Common Ingredients, Orographic Rain Index, and Flow Regimes Associated with Tropical Cyclones Passing over Mesoscale Mountain Ranges

Yuh-Lang Lin, Gökhan Sever, and Riem Rostom
North Carolina A&T State University
Email: ylin@ncat.edu

The common ingredients for heavy orographic precipitation proposed by Lin et al. (2001) and Lin (2007) are used to examine the orographic rainfall associated with the passage of Hurricanes Hugo (1989) and Isabel (2003) over the Appalachian Mountain Range of the U.S. The ARW-simulated flow fields and precipitation are used to examine the relative contribution of each individual ingredient in producing heavy orographic rainfall. It is found that both Isabel and Hugo shared several common ingredients, such as strong low-level jet and orographic lifting, and high relative humidity, similar to those found for typhoons passing over the Central Mountain Range of Taiwan (e.g., Tropical Storm Rachel (1999) – Chiao and Lin 2003; Supertyphoon Bilis (2000) - Witcraft et al. 2005; Typhoon Morakot (2009) - Huang and Lin 2014), although the relative contributions from individual ingredient varies. The 2D orographic rain index (ORI) proposed in Lin et al. (2001) is modified to be ORI = $(V_n dh/dn)(L_s/U)RH$, as a predictor for heavy orographic rainfall associated with a TC over mesoscale mountains, where V_n is the upstream total horizontal wind speed normal to the local mountain range, dh/dn the steepness normal to the mountain, RH the relative humidity, U the basic flow speed used as the proxy of TC movement speed, and L_s the horizontal scale of the TC. The ORIs estimated for six regions with local maximum rainfall correlates well with the average rainfall rates for both storms. The ORI will be further tested for typhoons over CMR and idealized simulations, and then improved to serve as a predictor for heavy orographic rainfall associated with the passage of a TC over mesoscale mountain ranges.

In light of the common ingredient argument, some fundamental dynamics may be gained by idealizing the problem as a strong, conditionally unstable, uniform flow (U) impinging on an idealized mountain range. Based on this concept, a series of idealized numerical simulations with a relatively low resolution (e.g., Δx=1 km) has been performed using the CM1 model for a relative wider range of the basic flow speed (U) in a conditionally unstable uniform flow. 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 characterized by heavy precipitation with the maximum located at the peak and lack of upper-level wave breaking and turbulence over the lee slope, mimicking a moist evanescent flow. 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. Therefore, the critical basic wind speed for this regime transition can be predicted. 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. In Regime IV, orographic precipitation further increases due to enhanced warm-rain auto-conversion and accretion processes as well as enhanced graupel and snow formation when the blocking effect of wave breaking vanishes. On the other hand, evaporation and sublimation processes within strong convective downdrafts tend to reduce precipitation.

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.