4D.5 MULTIPLE EYEWALL STRUCTURE OF HURRICANE JULIETTE 2001

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1. INTRODUCTION

Concentric eyewalls are relatively rare and ephemeral. Only about 10% of all tropical cyclones develop concentric eyewalls, and once formed, they typically are not maintained for much longer than twelve hours. Multiple eyewalls are more commonly observed in intense tropical cyclones as compared to weaker storms. From a study of West Pacific storms during 1969-1971, Willoughby et al. (1982) estimate that approximately 50% of intense typhoons (winds greater than 65 m s^{-1}), 10% of weaker typhoons, and 0% of tropical storms exhibit concentric eyewalls.

There is an obvious question about the origin of multiple eyewall structures. Based on Doppler radar analysis of Typhoon Lekima (2001) and on nondivergent barotropic model simulations, Kuo et al. (2004) have argued that a secondary eyewall can form by the interaction between a small, intense vortex patch and a neighboring, large, weak vorticity area. In a typical case, e.g., when the neighboring vorticity has ten times the area but only one tenth the vorticity magnitude of the small intense patch, the larger area is completely strained out and wrapped around the other vortex to produce a concentric ring structure. This scenario seems to be in reasonable agreement with the limited observations on the formation of secondary eyewalls. As a complement to the study of Kuo et al., Rozoff et al. (2004) explore a related mechanism for the production of "vorticity haloes", or "moats". They consider the barotropic evolution of flow fields consisting of a strong central vortex embedded within a lumpy soup of cyclonically-biased vorticity, and how such a central vortex can organize the surrounding turbulent vorticity field. Not surprisingly, the type and degree of organization depends on the strength of the central vortex, which they allow to vary over the five categories of the Saffir-Simpson scale.

2. TROPICAL CYCLONE EVOLUTION

An interesting example of multiple eyewalls occurred during 25-26 September 2001 in the East Pacific basin. Tropical Depression Eleven formed off the Guatemalan coast at 0600 UTC on 21 September 2001 and was moving west-northwest, generally following the coastline. At 1200 UTC on 21 September, it was upgraded to Tropical Storm Juliette, then at 1200 UTC on 23 September it was upgraded to Hurricane Juliette. Two days after formation and slow organization, explosive deepening occurred toward the end of 23 September. The central pressure fell 35 hPa in the 12 hour period ending at 0000 UTC on 24 September (2.9 hPa hr^{-1}). Juliette reached an intensity of 941 hPa, then weakened slightly over the next day. Twenty four hours later (1800 UTC on 25 September), the storm re-intensified to a peak of 923 hPa and 64 m s^{-1} (Avila et al. 2003). Beginning at approximately this time, a second eyewall formed outside the initial "pinhole" eyewall. By the next day, aircraft and satellite data indicated that a third eyewall had formed outside the inner two.

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3. SATELLITE OBSERVATIONS

Fig. 1 shows the evolution of Juliette's inner core over a 45-hour period spanning the eyewall replacement cycle as observed by the SSM/I (Special Sensor Microwave Imager) instrument aboard several DMSP (Defense Meteorological Satellite Program) satellites. The images are constructed from both horizontal and vertical polarizations of the 85 GHz channel; dark shades show convective precipitation, while the lighter shades of gray indicate low clouds and water vapor.

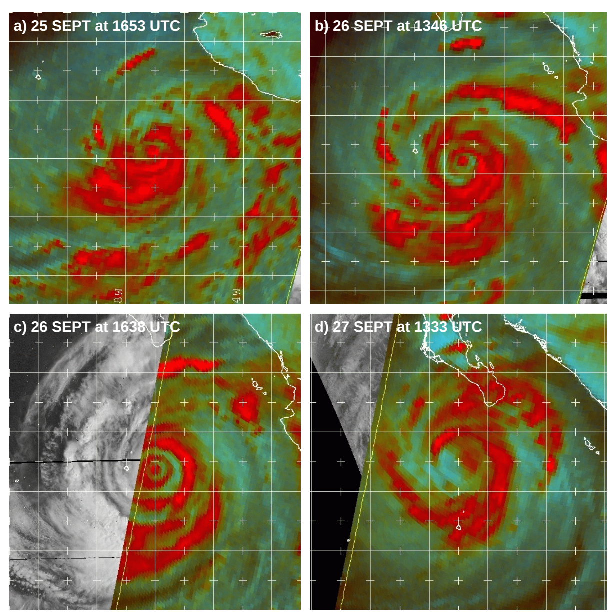

Figure 1: a) SSM/I overpass at 1653 UTC on 25 Sept, b) 1356 UTC on 26 Sept, c) 1638 UTC on 26 Sept, and d) 1333 UTC on 27 Sept. Images courtesy of NRLMRY.

