12A.1 THE EYEWALL EVOLUTION AND INTENSITY CHANGE IN A LANDFALLING TYPHOON

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1. INTRODUCTION

It is generally believed that the evolution of the eyewall is responsible for the intensity change of a TC. Therefore, the evolution of the eyewall has always been an intriguing issue in TC thermodynamics and dynamics. Here an interesting eyewall evolution is documented. The satellite images show that interesting eyewall evolution processes occurred during the period when Typhoon Zeb (1998) devastated Luzon The eyewall of Zeb shrank before landfall, and then its inland portion disappeared possibly due to the terrain effect and the covering of the high cloud. A few hours later, a wider eyewall reformed as Zeb left Luzon and reentered the ocean, The eyewall contracted again as it moved along the east coast of Taiwan (Fig. 1). Similar features have also been observed in other storms, such as Typhoon Dan (1999) over Luzon, and Hurricane Gilbert (1987) over Yucatan, but they have never been documented and investigated in details in the literature.

The MM5 with triply nested meshes of 54/18/6-km resolution was used to perform a 72-h simulation, starting from 0000 UTC 13 October 1998. The initial and lateral boundary conditions are based on the European Centre for Medium-range Weather Forecasts (ECMWF) global analysis. Three numerical experiments with different underlying surface conditions are conducted to investigate the effect of terrain, land surface, and ocean on the evolution of the eyewall of Zeb. The control experimnet (Expt. CTL) retains all the model-resolved terrain in the model domain. In the second simulation (Expt. NLT), the mountains of Luzon was flattened. In the third simulation (Expt. SEA), the land of Luzon was replaced by an area of water.

2. RESULTS

Except for a slight northward deflection at the initial 24 h and an eastward bias after 48 h, the tracks of all the three experiments (Fig. 1) are in general agreement with the best track analysis of Zeb. The evolution of the minimum sea level pressure (MSLP) is also well simulated in CTL. The Expt. NLT shows a similar MSLP tendency towards that in CTL.

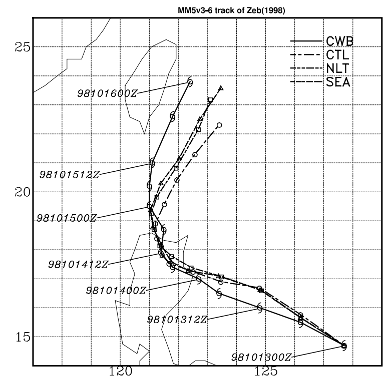

Fig. 1. Best and model tracks of Typhoon Zeb(1998).

The main features of eyewall contraction, breakdown and reformation processes during the period when Zeb is near Luzon are also well simulated in CTL. The radius of maximum mean tangential wind (RMTW) at σ = 0.995 (the lowest model level) reduces from 35 km at 18 h to 30 km at 24 h before the eyewall makes landfall (Fig. 2a). The maximum mean azimuthal flow also weakens from 51 to 48 m s^{-1}. Apparently, such eyewall contraction with decreasing intensity is different from the finding of eyewall contraction with strengthening intensity before Andrew (1992) made landfall near Miami (Willoughby and Black 1996). Such a difference is likely to result from the stronger dissipation and drying effect from the terrain as Zeb approached and made landfall at Luzon.

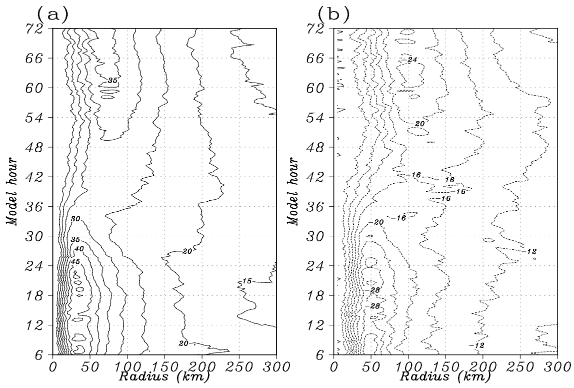

Fig. 2. Radius-time Hovmöller diagram of the azimuthal mean wind in the control experiment (m s^{-1}): (a) tangential wind; (b) radial wind.

