000 ft.

Frontal speed determines intensity based on the temperature gradient in the cold sector—the region of colder air at the frontal boundary. Many factors affect frontal movement, such as temperature, moisture, stability, terrain, and upper-level systems. The closer the front to the jet stream the steeper the slope, and typically the stronger the front.

A front with waves indicates weak low pressure centers or portions of the front moving at different speeds. A front with waves should be watched. The weak low pressure areas can intensify, producing significant weather.

Frontal boundaries extend vertically as well as horizontally, upward over the colder, denser air and exhibit temperature difference throughout their vertical extent. The permanent, undulating polar front boundary is known as a *baroclinic* zone. A baroclinic atmosphere results in a strong, active front. In a *barotropic* atmosphere the density across the front is small, resulting in a weak, inactive front. We'll tie this all together in chapter 4, Upper-Level Weather Systems.

The width of a frontal zone depends on wind and temperature differences between the two air masses. The greater the temperature difference—other things being equal, the narrower the front; the stronger the wind component along and behind the front, the narrower the front. For example, a front moving 35 to 45 knots with a temperature contrast of 20°C or more may have a surface frontal boundary of one mile or less. A front with only a few degrees temperature difference with a weak circulation may be as much as 50 miles wide. The movement and effects of wide fronts, with low temperature differences, and weak circulation, are difficult to forecast. The following case studies illustrate weather associated with strong and weak fronts.

Case Study

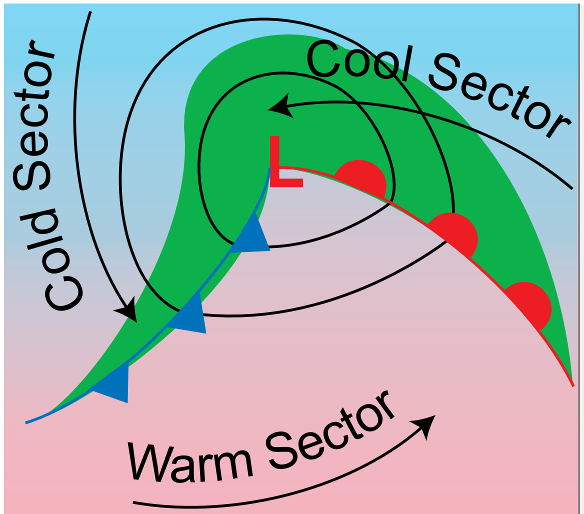
> We were trying to fly from Springfield, Illinois to Oklahoma City. Arriving in St. Louis the ground based weather radar showed cell after cell along our route to the southwest. We decided to wait until the next day. However, at about six that evening the front passed and the weather cleared. We decided to continue to Kansas City which was also behind the front. As darkness fell, the southern horizon was ablaze with continuous lightning.
>
> Checking weather from Kansas City to Oklahoma City indicated clearing, but still some thunderstorm activity. After departure we again saw lightning on the horizon. That night it just wasn't meant to be! We returned to Kansas City and spent the night. The next day was bright and clear. I was attending the FAA's Air Route Traffic Control school at the time. I missed half a day. It would have been embarrassing to have been involved in an aircraft accident!

This is an example of a strong cold front. On another occasion we were confronted with a weak cold front moving through the area.

Case Study

> We were attempting to fly from Huntington, West Virginia to Cincinnati's Lunken Field to have the airplane's radio transmitter repaired. The weather in Cincinnati was good; we were just waiting for the front to pass. After several hours, the weather was just VFR. (If you have a choice, it's always best to fly from poor to good weather.) We departed, using "light signals" from the tower—and proceeded I-F-R (I follow rivers). About 20 miles northwest of Huntington we broke into the clear. As we'll see in Part Two: This was "acceptable risk." The greatest hazard were those nasty cables across the river.

Often the exact location, and sometimes even the presence, of a front is a matter of judgment. Additionally, fronts do not necessarily reach the surface; they might be found in layers aloft. This is especially true in the western United States and the Appalachians where mountain barriers break up fronts. Therefore, there might be differences between the position of a front and the location on charts or described in forecasts.



friction layer—The layer of the atmosphere from the Earth's surface up to about 3000 ft. Within this layer wind flow is affected by the frictional effect of terrain.

Cold Fronts

When a cold (dense) air mass undercuts, lifts, and replaces a warmer (less dense) air mass at or near the surface, it forces the warm air aloft. This results in a cold front. The cold sector lies behind the cold front, the warm sector ahead of the front—as illustrated in the callout. A cold front moves at about the speed of the wind component perpendicular to the front just above the *friction layer* between the surface and free air.

