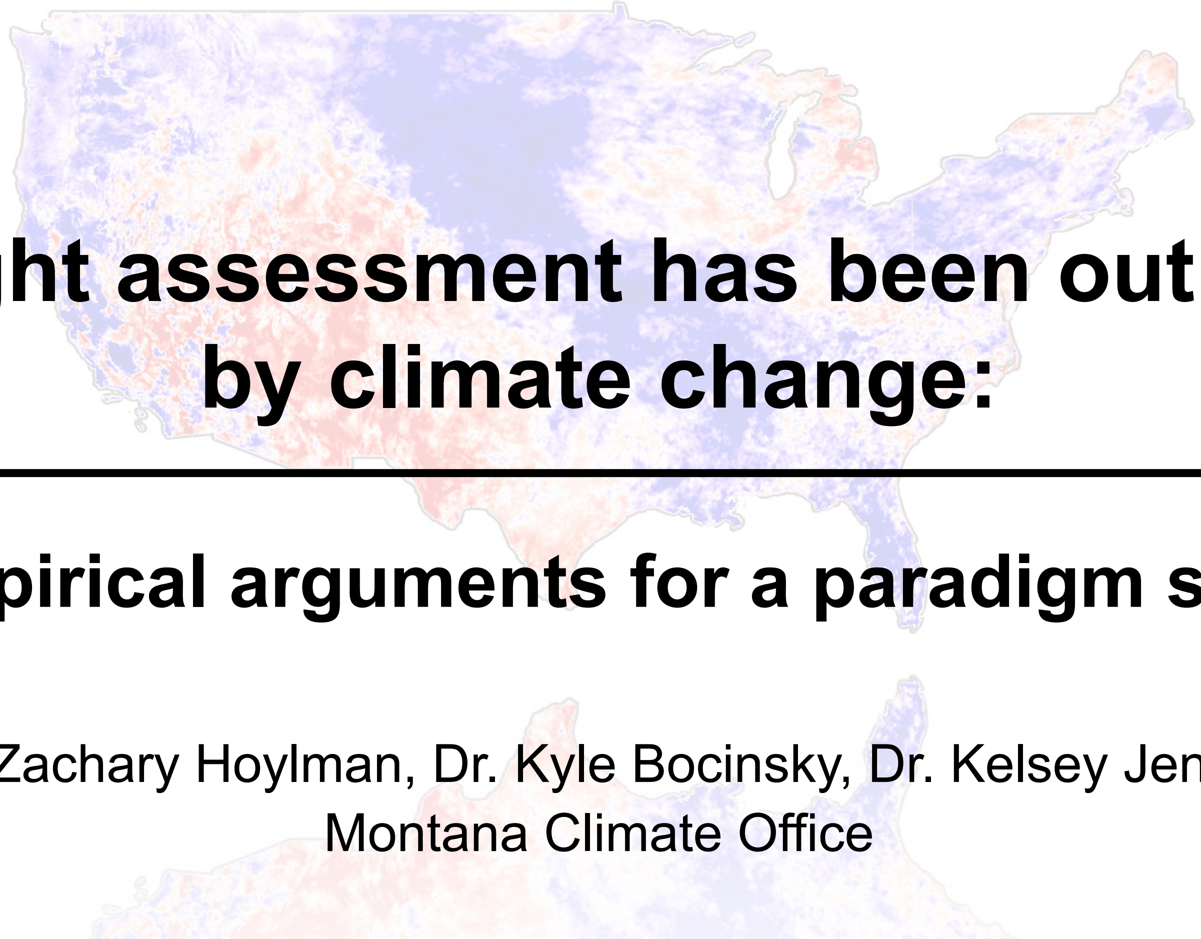


Drought assessment has been outpaced by climate change:

Empirical arguments for a paradigm shift

Dr. Zachary Hoylman, Dr. Kyle Bocinsky, Dr. Kelsey Jencso
Montana Climate Office

Drought in the United States

- Drought has significant impacts on communities across the country
- National risk mitigation efforts are in place to help communities impacted by drought
- Financial assistance is very important to sustain our national agrosystem through periods of abnormal dryness
- Drought monitoring and reporting trigger economic relief programs

