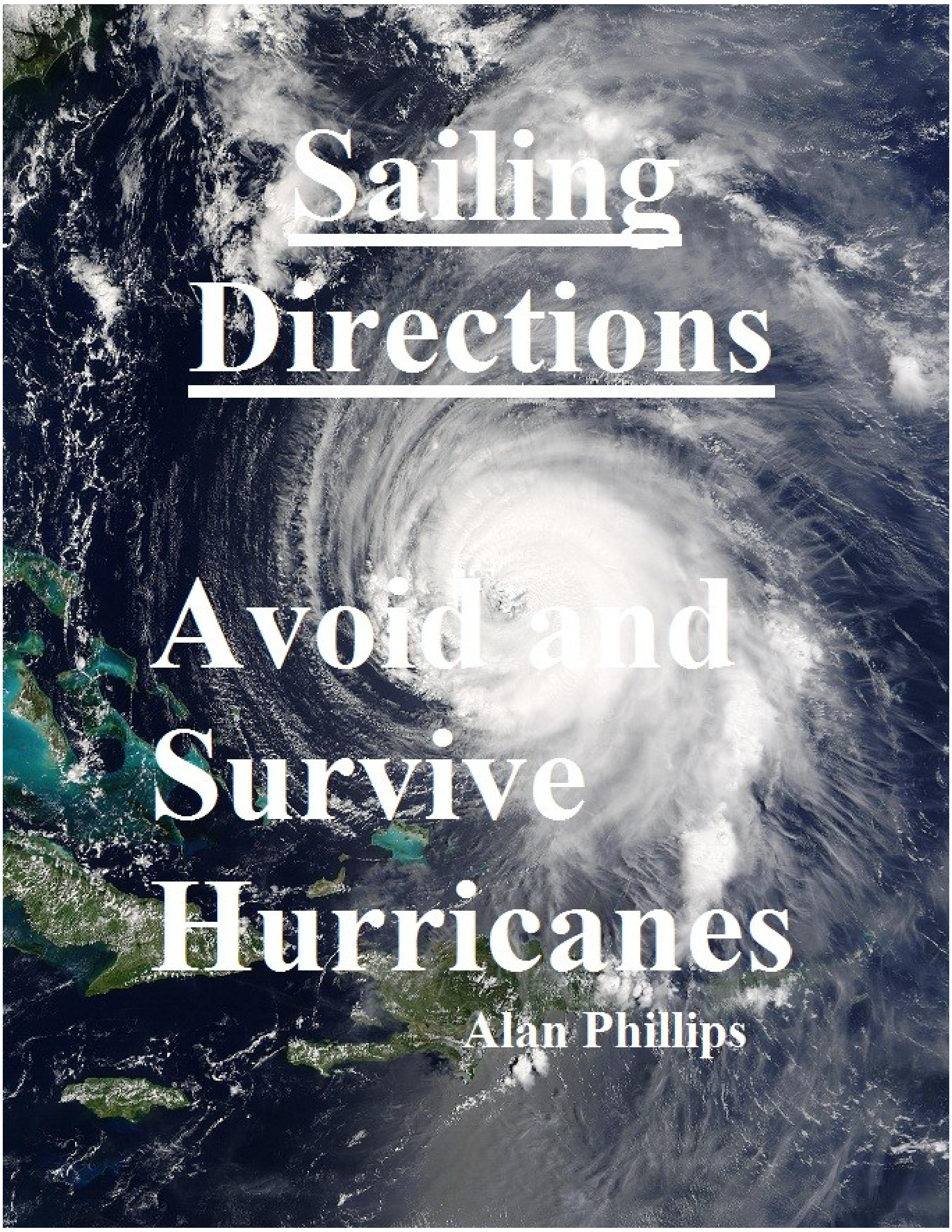

Sailing Directions
Avoid and Survive Hurricanes

BY Alan Phillips

Smashwords Edition

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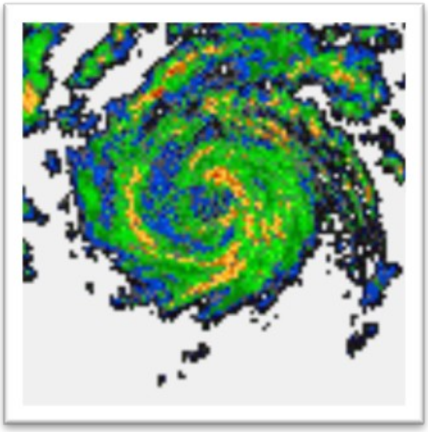


Sailing Directions
Avoid and Survive Hurricanes

The terms "hurricane", and "typhoon" are regionally specific names for a strong "tropical cyclone". A tropical cyclone is the generic term for a non-frontal synoptic scale low-pressure system over tropical or sub-tropical waters with organized convection (i.e. thunderstorm activity) and definite cyclonic surface wind circulation.

Tropical cyclones with maximum sustained surface winds of less than 17 m/s (34 kt, 39 mph) are called "tropical depressions" (This is not to be confused with the condition mid-latitude people get during a long, cold and grey winter wishing they could be closer to the equator. Once the tropical cyclone reaches winds of at least 17 m/s (34 kt, 39 mph) they are typically called a "tropical storm" and assigned a name. If winds reach 33 m/s (64 kt, 74 mph), then they are called: "hurricane" (the North Atlantic Ocean, the Northeast Pacific Ocean east of the dateline, or the South Pacific Ocean east of 160E)

"typhoon" (the Northwest Pacific Ocean west of the dateline)

"severe tropical cyclone" (the Southwest Pacific Ocean west of 160E or Southeast Indian Ocean east of 90E)

"tropical cyclone" (the Southwest Indian Ocean)

"severe cyclonic storm" (the North Indian Ocean)

Hurricane season in the northern hemisphere is June, July, August September and October. The most dangerous months are August and September.

They spin anti-clockwise and move in a west or north-west direction. They may curve back to the east as they mature.

When the barometer has fallen 5 milibars and the wind has increased to near gale (at 28 knots) you need to take evasive action. You may be around 200 miles from the eye. To work out where the eye is you should face into the wind and then the eye of the hurricane is 100-125 degrees on your RIGHT side. As it approaches this angle gets closer to 90 degrees. You need to get south of it and head towards the equator. See diagram. Basically the idea is to run south.

If you heave-to put the wind on your starboard bow.

SOUTHERN HEMISPHERE

In the southern hemisphere the months are December, January, February, and March. Most dangerous are Feb and March.

They spin clockwise and move west or south-west. They may curve back to the east as they mature.

When the barometer has fallen 5 milibars and the wind has increased to near gale (at 28 knots) you need to take evasive action. You may be around 200 miles from the eye. To work out where the eye is you should face into the wind and then the eye of the hurricane is 100-125 degrees on your LEFT side. As it approaches this angle gets closer to 90 degrees. You need to get north of it and head towards the equator. See diagram. You should run north.

If you heave-to put the wind on your port bow.

GENERAL

No month is entirely safe as hurricanes can occur in any month. They form at 5-7 degrees from the equator, start to move away at 10 knots and intensify from there.

In all areas they occur between 5 Degrees and 25 Degrees latitude. They can go past 30 degrees latitude and the effects are felt by a sailing yacht over 1,000 miles away.

Hurricanes can cause danger even to large and well found ships. In our small boats we should not get within 100 miles of the centre Now I personally have been through two hurricanes at sea and a couple along the coast of Australia.

The first time I simply allowed the yacht to go free; lay a-hull. My family and I sheltered on the saloon floor under the table with the cushions pulled down around us. The waves were 12 metres (40 feet) high but were in very long trains with the crests more than 200 metres apart. The difficulty for the boat and the crew was the few seconds as we went over the crests. It was a 4 metre waterfall and the boat took a huge hit at this minute. Then there was a few minutes respite till the next breaker arrived.

The second time I was enroute from Bali back to Darwin in Australia. My motor had been out of operation for months and I had been enjoying the sailing. However I was in the cyclone season and became becalmed for three weeks; then faced a cyclone. This time I needed to use the hurricane force winds to move the boat towards Australia before we ran out of food and water. So we kept a little staysail up and steered by hand. We had no problem other then to control our own fear. The waves were 14 metres (47 feet) high and breaking furiously at the crests. We sailed through the eye of that one without injury or breakage.

Other yachts and fishing trawlers were not so fortunate. In Cyclone Tracy **every small ship** at sea was lost with all crew killed.

Torrential rain and sheets of continuous spray mean visibility is almost nil. In actual fact you cannot turn your eyes towards the wind. I carry ski goggles now for use in strong winds. The other thing to realize is the extreme levels of noise. If you are on deck you must cup your hands within a centremetre of the others ears for him to hear. Down below it sounds as if the yacht is breaking up. This heightens the fear.

When I have been along the coast and a cyclone comes along I move my boat out of the anchorage or out of the marina. Your anchors probably cannot hold your boat in hurricane force winds so take other shelter and do not rely on your anchors in a harbour. I go to a creek or muddy inlet where I take my boat into the mangroves or under an overhanging bank. I like to ram it into the mud at high tide and tie it to the trees. I leave my anchor behind me for kedging off later. I have been very happy and contented during cyclones baking cakes, drinking rum and reading books.

Ships sometimes put out to sea to ride it out. Sometimes the harbours are closed and all ships forced to leave or unable to get permission to come in. Forget all that; that does not apply to us. We do not go to sea; we seek shelter.

Tropical Cyclones

A tropical cyclone is a warm-core; low-pressure system that develops over the warm waters of the tropical oceans, and exhibits a rotary, counterclockwise circulation in the northern hemisphere (clockwise in the southern hemisphere). Although relatively small in area coverage, this storm can attain awesome strength, with winds near its center reaching 175 knots or more. Tropical cyclones occur almost entirely in six rather distinct regions of the world; one of these, the North Atlantic Region (West Indies, Caribbean Sea, Gulf of Mexico, and waters off the east coast of the United States), includes the area covered by this Coast Pilot. In this region, tropical cyclones with winds of 34–63 knots are called tropical storms, while tropical cyclones with winds greater than 63 knots are called hurricanes. Hurricanes are infrequent in comparison with middle- and high-latitude storms, but they have a record of destruction far exceeding that of any other type of storm. Because of their fury, and the fact that they are predominately oceanic, they merit the special attention of all mariners, whether professional or amateur.

Rarely does the mariner who has experienced a fully developed tropical cyclone (hurricane) at sea wish to encounter a second one. He has learned the wisdom of avoiding them if possible. The uninitiated may be misled by the deceptively small size of a tropical cyclone as it appears on a weather map, and by the fine weather experienced only a few hundred miles from the reported center of such a storm. The rapidity, with which the weather can deteriorate with approach of the storm, and the violence of the hurricane, are difficult to visualize if they have not been experienced.

As a tropical cyclone moves out of the tropics to higher latitudes, it normally loses energy slowly, expanding in area until it gradually dissipates or acquires the characteristics of extratropical cyclones. At any stage, a tropical cyclone normally loses energy at a much faster rate if it moves over land. As a general rule, tropical cyclones of the North Atlantic Region move with the prevailing winds of the area. In small hurricanes the diameter of the area of destructive winds may not exceed 25 miles while in some of the greatest storms the diameter may be as much as 400 to 500 miles.

At the center is a comparative calm known as the "eye of the storm." The diameter of this "eye" varies with individual storms and may be as little as 7 miles but is rarely more than 30 miles. The average is 15 to 20 miles. This center is the region of low atmospheric pressure around which winds blow in a more or less circular course, spiralling inward in a counterclockwise direction. Winds at the outer edge of the storm area are light to moderate and gusty, and often increase toward the center to speeds too high for instrument recording. Although the air movement near the center of the hurricane is usually light and fitful, the seas in this area are in most cases very heavy and confused, rendered so by the violent shifting winds which surround it. Furthermore, after the center has passed a vessel, she may expect a sharp renewal of the gales, with winds from a more or less opposite direction. The hurricane may affect an area covering tens of thousands of square miles.

(260) In the North Atlantic, tropical cyclones form over a wide range of ocean between the Cape Verde Islands and the Windward Island, over the western part of the Caribbean Sea, and the Gulf of Mexico. While some may initially move northward, especially those that form southeast of Bermuda, the majority take a westerly to northwesterly course. Of these, some curve gradually northward, either east of or above the larger islands of the West Indies, then turn northeastward or eastward for varying distances from the Atlantic Coast of the United States. Others pass over or to the south of the larger islands and enter the Gulf of Mexico, then curve northward or northeastward and strike some part of the east Gulf Coast. Others may continue westward and strike the west Gulf Coast.

(261) The most common path is curved, the storms moving generally in a westward direction at first, turning later to the northwestward and finally to the northeastward. A considerable number, however, remain in low latitudes and do not turn appreciably to the northward. Freak movements are not uncommon, and there have been storms that described loops, hairpin-curved paths, and other irregular patterns. Movement toward the southeast is rare, and in any case of short duration. The entire Caribbean area, the Gulf of Mexico, the coastal regions bordering these bodies of water, and the Atlantic Coast are subject to these storms during the hurricane season.

(262) Hurricanes develop over the southern portions of the North Atlantic, including the Gulf of Mexico, and Caribbean Sea, mostly from June through October, infrequently in May and November, and rarely in other months; the hurricane season reaches its peak in September. An average of nine tropical cyclones form each year (reaching at least tropical storm intensity) and five of these reach hurricane strength. June and July storms tend to develop in the northwestern Caribbean or Gulf of Mexico while during August there is an increase in number and intensity, and the area of formation extends east of the Lesser Antilles. September storms develop between 50°W. and the Lesser Antilles; in the southern Gulf of Mexico, the western Caribbean, near the Bahamas, and around the Cape Verde Islands. Formation in October shifts primarily to the western Caribbean and off-season storms are widespread with a slight concentration in the southwestern Caribbean.

(263) The average speed of movement of tropical cyclones in the Tropics is about 10 to 15 knots. This speed, however, varies considerably according to the location of the storm, its development, and attendant meteorological conditions. The highest rates of progression usually occur when the storm is moving northward or northeastward in the middle or higher latitudes.

Locating and tracking tropical cyclones

(264) The National Hurricane Center/Tropical Prediction Center located near Miami Florida collects weather observations hourly, depending on the source, from land stations, ships at sea, aircraft and satellites. When a tropical cyclone is located, usually in its early formative stage (a tropical "wave"), it is followed closely. In the North Atlantic, U.S. Navy, Air Force, and NOAA aircraft make frequent flights to the vicinity of such storms to provide information needed for tracking the tropical cyclone and determining its intensity. With the implementation of the NEXt Generation Weather

RADar (NEXRAD), coastal radar sites follow the movement of the storm's precipitation area when it is in range. The network provides total coastal coverage from Eastport Maine through Brownsville Texas. Advisories from the Hurricane Center are made available on a 6-hour basis giving information on each storm's location, intensity, and movement. These advisories become more frequent if landfall is imminent. As a further aid, the mariner may obtain weather reports by radio directly from other ships in the vicinity of a tropical cyclone.

Signs of approach

(265) Although radio reports and satellite data, if available, normally prove adequate for locating and avoiding a tropical cyclone, knowledge of the appearance of the sea and sky in the vicinity of such a storm is useful to the mariner. The passage of a hurricane at sea is an experience not soon to be forgotten.

(266) An early indication of the approach of such a storm is the presence of a long swell. In the absence of a tropical cyclone, the crests of swell in the deep waters of the Atlantic pass at the rate of perhaps eight per minute. Swell generated by a tropical cyclone is about twice as long, the crests passing at the rate of perhaps four per minute. Swell may be observed several days before arrival of the storm.

(267) When the storm center is 500 to 1,000 miles away, the barometer usually rises a little, and the skies are relatively clear. Cumulus clouds, if present at all, are few in number, and their vertical development appears suppressed. Nearly perfect tropical blue skies are usually present. The barometer usually appears restless, pumping up and down a few hundredths of an inch. You are in the subsidence sector of the storm, under the influence of the upper-level high pressure system that is acting as the exhaust system for the storm.

(268) As the tropical cyclone comes nearer, a cloud sequence begins which resembles that associated with the approach of a warm front in middle latitudes. Snow-white, fibrous “mare’s tails” (cirrus at about 22,000 to 30,000 feet in altitude (6,700 to 9,100 m)) appear when the storm is about 300 to 600 miles away. Usually these seem to converge, more or less, in the direction from which the storm is approaching. This convergence is particularly apparent at about the time of sunrise and sunset.

(269) Shortly after the cirrus appears, but sometimes before, the barometer starts a long, slow fall. At first the fall is so gradual that it only appears to alter somewhat the normal daily cycle (two maximums and two minimums in the Tropics). As the rate of fall increases, the daily pattern is completely lost in the more or less steady fall.

(270) The cirrus becomes more confused and tangled, and then gradually gives way to a continuous veil of cirrostratus. Below this veil, altostratus forms, and then stratocumulus. These clouds radually become more dense, and as they do so, the weather becomes unsettled. A fine, mistlike rain begins to fall, interrupted from time to time by showers. The barometer has fallen perhaps a tenth of an inch.

(271) As the fall becomes more rapid, the wind increases in gustiness, and its speed becomes greater, reaching a value of perhaps 22 to 40 knots (Beaufort 6-8). On the horizon appears a dark wall of heavy cumulonimbus, the bar of the storm. Portions of this heavy cloud become detached from time to time and drift across the sky, accompanied by rain squalls and wind of increasing speed. Between squalls, the cirrostratus can be seen through breaks in the stratocumulus.

(272) As the bar approaches, the barometer falls more rapidly and wind speed increases. The seas, which have been gradually mounting, become tempestuous and, squall lines, one after another, sweep past in ever increasing number and intensity.

