What can we learn from millennial-scale climate simulations about temperature extremes?

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Data Science: Theory Applications

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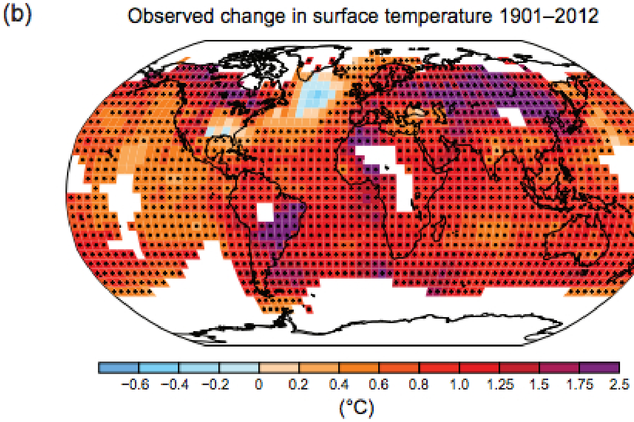
WILLIAM & MARY

Outline

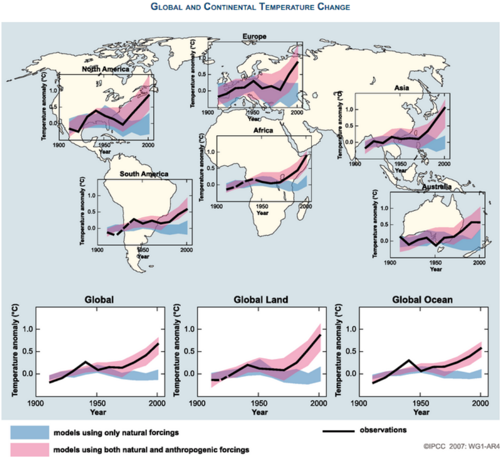
Intergovernmental Panel on Climate Change (IPCC) findings

"Warming of the climate system is unequivocal." – IPCC AR4



IPCC findings: human influence on climate change

"Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations" – IPCC AR4



Extremes in a changing climate

> "The climate change has begun to affect the frequency, intensity, and duration of extreme events such as extreme temperatures, extreme precipitation, etc" – IPCC AR4, IPCC SREX

Question:
how temperature extremes might change under future climate conditions?

We use climate models along with statistical approaches to this inquiry in simplified settings

