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Tropical Cyclones

Background Information for Teachers

Of all the weather systems on Earth, Tropical cyclones produce some of the most intense and damaging weather. Known as Hurricanes in the Atlantic and north-east Pacific, Typhoons in the west Pacific and Cyclones in the Indian Ocean, these storm systems often make the news when they make landfall in populated areas, and sometimes cause widespread devastation to homes, infrastructure and crops.

The largest losses of human life due to weather events are also associated with these systems, with death tolls sometimes into the 100s and even 1000s. Usually the majority of deaths occur not whilst the system is actively affecting a region which may be for periods of less than a day, but in the aftermath as flooding and damage to the local infrastructure lead to disease, drowning and lack of a clean water supply. The image below shows a satellite image of Hurricane Katrina which hit the Gulf coast of the USA near New Orleans in August 2005. This storm led to an estimated 1800 deaths mostly through disease and dehydration in the days following the storm.

Satellite image of Hurricane Katrina over the Gulf of Mexico, August 28th, 2005. © NASA's Earth Observatory website

Whilst intense storms are very common throughout the Tropics, tropical cyclones need a very specific set of ingredients in order to form. These are:

- Warm ocean temperatures, greater than 26°C to a depth of at least 60m. Tropical cyclones only form over oceans, never over land, as they need sources of both heat and moisture. Even if the surface waters are very warm, the strong winds in a developing cyclone cause mixing of the surface layer of the ocean, bringing water up from below the surface. If this water is very much cooler than the surface, the supply of heat to the system will be reduced.
- Latitudes greater than 5° North or South of the equator. Cyclones are rotating systems and so only form in regions with a sufficient component of the Earth's rotation about the local vertical (the Coriolis Effect – see Chapter 8). This is zero on the equator itself and only becomes large enough to generate rotation within a weather system poleward of 5° of latitude. Tropical cyclones, like mid-latitude weather systems (Chapter 17), rotate in an anticlockwise direction in the Northern Hemisphere and a Clockwise direction in the Southern Hemisphere (see, e.g. https://www.rmets.org/metmatters/indian-ocean-tropical-cyclones)
- No large changes in wind speed and direction with height (known in meteorological terms as low wind shear). Cyclones rely on the development of tall columns of convective cloud which extend about 10 km

upwards. If the wind is changing too much with height, these columns of cloud cannot form through a great enough depth of the atmosphere as the tops will be constantly blown away.

- Lots of moisture through the depth of the atmosphere. As well as large wind shear, a dry atmosphere can also act to prevent deep columns of cloud forming.
- A pre-existing disturbance in the atmosphere. Tropical cyclones do not form spontaneously from nothing. There needs to be an area of enhanced thunderstorm activity which can act as a focus for the development of the cyclone in the presence of all the other conditions listed above. Forecasting the formation of Tropical cyclones relies on early identification of these pre-existing disturbances and then recognising which ones will amplify into full-blown cyclones.

The development of Tropical cyclones is a complex process and is still the subject of much research. In simple terms, a cyclone acts like an engine. It converts the energy available from a warm ocean surface into strong vertical air currents and horizontal wind speeds via the evaporation of warm water from the ocean surface and the subsequent condensation of this water vapour in deep columns of cloud around the centre of the storm. This deep cloud often forms an almost circular ring called the eyewall around the very centre of the storm which is itself free from clouds. Thankfully cyclones are rather inefficient engines, converting less than 10% of the available heat energy from condensation in the clouds into the mechanical energy of the motion of the winds.

There is an important positive feedback mechanism which allows cyclones to develop into intense systems. As the system starts to form, evaporation from the ocean surface acts as the source of heat and moisture for the formation of deep clouds. As these clouds intensify, strong rising currents of air in the eyewall develop around the storm centre. Near the surface, air is drawn into the centre of the storm to replace the rising air. This inrushing air near the surface results in strong winds which increase the evaporation from the ocean surface. This evaporation provides more heat and moisture to the clouds making the rising air currents within them stronger and thus intensifying the surface winds even further. As the system develops the Earth’s rotation acts on the inrushing winds, deflecting them into a pattern that rotates about the centre of the storm, spiralling in towards the centre.

