WCRP EPESC – LEADER Science Meeting

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# Anthropogenic amplification of precipitation variability over the past century

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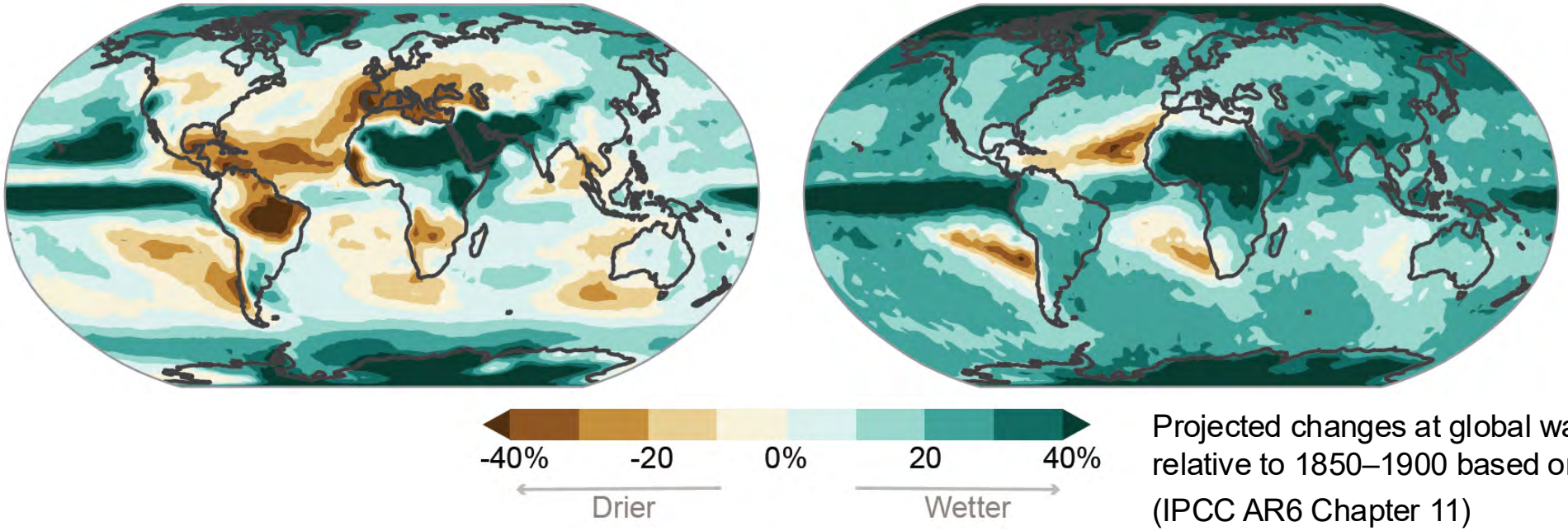
Thanks to Tianjun Zhou, Peili Wu

