# Guide to the Science of Climate Change in the 21$^{st}$ Century

## Chapter 10
## Hurricanes, Typhoons and Cyclones

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2020

Eco-print, “Iota”, Nora Manz 2020

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# 10.0 Hurricanes, Typhoons and Cyclones

10.1 Introduction

Hurricanes, typhoons and cyclones are known as tropical cyclones which may also be called tropical storms, tropical depressions and cyclonic storms. Their dynamics are the same.

Tropical cyclones are of particular interest because of their role in transferring heat energy from ocean water near the equator to northern latitudes, the nature of the dynamic relationship between ocean characteristics (sea surface temperature in particular) and the atmosphere, and most significant, their destructive potential.

The World Meteorological Organization defines tropical cyclones as follows:
A tropical cyclone is a rapidly rotating storm originating over tropical oceans from where it draws the energy to develop. It has a low-pressure centre and clouds spiraling towards the eyewall surrounding the "eye", the central part of the system where the weather is normally calm and free of clouds. Its diameter is typically around 200 to 500 km, but can reach 1000 km. A tropical cyclone brings very violent winds, torrential rain, high waves and, in some cases, very destructive storm surges and coastal flooding. The winds blow counter clockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. Tropical cyclones above a certain strength are given names in the interests of public safety. The classification of tropical cyclones is shown in Table 10.1. The Saffir-Simpson hurricane wind scale, used to categorize hurricanes, is shown in greater detail in Table 10.2. The size description of tropical cyclones is shown in Table 10.3.

These scales do not take into account other potentially deadly hazards such as storm surge, rainfall flooding, and tornadoes.

| Tropical Cyclone Classifications | | | | | | | | | [hide] |
|---|---|---|---|---|---|---|---|---|---|
| Beaufort scale | 1-minute sustained winds (NHC/CPHC/JTWC) | 10-minute sustained winds (WMO/JMA/MF/BOM/FMS) | NE Pacific & N Atlantic NHC/CPHC[41] | NW Pacific JTWC | NW Pacific JMA | N Indian Ocean IMD[43] | SW Indian Ocean MF | Australia & S Pacific BOM/FMS[45] | |
| 0–7 | <32 knots (37 mph; 59 km/h) | <28 knots (32 mph; 52 km/h) | Tropical Depression | Tropical Depression | Tropical Depression | Depression | Zone of Disturbed Weather | Tropical Disturbance | |
| 7 | 33 knots (38 mph; 61 km/h) | 28–29 knots (32–33 mph; 52–54 km/h) | | | | Deep Depression | Tropical Disturbance | Tropical Depression | |
| 8-9 | 34–37 knots (39–43 mph; 63–69 km/h) | 30–33 knots (35–38 mph; 56–61 km/h) | Tropical Storm | Tropical Storm | | | Tropical Depression | Tropical Low | |
| 9–10 | 38–54 knots (44–62 mph; 70–100 km/h) | 34–47 knots (39–54 mph; 63–87 km/h) | | | Tropical Storm | Cyclonic Storm | Moderate Tropical Storm | Category 1 Tropical Cyclone | |
| 10-11 | 55–63 knots (63–72 mph; 102–117 km/h) | 48–55 knots (55–63 mph; 89–102 km/h) | | | Severe Tropical Storm | Severe Cyclonic Storm | Severe Tropical Storm | Category 2 Tropical Cyclone | |
| 12+ | 64–71 knots (74–82 mph; 119–131 km/h) | 56–63 knots (64–72 mph; 104–117 km/h) | Category 1 Hurricane | Typhoon | | | | | |
| | 72–82 knots (83–94 mph; 133–152 km/h) | 64–72 knots (74–83 mph; 119–133 km/h) | | | Typhoon | Very Severe Cyclonic Storm | Tropical Cyclone | Category 3 Severe Tropical Cyclone | |
| | 83–95 knots (96–109 mph; 154–176 km/h) | 73–83 knots (84–96 mph; 135–154 km/h) | Category 2 Hurricane | | | | | | |
| | 96.4–97 knots (110.9–111.6 mph; 178.5–179.6 km/h) | 84–85 knots (97–98 mph; 156–157 km/h) | Category 3 Major Hurricane | | Very Strong Typhoon | | | | |
| | 98–112 knots (113–129 mph; 181–207 km/h) | 86–98 knots (99–113 mph; 159–181 km/h) | | | | Extremely Severe Cyclonic Storm | Intense Tropical Cyclone | Category 4 Severe Tropical Cyclone | |
| | 113–122 knots (130–140 mph; 209–226 km/h) | 99–107 knots (114–123 mph; 183–198 km/h) | Category 4 Major Hurricane | | | | | | |
| | 123–129 knots (142–148 mph; 228–239 km/h) | 108–113 knots (124–130 mph; 200–209 km/h) | | | Violent Typhoon | | | Category 5 Severe Tropical Cyclone | |
| | 130–136 knots (150–157 mph; 241–252 km/h) | 114–119 knots (131–137 mph; 211–220 km/h) | | Super Typhoon | | Super Cyclonic Storm | Very Intense Tropical Cyclone | | |
| | >137 knots (158 mph; 254 km/h) | >120 knots (138 mph; 222 km/h) | Category 5 Major Hurricane | | | | | | |

