13D.2 TROPICAL CYCLONE STRUCTURE AND TRACK CHANGES PRIOR TO LANDFALL

Martin L. M. Wong and Johnny C. L. Chan[*]
Laboratory for Atmospheric Research, Dept. of Physics and Materials Science, City University of Hong Kong

1. INTRODUCTION

Track changes of tropical cyclones (TC) due to topography have been investigated in some previous studies (e.g. Kuo et al. 2000). The influence on the structure of a TC by a flat surface and a straight coast has also been studied recently (e.g. Chan and Liang 2003, Chen and Yau 2003). These studies addressed the asymmetry in rainfall and spiral bands. A natural question regarding the asymmetry is the associated track changes. Although significant track deflections from the steering were not noted, it could be a considerable contribution to the track of a TC, especially when the steering is weak. In the current study the track changes of a TC near landfall is investigated.

2. MM5 MODEL SETUP

Nested domains of 45 and 15 km resolution are employed. Physics parameterizations include the Mellor-Yamada PBL scheme implemented in the Eta model, the Betts-Miller cumulus scheme and a microphysics scheme (Dudhia 1989). The sea surface temperature and the temperature over land are kept constant at 28.5 ^{o}C during the 6-day simulation. The land surface has a roughness length of 50 cm. Experiments including and excluding the effects of surface sensible and latent heat fluxes over land are performed with the spun-up vortex placed at 150 km from the coast. The model is run on an *f* plane.

3. RESULTS

The track of the TC is characterized by landward displacement and landfalling of the TC occurred near *t* = 96 h (Fig. 1a). A small deviation to the south and looping motions are also evident. The overall movement, as expected, is small and is only ~ 300 km in 6 days. However, a plot of the zonal position of the TC reveals clearly that it has a tendency to accelerate (Fig. 1b).

The immediate response of the TC to a surface with different surface roughness is the development of an asymmetric horizontal circulation characterized by convergence (divergence) on the onshore (offshore) side. This is obviously true for the lowest model layer (Fig. 2a). However, this pattern is shallow. Not too high above the surface ($\sigma = 0.915$), the pattern of the flow is already different (Fig. 2b). In fact, the region that the convergent/divergent line is seen near the surface has become just the opposite.

During subsequent times, the pattern seen in Fig. 2b further developed into prominent gyres. This pair of gyres with the gyre centers 1000 km from the TC represent the synoptic-scale steering that drives the TC towards land. The orientation of the asymmetric flow averaged between $\sigma = 0.87$ and $\sigma = 0.25$ during the 6-day simulation is consistent with the synoptic-scale (translational) movement of the TC (Fig. 3). The gyres also have a tendency to rotate cyclonically about the TC (not shown), apparently resulting from the advection by the mean tangential wind of the TC. Therefore, the TC also tends to move more to the southwest during the later part of the simulation.

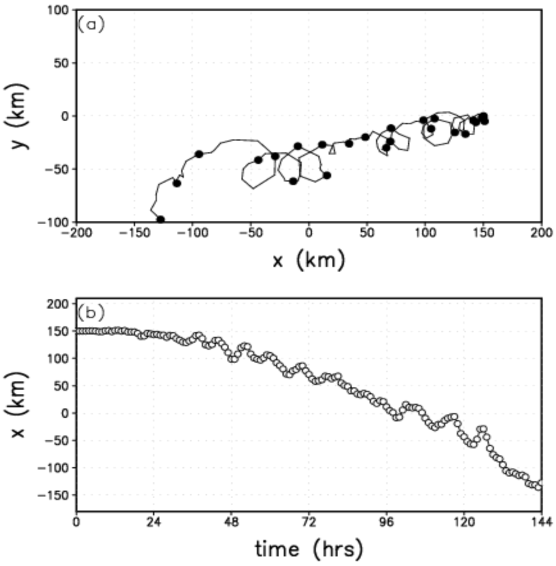

Fig. 1. Movement of the model vortex. Zonal distances are plotted relative to the coastline, negative values being over land, and 0 km indicating the start of the coastline. (a) Track, with dots representing 6-hourly positions. The vortex is initially at coordinates (150, 0). (b) Zonal displacement.

The motion of the TC in Fig. 1 also appears to be closely related to the convective asymmetries. As found by Chan and Liang (2003), rainfall is mainly confined to the landward side of the TC. Here the results show that the TC moves generally towards (or slightly towards the right of) the area of maximum

---

[*] *Corresponding author address*: Johnny Chan, Dept. of Physics and Mat. Science, City University of Hong Kong, Tat Chee Ave., Kowloon, Hong Kong, China. Email: Johnny.Chan@cityu.edu.hk

rainfall (Fig. 4), which could be due to the asymmetric potential vorticity tendency associated with the asymmetric diabatic heating, as discussed in Chan et al. (2002). As the rainfall maximum rotates cyclonically in time, the instantaneous motion of the TC may not necessarily follow the large-scale steering flow so that looping motion can be realized.

