Radar Analysis for the Characteristics of Typhoon Rainband over the Open Ocean

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Abstract

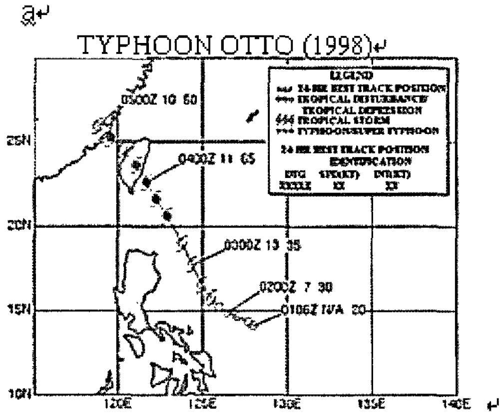
The study focuses on the characteristic of the eyewall and rainbands embedded within the typhoon Otto (1998) and Bilis (2000) during developing over the open ocean by applying the bounded volume scans in long range (480 km) which offered three dimensional messages of typhoons. Both typhoons propagated in northwestward path but along different intensity. The eyewall of typhoon Otto was not well organized. Marked rainbands which were located out of core region at the first and second quadrant relative to the moving direction of typhoon are embedded with active convections Typhoon Bilis exhibited its double eyewall characteristic off the southeastern cost of Taiwan by around 300 km. Cellular convections only accompanied with the outermost rainband. The vertical structure for rainbands and the typhoon entity shows that the outer rainbands tilted outward and were more intense than the core region. The result suggested that the deep convection associated with typhoon system would like developed in the outer region rather than the core region, less regarding with the intensity of typhoon.

1. Introduction

The observation for the structure of tropical cyclone developing over the open ocean primarily depends upon the meteorological satellite and airborne instruments before the implementation of weather radar. The analysis by the passive microwave radiometer reveals that the total rainfall rate of a matured hurricane is twice lower than a tropical depression (Adler and Roger 1977, Roger and Adler 1981). Roger et al. (1994) discussed the structural difference between a intensifying hurricane and a weakening one by the data collected from the DMSP-Special Sensor Microwave (Imager). The result showed that the rainfall rate intensified near the core region of hurricane (<220 km), and tended to weaken around the outer (222~444 km). Parish (1982) analyzed the precipitation characteristic of Hurricane Fredric (1979) during its landfall by using the radar data. They found that the principal precipitation area is located at the left flank along the moving direction of the storm before 22 hour of landfall. When the central circulation of cyclone fast closed to the coastal line, there developed convection at the northern flank of the eyewall. Marks (1985) discussed the precipitation structure for the hurricane Allen (1980) by analyzing the airborne radar data. Burpee and Black (1989) integrated the conclusion by Marks (1985) and analyzed Hurricane Alicia (1983) and Elena (1985) to study the precipitation characteristics, for these hurricanes are in different moving speed. The result shows that the principal rainband embedded within the slowly propagating hurricane developed in front of the moving direction of the storm, and the one associated with the fast propagating hurricane is located in the left flank along the moving direction. The proposal for the active radar observation boarding on a satellite has been activated in the late twenty century. An X-band precipitation radar by an international cooperation was installed on a lower orbit satellite during the Tropical Rainfall Measuring Mission (TRMM). It has provided remarkable findings for monitoring the category and characteristic of the precipitation system over the tropical ocean (Kummerow et al. 2000). The previous studies summarized that the precipitation characteristic of a hurricane related to its intensity and moving speed. And these studies, however, barely describe the variation for the mesoscale structure of rainband embedded within the hurricane. The Green Island weather radar, which is deployed at a small island off southeastern Taiwan, operated volume scans consisting of multi-sweeps in lower pulse repetition frequency (PRF) since typhoon Otto (1998) had propagated into the vicinity of southeastern Taiwan. The research for the typhoon by Hor et al. (2005) by using the data showed that such a scanning strategy could provide feasible 3-D illustration to analyze the mesoscale characteristic of typhoon. The present research investigated the structural characteristic of northwestward propagating typhoons, typhoon Otto and super typhoon Bilis, developing over the open ocean by long range volume scan collected from Green Island radar.