Table 10.1 Classifications of tropical cyclones.

| Category | Sustained Winds | Types of Damage Due to Hurricane Winds |
|---|---|---|
| 1 | 74-95 mph<br>64-82 kt<br>119-153 km/h | **Very dangerous winds will produce some damage:** Well-constructed frame homes could have damage to roof, shingles, vinyl siding and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days. |
| 2 | 96-110 mph<br>83-95 kt<br>154-177 km/h | **Extremely dangerous winds will cause extensive damage:** Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks. |
| 3<br>(major) | 111-129 mph<br>96-112 kt<br>178-208 km/h | **Devastating damage will occur:** Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes. |
| 4<br>(major) | 130-156 mph<br>113-136 kt<br>209-251 km/h | **Catastrophic damage will occur:** Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months. |
| 5<br>(major) | 157 mph or higher<br>137 kt or higher<br>252 km/h or higher | **Catastrophic damage will occur:** A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months. |

Table 10.2 Classification of hurricanes https://www.nhc.noaa.gov/aboutsshws.php .

| Size descriptions of tropical cyclones | |
|---|---|
| **ROCI (Diameter)** | **Type** |
| Less than 2 degrees latitude | Very small/minor |
| 2 to 3 degrees of latitude | Small |
| 3 to 6 degrees of latitude | Medium/Average/Normal |
| 6 to 8 degrees of latitude | Large |
| Over 8 degrees of latitude | Very large[20] |

2 degrees latitude is 222 km.

Table 10.3 Size description of tropical cyclones.

## 10.2 Description of hurricanes and tropical cyclones

A hurricane is a tropical cyclone that occurs in the Atlantic Ocean and northeastern Pacific. A typhoon occurs in the northwestern Pacific Ocean. Tropical cyclones in the south Pacific and Indian Ocean are referred to as tropical cyclones or severe cyclonic storms. Figure 10.1 illustrates where the different tropical cyclones occur.

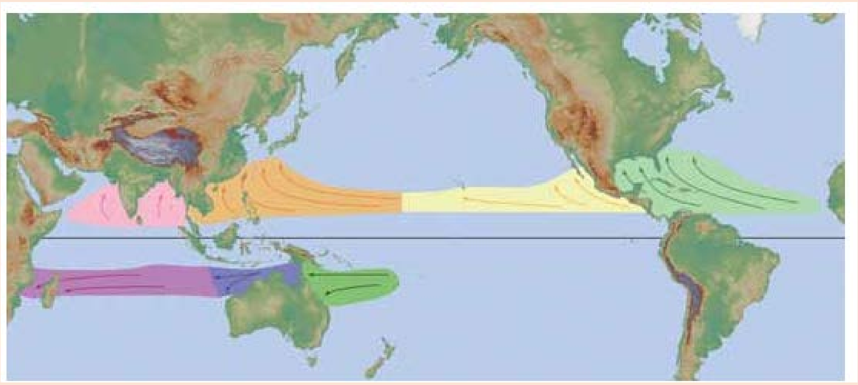


Figure 10.1 Regions of the world where tropical cyclones occur.

Tropical cyclones form between 5- and 20-degrees latitude, over warm ocean water, north and south of the equator (Minimum sea surface temperature is 26.5° C.). The warm layer of water must be fairly deep to contain enough energy to fuel a tropical cyclone and so that turbulence and mixing don't bring cold water up to the ocean surface.

The atmosphere must be unstable so that thunderstorms can develop (See Figure 10.2.). The thunderstorms coalesce to form a tropical depression that may strengthen to become a tropical cyclone as shown in Figure 10.3. Severe thunderstorms and tropical cyclones typically reach the tropopause.

