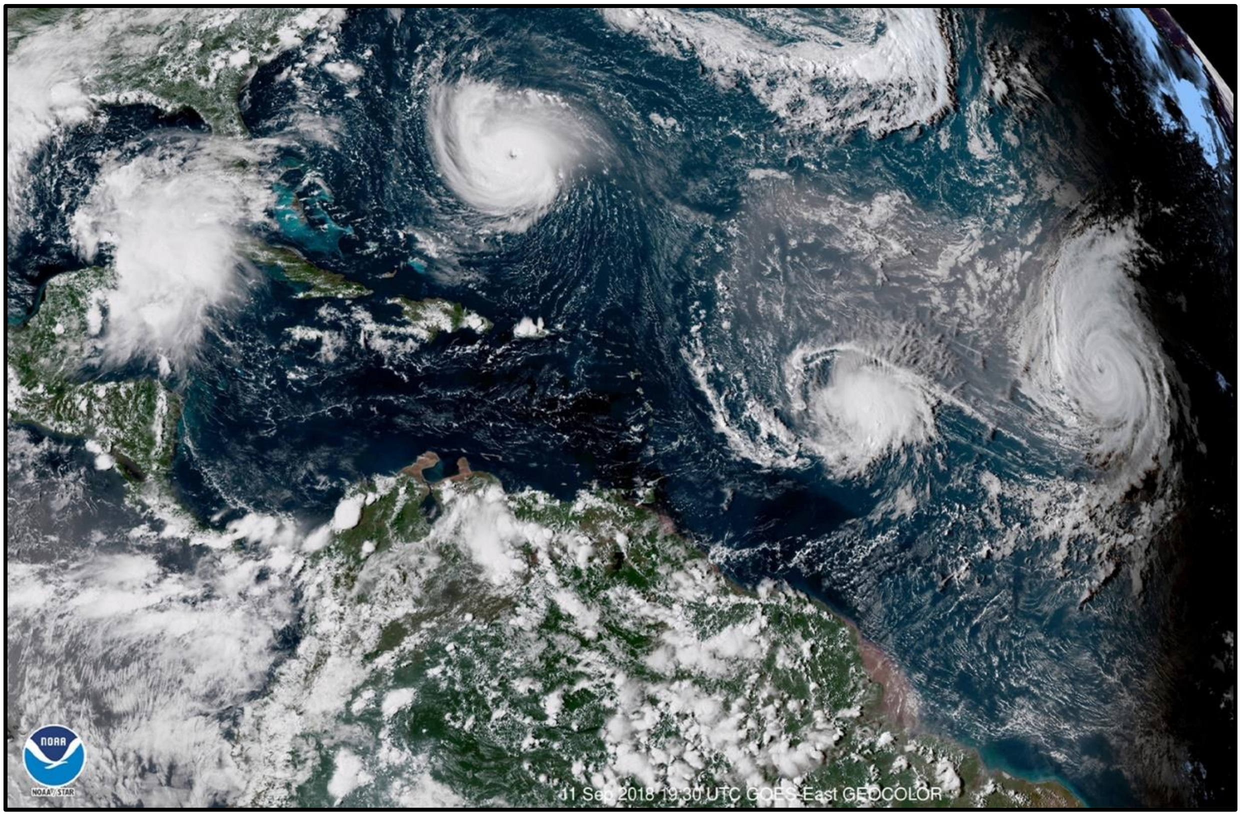
Mariner's Tropical Cyclone Guide



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May 2023

Websites of Interest to the Mariner

National Hurricane Center (NHC):	hurricanes.gov
Central Pacific Hurricane Center (CPHC):	hurricanes.gov/chpc
Joint Typhoon Warning Center (JTWC):	metoc.navy.mil/jtwc/jtwc.html
Ocean Prediction Center (OPC):	ocean.weather.gov/
Global Tropical Cyclone Centers (RSMC):	nhc.noaa.gov/aboutrsmc.shtml

National Weather Service (NWS) Home Page:	weather.gov
NWS Marine Dissemination Page:	weather.gov/marine
Weather Ready Nation Marine Ambassador:	weather.gov/wrn/wrna-marine
NWS Marine Text Products:	weather.gov/marine/forecast
NWS Radio Facsmile (Radiofax) Charts:	weather.gov/marine/radiofax_charts
NHC Marine Products:	nhc.noaa.gov/marine
NHC Marine Composite Page:	nhc.noaa.gov/marine/forecast/
Sea Surface Temperature:	nhc.noaa.gov/sst/
Tropical Cyclone Climatology:	nhc.noaa.gov/climo
NOAA Weather Radio:	weather.gov/nwr
National Data Buoy Center:	ndbc.noaa.gov
National Ocean Service (NOS):	oceanservice.noaa.gov
NOS Tide Data:	tidesandcurrents.noaa.gov
Voluntary Observing Ship Program (VOS)	vos.noaa.gov
Global High Seas Forecasts:	wwmiws.wmo.int/
USCG Navigation Center:	navcen.uscg.gov
American Practical Navigator (Bowditch):	msi.nga.mil/Publications/APN
Fleet Weather Center Norfolk:	metoc.navy.mil/fwcn/fwcn.html
Fleet Weather Center San Diego:	metoc.navy.mil/fwcsd/fwc-sd.html
Hurricane Havens (North Atlantic):	nrlmry.navy.mil/port_studies/tr8203nc/
Typhoon Havens (Pacific):	nrlmry.navy.mil/port_studies/thh-nc/

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Introduction

"As the bar[1] 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." – Bowditch

The purpose of this manual is to help mariners avoid experiencing the "awesome fury" described in Bowditch. It was heavily inspired by former National Hurricane Center meteorologist Eric Holweg's *Mariner's Guide for Hurricane Awareness in the North Atlantic Basin*. Mr. Holweg published his guide in the year 2000, when NHC only provided tropical cyclone forecasts to 72 hours, with track errors 2-3 times today's average and severely limited wind radii guidance.

Due to advances in forecast skill and enhanced support products, some of the old recommendations, including the famous 1-2-3 rule, are no longer endorsed by the National Hurricane Center. This manual covers the latest science and best practices while expanding in scope to cover all tropical cyclone basins.

This guide is divided into four chapters designed to answer the following questions:

- What are tropical cyclones?
- When and where do they occur?
- How can I receive the latest forecast?
- What should I do with this information?

Disclaimer

This manual is provided as a courtesy of the National Weather Service. Following the methodologies outlined within will not eliminate the risks of harm from tropical cyclones. All actions should only be performed as safe navigation permits. Anyone following the recommendations contained in this guide does so at their own risk.

[1] **Bar** is defined earlier in Bowditch as "the heavy bank of clouds comprising the main mass of the cyclone."

Chapter 1 – Tropical Cyclone Basics

Tropical cyclones are warm core, non-frontal, low-pressure systems of synoptic scale that develop over tropical or subtropical waters and have a definite organized surface circulation. Tropical depressions, tropical storms, hurricanes, typhoons, and cyclones are all forms of tropical cyclones, differentiated only by their basin and intensity.

Definitions and Terminology

Tropical Wave

A tropical wave is a trough or cyclonic curvature maximum in the trade wind easterlies. These waves tend to reach maximum amplitude in the lower to middle troposphere[2] and may or may not be accompanied by thunderstorm clusters. If atmospheric and oceanic conditions are favorable, tropical cyclones can develop from these waves, although the majority do not spawn tropical cyclones. Either way, the passage of these waves is often accompanied by squally weather with brief periods of higher sustained winds. It is uncommon, but not unheard of, for tropical waves to have sustained tropical storm (gale) force winds, especially for strong, fast-moving waves. Refer to **Figure 1** for an example of a tropical wave.

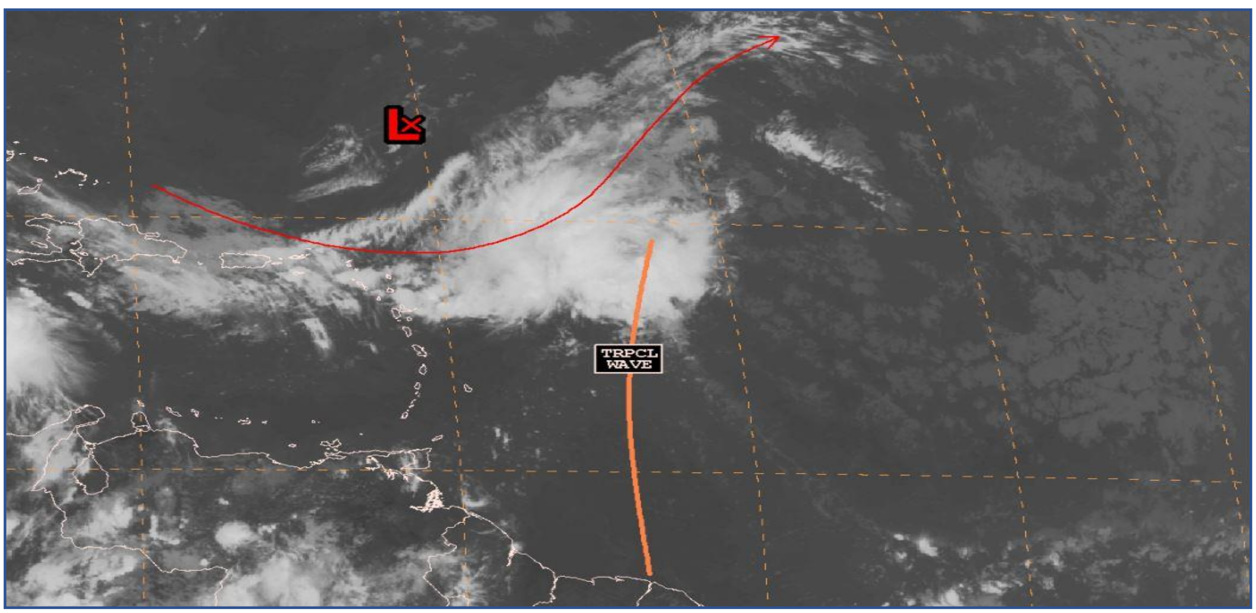


Figure 1: Satellite image of a tropical wave approaching the Lesser Antilles. This wave did not develop into a tropical cyclone, in part due to the upper-level low to the NW. Although the interaction with upper-level lows is unfavorable for tropical cyclogenesis, it can often induce heavy rainfall.

[2] The **troposphere** is the lowest layer of the atmosphere where all weather occurs. It extends roughly 8 mi/12 km from the surface.

Tropical Disturbance

A tropical disturbance is a discrete tropical weather system with apparently organized convection (generally 100 to 300 miles in diameter) originating in the tropics or subtropics, having a non-frontal migratory character, and maintaining its identity for 24 hours or more. It may or may not be associated with a detectable perturbation of the wind field. Tropical disturbances include tropical waves, surface troughs, and dissipating frontal boundaries. Importantly, tropical disturbances do not have a closed surface wind circulation and are therefore not classified as tropical cyclones. Refer to **Figure 2** for an example of a tropical disturbance.

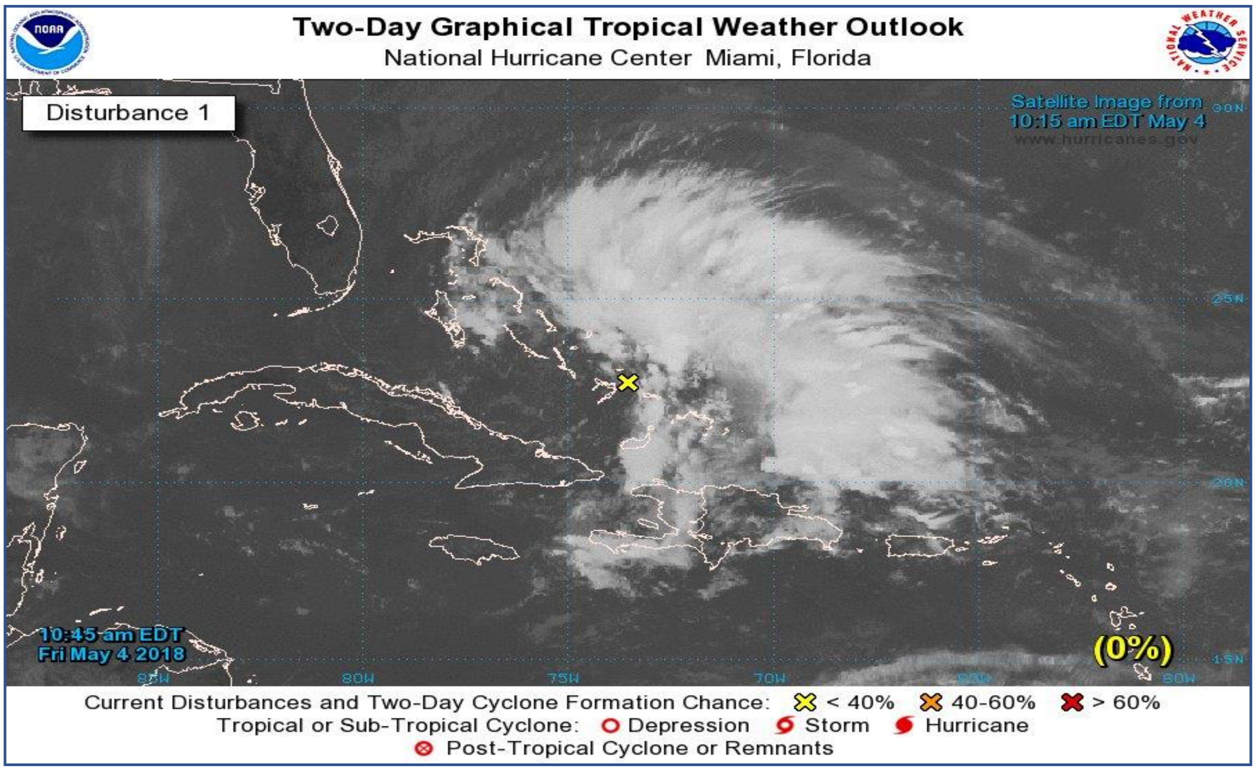


Figure 2: NHC Tropical Weather Outlook identifying a tropical disturbance over the Bahamas. This was a pre-season event and conditions were not favorable for development. NHC assigned a 0% probability of development into a tropical cyclone over 48 hours.

Potential Tropical Cyclone

“Potential Tropical Cyclone” is a term used by the National Weather Service[3] to describe a disturbance that is not yet a tropical cyclone but poses the threat of bringing tropical storm or hurricane conditions to land within 48 hours. NHC will give the disturbance a number, complete advisory packages will begin, and watches or warnings will be issued for the affected areas.

[3] Potential Tropical Cyclones are issued by NHC and CPHC. They are not used in the West Pacific or Indian Ocean.

Tropical Cyclone

A tropical cyclone is a warm core, non-frontal, synoptic-scale cyclone originating over tropical or subtropical waters, with organized deep convection and a closed surface wind circulation about a well-defined low-pressure center. Once formed, a tropical cyclone extracts heat energy from the ocean as fuel.[4] Tropical cyclone is a generic term that encompasses tropical depressions, tropical storms, hurricanes and typhoons.

Tropical Depression

A tropical depression is a tropical cyclone with maximum sustained surface winds (1-minute mean) of 33 kt or less. Once a system attains tropical depression status, the National Hurricane Center will assign a number based on how many systems have received advisories in a given season. If a named system degrades into a depression, it will keep its name. Refer to **Figure 3** for an image of a tropical depression.

Figure 3: Tropical Depression Fred on August 12, 2021. The center of circulation is just north of southeastern Cuba. Due to approximately 20 kt of westerly shear, the convection is asymmetrical and displaced from the circulation center. Asymmetry is common with depressions and inhibits further development.

Tropical Storm

A tropical storm is a tropical cyclone with maximum sustained surface winds (1-minute mean) ranging from 34 to 63 kt. Once a system attains tropical storm status, the National Hurricane Center will assign a name from a predetermined alphabetical list (nhc.noaa.gov/aboutnames.shtml). Names in other basins come from the applicable Regional Specialized Meteorological Center (RSMC). Refer to **Figure 4** for an image of a tropical storm.

[4] In this way, tropical cyclones differ from extratropical cyclones, which derive energy from horizontal temperature contrasts in the atmosphere (baroclinic effects).

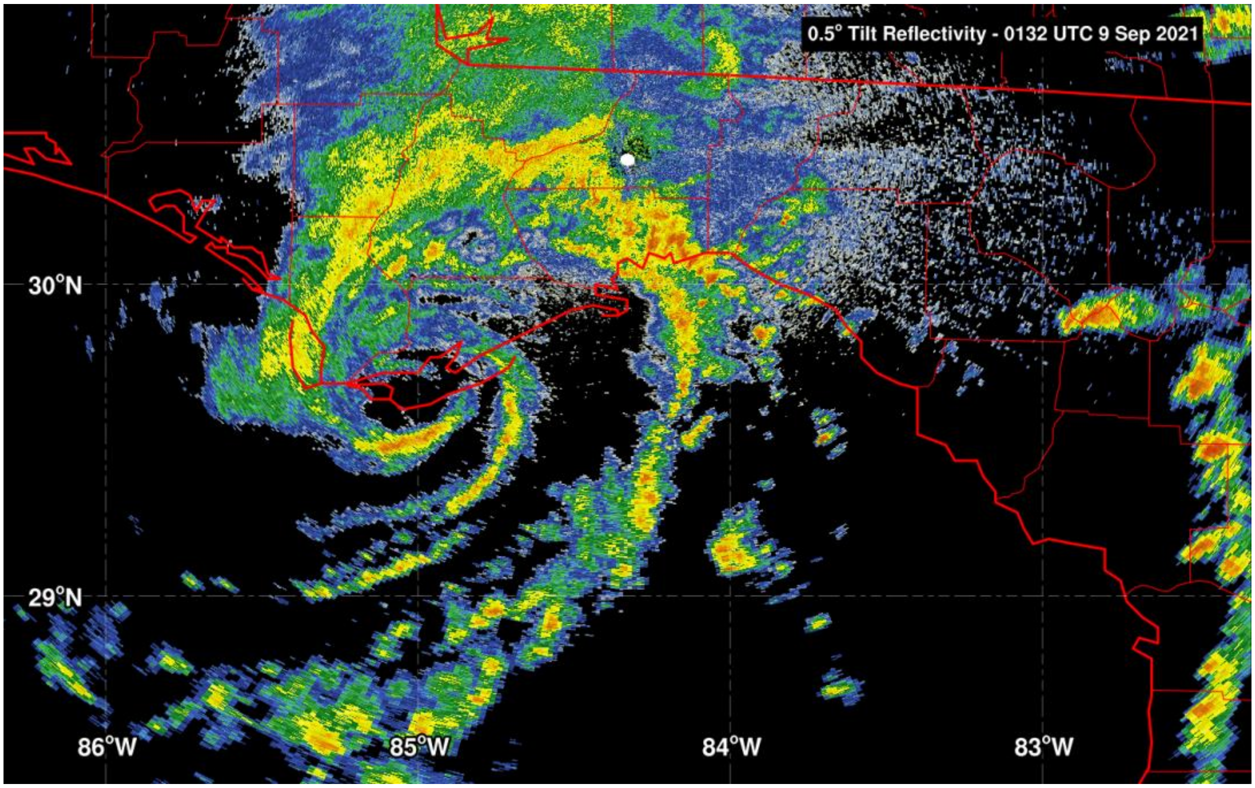


Figure 4: Radar reflectivity image of Tropical Storm Mindy making landfall along the Florida panhandle in 2021.

Hurricane

A hurricane is a tropical cyclone with maximum sustained surface winds (1-minute mean) greater than or equal to 64 knots. A tropical cyclone of this strength is known as a hurricane in the Atlantic, NE Pacific, and North Central Pacific; a typhoon in the NW Pacific; a very severe cyclonic storm in the North Indian Ocean; a tropical cyclone in the SW Indian Ocean; and a category 3 tropical cyclone in the SE Indian Ocean and SW Pacific Ocean[5] (**Table 1**). Refer to **Figure 5** for an example of a major hurricane.

North Atlantic	**Hurricane**
Northeast Pacific	**Hurricane**
Northwest Pacific	**Typhoon**
North Indian	**Very Severe Cyclonic Storm**
Southwest Indian	**Tropical Cyclone**
Southeast Indian	**Category 3 Tropical Cyclone**
Southwest Pacific	**Category 3 Tropical Cyclone**

Table 1: Global names for tropical cyclones producing 64-kt sustained winds.

[5] One exception is the National Weather Service office in American Samoa. They follow NHC/CPHC convention and use the term hurricane at 64 knots.

Figure 5: Hurricane Florence as seen from the International Space Station on September 12, 2018. Note the clear eye surrounded by dense, symmetrical overcast. At this time Florence was a category 4 hurricane with sustained winds of 115 kt. Due to the large size and long duration of Florence, 12-ft (3.7-m) seas extended up to 300 NM from the storm center.

Saffir-Simpson Hurricane Wind Scale

Hurricanes are categorized according to the strength of their winds using the Saffir-Simpson Hurricane Wind Scale (SSHWS) (**Table 2**). A category 1 storm has the lowest wind speeds, while a category 5 has the highest. Major hurricanes are category 3 or higher. Typhoons and Cyclones are also divided into various categories based on the applicable RSMC. The Joint Typhoon Warning Center (JTWC) uses the term “Super Typhoon” for storms with maximum sustained winds of at least 130 kt.

A higher category hurricane is generally more dangerous; however, these terms are based solely on the maximum sustained wind speed and do not translate directly to impacts. A lower category storm with a larger wind field can be more hazardous to the mariner by generating a larger area of rough seas and requiring additional evasive action. Other considerations are storm speed, angle of approach to the ship, distribution of the wind field, direction of winds and swell, size of the dynamic fetch area, and many other aspects particular to each system. Additionally, the forecast is more challenging with weaker or less organized systems.

Category	Wind Speed (Knots)
Tropical Depression	<34
Tropical Storm	34-63
1	64-82
2	83-95
3	96-112
4	113-136
5	>136

Table 2: The Saffir-Simpson Hurricane Wind Scale and related classifications.

Subtropical Cyclone

A subtopical cyclone is a non-frontal cyclone with both tropical and extratropical characteristics. They originate over tropical or subtropical waters and have a closed surface wind circulation about a well-defined center. In addition, they have organized moderate to deep convection but lack a central dense overcast. Unlike tropical cyclones, they derive a significant proportion of their energy from baroclinic sources. Subtropical cyclones are generally cold-core in the upper troposphere, often associated with an upper-level low or trough. These systems typically have a radius of maximum winds occurring relatively far from the center (usually greater than 60 NM) and may be asymmetric.

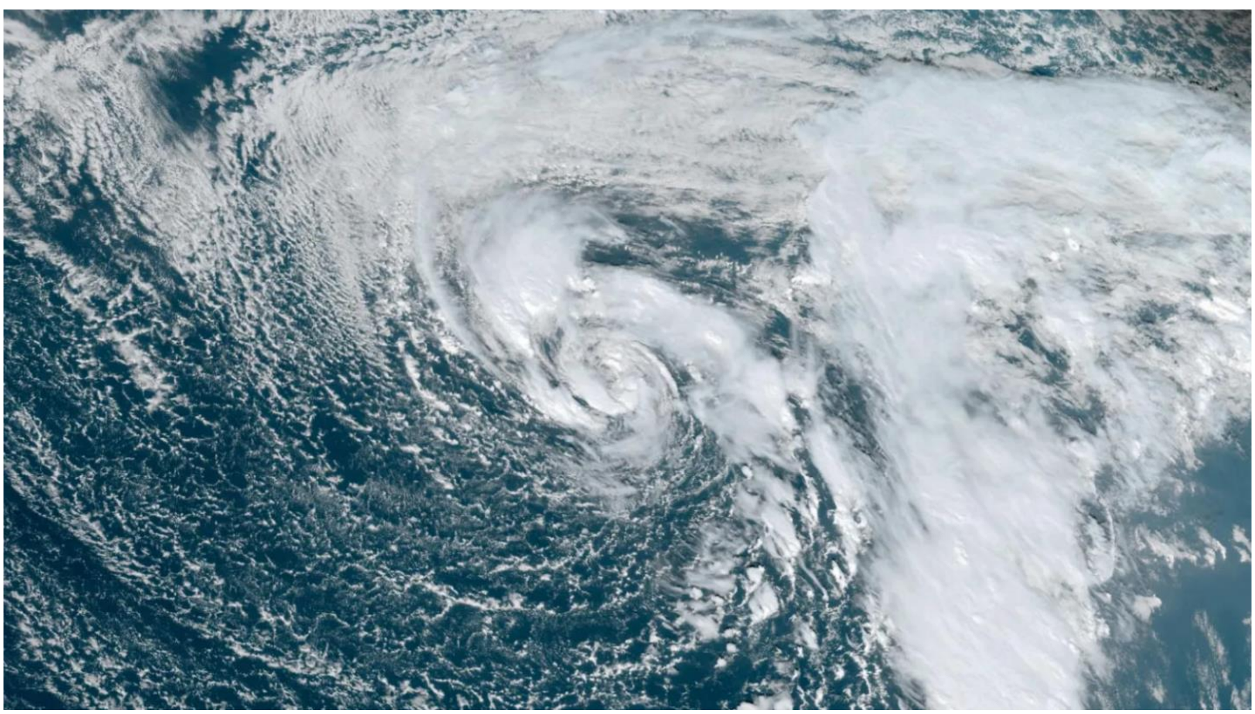


Figure 6: Subtropical Storm Wanda after transitioning from a Nor'easter in 2021.

Formation and Life Cycle of Tropical Cyclones

Ingredients for Development & Intensification

Several environmental conditions need to align to allow tropical cyclones to thrive. When they do, strong, upward motion cools maritime tropical air, condensing water vapor into clouds that become thunderstorms. With effective spin and upper-level outflow, this process forms an elegant loop fueled by the warm ocean. The individual ingredients needed to support this process are explored below:

1. **A pre-existing surface disturbance with thunderstorms**: As warm core systems, tropical cyclones rely on a build-up of heat energy within the atmospheric column above them to grow and develop. A thunderstorm complex acts as a vertical transport mechanism for heat, moisture, and the cyclonic turning of winds into the upper levels of the atmosphere. This vertical transport into higher levels of the atmosphere aids the incipient tropical cyclone in growing and developing. Tropical waves often provide this trigger, as do surface troughs and dissipating frontal boundaries.

2. **Warm ocean**: Tropical cyclones draw on the heat energy stored in the ocean. Sea surface temperatures of at least 80ºF or 26.5ºC are needed to support development and intensification. Evaporation of this warm water begins the process of energizing the atmospheric column. In addition to sea surface temperature, the mixed layer (zone with nearly constant ocean temperature with depth) should be at least 60 m deep. A deep mixed layer is essential as the strong winds of a tropical cyclone cause a turbulent sea that mixes the warm surface water with cooler, deeper water.

3. **Low vertical wind shear**: Little change in wind speed or direction throughout the depth of the troposphere. Tropical cyclones rely on a vertically stacked structure to grow or maintain intensity. In other words, the ideal tropical cyclone will have its cyclonic circulation in the upper levels of the atmosphere located directly above the circulation of the low levels of the atmosphere. Changes in environmental wind speed or direction with height will tilt the vertical structure of a tropical cyclone. This vertical tilting of the system inhibits growth and may cause the system to decay.

4. **Unstable atmosphere:** Temperature decreases quickly with height in an unstable atmosphere. Typically, the warmest air over the ocean is near the surface. Imagine filling a weightless balloon with a hair dryer. When released, the balloon's air is warmer than the environment and begins to rise. The balloon expands and cools steadily as the surrounding atmospheric pressure decreases. The rate of cooling is referred to as the lapse rate. If the environmental lapse rate exceeds the balloon's, the balloon will remain warmer than the environment and continue to rise. This situation is an example of an unstable atmosphere. If the balloon cools faster than the environment, the atmosphere is stable, and the balloon's vertical motion will be limited. Rising air is needed to warm the tropical cyclone core, and an unstable atmosphere is necessary to support rising air.[6]

[6] Interestingly, a tropical cyclone's warm core actually stabilizes the atmosphere, making it more difficult for thunderstorms to form. This phenomenon explains why lightning in tropical cyclones is much less frequent than within other oceanic thunderstorms.

5. **High atmospheric moisture content:** Cloud formation is limited if the atmospheric column is too dry. Rising air will cool but struggle to reach the low dew point. Even if the maritime tropical air near the surface is moist, it will mix with dry mid-levels of the atmosphere and inhibit condensation. Without condensation, there is no latent heat release to create and support the warm core. Additionally, rising dry air cools faster than moist air, which gains some heat back through the latent heat released during condensation. Because of this discrepancy, the environment is often stable for dry parcels of air but unstable for moist air.

6. **Upper-level outflow:** An exhaust mechanism is needed above a system to perpetuate the strong upward motion. This upper-level mass removal causes the pressure at the surface to drop. As a system develops, low-level cyclonic flow pulls mass toward the center. The flow then turns upward as intense vertical motion associated with thunderstorms. This process is known as "the in-up-and-out" circulation. Without a method to dispose of the mass above a tropical cyclone, low-level converging flow toward the center will halt as the system suffocates.

7. **Adequate Coriolis force**: Due to the earth's rotation, the Coriolis force causes tropical cyclones to spin counter-clockwise in the northern hemisphere and clockwise in the southern hemisphere. This spin is a critical component for development and intensification. Tropical cyclones rarely develop within 5 degrees of the equator, where this force is weakest (**Figure 7**).

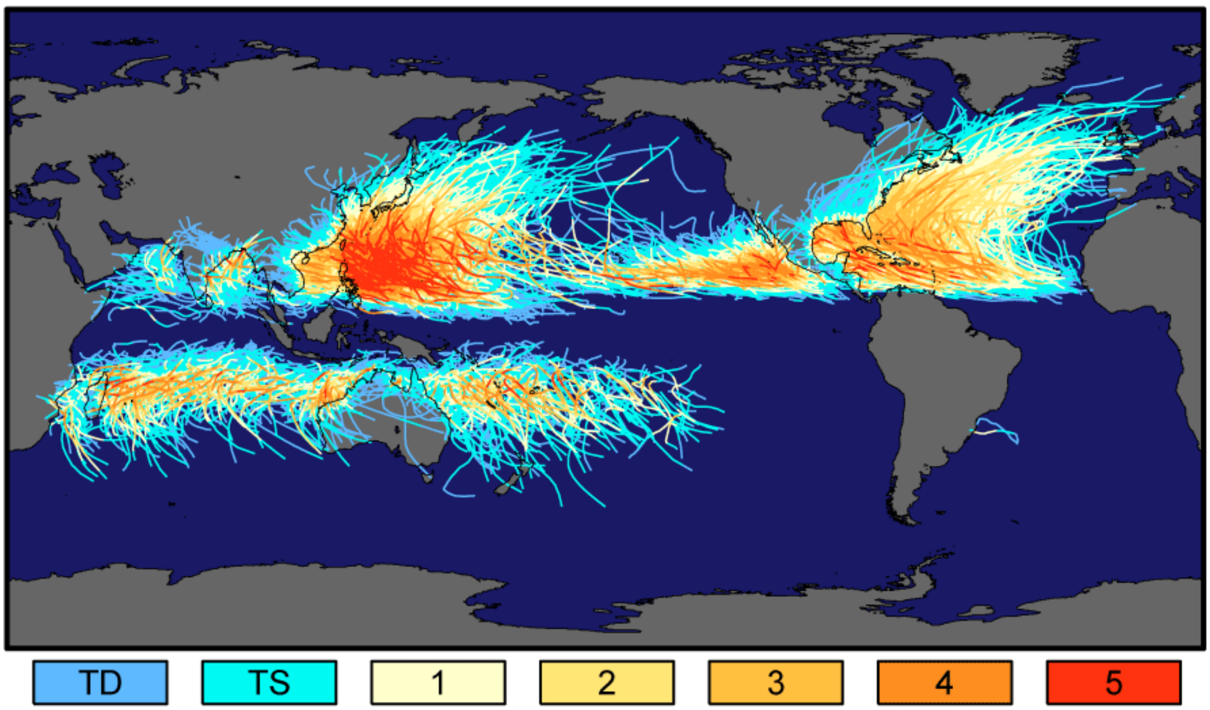


Figure 7: Global distribution of tropical cyclone tracks. This map highlights the lack of tropical cyclones around the equator (insufficient Coriolis force), south Atlantic (high vertical wind shear and lack of disturbances) and southeast Pacific (high shear, lack of disturbances and cooler water).

Formation

Tropical cyclones typically originate from a convectively active disturbance. These initial clusters of thunderstorms begin the process of latent heat release that serves as the mechanism to transport ocean heat energy into the atmosphere. If this process persists, the warming air will induce lower atmospheric pressure, causing air to approach from surrounding areas. The Coriolis force will cause the encroaching air to develop cyclonic curvature around the low-pressure center. If the atmosphere is unstable enough for the thunderstorms to persist, the pressure gradient will increase, causing fresh to strong winds. With light wind shear and adequate Coriolis force, the cyclonic winds will wrap around the low-pressure center. At this point, the system has become a tropical depression.

Intensification

While conditions remain favorable, energy from the warm ocean will continue to heat the atmosphere. As the atmosphere warms, the pressure decreases, and the wind speed increases. If the sustained winds at the surface reach 34 kts or more, the system has achieved tropical storm status. At this point, the storm will begin to take on a familiar spiral appearance with increasing cyclonic wind flow around the low-level circulation center. The storm becomes a hurricane (or regional equivalent) when the surface winds reach 64 kts. At this point, outer rain bands will form around a concentric ring of thunderstorms (eyewall) while the tops of tall thunderstorms spread out to form a blanket of high cirrus overcast. Finally, the system becomes a major hurricane if the winds reach 96 kts (category 3 strength). At this point, the storm is very well organized, and the eye will likely begin to clear.

Typical rates of intensification under favorable conditions range from 10-20 kts per day. However, when conditions are very favorable, a system may undergo rapid intensification (RI), defined as an increase in the maximum sustained wind speed of 30 kts or more in 24 hours. RI occurs in about 5% of observed intensity changes. Unfortunately, RI is challenging to forecast as it is a standard characteristic of the strongest tropical cyclones. In fact, RI occurred in all Atlantic category 4 and 5 storms on record, as well as 90% of super typhoons in the western North Pacific.

Dissipation and Transition

The tropical cyclone will continue to grow and sustain itself until one or more of the necessary ingredients is either lost or undergoes a significant change. Wind shear can tear a system apart, separating the vertically stacked warm core aloft from its low-level circulation. Movement of these systems into regions of drier mid-level air can inhibit convection and cause a weakening of the tropical cyclone. Movement over cooler water or landfall events will shut down a tropical cyclone’s energy source and, therefore, its fuel to survive.

A tropical cyclone interacting with a mid-latitude front will likely transition into an extratropical storm. This transition can cause rapid structural changes in the cyclone, dramatically changing the storm’s size, speed, and direction. This transition occurs at higher latitudes, often in the vicinity of major transatlantic and transpacific shipping lanes.