Climate modeling 101

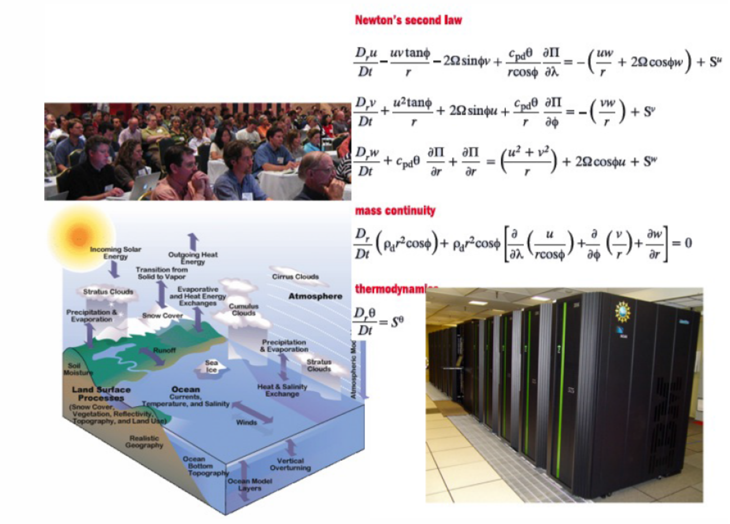


Figure: Slide courtesy of Steve Sain

Climate modeling 101

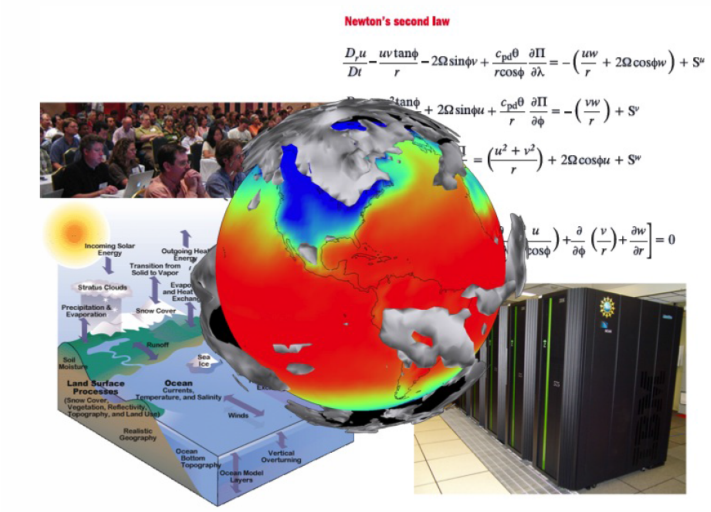
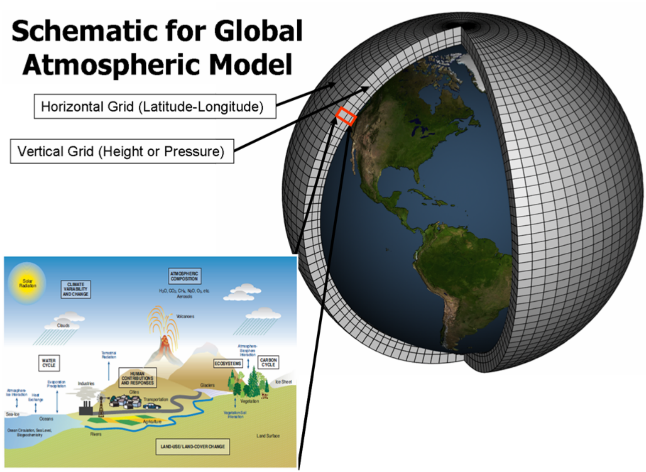


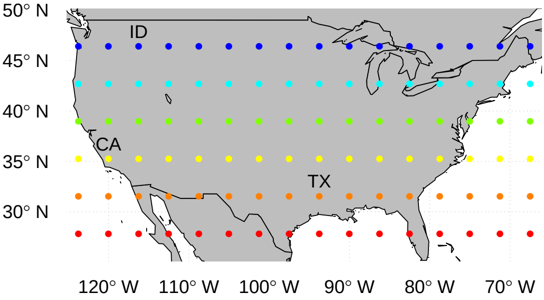
Figure: Slide courtesy of Steve Sain

Atmosphere-Ocean General Circulation Models (GCMs)



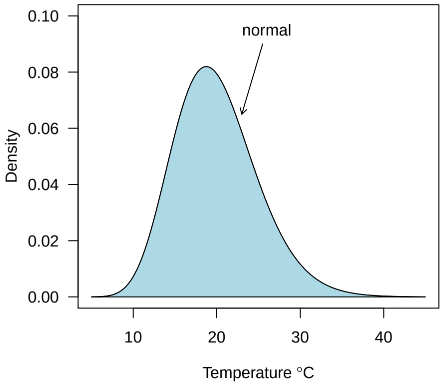
This project

- **Data**: 1000-year CCSM3 (a NCAR GCM model) runs, fully equilibrated pre-industrial and future (700 ppm $\mathrm{CO_2}$) conditions
- **Method**: fit generalized extreme value (GEV) distribution to annual maxima/minima daily temperatures, compute the changes in return levels



