A study of mesoscale features associated with Typhoon Mindulle (2004)

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Abstract

In this study, a simulation of Typhoon Mindulle (2004)as it affects Taiwan is performed using the MM5 model with the finest grid size of 5 km. The evolution of secondary vortex can be divided into two stages according to the timing of typhoon landfall. First, as Mindulle is located near the coast of Hualien/Taitung, an area of weak surface low pressure to the west of the CMR is induced by the downslope adiabatic warming. Simultaneously, the wind shear vorticity that forms because the typhoon airflow circles around the CMR is transported by the cyclonic environmental flow into the weak surface low pressure region. This results in the formation of a secondary vortex. Secondly, after Mindulle made landfall, the low-level typhoon circulation lost its characteristics owing to terrain destruction, but the remnants of the typhoon vorticity along the eastern coast of Taiwan is also transported by the cyclonic environmental flow into the region of secondary vortex. At the same time, the upper-level typhoon vorticity passes over the CMR without maintain block, and it couples with the low-level secondary vortex that develops upward at leeside. Consequently, the intensity of the secondary center enhances after 0000 UTC 2 July.

1. Introduction

Typhoon Mindulle (2004) is a unique case. It and the following southwesterly monsoonal flow brought a total of 1,862 mm rainfall and caused serious disasters over the central-southwestern Taiwan. Lee et al. (2007) pointed out that there were three phases during the whole rainfall event. At the first phase, the heavy rainfall occurred mainly at the eastern part of Taiwan and was caused by the typhoon circulation and the topographical lifting. During the second phase when the typhoon moved off-shore and away from Taiwan, both typhoon circulation and the southwesterly flow had significant effects to the occurrence of the heavy rainfall. While at the third phase when typhoon was far north of Taiwan, the southwesterly flows played the major role in producing the heavy rainfall. The objectives of this paper attempts to examine the mesoscale features that were responsible for the heavy rainfall during the second phase of this typhoon event, and we will focus on twofold: first, to understand the evolution of a leeside secondary vortex when Typhoon Mindulle approached Taiwan, and the interaction between the secondary vortex and Typhoon Mindulle; and second, the impact of the secondary vortex on rainfall occurred at the second phase.

2. Case description

The CWB mesoscale analysis (see Fig. 1) provides a good indication as to what happened at landfall during night time. At 1500 UTC 1 July (Fig. 1a) Mindulle was approaching the southeast coast of Taiwan, two *secondary low accompanied with the cyclonical wind* field have existed in the lee side of the CMR. Six hours later (Fig. 1b), the primary storm center has moved to the northern Taiwan, and one of the two secondary low continued developing, which resulted in more intensive cyclonical wind field.

(a) 1500 UTC 1 July (b) 2100 UTC July 1

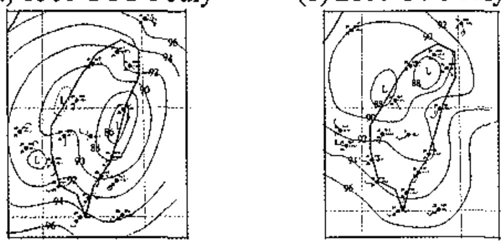

Fig.1. Surface analysis for Mindulle (2004) from the Central Weather Bureau (CWB). Time are indicated on the figures. Values from 86 to 96 indicate pressure between 896 and 996 hPa.

3. Model simulation results and discussion

From the observational data analysis, it shows when typhoon center approaches Taiwan, a secondary vortex formed in the lee side of the CMR. Figure 2 shows the vertical structures of the primary typhoon and the secondary low. Figure 2a shows the lowest-, lower-, and mid-level storm center remain vertical stacked before Mindulle makes landfall, and it accompanies a secondary low produced in the lee side of the CMR. The secondary low develops from the low level with vertically titling structure. Later (Fig 2b), after Mudulle makes landfall, its structure below 700 hPa is unobvious due to the terrain effect, but there is a weak pressure low over the CMR at 500 hPa, which implies the typhoon center at 500 hPa are running over the CMR. The secondary vortex keeps developing upward above

700hPa, and still has vertically titling structure. After the typhoon center runs cross the CMR (Fig 2c), it combines *with the secondary low resulting in the well-developed* to 500 hPa with vertical stacked structure of the secondary vortex. The secondary vortex did cyclonical motion over the Strait during the developing period, and then makes landfall at Hsinchu (Fig 2d). After it makes landfall, the low level structure of the secondary low is destroyed by the terrain, and then weakens gradually upward. At this period, Mindulle goes to sea again, and the pressure center is limited to low level, which indicates that there is no support from the upper level. Although without support for the high level, the ocean provide plenty of vapor, which makes the typhoon center redevelops upward, however, still under 700hPa.

