Climate change, extreme precipitation events, and some implications for risk analysis

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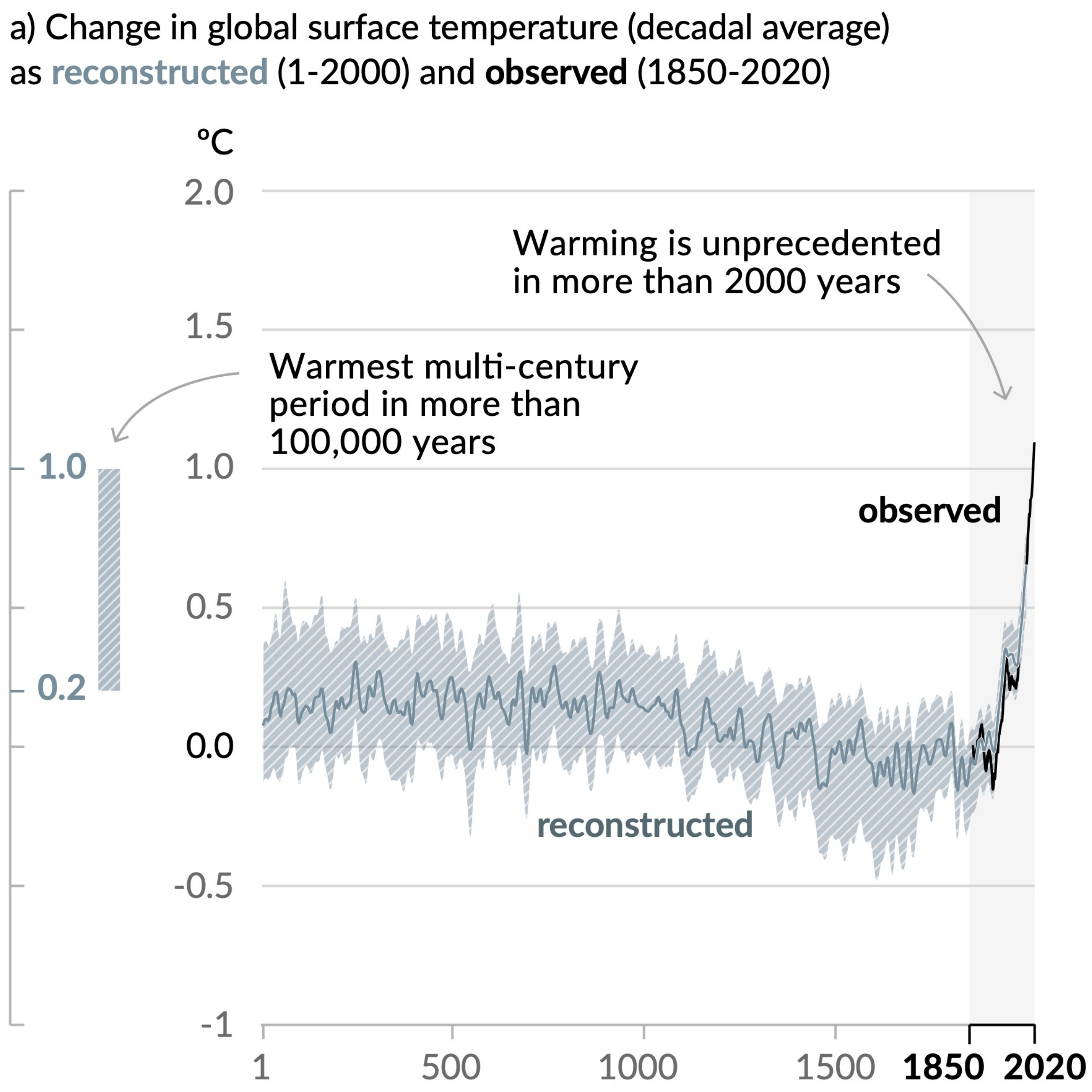
Sheringham Point Lighthouse, Shirley, BC

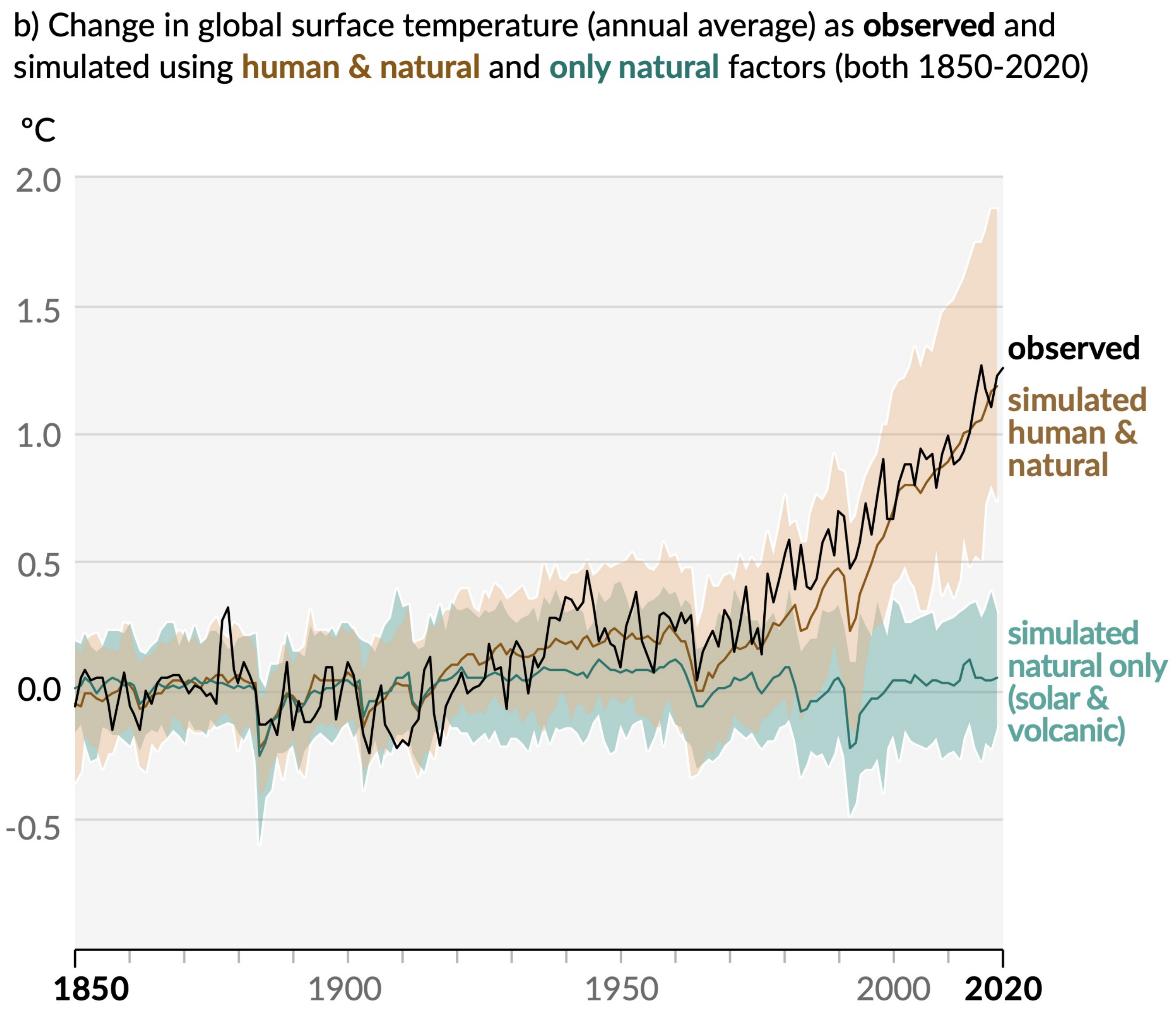
Outline

- Observed warming and its causes
- Observed changes in precipitation extremes and causes
- Projections of future change
- Some implication for infrastructure design
- Some challenges
- Questions


Observed warming and its causes
Mount Robson, BC

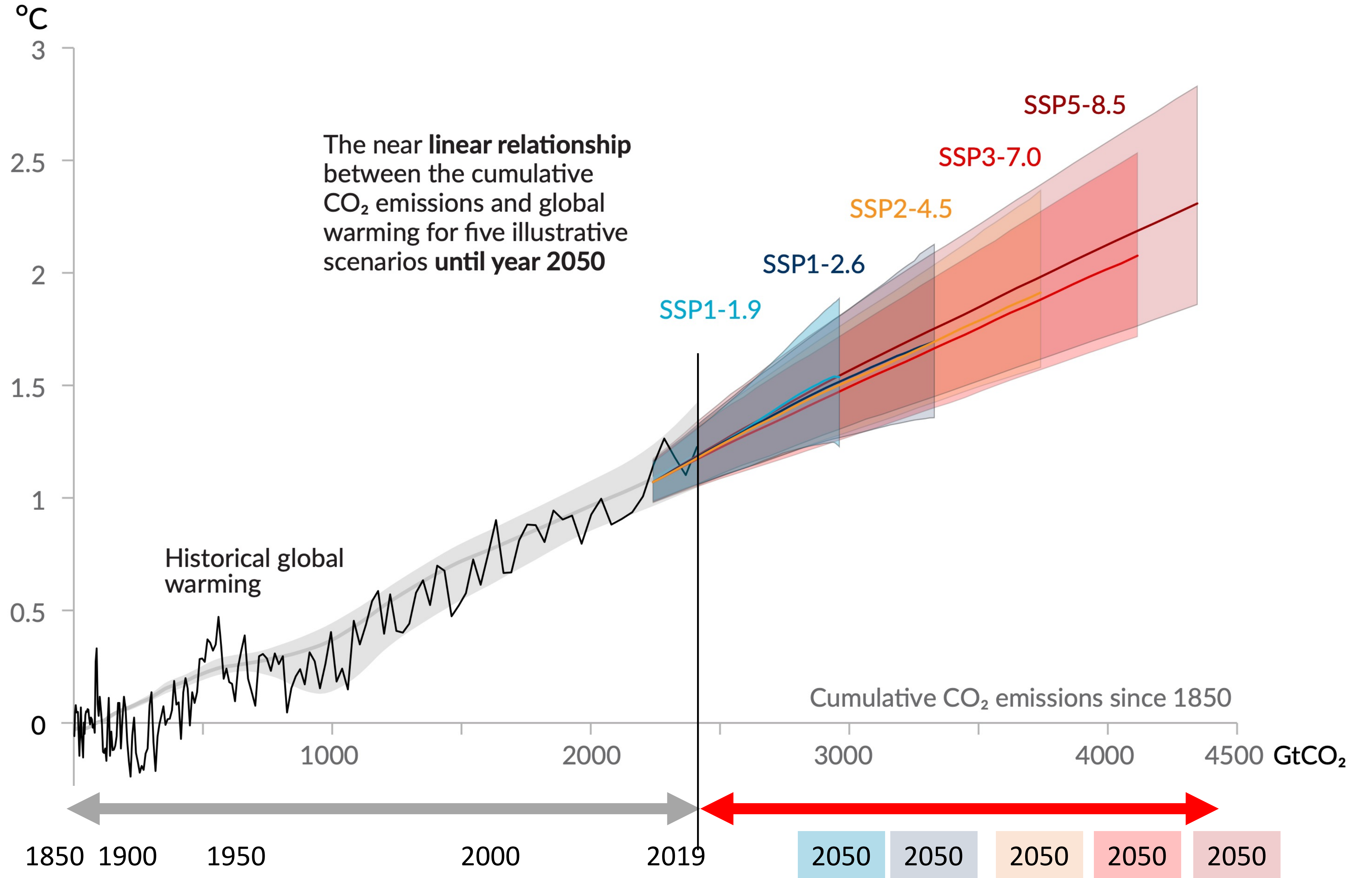
Observed global surface temperature relative to 1850-1900





IPCC WGI, 6th Assessment, Fig. SPM.1

Global surface temperature increase since 1850-1900 (°C) as a function of cumulative CO_2 emissions ($GtCO_2$)