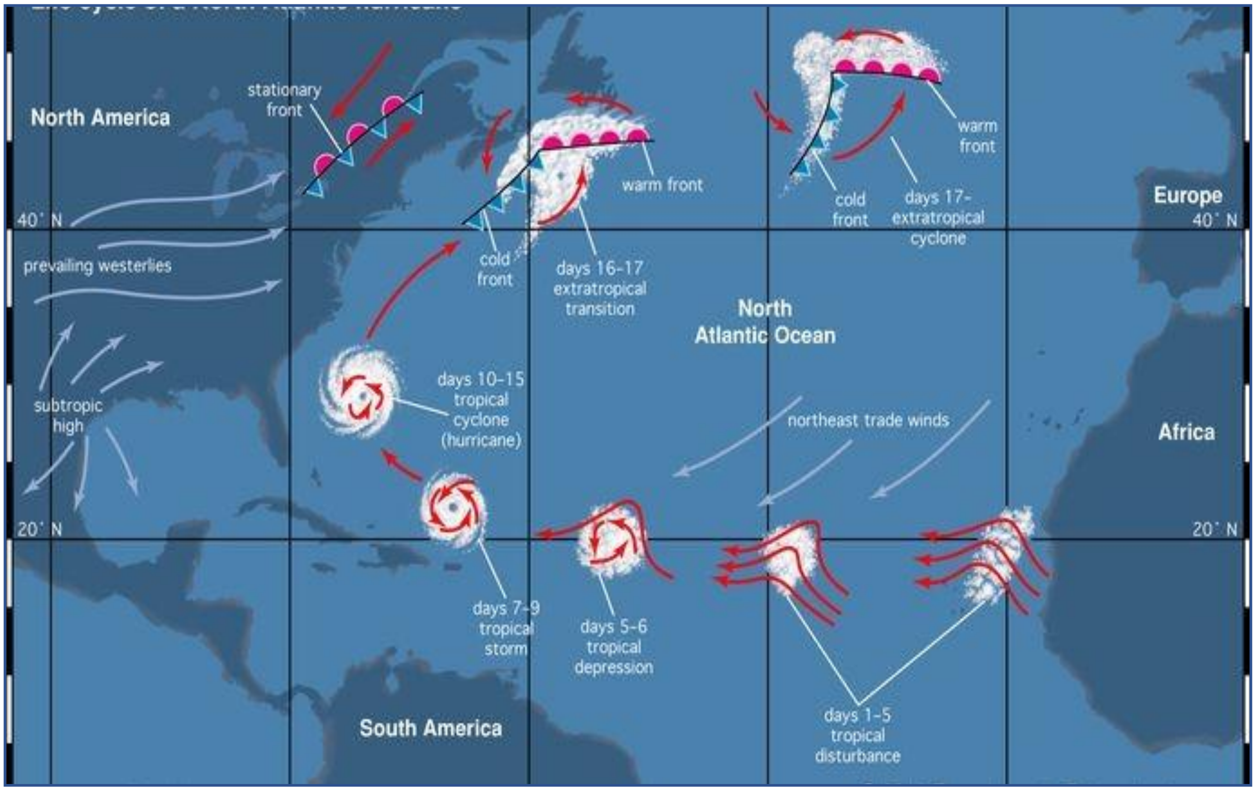


Figure 8. Typical lifecycle of a North Atlantic hurricane. Note that formation can occur outside of the main development region.

Tropical Cyclone Characteristics

Tropical Cyclone Size

One of the most important considerations for the mariner when determining tropical cyclone impacts is the size. Unfortunately, many popular products, including the famous cone of uncertainty graphic, do not fully account for this feature, which can vary dramatically (**Figure 9**). To determine the size of a tropical cyclone, mariners should take note of the area of 34-kt winds and 12-ft (3.7-m) seas. Similarly, the tropical cyclone path is a swath of impacts rather than a line between center fixes. This swath requires the mariner to take precautions far from the center.

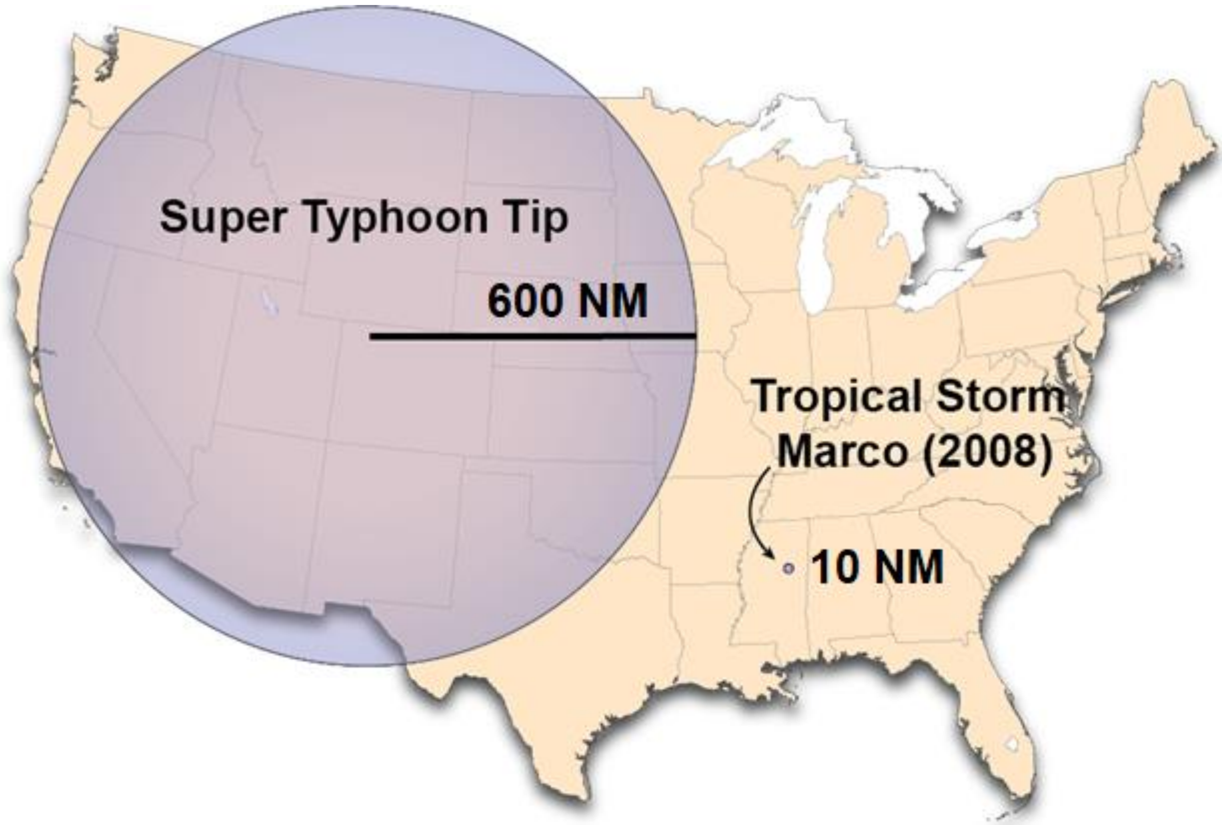


Figure 9: Size comparison between the largest and smallest tropical cyclones on record. Super Typhoon Tip (West Pacific, 1979) had tropical storm force winds 600 NM from its center, while Tropical Storm Marco (Gulf of Mexico, 2008) only extended tropical storm force winds 10 NM.

While Super Typhoon Tip was significantly stronger than Tropical Storm Marco, size still varies considerably for storms with similar intensity. As **Figure 10** shows, Nicole (2022) and Humberto (2019) were both classified as tropical storms in a similar location near the NW Bahamas, but their size varied tremendously. While tropical storm force winds from Humberto were not quite reaching the Bahamas, Nicole extended these winds to the Florida coast. Additionally, 12-ft seas from Nicole were reaching Bermuda while Humberto wasn't even producing 12-ft seas.

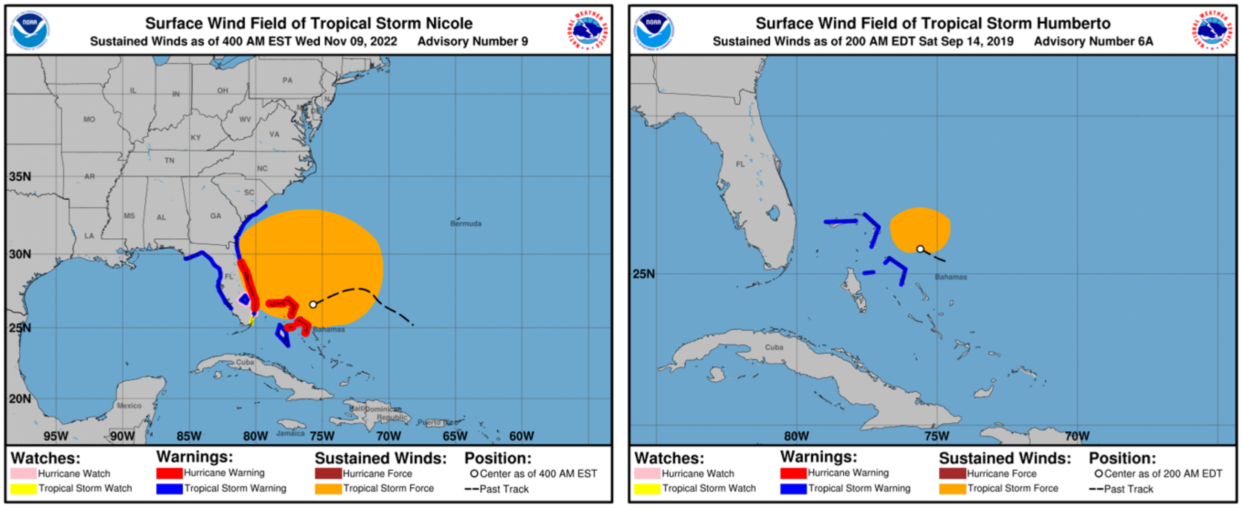


Figure 10: Tropical storm force wind extent of Tropical Storm Nicole (left) and Humberto (right). At this time, the maximum radius of 34-kt winds associated with Nicole was 400 NM while 12 ft seas extended up to 600 NM. On the other hand, Humberto only extended tropical storm force winds 80 NM with no 12-ft seas.

Therefore, do not focus on the location and track of the center because a tropical cyclone's destructive winds and high seas cover a broad swath. Hurricane-force winds can extend outward about 20 NM from the storm center of a small hurricane to more than 150 NM for a large one. The range over which tropical storm force winds occur is even greater.

Wind Field

Another aspect highlighted in **Figure 10** is the asymmetric wind field. Both tropical storms were larger in the northern semi-circle. This asymmetry is common as each tropical cyclone takes on characteristics determined by the environment in which it develops. While tropical cyclones come in many shapes and sizes, there are some generalizations about the wind field.

Winds are generally light in the eye of a tropical cyclone; however, the strongest winds occur in the nearby eyewall. Outside the radius of maximum winds, the speed decreases with distance from the center. Winds turn cyclonically (counter-clockwise in the northern hemisphere) about the center of circulation and can vary significantly in their speed and distribution within the storm. As a general rule of thumb in the northern hemisphere, a tropical cyclone's right side (relative to the direction it is traveling) is more dangerous. This trait is due primarily to the additive effect of the rotational and translational wind speeds. In other words, the wind speed generated by the storm combines with the storm's forward motion (**see Figure 11**). Alternatively, winds are weaker on the left side of a storm. The storm's right side also tends to generate higher seas and, in landfall situations, more storm surge and a more significant tornado threat. Importantly for the mariner, the front right quadrant is particularly dangerous as the wind direction tends to push a vessel towards the future center of the storm. **Chapter 4** will discuss this situation in greater detail. Tropical cyclones spin clockwise in the southern hemisphere. As a result, the left side is more dangerous south of the equator.

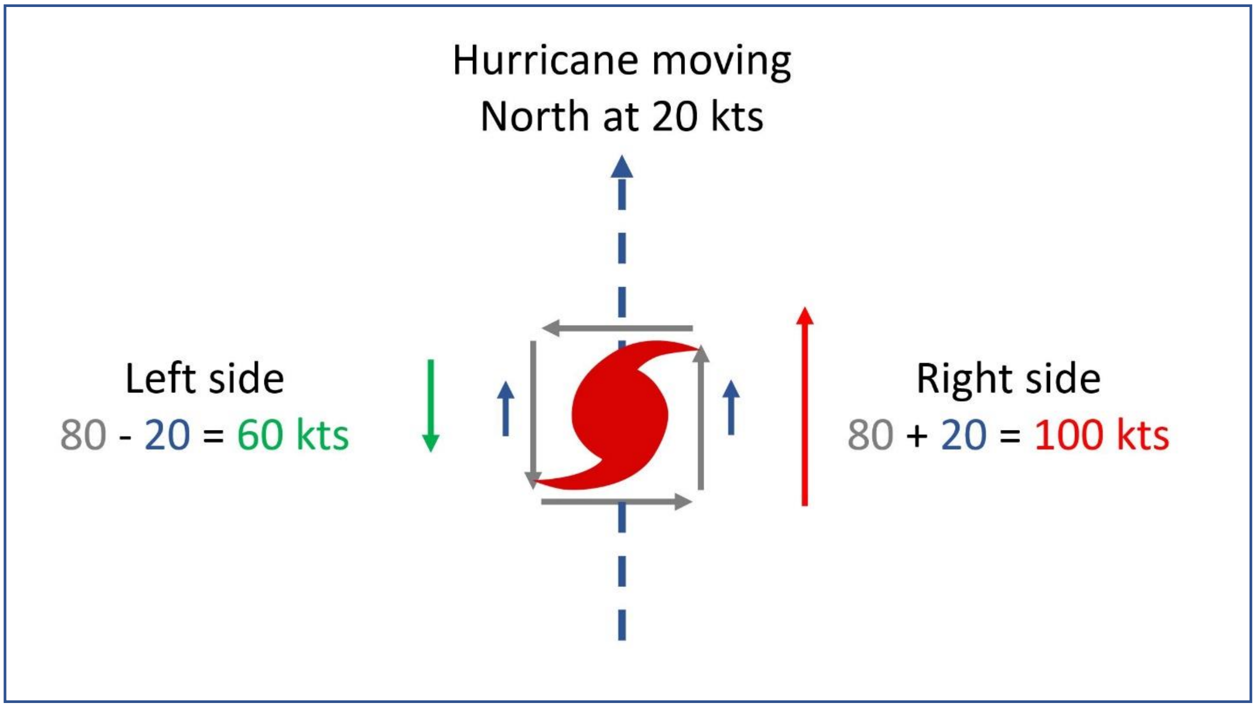


Figure 11: The additive effect of rotational (grey) and translational (blue) wind speed leads to stronger wind on the right side of a storm in the northern hemisphere. In this case the advisory would indicate the system has a peak wind of 100 kt. [7]

Many other factors determine the exact wind field. For example, the location of the strongest thunderstorm activity and the tropical cyclone's position compared to other synoptic scale features play a significant role in the wind field structure. Similarly, proximity to land, especially with high terrain, can significantly alter the wind field. Official forecasts of wind radii take all of these factors into account.

To describe the complex wind field, the National Hurricane Center and the Joint Typhoon Warning Center both provide 64-kt, 50-kt, and 34-kt wind radii for the four quadrants of the storm (NE, SE, SW, NW) (**Figure 12**). Importantly, these values correspond to the ***farthest extent of winds in each quadrant*** rather than suggesting conditions are ubiquitous in that portion of the storm. Additionally, wind radii are only valid over open water, where surface friction is minimal.

[7] The advertised wind speed in tropical cyclone advisories already accounts for this phenomenon. It is, therefore, not necessary to add the movement speed of the system to the maximum winds stated in the advisory.

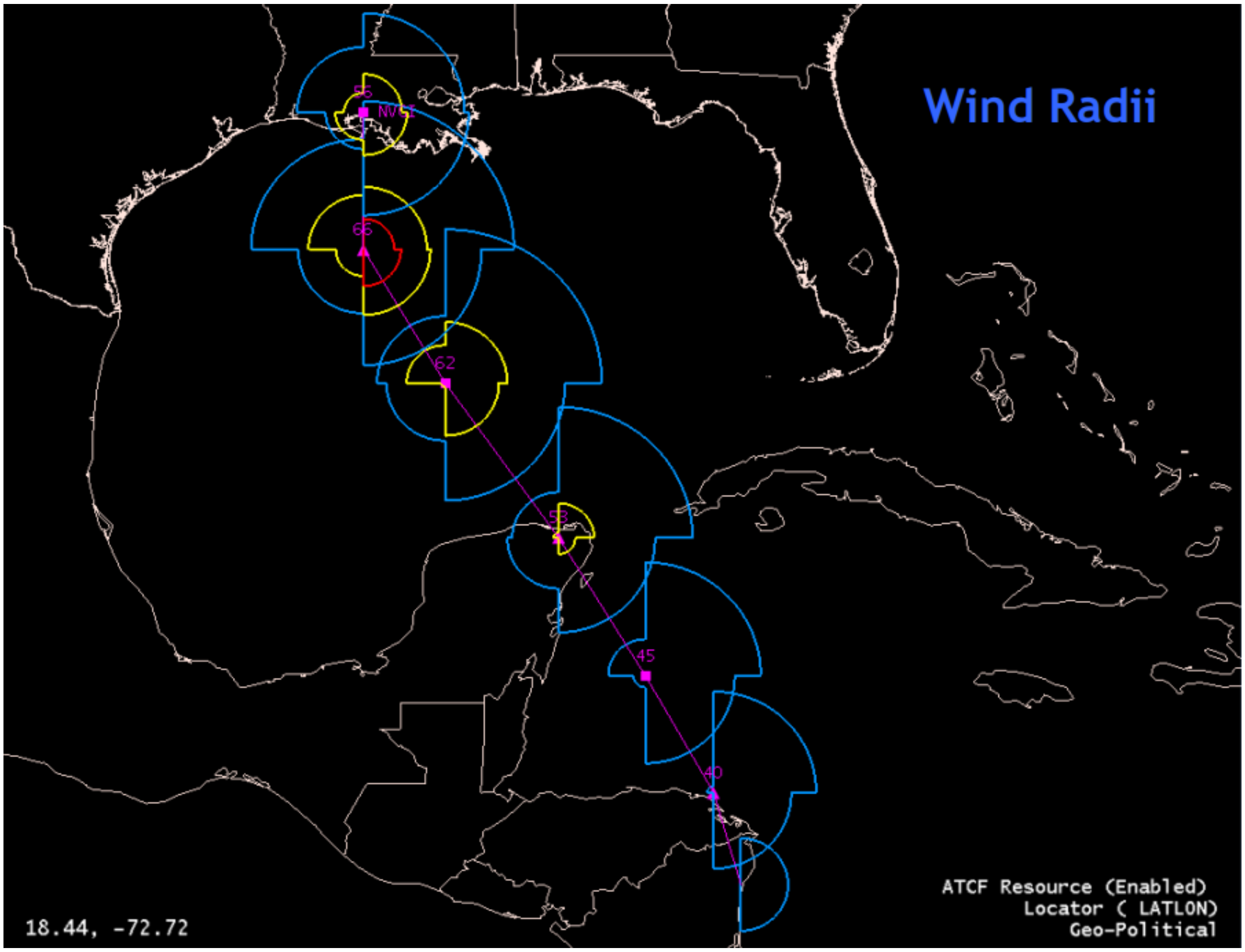


Figure 12: Wind radii visualization. The wind distribution is characterized by the farthest extent of 34-kt (blue), 50-kt (yellow), and 64-kt (red) sustained winds in each quadrant.

State of the Sea

Wave[8] growth depends on wind speed, wind duration, and fetch length. Fetch is the distance of relatively consistent wind speed and direction that causes a wave group to build. Waves grow when the wind speed exceeds the wave speed. Waves eventually propagate away from their generation area, becoming swell.

[8] Significant wave height will be used exclusively in this manual to describe the state of the sea, though it will often be referred to as wave height, sea height, or simply seas. Significant wave height is defined as the average height of the highest 1/3 of passing waves. Individual waves can reach twice the height of the significant wave height.

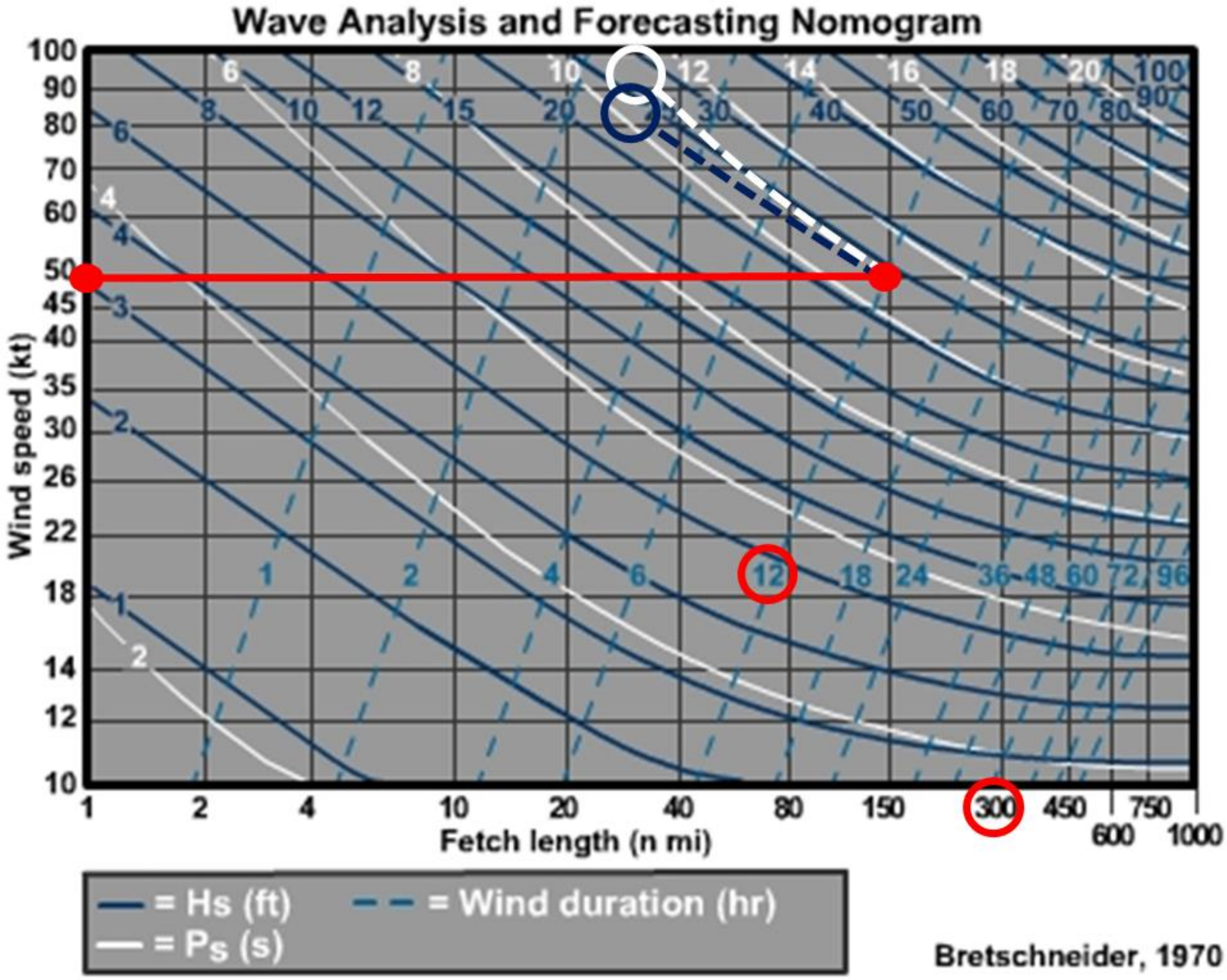


Figure 13: Wave height nomogram.

To use the nomogram in **Figure 13,** find the wind speed on the y-axis and draw a horizontal line to either the wind duration (blue dashed line) or fetch length (x-axis). Whatever appears first is the limiting factor in the wave height (e.g., duration limited or fetch limited). The expected wave height and period are identified by the solid blue and white lines at the intersection, respectively. For example, a 50-kt wind with a 300 NM fetch and 12-hour duration will produce duration-limited 24-ft (7.3-m) seas with an 11-second period (example drawn on **Figure 13**). Alternatively, if these same winds blow for 36 hours, they will produce fetch-limited 30-ft (9.1-m) seas with a 12-second period.

Fully developed seas are achieved for a given wind speed when the dark blue line flattens out, and the wave height will no longer increase with added fetch length or wind duration. For example, 15-kt winds can only create 6-ft (1.9-m) seas, while 22-kt winds can generate 12-ft (3.7-m) seas. Achieving fully developed seas becomes less likely with higher wind speeds and is nearly impossible with tropical cyclones.

A tropical cyclone produces wind waves that move outward from the storm's center. Wave height and propagation speed depend on the intensity, size, and movement of the tropical cyclone, as well as the fetch length. As these wind waves move farther from the center, they transition to swell as the height gradually decreases and the wavelength increases. The more intense the system, the larger the swell, the longer the period, and the farther the propagation.

The swell from a tropical cyclone can travel on the order of 750 NM per day and may extend more than 3000 NM from the storm center. In the days before weather satellites and radio communication, the long period swell was often the first warning to the mariner of an impending tropical cyclone.

For multiple reasons, the highest seas are found on the right side of a northern hemisphere tropical cyclone. First, stronger winds on the right side create higher waves (**Figure 11**). Second, the right side can create a dynamic fetch area, allowing seas to develop further (**Figure 14**). This effect is more dramatic in faster, straight-moving storms. If the tropical cyclone moves at the same speed as the waves, the strongest winds will continue to force larger waves. In addition to being larger, dynamic fetch waves move faster than the surrounding waves, causing sea heights to build very quickly as the front right quadrant of a tropical cyclone approaches.

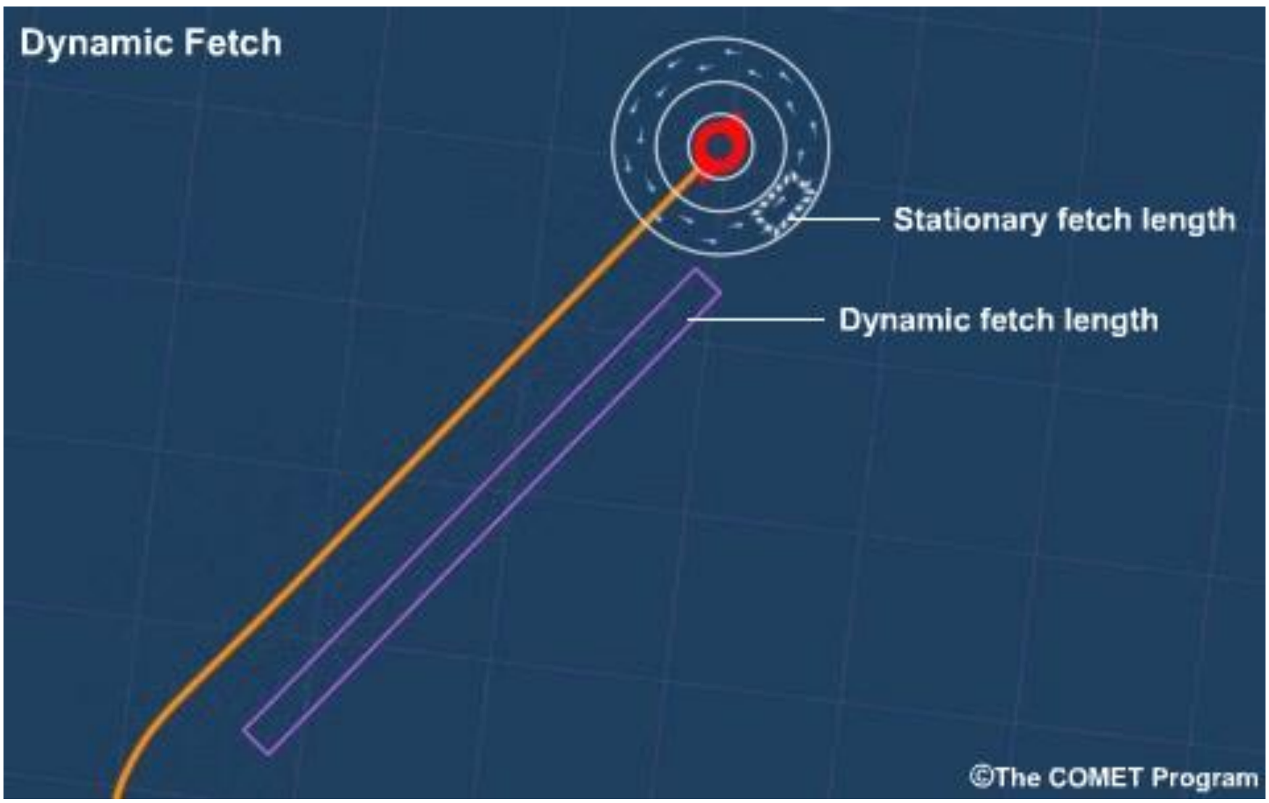


Figure 14: Dynamic Fetch Diagram. Wind direction and storm direction are the same on the right side of a northern hemisphere storm. If the storm direction is fairly straight and the speed isn't too fast or too slow, the wave generation area can travel with the storm, increasing wave heights well above what the stationary fetch length of the storm can produce.

While the eye of a strong tropical cyclone often has clear skies and calm winds, the sea heights are near their maximum and come from various directions (**Figure 15**). The dangerous combination of wave directions and periods creates the conditions necessary to generate phenomenal rogue waves. This effect is most evident near the eye and in the rear semi-circle relative to the storm's motion.

Figure 15: Image from a Saildrone inside the eyewall of 2021's category 4 Hurricane Sam in the north Atlantic. The autonomous science vessel measured a significant wave height of approximately 15 meters while recording the video containing this image. This mission was historic and provided some of the best data and footage of the marine conditions inside a major hurricane.

Tropical Cyclone Structure

The main parts of a tropical cyclone shown in **Figure 16** are the eye, eyewall, and rain bands. Air at the surface spirals toward the center in a cyclonic pattern then turns upward through the eyewall before flowing out of the top in an anticyclonic manner (in-up-and-out circulation). At the very center of the storm, air sinks, forming the warm core and relatively cloud-free eye.

The Eye

The tropical cyclone's center is a relatively calm, clear area, usually 10-40 nautical miles wide, containing the lowest surface pressure in the tropical cyclone. The eye forms due to intense convection within the eyewall that forces air to rise rapidly upward. Upon reaching the top of the troposphere (around 12-15 km up), this air spreads out horizontally in an anticyclonic manner away from the system's center. Some of this air is turned inward toward the center of the circulation, then forced downward into the eye. This downward motion results in warming and drying as air is compressed, helping to develop and maintain the eye of a hurricane.

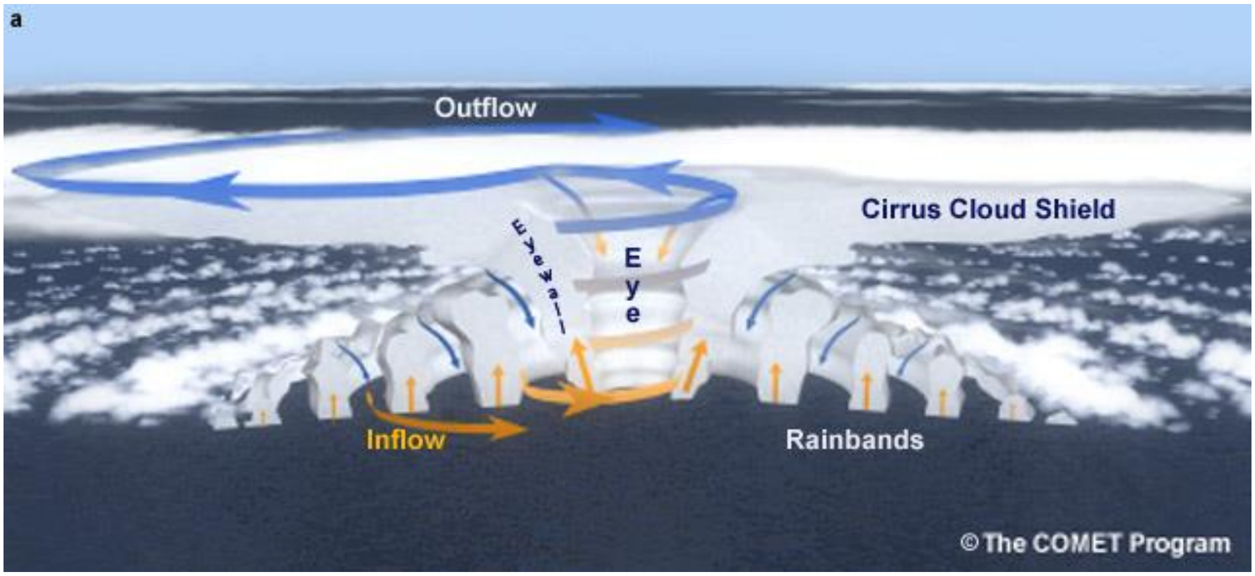


Figure 16: Tropical cyclone structure.[9]

The Eyewall

The innermost convective ring of thunderstorms that surrounds the eye of a hurricane is known as the eyewall. This region is home to the most intense winds and fiercest rain within a tropical cyclone and has a typical width of anywhere from 5 to 25 NM. Additionally, it is the most significant contributor to the vertical transport of warm moist air from the lower levels of the storm into the middle and upper levels of the troposphere over a tropical cyclone. Eyewalls may not be evident in tropical depressions and tropical storms.

Changes in the structure of the eye and eyewall can cause changes in surface pressure and wind speed in a tropical cyclone. The eye can grow or shrink in size, and double eyewalls can form. Long-lived systems may undergo eyewall replacement cycles when a concentric outer eyewall forms and cuts off the inflow needed to support the inner eyewall. Eventually, the outer eyewall can contract inward and become the dominant feature as the inner eyewall dissipates. This process typically causes a temporarily weaker but larger storm.

Rain bands

The storm's outer rain bands can extend a few hundred miles from the center; however, the extent of these features differs tremendously from storm to storm. For example, Hurricane Andrew's (1992) rain bands reached only 100 NM from the eye, while those in Hurricane Gilbert

[9] Note that the vertical extent of the tropical cyclone is exaggerated in this figure. The typical vertical length from the ocean to the top of the cirrus cloud shield is around 7-8 NM, while the outer circulation extends 250-500 NM. Thus, the actual structure resembles a pancake in that it is quite short in height but wide in horizontal size.

(1988) stretched out over 500 NM. These dense bands of thunderstorms, which spiral slowly counter-clockwise, range in width from a few miles to tens of miles and are typically hundreds of miles long. Convective cells in these rain bands often produce gusts much stronger than the maximum sustained winds advertised in the forecast. **Figure 17** depicts the rain bands associated with Hurricane Irma.

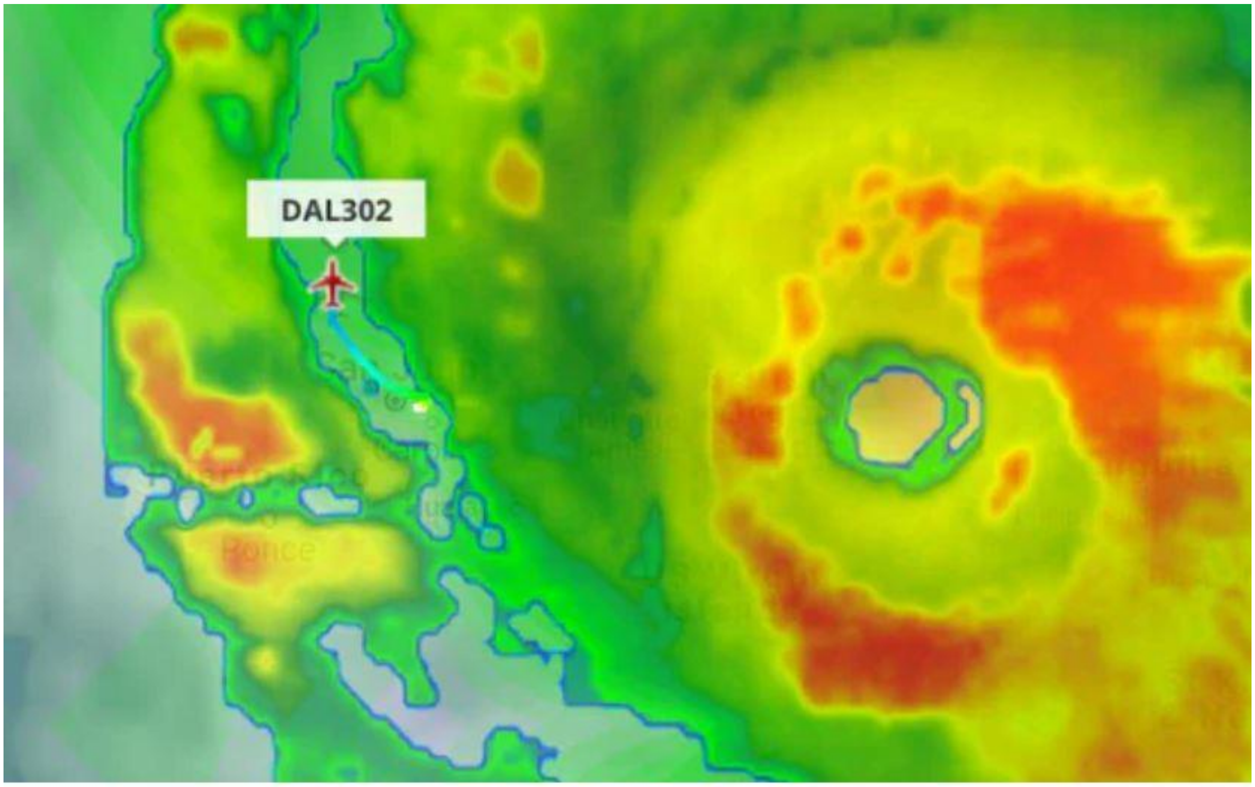


Figure 17: The last commercial flight to leave San Juan, PR ahead of category 5 Hurricane Irma (2017). Capt. Ben Vorhees and his crew navigated between the rain bands to make this evacuation flight possible. The airport closed 8 minutes after takeoff.