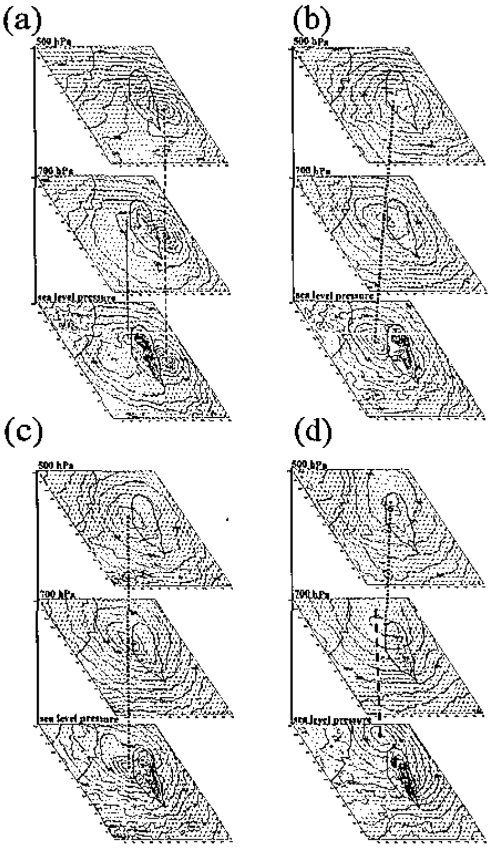

Fig. 2. The vertical profile of geopotential height (contour) and the wind field (full barb is 5 m s^{-1}, half barb is 2.5 m s^{-1}) from sea level pressure to 500 hPa, at (a) 12 hr (1200 UTC 1 July 2004), (b) 20 hr (2000 UTC *1 July), (c) 28 hr (0400 UTC 2 July),* and (d) 36 hr (1200 UTC 2 July).

Shown in figure 3 is the 925-hPa vorticity, sea level pressure, and wind field 10 above the ground. During 0800 to 1200 UTC 1 July when typhoon center was located near the coast of east of Taiwan (Figs. 3a and 3b), an area of weak low pressure was to the lee side of CMR. At the same time, wind shear vorticity that forms because the approaching typhoon airflow circles around the CMR is transported by the cyclonic environmental flow into the weak surface low pressure region. This results in the formation of the secondary low at low level. After Mindulle makes landfall (Fig 3c), the low-level typhoon circulation lost its characteristics owing to terrain destruction, but the remnants of the typhoon vorticity along the eastern coast of Taiwan is *also transported by the cyclonic environmental flow into* the region of secondary low. This enhances the secondary low with axial symmetry center. During the enhancing period, the secondary low moves in cyclonical movement near the coast of Taichung and then moves to terrain after 0400 UTC 2 July. After the secondary low make landfall near the Miaoli (Fig 3d), the typhoon center goes to sea again, and then moves northward to the Easter Sea.

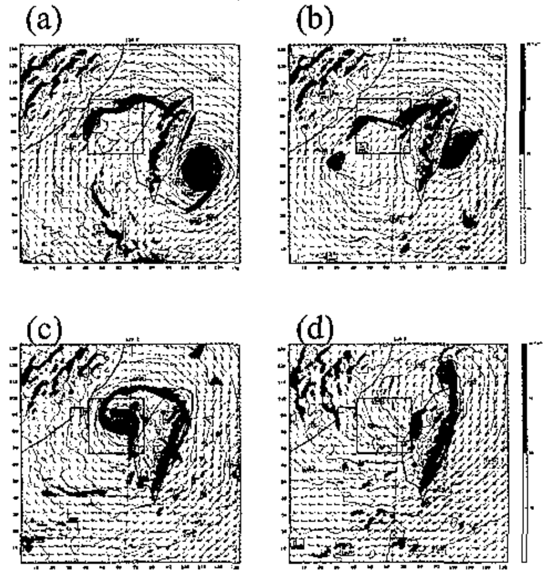

Fig. 3. The simulated 925-hPa vorticity (shading with interval of $20\times10^{-5}s^{-1}$), sea level pressure (contour interval of 1 hPa), and wind field 10 m above the ground at (a) 8 hr (0800 UTC 1 July 2004),(b) 12 hr (1200 UTC 1 July), (c) 21 hr (2100 UTC 1 July 2004),and (d) 32 hr (0800 UTC 2 July).

