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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

William Agyakwah
North Carolina Agricultural and Technical State University

Yuh-Lang Lin
North Carolina Agricultural and Technical State University

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Authors: William Agyakwah[1], Yuh-Lang Lin[1,2]
[1]Applied Science & Technology PhD Program, [2]Department of Physics
North Carolina A&T State University
Program: Applied Science & Technology (PhD)
Advisor: Dr. Yuh-Lang Lin

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; Witcraft 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:

$$\mathbf{P} = E\left(\frac{\rho_a}{\rho_w}\right)(w_{oro} + w_{env})q_v\left(\frac{L_s}{C_s}\right)$$

where ρ_w and ρ are the liquid water density and air density, respectively, ε is the precipitation efficiency, w_{oro} and w_{env} are the vertical velocity forced by orography and environment, respectively, q_v is the water vapor mixing ratio, L_s and c_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 03 – 10, 2009

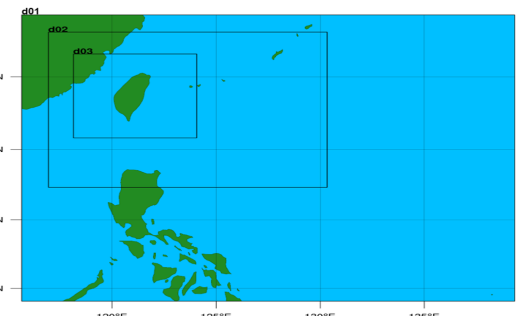

Fig. 1. Domain configuration for Typhoon Morakot simulations with three domains of 27km (d01), 9km (d02), and 3km (d03) grid resolutions.

- **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 – VERIFICATION OF CONTROL (CTL) CASE

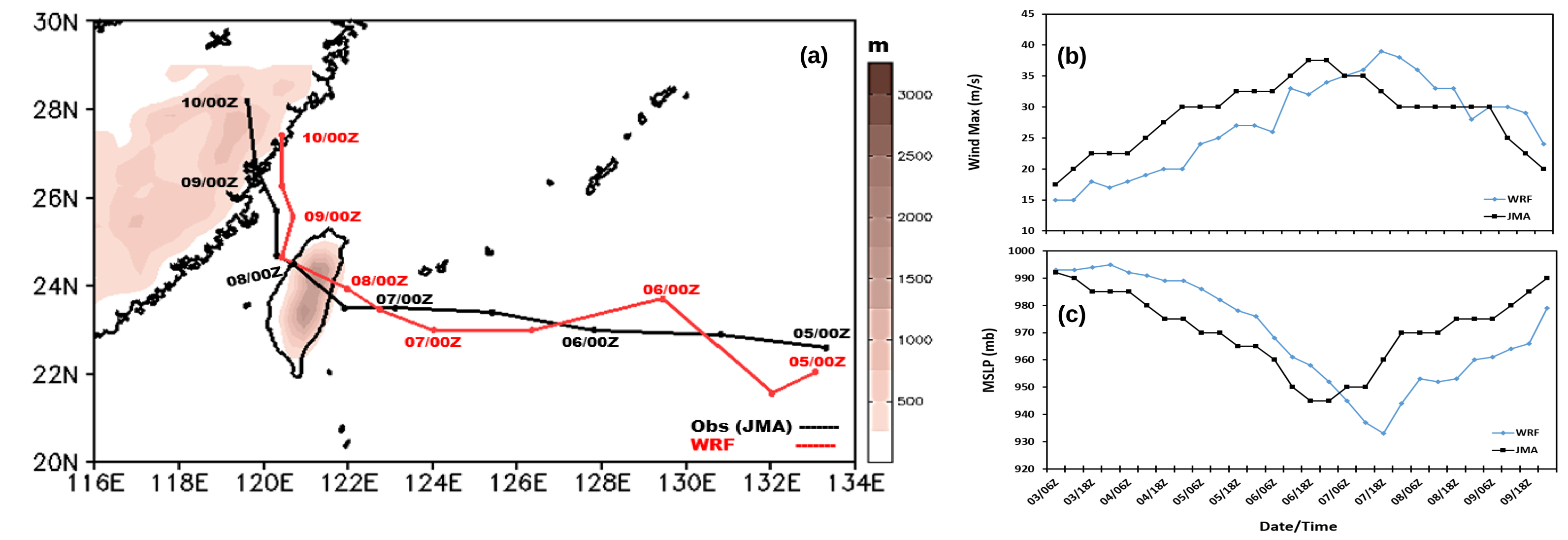

Fig. 2. (a) Best track data from JMA compared with WRF simulated track data for the period of Aug 5, 00Z to Aug 10, 00Z. (b) Maximum wind speed and (c) minimum sea level pressure (MSLP) data from JMA are compared with WRF simulated data for the period of Aug 3, 06Z to Aug 10, 00Z

