

Understanding regional and seasonal changes in extreme precipitation

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MIT Climate Grand Challenge on Extreme Weather and Climate

>30 years ago climate models predicted that precipitation extremes would intensify with global warming

Simulated changes in daily rainfall intensity due to the enhanced greenhouse effect: implications for extreme rainfall events

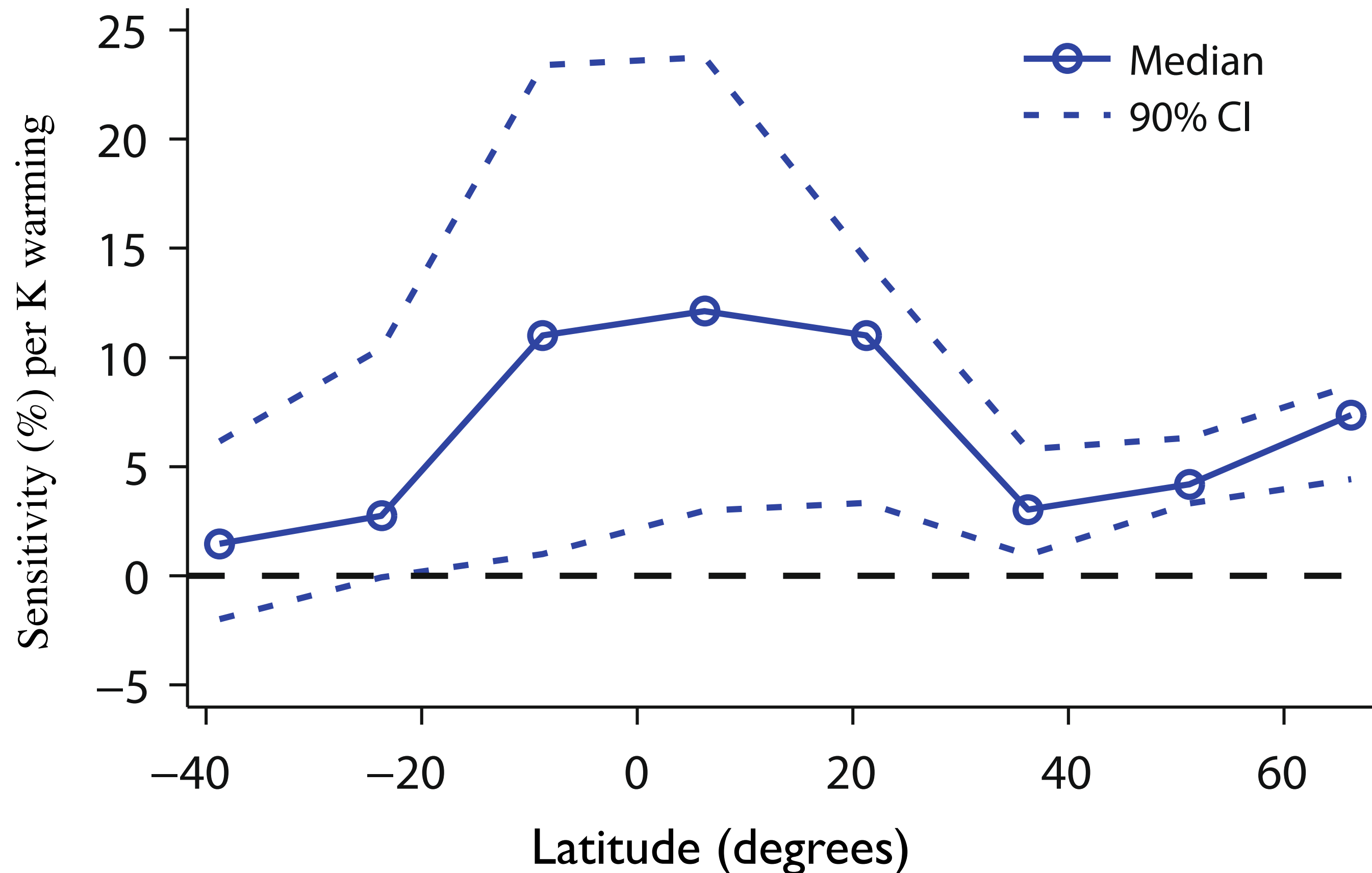
HB Gordon, PH Whetton, AB Pittock, AM Fowler, MR Haylock

**Climate
Dynamics**
© Springer-Verlag 1992

How do we measure precipitation extremes?

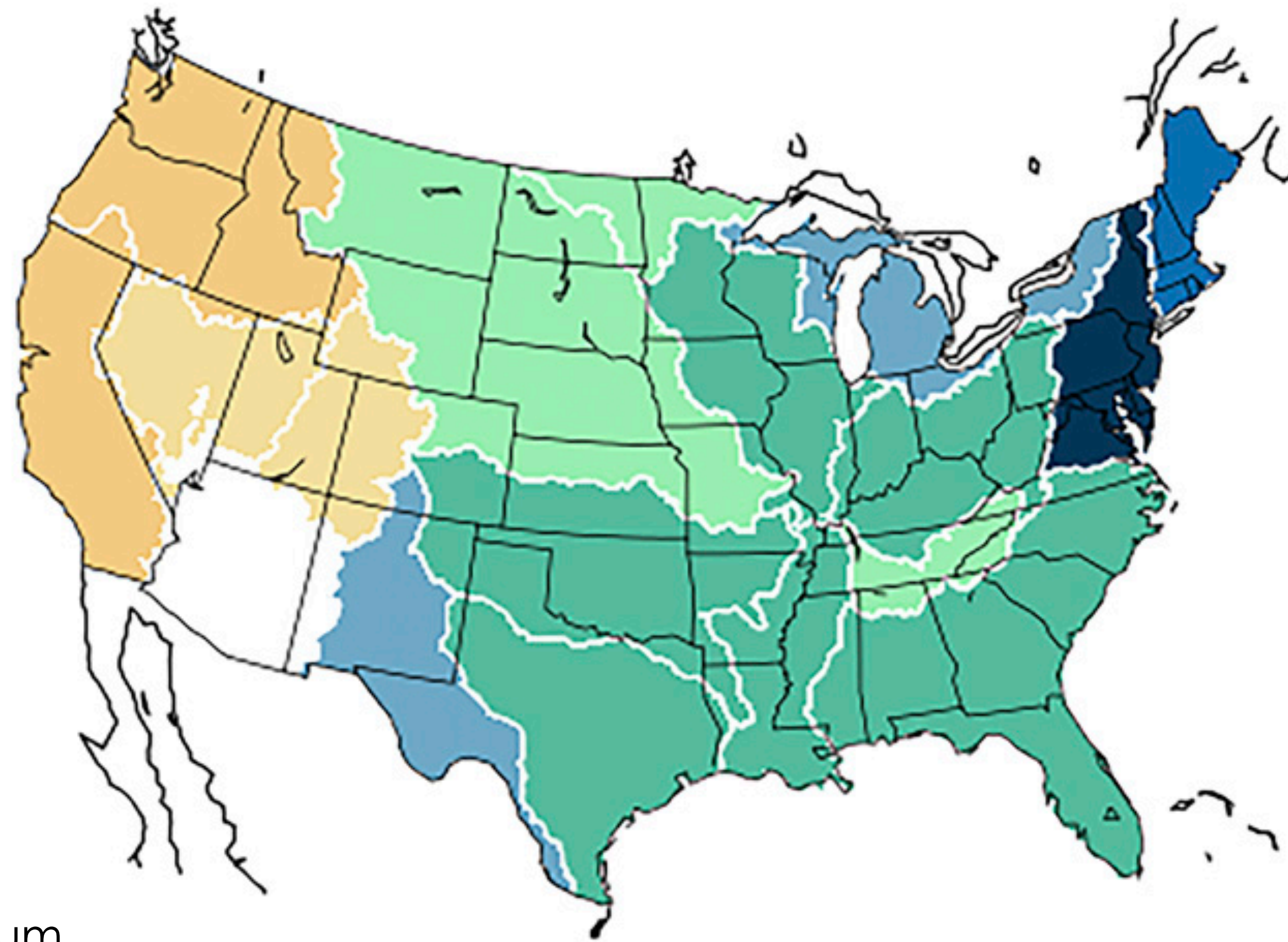
- Annual-maximum daily precipitation (1/365 event) called Rx1 day
- Normalize fractional changes by global-mean surface warming to give % change per degree warming

