A Physical Storyline for the Response of Orographically-Locked Diurnal Convection in a Warming Scenario

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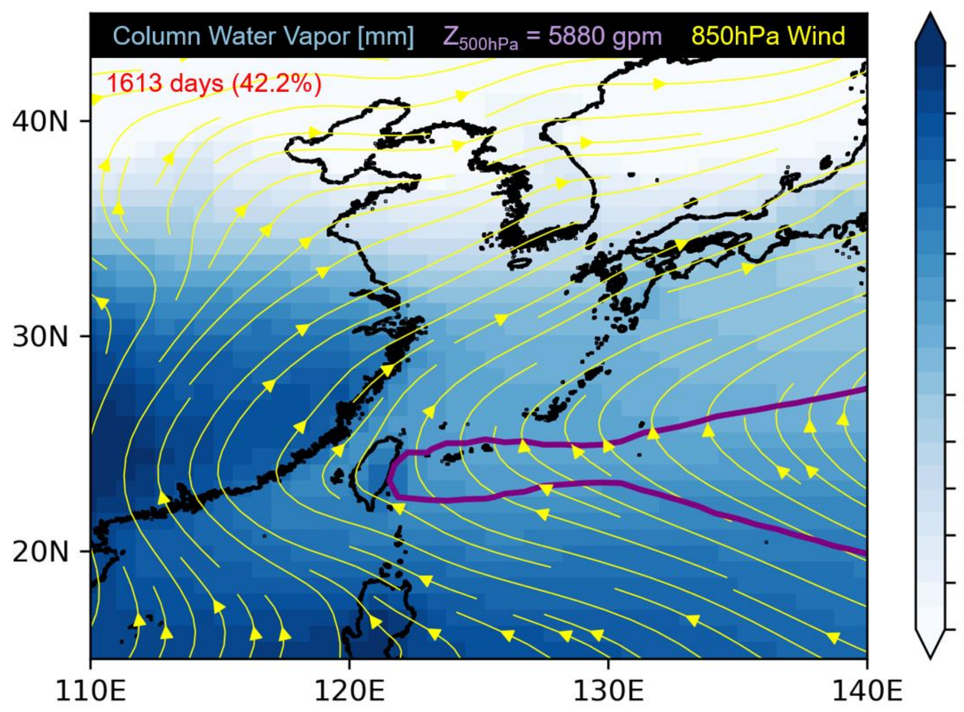
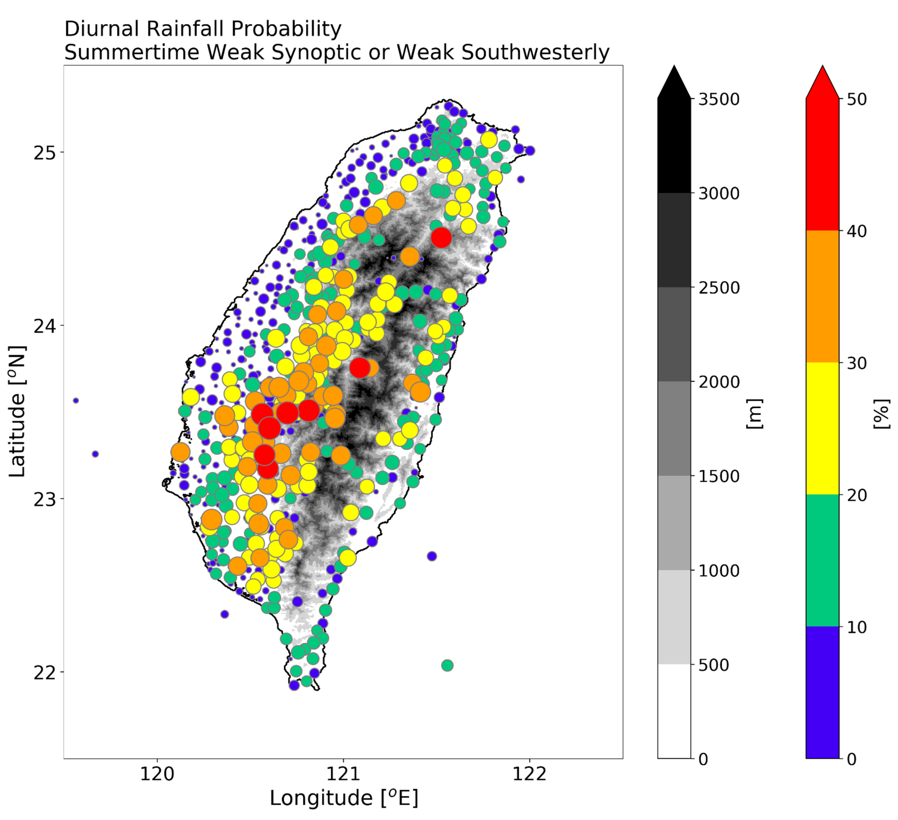
Abstract Over complex topography in Taiwan, organized orographically-locked diurnal convection contributes to extreme rainfall during the summer monsoon season under local circulation dominance. Understanding its responses to global warming is essential. While previous research has explored the impact of global warming on diurnal rainfall [Rasmussen et al., 2020], a greater focus on the physical mechanisms of local-scale convective processes over complex topography is needed. Addressing this research gap, we employ TaiwanVVM [Wu et al., 2019] to simulate a pseudo global warming (PGW) scenario through the storyline approach [Shepherd et al., 2018], which aims to unveil extreme event responses to global warming under a specific dynamical regime. By ideally raising initial temperature profiles by 3 K while maintaining fixed relative humidity in the initial conditions of future climate simulations, we notice an elevated precipitation intensity, surpassing the expectation from the Clausius-Clapeyron relation. We also identify the expansion of extreme convective systems towards the plains while remaining orographically-locked, which relates to their initiation location and translation direction. Overall, our findings highlight that the TaiwanVVM semi-realistic large-eddy simulation (LES) framework is relevant for examining the physical mechanisms of local-scale convective processes over complex topography and assessing their responses to global warming.

