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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).

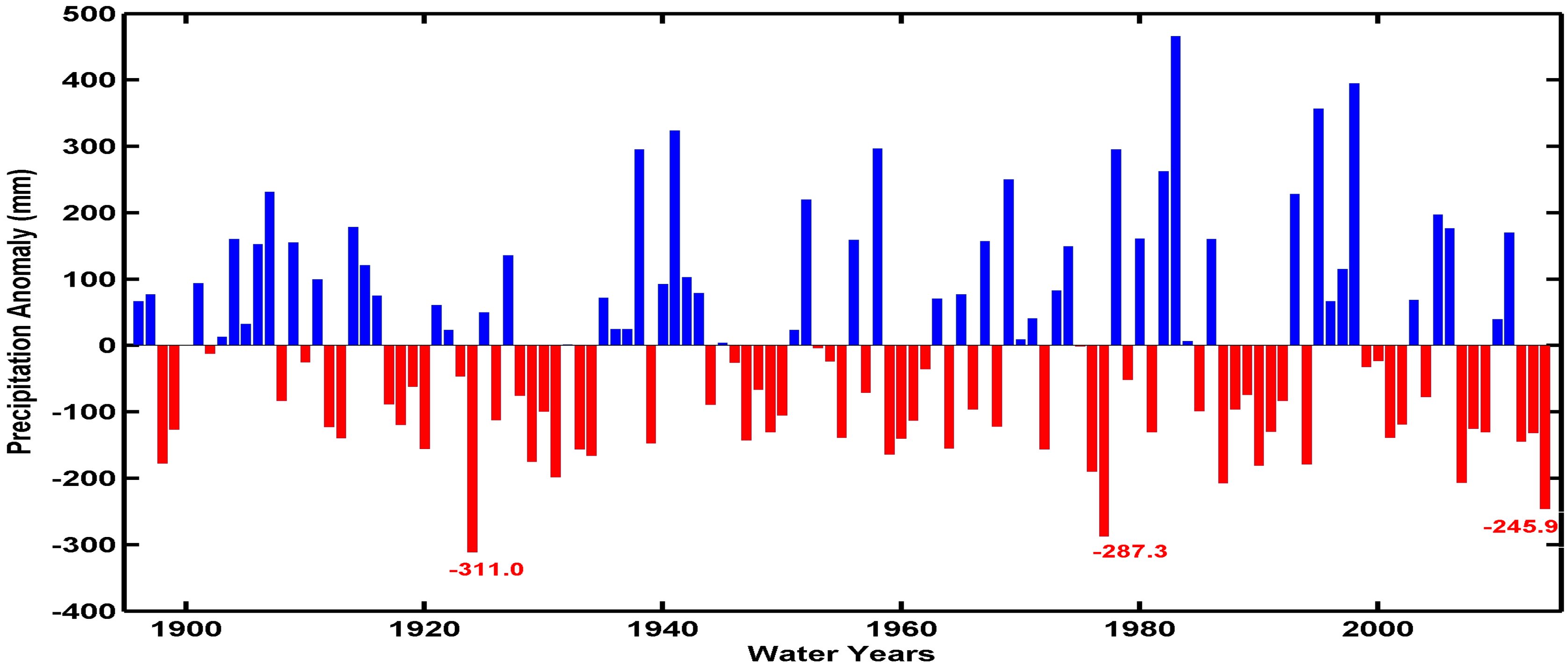


Figure 1 119-year Water Year Precipitation Anomaly

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,

i.e., $$S_i = -\sum_{j=1}^{d_i} Anomalies_j$$

(note: the negative of anomalies is used in Case 1 for convenience)

