Compound and Concurrent Climate Extremes: Detection, Modeling and Risk Analysis

Amir AghaKouchak,

University of California, Irvine

Hamed Moftakhari, Elisa Ragno, Moji Sadegh, Felicia Chiang, Linyin Cheng, Omid Mazdiyasni, Gianfausto Salvadori, Brett Sanders, Richard Matthew

Email: amir.a@uci.edu

: @AghaKouchak

Coastal Flooding

Compound Extreme Events

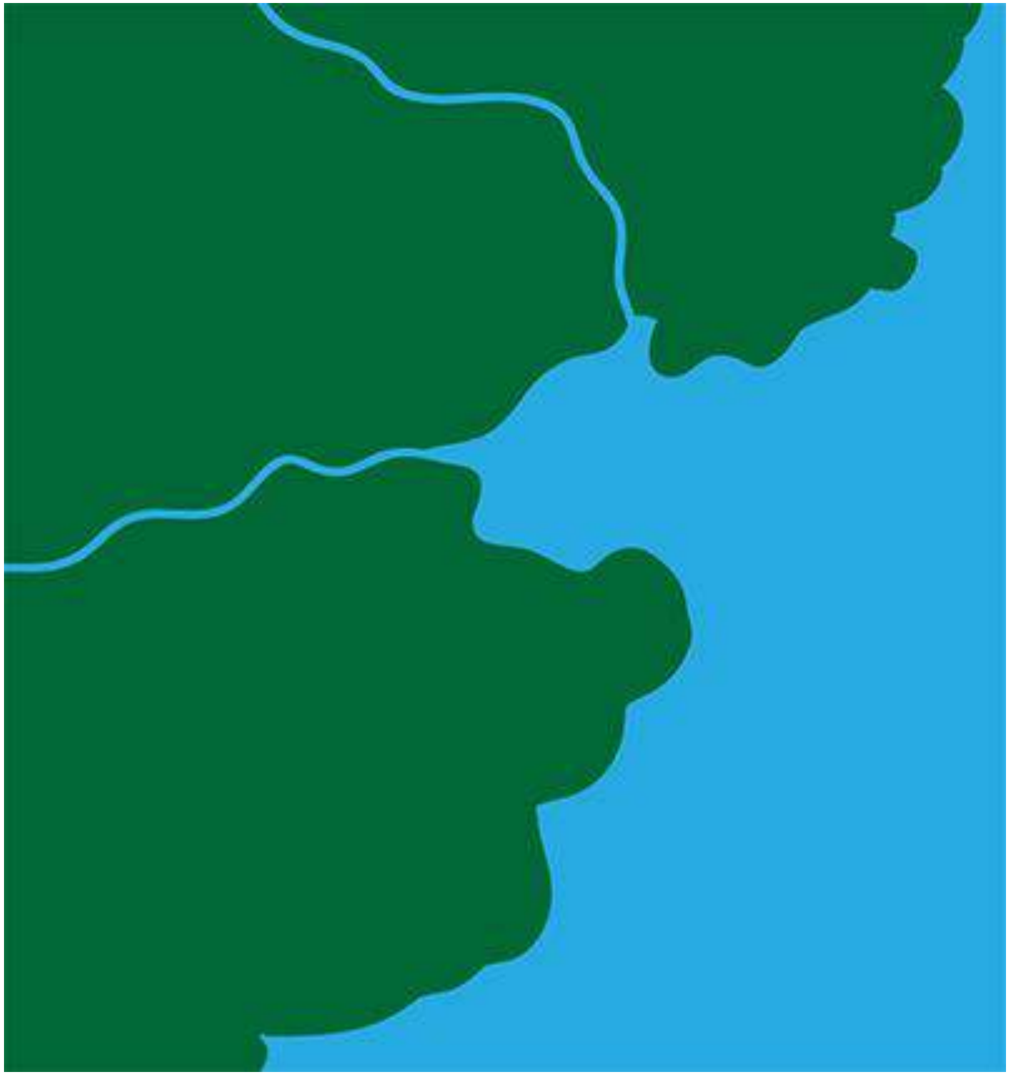


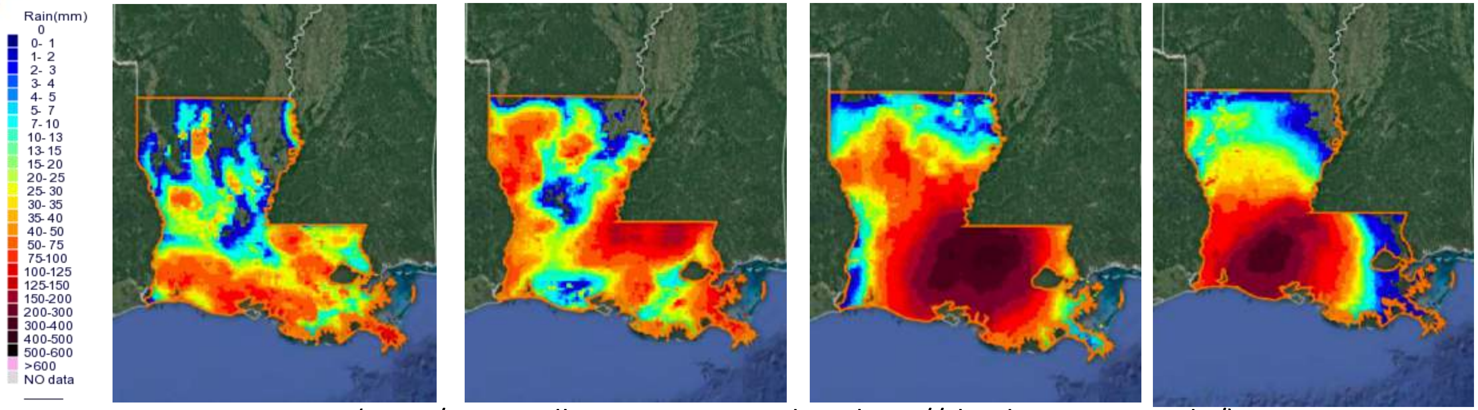
Image Credit: NASA/JPL

Compound Ocean-Fluvial Flooding

Compound Ocean-Fluvial (terrestrial)-Pluvial (local rain) Flooding

Motivation

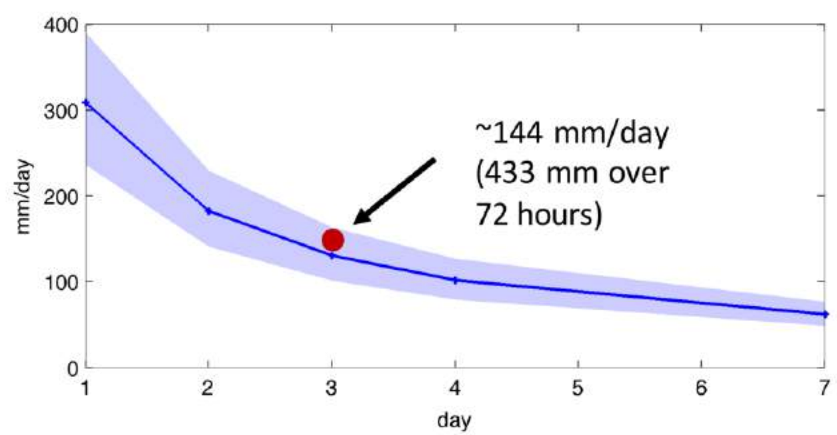
Aug. 10, 2016 | Aug. 11, 2016 | Aug. 12, 2016 | Aug. 13, 2016



(CHRS/UCI Satellite Precipitation data: http://chrsdata.eng.uci.edu/)

Louisiana 2016 Flood

13 death; 60,000 homes damaged; 20,000 people evacuated



The Amite river crest rose to 5.3 m, 0.9 m above the 1983 record (~ 1000-yr flood). The record flood stage was the result of compounding effects of multiple local floods. Several creeks and rivers across a large area in southern Louisiana flooded simultaneously, which led to overtopping of levees and floodwalls.

