Extreme Precipitation Scaling with Temperature at the Weather Timescale and Implications for Climate Prediction

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U.S. DEPARTMENT OF ENERGY

NCAR UCAR CISL Computational & Information Systems Lab

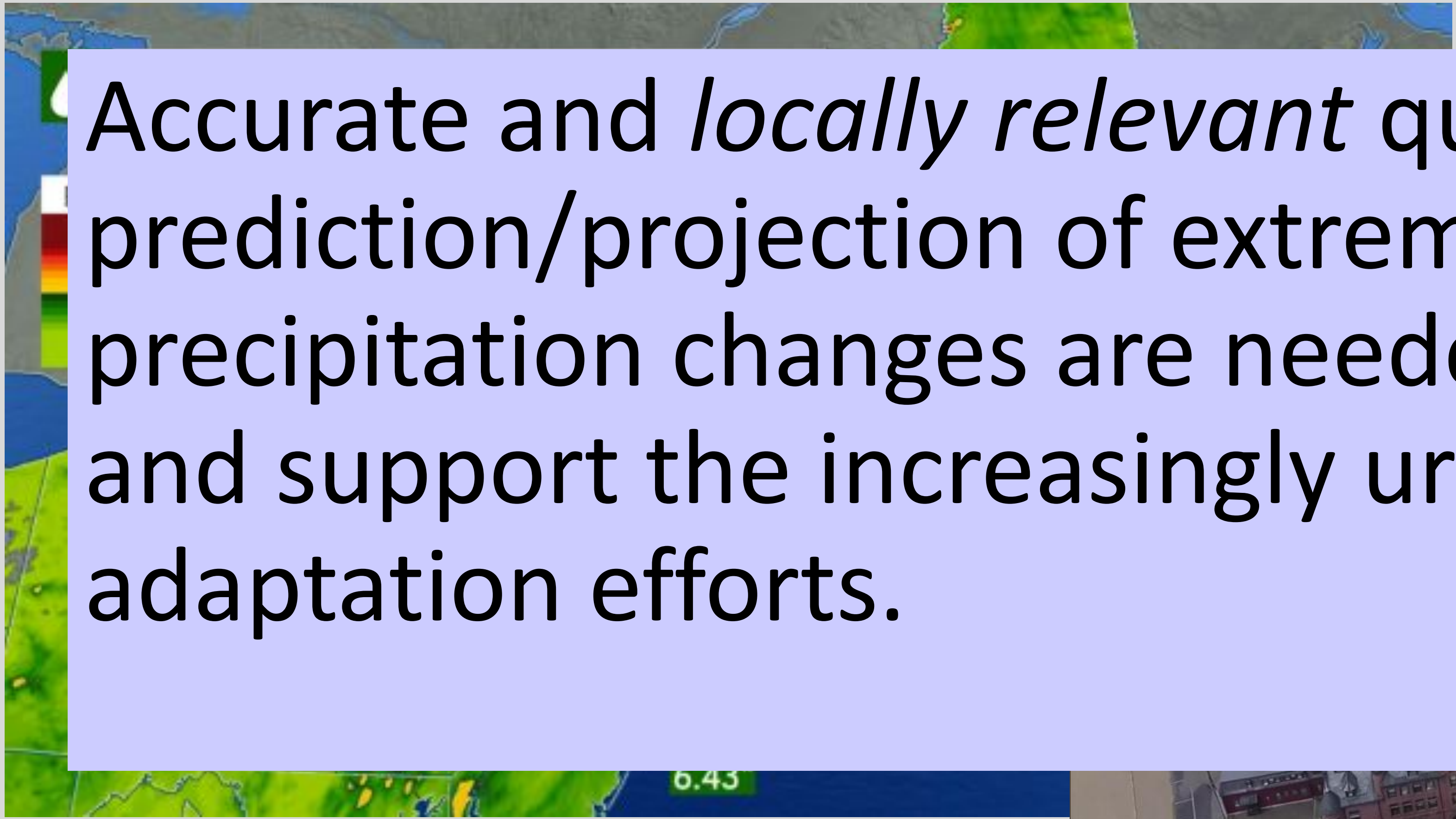
NERSC National Energy Research Scientific Computing Center