The intense thunderstorm activity in a tropical cyclone generates large amounts of high-level cirrus clouds in the upper regions of the troposphere. Sometimes these high-level clouds obscure the surface center on satellite imagery, making it difficult for forecasters to monitor a storm's position and development. However, data and images from additional satellite and radar sensors shown in **Figure 18** help see through these clouds to find the low-level center and rain bands of a tropical cyclone. This imagery is very beneficial, though not always available, due to the limited coverage of various satellite orbits and aircraft operations.

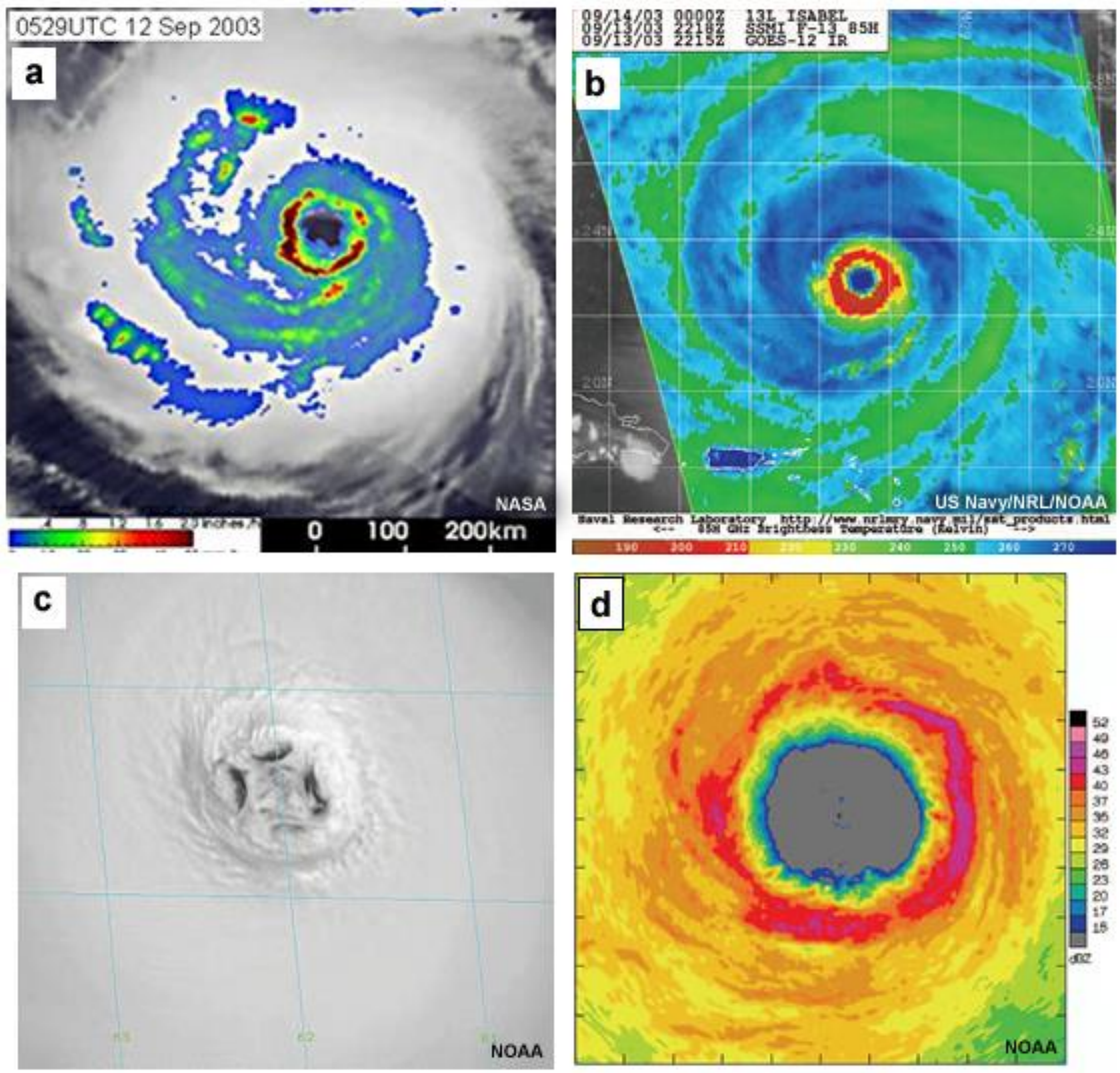


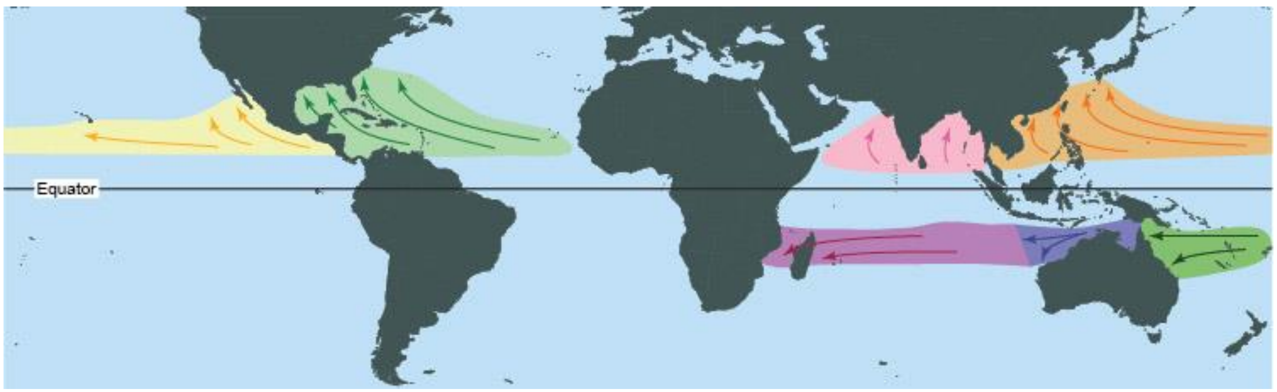
Figure 18: Various satellite and radar images of Hurricane Isabel (2003)

- **A) Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar (PR)**
- **B) Special Sensor Microwave/Imager (SSMI) 85-GHz brightness temperature**
- **C) Geostationary Operational Environmental Satellite (GOES) visible image**
- **D) Radar reflectivity (dBZ) from NOAA aircraft while flying in the eye at ~6,000 m**

Chapter 2 – Climatology

Tropical Cyclone Seasons

Tropical cyclones typically form between 5-30 degrees latitude in many of the world's oceans. Water temperature and vertical wind shear are two primary development ingredients that fluctuate throughout the year. This annual variability leads to global tropical cyclone seasons that typically peak in late summer or early autumn. The climatology of different ocean basins determines when tropical cyclones tend to form, where they move and how strong they become.



North Atlantic	**June 1st – November 30th**
Northeast Pacific	**May 15th – November 30th**
Central Pacific	**June 1st – November 30th**
Northwest Pacific	**Year round**
North Indian	**April – May, October – November**
Southwest Indian	**November 15th – April 30th**
Southeast Indian	**Late October – May**
Southwest Pacific	**Late October – Early May**

Figure 19: Global Tropical Cyclone Seasons.

North Atlantic

The North Atlantic hurricane season is officially June 1st – November 30th. There is a sharp peak in September, and 96% of major hurricanes (category three or higher on the Saffir-Simpson Hurricane Wind Scale) occur between August and October. It is not uncommon for named systems to form in May or December, but they rarely reach hurricane strength outside of the official season.

Based on a 30-year climate record from 1991-2020, the North Atlantic averages 14 named systems (tropical or sub-tropical storms), seven hurricanes, and three major hurricanes. The first named storm typically forms in mid to late June, the first hurricane in early to mid-August, and the first major hurricane in late August or early September (**Figure 20**).

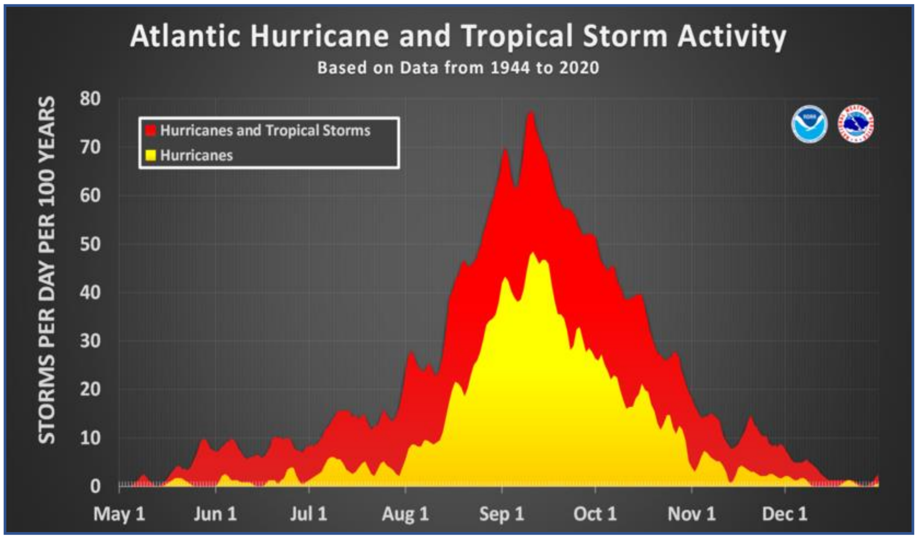


Figure 20: North Atlantic climatology. September 10th is the climatological peak of the season.

Early and late-season storms are usually confined to the area west of 50W. From August-October, tropical cyclones develop as far east as the Cape Verde Islands. These systems have ample time over water to develop and intensify. Tropical cyclones typically move westward or west-northwestward at 10-15 kts across the central Atlantic before recurving to the north and accelerating farther northeast (**Figure 21**). The National Hurricane Center issues official forecasts for the North Atlantic basin. For more information on the climatology of the North Atlantic basin, including the monthly area of occurrence maps, refer to the National Hurricane Center Climatology website at nhc.noaa.gov/climo/

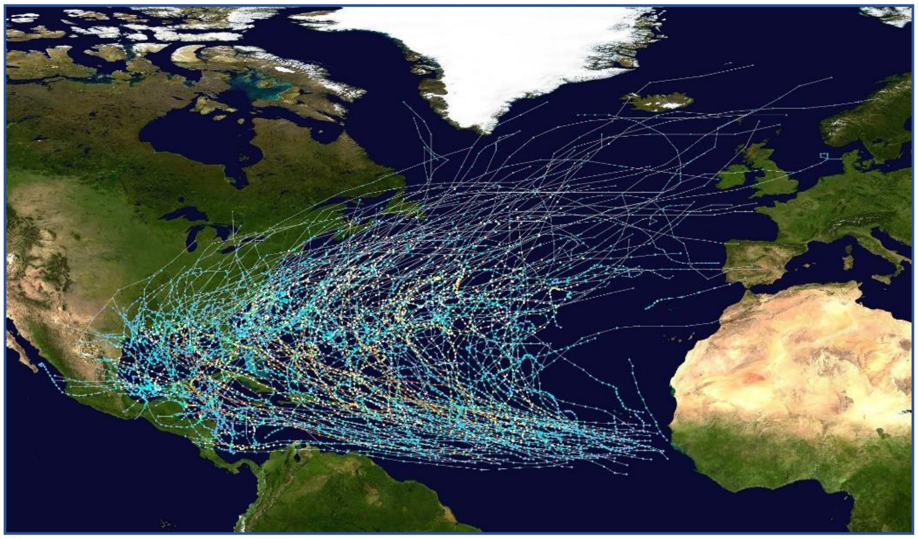


Figure 21: North Atlantic tropical cyclone tracks from 1980-2005.

Northeast Pacific

The Northeast Pacific hurricane season is officially from May 15th – November 30th. There is a peak in late August, but it is less pronounced than the north Atlantic peak, with activity spread more evenly through the season. Based on a 30-year climate record from 1991-2020, the eastern Pacific averages 15 named storms, eight hurricanes, and four major hurricanes. The first named storm typically forms in early to mid-June, the first hurricane tends to form in late June and the first major hurricane forms in mid-July (**Figure 22**).

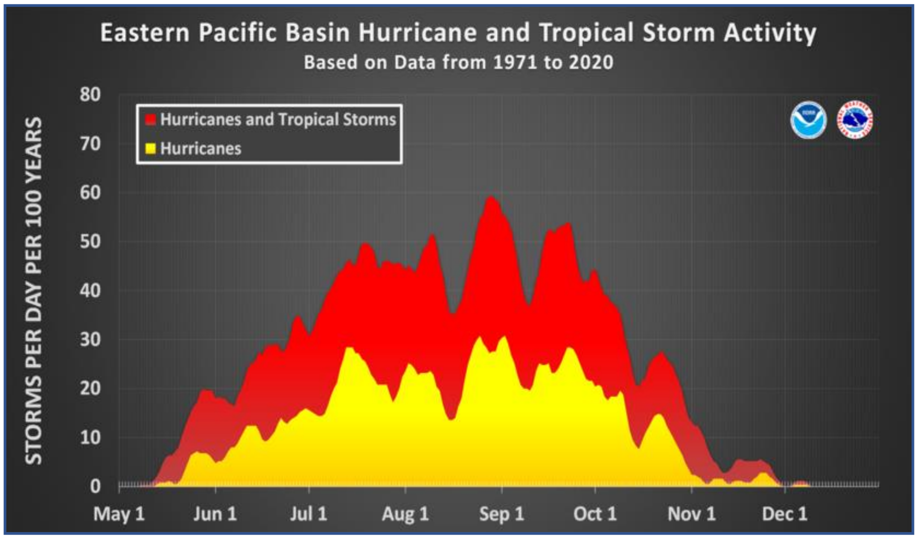


Figure 22: Northeast Pacific climatology. The season peaks in late August, but activity is more spread out than in the North Atlantic.

Tropical cyclones in this basin tend to have a more linear track and are often smaller than in the North Atlantic. In addition, they are typically confined south of 30N due to the cool waters from the California current. As a result, they rarely make landfall in the continental United States, though they occasionally impact and make landfall in Hawaii. While the Panama Canal is generally safe from tropical cyclones, storms in this basin impact several canal-based shipping lanes in the Northeast Pacific (**Figure 23**). The National Hurricane Center issues official forecasts for the Northeast Pacific basin.

In the central Pacific, advisories are issued by the Central Pacific Hurricane Center (CPHC). CPHC is based in Hawaii and a part of the U.S. National Weather Service with tropical cyclone responsibility north of the equator from 140W to 180W. This distinction is hardly noticeable to the user as CPHC offers identical products and now shares a website with NHC. The central Pacific is much less active than the eastern Pacific. Tropical cyclones can either form in this region or, more commonly, enter from farther east. For more information on the climatology of the Eastern Pacific basin, including the monthly area of occurrence maps, refer to the National Hurricane Center Climatology website at nhc.noaa.gov/climo/

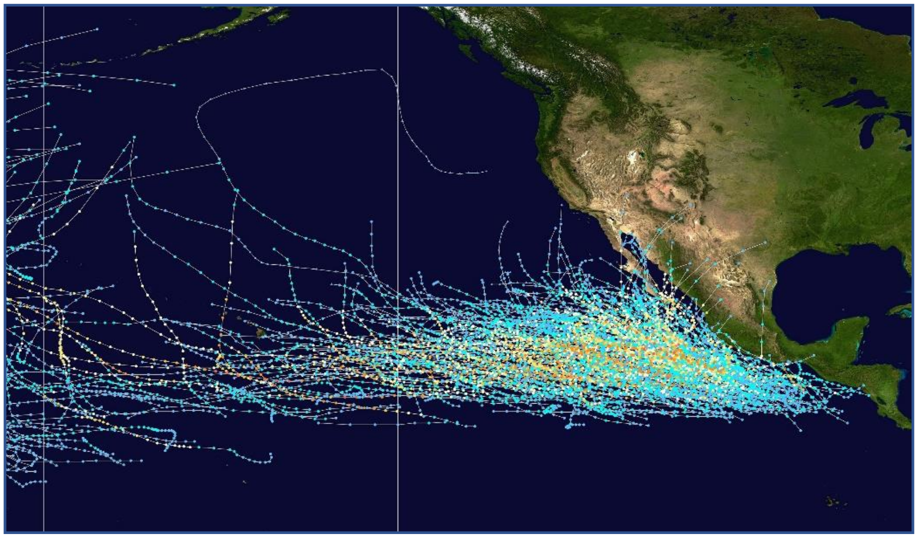


Figure 23: Eastern Pacific tropical cyclone tracks from 1980-2005.

Northwest Pacific

The Northwest Pacific is the most active basin on the planet, home to nearly 1/3 of all tropical cyclones, including the strongest. Tropical cyclones occur throughout the year, so there is no official season. The most active period is from July to November, with a peak in late August/early September. There is a distinct minimum from February through the first half of March (**Figure 29**). Systems in this basin typically form from the dateline to the Philippine Sea and move west towards the Philippines, China, and Japan. While less frequent, storms also develop in the South China Sea. Peak season storms from July-August tend to recurve north of the Philippines, while early and late season storms typically move through the Philippines before recurving (**Figure 24**).

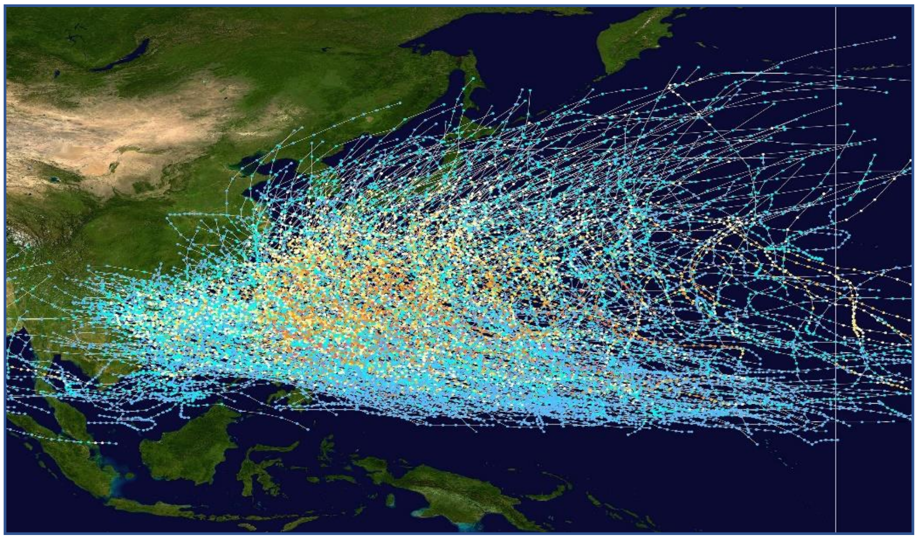


Figure 24: Northwest Pacific tropical cyclone tracks from 1980-2005.

North Indian Ocean

The North Indian Ocean essentially has 2 seasons per year. The basin is active from April – May and again from October – November. Increased wind shear from the Asian monsoon limits formation during the summer (**Figure 29**). While they regularly form in both basins, tropical cyclones are about twice as common in the Bay of Bengal than in the Arabian Sea (**Figure 25**).

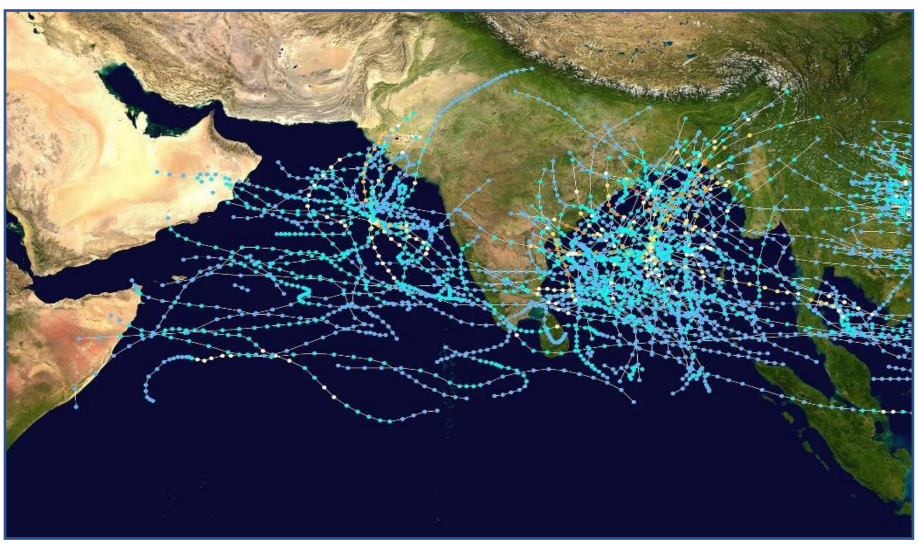


Figure 25: North Indian Ocean tropical cyclone tracks from 1980-2005.

Southwest Indian Ocean

The Southwest Indian Ocean basin season runs from November 15th – April 30th. There is a double peak in activity, first in mid-January and again in mid-February to early March **(Figure 29**). 50% of cyclones occur from January to February when the ocean is warmest (**Figure 26**).

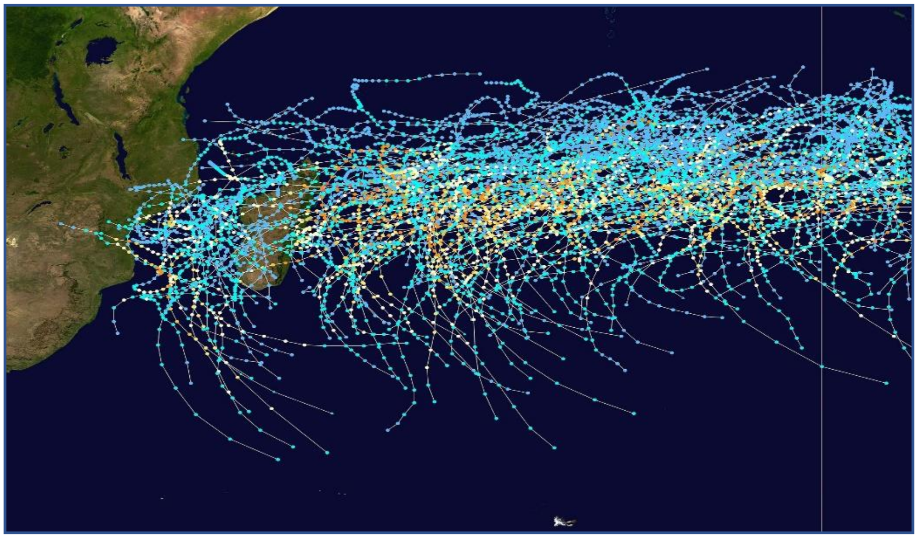


Figure 26: Southwest Indian Ocean tropical cyclone tracks from 1980-2005.

Southeast Indian Ocean (Australian Basin)

The Southeast Indian Ocean basin has a similar annual cycle to the Southwest Indian Ocean described above. Activity runs from late October through May (**Figure 29**). There is also a double peak in activity, though the lull is more distinct than in the Southwest Indian Ocean. Storms that make landfall in Australia typically form in the Timor or Arafura Sea (**Figure 27**).

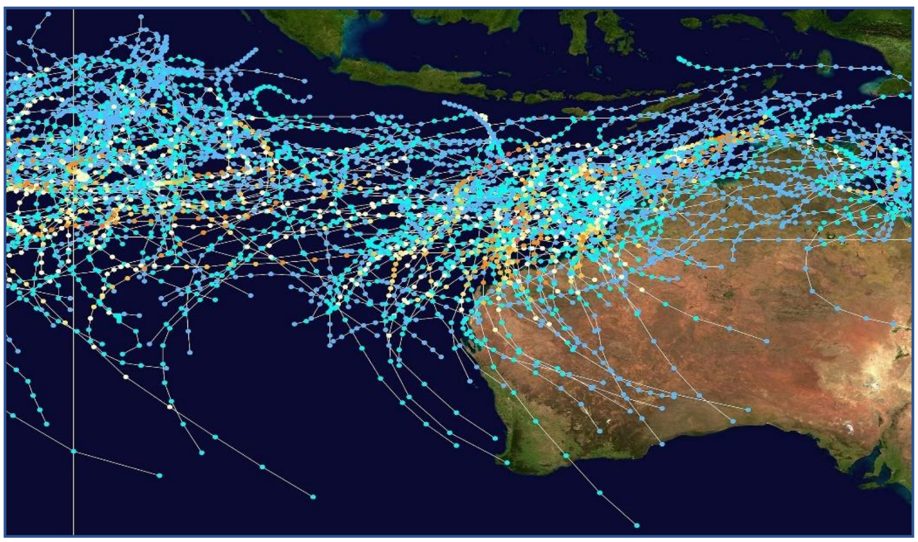


Figure 27: Southeast Indian Ocean tropical cyclone tracks from 1980-2005.

Southwest Pacific

The Southwest Pacific basin begins to get active in late October/early November, reaching a peak in late February/early March before tapering off in early May (**Figure 29**). Like the Australian basin, storms in this basin generally move southwestward and recurve southeastward. Decaying Coral Sea cyclones occasionally impact New Zealand (**Figure 28**).

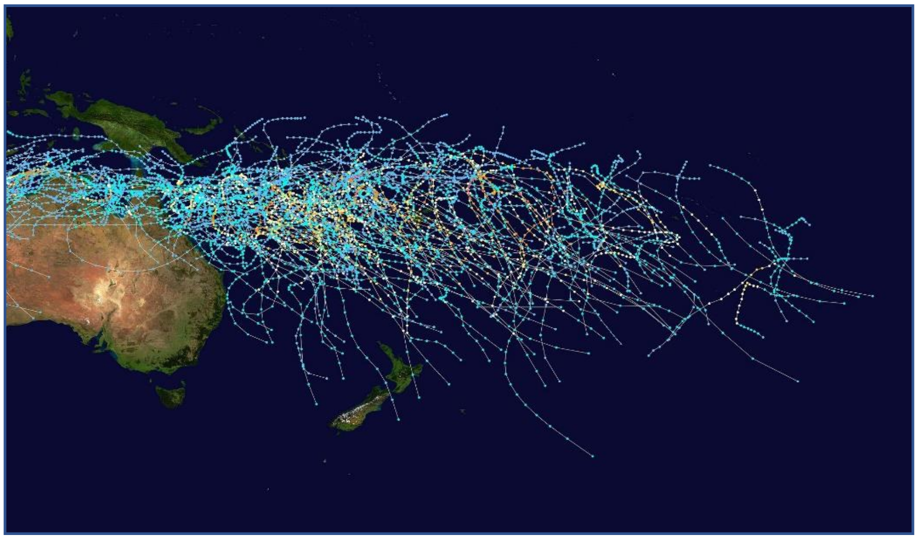


Figure 28: Southwest Pacific tropical cyclone tracks from 1980-2005.

Southeast Pacific

Due to cool water from strong upwelling along South America, a lack of disturbances, and a dry, stable atmosphere from semi-permanent high pressure, this basin is essentially void of tropical cyclones. Exceptions are extremely rare with only two weak subtropical storms on record. Unofficially named subtropical cyclone Katie formed in 2015 near Easter Island, and in 2018 an unnamed subtropical cyclone remarkably formed only a few hundred miles from the coast of Chile.

South Atlantic

Due to strong wind shear, a lack of disturbances, and relatively cool water, tropical cyclones are very rare in the South Atlantic. Those that do form are usually relatively weak subtropical storms. To date, the basin has only recorded one actual hurricane. In 2004, unofficially named Hurricane Catarina made landfall in southern Brazil.

Mediterranean Sea

On rare occasions, subtropical storms can form in late summer when extra-tropical low-pressure systems move over the warm waters of the central Mediterranean and transition to a more tropical structure. These are known colloquially as Medicanes.

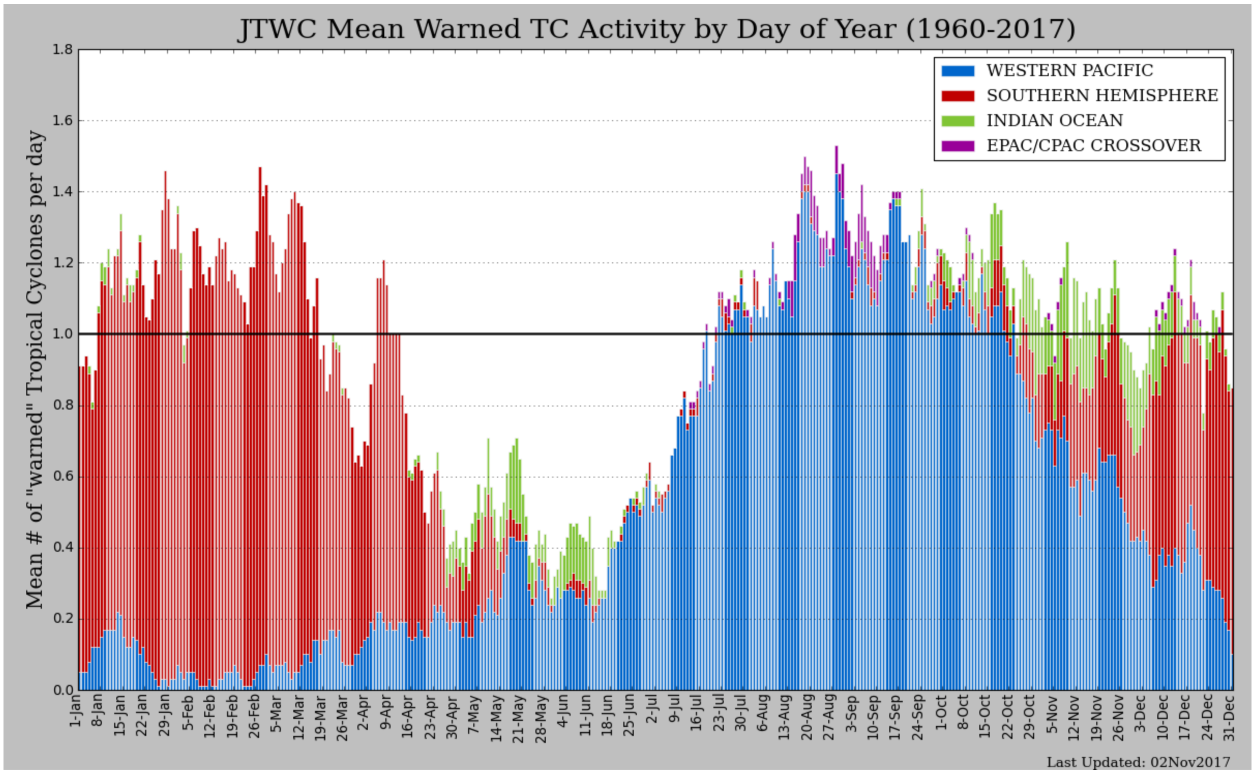


Figure 29: Tropical cyclone frequency in JTWC's area of responsibility (West Pacific, Indian Ocean and Southern Hemisphere). This graph is cumulative, the y-axis represents the average daily tropical cyclones throughout JTWC's area of responsibility while the colors differentiate between basins.

Seasonal Variability

The climate averages discussed above ebb and flow from year to year. Several factors make some tropical cyclone seasons, or periods within seasons, more active than others. Most of these influences are cyclical, with time scales ranging from weeks to years.

El Niño Southern Oscillation

The El Niño Southern Oscillation (ENSO) is caused by changes in the Pacific easterly trade wind strength and has global impacts. The cycle has three phases: El Niño, La Niña, and neutral. Episodes of El Niño and La Niña typically occur every two to seven years on an irregular schedule with significant variability. An episode usually lasts 9-12 months, while some events span years.

El Niño conditions occur when the easterly trade winds over the Pacific are weak. This weather pattern allows the warm water of the west Pacific to migrate east, creating warmer-than-average sea surface temperatures in the eastern Pacific. This warm water creates instability, increased convection, and lower pressure, affecting global circulation by producing a higher amplitude ridge over the subtropical Pacific and a downstream trough over the western Atlantic. As a result, wind shear is decreased in the ridge and increased in the trough, which enhances tropical cyclone activity in the eastern Pacific while decreasing activity in the Atlantic.

La Niña is the opposite of El Niño. It occurs when the easterly trade winds over the Pacific are strong. These winds pull the top layer of warm ocean water westward. As a result, cool water is upwelled along the South American coast and pulled into the central Pacific. This persistent cold water creates large-scale subsidence and reduced convection in the area. This pattern affects global circulation by producing an upper-level trough in the subtropical Pacific and a downstream ridge in the western Atlantic. As a result, wind shear is increased in the trough and decreased in the ridge, which causes decreased tropical cyclone activity in the eastern Pacific and enhanced activity in the Atlantic. **Table 3** outlines the ENSO effect on tropical cyclone basins worldwide.

Basin	El Niño	La Niña
North Atlantic	Decreased activity	Increased activity
Northeast Pacific	Increased activity	Decreased activity
Northwest Pacific	Genesis farther E & lower latitude, longer tracks	Genesis farther W & higher latitude, shorter tracks
North Indian	No significant effect	
Southwest Indian	No significant effect	
Southeast Indian	Decreased activity, genesis lower latitude	Increased activity, genesis higher latitude
Southwest Pacific	Decreased activity, genesis lower latitude	Increased activity, genesis higher latitude

Table 3: ENSO effect on various tropical cyclone basins. While direct impacts from changes in sea surface temperature can partially impact the Pacific basins, the indirect effect on global circulation is the primary driver of these trends.

Sub-Seasonal Variability

The Madden-Julian Oscillation (MJO) is an eastward propagating disturbance that crosses the earth every 30-60 days. There are two phases of the MJO, active and suppressed (**Figure 30**). Instability, precipitation, and tropical cyclone activity are enhanced during the active phase. Conversely, more stable conditions prevail during the suppressed phase, and tropical cyclone activity is limited. While the MJO is a global phenomenon, research indicates the strongest link with tropical cyclone activity in the Eastern Pacific and North Atlantic Basin. Typically, when one of these basins is active, the other is suppressed. Each phase of the MJO lasts for approximately two weeks.

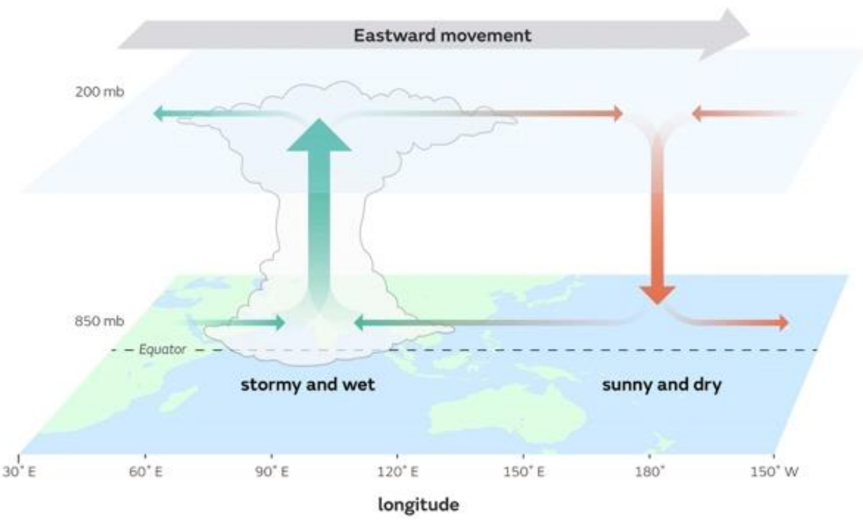


Figure 30: Madden-Julian Oscillation. This pattern drifts eastward, crossing the Earth every 30-60 days.

Smaller-scale disturbances impact tropical cyclone development within a basin. For example, tropical waves (defined in **Chapter 1**) develop over West Africa and propagate westward at 10-20 kts. While the dynamics are beyond the scope of this text, convectively-coupled kelvin waves (CCKW) propagate eastward but much faster than the MJO. Both tropical waves and CCKWs form a zone of enhanced development potential if the surrounding environment is supportive, particularly when intersecting.

Tropical Cyclone Motion

A tropical cyclone's speed and track depend on the environmental steering and the cyclone's internal influences. Typically, a tropical cyclone's forward speed averages around 13-17 kts, though there are exceptions. For example, storms can stall when the steering flow breaks down or accelerate tremendously after encountering the jet stream at higher latitudes.