Motivation

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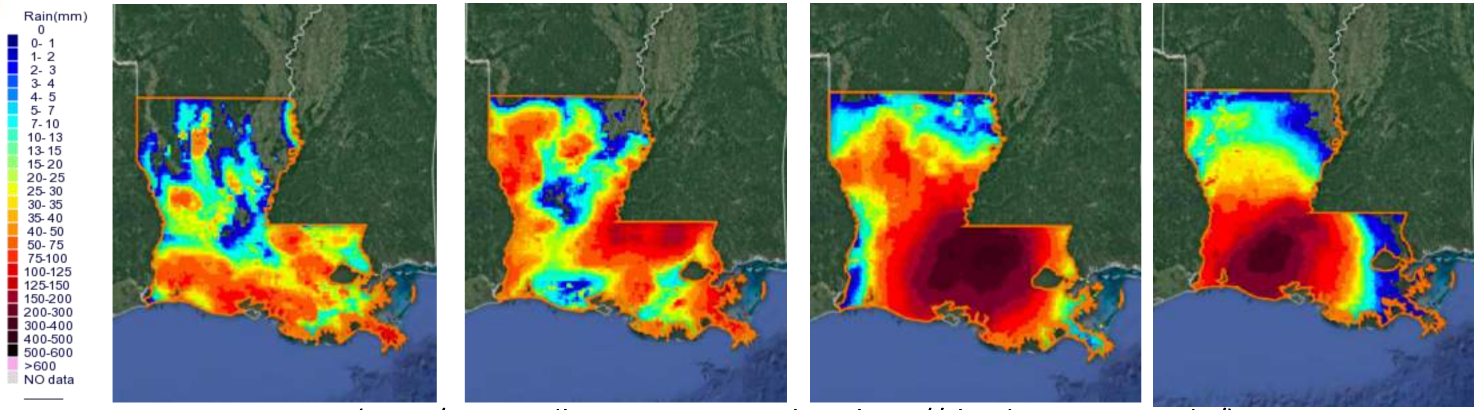

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Compound hazards yield Louisiana flood

Farshid Vahedifard[1,*], Amir AghaKouchak[2], Navid H. Jafari[3]

+ Author Affiliations

↵ *Corresponding author. Email: farshid@cee.msstate.edu

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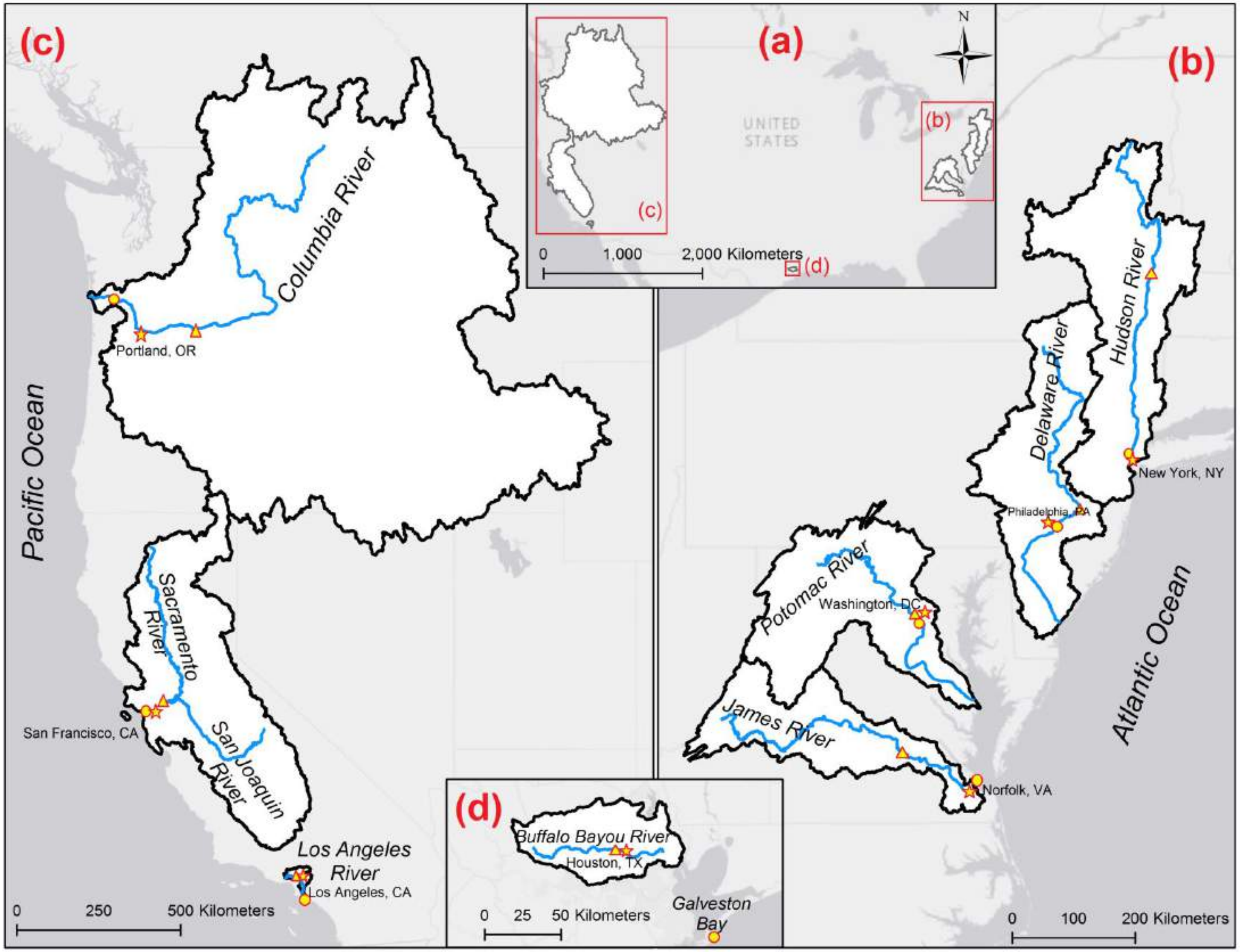
Compound Extreme Events

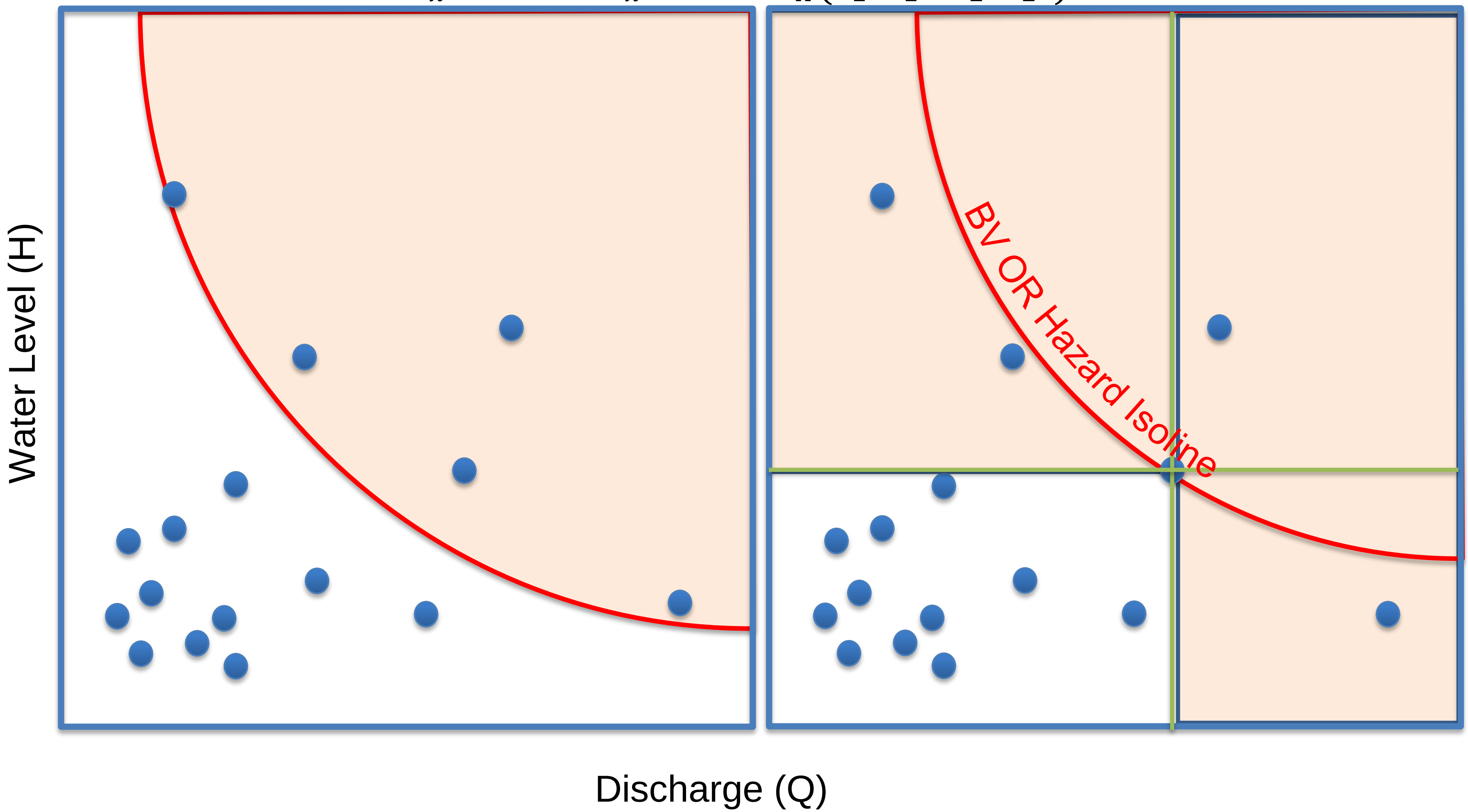
- ***Two or more extreme events occurring simultaneously or successively***
- ***Combinations of extreme events with underlying conditions that amplify the impact of the events***
- ***Combinations of events that are not themselves extremes but lead to an extreme event or impact when combined.***
- ***Consecutive inter-dependent events that do not occur at the same time, but they have compounding impacts.***

Compound Extreme Events



Compound Extreme Events

$$\alpha_x^{\vee} = P(X \in S_x^{\vee}) = 1 - C_X\big(F_1(x_1), F_2(x_2)\big)$$



Moftakhari H.M., Salvadori G., AghaKouchak A., Sanders, B.F., Matthew, R.A., 2017, Compounding Effects of Sea Level Rise and Fluvial Flooding, *Proceedings of the National Academy of Sciences*, doi: 10.1073/pnas.1620325114.