8/16/2021 - Garfield County, MT

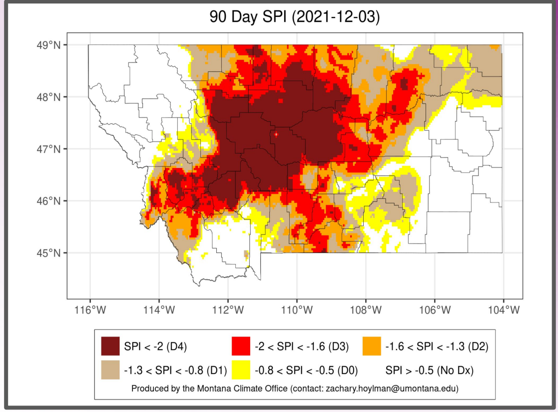
Source: MT Drought Impact Reporter

8/4/2021 - Chouteau County

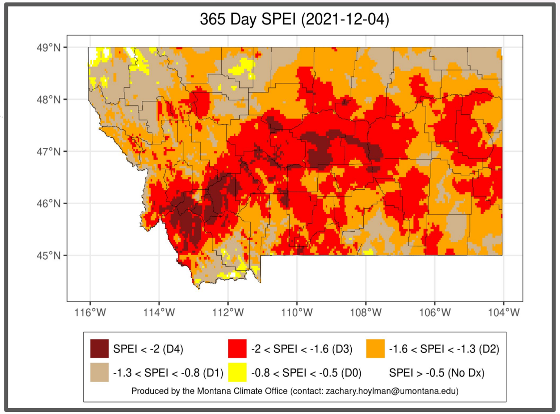
Source: MT Drought Impact Reporter

Drought Assessment using Drought Metrics

- **Drought is abnormal dryness** — it is a relative, temporary, and cyclic phenomena
- Use historical conditions to help contextualize current conditions - i.e. reference periods
- Conventional methods prefer long periods of record
    - Considered more robust as they include a wider range of events
- But what if the distribution is changing in time?
- If aridity becomes the new norm, is it still a drought?


90 Day SPI (2021-12-03)

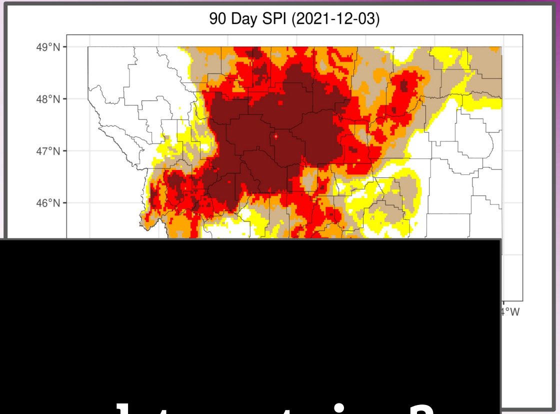
Produced by the Montana Climate Office (contact: zachary.hoylman@umontana.edu)


365 Day SPEI (2021-12-04)

Produced by the Montana Climate Office (contact: zachary.hoylman@umontana.edu)

Drought Assessment using Drought Metrics

- **Drought is abnormal dryness** — it is a relative, temporary, and cyclic phenomena