Adapted from IPCC WGI, 6th Assessment, Fig. SPM.10

Observed changes in precip extremes

University House 1

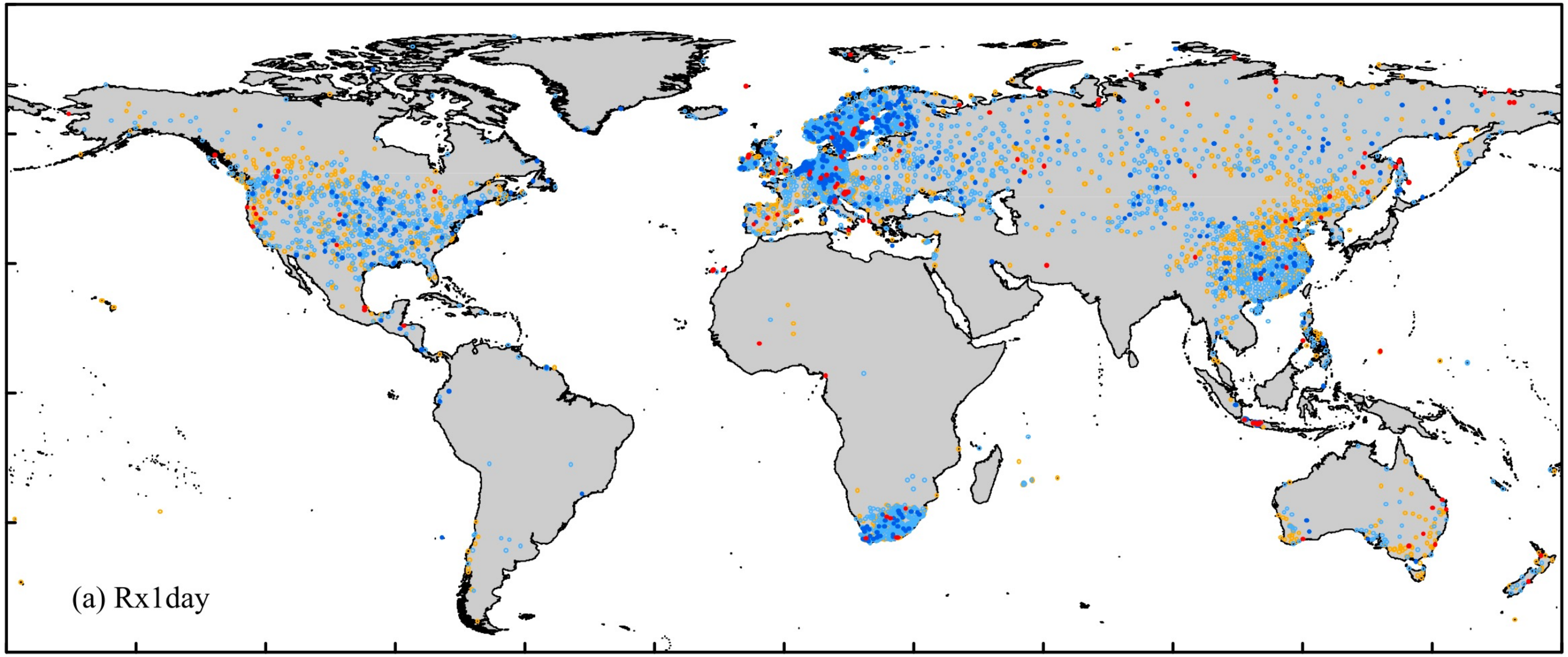
Observed changes in precipitation extremes

- Observational studies suggest intensification is occurring
  - Rate of intensification of annual max 1-day rainfall (Rx1day) is broadly consistent with the Clausius-Clapeyron relation
  - Growing number of studies of long-term changes in extreme precipitation point to greenhouse gas emissions as the cause
    - Min et al., 2011; Zhang et al., 2013; Dong et al., 2020; Kirchmeier-Young and Zhang, 2020; Paik et al., 2020; Sun et al., 2022

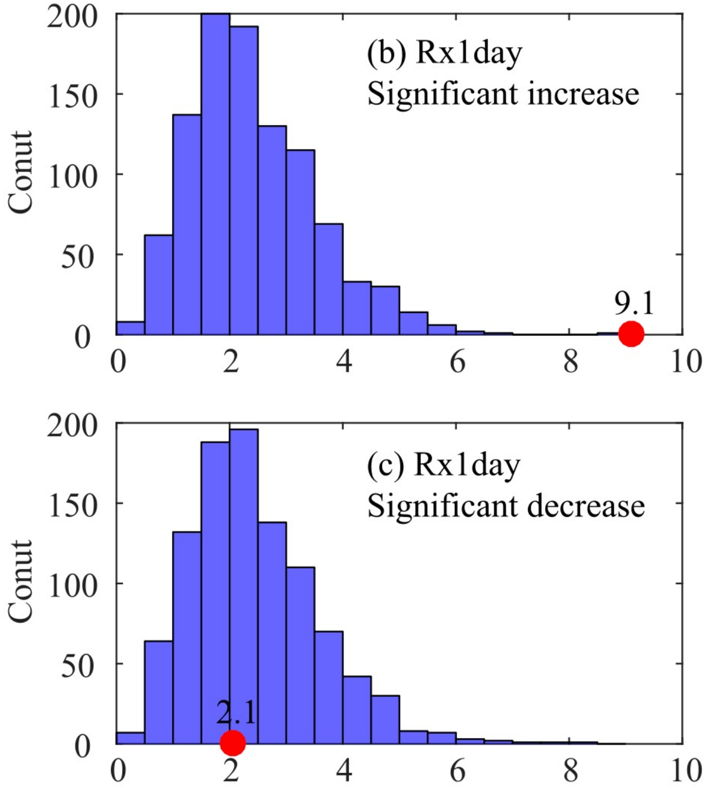
- Nevertheless, local detection of change is still very hard
    - Westra et al., 2013; Barbero et al., 2017; Li et al., 2019; Sun et al., 2021

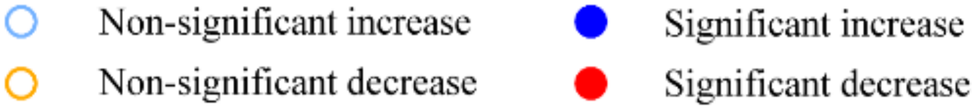
Observed trends in annual maximum 1-day precipitation

7293 stations, 1950-2018



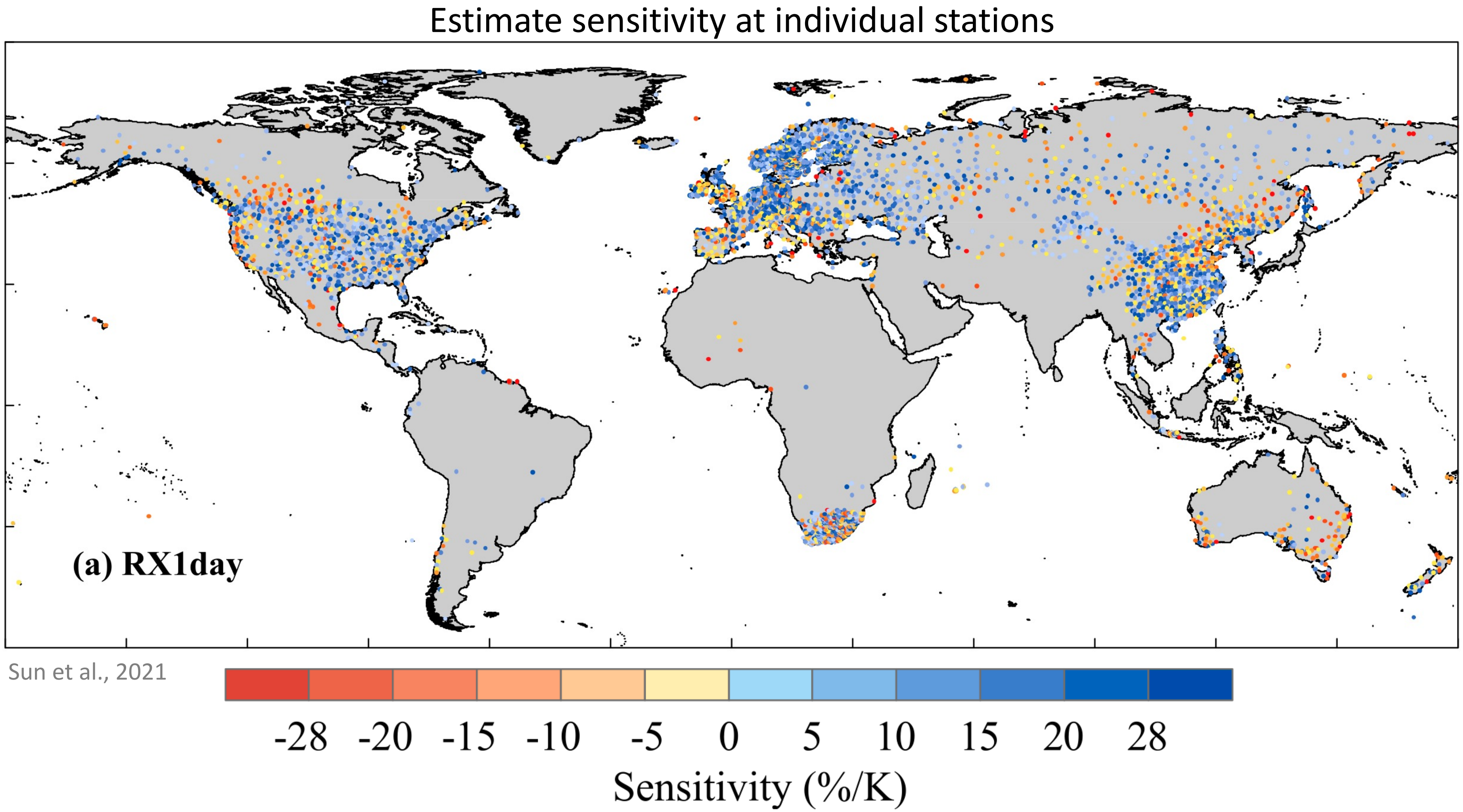
Sun et al., 2021



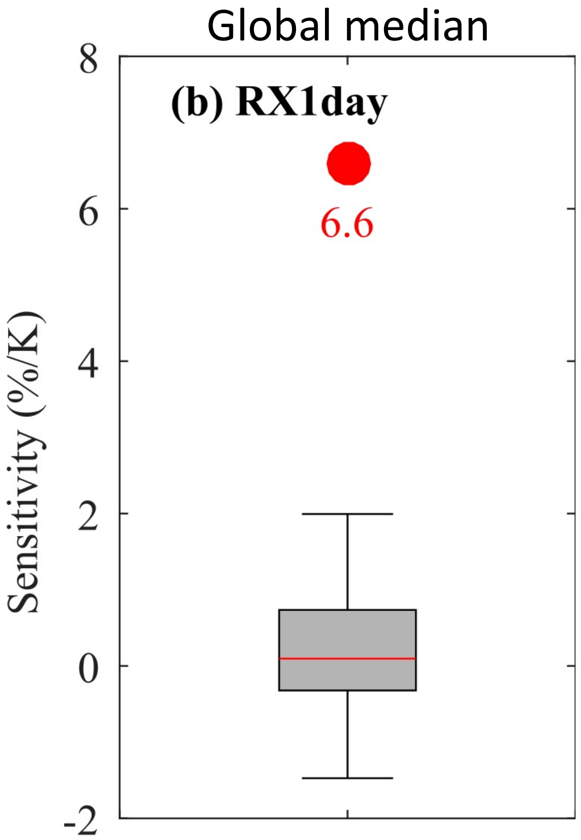


Based on non-parametric Mann-Kendall test (2-sided, 5% significance level)