A result of the mechanism for development described here is that the most severe weather, the heaviest rain and strongest winds, is strongly focused around the centre of the cyclone. In the figure below the diameter of the almost circular region of cloud associated with a Tropical Cyclone is about 800km. However, the most damaging winds and heaviest rain are all concentrated within the innermost 200km of the storm.

The Eye of the Storm

The ‘eye’ of the hurricane is the clear, almost circular area in the centre of the storm. In this area, the air is sinking – as it sinks, the pressure of the sinking air increases (because there is more air above it – see Chapter 8) and, as its pressure increases, the air warms. As the air warms, the rate of evaporation increases and so any cloud droplets disappear – the air is clear.

However, despite the fact that the air is sinking in this area, the surface pressure is low. In fact, the lowest surface pressures are in the centre of the tropical cyclone. This is because the other air motions associated with the tropical cyclone are taking air away from the area – there is less air above the surface. This is a common misconception to look out for! In mid-latitude cyclones, depressions, we associated rising air with low surface pressure.

The physics behind why there is sinking, warming and therefore clear air in the eye of the storm is still an area of active research.

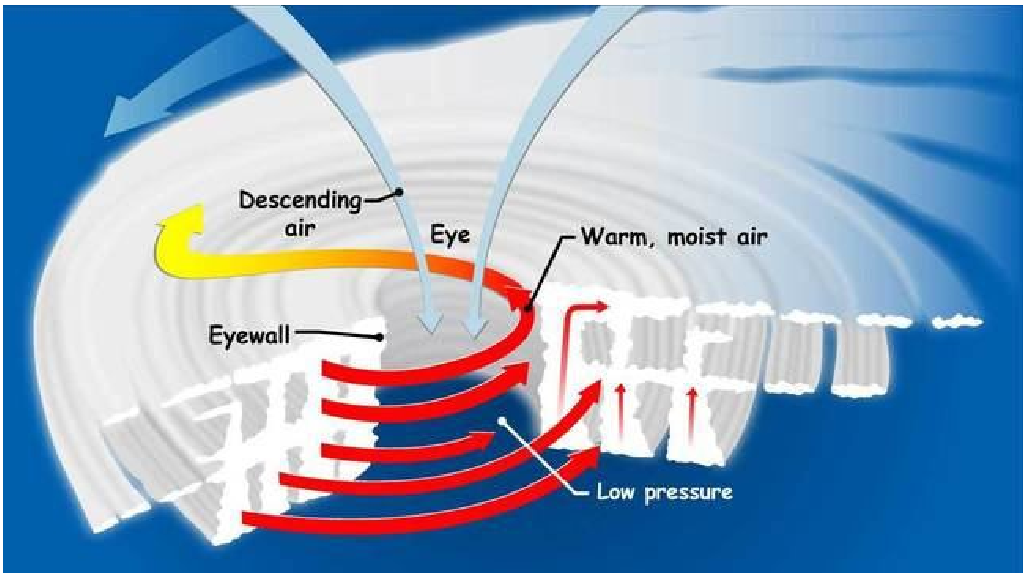
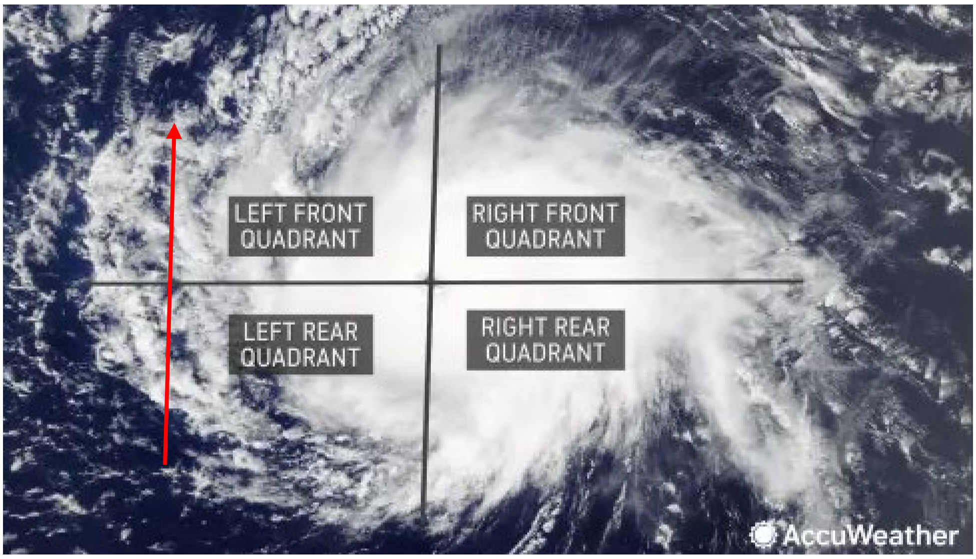


