Tropical Cyclone Motion and Asymmetry due to Land-sea Friction Contrast

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Massive destruction of life, property and infrastructure occurs when a tropical cyclone (TC) is near a densely populated region. The movement of a TC near such a region is therefore of more social and economic interests than when it is in the open sea. While significant track deflection can occur when a TC interacts with topography, the possibility of a track deflection due to the different surface fluxes of momentum, heat and moisture have not been addressed. This study investigates such possible vortex motion using the Pennsylvania State University-National Center for Atmospheric Research MM5 model.

Idealized numerical experiments are performed on an *f* plane under no background flow, with an initially symmetric, baroclinic vortex placed 150 km due east of an infinitely long coastline separating land (west of the coast) and sea (east of the coast). The surface temperature is held fixed at 28.5^{o}C over the entire modeling domain. With a specified roughness length of 0.5 m and abundant surface moisture supply (moisture availability 100%) over land, the vortex is found to drift towards land (Fig. 1), with a speed of about 4 km h^{-1}. Using a moisture availability of 5% also results in a similar drift but altering the moisture availability only does not result in a drift (not shown). The difference in surface momentum flux appears to be the cause of the drift.

The difference in surface friction between land and sea could influence the symmetric structure of a TC, and results in vortex drift and asymmetry in rainfall. Two possible mechanisms have been identified. First, boundary-layer convergence is stronger along the coast to the north than to the south of the TC. The convergence pattern above the boundary layer is found to be out-of-phase from that within the boundary layer, and results in the development of larger vorticity to the south than to the north, due to the divergence term in the vorticity equation. The flow within the lower to mid troposphere ($0.9 \geq \sigma \geq 0.55$) indicates the development of an asymmetry consistent with the vorticity development by the divergence term and rotation by the TC circulation (Figs. 2a and 2b). Within the upper troposphere ($0.55 \geq \sigma \geq 0.25$), the asymmetric flow is different (Fig. 2c) and represents a vertical shear of this large-scale asymmetric flow.

The presence of an asymmetric flow represents a 'steering' effect and the vertical shear could generate an asymmetry in vertical motion and rainfall (e.g. Wong and Chan 2004). The direction of the shear vector and the development of a vertical tilt are found to be consistent with the asymmetry in vertical motion and rainfall, which is also found in some previous studies (e.g. Chan and Liang 2003). However, the TC does not move with the steering flow. Investigation of the various terms in the potential vorticity (PV) equation indicates that the vertical advection and diabatic heating terms are also important in determining the PV tendency.

Second, the boundary-layer convergence could force an asymmetry in vertical motion. Additional experiments are performed with the exclusion of moisture and latent heating. The TCs are placed at -150, -100, -50, 0, 50, 100 and 150 km east of the coast. The mass fields (i.e. temperature, pressure) are not allowed to change with time during the 24 h simulation, while the 3-dimensional winds are allowed to adjust to the mass fields and the drag from the surface. When the TC is placed at 50, 100 and 150 km east of the coast, boundary-layer ($1.0 \geq \sigma \geq 0.9$) convergence is much stronger west of the TC, though the averaging area covers the sea only for the TCs placed 100 and 150 km east of the coast (Fig. 3). There is also a small tendency for the asymmetry to rotate slightly anticyclonically as the vortex 'edges closer' to the coast, from 150 km to 50 km (dotted and solid lines respectively). These results are also consistent with the asymmetry in rainfall and vertical motion (not shown). When the TC is placed at the coast or west of the coast, however, the asymmetry diminishes (not shown).

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

References

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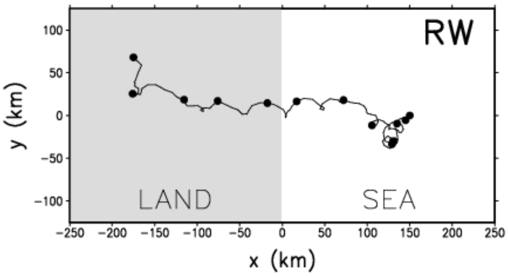

Fig. 1. Track of the TC surface center. Dots denote 12-hourly TC positions. The origin is the location of the domain center.

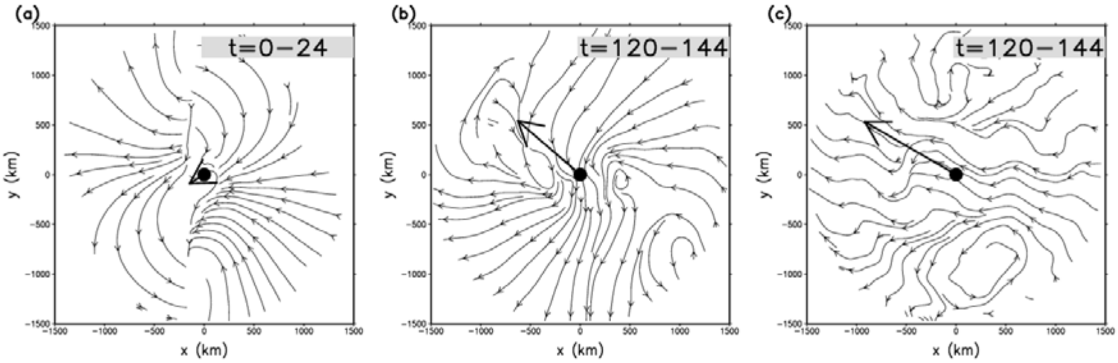

Fig. 2. Time composite of the asymmetric component of the flow for the (a) first day within $0.9 \geq \sigma \geq 0.55$, (b) sixth day within $0.9 \geq \sigma \geq 0.55$ and (c) sixth day within $0.55 \geq \sigma \geq 0.25$. The big arrow indicates the overall movement of the center during that day.

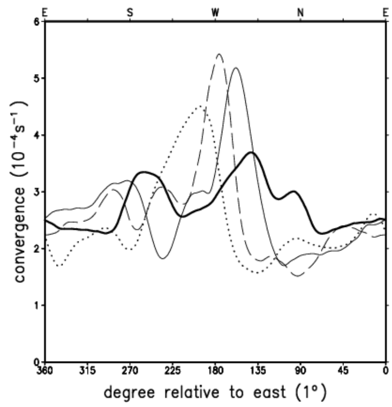

Fig. 3. Boundary-layer ($1.0 \geq \sigma \geq 0.9$) convergence averaged within 100 km at each azimuth for the experiments where the mass fields of the TC are fixed: the TCs are located at 50 (solid), 100 (dashed) and 150 km (dotted) east of the coast. The bold solid line corresponds to the case where the TC is located at the coast.