Orographic Influence on Rainfall Enhancement and Track Deflection Associated with Tropical Cyclones Passing over Mesoscale Mountain Ranges

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The common ingredients for orographic precipitation enhancement associated with the passage of tropical cyclones (TCs) over mesoscale mountains are reviewed and applied to Hurricanes Hugo (1989) and Isabel (2003) over the Appalachian Mountain Range of the U.S. and to Typhoon Morakot (2009) over Taiwan's Central Mountain Range (CMR). The 2D orographic rain index (ORI) proposed in Lin et al. (2001) is modified for rainfall enhancement associated with a TC over mesoscale mountains. Some fundamental dynamics are explored by performing idealized simulations of a strong, conditionally unstable, uniform flow (U) impinging on an idealized mountain range. In addition to the three moist flow regimes identified by Chu and Lin (2000), a new flow regime (Regime IV, when U > 36 m s^{-1}), is found and discussed. By extending an existing mountain wave theory, it is proposed that the transition from Regime III to IV is analogous to that from upward propagating gravity waves to evanescent flow. It is also found that in order to be more accurately simulating orographic rain intensity and distribution under high wind regimes (e.g., U>30 m s^{-1}), a higher resolution (e.g., Δx=100 m) and 3D simulation are needed. In Regime III, based on 3D simulations, gravity wave-induced severe downslope winds and turbulent mixing within hydraulic jump tend to reduce orographic precipitation. The changes in rainfall amount and distribution under high wind condition is explained by some key microphysical processes. The same set of experiments but with a low CAPE sounding, as often observed within TCs, have been performed to examine the evolution of orographic precipitation. It is interesting to find that under high wind regimes (III and IV), the precipitation is nearly doubled when the CAPE is reduced from 2000 to 100 J kg^{-1}. This counter-intuitive phenomenon is explained by some key microphysical cloud processes, turbulence and gravity waves, and may be used to explain why record rainfall associated TCs are often occurred over mountains.

In addition to orographic enhancement of TC rainfall, mechanisms proposed to explain track deflection of TCs over mesoscale mountain ranges are reviewed briefly and examined by a series of idealized numerical experiments using the Advanced Research WRF (ARW) model and vorticity budget analyses. When a TC is embedded in a uniform, easterly flow and passes over a mountain with a moderate Froude number, it is deflected to the south upstream, moves over the mountain anticyclonically, and then resumes its westward movement. The vorticity budget analysis indicates that the TC movement can be predicted by the maximum vorticity tendency (VT). The orographic effects on the above TC track deflection are explained by: (a) upstream of the mountain, the basic flow is decelerated due to orographic blocking that causes the flow to become subgeostrophic which advects the TC to the southwest, analogous to the advection of a point vortex embedded in a flow. The VT is primarily dominated by the horizontal vorticity advection. (b) the TC passes over the mountain anticyclonically, mainly steered by the orographically-generated high pressure. This makes the TC moving southwestward (northwestward) over the upslope (lee) slope.