Attribution of heavy precipitation event using pseudo global warming simulations: sensitivity to vertical temperature changes
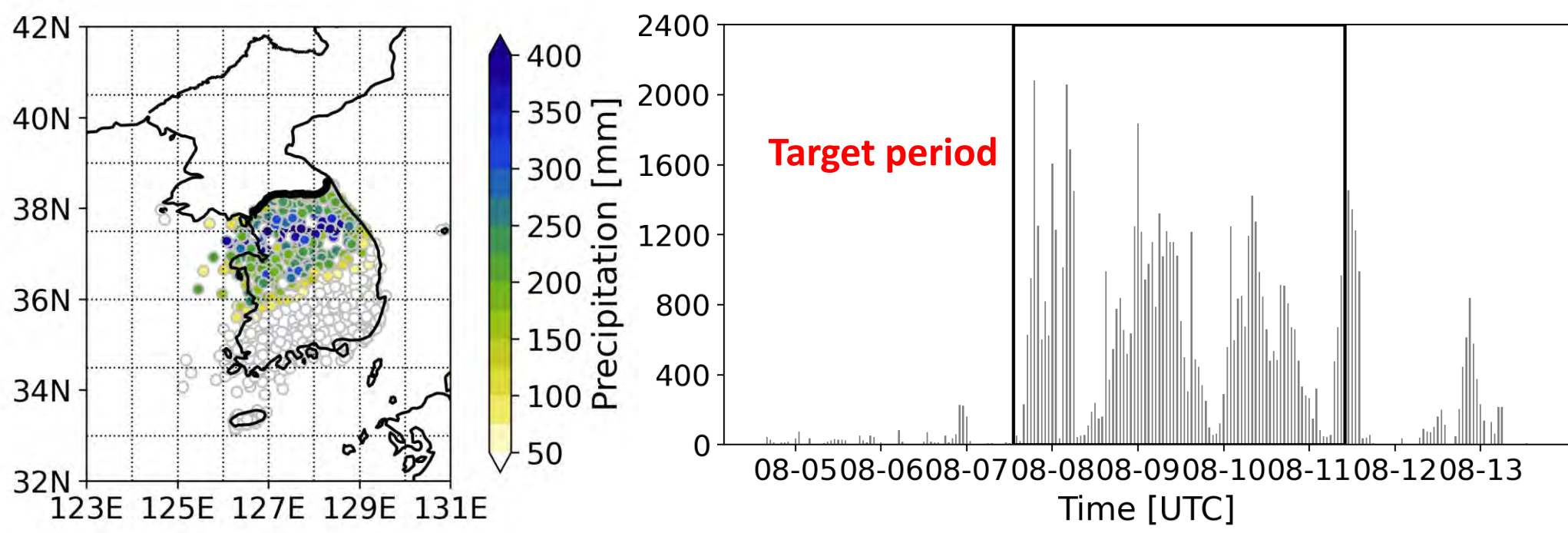
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Introduction

- Heavy precipitation event: 8-11 August 2022, South Korea
- Damage / Maximum hourly precipitation (AWS): 46 casualties / 141.5 mm/h

"How did anthropogenic forcing affect the event?"

Data and Method

❖ Data

- Observation & Reanalysis

Precipitation: AWS station data, MSWEP

Lateral boundary & Initial condition: ERA5 reanalysis

- CMI6 models

Experiments: Historical+SSP2-4.5, Historical natural-only

Period: 2011-2020, August

Variables: surface temperature, air temperature, relative humidity

❖ Experiments

- Control run

  ALL: include all forcings

- Pseudo non-warming run

Subtract anthropogenic forcings from control run + pre-industrial GHGs concentration

  NAT_T: calculate anthropogenic forcings using all available CMIP6 models

  NAT_W: calculate anthropogenic forcings using CMIP6 models with weak static stability in temperature delta

❖ PGW (Pseudo-Global Warming) method

Δ Delta = All forcings – Natural forcing = Anthropogenic forcing
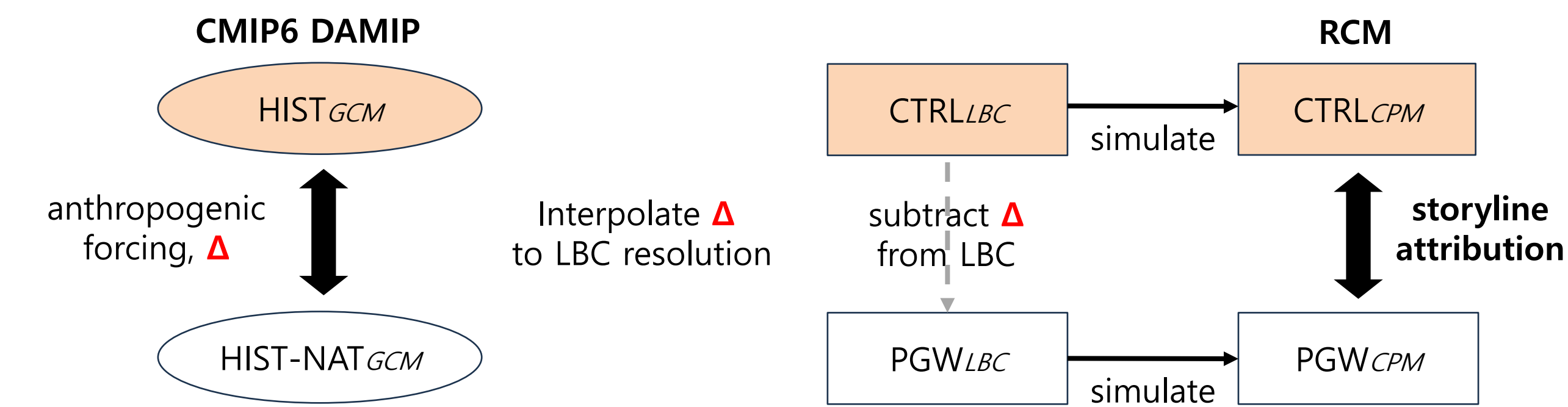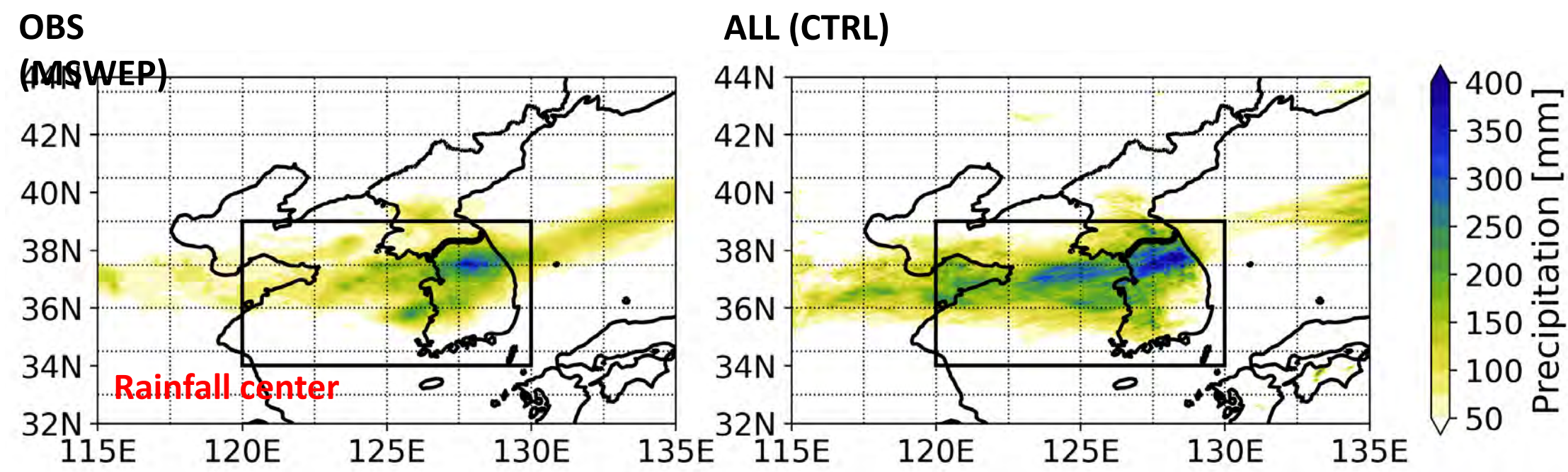