Failure Probability

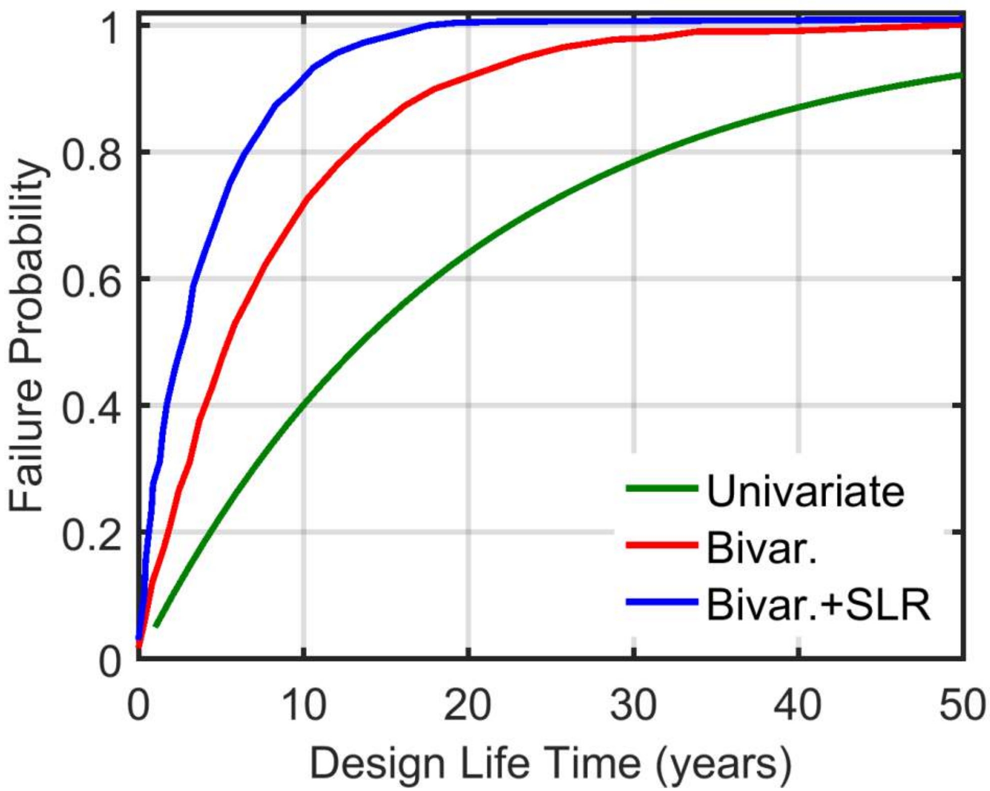
For a given design life time of T the failure probability ($\check{P}_T$) is calculated as

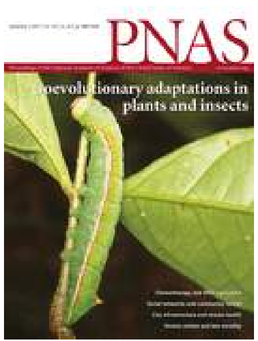
Univariate

$$\check{P}_T = 1 - (1 - p)^T$$

Multivariate

$$\check{P}_T = 1 - P\left(X_1 \in S_1^C, \ldots, X_T \in S_T^C\right)$$
$$= 1 - \left(C_X\left(F_1(\tilde{x}_1), F_2(\tilde{x}_2)\right)\right)^T$$