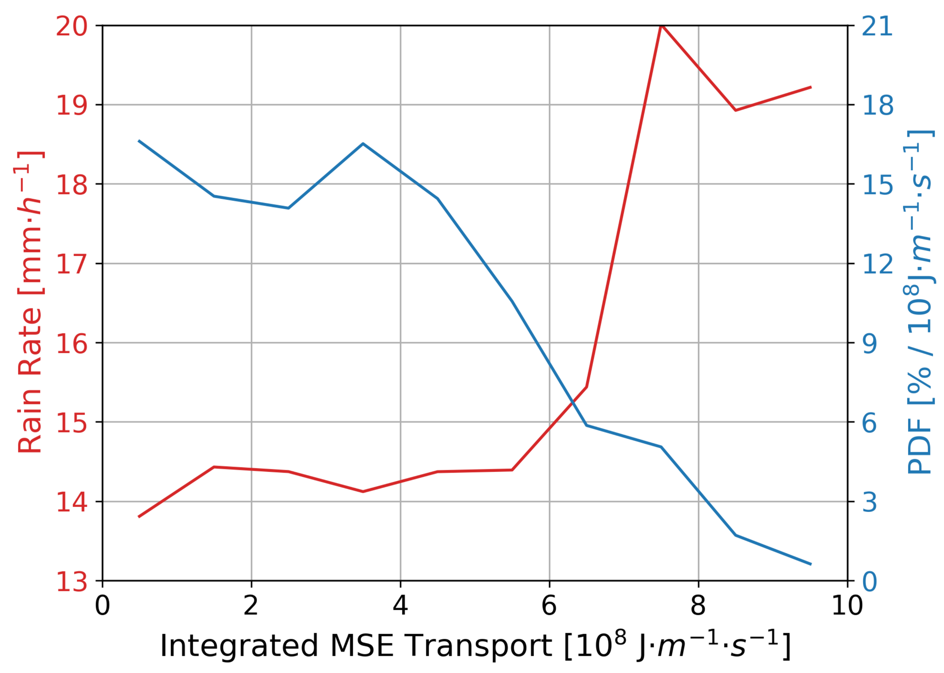
Synoptic Scenario Favoring Diurnal Convection Development



- The wind field around Taiwan is dominated by the local circulation (land-sea-mountain-valley breeze) instead of the synoptic-scale flow.
- Taiwan is at the edge of the high-pressure system.
- Moisture around Taiwan is high (about 49.5 mm).