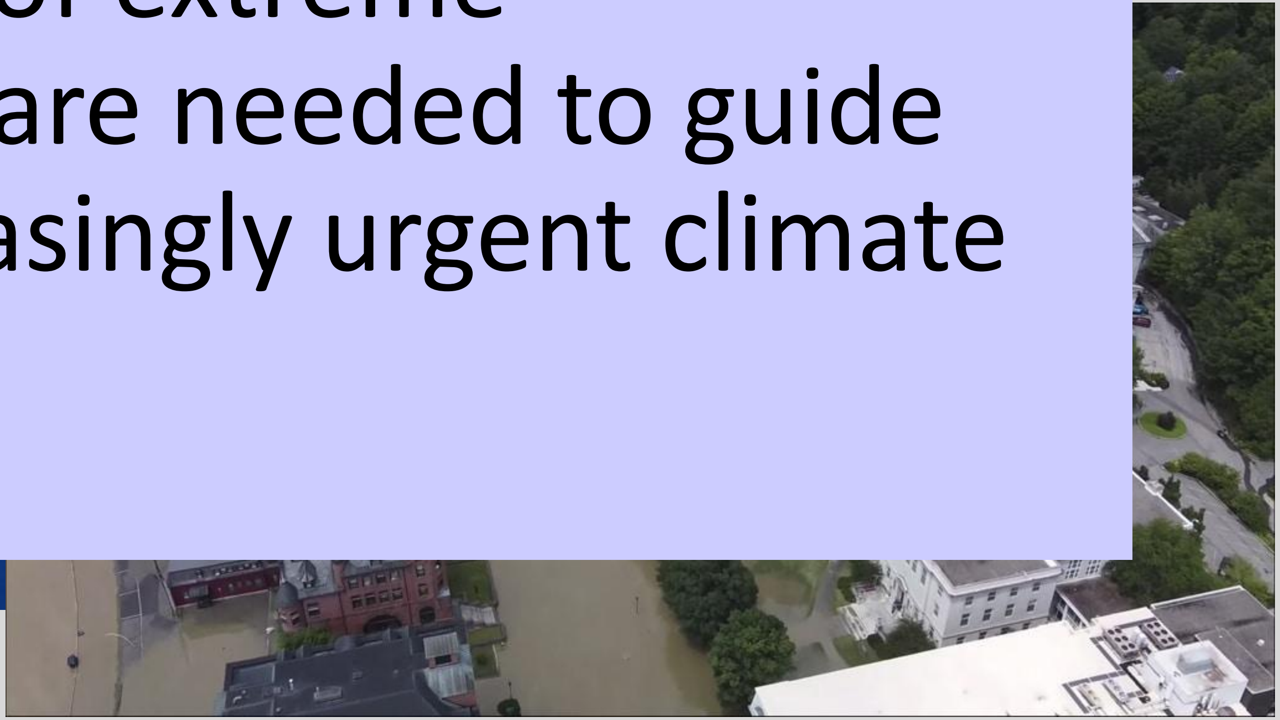
Tennessee, August 2021 (425mm or 17inches in 24 hrs)

Kentucky, July 28, 2022 (peak rain rate > 4 inches/hour)

New York City, September 2021 (tropical storm Ida)
(record rain intensity at central park: 79mm (3.15 inches) per hour)

July 10-11, Northeast, 2023
(48 hr total up to 10.49 inches)