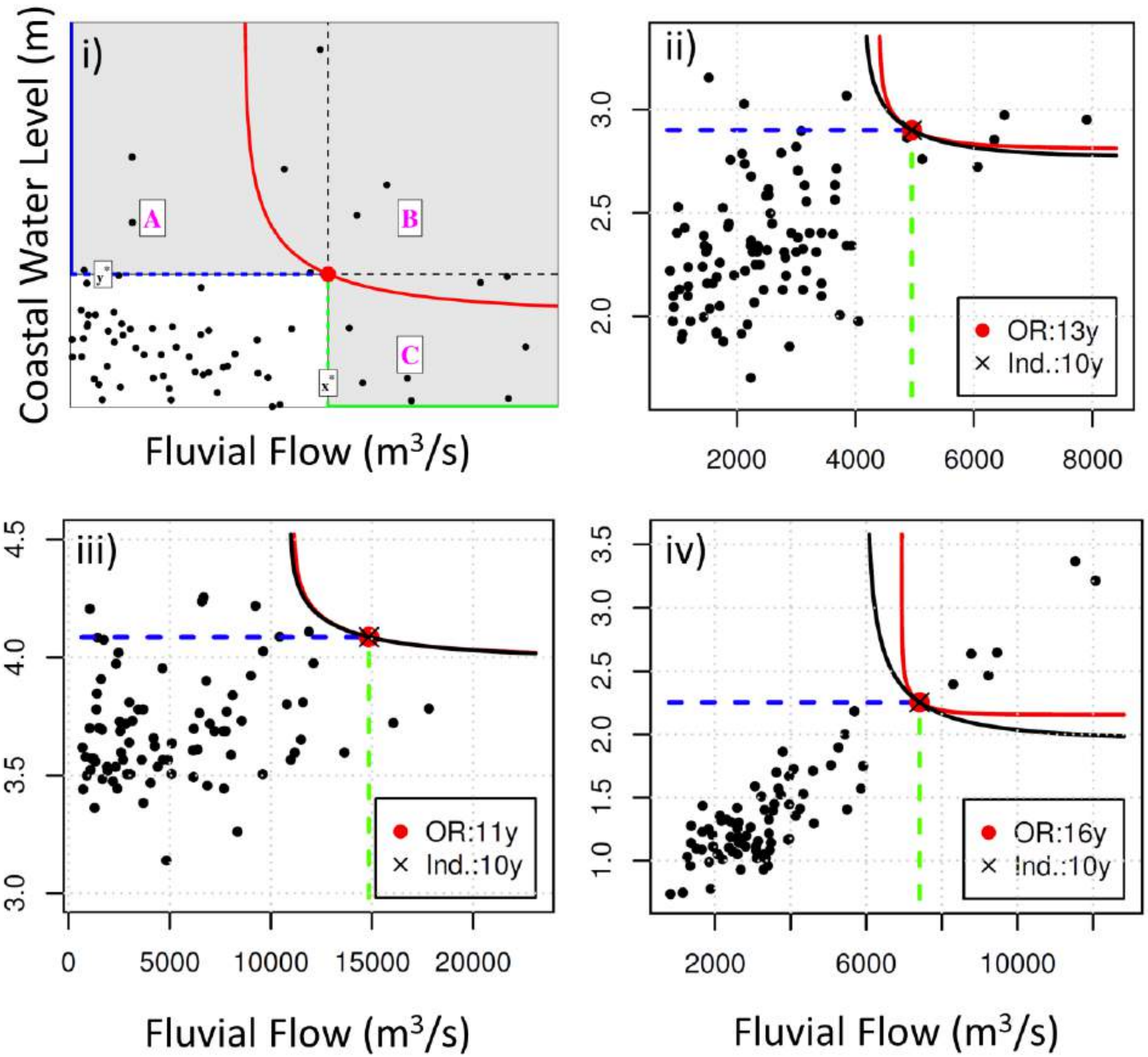




Compounding effects of sea level rise and fluvial flooding

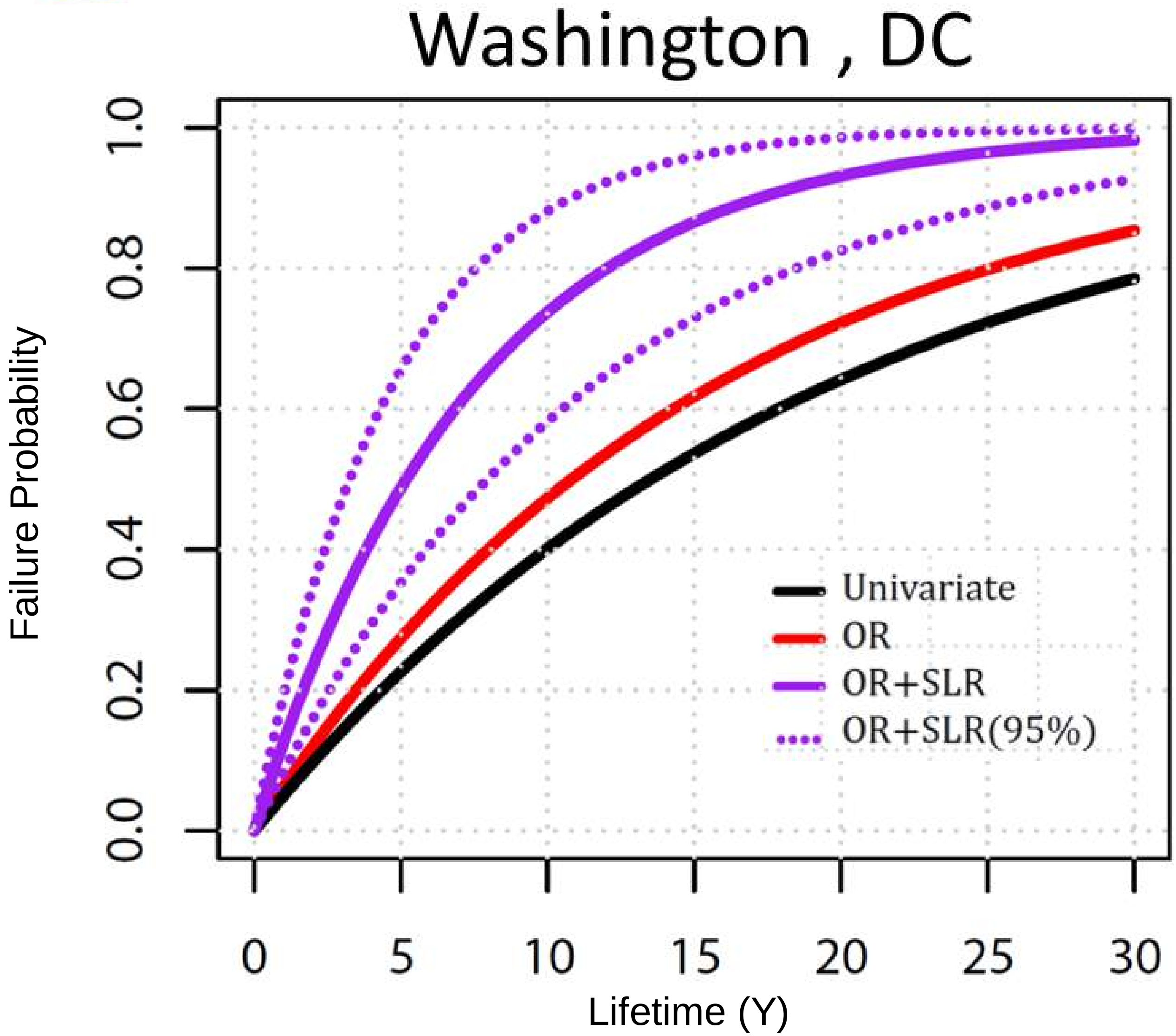
Hamed R. Moftakhari[a], Gianfausto Salvadori[b], Amir AghaKouchak[a,c,1], Brett F. Sanders[a,d], and Richard A. Matthew[d,e]

Compound Extreme Events



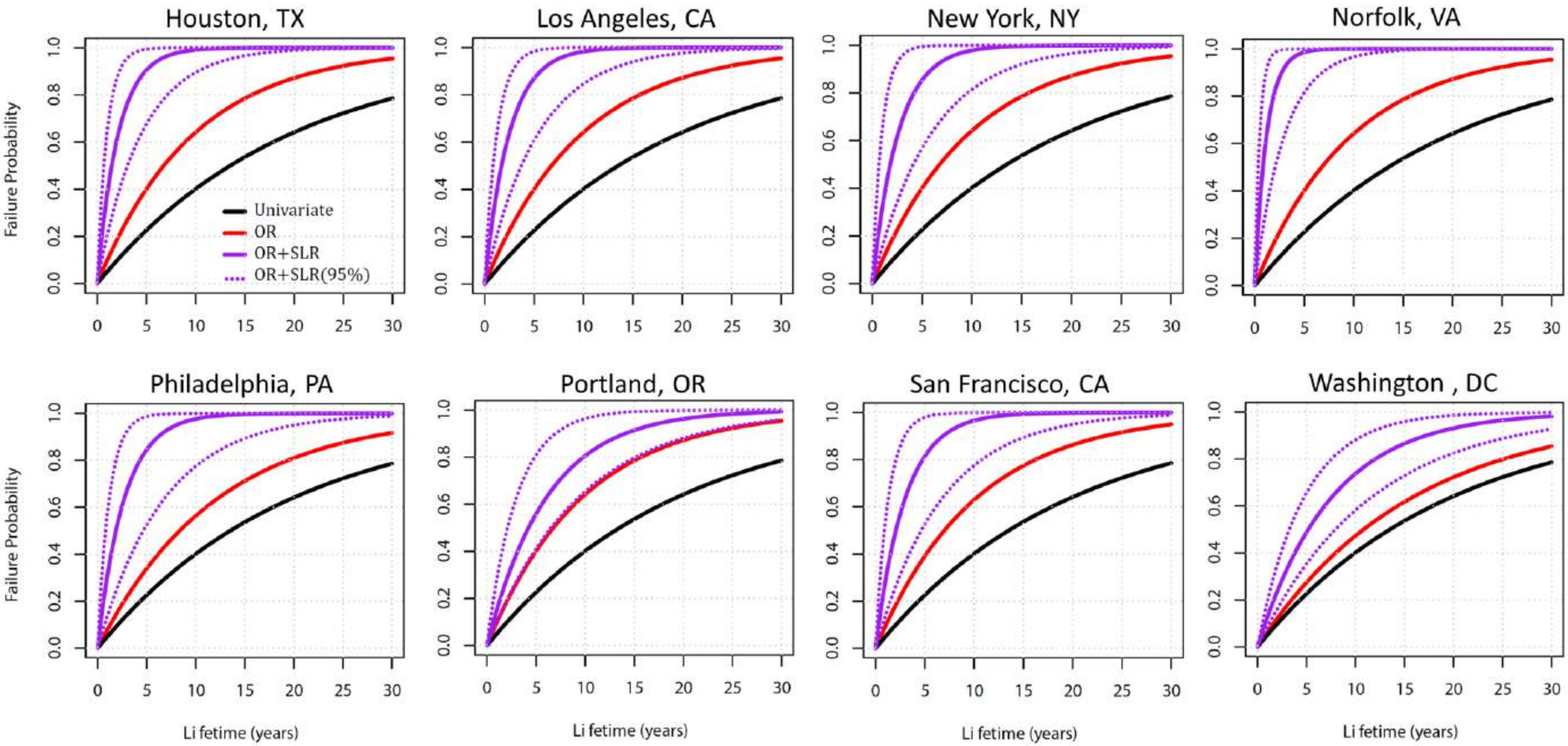
i) Illustration of the univariate and bivariate Hazard Scenarios. The black circles represent observed bivariate occurrences, the red circle is the reference occurrence $z^* = (x^*, y^*)$, the red line is the isoline of F_{XY} crossing z^*, with level $F_{XY}(x^*, y^*) \leq min\{F_X(x^*), F_Y(y^*)\}$, and the black line is the isoline of F_{XY} crossing z^*, under the simplifying assumption of independence between Fluvial Flow and Coastal WL. The hazardous regions A, B, and C are indicated as dashed areas. The estimates of the bivariate OR RP's associated with the occurrence z^* are indicated in the legends for Philadelphia, PA (Figure 1ii), San Francisco, CA (Figure 1iii), and Washington, DC (Figure 1iv).