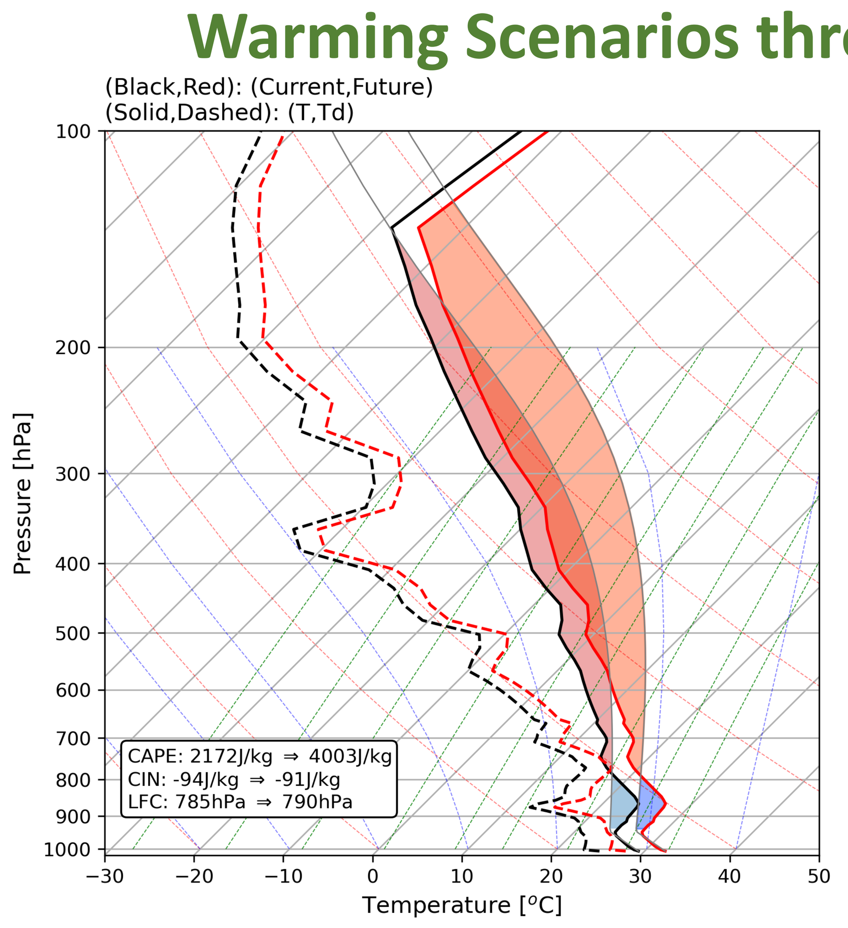
Organized Diurnal Convection is Orographically-Locked over Complex Topography





- Clusters of diurnal convection hotpots:
  - Northern tip of the CMR
  - Southwestern mountains of Taiwan
- The terrain-constrained path of coherent inflow layer by local circulation, bringing in high MSE, intensifies convection development over the precipitation hotspots [Chang et al., 2023].