(273) With the arrival of the bar, the day becomes very dark, squalls become virtually continuous and the barometer falls precipitously, with a rapid increase in the wind speed. The center may still be 100 to 200 miles away in a hurricane. As the center of the storm comes closer, the ever-stronger wind shrieks through the rigging and about the superstructure of the vessel. As the center approaches, rain falls in torrents. The wind fury increases. The seas become mountainous. The tops of huge waves are blown off to mingle with the rain and fill the air with water. Objects at a short distance are not visible. Even the largest and most seaworthy vessels become virtually unmanageable, and may sustain heavy damage. Less sturdy vessels do not survive. Navigation virtually stops as safety of the vessel becomes the prime consideration. The awesome fury of this condition can only be experienced. Words are inadequate to describe it.

(274) If the eye of the storm passes over the vessel, the winds suddenly drop to a breeze as the wall of the eye passes. The rain stops, and skies clear sufficiently to permit the sun to shine through holes in the comparatively thin cloud cover. Visibility improves. Mountainous seas approach from all sides, apparently in complete confusion. The barometer reaches its lowest point, which may be 1½ or 2 inches below normal in hurricanes. As the wall on the opposite side of the eye arrives, the full fury of the wind strikes as suddenly as it ceased, but from the opposite direction. The sequence of

conditions that occurred during approach of the storm is reversed and passes more quickly, as the various parts of the storm are not as wide in the rear of a storm as on its forward side.

Locating the center of a tropical cyclone

(275) If intelligent action is to be taken to avoid the full fury of a tropical cyclone, early determination of its location and direction of travel relative to the vessel is essential. The bulletins and forecasts are an excellent general guide, but they are not infallible and may be sufficiently in error to induce a mariner in a critical position to alter course so as to unwittingly increase the danger of the vessel. Often it is possible, using only those observations made aboard ship, to obtain a sufficiently close approximation to enable the vessel to maneuver to the best advantage.

(276) As previously stated, the presence of an exceptionally long swell is usually the first visible indication of the existence of a tropical cyclone. In deep water it approaches from the general direction of origin (the position of the storm center when the swell was generated).

However, in shoaling water this is a less reliable indication because the direction is changed by refraction, the crests being more nearly parallel to the bottom contours.

(277) When the cirrus clouds appear, their point of convergence provides an indication of the direction of the storm center. If the storm is to pass well to one side of the observer, the point of convergence shifts slowly in the direction of storm movement. If the storm center will pass near the observer, this point remains steady. When the bar becomes visible, it appears to rest upon the horizon for several hours. The darkest part of this cloud is in the direction of the storm center. If the storm is to pass to one side, the bar appears to drift slowly along the horizon. If the storm is heading directly toward the observer, the position of the bar remains fixed. Once within the area of the dense, low clouds, one should observe their direction of movement, which is almost exactly along the isobars, with the center of the storm being 90° from the direction of cloud movement (left of direction of movement in the Northern Hemisphere.)

(278) The winds are probably the best guide to the direction of the center of a tropical cyclone. The circulation is cyclonic, but because of the steep pressure gradient near the center, the winds there blow with greater violence and are more nearly circular than in extratropical cyclones.

(279) According to Buys Ballot's law, an observer who faces into the wind has the center of the low pressure on his right (northern hemisphere) and somewhat behind him. If the wind followed circular isobars exactly, the center would be exactly eight points, or 90°, from dead ahead when facing into the wind. However, the track of the wind is usually inclined somewhat toward the center, so that the angle dead ahead varies between perhaps 8 and 12 points (90° to 135°). The inclination varies in different parts of the same storm. It is least in front of the storm, and greatest in the rear, since the actual wind is the vector sum of that due to the pressure gradient and the motion of the storm along the track. A good average is perhaps 10 points in front, and 11 or 12 points in the rear. These values apply when the storm center is still several hundred miles away. Closer to the center, the wind blows more nearly along the isobars, the inclination being reduced by one or two points at the wall of the eye. Since wind direction usually shifts temporarily during a squall, its direction at this time should not be used for determining the position of the center.

(280) When the center is within radar range, it might be located by this equipment. However, since the radar return is predominately from the rain, results can be deceptive, and other indications should not be neglected.

(281) Distance from the storm center is more difficult to determine than direction. Radar is perhaps the best guide. The rate of fall of the barometer is of some help; this is only a rough indication however, for the rate of fall may be quite erratic and will vary somewhat with the depth of the low at the center, the speed of the storm center along its track, and the stage in the life cycle of the storm.

Maneuvering to avoid the storm center

(282) The safest procedure with respect to tropical cyclones is to avoid them. If action is taken sufficiently early, this is simply a matter of setting a course that will take the vessel well to one side of the probable track of the storm, and then continuing to plot the position of the storm center, as given in the weather bulletins, revising the course as needed. Detailed information on the vulnerability of North Atlantic ports to hurricanes may be found in the Hurricane Havens Handbook for the North Atlantic Ocean published by the Marine Meteorology Division, Naval Research Laboratory, Monterey, CA 93943 and available on the internet at http://www.nrlmry.navy.mil/pubs.htm.

(283) However, such action is not always possible. If one finds himself within the storm area, the proper action to take depends in part upon his position relative to the storm center and its direction of travel. It is customary to divide the circular area of the storm into two parts.

In the northern hemisphere, that part to the right of the storm track (facing in the direction toward which the storm is moving) is called the dangerous semicircle. It is considered dangerous because (1) the actual wind speed is greater than that due to the pressure gradient alone, since it is augmented by the forward motion of the storm, and (2) the direction of the wind and sea is such as to carry a vessel into the path of the storm (in the forward part of the semicircle). The part to the left of the storm track is called the navigable semicircle. In this part, the wind is decreased by the forward motion of the storm, and the wind blows vessels away from the storm track (in the forward part). Because of the greater wind speed in the dangerous semicircle, the seas are higher here than in the navigable semicircle.

(284) A plot of successive positions of the storm center should indicate the semicircle in which a vessel is located. However, if this is based upon weather bulletins, it is not a reliable guide because of the lag between the observations upon which the bulletin is based and the time of reception of the bulletin, with the ever present possibility of a change in the direction of motion of the storm. The use of radar eliminates this lag, but the return is not always a true indication of the center. Perhaps the most reliable guide is thewind.Within the cyclonic circulation, a veering wind (one changing direction to the right in the northern hemisphere and to the left in the southern hemisphere) indicates a position in the dangerous semicircle, and a backing wind (one changing in a direction opposite to a veering wind) indicates a position in the navigable semicircle. However, if a vessel is underway, its motion should be considered. If it is outrunning the storm or pulling rapidly toward one side (which is not difficult during the early stages of a storm, when its speed is low), the opposite effect occurs. This should usually be accompanied by a rise in atmospheric pressure, but if motion of the vessel is nearly along an isobar, this may not be a reliable indication. If in doubt, the safest action is usually to stop long enough to determine definitely the semicircle. The loss in valuable time may be more than offset by the minimizing of the possibility of taking the wrong action and increasing the danger to the vessel. If the wind direction remains steady (for a vessel which has stopped), with increasing speed and falling barometer, the vessel is in or near the path of the storm. If it remains steady with decreasing speed and rising barometer, the vessel is on the storm track, behind the center.

(285) The first action to take if one finds himself within the cyclonic circulation is to determine the position of his vessel with respect to the storm center. While the vessel can still make considerable way through the water, a course should be selected to take it as far as possible from the center. If the vessel can move faster than the storm, it is a relatively simple matter to outrun the storm if sea room permits. But when the storm is faster, the solution is not as simple. In this case, the vessel, if ahead of the storm, will approach nearer to the center. The problem is to select a course that will produce the greatest possible minimum distance. This is best determined by means of a relative movement plot.

(286) As a very general rule, for a vessel in the Northern Hemisphere, safety lies in placing the wind on the starboard bow in the dangerous semicircle and on the starboard quarter in the navigable semicircle. If on the storm track ahead of the storm, the wind should be put about two points on the starboard quarter until the vessel is well within the navigable semicircle, and the rule for that semicircle then followed. With a faster than average vessel, the wind can be brought a little farther aft in each case. However, as the speed of the storm increases along its track, the wind should be brought farther forward. If land interferes with what would otherwise be the best maneuver, the solution should be altered to fit the circumstances. If the speed of the vessel is greater than that of the storm, it is possible for the vessel, if behind the storm, to overtake it. In this case, the only action usually needed is to slow enough to let the storm pull ahead.

(287) In all cases, one should be alert to changes in the direction of movement of the storm center, particularly in the area where the track normally curves toward the pole. If the storm maintains its direction and speed, the ship's course should be maintained as the wind shifts.

(288) If it becomes necessary for a vessel to heave to, the characteristics of the vessel should be considered. A power vessel is concerned primarily with damage by direct action of the sea. A good general rule is to heave to with head to the sea in the dangerous semicircle or stern to the sea in the navigable semicircle. This will result in greatest amount of headway away from the storm

center, and least amount of leeway toward it. If a vessel handles better with the sea astern or on the quarter,

it may be placed in this position in the navigable semicircle or in the rear half of the dangerous semicircle, but never in the forward half of the dangerous semicircle. It has been reported that when the wind reaches hurricane speed and the seas become confused, some ships ride out the storm best if the engines are stopped, and the vessel is permitted to seek its own position. In this way, it is said, the ship rides with the storm instead of fighting against it.

(289) In a sailing vessel, while attempting to avoid a storm center, one should steer courses as near as possible to those prescribed above for power vessels. However, if it becomes necessary for such a vessel to heave to, the wind is of greater concern than the sea. A good general rule always is to heave to on whichever tack permits the shifting wind to draw aft. In the northern hemisphere this is the starboard tack in the dangerous semicircle and the port tack in the navigable semicircle.

Practical rules

(290) When there are indications of a hurricane, vessels should remain in port or seek one if possible. Changes in barometer and wind should be carefully observed and recorded, and every precaution should be taken to avert damage by striking light spars, strengthening moorings, and if a steamer, preparing steam to assist the moorings. In the ports of the southern States hurricanes are generally accompanied by very high tides, and vessels may be endangered by overriding the wharf where moored if the position is at all exposed.

(291) Vessels in the Straits of Florida may not have sea room to maneuver so as to avoid the storm track, and should try to make a harbor, or to stand out of the straits to obtain sea room. Vessels unable to reach a port and having sea room to maneuver usually observe the previously discussed general rules for avoiding the storm center, which, for power-driven vessels, are summarized as follows:

Right or dangerous semicircle

(292) Bring the wind on the starboard bow (045° relative), hold course and make as much way as possible. If obliged to heave to, do so with head to the sea. Left or navigable semicircle

(293) Bring the wind on the starboard quarter (135° relative), hold course and make as much way as possible. If obliged to heave to, do so with stern to the sea.

On storm track,ahead of center

(294) Bring the wind two points on the starboard quarter (157½° relative), hold course and make as much way as possible. When well within the navigable semicircle, maneuver as indicated above.

On storm track, behind center

(295) Avoid the center by the best practicable course, keeping in mind the tendency of tropical cyclones to curve northward and eastward.

Coastal effects

(296) The high winds of a hurricane inflict widespread damage when such a storm leaves the ocean and crosses land. Aids to navigation may be blown out of position or destroyed. Craft in harbours, unless they are properly secured, drag anchor or are blown against obstructions.

Ashore, trees are blown over, houses are damaged, powerlines are blown down, etc. The greatest damage usually occurs in the dangerous semicircle a short distance from the center, where the strongest winds occur. As the storm continues on across land, its fury subsides faster than it would if it had remained over water.

(297) Along the coast, particularly, greater damage may be inflicted by water than by wind. There are at least four sources of water damage. First, the unusually high seas generated by the storm winds pound against shore installations and craft in their way. Second, the continued blowing of the wind toward land causes the water level to increase perhaps 3 to 10 feet above its normal level. This storm tide, which may begin when the storm center is 500 miles or even farther from the shore, gradually increases until the storm passes. The highest storm tides are caused by a slow-moving hurricane of larger diameter, because both of these effects result in greater duration of wind in the same direction. The effect is greatest in a partly enclosed body of water, such as the Gulf of Mexico, where the concave coastline does not readily permit the escape of water. It is least on small islands, which present little obstruction to the flow of water. Third, the furious winds which blow around the wall of the eye often create a ridge of water called a storm surge, which strikes the coast and often

inflicts heavy damage. The effect is similar to that of a Tsunami (seismic sea wave) caused by an earthquake in the ocean floor. Both of these waves are popularly called tidal waves, Storm surges of 20 feet or more have occurred. About 3 or 4 feet of this is due to the decrease of atmosphere pressure, and the rest to winds. Like the damage caused by wind, that due to high seas, the storm tide, and the storm surge is greatest in the dangerous semicircle, near the center. The fourth source of water damage is the heavy rain that accompanies a tropical cyclone. This causes floods that add to the damage caused in other ways.

(298) When proceeding along a shore recently visited by a hurricane, a navigator should remember that time is required to restore aids to navigation which have been blown out of position or destroyed. In some instances the aid may remain but its light or sound apparatus may be inoperative. Landmarks may have been damaged or destroyed.

Wave Heights from Significant Wave Heights (SWH)

Most frequent wave heights: 0.5 x SWH Average wave heights: 0.6 x SWH

Significant wave height (average height of highest 33%) 1.0 x SWH Height of highest 10% of the aves: 1.3 x SWH One wave in 1,175 waves: 1.9 x SWH One wave in 300,000 waves: 2.5 x SWH

(220) This table can be used to project a range of wave heights that might be expected in deep water. If significant wave heights of 10 feet (3 m) are forecast, then the most frequently observed waves should be in the 5- to 6-foot (1.5 to 1.8 m) range while one wave in 100 should reach 17 feet (5.2 m). A giant or rogue wave might reach 25 feet (7.6 m) in these circumstances.

These rogue or "killer" waves occur when the large number of different waves that make up a sea occasionally reinforce each other. This action creates a wave that is much steeper and higher than the surrounding waves. These rogue waves often occur in a stormy sea and are described by mariners who have experienced them as coming out of nowhere and disappearing just as quickly. If significant wave heights are observed at 20 feet (6.1 m), then a rogue wave could reach 50 feet (15.2 m) if the water depth could support it.

(221) Rough sea conditions are usually generated by gales out of the northwest through northeast. Waves greater than 10 feet (3 m) occur about 10 to 15 percent of the time in winter. From fall through spring, wave heights of more than 7 feet (2.1 m) frequently last one day or more; in midwinter they often last 2 days or more.

(222) In addition to coastal storms, cold fronts with rapidly shifting winds can also create dangerous seas.

(223) Steep waves are often more dangerous than high waves with a gentle slope. Waves appear menacing when the ratio of wave height to length reaches about 1/18. They begin to break when this ratio is about 1/10. Steepest waves develop when strong winds first begin to blow or early in a storm's life. The ship no longer rides easily, but is slammed. Steep waves are particularly dangerous to small craft. When wave heights are greater than 5 feet (1.5 m), periods of less than 6 seconds can create problems for boats under 100 feet (under 31 m) long. Waves of 10 feet (3 m) or more with periods of 6 to 10 seconds can affect comfort in 100- to 200-foot (31 to 61 m) vessels. When wind waves reach 20 feet (6.1 m) , they become hazardous to vessels under 200 feet (61 m) long and provide a rough ride for larger ships. Waves moving into shallow water become steeper and break when the depth is about 1.3 times the wave height. Areas such as Cultivator Shoal and Georges Shoal are dangerous in heavy weather. Wave steepness is also increased by tidal currents, particularly when they oppose the wind.

(224) Swells can create problems for larger vessels. In these waters, about one-half of the waves of 10 feet (3 m) or more are swells from distant storms. They are uncomfortable to ships that roll or pitch in sympathy.

Swells with 500- to 1,000-foot (153 to 305 m) wave lengths affect ships of these lengths. When steaming into such swells a resonance is set up until the bow digs into the waves. The resulting pitch will cause more of a power loss than a roll caused by a sea. Swells with wave lengths that range from about three-fourths to twice the ship's length can have this effect. Pitching is heaviest when the ship's speed produces synchronism between the period of encounter and the ship's natural pitching period; this often occurs at or near normal ship speeds.

(225) When running before a following sea, the greatest danger arises when ship speed is equal to that of the waves or when the waves overtake the ship so slowly that an almost static

situation is created with the vessel lying on the wave crest. In this latter case, stability is so reduced that a small vessel could capsize. Waves on the quarter or stern can also result in very poor steering quality. As seas move along the vessel from aft to forward, the rudder is less effective and the boat may be slewed across the face of a sea, filling the decks with water as it broaches. It could lose its stability and capsize, particularly if the boat is trimmed By the head.

Extratropical Cyclones

(202) One of the biggest problems in these waters is the winter storm; the most powerful of these is the "Nor'easter". It generates rough seas, strong winds, and high tides that threaten safety at sea and cause damage in port. These storms do not often come without warning. They are usually well forecasted, whether approaching from the U.S. mainland or from the seas to the south.

(203) Difficulty arises when they develop or deepen explosively off the mid-Atlantic coast. Sometimes called "Hatteras Storms", these lows can grow from small, weak frontal waves to full blown systems in less than 24 hours. Not only can their circulation expand to cover most of the western North Atlantic, but they often accelerate rapidly northeastward. Within the Gulf of Maine, these storms can generate 30-foot waves and hurricane-force winds. Each year more than 40 extratropical systems move across or close to the Gulf of Maine. They average about 2 to 4 per month, but as many as 10 can affect the region in a single month. Most systems are weak, but a few generate gales and rough seas for hundreds of miles, particularly from September through April.

(204) Signals from a distant "Hatteras Storm" include 5-to 10-foot (1.5 to 3 m) swells, with periods of 10 seconds or more, rolling in from the southeast. The most dependable early indicator is falling pressure. A definite weather change is likely if you observe pressure falls exceeding 2 mb every 3 hours. A drop of 5 mb in 3 hours indicates a strong change, while 10 mb in 3 hours warns of an impending extreme event.

