1 The Flight Environment

To understand the weather let's begin with a description of the atmosphere—our flight environment. (Graphical depictions of the phenomena in this introduction are provided in the illustrations throughout the chapter.) For our purposes we'll include the two lower layers of the atmosphere: the troposphere and stratosphere. We must also recognize the effects of the tropopause—the boundary between the troposphere and the stratosphere—and the jet stream. OK, we aren't going to get our Turbo 152s and Piper Warriors to these altitudes, but these layers influence the weather in the lower troposphere—at times all the way to the surface.

Wind transports atmospheric properties: temperature, moisture, and stability—the capacity of an air mass to remain in equilibrium; to resist displacement from its initial position. This is known as *advection*. As the air moves its characteristics are influenced by the temperature and moisture properties of the surface, modifying the atmosphere. (More in chapter 2, Atmospheric Properties.)

Planetary scale circulation deals with the general circulation: long-wave troughs and ridges, subtropical highs, the polar front, and the intertropical convergence zone. Individual highs and lows, air masses, fronts, and troughs and ridges make up Synoptic scale events. Thermal advection, squall lines, and large scale terrain effects constitute Mesoscale circulation. Microscale covers local weather, on the size of individual tornadoes, microbursts, and local terrain features such as mountains, passes, or lakes.

An *air mass* is a widespread body of air with homogeneous—similar—properties. Air masses take on the characteristics of the region where they originate—air mass source regions. Air masses have similar temperature and moisture content through their horizontal and vertical extent. As air masses migrate, they undergo modifications to their temperature, moisture, and stability.

Don't become overly concerned with the discussion in the introduction to this chapter. It's background information that will help your understanding of the terms and concept in subsequent sections and chapters.

trough—An elongated area of low pressure.

ridge—An elongated area of high pressure.

convergence—Air flowing together near the surface is forced upward due to convergence. It is a vertical motion producer that tends to destabilize the atmosphere near the surface.

divergence—Subsiding air diverges, or spreads, at the surface. Divergence is a downward motion producer that tends to stabilize the atmosphere near the surface.

Pressure patterns indicate the distribution of highs, lows, troughs, and ridges. The terms high and low, like hot and cold, are relative. A *high* is simply an area surrounded by lower pressure—regardless of the value of its central pressure. Conversely, a *low* is an area surrounded by higher pressure. Convergence occurs in areas of low pressure, divergence in areas of high pressure. Surface convergence and divergence only affect the lower 10,000 ft of the atmosphere but can have a significant impact on the weather—vertical motion. (We'll expand on the discussion of vertical motion in chapter 2.) In general areas of low pressure are associated with poor weather, high pressure good weather; no absolutes, there are exceptions to these generalizations.

The atmosphere is three dimensional. Surface highs and lows may be reflected through the top of the troposphere. Surface high pressure may underlie low pressure or a trough aloft. Surface low pressure may lie beneath higher pressure or a ridge aloft. The centers of high and low pressure may tilt through the atmosphere. The vertical distribution of pressure influences their strength and movement, and that of surface systems. The most severe weather is usually a result of this tilt. (More in chapter 4, Upper-Level Weather Systems.)

Case Study

> We stayed overnight in Las Vegas, Nevada because of the weather. The next day continued to be blustery. The route to Van Nuys, California was plagued with low clouds, mountain obscuration, and turbulence. I went into the Las Vegas Flight Service Station for a briefing. After providing the briefer with necessary background information for the flight, this little old codger replied, "Well, you aren't going today!" This individual's technique was so obnoxious that without even thinking I replied, "Oh yes I am!" And, I hadn't looked at the weather.
>
> An upper-level low was over the area—with no associated fronts, and this kind of system tends to bring poor weather for days. The briefer was correct in part, we were not going to fly direct. As well as low ceilings and visibilities, the route was dominated by scattered rain showers and isolated thunderstorms. However, a careful check of the weather showed that a route from Las Vegas, to Needles, California, then to Daggett and Palmdale was

feasible. This route has the lowest terrain, with plenty of alternate airfields. By circumnavigating the rain showers the flight was mostly smooth and without incident.

Structure of the Atmosphere

As shown in Fig. 1-1, beginning at the Earth's surface the troposphere extends to an average height of about seven miles. Thickness varies from the equator to the poles, averaging 25,000 to 30,000 ft at the poles and 55,000 and 65,000 ft at the equator—higher in the warm than in the cool season. Why? Warm columns of air are taller than cool columns. Near the equator the Sun heats the surface, which in turn warms the air. This also explains why the troposphere extends to a higher altitude in the warm season; more solar radiation during these months—the troposphere is warmer.