In 2019, Hurricane Dorian nearly stopped over the NW Bahamas with a recorded speed of 1 kt or less for 27 hours (**Figure 31**). This stall caused tropical storm force or greater conditions to impact Great Abaco Island for about 72 hours. Four days later, Dorian got caught in the mid-latitude flow and was moving northeast at 25 kts before hitting Nova Scotia as an extra-tropical cyclone.

Figure 31: Official 3-day forecasts for Hurricane Dorian showing a large acceleration.

Environmental steering

Environmental steering is the most important influence on tropical cyclone motion. Steering features, including subtropical ridges and the jet stream, are much larger than the tropical cyclones they influence. Consider the atmosphere as a constantly moving river of air. The tropical cyclone acts as a cork in the river as it flows along a path guided by the environment.

Generally speaking, a tropical cyclone's motion depends on the average direction and speed of the environmental steering throughout the depth of the atmosphere. Weak and poorly organized tropical systems will generally be guided by environmental steering in the lower to middle levels of the atmosphere. On the other hand, intense storms have a greater vertical extent, and their motion is impacted more by higher levels of the atmosphere.

The subtropical ridge's position is crucial for determining a tropical cyclone's track. In the North Atlantic, stronger high pressure in the western Atlantic creates the steering flow necessary for U.S. landfalls. A weaker ridge allows for systems to recurve earlier in the Atlantic. The ridge is often weakened by incoming troughs, or jet stream dips, approaching from the west. A cold front generally accompanies these troughs. When cold fronts encounter tropical cyclones, the interaction will change the dynamics of the cyclone, a process called extra-tropical transition. Although this may cause the cyclone to lose its name, marine impacts remain similar.

To illustrate how the large-scale steering flow determines where a tropical cyclone will move, consider the following comparison. On September 5th, 2017, Hurricane Irma was located east of the Leeward Islands with category four intensity. The environmental steering flow was dominated by subtropical high pressure, as shown in the 500 mb[10] chart in **Figure 32**. This pattern caused Irma to take a west-northwestward trajectory toward an eventual landfall in south Florida. Just four days later, Hurricane Jose was in nearly an identical location with a similar intensity and size. The only significant difference was a trough of low pressure had begun to approach the east coast (**Figure 33**). This trough caused a weakness in the ridge and allowed Jose to recurve much earlier than Irma, sparing the U.S. of direct landfall.

[10] While tropical cyclones are steered by the entire depth of the atmosphere that corresponds with their height, meteorologists will often refer to a 500 mb geopotential height and wind chart to understand the steering flow in the middle levels of the atmosphere. Geopotential height measures how high a balloon has to rise above the earth's mean sea level before the pressure drops to 500 mb, roughly half the atmospheric pressure at the surface. Higher heights correspond to higher average pressure through the entire column of air. 500 mb charts are available as a Radiofax/low-bandwidth product from the Ocean Prediction Center for use at sea. More information on Radiofax is provided in chapter 3.

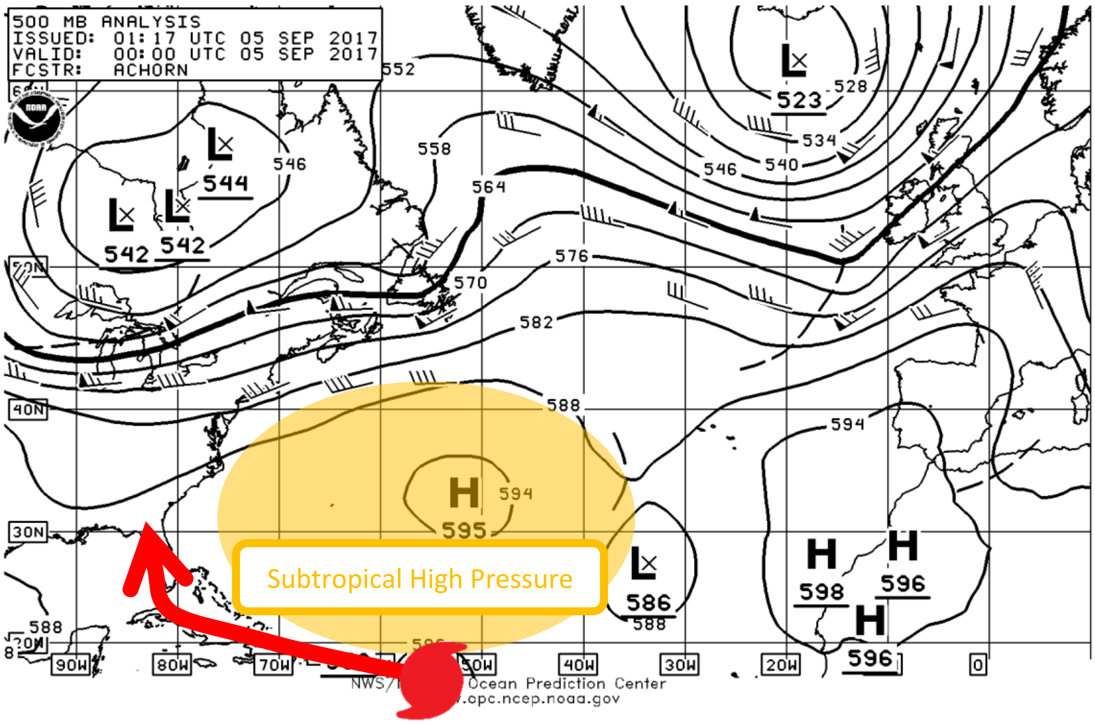


Figure 32: 500 mb height analysis indicating a subtropical ridge in the middle atmosphere. This steering pattern caused Hurricane Irma to take a WNW track and make landfall in Florida.

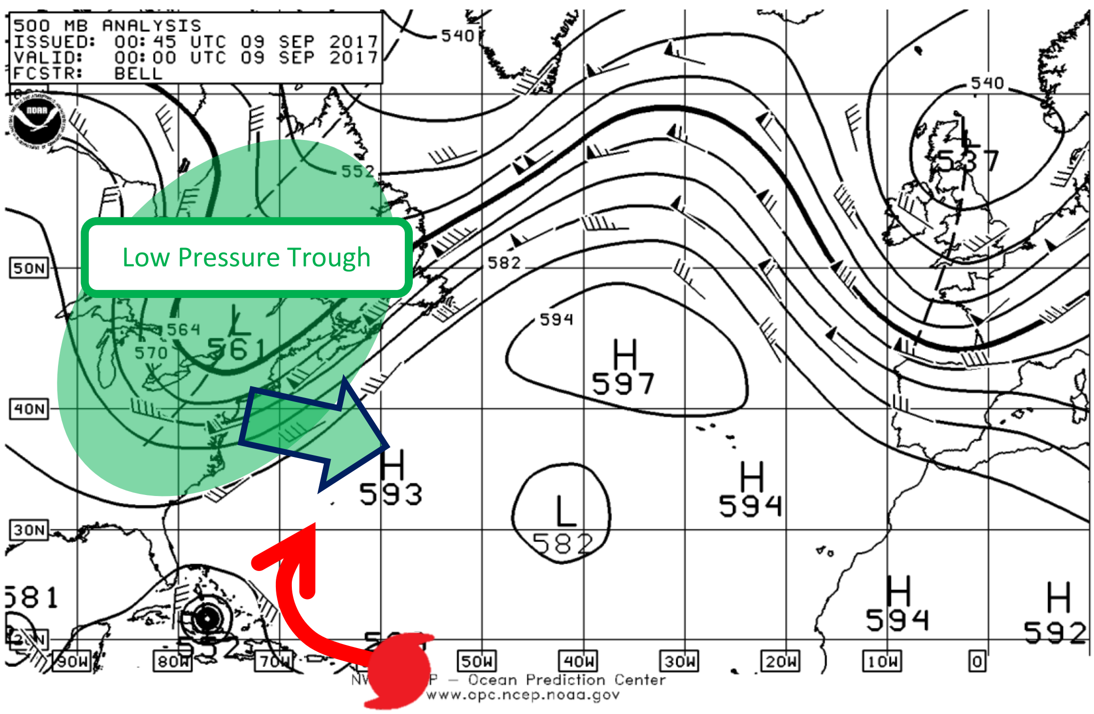


Figure 33: 500 mb height analysis indicating a strong short-wave trough in the middle atmosphere. As this trough progressed east, it weakened the ridge and allowed Hurricane Jose to recurve towards Bermuda.

Internal Effects

A second, much less noticeable factor regarding tropical cyclone motion is the storm's internal effects. Increasing Coriolis force with latitude causes tropical cyclones to drift westward and poleward. This is called the beta effect and will cause a tropical cyclone to drift in the absence of steering flow. Additionally, uneven convection in the eyewall can cause the eye of a tropical cyclone to wobble somewhat unpredictably by approximately 10-20 NM. These internal effects are often negligible compared to environmental steering but are more important when the steering flow breaks down.

The Fujiwhara Effect

When two tropical cyclones are within about 750 NM of each other, they begin an elegant dance known as the Fujiwhara Effect, where the two storms rotate cyclonically around each other (**Figure 34**). If one tropical cyclone is significantly stronger than the other, the weaker storm will rotate around and be swept up into the circulation of the stronger system. The Fujiwhara effect is relatively rare, happening most often in the Northwest Pacific.

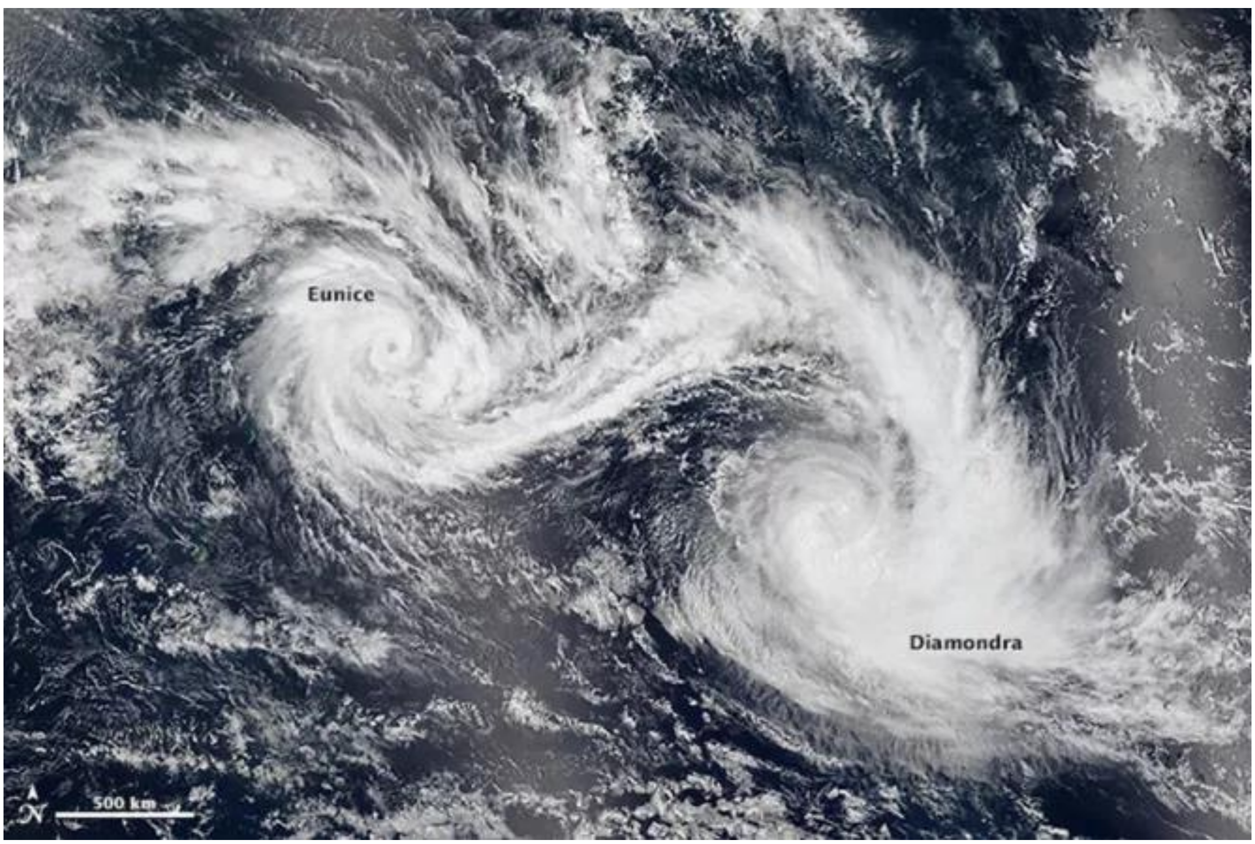


Figure 34: The Fujiwhara Effect between Tropical Cyclone Eunice (left) and Tropical Cyclone Diamondra (right) in the Southern Indian Ocean on January 28, 2015.

Forecasting Trends

Track Forecasting

Forecasts made by the National Hurricane Center and other agencies account for all of the influences discussed above to the greatest extent possible. Driven mainly by improvements in weather models due to massive increases in computer power and the assimilation of more satellite-based observations, tremendous strides have been made in track forecast accuracy over the last few decades (**Figure 35**). These models rely on observations to determine the current state of the atmosphere on which to generate the forecast. For certain tropical cyclones, the National Weather Service will receive additional, targeted observations from weather reconnaissance aircraft ("The Hurricane Hunters"), upper air balloon soundings, and in-situ marine observations.

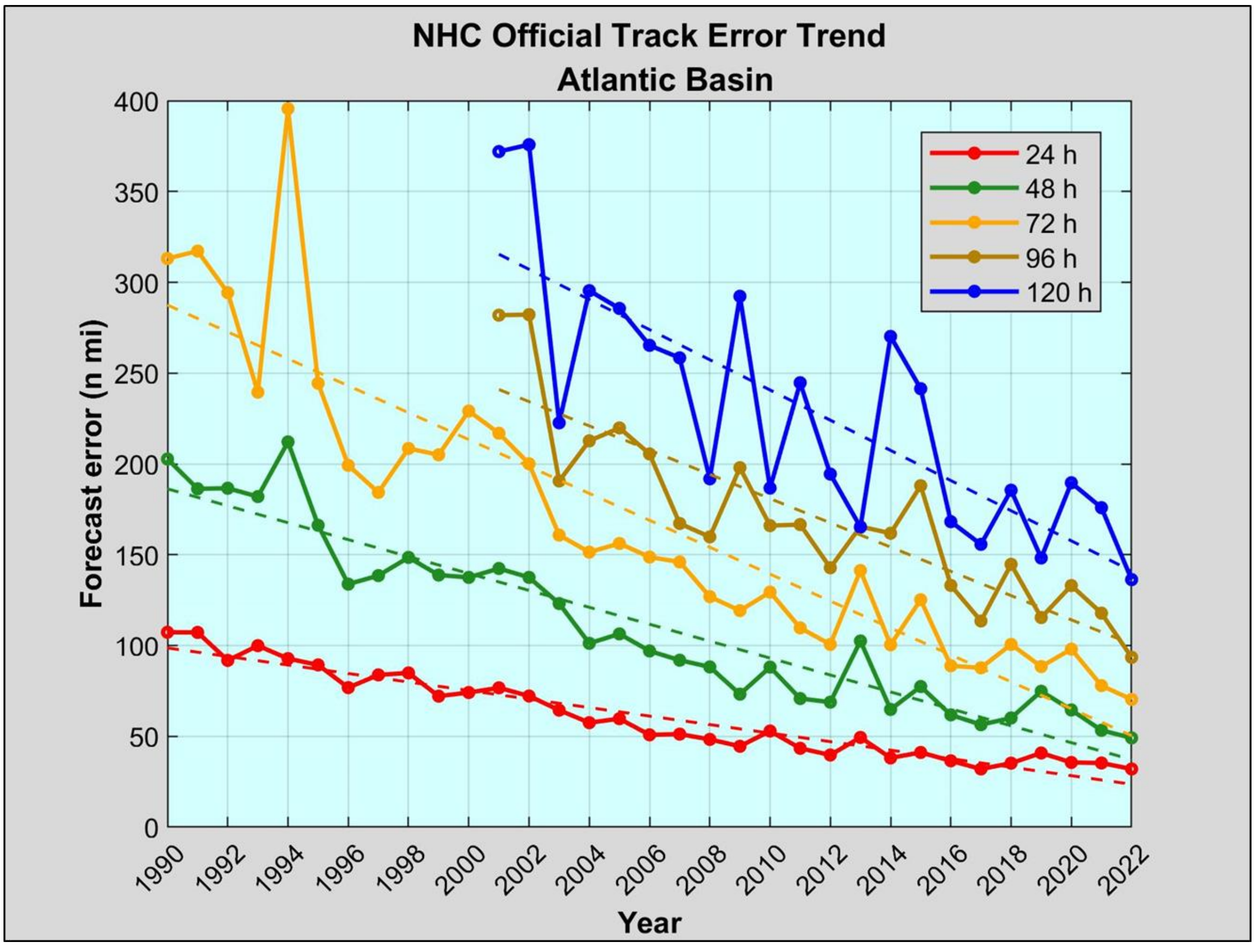


Figure 35: NHC track errors from 1990-2022 for the North Atlantic Basin. The improvements over this period are remarkable. For example, a 3-day forecast in 1990 had an average error of about 300 NM, while the average error today is only about 100 NM – a two-thirds reduction!

Intensity Forecasting

Tropical cyclone forecasts made by the National Hurricane Center and other agencies will include intensity predictions in the form of maximum sustained wind speed and maximum gusts. While it's commonly understood that track forecasts are not perfect, it is important to realize that large errors can also exist in intensity and size forecasts. Due to limited weather observations over the open ocean, even the current intensity of a tropical cyclone is often an estimate. Unlike track forecasts, intensity forecasting improved little from 1970-2010 (**Figure 36**). However, advancements in weather models and a better understanding of rapid intensification events have caused errors to decrease more substantially over the last decade.

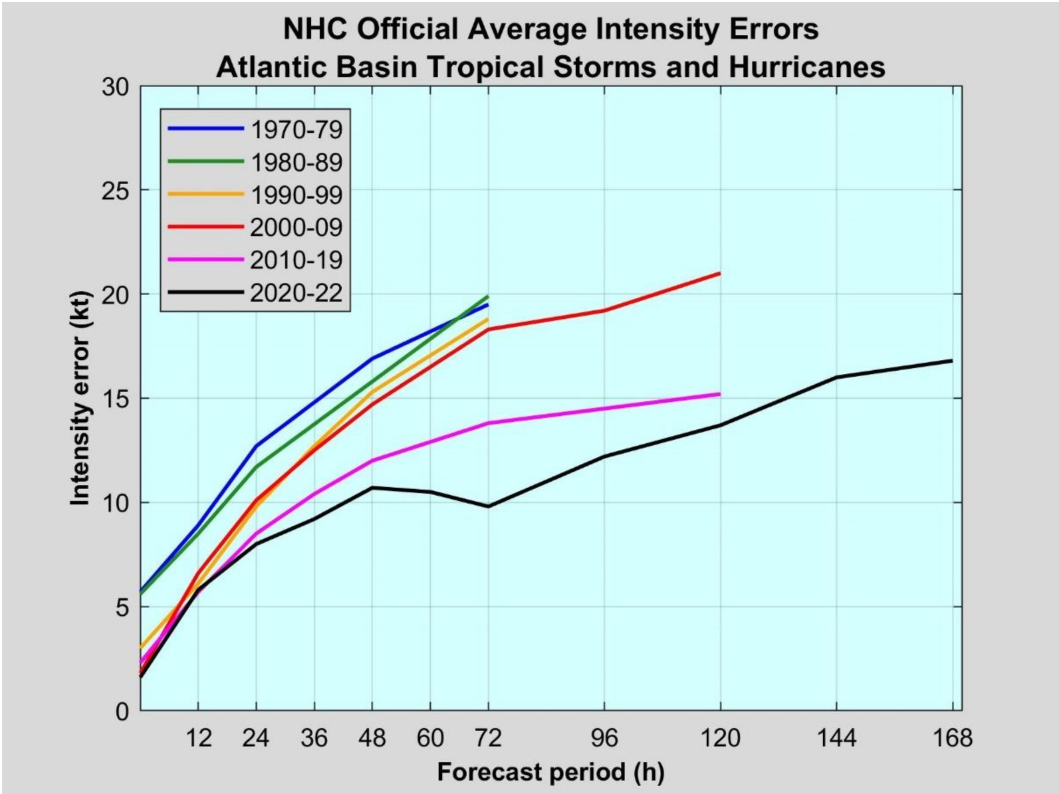


Figure 36: NHC intensity errors by decade from 1970-2022 for the North Atlantic. After several decades with little improvement, errors have decreased in recent years.

Size Forecasting

Forecasts account for the size of tropical cyclones in the form of 34, 50, and 64-kt wind radii for each of the four quadrants (NE, SE, SW, NW). Importantly for the mariner, size is also conveyed as the maximum radius of 12-ft (3.7-m) seas. Conveying size in quadrants also gives information on the "shape" of a tropical cyclone, which can be asymmetrical in terms of impacts. As with track and intensity, errors also exist in the analysis and forecast of the wind and sea radii. However, these have improved with aircraft reconnaissance and satellite-based observations of wind speed and sea heights.

Chapter 3 - Monitoring Tropical Cyclones

Tropical cyclone forecasts are freely available across the globe. The World Meteorological Organization has tasked several Regional Specialized Meteorological Centers with this official responsibility (**Figure 37, Table 4**). At a minimum, these centers provide the current position and intensity of the storm and a simple forecast. Unfortunately for the mariner, the format varies significantly between centers.

The Joint Typhoon Warning Center (JTWC) creates forecasts for the U.S. Department of Defense in areas not covered by the U.S. National Weather Service (NWS). JTWC products have a consistent, mariner-friendly format across basins. For this reason, ***many mariners rely on NWS products in the Atlantic, eastern and central Pacific and JTWC products elsewhere***. This chapter will focus primarily on these two agencies. After determining which agency is creating the forecast, mariners must receive the information onboard. This chapter will serve as a reference to identify, receive, and interpret tropical cyclone products around the world.

Regional Specialized Meteorological Centers

The following centers provide official tropical cyclone analysis and forecasts across the world. Their websites and products can be found on **page 2** of this guide. While these centers have the official responsibility, JTWC advisories are generally more useful to the global mariner.

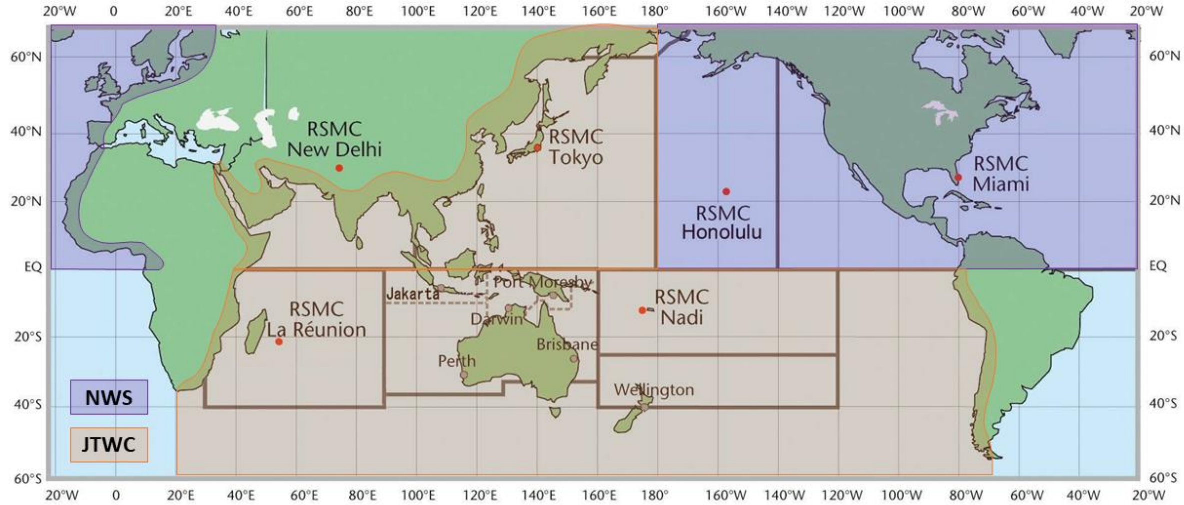


Figure 37: Regional Association (RA) map for Regional Specialized Meteorological Centers (RSMC) and Tropical Cyclone Warning Centers (TCWC). Joint Typhoon Warning Center and U.S. National Weather Service areas of responsibility are shaded in orange and purple, respectively.

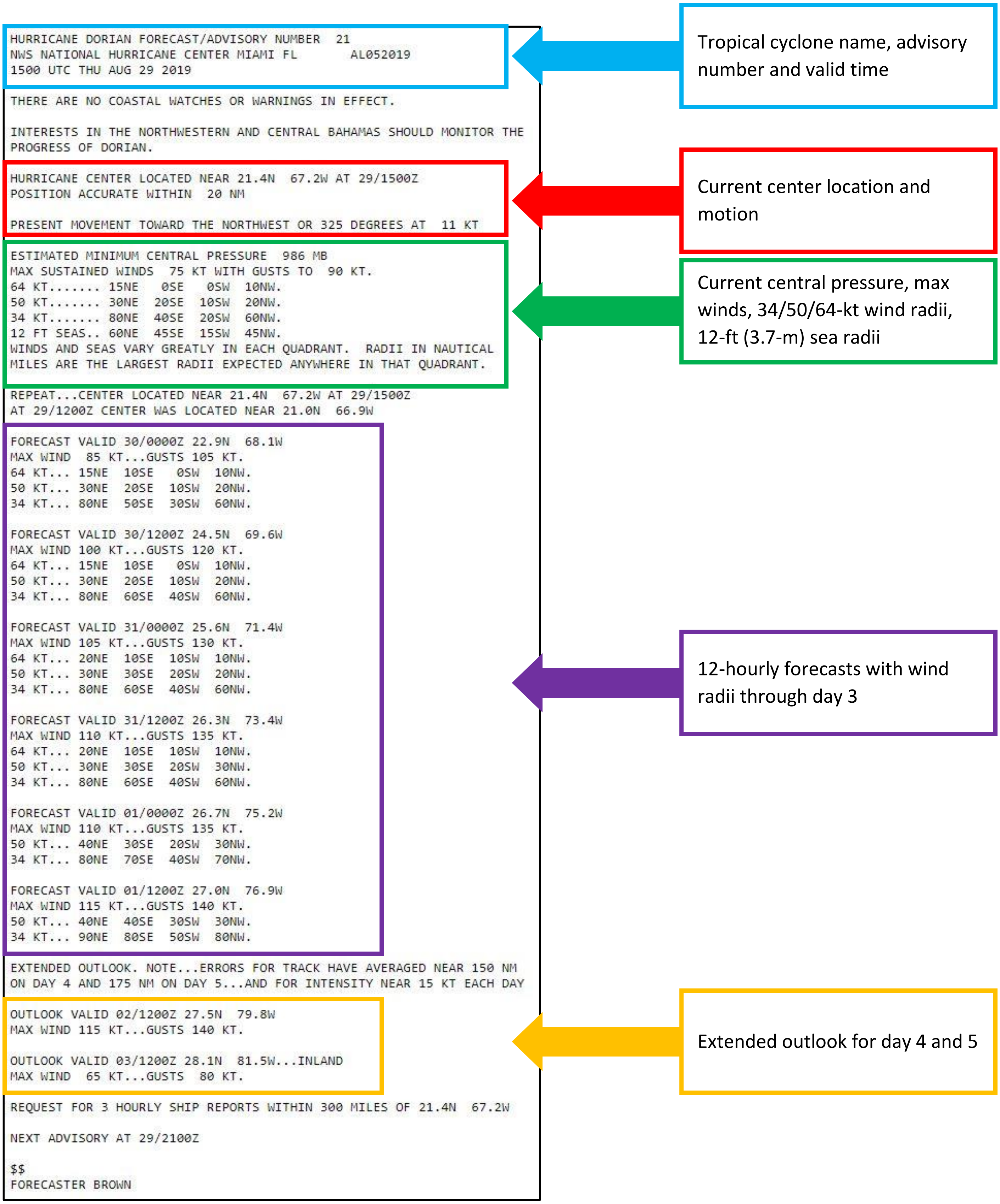
RSMC/TCWC	Agency
RSMC Miami	U.S. National Hurricane Center
RSMC Honolulu	U.S. Central Pacific Hurricane Center
RSMC Tokyo	Japan Meteorological Agency Typhoon Center
RSMC New Delhi	India Meteorological Department Tropical Cyclone Center
RSMC La Réunion	Météo France Tropical Cyclone Centre
RSMC Nadi	Fiji Meteorological Service Tropical Cyclone Centre
TCWC Wellington	Meteorological Service of New Zealand
TCWC Melbourne	Australian Bureau of Meteorology
TCWC Jakarta	Indonesian Meteorological and Geophysical Agency
TCWC Port Moresby	National Weather Service, Papua New Guinea

Table 4: Global RSMC and TCWC agencies. Areas covered by the U.S. National Weather Service are shaded in purple. Areas covered by the Joint Typhoon Warning Center are shaded in orange.

NHC Text Products for the Mariner

Tropical Cyclone Forecast/Advisory (TCM)

The TCM is the single most important text product for the mariner. Issued whenever a tropical or subtropical cyclone is active, the TCM includes information on the current position, intensity, motion, 34, 50, and 64-kt wind speed radii, and 12-ft (3.7-m) sea radii. Forecast information is included in 12-hour intervals with 64-kt wind radii out to 48 hours and 34- and 50-kt wind radii to 72 hours. An extended outlook provides the position and intensity at 96 and 120 hours. TCMs are storm specific and issued every 6 hours (0300, 0900, 1500, 2100 UTC) for the life of the system. Additional special advisories are issued at 0000, 0600, 1200, and 1800 UTC when there are active coastal watches or warnings to provide 3-hourly updates to the storm's position and intensity (see public advisory below). Unlike many public support products, the TCM benefits the mariner by using knots, nautical miles, and UTC. INMARSAT-C Safetynet freely transmits TCMs as a requirement under GMDSS regulations. **Figure 38** on the following page is an annotated example of a TCM.



```
HURRICANE DORIAN FORECAST/ADVISORY NUMBER  21
NWS NATIONAL HURRICANE CENTER MIAMI FL       AL052019
1500 UTC THU AUG 29 2019

THERE ARE NO COASTAL WATCHES OR WARNINGS IN EFFECT.

INTERESTS IN THE NORTHWESTERN AND CENTRAL BAHAMAS SHOULD MONITOR THE
PROGRESS OF DORIAN.

HURRICANE CENTER LOCATED NEAR 21.4N  67.2W AT 29/1500Z
POSITION ACCURATE WITHIN  20 NM

PRESENT MOVEMENT TOWARD THE NORTHWEST OR 325 DEGREES AT  11 KT

ESTIMATED MINIMUM CENTRAL PRESSURE  986 MB
MAX SUSTAINED WINDS  75 KT WITH GUSTS TO  90 KT.
64 KT....... 15NE   0SE   0SW  10NW.
50 KT....... 30NE  20SE  10SW  20NW.
34 KT....... 80NE  40SE  20SW  60NW.
12 FT SEAS.. 60NE  45SE  15SW  45NW.
WINDS AND SEAS VARY GREATLY IN EACH QUADRANT.  RADII IN NAUTICAL
MILES ARE THE LARGEST RADII EXPECTED ANYWHERE IN THAT QUADRANT.

REPEAT...CENTER LOCATED NEAR 21.4N  67.2W AT 29/1500Z
AT 29/1200Z CENTER WAS LOCATED NEAR 21.0N  66.9W

FORECAST VALID 30/0000Z 22.9N  68.1W
MAX WIND  85 KT...GUSTS 105 KT.
64 KT... 15NE  10SE   0SW  10NW.
50 KT... 30NE  20SE  10SW  20NW.
34 KT... 80NE  50SE  30SW  60NW.

FORECAST VALID 30/1200Z 24.5N  69.6W
MAX WIND 100 KT...GUSTS 120 KT.
64 KT... 15NE  10SE   0SW  10NW.
50 KT... 30NE  20SE  10SW  20NW.
34 KT... 80NE  60SE  40SW  60NW.

FORECAST VALID 31/0000Z 25.6N  71.4W
MAX WIND 105 KT...GUSTS 130 KT.
64 KT... 20NE  10SE  10SW  10NW.
50 KT... 30NE  30SE  20SW  20NW.
34 KT... 80NE  60SE  40SW  60NW.

FORECAST VALID 31/1200Z 26.3N  73.4W
MAX WIND 110 KT...GUSTS 135 KT.
64 KT... 20NE  10SE  10SW  10NW.
50 KT... 30NE  30SE  20SW  30NW.
34 KT... 80NE  60SE  40SW  60NW.

FORECAST VALID 01/0000Z 26.7N  75.2W
MAX WIND 110 KT...GUSTS 135 KT.
50 KT... 40NE  30SE  20SW  30NW.
34 KT... 80NE  70SE  40SW  70NW.

FORECAST VALID 01/1200Z 27.0N  76.9W
MAX WIND 115 KT...GUSTS 140 KT.
50 KT... 40NE  40SE  30SW  30NW.
34 KT... 90NE  80SE  50SW  80NW.

EXTENDED OUTLOOK. NOTE...ERRORS FOR TRACK HAVE AVERAGED NEAR 150 NM
ON DAY 4 AND 175 NM ON DAY 5...AND FOR INTENSITY NEAR 15 KT EACH DAY

OUTLOOK VALID 02/1200Z 27.5N  79.8W
MAX WIND 115 KT...GUSTS 140 KT.

OUTLOOK VALID 03/1200Z 28.1N  81.5W...INLAND
MAX WIND  65 KT...GUSTS  80 KT.

REQUEST FOR 3 HOURLY SHIP REPORTS WITHIN 300 MILES OF 21.4N  67.2W

NEXT ADVISORY AT 29/2100Z

$$
FORECASTER BROWN
```


Figure 38: Annotated Tropical Cyclone Forecast/Advisory (TCM).

Tropical Cyclone Discussion (TCD)

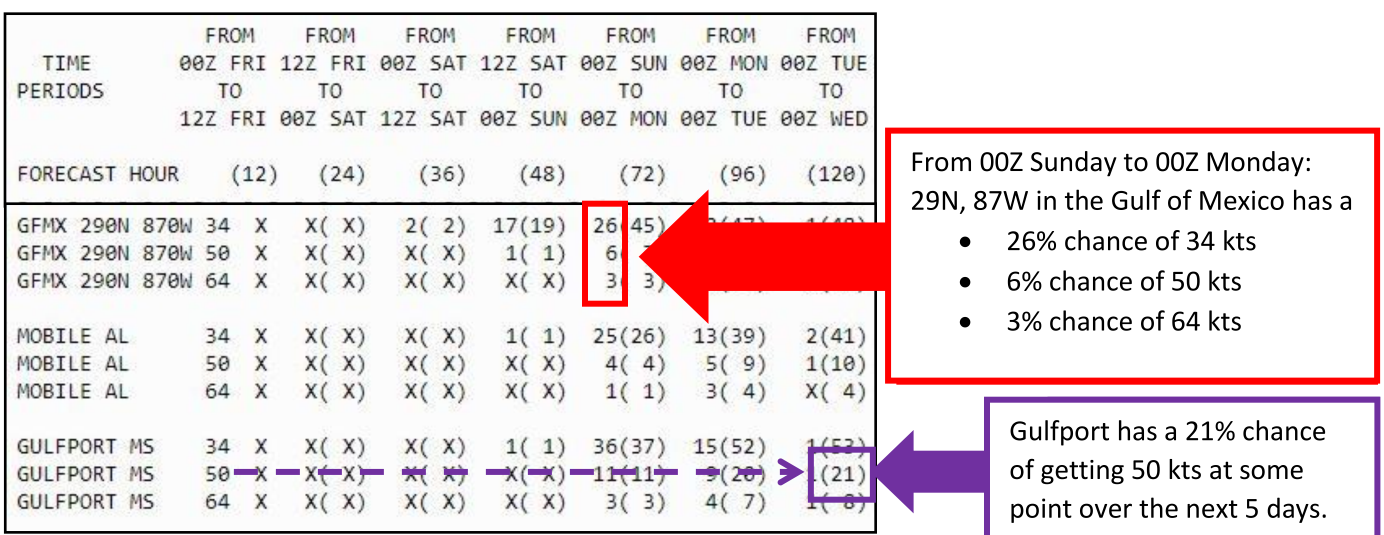
NHC issues this product to explain the Hurricane Specialist's reasoning behind the latest analysis and forecast of a tropical cyclone. The message may also provide indications of track or intensity tendencies that may be occurring while giving some insight into the current computer model guidance and any alternate forecast scenarios. The TCD also contains a table with all forecast positions and maximum wind speeds. The issue times of the discussion are 0300, 0900, 1500, and 2100 UTC to coincide with the release of the TCM. Finally, the TCD will include Key Messages (a few bullet points highlighting the impacts). This product is the best way to understand the analysis and forecast process and gauge the level of confidence.