Estimated sensitivity to global warming



Sun et al., 2021



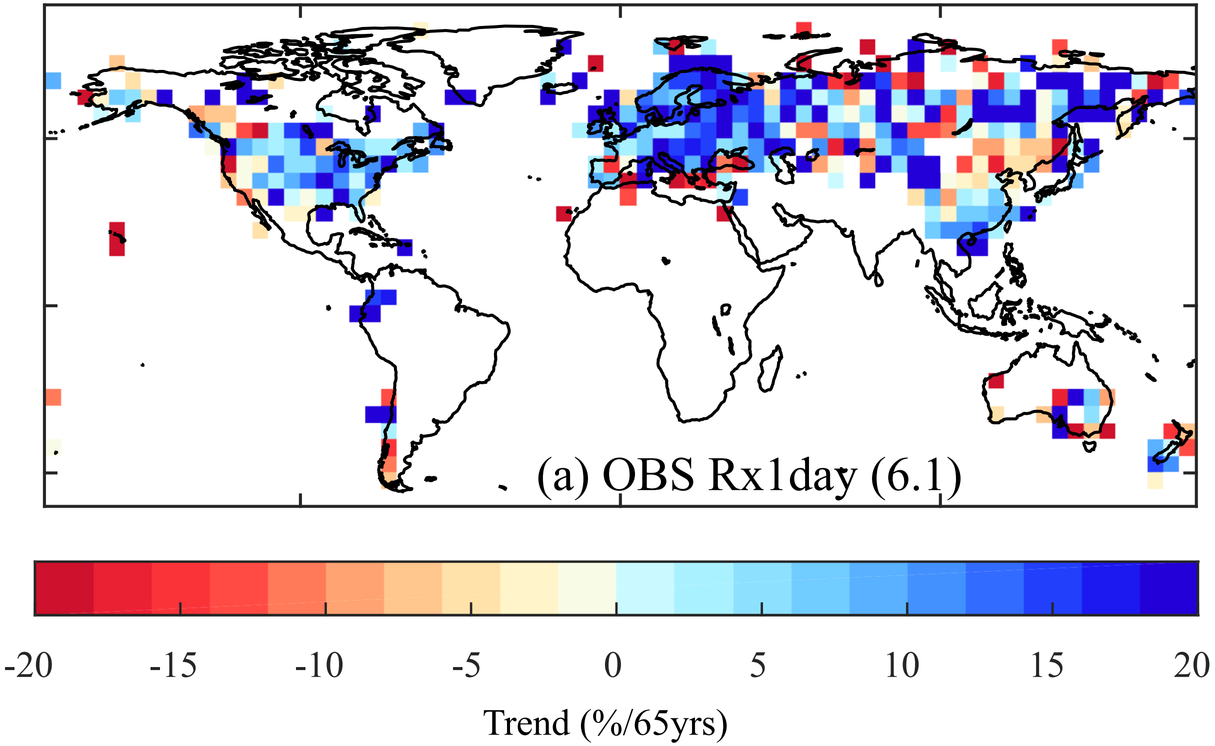
Attribution of changes in precip extremes

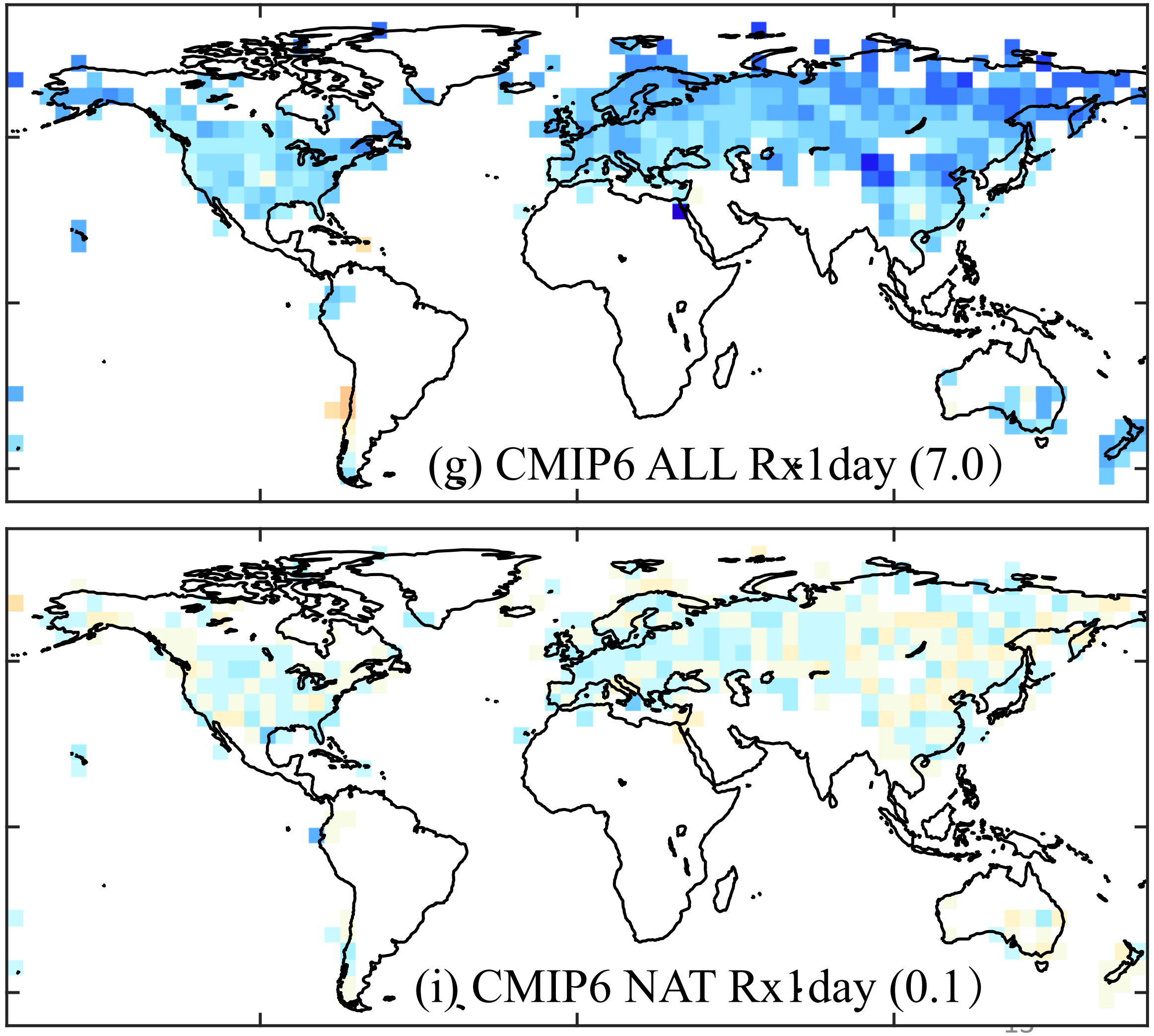
23 Oct 2022 Colorado low beginning to exert its influence on southern Saskatchewan

Detection and attribution directly on station data

- Detection and attribution (D&A) studies look for evidence that the climate model simulated responses to external forcing are present in observations
- They use regression models where the predictors are climate model simulated responses to forcing
- We recently developed a technique that
  - Is adapted specifically to extremes
  - Uses station values of $\ln(Rx1day)$ as the predictand
  - Uses climate models only to estimate the expected changes in $\ln(Rx1day)$
- Why $\ln(Rx1day)$?
  - The CC relation suggests $Rx1day$ should increase exponentially with warming → $\ln(Rx1day)$ should increase linearly
  - This scaling should be independent of spatial scale differences (e.g., point scale vs grid box scale) to first order

Trends (1950-2014) in log observations and CMIP6 signals transformed back to physical units



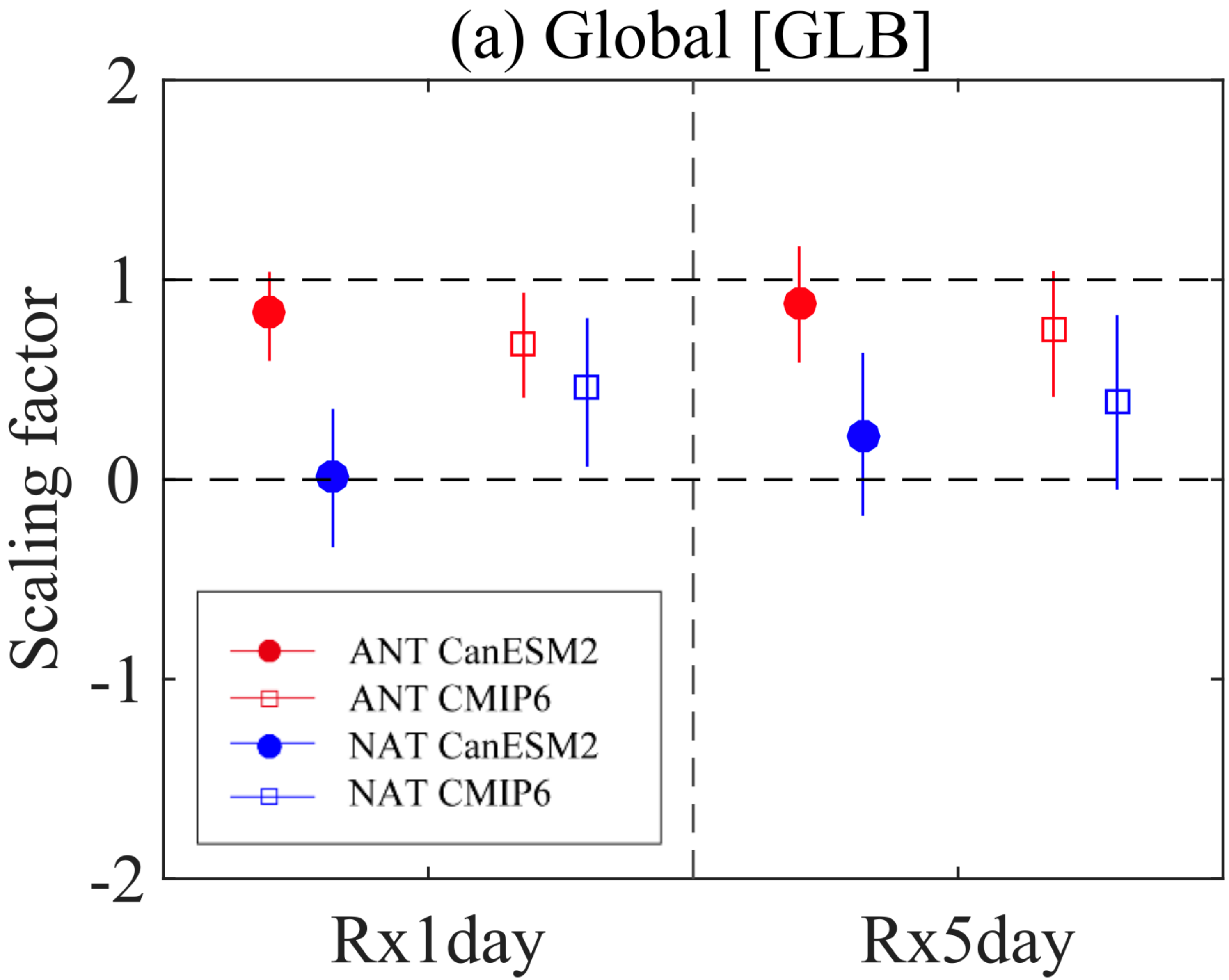


CMIP6 models (ALL and NAT forcing, 46 members each):