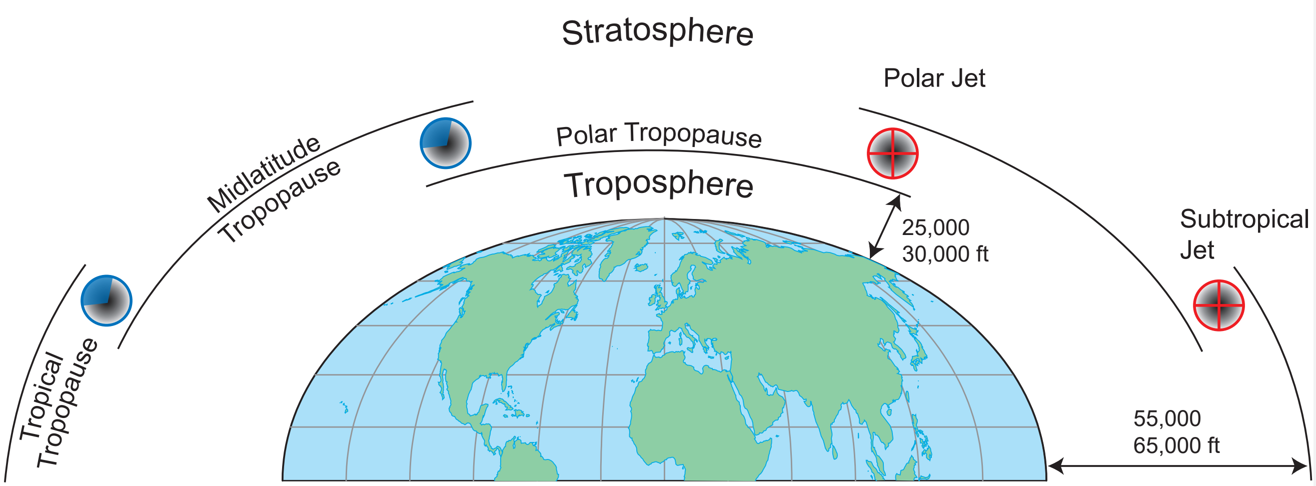
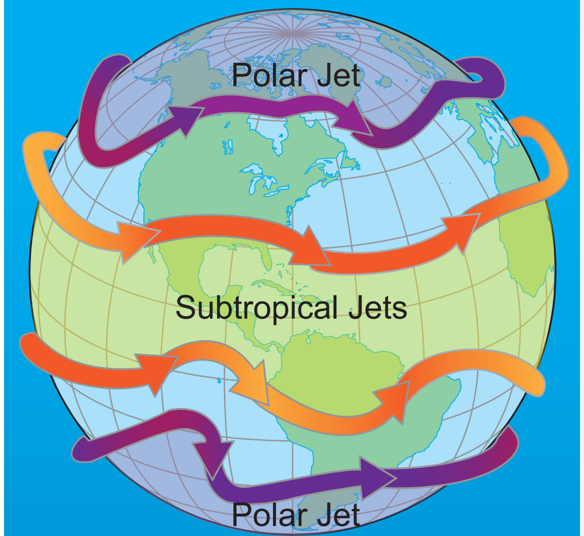


Fig. 1-1. *We're concerned with the two lower layers of the atmosphere: the troposphere and stratosphere, and their boundary the tropopause.*

The tropopause marks the boundary between the troposphere and the stratosphere. In this layer temperature remains relatively constant with height. Not continuous, breaks in the tropopause occur, on average, between the polar tropopause and midlatitude tropopause, and the midlatitude tropopause and the tropical tropopause (Fig. 1-1). The jet stream lies in these breaks. Bullets in Fig. 1-1, on the left, represent the jet stream coming out of the illustration; arrow feathers, on the right, indicate the jet going into



The jet stream was virtually unknown until World War II when pilots flying at high altitudes reported turbulence and unusually strong winds. These winds blew from west to east near the top of the troposphere. Not until 1946 was the jet stream fully recognized as a meteorological phenomenon.

the illustration. The jet stream generally blows from west to east in both hemispheres (callout).

The tropopause acts like a lid that resists the exchange of air between the troposphere and the stratosphere. This restricts almost all water vapor and weather to the troposphere. A slight increase in temperature with height occurs in the stratosphere. That is, an isothermal layer—constant temperature with height, or an inversion—increase in temperature with height. An inversion strongly resists vertical motion.