Tropical Cyclone Public Advisory (TCP)

Intended for the general public, the TCP explains the current hazards and identifies any coastal tropical storm or hurricane watches and warnings in effect. For the United States, it also includes any storm surge watches or warnings in effect. The TCP is generally updated every 6 hours, with the frequency increasing to every 3 hours if watches and warnings are issued (typically 48 hours before the conditions begin). The TCP includes information on expected storm surge, wind, rainfall, tornadoes, and coastal surf impacts.

Tropical Cyclone Surface Wind Probabilities (PWS)

The PWS lists the probability of reaching or exceeding 34, 50, and 64-kt sustained winds at select coastal, inland, and offshore locations, including buoys and some marine coordinate intersections (**Figure 39**). Two values are listed for each location, time, and threshold to capture timing information. The first is an onset percentage, meaning the probability that winds will begin during the given forecast period. Onset percentages are only available in the text product. The second value is the cumulative percentage, meaning the probability that winds will begin within the period up to and including the given forecast period. Cumulative values are displayed in parenthesis and depicted on the Graphical Wind Speed Probability products. In addition to the NHC and CPHC advisories, the NWS office in Guam issues a PWS for any system JTWC is warning on from 0-25N, between 180-130E.



TIME PERIODS		FROM 00Z FRI TO 12Z FRI	FROM 12Z FRI TO 00Z SAT	FROM 00Z SAT TO 12Z SAT	FROM 12Z SAT TO 00Z SUN	FROM 00Z SUN TO 00Z MON	FROM 00Z MON TO 00Z TUE	FROM 00Z TUE TO 00Z WED
FORECAST HOUR		(12)	(24)	(36)	(48)	(72)	(96)	(120)
GFMX 290N 870W	34	X	X(X)	2(2)	17(19)	26(45)	[illegible]	[illegible]
GFMX 290N 870W	50	X	X(X)	X(X)	1(1)	6[illegible]	[illegible]	[illegible]
GFMX 290N 870W	64	X	X(X)	X(X)	X(X)	3(3)	[illegible]	[illegible]
MOBILE AL	34	X	X(X)	X(X)	1(1)	25(26)	13(39)	2(41)
MOBILE AL	50	X	X(X)	X(X)	X(X)	4(4)	5(9)	1(10)
MOBILE AL	64	X	X(X)	X(X)	X(X)	1(1)	3(4)	X(4)
GULFPORT MS	34	X	X(X)	X(X)	1(1)	36(37)	15(52)	1(53)
GULFPORT MS	50	X	X(X)	X(X)	X(X)	11(11)	9(20)	[illegible](21)
GULFPORT MS	64	X	X(X)	X(X)	X(X)	3(3)	4(7)	1(8)

Figure 39: Annotated Tropical Cyclone Surface Wind Probabilities (PWS).

Tropical Weather Outlook (TWO)

The Tropical Weather Outlook discusses significant areas of disturbed weather and their potential for development during the next seven days, including separate forecast probabilities for tropical cyclone formation during the first 48 hours and throughout the entire 7-day forecast period. The 2-day and 7-day formation probabilities for each disturbance are given to the nearest 10% and expressed as one of the following categories: low (0-30%), medium (40-60%), and high (70-100%). This product will also indicate if advisories are being issued for any active, potential, or post-tropical cyclones in the basin.

Tropical Weather Discussion (TWD)

The Tropical Weather Discussion explains the current and future state of the atmosphere and ocean surface to assist mariners in making decisions. The TWD provides significant weather features, areas of disturbed weather, expected trends, the meteorological reasoning behind the forecast, model performance, and in some cases, a degree of confidence. Special features, including marine warnings and active tropical cyclones, are discussed when applicable. The Tropical Analysis and Forecast Branch (TAFB) of NHC issues separate TWDs for the Atlantic and East Pacific areas, each updated every 6 hours (**Figure 40**). The NWS office in Guam issues a daily TWD for the NW Pacific.

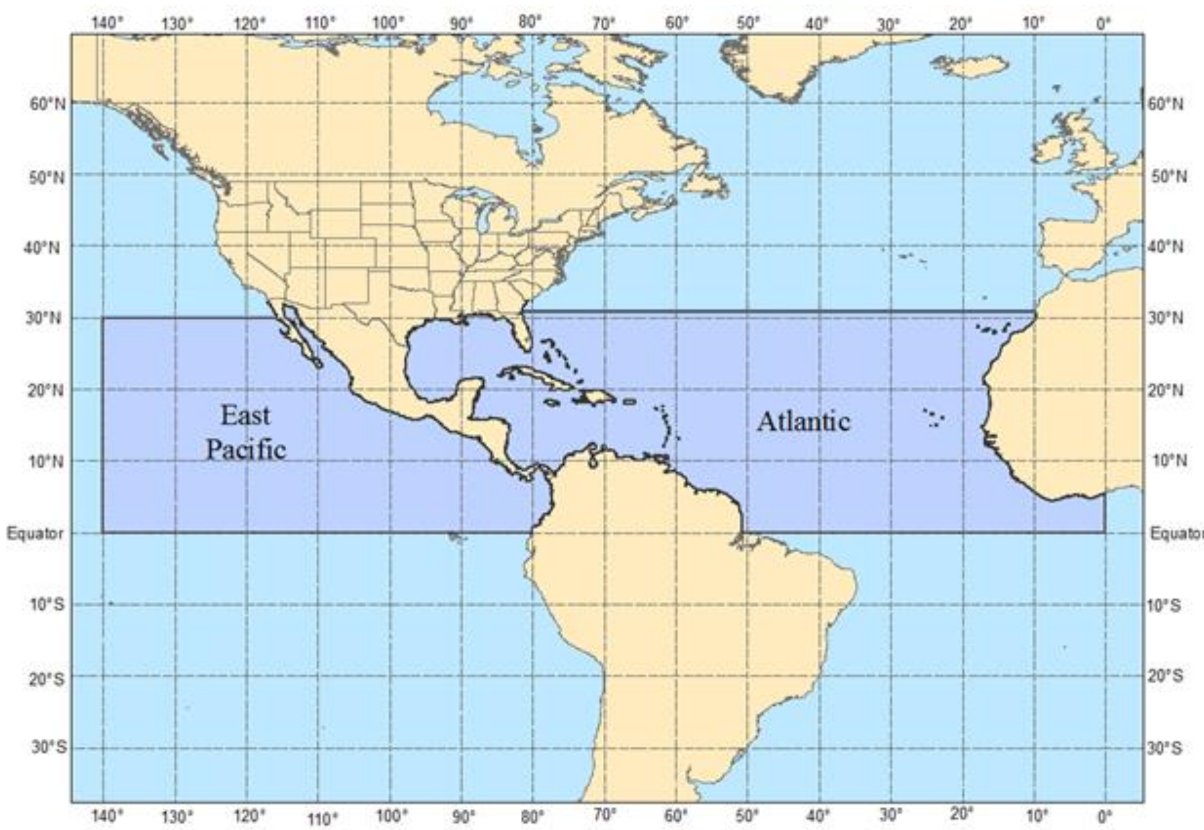


Figure 40: Tropical Weather Discussion areas of responsibility.

Coastal, Offshore, and High Seas Forecast Text Products

The NWS provides different marine zone text products based on distance from the coast. Local NWS Weather Forecast Offices issue coastal zone forecasts that extend up to 60 NM. Offshore marine zone forecasts are issued by TAFB, OPC, and NWS offices in Alaska and Hawaii. They cover the Gulf of Mexico, Caribbean, portions of the western Atlantic and eastern Pacific and within a few degrees of Alaska and Hawaii. High seas forecasts are simple text products that include marine and tropical cyclone warnings. As part of the Global Marine Distress and Safety System (GMDSS), they cover all of the world's oceans and are issued by various national meteorological centers. The METAREAs and country responsible for High Seas forecasts and warnings are shown if **Figure 41** with forecasts at wwmiws.wmo.int/. The NWS issues marine forecasts and warnings for all of the coastal, offshore and high seas zones shown in **Figure 42**.

The high seas forecast format varies between these boundaries. In areas covered by the United States, the high seas forecasts will include information from the tropical cyclone advisories, with additional marine details. Specifically, the high seas forecast includes maximum sea height and 12-ft (3.7-m) sea radii through 48 hours. The high seas forecast details all significant marine weather, not just tropical cyclones. The NWS issues High Seas forecasts and warnings every 6 hours. The NWS also issues high seas forecasts and warnings for smaller areas within METAREAs IV and XII. More details: weather.gov/marine/hsmz

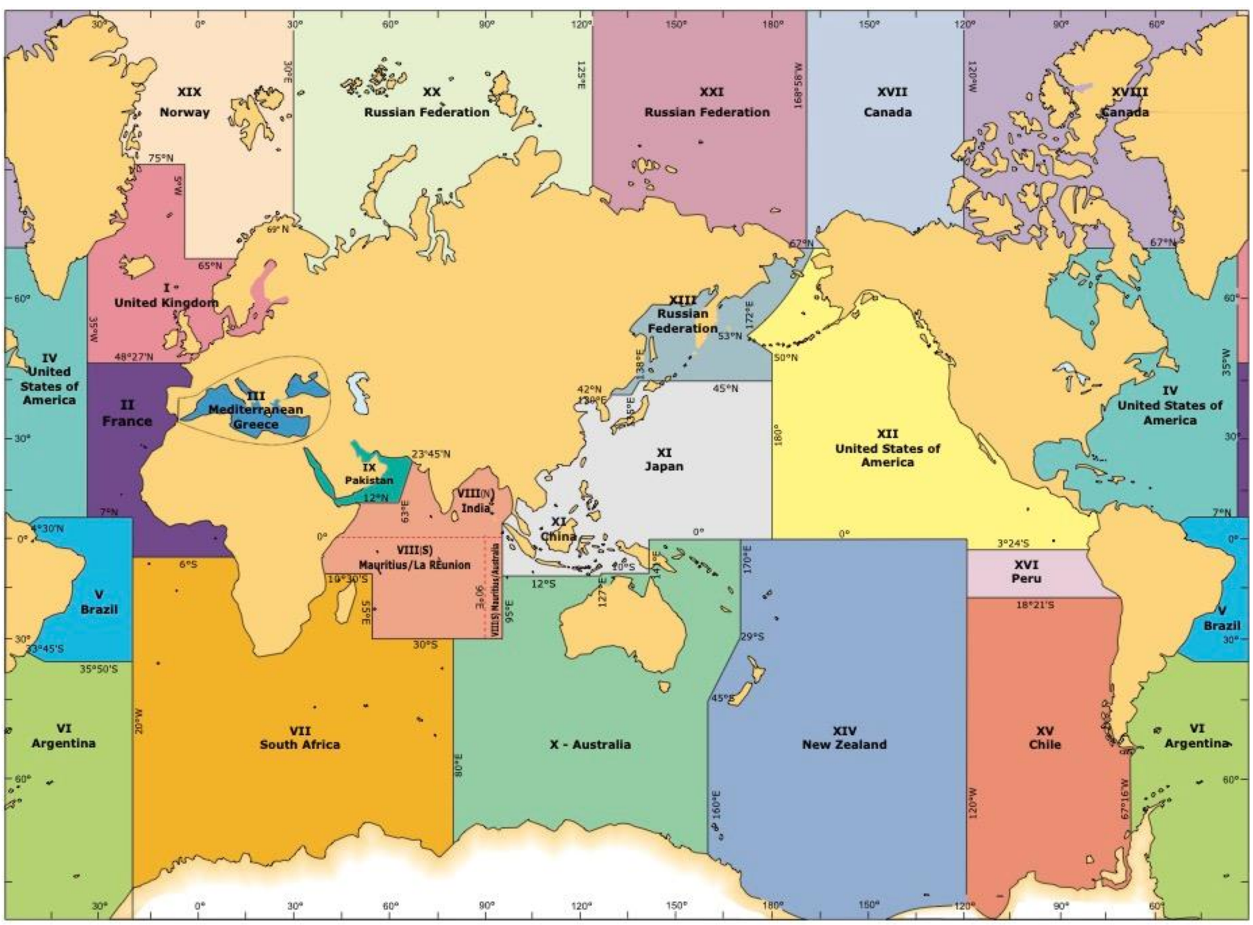


Figure 41: Global METAREA marine areas of responsibility.

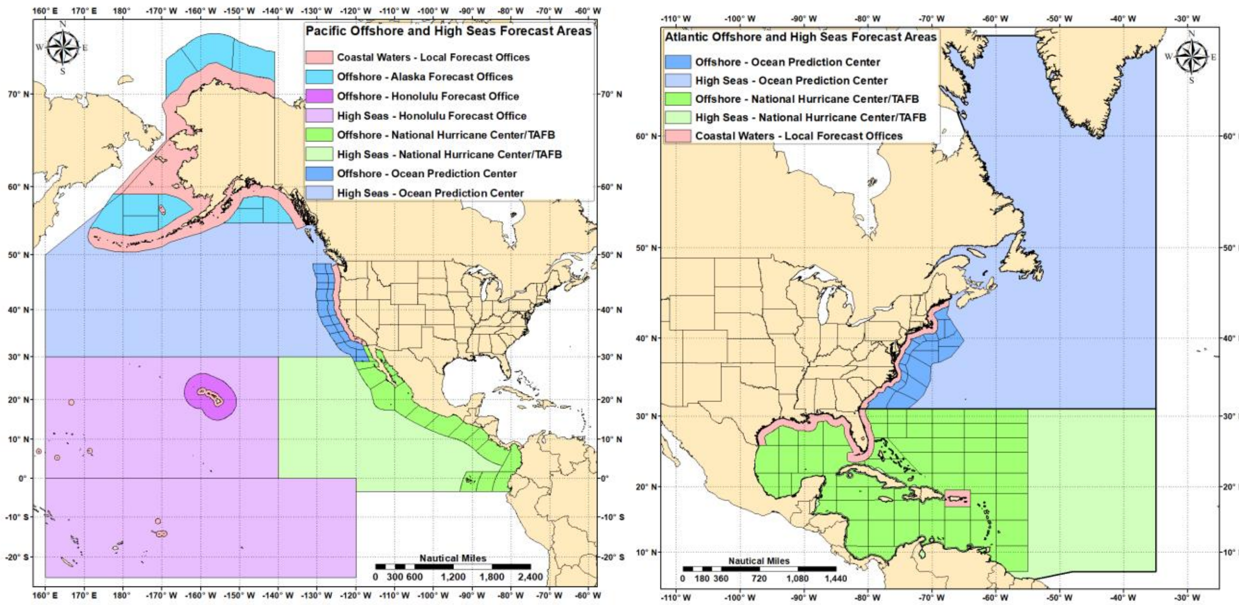


Figure 42: National Weather Service marine areas of responsibility.

NHC Graphic Products for the Mariner

The products described in this section are designed for use with a stable broadband internet connection and are available on the NHC/CPHC website.[11] Low-bandwidth and radiofax products are described in the next section.

Cone of Uncertainty

While this may be the most popular graphic produced by the National Hurricane Center, it is often misunderstood. The storm's current size is shown as the extent of tropical storm (orange) and hurricane (brown) winds. Forecast positions are shown with black circles (white for pre, post, or extratropical) and the following symbols:

D: Tropical Depression – wind speed less than 34 kts
S: Tropical Storm – wind speed between 34 kts and 63 kts
H: Hurricane – wind speed between 64 kts and 95 kts
M: Major Hurricane – wind speed greater than 95 kts

Forecast tracks are not perfect. The error cone conveys uncertainty. The solid white area depicts the track forecast uncertainty for days 1-3, while the stippled area depicts the uncertainty on days 4-5 (**Figure 43**). Historical data indicate that the entire 5-day path of the tropical cyclone's center will remain within the cone about 60-70% of the time. To form the cone, imaginary circles are placed along the forecast track at the 12, 24, 36, 48, 72, 96, and 120-hour positions, where the size of each circle encloses 67% of the previous five year's official forecast

[11] In addition to the standard NHC and CPHC areas, the Cone of Uncertainty, Wind Speed Probability and Time of Arrival graphics are available for JTWC forecasts in the West Pacific from 0-25N, between 180-130E and the South Pacific from 10-20S, between 164.5-178.5W. Refer to the NWS Guam and NWS American Samoa websites.

errors. The cone is then formed by smoothly connecting the area swept out by the set of circles. While this is a popular graphic, it is important to realize that tropical cyclones are not points. Their effects can span hundreds of miles from the center, and this graphic does not include information about the forecasted wind field, wave height, storm surge, or rainfall threats.

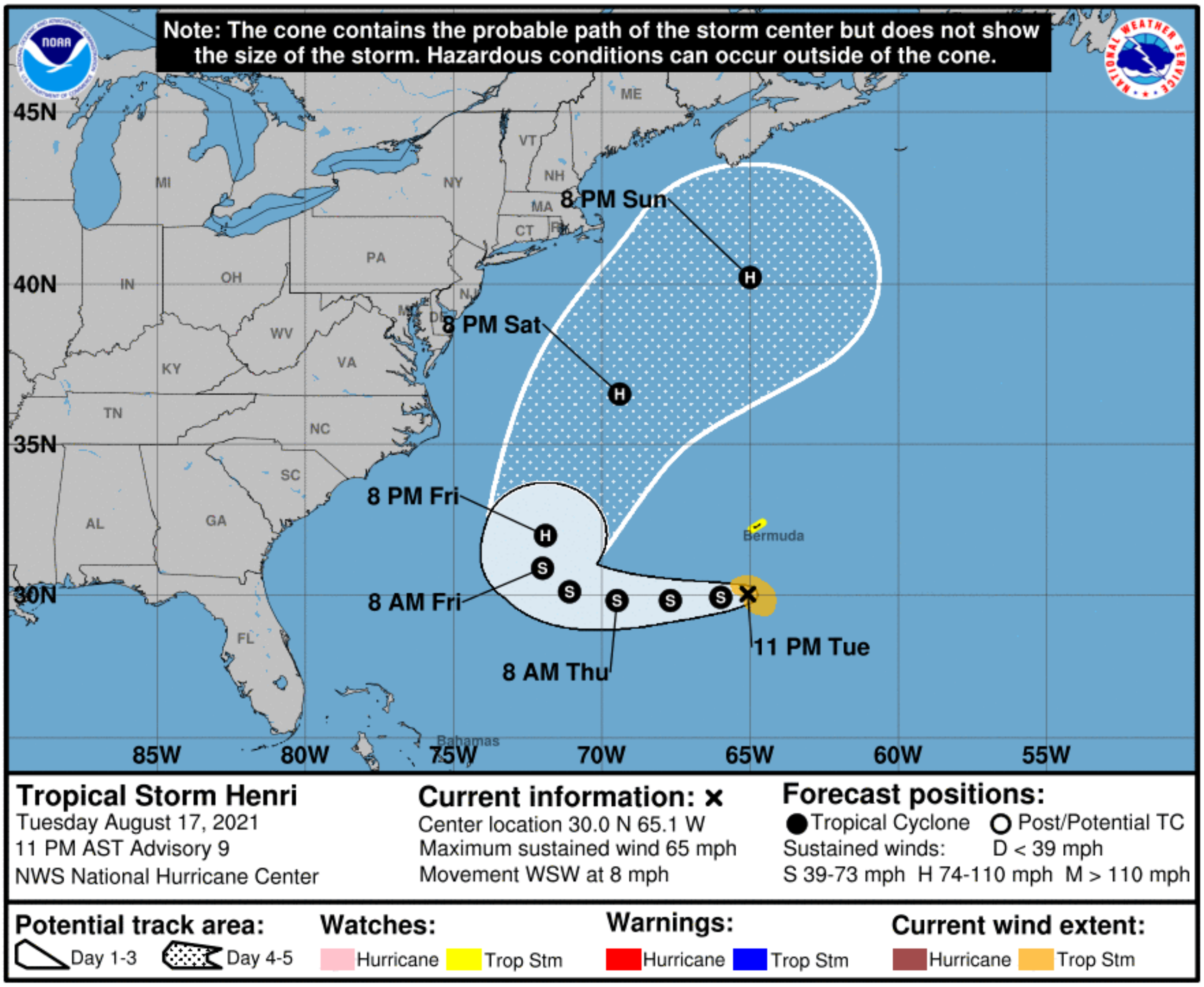


Figure 43: NHC Cone of Uncertainty graphic.

Wind Speed Probabilities

The Wind Speed Probability graphics (**Figure 44**) offer a better representation of storm size than the Cone of Uncertainty (**Figure 43**). These are graphical depictions of the Tropical Cyclone Surface Wind Probabilities (PWS) text product described earlier. The wind speed probabilities account for typical uncertainties in track, intensity, and size by using a set of 1000 alternate but plausible scenarios that use knowledge of NHC's historical 5-year errors. An advantage of the wind speed probabilities versus the cone is that the Wind Speed Probability graphics account for the size of the tropical cyclone rather than just the center location. The probabilities displayed are the cumulative chance of a location's risk of receiving 34, 50, or 64-kt winds over the entire forecast period (three or five-day options are available).

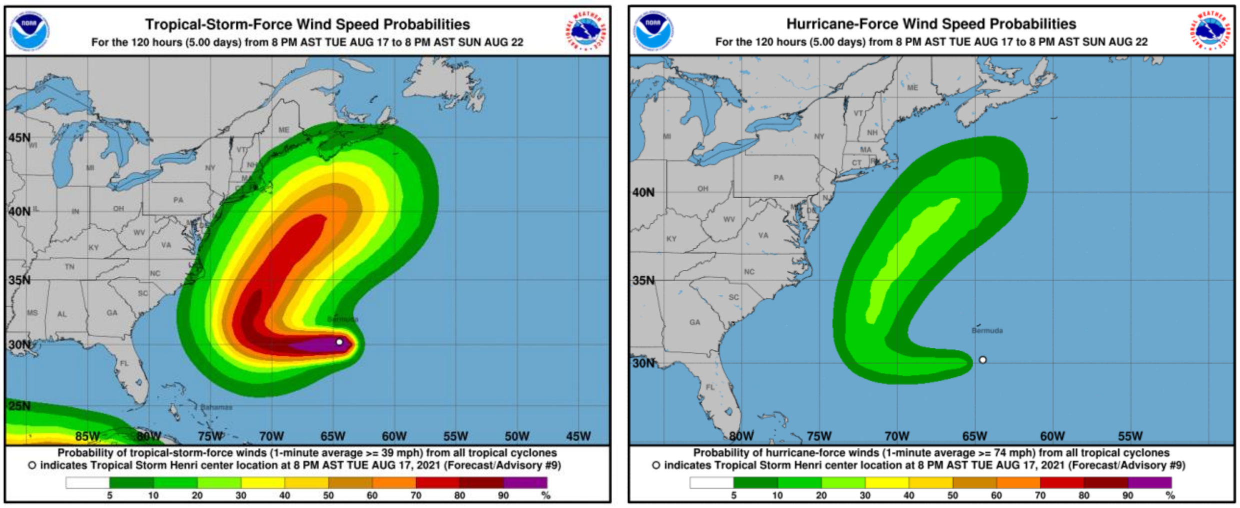


Figure 44: 34-kt and 64-kt Wind Speed Probabilities graphics for Tropical Storm Henri.

Arrival Time of Tropical Storm Force Winds

To provide information on the potential time of arrival of tropical storm force winds, NHC issues the Arrival Time of Tropical Storm Force Winds graphics. These products aim to help coastal communities know when preparations should be complete, as it is often too dangerous once tropical storm force winds have begun. While this information is relevant to the mariner at sea, it is particularly important while in port. Versions of this product depict the most likely or earliest reasonable arrival time.

The most likely arrival time represents the best guess at the onset of tropical storm force winds. In other words, it shows the time when there is an equal chance (50/50) of winds beginning either before or after. The earliest reasonable arrival time identifies the time before which there is no more than a 10% chance of the onset of tropical storm force winds. The purpose of this product is to account for systems that move faster or are larger than anticipated. This is the primary graphic aimed at those with a low tolerance for risk. Additionally, these graphics are available with the cumulative chance of tropical storm force winds as an underlay. These combination graphics provide a quick look at the likelihood and timing of tropical storm force wind impacts. Examples of the Most Likely and Earliest Reasonable Arrival Time graphics are provided in **Figure 45** and **Figure 46**, respectively.

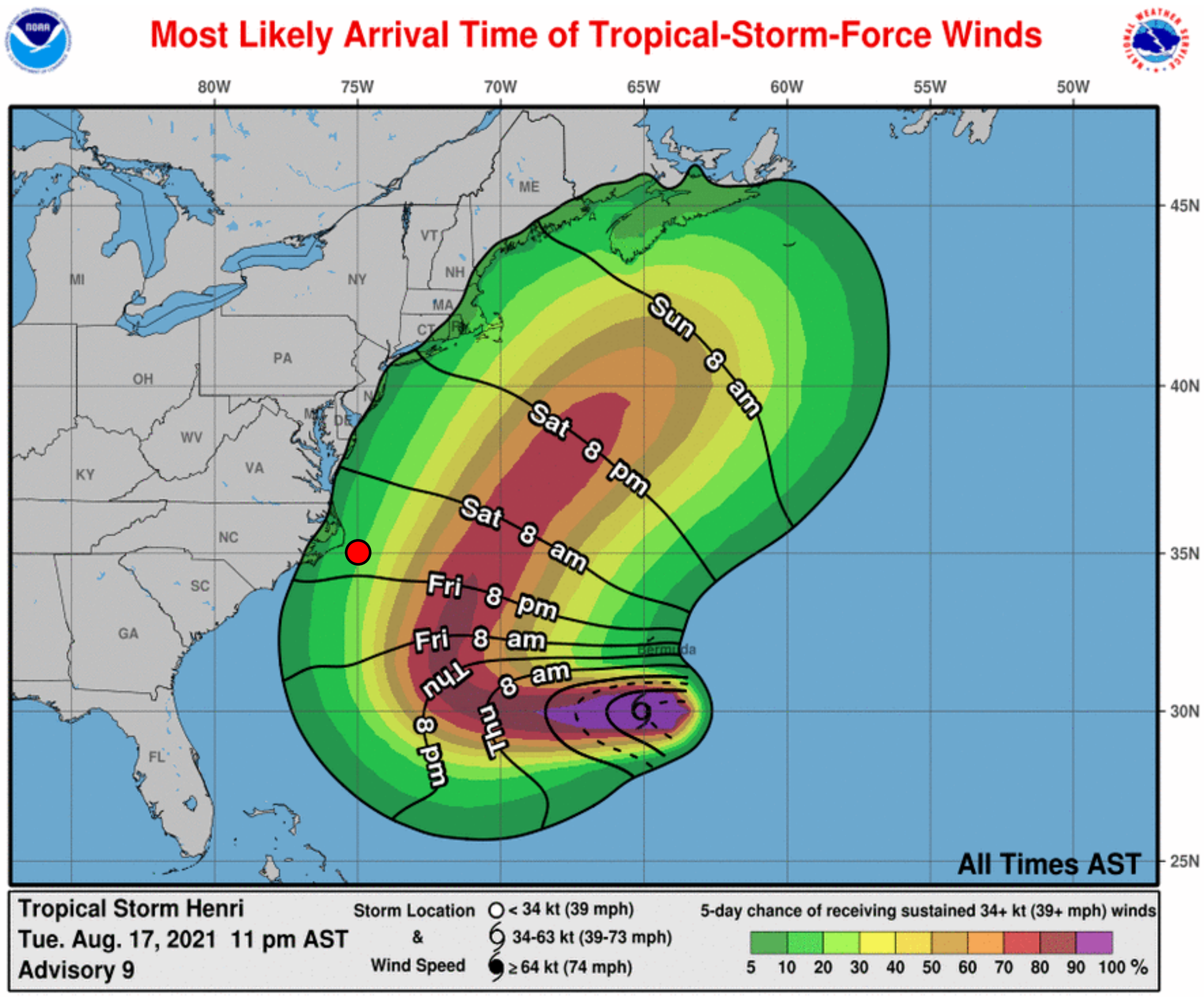


Figure 45: Most Likely Arrival Time of Tropical Storm Force Winds graphic (black lines) with the probabilities underlaid (colors). For example, a ship off Cape Hatteras at 35N75W has a 20% chance of receiving tropical storm force winds. If these winds occur, the most likely onset time is around 10 pm AST Friday, meaning there is an equal chance they begin before or after that time.

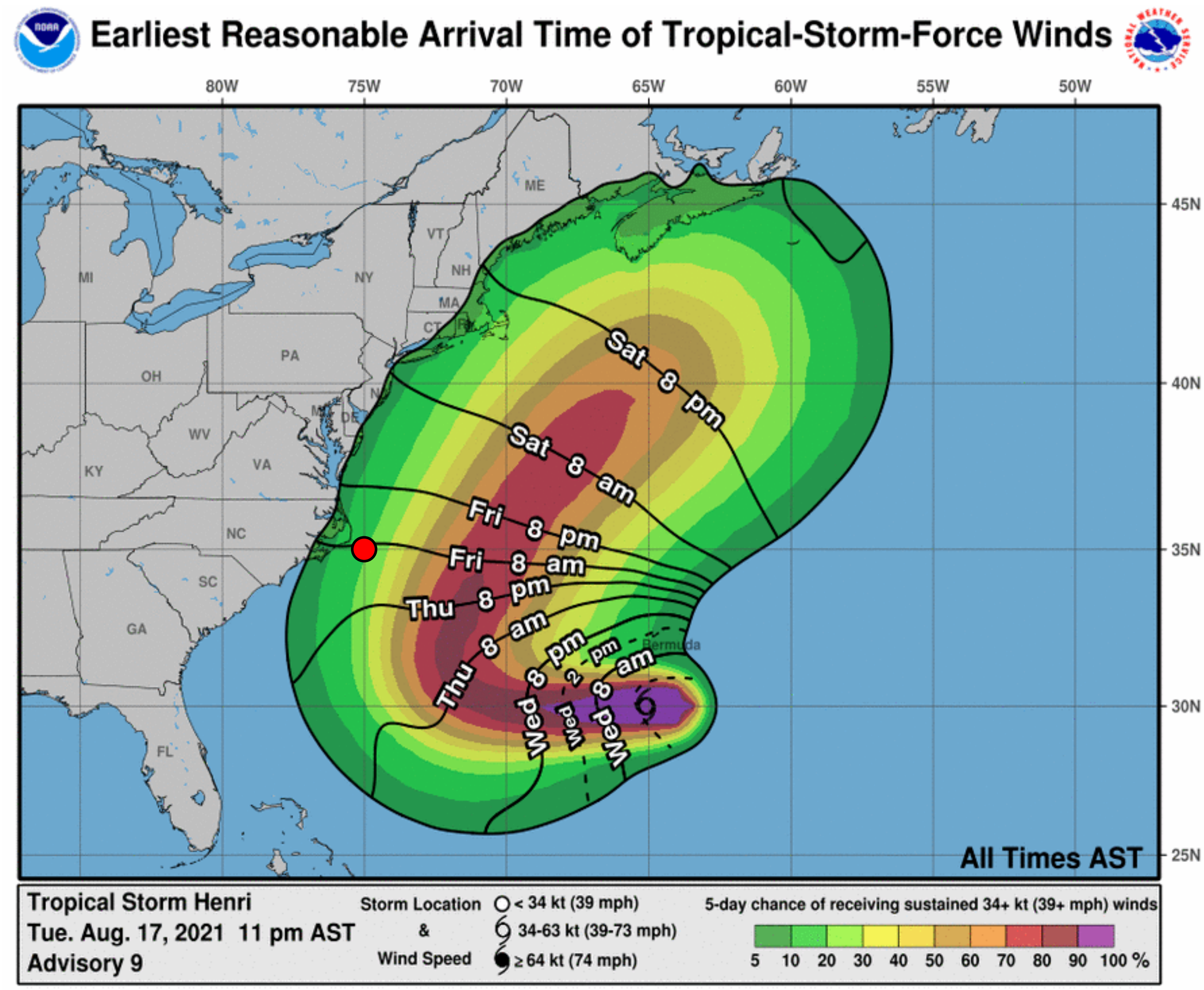


Figure 46: Earliest Reasonable Arrival Time of Tropical Storm Force Winds graphic (black lines) with the probabilities underlaid (colors). For example, a ship off Cape Hatteras at 35N75W has a 20% chance of receiving tropical storm force winds. If these winds occur, the earliest reasonable time they will begin is around 8 am AST Friday. Specifically, there is only a 10% chance they will begin before this time.

Graphical Tropical Weather Outlook

The Graphical Tropical Weather Outlook displays significant areas of disturbed weather and their potential for tropical cyclone development over the next 48 hours and seven days. The 2-day and 7-day probabilities of formation for each disturbance are given to the nearest 10% and expressed in terms of one of the following categories: low (yellow, 0-30%), medium (orange, 40-60%), and high (red, 70-100%). The 48-hour outlook is overlaid on a current satellite image. Outlooks are updated every 6 hours at 0000Z, 0600Z, 1200Z, and 1800Z. The hatched areas on the 7-day graphic show where formation may occur (**Figure 47**).

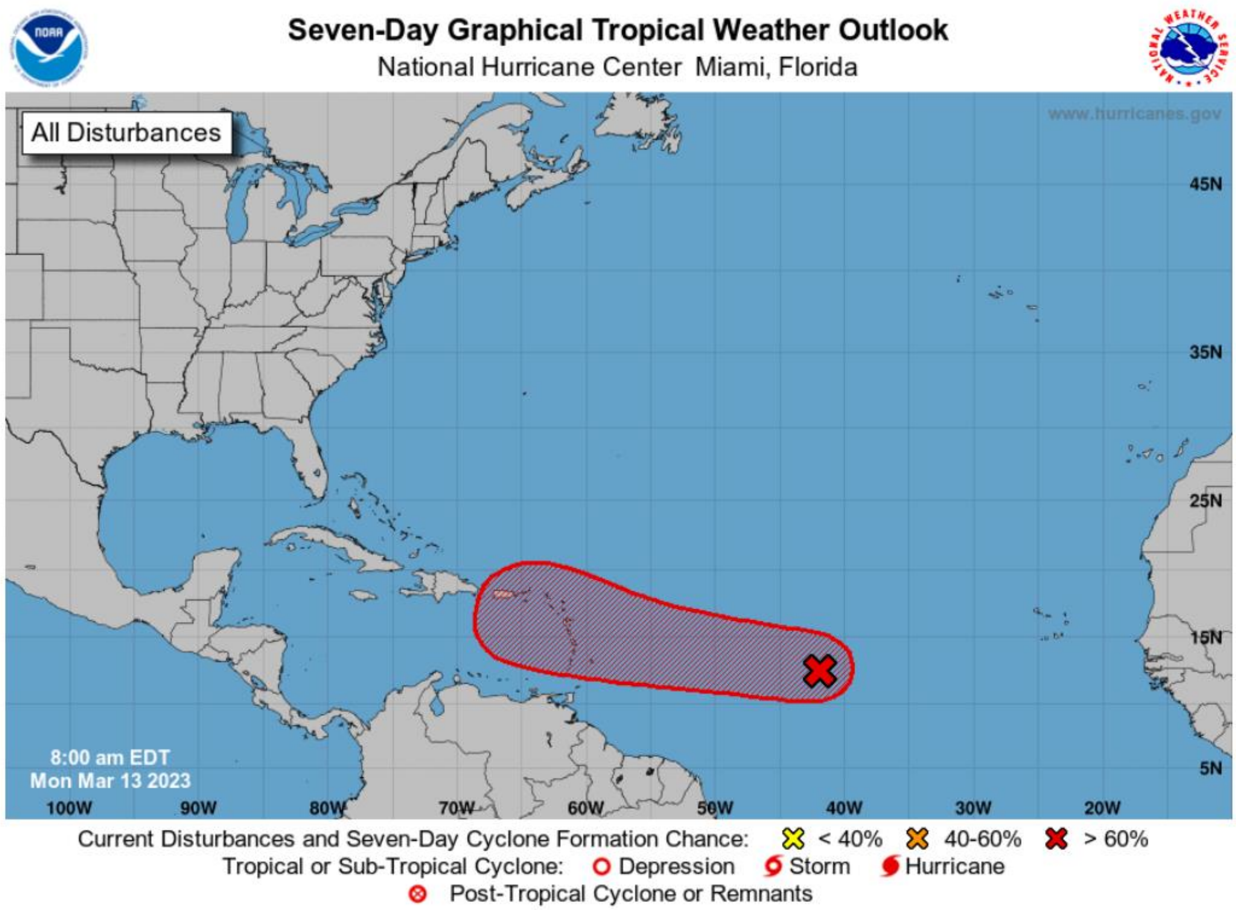


Figure 47: An example 7-day[12] Graphical Tropical Weather Outlook.

