Characteristic Study on Mesoscale Structures of Typhoon Otto (1998) in Use of the Green Island Doppler Radar Data

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Abstract

This study focuses on the mesoscale analysis of inner and outer rainband features of Typhoon Otto (1998) before and after affected by the Central Mountain Range (CMR) which exceeds 1500 m in elevation while it was approaching the southeast coast of Taiwan in the northwestward movement on the third and fourth of August, 1998.

While the typhoon was over open ocean, the maximum averaged wind speed near the typhoon center was about 25 m/s with gusty wind of 33 m/s. The radar echoes displayed that the circulation was not well organized with an opened eyewall which was distributed around the first and second quadrants accompanying with several prominent rainbands separated from eyewall. The propagating speed of the outer rainband in the first quadrant was obviously faster than that of the system itself. The vertical cross section along the radial showed that the outer rainbands tilting outward with maximum reflectivity larger than 45 dBZ were more developed than the inner core clouds with maximum reflectivity larger than 30 dBZ and the minimum distance of eyewall larger than 30 dBZ in reflectivity was about 30 km away from the typhoon center.

While the typhoon system was gradually affected by the topography of Taiwan, its moving direction changed to north-north-west and propagating speed went up to 33 km/h. The opened eyewall clouds shifted to the second and third quadrants due to that the blocking effect made wind deceleration in the first quadrant at lower atmosphere. Based on the vertical structures of the system, the strength of the eyewall became more intense compared with the outer rainbands and its height could reach more than 12 km. Also, the radius of the eyewall curvature was getting smaller with 15 km in minimum. It tells the typhoon system was more organized at the second and third quadrants. Meanwhile, the confluence of the southwesterly flow triggered by the further outer circulation of the storm around the island and the northwesterly flow from the inner circulation of the storm played an important role to accumulate air mass and accelerate air speed in the second and third quadrants of the system at lower atmosphere. Therefore, the left quadrant in the lower portion (below 1.5 km in altitude) possessed stronger radial winds (51 m/s in maximum) than the right quadrant (44 m/s in maximum) in the same layer. However, the upper portion (above 2.0 km) had the reverse mode. According to the estimation of typhoon center by using the Wood and Brown (1992) scheme and an adjustment by the least reflectivity method, the center of system at the level of 1.0 km in altitude with a slower propagating speed didn coincide with the centers above that level and therefore, it showed a distorted appearance.

1. Introduction

By using the observational data collected by the DWSR-92C Doppler weather radar (287 m above sea surface) which was deployed at the Green Island (hereafter, GRI, 22.6667°N and 121.4833°E, at about 36 km off the southeast coast of Taiwan) by the Chinese Air Force Weather Wing in the late 1997, this study of orographic effect on typhoon will focus on the mesoscale analysis of eyewall, inner and outer rainband features of Typhoon Otto (1998) while it was approaching the southeast coast of Taiwan in the northwestward movement with speed of 20 km/hr on the 3 and 4 August 1998. Due to lack of aerial measurements as well as surface observations over the western North Pacific Ocean, it was quite difficult to provide a lot of real time observations on the mesoscale structures of typhoons. Therefore the unique integration of the GRI Doppler radar data and the limited conventional observations over land became a key tool to support this study. Typhoon Otto (1998) was the first westward-moving typhoon reconnoitered by the GRI Doppler radar. The radar data gave a more detailed information to improve the accuracy of storm track forecast, to realize the possible precipitation and wind field distributions as well as to illustrate the variations of eyewall and rainband structures before its landfall at about 0420 UTC 4 August. Also, the invaluable radar data helped us to elucidate the exclusive variations of structures for westward moving typhoons while it was over the open ocean and while it was affected by the CMR of Taiwan Island.

2. Radar analysis of Typhoon Otto over the open Ocean

During the surveillance of Typhoon Otto, there were two scanning strategies and two range resolutions being employed. Firstly, as the typhoon was located at a distance more than 120 km away from the radar site, the radar only executed the non-Doppler mode scanning strategy with range of 480 km, resolution of 2 km and elevation angles of -0.4, 0.3, 1.2, 2.4, 4.0 and 6.6 degrees. This long range mode was executed at the minute of 00, 20 and 40 for each hour. Secondly, the Doppler mode scanning strategy was applied while typhoon moved near the vicinity of 120 km range, and consisted of the elevation angles of 0.4, 1.0, 1.7, 2.6, 3.6, 4.8, 6.0, 7.5, 9.5, 12.5, 16.5, 24.0 and 38.0 degrees with range of 120 km and resolution of 500 m and executed at the 30th and the 50th minute each hour.

