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

Whitney Huang[1]
Joint work Michael Stein[2], Elisabeth Moyer[2], Shanshan Sun[2], and David McInerney[3]

Purdue University[1], University of Chicago[2], University of Adelaide[3]

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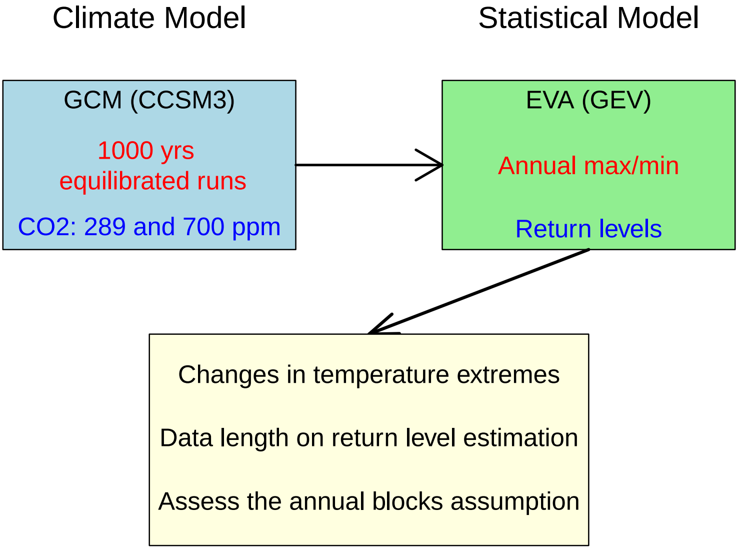
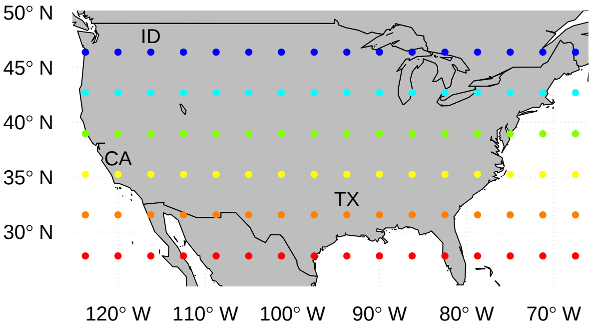
Overview


Climate Model
Statistical Model
GCM (CCSM3)
1000 yrs
equilibrated runs
CO2: 289 and 700 ppm
EVA (GEV)
Annual max/min
Return levels
Changes in temperature extremes
Data length on return level estimation
Assess the annual blocks assumption

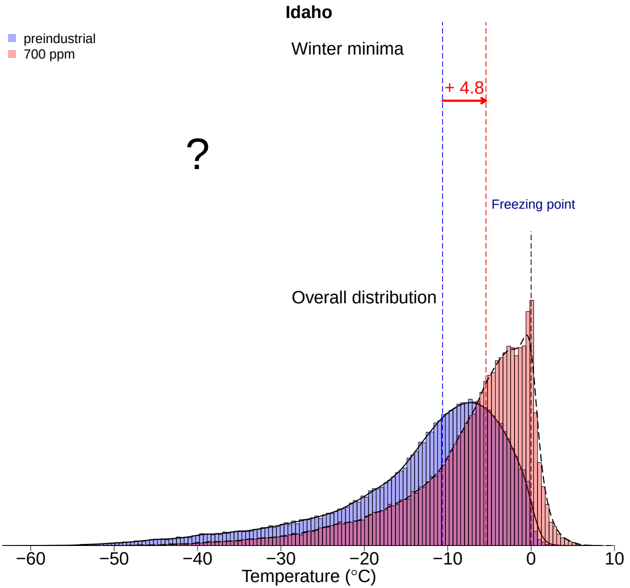
Our millennial-scale CCSM3 runs

- Fully equilibrated pre-industrial and future (700 ppm CO_2) climate simulations
- 1000-year daily output (T_{max}, T_{min}) ☺
- T31 spatial resolution (3.75°× 3.75° grid) ☹