# The hydrological cycle is intensifying as climate warms

Changes in mean precipitation

Changes in extreme precipitation

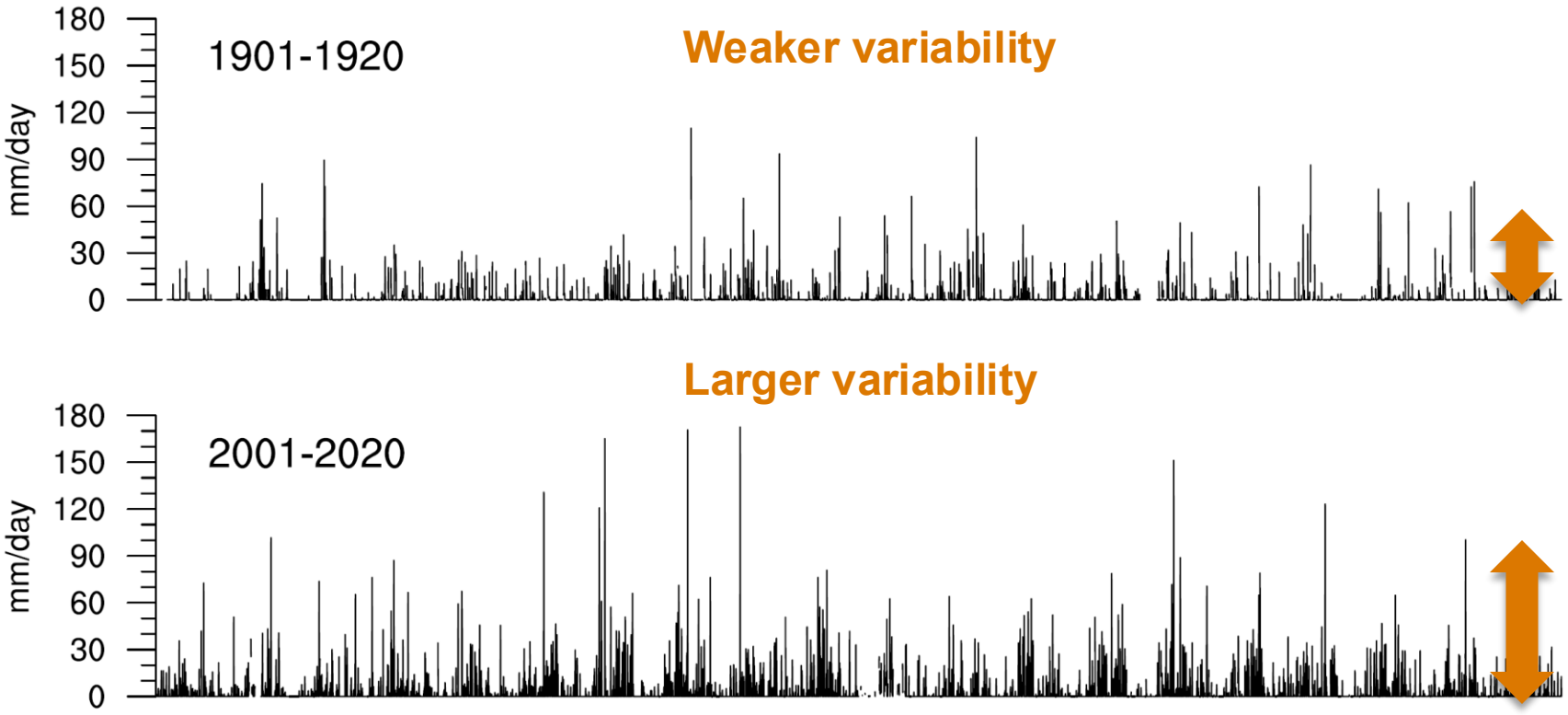



Projected changes at global warming of 4°C relative to 1850–1900 based on CMIP6 (IPCC AR6 Chapter 11)

**What other changes are we experiencing?**

# Changes in climate variability

Precip variability: range of precip fluctuations
(measured by temporal variance or standard deviation)




Daily precip time series over North America

Larger variability means

- intensified wet and dry periods
- greater swings between them
- Less reliable freshwater supply

# How does precipitation variability change in a warming climate?

- Observed changes
- Physical processes
- Anthropogenic influence
- Contribution of extreme precipitation change