Outline

Normal distribution for sample averages

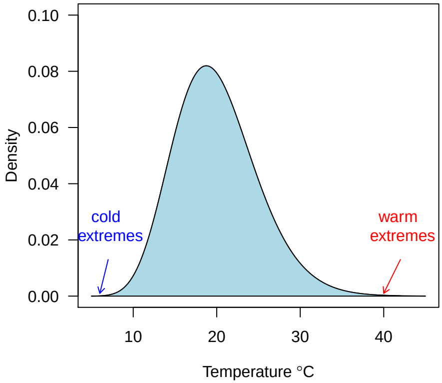


If $Y_1, Y_2, \cdots, Y_n$ is a random sample from a underlying distribution, then (under some mild conditions)

$$\bar{Y}_n = \frac{1}{n}\sum_{i=1}^{n} Y_i \approx N(\mu, \frac{\sigma^2}{n})$$

- μ: population mean
- σ^2: population variance

Generalized extreme value (GEV) distribution for sample maxima/minima



If $Y_1, Y_2, \cdots, Y_n$ is a random sample, then

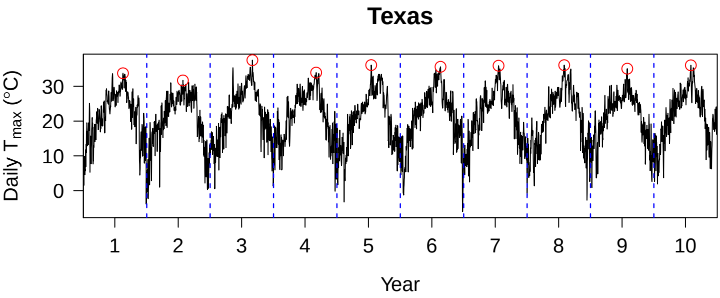
$$\max_{1 \leq i \leq n} Y_i \approx \text{GEV}(\mu_{(n)}, \sigma_{(n)}, \xi)$$

- $\mu_{(n)}$: location, describe the "center" of extremes
- $\sigma_{(n)}$: scale, describe the "spread" of extremes
- ξ: shape, describe the tail "heaviness" of extremes

Model "block extremes" as GEV distributions

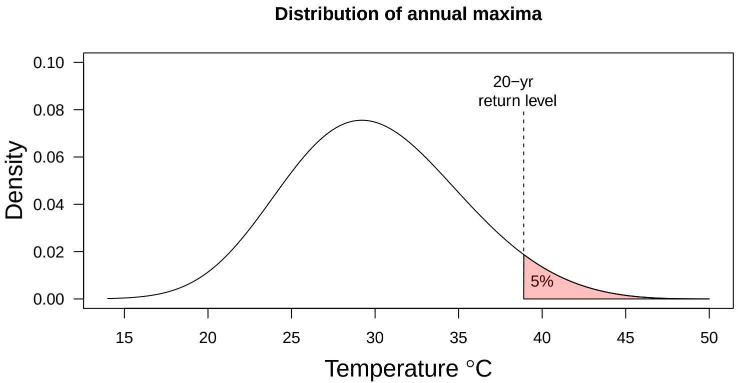
- Determine the block size and compute maxima/minima for blocks
- Fit the GEV to the block maxima/minima

