

Tropical Cyclone Motion

This information has been summarised from the Introduction to Tropical Meteorology (2nd Edition) which can be accessed, free of charge, on the [MetEd/ COMET](#) website (requires free registration).

Motion

For over a century we have known that a tropical cyclone will move in response to the other weather systems in its environment. This view of tropical cyclone motion pictures it as a passive "cork in a stream" being "steered" by the other weather systems around it.

Certainly, environmental steering (advection – the transfer of heat horizontally in the atmosphere) is the dominant contribution to tropical cyclone motion and can be approximated by the average wind through a deep layer of the atmosphere (the deep-layer mean wind). When calculating this wind from standard pressure level data, it is necessary to weight each level by the mass of the layer it represents.

For tropical cyclone motion, the average from 850-200 hPa (c1.5–10km altitude) is used most often, however the choice of the averaging layer for the advection has been shown to be weakly related to storm intensity with a shallower (say 850-500 hPa) (c5.5-10km) layer often estimating the steering better for weaker storms.

While advection is clearly important, the limited success of forecasts using this approach led scientists to consider other mechanisms that also contribute to the motion of a tropical storm.

Visualising the wind field

The website <https://earth.nullschool.net/> provides a 3D globe that visualises near real-time weather data across Earth. Values measured can be found listed and described on <https://earth.nullschool.net/about.html>. To get started, go to the site and click the word 'Earth' in the lower-left corner. The default is to see the global wind field at sea level (1000hPa). Change this to 850, and then 250 to explore the differences with altitude. If a hurricane is currently occurring you can explore the wind field in which it exists, and how winds differ with height.

The " β -Effect" and Environmental " β " effect

The most straightforward approach to the study of storm motion is to consider the motion due to the flow averaged through a deep layer but we must also consider the B -effect - the north-south variation of the Coriolis effect.

In addition to vortex motion due to steering by the large-scale flow, there is a contribution to tropical cyclone motion resulting from vortex interaction with the Earth's background vorticity gradient (existing rotational movements of air in the atmosphere), known as the β -effect.

Typically, smaller than the steering (often only a couple of m s^{-1} forward speed), its impact on the storm direction can sometimes have substantial impacts on the storm evolution because the change in direction can result in the storm interacting with different phenomena (other weather systems, SST anomalies, etc.). Also, failing to account for its effect in the motion of a cyclone creates errors that quickly mount, decreasing the accuracy of the forecast track.

Propagation (motion that is not advection) of a tropical cyclone could not occur without the north/south variation in the Coriolis effect. (Wind deflection due to the Coriolis effect increases with latitude).

Atmospheric modelling suggests that the rotating winds of a tropical cyclone, combined with the north/south variation in the Coriolis effect, induce asymmetries in the tropical cyclone called the β -gyres that are associated with winds that produce a net flow across the tropical cyclone centre. Generally, the β -drift is towards the northwest at a few knots; the speed and actual direction is related to the vortex size and strength.

β -gyres initially form symmetrically, East and West of the centre of the storm, before moving further out and being themselves rotated cyclonically by the storm's rotational winds. This final location and orientation of the β -gyres results in associated winds that cause the tropical cyclone to propagate poleward and westward in both hemispheres.

However, in the real atmosphere we cannot see the β -gyres evolve in this way. *In reality, development of the β -gyres occurs concurrently with the evolution of the tropical cyclone and its environment.*

Interaction of Vortices: The Fujiwhara Effect

For over a century it has been known that vortices will move in response to other vortices, even in an otherwise quiescent environment. Dynamically, this is just steering and environmental β -effect of one vortex on the other.

Observational studies of the western North Pacific and North Atlantic document binary storm interactions on average 1.5 times per year for the western North Pacific and once every three years in the North Atlantic (for the period 1945-1981). Binary interactions occurred when the tropical cyclone centres were separated by distances of less than 1300-1400 km, with this critical separation distance depending on the sizes of the

interacting systems. Of these interacting cyclones, 70% orbited cyclonically around one another with slower speeds of rotation around the other vortex with larger separation distance.

The observed tropical cyclone motion is the combination of this rotation around the other vortex and any other environmental steering. The rotation of the two tropical cyclones around each other can be visualized by subtracting the average motion of the two storms from the motion of each storm separately.

A comprehensive analysis of ten cases of tropical cyclone interaction provided a framework for discussion of binary storm interactions. By considering the centroid-relative track of the vortex pair, the storm-storm interactions can be separated into four components: (i) Approach and Capture, (ii) Mutual Orbit, (iii) Merger, and (iv) Escape (Fig. 1).

Typically, only smaller tropical storms will merge, though hurricanes may absorb smaller storms. A selection of examples across several basins is available from https://en.wikipedia.org/wiki/Fujiwhara_effect.

