8. Tropical Revolving Storms

8.1 Characteristics and terms

Tropical Revolving Storms (TRSs) are one of the most dangerous natural hazards; every year they cause considerable loss of life and do immense damage to property. In terms of the Earth's atmosphere they are an essential feature as they transfer heat and energy between the equator and the cooler regions nearer the poles.

These storms are known regionally as *hurricanes*, *cyclones* or *typhoons*.

For the purpose of explanation, the term hurricane will be used where appropriate.

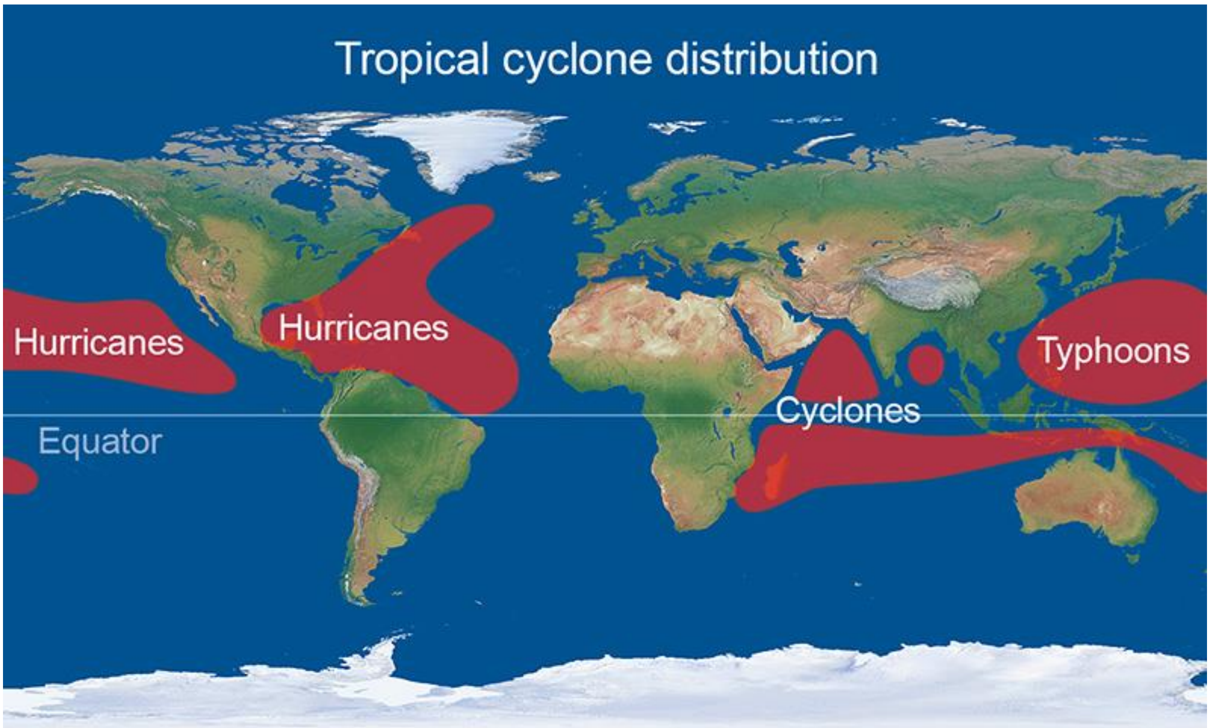

Fig. 8.1 - Regional names and areas of occurrence of TRSs.

8.1.1 General characteristics of a TRS

A tropical revolving storm is the generic term for a low-pressure system over tropical or sub-tropical waters which has some or all of the following characteristics:

- Organised convection such as thunderstorm activity.
- Winds at low levels circulating either anti-clockwise (in the northern hemisphere) or clockwise (in the southern hemisphere).
- The system may be up to 10 km in height.
- Isobars are close to being true circles.
- Very steep pressure gradients.

- No fronts.
- A diameter of circulation of some 400-500 miles compared to 1000-1000 miles for a middle latitude depression.
- It typically moves forward at speeds of 10-15 mph, but can travel as fast as 40 mph.
- In its very early and weak stages it is called a Tropical Depression.

8.1.2 Terms relating to intensity

The following terms are used to describe tropical circulations at various stages of intensity:

Descriptive term	***Wind force (Beaufort)***
Tropical depression	Force 7 or less
Tropical storm	Force 8 and 9
Severe tropical storm	Force 10 and 11
Typhoon, hurricane, cyclone	Force 12 and above

Table 8.1 - Terms relating to TRS intensity.