2. Synoptic Aspect

The origin for the initiation of typhoon Otto and Bilis (Fig 1) were somewhat different though they were located over the ocean out of eastern Philippines. In fact, the source for Typhoon Bilis was farther east than that for typhoon Otto. The longer path over the ocean brought more opportunities to strengthen the development of typhoon Bilis. From surface to 700 hPa weather a



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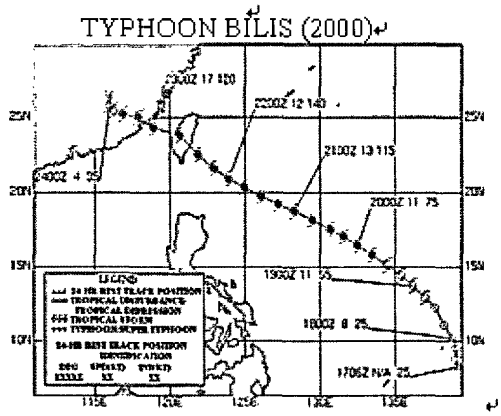

Fig. 1. Track maps of (a) Typhoon Otto (1998) and (b) Bilis (2000) reported by the Joint Typhoon Warning Center (JTWC).

charts (Fig 2,3) depicted that both typhoons were steered by the outer flow of the subtropical high without the influence of midlatitute frontal system. The orientation and intensity of subtropical high during both typhoons were approaching Taiwan area, however, were slightly different. The ridge of high pressure system was confined to the western Pacific Ocean at 500 hPa (Fig 2g, h and Fig 3g, h) for the environment of typhoon Otto, leading the typhoon moved more north-northwestward. The typhoon Bilis propagated northwestward stably since the pressure ridge extended to the East Asia and mainland China along 30°N. The environmental conditions at the lower level (below 850 hPa) for both typhoons were similar so that their path and moving speed (10 to 15 km h^{-1}) were also alike in the vicinity of eastern Taiwan.

3. Description of radar data

The characteristic of Green Island weather radar and the scanning strategy for typhoon Otto has been described by Hor et al. (2005). The lower PRF scanning set up 6 sweeps for a volume scan, which included the lowest elevation angle of -0.4 degree. It could extend to 480 km of range with spacing resolution of 2 km for every twenty minutes. During the surveillance of typhoon Bilis, there were 4 sweeps consisting with elevation angles of 0.4, 1.0, 2.4 and 4.0 degree within a volume scan. Two kinds of resolution of 1 and 2 km for maximum range of 240 and 480 km were proposed respectively. The time interval for every volume scan was 20 minutes.

4. Radar analysis of typhoon Otto over the open ocean – an overview

The characteristic of typhoon Otto while developing over the open ocean has been discussed by Hor et al. (2005). Their study illustrated that the eyewall and inner rainbands of typhoon Otto were less organized, even Spiral rainabnds were hard to be determined.

(Fig 4). Rainbands located at the first and second quadrants still exhibited curve shaped with maximum echoes less than 40 dBZ. The most developing and organized rainband was located at the outer area of the first quadrant by 1320 UTC 4 August 1998. The pronounced cellular convection was associated with the rainband. It intensified between 1320 UTC and 1400 UTC, and sustained no less than 2 hours before moving inland. It propagated north-northwestward in speed of 45 km h^{-1} (12 m s^{-1}) relative to the ground which was almost twice faster than the moving speed of typhoon entity.

The vertical cross section of rainbands demonstrated that the development and intensity of the rainband were proportional to the distance from the center of typhoon (Fig 5). An active convection, which extended to 12 km in height with echo larger than 45 dBZ, was developing over the distance of 210 km out of center. It tilted outward with 34 to 44 degree from the vertical. On the contrary, the core area had no marked slanting characteristic, with maximum reflectivity less than 35 dBZ.