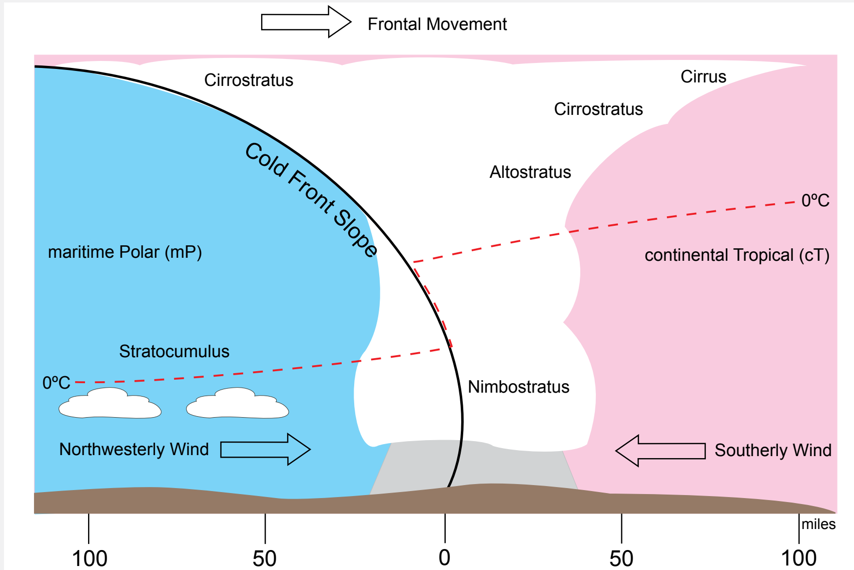


Fig. 3-1. *Cold fronts associated with stable air produce stratiform clouds over relatively short distances.*

Figure 3-1 illustrates a cold front with cold maritime Polar air underrunning warm, stable continental Tropical air. Stable stratified clouds form above the front. Stable cloud types consist of cirrostratus, altostratus, and nimbostratus. This succession of clouds announces the approach of the front. The cold air is stable except where surface heating creates a shallow convective layer, producing stratocumulus clouds behind the front. Precipitation associated with the stable air mass is generally light to moderate and steady, resulting in low ceilings and visibilities associated with the stable air.

Figure 3-2 illustrates a cold front with cold, slightly unstable continental Polar air underrunning warm, moist, unstable, maritime Tropical air. Cirrus clouds that thicken into cirrostratus often signal the approach of the front. Next appears a thickening band of altocumulus; quickly followed by cumulonimbus clouds, heavy rain showers, and low ceilings and visibilities—associated with the unstable air mass. Abrupt lifting near the surface frontal position and unstable air produce thunderstorms. Behind the front fair weather cumulus develop in the slightly unstable cold air.

Towering cumulus may develop ahead of the front due to surface heating in the warm sector along with wave action generated by the front. Towering cumulus should be treated with the same respect as cumulonimbus clouds. These clouds may develop into pre-frontal thunderstorms or *squall lines*—an organized line of thunderstorms—50 to 300 miles ahead of the cold front.

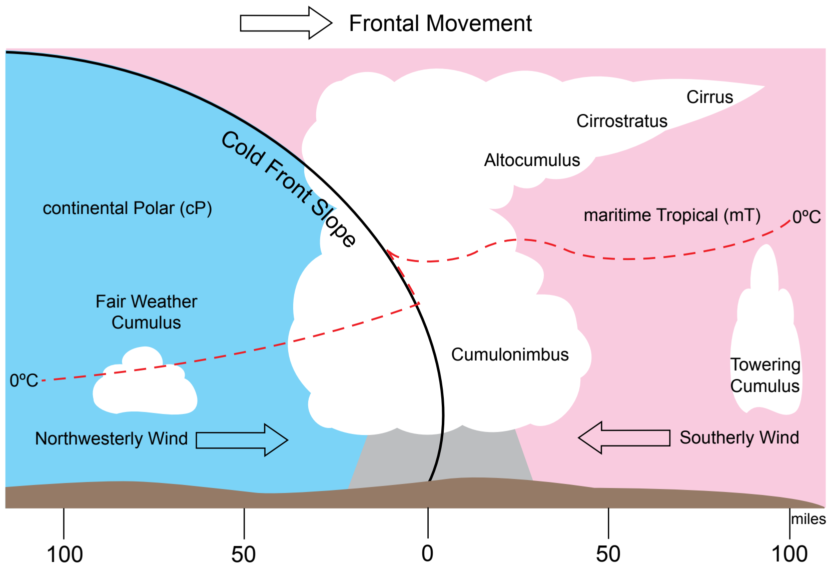


Fig. 3-2. *A cold front underrunning warm, moist, unstable air results in abrupt lifting and thunderstorms.*

Towering cumulus are growing cumulus that resemble a cauliflower, but with tops that have not yet reached the cirrus level.

Warning

A *cumulonimbus cloud* is a thunderstorm! Therefore, any reference in text or graphic, or during a weather briefing to cumulonimbus (CB) should be interpreted as a thunderstorm—with all its ominous implications.

The freezing level lowers with the approach of the front, drops dramatically at the frontal boundary, and continues to lower in the cold air behind the front. Surface winds are typically out of the northwest quadrant in the cold sector and the southern quadrant in the warm sector. Pressure decreases with the approach of the front and increases after frontal passage. Temperature decreases with frontal passage. Cold fronts typically produce a relatively narrow band of weather, most often accompanied by rapid clearing following frontal passage.