Part 1: Changes in temperature extremes

Extremes may shift differently than means



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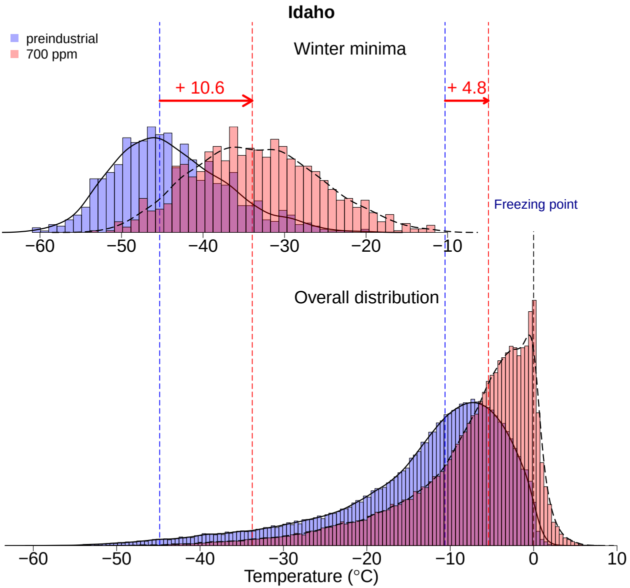
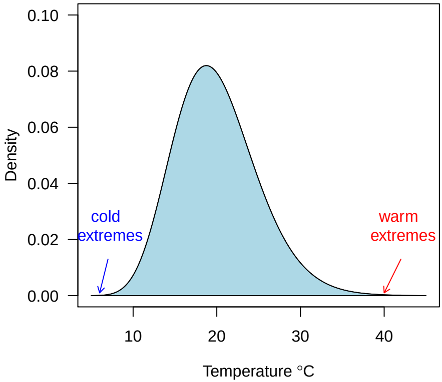


Generalized extreme value (GEV) distribution for sample maxima/minima



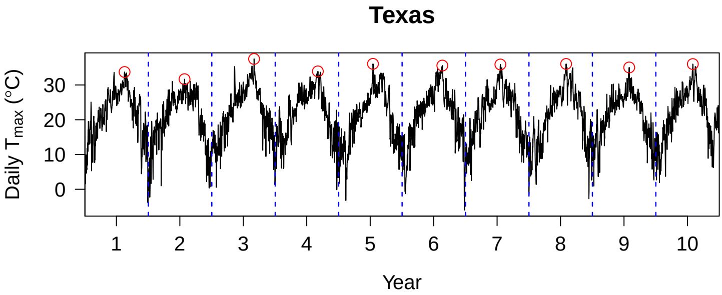
If $Y_1, Y_2, \cdots, Y_n$ is a random sample, then

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

- Location ($\mu_{(n)}$): the "center" of extremes
- Scale ($\sigma_{(n)}$): the "spread" of extremes
- Shape (ξ): the tail "heaviness" of extremes

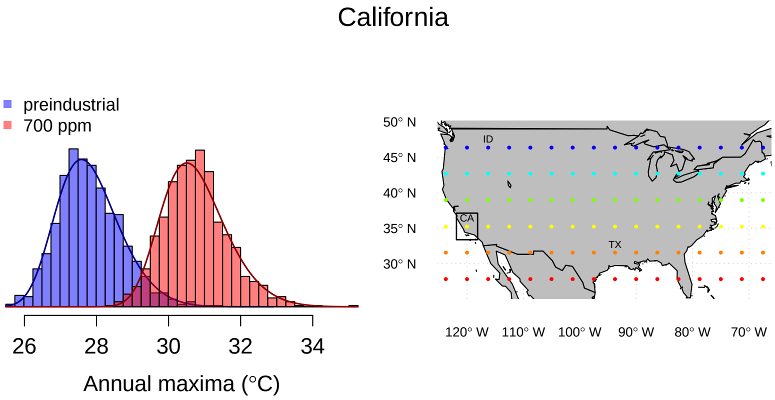
Model annual extremes as GEV distributions