The PPI pictures at 1320 UTC on 3 August 1998 at the -0.4 deg elevation angle of long range scanning (480 km) could provide an entire picture for the evolution of rainbands appeared over the open ocean (Fig. 1). The intensity of inner core region including the typhoon center and the core bands was less than 35 dBZ in reflectivity and it was difficult to determine the appearance of eyewall due to the weaker echoes at the inner core region. It was obviously that the most intense portion of rainbands existed at the outer ring of the first quadrant. Several convective cells in linear orientation with maximum intensity up to 45 dBZ were embedded inside the farthest outer rainband. Their patterns seemed different from the model of the stationary band complex (Willoughby, 1984). The convective system propagated north-northwestward in a speed of 12.5 m/s (45 km/h) relative to ground which was faster than the moving speed of typhoon itself and the main portion of outer rainband.

The combination of six sweeps in each long range scanning elucidates the illustrations of PPIs in vertical cross section. At 1320 UTC, cross section A-B and A-C (Fig. 2) clearly depicted that the most intense cell was the farther one with maximum intensity up to 40 dBZ and the shaded area of 10 dBZ extended upward over than 12 km in height. In contrast, there was no prominent convection appearing at the inner core. Thus the distribution of rainband echoes at this azimuth was more intense outward. The vertical cross sections along the radial showed that the rainbands tilted outward with the maximum reflectivity larger than 45 dBZ and the maximum altitude more than 12 km and were more developed than the core band with the maximum reflectivity of 35 dBZ and the maximum altitude less than 10 km. Moreover, the minimum distance of the core band with reflectivity of 20 dBZ was about 30 km away from the typhoon center. However, the eyewall structure was actually difficult to be determined over the open ocean.

3. Mesoscale behaviors of Typhoon Otto in the presence of orographic effect

While the Typhoon Otto was approaching the Taiwan coastal line and had been affected by the Taiwan orography, the series of CAPPIs, including both Doppler and non-Doppler observations could identify the temporal variations of structure inside the typhoon. The datasets in Doppler mode which involved the maximum positive and negative radial velocities were primarily executed to derive the position of typhoon centers via the scheme initiated by Wood and Brown (1992). Then the estimated centers were subjectively modified referring to the geometric centers of area enclosed by weaker echoes; However, the assessment of centers for non-Doppler observations only referred to the geometric centers of area with minimum echoes. During this period, the direction of the storm movement changed from northwest to north-northwest in the maximum speed of 35 km/h. As the typhoon had approached the sea shore closely since 2230 UTC 3 August (Fig. 3), the eye wall could be identified obviously. Some convective cells distributed over the first and second quadrants were propagating westward and west-northwestward, and had an angular difference larger than 10 degrees with respect to the moving direction of typhoon (~345 deg). Their mean propagating speed was 60 km/h (25 km/h relative to the storm motion), about 2 times larger than that of typhoon system. In addition, the outer rainbands in the second and third quadrants also shifted inward step by step and intensified the inner rainbands and the eyewall eventually. Furthermore, the inner rainbands propagated inward and merged with the eyewall, making it more organized. The propagating speed of the bands was about 30 km/h relative to ground. Due to the event occurred discontinuously, it made the development of eyewall periodically. Conclusively speaking, the rainbands at the second and third quadrants were less intense than the eyewall, which was opposite to the findings over the open ocean. The isotach patterns illustrated in the stream line analysis at 0300 and 0500 UTC 4 August (not shown) gave the evidence that the mechanism for maintaining the development of inner rainbands and eyewall was related to the confluence between the southwesterly flow in speed of 25 m/s triggered by the farther outer circulation of the storm around the island and the northwesterly flow in speed of 15 m/s near the inner circulation of storm itself.

The vertical characteristics of rainbands inside the storm was apparently different from those existed over the open ocean. Based on the vertical echo structures of the system at the 0050UTC and 0130 UTC on the 4 August along the 240 - 260 deg in azimuth (Fig. 4), the strength of the eyewall (>10 dBZ in reflectivity) became more intense compared with the outer rainbands and its height could reach more than 12 km (>10 dBZ). Also, the radius of the eyewall curvature (>10 dBZ) was getting smaller with 10 km in minimum. The composite of the Doppler velocity field as well as the reflectivity field were pretty in phase in the vicinity of eyewall. The gradient of Doppler velocity was quite great, especially at the inward and upward sides. It implied that the intense vertical wind shear as well as the horizontal wind shear existed over this region accordingly.