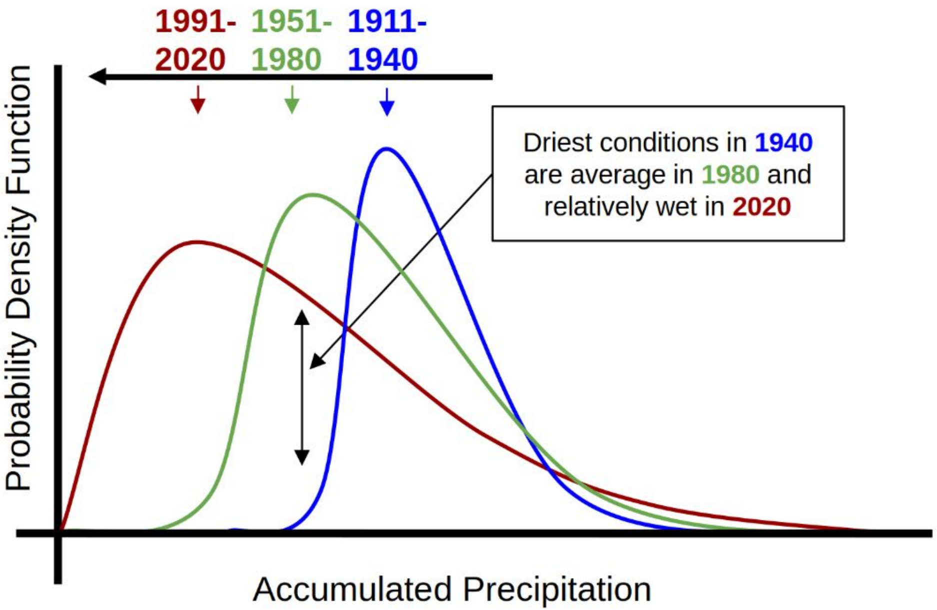
Major Questions

Q1: How much data is needed to compute drought metrics?

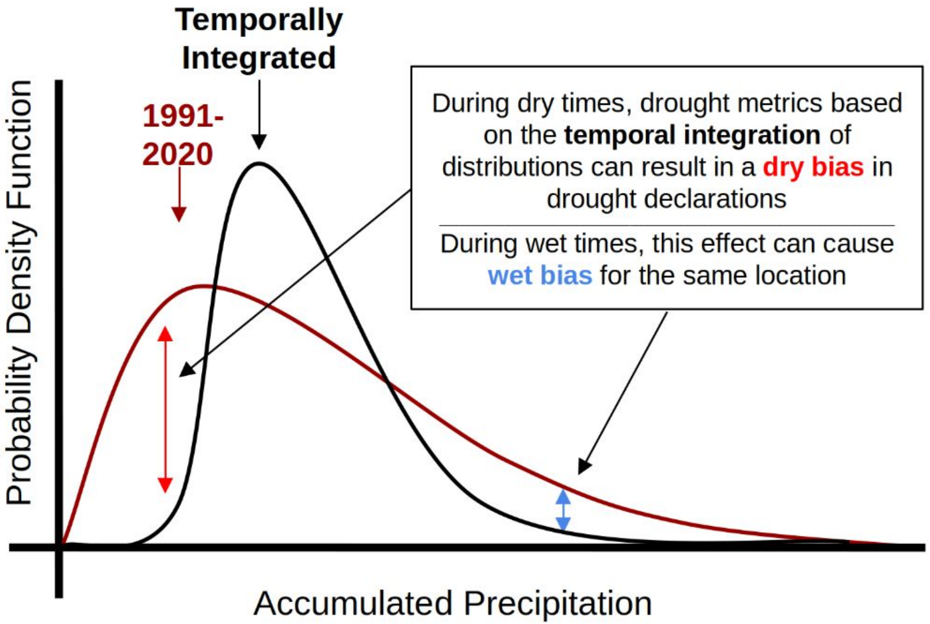
Q2: Do long climatology lengths (reference periods) bias drought severity assessment?

Conceptual Model

Temporal Shift



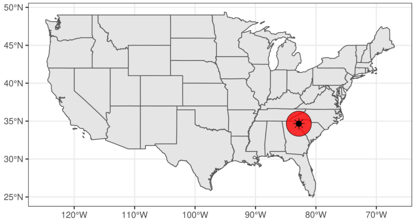
Driest conditions in **1940** are average in **1980** and relatively wet in **2020**