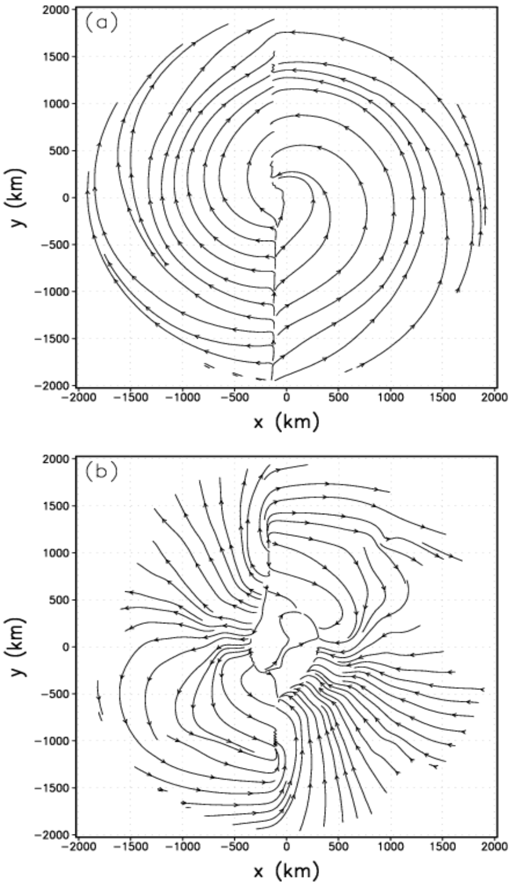

Fig. 2. Time-averaged asymmetric flow in the first 24 hours. (a) σ = 0.995 and (b) σ = 0.915. The coordinate (0, 0) is the TC center.

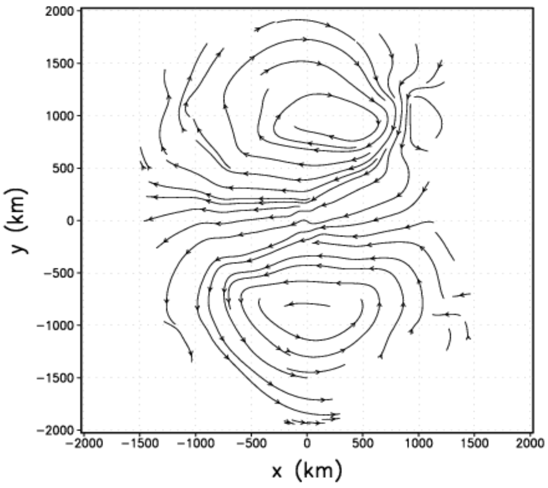

Fig. 3. 6-day layer-averaged (between σ = 0.87 and σ = 0.25) asymmetric flow of the TC. The coordinate (0, 0) is the TC center.

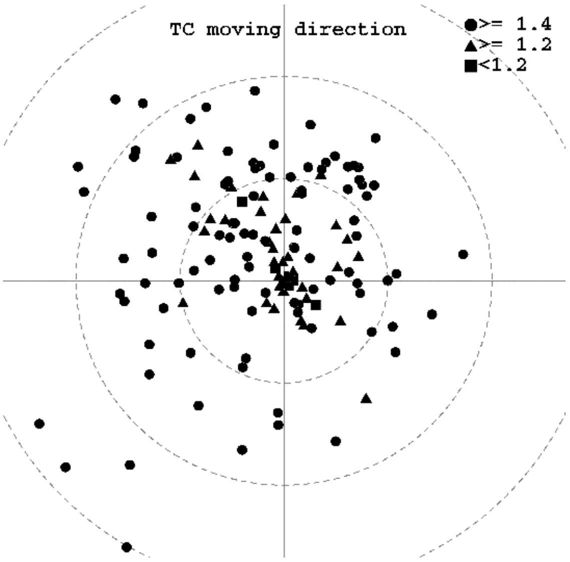

Fig. 4. The relationship between location of largest rainfall and direction of TC movement. Each dot represents the location of maximum rainfall at a particular hour. Rainfall > 1.4 times the azimuthal average value (strongly asymmetric rainfall) is marked by a closed circle. Dots plotted at a larger radius correspond to faster TC movement during that hour.

4. CONCLUDING REMARKS

The results obtained suggest that, *even on an f plane*, a TC has a tendency to move towards land in the presence of a long coast, which forces the large scale asymmetric flow that steers the TC. The looping is related to the asymmetry and rotation of the core convection. A more sophisticated investigation of the mechanisms is under way. We also anticipate that the results could be significantly different when more complicated coastline (e.g. of smaller length relative to the TC) is used instead.

Acknowledgments. This research is sponsored by the Research Grant Council of the Hong Kong Special Administrative Region, China Grant CityU 100203.

REFERENCES

Chan, J. C. L., F. M. F. Ko and Y. M. Lei, 2002: Relationship between potential vorticity tendency and tropical cyclone motion. *J. Atmos. Sci.*, **59,** 1317-1336.

Chan, J. C. L., and X. Liang, 2003: Convective asymmetries associated with tropical cyclone landfall. Part I: f-plane simulations. *J. Atmos. Sci.,* **60,** 1560-1576.

Chen, Y., and M. K. Yau, 2003: Asymmetric structures in a simulated landfalling hurricane. *J. Atmos. Sci.,* **60,** 2294-2312.

Dudhia, J., 1989: Numerical study of convection observed during the winter monsoon experiment using a mesoscale two-dimensional model. *J. Atmos. Sci.,* **46,** 3077-3107.

Kuo, H. C., R. T. Williams, J. H. Chen, and Y. L. Chen, 2000: Topographic effects on barotropic vortex motion: No mean flow. *J. Atmos. Sci.,* **58,** 1310-1327.