TROPICAL CYCLONES

The tropical cyclone is the typhoon of the Pacific Ocean and hurricane of the Atlantic. It is a vortex or circular storm that rotates counterclockwise in the northern hemisphere and clockwise in the southern hemisphere. The tropical cyclone gets its energy from the latent heat of condensation. The energy in an average hurricane may be equivalent to more than 10,000 atomic bombs the size of the Nagasaki bomb. These storms range in size from a few kilometers to several hundred kilometers in diameter. In the middle is an eye that can be as large as 65 kilometers across. The total area involved may be as much as 52,000 square kilometers.

The atmospheric pressure is nearly symmetrical about the center (Fig. 9.2). The pressure may go as low as 650 millimeters, but this is rare. Such a drop in pressure represents a change of about 13 percent from normal. It is not an explosive drop since it takes place over a distance of many kilometers. The wind system associated with

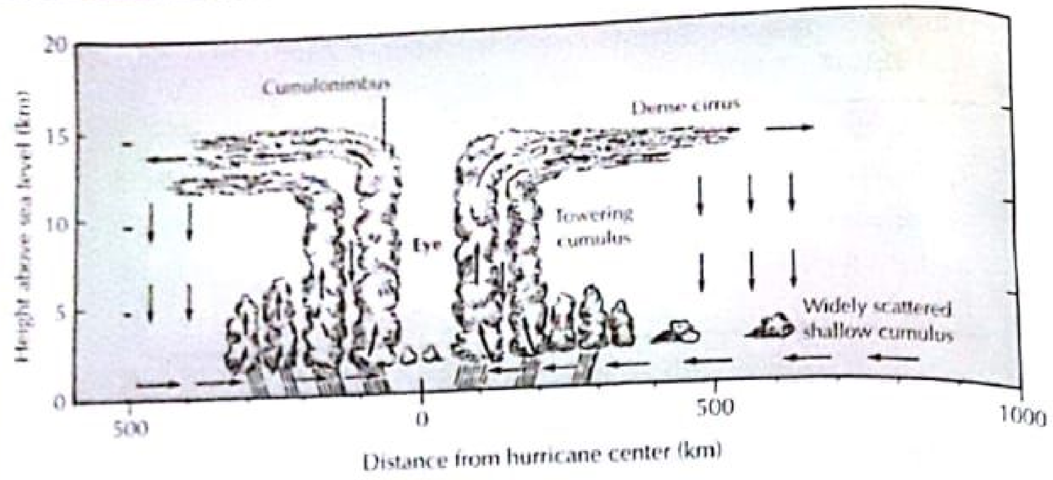


Figure 9.2
Vertical structure of a hurricane showing the cloud pattern and wind flow.

hurricanes is one of contrasts. In the eye of the storm, the winds are light and variable and of velocities not usually exceeding 25 kilometers. The wind velocities increase rapidly away from the eye, reaching their highest velocities just outside the eye and at a height of about 0.8 kilometers. To be classified as a hurricane, winds must exceed 125 kilometers per hour. The maximum winds in most well-developed hurricanes reach 200 kilometers per hour, but in extreme cases may reach 300 kilometers per hour. Hurricane-velocity winds may extend over an area of 300 to 500 kilometers in diameter, and gale force winds (65 km/hr) over an area of 600 to 800 kilometers in diameter. Anemometers reinforced against hurricanes have measured such winds at velocities greater than 250 kilometers per hour. Although the winds within the storm area are of very high velocity, the storm moves at a relatively slow speed, averaging only 15 to 30 kilometers per hour. In Hurricane Gilbert of 1988, the central pressure dropped to 885 millibars (26.13 in). This is the lowest pressure ever recorded in a western hemisphere hurricane. It produced 152 knot (175 mph) winds and pushed a hurricane surge of 4.5 meters (15 ft) in front of it.