(205) As a storm approaches, winds strengthen, clouds thicken and lower, and precipitation begins. Early in the storm's life, wind waves can very quickly become steep. This can make it difficult to reach port, especially when you have to navigate an inlet with treacherous breaking waves. In deeper waters, waves can build to over 20 feet (over 6 m). During winter, the possibility of superstructure icing calls for early action based on the latest forecast and a knowledge of your vessel.

Cold Fronts

(206) These usually approach from west through north. Ahead of the front, winds are usually squally and often blow out of the south through southwest. Cirrus clouds give way to altocumulus or altostratus and nimbostratus, then cumulonimbus. Pressure falls moderately, seas become choppy, and showers, perhaps thunderstorms, occur. With the frontal passage, winds shift rapidly to the west and northwest. Strong gusts and squalls continue. Clearing usually occurs a short distance behind the front as the cold air moves in. Cold fronts can move through the area quite rapidly; their speed varies from about 10 to 20 knots in summer up to 40 knots in winter. From spring through fall, these fronts are often preceded by dense fog.

(207) During the spring and summer when the air ahead of the cold front may be very unstable, a line of thunderstorms, known as a squall line, may develop. These instability lines can form 50 to 300 miles ahead of a fast-moving front. They may even contain tornados or waterspouts and can inflict considerable damage on fishing vessels and small craft.

TROPICAL STORMS

DESCRIPTION AND CAUSES

3500. Introduction

A tropical cyclone is a cyclone originating in the tropics or subtropics. Although it generally resembles the extratropical cyclone of higher latitudes, there are important differences, the principal one being the concentration of a large amount of energy into a relatively small area. Tropical cyclones are infrequent in comparison with middle and high latitude storms, but they have a record of destruction far exceeding that of any other type of storm. Because of their fury, and because they are predominantly oceanic, they merit special attention by mariners.

A tropical storm may have a deceptively small size, and beautiful weather may be experienced only a few hundred miles from the center. The rapidity with which the weather can deteriorate with approach of the storm, and the violence of the fully developed tropical cyclone, are difficult to imagine if they have not been experienced. On his second voyage to the New World, Columbus encountered a tropical storm. Although his vessels suffered no damage, this experience proved valuable during his fourth voyage when his ships were threatened by a fully developed hurricane. Columbus read the signs of an approaching storm from the appearance of a southeasterly swell, the direction of the high cirrus clouds, and the hazy appearance of the atmosphere. He directed his vessels to shelter. The commander of another group, who did not heed the signs, lost most of his ships and more than 500 men perished.

Definitions

Tropical cyclones are classified by form and intensity as they increase in size.

A tropical disturbance is a discrete system of apparently organized convection, generally 100 to 300 miles in diameter, having a nonfrontal migratory character, and having maintained its identity for 24 hours or more. It may or may not be associated with a detectable disturbance of the wind field. It has no strong winds and no closed isobars i.e., isobars that completely enclose the low.

At its next stage of development it becomes a tropical depression. A tropical depression has one or more closed isobars and some rotary circulation at the surface. The highest sustained (1-minute mean) surface wind speed is 33 knots.

The next stage is tropical storm. A tropical storm has closed isobars and a distinct rotary circulation. The highest sustained (1-minute mean) surface wind speed is 34 to 63 knots.

When fully developed, a hurricane or typhoon has closed isobars, a strong and very pronounced rotary circulation, and a sustained (1-minute mean) surface wind speed of 64 knots or higher.

3502. <u>**Areas of Occurrence**</u>

Tropical cyclones occur almost entirely in six distinct areas, four in the Northern Hemisphere and two in the

Southern Hemisphere, as shown in Figure 3502. The name by which the tropical cyclone is commonly known varies somewhat with the locality.

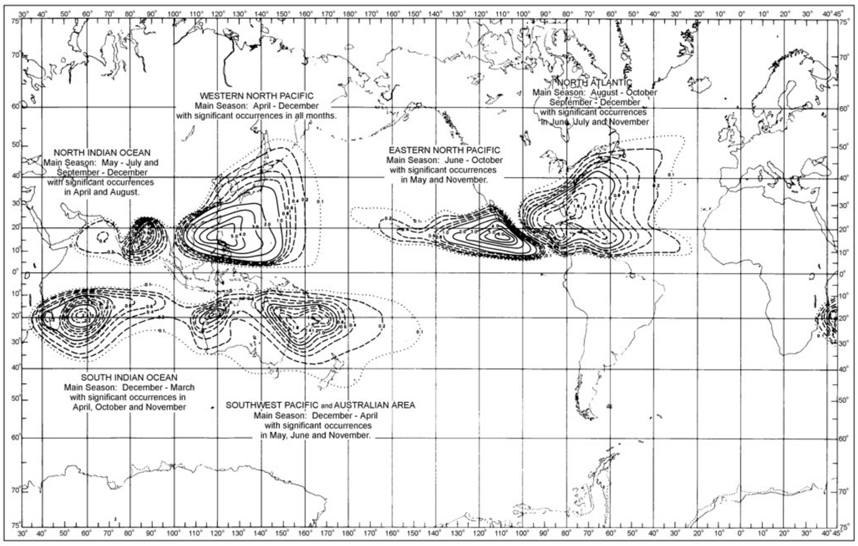
1. North Atlantic. A tropical cyclone with winds of 64 knots or greater is called a hurricane.
2. Eastern North Pacific. The name hurricane is used as in the North Atlantic.
3. Western North Pacific. A fully developed storm with winds of 64 knots or greater is called a typhoon or, locally in the Philippines, a baguio.
4. North Indian Ocean. A tropical cyclone with winds of 34 knots or greater is called a cyclonic storm.
5. South Indian Ocean. A tropical cyclone with winds of 34 knots or greater is called a cyclone.
6. Southwest Pacific and Australian Area. The name cyclone is used as in the South Indian Ocean. A severe tropical cyclone originating in the Timor Sea and moving southwest and then southeast across the interior of northwestern Australia is called a willywilly.

Tropical cyclones have not been observed in the South Atlantic or in the South Pacific east of 140°W.

<u>**Origin, Season and Frequency**</u>

Origin, season, and frequency of occurrence of the tropical cyclones in the six areas are as follows:

<u>North Atlantic: Tropical</u> cyclones can affect the entire North Atlantic Ocean in any month. However, they are mostly a threat south of about 35°N from June through November; August, September, and October are the months of highest incidence. See Figure 3503b. About 9 or 10 tropical cyclones (tropical storms and hurricanes) form each season; 5 or 6 reach hurricane intensity (winds of 64 knots and higher). A few hurricanes have generated winds estimated as high as 200 knots. Early and late season storms usually develop west of 50°W; during August and September, this spawning ground extends to the Cape Verde Islands. These storms usually move westward or west northwestward at speeds of less than 15 knots in the lower latitudes. After moving into the northern Caribbean or Greater Antilles regions, they usually either move toward the Gulf of Mexico or recurve and accelerate in the North Atlantic. Some will recurve after reaching the Gulf of Mexico, while others will continue westward to a landfall in Texas or Mexico.



Eastern North Pacific: The season is from June through October, although a storm can form in any month.

An average of 15 tropical cyclones form each year with about 6 reaching hurricane strength. The most intense storms are often the early- and late-season ones; these form close to the coast and far south. Mid season storms form anywhere in a wide band from the Mexican-Central American coast to the Hawaiian Islands. August and September are the months of highest incidence. These storms differ from their North Atlantic counterparts in that they are usually smaller in size. However, they can be just as intense.

<u>Western North Pacific:</u> More tropical cyclones form in the tropical western North Pacific than anywhere else in the world. More than 25 tropical storms develop each year, and about 18 become typhoons. These typhoons are the largest and most intense tropical cyclones in the world. Each year an average of five generate maximum winds over 130 knots; circulations covering more than 600 miles in diameter are not uncommon. Most of these storms form east of the Philippines, and move across the Pacific toward the Philippines, Japan, and China; a few storms form in the South China Sea. The season extends from April through December. However, tropical cyclones are more common in the off-season months in this area than anywhere else. The peak of the season is July through October, when nearly 70 percent of all typhoons develop. There is a noticeable seasonal shift in storm tracks in this region. From July through September, storms move north of the Philippines and recurve, while early- and late-season typhoons move on a more westerly track through the Philippines before recurving.

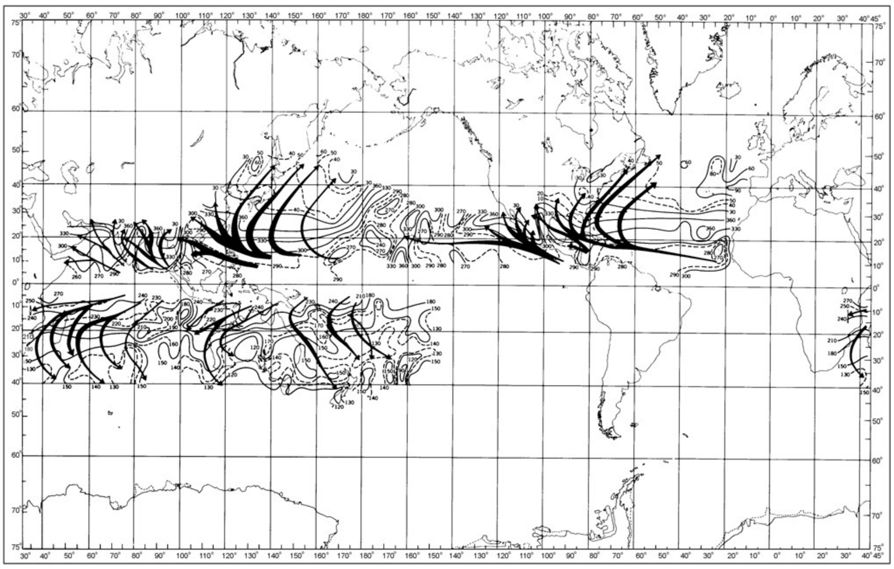


Figure 3503a. Storm tracks.The width of the arrow indicates the approximate frequency of storms; the wider the arrow the higher the frequency. Isolines on the base map show the resultant direction toward which storms moved. Data for the entire year has been summarized for this figure.

North Indian Ocean—Tropical cyclones develop in the Bay of Bengal and Arabian Sea during the spring and fall. Tropical cyclones in this area form between latitudes 8°N and 15°N, except from June through September, when the little activity that does occur is confined north of about 15°N. These storms are usually short-lived and weak; however, winds of 130 knots have been encountered. They often develop as disturbances along the Intertropical Convergence Zone (ITCZ); this inhibits summertime development, since the ITCZ is usually over land during this monsoon season. However, it is sometimes displaced southward, and when this occurs, storms will form over the monsoon-flooded plains of Bengal. On the average, six cyclonic storms form each year. These include two storms that generate winds of 48 knots or greater. Another 10 tropical cyclones never develop beyond tropical depressions. The Bay of Bengal is the area of highest incidence. However, it is not unusual for a storm to move across southern India and reintensify in the Arabian Sea.

This is particularly true during October, the month of highest incidence during the tropical cyclone season. It is also during this period that torrential rains from these storms, dumped over already rain-soaked areas, cause disastrous floods.

South Indian Ocean—Over the waters west of 100°E, to the east African coast, an average of 11 tropical cyclones (tropical storms and hurricanes) form each season, and about 4 reach hurricane intensity. The season is from December through March, although it is possible for a storm to form in any month. Tropical cyclones in this region usually form south of 10°S. The latitude of recurvature usually migrates from about 20°S in January to around 15°S in April. After crossing 30°S, these storms sometimes become intense extratropical lows.

Southwest Pacific and Australian Area—

These tropical waters spawn an annual average of 15 tropical cyclones 4, of which reach hurricane intensity. The season extends from about December through April, although storms can form in any month. Activity is widespread in January and February, and it is in these months that tropical cyclones are most likely to affect Fiji, Samoa, and the other eastern islands. Tropical cyclones usually form in the waters from 105°E to 160°W, between 5° and 20°S.

Storms affecting northern and western Australia often develop in the Timor or Arafura Sea, while those that affect the east coast form in the Coral Sea. These storms are often small, but can develop winds in excess of 130 knots. New Zealand is sometimes reached by decaying Coral Sea storms, and occasionally by an intense hurricane. In general, tropical cyclones in this region move southwestward and then recurve southeastward.

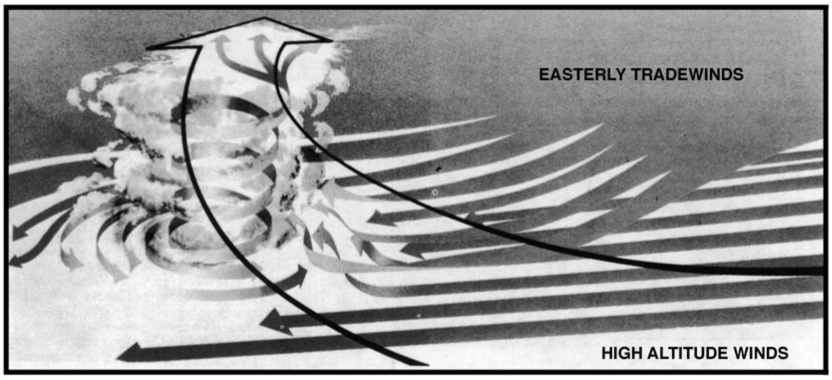


Figure 3504. Pumping action of high-altitude winds.

ANATOMY OF TROPICAL CYCLONES

3504. **Formation**

Hurricane formation was once believed to result from an intensification of convective forces which produce the towering cumulonimbus clouds of the doldrums. This view of hurricane generation held that surface heating caused warm moist air to ascend convectively to levels where condensation produced cumulonimbus clouds, which, after an inexplicable drop in atmospheric pressure, coalesced and were spun into a cyclonic motion by Coriolis force.

This hypothesis left much unexplained. Although some hurricanes develop from disturbances beginning in the doldrums, very few reach maturity in that region. Also, the high incidence of seemingly ideal convective situations does not match the low incidence of Atlantic hurricanes. Finally, the hypothesis did not explain the drop in atmospheric pressure, so essential to development of hurricane-force winds.

There is still no exact understanding of the triggering mechanism involved in hurricane generation, the balance of conditions needed to generate hurricane circulation, and the relationships between large- and small-scale atmospheric processes. But scientists today, treating the hurricane system as an atmospheric heat engine, present a more comprehensive and convincing view.

They begin with a starter mechanism in which either internal or external forces intensify the initial disturbance. The initial disturbance becomes a region into which lowlevel air from the surrounding area begins to flow, accelerating the convection already occurring inside the disturbance. The vertical circulation becomes increasingly well organized as water vapor in the ascending moist layer is condensed (releasing large amounts of heat energy to drive the wind system), and as the system is swept into a counterclockwise cyclonic spiral. But this incipient hurricane would soon fill up because of inflow at lower levels, unless the chimney in which converging air surges upward is provided the exhaust mechanism of high-altitude winds.

Monthly values cannot be combined because single storms overlapping two months were counted once in each month and once in the annual.

These high-altitude winds pump ascending air out of the cyclonic system, into a high-altitude anticyclone, which transports the air well away from the disturbance, before sinking occurs. See Figure 3504. Thus, a large scale vertical circulation is set up, in which low-level air is spiraled up the cyclonic twisting of the disturbance, and, after a trajectory over the sea, returned to lower altitudes some distance from the storm. This pumping action-and the heat released by the ascending air may account for the sudden drop of atmospheric pressure at the surface, which produces the steep pressure gradient along which winds reach hurricane proportions.

It is believed that the interaction of low-level and high altitude wind systems determines the intensity the hurricane will attain. If less air is pumped out than converges at low levels, the system will fill and die out. If more is pumped out than flows in, the circulation will be sustained and will intensify.

Scientists have found that any process which increases the rate of low-level inflow is favorable for hurricane development, provided the inflowing air carries sufficient heat and moisture to fuel the hurricane's power system. It has also been shown that air above the developing disturbance, at altitudes between 20,000 and 40,000 feet, increases 1° to 3°F in temperature about 24 hours before the disturbance develops into a hurricane. But it is not known whether lowlevel

inflow and high-level warming cause hurricanes. They could very well be measurable symptoms of another effect which actually triggers the storm's increase to hurricane intensity.

The view of hurricanes as atmospheric engines is necessarily a general one. The exact role of each contributor is not completely understood. The engine seems to be both inefficient and unreliable; a myriad of delicate conditions must be satisfied for the atmosphere to produce a hurricane.

Their relative infrequency indicates that many potential hurricanes dissipate before developing into storms.

Portrait of a Hurricane

In the early life of the hurricane, the spiral covers an area averaging 100 miles in diameter with winds of 64 knots and greater, and spreads gale-force winds over a 400- mile diameter. The cyclonic spiral is marked by heavy cloud bands from which torrential rains fall, separated by areas of light rain or no rain at all. These spiral bands ascend in decks of cumulus and cumulonimbus clouds to the convective limit of cloud formation, where condensing water vapor is swept off as ice-crystal wisps of cirrus clouds. See Figure 3505. Thunderstorm electrical activity is observed in these bands, both as lightning and as tiny electrostatic discharges.

In the lower few thousand feet, air flows in through the cyclone, and is drawn upward through ascending columns of air near the center. The size and intensity decrease with altitude, the cyclonic circulation being gradually replaced above 40,000 feet by an anticyclonic circulation centered hundreds of miles away, which is the exhaust system of the hurricane heat engine.