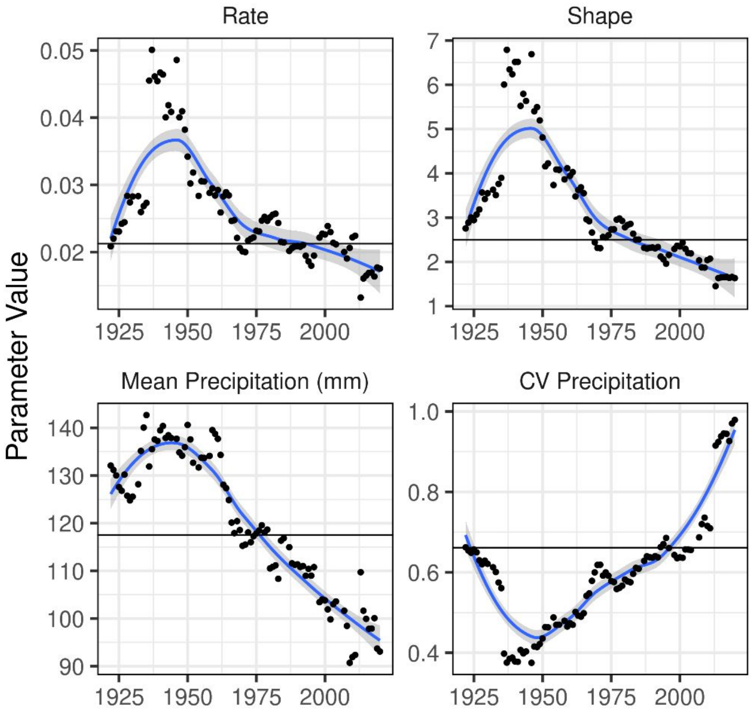
During dry times, drought metrics based on the **temporal integration** of distributions can result in a **dry bias** in drought declarations

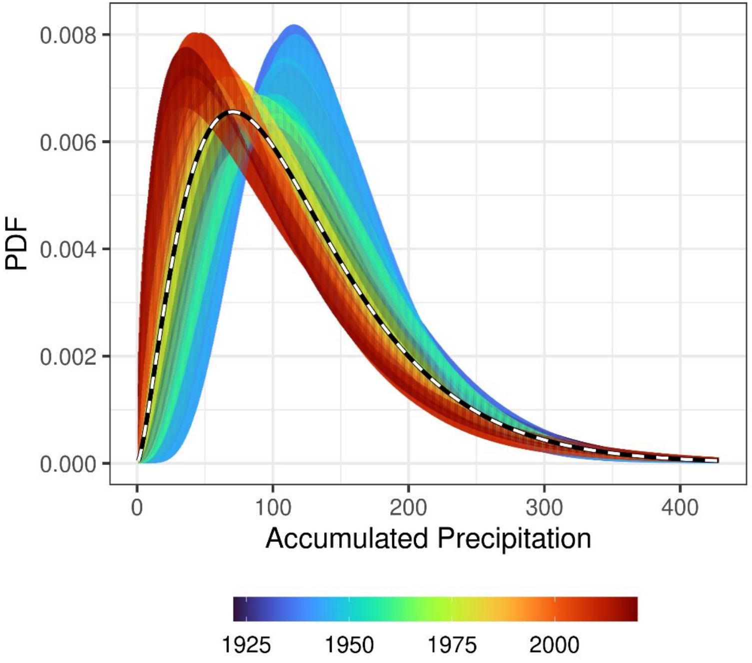
During wet times, this effect can cause **wet bias** for the same location

The Climate of the U.S. is Non-Stationary



30 Day Timescale for August 1
GHCN Site #: USC00381770 (CLEMSON UNIV, SC)





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Drought Assessment and Climate Change
Zachary Hoylman, Kyle Bocinsky & Kelsey Jencso
Montana Climate Office
NIDIS Joint DEWs (Omaha, NE - 10/13/2022)

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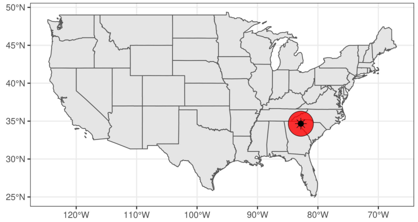