The circulation variations were critical between lower (< 2 km) and upper (> 2 km) levels due to the orographic effect. At 0050 UTC on 4 August, the radial velocity fields showed that the maximum wind speed at the first quadrant (with 42 m/s at the 1 km level, shown in Fig. 5) was less than that at the second quadrant (with 50 m/s at the same level) below 2 km in height. However, the radial velocity fields at the upper levels had the opposite situation (not shown). It means that the obstacle blocking at the average altitude of 2000 m in the southernmost part of CMR was the key factor for the wind deceleration at the first quadrant of the storm in lower atmosphere.

4. Summaries

Basically, the following summaries can be made after the above analyses:

a. While the typhoon was over the open ocean, it steadily moved northwestward in speed of 25 km/h. The radar echoes displayed that the eyewall was not well organized and the rainbands around the first and second quadrants separating from the inner core region were embedded with cellular convections. The outer rainbands were more intense than the core band. The propagating speed of the farther outer rainbands in the first quadrant was obviously faster than that of the system itself. The vertical cross section along the radial showed that the outer rainbands tilting outward and extending upward over 10 km with maximum reflectivity larger than 45 dBZ were better organized than the inner clouds with height less than 10 km and maximum reflectivity larger than 30 dBZ. The life duration of the farther outer rainbands at the first quadrant could last more than 2 hours usually.

b. As the typhoon system was approaching the Taiwan coastal line gradually, its moving direction changed to north-north-west and propagating speed went up to 35 km/h. The semi-elliptic eyewall was built up at the second and third quadrants due to the low level confluence between the southwesterly flow triggered by the farther outer circulation of the storm around the island and the northwesterly flow near the inner circulation of storm itself. This intense southwesterly flow pushed the rainbands inward and gradually merged with the eyewall. The phenomenon was probably the primary mechanism to maintain the development of eyewall. Therefore, based on the vertical structures of the system, the strength of the eyewall became more intense (more than 40 dBZ in reflectivity) comparing with the outer rainbands and its height could reach more than 12 km. Such characteristics were opposite to those of typhoon without the influence of orography. The linear rainband at the first quadrant propagated outward and behaved a well organized feature just off the coastal line seemingly due to a localized and unique confluence at that region.

References

Willoughby, H. E., F. D. Marks, Jr., and R. J. Feinberg, 1984: Stationary and moving convective bands in hurricane. *J. Atmos. Sci.*, **41**, 3189-3211.

Wood, V. T. and, R. A. Brown, 1992: Effects of Radar Proximity on Single-Doppler Velocity Signatures of Axisymmetric Rotation and Divergence. *Mon. Wea. Rev.*, **120**, 2798 807.

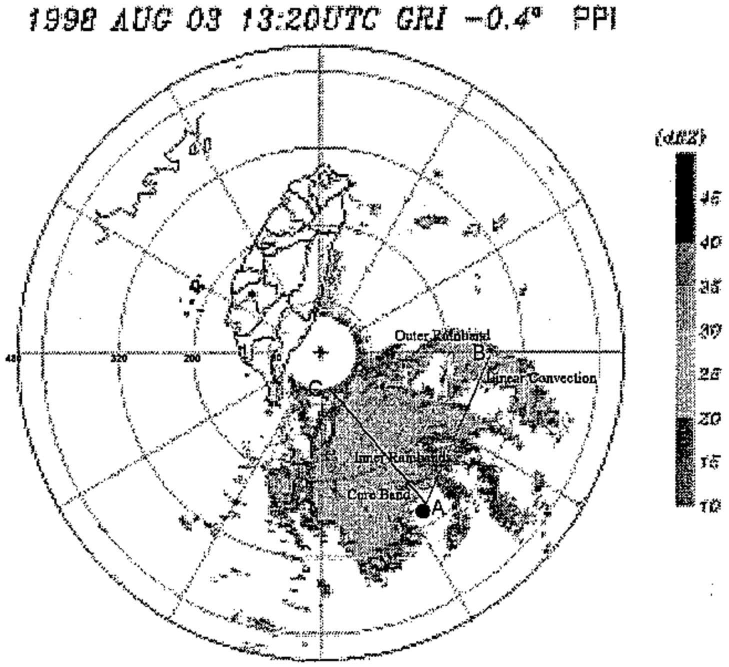

Fig. 1 The reflectivity analysis of PPI for long range scanning (480 km) at -0.4 degree elevation angle at 1320 UTC 3 August 1998. The inner circular range is 80 km, and the outermost ring is 480 km. The radar site is at the center of the circles. The solid lines represent the locations of vertical cross sections shown in Fig. 2 (a).

