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Orographic Influence on Propagating Tropical Cyclones

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In this study, a primitive-equation numerical model (see Weglarz, 1994, Lin and Jao, 1995 and Lin and Wang, 1996 for details) with prescribed latent heating is adopted to investigate the orographic influence on a propagtaing cyclone over an idealized topography similar to that of Taiwan. A review of this topic may be found in Lin (1993).

For a cyclone propagating from the east and impinging on the central portion of the mountain, a northerly surface jet tends to form upstream of the mountain in between the primary cyclone and the mountain when there exists a significant portion of the cyclonic flow associated with the primary cyclone is normal to the mountain range. When the cyclone approaches the mountain, the low-level vortex and low pressure centers decelerate slightly and turn northward upstream of the mountain due to orographic blocking which tends to redistribute the vorticity field to be more asymmetric, as well as producing new potential vorticity through turbulence and diffusion. The stagnation point in this case is located further to the north of the original undisturbed storm track. At the same time, the upstream low-level vorticity is blocked by the mountain. The regime transition from flow dominated by flow-splitting to that dominated by wave-overturning generates an abrupt increase and contraction of low-level vorticity over the lee slope through the generation of new potential vorticity. Instead of the downward extension of upper-level vorticity as proposed by Yeh and Elsberry (1993b), the abrupt increase of surface vorticity is now explained by the generation of new potential vorticity due to wave breaking. The generation of new potential vorticity is evidenced by the dominance of diffusion, which here is equivalent to friction term in the real atmosphere, in the vorticity budget and the evolution of the nondimensional mountain height (inverse Froude number) in the regime diagram proposed by Smith (1989b, c). During this process, the vortex and low pressure centers appear to accelerate or jump over the mountain. At the same time, the surface low shifts to the north of the original westward track, which is influenced primarily by strong adiabatic warming associated with the downslope wind. The primary surface vortex then resumes its original westward track on the lee side once it moves away from the mountain. The deflection of the vortex and low pressure centers at midlevels (e.g., σ=3 km) are much weaker than those at the surface and resume their original tracks earlier due to less blocking and weaker downslope winds at this level. This type of southward upstream deflection has also been observed for typhoons crossing the Central Mountain Range of Taiwan (Wang, 1980).

When a westward propagating cyclone impinges on the mountain range, pressure ridges and troughs may be produced, and are signatures of hydrostatic mountain waves. These pressure ridges and troughs have also been observed (Wang, 1980). A smaller vortex tends to be deflected to the south upstream of the mountain since the stagnation point occurs to the south of the original undistrubed storm track. Thus, track deflection depends on the size of the cyclone.

A cyclone propagating from the east and impinging on the northern (southern) portion of the mountain range experiences a northward (southward) upstream deflection of the primary surface vortex due to orographic blocking. The maximum vorticity region wraps around the northern (southern) part of the mountain cyclonically. A strong interaction of the primary vorticity and mountain-induced lee side vorticity occurs for southerly impinging cyclones (Case MVE_S), which leads to a region of elongated surface vorticity. Thus, the primary surface vortex center is located further downstream from the surface low in this case. In this case, the surface low is deflected significantly northward on the lee slope by the adiabatic warming associated with the severe downslope wind. The trajectories of the vortex and low pressure centers appear to be more continuous for cyclones impinging on the northern and southern parts of the mountain range compared to those impinging on the central part, due to less blocking.

The flow field for a cyclone propagating from the southeast may be roughly described by a superposition of: (1) the basic flow, (2) a divergent flow whose center is located on the upslope, (3) a strong cyclonic flow associated with the primary cyclone, and (4) a weak drifting mountain-induced cyclone on the lee side. Similar to the case for a vortex propagating from the east, the leftward turning of the vortex center is strongly influenced by orographic blocking. The primary and secondary vortices interact with each other initially, rotate cyclonically, and eventually merge as they propagate further downstream from the mountain range.

Multiple secondary low pressure centers may form over the lee slope as a northwestward propagating cyclone impinges on the mountain range at an appropriate angle, such as Case MVSE_S. These low pressure centers are produced by strong downslope winds which occupy almost the entire lee slope since a significant portion of the total flow is perpendicular to the mountain range. Therefore, the formation of secondary lows depends on the impinging angle and landfall location. This appears to require a significant portion of the total wind to be oriented perpendicular to the cerntal portion of the mountain range. In summary, the movement of the vortex (low pressure) center is influenced primarily by orographic (thermal) forcing.

Thr sudden increase of relative vorticity over the lee slope when the upper-level vortex crosses the mountain peak is associated with the generation of potential vorticity through the mechanisms of upstream blocking and wave overturning. This finding is similar to that found by Smith and Smith (1995) in the context of shallow water theory. However, the main difference for stratified flow, such as that presented here, is the regime transition from flow dominated by flow-splitting to that dominated by wave-breaking, instead of a regime transition from irrotational flow to flow over the mountain with wakes.

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