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Generation and Enhancement Mechanisms and Essential Ingredients for the Extreme Orographic Rainfall Associated with Typhoon Morakot (2009) Passing over Taiwan’s Central Mountain Range

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INTRODUCTION

- It has been shown that several heavy orographic rainfall cases that occurred during the passage of typhoons over Taiwan’s Central Mountain Range (CMR) are closely related to some common ingredients (e.g. Yang and Ching 2005; Wicraft et al. 2005; Yang et al. 2008).
- Several studies have been done on typhoon Morakot (2009) about general factors responsible for the extremely heavy rainfall (e.g. C.-Y. Lin et al. 2010; Yu and Chen, 2013; Huang and Lin, 2014) but, less is known about the generation and enhancement mechanisms.
- Lin et al. (2001), extended Doswell et al.’s (1996) ingredient argument, in which the orographic precipitation (P) is determined by the following equation:
  \[ P = E \left( \frac{\rho_w}{\rho_l} (w_{vap} - w_{dry}) + T \right) \]
  where \( \rho_w \) and \( \rho_l \) are the liquid water density and air density, respectively, \( E \) is the precipitation efficiency, \( w_{vap} \) and \( w_{dry} \) are the vertical velocity forced by orography and environment, respectively, \( q_s \) is the water vapor mixing ratio, \( L_a \) and \( L_s \) are the horizontal scale of the precipitating system and its moving speed, respectively.

METHODOLOGY

- REAL CASE SIMULATION
  - ARW-WRF Model V3.3.1
  - Initialized by NCEP Global Forecast System (GFS) Data
    - Daily data (00Z) from Aug 3 – 10, 2009
  - Grid Dimensions:
    - Nested grid (27, 9, 3 km)
    - 28 stretched vertical levels
  - Physics Parameterization Schemes:
    - Microphysics – Goddard
    - Cumulus parameterization – Kain-Fritsch
    - PBL – YSU
    - Surface layer – Monin-Obukov
    - Longwave – RRTM
    - Shortwave – Dudhia
  - Observed Data:
    - Typhoon best track data from Japan Meteorological Agency (JMA)

RESULTS – OROGRAPHIC RAIN INGREDIENTS

- a) The wind speed over the selected area has an average and max LLJ of 23ms^{-1} and 40ms^{-1} respectively. The Strong LLJ is enough to produce orographic lifting.
- b) The averaged and maximum CAPE over the selected areas are 185 KJkg^{-1} and 793 KJkg^{-1} respectively.
- c) The potential instability (\( \partial \theta / \partial z \)) for the selected area had no negative values (\( \partial \theta / \partial z > 0 \)), thus, the atmosphere was potentially stable. This implies potential instability played an insignificant role in the formation of heavy orographic rainfall.
- d) The averaged and max. mixing ratio over the selected area are 18.9 gkg^{-1} and 22.6 gkg^{-1} respectively.

RESULTS – VERIFICATION OF CONTROL (CTL) CASE

- a) The WRF simulated max rainfall is 8% lower than the observed value of 1402 mm.
- b) Since the simulated results compared well with the observed data, it assures us to use the simulated results to examine the essential orographic rain ingredient\( c \), and the generation and enhancement mechanisms related to Typhoon Morakot (2009).

RESULTS – VERTICAL CROSS-SECTION & CONCEPTUAL MODEL

- a) Orographic rain was initiated by terrain on 8/7/02 because typhoon center was about 300km away from the CMR (shown by the blue line).
- b) Rainfall steadily increased and max rain of 140mm occurred on 8/7/12Z as shown by the red line. The second curve (red line) is the rain related to the eyewall.
- c) The enhancement was due to the merging of orographic initiated rain and tropical cyclone (TC) rain.
- d) Damage of typhoon’s structure and weakening of its convection declined the rainfall on 8/8/02.

CONCLUSIONS

- a) The orographically initiated convection in SW CMR was able to develop further and produced heavier rainfall than in the NE CMR.
- b) The increase of strong, moist, unstable flow associated with the TC rainband impinging on the southwest CMR steep terrain possesses enough key ingredients for producing heavy rainfall.
- c) When the TC convection merged with the orographically initiated convection, the orographic rainfall was decreased, mainly due to the destruction of Morakot’s structure.
- d) Strong downslope winds and gravity waves help cut off rainfall on the lee slope.

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