8.1.3 Terms relating to hurricane wind strength

The Saffir Simpson Scale was developed in the USA to grade hurricane wind strength; this scale is widely used.

Category	***Wind speed (Knots)***	***Pressure (hPa)***
1	64-82	>980
2	83-95	965-979
3	96-112	945-964
4	113-136	920-944
5	>137	<919

Table 8.2 - TRS wind strength categories.

8.2 General formation and movement

8.2.1 Formation

Tropical revolving storms (TRSs) develop in tropical oceans at least 5°-30° latitude north or south of the equator, where the sea temperature is at least 27°C.

In the tropics there is a broad zone of low pressure which stretches either side of the equator. In this zone the NE and SE Trade winds meet.

Within this area of low pressure, the air is heated over the warm tropical ocean. This air rises in discrete parcels, causing thundery showers to form. These showers usually come and go, but from time to time, they group together into large clusters of thunderstorms. This creates a flow of very warm, moist, rapidly rising air, leading to the development of a centre of low pressure, or depression, at the surface.

There are various trigger mechanisms required to transform these cloud clusters into a TRS. These trigger mechanisms depend on several conditions being present at the same time.

The most influential factors are:

- a source of warm, moist air derived from tropical oceans with sea surface temperatures normally in the region of, or in excess, of 26°C;
- winds near the ocean surface blowing from different directions converging and causing air to rise and storm clouds to form;
- winds which do not vary greatly with height (known as low wind shear). This allows the storm clouds to rise vertically to high levels;
- sufficient distance from the equator for Coriolis to promote circulation.

The Coriolis force caused by the rotation of the Earth helps the spin of the column of rising air.

The development of the surface depression causes an increase in the strength of the trade winds. The spiralling winds accelerate inwards and upwards, releasing heat and moisture as they do so.

As the depression strengthens it becomes a tropical storm and eventually a hurricane. A mature hurricane takes the form of a cylinder of deep thundercloud around a centre that is relatively free from clouds. There is a relatively small area of intense horizontal winds at the surface, often well over 100 mph, while air rises strongly above, maintaining the deep cumulonimbus clouds.

Further aloft at about 10 km, the cloud tops are carried outwards to give thick layer clouds due to the outward-spiralling winds leaving the tropical cyclone core. At the centre of the hurricane air is subsides which makes it dry and often cloud free; there is little or no wind at the surface. This is called the eye of the storm.

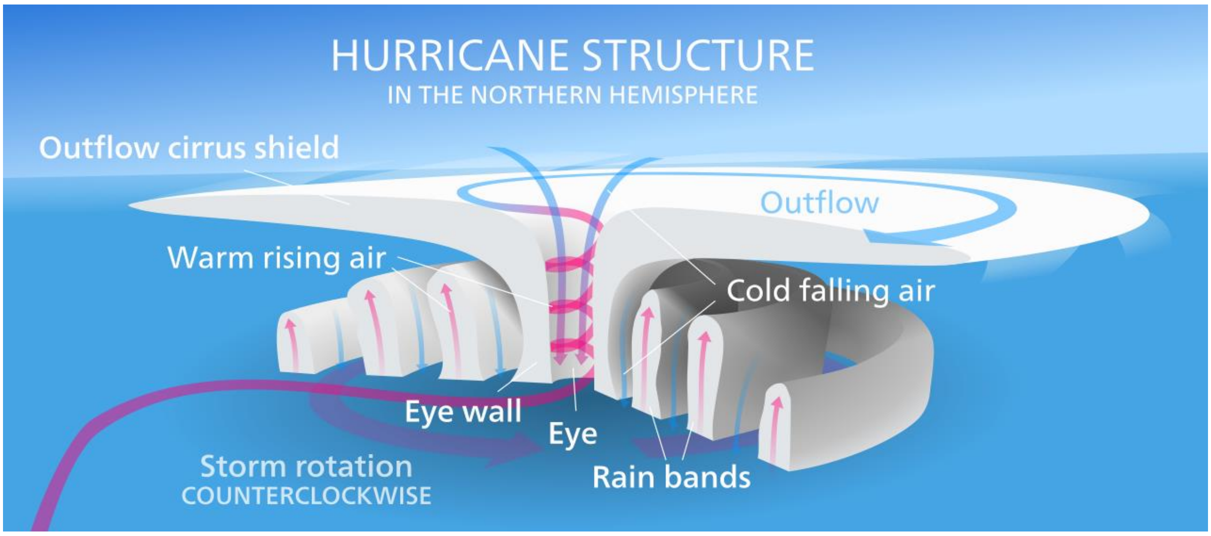

Fig. 8.2 - Structure of a tropical revolving storm.
https://upload.wikimedia.org/wikipedia/commons/thumb/4/4f/Hurricane-en.svg/1280px-Hurricane-en.svg.png