Some of the heaviest rains on record in low latitudes came from these storms. Records of 500 millimeters of rain over a 48-hour period are relatively common. One typhoon in the Philippines produced over 1600 millimeters of rain. Radar observations show that 500 to 800 kilometers ahead of the storm there are often fairly well-defined lines of thunderstorms. These storms generate waves as high as 13 meters. Long sea swells as far as 1600 kilometers from the center are evidence of the storms' strength. Near the wall of the hurricane eye, wind often blows the tops off the waves, but in the eye the waves are often very high.

Formation of Tropical Cyclones

There is no agreement yet as to why these storms form. The weather conditions required to produce them are known; once formed, the storms can be tracked. The precise set of factors that trigger tropical storms requires further research. The storms only form over large bodies of warm water when both the air and water temperatures are higher than normal. Thus, they only form in summer over tropical oceans. Temperatures of only a few degrees above normal are enough. Hurricanes form in an atmosphere of essentially uniform pressure and are not associated with atmospheric fronts. They appear to build on a wave of low pressure or on a minor disturbance in wind circulation. These atmospheric ripples may result from local differences in water heating or instability in masses of tropical air.

The trade wind belt is typically a relatively shallow layer of warm, moist air above which is a deep layer of warmer, dry subsiding air. This forms the Trade Wind Inversion—a characteristic that limits the vertical development of clouds. The inversion is sometimes interrupted by a low-pressure trough, which allows thunderstorm development behind the wave. Increased convection and the normal pattern of high-altitude winds cause the trough to deepen so an isolated low-pressure system is formed. If the pressure continues to fall, winds accelerate and a tropical storm is born. The change in status from tropical storm to hurricane requires a mechanism to stimulate vertical air motion and convergence of air. Several possible trigger mechanisms exist, with an intruding high-altitude, low-pressure system being the most often cited cause. Derived from the remains of an upper tropospheric cyclone wave, these abandoned waves act in two ways to promote instability. First, there is divergence on the eastern side of the abandoned system; second, the low has a cold core so the lapse rate below is changed. Both the divergence and altered stability enhance surface pressure differences enough to generate a tropical cyclone. Once a hurricane begins to form, moist air from all sides converges toward the storm center. Condensation supplies the energy needed to develop the storm, and therefore a constant supply of water vapor is essential for the storm's continued existence.

The storm moves slowly at first, usually moving from east to west in low latitudes. As it gains strength, the speed increases and its path curves gradually toward the pole. As long as the storm remains over warm water, it can grow in intensity. A storm can travel far north along the East Coast of the United States because it follows the warm Gulf Stream. When a storm moves over the cold Labrador Current, it dissipates rapidly. If it moves over land, increased friction with the land surface and loss of the energy supply causes the storm to quickly dissolve.

The Time and Place of Occurrence

Tropical cyclones only occur in certain regions (Fig. 9.3). They start over the tropical oceans between latitudes of 5° and 20°, and most form over the western sides of the oceans. They are absent along the equator due to the weakness of the Coriolis effect. There are six general regions of occurrence: the Caribbean Sea and the Gulf of Mexico, the Northwest Pacific from the Philippines to the China Sea, the Pacific Ocean west of Mexico, the South Indian Ocean east of Madagascar, the North Indian Ocean in the Bay of Bengal, and the Arabian Sea. Over the central and western portions of the Pacific Ocean, an average of 20 tropical cyclones occur each year, mostly from June to October. In the eastern Pacific, southwest of Mexico, an average of three hurricanes form each season, but most rarely reach land. Some hurricanes occur outside these regions, but these are the areas of highest frequency. It is of some interest that they do not occur south of the equator in the Atlantic Ocean. Apparently the equatorial convergence zone does not migrate far enough south to provide the necessary convergence.

Hurricanes also occur at particular times. The peak frequency corresponds to the period of highest sea temperature during the year and the time of the maximum displacement of the convergence zone. Thus, late summer and early fall are the seasons of maximum occurrence.