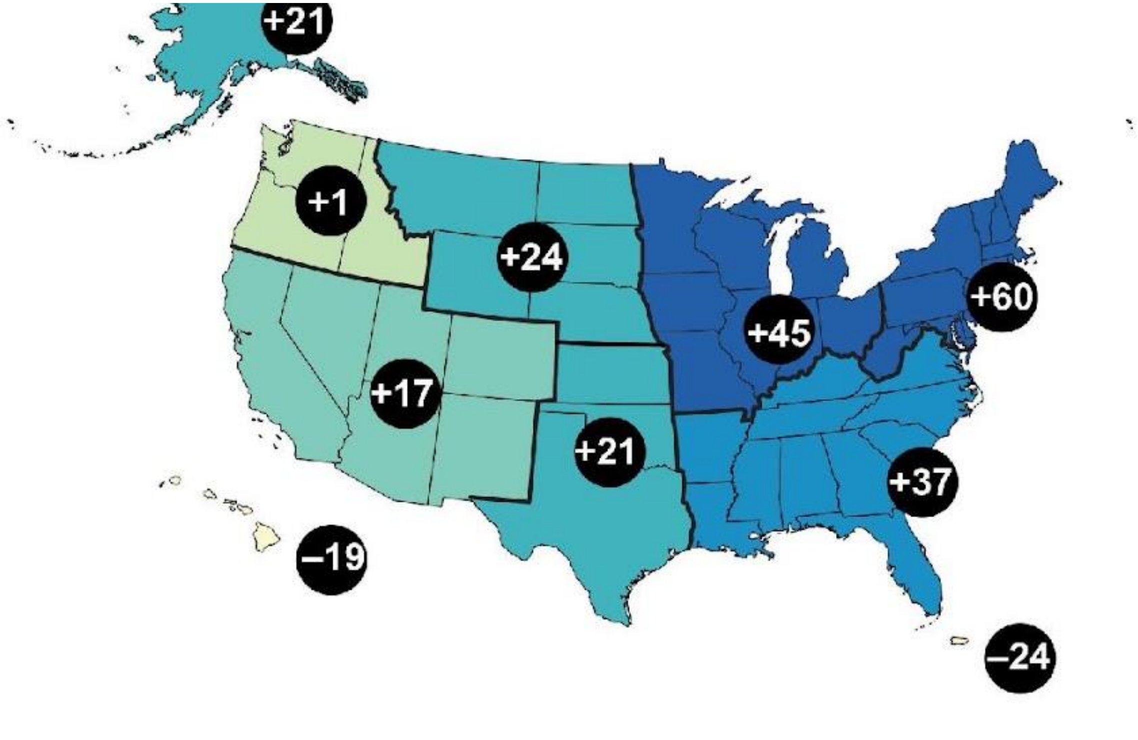


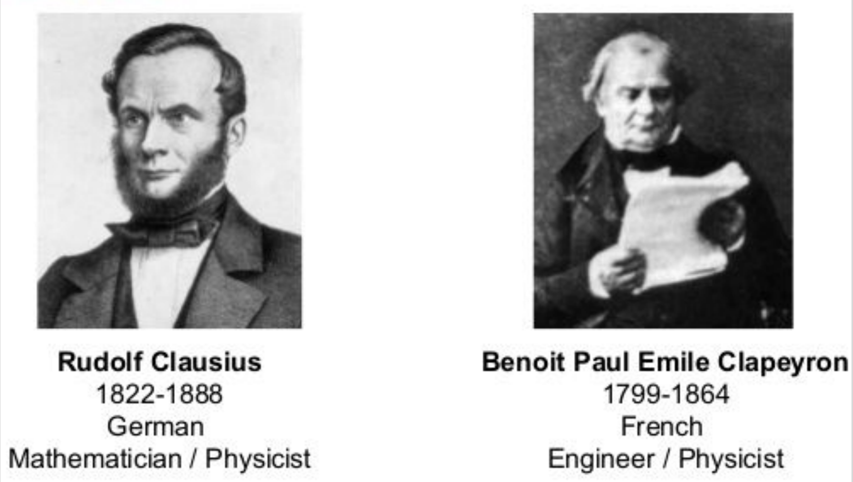
Accurate and *locally relevant* quantitative prediction/projection of extreme precipitation changes are needed to guide and support the increasingly urgent climate adaptation efforts.

Extreme Precipitation on the rise:
Observations & Theoretical predictions

Marvel et al. (2023, 5th *National Climate Assessment*)

Observed changes of precipitation on the heaviest 1% of days, during 1958-2021





- Thermodynamics: rain intensity increasing with temperature exponentially, at ~7% K^{-1} (C-C relationship)
- Further modification due to changes of atmospheric dynamics, etc

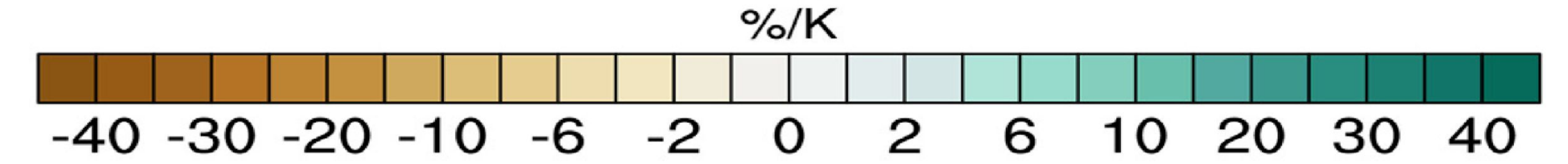
Extreme Precipitation on the rise:
Predictions from CMIP6 ESMs (John et al., 2022)

Projected relative changes (in % /K) of 20-year return values of Rx1day show a strong model dependence:

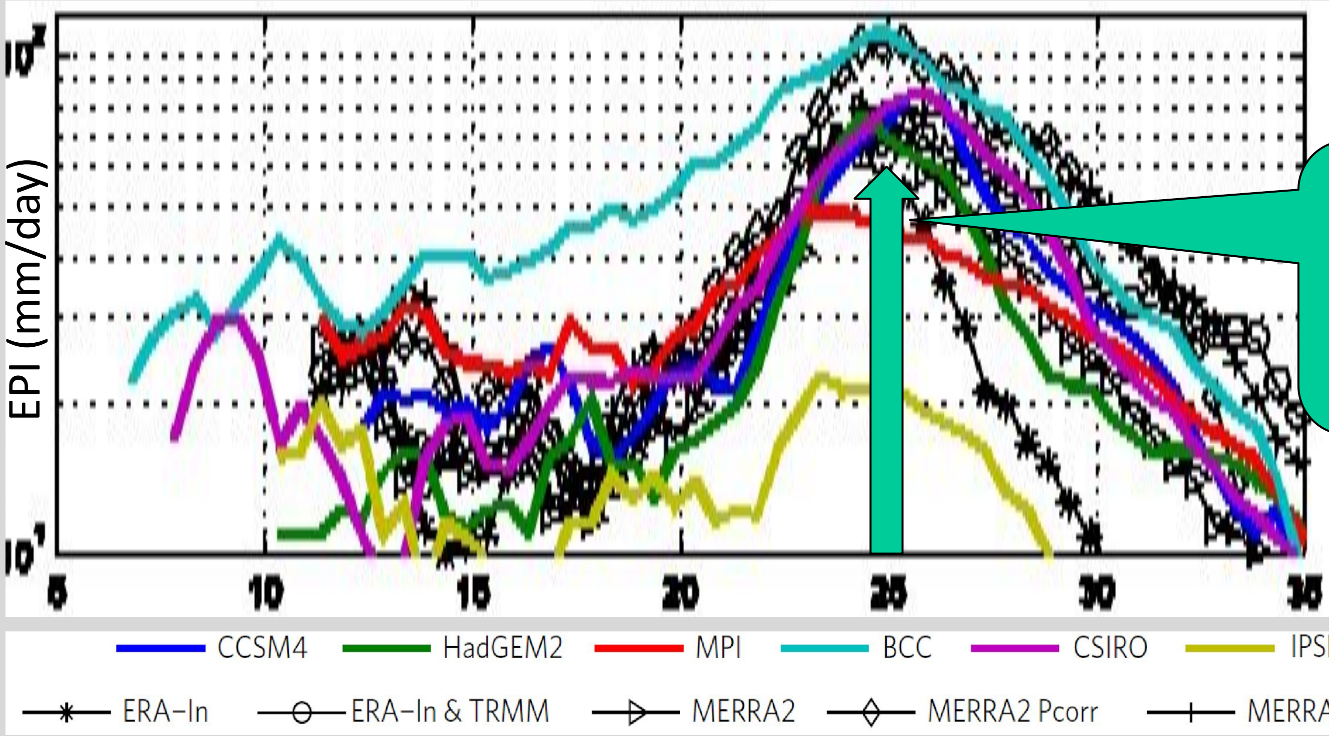
MME 10th Percentile **MME 90th Percentile**

Challenge: How to reduce the uncertainties of future projections?