Compound Extreme Events - Failure Probability 2030 RCP4.5



Link: http://www.pnas.org/content/early/2017/08/22/1620325114

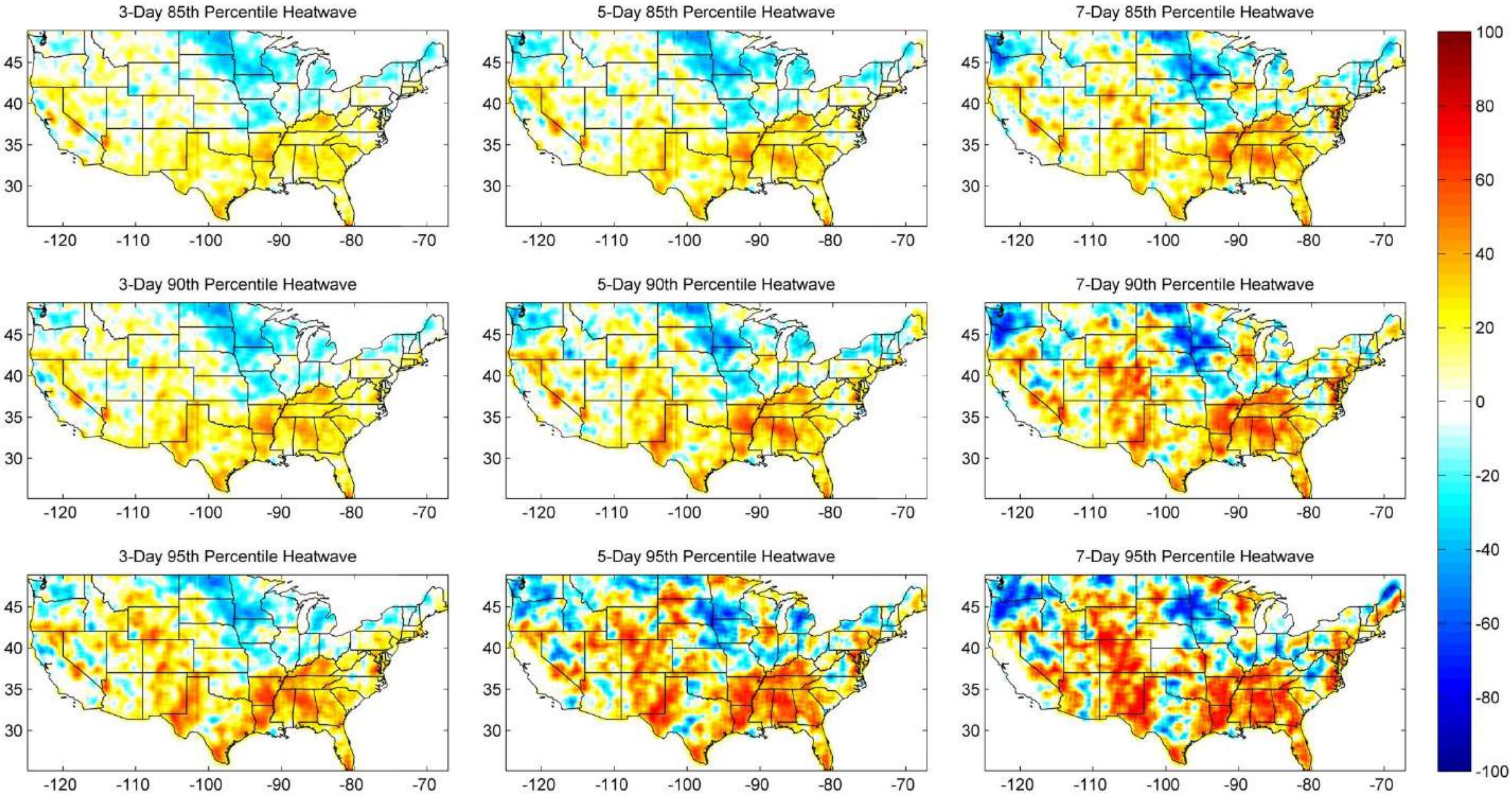
Compound Extreme Events



Estimated failure probability for a temporal horizon of 30 years. The solid black and red curves show, respectively, the estimated failure probability computed based on the univariate and bivariate OR hazard scenarios, according to the presently observed climate conditions. The solid and dashed purple curves show the estimated probability of failure using a bivariate OR approach and an associated 95% confidence band considering the projected SLR for 2030 under RCP 4.5.

Drought and Heatwaves

Droughts and Heatwaves



Mazdiyasni O., AghaKouchak A., 2015, Substantial Increase in Concurrent Droughts and Heatwaves in the United States, *Proceedings of the National Academy of Sciences*, doi: 10.1073/pnas.1422945112.

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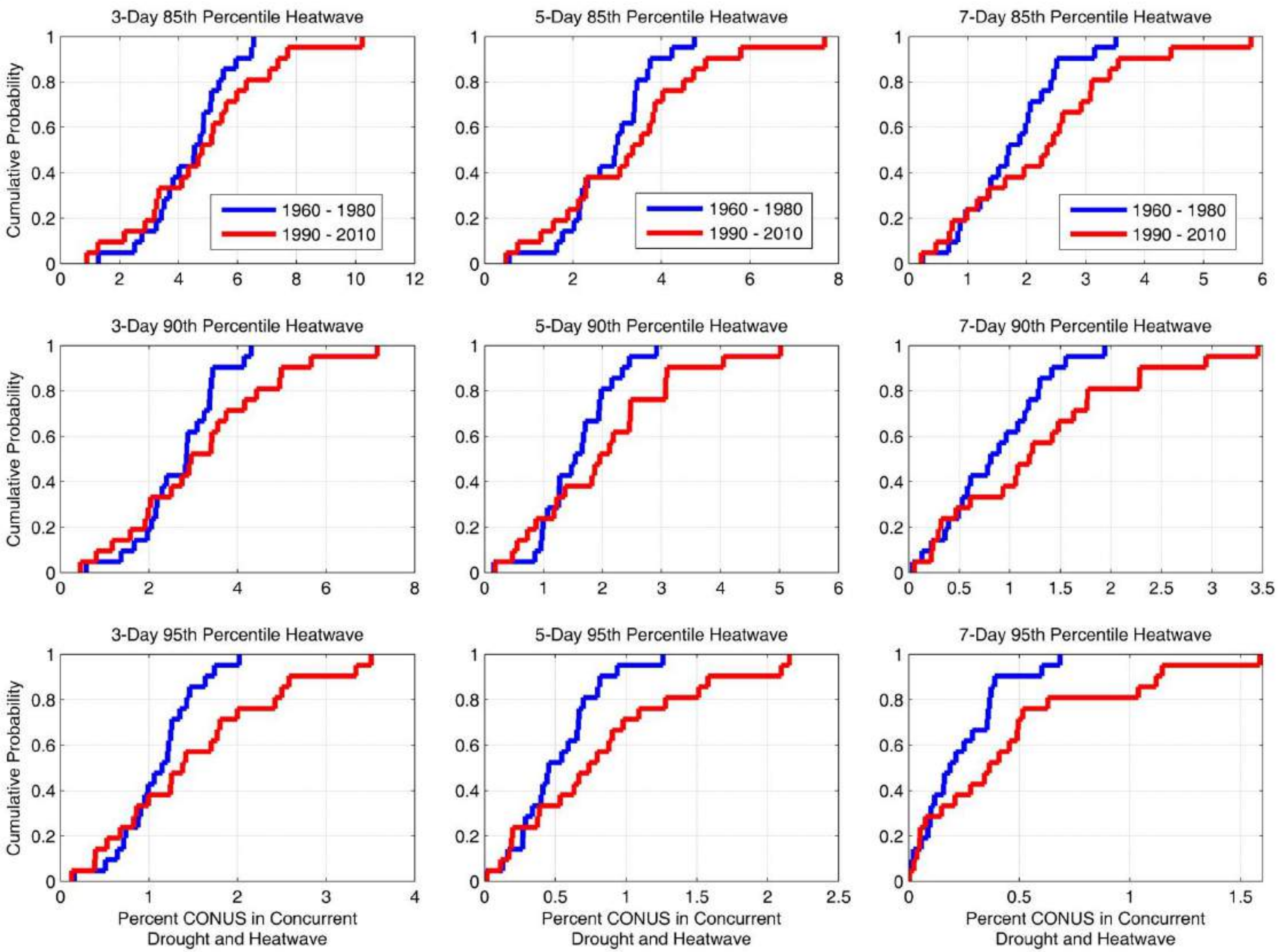

Mazdiyasni O., AghaKouchak A., 2015, Substantial Increase in Concurrent Droughts and Heatwaves in the United States, *Proceedings of the National Academy of Sciences*, doi: 10.1073/pnas.1422945112.