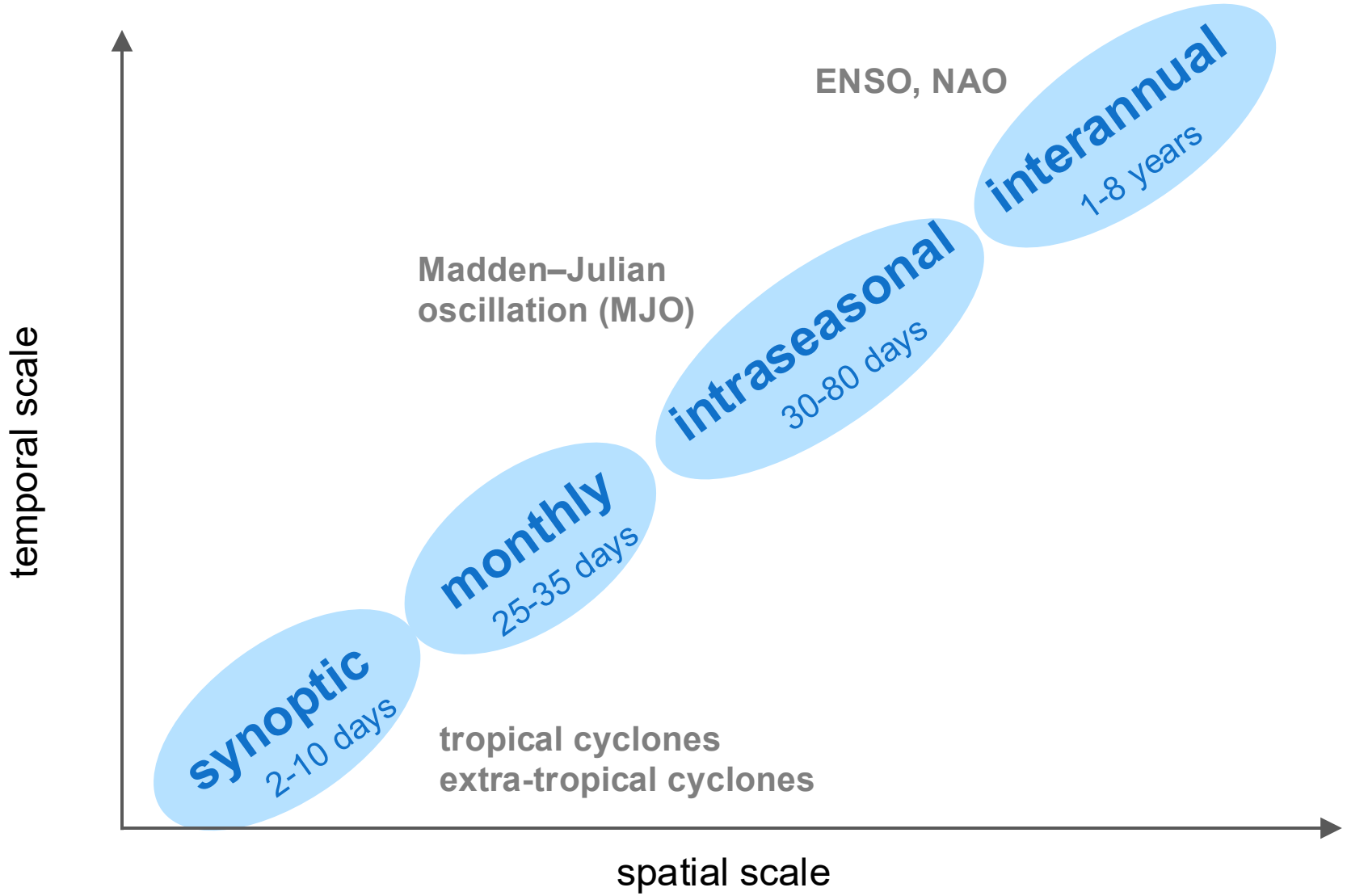
# Observational data

## 13 sets of daily precip observations (with timespan of ~40 years or more)

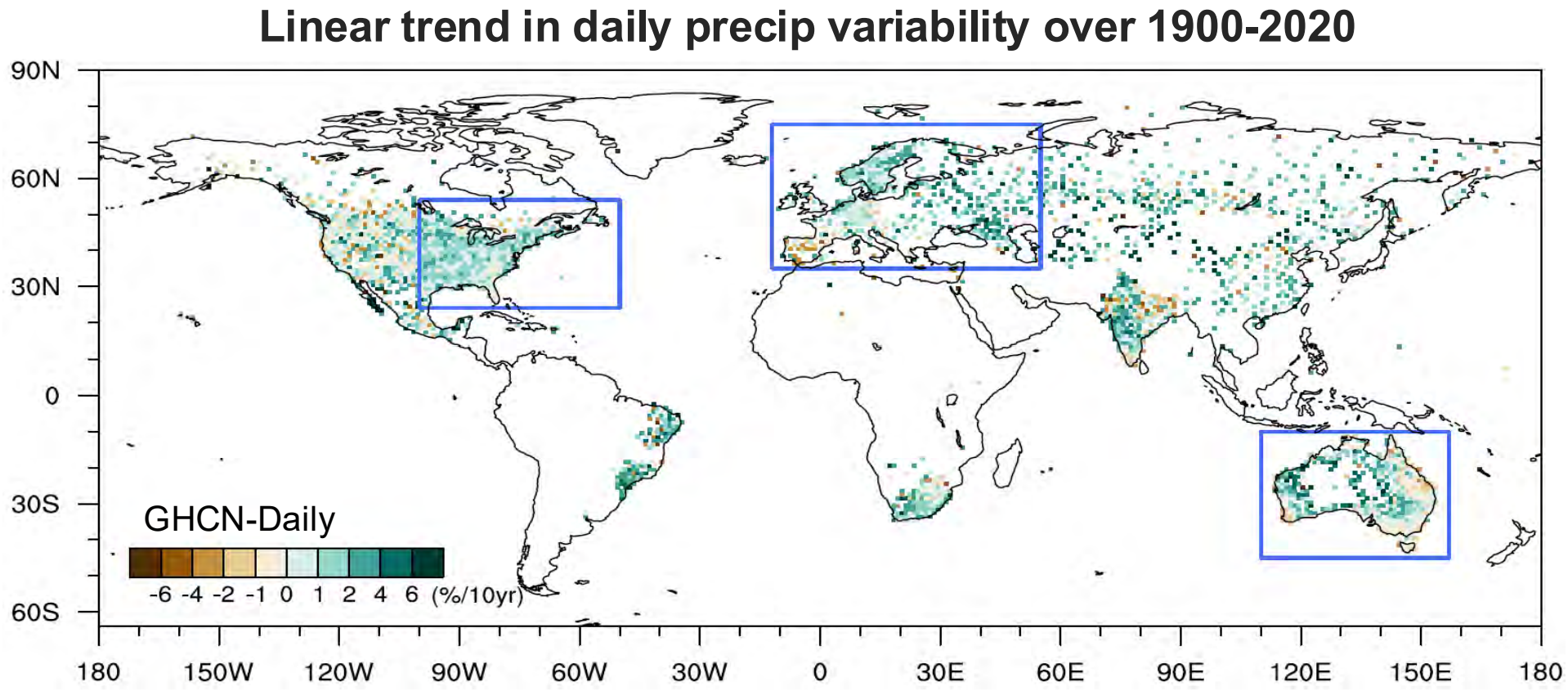
| Region | Dataset | Time span | Spatial resolution | Data type |
|---|---|---|---|---|
| Global land | GHCN-Daily | station-dependent | - | Gauge |
| | REGEN_LONG | 1950-2016 | 1° ×1° | Gauge-based g<br>term stations only) |
| | CPC_Global | 1979 to present | 0.5° ×0.5° | Gauge-based analysis |
| | GPCC Full Daily v2020 | 1982-2019 | 1° ×1° | Gauge-based gridded data |
| | MSWEP | 1979 to present | 0.1° ×0.1° | Gauge, satellite, and reanalysis combined gridded product |
| Low-to-mid latitudes | CHIRPS | 1981 to present | 1° ×1° | Gauge and satellite combined gridded product |
| Australia | AWAP | 1900 to present | 0.25° ×0.25° | Gauge-based gridded data |
| Europe | E-OBS | 1920 to present | 0.25° ×0.25° | Gauge-based gridded data |
| Conterminous United States | CPC_CONUS | 1948 to present | 0.25° ×0.25° | Gauge-based analysis |
| China | CN05.1 | 1961 to present | 0.25° ×0.25° | Gauge-based gridded data |
| Monsoon Asia | APHRO_MA | 1951-2015 | 0.5° ×0.5° | Gauge-based gridded data |
| Middle East | APHRO_ME | 1951-2007 | 0.5° ×0.5° | Gauge-based gridded data |
| Northern Eurasia | APHRO_RU | 1951-2007 | 0.5° ×0.5° | Gauge-based gridded data |

