P1.8 Orographic Influence on Rainfall and Track Associated with the Passage of Tropical Cyclones

Yuh-Lang Lin*, Darrell B. Ensley, Sen Chiao, Christopher M. Hill
North Carolina State University, Raleigh, North Carolina, USA
Ching-Yuang Huang
National Central University, Chung-Li, Taiwan

1. Simulations of Supertyphoon Bilis

Supertyphoon Bilis (2000) followed a very straight track approaching Taiwan and was a very intense Category 5 typhoon with a minimum pressure of 915 mb as it made landfall on the southeast coast of Taiwan around 8/22/14Z. Just before landfall, Bilis turned north and followed a cyclonic track across the island, which is similar to many previous observed and simulated TCs passing over Taiwan. In this study, we adopt the NRL's COAMPS to simulate Bilis and investigate the rainfall and track deflection induced by Taiwan's Central Mountain Range (CMR). Three horizontal nested grids of 45 km (91x101), 15 km (151x151) and 5 km (133x133) resolution were used, as well as 30 layers in the vertical. In this study, the simulations are initialized from the 1.0°x1.0° NOGAPS global model data with multiple restarts afterwards. Three grid meshes of 45 km, 15 km, and 5 km, which were required to be started and run at the same time.

The intensities predicted by these control numerical simulations (CON-45, CON-15, CON-5) were much weaker than the observed intensity, due to the lack of bogussing the initial typhoon vortex. These simulations still, however, serve our purpose in examining the orographically induced track deflections and rainfall for weak to moderate typhoons. Both storm CON-15 and the observed Bilis exhibited the northward deflection when they approached Taiwan, with a turn to the southwest after passage (Fig. 1). While the observed Bilis took a continuous track crossing CMR, the CON-15 storm took a discontinuous track, with a secondary low forming on the *northwest* Taiwan before 8/22/12Z, strengthening and becoming the primary low center after 8/22/18Z as it left Taiwan. Overall, the CON-15 storm track agrees quite well with the observed track.

At 8/22/12Z, the simulated storm approached the southeast coast of Taiwan with a thoroughly coherent low-pressure center over a vertical depth. A strong, *secondary low* pressure area was produced over the northwest coast of Taiwan, which apparently was generated by vorticity stretching and adiabatic warming, which was consistent with observations (e.g. Wang 1980; Chang 1982). The outer circulation of Bilis was channeled through the coastal mountains on both sides of the Taiwan Strait and formed a *northeasterly gap flow* or *barrier jet*. One significant effect of this channel or gap flow between Taiwanese and Chinese coastal mountains was to contribute to the formation of the secondary vortex on the southwest lee side of CMR. At 8/22/15Z, Bilis made landfall on southeast Taiwan. The 500 mb and 700 mb lows were blocked by the mountains to the east of Taiwan, while a secondary surface low developed to the northwest of Taiwan, which were A secondary vortex formed to the southwest coast of Taiwan at this time, which was able to make track deflection of the parent vortex. Both low and vorticity centers of CON-15 storm had *discontinuous tracks*.