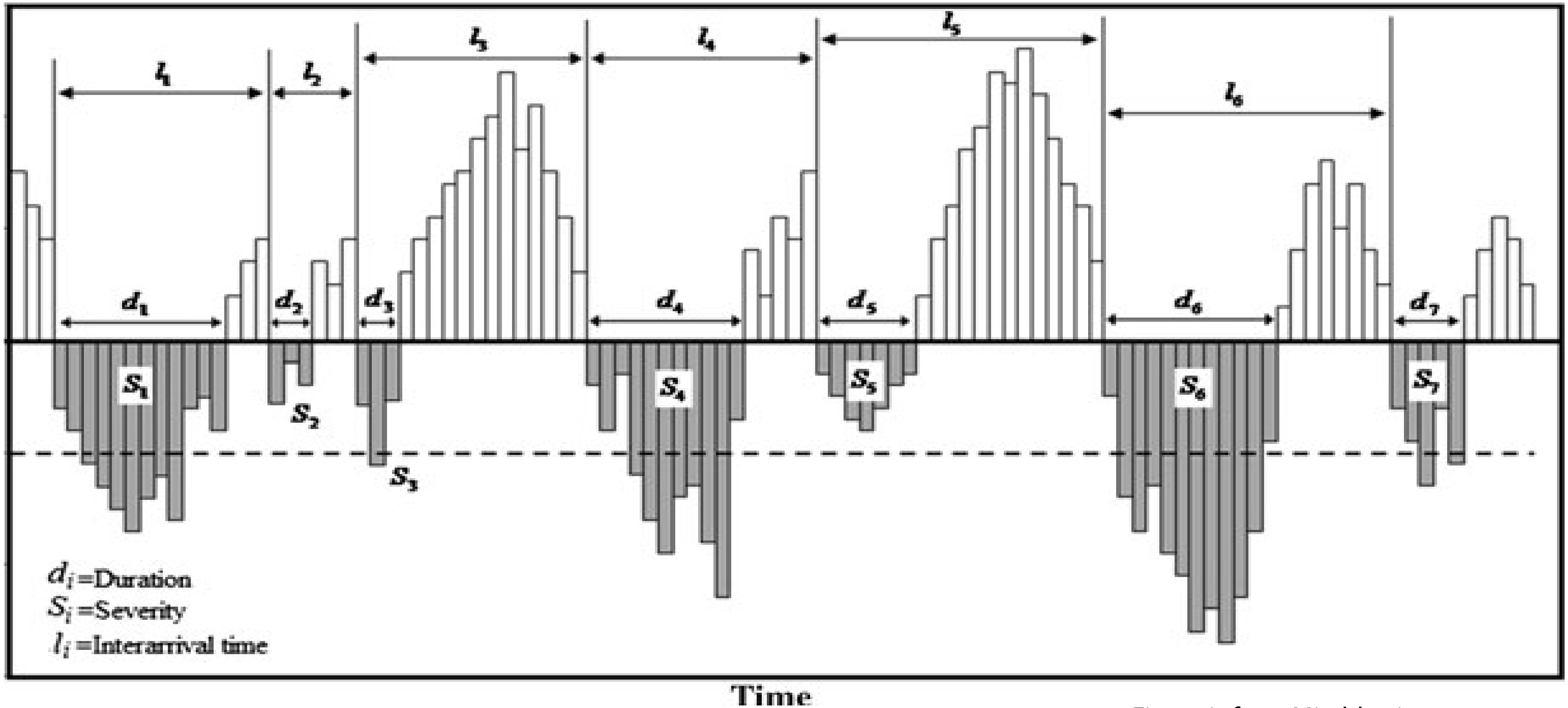