Such a weakening tendency continues until Zeb leaves Luzon at 44 h. The RMTW keeps increasing during 44 and 50 h with a slight increase of the maximum mean tangential wind. From 51 to 72 h, Zeb re-intensifies with the maximum azimuthal wind

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increase from 46 to 56 m s^{-1} while the RMTW decreases with time from 80 to 70 km (i.e., the eyewall contracts again). All the above-mentioned processes are generally consistent with the evolution of the mean radial inflow (Fig. 2b), with the radius of the maximum radial inflow slightly greater than RMTW.

With the terrain removed in NLT, the eyewall do not shrink before landfall although its breakdown and reformation processes resemble those in CTL. On the other hand, the simulated storm in SEA intensifies from the beginning of the integration until 50 h and shows no remarkable change in the eyewall size (Fig. 3). The radius-time Hovmöller diagrams of the axisymmetric tangential wind of the three experiments indicate that the contraction of the eyewall before landfall is related to the orographic effect of Luzon. The breakdown and reformation of the eyewall are associated with the effects of the different underlying surfaces. Therefore, the existence of Luzon plays the key role in the eyewall evolution in this case.

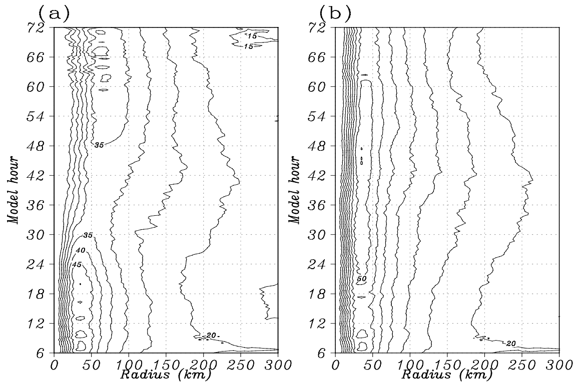

Fig. 3. Radius-time Hovmöller diagram of the azimuthal mean tangential wind (m s^{-1}): (a) the NLT experiment; (b) the SEA experiment.

In this study, the thermodynamic and kinematic fields at different stages of the eyewall evolution are analyzed. It is shown that the eyewall contraction occurred due to an increased inflow in the coastal region before landfall, which is accompanied by the weakening of the storm. The analyses of the surface sensible heat and latent heat flux in these three experiments indicate that most of the heat flux from the ocean under the storm is strongly reduced when the eyewall of the storm makes landfall. The weakening of the storm, the presence of the ambiguous eyewall, and its quasi-breakdown after landfall are likely due to both the strong dissipation due to terrain and the water vapor cutoff, while the outer circulation is less affected. Finally the outer circulation reorganizes and leads to the formation of the new large eyewall and its subsequent contraction in the open ocean.

The low-level (averaged between σ=0.995 and 0.910) potential vorticity (PV) profiles in the landfalling experiments (Expt. CTL and Expt. NLT) show a PV evolution similar to the PV mixing between the eye and the eyewall as described in Kossin and Eastin (2001), though in our study the terrain plays an extra role in leading to the PV mixing while weakening. The budget analyses of the angular momentum show that the mean flux convergence weakens considerably after landfall due to the weakening of the mean transverse circulation. However, the eddy flux convergence increases remarkably when the storm reenters the ocean. The evolution of the eyewall is possibly also related to the activity of vortex-Rossby waves near the eyewall. Accordingly, the feedback from these waves near the eyewall will be analyzed in a follow-up study.

The results shown here may stimulate further detailed investigations, thus enhancing our understanding of interactions among the TC eyewall and its larger circulation, the underlying surface and terrain and their effect on storm structure and intensity changes. We propose that such eyewall evolution may often occur when a storm encounters terrain with the size comparable to the vortex size.

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