Synergistic Effects of Low-level Dynamics and Thermodynamic Preconditioning on Extreme Afternoon Convective Precipitation in Taipei

〇Chi CHANG, Kosei YAMAGUCHI

Extreme afternoon convective precipitation represents a major hydrometeorological hazard in the Taipei Basin, frequently producing localized heavy rainfall and associated urban impacts. Despite its importance, the environmental factors controlling the intensity of these events remain incompletely understood, particularly with regard to how thermodynamic conditions and low-level dynamic forcing interact. This study examines the joint influence of thermodynamic preconditioning and low-level dynamics on extreme afternoon convective precipitation using a 25-year dataset spanning 2000–2024.

An event-based analysis framework is employed to isolate afternoon convective rainfall under hot-day conditions. Thermodynamic environments are characterized primarily by near-surface moisture indicators, including 2-m dew point temperature and equivalent potential temperature, while low-level dynamics are represented by convergence and vertical motion in the lower troposphere. Conditional quantile diagnostics are used to assess how upper-tail precipitation intensity varies across different thermodynamic and dynamic regimes.

The results indicate that extreme precipitation intensity exhibits a non-linear and regime-dependent relationship with low-level dynamic forcing. In particular, stronger ascent or convergence does not necessarily correspond to systematically higher precipitation at upper quantiles. Instead, precipitation intensity tends to vary across different ranges of dynamic forcing, suggesting that the effectiveness of low-level dynamics in producing extreme rainfall depends on the accompanying thermodynamic conditions.

The importance of thermodynamic preconditioning is further supported by the sensitivity of upper-quantile precipitation to near-surface moisture. Higher dew point temperatures are generally associated with enhanced extreme precipitation, indicating that sufficient moisture availability plays a key role in enabling intense convective rainfall. However, the relationship between moisture and precipitation intensity remains modulated by the strength and structure of low-level dynamic forcing.

To examine potential temporal variability, the dataset is divided into two subperiods, 2000–2012 and 2013–2024. Rain-aligned composite analyses suggest that the later period is characterized by a warmer and moister thermodynamic background, while the overall characteristics of low-level dynamic forcing show broadly comparable behavior between the two periods. These results imply that changes in extreme precipitation may be influenced by shifts in background thermodynamic conditions, although dynamic processes continue to play an essential role.

Overall, this study highlights the coupled and non-linear nature of thermodynamic and dynamic controls on extreme afternoon convective precipitation in the Taipei Basin. By emphasizing how moisture conditions modulate the response of precipitation to low-level forcing, the findings provide a flexible and physically grounded framework for interpreting extreme rainfall variability and offer insights relevant to high-impact weather risk assessment under a changing climate.