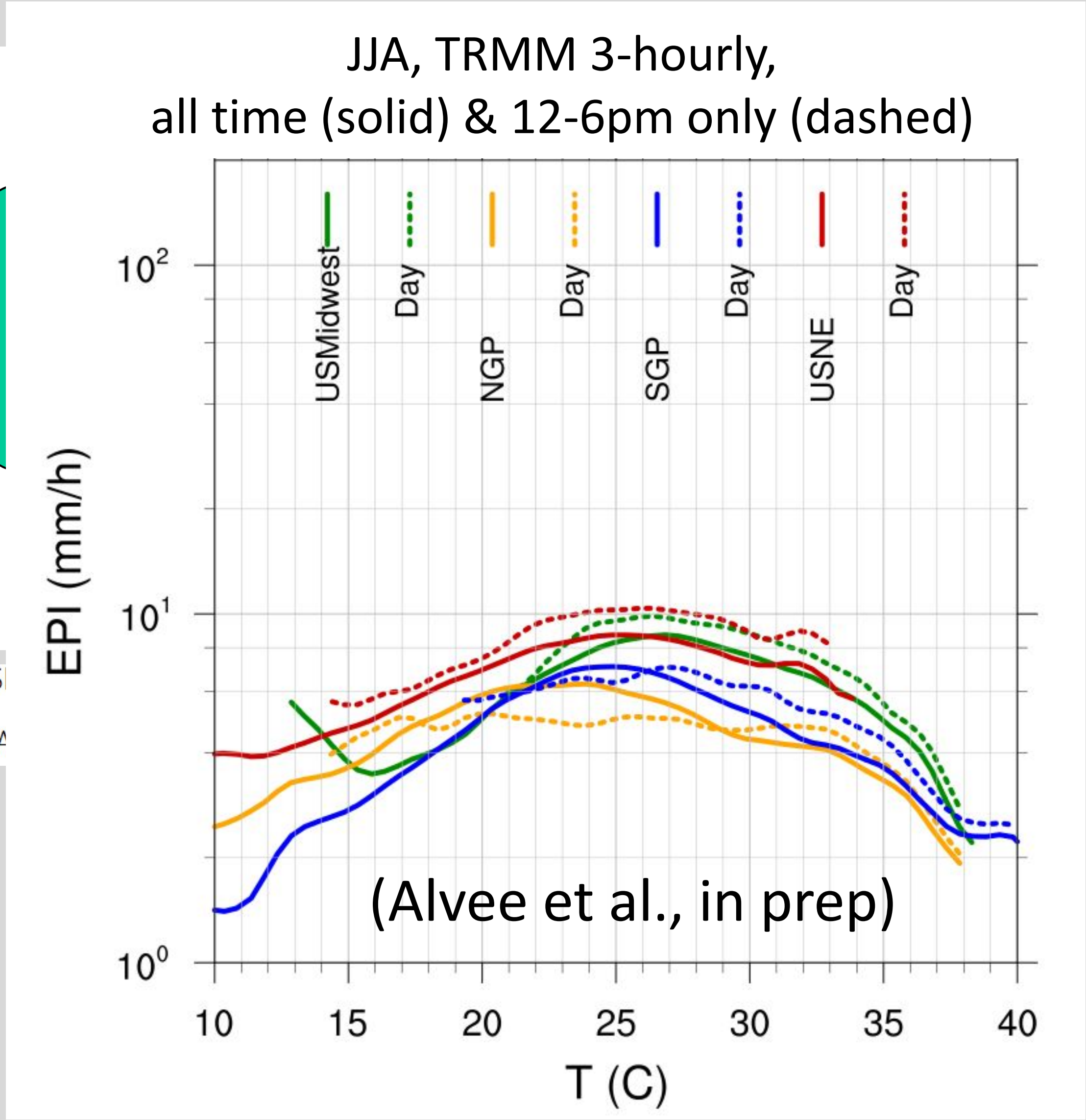
- Improving ESM physics and dynamics (long-term effort)
- Constraining model-projected future changes using emergent constraints



At the weather timescale:
Negative scaling of Extreme Precipitation Intensity (EPI) at High Temperatures



(Wang et al., 2017)