The Jet Stream

In polar regions the atmosphere compensates for extremely cold temperatures in the troposphere with relatively warmer air above. This relatively warmer air above the tropopause extends well into the stratosphere. These sharp horizontal temperature differences cause strong pressure gradients that result in the jet stream (Fig. 1-2). *Isotherms*—lines of equal temperature (dashed red lines Fig. 1-2)—indicate strong temperature gradients that change rapidly with height. Since fronts lie in zones of temperature contrast, the jet stream is closely linked to frontal boundaries. (Chapter 3 presents a comprehensive discussion of fronts.) *Isotachs*—lines of equal wind speed (dashed blue lines Fig. 1-2)—indicate maximum winds in the jet core.

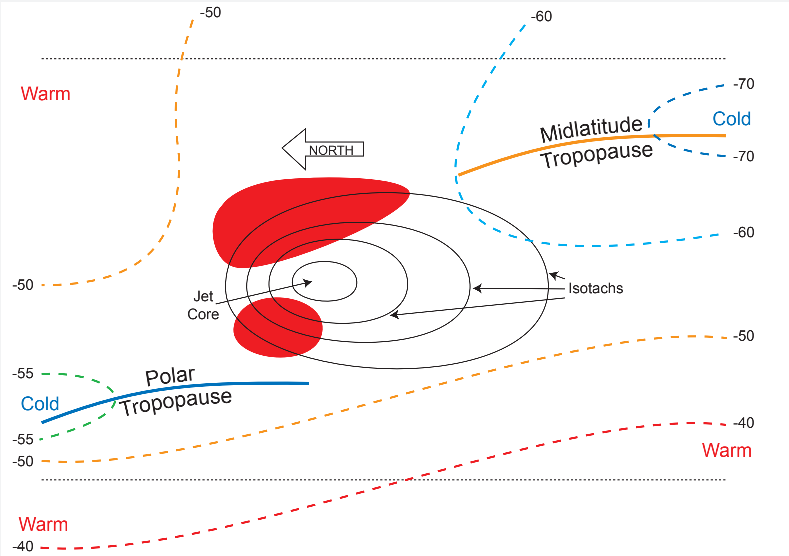


Fig. 1-2. *Sharp horizontal temperature differences cause strong pressure gradients that result in the jet stream.*

Note

We often use the term "relative" to describe differences in atmospheric characteristics—temperature, pressure, moisture, density, stability. We're not referring to absolute values, but the relationship between values. In Fig. 1-2 -40 is warmer than -70; -55 is colder than -50. The absolute values are all extremely cold, but some are "relatively" warmer/colder than others. Stated another way, we may refer to a region or an air mass, as warm. This means it's warmer than the surrounding air or surface.

The jet stream is a narrow, shallow, meandering band of strong winds embedded in breaks in the tropopause; most frequently found in segments of 1000 to 3000 miles, 100 to 400 miles wide, and 3000 to 7000 ft deep. To be classified a jet stream, winds must be 50 knots or greater; although, jet stream winds generally range between 100 and 150 knots. Wind speeds can reach 200 knots along the east coast of North America and Asia in the cool season when temperature contrasts are greatest. Jet streams shift south and at lower altitudes during the cool season, with the seasonal migration of the polar front.

Jet stream wind shear turbulence results from rapid changes in wind speed—both horizontal and vertical, or wind direction, or both. A significant change over a relatively small distance may produce severe turbulence. The maximum curvature (greatest change in direction) and closest spacing (greatest change in horizontal and vertical distance) of the isotachs surrounding the jet core occur on the polar side of the jet core. Maximum jet stream turbulence tends to occur above the jet core and just below the core on the polar side, as shown by the red shading in Fig. 1-2. Additional areas of probable severe turbulence occur where polar and subtropical jets merge or diverge. With an average depth of 3000 to 7000 ft, a change in altitude of a few thousand feet will often take the aircraft out of the worst turbulence and strongest winds.

Case Study

A Boeing 747 experienced severe turbulence which caused injuries on a flight from Tokyo to Honolulu. The initial encounter resulted in an altitude gain of 500 ft, then a 1500 ft loss. The temperature dropped from -37ºC to -40ºC in about two seconds. The reporter stated the turbulence was so severe that the instruments could not be read, except in peaks and valleys. The turbulence lasted several minutes. A TCAS alert was received for an airplane at FL350. This aircraft only experienced 100 fpm up and downdrafts.

TCAS (Traffic Alert and Collision Avoidance System)—An airborne collision avoidance system based on radar beacon signals which operates independent of ground-based equipment.

Ice Age

One theory holds that the Ice Age was, at least in part, caused by the deflection of the jet stream due to the creation of the Himalayan Mountain range.

Small, sudden changes in the jet stream often coincide with the development of surface storms systems. These changes also affect the upper wind patterns both upstream and downstream from the occurrence. This has the effect of strengthening or weakening surface weather systems. (More about this process in subsequent chapters.)

