Simulating Precipitation Efficiency Across the Deep Convective Gray Zone

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PRECIPITATION EFFICIENCY (PE)

$$PE = \frac{\text{surface precipitation rate [kg m}^{-2}\text{ s}^{-1}]}{\text{condensation rate [kg m}^{-2}\text{ s}^{-1}]}$$

- PE changes due to global warming may impact convective storms and regional precipitation patterns
- Kilometer-scale (km-scale) climate models are valuable tools for studying climate change effects on precipitation

How can we quantify the PE of convective storms simulated by km-scale models?

- Storm updraft and downdraft characteristics are linked to PE through condensation and evaporation
- Km-scale models do not properly resolve entrainment

How well do km-scale models simulate the PE?

IDEALIZED WRF SIMULATIONS

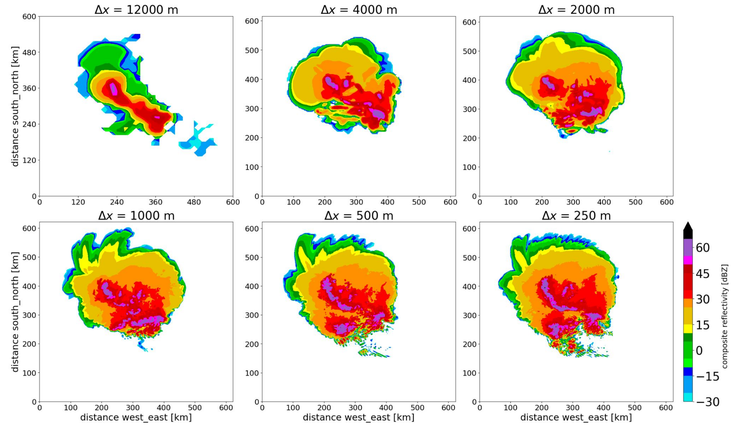


Fig 1.: Instantaneous composite radar reflectivity from one of 20 simulated cases of organized convective storms over the contiguous United States (CONUS). The idealized simulations were performed using the Weather Research and Forecasting (WRF) model at six different horizontal grid spacings, with initial conditions derived from soundings in the inflow regions of convective storms, as tracked in a downscaled km-scale regional climate reanalysis.

TWO NOVEL METHODS

State variable (SV) method

$$C = gw\left(-\frac{dq_s}{dT}c_p^{-1}\frac{q_s\rho}{p-e}\right)\left(1+\frac{dq_s}{dT}\frac{L_v}{c_p}\right)$$

We leverage the **saturation adjustment technique** to estimate condensation from **vertical velocity (w)**, **pressure (p)**, and **temperature (T)**.

Ice water path (IWP) method

$$C = P + E + \frac{\delta IWP}{\delta t}[>0] + \frac{\delta IWP}{\delta t}[<0]$$

We leverage the **bulk water budget** to estimate condensation from **ice water path (IWP)** and **precipitation (P)**.

Validation against condensation rates simulated by the Thompson scheme

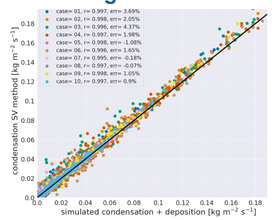


Fig. 2: Scatterplot with correlation and errors of grid-cell-scale instantaneous (5 min) condensation rates estimated by the **SV method** compared to the corresponding simulated condensation rates.

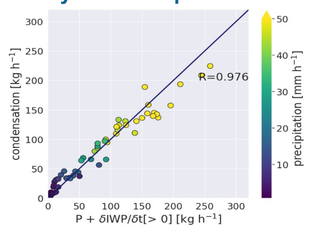


Fig. 3: Scatterplot and correlation of domain-averaged hourly condensation rates estimated by the **IWP method** compared to the corresponding simulated condensation rates