- Example: annual maxima at Texas grid cell

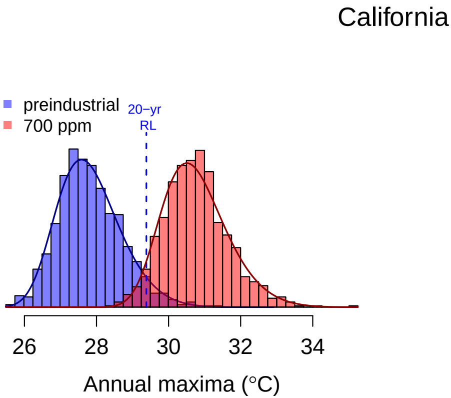


- Fit a $\text{GEV}(\mu, \sigma, \xi)$ distribution to annual max/min

Fit GEV to annual max

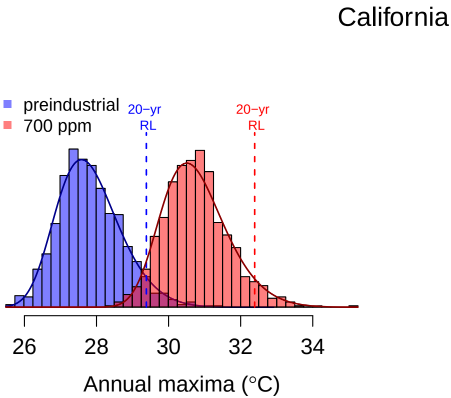


Compute the r-year return level for 289 ppm climate



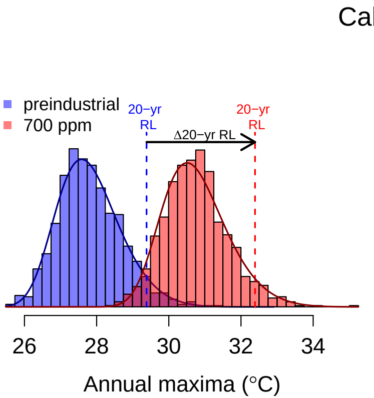
$$\hat{RL}_{20} = \hat{\mu}_0 - \frac{\hat{\sigma}_0}{\hat{\xi}_0}\left\{1 - \left(-\log\left(1 - 0.05\right)\right)^{-\hat{\xi}_0}\right\}$$

Compute the r-year return level for 700 ppm climate



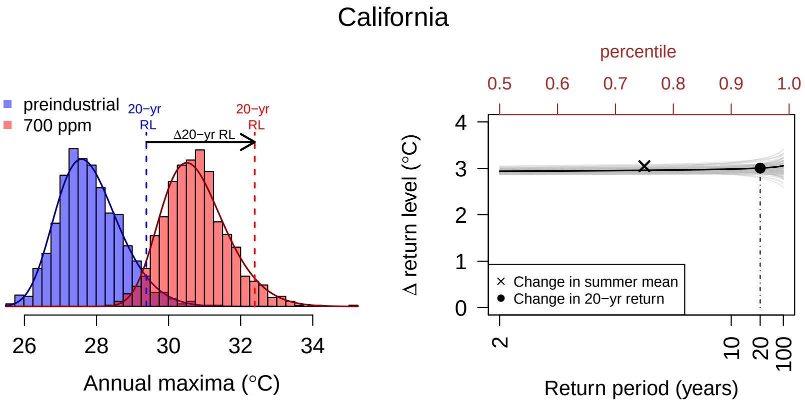
$$\hat{RL}_{20} = \hat{\mu}_1 - \frac{\hat{\sigma}_1}{\hat{\xi}_1}\left\{1 - \left(-\log\left(1 - 0.05\right)\right)^{-\hat{\xi}_1}\right\}$$

Compute the difference in r-year return level



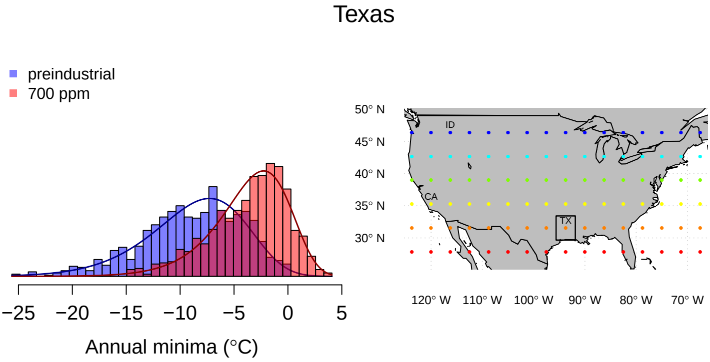
$$\Delta\text{20-yr RL} = \color{red}{\hat{RL}_{20}} - \color{blue}{\hat{RL}_{20}}$$