Note

> The actual location of jet streams results from complex interactions, such as the location of high and low pressure systems, warm and cold air, and seasonal changes. They meander around the globe, dipping and rising in altitude and latitude, splitting at times and forming eddies, and disappearing altogether.

General Circulation

Three-dimensional motion in the atmosphere results from differential heating of the Earth's surface, causing pressure differences. In 1735, George Hadley added an important notion to the understanding of the general circulation. Hadley proposed that the Earth's rotation produced a deflective force on large-scale wind flows. Hadley was the first to conceive a direct thermally-driven and zonally symmetric circulation as an explanation for the trade winds (trades). This consisted of the equatorward movement of the trade winds between about 30° latitude and the equator, with rising components near the equator, poleward flow aloft, and descending components at about 30° again (Hadley cell). William Ferrel in 1859 proposed a circulation pattern in the middle and high latitudes in which the flow is poleward near the ground and equatorward at an intermediate level (Ferrel cell). A third component exists between about 60° latitude and the poles. Air rises, diverges, and travels toward the poles. Over the poles, the air sinks, forming the polar highs (Polar cell). There are typically three in each hemisphere, as illustrated in Fig. 1-3. This causes zonal wind patterns with strong easterly and westerly components which result in the basic motion system of the general circulation.

The converging northeast and southeast trades produce the intertropical convergence zone (ITCZ). The ITCZ fluctuates in position and intensity; it can be weak and discontinuous. This can be seen in Fig. 1-4 a satellite view of the North Pacific Ocean. The

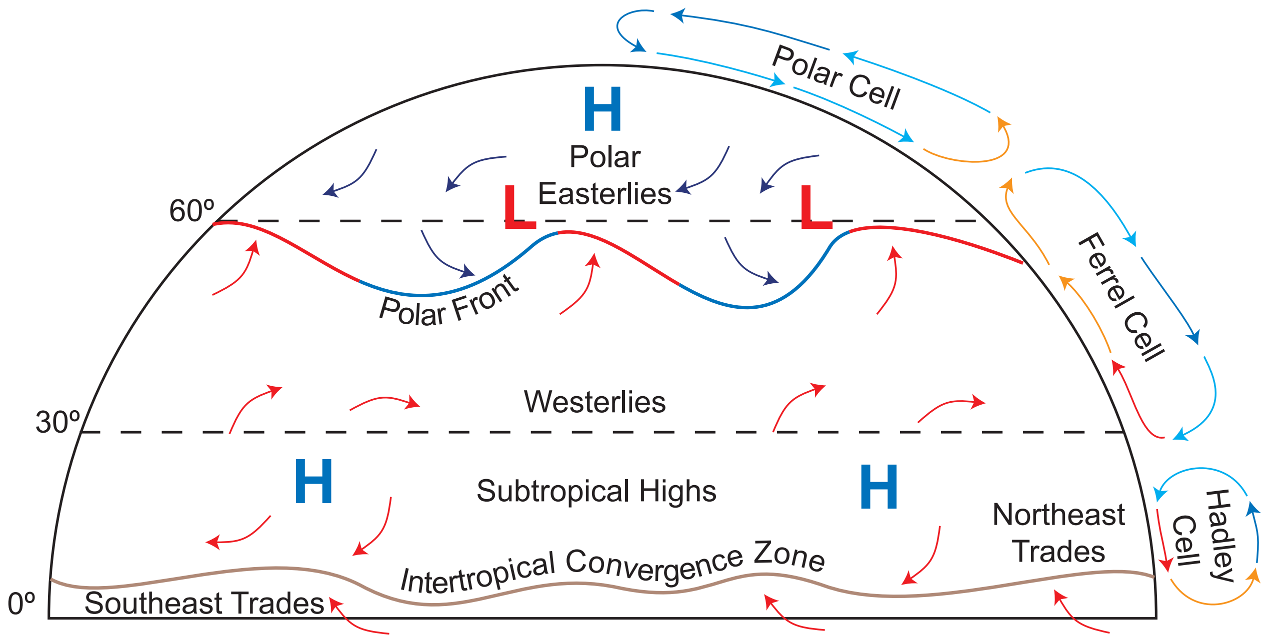


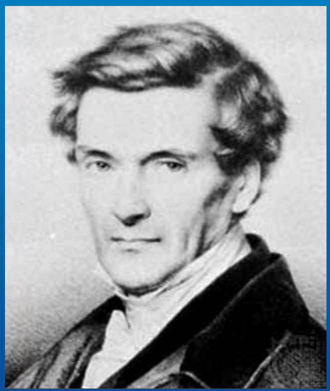
Fig. 1-3. *The general circulation at the surface consists of the polar high, polar front, subtropical highs, and intertropical convergence zone.*

source of the trades are the subtropical highs. Note the location of the high pressure cells ("H") in Fig. 1-3 and Fig. 1-4. It should be no surprise that in the vicinity of the ITCZ there is rising air—convergence; and, in the area of the subtropical highs descending air—divergence.