Cold fronts characteristics:

- Primarily cumuliform clouds with unstable air; stratiform clouds in stable air.
- Generally fast moving; southeasterly at about 20 to 25 knots.
- Precipitation showery, heavy at times.
- Good visibility prior to and after frontal passage.
- Turbulence in the frontal zone.
- Icing mixed or clear in the frontal zone above the freezing level.
- Large wind shifts from southwesterly to northwesterly with frontal passage.
- Pressure falls as the front approaches, then rises after frontal passage.
- Significant temperature changes over relatively small distances.
- Weather is generally in a narrow band.

Lack of cloud cover and little or no precipitation typify weak or dry cold fronts. Both cold and warm air masses are dry and stable. The warm air must reach significant heights before condensation occurs. Clouds may be a considerable distance from the surface position of the front and at high levels—the height depending on the moisture content of the warm air. With low-level moisture, weak cold fronts may result in low cloud tops.

Case Study

> On a flight from Van Nuys to San Luis Obispo in California we were able to top the clouds of a weak, dissipating cold front at 6500 ft. With this front cloud tops were lower than those produced by deep coastal marine stratus layers, which can at times exceed 8000 ft!

Warm Fronts

Cyclonic flow around a low pressure center causes the cool air in the cool sector to retreat. As the cool air retreats, warm air overrides and replaces the cool air. This boundary forms a warm front. Winds in the warm sector must exceed the speed of the warm front, which averages about 10 knots. Since the air mass along a warm frontal boundary is less dense than along the cold frontal boundary, the slope and speed of a warm front are considerably less than that of a cold front.

Figure 3-3 illustrates a warm front with warm moist, stable air overriding cool stable

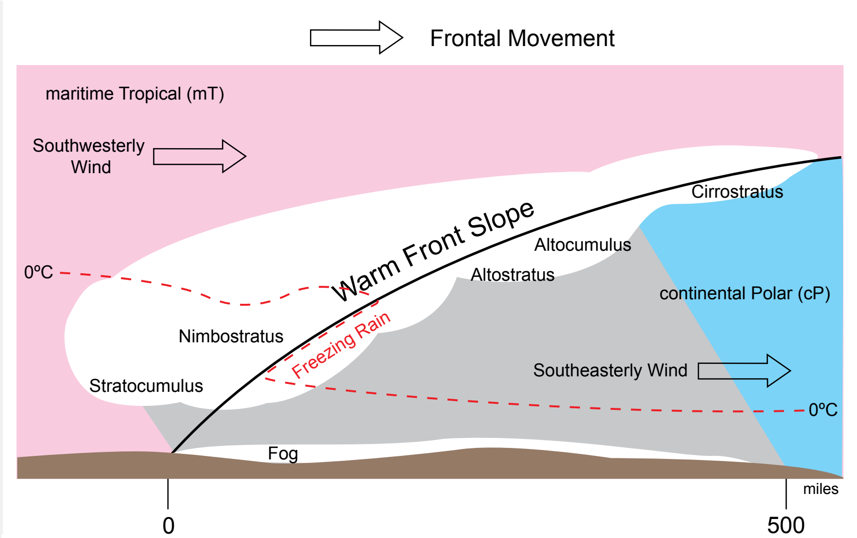


Fig. 3-3. *A warm front with warm moist, stable air overriding cool stable air results in stratiform clouds.*

air. Lifting along the shallow front is more gradual than along a cold front. Cloud types are widespread and stratiform. Cirrostratus, altocumulus and altostratus, and nimbostratus signal the approach of the front. Precipitation is generally light to moderate, steady, and widespread associated with the stable air mass. Precipitation, and low ceilings and visibilities extend well in advance of the front.

Figure 3-4 shows a warm front with warm moist, unstable maritime Tropical air overriding cool stable continental Polar air. Showers and thunderstorms are spread out above the frontal surface rather than in the vicinity of the surface frontal location. Precipitation is generally light to moderate, steady, and widespread, with embedded areas of heavy, showery precipitation associated with the unstable air mass. These convective clouds may be embedded in thick stratiform layers—a serious hazard, especially for

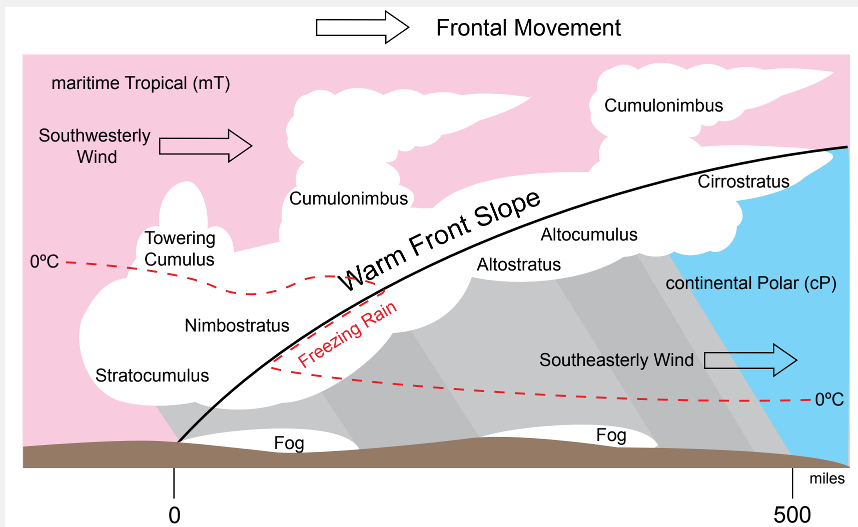


Fig. 3-4. *Instability showers and thunderstorms spread out above the frontal surface, often embedded in stratiform layers.*

aircraft without storm avoidance equipment.