Extratropical cyclones, sometimes called **mid-latitude cyclones** or **wave cyclones**, are low-pressure areas which, along with the anticyclones of high-pressure areas, drive the weather over much of the Earth. Extratropical cyclones are capable of producing anything from cloudiness and mild showers to heavy gales, thunderstorms, blizzards, and tornadoes. These types of cyclones are defined as large scale (synoptic) low pressure weather systems that occur in the middle latitudes of the Earth. In contrast with tropical cyclones, extratropical cyclones produce rapid changes in temperature and dew point along broad lines, called weather fronts, about the center of the cyclone.[1]

The term "cyclone" applies to numerous types of low pressure areas, one of which is the extratropical cyclone. The descriptor *extratropical* signifies that this type of cyclone generally occurs outside the tropics and in the middle latitudes of Earth between 30° and 60° latitude. They are termed *mid-latitude cyclones* if they form within those latitudes, or post-tropical cyclones if a tropical cyclone has intruded into the mid latitudes.[1][2] Weather forecasters and the general public often describe them simply as "depressions" or "lows". Terms like frontal cyclone, frontal depression, frontal low, extratropical low, non-tropical low and hybrid low are often used as well.

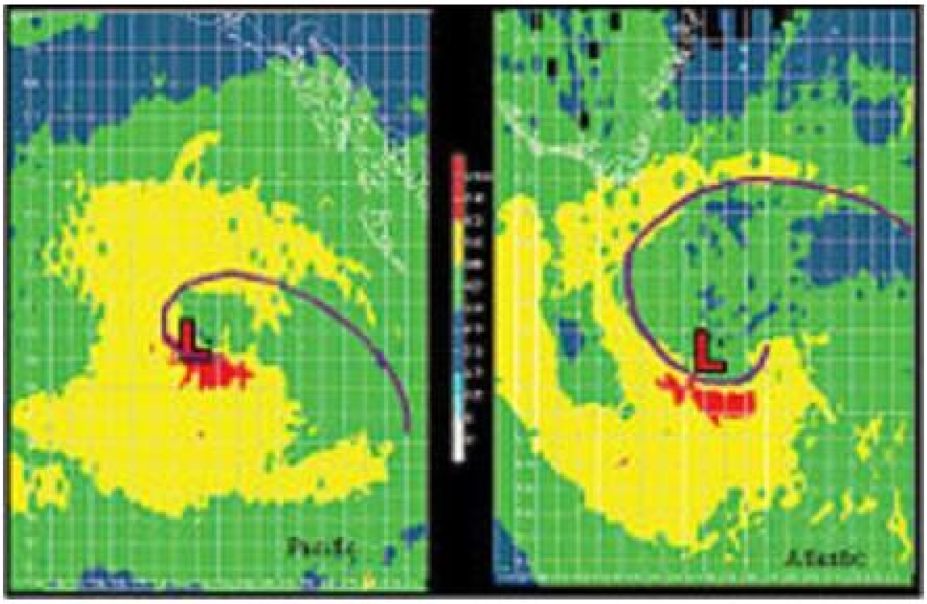
Extratropical cyclones are classified mainly as baroclinic, because they form along zones of temperature and dewpoint gradient known as frontal zones. They can become barotropic late in their life cycle, when the distribution of heat around the cyclone becomes fairly uniform with its radius.[3]

Extratropical cyclones form anywhere within the extratropical regions of the Earth (usually between 30° and 60° latitude from the equator), either through cyclogenesis or extratropical transition. A study of extratropical cyclones in the Southern Hemisphere shows that between the 30th and 70th parallels, there are an average of 37 cyclones in existence during any 6-hour period.[4] A separate study in the Northern Hemisphere suggests that approximately 234 significant extratropical cyclones form each winter.[5]

^ Structure

See also: Weather fronts

Surface pressure and wind distribution



QuikSCAT image of typical extratropical cyclones over the ocean. Note the maximum winds are on the outside of the occlusion.

The windfield of an extratropical cyclone constricts with distance in relation to surface level pressure, with the lowest pressure being found near the center, and the highest winds typically just on the cold/poleward side of warm fronts, occlusions, and cold fronts, where the pressure gradient force is highest.[29] The area poleward and west of the cold and warm fronts connected to extratropical cyclones is known as the cold sector, while the area equatorward and east of its associated cold and warm fronts is known as the warm sector.