**Data selection:**
**sufficient sampling frequency and timespan**

# Climate variability at a wide variety of scales



# Amplified precip variability since 1900s

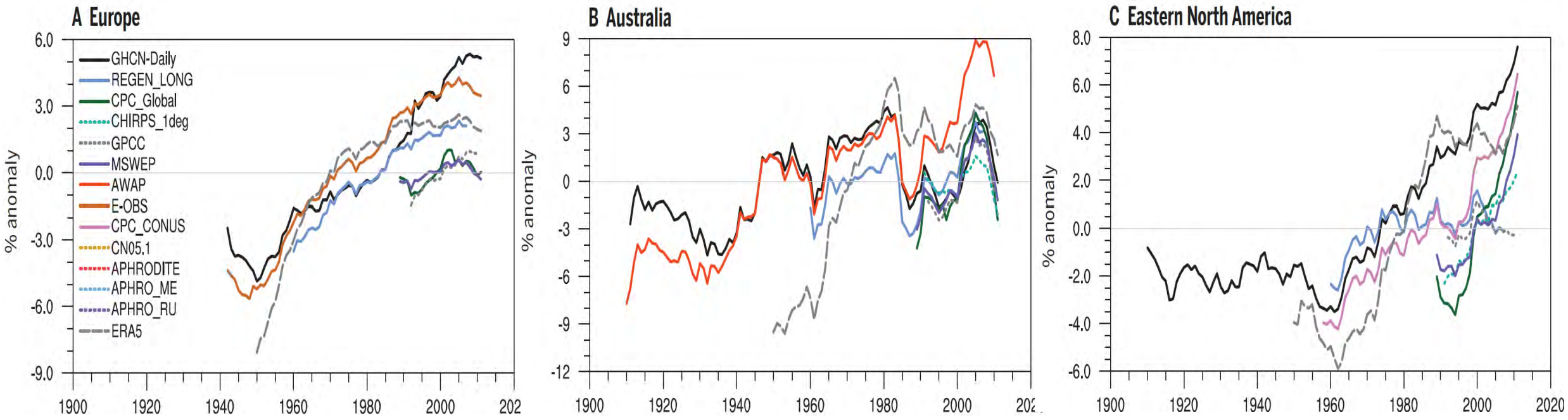



- **Over land regions with sufficient data, precip variability has amplified over ~75% of area**
- **Daily variability increased by ~1.2%/decade globally**

(Zhang et al., 2024)

# Hotspots: Europe, Australia and eastern North America

Long-term change in daily precip variability



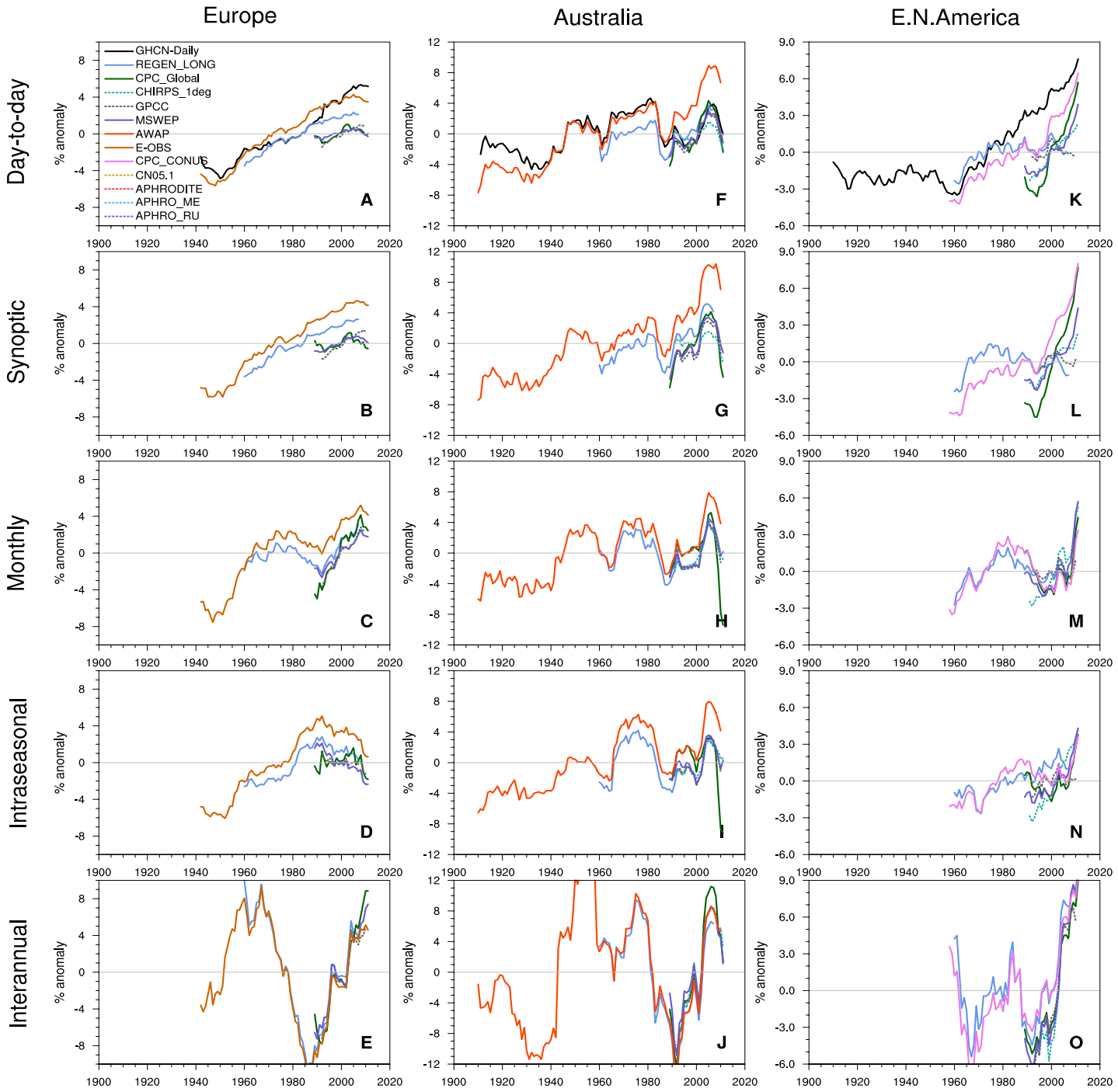

**The consistency across multiple observations confirms the robustness of the increasing trend.**

(Zhang et al. 2024)

# Amplified across timescales

- The synoptic, monthly and intraseasonal variability show consistent increases
- For interannual variability, no significant trend has emerged from the strong inter-decadal variability

(Zhang et al. 2024)



# Why does precipitation variability amplify?

**Moisture budget equation (suitable for diagnosing mean state)**

$$P - E = -<\omega \partial_p q> - <V \cdot \nabla q> + \delta_0$$

**Adjusted equation (suitable for diagnosing std)**

$$\Delta\sigma[P_f] \approx \Delta\sigma\left[\left(-\frac{\omega_m q_l}{g}\right)_f\right]$$ Vertical moisture advection