ACCESS-CM2, BCC-CSM2-MR, CanESM5, CNRM-CM6-1, CESM2, HadGEM3-GC31, IPSP-CM6A-LR, MIROC6, MRI-ESM2-0, NorESM2-LM

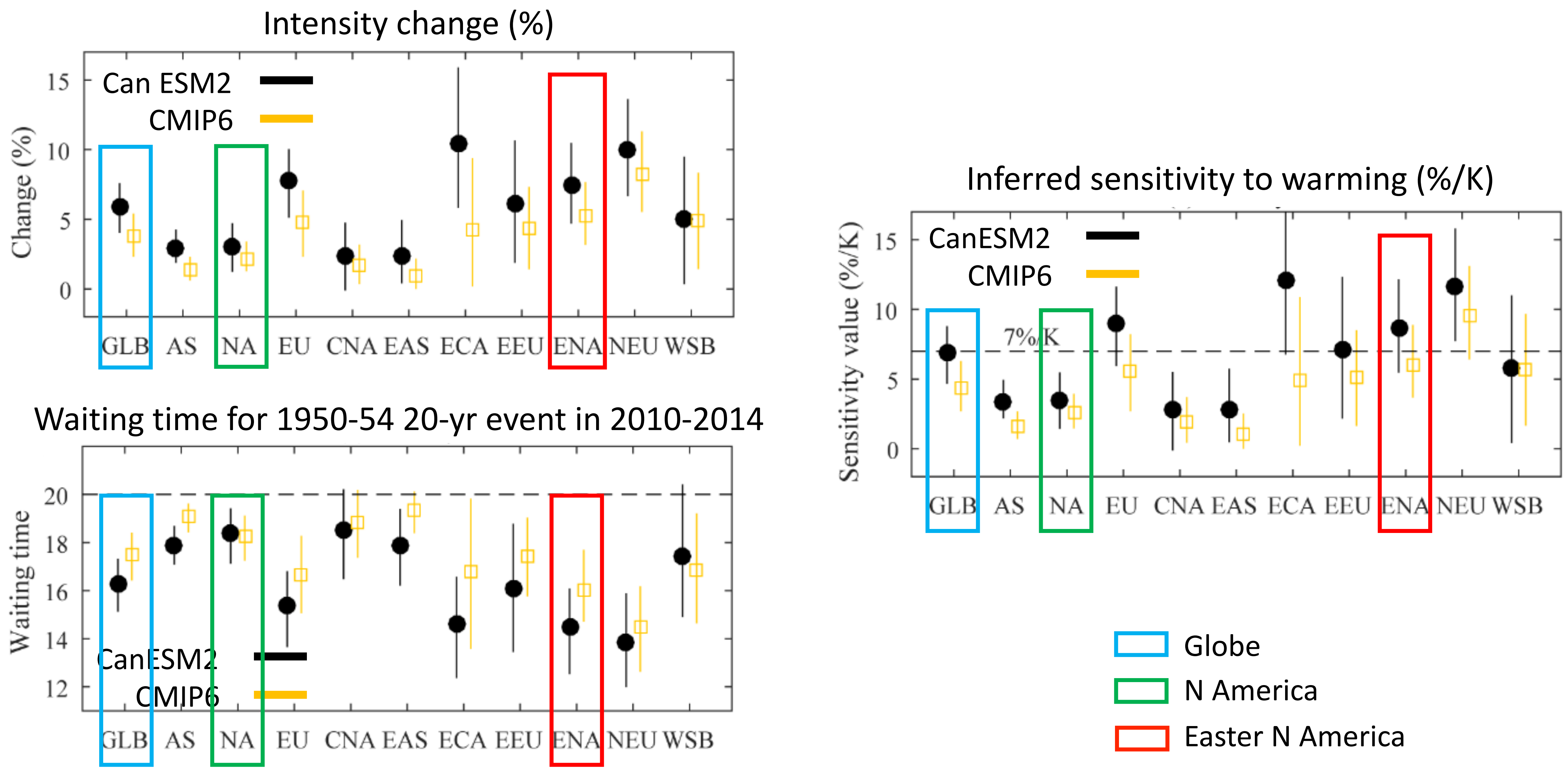
Also separately used CanESM2 large ensembles (ALL and NAT forcing, 50 members each)

2-signal D&A results (ANT and NAT forcings)