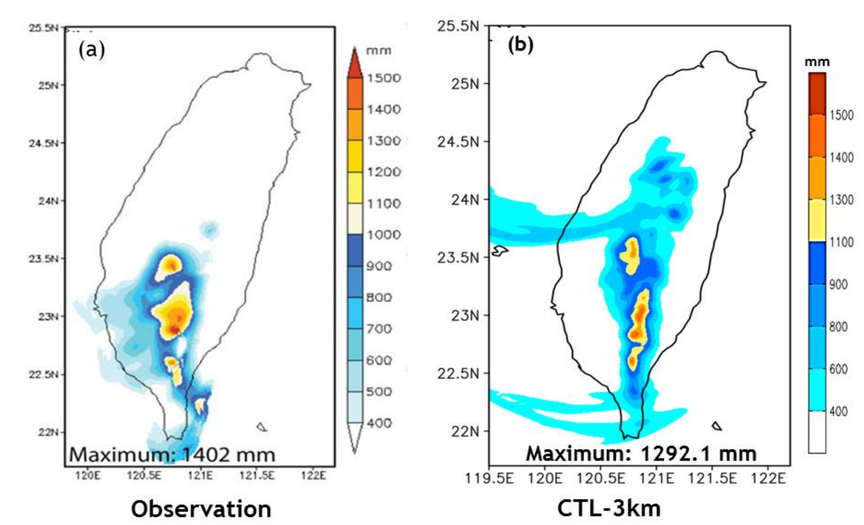

Fig. 3. Comparison of 24hr accumulated rainfall for (a) observation and (b) WRF simulated fields during 8/8/00Z – 8/9/00Z.

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 ingredients, and the generation and enhancement mechanisms related to Typhoon Morakot (2009).

RESULTS – OROGRAPHIC RAIN INGREDIENTS

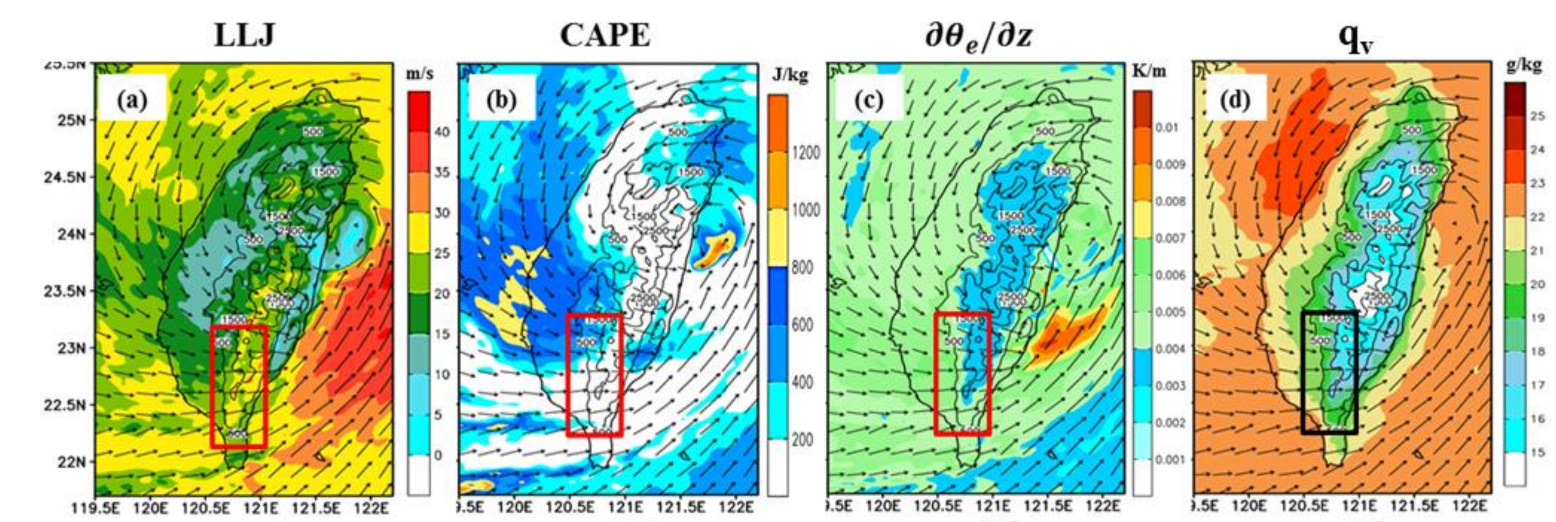

Fig. 4. (a) Low-level jet winds on 8/8/00Z with wind speed at 10m level (shaded contours). 24h (8/8/00Z - 8/9/00Z) averaged, from surface to 850mb for (b) CAPE (c) potential instability ($\partial\theta_e/\partial z$) (d) water vapor mixing ratio (q_v) with wind field at 8/8/00Z. The contour lines are terrain height with an interval of 1000 m.