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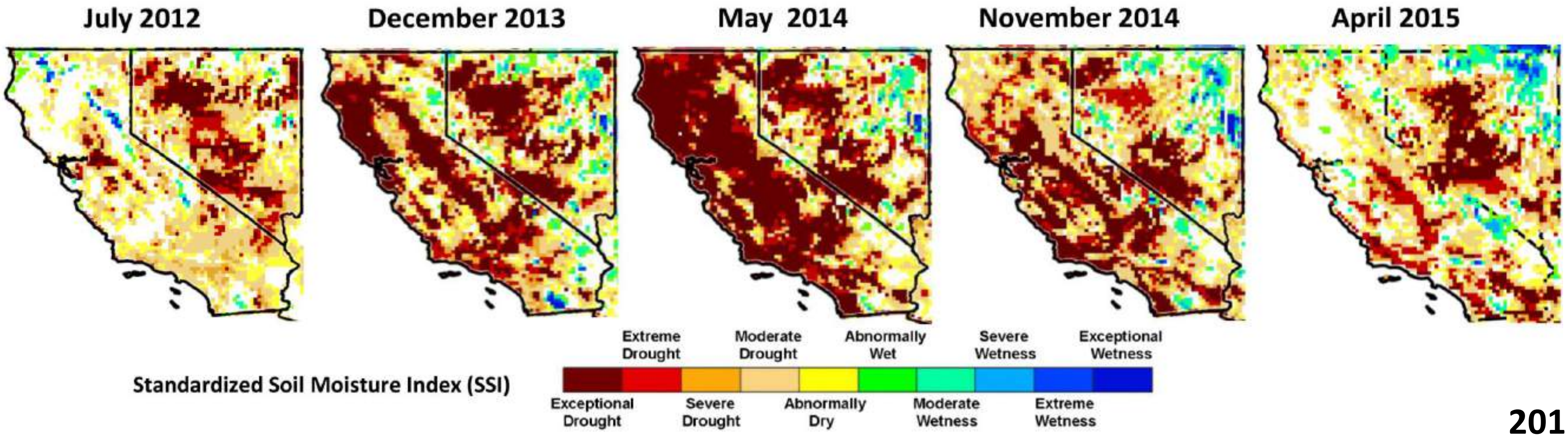
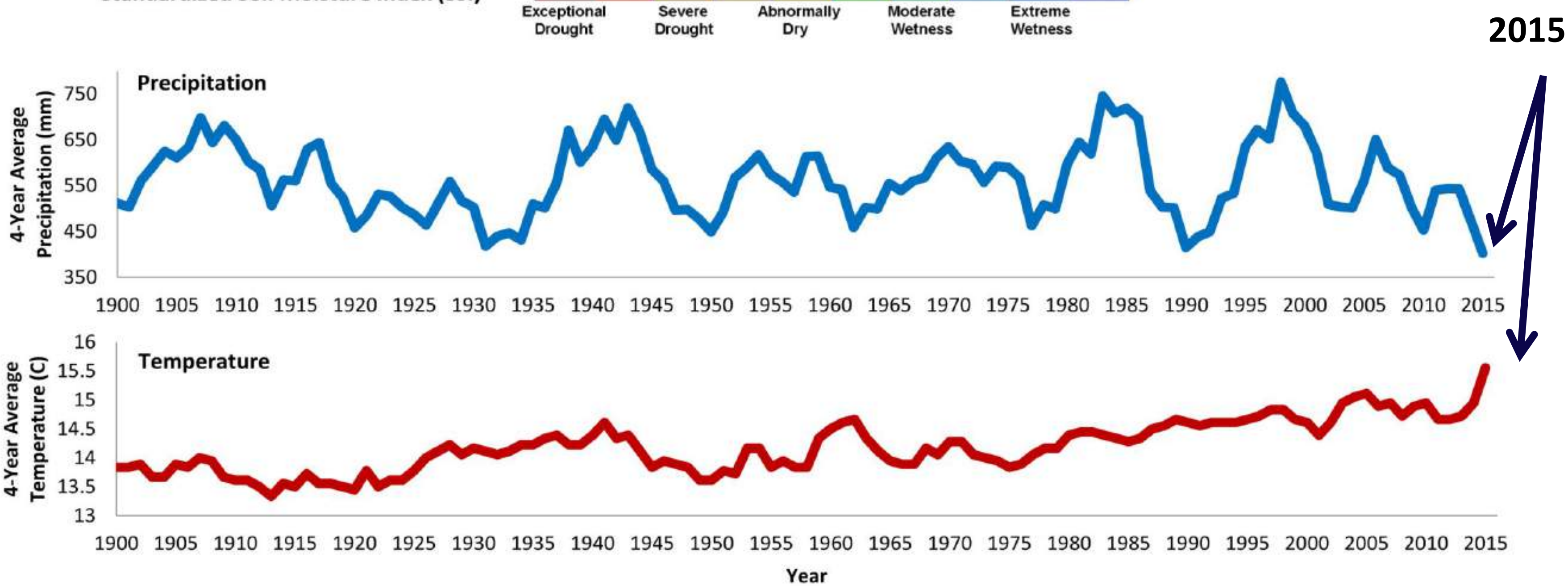
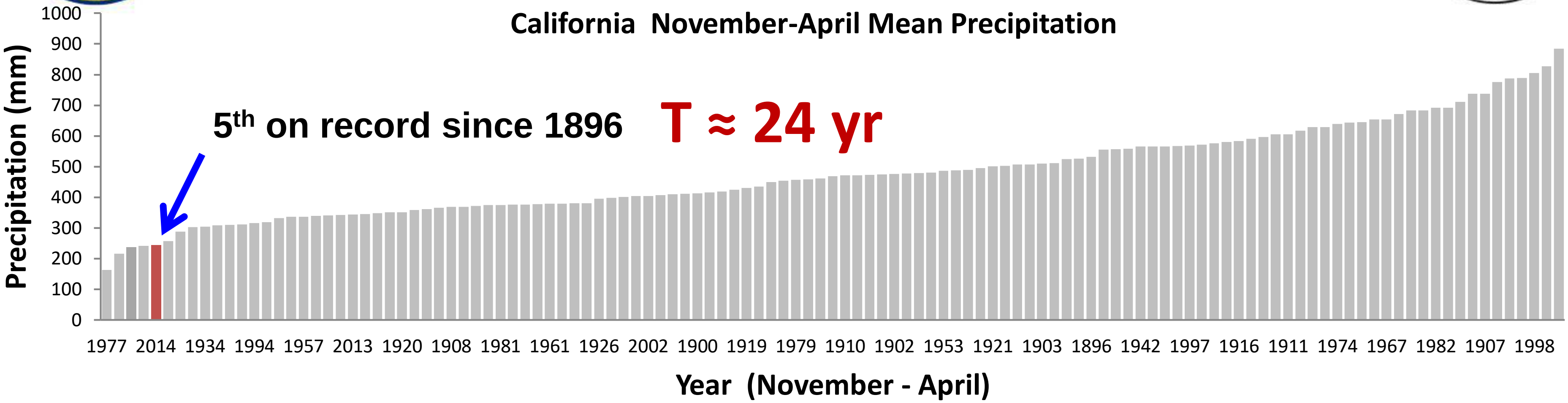
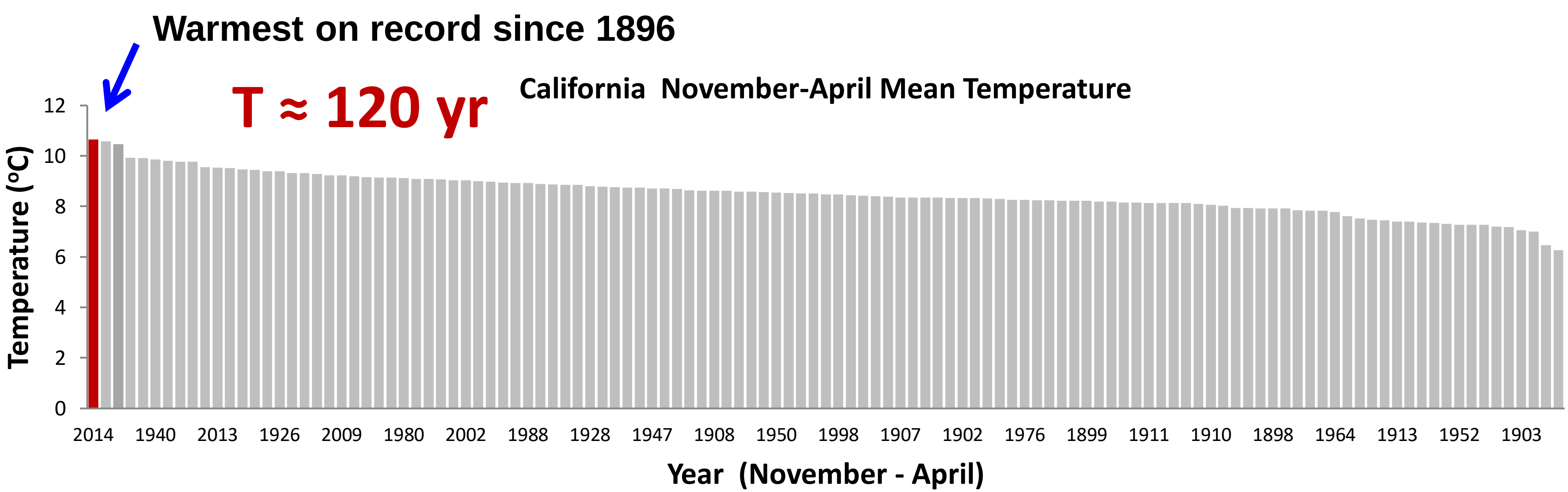




AghaKouchak A., Cheng L., Mazdiyasni O., Farahmand A., 2014, Global Warming and Changes in Risk of Concurrent Climate Extremes: Insights from the 2014 California Drought, *Geophysical Research Letters*, doi: 10.1002/2014GL062308.