Example: annual maximum temperature



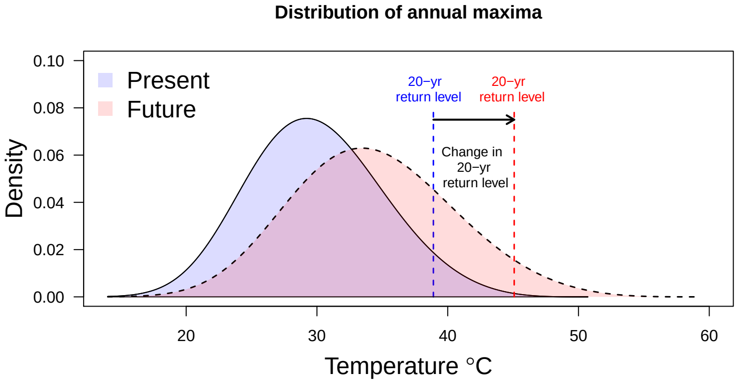
Return levels

***r*-year return level**: the magnitude of a rare event exceeded on average once per *r* years

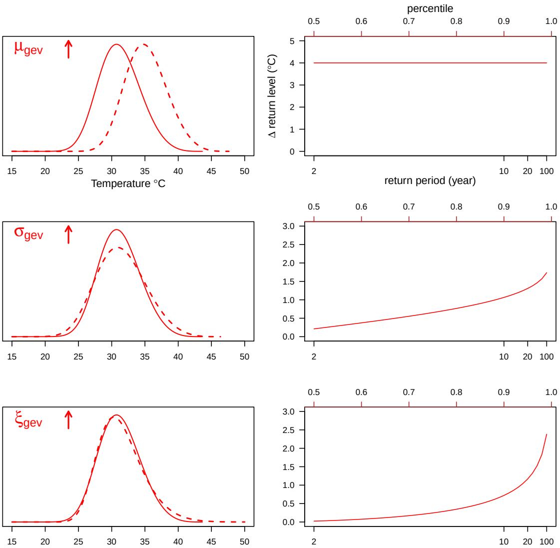


Changes in extremes

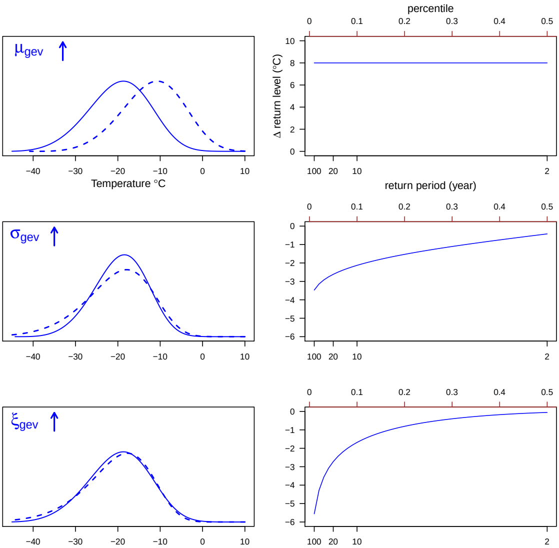
Changes in extremes is usually summarized by changes in return levels