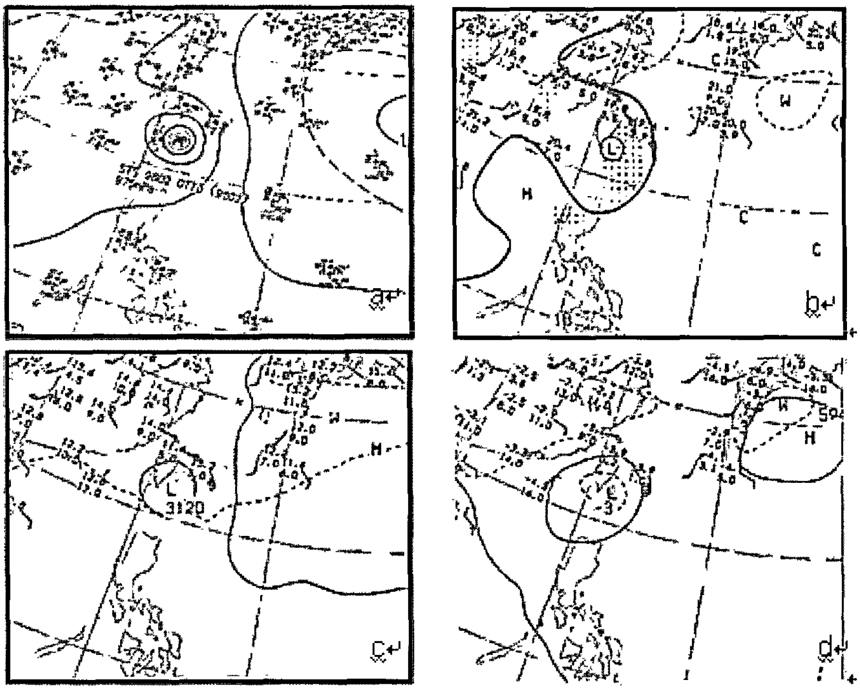

Fig. 2. Weather charts over the East Asian region for typhoon Otto by 0000 UTC 4 August 1998. (a) surface, (b) 850 hPa, (c) 700 hPa and (d) 500 hPa. (Adopted from Japan Meteorological Agency)

5. Characteristic of typhoon Bilis over the open ocean

The entire feature of the typhoon, including rainband and double eyewall, did not appear until 0200 UTC 22 August at the lowest elevation of PPI. It

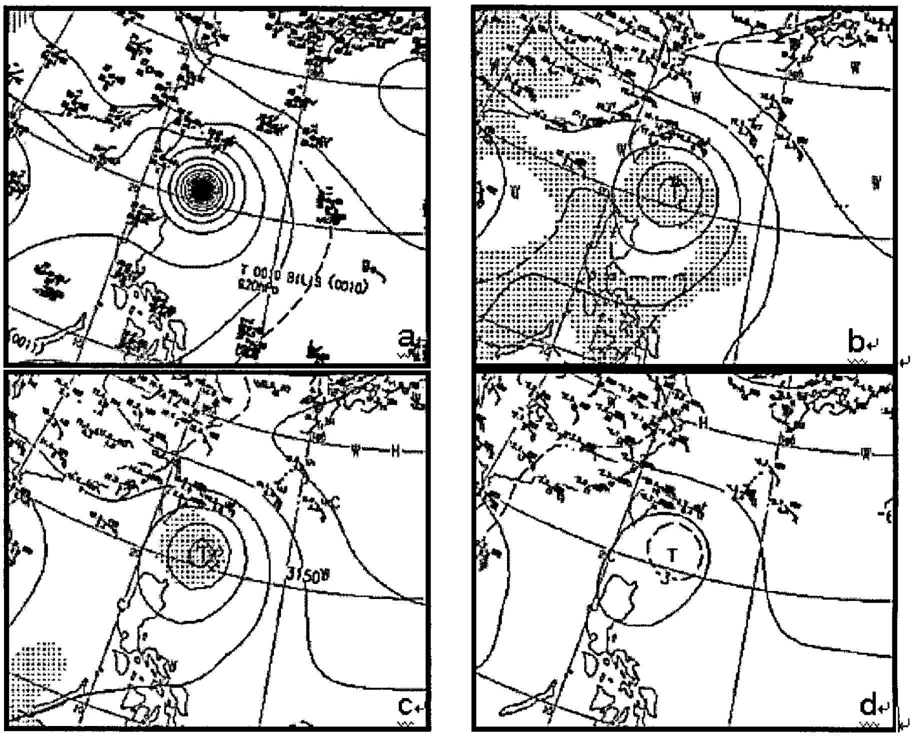

Fig. 3. Weather charts over the East Asian region for typhoon Bilis by 0000 UTC 22 August 2000. (a) surface, (b) 850 hPa, (c) 700 hPa and (d) 500 hPa. (Adopted from Japan Meteorological Agency)

was evident that the double eyewall had established while had been positioning by 300 km far from the radar site.

