A comparison of U.S. precipitation extremes under two climate change scenarios

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September 2013 Boulder Flood (source: bouldercast.com)
Motivation

Global warming already driving increases in rainfall extremes
Precipitation extremes are affecting even arid parts of the world, study shows.

Climate Change Played Huge Role in Deadly Louisiana Flooding, Scientists Say
By John Upton  |  Published Sep 8 2016 11:57 AM EDT  |  Climate Central

Climate change raises flood risk, researchers say
By Richard Black
Environment correspondent, BBC News
Benefits of Reduced Anthropogenic Climate Change

We investigate two Representative Concentration Pathways (RCPs):

- **RCP8.5**: higher emissions (business-as-usual scenario)
- **RCP4.5**: lower emissions (moderate mitigation scenario)

BRACE\(^1\) explores avoided impacts in RCP4.5 vs. RCP8.5

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\(^1\)https://chsp.ucar.edu/brace-benefits-reduced-anthropogenic-climate-change
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A unique “dataset”

We use output from two initial condition ensembles conducted with NCAR’s Community Earth System Model (CESM):

- **Large Ensemble** of 30 runs under RCP8.5 for 2006-2100 (CESM-LE; Kay et al. 2014)
- **Medium Ensemble** of 15 runs under RCP4.5 for 2006-2080 (CESM-ME; Sanderson et al. 2015)
- Both ensembles use historical forcings for 1920-2005

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Fit nonstationary generalized extreme value (GEV) models to annual maximum daily precipitation simulated from CESM-LE (RCP8.5) and CESM-ME (RCP4.5) over the contiguous U.S.
Study objectives

- Fit nonstationary **generalized extreme value (GEV) models** to annual maximum daily precipitation simulated from CESM-LE (RCP8.5) and CESM-ME (RCP4.5) over the contiguous U.S.

- Compare impacts using the **1% annual exceedance probability (AEP) level**, which is the amount of daily rainfall with only a 1% chance of being exceeded in a given year.
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- Compare impacts using the **1% annual exceedance probability (AEP) level**, which is the amount of daily rainfall with only a 1% chance of being exceeded in a given year.

- Explore a **pattern scaling** approach for extremes.
Let $M$ be the random variable representing the annual maximum daily precipitation amount. We assume

$$P(M \leq y) = \exp \left[ - \left( 1 + \xi \frac{y - \mu}{\sigma} \right) \right]^{1/\xi}$$

The case of $\xi = 0$ is interpreted as the limit as $\xi \to 0$. 
GEV model

Let $M(s)$ be the random variable representing the annual maximum daily precipitation amount for grid cell $s$. We assume

$$P(M(s) \leq y) = \exp \left[ - \left( 1 + \xi(s) \frac{y - \mu(s)}{\sigma(s)} \right)^{-1/\xi(s)} + \right]$$

The case of $\xi(s) = 0$ is interpreted as the limit as $\xi(s) \to 0$. 
Let $M(s, t)$ be the random variable representing the annual maximum daily precipitation amount for grid cell $s$ and year $t$. We assume

$$P(M(s, t) \leq y) = \exp \left[ - \left( 1 + \xi(s) \frac{y - \mu(s, t)}{\sigma(s, t)} \right)^{-1/\xi(s)} \right]$$

The case of $\xi(s) = 0$ is interpreted as the limit as $\xi(s) \to 0$. 
Let $x(t)$ be the global mean temperature in year $t$. Let $M(s, t)$ be the random variable representing the annual maximum daily precipitation amount for grid cell $s$ and year $t$. We assume

$$P(M(s, t) \leq y) = \exp \left[ - \left( 1 + \xi(s) \frac{y - \mu(s, x(t))}{\sigma(s, x(t))} \right)^{-1/\xi(s)} \right]$$

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![Graph of Global Mean Temperature](image)
GEV model

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$$\mu(s, x(t)) = \mu_0(s) + \mu_1(s)(x(t) - x(2005)), \text{ and}$$

$$\phi(s, x(t)) := \log(\sigma(s, x(t))) = \phi_0(s) + \phi_1(s)(x(t) - x(2005))$$
GEV model

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$$\phi(s, x(t)) := \log(\sigma(s, x(t))) = \phi_0(s) + \phi_1(s)(x(t) - x(2005))$$

We fit separate models to CESM-LE (RCP8.5) and CESM-ME (RCP4.5).
Ensemble advantage

\[ \hat{\xi}(s) \]

Single ensemble member

All ensemble members
Ensemble advantage

\[ \hat{\xi}(s) \]

Single ensemble member

Single smoothed member (Tye & Cooley 2015)
Parameter estimates and SEs: $\mu_0$

(a) Parameter estimates

(b) Standard errors
Parameter estimates and SEs: $\mu_0, \mu_1$
Parameter estimates and SEs: $\phi_0$

(e) Parameter estimates map

(f) SEs map
Parameter estimates and SEs: $\phi_0, \phi_1$

Fix, Cooley, Sain, Tebaldi  
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Results

1% AEP level in 2005
1% AEP level in 2080 under RCP8.5
Results

Percentage change in 1% AEP level from 2005 to 2080 under RCP8.5
Results

Percentage change in 1% AEP level from 2005 to 2080 under RCP4.5
Results

Relative change in 2080 1% AEP level under RCP4.5 vs. RCP8.5
Q: What is extreme behavior under a different scenario?

A: Run GCM under the new scenario, apply extreme value methods to the new model output (e.g. precipitation maxima) and get answers. This is expensive.
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- Build a conditional extreme value model
Q: What is extreme behavior under a different scenario?

A2: Assuming covariate(s) adequate for describing behavior,
   
   - Build a conditional extreme value model
   - Run a cheap climate model to obtain covariate(s), e.g. global mean temperature, under the new scenario
Q: What is extreme behavior under a different scenario?

A2: Assuming covariate(s) adequate for describing behavior,
- Build a conditional extreme value model
- Run a cheap climate model to obtain covariate(s), e.g. global mean temperature, under the new scenario
- Apply conditional model to covariate(s) from new scenario
Q: What is extreme behavior under a different scenario?

A2: *Assuming covariate(s) adequate for describing behavior,*

- Build a conditional extreme value model
- Run a cheap climate model to obtain covariate(s), e.g. global mean temperature, under the new scenario
- Apply conditional model to covariate(s) from new scenario

The CESM-ME RCP4.5 runs allow us to evaluate pattern scaling, where the GEV model is fit only to RCP8.5 output.
Evaluating pattern scaling

(a) Map of the United States with color-coded data points indicating precipitation levels across different latitudes and longitudes.

(b) Graph showing the annual maximum daily precipitation (mm) with a density distribution curve.
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Fix MJ, Cooley DS, Sain SR, Tebaldi C (2016)
A comparison of U.S. precipitation extremes under RCP8.5 and RCP4.5 with an application of pattern scaling

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Bulletin of the American Meteorological Society 96(8):1333-1349

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Climatic Change doi:10.1007/s10584-015-1567-z

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Journal of Hydrology 530:15-23