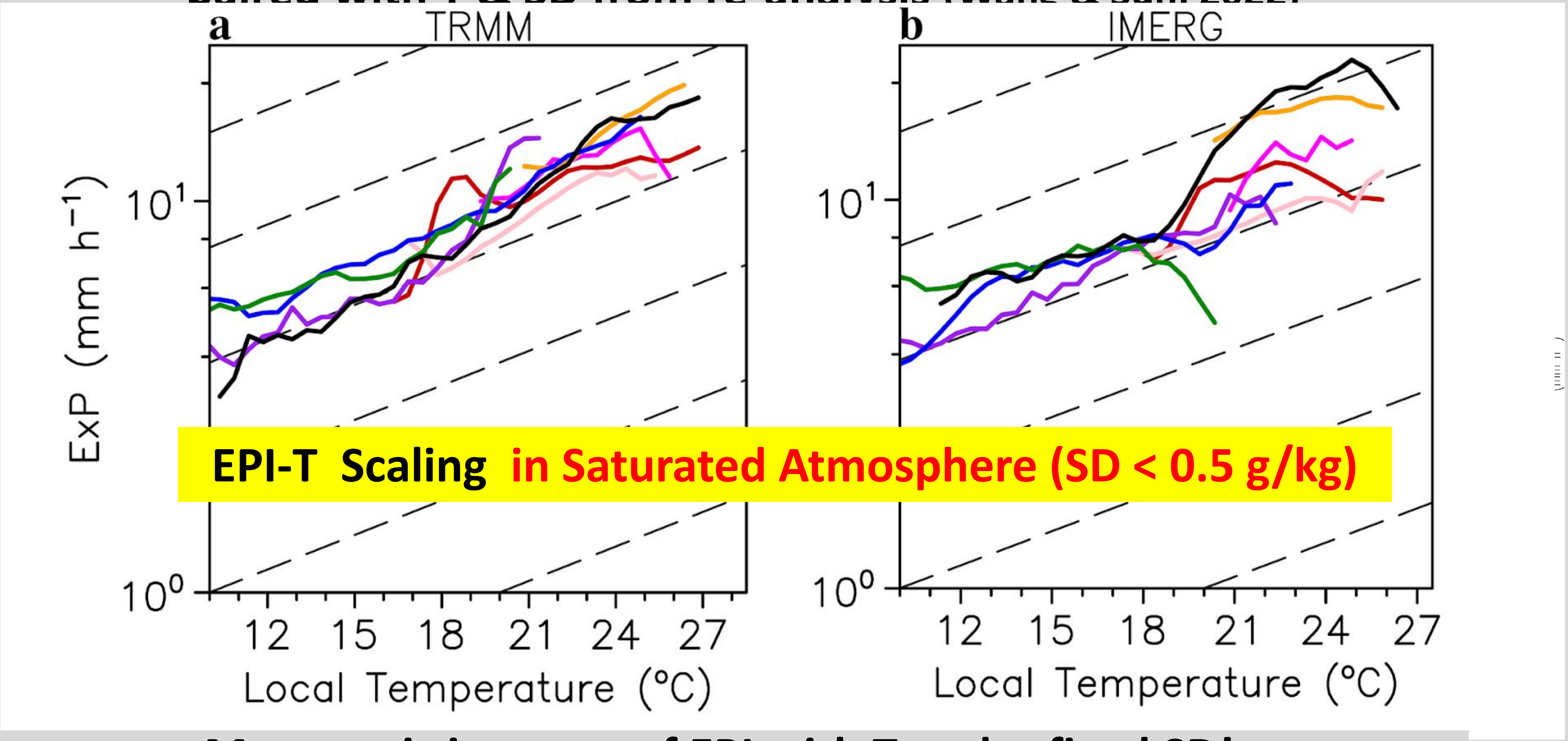
(Alvee et al., in prep)

Causes for the Negative Scaling at the Weather Timescale

- **Atmospheric moisture limitation** (primary cause over land, Wang & Sun, 2022): High air temperature leads to a large saturation deficit (SD), which suppresses heavy precipitation through multiple mechanisms (e.g., raising LCL, dry air entrainment, hydrometeor re-evaporation)

- **Other factors:**
  - *Different precipitation types (e.g., MCS vs. non-MCS) (Hu et al., in review)*
  - *Precipitation-induced cooling (primary cause over ocean) (Sun & Wang, 2022)*
  - *Anti-cyclonic warming*
  - *….*

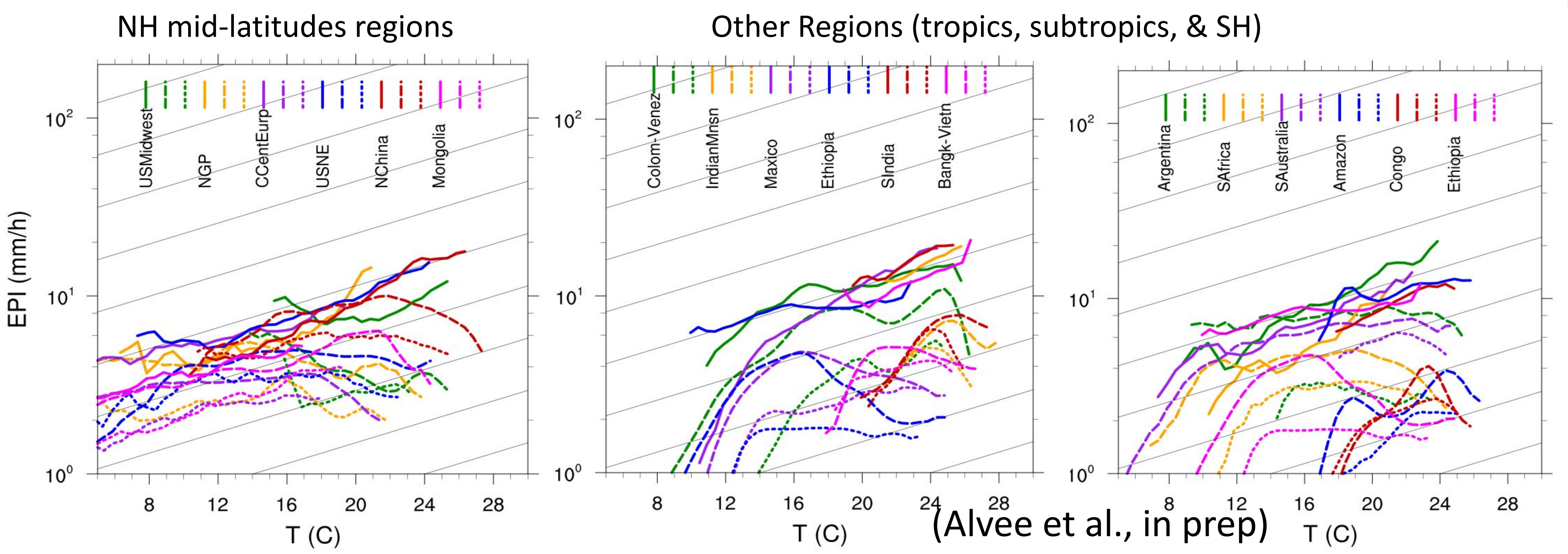
EPI (T, SD) relationship, based on TRMM /IMERG precipitation paired with T & SD from re-analysis (Wang & Sun, 2022)



