Current Effects of Human-Induced Climate Change on California Drought

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Multivariate Assessment on 2011-2014 California Drought:

- Use historical observed *Precipitation* to characterize the 3-year CA drought

What is the *human-induced* climate change effect on California drought?

- Use *Precipitation* and *Soil Moisture* from historical CCSM4 simulations
Case 1: California Drought using Precipitation Observations

Data: from CA Climate Division Precipitation Data (Oct. 1895~ Sep. 2014)
A time series of 119-year record of water year (hereafter, WY, accumulated from Oct. to Sep. next year) anomalies (i.e., departures from the climatological mean value).

Figure 1 119-year Water Year Precipitation Anomaly
Case 1: Using observed *Precipitation* Anomalies

**Bivariate Analysis:** Drought Severity and Duration

**Define:**

*Drought Duration:* defined as the number of consecutive intervals (e.g., $d_i$ is no. of years) where anomalies remain below the threshold value (i.e., climatology mean of CA precipitation = 563 mm)

*Drought Severity:* defined as cumulative anomalies during a drought period,

\[ S_i = - \sum_{j=1}^{d_i} \text{Anomalies}_j \]

(note: the negative of anomalies is used in Case 1 for convenience)
Figure is from Mirabbasi 2012 paper

d_i = Duration
S_i = Severity
l_i = Interarrival time

Time
Total drought events in history are 30 events.
Case 1: Drought Severity and Duration using Precipitation Observations

Univariate: the current CA drought duration is 3 years (ranked 7th, Return Period = 19 yr)
the 3-year precipitation deficit is 522 mm (ranked 3rd, Return Period = 41 yr)

Figure 2 Univariate return period for drought duration (left) and severity (right) fitted to Gamma distribution
Assuming two variables (duration) and (severity) with cumulative distribution functions:

\[ F_X(x) = \Pr (X \leq x) \quad \text{and} \quad F_Y(y) = \Pr (Y \leq y) \]

the copula \( \mathcal{C} \) can be used to obtain their joint distribution function:

\[ F(x, y) = C(F_X(x), F_Y(y)) \]

<table>
<thead>
<tr>
<th>Copula</th>
<th>Formula</th>
<th>Parameter Constraints</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gaussian</td>
<td>( \Phi_G[\Phi^{-1}(u_1), \Phi^{-1}(u_2); \theta] )</td>
<td>(-1 &lt; \theta &lt; +1)</td>
<td>( \frac{2}{\pi} \arcsin(\theta) ), ( \frac{6}{\pi} \arcsin\left(\frac{\theta}{2}\right) )</td>
</tr>
<tr>
<td>Clayton</td>
<td>( (u_1^{-\theta} + u_2^{-\theta} - 1)^{-1/\theta} )</td>
<td>( \theta \in (0, \infty) )</td>
<td>( \frac{\theta}{\theta + 2} )</td>
</tr>
<tr>
<td>Frank</td>
<td>(-\frac{1}{\theta} \log \left( 1 + \frac{(e^{-\theta u_1} - 1)(e^{-\theta u_2} - 1)}{e^{-\theta} - 1} \right) )</td>
<td>( \theta \in (-\infty, \infty) )</td>
<td>( 1 - \frac{4}{\theta} [1 - D_1(\theta)] ), ( 1 - \frac{12}{\theta} [D_1(\theta) - D_2(\theta)] )</td>
</tr>
<tr>
<td>Ali-Mikhail-Haq</td>
<td>( u_1 u_2 (1 - \theta(1 - u_1)(1 - u_2))^{-1} )</td>
<td>(-1 \leq \theta \leq 1)</td>
<td>( (\frac{3\theta - 2}{\theta}) )</td>
</tr>
</tbody>
</table>

\( D_1(\theta) \) and \( D_2(\theta) \) are given by:

\[ D_1(\theta) = \frac{\theta}{\theta + 2} \quad \text{and} \quad D_2(\theta) = \frac{\theta}{\theta + 2} (\frac{3\theta - 2}{\theta}) \]
Case 1: Drought Severity and Duration using *Precipitation* Observations

**Bivariate Return Period**: Joint analysis of CA drought duration and severity using copulas

Figure 3 Joint return period of CA drought duration and severity
**Bivariate Return Period**: Joint analysis of CA drought duration and severity based on SPI

![Graph showing joint return period of CA drought duration and severity based on observed SPI18](image-url)

Figure 4 Joint return period of CA drought duration and severity based on observed SPI18
Multivariate Assessment on California Drought:

• Use *Precipitation* from Climate Division and CCSM4 simulations

What is the *human-induced* climate change effect on California drought?

• Use *Precipitation* and *Soil Moisture* from historical CCSM4 simulations
Two equilibrium runs with 2000-year monthly data

\[ \text{Y1850: preindustrial} \]

\[ \text{Y2000: industrial (current climate)} \]

<table>
<thead>
<tr>
<th>Climatology Mean (WY)</th>
<th>Temp</th>
<th>WY Prcp</th>
<th>SM 10cm</th>
<th>SM 1m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y1850</td>
<td>14.57 °C</td>
<td>762.31mm</td>
<td>22.31 kg/m²</td>
<td>218.87 kg/m²</td>
</tr>
<tr>
<td>Y2000 (warm wet)</td>
<td>16.22 °C</td>
<td>817.0 mm</td>
<td>22.33 kg/m²</td>
<td>220.39 kg/m²</td>
</tr>
<tr>
<td>Y2000-Y1850</td>
<td>1.65 °C</td>
<td>54.69 mm</td>
<td>0.02 kg/m²</td>
<td>1.52 kg/m²</td>
</tr>
</tbody>
</table>

Statistics of two runs:

- Soil moisture at 10cm is very close in Y1850 and Y2000
- Y2000 has more deep soil moisture than Y1850
Case 2: **Precipitation** and **Soil Moisture** (at 10cm) from Y1850 and Y2000

**Data:** simulated Precipitation and Soil Moisture at 10cm from CCSM4 Model
  two runs with 2000 period: Y1850: preindustrial; Y2000: industrial

**Bivariate Analysis:** 2~4-yr WY total prcp anomalies and WY averaged soil moisture anomalies (baseline is the climatology of Y1850).
Case 2: *Precipitation* and *Soil Moisture* (at 10cm) from Y1850 and Y2000

Figure 5 Joint return period of precipitation anomalies and SM anomalies at 10cm using Y1850 (black dots) and Y2000 (blue dots); joint contour line is based on Y1850
Case 3: **Precipitation** and **Soil Moisture** (at 1m) from Y1850 and Y2000

![Graph showing joint return period of precipitation anomalies and SM anomalies at 1m using Y1850 (black dots) and Y2000 (blue dots); joint contour is based on Y1850](Image)

Figure 6 Joint return period of precipitation anomalies and SM anomalies at 1m using Y1850 (black dots) and Y2000 (blue dots); joint contour is based on Y1850
Summary and Conclusions

• The 2011-2014 (3-year) CA drought is not an exceptional rare event from the bivariate perspective of duration and severity using precipitation, nor is the 2011-2015 (4-year) CA drought.

• Different land surface (soil moisture) responses to climate change:

1) Using a bivariate drought definition of 10-cm soil moisture and precipitation, droughts of all severities of the 1850-vintage become more frequent in the current climate.

2) Using a bivariate drought definition of 1-m soil moisture and precipitation, moderate-severe droughts of the 1850-vintage become less frequent in the current climate.
Figure 7 Joint return period of drought duration and severity; red dots are similar to observations