Fig. 8.3 - Hurricane Katrina (2005).
http://www.atmo.arizona.edu/students/courselinks/spring13/atmo170a1s1/lecture_notes/hurricanes/katrina-08-29-2005-1515z2.jpg

8.2.2 Energy transfer

Great amounts of energy are transferred when warm water is evaporated from tropical seas. This energy is stored within the water vapour contained in moist air.

As this air ascends, 90% of the stored energy is released by condensation, giving rise to the towering cumulus clouds and rain. The release of heat energy warms the air locally, causing a further decrease in pressure aloft. Consequently, air rises faster to fill this area of low pressure and more warm, moist air is drawn off the sea, feeding further energy to the system. Thus, a self-sustaining heat engine is created.

8.2.3 Location of TRSs

TRSs occur around the equator at 5°-30° N or S at the western sides of the oceans where their path takes them around the western boundaries of oceanic high-pressure systems.

Initially they move westward, being driven by easterly winds, and move slightly towards the poles. Many TRSs eventually drift far enough from the equator to move into areas dominated by westerly winds in the middle latitudes. These winds tend to reverse the direction of the TRS to an eastward path. As the TRS moves poleward it picks up forward speed and may reach 30 mph or more. An average TRS can travel about 300 to 400 miles a day, or about 3,000 miles before it eventually fills and decays.

TRSs are most frequently seen to make landfall and impact in the USA and Asia.

There are seven basins in which they are seen to form regularly at different times throughout the year, these are referred to as seasons.

- Atlantic basin: June to November
- North- East Pacific basin: May/June to October/November
- North-West Pacific basin: Occur all year round with the main season being July to November
- North Indian basin: April to December
- South-West Indian basin: October/November to May
- South-East Indian/Australian basin: October/November to May
- Australian/South-West Pacific basin: October/November to May