**Thermodynamic:**
**Atmospheric moisture increase**

$$TH \approx \delta\bar{q}_l$$

**Dynamic:**
**Change in atmospheric circulation variability**

$$DY \approx \delta\sigma[-(\omega_m)_f]$$

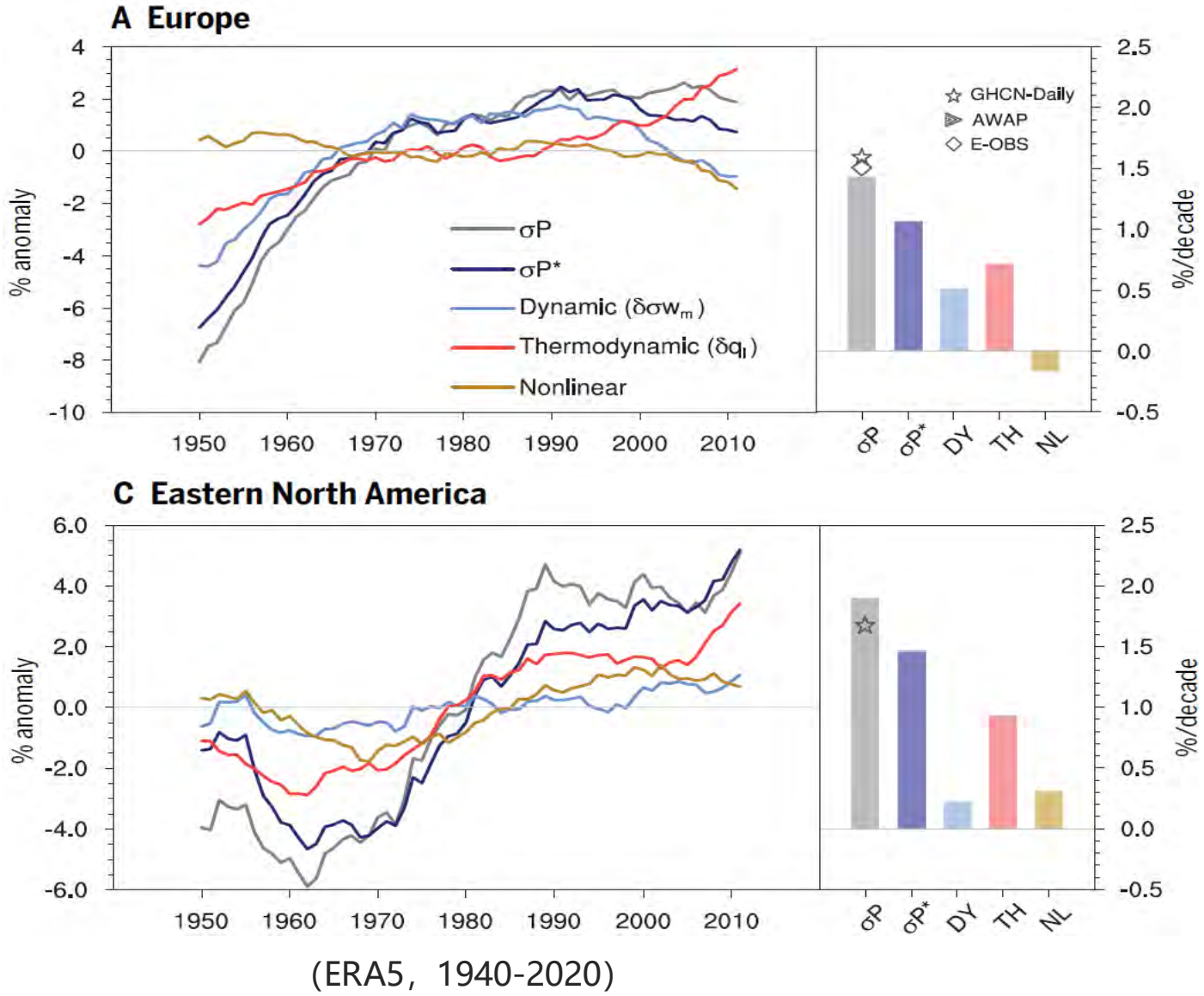
**Non-linear:**
**Due to changes in humidity & circulation**

$$NL \approx \Delta\sigma\left[\left(-\frac{\omega_m q_l}{g}\right)_f\right] - TH - DY$$

$P$: precipitation
$E$: evaporation
$\omega$: vertical motion
$\boldsymbol{V}$: horizontal wind
$q$: specific humidity
<>: vertical integration
*f:* variation at specific time scale
$\omega_m$: 500hPa omega
$q_l$: 850hPa specific humidity
$\sigma$: standard deviation
$\delta$: relative change

(He and Li, 2019; Zhang et al. 2021)

# Why does precipitation variability amplify?




(ERA5, 1940-2020)