General
EFFECT

Extratropical cyclones can bring mild weather with a little rain and surface winds of 15–30 km/h (9.3–18.6 mph), or they can be cold and dangerous with torrential rain and winds exceeding 119 km/h (74 mph),[46] (sometimes referred to as windstorms in Europe). The band of precipitation that is associated with the warm front is often extensive. In mature extratropical cyclones, an area known as the **comma head** on the northwest periphery of the surface low can be a region of heavy precipitation, frequent thunderstorms, and thundersnows. Cyclones tend to move along a predictable path at a moderate rate of progress. During fall, winter, and spring, the atmosphere over continents can be cold enough through the depth of the troposphere to cause snowfall.

THUNDERSTORMS

Observers for the National Weather Service consider a thunderstorm to begin when thunder is heard or overhead lightning or hail is observed. Severe thunderstorms require three-quarter-inch hail and/or wind gusts of 50 knots. The storm is considered ended 15 minutes after the last thunderclap is heard. Note that this definition makes no mention of rainfall; in fact, in dry climates, thunderstorms often occur without measurable precipitation.

Regardless of whether precipitation occurs, thunderstorms form from an initial uplift of moist, unstable air and the release of sufficient latent heat to cause continued uplift. Thus, the keys to storm formation are a source of moist air and a mechanism to produce the required uplift. Given moisture and convective heat sources, the greatest number of thunderstorms occur in moist, tropical realms, especially in Africa. The second requirement, which is a mechanism to initiate cumulonimbus cloud development and, hence, thunderstorms, is obviously more varied; it can result from intense convective activity to forced uplift at fronts or squall lines.

Isolated thunderstorms that occur in summer in the mid-latitudes typify the air-mass thunderstorm. They occur in a disorganized manner, often consisting of a single cell or several distinct cells less than 10 kilometers wide. While air-mass thunderstorms sometimes occur because of differences in surface heating, other trigger effects often cause their development. Alternate mechanisms responsible for growth include converging winds and topography. An example of the former occurs in Florida, where convergence of the moist ocean air along both coasts produces frequent thunderstorms over the peninsula. The role of topography is apparent on the slopes of the Rockies. There air near the slope is heated more intensely than air at similar levels over flat land, resulting in a distinct upslope movement and the potential for the formation of cumulonimbus clouds.

Single-cell thunderstorms are generally much less violent than those associated with the forced upward motion of air that occurs along cold fronts and squall lines. Some of the most severe thunderstorms are associated with squall lines. These occur mostly ahead of cold fronts and, unlike the isolated air-mass type, are an integral part of large-scale circulation patterns. (The schematic sequence given in Figure 9.4 provides the essential details of the storm.) Warm, moist air at surface levels lies ahead of an advancing cold front. At the 850-millibars level (about 1500 m), this air flows from a warm, southerly source. In contrast, at 500 millibars (about 5500 m), a westerly stream of cool, dry air—with divergence—flows across the surface systems. The combination of the unstable surface air and the divergence aloft leads to extensive vertical development of clouds and a line of thunderstoms. The differential flow of air at varying altitudes adds to the severity of the storm. The westerly high-level flow tilts the top of the storm clouds so that falling precipitation does not slow the updrafts, as it does at the mature stage of air-mass thunderstorms, thus extending the storm's life and increasing the potential for hail to form. At times the size and severity of the storms allow them to be classed as supercells. These are enormous storms whose updrafts and downdrafts are sufficiently balanced to enable cells to last many hours. Note that the squall line may be located hundreds of kilometers ahead of the cold front. In fact, squall lines in tropical climates do not require the presence of a front for their formation.

When a number of individual thunderstorms grow in size and organize into a large convective system it is termed a *mesoscale convective complex*. These are often large enough to cover an entire state in the Mid-west and can persist for more than 12 hours.