Since the slope of a warm front is shallow, expect to penetrate the frontal boundary some distance from its surface location. The freezing level rises with the approach of the front and continues to rise along the frontal slope—the frontal inversion. Rain falling from above freezing temperatures form large, supercooled water droplets in the freezing air below. (Supercooled liquid water can exist at temperatures below freezing. Supercooled water drops produce airframe icing.) Areas of freezing precipitation present a significant icing hazard, including aircraft with ice protection equipment. After frontal passage aloft the freezing level continues to rise in the warm air behind the front.

Widespread ceilings and visibility lower with the approach of the front. Stratus fractus or precipitation-induced fog may form due to evaporation of water from relatively warm rain and subsequent condensation in the cool air below the frontal surface. Surface winds are typically out of the southwestern quadrant in the warm sector and the southeastern quadrant in the cool sector. With the approach of a warm front pressure lowers and temperature rises with frontal passage. Expect widespread bands of weather associated with a warm front. A temperature rise, a wind shift from southeast to southwest, increasing pressure, and clearing skies indicate surface warm front passage; although, visibility may continue to be reduced in the humid air behind the front.

Unlike "classical" warm fronts, in the western third of the United States warm fronts are relatively rare and usually weak, due to the absence of a moist, unstable, southerly flow. Expect "classical" warm fronts as illustrated in Fig. 3-3 and Fig. 3-4 east of the continental divide. In these regions the moist, southerly flow provides the fuel—moisture—for activity along the front. In the Midwest and east warm fronts can produce extensive areas of low ceilings, low visibilities, freezing precipitation, and embedded thunderstorms —a thunderstorm that occurs within non-convective precipitation, hidden in stratiform clouds. This does not mean, however, that warm fronts don't occur in the west.

Although stable fronts are more typical in the west and unstable fronts in the Midwest and east, no absolutes. Fronts in the west can produce thunderstorms, just as fronts in the Midwest and east may be stable.

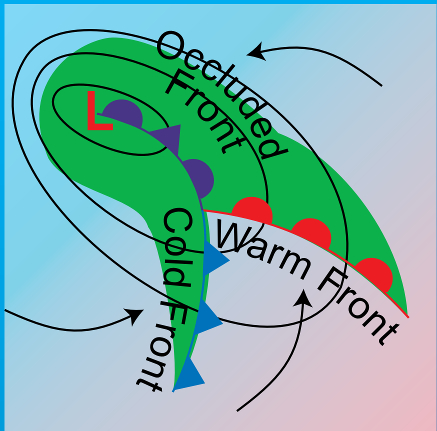
Characteristics of warm fronts:

- Primarily stratiform clouds, but cumuliform clouds may develop in unstable air above the frontal surface.
- Slow moving. Front tends to move northeasterly at about 10 knots.
- Precipitation is generally widespread, light to moderate, and steady, except in areas of embedded cumuliform clouds which produce heavy, showery precipitation.
- Poor visibility before frontal passage, usually good after frontal passage, except in areas of humid air.
- Smooth, except in areas of embedded cumulonimbus.
- Icing is widespread above the freezing level, with areas of freezing rain or freezing drizzle, especially during the cool season.
- Moderate wind shifts from southeasterly to southwesterly with frontal passage.
- Moderate pressure gradients: pressure falls as the front approaches, then rises after surface frontal passage.
- Moderate temperature changes over relatively large areas: temperature increases with frontal passage.
- Weather generally covers a widespread area.

Weak warm fronts are characterized by the lack of cloud cover and no precipitation. Should clouds form, they are high and a great distance from the front's surface location. High clouds with a dry warm front will clear several hours before surface frontal passage.

Case Study

> I had taken my Turbo Cessna 150—all right, it wasn't turbocharged that's an attempt at a little humor—for its annual inspection from Lovelock to Winnemucca in Nevada. A warm front moving through the area produced thunderstorms and small hail. I had planned to fly back with the mail pilot in a Piper Twin Comanche. It wasn't to be. I had to come back by dog, Greyhound to be exact—yes, the bus! Object lesson: My experienced mail pilot knew a light twin without storm avoidance equipment had no business flying in an area of thunderstorms, possibly embedded.



Occluded Fronts

Cold fronts move faster than warm fronts. As a cold front overtakes a warm front an occlusion or occluded front develops. Density differences force one of the fronts aloft. This results in either a *cold front occlusion* or a *warm front occlusion* depending on the density of the air behind the cold front and ahead of the warm front. Like warm fronts, "classic" occlusions typically occur in the eastern two-thirds of the continental United States.