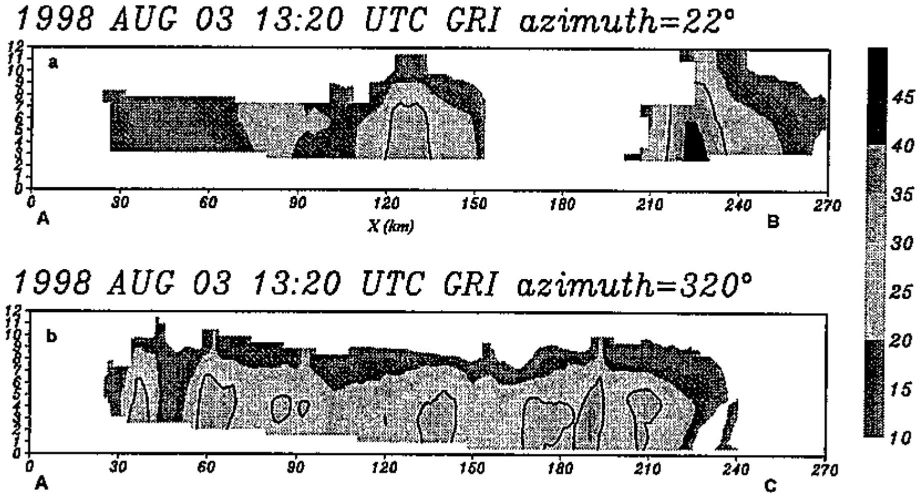

Fig. 2 The vertical cross sections of reflectivity of Typhoon Otto at (a) 1320 UTC 3 August at azimuthal angle of 22 degree and (b) 1320 UTC 3 August at azimuthal angle of 320 degree degree. The typhoon center is located at the position of X=0.

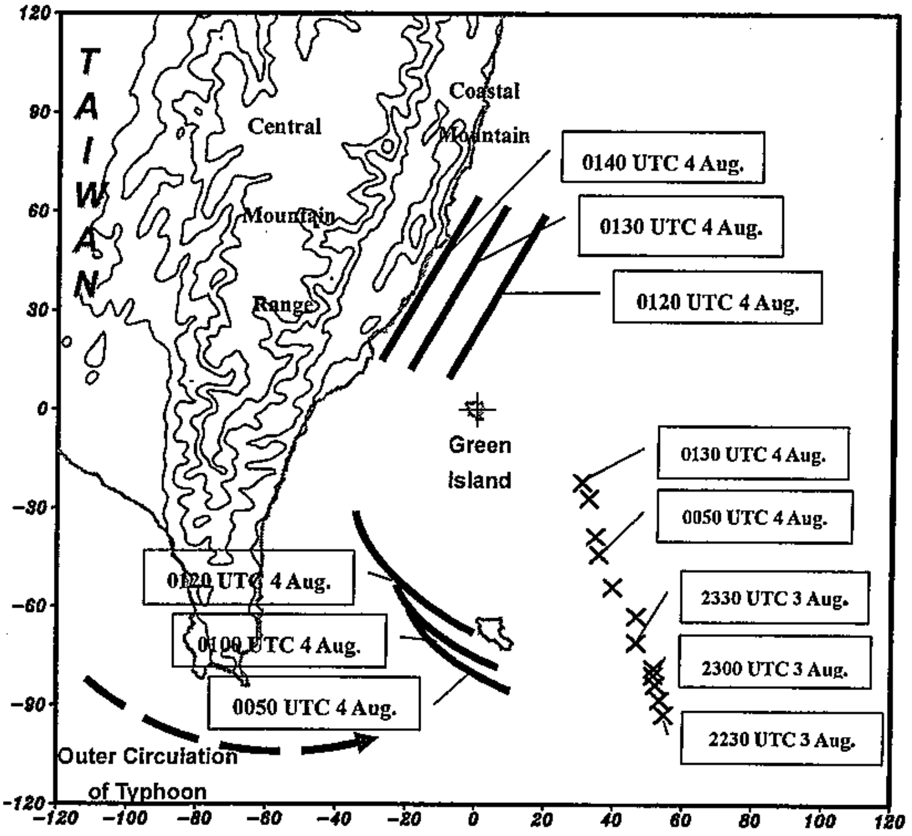

Fig. 3 The schematic diagram for the temporal variation of typhoon center and related rainbands in the presence of orography. The symbol stands for the radar site and the symbol represents the typhoon center. The solid straight and curve lines symbolize the rainbands related to the typhoon system. The dashed line with arrow means the outer circulation of typhoon. The values for each isopleths of height in Taiwan are 100, 500, 1000 and 1500 m ASL, respectively.

