Structures and Intensity Changes of Concentric Eyewall Typhoons from Satellite Data

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1. ABSTRACT

Double eyewall (or concentric eyewall) structures, often appear in strong tropical cyclones. As the strong intensity and the dramatic structure changes they have, to study their physical features and to improve the accuracy of forecasting are very important for weather monitoring, especially for coastal area.

In this work, each hourly GSMaP image was divided into 12 sections, and the locations of the inner and outer eyewalls at each satellite observation time from the locations of the local maximum precipitation in each section were identified, and the precipitation intensity for each eyewall cases were determined. Then, the concentric eyewall typhoons were classified into 2 types: replacement type and non-replacement type. The replacement type (non-replacement) cases have much (less) significant replacement features when the outer eyewalls contracts , and generally their outer eyewalls form with larger (smaller) radius and replacements take less (more) time. More cases are needed to investigate the relationship between typhoon intensity and eyewall sizes and replacements.

KEY WORDS: Typhoon, Tropical Cyclone, Double Eyewall, Concentric Eyewall (CE), Eyewall Replacement Cycle, GSMaP.

2. INTRODUCTION

Concentric Eyewall (CE) typhoon has an inner eyewall and outer eyewall separated by the moat which is convective minimum region. This structure usually occur in strong typhoon. Hawkins and Helveston (2004) used passive microwave satellite image to research every ocean. Their results suggested that in 1997-2002, typhoons exhibiting double eyewalls had reached an intensity equal to or greater than 120 kts, Atlantic - 70%, Eastern Pacific – 50%, Western Pacific – 80%, and Southern Hemisphere – 40%. Concerning the intensity and structure variety of double eyewalls, Willoughby et al. (1982) indicated the eyewall replacement cycle dynamics. Radius outer eyewall contract and increase intensity. Conversely, radius inner eyewall decreased intensity. When intensity of the outer eyewall is stronger than the inner eyewall, the intensity of typhoons depend on the outer eyewall. Finally, the inner eyewall replaced by the outer eyewall, the intensity will enhance again.

Kuo et al. (2009) researched the moat dynamic and intensity changes of CE typhoons. According to this study, Yang et al. (2013) developed an objective method to judge the formation of CE and found some cases are different from standard eyewall replacement cycle. Because of this different, Yang et al. seperate CE typhoons into three kinds by time of CE structure maintenance: a CE with an eyewall replacement cycle (ERC; 37 cases), a CE with no replacement cycle (NRC; 17 cases),and a CE that is maintained for an extended period (CEM; 16 cases). Unlike Atlantic, there is no regular flight observations in West north Pacific. Instead, researchers use satellite-retrieved information as database. However, passive microwave observations are temporal discontinuously in tropical cyclone monitoring. Fortunately, Ushio et al.（2009）applied Kalman filter to combine infrared and passive microwave data to estimate the hourly precipitation rate, named as Global Satellite Mapping of Precipitation(GSMaP). The development of GSMaP provide possibility to analyze West north Pacific's double eyewall typhoons temporal continuously as Atlantic's.

The primarily goal of this study is to find the time series variety of CE intensity and structure, then hoping to find some characteristics of CE typhoons and can offer a reference to forecasts of CE typhoons intensity and structural.

3. MATERIALS AND METHODS / EXPERIMENTAL

We choose the GSMaP-MVK(Global Satellite Mapping of Precipitation-Moving Vector with Kalman filter) reanalysis data for our analysis. The product’s highest space and time resolutions are 0.1 and 1 hour, respectively. Spatial Coverage: $59.95^{\circ}\mathrm{N}-59.95^{\circ}\mathrm{S}$; $0.05^{\circ}\mathrm{E}-0.05^{\circ}\mathrm{W}$. Temporal Range: 2000 to 2010. In addition, JTWC(Joint Typhoon Warning Center) Tropical Cyclone Best Track Data is used. The time resolution of the best tracks are 6 hourly per day (0000, 0600, 1200, 1800 UTC) and the data contains the center coordinates, maximum average wind speed, minimum center pressure and intensity of the tropical cyclones. Because of time resolution of the best tracks are 6 hourly per day that can’t offer hourly data for the study needed, this best tracks data is for reference only.