Note

> We're not really interested in whether it's a warm or cold front occlusion, stability in the warm sector and freezing level are the most significant factors to aviation operations.

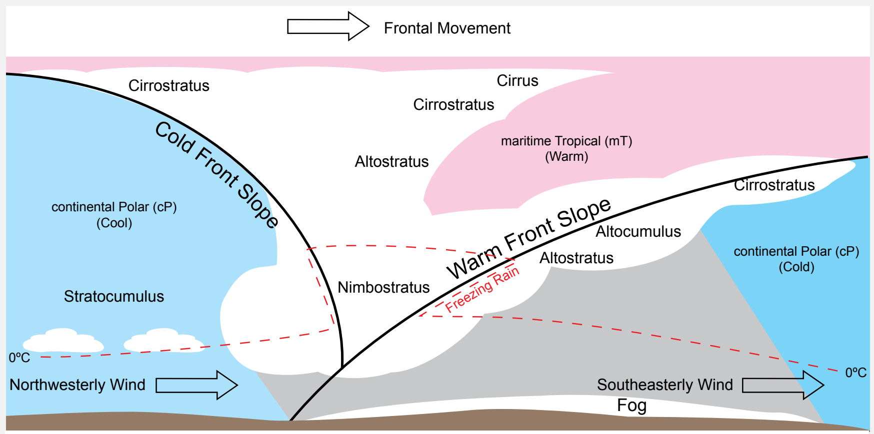


Fig. 3-5. *With a warm front occlusion cool air overrides cold air forcing the cold front aloft.*

Figure 3-5 illustrates an occluded front where cool maritime Polar air has caught up with a warm front overriding colder continental Polar air. The less dense cool air of the cold front rides up and over the denser cold air at the surface forcing the cold front aloft—a warm front occlusion. The cool and warm air are stable, resulting in stratiform cloud types. Cloudiness has the features of both stable cold and stable warm fronts. Expect generally light to moderate and steady precipitation, associated with the stable air mass.

Figure 3-6 illustrates an occluded front where cold continental Polar air has caught up with a warm front overriding cool continental Polar air. The denser cold air behind the cold front forces the warm front aloft along the cold front surface—a cold front occlusion. Since the cold air is slightly unstable and warm air unstable, cumuliform clouds have developed along the cold front boundary and embedded along the warm front surface. Cloudiness has the features of both unstable cold and unstable warm fronts. Maximum convection occurs along the cold front aloft; stratified clouds with possible embedded thunderstorms develop above the warm front surface. Precipitation is generally light to moderate and steady, with embedded areas of heavy, showery precipitation associated with the unstable warm air mass. Fair weather cumulus has formed in the slightly unstable air behind the cold front.

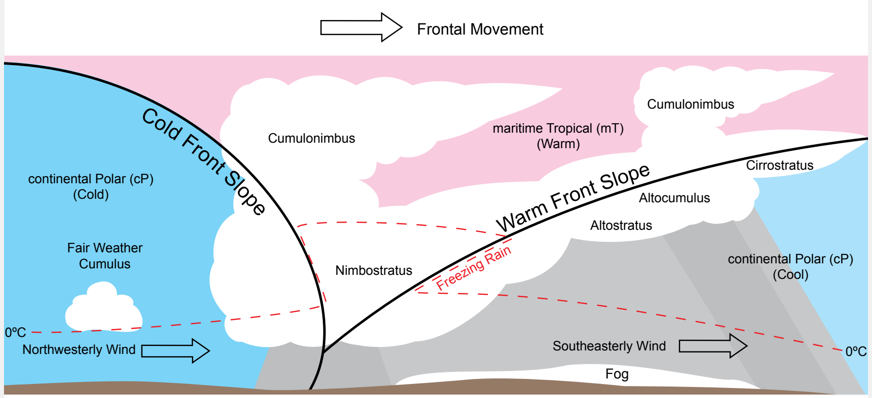


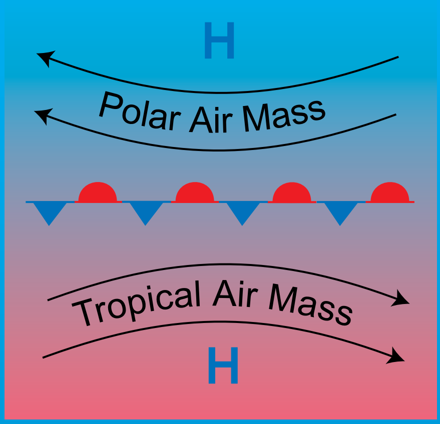
Fig. 3-6. *With a cold front occlusion cold air from the cold front replaces the cool air at the surface forcing the warm front aloft.*

Note

A warm front occlusion does not in itself indicate stable air; nor does a cold front occlusion infer unstable weather. Frontal characteristics depend on the stability of the air in the warm sector.