Changes in warm temperature extremes

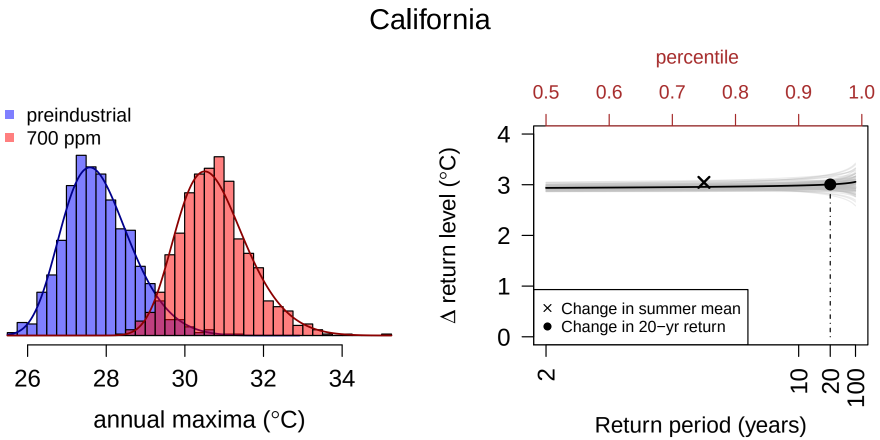


Changes in cold temperature extremes

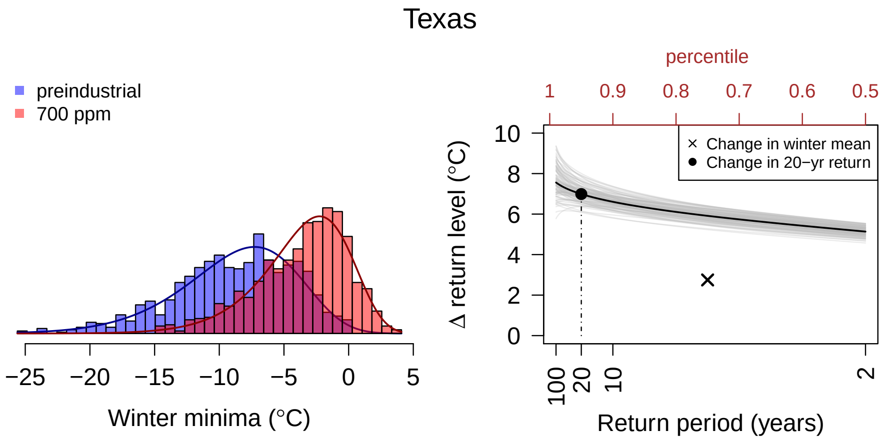


Outline

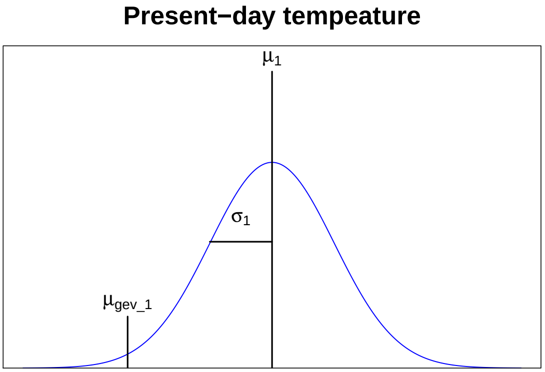
Summer warm extremes shift with means



Winter cold extremes shift more than means with changes in spread



Can cold extreme shifts be explained by changes in mean/standard deviation of overall distribution?



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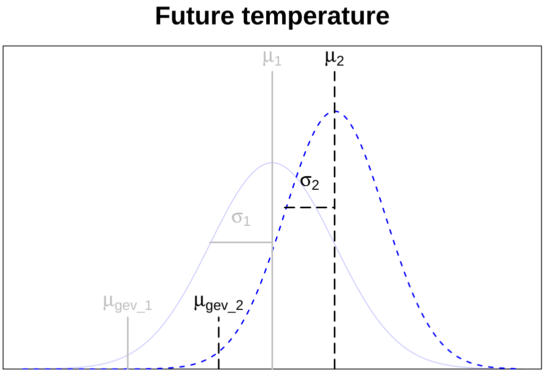

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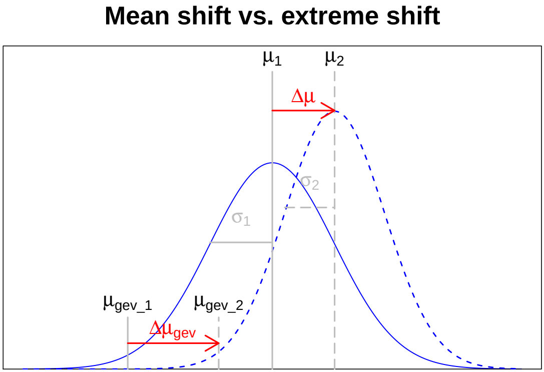
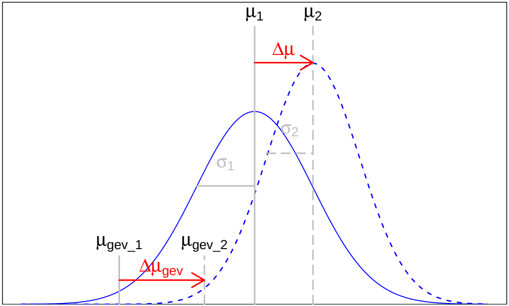