The whole system of clouds and wind spins and grows, fed by the ocean's heat and water evaporating from the ocean surface. As the storm system rotates faster and faster, an eye forms in the centre. It is very calm and clear in the eye, with very low air pressure. Higher pressure air from above flows down into the eye.

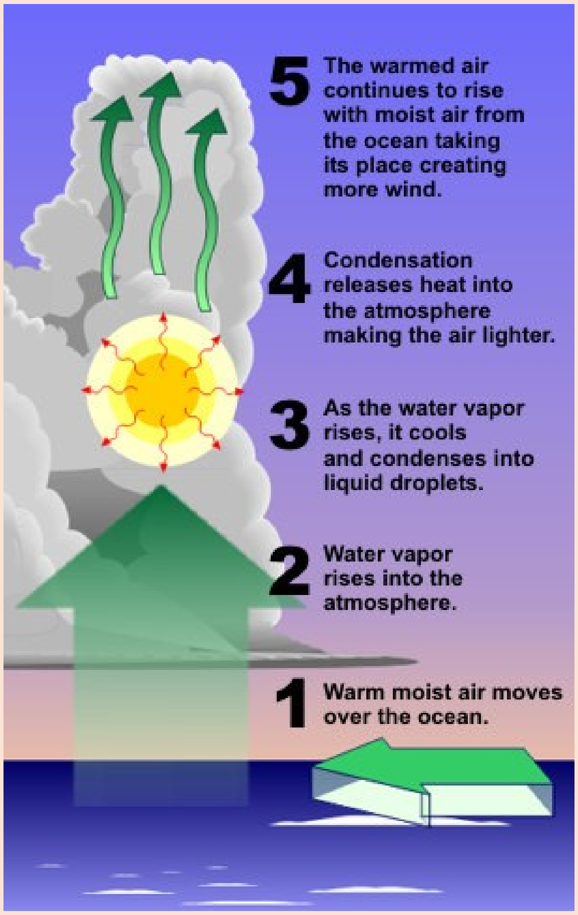
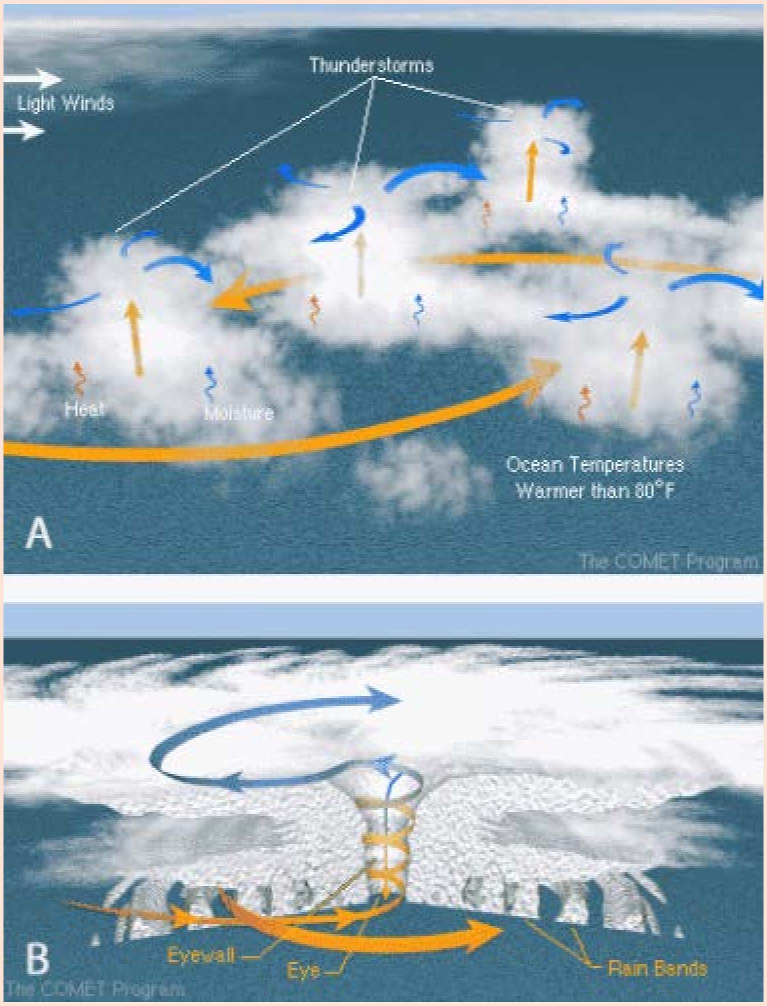



Figure 10.2 Formation of a thunderstorm over the ocean.