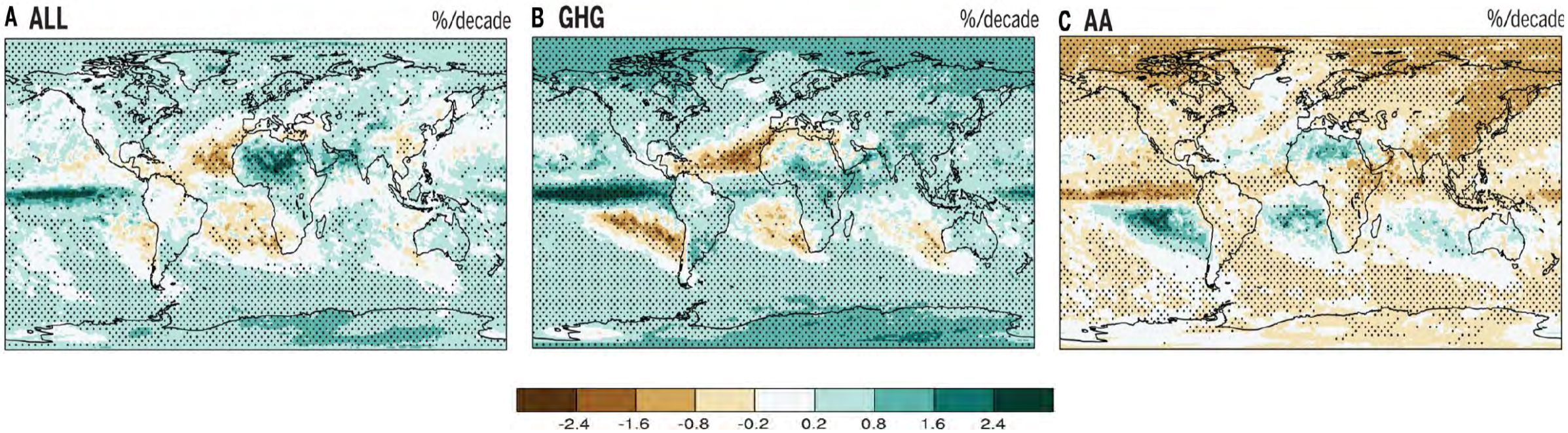
$$\Delta\sigma[P_f] \approx \Delta\sigma\left[\left(-\frac{\omega_m q_l}{g}\right)_f\right]$$

- **Dominated by the thermodynamic effect due to atmospheric moistening, with a contribution of ~60% at regional scale**
- **Modulated at decadal timescales by atmospheric circulation changes**

(Zhang et al. 2024)

# Detecting anthropogenic fingerprints

**Forced responses of precip variability over 1900-2020** (CMIP6 DAMIP ensemble)

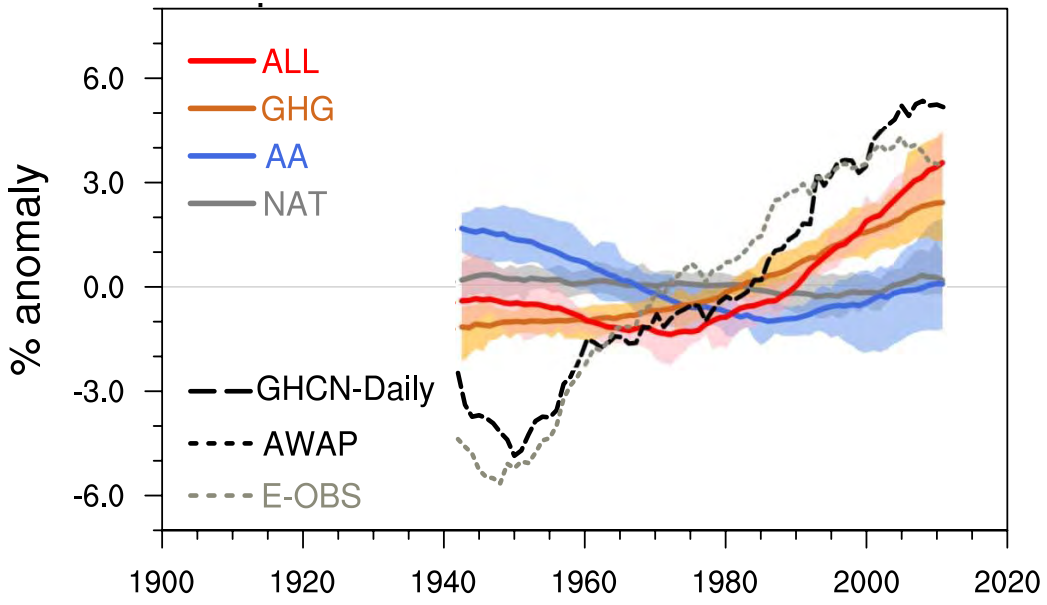



- **The global-scale amplification of precip variability in OBS can be reproduced with ALL forcings**
- **Tug-of-war between GHG and AA forcings**
- **Model-OBS discrepancy over East Asia (too strong AA forcing)**

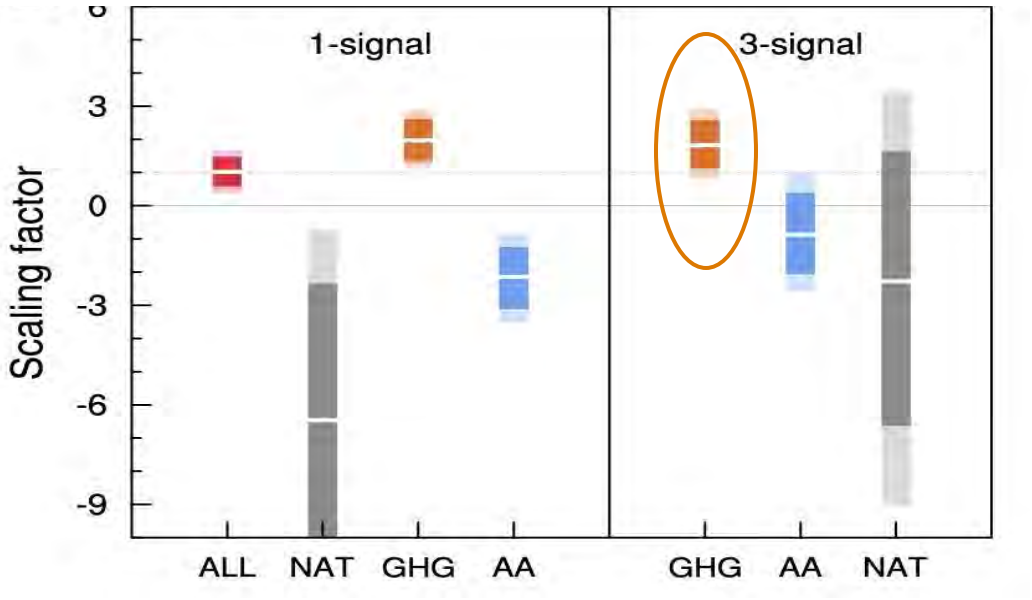
(Zhang et al. 2024)