At lower levels, where the hurricane is more intense, winds on the rim of the storm follow a wide pattern, like the slower currents around the edge of a whirlpool; and, like those currents, these winds accelerate as they approach the center of the vortex. The outer band has light winds at the rim of the storm, perhaps no more than 25 knots; within 30 miles of the center, winds may have velocities exceeding 130 knots. The inner band is the region of maximum wind velocity, where the storm's worst winds are felt, and where ascending air is chimneyed upward, releasing heat to drive the storm. In most hurricanes, these winds reach 85 knots, and more than 170 knots in severe storms.

In the hurricane, winds flow toward the low pressure in the warm, comparatively calm core. There, converging air is whirled upward by convection, the mechanical thrusting of other converging air, and the pumping action of highaltitude circulations. This spiral is marked by the thick cloud walls curling inward toward the storm center, releasing heavy precipitation and enormous quantities of heat energy. At the center, surrounded by a band in which this strong vertical circulation is greatest, is the eye of the hurricane.

On the average, eye diameter is about 14 miles, although diameters of 25 miles are not unusual. From the heated tower of maximum winds and cumulonimbus clouds, winds diminish rapidly to something less than 15 miles per hour in the eye; at the opposite wall, winds increase again, but come from the opposite direction because of the cyclonic circulation of the storm. This sudden transformation of storm into comparative calm, and from calm into violence from another quarter is spectacular.

The eye's abrupt existence in the midst of opaque rain squalls and hurricane winds, the intermittent bursts of blue sky and sunlight through light clouds in the core of the cyclone, and the galleried walls of cumulus and cumulonimbus clouds are unforgettable.

Every hurricane is individual, and the more or less orderly circulation described here omits the extreme variability and instability within the storm system. Pressure and temperature gradients fluctuate wildly across the storm as the hurricane maintains its erratic life. If it is an August storm, its average life expectancy is 12 days; if a July or November storm, it lives an average of 8 days.

3506. Life of a Tropical Cyclone

Reports from ships in the vicinity of an easterly wave (a westward-moving trough of low pressure embedded in deep easterlies) may indicate that the atmospheric pressure in the region has fallen more than 5 hectopascals (hPa) in the past 24 hours. This is cause for alarm, because in the Tropics pressure varies little; the normal diurnal pressure change is only about 3 hPa. Satellite pictures may indicate thickening middle and high clouds. Squalls are reported ahead of the easterly wave, and wind reports indicate a cyclonic circulation is forming. The former easterly wave, now classified a tropical disturbance, is moving westward at 10 knots under the canopy of a large high-pressure system aloft. Sea surface temperatures in the vicinity are in the 28°-30°C range.

Within 48 hours winds increase to 25 knots near the center of definite circulation, and central pressure has dropped below 1000 hPa. The disturbance is now classified as a tropical depression. Soon the circulation extends out to 100 miles and upward to 20,000 feet. Winds near the center increase to gale force, central pressure falls below 990 hPa, and towering cumulonimbus clouds shield a developing eye; a tropical storm has developed.

Satellite photographs now reveal a tightly organized tropical cyclone, and reconnaissance reports indicate maximum winds of 80 knots around a central pressure of 980 hPa; a hurricane has developed. A ship to the right (left in the Southern Hemisphere) of the hurricane's center (looking toward the direction of storm movement) reports 30- foot seas. The hurricane is rapidly maturing as it continues westward.

A few days later the hurricane reaches its peak. The satellite photographs show a textbook picture (Figure 3506), as 120-knot winds roar around a 940-hPa pressure center; hurricane-force winds extend 50 miles in all directions, and seas are reported up to 40 feet. There is no

Figure 3505. Cutaway view of a hurricane greatly exaggerated in vertical dimension. Actual hurricanes are less than 50,000 feet high and may have a diameter of several hundred miles.

further deepening now, but the hurricane begins to expand.

In 2 days, gales extend out to 200 miles, and hurricane winds out to 75 miles. Then the hurricane slows and begins to recurve; this turning marks the beginning of its final phase.

The hurricane accelerates, and, upon reaching temperate latitudes, it begins to lose its tropical characteristics.

The circulation continues to expand, but now cold air is intruding. (Cold air, cold water, dry air aloft, and land aid in the decay of a tropical cyclone.) The winds gradually abate as the concentrated storm disintegrates. The warm core survives for a few more days before the transformation to a large extratropical low-pressure system is complete.

Not all tropical cyclones follow this average pattern. Most falter in the early stages, some dissipate over land, and others remain potent for several weeks.

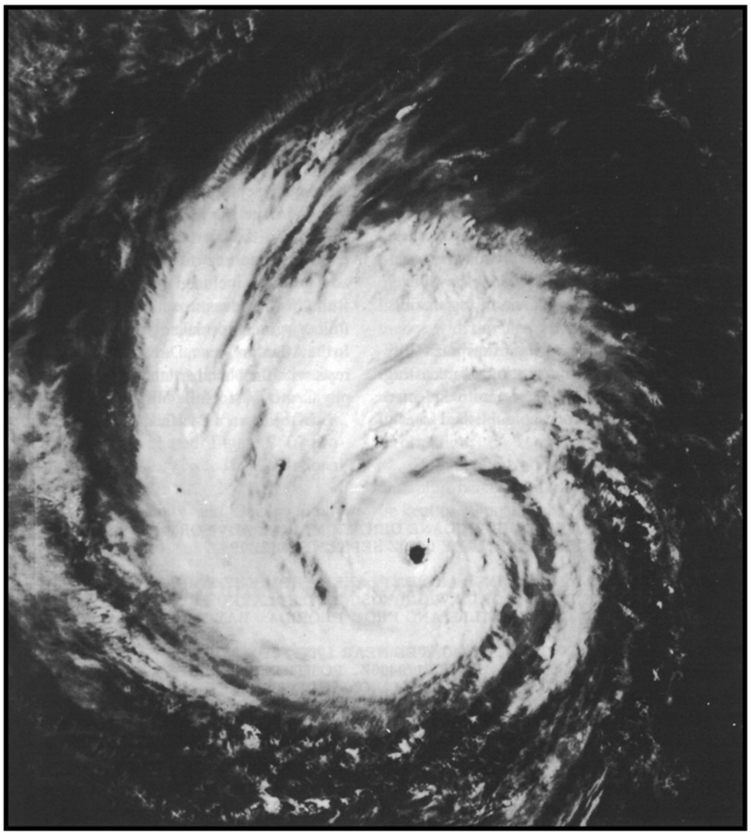


Figure 3506. Satellite photograph of a hurricane.

FORECASTING AND PREDICTING TROPICAL CYCLONES

3507. Weather Broadcasts and Radiofacsimile

The marine weather broadcast and radiofacsimile weather maps are the most important tools for avoiding tropical cyclones. These broadcasts, covering all tropical areas, provide information about the tropical cyclone’s location, maximum winds and seas, and future conditions expected.

The U S. Navy, the National Oceanic and Atmospheric Administration, and the U.S. Air Force have developed a highly effective surveillance system for the tropical cyclone-prone areas of the world. Routine and special weather reports enable accurate detection, location, and tracking of tropical cyclones. International cooperation is effective. These reports originate from land stations, ships at sea, aircraft, weather satellite imagery, and specially instrumented weather reconnaissance aircraft of National Oceanic and Atmospheric Administration and the U.S. Air Force. Data buoys, both moored and drifting, provide another source of information.

The tropical warning services have three principal functions:

1. Collection and analysis of data
2. Preparation of timely and accurate warnings
3. The distribution of advisories

To provide timely and accurate information and warnings regarding tropical cyclones, the oceans have been divided into overlapping geographical areas of responsibility.

For detailed information on the areas of responsibility of the countries participating in the international forecasting and warning program, and radio aids, refer to Selected Worldwide Marine Weather Broadcasts, published jointly by the Naval Meteorology and Oceanography Command and the National Weather Service.

Although the areas of forecasting responsibility are fairly well defined for the Department of Defense, the international and domestic civilian system provides many overlaps and is dependent upon qualitative factors. For example, when a tropical storm or hurricane is travelling westward and crosses 35°W longitude, the continued issuance of forecasts and warnings to the general public, shipping interests, etc., becomes the responsibility of the National Hurricane Center of the National Weather Service at Miami, Florida. When a tropical storm or hurricane crosses 35°Wlongitude traveling from west to east, the National Hurricane Center ceases to issue formal public advisories, but will issue marine bulletins on any dangerous tropical cyclone in the North Atlantic, if it is of importance or constitutes a threat to shipping and other interests. These advisories are included in National Weather Service Marine Bulletins broadcast to ships over radio station NAM Norfolk, Virginia. Special advisories may be issued at any time.

In the Atlantic Ocean, Department of Defense responsibility rests with the Naval Atlantic Meteorology and Oceanography Center in Norfolk, Virginia.

In the eastern Pacific east of longitude 140°W, responsibility for the issuance of tropical storm and hurricane advisories and warnings for the general public, merchant shipping, and other interests rests with the National Weather Service Eastern Pacific Hurricane Center, San Francisco, California. The Department of Defense responsibility rests with the Naval Pacific Meteorology and Oceanography Center, Pearl Harbor, Hawaii. Formal advisories and warnings are issued daily and are included in the marine bulletins broadcast by radio stations KFS, NMC, and NMQ.

In the central Pacific (between the meridian and longitude 140°W), the civilian responsibility rests with the National Weather Service Central Pacific Hurricane Center, Honolulu, Hawaii. Department of Defence responsibility rests with the Naval Pacific Meteorology and Oceanography Centre in Pearl Harbor. Formal tropical storm and hurricane advisories and warnings are issued daily and are included in the marine bulletins broadcast by radio station NMO and NRV.

Tropical cyclone messages contain position of the storm, intensity, direction and speed of movement, and a description of the area of strong winds. Included is a forecast of future movement and intensity. When the storm is likely to affect any land area, details on when and where it will be felt, and data on tides, rain, floods, and maximum winds are also included. Figure 3507 provides an example of a marine advisory issued by the National Hurricane Center.

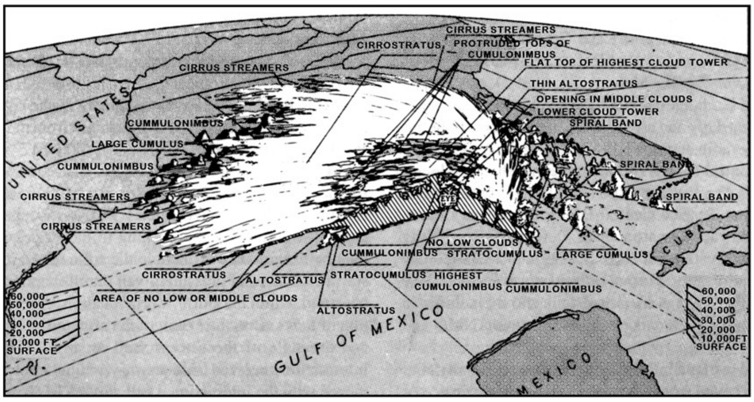
The Naval Pacific Meteorology and Oceanography Center Center-West/Joint Typhoon Warning Center (NPMOC- W/JTWC) in Guam is responsible for all U.S. tropical storm and typhoon advisories and warnings from the 180th meridian westward to the mainland of Asia. A secondary area of responsibility extends westward to longitude 90°E. Whenever a tropical cyclone is observed in the western North Pacific area, serially numbered warnings, bearing an “immediate” precedence are broadcast from the NPMOC-W/JTWC at 0000, 0600, 1200, and 1800 GMT.

The responsibility for issuing gale and storm warnings for the Indian Ocean, Arabian Sea, Bay of Bengal, Western Pacific, and South Pacific rests with many countries.

In general, warnings of approaching tropical cyclones will include the following information: storm type, central pressure given in hPa, wind speed observed within the storm, storm location, speed and direction of movement, the extent of the affected area, visibility, and the state of the sea, as well as any other pertinent information received. All storm warning messages commence with the international call sign “TTT.”

These warnings are broadcast on specified radio frequency bands immediately upon receipt of the information and at specific intervals thereafter. Generally, the broadcast interval is every 6 to 8 hours, depending upon receipt of new information.

Bulletins and forecasts are excellent guides to the present and future behavior of the tropical cyclone, and a plot should be kept of all positions.



AVOIDING TROPICAL CYCLONES

Approach and Passage of a Tropical Cyclone

An early indication of the approach of a tropical cyclone is the presence of a long swell. In the absence of a tropical cyclone, the crests of swell in the deep waters of the Atlantic pass at the rate of perhaps eight per minute. Swell generated by a hurricane is about twice as long, the crests passing at the rate of perhaps four per minute. Swell may be observed several days before arrival of the storm.

When the storm center is 500 to 1,000 miles away, the barometer usually rises a little, and the skies are relatively clear. Cumulus clouds, if present at all, are few in number and their vertical development appears suppressed. The barometer usually appears restless, pumping up and down a few hundredths of an inch.

As the tropical cyclone comes nearer, a cloud sequence begins which resembles that associated with the approach of a warm front in middle latitudes. Snow-white, fibrous “mare’s tails” (cirrus) appear when the storm is about 300 to 600 miles away. Usually these seem to converge, more or less, in the direction from which the storm is approaching.

This convergence is particularly apparent at about the time of sunrise and sunset.

Shortly after the cirrus appears, but sometimes before, the arometer starts a long, slow fall. At first the fall is so gradual that it only appears to alter somewhat the normal daily cycle (two maxima and two minima in the Tropics).

As the rate of fall increases, the daily pattern is completely lost in the more or less steady fall.

The cirrus becomes more confused and tangled, and then gradually gives way to a continuous veil of cirrostratus. Below this veil, altostratus forms, and then stratocumulus.

These clouds gradually become more dense, and as they do so, the weather becomes unsettled. A fine, mist-like rain begins to fall, interrupted from time to time by rain showers.

The barometer has fallen perhaps a tenth of an inch.

As the fall becomes more rapid, the wind increases in gustiness, and its speed becomes greater, reaching perhaps 22 to 40 knots (Beaufort 6-8). On the horizon appears a dark wall of heavy cumulonimbus, called the bar of the storm.

This is the heavy bank of clouds comprising the main mass of the cyclone. Portions of this heavy cloud become detached from time to time, and drift across the sky, accompanied by rain squalls and wind of increasing speed.

Between squalls, the cirrostratus can be seen through breaks in the stratocumulus.

As the bar approaches, the barometer falls more rapidly and wind speed increases. The seas, which have been gradually mounting, become tempestuous. Squall lines, one after the other, sweep past in ever increasing number and intensity.

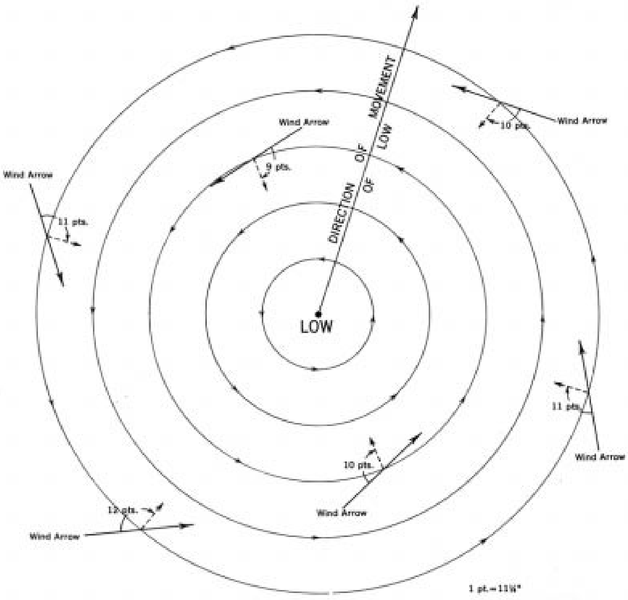
With the arrival of the bar, the day becomes very dark, squalls become virtually continuous, and the barometer falls precipitously, with a rapid increase in wind speed. The center may still be 100 to 200 miles away in a fully developed tropical cyclone. As the center of the storm comes closer, the ever-stronger wind shrieks through the rigging, and about the superstructure of the vessel. As the center approaches, rain falls in torrents. The wind fury increases. The seas become mountainous. The tops of huge waves are blown off to mingle with the rain and fill the air with water. Visibility is virtually zero in blinding rain and spray. Even the largest and most seaworthy vessels become virtually unmanageable, and may sustain heavy damage.

Less sturdy vessels may not survive. Navigation virtually stops as safety of the vessel becomes the only consideration. The awesome fury of this condition can only be experienced. Words are inadequate to describe it.

If the eye of the storm passes over the vessel, the winds suddenly drop to a breeze as the wall of the eye passes. The rain stops, and the skies clear sufficiently to permit the Sun or stars to shine through holes in the comparatively thin cloud cover. Visibility improves. Mountainous seas approach from all sides in complete confusion. The barometer reaches its lowest point, which may be 11/2 or 2 inches below normal in fully developed tropical cyclones.

As the wall on the opposite side of the eye arrives, the full fury of the wind strikes as suddenly as it ceased, but from the opposite direction. The sequence of conditions that occurred during approach of the storm is reversed, and passes more quickly, as the various parts of the storm are not as wide in the rear of a storm as on its forward side.

Typical cloud formations associated with a hurricane are shown in Figure 3508.