Warm extremes shift with summer means

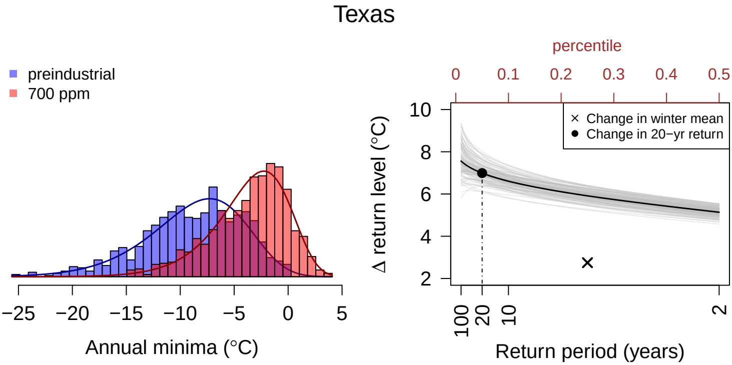


$$(\Delta\hat{\mu}, \Delta\hat{\sigma}, \Delta\hat{\xi}) = (2.9**, 0.02, 0.01)$$

Fit GEV to annual min

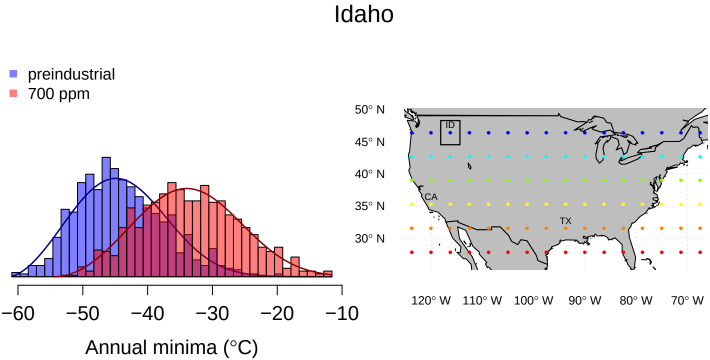


Cold extremes shift more than winter means



$$(\Delta\hat{\mu}, \Delta\hat{\sigma}, \Delta\hat{\xi}) = (4.8**, -1.1**, 0.05)$$

Fit GEV to annual min



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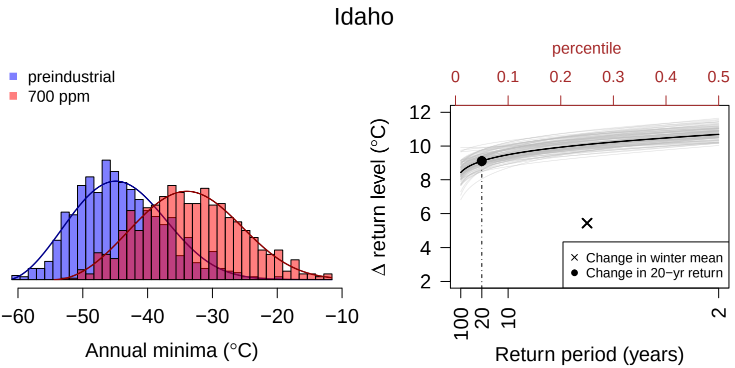
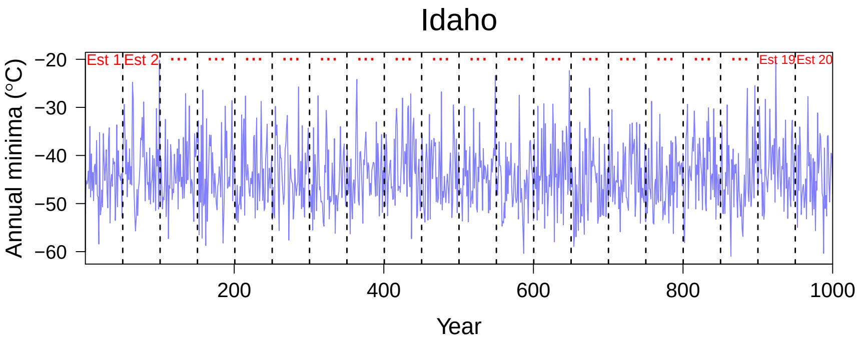


$$(\Delta\hat{\mu}, \Delta\hat{\sigma}, \Delta\hat{\xi}) = (11.0 **, 0.7 **, 0.03)$$