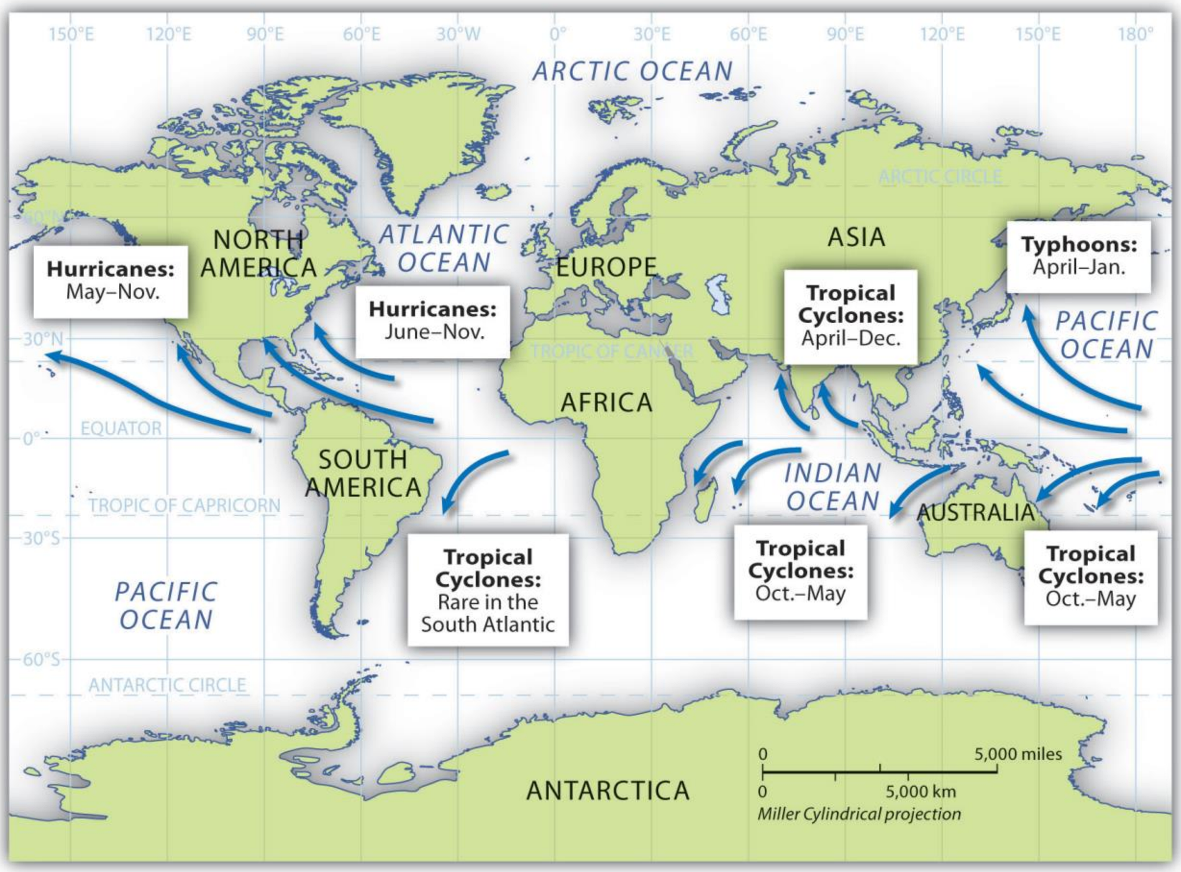

Fig. 8.4 - Typical TRS tracks.
https://2012books.lardbucket.org/books/regional-geography-of-the-world-globalization-people-and-places/s08-05-tropical-cyclones-hurricanes.html

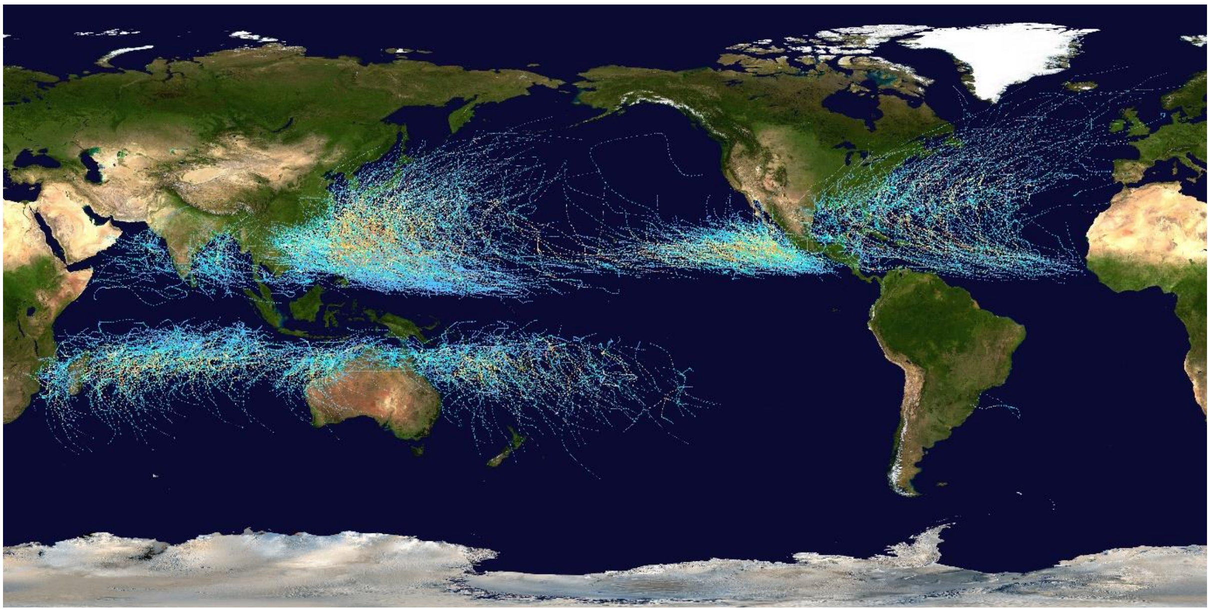

Fig. 8.5 - TRS tracks 1985 to 2005.
https://www.metoffice.gov.uk/learning/storms/tropical-cyclones/location

8.2.4 Decay of a TRS

Considering the general track of a TRS which starts heading westward and then curves poleward a number of factors can result in the decay of the storm.

Colder sea surface temperatures: as the TRS moves poleward it will encounter cooler sea surface temperatures which will cause air to sink. A minimum sea surface temperature of 26°C is required to for the storm to be sustained. Eventually as the storm moves further poleward it will begin to fill and dissipate.