3509. **Locating the Center of a Tropical Cyclone**

If intelligent action is to be taken to avoid the full fury of a tropical cyclone, early determination of its location and direction of travel relative to the vessel is essential. The bulletins and forecasts are an excellent general guide, but they are not infallible, and may be sufficiently in error to induce

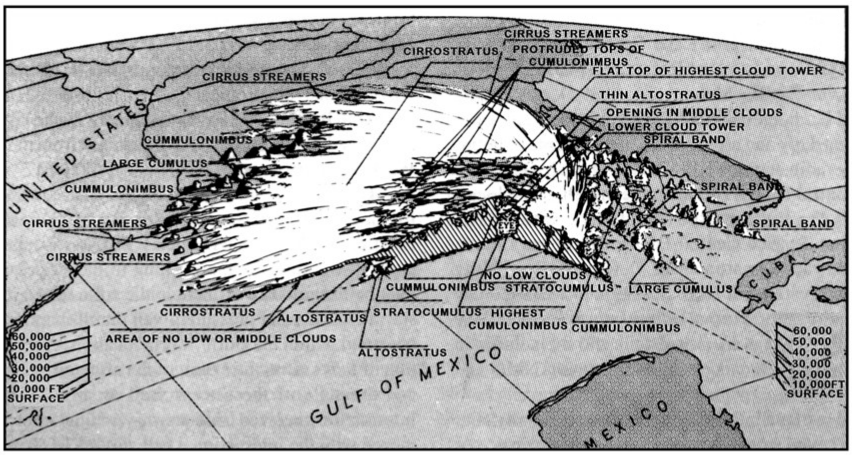


Figure 3508. Typical hurricane cloud formations.

a mariner in a critical position to alter course so as to unwittingly increase the danger to his vessel. Often it is possible, using only those observations made aboard ship, to obtain a sufficiently close approximation to enable the vessel to maneuver to the best advantage.

The presence of an exceptionally long swell is usually the first visible indication of the existence of a tropical cyclone. In deep water it approaches from the general direction of origin (the position of the storm center when the swell was generated). However, in shoaling water this is a less reliable indication because the direction is changed by refraction, the crests being more nearly parallel to the bottom contours.

When the cirrus clouds appear, their point of convergence provides an indication of the direction of the storm center. If the storm is to pass well to one side of the observer, the point of convergence shifts slowly in the direction of storm movement. If the storm center will pass near the observer, this point remains steady. When the bar becomes visible, it appears to rest upon the horizon for several hours. The darkest part of this cloud is in the direction of the storm center. If the storm is to pass to one side, the bar appears to drift slowly along the horizon. If the storm is heading directly toward the observer, the position of the bar remains fixed. Once within the area of the dense, low clouds, one should observe their direction of movement, which is almost exactly along the isobars, with the center of the storm being 90° from the direction of cloud movement (left of direction of movement in the Northern Hemisphere, and right in the Southern Hemisphere).

The winds are probably the best guide to the direction of the center of a tropical cyclone. The circulation is cyclonic, but because of the steep pressure gradient near the center, the winds there blow with greater violence and are more nearly circular than in extratropical cyclones.

According to Buys Ballot's law, an observer whose back is to the wind has the low pressure on his left in the Northern Hemisphere, and on his right in the Southern Hemisphere.

If the wind followed circular isobars exactly, the center would be exactly 90° from behind when facing away from the wind. However, the track of the wind is usually inclined somewhat toward the center, so that the angle from

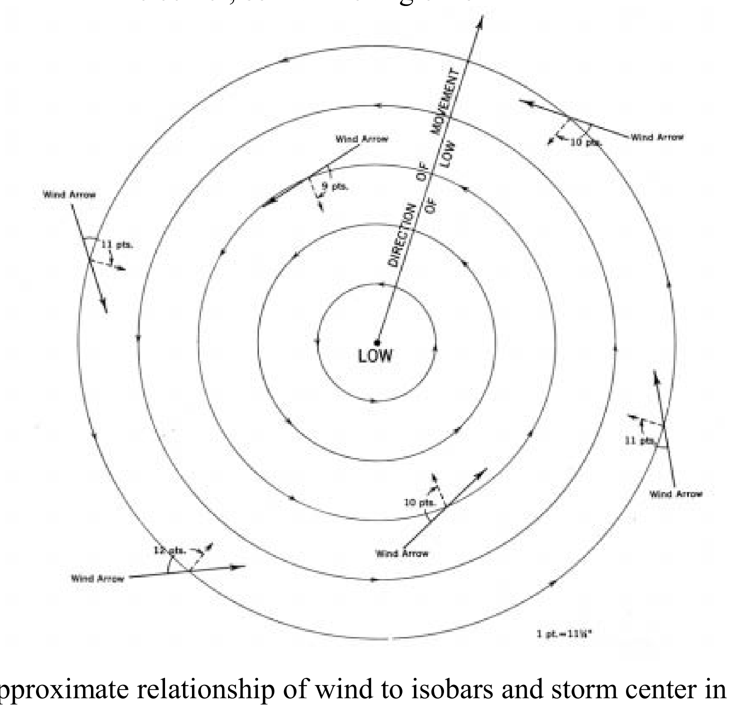


Figure 3509a. Approximate relationship of wind to isobars and storm center in the Northern Hemisphere.

dead astern varies between perhaps 90° to 135°. The inclination varies in different parts of the same storm. It is least in front of the storm, and greatest in the rear, since the actual wind is the vector sum of the pressure gradient and the motion of the storm along the track. A good average is perhaps 110° in front, and 120-135° in the rear. These values apply when the storm center is still several hundred miles away.

Closer to the center, the wind blows more nearly along the isobars, the inclination being reduced by one or two points at the wall of the eye. Since wind direction usually shifts temporarily during a squall, its direction at this time should not be used for determining the position of the center.

When the center is within radar range, it will probably be visible on the scope. However, since the radar return is predominantly from the rain, results can be deceptive, and other indications should not be neglected. Figure 3509b shows a radar PPI presentation of a tropical cyclone. If the eye is out of range, the spiral bands (Figure 3509b) may indicate its direction from the vessel. Tracking the eye or upwind portion of the spiral bands enables determining the direction and speed of movement; this should be done for at least 1 hour because the eye tends to oscillate. The tracking of individual cells, which tend to move tangentially around the eye, for 15 minutes or more, either at the end of the band or between bands, will provide an indication of the wind speed in that area of the storm.

Distance from the storm center is more difficult to determine than direction. Radar is perhaps the best guide. However, the rate of fall of the barometer is some indication.

Statistical Analysis of Barometric Pressure

The lowest-sea-level pressure ever recorded was 877 hPa in typhoon Ida, on September 24, 1958. The observation was taken by a reconnaissance aircraft dropsonde, some 750 miles east of Luzon, Philippines. This observation was obtained again in typhoon Nora on October 6, 1973. The lowest barometric reading of record

for the United States is 892.3 hPa, obtained during a hurricane at Lower Matecumbe Key, Florida, in September 1935. In hurricane Camille in 1969, a 905 hPa pressure was measured by reconnaissance aircraft. During a 1927 typhoon, the S.S. Sapoeroea recorded a pressure of 886.6 hPa, the lowest sea-level pressure reported from a ship.

Pressure has been observed to drop more than 33 hPa per hour, with a pressure gradient amounting to a change of 3.7 hPa per mile.

A method for alerting the mariner to possible tropical cyclone formation involves a statistical comparison of observed weather parameters with the climatology (30 year averaged conditions) for those parameters. Significant fluctuations away from these average conditions could mean the onset of severe weather. One such statistical method involves a comparison of mean surface pressure in the tropics with the standard deviation (s.d.) of surface pressure. Any significant deviation from the norm could indicate proximity to a tropical cyclone. Analysis shows that surface pressure can be expected to be lower than the mean minus 1 s.d. less than 16% of the time, lower than the mean minus 1.5 s.d. less than 7% of the time, and lower than the mean minus 2 s.d. less than 3% of the time.

Comparison of the observed pressure with the mean will indicate how unusual the present conditions are. As an example, assume the mean surface pressure in the South China Sea to be about 1005 mb during August with a s.d. of about 2 mb. Therefore, surface pressure can be expected to fall below 1003 mb about 16% of the time and below 1000 mb about 7% of the time. Ambient pressure any lower than that would alert the mariner to the possible onset of heavy weather. Charts showing the mean surface pressure and the s.d. of surface pressure for various global regions can be found in the U.S. Navy Marine Climatic Atlas of the World.

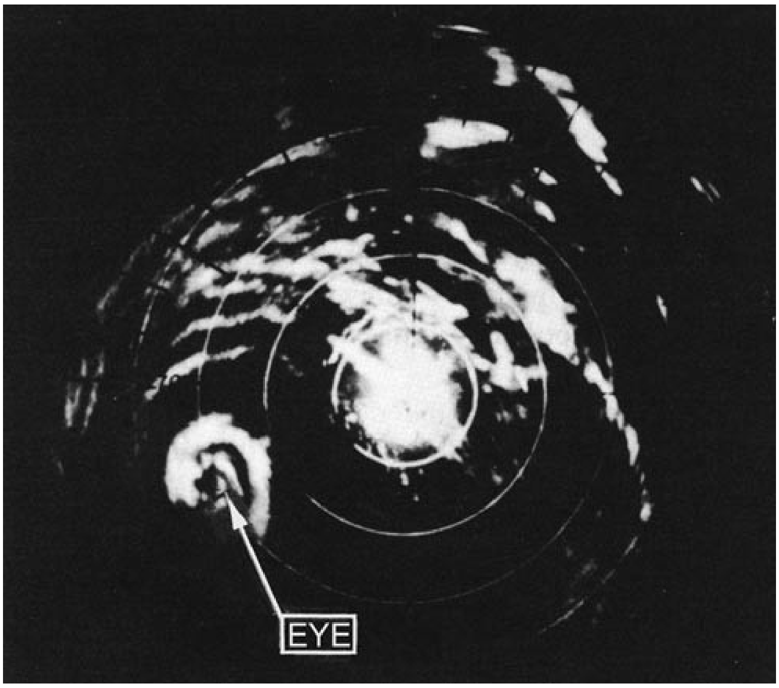


Figure 3509b. Radar PPI presentation of a tropical cyclone.

Maneuvering to Avoid the Storm Center

The safest procedure with respect to tropical cyclones is to avoid them. If action is taken sufficiently early, this is simply a matter of setting a course that will take the vessel well to one side of the probable track of the storm, and then continuing to plot the positions of the storm center as given in the weather bulletins, revising the course as needed.

However, this is not always possible. If the ship is found to be within the storm area, the proper action to take depends in part upon its position relative to the storm center and its direction of travel. It is customary to divide the circular area of the storm into two parts.

In the Northern Hemisphere, that part to the right of the storm track (facing in the direction toward which the storm is moving) is called the dangerous semicircle. It is considered dangerous because (1) the actual wind speed is greater than that due to the pressure gradient alone, since it is augmented by the forward motion of the storm, and (2) the direction of the wind and sea is such as to carry a vessel into the path of the storm (in the forward part of the semicircle).

The part to the left of the storm track is called the less dangerous semicircle, or navigable semicircle. In this part, the wind is decreased by the forward motion of the storm, and the wind blows vessels away from the storm track (in the forward part). Because of the greater wind speed in the dangerous semicircle, the seas are higher than in the less dangerous semicircle. In the Southern Hemisphere, the dangerous semicircle is to the left of the storm track, and the less dangerous semicircle is to the right of the storm track.

A plot of successive positions of the storm center should indicate the semicircle in which a vessel is located. However, if this is based upon weather bulletins, it may not be a reliable guide because of he lag between the observations upon which the bulletin is based and the time of reception of the bulletin, with the ever-present possibility of a change in the direction of the storm. The use of radar eliminates this lag at short range, but the return may not be a true indication of the center. Perhaps the most reliable guide is the wind. Within the cyclonic circulation, a wind shifting to the right in the northern hemisphere and to the left in the southern hemisphere indicates the vessel is probably in the dangerous semicircle. A steady wind shift opposite to this indicates the vessel is probably in the less dangerous semicircle.

However, if a vessel is underway, its own motion should be considered. If it is outrunning the storm or pulling rapidly toward one side (which is not difficult during the early stages of a storm, when its speed is low), the opposite effect occurs. This should usually be accompanied by a rise in atmospheric pressure, but if motion of the vessel is nearly along an isobar, this may not be a reliable indication. If in doubt, the safest action is usually to stop long enough to define the proper semicircle. The loss in time may be more than offset by the minimizing of the possibility of taking the wrong action, increasing the danger to the vessel. If the wind direction remains steady (for a vessel which is stopped), with increasing speed and falling barometer, the vessel is in or near the path of the storm. If it remains steady with decreasing speed and rising barometer, the vessel is near the storm track, behind the center.

The first action to take if the ship is within the cyclonic circulation is to determine the position of his vessel with respect to the storm center. While the vessel can still make considerable way through the water, a course should be selected to take it as far as possible from the center. If the vessel can move faster than the storm, it is a relatively simple matter to outrun the storm if sea room permits. But when the storm is faster, the solution is not as simple. In this case, the vessel, if ahead of the storm, will approach nearer to the center. The problem is to select a course that will produce the greatest possible minimum distance. This is best determined by means of a relative movement plot, as shown in the following example solved on a maneuvering board.

Example: A tropical cyclone is estimated to be moving in direction 320° at 19 knots. Its center bears 170°, at an estimated distance of 200 miles from a vessel which has a maximum speed of 12 knots.

Required:

(1) The course to steer at 12 knots to produce the greatest possible minimum distance between the vessel and the storm center.

(2) The distance to the center at nearest approach.

(3) Elapsed time until nearest approach.

Solution: (Figure 3511) Consider the vessel remaining at the center of the plot throughout the solution, as on a radar PPI.

(1) To locate the position of the storm center relative to the vessel, plot point C at a distance of 200 miles (scale 20:1) in direction 170° from the center of the diagram. From the center of the diagram, draw RA, the speed vector of the storm center, in direction 320°, speed 19 knots (scale 2:1). From A draw a line tangent to the 12-knot speed circle (labeled 6 at scale 2:1) on the side opposite the storm center. From the center of the diagram, draw a perpendicular to this tangent line, locating point B. The line RB is the required speed vector for the vessel. Its direction, 011°, is the required course.

(2) The path of the storm center relative to the vessel will be along a line from C in the direction BA, if both storm and vessel maintain course and speed. The point of nearest approach will be at D, the foot of a perpendicular from the center of the diagram. This distance, at scale 20:1, is 187 miles.

(3) The length of the vector BA (14.8 knots) is the speed of the storm with respect to the vessel. Mark this on the lowest scale of the nomogram at the bottom of the diagram. The relative distance CD is 72 miles, by measurement. Mark this (scale 10:1) on the middle scale at the bottom of the diagram. Draw a line between the two points and extend it to intersect the top scale at 29.2 (292 at 10:1 scale). The elapsed time is therefore 292 minutes, or 4 hours 52 minutes.

Answers: (1) C 011°, (2) D 187 mi., (3) 4h 52m.

The storm center will be dead astern at its nearest approach.

As a general rule, for a vessel in the Northern Hemisphere, safety lies in placing the wind on the starboard bow in the dangerous semicircle and on the starboard quarter in the less dangerous semicircle. If on the storm track ahead of the storm, the wind should be put about 160° on the starboard quarter until the vessel is well within the less dangerous semicircle, and the rule for that semicircle then followed. In the Southern Hemisphere the same rules hold, but with respect to the port side. With a faster than average vessel, the wind can be brought a little farther aft in each case. However, as the speed of the storm increases along its track, the wind should be brought farther forward.

If land interferes with what would otherwise be the best maneuver, the solution should be altered to fit the circumstances.

If the vessel is faster than the storm, it is possible to overtake it. In this case, the only action usually needed is to slow enough to let the storm pull ahead.

In all cases, one should be alert to changes in the direction of movement of the storm center, particularly in the area where the track normally curves toward the pole. If the storm maintains its direction and speed, the ship's course should be maintained as the wind shifts.

If it becomes necessary for a vessel to heave to, the characteristics of the vessel should be considered. A power vessel is concerned primarily with damage by direct action of the sea. A good general rule is to heave to with head to the sea in the dangerous semicircle, or stern to the sea in the less dangerous semicircle. This will result in greatest amount of headway away from the storm center, and least amount of leeway toward it. If a vessel handles better with the sea astern or on the quarter, it may be placed in this position in the less dangerous semicircle or in the rear half of the dangerous semicircle, but never in the forward half of the dangerous semicircle. It has been reported that when the wind reaches hurricane speed and the seas become confused, some ships ride out the storm best if the engines are stopped, and the vessel is left to seek its own position, or lie ahull. In this way, it is said, the ship rides with the storm instead of fighting against it.

In a sailing vessel attempting to avoid a storm center, one should steer courses as near as possible to those prescribed above for power vessels. However, if it becomes necessary for such a vessel to heave to, the wind is of greater concern than the sea. A good general rule always is to heave to on whichever tack permits the shifting wind to draw aft. In the Northern Hemisphere,this is the starboard tack in the dangerous semicircle, and

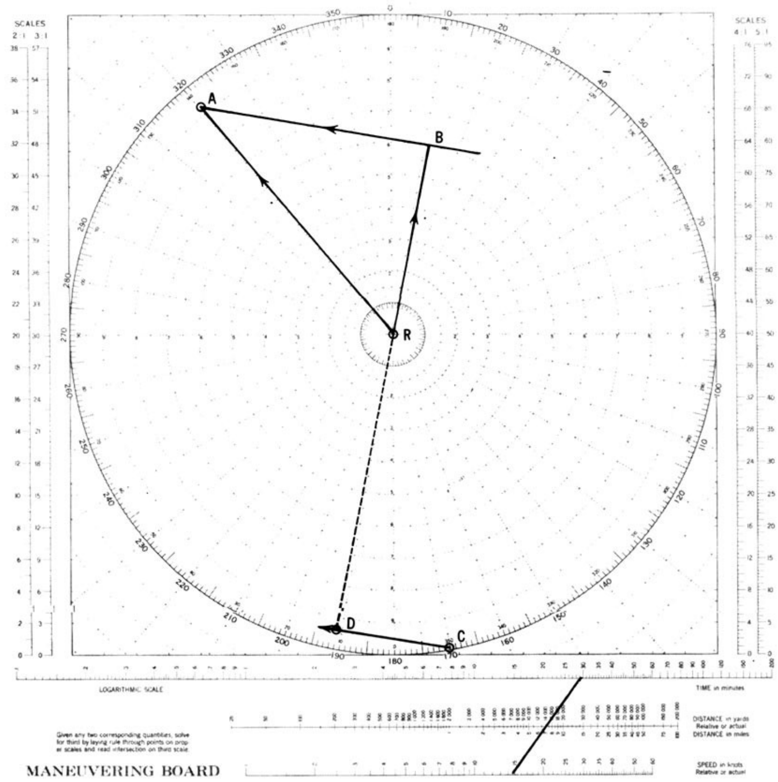


Figure 3511. Determining the course to avoid the storm center.

the port tack in the less dangerous semicircle. In the Southern Hemisphere these are reversed. While each storm requires its own analysis, and frequent or continual resurvey of the situation, the general rules for a steamer may be summarized as follows:

<u>Northern Hemisphere</u>

Right or dangerous semicircle: Bring the wind on the starboard bow (045° relative), hold course and make as much way as possible. If necessary, heave to with head to the sea.