GRID SPACING SENSITIVITY

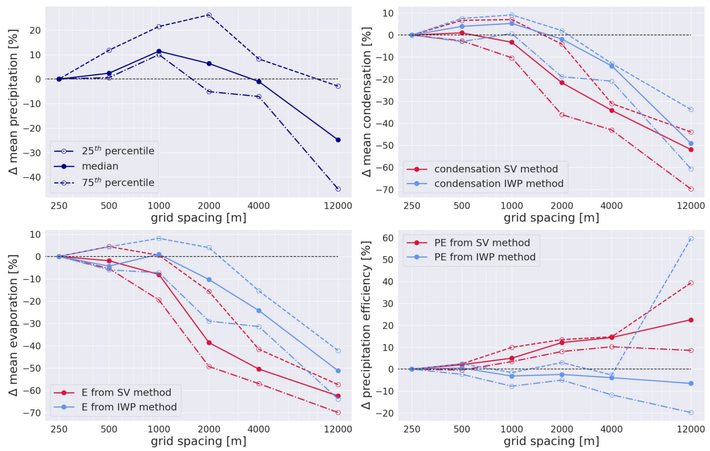


Fig. 4: Grid spacing sensitivity of bulk precipitation, evaporation, condensation and PE of 10 storm cases. All quantities are averaged over the storms' lifetime and area. The y-axis indicates the ensemble mean (and 25th/75th percentiles) between each case at different horizontal grid spacings and the corresponding cases simulated with a 250 m grid spacing. The PE shows less sensitivity to grid spacing and smaller variability between cases compared to condensation and evaporation. **The accuracy of simulated PE at a 4 km grid spacing is ~15% relative to simulations at 250 m.**

CLIMATE CHANGE SIGNAL

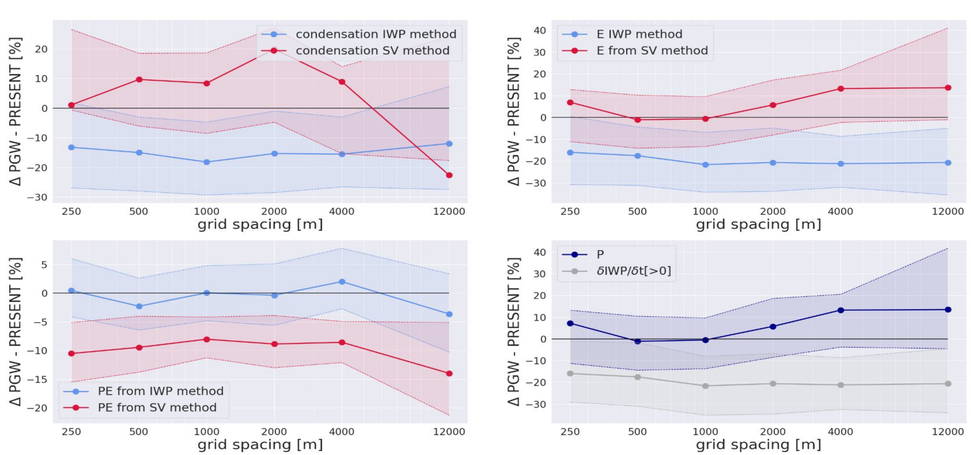


Fig. 5: Percentage difference between 10 present-climate and 10 future-climate storm cases. The idealized future-climate simulations were initialized with soundings derived from a km-scale pseudo-global warming (PGW) climate simulation over CONUS. These simulations were forced with the observed large-scale circulation from the ERA5 reanalysis, but with a warmer (~2K) and moister atmosphere. **The SV method suggests a future decrease in PE due to a larger increase in condensation than in precipitation**.

KEY POINTS

- Precipitation efficiency (PE) can be estimated from **vertical velocity**, **pressure**, and **temperature** with an error of < 5% for km-scale models **(SV method)**
- The bulk PE over the storm's lifetime can be estimated from **ice water path** and **surface precipitation (IWP method)** → this allows for comparison with satellite observations
- A 4 km grid spacing model captures PE within 15% accuracy of a 250 m model
- Km-scale and sub-km-scale simulations agree on a decrease in PE with climate warming
- **Future outlook:** Apply both PE methods on storms tracked in downscaled km-scale climate simulations

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