Sun et al., 2022

1950-2014 changes in Rx1day attributed to ANT forcing

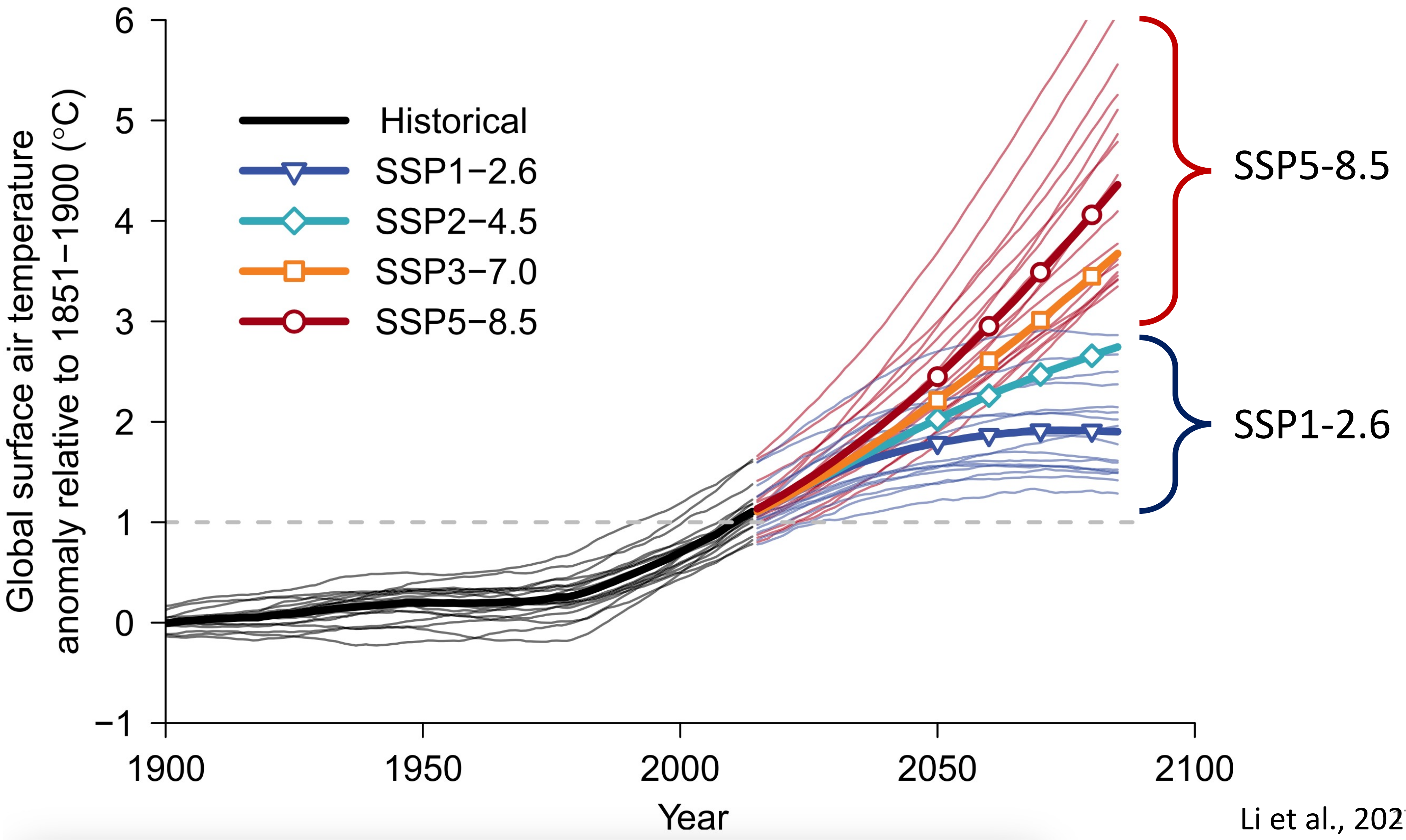


Sun et al., 2022

Projections of future change

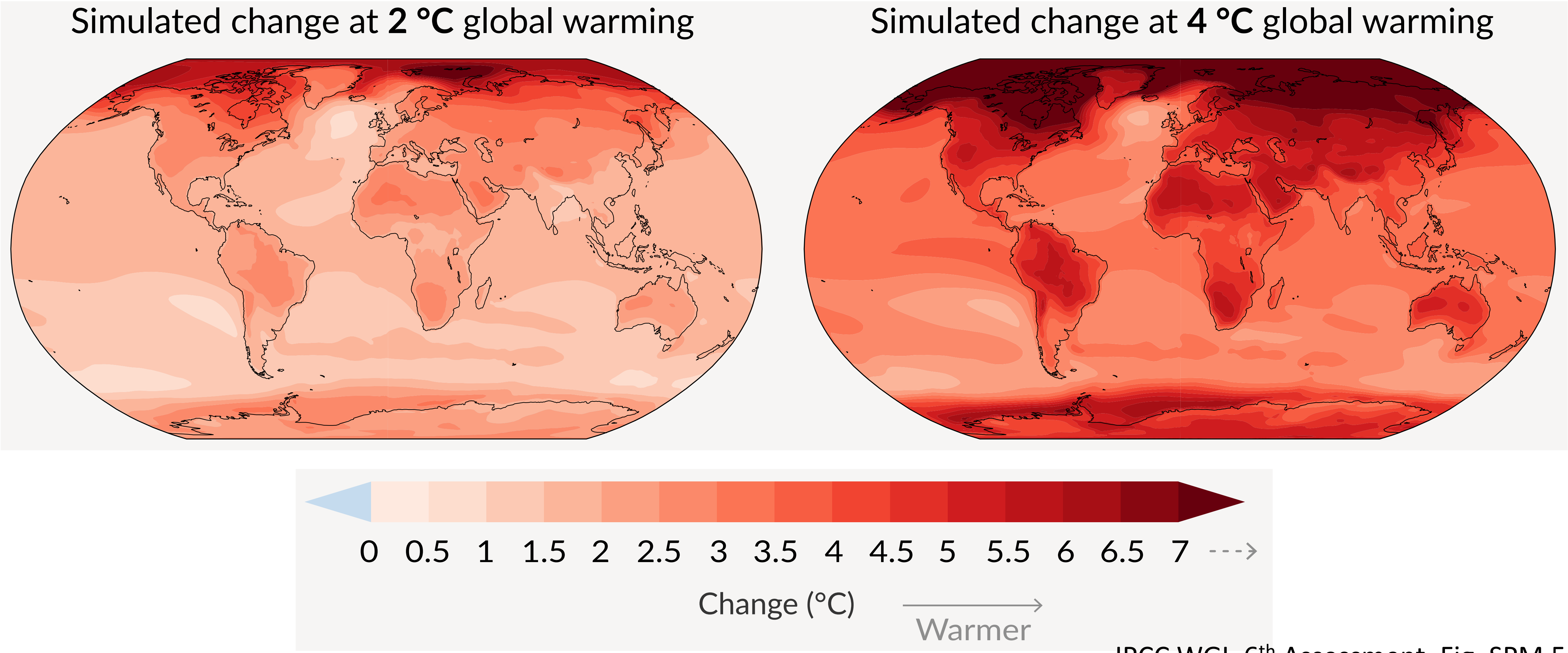
Dempster Highway, Yukon

Change in global mean temperature relative to 1851-1900



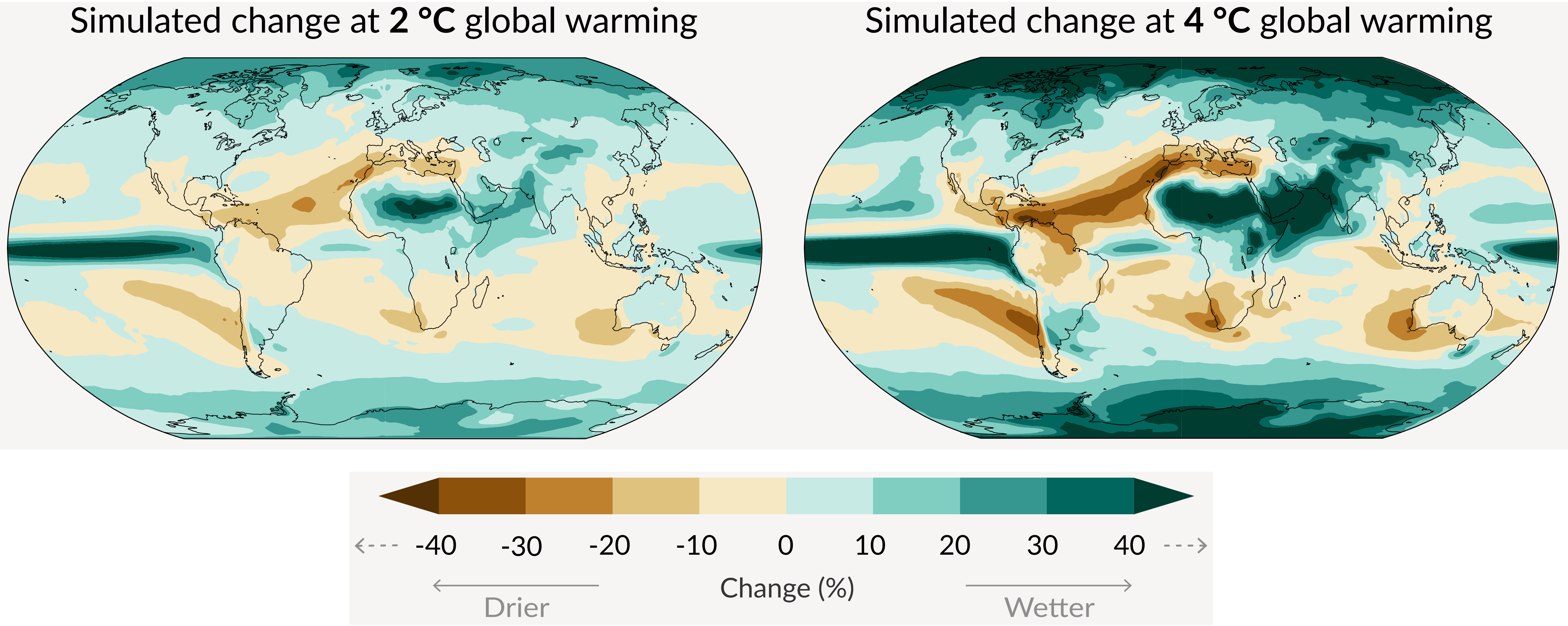
Li et al., 2021, Fig 1c

The link between global and local temperature change



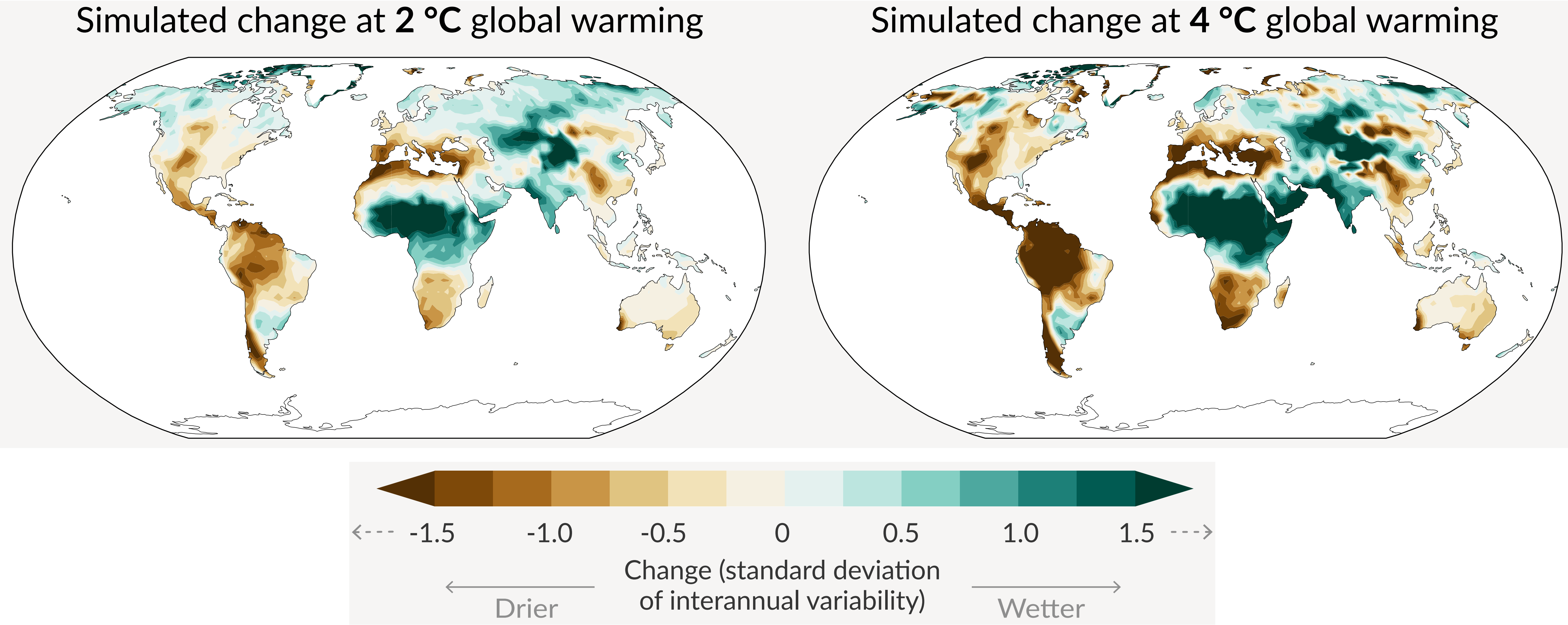
IPCC WGI, 6th Assessment, Fig. SPM.5

The link between global temperature change and local annual mean precipitation change



IPCC WGI, 6th Assessment, Fig. SPM.5

The link between global temperature change and local annual mean soil moisture change

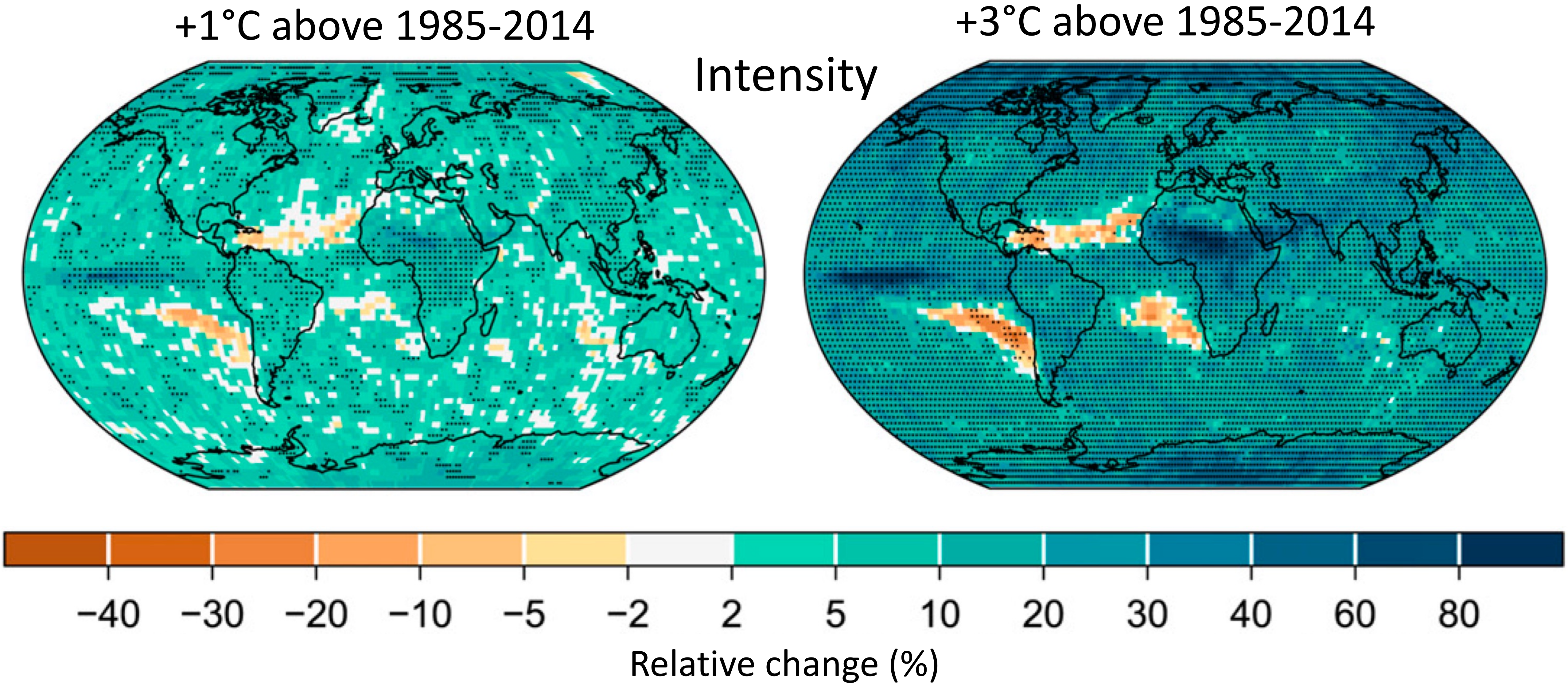


IPCC WGI, 6th Assessment, Fig. SPM.5

The future of precipitation extremes

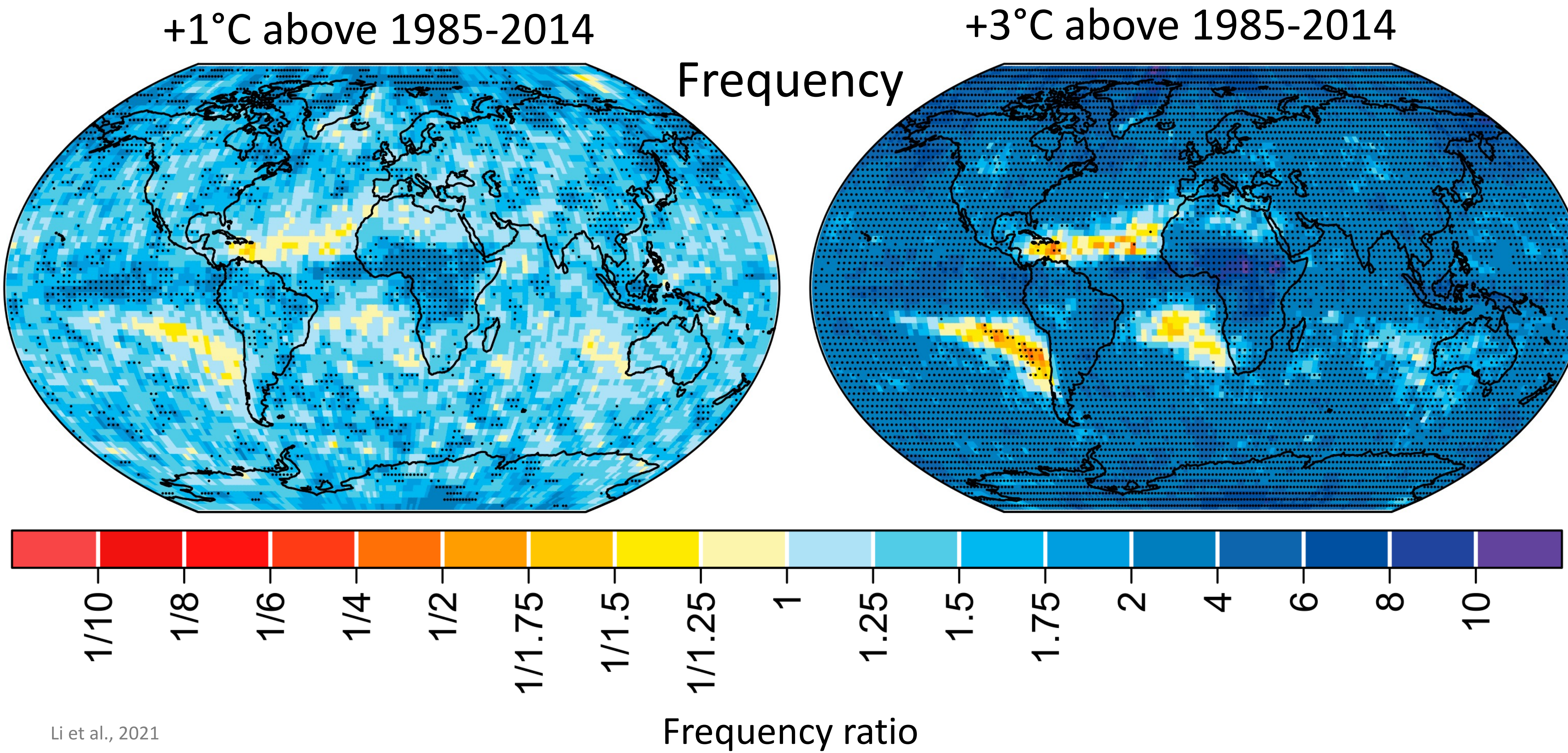
Shower over Juan de Fuca Strait

Projected changes in 50-year 1-day precipitation extremes



Li et al., 2021

Projected changes in 50-year 1-day precipitation extremes



Li et al., 2021

Climate Change and Extreme Precipitation

- Global warming
  - Global mean surface air temperature during 2001-2020 was about 1°C higher than during the early industrial period 1850-1900 (IPCC, 2021)
  - Canada has warmed about twice as fast as the global average, with more than double the rate of global warming in the North (CCCR, 2019)
  - Almost all of this warming is due to greenhouse gas concentration increases
- Impact on extreme precipitation
  - Theory and climate models suggest that the intensity of extreme rainfall will increase about 6-7% for each 1°C of warming
  - Observed trends in extreme precipitation at long running meteorological stations across the globe confirm that this is happening (Sun, et a, 2021)
  - Local trends are noisy, however, making this change difficult to see at individual observing stations
  - Nevertheless, the evidence indicates that greenhouse gas increases have increased the risk of extreme precipitation events (IPCC, 2021; Sun et al, 2022), including in North America (Kirchmeier-Young et al, 2020)
- Climate change projections indicate that these risks will continue to increase (Li et al, 2021)