Left or less dangerous semicircle: Bring the wind on the starboard quarter (135° relative), hold course and make as much way as possible. If necessary, heave to with stern to the sea.

On storm track, ahead of center: Bring the wind 2 points on the starboard quarter (about 160° relative), hold course and make as much way as possible. When well within the less dangerous semicircle, maneuver as indicated above. On storm track, behind center: Avoid the center by the best practicable course, keeping in mind the tendency of tropical cyclones to curve northward and eastward.

Southern Hemisphere

Left or dangerous semicircle: Bring the wind on the port bow (315° relative), hold course and make as much way as possible. If necessary, heave to with head to the sea.

Right or less dangerous semicircle: Bring the wind on the port quarter (225° relative), hold course and make as much way as possible. If necessary, heave to with stern to the sea. On storm track, ahead of center: Bring the wind about 200° relative, hold course and make as much way as possible. When well within the less dangerous semicircle, maneuver as indicated above.

On storm track, behind center: Avoid the center by the best practicable course, keeping in mind the tendency of tropical cyclones to curve southward and eastward. It is possible, particularly in temperate latitudes after the storm has recurved, that the dangerous semicircle is the left one in the Northern Hemisphere (right one in the Southern Hemisphere). This can occur if a large high lies north of the storm and causes a tightening of the pressure gradient in the region.

The *Typhoon Havens Handbook* for the Western Pacific and Indian Oceans is published by the Naval Oceanographic and Atmospheric Research Lab (NOARL) Monterey, California, as an aid to captains and commanding officers of ships in evaluating a typhoon situation, and to assist them in deciding whether to sortie, to evade, to remain in port, or to head for the shelter of a specific harbor.

CONSEQUENCES OF TROPICAL CYCLONES

High Winds and Flooding

The high winds of a tropical cyclone inflict widespread damage when such a storm leaves the ocean and crosses land. Aids to navigation may be blown out of position or destroyed. Craft in harbors, often lifted by the storm surge, break moorings or drag anchor and are blown ashore and against obstructions. Ashore, trees are blown over, houses are damaged, power lines are blown down, etc. The greatest damage usually occurs in the dangerous semicircle a short distance from the center, where the strongest winds occur.

As the storm continues on across land, its fury subsides faster than it would if it had remained over water. Wind instruments are usually incapable of measuring the 175 to 200 knot winds of the more intense hurricanes.

Even if the instrument holds up, often the supporting structure is destroyed. Doppler radar may be effective in determining wind speeds, but may also be blown away.

Wind gusts, which are usually 30 to 50 percent higher than sustained winds, add significantly to the destructiveness of the tropical cyclone. Many tropical cyclones that reach hurricane intensity develop winds of more than 90 knots sometime during their lives, but few develop winds of more than 130 knots.

Tropical cyclones have produced some of the world's heaviest rainfalls. While average amounts range from 6 to 10 inches, totals near 100 inches over a 4-day period have been observed. A 24-hour world's record of 73.62 inches fell at Reunion Island during a tropical cyclone in 1952.

Forward movement of the storm and land topography have a considerable influence on rainfall totals. Torrential rains can occur when a storm moves against a mountain range; this is common in the Philippines and Japan, where even weak tropical depressions produce considerable rainfall. A 24-hour total of 46 inches was recorded in the Philippines during a typhoon in 1911. As hurricane Camille crossed southern Virginia's Blue Ridge Mountains in August of 1969, there was nearly 30 inches of rain in about 8 hours.

This caused some of the most disastrous floods in the state's history.

Flooding is an extremely destructive by-product of the tropical cyclone's torrential rains. Whether an area will be flooded depends on the physical characteristics of the drainage basin, rate and accumulation of precipitation, and river stages at the time the rains begin. When heavy rains fall over flat terrain, the countryside may lie under water for a month or so, and while buildings, furnishings, and underground power lines may be damaged, there are usually few fatalities. In mountainous or hill country, disastrous floods develop rapidly and can cause a great loss of life.

There have been occasional reports in tropical cyclones of waves greater than 40 feet in height, and numerous reports in the 30- to 40-foot category. However, in tropical cyclones, strong winds rarely persist for a sufficiently long time or over a large enough area to permit enormous wave heights to develop. The direction and speed of the wind changes more rapidly in tropical cyclones than in extratropical storms. Thus, the maximum duration and fetch for any wind condition is often less in tropical cyclones than in extratropical storms, and the waves accompanying any given local wind conditions are generally not so high as those expected, with similar local wind conditions, in the high-latitude storms. In hurricane Camille, significant waves of 43 feet were recorded; an extreme wave height reached 72 feet. Exceptional conditions may arise when waves of certain dimensions travel within the storm at a speed equal to the storm's speed, thus, in effect, extending the duration and fetch of the wave and significantly increasing its height. This occurs most often to the right of the track in the Northern Hemisphere (left of the track in the Southern Hemisphere). Another condition that may give rise to exceptional wave heights is the intersection of waves from two or more distinct directions. This may lead to a zone of confused seas in which the heights of some waves will equal the sums of each individual wave train. This process can occur in any quadrant of the storm, so it should not be assumed that the highest waves will always be encountered to the right of the storm track in the Northern Hemisphere (left of the track in the Southern Hemisphere).

When these waves move beyond the influence of the generating winds, they become known as swell. They are recognized by their smooth, undulating form, in contrast to the steep, ragged crests of wind waves. This swell, particularly that generated by the right side of the storm, can travel a thousand miles or more and may produce tides 3 or 4 feet above normal along several hundred miles of coastline. It may also produce tremendous surf over offshore reefs which normally are calm.

When a tropical cyclone moves close to a coast, wind often causes a rapid rise in water level, and along with the falling pressure may produce a storm surge. This surge is usually confined to the right of the track in the Northern Hemisphere (left of the track in the Southern Hemisphere) and to a relatively small section of the coastline. It most often occurs with the approach of the storm, but in some cases, where a surge moves into a long channel, the effect may be delayed. Occasionally, the greatest rise in water is observed on the opposite side of the track, when northerly winds funnel into a partially landlocked harbor. The surge could be 3 feet or less, or it could be 20 feet or more, depending on the combination of factors involved.

There have been reports of a "hurricane wave," described as a "wall of water," which moves rapidly toward the coastline. Authenticated cases are rare, but some of the world's greatest natural disasters have occurred as a result of this wave, which may be a rapidly rising and abnormally high storm surge. In India, such a disaster occurred in 1876, between Calcutta and Chittagong, and drowned more than 100,000 persons.

Along the coast, greater damage may be inflicted by water than by the wind. There are at least four sources of water damage. First, the unusually high seas generated by the storm winds pound against shore installations and craft in their way. Second, the continued blowing of the wind toward land causes the water level to increase perhaps 3 to 10 feet above its normal level. This storm tide, which may begin when the storm center is 500 miles or even farther from the shore, gradually increases until the storm passes. The highest storm tides are caused by a slow-moving tropical cyclone of large diameter, because both of these effects result in greater duration of wind in the same direction. The effect is greatest in a partly enclosed body of water, such as the Gulf of Mexico, where the concave coastline does not readily permit the escape of water. It is least on small islands, which present little obstruction to the flow of water. Third, the furious winds which blow around the wall of the eye create a ridge of water called a storm wave, which strikes the coast and often inflicts heavy damage. The effect is similar to that of a seismic sea wave, caused by an earthquake in the ocean floor. Both of these waves are popularly called tidal waves. Storm waves of 20 feet or more have occurred. About 3 or 4 feet of this wave might be due to the decrease in atmospheric pressure as the sea surface is drawn up into the low pressure area, and the rest to winds. Like the damage caused by wind, damage due to high seas, the storm surge and tide, and the storm wave is greatest in the dangerous semicircle, near the center. The fourth source of water damage is the heavy rain that accompanies a tropical cyclone. This causes floods that add to the damage caused in other ways.

There have been many instances of tornadoes occurring within the circulation of tropical cyclones. Most of these have been associated with tropical cyclones of the North Atlantic Ocean and have occurred in the West Indies and along the gulf and Atlantic coasts of the United States.

They are usually observed in the forward semicircle or along the advancing periphery of the storm. These tornadoes are usually short-lived and less intense than those that occur in the midwestern United States.

When proceeding along a shore recently visited by a tropical cyclone, a navigator should remember that time is required to restore aids to navigation which have been blown out of position or destroyed. In some instances the aid may remain but its light, sound apparatus, or radiobeacon may be inoperative. Landmarks may have been damaged or destroyed, and in some instances the coastline and hydrography may be changed.

Hurricane Basics For More Information Websites: NOAA - www.noaa.gov

National Hurricane Center - www.nhc.noaa.gov

National Hurricane Center Public Affairs (305) 229-4404

National Weather Service Public Affairs (301) 713-0622

What is a Hurricane?

A "hurricane" is the most severe category of the meteorological phenomenon known as the "tropical cyclone."

Tropical cyclones are low pressure systems that have thunderstorm activity and rotate counterclockwise. A tropical cyclone that has winds of 38 mph (33 kt) or less is called a tropical depression. When the tropical cyclone's winds reach 39-73 mph (34-63 kt), it is called a tropical storm. When the winds exceed 74 mph (64 kt), the storm is considered to be a hurricane.

The Saffir-Simpson Hurricane Scale defines hurricane strength by categories. A Category 1 storm is the weakest hurricane (winds 74-95 mph or 64-82 kt); a Category 5 hurricane is the strongest (winds greater than 155 mph or 135 kt).

The category of the storm does not necessarily relate directly to the damage it will inflict. Lower category storms (and even tropical storms) can cause substantial damage depending on what other weather features they interact with, where they strike, and how slow they move.

Anatomy of a Hurricane Typical hurricanes are about 300 miles wide although they can vary considerably in size.

The eye at a hurricane's center is a relatively calm, clear area approximately 20-40 miles across.

The eyewall surrounding the eye is composed of dense clouds that contain the highest winds in the storm.

The storm's outer rainbands (often with hurricane or tropical storm-force winds) are made up of dense bands of thunderstorms ranging from a few miles to tens of miles wide and 50 to 300 miles long.

Hurricane-force winds can extend outward to about 25 miles in a small hurricane and to more than 150 miles for a large one. Tropical storm-force winds can stretch out as far as 300 miles from the center of a large hurricane.

Frequently, the right side of a hurricane is the most dangerous in terms of storm surge, winds, and tornadoes.

A hurricane's speed and path depend on complex ocean and atmospheric interactions, including the presence or absence

of other weather patterns. This complexity of the flow makes it very difficult to predict the speed and direction of a hurricane.

Do not focus on the eye or the track–hurricanes are immense systems that can move in complex patterns that are difficult to predict. Be prepared for changes in size, intensity, speed, and direction.

How Tropical Cyclones are Observed http://hurricanes.noaa.gov www.nws.noaa.gov www.noaa.gov

Direct measurements of tropical storm and hurricane dimensions and wind speeds are taken primarily by reconnaissance aircraft, although ships and buoys also take important measurements. Once a hurricane is near and/or on land, Automated Surface Observation Systems (ASOS) provide surface conditions, and radio sondes take upper air measurements.

Indirect observational methods include satellite imagery and Doppler radar. In particular, satellites have greatly improved our ability to monitor and understand hurricanes. Radar data are important once the storm comes close to shore and after landfall for forecasting hurricane-related weather.

Hurricane Fast Facts

Hurricane Basics

There is nothing like them in the atmosphere. Born in warm tropical waters, these spiraling masses require a complex combination of atmospheric processes to grow, mature, and then die. They are not the largest storm systems in our atmosphere or the most violent, but they combine these qualities as no other phenomenon does.

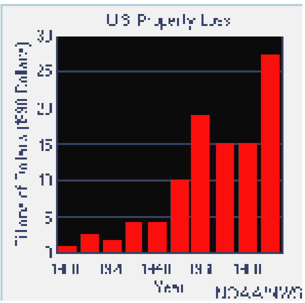
In the Atlantic Basin, they are called hurricanes, a term that echoes colonial Spanish and Caribbean Indian words for evil spirits and big winds. These awesome storms have been a deadly problem for residents and sailors ever since the early days of colonization. Today, hurricane damage costs billions of dollars. During this century, 23 hurricanes have each caused damage in excess of $1 billion (adjusted for inflation). Damage from Hurricane Andrew (1992) alone was estimated at more than $25 billion in South Florida and Louisiana and undoubtedly would have been higher had the storm hit Miami directly.

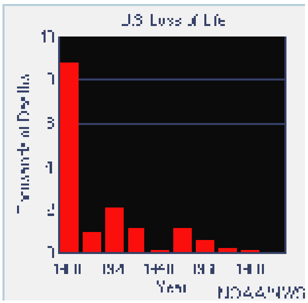
Thankfully, the number of people injured or killed during tropical cyclones in the United States has been declining, largely because of improvements in forecasting and emergency preparedness. Nonetheless, our risk from hurricanes is increasing. With population and development continuing to increase along coastal areas, greater numbers of people and property are vulnerable to hurricane threat. Large numbers of tourists also favor coastal locations, adding greatly to the problems of emergency managers and local decision makers during a hurricane threat.

Hurricanes cannot be controlled, but our vulnerability can be reduced through preparedness. Local decision makers must make difficult choices between public safety and possible economic losses when faced with a hurricane, but these decisions will be solid if they are based on an understanding of hurricanes, their hazards, the value and limitations of forecasts, and a good decision-making process.

The Richelieu Apartments before Hurricane Camille

The Richelieu Apartments after Hurricane Camille





Hurricane Basics

The ingredients for a hurricane include a pre-existing weather disturbance, warm tropical oceans, moisture, and relatively light winds aloft. If the right conditions persist long enough, they can combine to produce the violent winds, incredible waves, torrential rains, and floods we associate with this phenomenon.

Each year, an average of ten tropical storms develop over the Atlantic Ocean, Caribbean Sea, and Gulf of Mexico. Many of these remain over the ocean. Six of these storms become hurricanes each year. In an average 3-yearperiod, roughly five hurricanes strike the United States coastline, killing approximately 50 to 100 people anywhere from Texas to Maine. Of these, two are typically major hurricanes (winds greater than 110 mph).

What is a Hurricane?

A hurricane is a type of tropical cyclone, which is a generic term for a low pressure system that generally forms in the tropics. The cyclone is accompanied by thunderstorms and, in the Northern Hemisphere, a counterclockwise circulation of winds near the earth's surface. Tropical cyclones are classified as follows:

Tropical Depression

An organized system of clouds and thunderstorms with a defined surface circulation and maximum sustained winds* of 38 mph (33 kt**) or less

Tropical Storm

An organized system of strong thunderstorms with a defined surface circulation and maximum sustained winds of 39-73 mph (34-63 kt)

Hurricane

An intense tropical weather system of strong thunderstorms with a well-defined surface circulation and maximum sustained winds of 74 mph (64 kt) or higher

* Sustained winds are defined as a 1-minute average wind measured at about 33 ft (10 meters) above the surface.

** 1 knot = 1 nautical mile per hour or 1.15 statute miles per hour. Abbreviated as "kt".

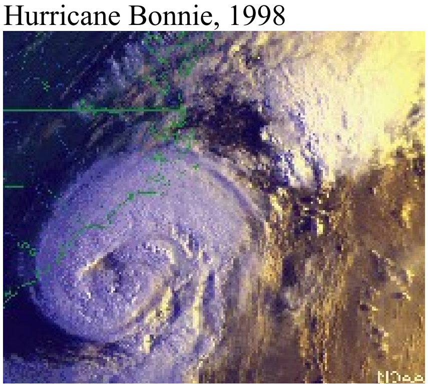
Hurricanes are categorized according to the strength of their winds using the Saffir-Simpson Hurricane Scale


A Category 1 storm has the lowest wind speeds, while a Category 5 hurricane has the strongest. These are relative terms, because lower category storms can sometimes inflict greater damage than higher category storms, depending on where they strike and the particular hazards they bring. In fact, tropical storms can also produce significant damage and loss of life, mainly due to flooding.

Hurricane Names

When the winds from these storms reach 39 mph (34 kt), the cyclone is given a name. Years ago, an international committee developed six separate lists of names for these storms . Each list alternates between male and female names. The use of these easily remembered names greatly reduces confusion when two or more tropical cyclones occur at the same time. Each list is reused every six years, although hurricane names that have resulted in substantial damage or death are retired.