Thunderstorms forming over warm ocean water. These gradually coalesce to form a tropical depression and tropical storm (A).

A large tropical cyclone may form consisting of huge rotating rain bands with a center of clear skies called the eye which is surrounded by the fast winds of the eyewall (B).

Figure 10.3 Formation of a tropical cyclone.

Tropical cyclones will only form when there is very little or no vertical wind shear (changing wind direction or wind speed with altitude) as this would interfere and potentially prevent the upward flow of air. Tropical cyclones don't form at the equator because there is no Coriolis force there (the Coriolis force is what gives hurricanes their spin and it causes hurricanes to spin in opposite directions in the northern and southern hemispheres). Wind shear near the subtropical jet stream (approximately 30° latitude) inhibits formation of hurricanes. Sea surface temperature at higher latitudes is too low to support formation of hurricanes.

The strengthening or weakening of the tropical jet streams will decrease or increase tropical cyclone formation respectively.

When the winds in the rotating storm reach 39 mph (63 kmph), the storm is called a “tropical storm”. And when the wind speeds reach 74 mph (119 kmph), the storm is officially a “tropical cyclone”, hurricane or typhoon.

Another view of the anatomy of a tropical cyclone is shown is Figure 10.4.

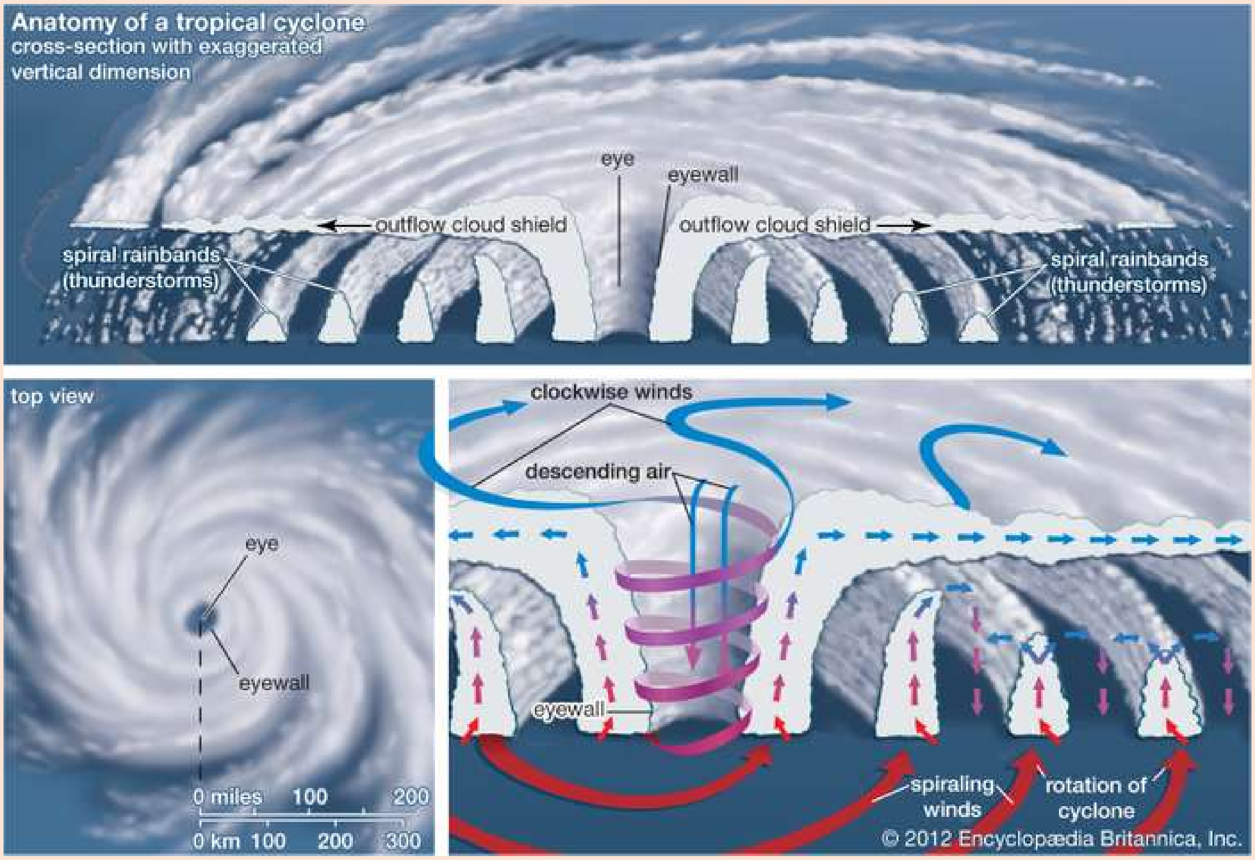



Figure 10.4 Anatomy of a tropical cyclone (northern hemisphere).