EPI-T Scaling in Saturated Atmosphere (SD < 0.5 g/kg)

Monotonic increase of EPI with T under fixed SD!

EPI-T in Saturated Atmosphere (E3SM, 18 sample regions)
(Extremes defined as those exceeding the 99.9th percentile of 3-hourly precipitation)



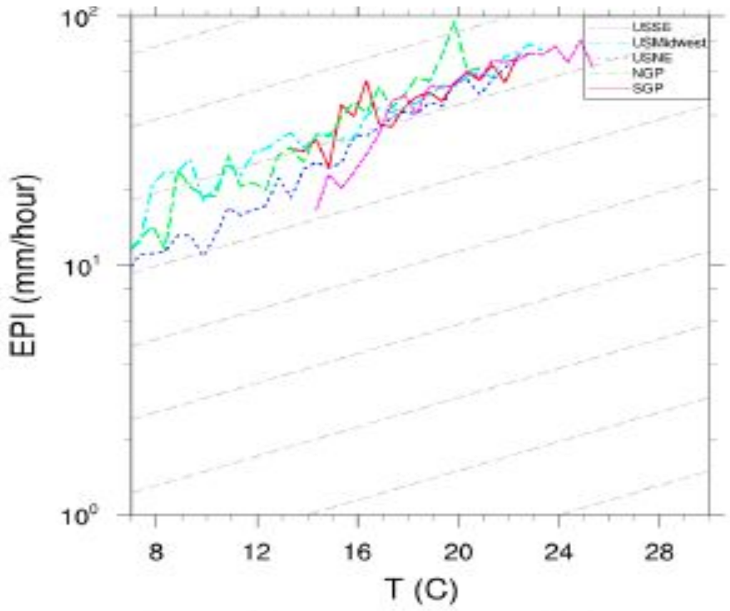
TRMM (solid lines)
E3SM 0.25° (dashed)
E3SM 1° (dotted)

Would convection-permitting model make a difference?
-- work in progress based on output from SCREAM (DYAMOND)

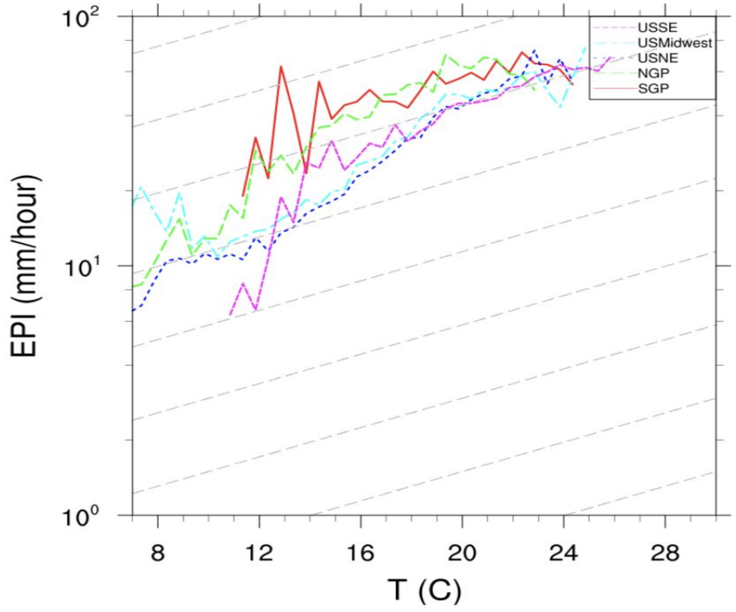
EPI-T In Saturated Atmosphere (WRF, 5 sub-regions of U.S.)