- Variables: Temperature (air temperature, sea-surface temperature), Relative humidity
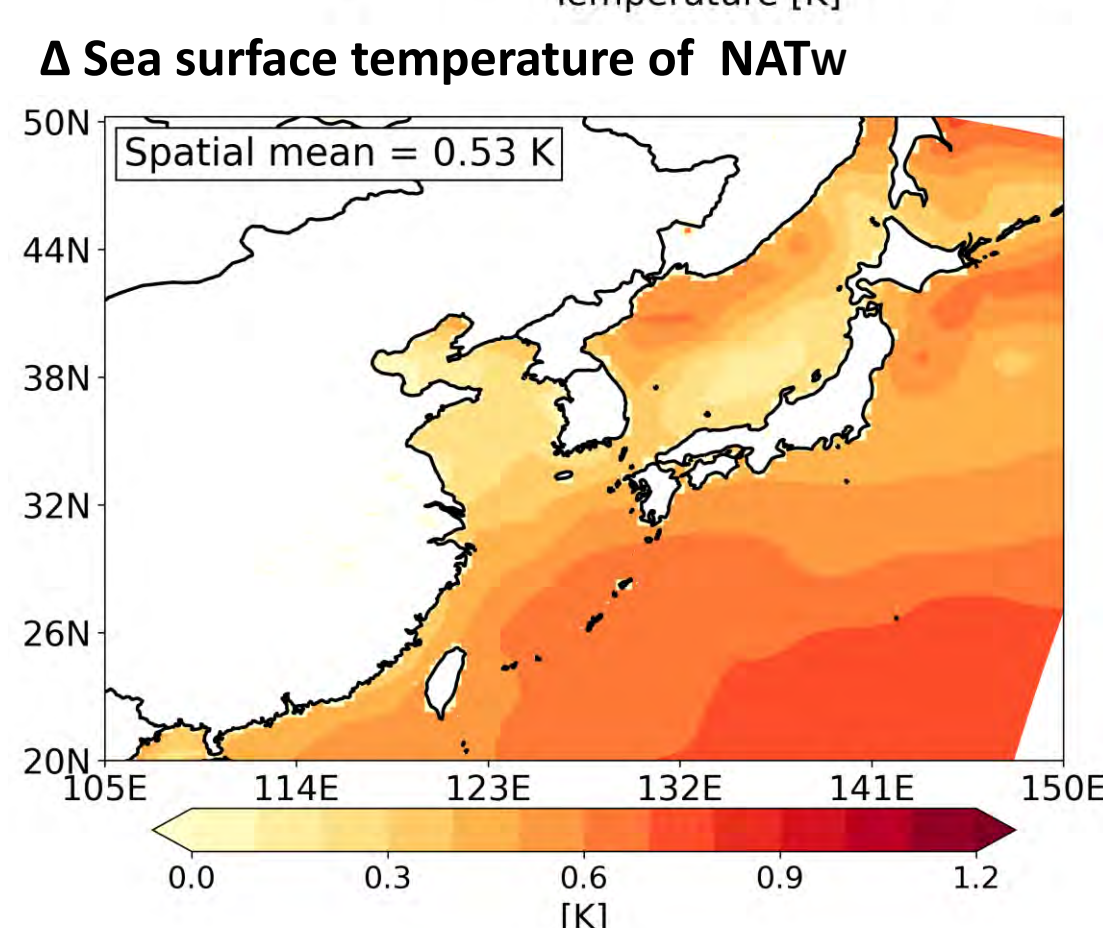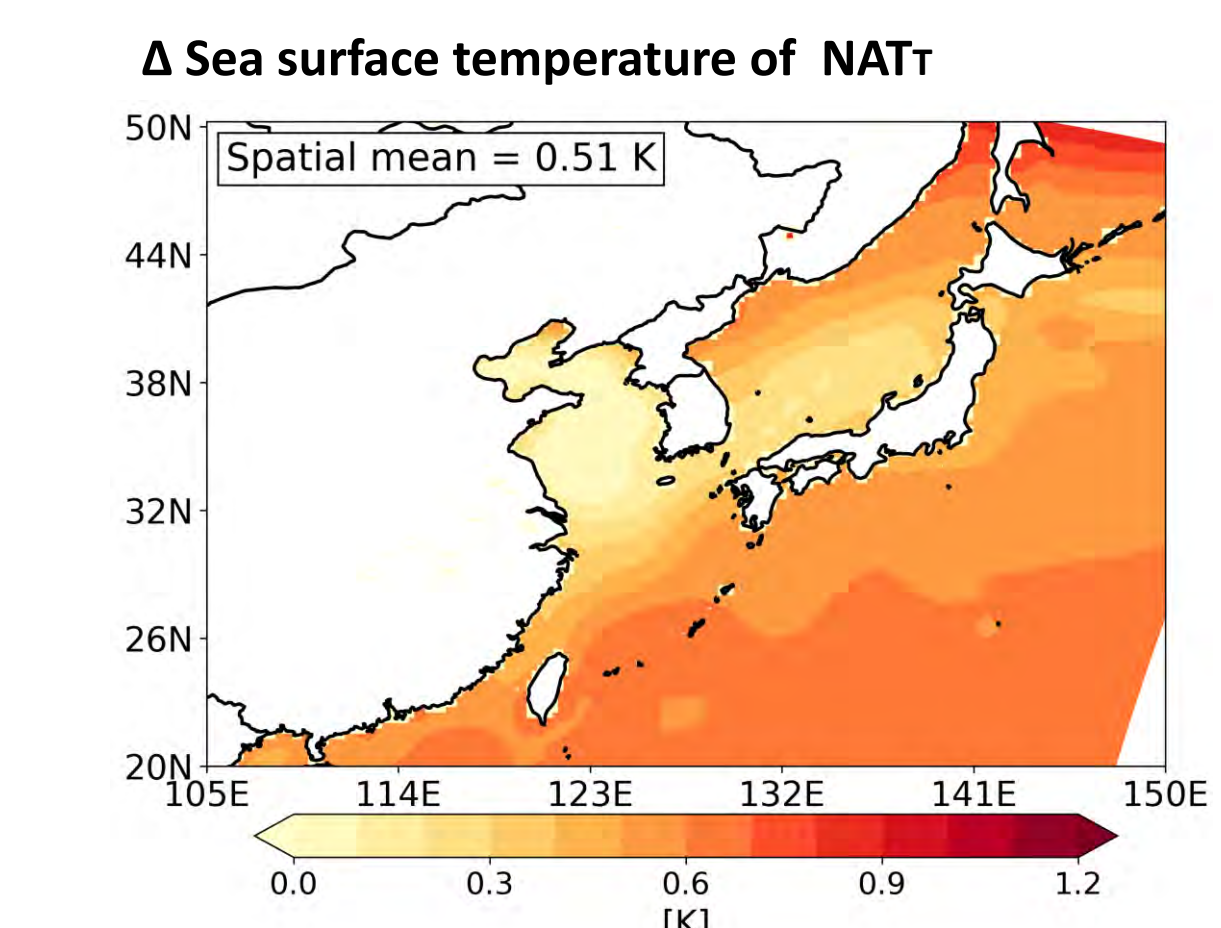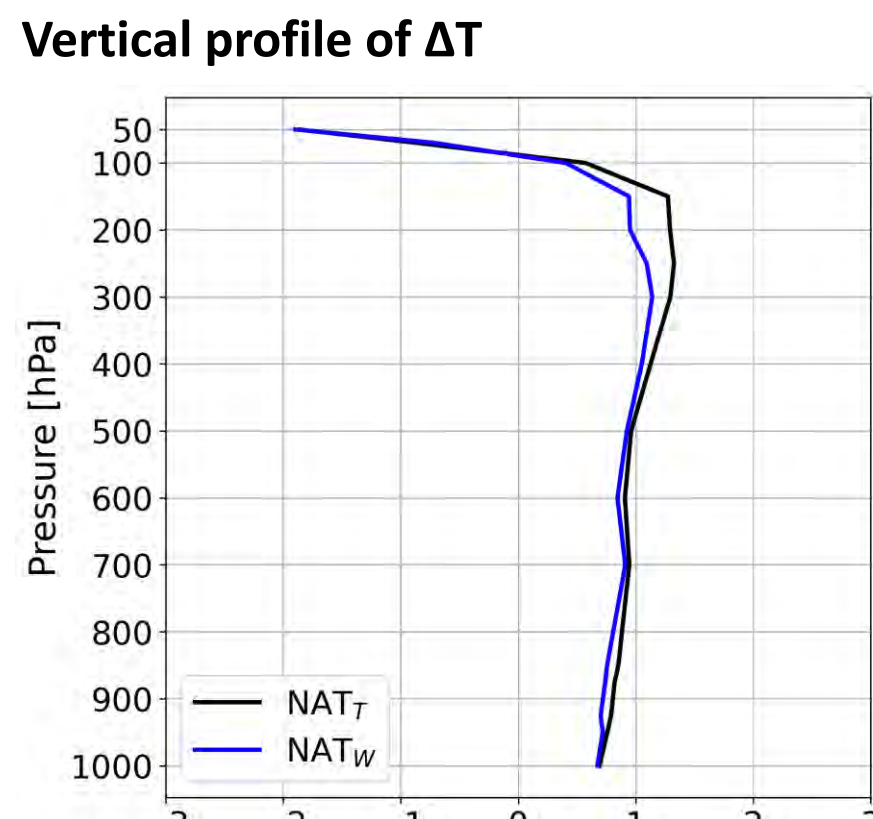