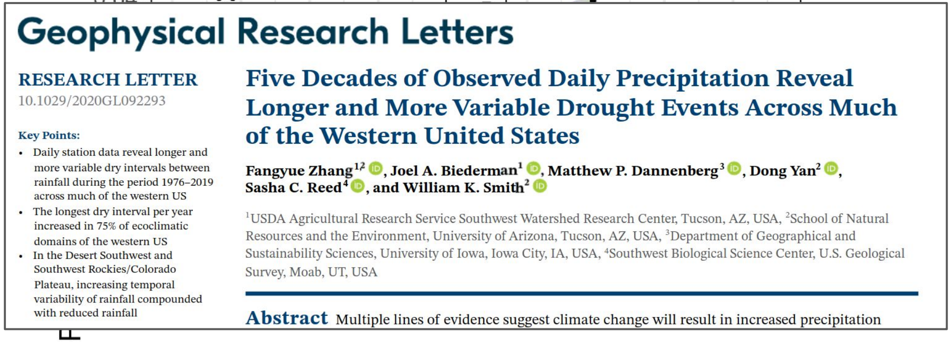
POLICYFORUM

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

P. C. D. Milly,[1]* Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]



Geophysical Research Letters

RESEARCH LETTER

10.1029/2020GL092293

Key Points:

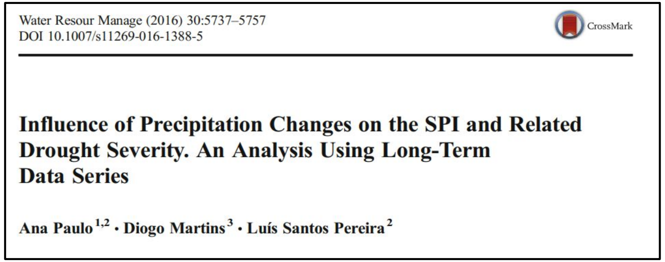
- Daily station data reveal longer and more variable dry intervals between rainfall during the period 1976–2019 across much of the western US
- The longest dry interval per year increased in 75% of ecoclimatic domains of the western US
- In the Desert Southwest and Southwest Rockies/Colorado Plateau, increasing temporal variability of rainfall compounded with reduced rainfall

Five Decades of Observed Daily Precipitation Reveal Longer and More Variable Drought Events Across Much of the Western United States

Fangyue Zhang[1,2], Joel A. Biederman[1], Matthew P. Dannenberg[3], Dong Yan[2], Sasha C. Reed[4], and William K. Smith[2]

[1]USDA Agricultural Research Service Southwest Watershed Research Center, Tucson, AZ, USA, [2]School of Natural Resources and the Environment, University of Arizona, Tucson, AZ, USA, [3]Department of Geographical and Sustainability Sciences, University of Iowa, Iowa City, IA, USA, [4]Southwest Biological Science Center, U.S. Geological Survey, Moab, UT, USA

Abstract Multiple lines of evidence suggest climate change will result in increased precipitation

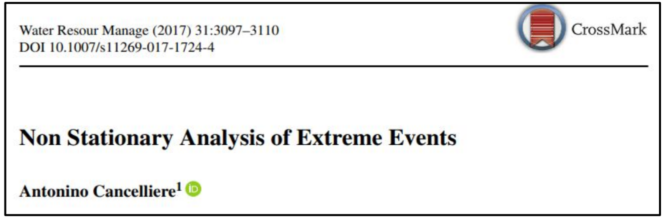


Water Resour Manage (2016) 30:5737–5757
DOI 10.1007/s11269-016-1388-5

CrossMark

Influence of Precipitation Changes on the SPI and Related Drought Severity. An Analysis Using Long-Term Data Series

Ana Paulo[1,2] · Diogo Martins[3] · Luís Santos Pereira[2]



Water Resour Manage (2017) 31:3097–3110
DOI 10.1007/s11269-017-1724-4

CrossMark

Non Stationary Analysis of Extreme Events

Antonino Cancelliere[1]

Contribution of historical precipitation change to US flood damages

Frances V. Davenport[a,1], Marshall Burke[a,b,c], and Noah S. Diffenbaugh[a,d]

[a]Department of Earth System Science, Stanford University, Stanford, CA 94305; [b]Center on Food Security and the Environment, Stanford University, Stanford, CA 94305; [c]Environment and Energy Economics, National Bureau of Economic Research, Cambridge, MA 02138; and [d]Woods Institute for the Environment, Stanford University, Stanford, CA 94305