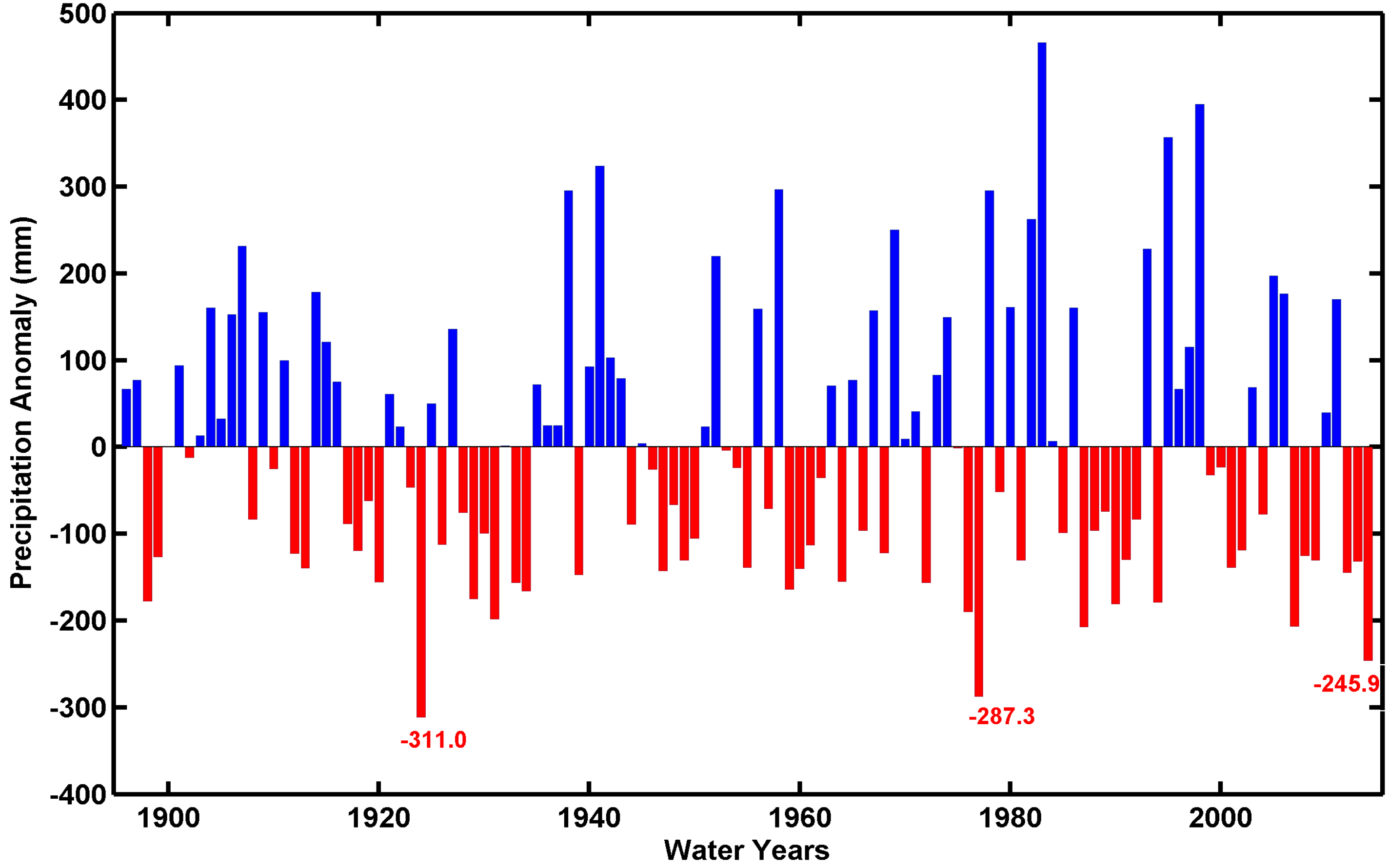