Observations now confirm an overall increase in intensity of precipitation extremes with global warming when aggregate to large scales

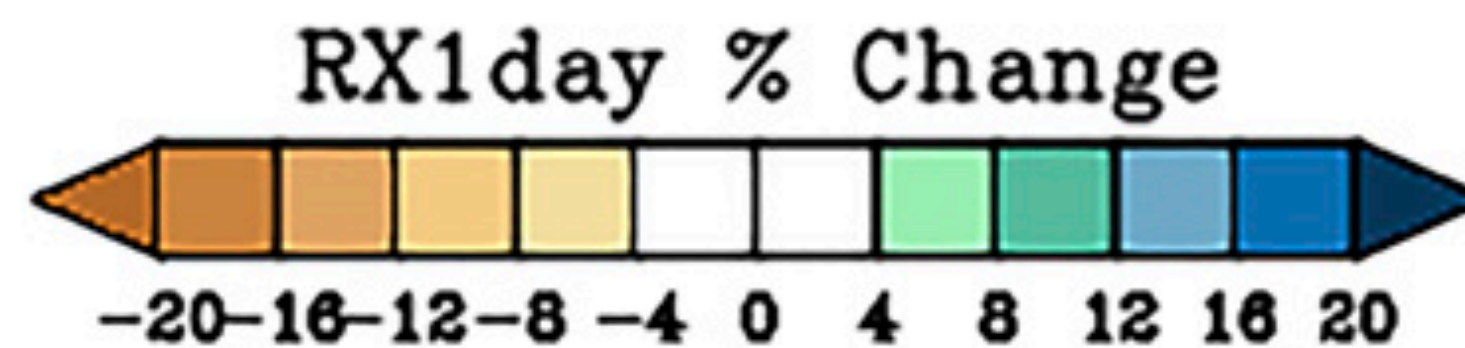


Sensitivity (%) of annual maximum daily precipitation per °C warming of surface temperature at that latitude over 1901-2010 (records > 30 years in Hadex2)

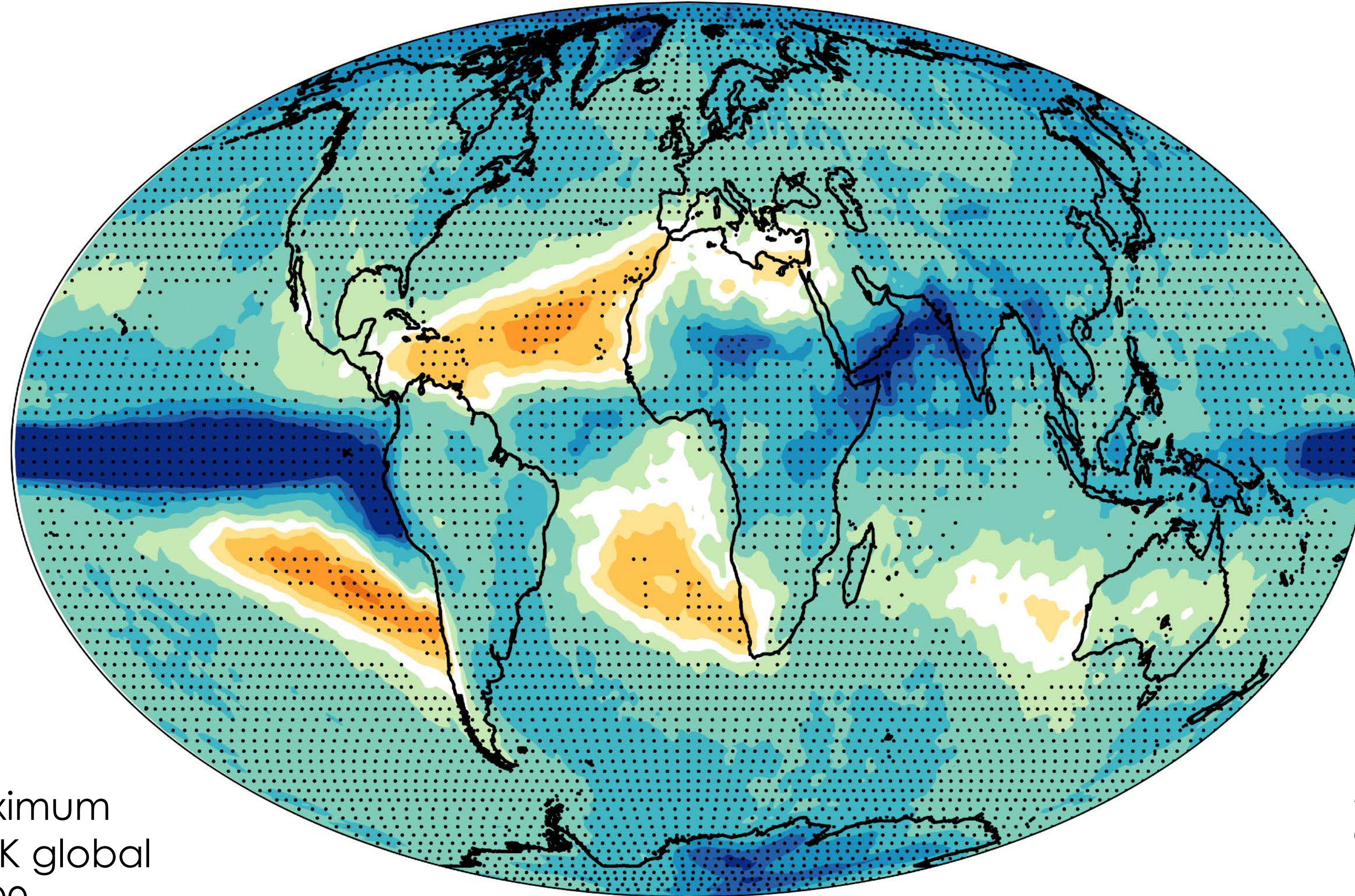
But regional observed changes are heterogeneous: how much of this is shorter-term unforced variability unrelated to climate change?