Edited by Kerry A. Emanuel, Massachusetts Institute of Technology, Cambridge, MA, and approved December 16, 2020 (received for review August 18, 2020)

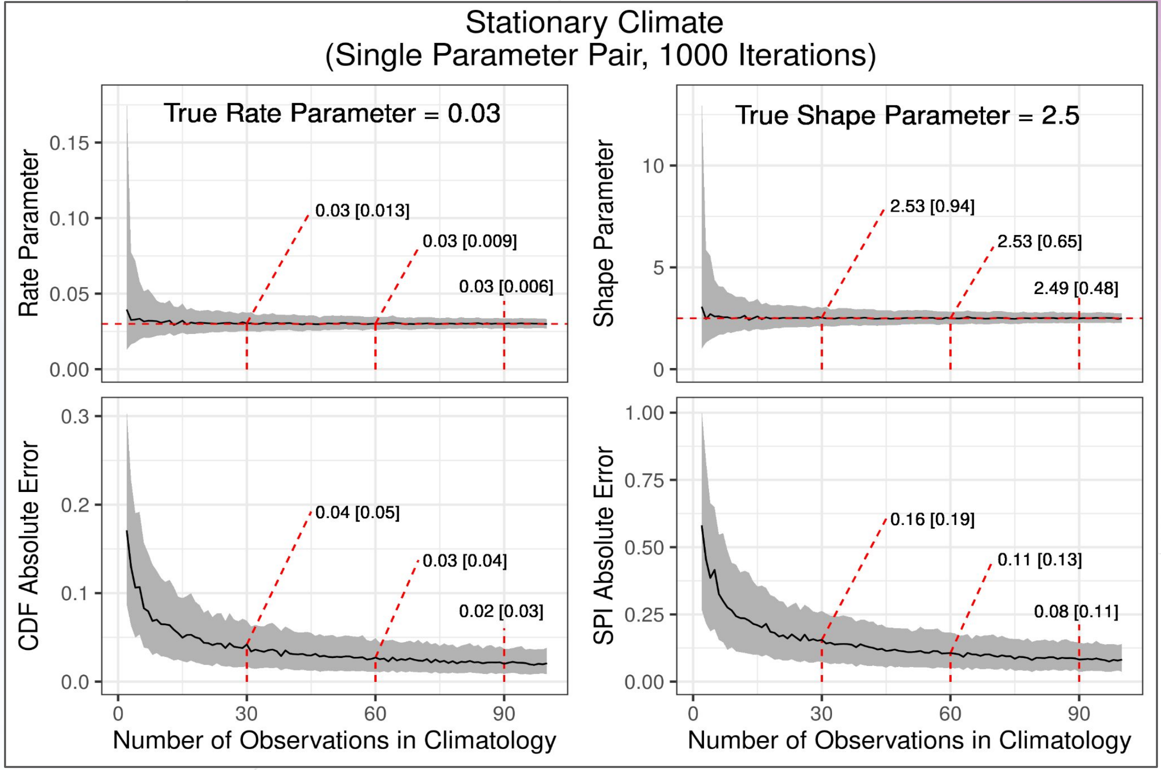
Methods, Data and Analysis (Q1)

Question #1: How much data is needed to compute drought metrics?