Figure is from Mirabbasi 2012 paper



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)

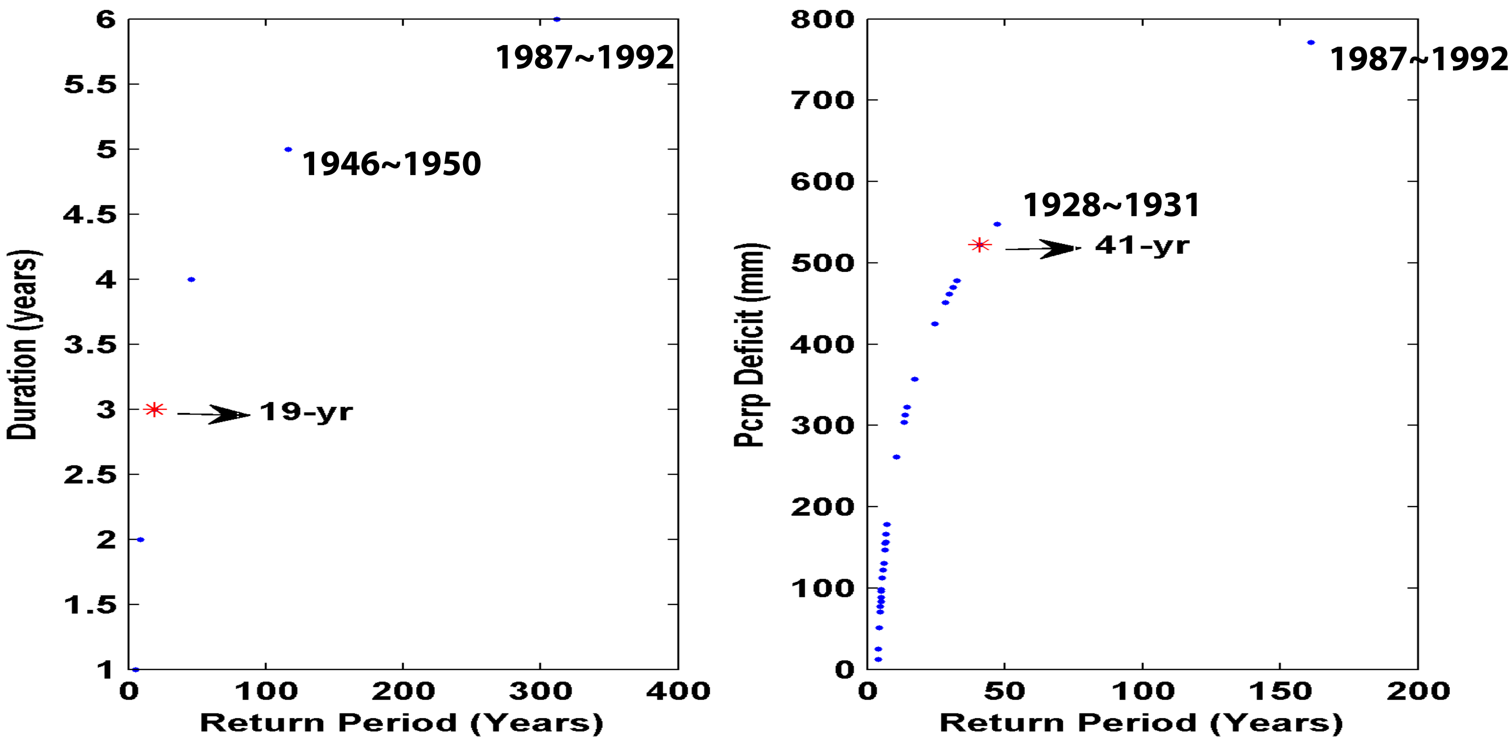


Figure 2 Univariate return period for drought duration (left) and severity (right) fitted to Gamma distribution

Assuming two variables X (duration) and Y (severity) with cumulative distribution functions:

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

the copula (C) can be used to obtain their joint distribution function:

$$F(x, y) = C\big(F_X(x), F_Y(y)\big)$$

Gaussian	$\Phi_G[\Phi^{-1}(u_1), \Phi^{-1}(u_2); \theta]$	$-1 < \theta < +1$	$\frac{2}{\pi}\arcsin(\theta)$	$\frac{6}{\pi}\arcsin(\frac{\theta}{2})$
Clayton	$(u_1^{-\theta} + u_2^{-\theta} - 1)^{-1/\theta}$	$\theta \in (0, \infty)$	$\frac{\theta}{\theta+2}$	*
Frank	$-\frac{1}{\theta}\log\left(1 + \frac{(e^{-\theta u_1} - 1)(e^{-\theta u_2} - 1)}{e^{-\theta} - 1}\right)$	$\theta \in (-\infty, \infty)$	$1 - \frac{4}{\theta}[1 - D_1(\theta)]$	$1 - \frac{12}{\theta}[D_1(\theta) - D_2(\theta)]$
Ali-Mikhail-Haq	$u_1 u_2 (1 - \theta(1 - u_1)(1 - u_2))]^{-1}$	$-1 \leq \theta \leq 1$	$(\frac{3\theta - 2}{\theta})$	*
			$-\frac{2}{3}(1 - \frac{1}{\theta})^2 \ln(1 - \theta)$	