Using TaiwanVVM Ensemble to Simulate Pseudo Global Warming Scenarios through the Storyline Approach

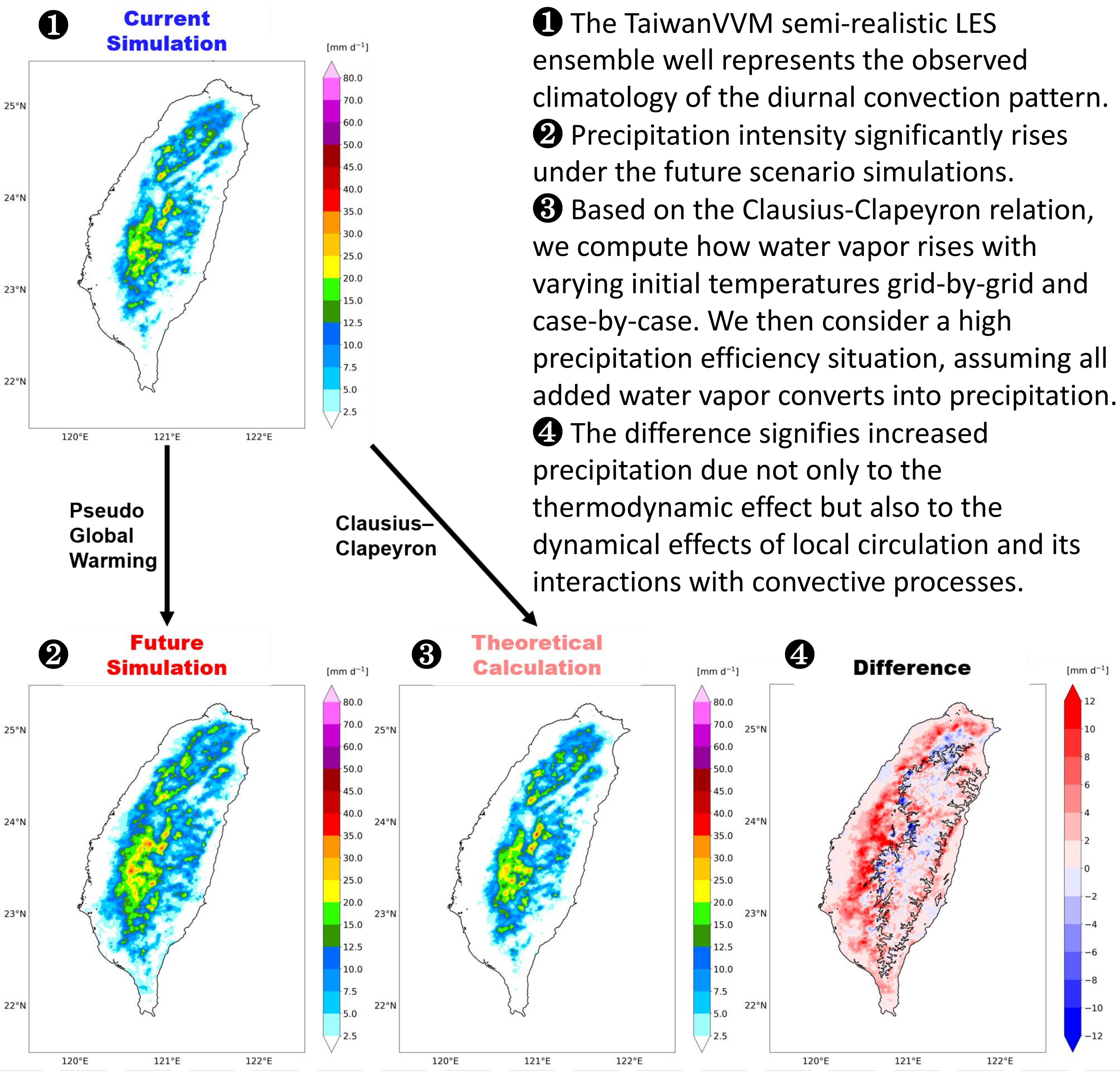


- The PGW approach applies specific climate forcings to a regional simulation [Brogli et al., 2023]. This method directly evaluates how atmospheric phenomena might unfold under altered climatic conditions, referred to as the "storyline" approach.
- Idealized forcings on initial condition:
  - Temperature: +3 K
  - Relative Humidity: fixed
- Since the temperature increases evenly over land and ocean, the strength of the land-sea breeze remains the same.
- The difference in LFC is trivial, but CAPE increases significantly.