Before the primary entity of typhoon was captured by the GRI radar, the outermost rainbands of typhoon Bilis exhibited linear convection which is constructed by isolate cells (enclosed with 30 dBZ contours). The orientation of each organized rainband almost parallels along the Coastal Mountain while propagating inland. But the cells, orienting northwest-southeastward, has a significant angle with the band. They propagated outward wave by wave with speed of 40 km h^{-1} (10 m s^{-1}) since 1620 UTC 21 August (fig 6a).

Since the entity of typhoon was well organized, spiral rainbands associated with core area (including eyewall), inner and outer as well as outermost rainband are distinctive by an apparent gap when the eye of typhoon is propagating into the 240 km ring (fig 6b) by 0500 UTC. Outermost rainbands at the first and second quadrants were separated by a gap which is 20-40 km wide. Isolated cellular convections, which managed to be east-west orientation, were still organized so that the rainband was more intense than other spiral bands embedded within the storm. In addition to the outermost rainband, the eyewall and inner rainband seemed to be identical in strength.

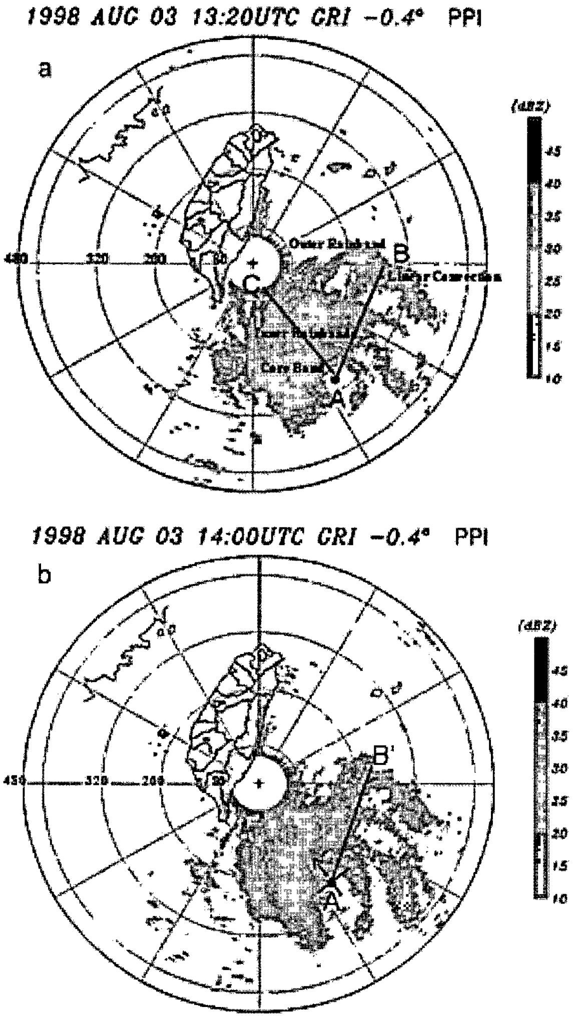

Fig. 4. The reflectivity analysis of PPI for long range scanning (480 km) at -0.4 degree elevation angle. (a) 1320 UTC and (b) 1400 UTC 3 August 1998. The inner circular range is 80 km, and the outermost ring is 480 km. The radar site is at the center of the circles. The solid lines represent the locations of vertical cross sections shown in Fig. 5. (Adopted from Hor et al. 2005)

The non-Doppler mode scan for the surveillance of typhoon Bilis was also consisted of multiple sweepings so that it could made the three dimensional structure of typhoon feasible.