Case 1: Drought Severity and Duration using ***Precipitation*** Observations

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

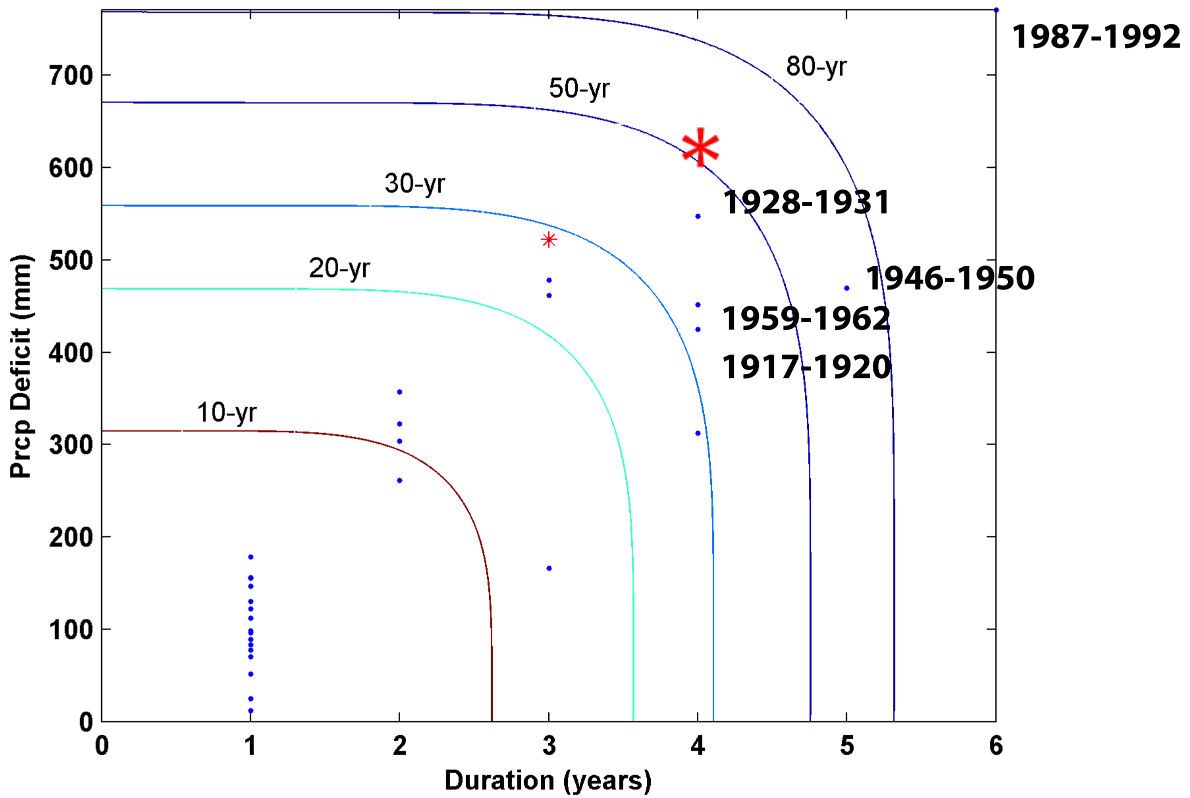


Figure 3 Joint return period of CA drought duration and severity

<u>Bivariate Return Period</u>: Joint analysis of CA drought duration and severity based on **SPI**

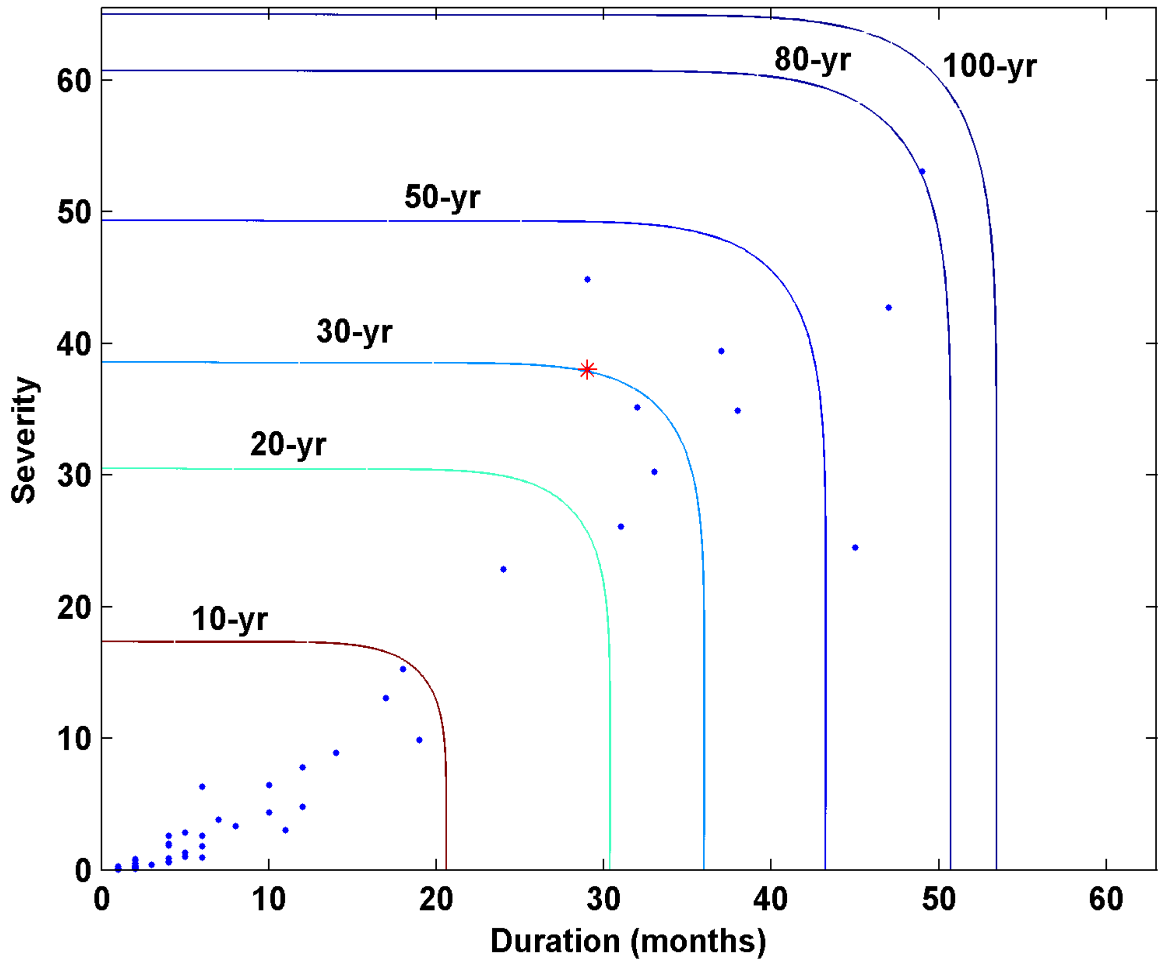


Figure 4 Joint return period of CA drought duration and severity based on observed SPI18