Moving north, about 30° latitude, are the prevailing westerlies. These result from the subtropical highs. Another area of subsidence occurs at the poles. This is the region of the polar high—some of the highest atmospheric pressures ever recorded have occurred in these areas—resulting in the polar easterlies at about 60° latitude.

Between the polar easterlies and the midlatitude westerlies is the polar front. This is another area of global convergence of warm air from the south and cold air from the north. The polar front is continuous around the world as shown in Fig. 1-3. However, where it is weak there may be areas of little or no weather—as illustrated in Fig. 1-4 over the central Pacific and western continental United States.

isobars—Lines connecting equal values of pressure.



Gaspard de Coriolis
1792-1843

Differences in pressure produce *pressure gradient force*. Pressure gradient force determines the strength of the wind. The stronger the pressure gradient force, the stronger the wind. On weather charts (chapter 11, Graphical Observational Products and chapter, 16 Enroute Forecast Products) areas of strong winds are identified by close spacing of isobars, areas of weak winds by wide spacing of isobars.

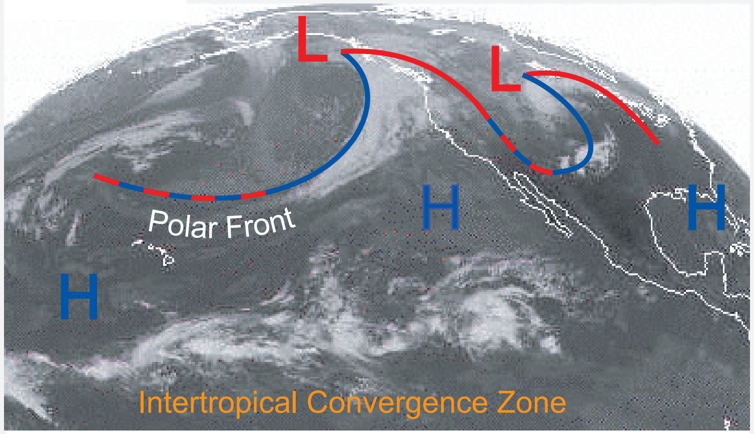


Fig. 1-4. *The components of the general circulation are easily identified on satellite imagery.*

At least initially, the wind wants to blow from areas of high to low pressure. If pressure gradient was the only force acting on the wind, wind would always blow perpendicular to isobars—directly from high to low pressure.

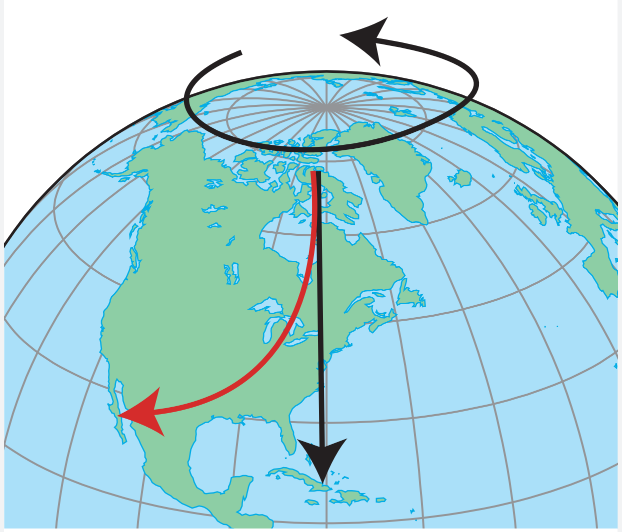


Fig. 1-5. *Wind is directed by three forces: pressure gradient, Coriolis, and friction.*

Because the Earth rotates there is an apparent force that deflects the wind from a straight path relative to the Earth's surface. This is *Coriolis force*, illustrated in Fig. 1-5.

Note

In 1856 an American William Ferrel published *Essay on the Winds and Currents of the Ocean*. He showed mathematically that winds are affected by the rotation of the Earth. Gaspard de Coriolis, a French mathematician, in 1835 had already developed the theory of an apparent deflection force produced by angular rotation. Although

Ferrel applied the theory, in meteorology the effect is referred to as "Coriolis Force."