2. Orographic Influence on Rainfall

Based on the ingredient argument proposed by Lin et al. (2001), heavy orographic rainfall requires significant contributions from any combination of the following common ingredients: (1) high precipitation efficiency of the incoming airstream, (2) a low-level jet, (3) a steep mountain, (4) high moisture flow upstream, (5) favorable mountain geometry and confluence flow field, such as a concave geometry, (6) strong synoptically forced upward motion, (7) a large convective system, (8) slow movement of the convective system and (9) an upstream conditionally or potentially unstable airstream. The synoptic and mesoscale environments of Bilis contained these common ingredients. In order to apply this argument to the prediction of orographic heavy rainfall formation and distribution, an index composed of ingredients (2)-(5), as listed above, has been proposed by Lin et al. (2001). This index is represented by the orographic vertical moisture flux, $(\boldsymbol{V} \cdot \nabla h)q$, where q is the water vapor mixing ratio of the incoming flow. This index may be estimated by upstream soundings as well as with model output. A more general vertical moisture flux, *wq*, is also calculated. Fig. 2 shows the observed 3-h accumulated precipitation (in mm) valid for 8/22/12-15Z and the corresponding simulated (Case CON-15) precipitation. During this period, the CON-15 predicted two maxima of precipitation (Fig. 2b). The predicted rainfall distribution over the east coast roughly matches the overall observed pattern (Fig. 2a), but not the detailed distribution. Fig. 3 shows the orographically induced vertical moisture flux and the general vertical moisture flux estimated from the CON-15 simulated wind and moisture fields. Surprisingly, both positive areas of these two fluxes match very well with the observed rainfall pattern.

Corresponding author address: Yuh-Lang Lin, Department of Marine, Earth and Atmospheric Sciences, North Carolina State University, Raleigh, NC 27695-8208. E-mail: yl_lin@ncsu.edu.

3. Orographic Influence on Track Deflection of Tropical Cyclones

In order to find non-dimensional parameters which control the continuity of the tracks of TCs propagating from east, we analyzed results from previous studies of idealized simulations and observational analysis. Using the basic flow and orographic parameters, we estimate the following non-dimensional parameters: U/Nh, $V_{\max}/Nh$, h/L_x, $R_{\max}/L_x$, Nh/fL_x, L_y/L_x, $V_{\max}/U$, U/fL_x, and $V_{\max}/Rf$. Based on the analysis, we found that the non-dimensional parameters $V_{\max}/Nh$ and $V_{\max}/Rf$ may serve as control parameters for determining continuous or discontinuous track of a TC passing over a mountain range. Roughly speaking, the larger these 2 parameters the more continuous the track.

4. Concluding Remarks

The COAMPS model performed well with respect to the prediction of Bilis's track and the orographic rainfall distribution. The prediction of accumulated rainfall was less successful, however, especially in the case with 5-km resolution (CON-5). In general, there is an overprediction problem with orographic rainfall.

Both distributions of the orographically induced vertical moisture flux and the general vertical moisture flux calculated from the 15-km resolution model simulated wind and moisture fields compared reasonably well with the observed rainfall distribution. Thus, *these two fluxes diagnosed from a lower-resolution model outputs may be used to help predict heavy orographic rainfall.* The orographically induced vertical moisture flux may also be estimated from the surface observation network. Based on previous studies of tropical cyclones passing over Taiwan's CMR, we hypothesize that the non-dimensional parameters V_{max}/Nh and V_{max}/Rf may serve as 2 control parameters for determining the track continuity.

Acknowledgments: The authors would like to thank Dr. C.-H. Liu at PCCU, Taiwan for providing observed-rainfall data. This study is supported by the NSF Grant ATM-0096876.

References

Chang, S. W.-J., 1982: The orographic effects induced by an island mountain range on propagating tropical cyclones. Mon. Wea. Rev., 110, 1255-1270.

Lin, Y.-L., J. Han, D. W. Hamilton, and C.-Y. Huang, 1999: (LHHH) Orographic influence on a drifting cyclone. J. Atmos. Sci., 56, 534-562.

Lin, Y.-L., S. Chiao, T.-A. Wang, M. L. Kaplan, and R. P. Weglarz, 2001a: Some common ingredients of heavy orographic rainfall. Wea. Forecasting, 16, 633-660.

Wang, S.-T., 1980: Prediction of the movement and strength of typhoons in Taiwan and its vicinity (in Chinese), Res. Report 108, National Science Council, Taipei, Taiwan, 100pp.