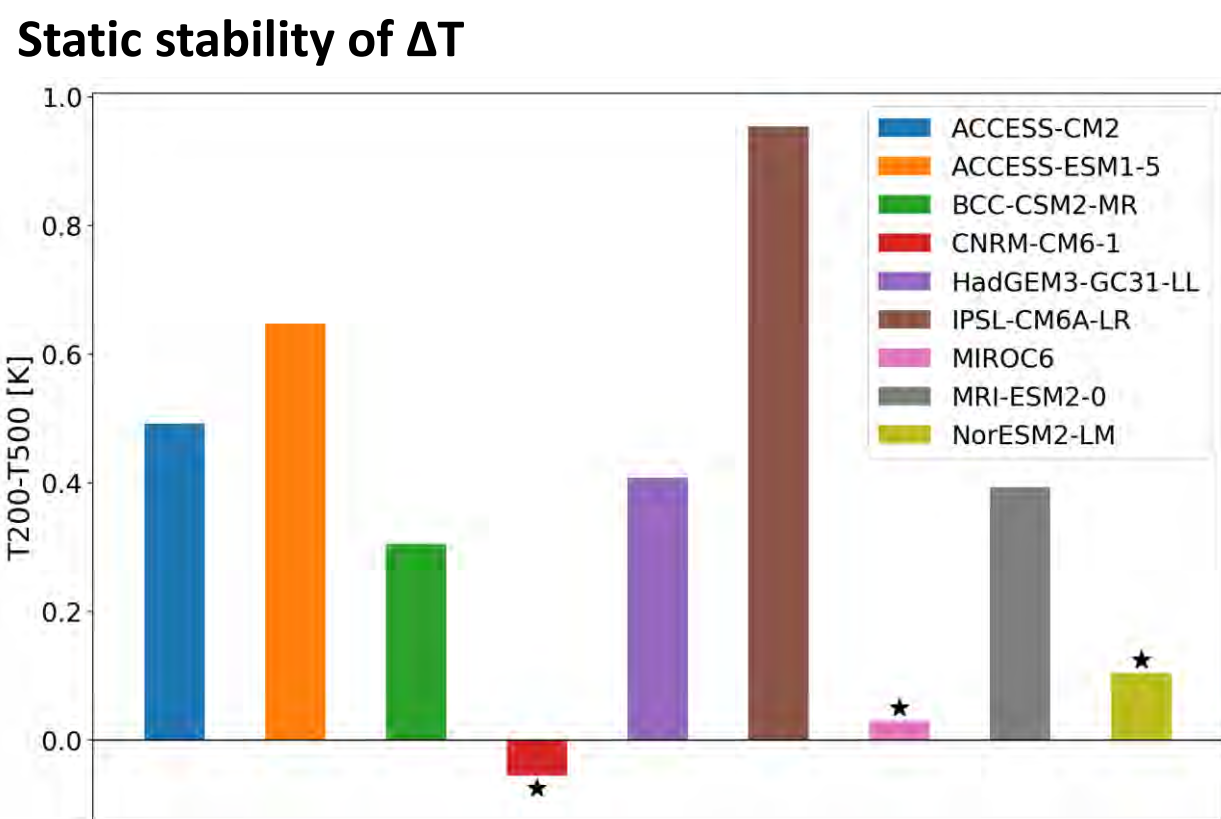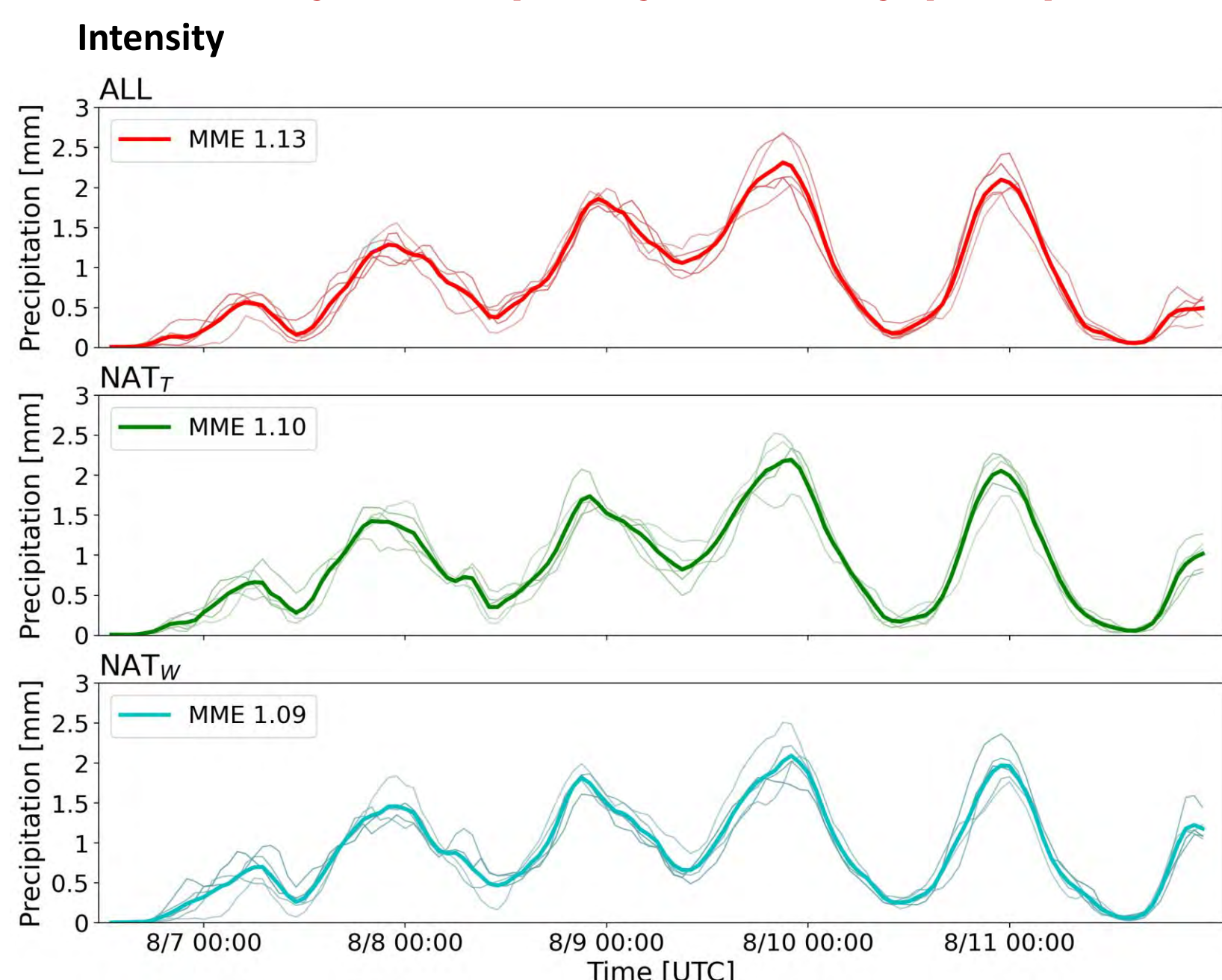