Summary

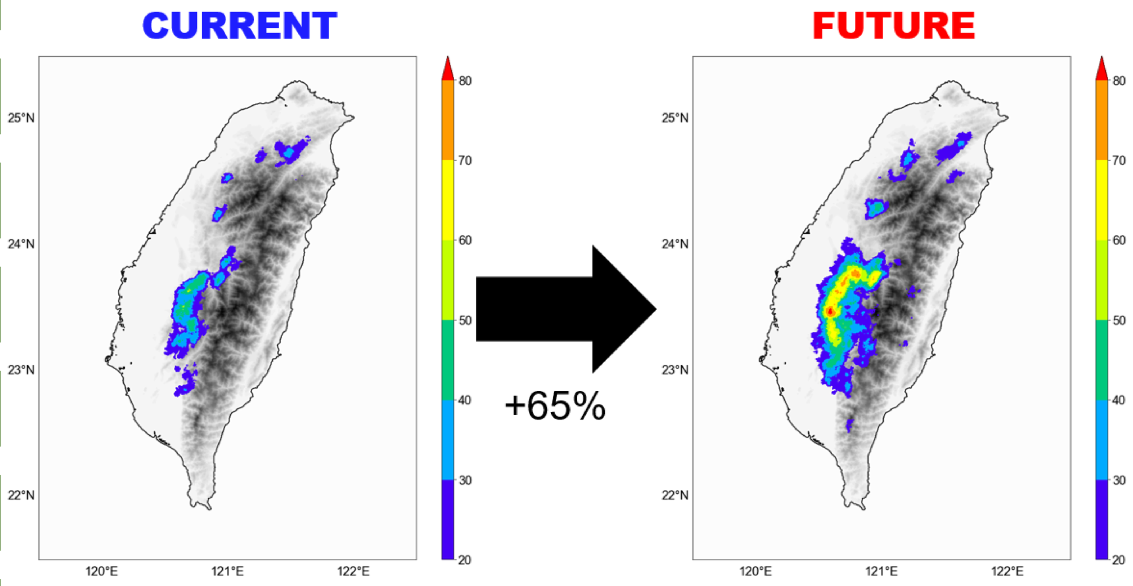
- Using TaiwanVVM to simulate a PGW scenario through the storyline approach, we notice an increase in precipitation intensity, surpassing what would be expected solely based on the Clausius–Clapeyron relation.
- In the future climate, extreme convective systems over the precipitation hotspot expand toward the plain while still being orographically-locked, which is a behavior related to their initiation location (more over the plain area) and translation direction (higher variability).

Precipitation Intensity Rises more in the Future Simulation than in the Theoretical Clausius-Clapeyron Relation Calculation