Tropical Surface Analysis

The Tropical Surface Analysis is created every six hours to depict the current state of the atmosphere, specifically the sea level pressure field, and any relevant synoptic-scale surface features (**Figure 48**). The Tropical Surface Analysis is attached to the surface analyses over North America, the North Atlantic Ocean, the North Pacific Ocean, and the West Pacific Ocean to create the National Weather Service Unified Surface Analysis, updated every 6 hours.

[12] In 2023, NHC extended the Tropical Weather Outlook from 5-days to 7-days. This longer window resulted in systems reaching higher long-range development probabilities sooner as well as longer hatched genesis areas, especially for fast moving disturbances.

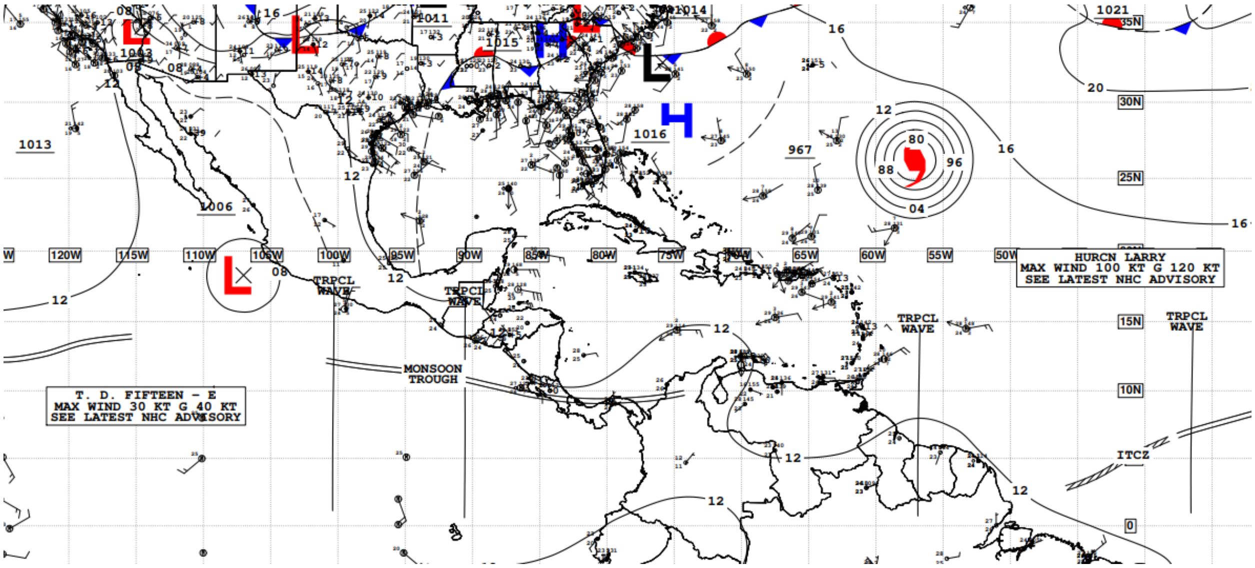


Figure 48: Tropical Surface Weather Analysis.

Twitter

Table 5 outlines several Twitter accounts managed by NHC. Of these, @NHC_TAFB is aimed at the mariner. This account will send automatic tweets with a link to the High Seas Forecast whenever there is an active marine warning. Manually generated tweets are also issued at least once per day. A sample tweet for Hurricane Fiona is shown in **Figure 49**. @NHC_Atlantic and @NHC_Pacific are also worth following if operating in those basins during the hurricane season. When released, these accounts will send automatic tweets with a link to the new advisory, in addition to manual tweets from the Hurricane Specialists. As a disclaimer, National Weather Service Twitter feeds are a supplemental service provided to extend the reach of information. Twitter feeds and tweets do not always reflect the most current information for forecasts, watches, and warnings. For the most current official info, visit weather.gov.

@NWSNHC	Official Twitter account for the National Hurricane Center.
@NHC_TAFB	Run by the National Hurricane Center's Tropical Analysis and Forecast Branch. Aimed at the maritime community.
@NHC_Atlantic	Run by the Hurricane Specialists Unit providing information on tropical cyclone advisories, watches, and warnings in the Atlantic basin.
@NHC_Pacific	Run by the Hurricane Specialist Unit providing information on tropical cyclone advisories, watches, and warnings in the eastern Pacific Basin.
@NHC_Surge	Run by the Storm Surge Unit at the National Hurricane Center.

Table 5: Different Twitter accounts managed by the National Hurricane Center.

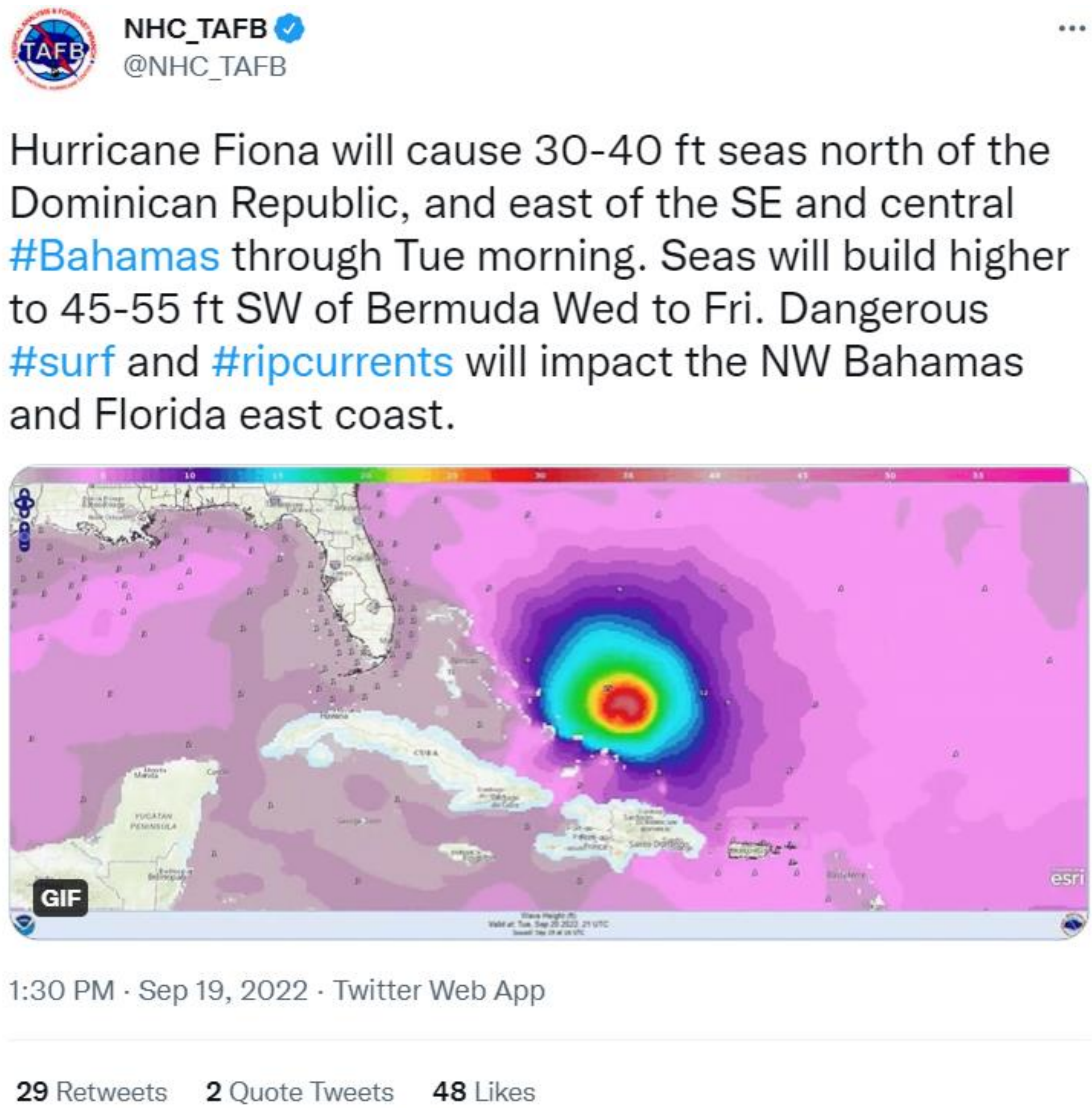


Figure 49: Example tweet from TAFB during Hurricane Fiona in 2022.

Tropical Atlantic Marine Weather Briefings

TAFB began offering Tropical Atlantic Marine Weather Briefings to the public in January 2023. These short (roughly 5-minute) videos provide an update on the marine conditions expected during the next five days over the Gulf of Mexico, Caribbean Sea, and tropical North Atlantic. A TAFB forecaster creates the briefing slides and discusses them in the video. They are created on Sunday and Thursday afternoons and uploaded to the NHC Youtube page.

NWS Low-Bandwidth Graphic Products for the Mariner

The products described below are produced in a low-bandwidth format for mariners. They are all available via radiofax transmission for users with no internet access. Alternatively, mariners can access these products via FTPMail or direct link from the website for users with some internet access but limited bandwidth. File sizes are generally 30-100 kB. Many of the products described in this section are available for different areas from the National Hurricane Center, the Ocean Prediction Center, and the Honolulu Forecast Office (HFO). The product boundaries align with the NWS marine areas of responsibility shown in **Figure 42**. Instructions for using FTPMail and radiofax to access these products are provided later in this chapter.

Tropical Cyclone Danger Graphic

The Tropical Cyclone Danger graphic is an excellent low-bandwidth ship routing tool. It outlines areas of possible (at least 5%) and likely (at least 50%) tropical storm force winds over the next 72 hours (**Figure 50**). The center location is shown in 12-hour increments. The underlying data is the same as the wind speed probabilities discussed earlier, only presented in a simplified format. It is updated four times per day, generally within an hour of the official warning (0400, 1000, 1600, and 2200 UTC). This tool replaces the antiquated 1-2-3 rule by outlining the probabilistic 34-kt ship avoidance area. Separate products are available for the Atlantic and East Pacific via the NHC website, FTPMail, and radiofax from May 15th – November 30th.

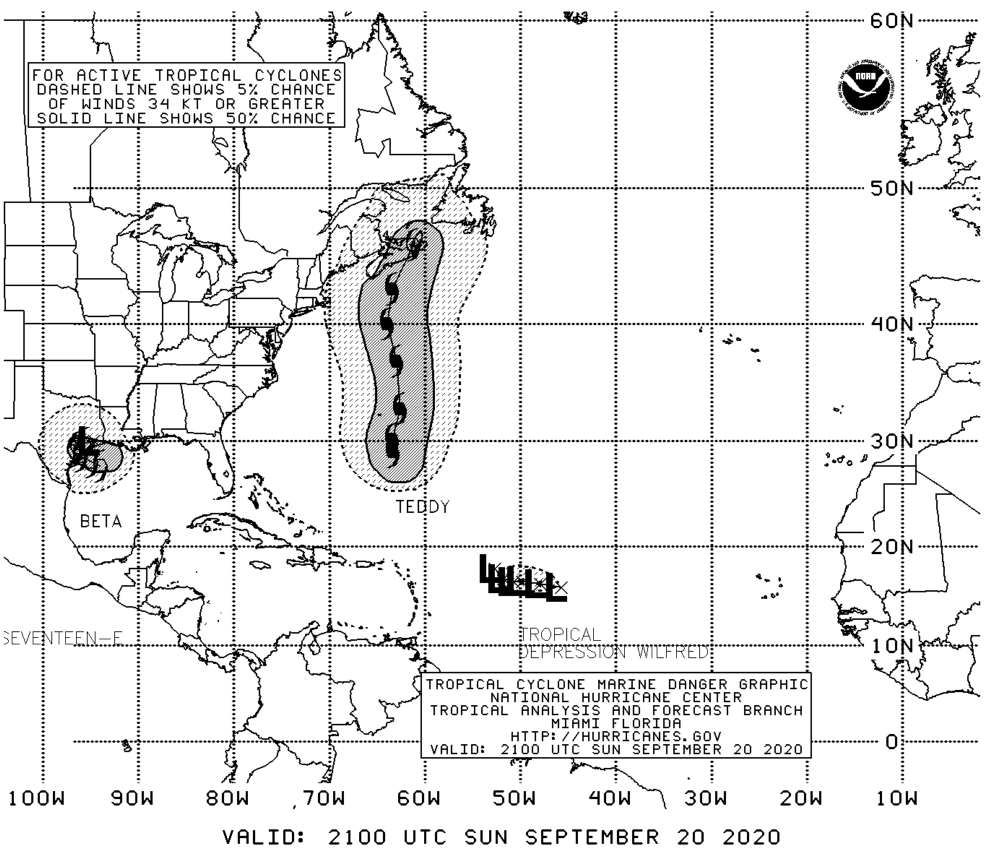


Figure 50: Tropical Cyclone Danger Graphic.

High Wind and Associated Seas

The National Hurricane Center produces the High Wind and Seas graphic to depict areas of gale, storm, and hurricane-force winds and the associated seas 48 hours in the future (**Figure 51**). It is produced between December 1st and May 14th (outside of hurricane season) under the same radiofax code as the Tropical Cyclone Danger Graphic.

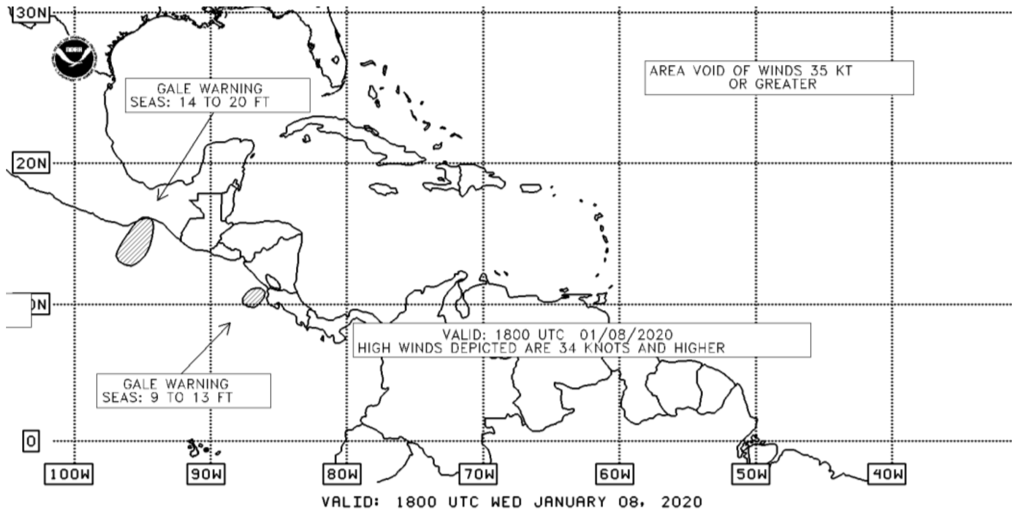


Figure 51: High Wind and Associated Seas Graphic.

Significant Wave Height Analysis

The wave height analysis is created every 12 hours, at 0000 and 1200 UTC, to depict the current significant wave height and primary swell direction field over the tropical and subtropical Atlantic and East Pacific waters (**Figure 52**). OPC produces this graphic for the mid-latitudes.

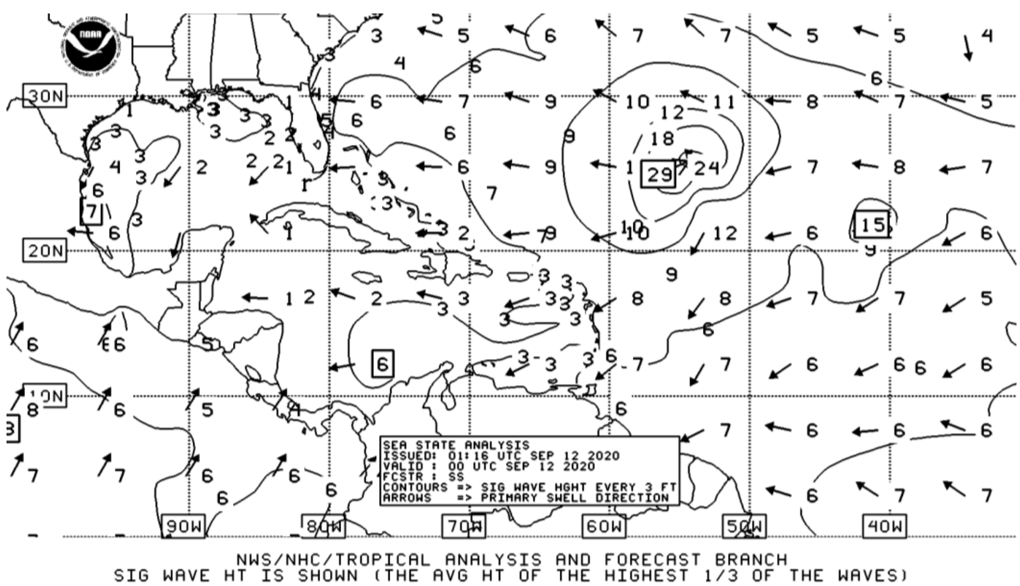


Figure 52: Significant Wave Height Analysis Graphic.

Wind and Wave Forecast Chart

NHC, OPC, and HFO produce wind and wave forecasts to depict the 24, 48, and 72-hour forecasts of surface wind speed and direction and significant wave heights over the Atlantic and Pacific waters. A typical 48-hour wind and wave forecast is shown in **Figure 53**. The wind/wave forecasts include wind barbs that indicate the wind speed and direction at specific points. The graphic also depicts tropical cyclones.

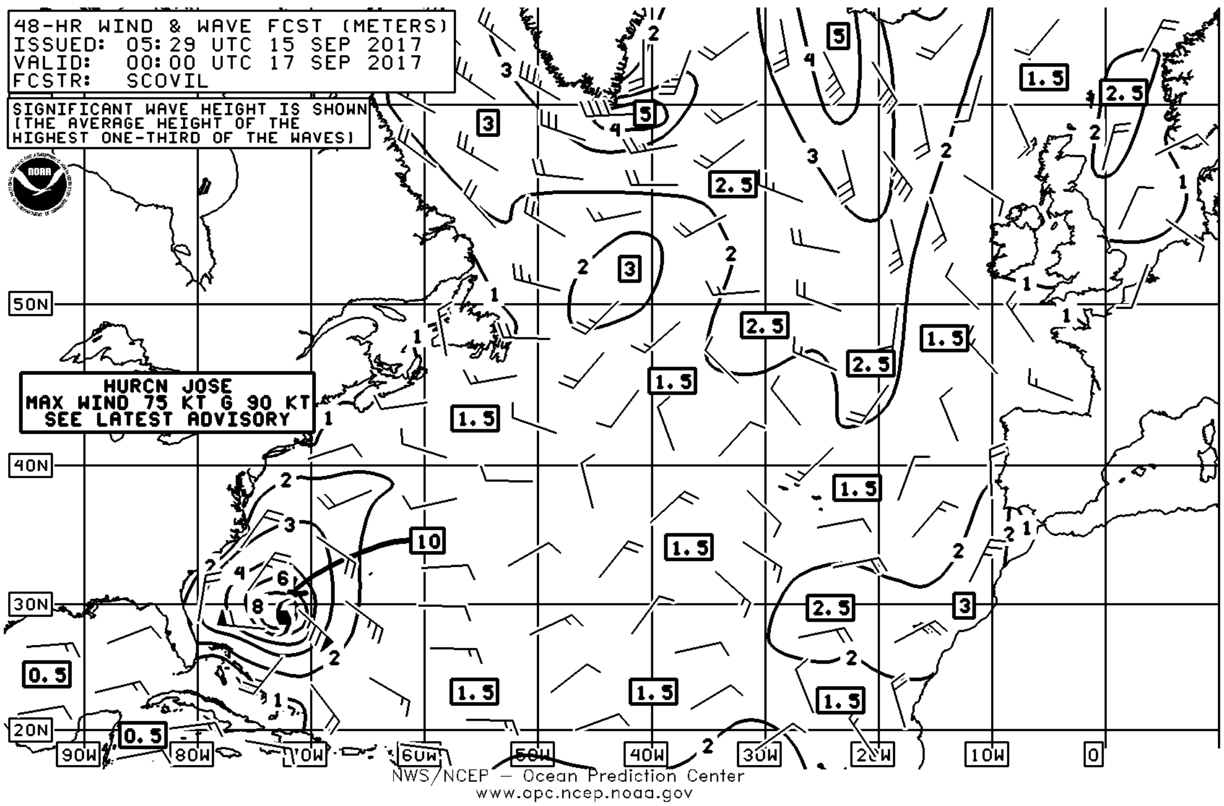


Figure 53: 48-hour Wind and Wave Forecast Graphic.

Surface Forecast Charts

NHC, OPC, and HFO offer surface forecast charts depicting tropical cyclones, marine warnings, fronts, and the pressure field, including high and low centers. A typical 48-hour wind and wave forecast is shown in **Figure 54**. They are available out to 72 hours (96 for OPC's area) and updated twice daily.

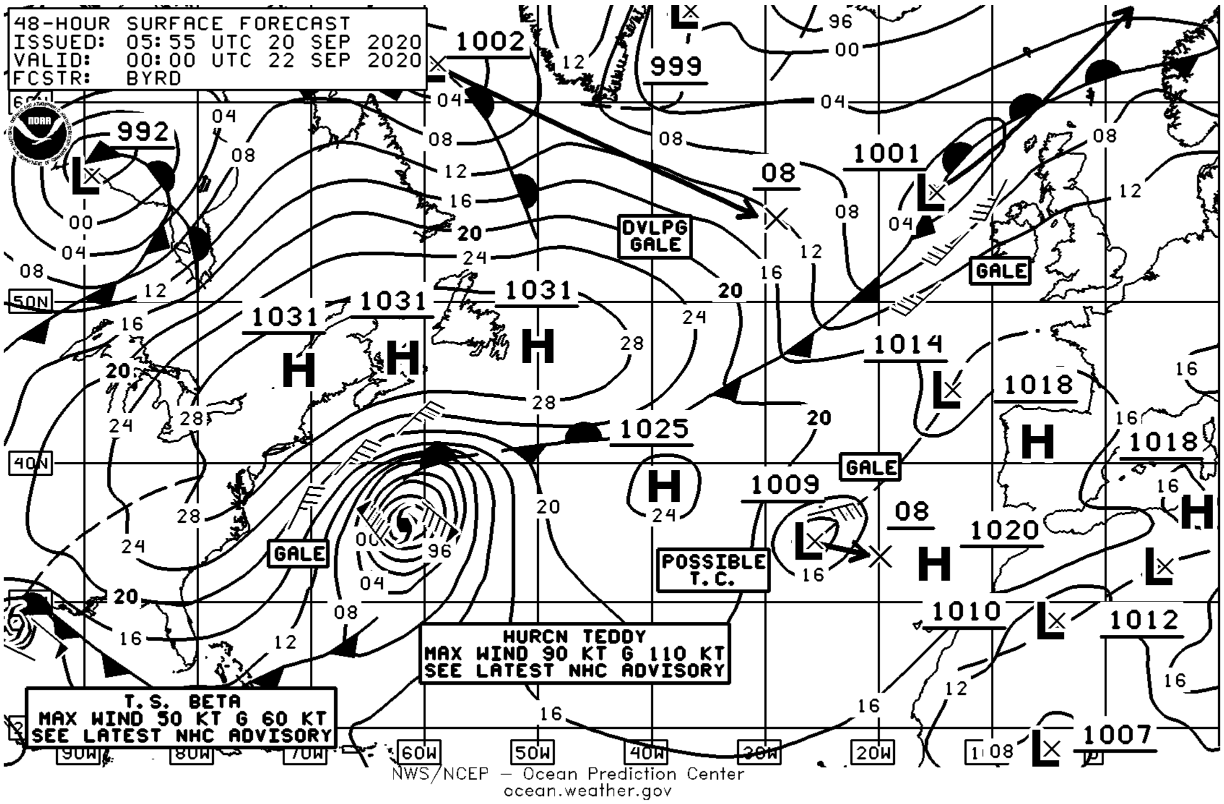


Figure 54: 48-hour Surface Forecast.

Peak Wave Period and Direction

NHC and OPC produce wave period and direction charts in both color and black and white (**Figure 55**). The arrows depict the dominant wave direction, and the colors depict the dominant wave period in seconds. The period is displayed numerically near the arrows in the black-and-white radiofax version. These charts are intended to be used with a wave height forecast chart. They are available out to 72 hours (96 hours for OPC's area) and are updated twice daily for both the Atlantic and Pacific.

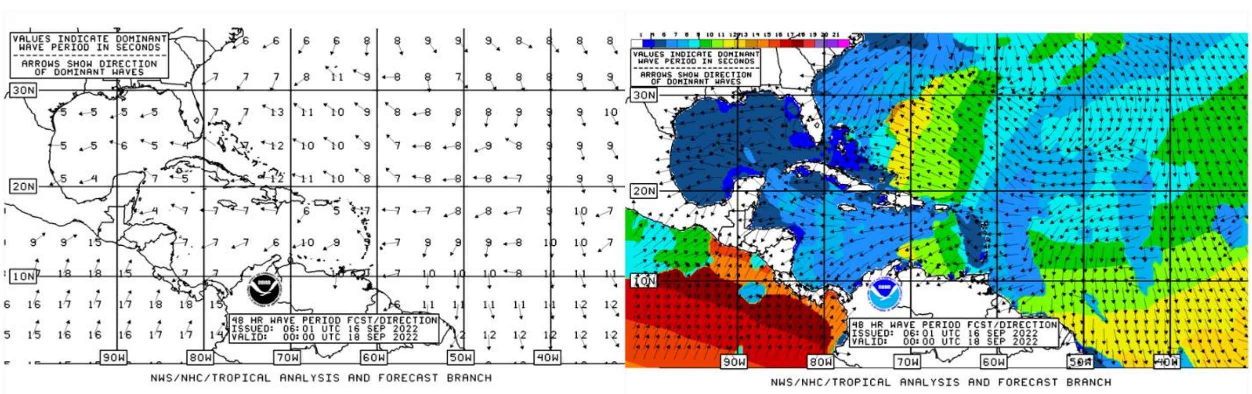


Figure 55: 48-hour Wave Period/Direction Forecast in both black-and-white and color.

Marine Composite Page

The Marine Composite Page (nhc.noaa.gov/marine/forecast) is a low-bandwidth, interactive tool designed for mariners. After selecting a basin to view, the user selects from the parameters listed on the left-hand side of **Figure 56** and uses the buttons on the top to toggle through 5 days of data in 12-hour increments. NHC developed the parameters based on feedback from the marine community. In addition to the standard 10-meter height, winds are also offered at 30 meters and 50 meters to account for the superstructure height of today's large commercial vessels. The wave height is provided in both feet and meters. Unlike raw model output available on the internet, highly trained meteorologists within the Tropical Analysis and Forecast Branch of NHC generate the data on the Marine Composite Page. They use their expertise to compare different models, real-world observations, and official tropical cyclone advisories to develop the official gridded forecast.

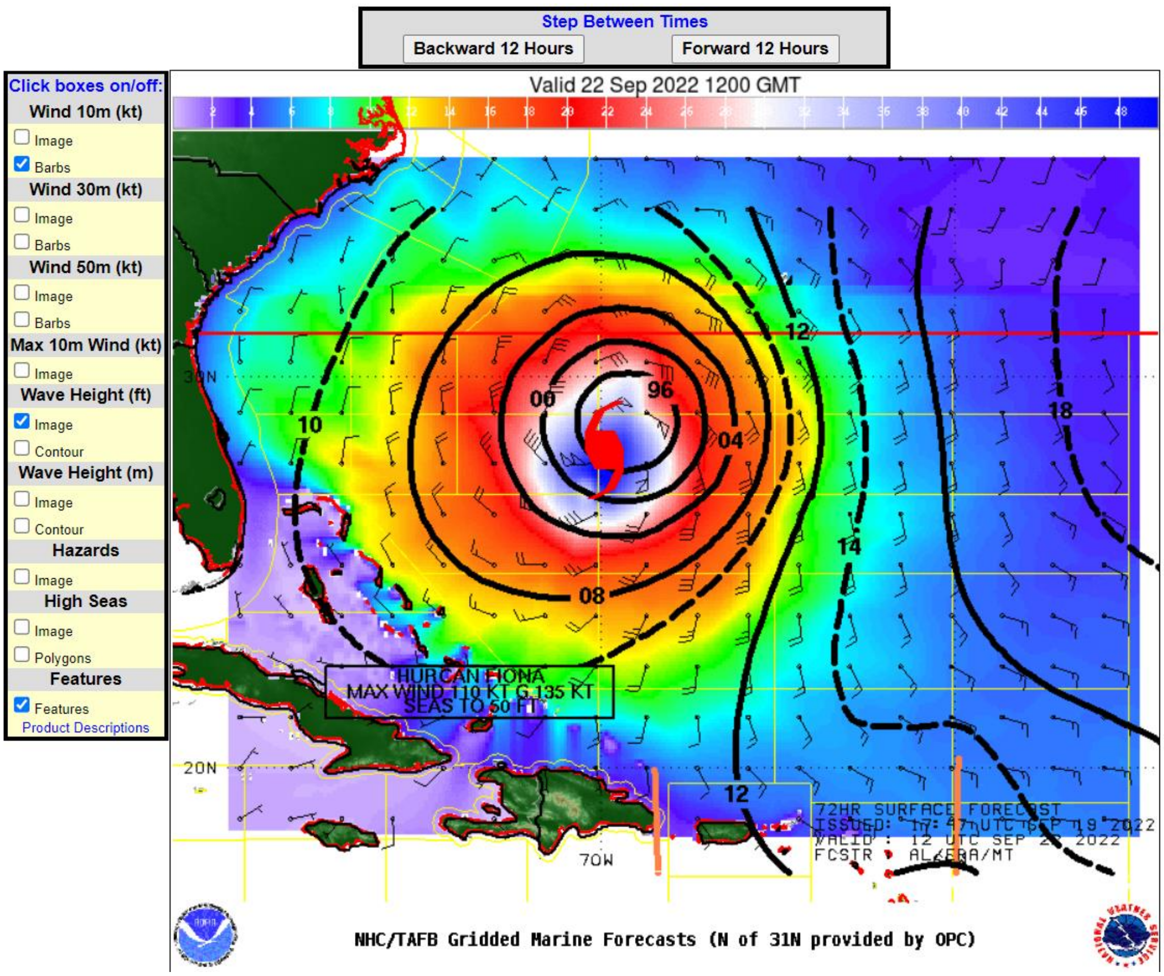


Figure 56: Marine Composite Page. The parameters on the left can be toggled on and off to suit the user's need.

Joint Typhoon Warning Center

The Joint Typhoon Warning Center (JTWC) issues tropical cyclone advisories for the entire Pacific and Indian Oceans for the U.S. Department of Defense (DOD). The Navy's Fleet Weather Center in Norfolk, Virginia has the same responsibility for the Atlantic basin. In areas covered by the U.S. National Weather Service, these agencies simply repackage the forecast into their format. However, JTWC meteorologists will generate an independent forecast outside the NWS area of responsibility.

Like the NWS, JTWC defines sustained winds as the 1-minute average wind speed at 10 meters. Some RSMCs use different definitions, many averaging over 10 minutes. This discrepancy can cause JTWC to report higher winds than RSMCs outside the United States. JTWC will reference the locally given tropical cyclone name when possible; however, they often start advisories before a name is designated. For this reason, JTWC refers to all tropical cyclones primarily by their storm number, which may differ from the locally assigned number due to differences in numbering conventions. While these forecasts are explicitly intended for use by the U.S. DOD, they have the distinct advantage to the mariner of a consistent format across all basins. The wind speed is in knots, the radii are in nautical miles, all times are in UTC, and the track extends 120 hours. All products are publicly available on the website listed on **page 2**.

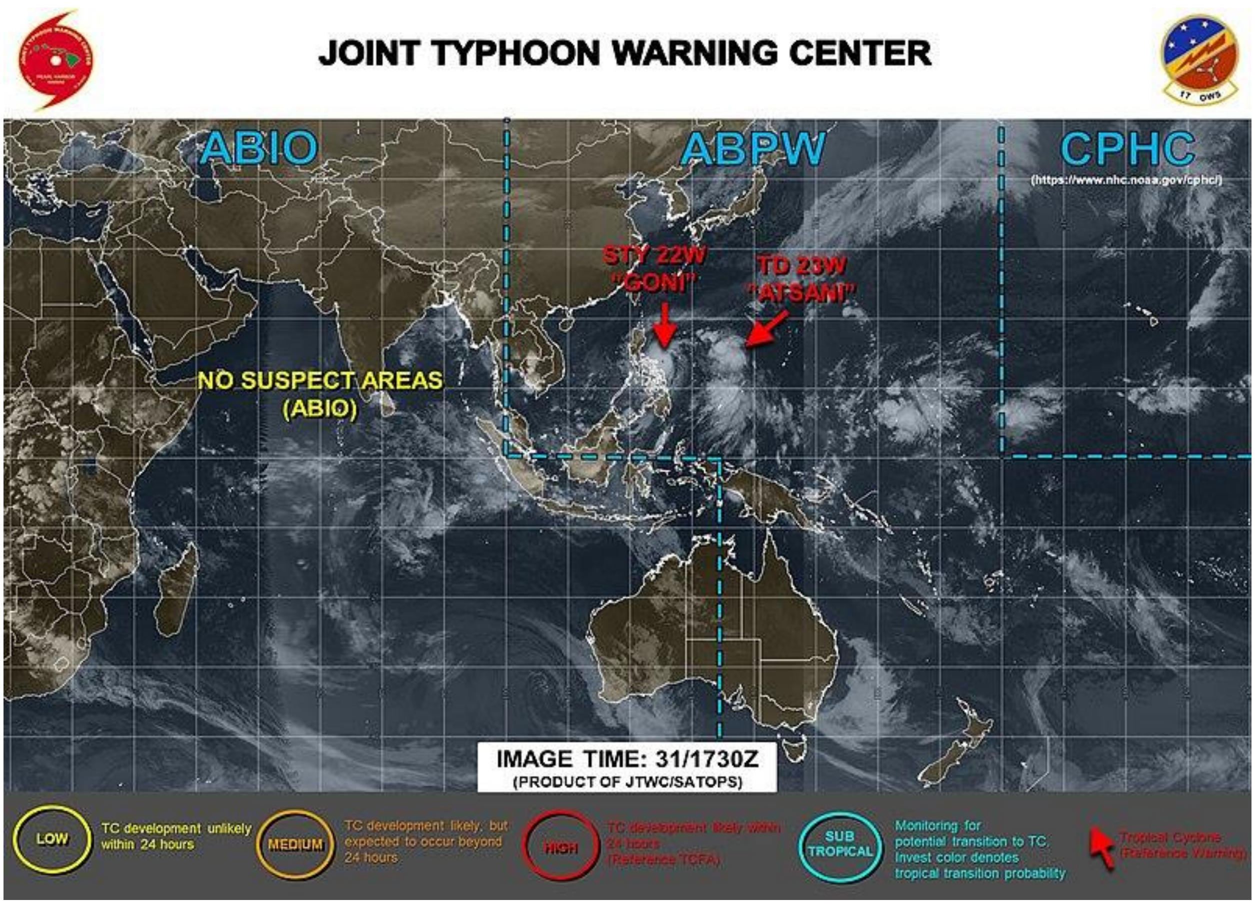


Figure 57: JTWC Homepage.