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 Y1850: preindustrial

Y2000 industrial (current climate)

Climatology Mean (WY)	Temp	WY Prcp	SM 10cm	SM 1m
Y1850	14.57 °C	762.31mm	22.31 kg/m^2	218.87 kg/m^2
Y2000 (warm wet)	16.22 °C	817.0 mm	22.33 kg/m^2	220.39 kg/m^2
Y2000-Y1850	1.65 °C	54.69 mm	0.02 kg/m^2	1.52 kg/m^2

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

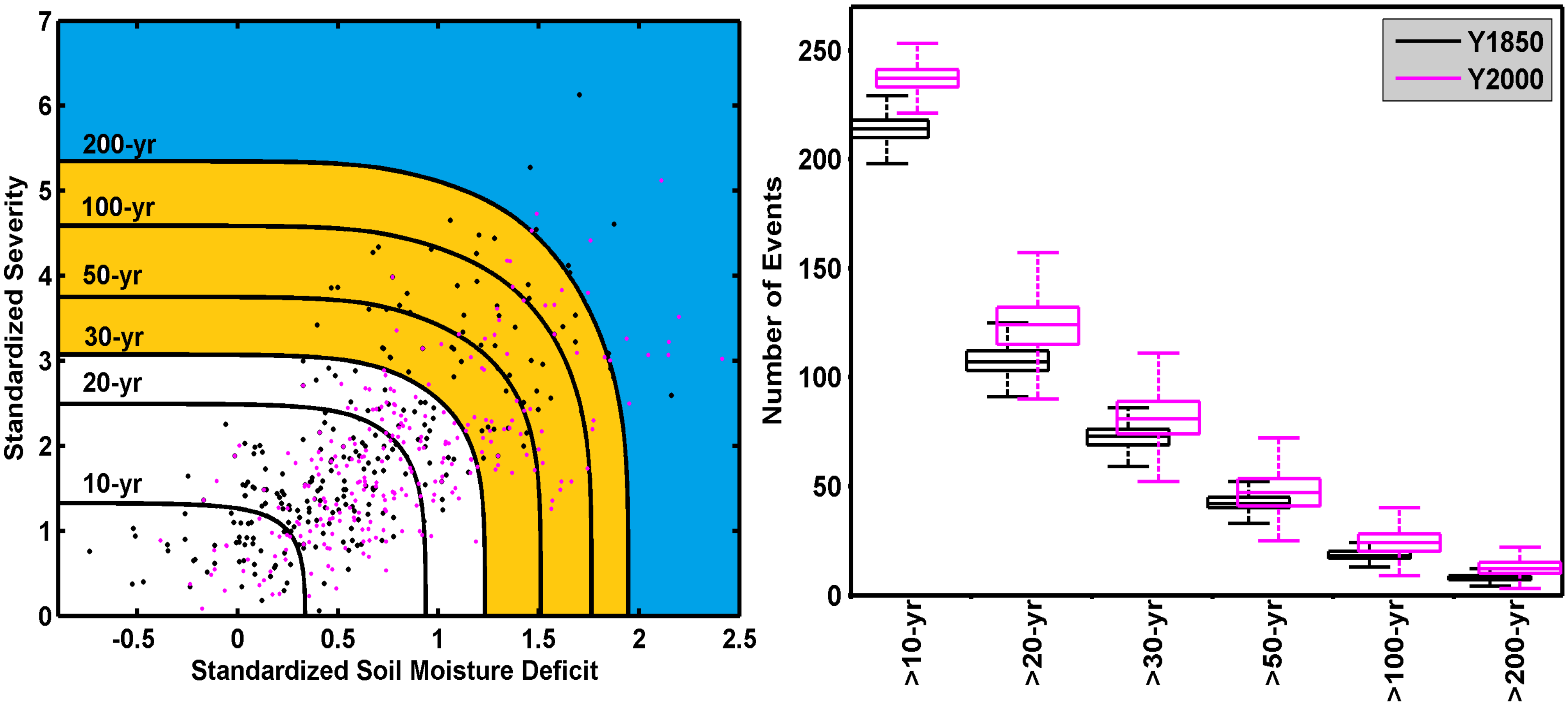
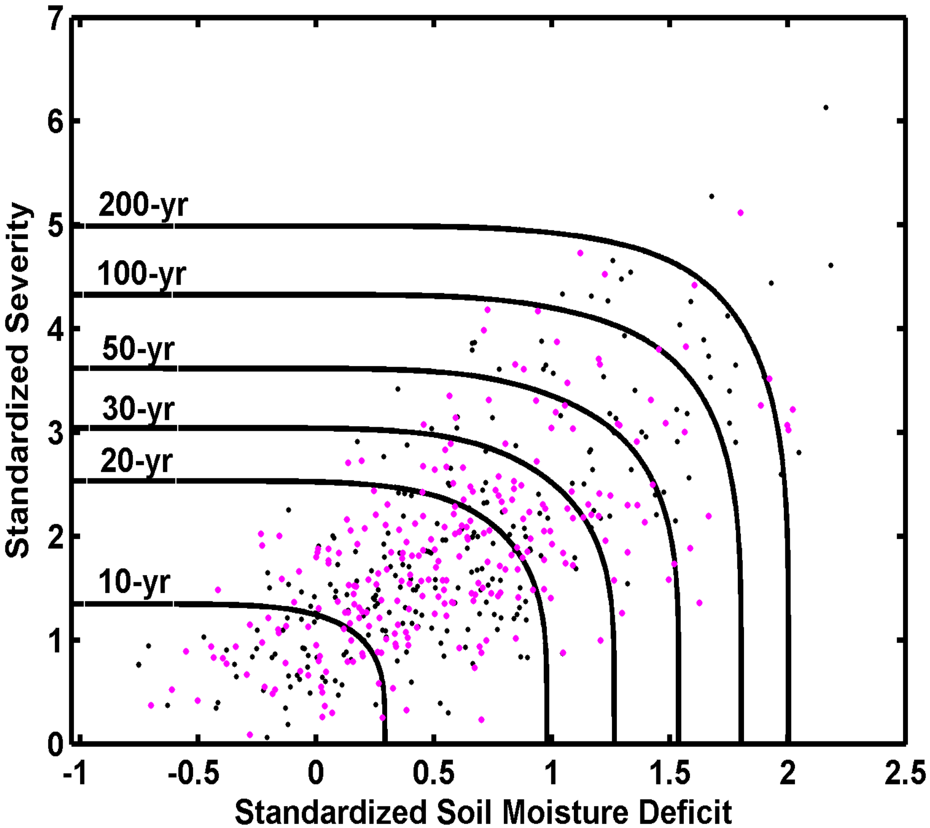