Results

❖ Model evaluation

- Both the location and quantity of precipitation were reasonably simulated in the model.

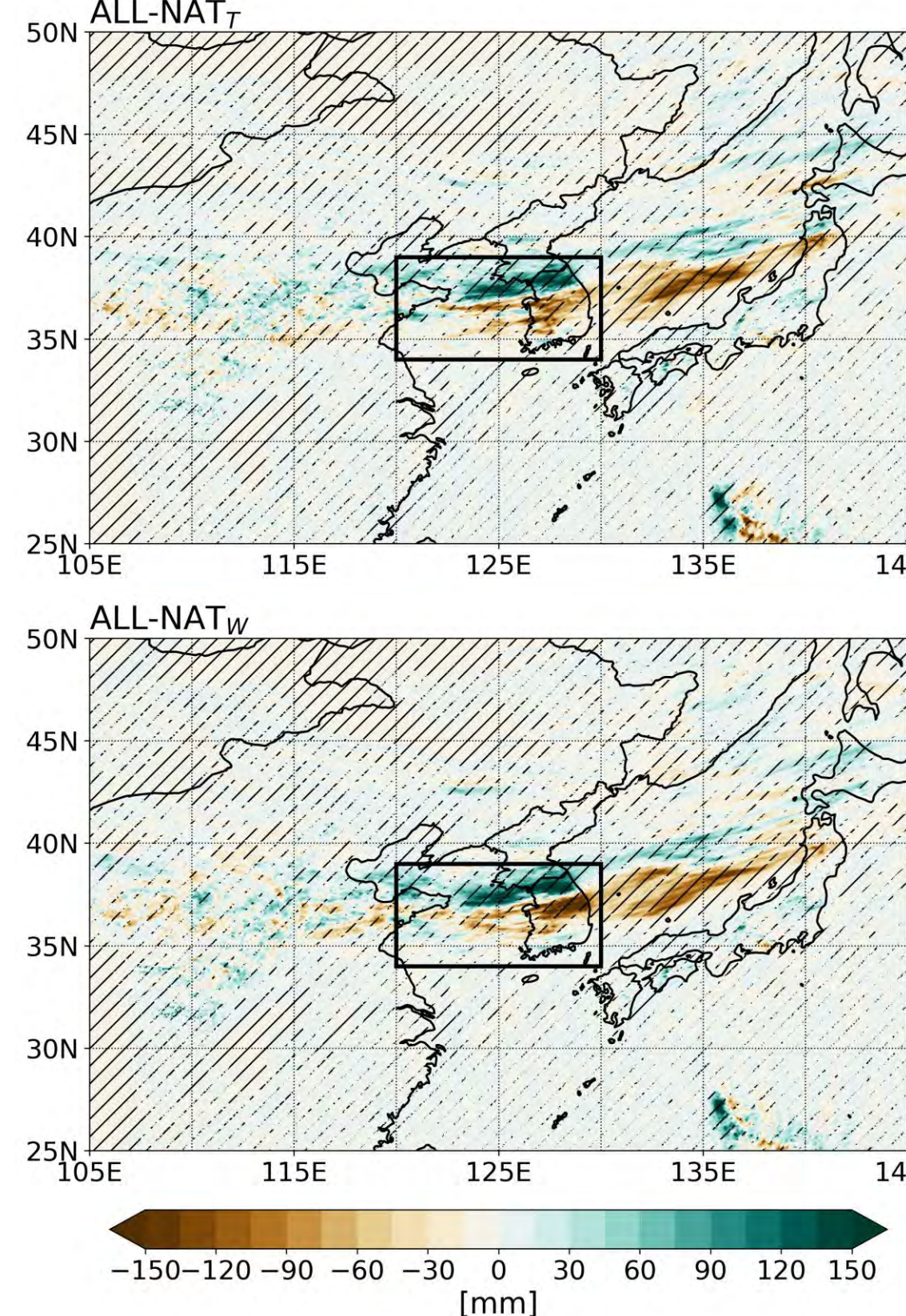### ❖ Intensity & Frequency of hourly precipitation