Part II: Data length on return level estimation

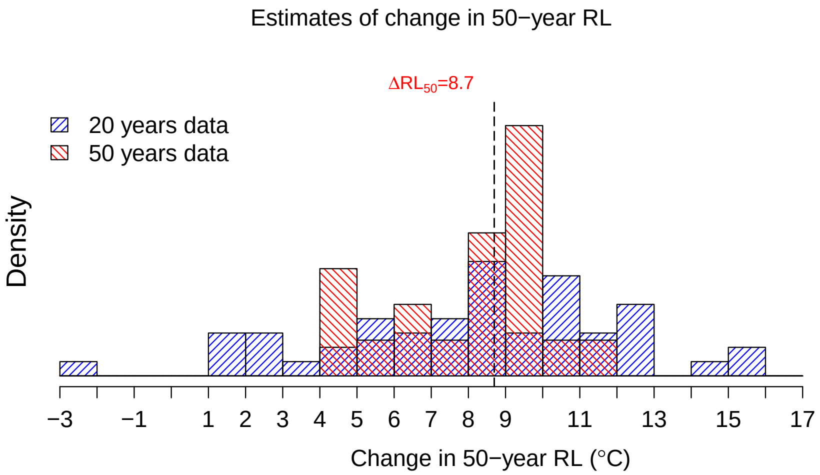
What if we have shorter runs or data?



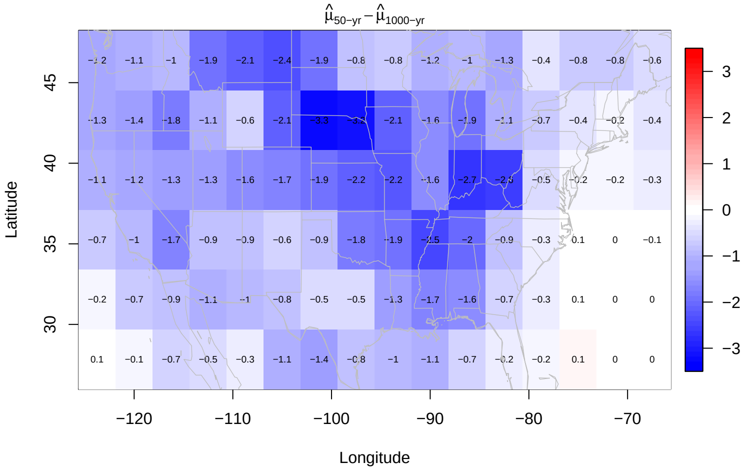
To assess the sampling error due to short runs

- divide the time series into segments
- refit GEV to each segment, compute the changes in return levels