Encountering wind shear aloft: a TRS is a vertically stacked system whereby clouds must build vertically to great heights in the troposphere. In order for this to happen, these storms must have light winds aloft. Hostile upper level wind conditions produce shearing, which blow off the high cloud tops of these storms, and causes them to become disorganised.

Sinking air or subsidence: subsidence from high pressure such as a subtropical ridge can also inhibit development. This prevents thunderstorm development which is critical in TRS development.

Making landfall: this will cut off the essential supply of moisture and friction restricts the circulation of the system. If the storm encounters high terrain such as mountains much of the forced rising of the air can result in extreme heavy rainfall and flooding.

8.3 Indications of the approach of a TRS

The following observable indications can warn of the threat of a TRS in the locality:

(1) The waves generated by the storm travel at a great speed away from the storm centre. This may give an early warning that a TRS is in the vicinity. The swell will arrive well in advance of clouds, pressure changes and other signs. The direction of the swell will give an indication of the position of the storm where the swell was generated. An allowance must be made for subsequent movement of the storm.

(2) A change in the intensity or direction of the trade winds.

(3) Irregularity in the semi diurnal range of barometric pressure, or the barometric pressure being 3 hPa or more below the seasonal normal for the particular region and time of day. A pressure reading of 5 hPa or more indicates that the presence of a TRS is very likely and avoiding action should be considered.

(4) An oppressive atmosphere with increasing humidity.

(5) An ugly lurid sky at Sunrise and Sunset.

As the storm approaches:

(6) Cirriform clouds in thick spiral bands are observable.

(7) Typical barometric pressure change will be:

500 miles to 120 miles from the centre - slow fall;

120 miles to 60 miles from the centre - distinct fall and diurnal variation in pressure is masked;

60 miles to centre - rapid fall.

Fig. 8.6 - Spiralling cirrus from a distant storm centre.

8.4 Obligatory reports

If the Master suspects the existence of or the ship is in the vicinity of a tropical storm the SOLAS convention requires that this information be communicated by all means available to the nearest coast radio station and to ships in the vicinity. A similar report is required if a ship should encounter winds of Force 10 or above.

8.5 Actions to take when in the path of a TRS

To decide the best course of action when a storm is in the vicinity two things need to be known:

- The bearing of the storm centre.
- The path of the storm.

If an observer faces the wind the centre of the storm will be 100-120° to the right in the NH when the storm is 200 miles away. This will be when the pressure has fallen by about 5 hPa and the wind speed has reached force 6.

The closer to the centre, the closer the angle will be to 90°.

8.5.1 Dangerous and navigable semicircles

Figure 8.7 illustrates the typical paths of tropical storms and identifies the dangerous and navigable semicircles. The advance quadrant of the dangerous semicircle is termed the dangerous quadrant as a ship is this area is under greatest threat.

A ship that was situated in the navigable semicircle will tend to be blown away from the storm centre and re-curvature of storm will increase the ship's distance from the centre.