- Intensity: Mean of hourly precipitation over the rainfall center (34-39°N, 120-130°E).
- Simulated precipitation intensity at the grid points defined as rainfall center is very similar in both trend and magnitude across all experiments.
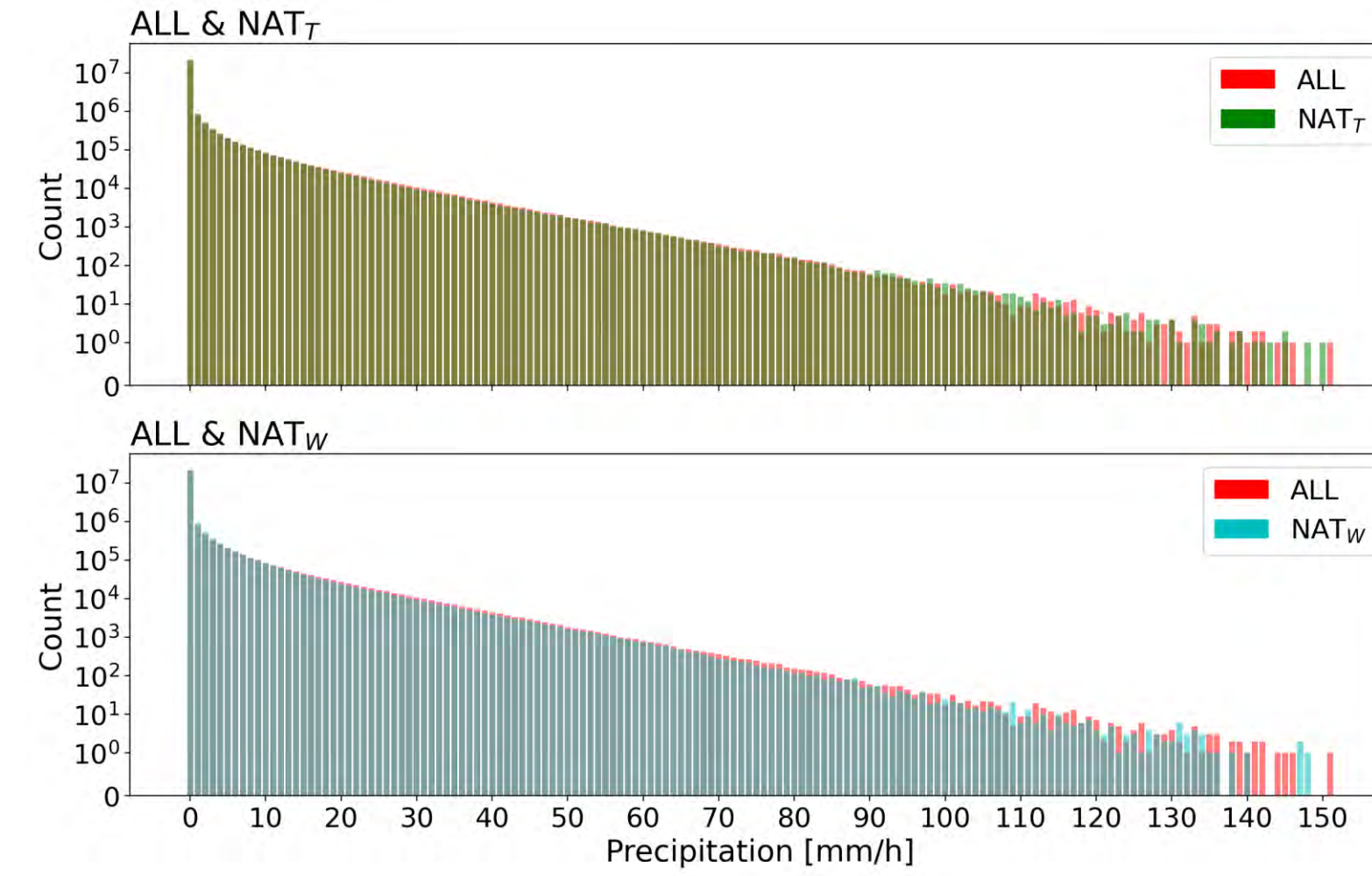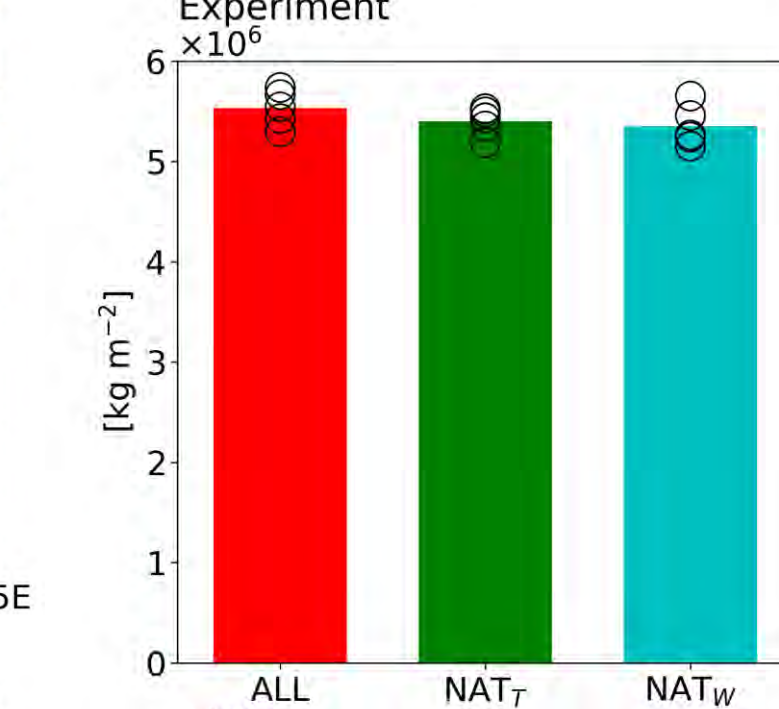

- Frequency: Number of grid points exceeding specified thresholds among the rainfall center grid points.
- Frequency of extreme hourly precipitation is slightly higher in ALL experiment than in both NAT experiments, but it is difficult to identify a significant difference between the experiments.
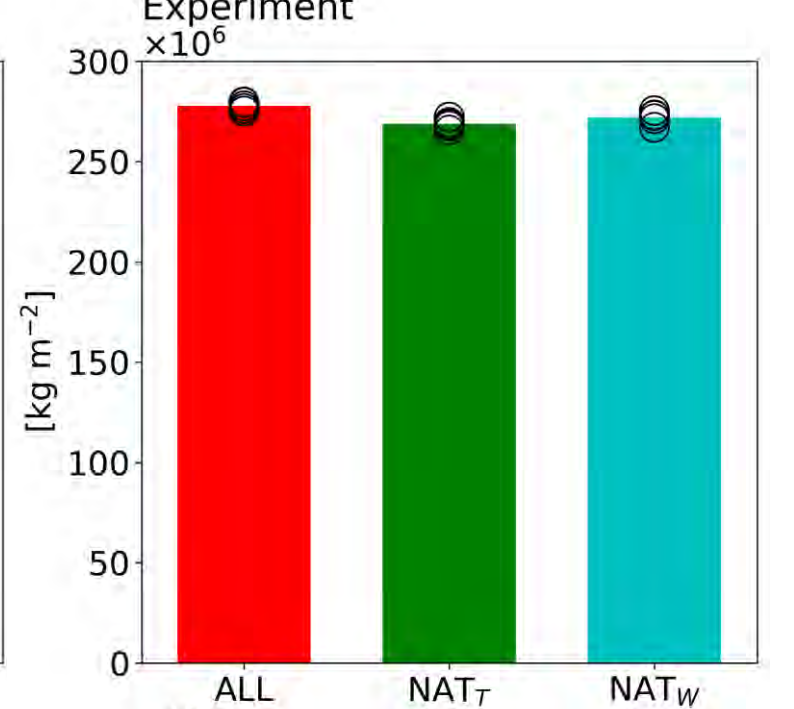
❖ Total precipitation & Precipitable water vapor