Change in annual maximum
daily precipitation: 1999-2018
minus 1958-1977

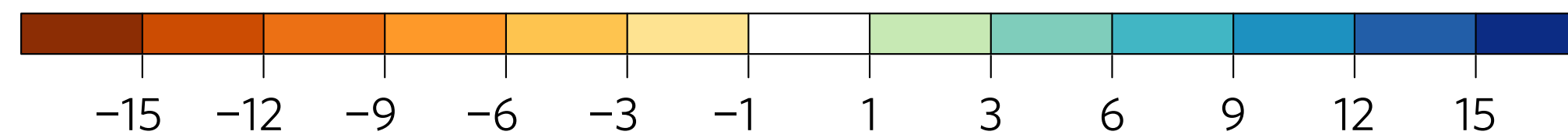


Model projections of precipitation extremes are also not uniform across different regions of the world



Change in annual maximum daily precipitation per K global warming over 1950-2100

Multimodel mean of CMIP5 simulations under RCP 8.5 scenario



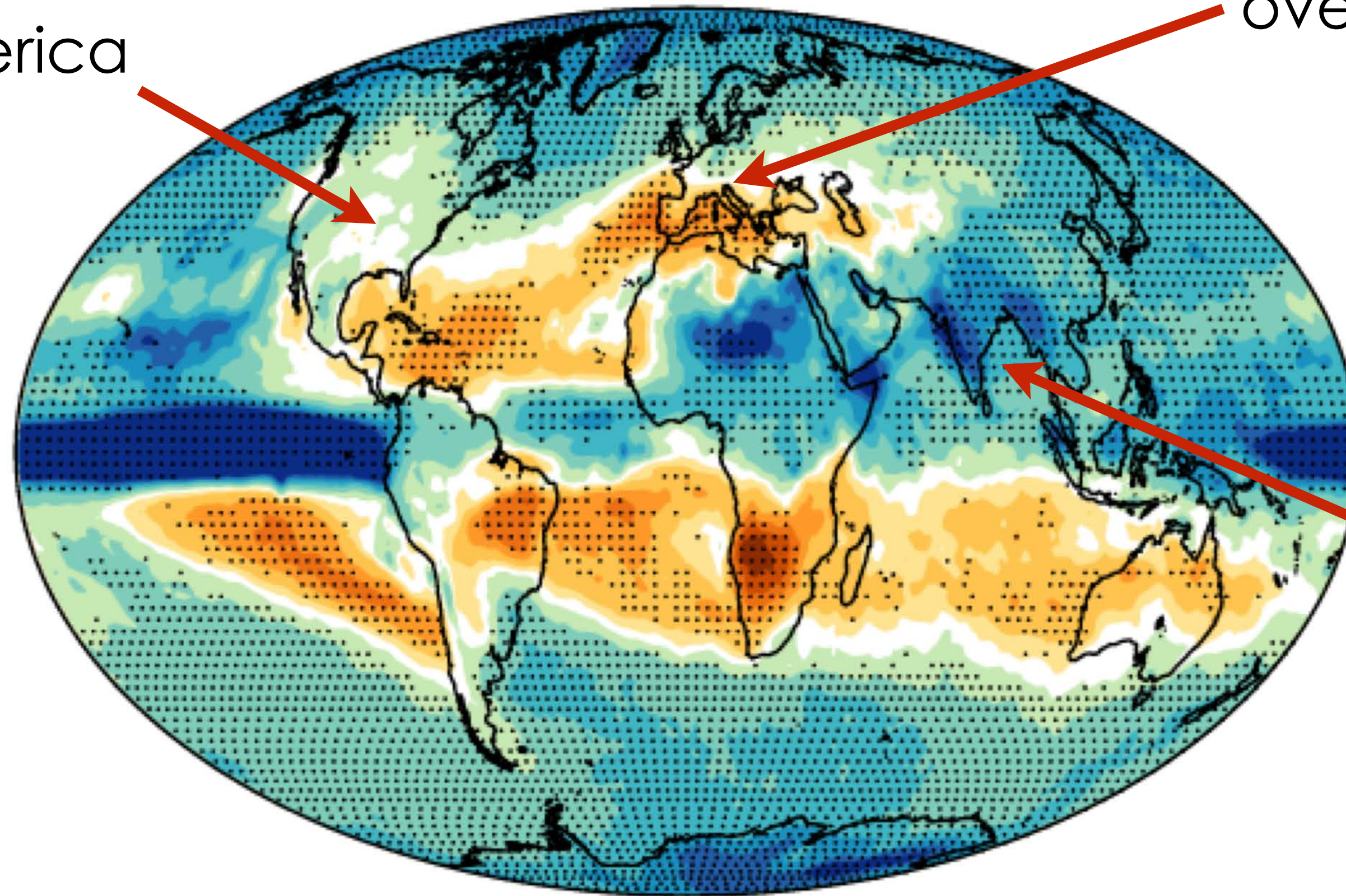
% change per °C warming

Pfahl, O'Gorman, Fischer, N. Clim. Chang., 2017

Northern summer (June-July-August) shows particularly large differences across land regions

Little change over North America

Little change over Western Europe



Large increase over India

Change in JJA maximum daily precipitation per °C global warming over 1950-2100 in global simulations



% change per °C warming

Pfahl, O'Gorman, Fischer, N. Clim. Chang., 2017

Given major impacts on society and ecosystems, important to understand how climate change affects precipitation extremes across regions/seasons