Figure 5 Joint return period of precipitation anomalies and SM anomalies at 10cm using Y1850 (black dots) and Y2000 (blue dots); joint contour line is based on Y1850

Case 3: ***Precipitation*** and ***Soil Moisture*** (at 1m) from Y1850 and Y2000



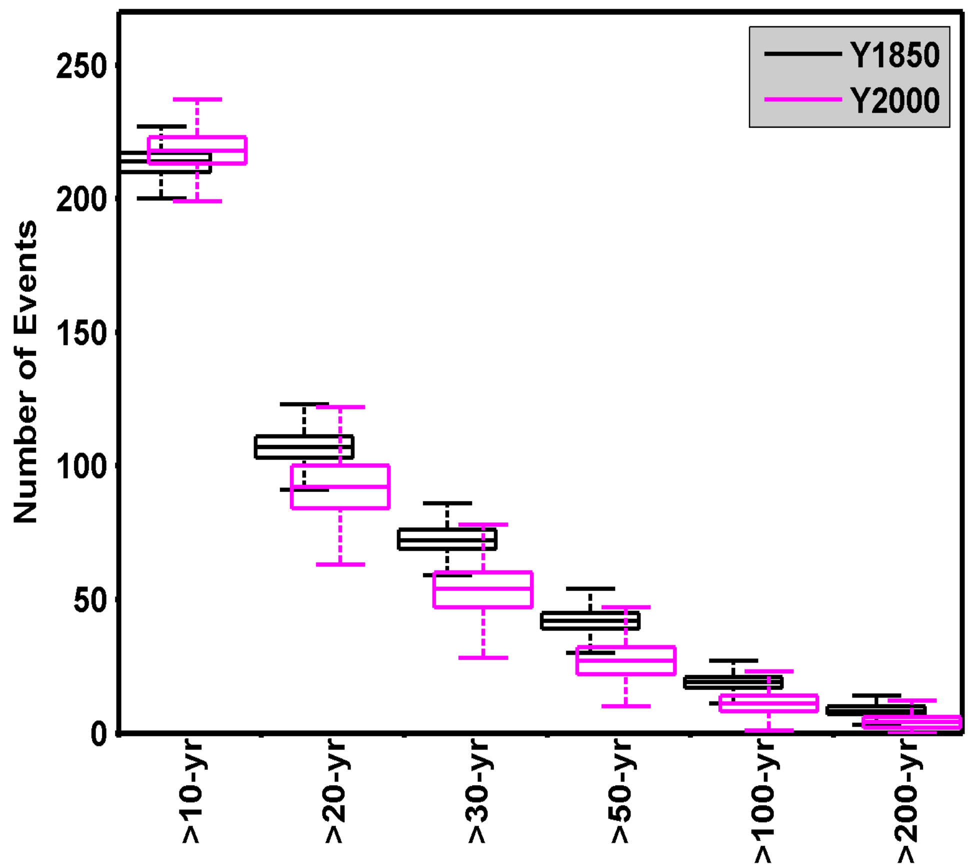