2014 California Drought: How Bad is It?





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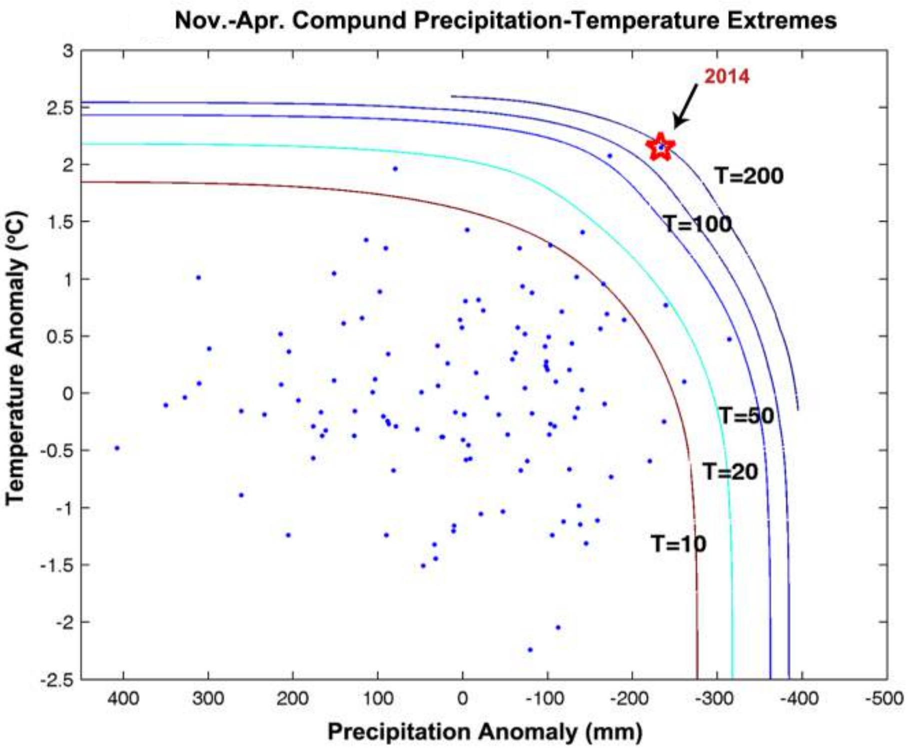


Assuming two variables X (precipitation) and Y (temperature) with cumulative distribution functions $F_X(x) = \Pr(X \le x)$ and $F_Y(y) = \Pr(Y \le y)$, the copula (C) can be used to obtain their joint distribution function: $F(x,y) = C\big(F_X(x), F_Y(y)\big)$, where $F(x,y)$ is the joint distribution function of X and Y:

$F(x,y) = \Pr(X \le x, Y \le y)$

The joint survival distribution $\bar{F}(x,y) = \Pr(X > x, Y > y)$ can be obtained using the concept of survival copula:

$\bar{F}(x,y) = \hat{C}\big(\bar{F}_X(x), \bar{F}_Y(y)\big)$

$\bar{F}_X$ and $\bar{F}_Y$ (i.e., $\bar{F}_X = 1 - F_X$, $\bar{F}_Y = 1 - F_Y$) are the marginal survival functions of X and Y, and $\hat{C}$ is the survival copula.

Survival critical layer (or isoline) is then defined as:

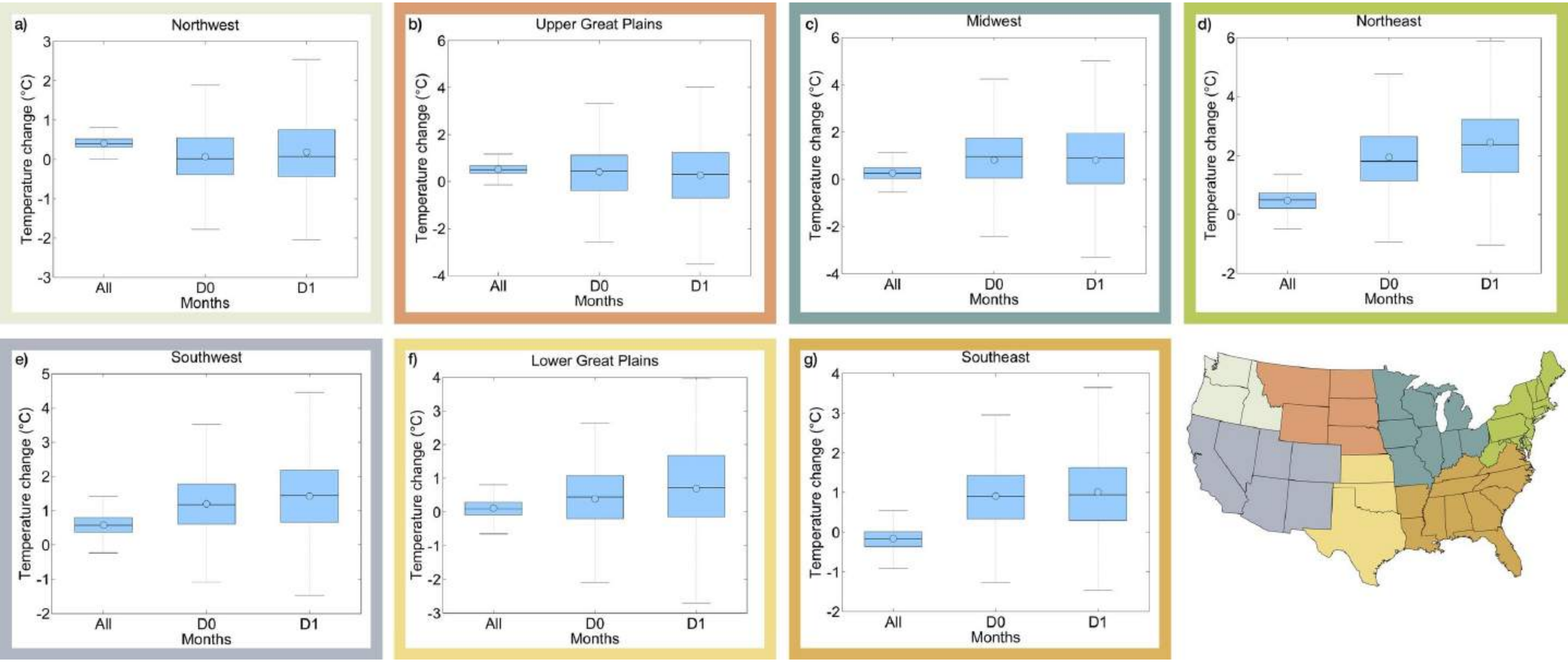
$\mathcal{L}_t^{\bar{F}} = \{x, y \in R^d \colon \bar{F}(x,y) = t\}$ where $\mathcal{L}_t^{\bar{F}}$ is the survival critical layer associated with the probability t.