- Precipitable water vapor (PWV) shows increase in ALL experiment compared to NAT experiments, reflecting moisture increases due to anthropogenic warming.
- In contrast, total precipitation differences between the experiments are less pronounced than those in PWV.
- Suggesting that other factors offset the moisture-induced increases in total precipitation.
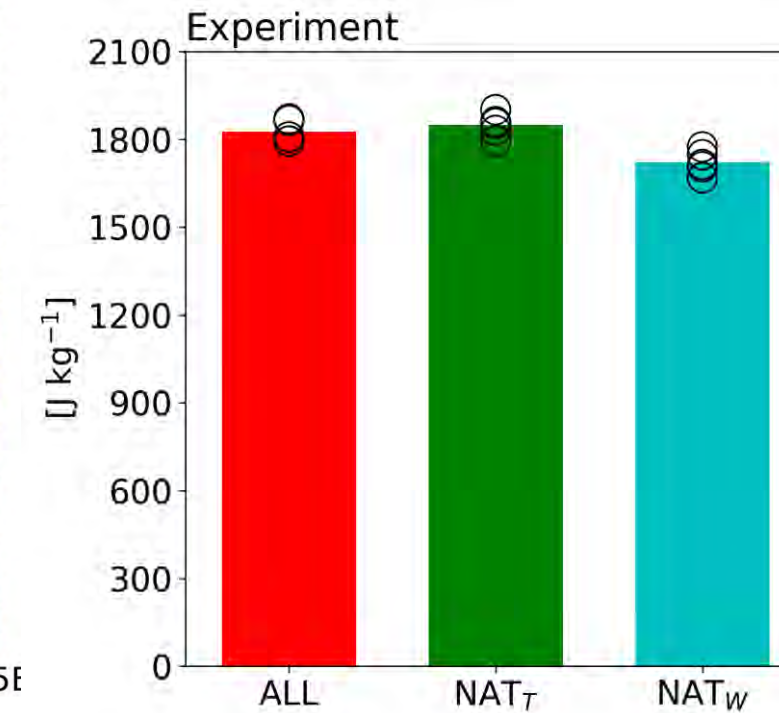
❖ Comparison of atmospheric instability

Applied PGW method only changed thermodynamical variables.

- Examine the difference in convective instability & moist-static stability.
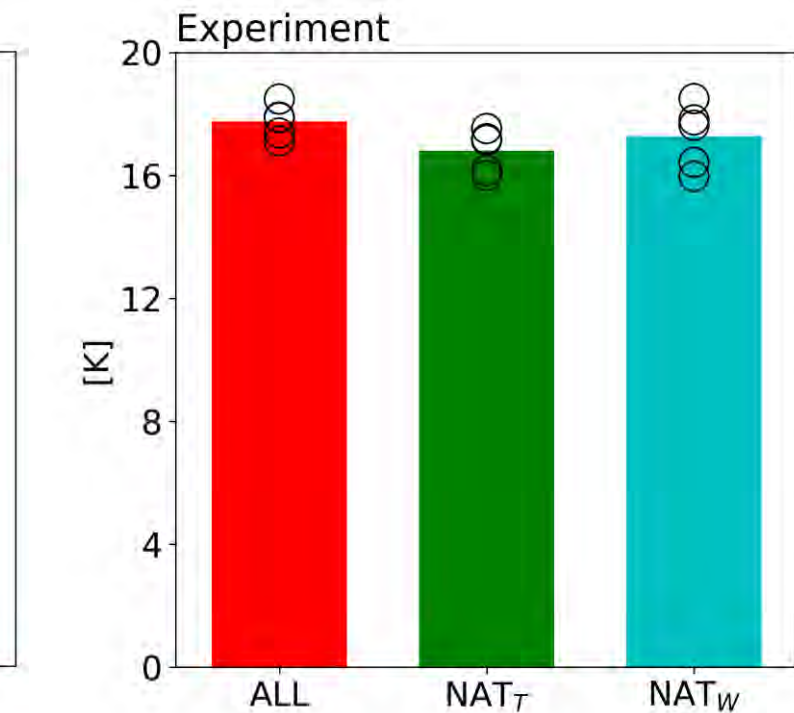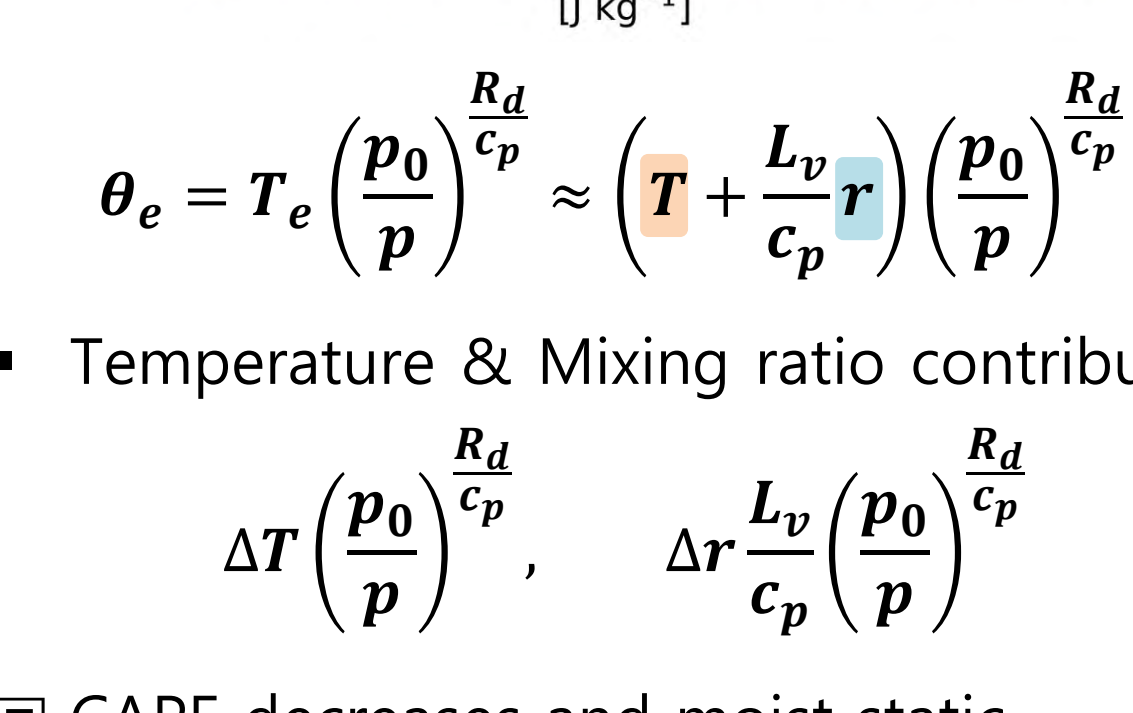