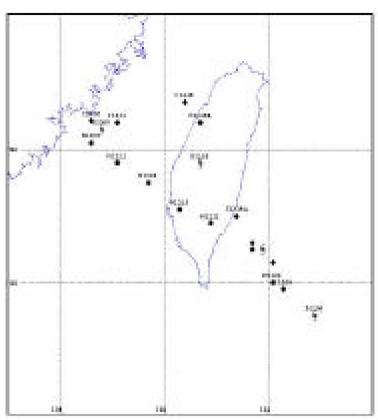
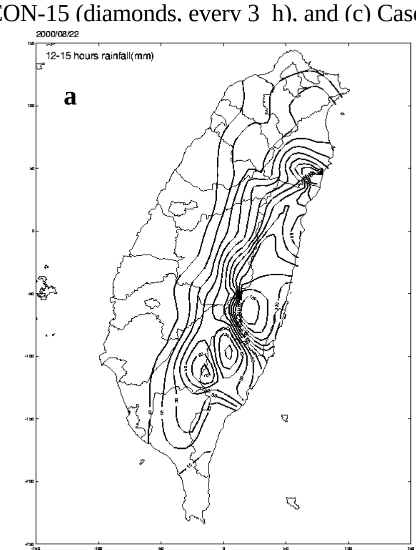


Fig. 1: Supertyphoon Bilis tracks from (a) observations (TC symbols, every 6 h), (b) Case CON-15 (diamonds, every 3 h), and (c) Case NT



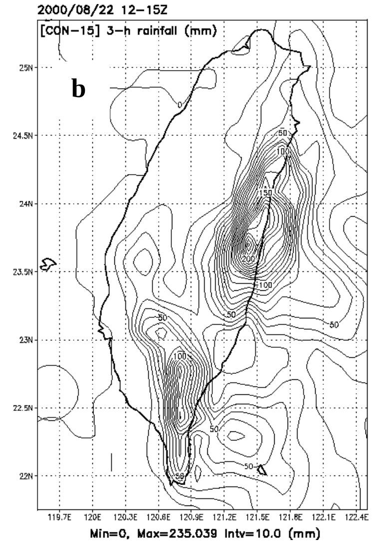


Fig. 2: Observed 3-h accumulated precipitation (in mm) valid for (a) 22/12-15Z. CON-15 precipitation is shown in (b).

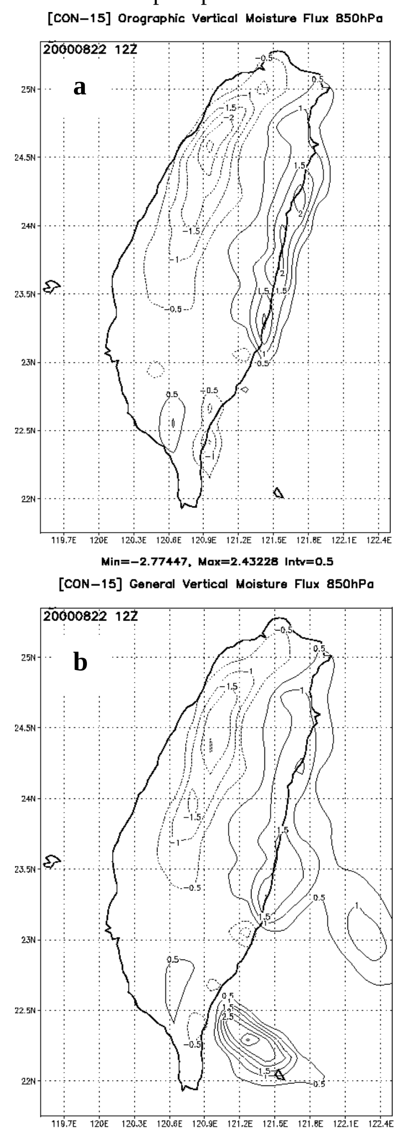


Fig. 3: Orographically induced vertical moisture flux, $(\boldsymbol{V}\cdot\nabla h)q$, valid at 22/12Z, base on CON-15. The general vertical moisture flux (wq) is shown in (b).