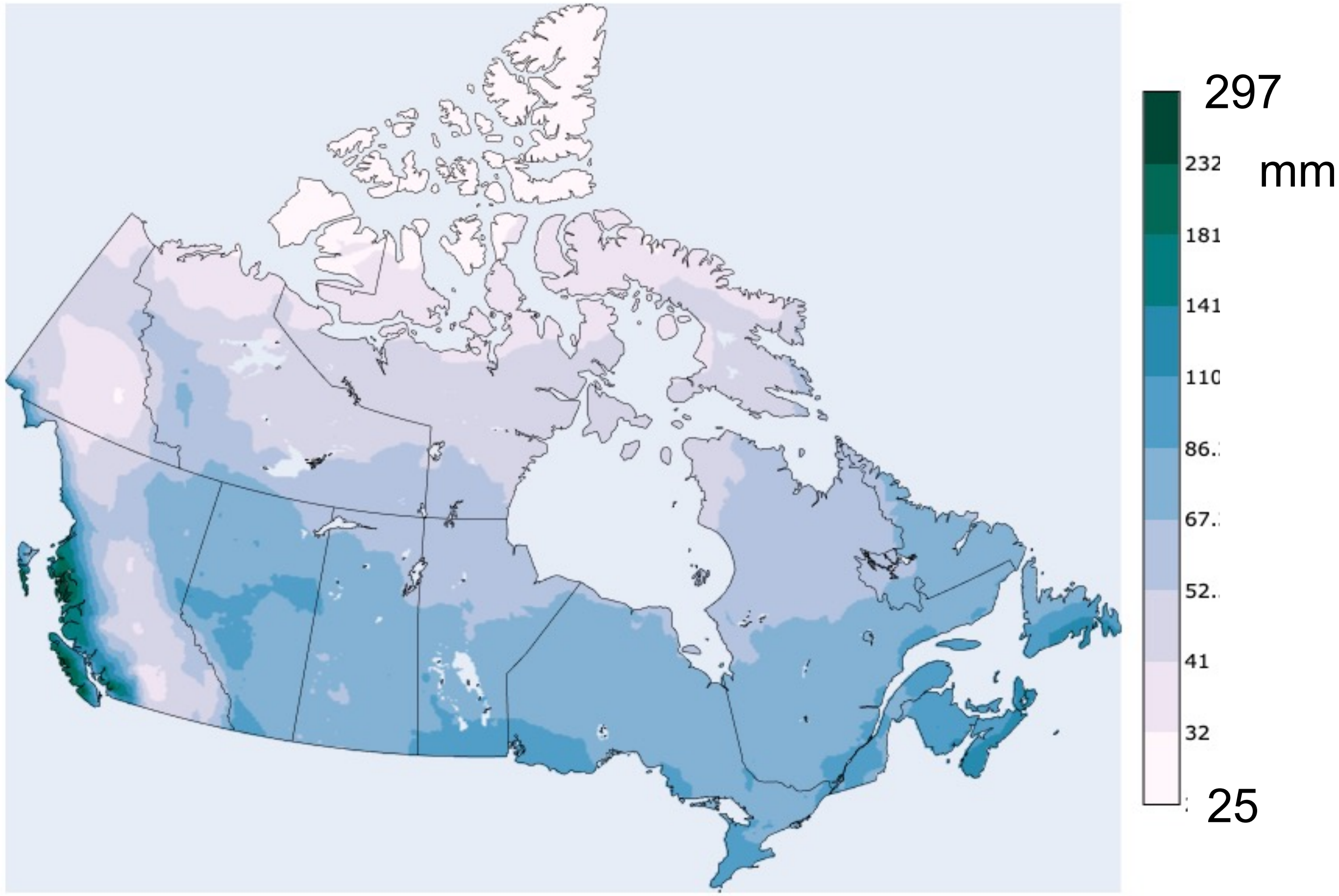
Designing infrastructure for a future climate

Inuvik-Tuktoyaktuk Highway, Northwest Territories.

Infrastructure design is a risk management exercise

- Need to look forward in different ways
  - The PCIC Design Value Explorer is one general tool that might be used
  - It incorporates an understanding of the assessments of projected climate change and provides engineers with information about how “climatic loads” needed to apply the National Building Code of Canada are projected to change.

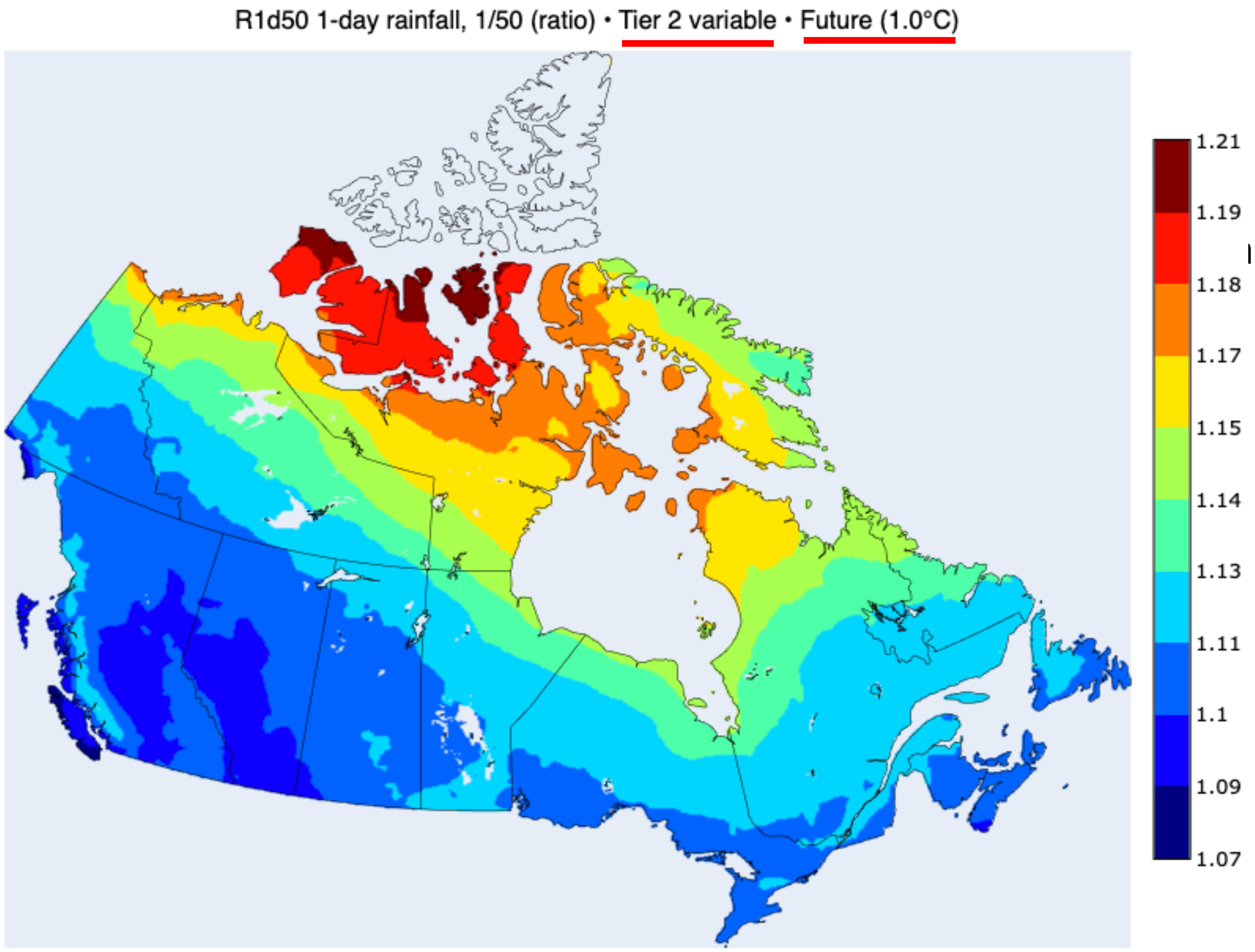
Historical magnitude of 50-year 1-day rainfall event



Infrastructure design is a risk management exercise

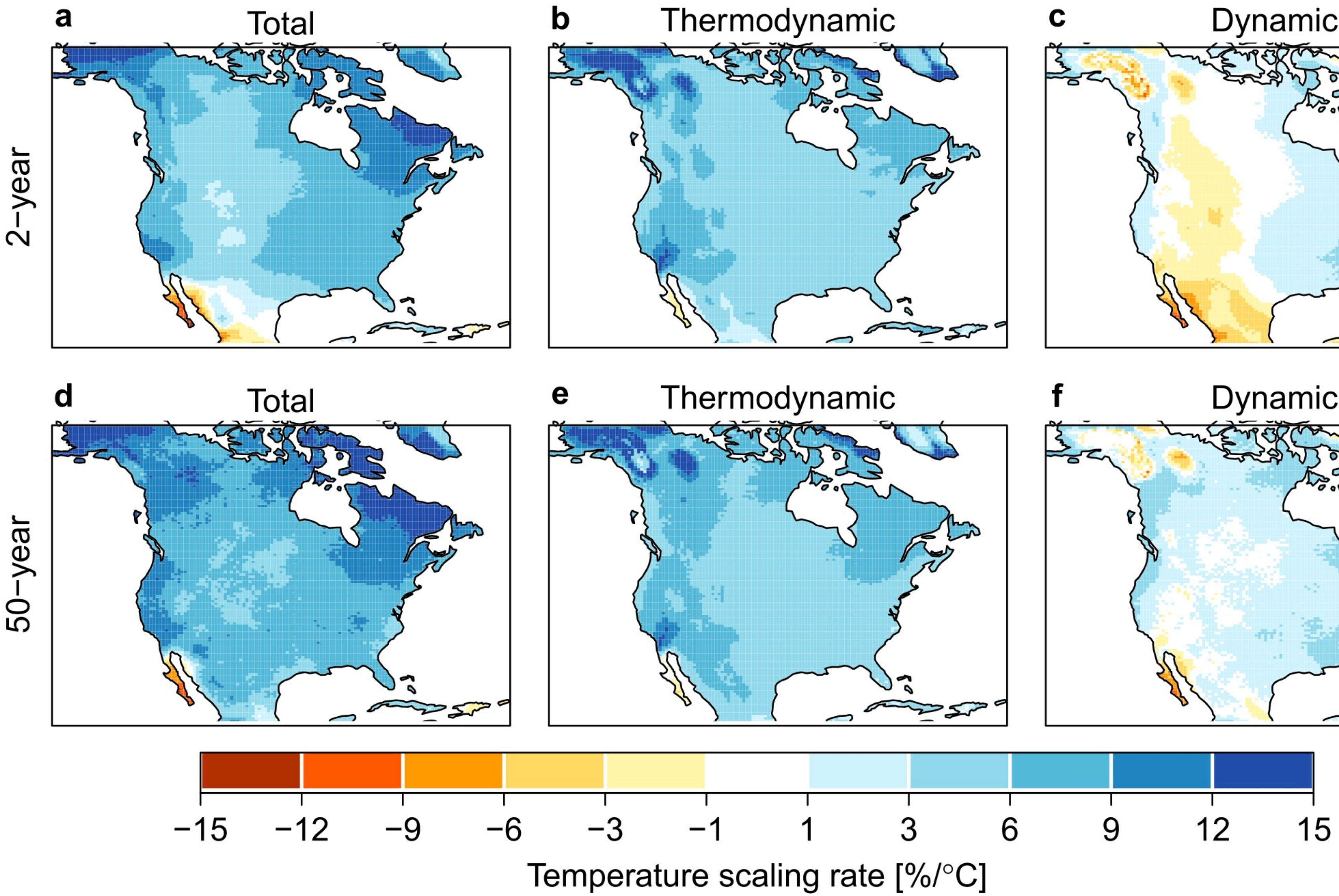
Future design values

- DVE provides change factors that can be used to modify historical design values
- Given as a function of the level of global warming above the 1986-2016 mean
- The change factor is multiplicative for the 50-year 1-day rainfall amount (a “Tier 2” variable) and is based on Clausius-Clapeyron temperature scaling



