The Role of Moist Absolutely Unstable Layer (MAUL) in Orographic Precipitation: A Case Study from TAHOPE IOP 2

Ming-Jen Yang[1#], Jyong-En Miao[1], Kristen Rasmussen[2], and Michael Bell[2]

[1]*National Taiwan University, Taiwan*

[2]*Colorado State University, USA*

#: Corresponding author: mingjenyang@ntu.edu.tw

Abstract

Terrain plays a significant role in modulating the diurnal cycle of moist convection and rainfall. During the warm season, mountainous regions exhibit pronounced day-night variations in convective activity and precipitation due to orographic lifting. Beyond the mechanical aspects of orographic lifting, these motions can destabilize the atmosphere by lifting moist and conditionally unstable air to saturation (Kirshbaum et al. 2018). This process can result in the formation of moist absolutely unstable layers (MAULs; Bryan & Fritsch 2000), where the lapse rate of a saturated layer exceeds the moist adiabatic lapse rate. Bryan and Fritsch (2000) and Mechem et al. (2002) first highlighted MAULs within MCSs over the midlatitude United States and the tropical western Pacific, respectively. In both studies, MAULs extended horizontally for hundreds of kilometers along the axis of MCSs and vertically up to ~100 mb, primarily formed by mesoscale lifting induced by cold pools. Although there is increasing recognition of MAUL as a critical factor in extreme precipitation, no prior studies have examined its occurrence in Taiwan's heavy rainfall events. This knowledge gap is particularly surprising given Taiwan's humid subtropical environment, which is often conducive to deep convection. This study seeks to address this gap by investigating whether complex terrain can induce MAUL formation and subsequently enhance extreme orographic rainfall during the TAHOPE/PRECIP IOP 2. The main objective is to identify the physical processes through which terrain contributes to MAUL development. In addition, the relationship between MAUL and heavy rainfall will be explored.

Using high-resolution WRF simulations with the control (CNTL) run with full terrain and the sensitivity tun without Taiwan terrain (NTER) in this study, we will show that Taiwan topography plays a critical role in enhancing moisture flux convergence

(MFC) and supporting the formation of deep in TAHOPE IOP 2, persistent MAULs that precede intense precipitation. The key physical processes are summarized in Figure 1 below.

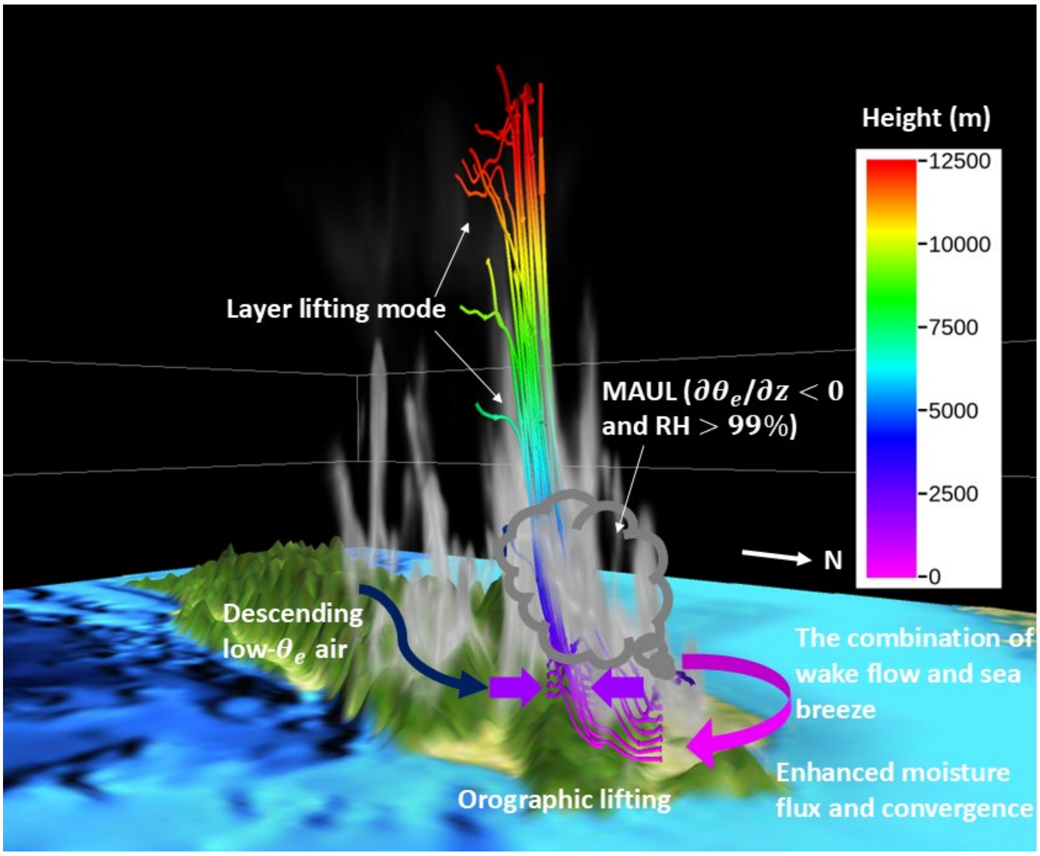

Figure 1. Conceptual 3D visualization of the physical processes leading to MAUL formation and extreme orographic rainfall in CNTL. Arrows illustrate the interaction of wake flow and sea breeze enhancing moisture flux convergence, with orographic lifting forcing layer lifting of inflow. The layer lifting mode supports the development of MAULs (defined by $d\theta_e/dz < 0$ and RH > 99%) and intense convection. Descending low-θ_e air intrudes from the southeast, possibly maintaining the low-level convergence. Trajectories are colored by altitude to illustrate the vertical extent of updrafts.

When the southwesterly monsoon is blocked by Taiwan's topography, enhanced MFC develops in the wake region. The interaction among wake flow, sea breeze, and upslope flow transports abundant moisture from the ocean toward the mountain slope, a process shown to be critical for mountain flooding. The sustained upslope lifting in CNTL leads to the development of deep MAULs extending from near the surface up to ~5 km altitude. Trajectory analysis reveals that these MAULs are associated with coherent layer lifting, in contrast to the shallower MAULs in NTER, where ascent is parcel-based and limited. These terrain-induced MAULs create a favorable thermodynamic environment for convection development. Moreover, our results suggest a consistent relationship between MAUL volume and subsequent hourly rainfall. When MAUL volume exceeds 2000 km^3 (3000 km^3), the following hour's peak rainfall often surpasses 40 mm (80 mm). While the timing of MAUL and rainfall peaks may differ, this threshold-like relationship highlights the diagnostic potential of MAUL volume as a precursor to extreme precipitation events. Thus, this suggests that terrain-enhanced moistening plays a critical role in preconditioning the environment for MAUL development and subsequent extreme rainfall. More details will be given at the presentation of the conference.