Hurricane Bonnie, 1998



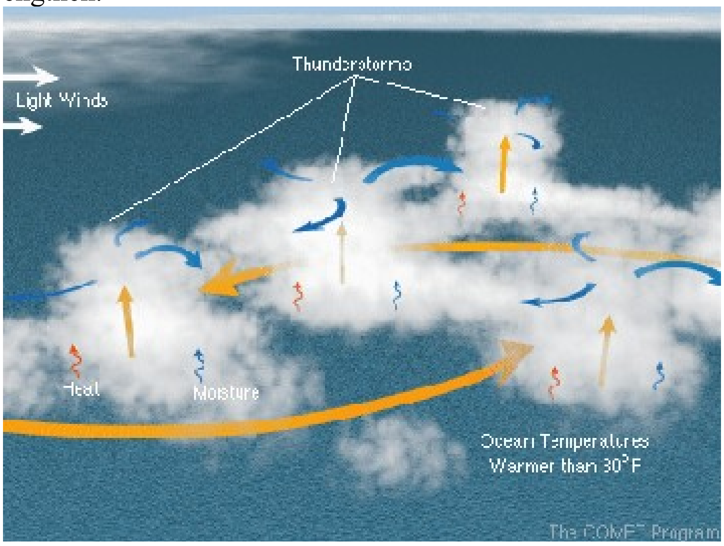
Origin and Life Cycle

The Birth of a Tropical Cyclone

Tropical cyclones form over warm waters from pre-existing disturbances. These disturbances typically emerge every three or four days from the coast of Africa as "tropical waves" that consist of areas of unsettled weather. Tropical cyclones can also form from the trailing ends of cold fronts and occasionally from upper-level lows.

The process by which a tropical cyclone forms and subsequently strengthens into a hurricane depends on at least three conditions shown in the figure below

1. A pre-existing disturbance with thunderstorms
2. Warm (at least 80ºF) ocean temperatures to a depth of about 150 feet
3. Light upper level winds that do not change much in direction and speed throughout the depth of the atmosphere (low wind shear) Heat and energy for the storm are gathered by the disturbance through contact with warm ocean waters. The winds near the ocean surface spiral into the disturbance's low pressure area. The warm ocean waters add moisture and heat to the air which rises. As the moisture condenses into drops, more heat is released, contributing additional energy to power the storm. Bands of thunderstorms form, and the storm's cloud tops rise higher into the atmosphere. If the winds at these high levels remain relatively light (little or no wind shear), the storm can remain intact and continue to strengthen.



Stages of Hurricane Development

Growth and Maturity

In these early stages, the system appears on the satellite image as a relatively unorganized cluster of thunderstorms. If weather and ocean conditions continue to be favorable, the system can strengthen and become a tropical depression (winds less than 38 mph or 33 kt). At this point, the storm begins to take on the familiar spiral appearance due to the flow of the winds and the rotation of the earth.

If the storm continues to strengthen to tropical storm status (winds 39-73 mph, 34-63 kt), the bands of thunderstorms contribute additional heat and moisture to the storm. The storm becomes a hurricane when winds reach a minimum of 74 mph (64 kt). At this time, the cloud-free hurricane eye typically forms because rapidly sinking air at the center dries and warms the area.

During their life span, hurricanes can last for more than two weeks over the ocean and can travel up the entire Atlantic Coast.

The Storm's End

Just as many factors contribute to the birth of a hurricane, there are many reasons why a hurricane begins to decay. Wind shear can tear the hurricane apart. Moving over cooler water or drier areas can lead to weakening as well. Landfall typically shuts off the hurricane's main moisture source, and the surface circulation can be reduced by friction when it passes over land.

Generally, a weakening hurricane or tropical cyclone can reintensify if it moves into a more favourable region or interacts with mid-latitude frontal systems.

Three stages of tropical cyclone development

Structure

Contrary to how many weather maps appear, a hurricane is more than a point on a weather map, and its path is more than a line. It is a large system that can affect a wide area, requiring that precautions be taken far from where the eye is predicted to come ashore.

Hurricane Structure

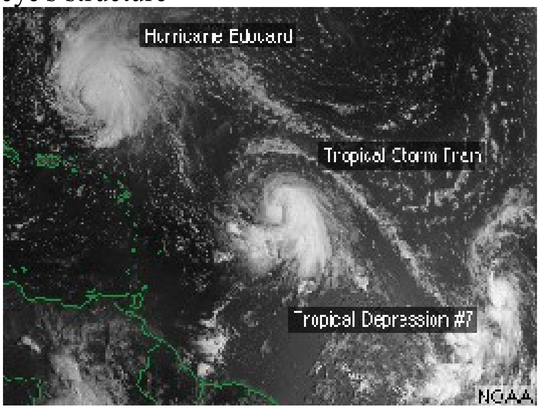
The main parts of a hurricane are the rainbands on its outer edges, the eye, and the eyewall.

Air spirals in toward the center in a counter-clockwise pattern, and out the top in the opposite direction. In the very center of the storm, air sinks, forming the cloud-free eye.

The Eye

The hurricane's center is a relatively calm, clear area usually 20-40 miles across. People in the midst of a hurricane are often amazed at how the incredibly fierce winds and rain can suddenly stop and the sky clear when the eye comes over them. Then, just as quickly, the winds and rain begin again, but this time from the opposite direction.

Details of the hurricane eye's structure



The Eyewall

The dense wall of thunderstorms surrounding the eye has the strongest winds within the storm. Changes in the structure of the eye and eyewall can cause changes in the wind speed, which is an indicator of the storm's intensity.

The eye can grow or shrink in size, and double (concentric) eyewalls can form.

The Spiral Rainbands

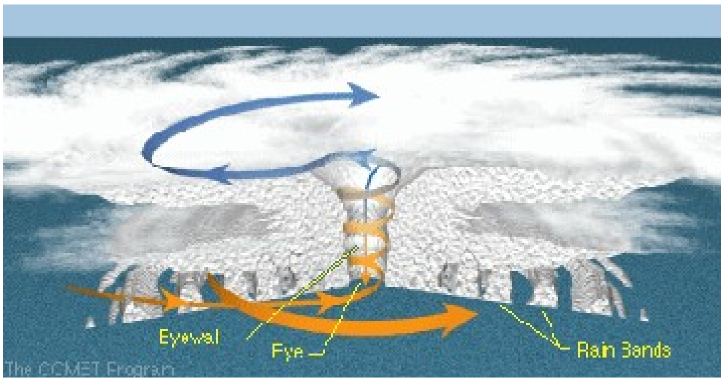
The storm's outer rainbands (often with hurricane or tropical storm-force winds) can extend a few hundred miles from the center. Hurricane Andrew's (1992) rainbands reached only 100 miles out from the eye, while those in Hurricane Gilbert (1988) stretched over 500 miles. These dense bands of thunderstorms, which spiral slowly counterclockwise, range in width from a few miles to tens of miles and are 50 to 300 miles long. Sometimes the bands and the eye are obscured by higher level clouds, making it difficult for forecasters to use satellite imagery to monitor the storm.

Hurricane Size

Typical hurricanes are about 300 miles wide although they can vary considerably, as shown in the two enhanced satellite images below. Size is not necessarily an indication of hurricane intensity. Hurricane Andrew (1992), the most devastating hurricane of this century, was a relatively small hurricane.

Hurricane destructive winds and rains cover a wide swath. Hurricane-force winds can extend outward to about 25 miles from the storm center of a small hurricane and to more than 150 miles for a large one.

The area over which tropical storm-force winds occur is even greater , ranging as far out as almost 300 miles from the eye of a large hurricane.



Hurricane Circulation and Movement

In the northern hemisphere, hurricane winds circulate around the center in a counter-clockwise fashion. This means that the wind direction at your location depends on where the hurricane's eye is.

A boat on the northern edge of the orange area in Hurricane Fran would experience winds from the east, while a boat on the southern edge would have westerly winds.

A hurricane's speed and path depend on complex interactions between the storm with its own internal circulations and the earth's atmosphere.

The air in which the hurricane is embedded is a constantly moving and changing "river" of air. Other features in that flow, such as high and low pressure systems, can greatly alter the speed and the path of the hurricane. In turn, it can modify the environment around the storm.

Typically, a hurricane's forward speed averages around 15-20 mph. However, some hurricanes stall, often causing devastatingly heavy rain. Others can accelerate to more than 60 mph.

Hurricane Hazel (1954) hit North Carolina on the morning of 15 October; fourteen hours later it reached Toronto, Canada where it caused 80 deaths. Some hurricanes follow a fairly straight course, while others loop and wobble along the path These seemingly erratic changes are difficult to forecast and will be discussed in more detail in the Forecasting section of this module.

The Right Side of the Storm

As a general rule of thumb, the hurricane's right side (relative to the direction it is travelling) is the most dangerous part of the storm because of the additive effect of the hurricane wind speed and speed of the larger atmospheric flow (the steering winds). The increased winds on the right side increase the storm surge. Tornadoes are also more common here.

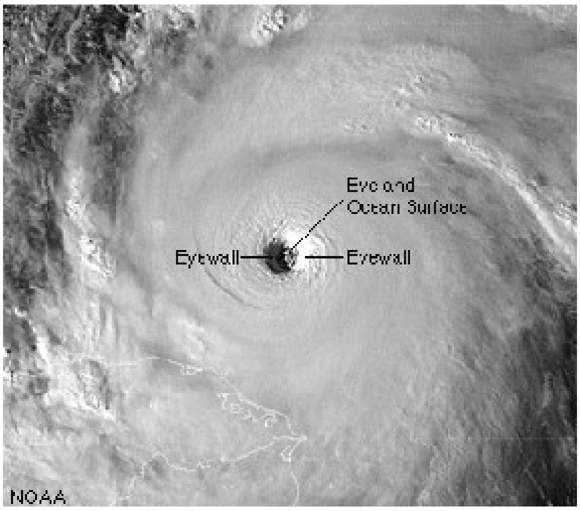
Looking at the figure above, pretend you are standing behind the hurricane with your back to the steering flow. In this case, the right side is the eastern section of the hurricane. (If it were travelling east to west, the right side would be the north section.) The winds around the hurricane's eye are moving in a counterclockwise fashion. At Point A, the hurricane winds are nearly in line with the steering wind, adding to the strength of the winds. For example, if the steering currents are 30 mph and the average hurricane winds are 100 mph, the wind speed would be 130 mph at Point A. On the other hand, the winds at Point B are moving opposite those of the steering wind and therefore slow to 70 mph (100 - 30 mph). Incidentally, National Huricane Center forecasts take this effect into account in their official wind estimates.

Observation

NOAA's National Weather Service (NWS) has several tools to monitor hurricanes. While they are still far out in the ocean, indirect measurements using satellites are the main tool, although ships and buoys also provide observations. Once the storms come closer to land, more direct measurements (reconnaissance aircraft, radiosondes, and Automated

Surface Observing Stations) are also used. Within about 200 miles of the coast, radar provide important indirect measurements of the storm.

Computer models used to forecast storm intensity and movement require a great deal of data about the atmosphere. Lack of observations (especially over the ocean) and errors and inconsistencies in the data are major sources of forecast errors.



Hurricane Hazards

The main hazards associated with tropical cyclones and especially hurricanes are storm surge, high winds, heavy rain, and flooding, as well as tornadoes. The intensity of a hurricane is an indicator of damage potential. However, impacts are a function of where and when the storm strikes. Hurricane Diane (1955) hit the northeastern U.S. and caused 184 deaths. It was only a Category 1 hurricane but the thirteenth deadliest since 1900. Hurricane Agnes

(1972), also a Category 1 hurricane, ranks fifth with damages estimated at 6.9 billion when adjusted for inflation[1].

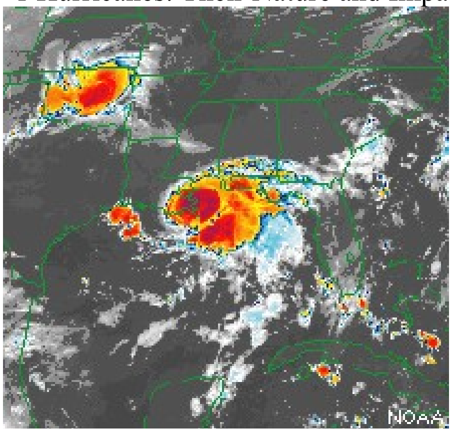
A storm surge is a large dome of water, 50 to 100 miles wide, that sweeps across the coastline near where a hurricane makes landfall. It can be more than 15 feet deep at its peak. The surge of high water topped by waves is devastating. Along the coast, storm surge is the greatest threat to life and property.

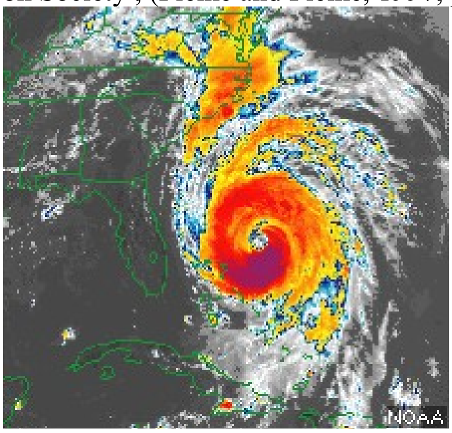
Hurricane winds not only damage structures, but the barrage of debris they carry is quite dangerous to anyone unfortunate enough (or unwise enough!) to be caught out in them. Damaging winds begin well before the hurricane eye makes landfall.

Tropical cyclones frequently produce huge amounts of rain, and flooding can be a significant problem, particularly for inland communities. A typical hurricane brings at least 6 to 12 inches of rainfall to the area it crosses. The resulting floods cause considerable damage and loss of life, especially in mountainous areas where heavy rains mean flash floods and can also result in devastating mudslides. Tornadoes spawned by landfalling hurricanes can cause enormous destruction. As a hurricane moves shoreward, tornadoes often develop on the fringes of the storm.

These hazards can bring other consequences not directly related to the storm. For example, hurricane-related deaths and injuries are often the result of fires started by candles used when the electricity fails. Heart attacks and accidents frequently occur during the clean-up phase. And depending on the industrial facilities in your area, hurricane damage might cause chemical spills that could make the disaster even worse.

1 Hurricanes: Their Nature and Impact on Society , (Pielke and Pielke, 1997, p. 125)





Hurricane Hazards Summary

Storm Surge

Storm surge is the greatest potential threat to life and property associated with hurricanes.

A storm surge is a large dome of water, 50 to 100 miles wide, that sweeps across the coastline near where a hurricane makes landfall. It can be more than 15 feet deep at its peak.

The level of surge in a particular area is primarily related to the intensity of the hurricane and slope of the continental shelf.

The Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model is used by communities to evaluate storm surge threat from different categories of hurricanes striking from various directions.

Because storm surge has the greatest potential to kill more people than any of the other hurricane hazards, it is wise to err on the conservative side by planning for a storm that is one category more intense than is forecast.

High Winds

Typically, the more intense the storm (in terms of the Saffir- impson Hurricane Scale), the more wind damage a community will sustain, particularly if it does not have an effective mitigation program and has not prepared in advance for the storm.

Tropical storm-force winds (39-73 mph) can also be dangerous, and it is wise to have evacuations completed before they reach your area.

Heavy Rains

Hurricanes (and some tropical storms) typically produce widespread rainfall of 6 to 12 inches or more, often resulting in severe flooding.

Inland flooding has been the primary cause of tropical cyclone-related fatalities over the past 30 years.

Rains are generally heaviest with slower moving storms (less than 10 mph).

The heaviest rain usually occurs to the right of the cyclone track in the period 6 hours before and 6 hours after landfall.

However, storms can last for days, depending on what inland weather features they interact with.

Large amounts of rain can occur more than 100 miles inland where flash floods and mudslides are typically the major threats.

Tornadoes

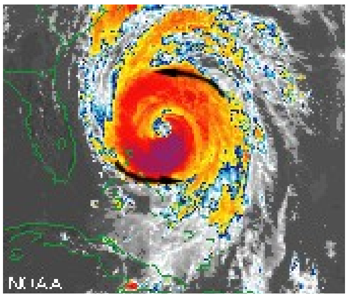
Tornadoes are most likely to occur in the right-front quadrant of the hurricane. However, they are also often found elsewhere in the rainbands.

Typically, the more intense a hurricane is, the greater the tornado threat.

Tornado production can occur for days after landfall.

Most tornadoes occur within 150 miles of the coast.

The National Weather Service's Doppler radar systems can provide indications of tornados from a few minutes to about 30 minutes in advance. Consequently, preparedness is critical.



Hurricane Forecasting

Over the past 20 years, improvements in hurricane computer modeling, observational instrumentation, and better training for forecasters have greatly increased forecast accuracy. New data systems give forecasters a greater understanding of tropical cyclones and provide better and more timely input for computer models used to predict hurricane behavior.

Despite these advances, the many complex interactions that occur within the atmosphere are not fully understood or adequately modeled, limiting the accuracy of forecasts. When all is said and done, hurricane forecasting is still a very difficult job.

The forecasting process that is the joint responsibility of NOAA's Tropical Prediction Center's National Hurricane Center (NHC) and the local Weather Forecast Offices (WFOs). The forecasting process contributes to a significant reduction in the number of deaths attributed to tropical cyclones and their related hazards.

Part of the mission of the National Weather Service (NWS) Tropical Prediction Center (TPC) is to save lives and protect property by issuing watches, warnings, forecasts, and analyses of hazardous weather conditions in the tropics.

The TPC is comprised of the National Hurricane Center (NHC), the Tropical Analysis and Forecast

Branch (TAFB), and the Technical Support Branch (TSB). During hurricane season, the latter two provide support to the NHC.

A Hurricane Liaison Team (HLT) is activiated during hurricanes to provide a link between the NHC and emergency managers and decision makers.

The local NWS Weather Forecast Offices (WFOs) in hurricane-prone areas are also important participants in the forecast process.

The NHC and your local WFO have various roles in the forecast process that are closely coordinated.

In general, the NHC provides products that have a broad view of the hurricane and its potential impacts, while the local forecast office (the WFO) takes the information from NHC and tailors it to their specific locale, providing local emergency managers with additional information about the hazards expected in their area. The NHC issues hurricane advisories, watches and warinings. Information includes strike probability and wind speeds.