The DVE assumes Clausius-Clapeyron temperature scaling

The response of extreme 6-hourly precipitation to warming in CanRCM4 (35-member ensemble, 1981-2100 under RCP8.5)



Li et al., 2019

Historical and future ENSO impact on 20-year Rx1day

- Based on CESM2, 50-member ensemble, SSP3-7.0, 2050-2099 vs 1950-1999

El Nino / La Nina intensity difference

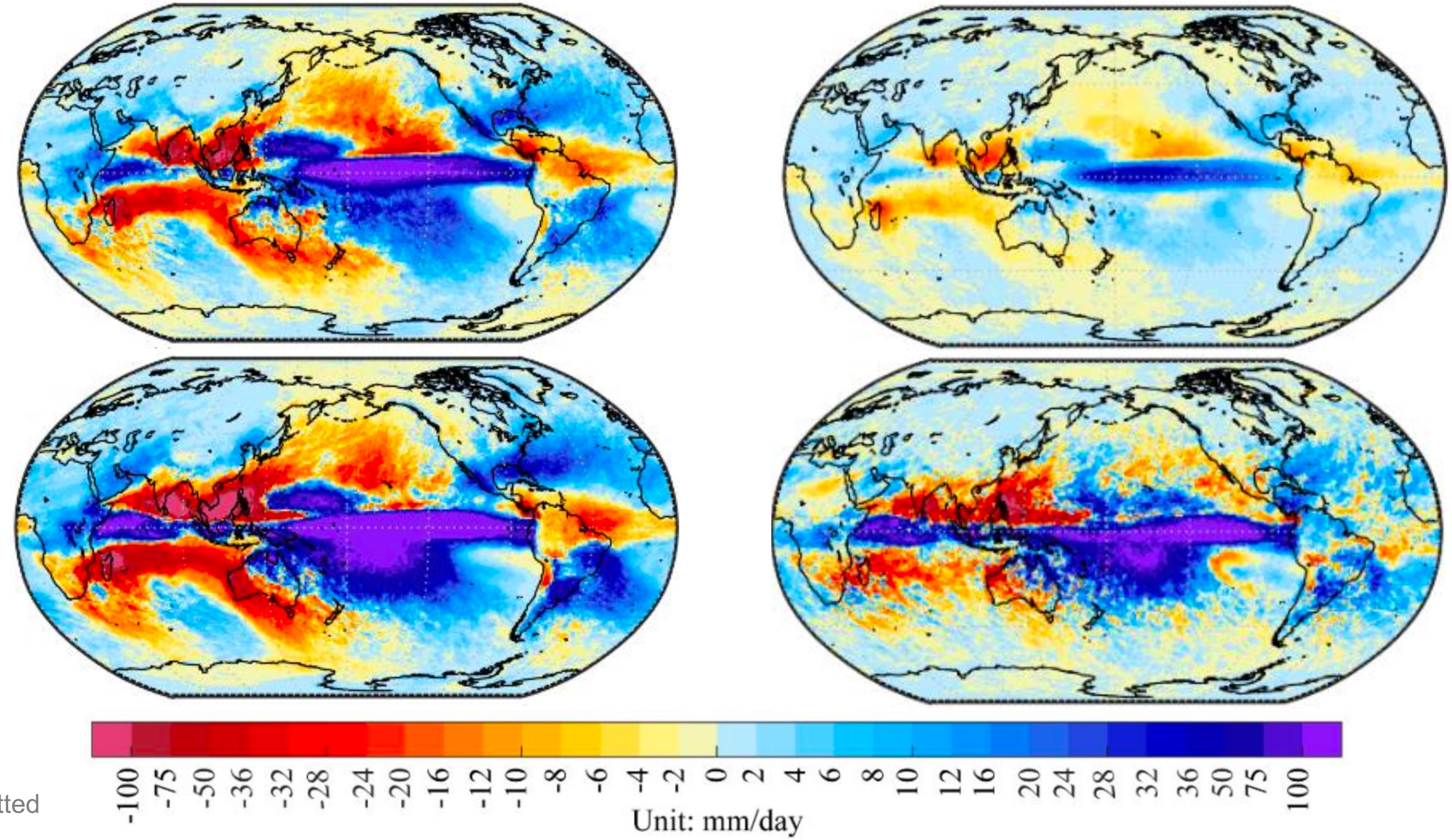
Change in ENSO impact

1950-1999

2050-2099

Thermo-dynamic component

Dynamic component



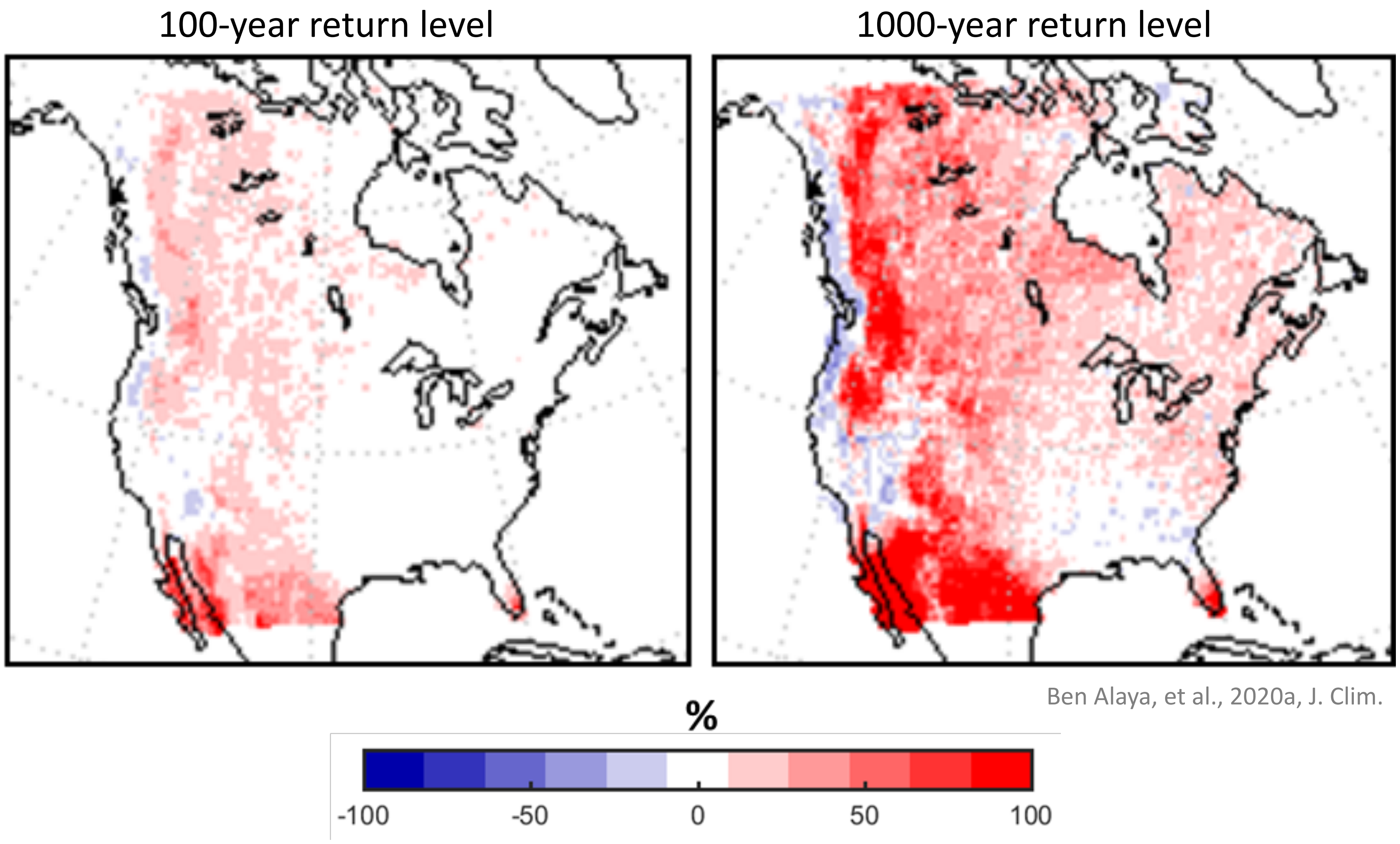
Sun et al., 2022, submitted

Infrastructure design is a risk management exercise

- Also need to look “forward” by considering the likelihood of very rare, very high impact, events (e.g., very long return period events)
- Most climate change assessments deal with ordinary, frequently occurring extremes (e.g., 20- or 50-year Rx1day events)
  - We have at least some observational data covering that length of period
  - Don’t need to extrapolate substantially beyond the available data
  - More confident that climate models represent at least some of the relevant processes
- But … critical infrastructure needs to be resilient to much rarer events corresponding to return periods of 1000’s of years
  - Hospitals, other key public buildings, dams and spillways, communications systems, power grid, etc.
- Can we rely on standard tools, and if not, how do we get that information?

Relative bias of extreme quantile estimates

Relative bias in extreme quantiles of CanRCM4 simulated 1-hour precipitation accumulations for 1951-2000 based on fitting a Generalized Extreme Value (GEV) distribution to 1750 annual extremes for 1951-2000