Regarding to deciding typhoon center, decision method depend on different situation. First, if eye is surrounded with an obviously inner eyewall then finding local minimum rain rate point is the typhoon center. Second, if inner eyewall is not clear, looking for the data of 2 hour before and after and assuming speed of typhoon is constant. Finally, interpolating a point and seeking local minimum rain rate point which distance with each other is minimum. Third, typhoon has ring or spiral rain bend, but center region doesn’t have weak rain rate region surrounded with an inner eyewall, it is all strong rain rate bend (Fig. 1). The maximum rain rate point is decided to the typhoon center. Fourth, if typhoon don’t has half or all closed inner eyewall and ring or spiral rain bend distribution, we skip this data.

Concerning eyewall recognition, a formula is used for verifying eyewall:

$$\frac{rr_{max}-rr_{inner\_min}}{rr_{max}}\times 100\% > 20\%$$

Where rr_{max} is maximum rain rate, rr_{inner_min} is minimum rain rate on the radially inner side. The 20% is experience that testing numerous cases, finally getting best reult. In addition to this formula, precipitation rate needs > 5 mm/hour.

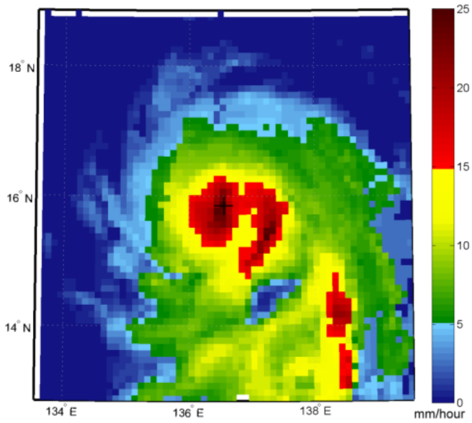

Fig 1. The chart of typhoon doesn't have clear eye.

About the time that eyewall formation or dissipating, it is hard to verify eyewall structure, the limit is added to enhance eyewall recognition: precipitation intensity of eyewall region should be tougher than precipitation intensity of typhoon area.

With respect to CE structure axisymmetry, hourly GSMaP imageries were divided into 12 section, outward from the center, every 10km setting a width of less than 45km ring band, and we identified the locations of inner and outer eyewall at each time from the locations of local maximum precipitation in each section, and at least eight out of twelve profiles satisfy that having inner and outer eyewall. During the above procedure, the temporal continuously imageries of eyewall rain rate intensity.

4. RESULT AND DISSCUSION

This study analyze the CE typhoons that in 2000-2010, West north pacific and didn't touch land during CE structure life cycle. Depending on inner and outer eyewall development, the two types of CE typhoons has been set: replacement and non-replacement type.

5.1 Replacement type case

In the cycle of eyewall replacement, inner eyewall's rain rate intensity weak and is once less than standard value or its structure dissipate in the cycle of eyewall replacement which is replacement type case defined in this research. From Fig. 2, red and blue points are the location of local maximum rain rate value, red and blue curves are cubic regression curve, bar charts are average rain rate that are the ring band rain rate average from the curve to radial outer direction 10 km and inner direction 10km, gray line is time series of JTWC maximum wind intensity. Fig. 2 is rate which is precipitation intensity of eyewall region divided by precipitation intensity of typhoon area, red line is inner eyewall, blue line is outer etewall. Point "a" present outer eyewall's formation from Fig. 2. After outer eyewall format, the direction of eyewall gradually contract and enhance its intensity. Point "g" is the time that the outer eyewall is first time stronger than the inner eyewall (Fig. 2). Inner eyewall still continuously weak with the time passing. Point "d", inner eyewall intensity ratio is less than 1, eyewall intensity is weaker than total typhoon intensity which is defined as the time that inner eyewall dispate and replacement cycle has been finished. The total time of eyewall replacement cycle is 12hr. The remaining eyewall still continuously contract.