Diagram of a tropical cyclone © NASA

The decay of a Tropical Cyclone usually occurs when the source of energy to the storm, the warm ocean surface, is removed. This may be due to the cyclone moving over land or into an ocean region with lower surface temperatures. An increase in vertical wind shear can also bring about the decay of a Tropical cyclone.

Storm Surges and Winds



Remembering that winds blow anticlockwise around a Low pressure system in the Northern Hemisphere (see chapter 8), then the fastest winds will be on the right side of the storm, where the rotation reinforces the direction the storm is moving in. When a hurricane makes landfall, areas hit by the right front quadrant typically sustain the worst of the damage.

Storm surges occur as a result of the combination of the low pressure – sea levels rise by 1cm when air pressure falls by 1hPa (1mbar) and the wind carrying surface waters in the direction of the coast. High tide can exacerbate the problem.

You can find Further Information about the following topics by following these links:

Distribution, Monitoring and Warning

Naming Tropical Cyclones

Cyclone Lifecycle

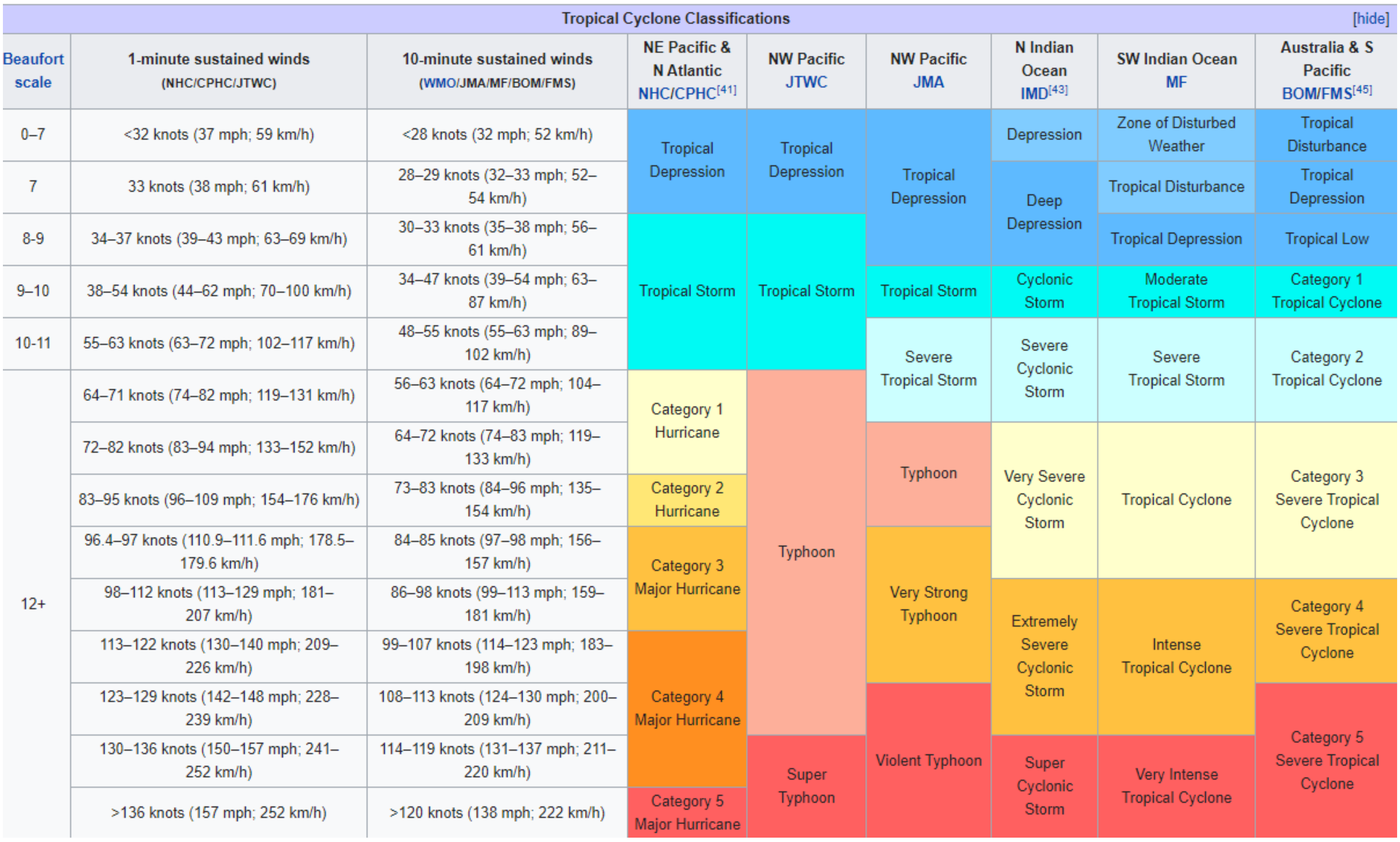
Using Remote Sensing to Measure Tropical Cyclone Intensity