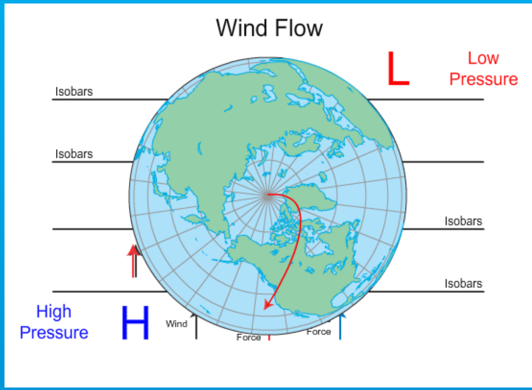
In the Northern Hemisphere Coriolis deflects the wind to the right (in the Southern Hemisphere to the left). Coriolis force is maximum at the poles and zero at the equator. Coriolis always acts at right angles to wind direction and proportional to wind speed. Coriolis balances pressure gradient force, causing wind to blow parallel to isobars—perpendicular to pressure gradient force.

Friction between moving air and the ground slows the wind at and near the surface. The rougher the terrain, the greater the frictional effect. (Over land frictional effect occurs to about 2000 ft, over oceans to about 1000 ft.) Frictional force always acts opposite to wind direction. As frictional force slows the wind, Coriolis force decreases. However, friction has no effect on pressure gradient force. At and near the surface the three forces eventually reach equilibrium. Pressure gradient balances the combined effect of frictional and Coriolis forces. As a result of these three forces wind blows across isobars at an angle out of higher pressure toward, and into, lower pressure.

At the surface in the Northern Hemisphere, wind blows out of high pressure toward low pressure in a clockwise direction; and, into low pressure in a counterclockwise direction. (Directions are reversed in the Southern Hemisphere.) This general flow is shown in Fig. 1-3.

We briefly touched on the transport of air at upper levels with the discussion of Hadley-Ferrel-Polar cell circulation illustrated in Fig. 1-3. The exchange of air at upper levels completes the circulation pattern. Winds in the upper troposphere and lower stratosphere compensate for, or balance, the movement of air in the lower troposphere.

Upper-level waves apparently result from the tendency of winds in large-scale systems to retain a constant *vorticity* about the Earth's rotation. (More about vorticity in chapter 4, Upper-Level Weather Systems.) As illustrated Fig. 1-6 the resulting long-wave, ridges and troughs extend for thousands of miles. There are normally three to seven circling the globe, moving generally eastward at up to 15 knots but can remain stationary for days or even retreat. Their length, amplitude, and position are influenced by differential heating at the surface and mountain barriers—such as the Rockies.



"Click" *Wind Flow* to view animation.

vorticity—Indicates a circulation or rotation within the atmosphere.

Only pressure gradient and Coriolis forces act on upper level winds. Without frictional force in play, these winds blow parallel to *contours* as depicted on upper level constant pressure charts (chapter 11, Graphical Observational Products). The solid lines in Fig. 1-6 represent lines of constant pressure height—contours—in the upper atmosphere.

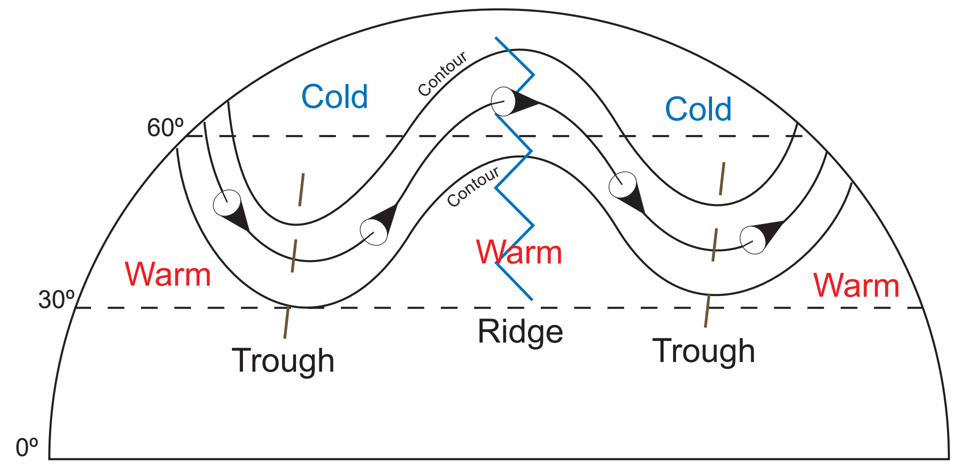


Fig. 1-6. *Planetary, or Rossby, waves have lengths of 2000 to 4000 miles, with normally three to seven circling the globe.*

Because the Earth's axis tilts about 23°, the Sun's maximum heat strikes different latitudes during the year. This causes the seasons. In the Northern Hemisphere the general circulation, described in Fig. 1-3, moves south during the cool season and north during the warm season.

Bermuda high—A semi-permanent suptropical high in the western North Atlantic ocean. In the midwest and eastern United States the Bermuda high brings moist, warm air to the region. This results in hot, humid conditions often resulting in severe weather.