$$\theta_e = T_e \left(\frac{p_0}{p}\right)^{\frac{R_d}{c_p}} \approx \left(T + \frac{L_v}{c_p} r\right) \left(\frac{p_0}{p}\right)^{\frac{R_d}{c_p}}$$
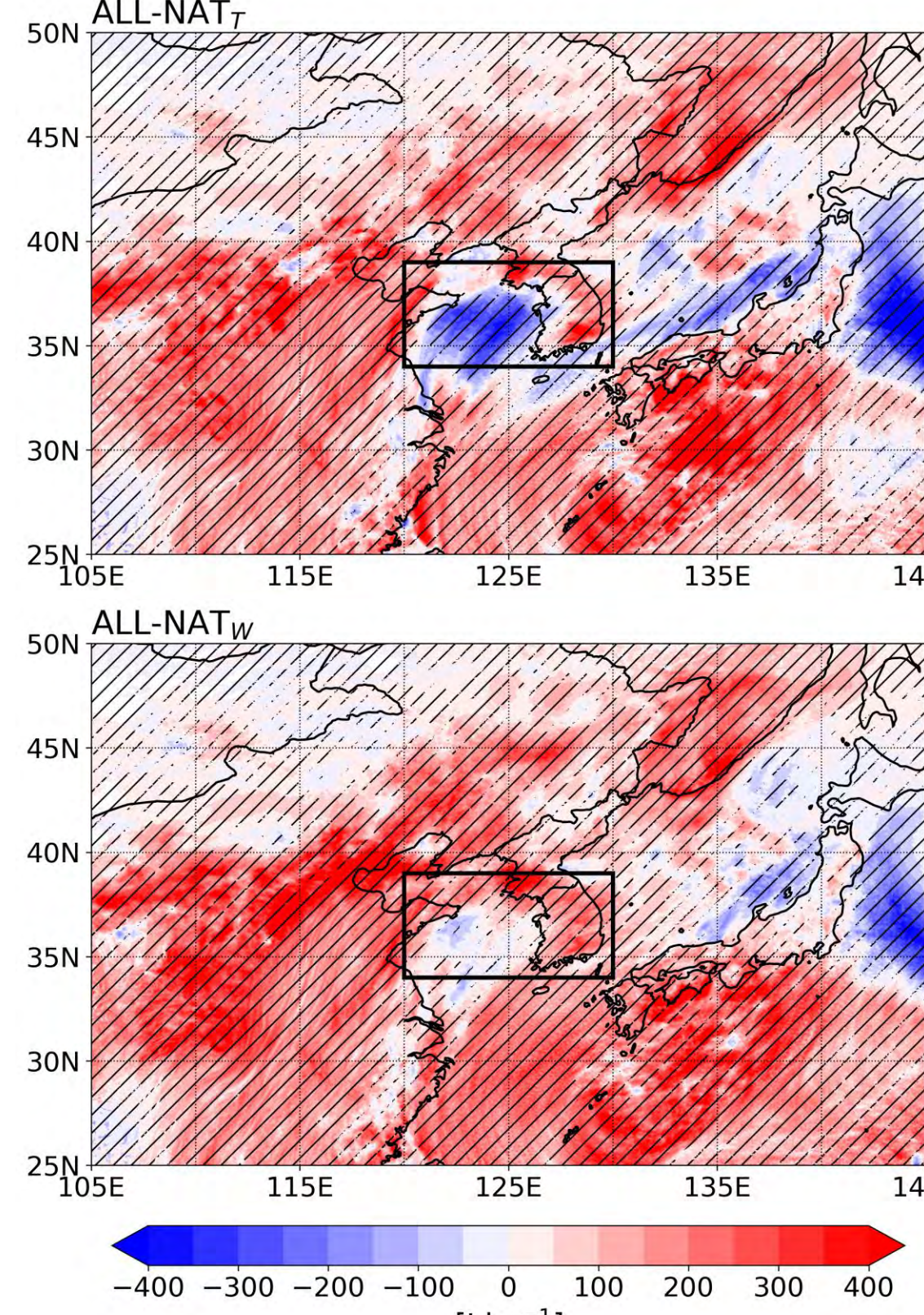
- Temperature & Mixing ratio contribution:

$$\Delta T \left(\frac{p_0}{p}\right)^{\frac{R_d}{c_p}}, \qquad \Delta r \frac{L_v}{c_p} \left(\frac{p_0}{p}\right)^{\frac{R_d}{c_p}}$$

- CAPE decreases and moist-static stability increases in the ALL experiment, indicating that the atmosphere is more stable under anthropogenic forcing.
- Decomposition of moist static stability changes reveals that temperature contributes more to the increase in atmospheric stability.

Summary & Discussion

- The anthropogenic impact is explored using pseudo non-warming experiments with considering different atmospheric warming patterns.
- Atmospheric moisture decreases in the NAT experiments as anthropogenic warming is removed, but increases in atmospheric instability, especially due to the removal of upper tropospheric warming, compensate for the effect of moisture reduction and maintain the intensity of the heavy precipitation event.
- The offset effect of atmospheric instability enhancement is relatively larger in NAT_T experiment, where the stronger warming is removed in the upper troposphere.
- Uncertainties in the temperature lapse rate response may influence PGW experiment outcomes, indicating the need for consideration and assessment of the warming structure when conducting event attribution studies.

Kwon, D., Min, S. K., Lee, M., Seo, G. Y., & Son, S. W. (2025). Attribution of 2022 August heavy precipitation event in South Korea using high-resolution pseudo global warming simulations: Sensitivity to vertical temperature changes. *Geophysical Research Letters*, 52(2), e2024GL112392.