The cellular structure of the outermost rainband is well pronounced after 1800 UTC 21 August. The enclosed area by 20 dBZ contours could extend to approximate 9 km in height upward. And the height of intense echo that was larger than 30 dBZ reach to 7 km in altitude. The vertical orientation of cells within the rainband exhibited slight slantwise outward with 25 degree from the vertical (fig 7a). By 0500 UTC, the outermost rainband also hold the similar characteristic (fig 7b). The cell declined toward to its moving direction with approximate 20 degree. According to its east-westward horizontal extension, the base of the cell possessed over 20 km.

The principal cross section across eyewall and outer rainband from the eye of typhoon illustrates in cross section C-C' (Fig 7c). The cellular structure exhibited outward slantwise with 20–25 degree, which was consistent with the cell associated with the outermost rainband, except that the inner eyewall extended vertically. The echo top of 30 dBZ for each cell could reach to 5 km. However, the inner eyewall extended over 10 km in height, which was higher than other rainbands, by shaded area of 20 dBZ. The eye was 15 km in diameter, and the distance between eyewall and inner eyewall was over 40 km. The cells between eyewall and outer rainband were spread by 20 km interval uniformly. The echo of cells associated with the outer rainband was less than 30 dBZ,

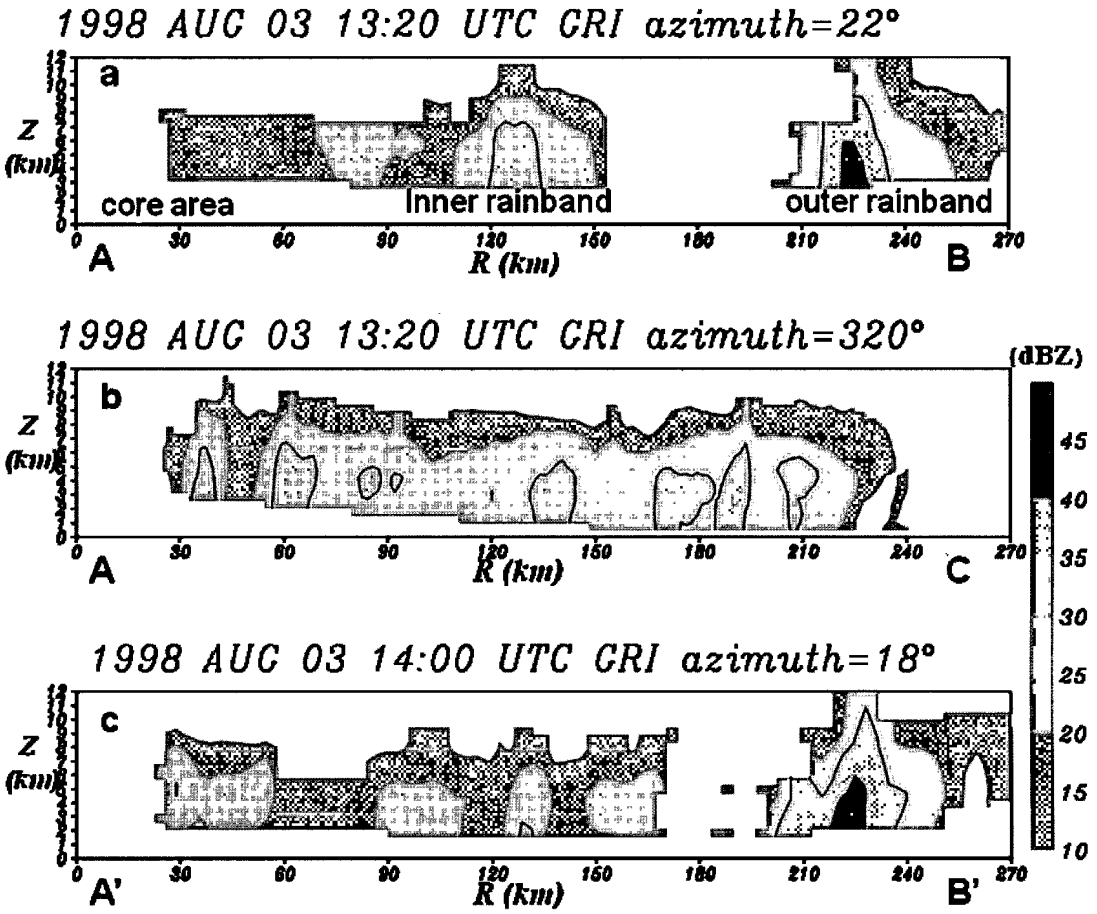

Fig. 5. The vertical cross sections of reflectivity of Typhoon Otto at (a) 1320 UTC 3 August at azimuthal angle of 22 degree, (b) 1320 UTC 3 August at azimuthal angle of 320 degree, (c) 1400 UTC 3 August at azimuthal angle of 18 degree and (d) 1440 UTC 3 August at azimuthal angle of 8 degree . The typhoon center is located at the position of R=0. (Adopted from Hor et al. 2005)