In the warm season the eastern Pacific high blocks weather systems approaching the northwest Pacific coast of the U.S., forcing the weather on a more northerly track into Canada. The Bermuda high brings a moist, warm southerly flow to the southeastern United States.

In the cool season the highs migrate southward. This allows Pacific storm systems to move into the Pacific Northwest, sometimes reaching all the way into Southern California and northern Mexico. The Bermuda high moves eastward. Storms continue through the central and southern plains, and along the eastern seaboard. As the polar high moves south, it reaches well into the United States several time a year. Occasionally, the polar air can reach as far south as California, Texas, the Gulf of Mexico, and Florida bringing subzero temperatures.

Air Masses

Recall that an air mass is a widespread body of air with homogeneous properties. To better understand air masses refer to Fig. 1-3, General Circulation. At the pole the polar high produces downward vertical motion—subsidence. (More on vertical motion in chapter 2, Atmospheric Properties.) Between the polar easterlies and the midlatitude westerlies an area of global convergence accounts for the polar front—upward vertical motion. At around 30° latitude subtropical highs, an area of surface divergence result in downward vertical motion. Near the equator the intertropical convergence zone, produces another area of surface convergence.

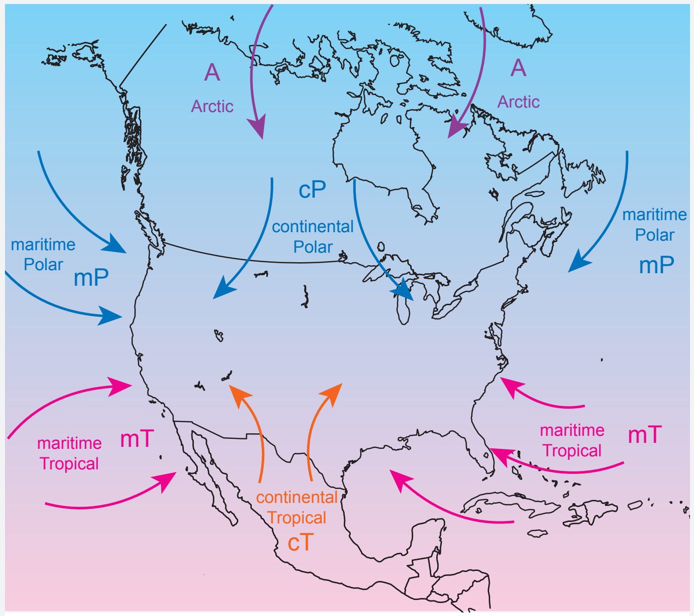


Fig. 1-7. *Air masses take on the characteristics of the region where they form.*

As depicted in Fig. 1-7, air mass source regions consist of arctic, polar, and tropical, which reflect their temperature. When air masses develop and remain relatively stationary in their source regions they take on the characteristics (temperature, moisture, and stability) of that region. To indicate moisture content air masses are classified as continental (dry) or maritime (moist). The following source regions affect North America.

- Polar ice cap
- Plains of northern Canada
- North Pacific Ocean
- North Atlantic Ocean
- Gulf of Mexico
- Southwestern United States
- Northern Mexico

Air that stagnates over northern continental regions forms continental polar or arctic air masses—depending on temperature. These air masses are characterized by cold, dry air reflecting their source region. They develop over Canada and Alaska and push down through Canada into the United States—cold, dry, and stable. (Atmospheric stability will be specifically addressed in chapter 2, Atmospheric Properties.)

Maritime polar air masses form over northern oceanic areas and are generally not as cold as continental polar air, especially in the cool season. Why? Water surfaces tend to retain heat, while land areas cool rapidly. Maritime polar air masses tend to contain more moisture than their continental counter parts. The North Pacific and North Atlantic oceans spawn maritime polar air masses—cold, moist, and conditionally unstable. With the general flow over midlatitudes from west to east, maritime polar air masses—that develop over the North Atlantic—rarely affected the United States.

Maritime tropical air masses develop over warm oceanic areas in lower latitudes. Maritime tropical air masses form over the southern portion of the U.S. west coast, Gulf coast, and southern Atlantic coast—warm, moist, and unstable.

Arid continental regions produce continental tropical air masses. They form over northern Mexico and the U.S. desert southwest—warm, dry, and unstable.

lapse rate—The decrease of an atmospheric variable with height, usually temperature.

Air mass modification occurs when an air mass moves over an area of different properties. Horizontal changes in temperature, moisture, and lapse rate gradually occur. For example, a maritime air mass that moves over the continent in the cool season is cooled from below. Its lapse rate becomes more stable. In the warm season the air mass is warmed from below, resulting in greater instability. Evaporation from a water surfaces and falling precipitation add water vapor; condensation and precipitation remove water vapor. These effects play an important part in the development and severity of storms.