Stratus fractus and precipitation-induced fog may form in the cool sector. Freezing levels are typical of both warm and cold fronts. Surface winds are typically out of the northwestern quadrant in the cold sector, southerly in the warm air mass above the warm front surface, and out of the southeastern quadrant in the cool air ahead of the warm front. A wind shift from southeasterly to southerly occurs at the warm front boundary, then becomes northwesterly at the cold front boundary. Pressure increases with the passage of the front. A temperature increase marks the warm front surface followed by a temperature decrease in the cold air behind the cold front boundary. Expect weather over a widespread area.

Stationary Fronts



Stationary fronts exhibit little or no movement—five knots or less. Both cold and warm fronts can slow and develop into stationary fronts. The slope is generally shallow, although it may be steep if the density changes across the front is large or wind distribution favorable. Winds across the frontal boundary are parallel and opposite in direction—callout. Weather associated with a stationary front depends on its moisture, stability, and circulation. When warm, moist stable air rides up and over cold air, widespread stratiform clouds and light precipitation may result. However, with moist, unstable air aloft even the minimal low-level lifting associated with a stationary front may be all that's required to initiate thunderstorms. If the front begins to move north a warm front develops. Should colder air from the north replaces warmer air to the south weather will be like that of a cold front. Waves in stationary fronts can spawn new, sometimes intense, weather systems.

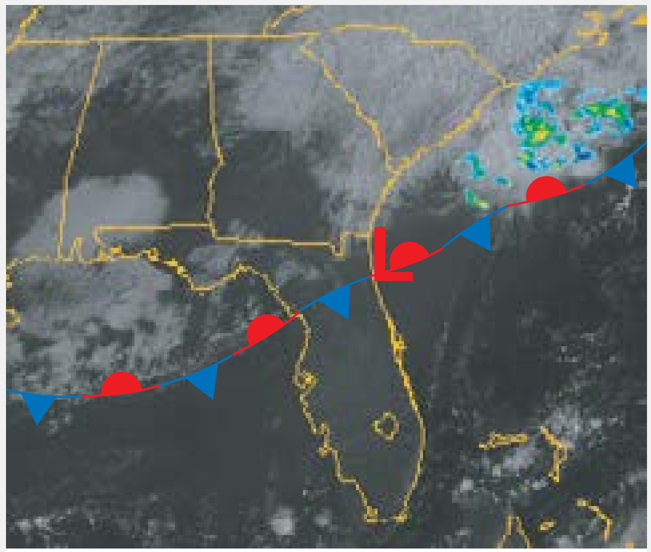


Fig. 3-7. *Stationary front weather depends on its moisture, stability, and circu*lation.

Figure 3-7 shows a stationary front in the southeastern United States. (The image is a surface analysis chart, infrared satellite, radar composite.) The front marks the boundary between mostly warm stable air from the southeast and cool stable air from the northwest. From the Gulf of Mexico, across Florida, into the Atlantic Ocean low clouds to clear skies with no precipitation indicate stable air. Off the Caroline coast radar shows convective activity due to unstable warm air in this region.

Weak stationary fronts are characterized by stratiform clouds with little precipitation or a complete lack of clouds and no precipitation. Pilots flying through a weak stationary front may only experience frontal passage through an area of light turbulence and a wind shift.

Case Study

The weather briefing indicated a weak stationary front along the route from Albuquerque to Tucumcari in New Mexico. The weather enroute was clear, except for few cirriform clouds. The only indication of frontal passage was brief light turbulence and a wind shift.

Characteristics of stationary fronts:

- Primarily stratiform clouds, but cumuliform clouds may develop with unstable warm air.
- Little movement, less than five knots.
- Precipitation, if it occurs, generally widespread, steady, and light, except in cumuliform clouds.
- Poor visibility.
- Freezing rain or freezing drizzle during the cool season.
- Little, if any, turbulence, except in cumuliform clouds.
- Small temperature changes over relatively large distances.
- Small shifts in wind direction; winds generally light and parallel to the front.
- Weak pressure gradients.

The Life Cycle of a Front

Recall the satellite image in Fig 1-4 (callout). Between the polar easterlies and subtropical westerlies lies the permanent polar front. The interaction of the polar easterlies and the subtropical westerlies results in a convergence zone—upward vertical motion. As shown in Fig. 3-8 this is the area where most midlatitude cyclones—low pressure areas—and frontal systems develop—frontogensis.

Figure 3-8a shows a stationary segment of the polar front. When winds are parallel there is little if any weather associated with the front. This type of flow sets up cyclonic wind shear. Under the right conditions, a kink or wave forms along the front. Winds are no longer parallel and frontogensis begins (Fig. 3-8b). (The green shading represent typical areas of precipitation.) The region of lowest pressure is at the boundary of the two air masses—along the front.