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 Jkg^{-1} and 793 Jkg^{-1} respectively.

c) The potential instability $(\partial\theta_e/\partial z)$ for the selected area had no negative values $(\frac{\partial\theta_e}{\partial z} > 0)$, 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 – VERTICAL CROSS-SECTION & CONCEPTUAL MODEL

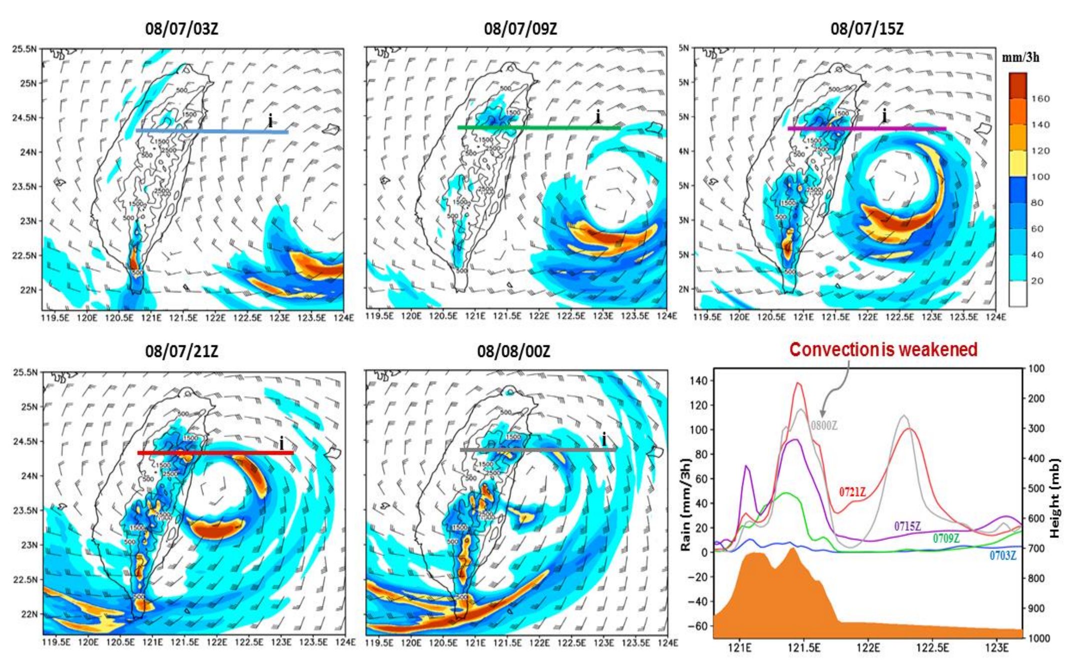

Fig. 5. Vertical cross-section i (24.3°N) and accumulated rainfall along the cross-section (08/07/03 – 08/08/00Z).

a) Orographic rain was initiated by terrain on 8/7/03Z 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 8/7/21Z; 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 8/8/00Z

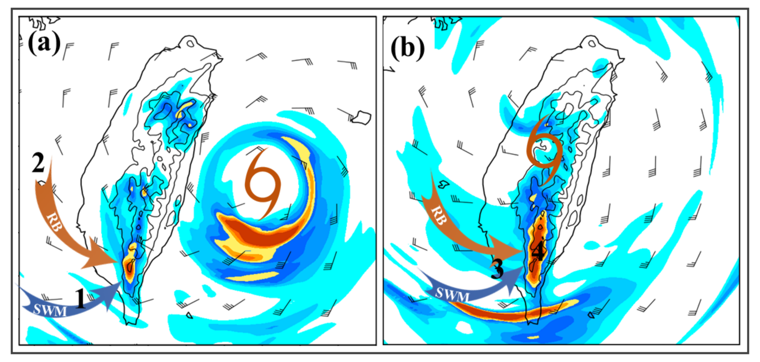

Fig. 6: A conceptual model showing four key processes associated with the generation and enhancement of orographic TC rain over the southwest of CMR during the passage of typhoon Morakot (2009).

a) Southwest monsoonal (SWM) current initiated orographic rainfall.

b) Northwest rainband (RB) moved in while typhoon approached northeast CMR.

c) Southwest monsoonal current and northwest rainband merged into a very moist LLJ with preexisting convection.

d) Orographic rain and TC rain merged and led to enhanced convection which produced extreme rainfall

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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Corresponding E-mail Addresses: Dr. Yuh-Lang Lin – ylin@ncat.edu
William Agyakwah – wagyakwa@aggies.ncat.edu