Table 1-1 compares the general characteristics of air mass modification.

From Table 1-1, an air mass “cooled from below” increases stability. Stable air typically results in poor visibility, smooth flying conditions, stratiform clouds, steady precipitation, and rime icing. An air mass “warmed from below” decreases stability. Unstable air typically produces good visibility—except in showers, turbulent air, cumuliform

Table 1-1. *Air Mass Modification*

Warm (Cooled from Below)	Cold (Warmed from Below)
Stablize Lapse Rate	Destablize Lapse Rate
Poor Visibility	Good Visibility
Smooth	Turbulent
Stratiform Clouds	Cumuliform Clouds
Steady Precipitation	Showery Precipitation
Rime Icing	Clear Icing

clouds, showery precipitation, and clear icing.

Almost always associated with cyclonic wind flow (counterclockwise in the northern hemisphere) lows and troughs destabilize the atmosphere. Not a trough a low refers to a closed circulation. Nor, are troughs fronts, although fronts normally lie in troughs. A front marks the boundary between air masses of different temperatures, whereas a trough is simply a line of low pressure. Both result in upward vertical motion.

An area of low pressure caused by high temperatures produced by intensive surface heating may result in a *thermal low*. Thermal lows develop over the desert southwest during the late cool through the late warm seasons. They tend to remain stationary. At times they can extend to the arid regions east of the Cascade Mountains in Washington and Oregon and the Snake River Valley in Idaho. Cyclonic circulation is generally weak and diffuse. They tend to lower pressures inland, increasing coastal marine stratus. They provide thermal convection and weak convergence which can trigger the development of air mass thunderstorms. They are not associated with fronts; although, weak fronts and troughs moving through the region can intensify convection.

Almost always associated with anticyclonic wind flow (clockwise in the northern hemisphere) highs and ridges stabilize the atmosphere. “Anticyclone” refers to a closed circulation and may be used interchangeably with “high.”

A misconception holds that high pressure always means good flying weather. Although good weather often results, no absolutes. Strong pressure gradients at the edge of highs can cause vigorous winds and severe turbulence. Near the center of a high or with weak pressure gradients, moisture and pollutants trapped in the lower levels of the atmosphere reduce visibilities and even produce zero-zero conditions in fog for days or even weeks.

stratiform —Stratiform describes clouds of extensive horizontal development, and a stable air mass. These cloud types include stratus, nimbostratus, stratocumulus, altostratus, and cirrostratus.

cumuliform —The category of clouds that are characterized by vertical development in the form of rising mounds, domes, or towers. These clouds include the cloud types cumulus, cumulonimbus, altocumulus, and cirrocumulus.

A *thermal high* results from the cooling of air by a cold underlying surface. For this to occur the air mass must remain relatively stationary over a cold surface; a factor in the development of continental Polar and Arctic air masses—which often result in extremely cold temperatures.

For operational and analysis purposes surface pressure is reduced to its "sea level" equivalent expressed in inches of mercury (in Hg) or millibars (mb). Figure 1-8 shows sea level pressure under the high as 1015,5 mb; under the low 975.5 mb. On constant pressure charts contours show the height in meters of the constant pressure surface (solid black lines Fig 1-8). The height of the 700 mb constant pressure surface under the high as about 11,000 ft, under the low about 9000 ft.

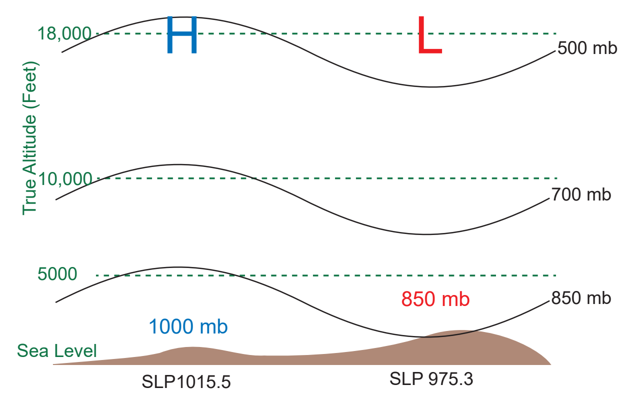


Fig. 1-8. *Surface pressures are reduced to sea level as a common reference.*

millibar (mb)—A unit of pressure. For aviation purposes we commonly relate atmospheric pressure to inches of mercury or millibars. (More about pressure units and their appication in the following chapters

Don't become overly concerned with the discussions in this chapter. It's background information that will help your understanding of aviation weather in subsequent chapters.