Cyclone Variability

Cyclone Motion

Impacts and Responses

Tropical Cyclone Naming Conventions



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	
	>136 knots (157 mph; 252 km/h)	>120 knots (138 mph; 222 km/h)	Category 5 Major Hurricane					

Source: Wikipedia

Tropical Cyclones and Climate Change

Given the relatively short period of observations of Tropical cyclones, it is very difficult to say whether there has been any significant change in the number or strength of Tropical Cyclones in any of the main regions.

The IPCC's 2018 1.5°C report summarised that Tropical Cyclones are projected to decrease in frequency but with an increase in the number of very intense cyclones. Heavy precipitation associated with Tropical Cyclones is projected to be higher at 2°C compared to 1.5°C of global warming.

In coastal regions, increases in heavy precipitation associated with Tropical cyclones combined with increased sea levels may lead to increased flooding. The direct force of wind and waves associated with larger storms, along with changes in storm direction, increases the risks of physical damage to coastal communities and to ecosystems such as mangroves and tropical coral reefs. These changes are associated with increases in maximum wind speed, wave height and the inundation, although trends in these variables vary from region to region. In some cases, this can lead to increased exposure to related impacts, such as flooding, reduced water quality and increased sediment runoff.

Sea level rise also amplifies the impacts of storms and wave action, with robust evidence that storm surges and damage are already penetrating farther inland than a few decades ago, changing conditions for coastal ecosystems and human communities. This is especially true for small islands and low-lying coastal communities, where issues such as storm surges can transform coastal areas. Changes in the frequency of extreme events, such as an increase in the frequency of intense storms, have the potential (along with other factors such as disease, food web changes, invasive organisms and heat stress-related mortality) to overwhelm the capacity for natural and human systems to recover following disturbances. This has recently been seen for key ecosystems such as tropical coral reefs, which have changed from coral-dominated ecosystems to assemblages dominated by other organisms such as seaweeds, with changes in associated organisms and ecosystem services.

Sources of Information

Wikipedia gives an overview of each hurricane and Tropical Cyclone season.

https://earth.nullschool.net provides a lovely visualisation of current and past tropical cyclones.

The Hurricane Research Division of the US National Oceanic and Atmospheric Administration (NOAA) also has a very informative FAQ on the subject.