The survival return period of X and Y is defined as: $\bar{\kappa}_{XY} = \frac{\mu}{1-\bar{K}(t)}$ where $\bar{\kappa}_{XY}$ is called the survival Kendall's return period; $\mu > 0$ is the average interarrival time of X and Y ($\mu = 1$ indicates the average interarrival time between subsequent values in the time series is one year); and $\bar{K}$ is the Kendall's survival function associated with $\bar{F}$ defined as:

$\bar{K}(t) = \Pr\big(\bar{F}(X,Y) \ge t\big) = \Pr(\hat{C}\big(\bar{F}_X(x), \bar{F}_Y(y)\big) \ge t)$

For any return period T, the corresponding survival critical layer $\mathcal{L}_t^{\bar{F}}$ can be estimated by inverting the Kendall's survival function $\bar{K}(t)$ at the probability level $p = 1 - \frac{\mu}{T}$: $\bar{q} = \bar{q}(p) = \bar{K}^{-\mathbf{1}}(p)$,

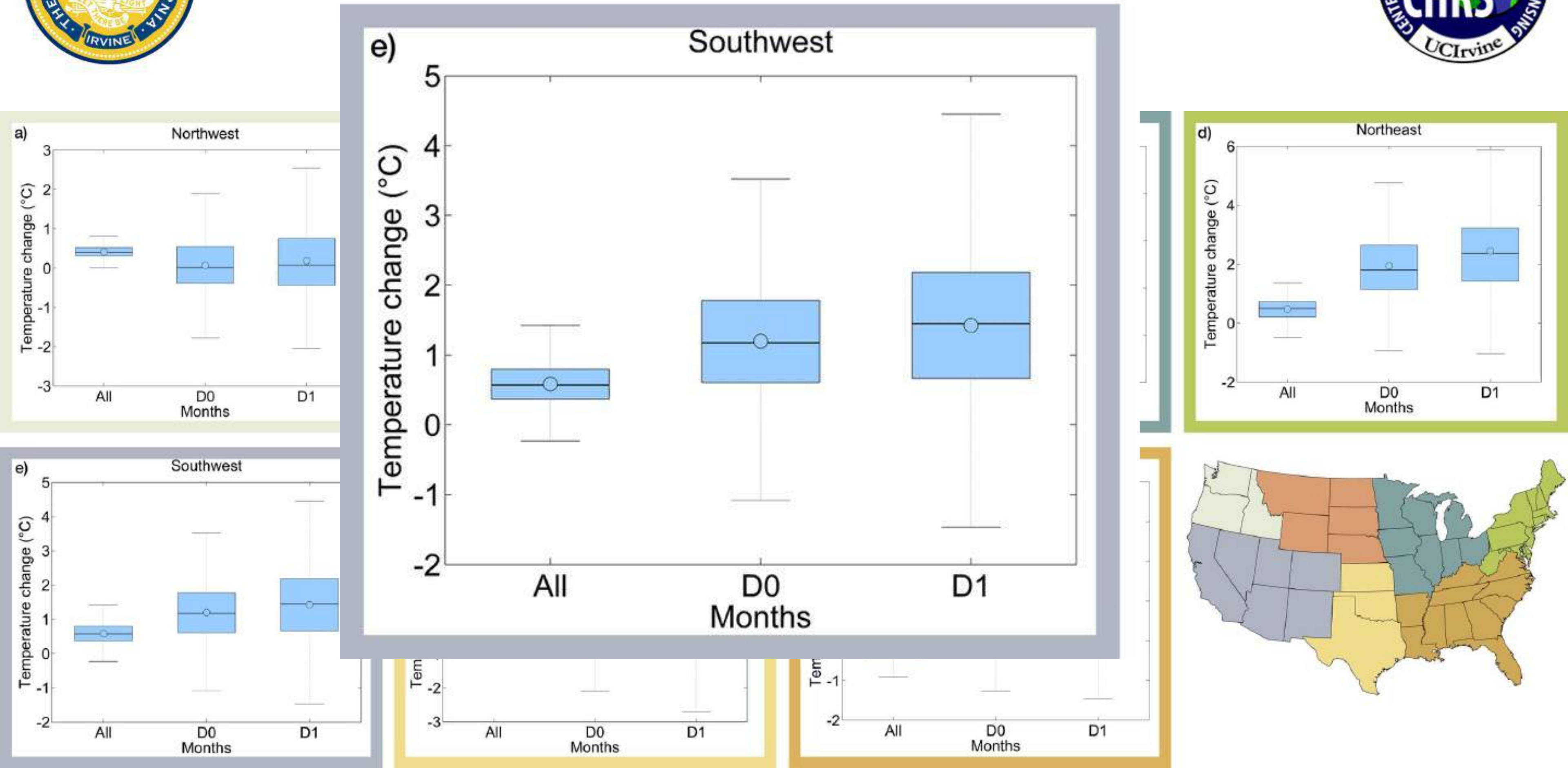
Hot Droughts



Regional boxplots display the temperature shifts corresponding to the average climate and different drought severity levels based on ground-based observations [1965-2014 relative to 1902-1951]

Chiang F., AghaKouchak, A, et al., 2018, in press.

Hot Droughts



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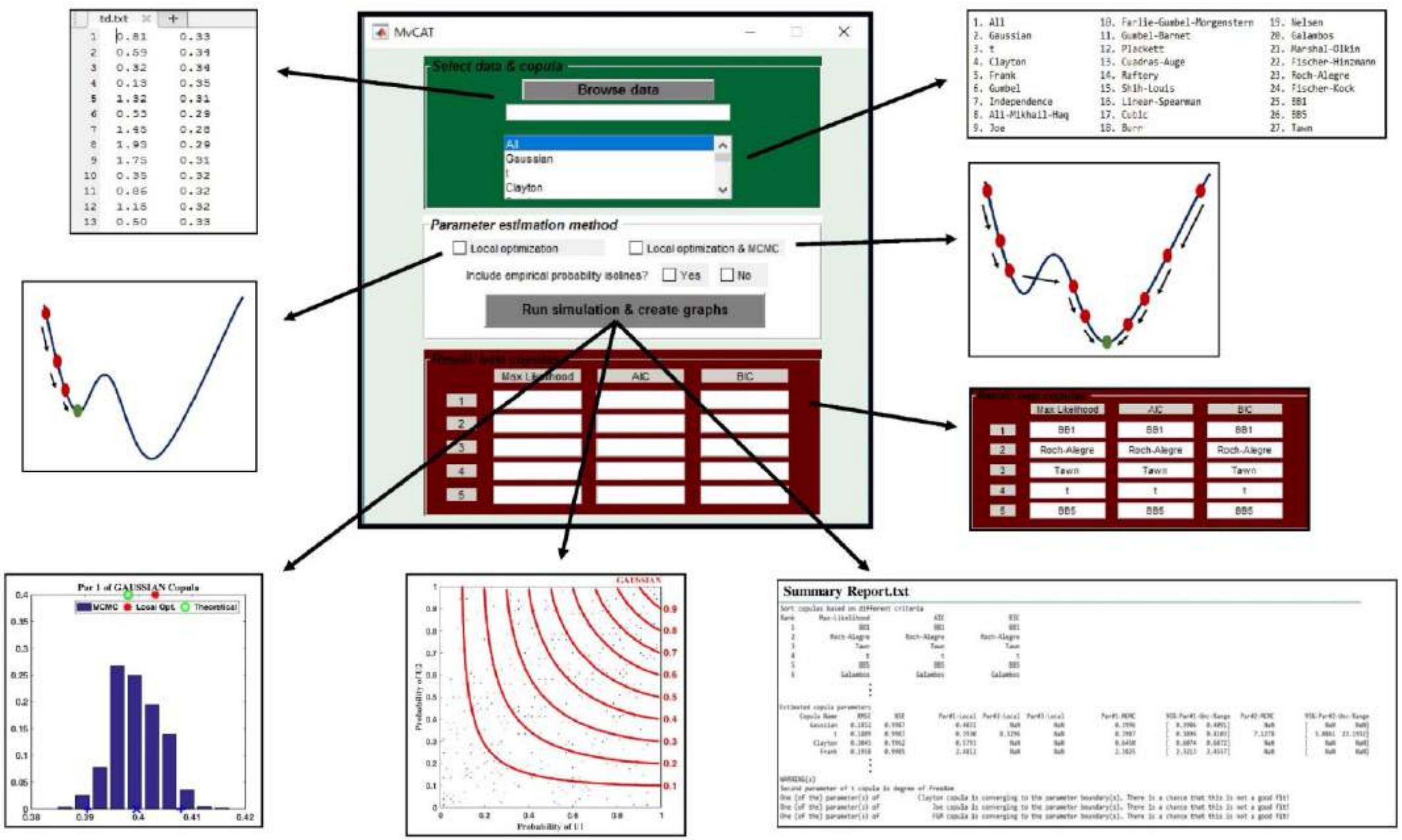
Chiang F., AghaKouchak, A, et al., 2018, in press.

MvCAT is freely available here:

http://amir.eng.uci.edu/software.php

Multivariate Copula Analysis Toolbox (MvCAT)



Sadegh, M., Ragno, E. and AghaKouchak, A. (2017), Multivariate Copula Analysis Toolbox (MvCAT): Describing dependence and underlying uncertainty using a Bayesian framework. *Water Resources Research*, 53, doi:10.1002/2016WR020242

Questions?

Amir AghaKouchak

Email: amir.a@uci.edu

: @AghaKouchak