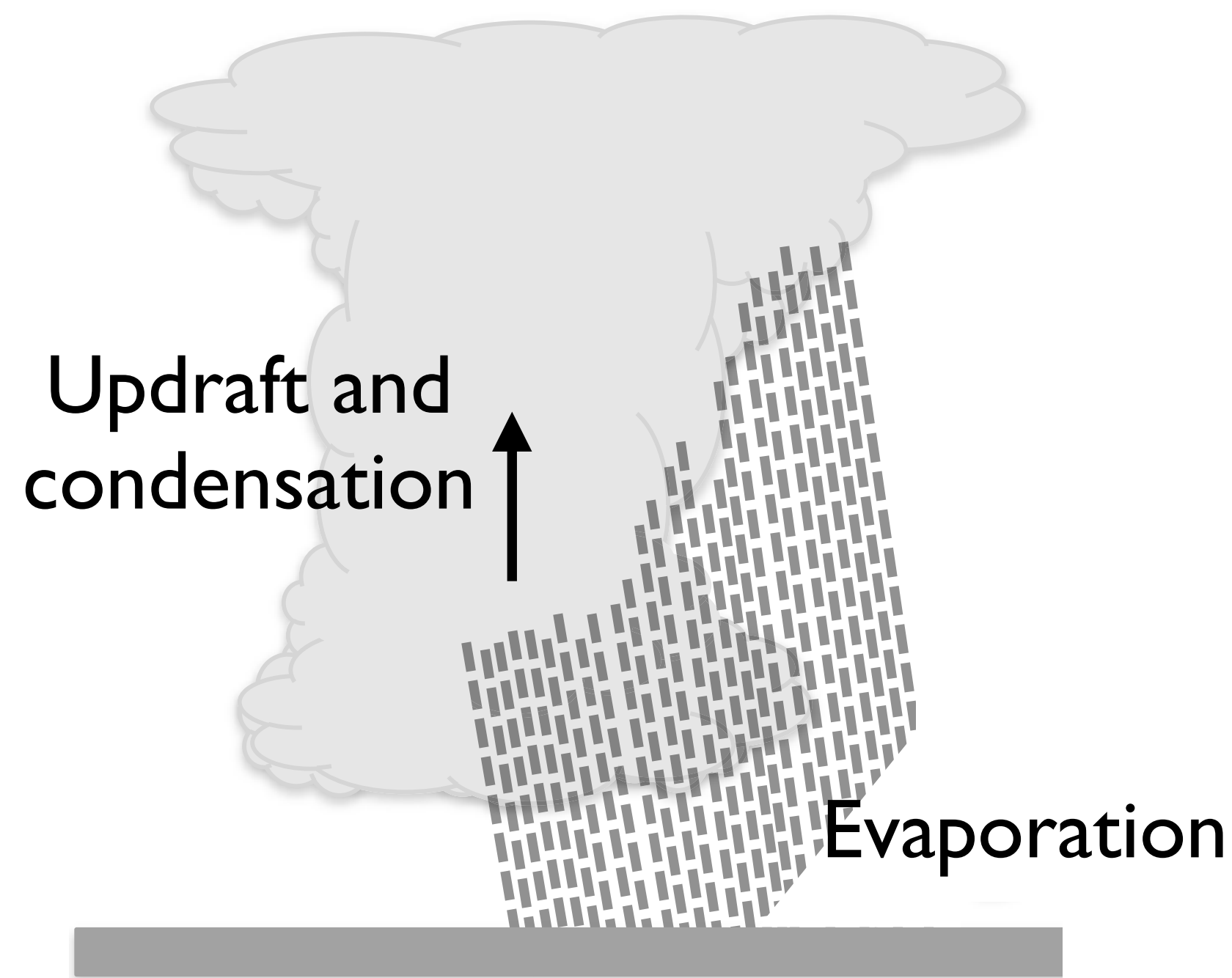
Image credit: Shahid Saeed Mirza/Agence France-Presse



Image credit: Rhein-Erft Municipality

Severe rain and flooding in Pakistan in August 2022 and Western Europe in July 2021

Changes in precipitation extremes come from multiple factors



1. **Thermodynamic**: increase in amount of water vapor at saturation
2. **Dynamic**: changes in upward speed of air
3. **Efficiency**: changes in how much precipitation reaches the surface rather than evaporating

Is there a simpler way to understand the patterns of change over land?

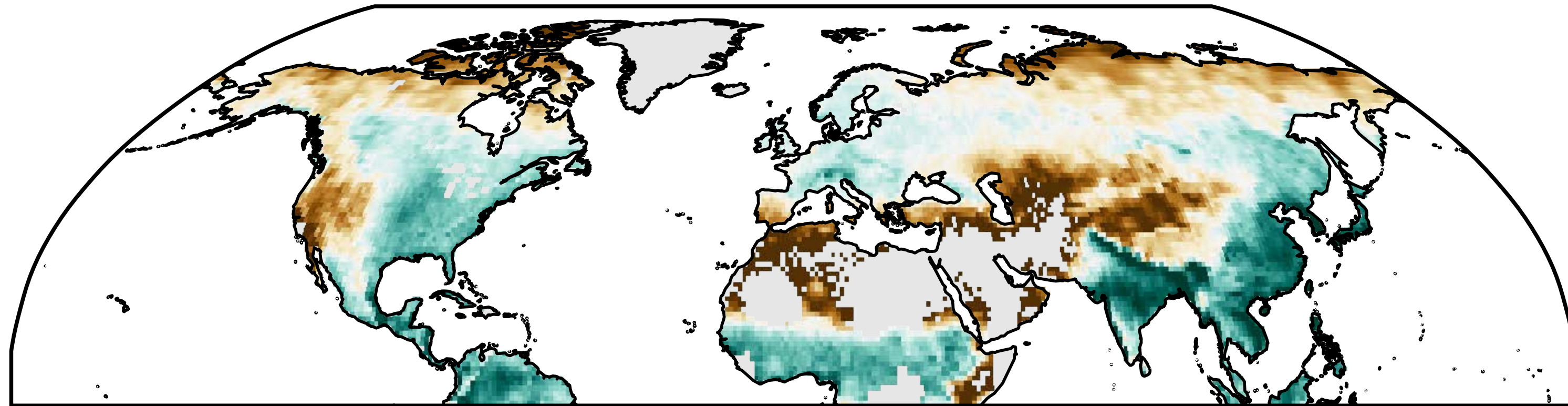
*e.g. Trenberth 1999; Allen and Ingram 2002;
O’Gorman and Schneider 2009; Abbot, Cronin and Beucler 2020*

Standard simple approach: Scaling with specific humidity

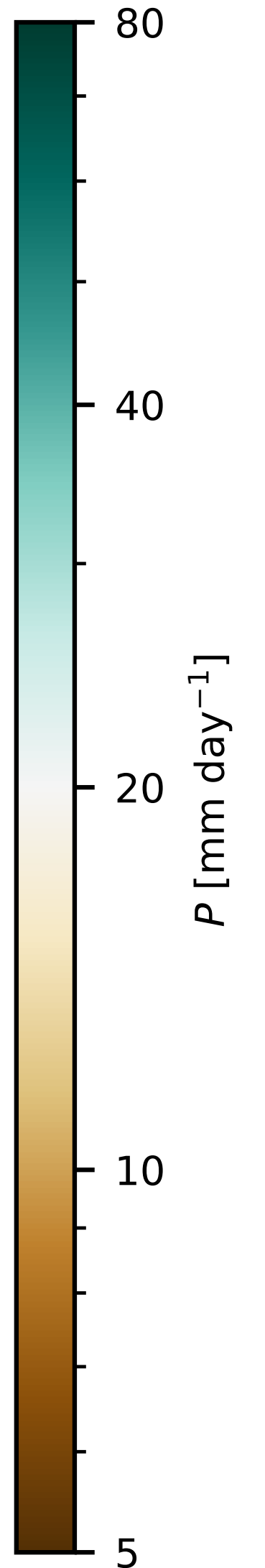
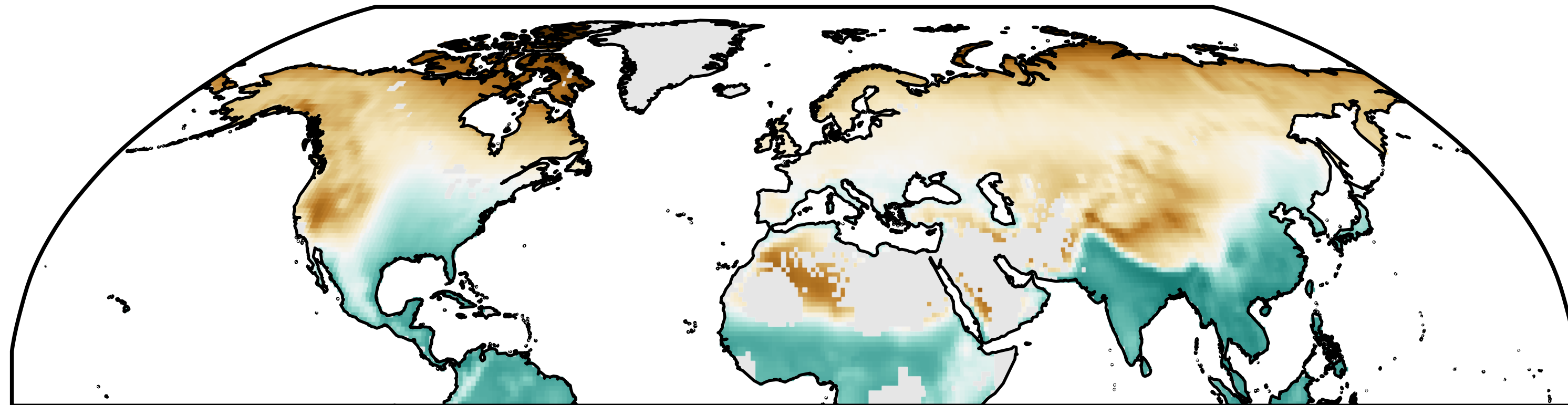
- Assumes precipitation scales with water vapor amount (e.g. $P \sim q$ or $P \sim q^2$)
- Same as Clausius-Clapeyron scaling with dewpoint temperature
- Sometimes used in assessment of impacts