Observation

Observations are the basis for all forecast and warning products issued by the NHC. Quality, timeliness, and quantity of remote sensing observations are critical for accurate and timely forecasts and warnings.

Analysis

The various observations are checked for quality, analyzed, and put into a suite of computer models

Central Model Guidance/Interpretation

The computer models take in the observations and perform millions of calculations to generate predictions of hurricane behavior and the general conditions of the atmosphere in which the hurricane is embedded. The model results are packaged as guidance for the appropriate national centers and local offices and for evaluation and use in the NWS's forecast and warning process.

Coordination within the NWS

Product Dissemination

Model results are coordinated between the national centers and local forecast offices to provide consistency, which is critical during severe weather episodes.

Once the coordination and collaboration process reaches group consensus, the issuing offices generate forecast and warning products for release to the public.

Product Dissemination

Timely and reliable dissemination of forecasts and warnings is critical to the protection of life and property.

Coordination with Customers

The NHC and the local WFO work with customers to determine the level of satisfaction with the service provided and, in particular, whether the forecast and warning products issued were useful.

Local Level: The Weather Forecast Office (WFO)

All of the National Weather Service Forecast Offices are staffed 24 hours a day and produce:

Watches and warnings for severe local storms, floods, flash floods, as well as local and zone public forecasts

Local aviation forecasts, watches, and warnings

Marine warnings and forecasts for coastal areas

Hydrologic services such as support for flood and run-off forecasts

Offices affected by hurricanes analyze the products created by the NHC and fine tune them for their own locale in order to provide local officials with the necessary information to make timely and efficient decisions.

The WFOs produce local weather statements to inform the public about current and anticipated storm effects in their area and to augment NHC advisories and releases. The local statements are highly specific and are designed to keep the media, local decision makers, and the public current on present and anticipated storm effects.

Local forecasters initiate or participate in inter-site coordination between NHC and other local WFOs to ensure forecast and warning consistency. Following product delivery, the local office coordinates with local officials, the media, and the emergency management community. These coordination calls focus on the pending weather threat and what implications the forecast or warning has for the local area. Following the storm, the local Warning Coordination Meteorologist evaluates the service with the forecast users.

Summary

Who Produces Hurricane Forecasts

NOAA's National Hurricane Center is responsible for providing information on the current status of the storm and future forecasts of its behavior.

Local NOAA Weather Forecast Offices fine tune NHC status reports and forecasts for their particular area.

Forecast Information

Tropical cyclone public advisories (issued every 6 hours) are intended for the general public in areas threatened by a tropical storm or hurricane.

Intermediate public tropical cyclone advisories are issued every 3 hours once a watch or warning has been issued and every 2 hours once a reliable center appears on radar. Hourly radar position estimates are issued between the 2-hourly public advisories. They are similar to the 6-hour product.

Tropical cyclone forecast/advisories (issued every 6 hours) are intended mainly for ships at sea and other marine interests, but also very useful to emergency managers because they contain wind field forecasts.

Tropical cyclone discussions (issued every 6 hours) explain the rationale for the current forecast level of confidence.

Tropical cyclone strike probability forecasts (issued every 6 hours) give the percentage chance that the center of a tropical cyclone will pass within 65 NM (75 mi) of specific locations within 72 hours.

Hurricane local statements are issued by the local WFO to keep the media, local decision makers, and the public current on present and anticipated storm effects in their specific area. They include any actions declared by local emergency managers.

Inland high wind watches and warnings are issued when hurricane-force winds are expected to occur beyond coastal areas.

Saffir-Simpson Hurricane Scale*

Category Definition—Likely Effects

ONE: Winds 74-95 mph: No real damage to building structures, Damage primarily to unanchored mobile homes, shrubbery, and trees. Also, some coastal road flooding and minor pier damage.

TWO: Winds 96-110 mph: Some roofing material, door, and window damage to buildings.

Considerable damage to vegetation, mobile homes, and piers. Small craft in unprotected anchorages break moorings.

THREE: Winds 111-130 mph: Some structural damage to small residences and utility buildings with a minor amount of curtainwall failures, Mobile homes are destroyed. Flooding near the coast destroys smaller structures with larger structures damaged by floating debris. Terrain may be flooded well inland.

FOUR: Winds 131-155 mph: More extensive curtainwall failures with some complete roof structure failure on small residences. Major erosion of beach areas. Major damage to lower floors of structures near the shore Terrain may be flooded well inland.

FIVE: Winds greater than 155 mph: Complete roof failure on many residences and industrial buildings. Some complete building failures with small utility buildings blown over or away.

Major damage to lower floors of all structures located near the shoreline. Massive evacuation of residential areas may be required.

*In operational use, the scale corresponds to the 1-minute average sustained wind speed as opposed to gusts which could be 20 percent higher or more.

Credits:
The COMET Program
University Corporation for Atmospheric Research
National Oceanic and Atmospheric Administration (NOAA)
Federal Emergency Management Agency (FEMA)

AUSTRALIA

1.0 GENERAL

Australia, the smallest continent and the barrier between the Indian and Pacific oceans, is located between Indonesia and Antarctica. The driest of all continents, approximately half of Australia's total area consists of desert regions. Population centers are on the coast, and large expanses of the immense, arid basin and plateau regions remain uninhabited.

Australia is a Commonwealth of six states: Northern Territory, Queensland, New South Wales, Victoria, South Australia, and Western Australia.

1.1 AUSTRALIAN WIND MEASUREMENT AND TROPICAL CYCLONE CLASSIFICATION

The Australian Bureau of Meteorology (BOM) uses different wind speed measuring criteria than that used by the United States. The BOM also uses a tropical cyclone classification system that differs from the United States classification system. It is important for fleet units of the U.S. Navy to understand the differences when operating in Australian waters.

1.2 WIND MEASUREMENT

Wind speeds in Australia are reported as 10-minute averages, i.e. the average wind speed observed over a 10-minute period of time. Wind speeds in the United States are reported as 1-minute averages, i.e. the average wind speed observed over a 1-minute period of time. The difference resulting from these two measurement periods is that the United States' wind speeds will be greater by a factor of 1.1 or 1.2. Consequently, a 10 kt wind as used in Australian observations, forecasts, and warnings would convert to a speed of 11 or 12 kt in United States' observations, forecasts, and warnings.

1.3 TROPICAL CYCLONE CATEGORIES

The tropical cyclone classification system that is used by Australian agencies is considerably different from that used by the United States. The Saffir/Simpson Hurricane Rating Scale, commonly used in the United States, classifies a minimum hurricane strength tropical cyclone (sustained wind ≥ 64 kt) as a Category 1 storm. A Category 1 storm using the Australian system uses the maximum gust (vs. sustained wind) of 68 kt or more. Sustained winds would be less. Table XI-1 and Table XI-2 present the two classification systems.

Scale Number	Central Pressure Millibars	Central Pressure Inches	Wind MPH	Wind Knots	Storm Surge (ft)	Damage
1	>980	>28.94	74 - 94	64 - 82	4 - 5	Minimal
2	965 - 979	28.48 - 28.93	95 -110	83 - 95	6 - 8	Moderate
3	945 - 964	27.89 - 28.47	111 - 130	96 - 113	9 - 12	Extensive
4	920 - 944	27.17 - 27.88	131 - 154	114 - 134	13 - 18	Extreme
5	<920	<27.17	>154	>134	>18	Catastrophic

Category	Strongest Gust		Typical Effects (Indicative only)
	km/h	Knots	
1	<125	<68	Negligible house damage. Damage to some crops, trees and caravans*. Small craft may drag moorings.
2	125-170	68-92	Minor house damage. Significant damage to signs, trees and caravans*. Heavy damage to some crops. Risk of power failure. Small craft may break moorings
3	170-225	92-122	Some roof and structural damage. Some caravans* destroyed. Power failure likely.
4	225-280	122-151	Significant roofing loss and structural damage. Many caravans* destroyed and blown away. Dangerous airborne debris. Widespread power failures.
5	>280	>151	Extremely dangerous with widespread destruction.

*House trailers or recreational vehicles (RVs).

2.8 THE DECISION TO SORTIE OR REMAIN IN PORT

2.8.1 General

The decision on whether to sortie or remain in port is largely based on the answer to a single question: Would the vessel in question be better off attempting an evasion at sea or by remaining in port? Evasion rationale should include consideration of the following general factors:

Vessel characteristics

Berth and anchorage conditions

Most recent hurricane warning advisory

Tropical cyclone climatology

Individual vessel characteristics and berth/anchorage conditions are best determined by those responsible for each vessel and local port authorities. Tropical cyclone warnings are issued by the Naval Pacific Meteorology and Oceanography Center/Joint Typhoon Warning Center Pearl Harbor for the U.S. Government and by the Australian Bureau of Meteorology Brisbane Tropical Warning Center. The interpretation of tropical cyclone climatology is addressed in the following sections.

2.8.2 Evasion at Sea

When planning a sortie, many factors should be considered, including vessel characteristics, the most recent tropical cyclone warning, tropical cyclone climatology, and the seaworthiness of the vessel. In all cases, the timing of the evasion is affected by:

The time required to make preparations to get underway.

The time required to reach open water and gain sea room.

The forward speed of the tropical cyclone.

The radius of hazardous winds and seas that can adversely impact a vessel's ability to reach open water.

Commanding officers and ship masters with access to tropical cyclone warnings and advisories coupled with OTSR services are most capable of making the safest and most prudent decision for successful storm evasion and avoidance. In all sortie situations, OTSR services from Naval Pacific Meteorology and Oceanography Center (NPMOC), Yokosuka should be requested and utilized. The best sortie route in a specific tropical scenario is largely dependant on the location of the tropical cyclone and the forecast track. During any tropical cyclone threat there is normally one to three options available to the commanding officer and ship master. Selection of the best option is the objective of all concerned!

In most potential tropical cyclone scenarios for Brisbane, the obvious and preferable evasion route for ships sortieing from the Port of Brisbane is southward along the Australian coast. It is the tendency for most tropical cyclones to recurve southeastward by the time they reach Brisbane's latitude; the coastline south of 30°S is free of tropical cyclone tracks for the 40-year period 1958-1997 (Figure XI-8 and Figure XI-9). Ships sortieing from Brisbane should depart sufficiently early so the ship can proceed northward through Moreton Bay and reach open sea prior to the arrival of strong winds and high waves from the approaching tropical cyclone. Once open sea is reached, the ship should proceed southward along the coast with all deliberate speed until far enough south to avoid the effects of the tropical cyclone. In most cases, 33YS would provide adequate clearance from the storm. A more northerly latitude may be sufficient, depending on the location and forecast movement of the tropical cyclone.

One exception to the preceding guidance would be when a tropical cyclone, such as one depicted in Figure XI-8, is forecast to pass south of Brisbane on a southeasterly course. In such a scenario, the obvious choice would be to proceed northeastward into the Coral Sea in order to avoid the tropical cyclone's effects. If this option is chosen, sortieing units must carefully monitor all tropical cyclone warnings to ensure that they do not encounter a different tropical cyclone over the Coral Sea.

2.8.3. Remaining in Port

Remaining at a berth in the Port is an option that should be considered only in specific tropical cyclone scenarios. Most of the time, a tropical cyclone will move south or southeastward east of Brisbane, placing the Port of Brisbane on its weaker right side. If such an event occurs, remaining at a structurally sound berth should be considered if (1) ships are not ordered to sortie by the Port of Brisbane, and (2) the storm is relatively weak and forecast to remain so. Due to the additional protection from wind provided by the adjacent terrain and man-made structures, the preferred berths are those on the Brisbane River. Another factor that must be considered if a berth on the river is used, is that the heavy rain that usually accompanies a tropical cyclone passage can cause increased current flow and higher water levels at the wharves. The Brisbane River is particularly susceptible to flooding and has experienced several disastrous floods in the past.

The berths at Fisherman Islands are structurally sound and their use may be considered if the wind is forecast to be southerly and remain within safe limits. Safe wind limits for remaining alongside a berth are best left to the judgment of the Commanding Officer or ship's master and Port of Brisbane authorities. An early consultation is advised. If any doubt exists as to how strong the wind will be at a particular berth, a sortie is the recommended course of action. The berths on the south side of the Brisbane River and those at Fisherman Islands will be subject to offsetting wind forces during southerly winds, and the use of cyclone moorings will be necessary. Northerly winds would be most hazardous to the berths on Fisherman Islands as they are exposed to northerly winds and waves. If strong northerly winds are forecast during the passage of the tropical cyclone, a sortie is recommended.

The Saffir-Simpson Hurricane Wind Scale

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The Saffir-Simpson Hurricane Wind Scale is a 1 to 5 categorization based on the hurricane's intensity at the indicated time. The scale provides examples of the type of damage and impacts in the United States associated with winds of the indicated intensity. In general, damage rises by about a factor of four for every category increase[1]. The maximum sustained surface wind speed (peak 1-minute wind at the standard meteorological observation height of 10 m [33 ft] over unobstructed exposure) associated with the cyclone is the determining factor in the scale. (Note that sustained winds can be stronger in hilly or mountainous terrain – such as the over the Appalachians or over much of Puerto Rico - compared with that experienced over flat terrain[2].) The historical examples provided in each of the categories correspond with the observed or estimated maximum wind speeds from the hurricane experienced at the location indicated. These do not necessarily correspond with the peak intensity reached by the system during its lifetime. It is also important to note that peak 1-minute winds in hurricane are believed to diminish by one category within a short distance, perhaps a kilometer [~ half a mile] of the coastline[3]. For example, Hurricane Wilma made landfall in 2005 in southwest Florida as a Category 3 hurricane. Even though this hurricane only took four hours to traverse the peninsula, the winds experienced by most Miami-Dade, Broward, and Palm Beach County communities were Category 1 to Category 2 conditions. However, exceptions to this generalization are certainly possible.

The scale does not address the potential for other hurricane-related impacts, such as storm surge, rainfall-induced floods, and tornadoes. It should also be noted that these wind-caused damage general descriptions are to some degree dependent upon the local building codes in effect and how well and how long they have been enforced. For example, building codes enacted during the 2000s in Florida, North Carolina and South Carolina are likely to reduce the damage to newer structures from that described below. However, for a long time to come, the majority of the building stock in existence on the coast will not have been built to higher code. Hurricane wind damage is also very dependent upon other factors, such as duration of high winds, change of wind direction, and age of structures.

Earlier versions of this scale – known as the Saffir-Simpson Hurricane Scale – incorporated central pressure and storm surge as components of the categories. The central pressure was used during the 1970s and 1980s as a proxy for the winds as accurate wind speed intensity measurements from aircraft reconnaissance were not routinely available for hurricanes until 1990[4]. Storm surge was also quantified by category in the earliest published versions of the scale dating back to 1972[5]. However, hurricane size (extent of hurricane-force winds), local bathymetry (depth of near-shore waters), topography, the hurricane's forward speed and angle to the coast also affect the surge that is produced[6,7]. For example, the very large Hurricane Ike

[1] R. A. Pielke, Jr. and colleagues, 2008 in *Natural Hazard Review*.

[2] C. A. Miller, and A. G. Davenport, 1998 in Journal of Wind Engineering and Industrial Aerodynamics.

[3] P. J. Vickery and colleagues, 2009 in Journal of Applied Meteorology and Climatology.

[4] R. C. Sheets, 1990 in *Weather and Forecasting*.

[5] National Hurricane Operations Plan, 1972.

[6] Jelesnianski, C. P., 1972 in *NOAA Technical Memorandum NWS 46*.

Storm Surge Scales and Storm Surge Forecasting

During the open public comment period for the draft of the Saffir-Simpson Hurricane Wind Scale, many people suggested that the National Weather Service develop a storm surge specific scale as well as improve its forecasting of storm surge. It is acknowledged that there are some researchers who advocate developing another scale for hurricanes specifically geared toward storm surge impact[1,2] by incorporating aspects of the system's size. However, the National Hurricane Center does not believe that such scales would be helpful or effective at conveying the storm surge threat. For example, if 2008's Hurricane Ike had made landfall in Palm Beach, Florida, the resulting storm surge would have been only 8', rather than the 20' that occurred where Ike actually made landfall on the upper Texas coast. These greatly differing surge impacts arise from differences in the local bathymetry (the shallow Gulf waters off of Texas enhance storm surge while the deep ocean depths off of southeastern Florida inhibit surge). The proposed storm surge scales that consider storm size do not consider these local factors that play a crucial role in determining actual surge impacts.

The National Weather Service believes that a better approach is to focus directly on conveying the depth of inundation expected at the coast and inland. Because storm surge-induced flooding has killed more people in the United States in hurricanes than all other hurricane-related threats (freshwater flooding, winds, and tornadoes) combined since 1900[3], the National Oceanic and Atmospheric Administration is working to enhance the analysis and prediction of storm surge. Direct estimates of inundation are being communicated in the NHC's Public Advisories and in the Weather Forecast Office's Hurricane Local Statements. New ways of communicating the threat have also been developed. NHC's probabilistic storm surge product, which provides the likelihood of storm surge values from 2 through 25 feet, became operational in 2009, and the NWS's Meteorological Development Laboratory is providing experimental, probabilistic storm surge exceedance products for 2010. In addition, coastal WFOs will provide experimental Tropical Cyclone Impacts Graphics in 2010; these include a qualitative graphic on the expected storm surge impacts. Finally, the NWS is exploring the possibility of issuing explicit Storm Surge Warnings, and such warnings could be implemented in the next couple of years. In all of these efforts, the NWS is working to provide specific and quantitative information to support decision-making at the local level.

[1] L. Kantha, 2006 in *EOS*.

[2] M. D. Powell and T. A. Reinhold, 2007 in *Bulletin American Meteorological Society.*

[3] E. S. Blake and colleagues, 2007 in *NOAA Technical Memorandum NWS TPC 5.*

THE END

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