JTWC Text Products for the Mariner

Tropical Cyclone Warning Text

Similar to NHC's TCM, JTWC's tropical cyclone warning text includes the current position, intensity, motion, 34, 50, and 64-kt wind speed radii, and 12-ft (3.7-m) sea radii. While the format is intentionally similar to NHC, the forecast information differs slightly. Unlike NHC, JTWC includes the analyzed maximum significant wave height on their warnings and has included wind radii at all forecast hours since 2016. Updates are provided every 6 hours in the northern hemisphere and portions of the southern hemisphere identified in **Figure 58**. Outside of these areas, warnings are disseminated every 12 hours in the southern hemisphere.

Figure 58: In the southern hemisphere, JTWC warning frequency increases from 2 per day to 4 per day within the blue boxes for DOD, American asset, and humanitarian reasons. JTWC always provides 4 warnings per day for storms in the northern Hemisphere.

Tropical Weather Advisories

Tropical weather advisories are released daily and discuss any significant tropical weather, including convection, tropical disturbances, and areas of potential tropical cyclone development. Invest areas are categorized as shown in **Table 6** and coded as ABPW10 and ABIO10 for the Pacific and Indian Oceans, respectively.

Low	Unlikely to develop within the next 24 hours
Medium	Elevated potential to develop, but will likely occur beyond 24 hours
High	Expected to develop within 24 hours, accompanied by a TCFA

Table 6: JTWC invest area designations

Tropical Cyclone Formation Alert (TCFA)

TCFAs describe where a disturbance may develop into a tropical cyclone within the next ***24 hours***. This product will briefly describe the meteorological environment and its effect on development potential. Fleet Weather Center Norfolk issues the same product for the Atlantic Basin. TCFAs are issued as needed and can either be upgraded to a warning, extended, or canceled.

JTWC Graphic Products for the Mariner

Tropical Cyclone Warning Graphic

JTWC's main graphic displays much of the information from the warning text in a low-bandwidth image tailored for mariners (**Figure 59**). Like NHC, the error cone accounts for basin-specific 5-year average uncertainty in the center location but is expanded to include the size of the storm (in the form of the maximum 34-kt wind radius at each time). For this reason, the JTWC error cone will always be larger than the NHC error cone, provided the tropical cyclone is producing at least 34-kt winds. On the graphic, this shaded zone represents the potential area of tropical storm force winds and is referred to as the avoidance area by Navy ship routing officers.

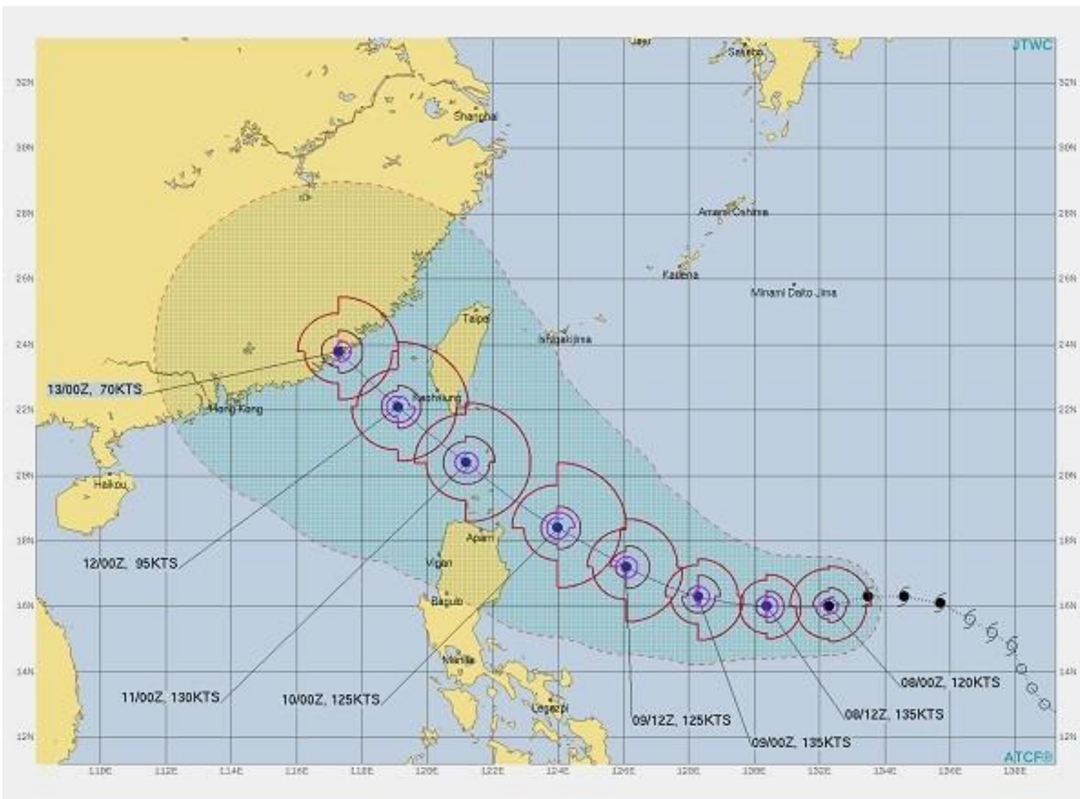


Figure 59: JTWC Warning Graphic.

Tropical Cyclone Formation Alert (TCFA)

In addition to the text product described on the previous page, TCFA graphics are also produced by JTWC (**Figure 60**). A rectangular TCFA area is issued when a developing cyclone's speed and direction of motion can be predicted with relatively high confidence. Circular TCFA areas are issued when a developing cyclone's speed and direction of motion are relatively difficult to predict or if the developing cyclone is nearly stationary.

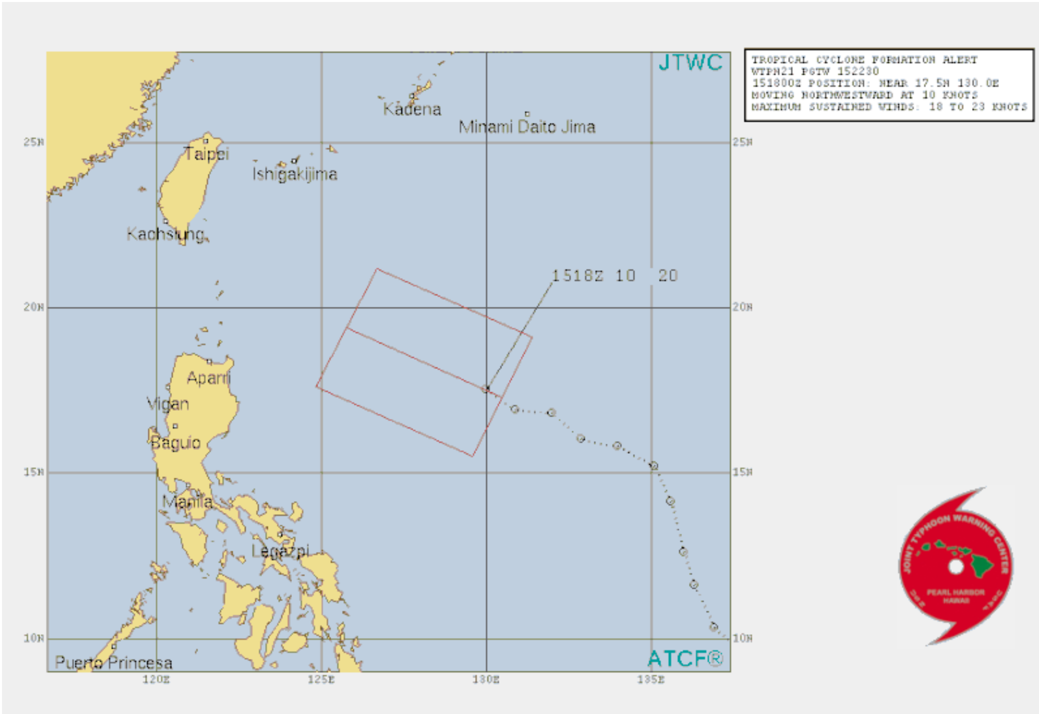


Figure 60: JTWC 24-hour Tropical Cyclone Formation Alert Graphic.

Receiving Tropical Cyclone Products at Sea

While it's rare for the modern mariner to be completely surprised by the existence of a tropical cyclone, it is essential to have a primary and backup method to receive updates and to download them often. Many mishaps involve mariners making decisions based on old forecasts. While tremendous strides have been made in the field of tropical cyclone forecasting, they remain one of the most challenging weather phenomena to predict. The forecast track can shift significantly between six-hourly updates. Therefore, mariners should become familiar with the advisory update schedule (0300, 0900, 1500, 2100 UTC, with intermediate 3-hourly updates when there are active coastal watches or warnings). It is critical to have reliable, timely access to the latest updates and the flexibility to adjust course as needed to maintain the proper stand-off distance. This section will describe the many ways tropical cyclone information is made available to the mariner.

Internet

All of the products described in this chapter, along with countless others, are readily available with a stable internet connection. A list of useful websites is included on **page 2** of this manual. For mariners with bandwidth restrictions, there are low-bandwidth mobile sites available from NHC and OPC. NHC also offers a text-only website. **Table 7** lists alternate websites with different bandwidth requirements to load the home page and navigate to either the surface analysis graphic or weather discussion (for the text-only site). Additional products will add to this, with graphics generally using more data than text products and satellite images using far more data than graphics.

Website	Data Usage	Link
NHC Full Site	4,411 kB	nhc.noaa.gov/
NHC Mobile Site	688 kB	nhc.noaa.gov/mobile/
NHC Text Site	162 kB	nhc.noaa.gov/?text
OPC Full Site	3,228 kB	ocean.weather.gov/
OPC Mobile Site	215 kB	ocean.weather.gov/mobile/
Direct Link	50 kB	ocean.weather.gov/UA/Atl_Tropics.gif
		ocean.weather.gov/UA/Pac_Tropics.gif

Table 7: Approximate data requirements needed to navigate through each site to the latest surface analysis graphic or discussion text. Saving the direct link is usually best.

Table 7 demonstrates that the best way to conserve bandwidth is to bookmark direct links to the products used most frequently. This avoids unnecessarily wasting data navigating to the links. In this case, the direct link to the graphical surface analysis uses 7% of the data needed to navigate to the same product through the mobile site and only 1% compared to the high-resolution version from the standard website.

E-mail

The National Weather Service offers text files and graphic charts through a File Transfer Protocol (FTPMail) server. This service allows access to NWS products for users who do not have direct internet access but do have an email system. Users send a short email requesting files from the NWS and have them automatically emailed back. While this is a free service, users should know their data costs when using satellite communications. The file sizes for NWS radiofax graphics average 35 kB, but some files can be much larger, especially satellite images that can approach 1 MB. For more information on how to get started with FTPMail see: weather.gov/marine/faq#3

FTPMail is unforgiving. The request email must use the correct case, and line breaks to receive a successful return file. Each product has a specific path and code that mariners must know. Ideally, this process will be rehearsed before it's needed underway. The best way to get started is to send the following test email:

To: NWS.FTPMail.OPS@noaa.gov
Subj: Anything that you like.
Body: help

You should receive a help file within a few minutes. This file will explain the procedures and methods of obtaining weather information along with an extensive list of available products. To explore tropical cyclone products, send the following request.

To: NWS.FTPMail.OPS@noaa.gov
Subj: Anything that you like
Body:

open
cd fax
get marine2.txt
get robots.txt
quit

This will return two emails: *marine2* and *robots*. The marine2 email explains how to request specific tropical cyclone text and graphic products from the National Hurricane Center and Joint Typhoon Warning Center. The robots email describes how to automate these requests.

Steps to Retrieve the Outlook, Advisories and Danger Graphic with FTPMail

The most important products are the **tropical weather outlook** (TWO), **technical advisories** (TCM), and the **danger graphic**. Together, these will provide great situational awareness of current and future tropical cyclones. The example below is for the eastern Pacific, but the same process works for the central pacific and Atlantic. Mariners should request these products every 6 hours as they become available.

Step 1: Retrieve the latest Tropical Weather Outlook (updated 00/06/12/18 UTC) and Tropical Weather Discussion (updated every 6 hours, schedule depends on basin)

To: NWS.FTPMail.OPS@noaa.gov
Subj: Anything that you like
Body:
open
cd data
cd hurricane_products
cd eastern_pacific
cd weather
get outlook.txt
get discussion.txt
quit

This request will retrieve the latest Tropical Weather Outlook (TWO) and Tropical Weather Discussion (TWD). The TWO is a useful product to determine if there are any active tropical cyclones in the basin and identify any systems that may soon develop. The outlook will include information about the storm's bin number for newly developed tropical cyclones. The bin number is chosen from a repeating sequence of 1-5 and is used to differentiate between active systems. Once assigned, a storm will keep its bin number through its lifecycle. The bin number can also be found in the TWD under the special features section. The bin number is necessary information to request the correct TCM advisory. Replace "eastern_pacific" with "central_pacific" or "atlantic" as needed.

Step 2: Identify active storms and their bin number from the Tropical Weather Outlook or Tropical Weather Discussion

Tropical Weather Outlook
NWS National Hurricane Center Miami FL
500 PM PDT Tue Jun 14 2022

For the eastern North Pacific...east of 140 degrees west longitude:

The National Hurricane Center is issuing advisories on Tropical Storm Blas, located a few hundred miles south of the southwest coast of Mexico.

NHC is issuing advisories on Tropical Storm Blas

Public Advisories on Blas are issued under WMO header WTPZ32 KNHC and under AWIPS header MIATCPEP2.
Forecast/Advisories on Blas are issued under WMO header WTPZ22 KNHC and under AWIPS header MIATCMEP2.

Tropical Storm Blas is in bin #2

Step 3: Retrieve the appropriate Tropical Cyclone Forecast/Advisory message(s) (TCM) (Updated 03/09/15/21 UTC)

To: NWS.FTPMail.OPS@noaa.gov
Subj: Anything that you like
Body:
open
cd data
cd hurricane_products
cd eastern_pacific
cd storm_2
get technical_advisory.txt
quit

This will return the latest TCM for the storm in bin 2. See **Figure 38** for an example. Be sure to request the correct basin and change *storm_2* to *storm_X*, where *X* is the bin number identified in step 2. If the bin number is unknown, the appropriate TCM(s) can be found by requesting all bins (1-5) and ignoring the outdated information from obsolete storms. Multiple TCMs can be requested using the following format (bins 2 and 3 in this case).

To: NWS.FTPMail.OPS@noaa.gov
Subj: Anything that you like
Body:
open
cd data

```
cd hurricane_products
cd eastern_pacific
cd storm_2
get technical_advisory.txt
cd /data
cd hurricane_products
cd eastern_pacific
cd storm_3
get technical_advisory.txt
quit
```

Step 4: Retrieve the Tropical Cyclone Danger Graphic (Updated 04/10/16/22 UTC)

To: NWS.FTPMail.OPS@noaa.gov
Subj: Anything that you like
Body:

```
open
cd fax
get PWFK11.TIF
quit
```

PWEK11.TIF	Atlantic
PWFK11.TIF	East Pacific
PWFK12.TIF	Central Pacific

This request will retrieve the latest Tropical Cyclone Danger Graphic for the East Pacific. This low-bandwidth product (~30 kB) shows the path of the storm and areas that are likely (50% chance) and possible (5% chance) to receive tropical storm force winds. See **Figure 50** for an example. Replace PWFK11 with PWEK11 for the Atlantic and PWFK12 for the Central Pacific.

Exploring the marine2 and help files reveals countless other products available through FTPMail, including those from JTWC and international meteorological agencies. For more information on marine weather products available via FTPMail, refer to weather.gov/media/marine/ftpmail.txt

USCG GovDelivery

The U.S. Coast Guard offers a convenient email subscription service via GovDelivery. Many useful products are available to mariners, including weekly weather briefs created by the Ocean Prediction Center. To sign-up for these reports, follow the prompts from this link (public.govdelivery.com/accounts/usdhscg/subscriber/new) and select the following products:

- Atlantic Hazardous Weather Outlook
- Eastern Pacific Hazardous Weather Outlook

Radiofax

Radiofax is a method to receive weather graphics from high-frequency radio transmissions without needing an internet connection. While this technology approaches its 100th birthday, it remains a practical method to stay informed at sea. High-frequency USCG transmitters in Boston, New Orleans, Anchorage, Point Reyes, and the DOD transmitter in Honolulu are part of an international network that continuously transmits weather information freely available to anyone with the proper receiving equipment. While radiofax is one of the most affordable options, there are downsides. A steep learning curve, specific transmission times, and reception-dependent results can lead to missed updates.

Dedicated radiofax receivers typically use assigned frequencies, while receivers or transceivers connected to external recorders or personal computers are operated in the upper sideband (USB) mode using the carrier frequencies. From the radiofax assigned frequencies, subtract 1.9 kHz for the carrier frequency. All broadcasts of NWS products use a radiofax signal of 120 lines-per-minute (LPM) and an Index-of-Cooperation (IOC) of 576. Although radio reception in the high-frequency band varies significantly with many factors, frequencies above 10 MHz generally work best during the day, while lower frequencies work best at night.

Worldwide transmission schedules and frequencies are available in the following document: weather.gov/media/marine/rfax.pdf

INMARSAT-C SafetyNET

Inmarsat-C SafetyNet is an internationally adopted, automated geostationary satellite system for promulgating weather forecasts and warnings, marine navigational warnings, and other safety-related information to all vessels as part of the Global Maritime Distress and Safety System (GMDSS). Different countries provide global meteorological data for their respective METAREAs (**Figure 41**) in the form of the High Seas Text Forecast. The National Weather Service also broadcasts tropical cyclone advisories and tsunami bulletins when applicable There are no user fees associated with receiving SafetyNET broadcasts.

Iridium SafetyCast

In 2020, Iridium emerged as another satellite-based GMDSS service provider via SafteyCast. Some countries have begun broadcasting their products operationally, and the U.S. plans to begin in 2023. When it does, the NWS will broadcast the same products via Iridium as are currently available via INMARSAT. Iridium uses polar-orbiting satellites, allowing global coverage, including the high latitudes not covered by INMARSAT. Iridium offers a single terminal that can be used for all 3 GMDSS services (Distress Alert, Safety Voice, and Maritime Safety Information). The Iridium website claims significant cost benefits over similarly capable INMARSAT equipment. As with INMARSAT-C SafetyNET, global High Seas forecasts, tropical cyclone advisories, and tsunami bulletins will be transmitted. After installation, there are no user fees associated with receiving SafetyCast broadcasts.

NAVTEX

NAVTEX is a low-cost, simple, and automated means of receiving important marine information aboard ships within about 200 NM of the coast (**Figure 61**). As an element in the Global Maritime Distress & Safety System, it uses an internationally accepted medium frequency (518 kHz) direct-printing service to deliver navigational information and meteorological warnings/forecasts to ships. All NAVTEX stations in the United States are operated by the U.S. Coast Guard and provide offshore forecasts of weather conditions for the region where the transmitter is located. All mariners in U.S. waters should program their NAVTEX receivers to include subject indicator "E" to receive both warnings & routine weather forecasts via NAVTEX. This will decrease the possibility of missing crucial tropical weather information at sea. More information, including broadcast schedules, can be found at the following link: weather.gov/marine/navprod

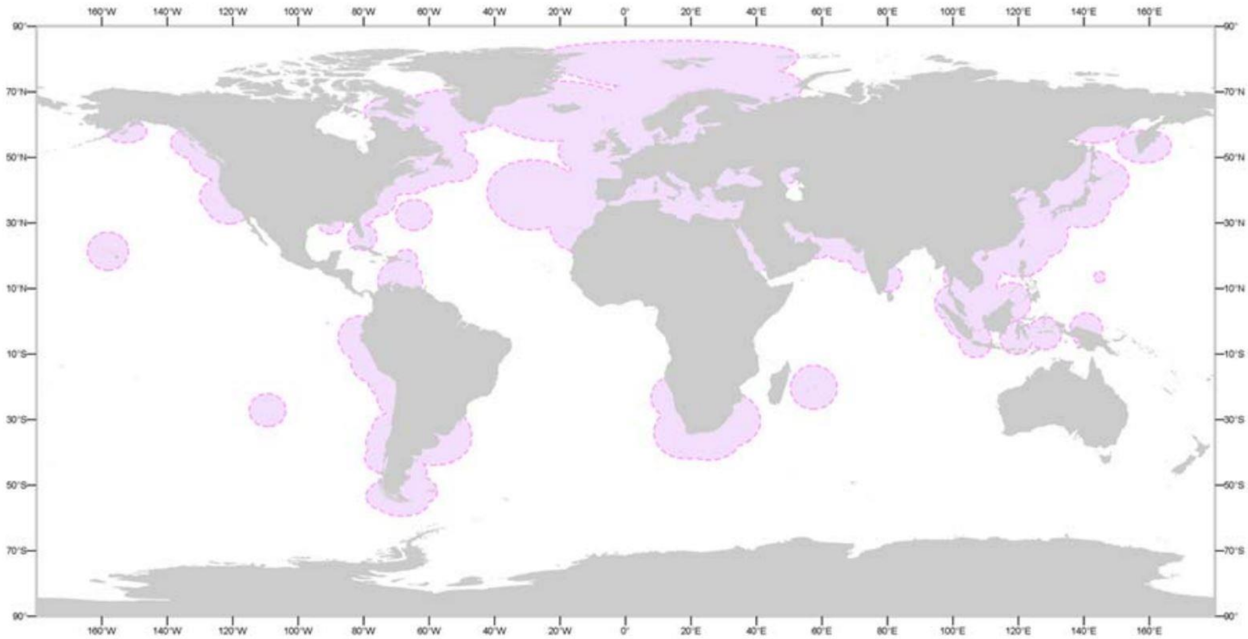


Figure 61: Worldwide NAVTEX Coverage.

U.S. Coast Guard VHF Voice

The Coast Guard VHF network provides nearly continuous coverage of all coastal areas of the United States to a range of approximately 20 NM from shore. Coastal water forecasts and storm warnings of interest to mariners are broadcast on VHF channel 22A (156.8 MHz VHF FM) after an initial announcement on VHF channel 16 (157.1 MHz VHF FM). In regions where NOAA weather radio broadcasts provide complete coverage of the USCG VHF network, the Coast Guard may only broadcast storm warnings rather than NWS marine weather information. Refer to the following link for a list of Coast Guard stations that transmit over VHF along with transmission times: weather.gov/marine/uscg_broadcasts

NOAA Weather Radio

Local and coastal marine forecasts & warnings are broadcast across the NOAA weather radio network. This network covers the coastal waters shown in **Figure 62**. Reception ranges of 25 NM from the coast are typical; however, coverage may vary depending on the vessel's location and transmitter. Most marine VHF radios can receive NOAA weather radio over the preset Wx channels or by tuning into the correct frequencies. While this is a convenient feature, it's prudent to have a dedicated NOAA Weather Radio receiver onboard to keep the marine VHF channels clear. Additionally, many NOAA weather radio receivers will emit a tone before giving information on severe weather, allowing the radio remain silent otherwise. Some receivers allow users to specify the event codes for which they wish to be notified. If the receiver contains this feature, the mariner should program their receiver for the event codes which apply to marine zones. See Emergency Alert System/NWR-SAME Event Codes and your receiver's operating manual for further information.

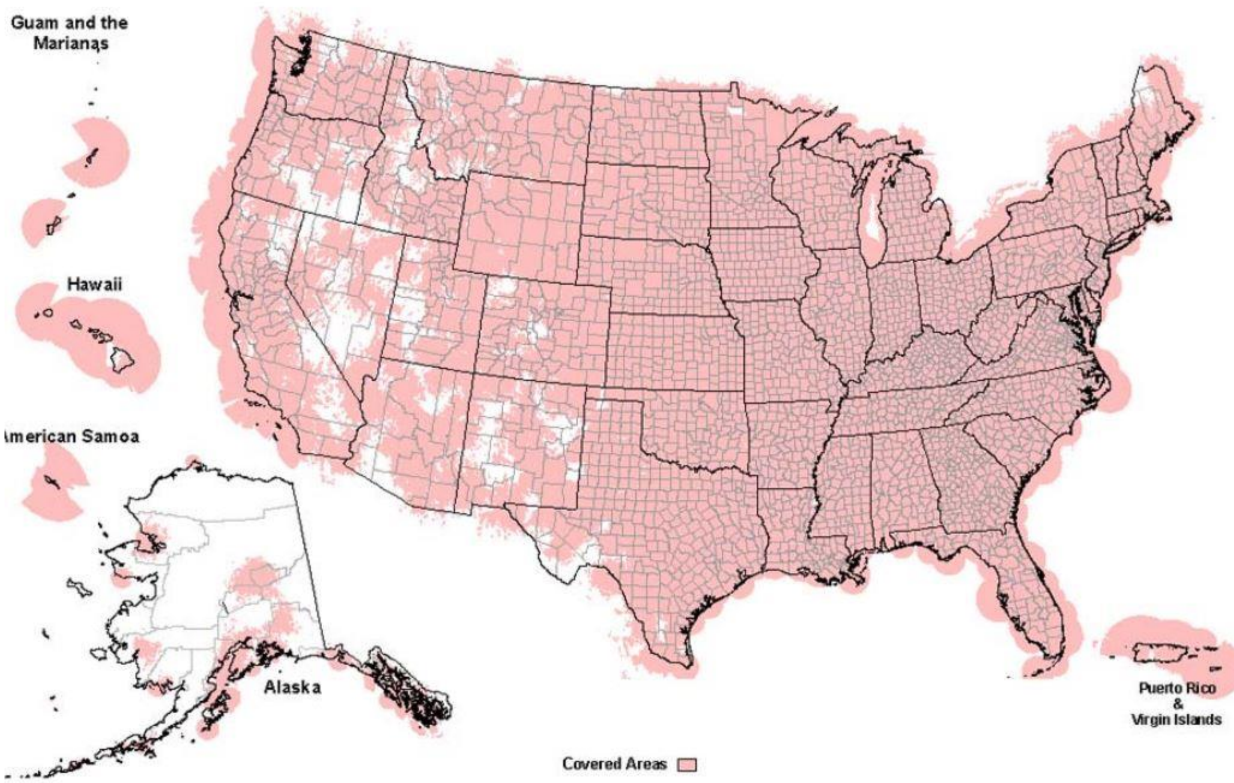


Figure 62: NOAA Weather Radio coverage.

Electronic Chart Display

As the marine community transitions from S-57 to S-100 hydrographic data for navigation, the opportunity exists to display weather information on an Electronic Chart Display and Information System (ECDIS). The Ocean Prediction Center is developing these products under the codes S-412 Weather and Wave Hazards, S-413 Weather and Wave Conditions, and S-414 Weather and Wave Observations. This will likely be available in the next few years.

Observations at Sea

While the modern mariner has access to many tools to alert of a tropical cyclone's presence, it is prudent to have a working knowledge of the self-reliant observational practices that have aided mariners for centuries. As mentioned earlier, tropical cyclones generally produce long-period swell that can propagate thousands of miles. In addition, the surface pressure decreases at an accelerating pace as the storm approaches. Finally, deep, persistent thunderstorm activity causes large amounts of high-level cirrus clouds to flow anticyclonically away from the system.

Using this information, we can briefly discuss four observations that may alert the mariner to an approaching tropical cyclone.

Figure 63: A U.S. Navy Aerographer's Mate recording a wind observation at sea.

Wind

In the absence of any other information, surface winds are usually the best guide to quickly determine the direction to the center of a tropical cyclone. The wind around a tropical cyclone flows cyclonically, or counter-clockwise in the northern hemisphere. If an observer puts the true wind direction on their back, the center of the cyclone will be to the left-hand side, bearing approximately 270 to 300 degrees relative to the direction they are facing.[13] This method is a good initial indication of the direction to the cyclone. In the southern hemisphere, tropical cyclones spin clockwise, and this effect is reversed.

Wave

Long-period swell is often the first indication of a tropical cyclone. The typical swell period in the Atlantic is 6-8 seconds. This period will roughly double when there is an active tropical cyclone in the region. Wave frequency may decrease to only four crests per minute several days before the arrival of a tropical cyclone. The swell's direction indicates where the tropical cyclone was

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[13] Buys Ballot's Law: In the Northern Hemisphere, if an observer stands with their back to the wind, the atmospheric pressure is low to the left, high to the right.

when the swell was generated. This method is less reliable in shoaling water as the direction of the swell is often altered by refraction.

Clouds

With a system 500-1000 NM away from a vessel, skies may appear relatively clear, and any low cumulus clouds will have a very shallow vertical extent. As the cyclone and the ship close to about 300-600 NM, high-level cirrus clouds will appear as a thin, wispy veil spreading away from the direction of the tropical system. If the separation between the tropical cyclone and the vessel continues to decrease, the cirrus will thicken and lower somewhat, taking on the layered appearance of a cirrostratus deck of clouds. Closer to the storm, layered altostratus clouds will begin to appear in the middle levels of the atmosphere. Finally, rain showers and thick, heavy walls of cumulonimbus clouds begin to indicate the proximity of outer rain bands in the tropical cyclone. At this point, the system's center may still be as much as 200-400 NM from the ship.

Surface Pressure

The barometer typically begins to fall when the outer cirrus clouds approach. Initially, this is so gradual that it may be masked by the typical daily cycle of two pressure maxima and minima per day. As the storm gets closer, the pressure drop accelerates into a steady fall. Small rises and falls in the surface pressure can be noticed in shipboard barometers as a pumping action in the pressure reading. The restlessness of the barometer is related to the intense upward motions and strong wind gusts along with the measurably lower surface pressures near the rain bands. Central pressures associated with tropical cyclones are typically less than 1008 mb for tropical storms and can reach extremely low values below 900 mb in the strongest systems. Within 30 degrees of the equator, any barometer reading below 1010 mb during the tropical cyclone season should be regarded with some caution.

Sending Observations

Weather observations are normally taken on the synoptic hours (0000, 0600, 1200, 1800 UTC); however, it is requested that mariners send three hourly reports when operating within 300 NM of a tropical cyclone. This helps forecasters and weather models analyze the current state of the atmosphere, which is the critical first step in developing an accurate forecast. A complete weather observation includes time, location, true wind speed, true wind direction, air temperature, dew point temperature, seal level pressure, 3-hour pressure tendency, past weather, cloud cover, sea surface temperature, sea period, sea height, primary swell period, direction and height, secondary swell period, direction and height, ice accretion and wet bulb temperature. Of these, the most important parameters are true wind speed, true wind direction, and sea level pressure. Wave information is also valuable, though more challenging to observe and report. These observations are crucial for the National Weather Service. Many large commercial vessels qualify for free observing instruments through the Voluntary Observing Ship Program (VOS). More information is available at the VOS website or through your Port Meteorological Officer (PMO). Smaller, recreational, or less active vessels may not qualify but are still encouraged to submit observations via the Marine Observation (MAROB) or Mariner Report (MAREP) programs. MAROBs are coded similarly to VOS reports and are automatically available for all NWS forecasters to view. However, due to a lack of verified instrument calibration, they may not get ingested into the weather models. MAREPs are much simpler plain text reports intended to aid coastal forecasters. These can often be reported via email, radio, or telephone, depending on the local Weather Forecast Office policy.

Chapter 4 – Tropical Cyclone Evasion

After obtaining and interpreting tropical cyclone advisories, mariners must know how to best respond to these forecasts. According to the NTSB report on the sinking of El Faro in 2015, the crew was well aware of Hurricane Juaquin, even discussing the latest media coverage on the bridge. The Captain, however, was unknowingly downloading old advisories from a private company and didn't realize the forecast was rapidly changing. He also sailed along an aggressive track with limited evasion options. The Captain refused pleas from his officers to change course and sailed directly into the hurricane, ultimately developing a heavy list and losing propulsion before the ship went down with all hands. So far, this guide has covered the basic tropical cyclone science, climatology, and monitoring options at sea. This final chapter will focus on applying these principles to ensure safe navigation.

Risk Analysis Checklist

During the tropical cyclone season, watchstanders should perform a routine risk analysis at sea and in port. This checklist serves as a situational awareness tool and should be performed regularly. The frequency depends on the threat. Checks should be performed daily during the season, increasing to every 6 hours when a system of interest is identified. Before beginning the checklist, mariners should identify their operational wind and sea height limitations, considering the vessel's current cargo and ballast.

Step 1 - Identify Storms of Interest

The first step is to take a basin-wide view of the current tropical cyclone activity. When operating in the U.S. NWS area of responsibility, this information is displayed on the NHC and CPHC homepage with more detail on developing systems in the Tropical Weather Outlooks for the Atlantic, East Pacific, and Central Pacific basins. Outside these areas, refer to the Joint Typhoon Warning Center homepage and their Significant Tropical Weather Advisories.

The key is identifying developing disturbances or active systems that may move near the ship's position or intended track. A forecast track may not be available if the disturbance has yet to develop into a tropical cyclone. In this case, keep climatology in mind (see **Chapter 2** and publications such as *Coast Pilots*, *Sailing Directions*, etc.) while making this assessment and upgrade from daily to 6-hourly checklist updates when appropriate. For example, if any active tropical cyclones are expected to pass within 1,000 nautical miles of the ship's track, upgrade to 6-hourly updates and proceed to step two.

Step 2 - Retrieve the Tropical Cyclone Advisory

After identifying a system of interest, determine its current location, intensity, and size from the NHC/CPHC/JTWC forecast advisory. These centers all report location in coordinates to the nearest 1/10th degree and intensity as the maximum sustained wind speed in increments of 5 kts. Size is given as 34, 50, and 64-kt wind radii quadrants, as well as the maximum radius of 12-ft (3.7-m) seas. These products also include forecast information out to 5 days. However, the 12-ft (3.7-m) sea radii are only included for the current time. These products are available through several means identified in **Chapter 3**.

Step 3 - Calculate Closest Point of Approach

After plotting the tropical cyclone track, determine the Closest Point of Approach (CPA) using a maneuvering board or similar method.[14] The CPA should generally fall outside the NWS tropical cyclone danger area or JTWC ship avoidance area. Repeat this process every 6 hours when the forecast update becomes available or whenever the ship's track changes. The CPA trend is an important statistic to monitor.

Step 4 - Factor Size and Uncertainty

The CPA only accounts for the storm's center, and impacts often extend hundreds of miles. To account for size, determine which quadrant(s) the ship will pass through. Then refer to the advisory text to find the largest 34-kt wind speed radius from the applicable quadrant(s) at or near CPA time. Subtract this radius from the CPA identified in step 4 to determine the CPA to 34-kt winds.

In addition to size, the forecast uncertainty must be accounted for. Track errors grow in time. A 120-hour CPA is less reliable than a 12-hour CPA. To account for uncertainty, refer to the NHC/CPHC Cone of Uncertainty, Wind Speed Probabilities, and Tropical Cyclone Danger Graphic, or JTWC's shaded area of potential tropical storm force winds. **The most important practice is to always refer to the latest forecast and remain flexible as it changes.**

Step 5 - Adjust Course

If the CPA is within the area of potential 34-kt winds, is uncomfortably close to this area, or has a decreasing trend, a course adjustment may be necessary. Ideally, this will be performed early while leaving multiple courses of action available should the forecast change significantly. If currently underway, refer to this chapter's **Evasion at Sea** section for the best practices. If in port, refer to the **Port Decisions** section to determine if evasion at sea is preferable.

Step 6 - Repeat Steps 1-5

Repeat this process every 6 hours as the latest forecast becomes available. Be sure to start at step one to identify any new threats in the outlook.

Evasion at Sea

Evading a tropical cyclone at sea is highly situationally dependent and will always rely on a mariner's best judgment. The following guidelines are offered as a framework to help this process. Mariners should remain prepared for any unexpected evasion by carrying extra fuel during the tropical cyclone season. In certain situations, evasions can add over 1000 NM and several days to a transit.

Avoiding the Dangerous Semicircle

As mentioned in **Chapter 1**, the right semicircle of a tropical cyclone is more dangerous in the Northern Hemisphere. Reasons for this include:

[14] The appendix provides an example of this calculation from the U.S. Merchant Marine Academy.

- higher wind-speed
- dynamic wave-growth fetch area
- more storm surge
- higher tornado threat at landfall

The right-front quadrant is particularly dangerous to the mariner as the wind direction tends to push a vessel towards the future track of the tropical cyclone center. Therefore, the right-front quadrant must be respected and requires a larger CPA. On the other hand, the left side of a tropical cyclone is generally more forgiving and is known as the navigable semicircle. In the Southern Hemisphere, this is reversed, with the left-front quadrant being the most dangerous and the right semicircle being more navigable.