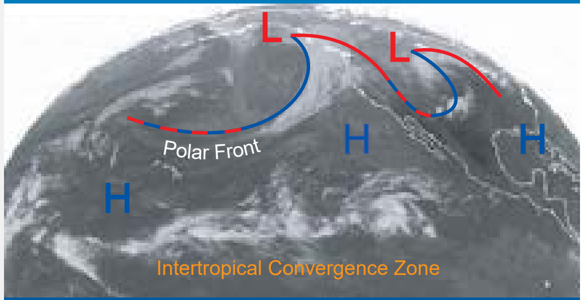
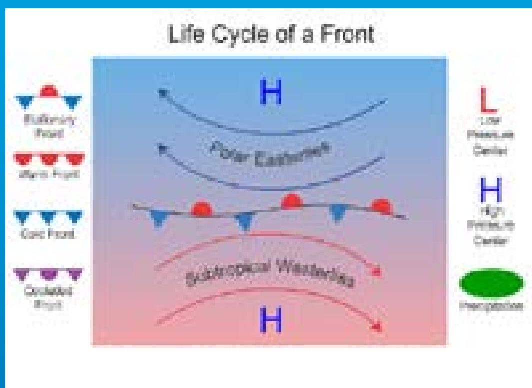


Fig. 1-4. *Satellite view of the General Circulation.*



“Click” *Life Cycle of a Front* to view animation.

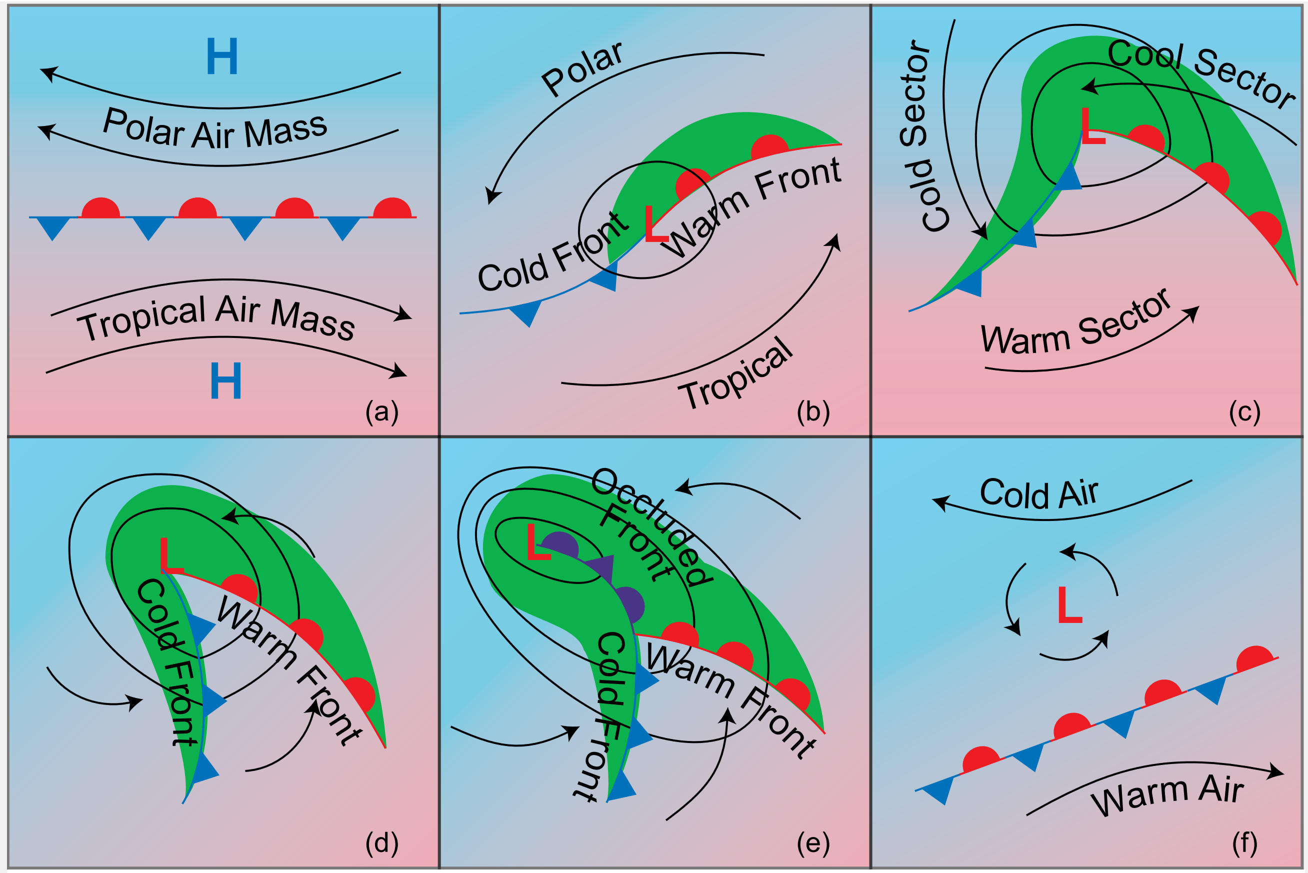


Fig. 3-8. *Frontogenesis occurs between the subtropical westerlies and polar easterlies along the, more or less permanent, polar front.*

As the colder polar air begins to push southward under the warmer tropical air a cold front develops. As the cool air retreats on the north side of the low the warm subtropical air moves in and replaces the cooler air (Fig. 3-8c). As the advancing warm air overrides and replaces the retreating cool air a warm front forms.