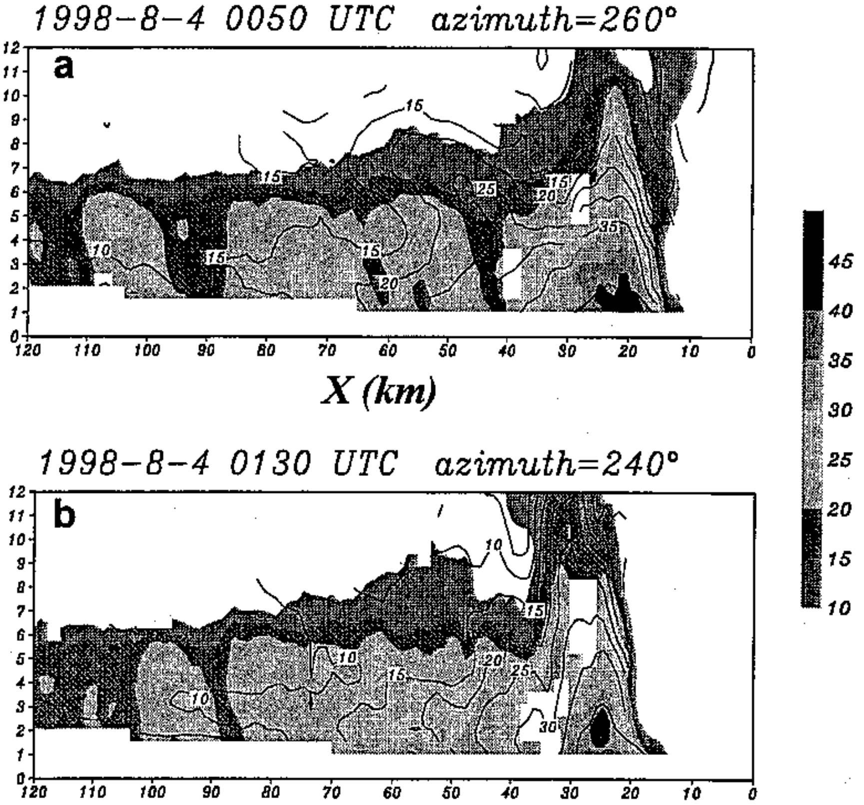

Fig. 4 The vertical cross sections of Typhoon Otto at (a) 0050 UTC 4 August at azimuthal angle of 260 degree, (b) 0130 UTC 4 August 1998 at azimuthal angle of 240 degree. The Doppler velocity is superimposed over reflectivity. The typhoon center is located at the position of X=0.

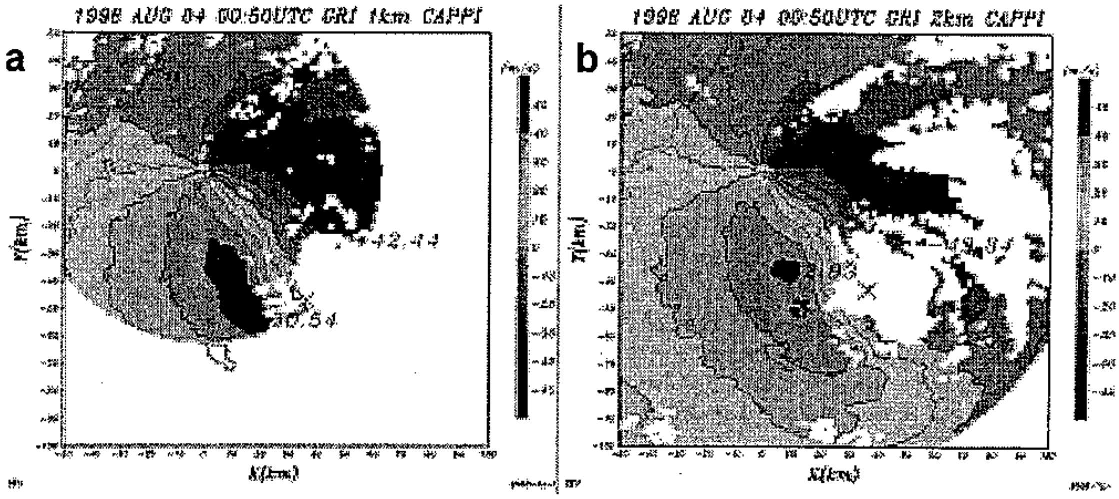

Fig. 5 The Doppler velocity analysis of CAPPIs at (a) 1 km, (b) 2 km in altitude at 0050 UTC 4 August 1998. The symbol stands for the radar site and the symbol represents the typhoon center. The domain size is bounded in 150X150 km^2.