The most intense winds are in the eye wall. Bands of thunderstorms extend outward from the eye. Warm moist air rises in each band, similar to Figure 10.1, where it cools and produces rainfall. The cool air at the highest elevation flows outward to the edge of the cyclone and downward between the bands to replace the warm air moving inward and upward. The cool air is then warmed by the sea surface and fuels the thunderstorms. The rainfall intensity is greatest near the eyewall.

Tropical cyclones usually weaken when they hit land, because they are no longer being “fed” by the energy from the warm ocean waters. However, they often move far inland, producing considerable rain and causing significant wind damage before they die out completely.

Generally, the warmer the sea surface temperature (assuming similar impact of wind shear) the greater frequency of formation of tropical cyclones and increase in the probability of the formation of larger and more intense the tropical cyclones.

## 10.3 Monitoring tropical cyclones

The formation and characteristics of tropical cyclones is monitored using airplanes, satellites and drones. Cyclone formation can often be observed from where tropical depressions are formed to where cyclones are fully developed. Satellite images of hurricanes are shown in Figure 10.5.

The track that a tropical cyclone will follow is determined by monitoring the cyclone itself and using a variety of computer models, called spaghetti models, which also predict how the intensity will change. An example of the use of the track and spaghetti models are shown in Figures 10.7 and 10.8. The track predictions are updated and confirmed by actual observations such as shown in Figure 10.9.

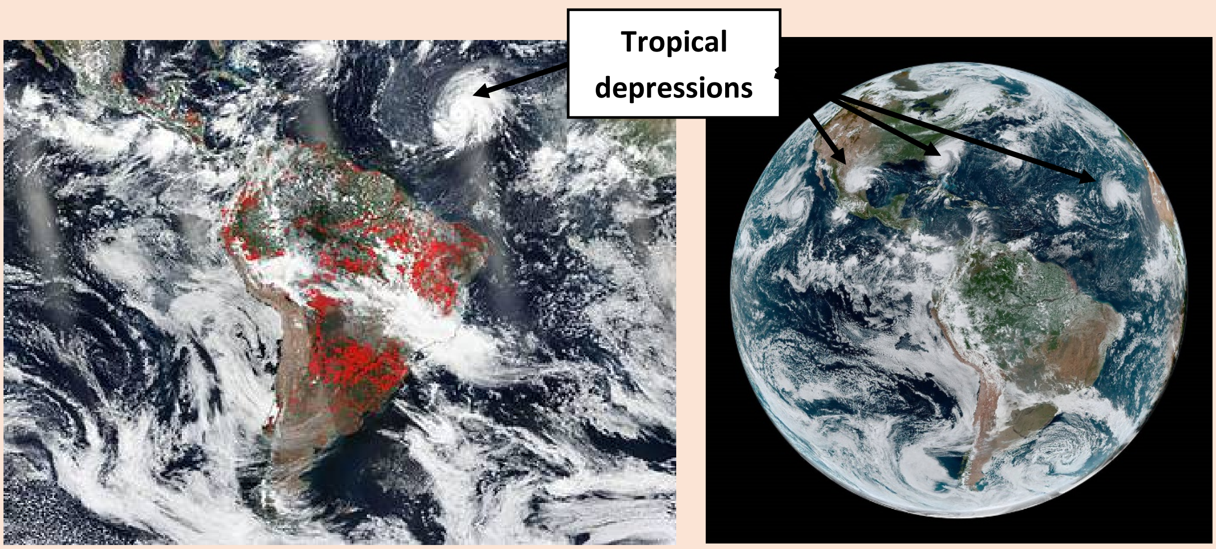



Figure 10.5 Satellite images of tropical depressions forming in the Atlantic off the coast of Africa and moving West.

Figure 10.6 Satellite images of a tropical hurricane in the Atlantic, northern hemisphere.