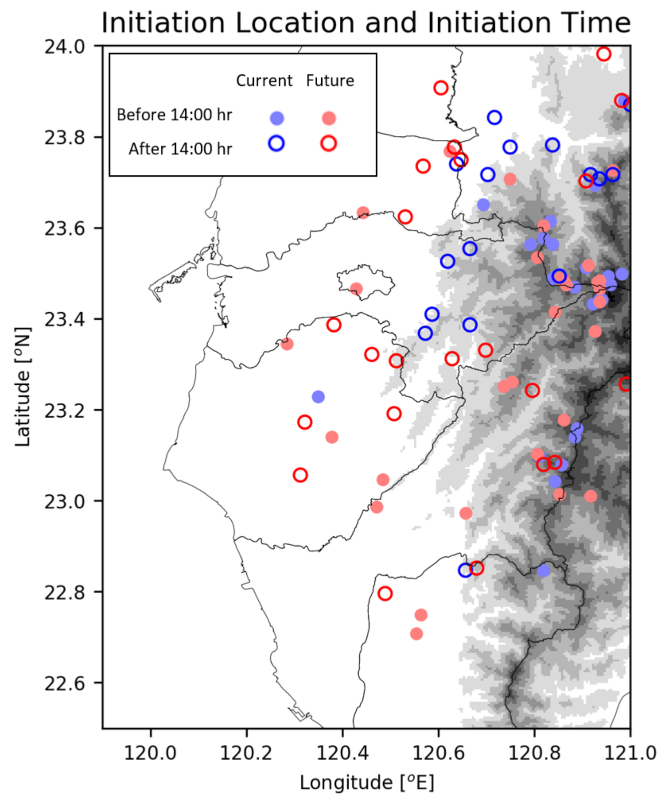


❶ The TaiwanVVM semi-realistic LES ensemble well represents the observed climatology of the diurnal convection pattern.
❷ Precipitation intensity significantly rises under the future scenario simulations.
❸ Based on the Clausius-Clapeyron relation, we compute how water vapor rises with varying initial temperatures grid-by-grid and case-by-case. We then consider a high precipitation efficiency situation, assuming all added water vapor converts into precipitation.
❹ The difference signifies increased precipitation due not only to the thermodynamic effect but also to the dynamical effects of local circulation and its interactions with convective processes.

Extreme Convective Systems over the Precipitation Hotspot Expand toward the Plain but are still Orographically-locked

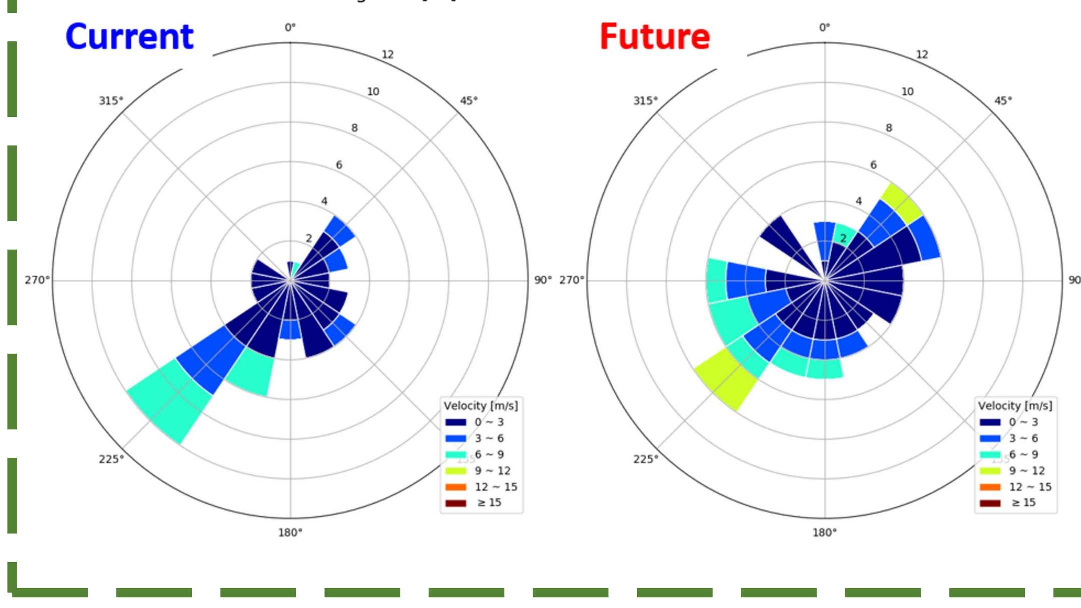


Possibilities:
❶More extreme convective systems initiate over the plain.
❷Extreme convective systems move toward the plain.



❶More extreme convective systems initiate over the plains

- In general, extreme convective systems initiate early in the mountains but late over the plains.
- Under the future climate, the initiation of extreme convective systems increases over the plains.



❷Movement of extreme convective systems changes

- Currently, extreme convective systems mostly move from SW toward NE.
- Under the future climate, the movement of extreme convective systems varies in all directions.

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