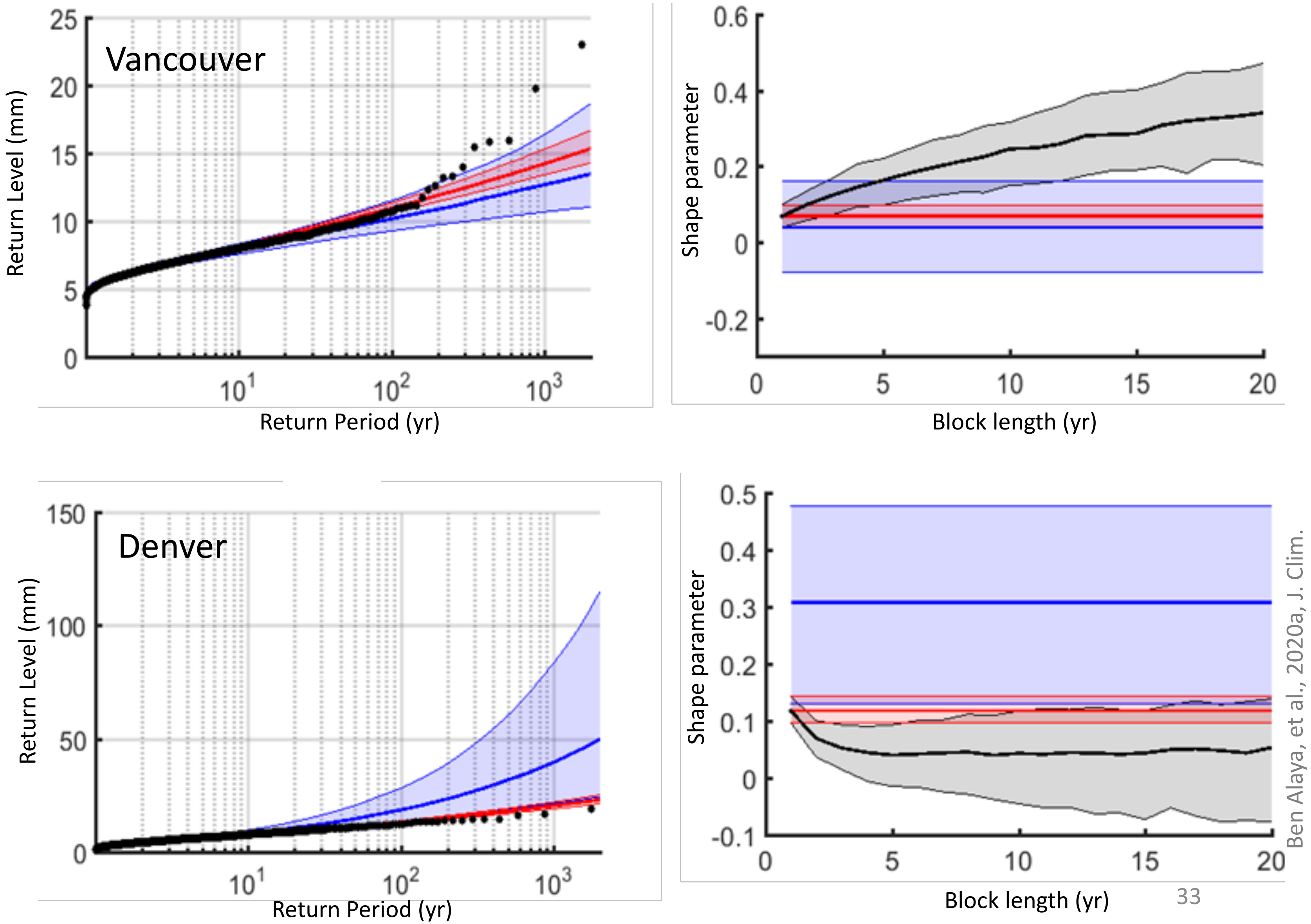


Ben Alaya, et al., 2020a, J. Clim.

GEV fits to block maxima at two locations

Extreme quantiles based on 1750-years of CanRCM4 simulated 1-hour precipitation accumulations for 1951-2000

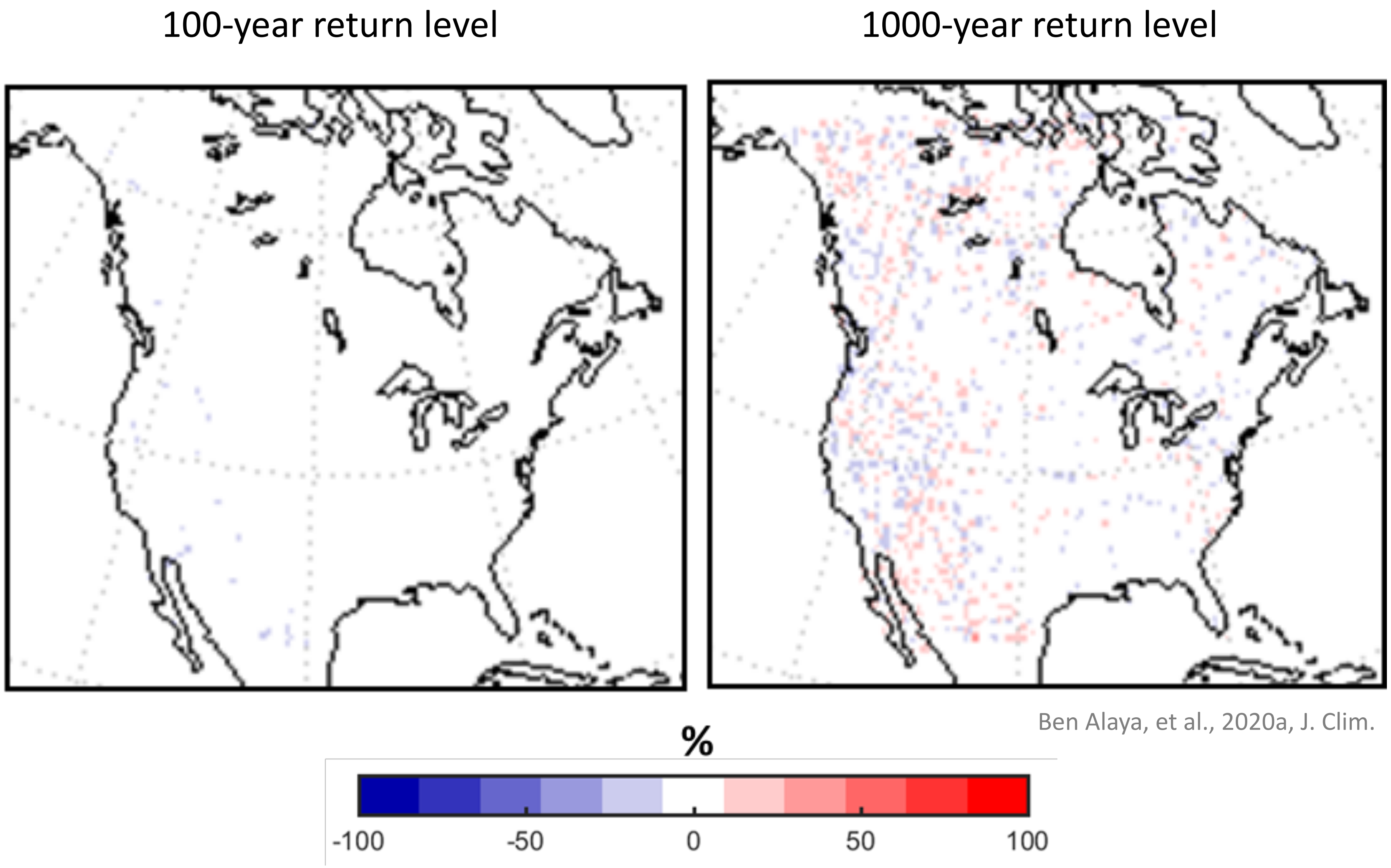
- Empirical distribution from 1750 annual maxima
- GEV from 50 annual maxima
- GEV from 1750 annual maxima
- GEV from 1 to 20 year block maxima



Ben Alaya, et al., 2020a, J. Clim.

Relative bias of extreme quantile estimates

Relative bias in extreme quantiles of CanRCM4 simulated 1-hour precipitation accumulations for 1951-2000 based on fitting a GEV distribution to 175 decadal extremes for 1951-2000



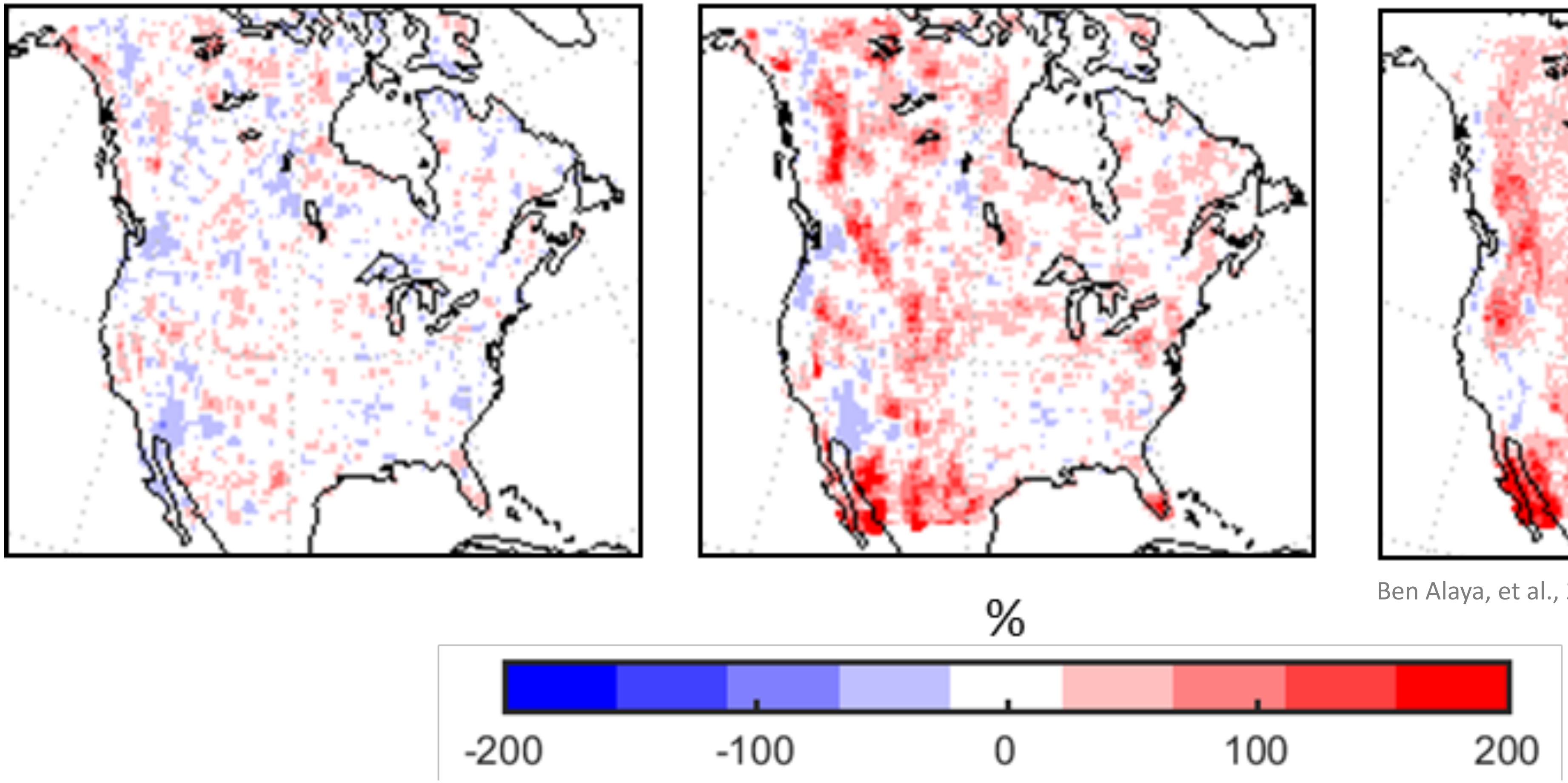
Ben Alaya, et al., 2020a, J. Clim.

Relative bias in 1000-year return level estimates for 6-hourly accumulations in CanRCM4 (1951-2000)

Compound Approach (50-year sample of precip components

Univariate Approach (50-year sample of annual maxima)

Univariate Approach (1750-year sample of annual maxima)



Ben Alaya, et al., 2020b, Weather and Climate Extremes

Challenges

Trout Creek #5 Bridge, Moores Mill, NB

Some risk quantification (and mitigation) challenges

- Objectively distinguish between the impact of changes in the climate hazard and the impact of changes in vulnerability
- Better quantify how the climate hazard changed over the last 50+ years
  - There are substantial data, climate model and analysis technique limitations
  - Yet, there is a demand for specificity (questions tend to be local)
  - And, we are increasingly asked to extrapolate far into the upper tail
- Better quantify how the climate hazard change over the next 50+ years
  - Projections indicate risks will increase, but confidence in the details remains low
  - Convection permitting models may offer a path forward, but are VERY expensive
- Develop adaptation strategies for non-stationary climate conditions
  - Engineering practice, for example, seems not to be ready

Some relatively low-hanging fruit

- Extend ”emergent constraints” to extreme precip (Li et al., 2023, in prep)
- Invest more deeply in learning to use products already available – we can’t afford not to use available information because we don’t know how
  - Assessments to assess what is known robustly (harder for smaller areas)
  - For each product, develop an understanding of its “skillful” scale (old idea)
  - Work with users to learn how to use information that is available at that scale
  - Improve understanding of processes and scaling properties, including the relationship between point scales and those that are skillfully resolvable in models
- In parallel with model improvements, continue to develop statistical and AI-based downscaling techniques and convection permitting model emulators

Questions

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Sundown over Juan de Fuca Strait, Shirley, British Columbia. Photo: Francis Zwiers