A Tropical Cyclone with a Very Large Eye

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1. Introduction

The well-defined eye of a mature tropical cyclone (TC) is probably one of nature’s most remarkable and awe-inspiring phenomena. In the Dvorak (1975) classification scheme, the intensity of a TC is estimated from characteristics of satellite imagery such as the distance of the low-level circulation center to the deep convection, the size of the central dense overcast, the cloud-top temperatures and horizontal width of the eyewall cloud, and the width and extent of peripheral banding features. The basic TC pattern types identified by Dvorak are 1) the “shear” pattern, 2) the “curved band” pattern, 3) the “central dense overcast” pattern, and 4) the “eye” pattern. Of these pattern types, the eye pattern is probably the most well known, certainly to the public.

The eye of a TC can be ragged or well defined. In general, the more sharply defined the eye of a TC becomes on satellite imagery, the more intense that TC is likely to be. The average satellite-observed diameter of the eye of a TC is between 30 and 45 nm (55–85 km) (Weatherford 1984). Eyes with diameters ~30 nm (~55 km) are considered to be small, while those with diameters ~45 nm (~85 km) are considered to be large. In the Dvorak scheme, the intensity of a TC with a large well-defined eye must be capped at 115 kt (59 m s\(^{-1}\)), and the intensity of a TC with a large ragged eye must be capped at 90 kt (46 m s\(^{-1}\)) regardless of other characteristics of the satellite imagery. Some extremes of eye sizes include the aircraft-observed, small 8-nm (15 km) eye diameter of Supertyphoon Tip (JTWC 1979) and the large 200-nm (370 km) radar-observed eye diameter of Typhoon Carmen as it passed over Okinawa (JTWC 1960).

Some TCs, especially the more intense, develop concentric eyes: an eye within an eye featuring two eyewall clouds separated by a relatively cloud-free moat. In such cases, the outer wall cloud may contract while the inner eyewall cloud collapses in a process known as eyewall replacement. The phenomenon of eyewall replacement has been discussed at length by Willoughby et al. (1982) and Willoughby (1990). These authors also note that TC eyes almost invariably contract during intensification so that small eyes and extreme intensity tend to be correlated. Sometimes TCs with large eyes become very intense as well, but usually after an eyewall replacement. The Dvorak scheme has no special rules for use on TCs with concentric wall clouds.

An interesting manifestation of concentric eyewall clouds occurred with Supertyphoon Winnie. As this typhoon moved toward Okinawa on 16 August 1997, a large outer rain band began to encircle the eye and the eyewall cloud. By the time the system passed near Okinawa, a complete ring of deep convection with a diameter of nearly 200 nm (370 km) encircled the original eye and eyewall cloud (Figs. 1 and 2).

2. Discussion

In a survey of past annual tropical cyclone reports published by the Joint Typhoon Warning Center (JTWC), Guam, the largest eye diameter ever reported was that of Typhoon Carmen (JTWC 1960) as it passed over Okinawa. By coincidence, Winnie, like Carmen, passed over Okinawa. Carmen’s eye diameter, as measured by the weather radar at Kadena Air Base, Okinawa, was 200 nm (370 km), the same diameter as Winnie’s satellite-observed outer eyewall cloud. Comments in the 1960 annual typhoon report include the following:

Another feature quite unusual about this typhoon was the diameter of its eye. Reconnaissance aircraft frequently reported eye diameters of 100 [nm], using as the basis of measurement, surface winds and pressure gradient. However, with respect to wall clouds surrounding the eye, radar photographs taken from the CPS-9 at Kadena AB
Fig. 1. Winnie’s outer eyewall cloud passes over Okinawa bringing hurricane-force winds to that island as the small inner eye and eyewall cloud (surrounded by a relatively cloud-free moat) passes well to the south. (0133 UTC 17 August visible Geostationary Meteorological Satellite imagery.) Black dot shows the location of the Kadena NEXRAD.

show quite clearly that on 20 August, the eye had a diameter of approximately 200 [nm]. ... The eye diameter of Carmen was probably one of the largest ever reported. ...

Supertyphoon Winnie, like Carmen, was also viewed by a radar at Kadena, this time a NEXRAD WSR 88D (Fig. 3a,b).