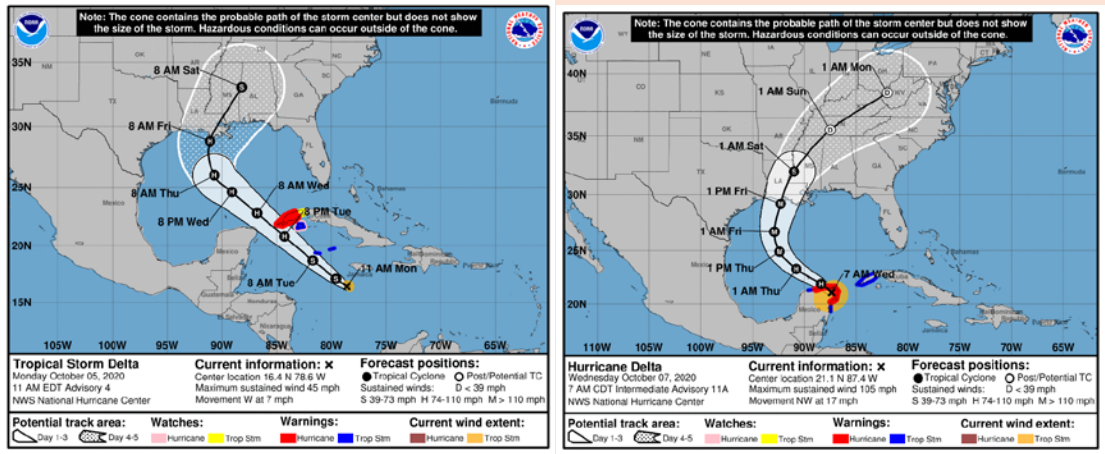



Figure 10.7 Forecast tracks for a tropical storm which becomes a hurricane.

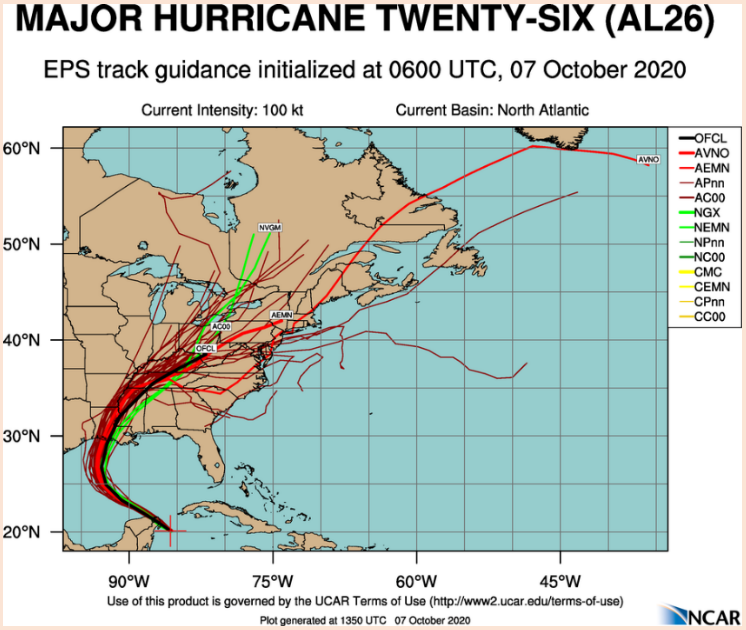



Figure 10.8 Spaghetti models on which the forecast tracks are based.

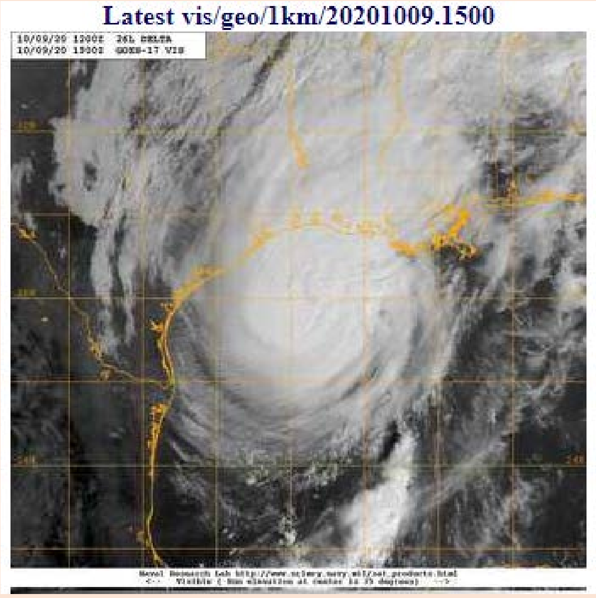



Figure 10.9 Satellite image of hurricane being tracked in Figures 10.7 and 10.8.