The first panel is from 25 Sept at 1653 UTC, at peak intensity of 64 m s^{-1} and with a pinhole eye approximately 10 km in diameter. A partial second ring formed near r = 60 km. By the next day at 1346 UTC, the inner eye shrunk even further and additional arcs almost completely surrounded the inner eyewall. Panel c is from just three hours after panel b yet it is clear that more coherent rings had formed, and although the microwave imager missed the western portions of the inner core, aircraft data confirm that three complete concentric eyewalls were present. Another pass made by the TRMM TMI (Tropical Rainfall Measuring Mission Microwave Imager) at 0303 UTC on 27 Sept still confirms the triple eyewall configuration (not shown). Panel d then suggests that in less than ten hours, the delicate structures collapsed and no complete eyewall existed; the intensity at this time was 44 m s^{-1}.

4. AIRCRAFT OBSERVATIONS

On 25 and 26 September, a U.S. Air Force WC-130 "Hurricane Hunter" aircraft flew through the intense hurricane, and not only found the second lowest pressure ever recorded in the East Pacific, but also a very unique inner core configuration. On 25 Sept, the aircraft was in the storm from 1745-2037 UTC, and on 26 Sept, it was in the storm from 1653-1933 UTC. The highlight of the flights was on 26 Sept when the crew found three eyewalls (defined by three peaks in tangential wind through a radial leg, and by three complete rings of enhanced radar reflectivity), with radii of 11, 56, and 90 km. Data from the Hurricane Hunter aircraft are shown in Fig. 2. The data shown were taken from 3 km altitude with 30 s temporal resolution (5.5 km radial resolution). The top panel shows the tangential winds from radial legs in the northwest quadrant of the storm on 25 and 26 September, and the bottom panel shows the relative vorticity from that same quadrant on both days. Some of the data in other quadrants were noisier or of poorer resolution, so this quadrant was chosen for containing the best data available; however, the features shown are azimuthally consistent. On 25 September between 1819 and 1849 UTC (corresponding to 1.5 hours after Figure 1a), the northwest quadrant contained a peak tangential wind v_{max} of 70 m s^{-1} at r = 9 km, and peak relative vorticity ζ = 383x10^{-4} s^{-1} at r = 7 km, then a secondary maximum of v_{max} = 40 m s^{-1} at 58 km with corresponding ζ = 14x10^{-4} s^{-1} at 55 km. By 26 September (1722-1755 UTC spans the northwest leg of the Hurricane Hunter flight, and corresponds to one hour after Figure 1c), the primary eyewall had weakened at the expense of not one, but two outer eyewalls. The inner pinhole eyewall had a tangential velocity of 42 m s^{-1} at r = 11 km, and relative vorticity of 134x10^{-4} s^{-1} at r = 9 km. The secondary intermediate eyewall had v_{max} = 47 m s^{-1} at 56 km and ζ = 19x10^{-4} s^{-1} at 54 km, and the tertiary outermost eyewall had v_{max} = 46 m s^{-1} at 90 km and ζ = 14x10^{-4} s^{-1} at 82 km. The eyewall sizes found by the aircraft match those seen in Figure 1 fairly well, with discrepancies due to lack of resolution on the SSM/I and the altitude at which each is sensing (aircraft is at 3 km; SSM/I "sees" precipitation well above the freezing level, typically 5 km).

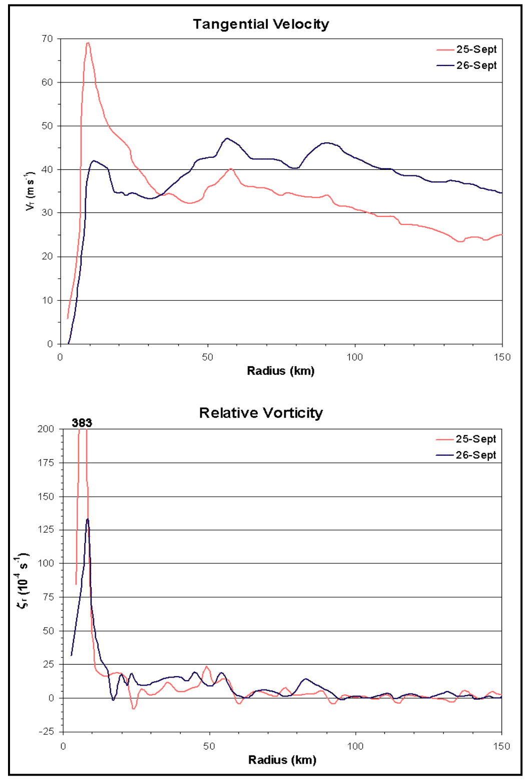

Figure 2: Radial profiles of a) tangential velocity and b) relative vorticity through the northwest quadrant of Juliette on 25 and 26 Sept., at 1819-1849 UTC and 1722-1755 UTC, respectively.

5. DISCUSSION

These observations will be discussed in the context of rotation-dominated (deformation<vorticity) and strain-dominated (deformation>vorticity) regions. This leads to comparing a filamentation timescale to a convective timescale, and the formation of "moats" as discussed in Rozoff et al. (2004).

6. REFERENCES

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