(Extremes defined as those exceeding the 99.9th percentile of hourly precipitation)

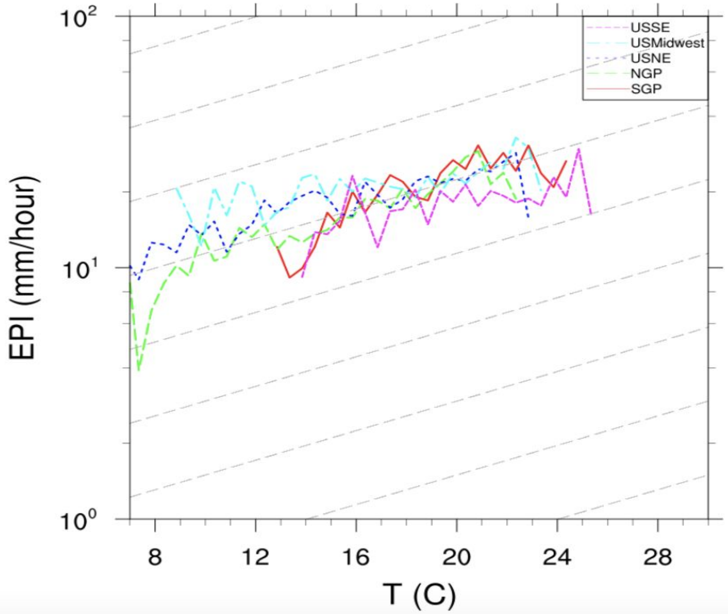
WRF-TGW (12km)



CONUS404 (4km)



IMERG



Scaling ratio is similar between 12km (with cumulus parameterization) and 4km (convection permitting) simulations.

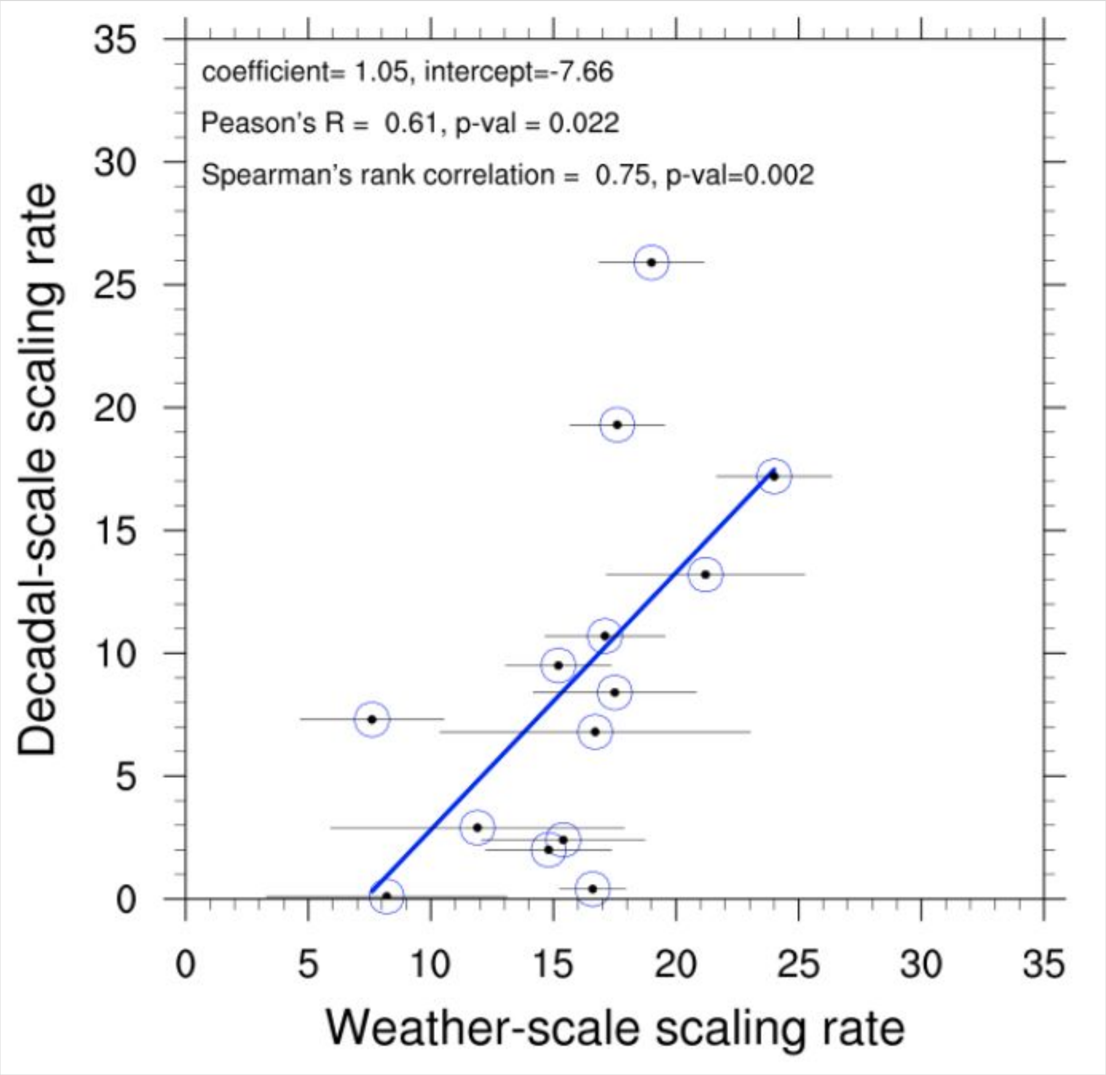
(Qin et al., Thursday Poster #072)

Questions

1) What may have caused the model biases in simulating the EPI-T scaling rate at the weather timescale?
   - Spatial resolution? (probably not)
   - Model physics & dynamics?
   - Background climate (e.g., wet bias/dry bias)?