Scaling with specific humidity (water vapor amount) captures only some of the observed current-climate pattern

Observed precipitation extremes (Rx1 day) in June-July-August

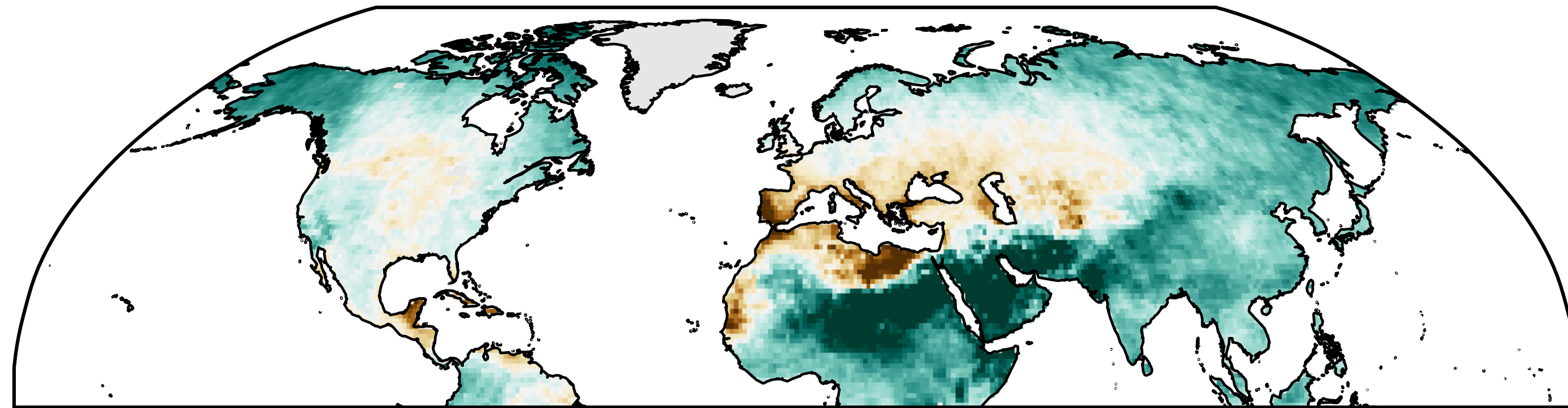


Scaling with mean surface specific humidity ($P \sim q^{1.3}$)

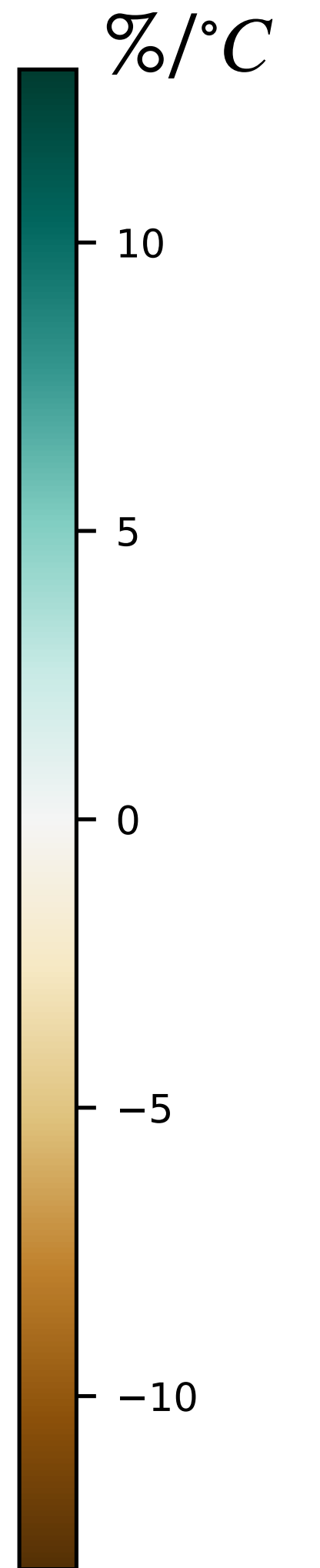
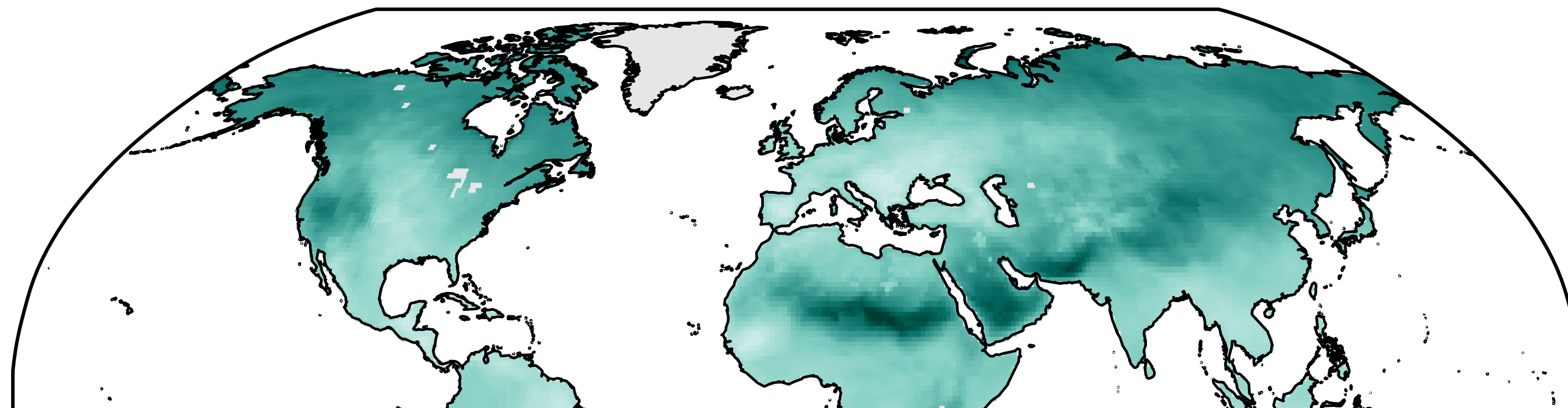