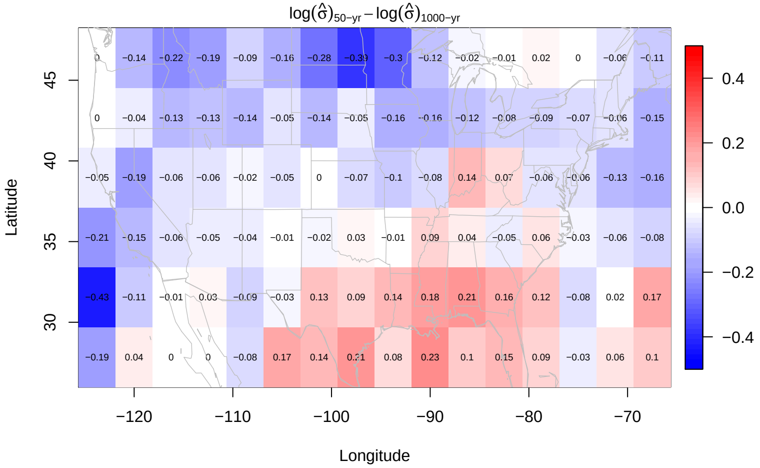
Sampling error is large for short runs



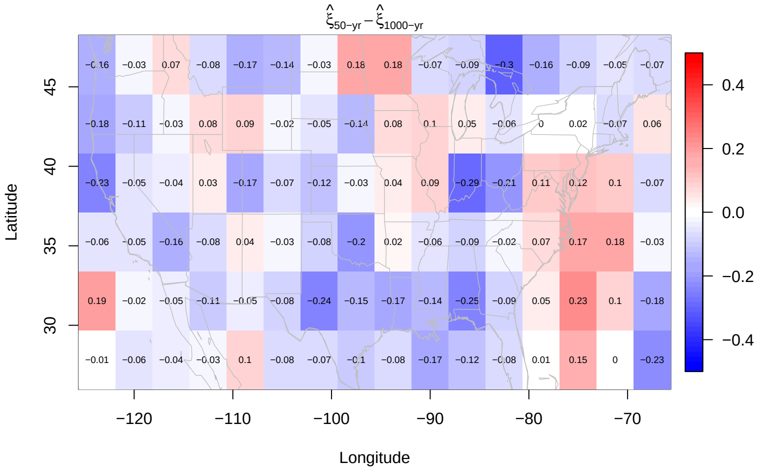
Sampling error: μ



Sampling error: $\log(\sigma)$



Sampling error: ξ



Part III: Is annual block size long enough?

GEV approximation to annual extremes

- Extremal Types Theorem: $X_1, \cdots, X_n \overset{\text{iid}}{\sim} F$, then

$$\frac{\max_{i=1}^{n} X_i - b_n}{a_n} \overset{n \to \infty}{\longrightarrow} G$$

- In practice: we assume annual extremes follow a GEV i.e. $\max_{t=1}^{365} Y_t \sim \text{GEV}(\mu_1, \sigma_1, \xi_1)$
- Question: Is annual block size long enough?

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Max-stability of GEV

- GEV is max-stable i.e.

$$G^k(a_k x + b_k) = G(x), \qquad \forall k \in \mathbb{N}$$

for some $a_k > 0$ and b_k

- Fit GEV to annual extremes and decadal extremes and compare their $\hat{\xi}$'s

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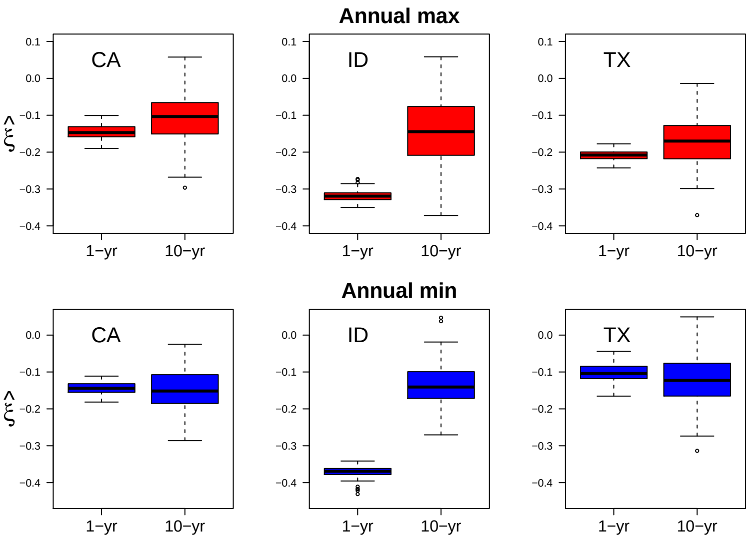
Idaho, we have a problem



Summary

Changes in temperature extremes (in our model runs)

- Warm extremes: mainly due to the summer mean shifts
- Cold extremes: shifts larger than the winter mean shifts, with some changes in spread/skewness

Data length on return level estimation

- Sampling error is large for studying extremes in short datasets

Acknowledgments

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