2) Is the weather-timescale EPI-T relationship relevant for climate changes? (Can it be used as an emergent constraint for future changes)?
   - Would regions/models with a higher scaling rate at the weather timescale experience faster extreme precipitation changes at the climate timescale?
   - Would the weather-scale biases propagate to influence the model projected future changes?

Scaling: Climate vs. weather (based on CONUS404)



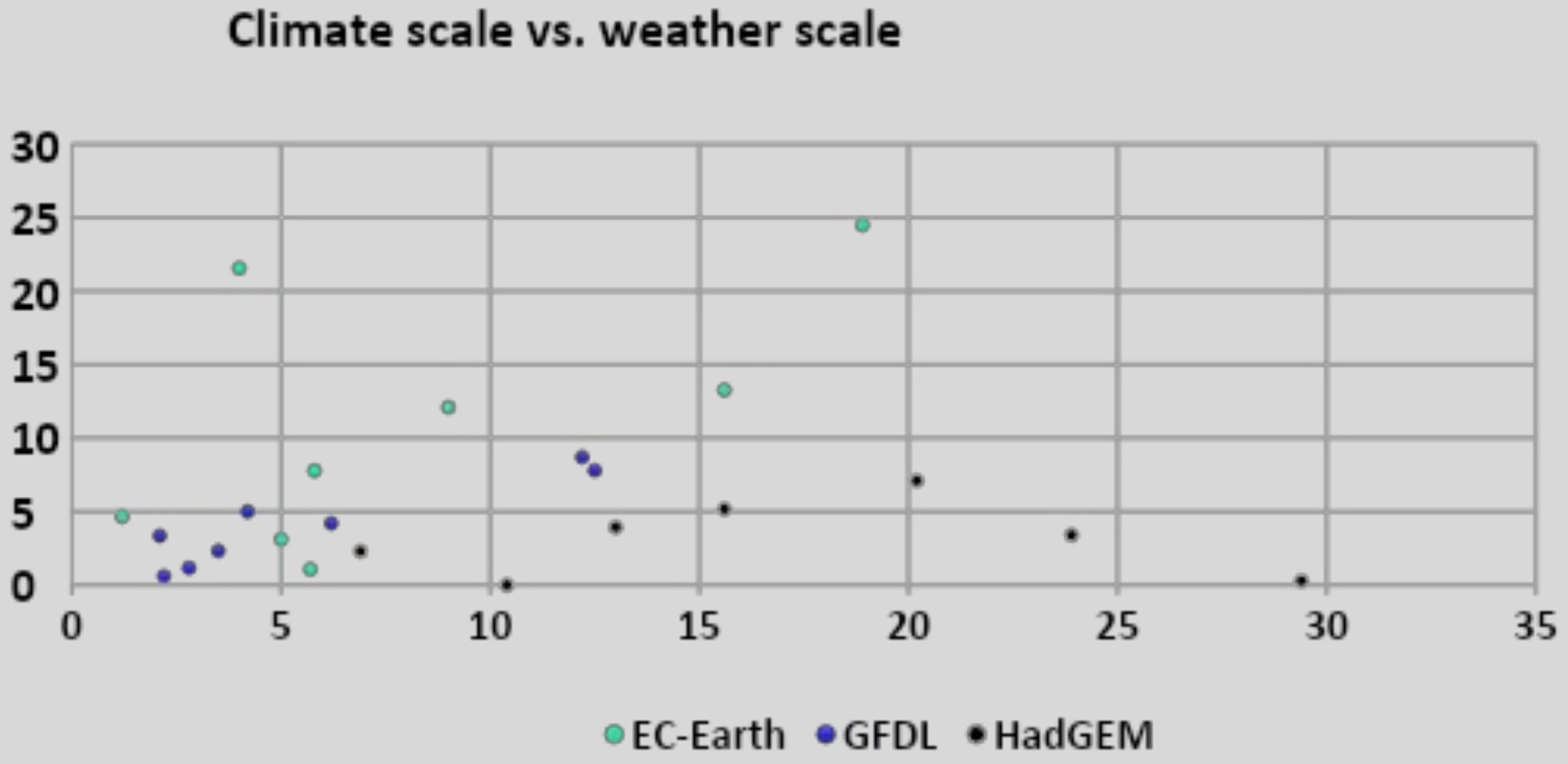
- 16 sub-regions of the U.S.
- Statistically significant (<u>albeit weak</u>) positive correlation between decadal-scale and weather-scale scaling rates.

(Qin et al., in prep; Thursday Poster #072)

Scaling Rates at Climate Timescale vs. Weather Timescale
(based on ESMs output for Warm Season)

Y-axis: $R1d_{max}$ changes scaled by local warming (%/K) (4XCO2 – piControl)

X-axis: Weather-scale p99 3hrly EPI-T scaling ratio under saturation (%/K) (piControl)



Thank you!

Attending AMS Annual Meeting (New Orleans, January 12-16, 2025)?

Consider submitting an abstract to the 39th Conference on Hydrology

- Abstract due date: August 15, 2024
- Session Topical Area: “**The Earth's Water Cycle: Variability, Changes, and Extremes**”
- Invited Speakers: L. Ruby Leung (PNNL), Kristen Findell (GFDL)
- Conveners: Guiling Wang (UConn), Kyle Knipper (USDA ARS & UC Davis)