Directed by the upper winds, the wave generally moves to the east or northeast. Central pressure lowers as cyclonic flow increases. Precipitation forms in a narrow band along and behind the cold front and a wide band ahead of the warm front.

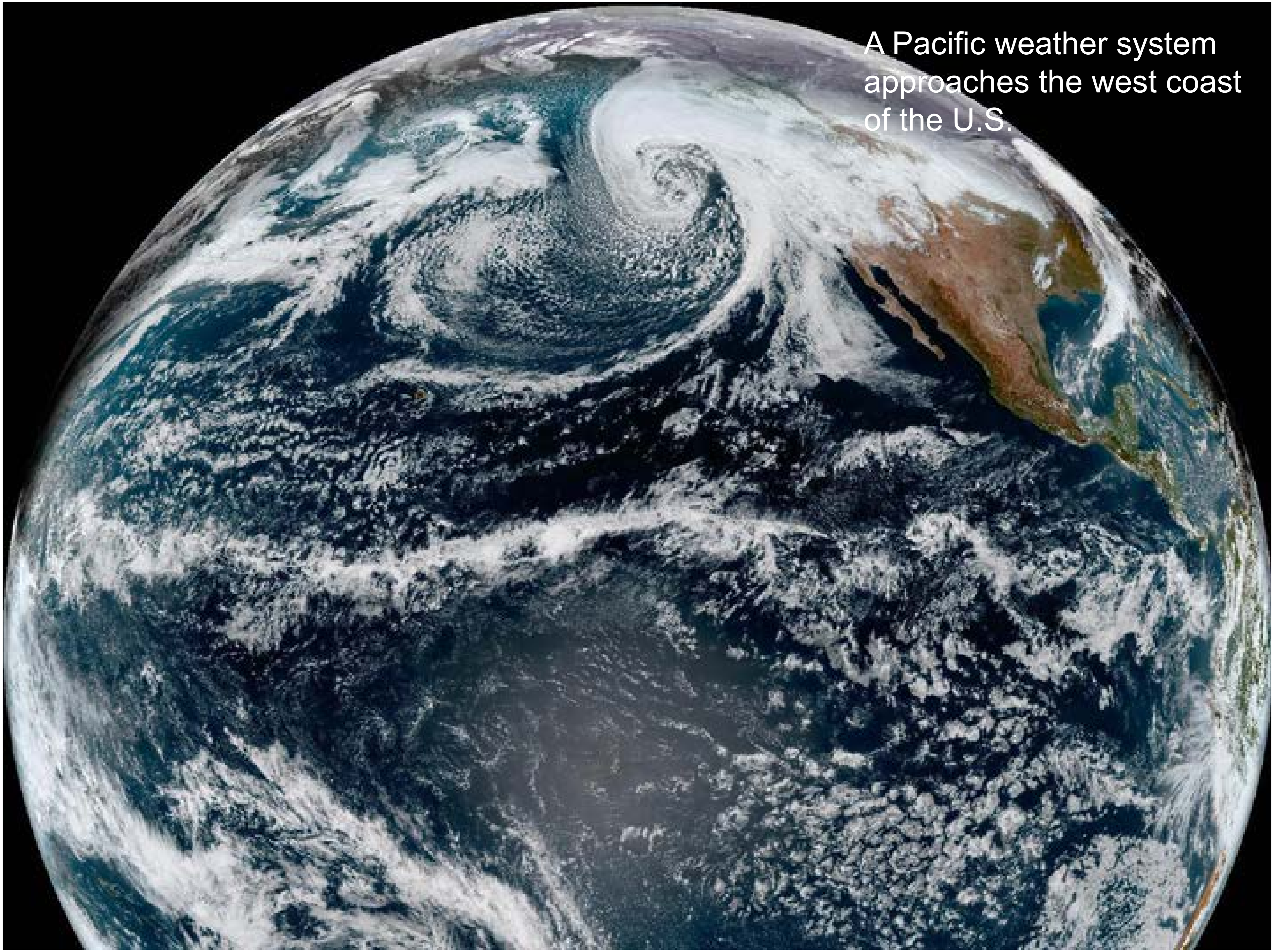
The faster moving cold front moves closer to the warm front. Eventually, the cold front overtakes the warm front and the system becomes occluded—an occluded front. At this point the storm is usually most intense with widespread clouds and precipitation (Fig. 3-8d and Fig. 3-8e).

As temperatures and pressures equalize, the front dissipates—frontolysis. Without the energy of the rising warm moist air, the old storm dies out and gradually dissipates (Fig. 3-8f).

The development or strengthening of a cyclone is known as cyclongenesis. This most often occurs over the Gulf of Alaska, the Great Basin, the eastern slopes of the Rockies, the Gulf of Mexico, and the Atlantic Ocean. Some waves develop into huge storms, others dissipate within days. The difference dependents on the upper level flow—which we'll take up in the next chapter.

Chapter 24, Weather Systems, contains techniques of strategies of flying frontal weather.

Great Basin—The area between the Rockies and Sierra Nevada mountains, consisting of southeastern Oregon, southern Idaho, western Utah, and Nevada.


A Pacific weather system approaches the west coast of the U.S.