indicating that the rainband was slight intensity comparing to the inner one due to the well organization of typhoon entity. Nevertheless, the outermost rainband was remarkable that it was constructed by pronounced convective cells which were intense than the other cells within the entity of typhoon. It strengthened when it got closer to the coast, suggesting the development of the outermost rainband was influenced by the orography of the southeastern Taiwan somehow.

6. Discussion and Summary

The analysis which studied two northwestward propagating typhoons by their different intensities demonstrated that the outermost rainband associated with typhoon system at first and second quadrants was more intense and well developing than rainbands embedded

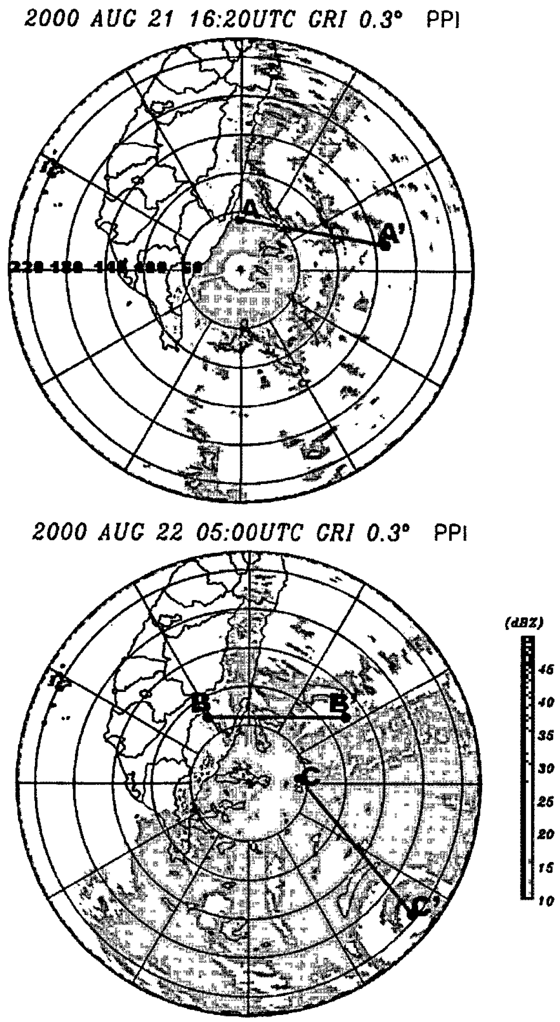

Fig6. The reflectivity analysis of PPI for long range scanning (240 km) at 0.3 degree elevation angle for typhoon Bilis. (a) 1620 UTC 21 August and (b) 0500 UTC 22 August 2000. The inner circular range is 60 km, and the outermost ring is 240 km. The radar site is at the center of the circles. The solid lines represent the locations of vertical cross sections shown in Fig. 7.

within the typhoon entity. The cellular convection constructed the outermost rainband tilting outward. The typhoon entity, however, had slight difference from the intensity of typhoon. The eyewall of typhoon Otto was not prominent comparing to the other rainbands. It was evident that the outer the rainband was located, the more the convection was active. The eyewall of typhoon Bilis was also in moderate intensity, which was no stronger than the other rainbands. All the eyewalls extended straightly in vertical. The characteristics for both typhoons were distinctive from PPI plot, for they were different category. The vertical characteristic for both typhoon, however, were somewhat alike based on the multi-sweeps scanning in lower PRF. Some preliminary findings are summarized as following:

1. Present northwest moving typhoons were all steered by the outer circulation of the subtropical high. The longer path over the open ocean brought the opportunity to enhance the intensity of typhoon Bilis.