# Detecting anthropogenic fingerprints

**OBS vs. forced changes (Europe)**




**Optimal fingerprinting detection and attribution**

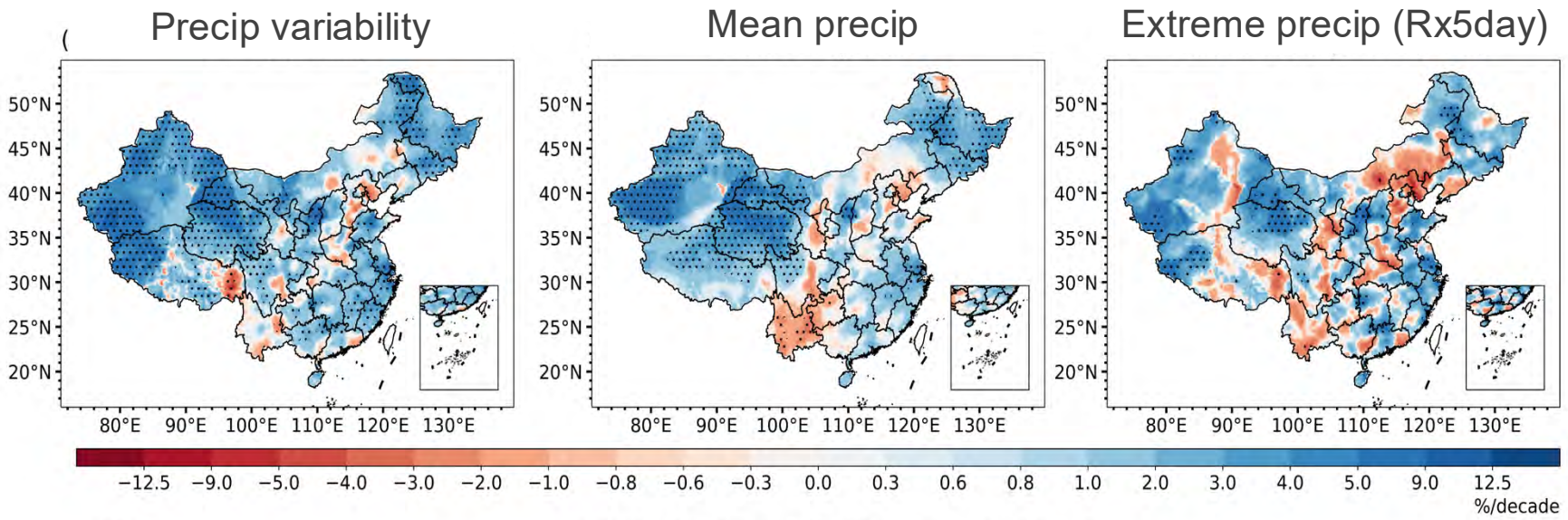


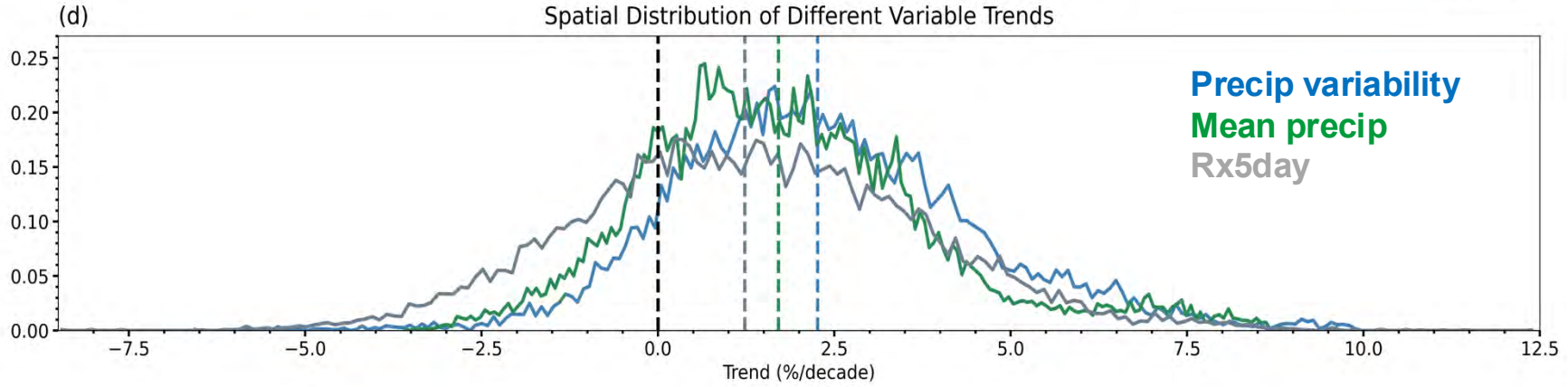

**D&A: the observed increase in precipitation variability over the past century is attributed to anthropogenic GHG forcing**

(Zhang et al. 2024)