10.4 Effect of ENSO on tropical cyclones

The effect of the El Niño-Southern Oscillation, ENSO, (discussed in Chapter 11) on hurricanes can be quite significant as shown in Table 10.4.

The classifications used to describe the strength or intensity of tropical cyclones are shown in Table 10.3.  The terms used to describe the size of a tropical cyclone are shown in Table 10.4.

From Australia Bureau of Meteorology

| Region | | El Niño Years | | Non-El Niño Years | |
|---|---|---|---|---|---|
| | | Number of Storms | Intensity | Number of Storms | Intensity |
| North Atlantic | | Large Decrease | Small Decrease | Small Increase | Small Increase |
| Eastern North Pacific | | Slight Increase | Increase | Slight Decrease | Decrease |
| Western North Pacific | Eastern half | Increase | No Change | Decrease | No Change |
| | Western half | Decrease | No Change | Increase | No Change |
| Indian Ocean (North / South) | | No Change | No Change | No Change | No Change |
| Australian Region | Western | Slight Decrease | No Change | Slight Increase | No Change |
| | Central and East | Decrease | Slight Decrease | Increase | Slight Increase |
| South / Central Pacific (>160°E) | | Increase | Increase | Decrease | Slight Decrease |

Table 10.4 Effect of ENSO on tropical cyclones.

10.6 Storm surges and storm tide

A storm surge is the rise of seawater level caused solely by a storm https://oceanservice.noaa.gov/facts/stormsurge-stormtide.html#:~:text=Storm%20surge%20is%20the%20rise,caused%20solely%20by%20a%20storm.  This is illustrated in Figure 10.10

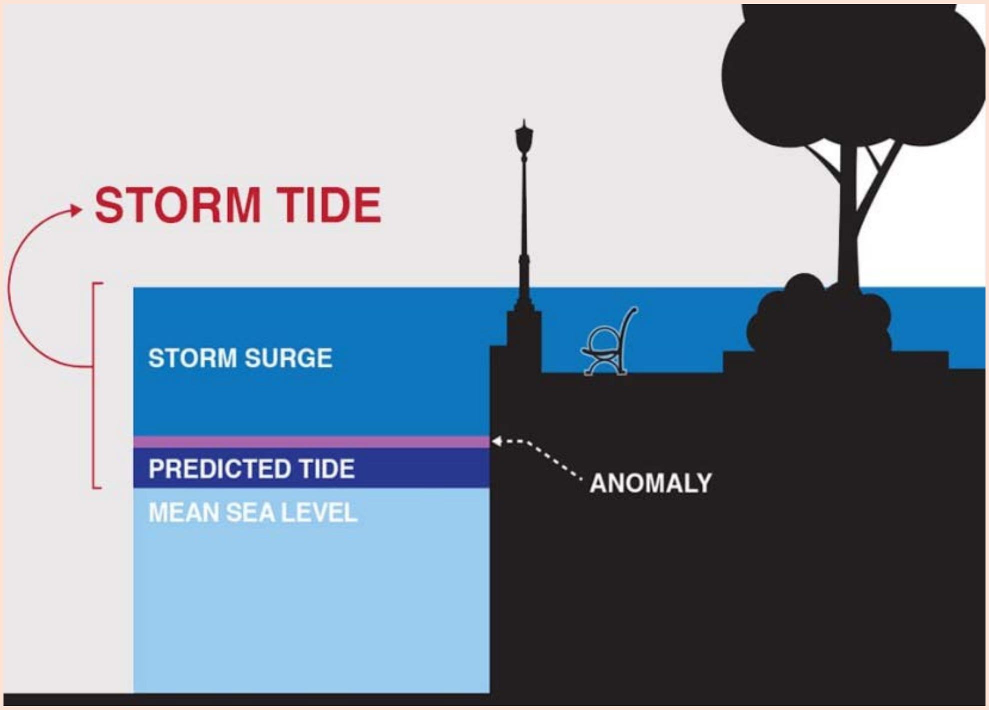



Figure 10.10 Storm surge is the abnormal rise in seawater level during a storm, measured as the height of the water above the normal predicted astronomical tide. https://oceanservice.noaa.gov/facts/stormsurge-stormtide.html#:~:text=Storm%20surge%20is%20the%20rise,caused%20solely%20by%20a%20storm. ***Storm surge** is the rise in seawater level caused solely by a storm. **Storm tide** is the total observed seawater level during a storm, which is the combination of storm surge and normal high tide*