Scaling with specific humidity (water vapor amount) does not match CMIP6 climate projections

Projected change in precipitation extremes (Rx1 day) in June-July-August

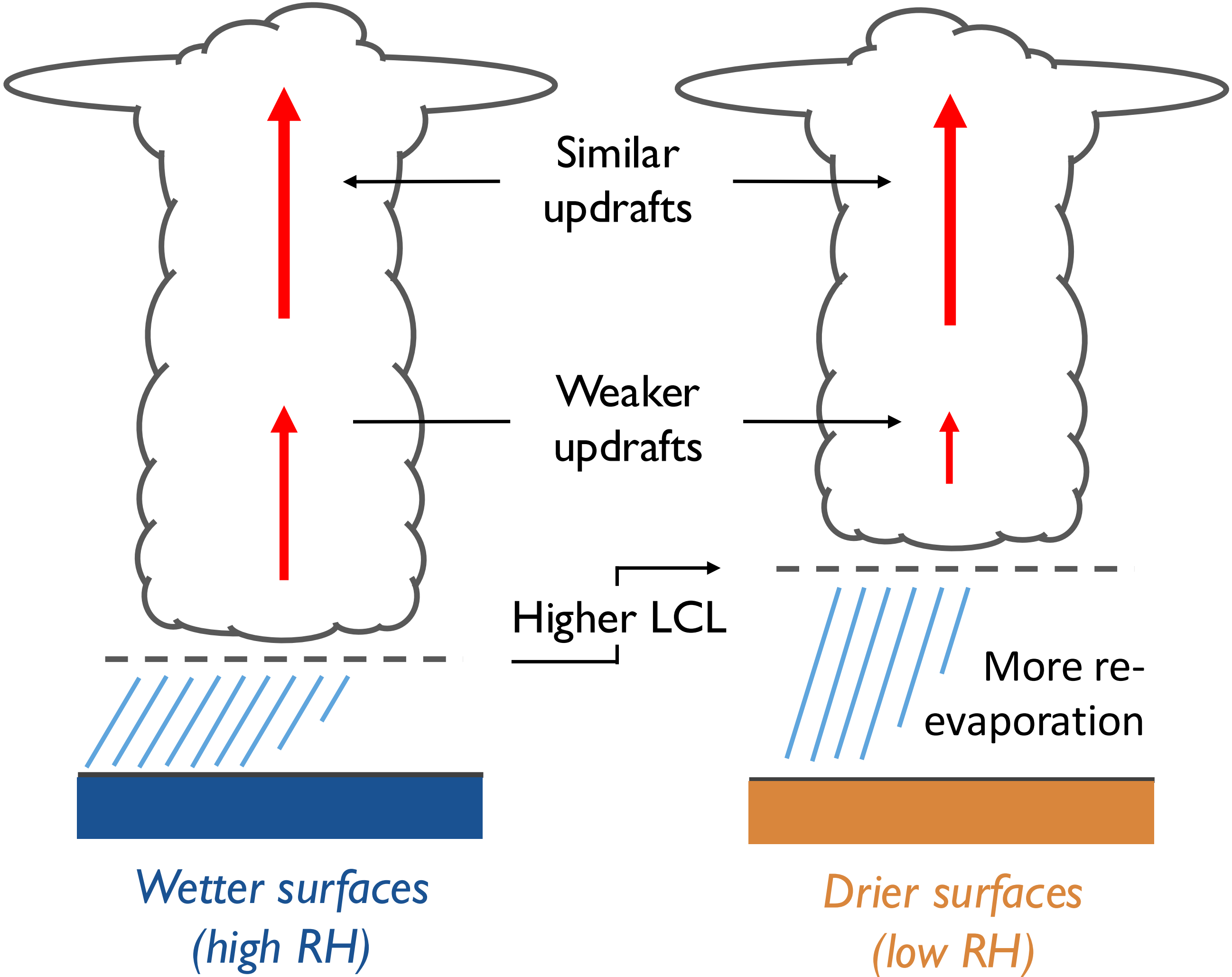


Scaling with mean surface specific humidity ($P \sim q^{0.9}$)



Can we do better with a simple approach?

Precipitation extremes are also sensitive to near-surface relative humidity (i.e., how close air is to saturation)



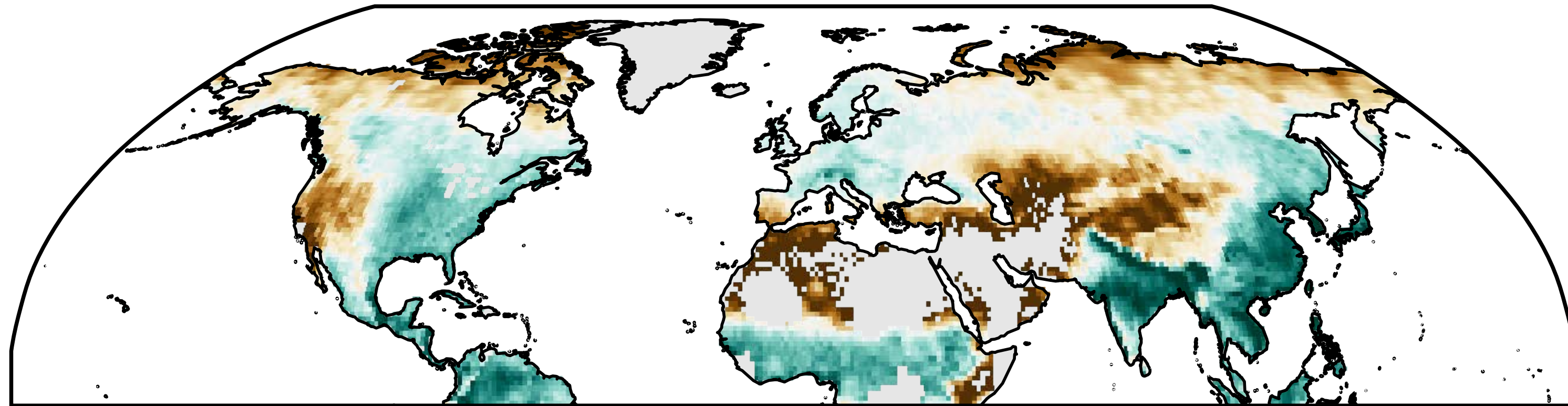
Decreases in near-surface relative humidity:

- 1. weaken updrafts because of higher cloud base
- 2. decrease precipitation efficiency because of a deeper and drier sub-cloud layer

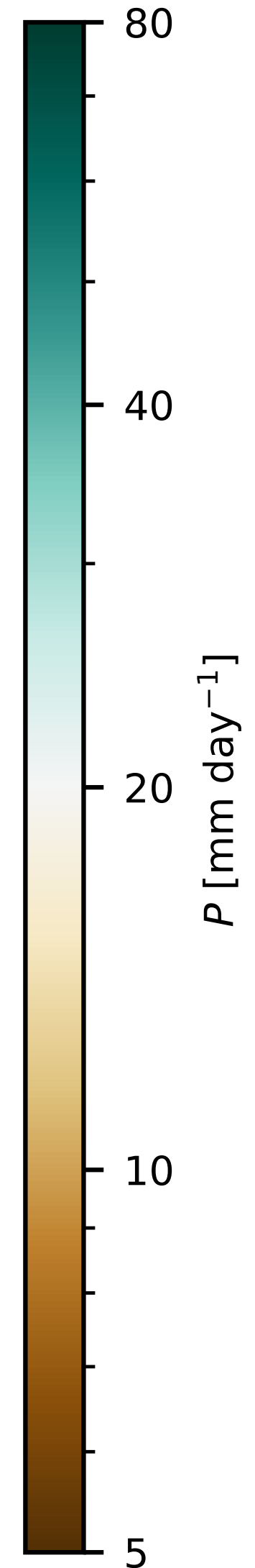
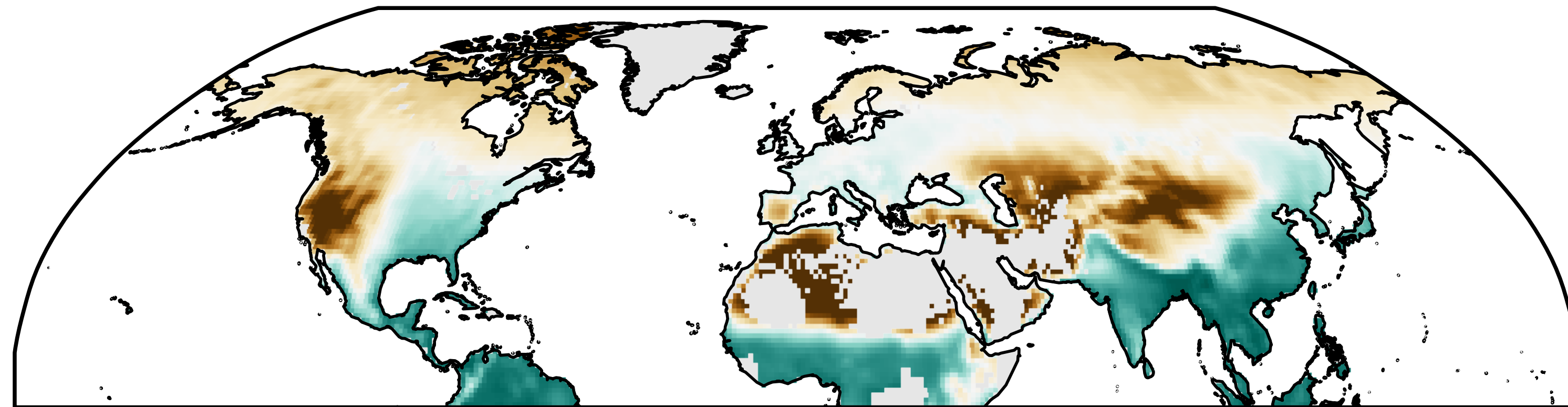
van der Drift and O’Gorman, *J. Climate*, 2025

Scaling with specific humidity and relative humidity captures observed precipitation extremes in current climate

Observed precipitation extremes (Rx1 day) in June-July-August

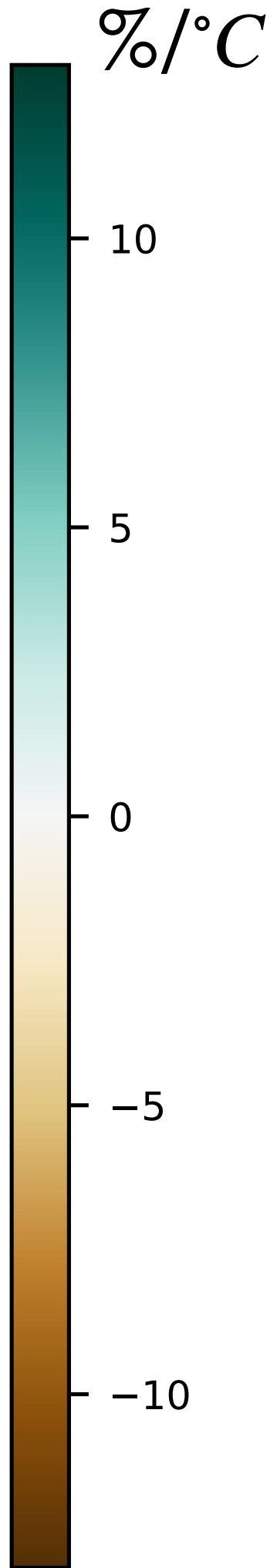
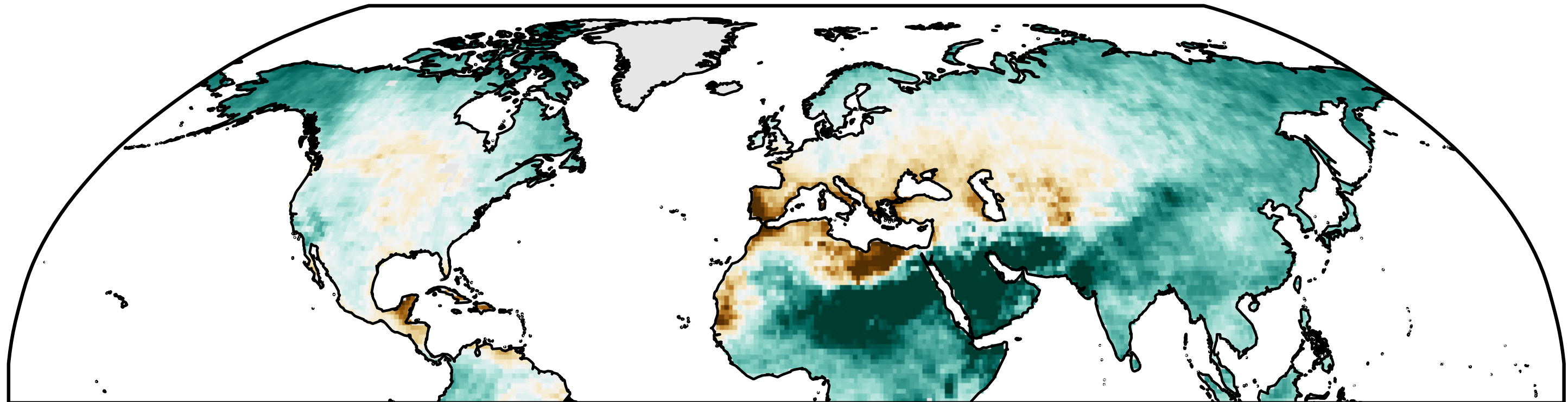