Winnie originated in the monsoon trough from a tropical disturbance east of Guam. As it traveled toward the west-northwest, it intensified and peaked at 140 kt (72 m s$^{-1}$) shortly after passing through the northern end of the Mariana Island chain. Later, as it slowly weakened, it continued on its west-northwest track and approached Okinawa. As the typhoon neared Okinawa on 16 August 1997, a large outer rainband began to encircle the eye and eyewall of the typhoon. By the time the system passed near Okinawa, a complete ring of deep convection with an inner diameter of nearly 200 nm (370 km) encircled the original eye and eyewall cloud. The outer ring of deep convection, or outer eyewall cloud, passed over Okinawa where wind gusts of 82 kt (42 m s$^{-1}$) were recorded (Fig. 4) and the sea level pressure (SLP) fell to 964 hPa (Fig. 5). The inner eye and spiral convective bands of the inner eyewall passed approximately 80 nm (150 km) south of Okinawa. Doppler radar indicated 100 kt (51 m s$^{-1}$) winds in the large outer eyewall in a layer from 3000 ft (0.9 km) to 6000 ft (1.8 km). Maximum low-level wind speeds and SLP for Winnie’s inner eye are not known. The NEXRAD base velocity product (Fig. 3b) does, however, show inbound wind speeds between 50 and 80 kt (26 and 41 m s$^{-1}$) at an altitude of 2.5 km above sea level on the eastern side of the inner eyewall cloud.

Winnie did not appear to undergo eyewall replacement; the TC retained its inner eye until it dissipated over mainland China. There are some theoretical ar-
Fig. 2. Winnie’s outer eyewall cloud (yellow, red, and black) shows distinctly in microwave imagery (which is especially sensitive to regions in deep convection containing large ice-phase particles—the smaller ice-phase particles of peripheral cirrus clouds are transparent). The inner eye and eyewall cloud are present but less distinct. The white dot indicates the location of the island of Okinawa. (1248 UTC 16 August 85-GHz microwave Defense Meteorological Satellite Program imagery courtesy of the Naval Research Laboratory, Monterey, CA.)

Arguments that would suggest that the contraction of a large-diameter eyewall cloud should require more time than the contraction of a smaller outer eyewall cloud. In the scaling of Shapiro and Willoughby (1982), the physical timescale for evolution of the eye is inversely proportional to its horizontal spatial scale. Relatively small outer eyewall clouds (~50 km radius) replace the inner eyewall clouds quickly, but large outer eyewall clouds (like the 250-km-diameter outer wall cloud of Hurricane Allen during 8–9 August 1980, an Atlantic case similar to Winnie) often run onshore or recurve before the process can complete. In the same scaling, the nondimensional dynamics of the eye depend only on wind speed. If one scales all winds with the maximum wind ($V_{\text{max}}$), horizontal distances with the radius of maximum wind ($R_{\text{max}}$), and times with the ratio $R_{\text{max}} / V_{\text{max}}$, the spatial scale cancels out. The only qualification is that the Rossby number must be greater than one. A nondimensional representation of Winnie’s outer eyewall cloud would be much like all others (regardless of
Fig. 3. Winnac’s outer wall cloud and smaller inner eye and eyewall cloud as depicted by the NEXRAD WSR 88D located near Kadena Air Base on Okinawa. (a) The base reflectivity at 0226 UTC 17 August and (b) the 0122 UTC 17 August base velocity product.
Fig. 3. Continued. Regions of range folding, where the velocity data is considered unreliable by NEXRAD algorithms, are displayed in purple. The NEXRAD is able to compute Doppler velocities within 124 nm (230 km) of the radar. The black dot (with arrow) shows the location of the NEXRAD in both panels.
diameter), and the reason that the outer wall cloud was not observed to contract was that not enough physical time passed.

3. Concluding remarks

The eye is one of the signature characteristics of a mature TC. It is a light-wind core composed in the vertical of gently subsiding warm dry air. The eye is typically surrounded by a more or less complete ring of deep convection where the extreme tangential and ascending wind velocities are located. The satellite-observed eye diameters of most TCs are <45 nm (<85 km). Many very intense TCs have eye diameters considerably less than 30 nm (<55 km), with some (like Opal in the Gulf of Mexico during 1995, Tip in the western North Pacific during 1979, and Tracy over the city of Darwin, Australia, on Christmas Eve of 1974) possessing eye diameters <10 nm (<20 km) at some time during their lives. Although concentric eyewall clouds are commonly observed, especially for the more intense TCs, the extreme diameter of Winnie’s outer eyewall cloud is perhaps a phenomenon restricted primarily to the western North Pacific basin, where even there it is a rare occurrence. In the Atlantic basin, TCs with large-diameter outer eyewall clouds include Allen (1980), Diana (1984), Gilbert (1988), and Luis (1995); all had outer eyewall clouds with diameters >250 km and very small inner eyewall clouds with diameters <25 km.

Some typhoons that form in the monsoon trough of the western North Pacific generate circulations and eyes at the large end of the global size distribution. The 370 km diameter of Winnie’s outer eyewall cloud when it passed over Okinawa is one of the largest ever observed in a TC. These cases are important because they define the extreme possibilities for TC dynamics.

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references