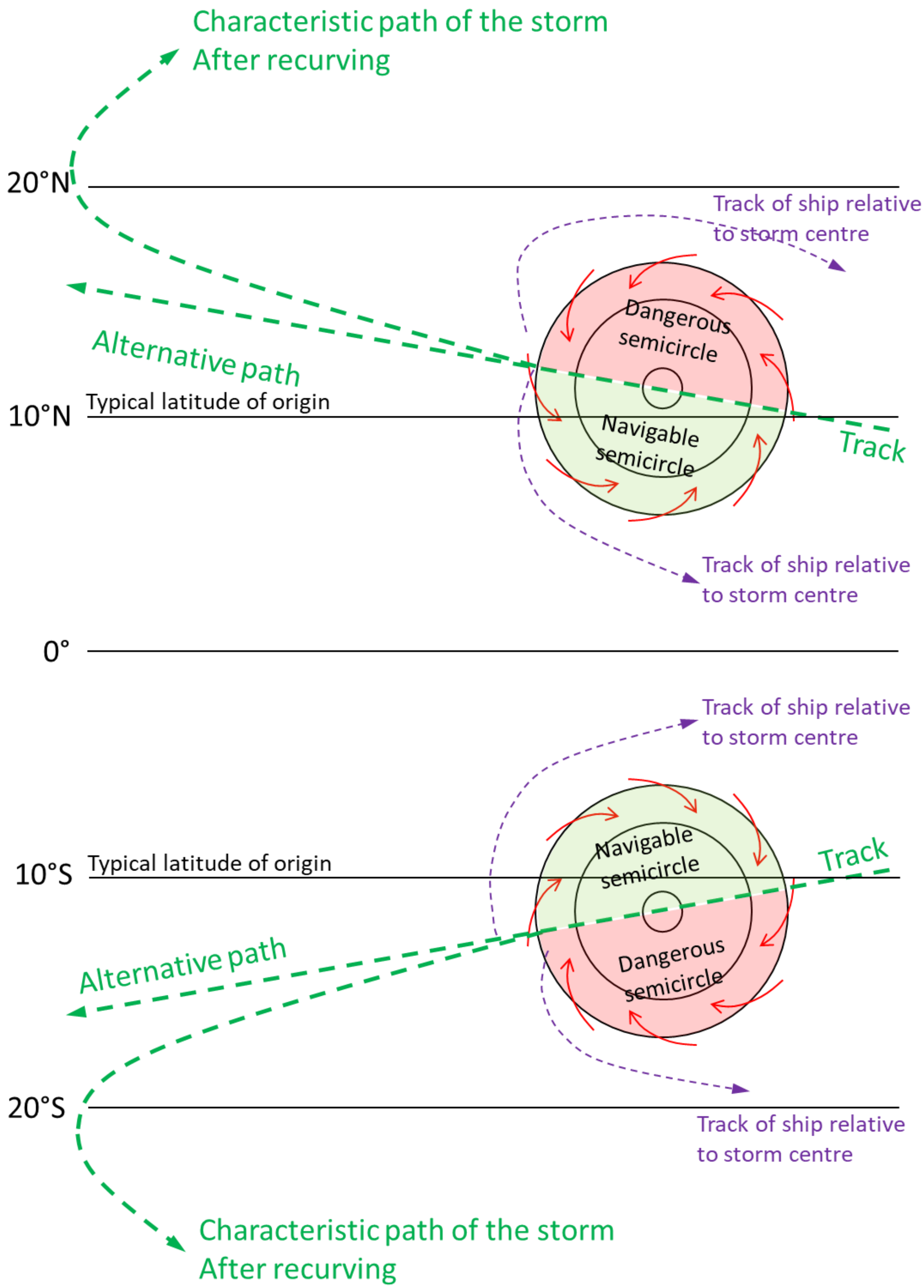

Fig. 8.7 - The dangerous and navigable semicircles. The purple tracks indicate the likely drift of a ship that is not making way dependent on where the TRS passes. These tracks also indicate the recommended route to clear the storm also.

8.5.2 Observations and actions

(1) Determine bearing and distance of storm centre:

- Buy Ballots Law
- Meteorological observation
- Radio information

(2) Construct a plot

- Position of TRS
- Position of ship
- Update as information available

(3) Determine/Predict the path of the storm

- History of previous TRS's
- Radio information
- Plotting information
- 40° either side of track

(4) Determine the vessel's relative position

- Pressure falling: vessel in advance of TRS
- Pressure rising: vessel at rear of TRS

Wind direction	*Northern Hemisphere*	*Southern Hemisphere*
Wind veers	Dangerous semi-circle	Navigable semi-circle
Wind backs	Navigable semi-circle	Dangerous semi-circle
Wind steady	In the path	In the path

- Be aware of possible re-curvature.

(5) Manoeuvre according to the rules

Northern Hemisphere	Dangerous semi-circle	Put wind on starboard bow and make best speed. Alter course to stbd. as the wind veers
	Navigable semi-circle & in the path	Put wind on starboard quarter and make best speed. Alter course to port as the wind backs
Southern Hemisphere	Dangerous semi-circle	Put wind on port bow and make best speed. Alter course to port as the wind backs
	Navigable semi-circle & in the path	Put wind on port quarter and make best speed. Alter course to stbd. as the wind backs

8.6 Storm tides and surges

The long swell ahead of a tropical revolving storm is sometimes experienced at a distance of more than 1,000 miles from the storm's centre. It travels much faster than the storm itself and, not infrequently, causes a *storm tide* which can result in disastrous flooding on coasts.

The water begins to rise one or two days before the arrival of the storm; that is when the storm is about 300 to 500 miles away, and continues to rise until the storm passes or curves away from the area. The rise of water may be in excess of 6m (18 feet) above the predicted level. The coastal flooding is particularly severe where a coast is low lying and when the storm tide arrives at the time of a high spring tide.