2. The rainband located at the outer area of the first quadrant was more intense than the typhoon entity, though the double eyewall of typhoon Bilis was well pronounced. It was constructed by well developing cellular convections.

3. The vertical characteristic of rainabnds showed that the eyewall extended straightly to 10 km in height. Other rainbands which were located out of eyewall stretched.

4. slantwise and were more intense than eyewall. Some of them could extend to over 12 km in height by the enclosed area of 30 dBZ.

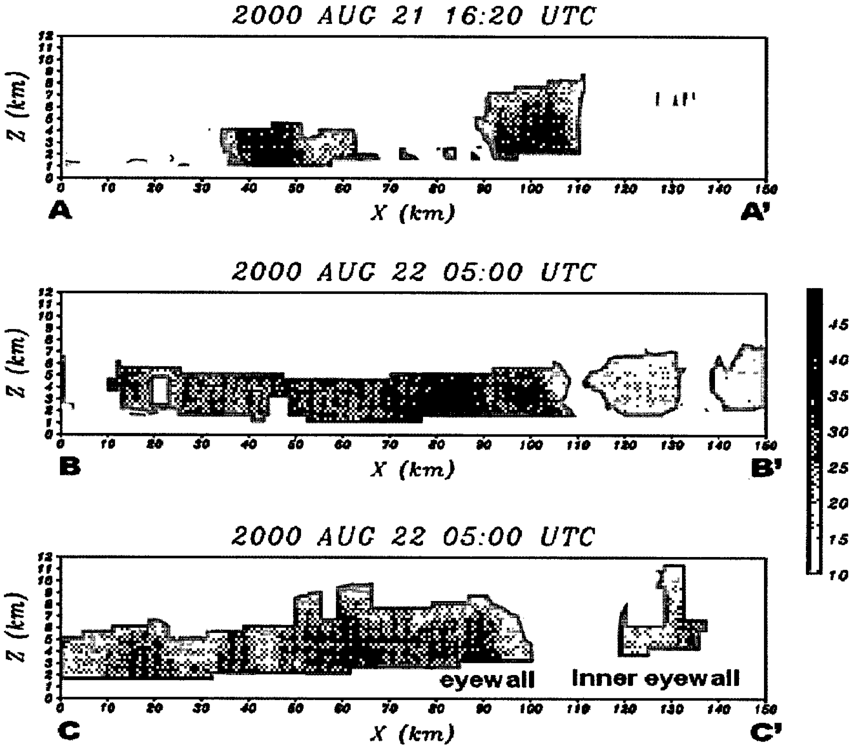

Fig. 7. The vertical cross sections of reflectivity of Typhoon Bilis at (a) 1620 UTC 21 August at cross section A-A', (b) 0500 UTC 22 August at cross section B-B', (c) 0500 UTC 22 August at cross section C-C'. The typhoon center is located at the position of R=0.

The intensive spatial (4-6 sweeps) and temporal (20 minutes interval) observation of radar in lower PRF is applicable for the development of tropical cyclone over the open ocean by the present study. It does not only extends the monitoring range of typhoons to 500 km off the coastline, but can elucidate the characteristics of rainband embedded within the typhoon of different category, though the active satellite radar is being implemented for the tropic now. Collecting similar cases unceasingly will be essential to improve the early warning of such northwestward moving typhoons for Taiwan area in the future.

Acknowledgment

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開闊洋面上颱風雨帶特徵之雷達分析

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摘要

本研究利用氣象雷達的長距離體積掃描資料，探討奧托（1998）與碧利斯（2000）颱風在開闊楊面上時雨帶及眼牆的三度空間特徵。此二颱風都是西北向行進的颱風，但是強度有顯著的差異。奧托颱風的眼牆並不顯著，但在第一與第二象限當中存在活躍的對流系統。而碧利斯颱風的雙眼牆結構，當颱風還遠在距台灣西南 300 公里的外海上時就已清晰可見，而包撞的對流僅出現在外圍的雨帶當中。外圍雨帶的垂直特徵呈現向外傾斜的現象，並且比颱風旺盛。初步結果發現颱風外圍雨帶比主體雨帶來的強烈，與颱風的強度關係不大。