Reduced wintertime variability would increase shift of cold extremes

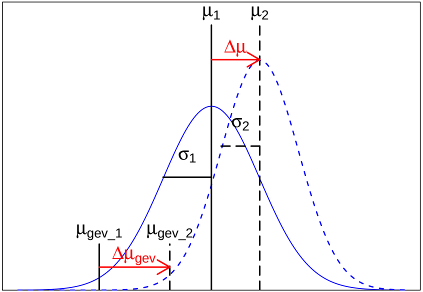


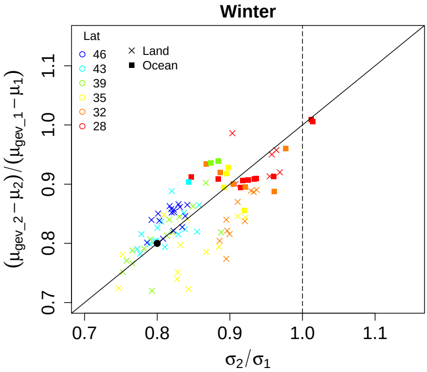
If all the changes from present to future are due to mean/standard deviation (i.e. $T_2 = \alpha + \beta T_1$), then

$$\frac{\mu_{\text{gev\_2}} - \mu_2}{\mu_{\text{gev\_1}} - \mu_1} = \frac{\sigma_2}{\sigma_1}$$

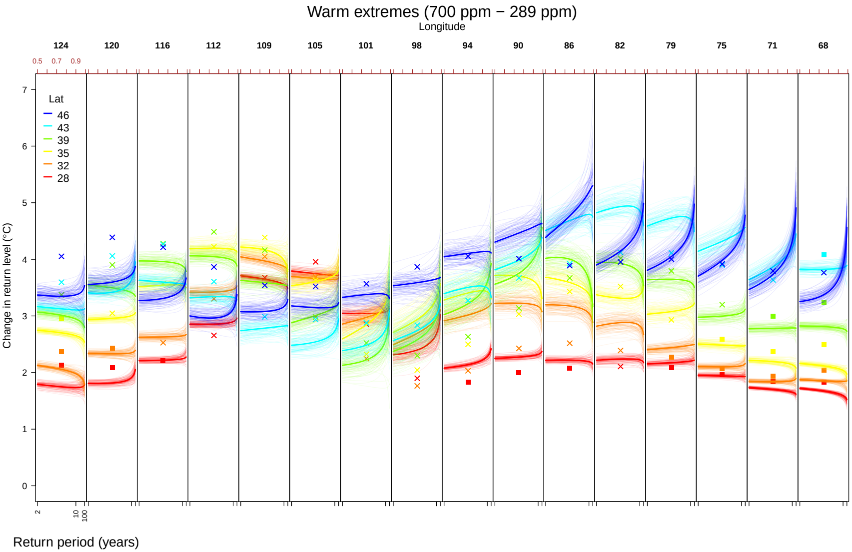
Warmer winter cold extremes largely explained by changes in overall distribution

1. Plot $\frac{\mu_{gev\_2} - \mu_2}{\mu_{gev\_1} - \mu_1}$ vs. $\frac{\sigma_2}{\sigma_1}$
2. 1:1 line: extreme shifts only due to overall mean/variance changes