# Changes in precip variability vs. mean precip vs. extreme precip

## Trend over 1961-2023



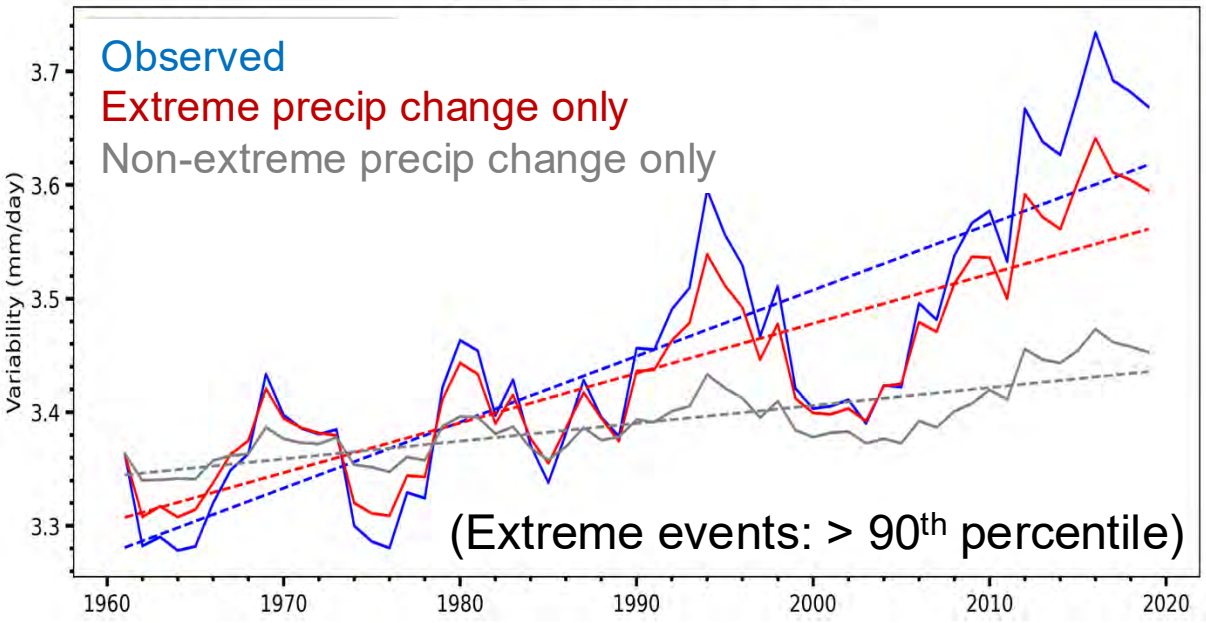




- **Similar spatial pattern: similar large-scale dynamic drivers**
- **Precip variability increases over a wider spatial extent and at a greater magnitude than mean and extreme precip**

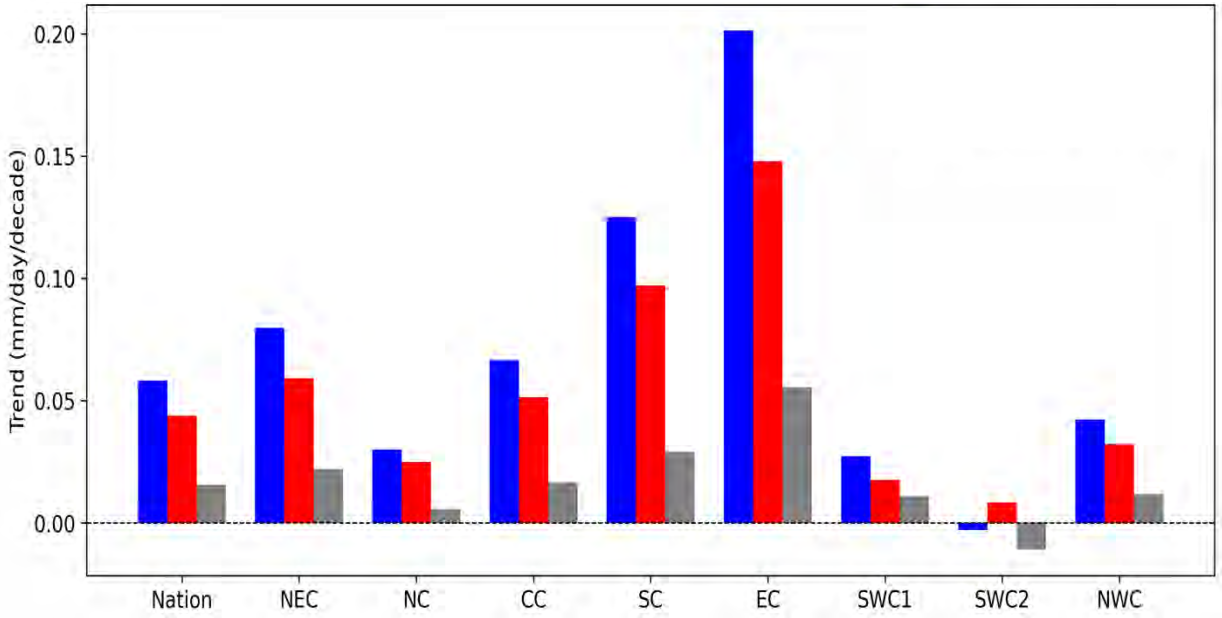
(Mo, Zhang, et al. in revision)

# Contribution of extreme precipitation change

Precip variability change in idealized scenarios




Contribution of extreme vs. non-extreme events




**Changes in extreme precip contributed ~75% to the amplification of precip variability over China.**

(Mo, Zhang, et al. in revision)

# Summary

- **Observed change**
  - Systematically amplified over the past century from global to regional scales and across timescales from daily to intra-seasonal
- **Physical processes**
  - Dominated by the thermodynamic effect due to atmospheric moistening
  - Modulated at decadal timescales by atmospheric circulation changes
- **Attributable to anthropogenic GHG forcing**
- **Contribution of extreme precipitation change**
  - Changes in extreme precip contributed ~75% to the amplification of precip variability


THANK YOU!