Figure 6 Joint return period of precipitation anomalies and SM anomalies at 1m using Y1850 (black dots) and Y2000 (blue dots); joint contour is based on Y1850

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.

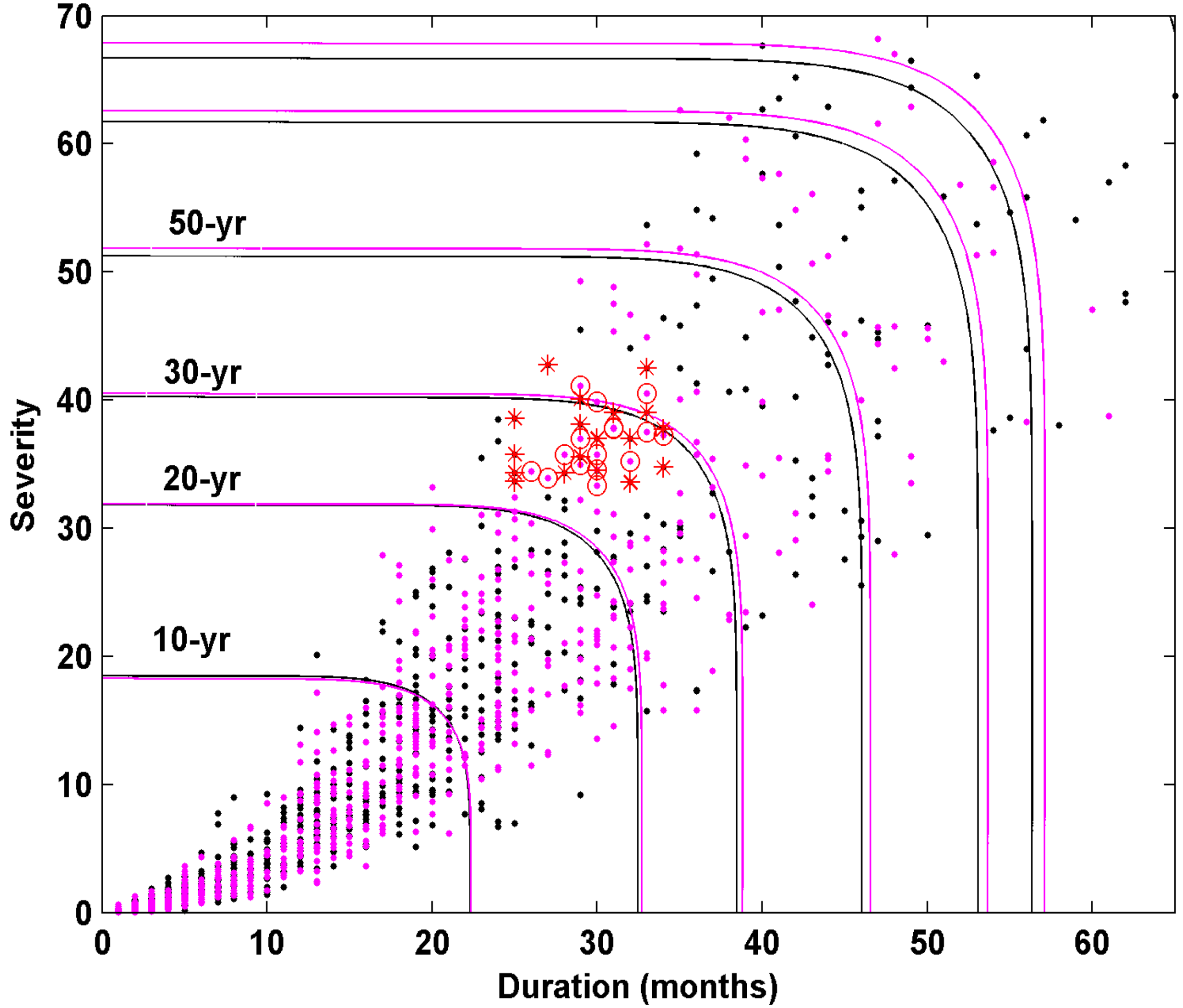


Figure 7 Joint return period of drought duration and severity; red dots are similar to observations