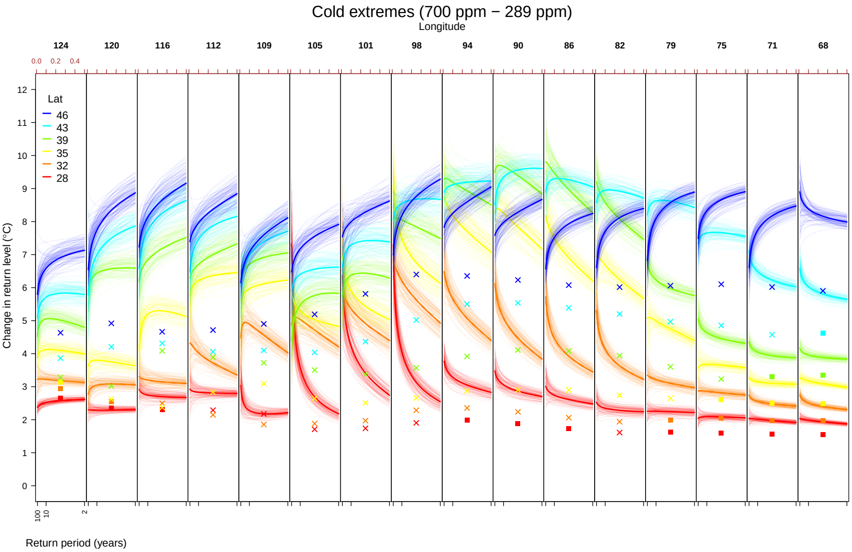




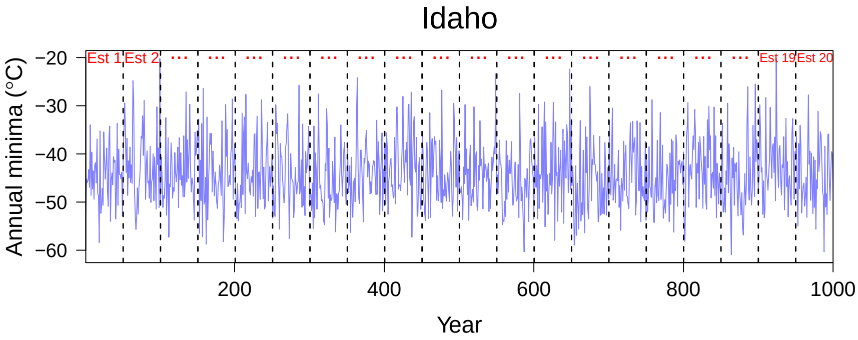
Changes in U.S. warm extremes



Changes in U.S. cold extremes



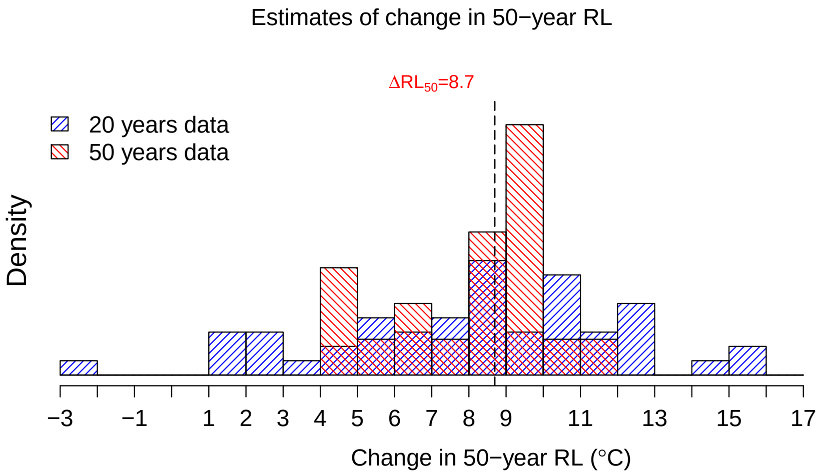
How well can we estimate the changes with shorter runs or data?



We assess this by

1. divide the time series into segments (e.g. 50-year)
2. redo the analysis to each segment, compare the results with the "ground truth"

Sampling error is large for short runs



Summary and discussion

- Warm extremes: mainly due to the summer mean shifts
- Cold extremes: shifts larger than the winter mean shifts, but are largely explainable by mean shifts combined with reduced wintertime temperature variability.
- Sampling error is large for studying extremes in short datasets

Acknowledgments

- RDCEP: Center for Robust Decision Making on Climate and Energy Policy

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