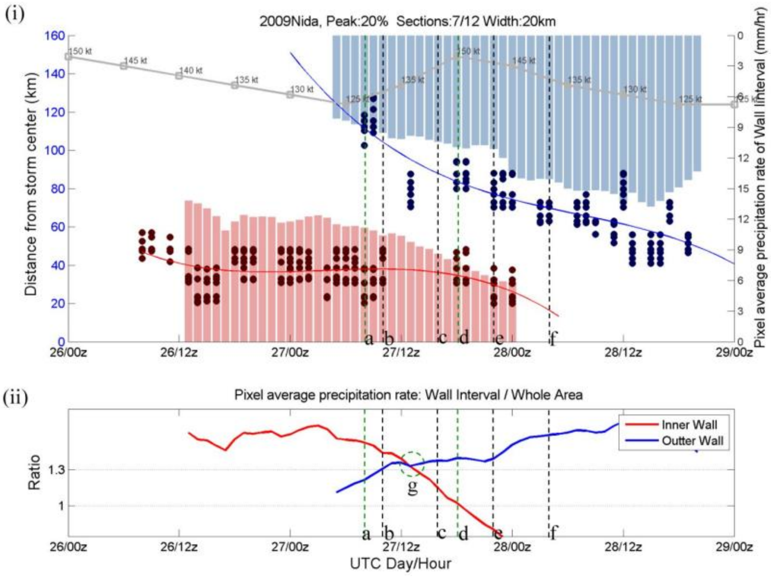

Fig 2. The chart of eyewalls rain rate intensity with time series. (2009 Nida)

5.2 Non-replacement case

In the cycle of eyewall replacement, inner eyewall's rain rate intensity is not less than standard value in the cycle of eyewall replacement which is replacement type case defined in this research. I this case the outer eyewall structure may dissipate or inner and outer eyewall combine each other into a eyewall. Point "a" present the formation of eyewall from Fig 3. After this time, the value that inner eyewall weak in non-replacement type is less than the value in replacement type. At the time in point "c", the CE structure still can be confirmed, but the moment in point "d" and "e", the shape of both eyewalls is not clear. The time in point "d", just one eyewall can be confirmed. From above situation, it has a possibility that both eyewalls combine with each other during the cycle.

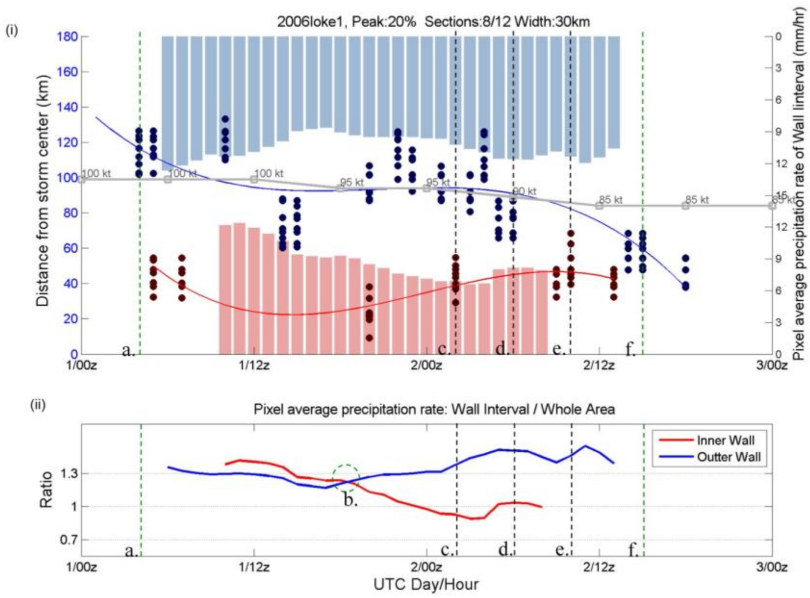

Fig 3. The chart of eyewalls rain rate intensity with time series. (2006 Ioke)

5. CONCLUSION

There are 21cases, 14cases are replacement type, 7 are non-replacement type. In 14 replacement type cases, average time of eyewall replacement is 16 hr (standard deviation is 14.7 hr), outer eyewall radius in formation time is 121.7 km (standard deviation is 29.2 km).

In 7 non-replacement type cases, average time of eyewall combination or dissipation is 33.4 hr (standard deviation is 14 hr), outer eyewall radius in formation time is 101km (standard deviation is 12.5 km).During the above discussion , we can find that replacement type (non-replacement) cases have much (less) significant replacement features when the outer eyewalls contracts , and generally their outer eyewalls form with larger (smaller) radius and replacements take less (more) time. Radius of formation eyewall, replacement type cases is larger than non-replacement type cases. This result confirm with the result which Didlake and Houze (2011) suggested.

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