Don't Cross the T

"Crossing the T" refers to crossing in front of a tropical cyclone's track. This practice is not advised as any engineering casualty or reduction in speed due to the conditions will leave a hindered vessel in the worst possible location, directly in the path of a tropical cyclone. It is far safer to navigate around and behind a tropical cyclone, as conditions will generally improve regardless of the vessel's course or speed.

The Outdated 1-2-3 Rule

For decades, the 1-2-3 rule was the gold standard for mariners to account for tropical cyclone forecast errors. First, a mariner would identify the position and maximum 34-kt wind speed radii from the forecast advisory at 24, 48, and 72 hours. Then, to account for the growing uncertainty, the mariner would add 100, 200, and 300 NM to the 24, 48, and 72-hour maximum wind speed radii, respectively. The area traced around these circles was to be avoided.

While the long-trusted 1-2-3 rule remains an effective tropical cyclone evasion tool, it is overly simplistic and unnecessarily conservative for today's more accurate tropical cyclone forecast era. For example, it assumes an average 72-hour forecast error of 300 NM. The average error at this lead time has been below 300 NM since the 1990s and is now well under 100 NM. Significant advances in tropical cyclone forecast skill, combined with the advent of new probabilistic tools that account for the uncertainty in a more scientific way, have enabled mariners to take advantage of more efficient strategies, such as the 34-kt rule.

The 34-kt Rule

Put simply; the 34-kt rule states that mariners should avoid the area of potential tropical storm force winds. While an appropriate threshold depends on the vessel's sea-worthiness and the tropical cyclone's characteristics, 34 kts is the critical value applicable to most open-ocean ships. As the wind speed doubles, the force it generates increases approximately by a factor of four. When 34 kt is reached, sea state development begins rapidly deteriorating ship maneuverability, restricting evasion options when they are needed most. As a rough approximation, 34-kt winds from a tropical cyclone generally align with 12-ft (3.7-m) wind waves. Like the old 1-2-3 rule, today's best tools to identify the ship avoidance area account for storm size and forecast uncertainty.

When operating in the National Weather Service tropical cyclone area of responsibility (Atlantic, Northeast Pacific, and North Central Pacific), the 34-kt Wind Speed Probability graphic can be used as the ship avoidance area. Users should identify what probability they are comfortable with, depending on individual risk tolerances. For example, U.S. Navy Ship Routing Officers typically avoid the area with more than a 5% probability of tropical storm force winds, which serves as a reasonable threshold for most large ships. **Figure 64** provides an example of identifying the danger area based on this 5% threshold. Users with bandwidth restrictions can refer to the **Tropical Cyclone Danger Graphic**, available via radiofax and FTPMail.

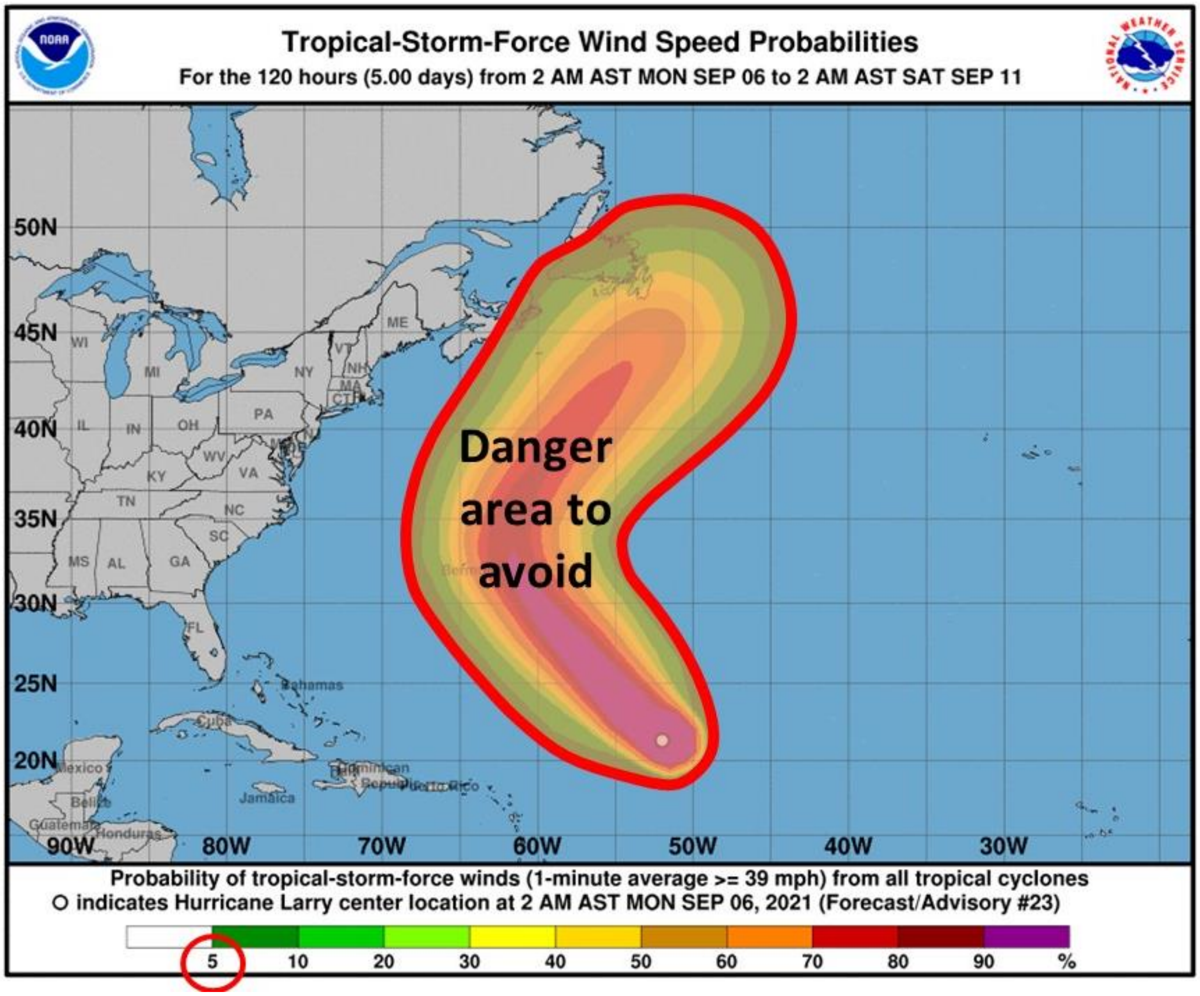

Figure 64: Using the Tropical-Storm-Force Wind Speed Probability graphic as a ship routing tool.

Outside of the NWS area of responsibility, the JTWC tropical cyclone warning graphic can be used instead. While no probabilistic information is displayed explicitly, the ship avoidance area does account for the average error in the particular basin and the storm's size.

Make Early Decisions

As with any ship routing decision, it is always easier to make a minor adjustment early than a large adjustment late. This is particularly true with tropical cyclones, as conditions degrade maneuverability as the system approaches. Port closures may also restrict sheltering options. The best way to stay abreast of the long-term conditions is to investigate any developing disturbances in addition to the active advisories.

Adjust Plans as Needed

Be flexible. Despite advances, tropical cyclone forecasting remains challenging. All plans should include a backup option, as the forecast may change significantly. Mariners should avoid navigating into areas with no escape. Most importantly, decisions must be based on the latest forecast and adapted as needed.

Port Decisions - Seek Shelter or Leave?

Ships in port can leave before receiving damage from a landfalling tropical cyclone. While this offers a distinct advantage over vulnerable coastal infrastructure, the decision should be taken seriously, as evading a tropical cyclone at sea can be challenging.

Determine Sortie Thresholds

The U.S. Navy refers to the action of leaving a vulnerable port to evade a tropical cyclone at sea as a "sortie." Before deciding to sortie, the mariner should have certain go/no-go thresholds in mind. The most important variable is wind speed, but a high storm surge can also trigger a sortie. A good starting point is 50-kt sustained wind or 4-ft (1.2-m) storm surge. These thresholds will vary with the size of the vessel, the quality of the heavy weather mooring, and the natural protection offered by the port. Mariners are encouraged to refer to the hurricane and typhoon haven handbooks (links on **page 2**)—these identify which ports provide adequate protection from tropical cyclones. While not every port has been studied, they provide a framework to analyze the protection offered by any port.

U.S. Coast Guard Port Conditions

Leaving port may not always be a voluntary decision. The U.S. Coast Guard has the authority to close the port and order vessels to leave ahead of a tropical cyclone. The typical threshold for this action is forecasted sustained tropical storm force winds onshore (at least 34 kts). **Table 8** outlines the different port conditions set by the USCG Captain of the Port with the general lead time and required actions. The port will typically reopen after the storm has passed and a damage assessment is conducted.

Port Condition	34-kt Wind Lead Time	Actions
Whisky	72 hours	Make all preparations to get underway. Set navigation and radio watch. Vessels unable to put to sea must notify the USCG Captain of the Port (COTP).
X-Ray	48 hours	All vessels should prepare to complete cargo operations and depart port in 24 hours, or when Port Condition Yankee is set. Vessels and barges unable to depart must contact the COTP.
Yankee	24 hours	Port is closed to incoming traffic without specific approval of the Captain of the Port. All Cargo operations should be secured. All vessels are encouraged to put to sea.
Zulu	12 hours	Port is closed. No terminal, facility, or vessel operations are permitted.

Table 8: USCG port closure timeline.

Cost/Loss Analysis

The cost/loss analysis provides a framework to make decisions based on probabilities. It is a good first step in determining whether to remain in port or evade at sea. To perform the cost/loss analysis:

1. Determine the cost to sortie (prepare)
2. Estimate how much damage may be caused if destructive winds hit the vessel in port (potential loss)
3. Divide the cost to prepare by the potential loss to determine the cost/loss ratio

Once the cost/loss ratio is determined, an optimal decision can be made based on the wind speed probabilities. A ship should sortie if the probability of destructive winds (typically 50 kts) exceeds the cost/loss ratio, assuming there is adequate time to do so safely. Otherwise, the ship should stay in port. While this method does not guarantee safety from destructive winds or eliminate unnecessary sorties, it mathematically minimizes the financial impact of both.

As an example, imagine a container ship in New Orleans. The Captain has estimated that 50-kt winds will cause approximately $500,000 in damage to their ship. Getting underway to evade at sea will cost $100,000 in food, fuel, and wages.

Cost to prepare / potential loss if unprepared = cost/loss ratio

$100,000 / $500,000 = 20%

In this case, the cost/loss ratio is 20%. Therefore, it makes sense to sortie whenever the probability of receiving damaging impacts exceeds this value. The Captain checks the cumulative wind speed probabilities from the National Hurricane Center and sees that New Orleans has a 30% chance of receiving 50-kt winds. Theoretically, this ship should get underway as the probability of 50-kt winds exceeds the cost/loss ratio. The cost to leave is worth avoiding the potential loss.

There are other factors to consider, however. This ship is in New Orleans, and there may not be time to get out of the Gulf of Mexico before the storm blocks the only two exit options. Sheltering in the SW or NE corner is risky because there are no options if the track changes. Heavy weather mooring mitigation options, such as doubling up the lines, should be considered if getting underway is ruled out.

Identify Timeline

The decision to get underway should be made early. In some cases, it must be made before the 5-day forecast track even reaches the port. The problem is the great distance needed to get clear of the storm, with the approach of rough seas typically being the driving factor. Additionally, the storm track may drift away from land after the sortie decision is made, essentially chasing the vessel. A good evasion is made early enough to outrun any reasonable possibility.

Develop a Sortie Plan

The best sortie plan is often simply to pull into another port with better protection or farther from the expected impacts. Sheltering in port should only be considered if there is availability on the pier, as anchoring in tropical cyclone conditions is unsafe. An open ocean sortie can be a viable backup plan. The most common version is to get out well ahead of the storm (to avoid "crossing the T"), linger in an operating area while waiting for the storm to pass, and follow the abating seas back into port. This operation takes about 5-7 days and may cover over 1000 NM. It should only be attempted by the most weather-savvy mariners, ideally with the assistance of a Ship Routing Officer. **Figure 65** provides two examples of planned sortie routes.

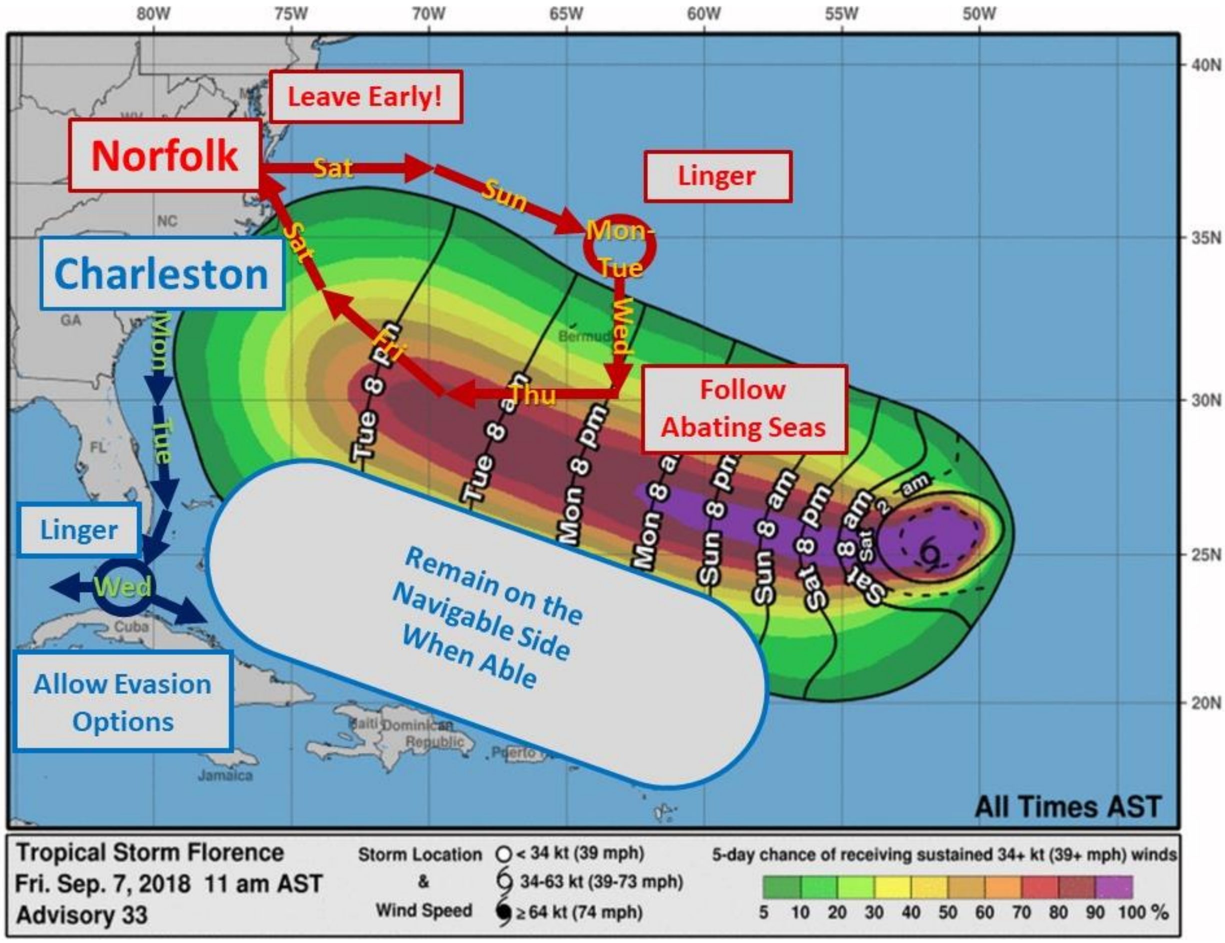

Figure 65: Example Sortie tracks from Norfolk, VA (red) and Charleston, SC (blue) based on the Probability/Arrival Time of Tropical Storm Force Wind graphic with guidelines to follow. At this time, Florence was expected to make landfall early Friday somewhere in the Carolinas as a major hurricane.

Emergency Actions when Caught at Sea

This final section is written with the hope it will not be needed. If avoidance fails, or a mariner is caught unaware by a tropical cyclone, there are some best practices to clear the worst impacts.

Find the Tropical Cyclone Center

The first step is to determine where the center of the storm is. This can be accomplished by plotting the vessel's location against the latest advisory position. In addition to the full 6-hourly advisories, position updates are available every 3 hours when there are active coastal watches and warnings. If the advisory is unavailable, the storm center can be surmised based on wind direction. In the northern hemisphere, low pressure will be on the observer's left when the wind is at their back (and on their right in the southern hemisphere).

Determine Storm Motion and Vessel Quadrant

The barometer will fall as the center approaches and rise as it departs. At a given location in the northern hemisphere, winds will veer (shift in a clockwise direction over time) in the dangerous semicircle and back (shift counterclockwise) in the navigable semicircle. The opposite is true in the southern hemisphere. If the wind direction stays constant, the storm has either stalled or the vessel is directly ahead or behind the storm, with the barometer trend differentiating between the two. Refer to **Table 9** and **Table 11** for more detail on making this determination in the northern and southern hemisphere, respectively. Note that vessel motion will need to be accounted for to determine changes in the true wind direction.

Emergency Navigation Actions

Once a mariner has determined their quadrant, they can take the appropriate evasive actions. The goal in all scenarios is to increase the CPA to the storm center as quickly as possible. **Table 10** and **Table 12** list the recommended navigation actions for different storm-relative vessel locations, while **Figure 66** and **Figure 67** provide a visual depiction in the northern and southern hemisphere, respectively.

If conditions make it necessary to heave to, vessels should heave into head seas in the dangerous semicircle and with following seas in the navigable semicircle. This will provide the best chance to maintain or increase the CPA to the storm center. If desired, mariners may also seek following seas when behind the storm but should never put wind waves on the stern or quarter in the forward quadrant of the dangerous side as this will steer the vessel toward the storm's center.

In general, sailing vessels are more concerned with wind than seas and should heave to on a tack that allows the shifting wind to draw aft. In the northern hemisphere, this would be a starboard tack in the dangerous semicircle and a port tack in the navigable semicircle.

If winds reach hurricane force and seas become confused, some mariners have reported achieving the best ride by turning the engines off and letting the vessel ride the storm instead of fight it. This should be a last resort, only after all other methods have failed.

Identify Quadrant (Northern Hemisphere)			
Wind Shift	**Barometer Trend**	**Vessel Location**	**Code**
Veering Clockwise	Falling	Dangerous semicircle, ahead of T.C.	**RF**
	Rising	Dangerous semicircle, behind T.C.	**RR**
Backing Counterclockwise	Falling	Navigable semicircle, ahead of T.C.	**LF**
	Rising	Navigable semicircle, behind T.C.	**LR**
Steady	Falling	Directly ahead of T.C.	**A**
	Rising	Directly behind T.C.	**B**

Table 9: Determine vessel quadrant in the Northern Hemisphere.

Navigation Actions (Northern Hemisphere)		
Vessel Location	**Code**	**Navigation Action**
Directly ahead of T.C.	**A**	Put the wind at 160º relative on the starboard quarter making best speed into the navigable semi-circle.
Ahead of T.C. Dangerous Semicircle	**RF**	Put the wind at 045º relative on the starboard bow and make best course and speed as the conditions allow.
Ahead of T.C. Navigable Semicircle	**LF**	Put the wind at 135º relative on the starboard quarter making best speed to increase distance to the tropical cyclone.
Behind T.C.	**RR** **LR** **B**	Keep the wind somewhere along the starboard side and adjust course and speed as needed to achieve best ride. Conditions should improve regardless of ship's speed.

Table 10: Emergency navigation actions in the Northern Hemisphere.

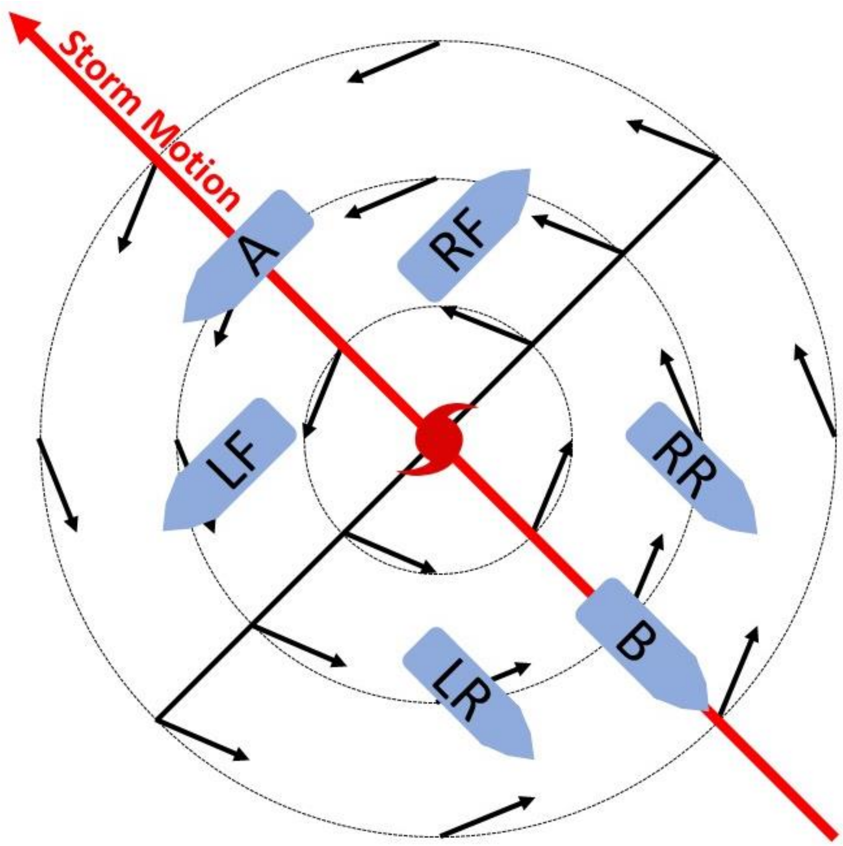

Figure 66: Northern hemisphere emergency navigation.

Identify Quadrant (Southern Hemisphere)			
Wind Shift	**Barometer Trend**	**Vessel Location**	**Code**
Veering Clockwise	Falling	Navigable semicircle, ahead of T.C.	**RF**
	Rising	Navigable semicircle, behind T.C.	**RR**
Backing Counterclockwise	Falling	Dangerous semicircle, ahead of T.C.	**LF**
	Rising	Dangerous semicircle, behind T.C.	**LR**
Steady	Falling	Directly ahead of T.C.	**A**
	Rising	Directly behind T.C.	**B**

Table 11: Determine vessel quadrant in the Southern Hemisphere.

Navigation Actions (Southern Hemisphere)		
Vessel Location	**Code**	**Navigation Action**
Directly ahead of T.C.	**A**	Put the wind at 200º relative on the port quarter making best speed into the navigable semi-circle.
Ahead of T.C. Dangerous Semicircle	**LF**	Put the wind at 315º relative on the port bow and make best course and speed as the conditions allow.
Ahead of T.C. Navigable Semicircle	**RF**	Put the wind at 225º relative on the port quarter making best speed to increase distance to the tropical cyclone.
Behind T.C.	**RR LR B**	Keep the wind somewhere along the port side and adjust course and speed as needed to achieve best ride. Conditions should improve regardless of ship's speed.

Table 12: Emergency navigation actions in the Southern Hemisphere.

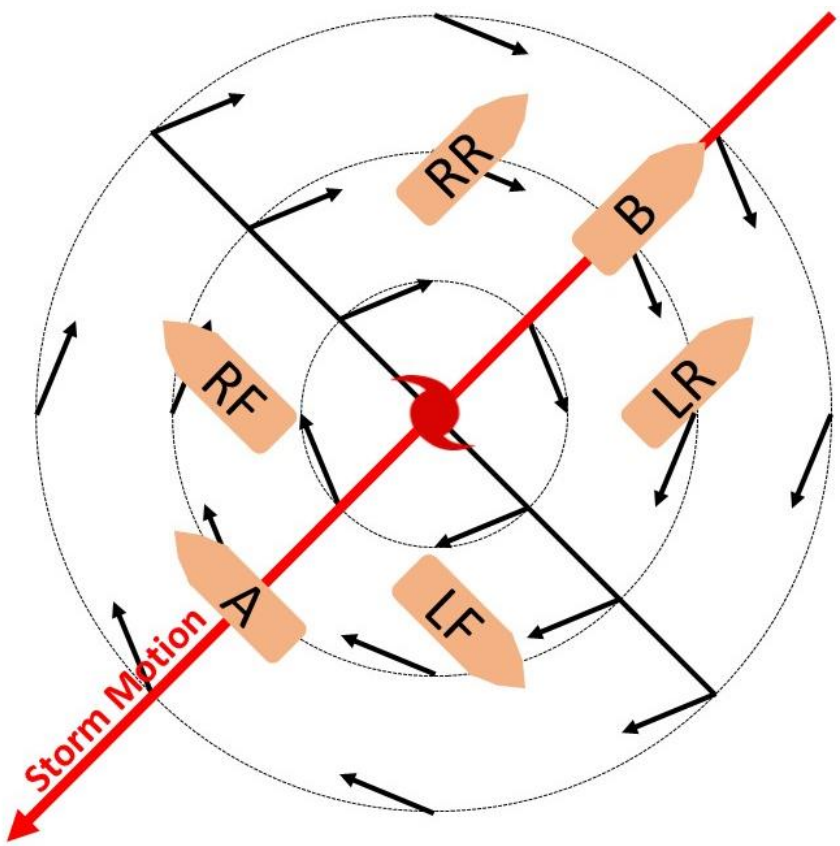

Figure 67: Southern hemisphere emergency navigation.

Summary and Acknowledgments

Christopher Columbus had two previous tropical cyclone encounters when he embarked on his fourth and final voyage to the New World in 1502. This time, Columbus noted the “oily swell,” “oppressive feeling in the air,” “veiled cirrus creating magnificent crimson sunsets,” “twinges in his rheumatic joints,” and “a large number of seals and dolphins on the surface of the ocean.” These signs caused him to send the first documented hurricane warning to Don Nicolas de Ovando, the newly appointed Governor of Hispaniola. Ovando scorned the warning, calling Columbus “a prophet and soothsayer” before sending a fleet of 30 ships back to Spain. Only one ship would complete the journey, while 20 were lost with over 500 sailors in a fierce hurricane. Meanwhile, Columbus’ squadron sought protected waters south of the island and emerged unscathed as the storm cleared.

Our understanding of tropical cyclones has advanced tremendously since the days of Columbus. Yet, while forecasts and warnings are more accurate and accessible than ever, these storms continue to pose a great threat to mariners. Vessels and lives are lost at sea every year in tropical cyclone mishaps around the world. Many of these tragedies could have been avoided with a better understanding of tropical cyclone dynamics, the degree of forecast uncertainty, and the inherent risk involved when sharing the sea with these tempests. The purpose of this manual is simply to help mariners better understand and avoid tropical cyclones. It will remain freely available in pursuit of this goal.

I would like to acknowledge those that helped me complete this project. First and foremost, **Eric Holweg**, whose original manual, *Mariner’s Guide to Hurricane Awareness in the North Atlantic Basin,* served as an inspiration and my primary reference material. Thanks also to **Eric Christensen**, a Lead Marine Forecaster at NHC, who encouraged me to tackle this project and make it my own. I would also like to thank the reviewers of this text; whose vast experience make them among the greatest minds in the field and helped shape this guide tremendously.

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Owen Shieh, Ph.D. Training Department Head, Joint Typhoon Warning Center
Brian Strahl Director, Joint Typhoon Warning Center
Captain Timothy Tisch, Ph.D. Master Mariner, U.S. Merchant Marine Academy

Finally, as Mr. Holweg did 22 years ago, I would like to thank **Patrick Dixon** who taught me everything I know about ship routing during my time in the Navy. He was an incredible mentor to the thousands of Sailors that passed through Fleet Weather Center Norfolk over the last 3 decades. Mr. Dixon passed away last year and this manual is dedicated to his memory.

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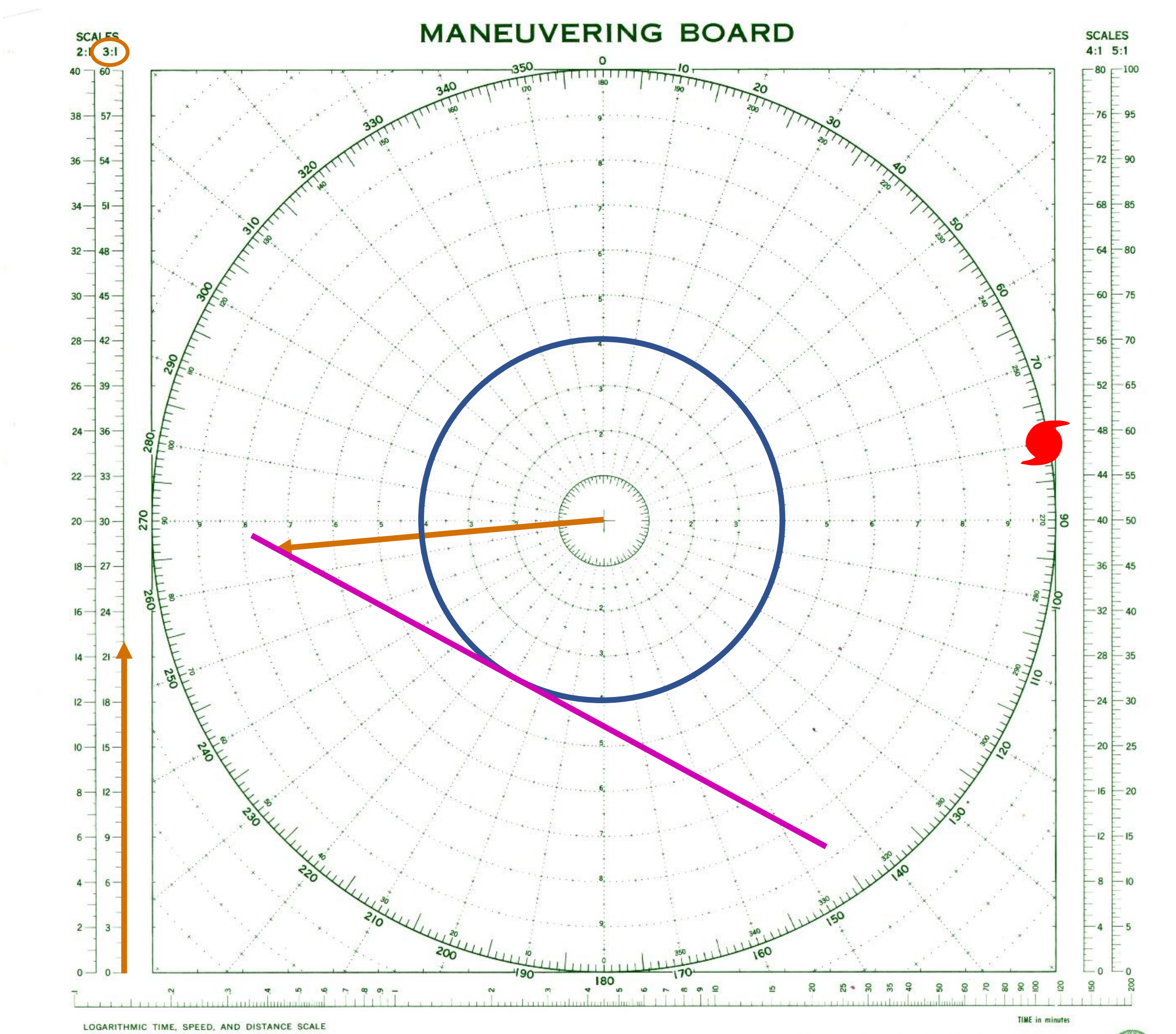
Appendix

Maximize Tropical Cyclone CPA Using a Maneuvering Board

The center of a hurricane bears 080ºT, 100 NM from your position. The NHC advisory indicates the hurricane is moving towards 265ºT at 22 knots. Your maximum speed is 12 knots. What course should you steer to have the maximum CPA and what could it be?

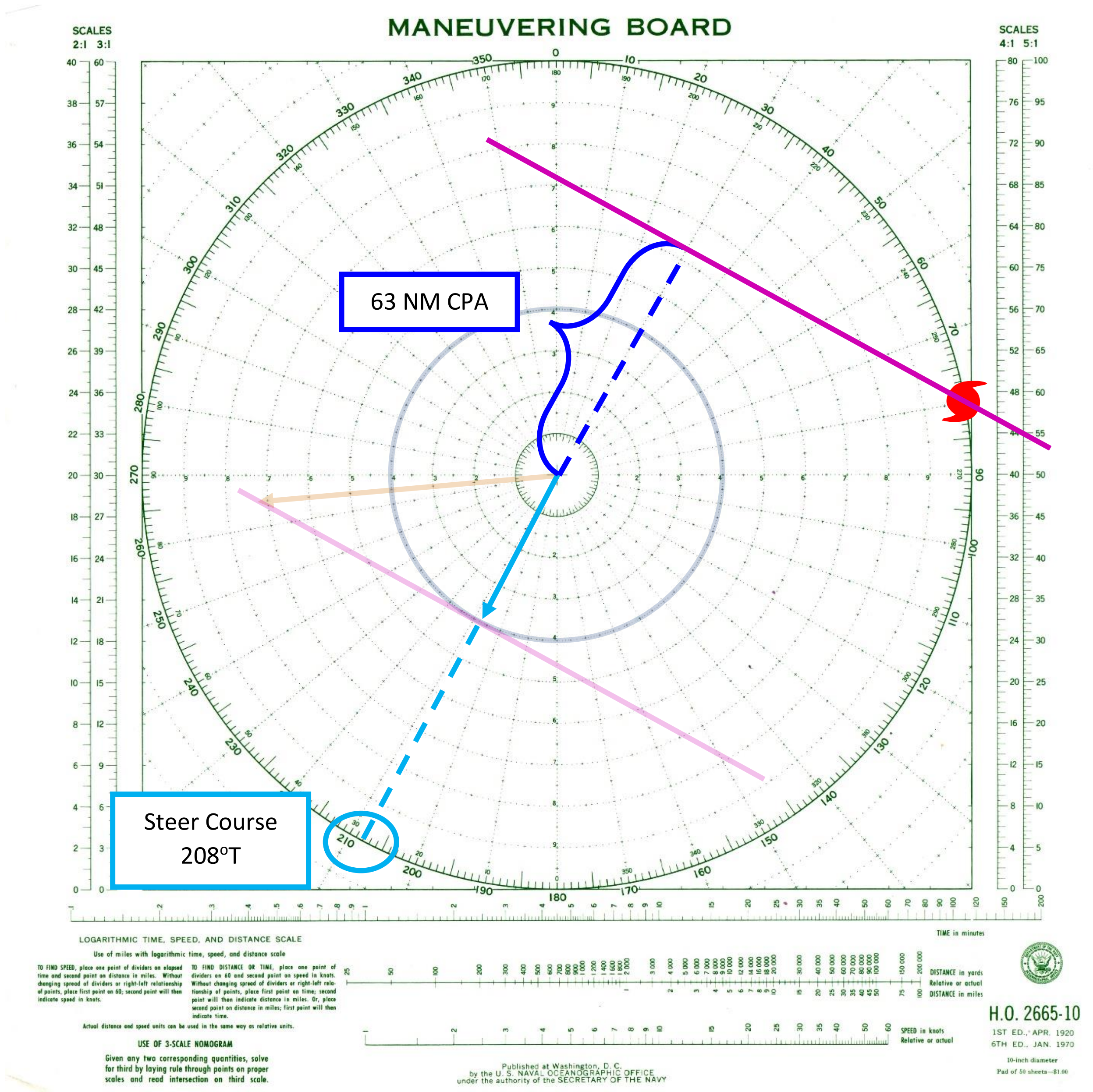


Step One: Using the 10:1 distance scale, plot the hurricane at 100 NM bearing 080ºT.

Step Two: Using the 3:1 speed scale, plot the hurricane's vector from the center towards 265ºT @ 22 knots.

Step Three: Using the 3:1 speed scale, plot the 12-knot speed ring.

Step Four: Determine the desired path of relative motion by drawing a line from the end of the storm vector tangent to the 12-knot speed ring



Step Five: Determine the course to steer by connecting the center of the maneuvering board to the point of tangency.

Step Six: Transfer the storm's relative motion line up to the storm. In other words, draw a parallel pink line that intersects the storm.

Step Seven: The CPA is then the minimum distance to the center using the 10:1 scale

Answer: Steer course 208°T to achieve a maximum CPA of 63 NM.