Scaling with mean specific humidity and relative humidity ($P \sim q^{1.1} rh^{1.3}$)

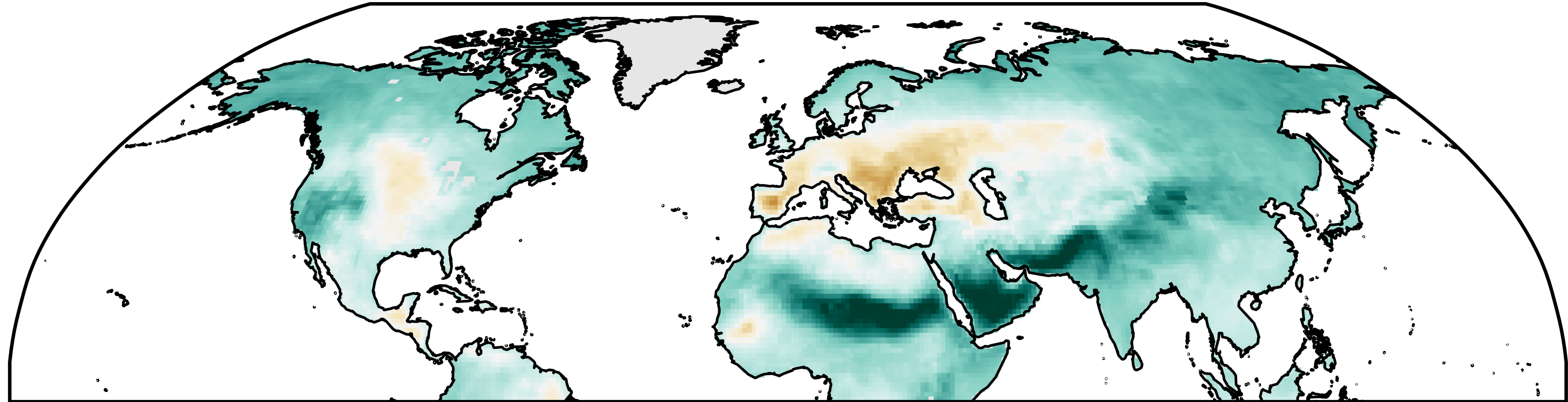


Scaling with specific humidity and relative humidity captures projected changes in warm-season precipitation extremes

Projected change in precipitation extremes (Rx1 day) in June-July-August

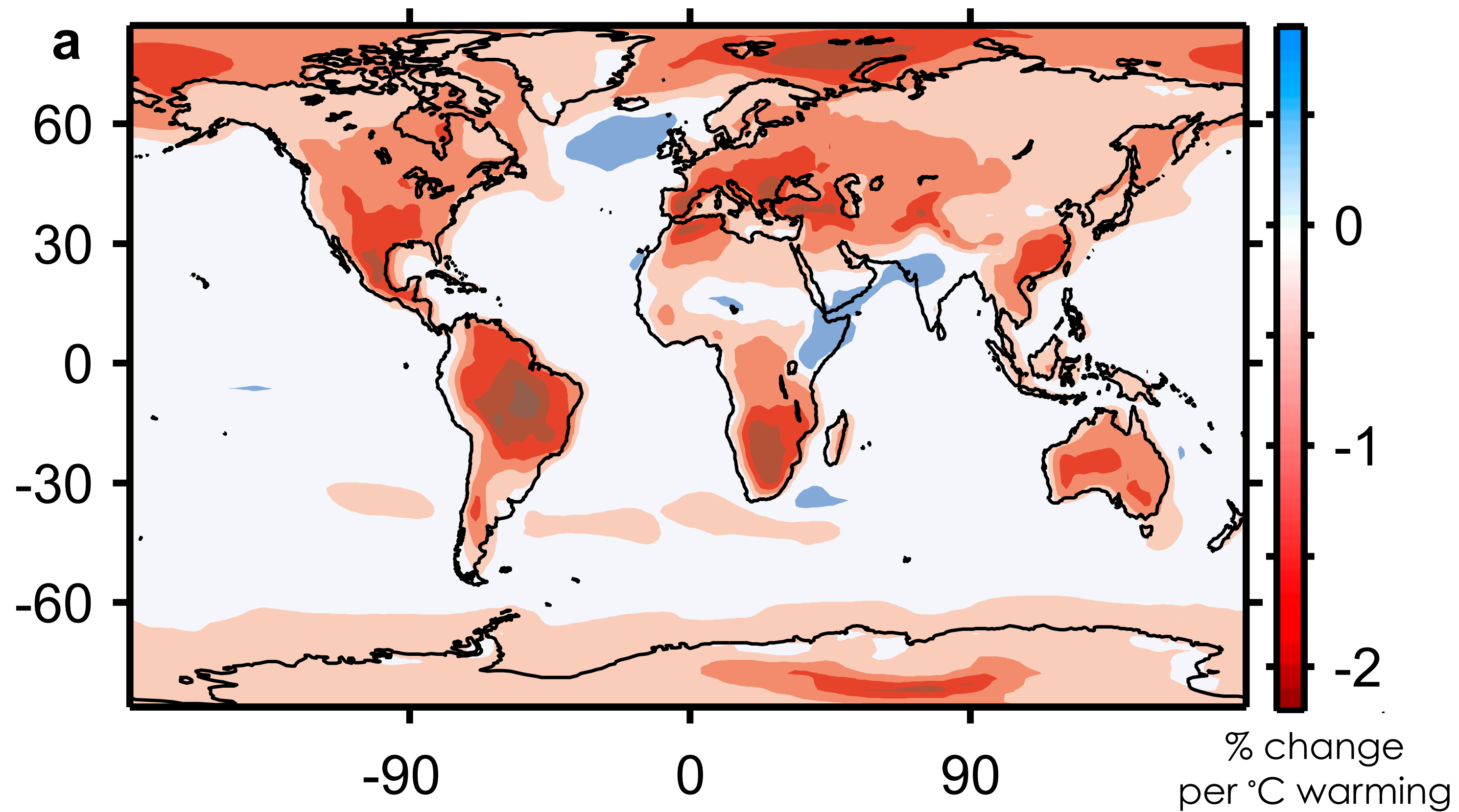


Scaling with mean specific humidity and relative humidity ($P \sim q^{0.8} rh^{1.0}$)



Becomes important to understand and better constrain decreases in relative humidity near surface over land

Projected change in near-surface relative humidity (RH)



Conclusions: precipitation extremes under climate change

► Progress in understanding: of regional changes in precipitation extremes when take relative humidity into account

► New tools are coming online:

1. Global convection resolving models and use of machine learning to improve accuracy of precipitation processes in model projections

2. Rare event sampling algorithms to better simulate the rarest extreme events (e.g., 500 year event)