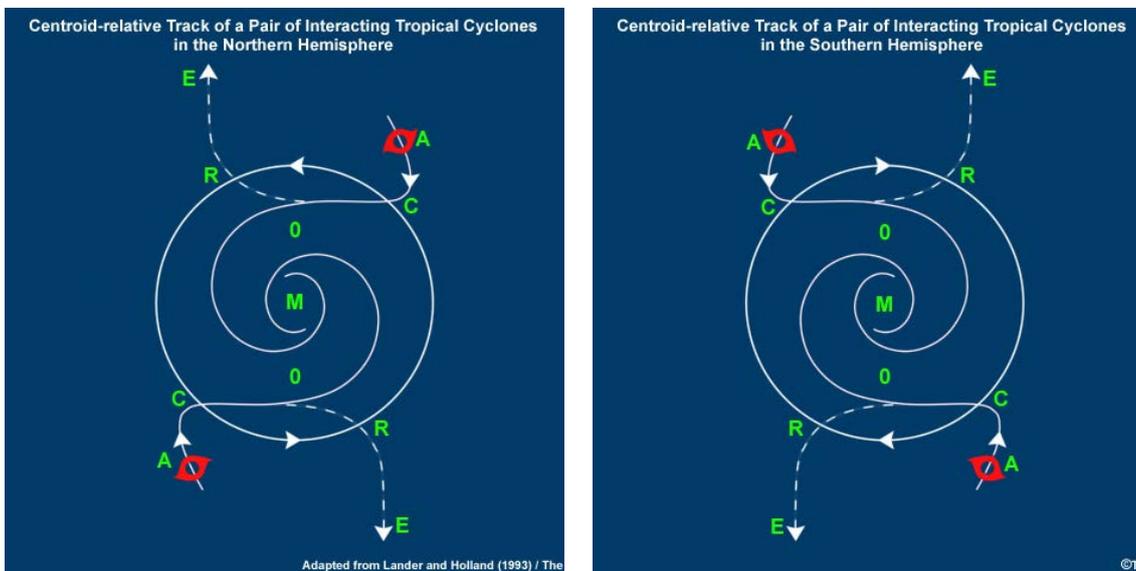


Figure 1 Centroid-relative track of a pair of interacting (a) Northern Hemisphere and (b) Southern Hemisphere tropical cyclones illustrating the four stages of storm-storm interactions: (i) Approach (A) and Capture (C), (ii) Mutual Orbit (O), and either (iii) Merger (M) or (iv) Escape (E) after Release (R).

Other Factors Impacting Tropical Cyclone Motion

A number of measures describe the radial structure of the rotational wind field:

- *intensity* (peak surface winds)
- *strength* (the average winds in an annulus outside the eyewall)
- *size*.

Storm intensity is only weakly, and indirectly, related to its motion. One study of tropical cyclones in the Australian region has demonstrated that tropical cyclone intensity is linked to the layer over which the environmental winds advect the storm, but no significant link has been drawn between propagation and tropical cyclone intensity.

Strength is a measure of the variation of the rotational wind with radius: the *shape* of the profile. Intuitively, you know that a storm whose intense winds extend out a very large distance will be more damaging than a storm in which these winds drop off rapidly. These intense winds correspond to larger inertial stability, and hence to a tropical cyclone that is more resilient to environmental influences.

In extreme cases such as Supertyphoon Tip in 1979 this can mean that the storm generates its own steering flow and its motion is not dominated by surrounding weather systems. However, these situations are extremely rare. More commonly, the increase in inertial stability that follows from increased intensity minimizes the impact of strong vertical or horizontal wind shear on the storm.

The relationship between the tropical cyclone motion and strength is generally closest when strength is evaluated between 3-5 degrees latitude radius (so approximately 300-500 km). Indeed, tropical cyclone propagation speed increases and its direction has a more westward component for increasing storm strength.

The size of a tropical cyclone also relates to its propagation speed, but not its *direction* of propagation: larger tropical cyclones have a larger propagation speed than smaller storms.

In summary, a tropical cyclone moves through a combination of advection by the average tropospheric winds of its environment and propagation due existing rotational atmospheric movement, and its environment (including other tropical cyclones in Fujiwhara interactions), as well as variations in motion due to horizontal and vertical wind shear.

The structure of the tropical cyclone (its size and inertial stability) will impact how the storm responds to all of these contributors to its motion: larger storms will have a larger propagation component of their motion; stronger storms will have a larger deviation between the direction of the advection and their motion.

Summary

- environmental steering is the dominant effect on cyclone motion
- other large-scale influences are the north-south variation in the Coriolis effect (which induce asymmetries called β -gyres)(the " β " effect) , and interaction with other vortices (the Fujiwhara Effect).
- Motion is also affected by peak surface winds, the strength of average winds outside the eyewall, and the size of the cyclone.