In order to analyze the evolution of the secondary low, we choose a box which contains maximum area of secondary low without too much terrain effect and choose the time period from 12 hr to 32hr to see the evolution of relative voticity. Figure 4 shows that the altitude of the vorticity over $5\times10^{-5}s^{-1}$ sharply raise from 700 hPa to 500 hPa at 14 hr, and it gets up to over 200 hPa again at 18 hr. This indicates at 14 hr and 18 hr an external vorticity merges to low-level secondary vortex, resulting in the violently upraising of vorticity. This sight matches with figure 2b. After the external vorticity megers to the low-level secondary vortex, the altitude of strong vorticity (over 21×10^{-5} s^{-1}) is increasing and reaching it highest altitude at 20 hr. This altitude maintains until 28 hr, and then the altitude of strong vorticity is decreasing over time. The decreasing altitude is caused from the secondary vortex which moves closer to terrain after 28 hr and then leaves the chosen box.

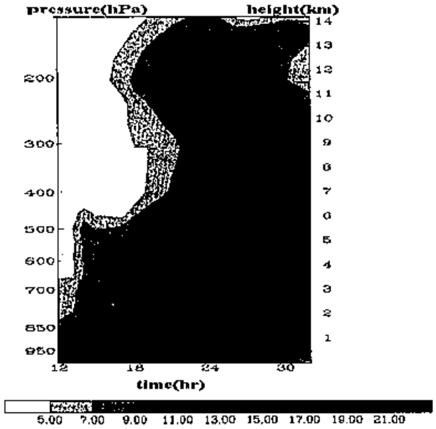

Fig. 4. Time-height section of domain average vorticity (unit of $10^{-5}s^{-1}$).

4. Conclusions

The evolution of secondary vortex can be described with the aid of figure 18, which shows a conceptual model for the evolution in the present case. It can be divided into two stages according to the time of typhoon landfall. First (Fig 18a), as the typhoon center is located near the coast of Hualien/Taitung, an area of weak surface low pressure to the west of the CMR is induced by the downslope adiabatic warming associated with over-mountain flow of the typhoon circulation. At the same time, the wind shear vorticity that forms because the typhoon airflow circles around the CMR is transported by the cyclonic environmental flow into the weak surface low pressure region. This results in the formation of a secondary vortex. Secondly (Fig 18b), after Mindulle made landfall, the low-level typhoon circulation lost its characteristics owing to terrain destruction, but the remnants of the typhoon vorticity along the eastern coast of Taiwan is also transported by the cyclonic environmental flow into the region of secondary vortex. Simultaneously, the upper-level typhoon vorticity passes over the CMR without maintain block, and it couples with the low-level secondary vortex that develops upward at leeside. Consequently, the intensity of the secondary center enhances after 0000 UTC 2 July. This mechanism is very similar with the studies of Jian at al. (2004) and Lin et al. (2006), however, there are still some differences among these three studies, which are presented as follows.

In this case, typhoon Mindulle is a northward-track typhoon, which is very different from the typhoon Dot (1990) and typhoon Toraji (2001), which are westward-track typhoons. According to the study of Lin et al. (1999), they propose that the formation of secondary vortex has indirect relationship with the intensity of vortex but with direct relationship with the track, the angle of terrain, and the landfall location of vortex. That's why although the main process of secondary vortex formation is quite the same in these three cases, there are still some differences from typhoon Mindulle to typhoon Dot (1990) and typhoon Toraji (2001). At typhoon Dot (1990) and Toraij (2001) cases, after typhoons make landfall, each of the secondary vortex developments to the leeside of the CMR and than replaces the original typhoon to keep moving westward. In typhoon Mindulle case, after typhoon make landfall, the intensity of the secondary vortex once stronger than the original typhoon. However, the secondary vortex doesn't replace the original typhoon and keep developing. The reasons that make his difference are presented as follows. First of all, after the typhoon Mindulle make landfall, there is remnants of strong vortictiy along the coast of the eastern Taiwan because of its northward track and the strong wind speed near the coast of eastern Taiwan, which continuously provides wind shear vorticity to maintain it. In addition, the average environmental wind flow at low level is northward, which keeps pushing the remnant of vorticity to go to sea again, and then results in the redevelopment and reorganization. Moreover, after the secondary vortex forms, although its intension once is stronger than the original typhoon, the remnants of vorticty along the eastern coast of Taiwan is strong enough to make interaction with the secondary vortex. This results that after the secondary vortex forms, it moves northeastward to closer to the terrain without replacing the original typhoon.

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