10.6 Bomb cyclone

The National Oceanic and Atmosphere Administration (NOAA) defines 'bomb cyclone' as "midlatitude cyclone that rapidly intensifies". https://oceanservice.noaa.gov/facts/bombogenesis.html . They continue to explain, "Bombogenesis, a term used by meteorologists, occurs when a midlatitude (the latitudes between the tropics and polar regions) cyclone rapidly intensifies, or strengthens, over a 24-hour period. This intensification is represented by a drop in millibars, a measurement of pressure used in meteorology. The intensification required to classify as "bombogenesis" varies by latitude. At 60 degrees latitude, it is a drop of at least 24 millibars (24 hectopascals) over 24 hours. At the latitude of New York City, the required pressure drop is about 17.8 millibars (17.8 hectopascals) over 24 hours."

Another term form bomb cyclone is 'explosive cyclogenesis' and is discussed thoroughly in https://en.wikipedia.org/wiki/Explosive_cyclogenesis .

An example of a bomb cyclone over the west coast of British Columbia, Canada is shown in Figure 10.11 https://www.cbc.ca/news/canada/british-columbia/what-is-a-bomb-cyclone-bombogenesis-1.6977647 .


A bomb cyclone, like the one forecast for Monday, occurs when a rapid drop in air pressure results in spiralling winds surrounding a low-pressure centre. (Meteorological Survey of Canada)

Figure 10.11 Bomb cyclone west coast of British Columbia, https://www.cbc.ca/news/canada/british-columbia/what-is-a-bomb-cyclone-bombogenesis-1.6977647 .

10.7 Information support

Key web sites:

1. Tropical cyclones. https://archive.ipcc.ch/publications_and_data/ar4/wg1/en/ch10s10-3-6-3.html

2. Classification of hurricanes https://www.nhc.noaa.gov/aboutsshws.php .

3. Hurricane development: from birth to maturity. http://www.hurricanescience.org/science/science/development/

4. Tropical cyclones: favorable conditions for formation, stages of formation & structure. https://www.pmfias.com/tropical-cyclones-favorable-conditions-tropical-cyclone-formation/

5. How do hurricanes form? A step-by-step guide. https://www.vox.com/science-and-health/2016/10/6/13191010/how-do-hurricanes-form-tropical-storms-guide

6. Tropical cyclone. https://en.wikipedia.org/wiki/Tropical_cyclone

7. Tropical cyclone. https://www.britannica.com/science/tropical-cyclone

8. How hurricanes form. https://scied.ucar.edu/learning-zone/storms/how-hurricanes-form

9. Cross-sections of a tropical cyclone. http://web.mit.edu/~twcronin/Public/Lupit_Cross_Sections.html

10. Recipe for a hurricane. https://www.nasa.gov/vision/earth/environment/HURRICANE_RECIPE.html#:~:text=Sea%20surface%20temperatures%20must%20be,tropical%20cyclone%20formation%20and%20sustenance.

11. Tropical cyclones. https://public.wmo.int/en/our-mandate/focus-areas/natural-hazards-and-disaster-risk-reduction/tropical-cyclones

12. Hurricanes and tropical cyclones image gallery. https://www.nasa.gov/mission_pages/hurricanes/images/index.html

13. Hurricane spaghetti models. https://www.cyclocane.com/spaghetti-models/

14. Impacts of ENSO on the hurricane season. https://www.climate.gov/news-features/blogs/enso/impacts-el-ni%C3%B1o-and-la-ni%C3%B1a-hurricane-season

15. Hurricane tracking. http://trackthetropics.com/

16. National hurricane center. https://www.nhc.noaa.gov/modelsummary.shtml

17. Storm surge and storm tide. https://oceanservice.noaa.gov/facts/stormsurge-stormtide.html#:~:text=Storm%20surge%20is%20the%20rise,caused%20solely%20by%20a%20storm.

18. Bomb cyclone, NOAA. https://oceanservice.noaa.gov/facts/bombogenesis.html .

19. Bomb cyclone, Andrew Kurjata, CBC News. https://www.cbc.ca/news/canada/british-columbia/what-is-a-bomb-cyclone-bombogenesis-1.6977647 .

20. Explosive cyclogenesis, Wikipedia. https://en.wikipedia.org/wiki/Explosive_cyclogenesis .