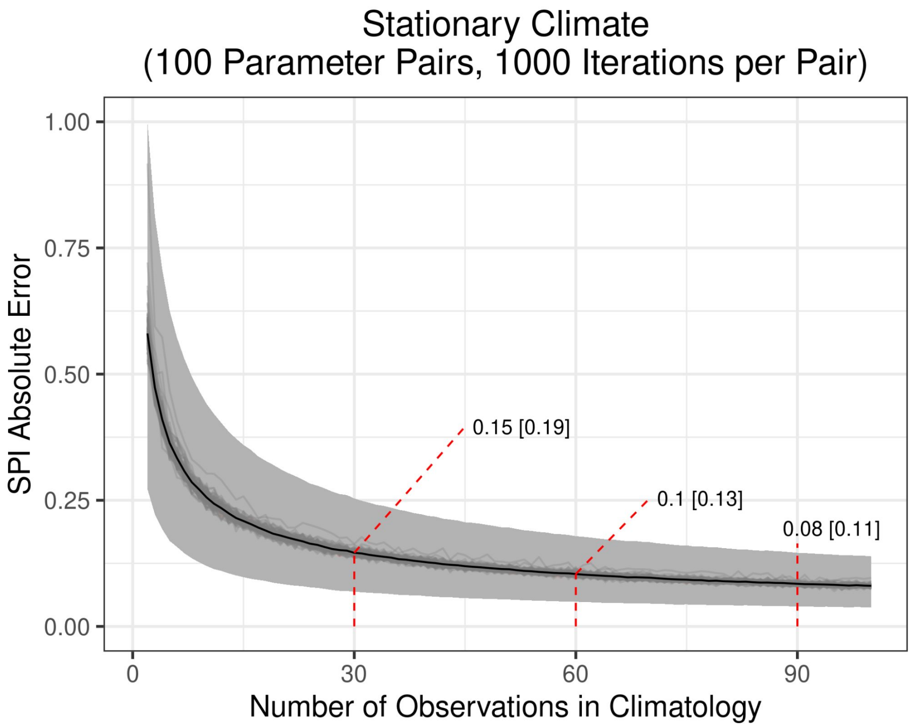
Method: Monte Carlo simulation to estimate drought metric error

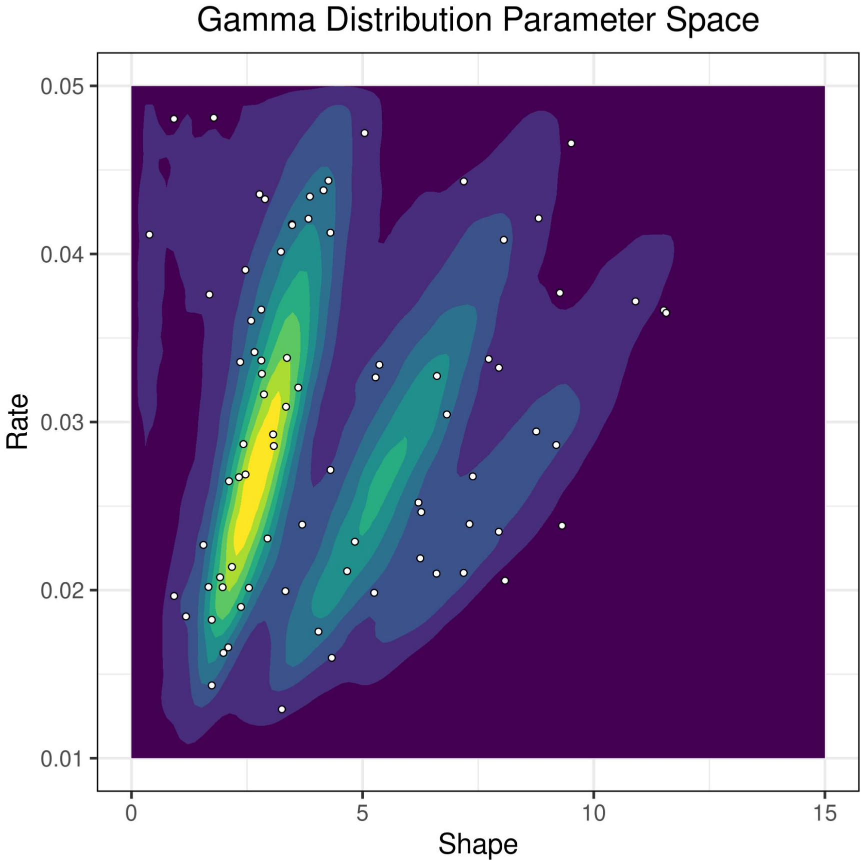
- Stationary climate assumptions (initially)
  - Quantify the relative change in error using short - long record lengths. Here we will use the Standardized Precipitation Index (SPI) to describe drought metric error
- Non-stationary climate simulations using observed climate velocities

Testing Conventional Assumptions - Climatology Length



Is This Parameter Specific?





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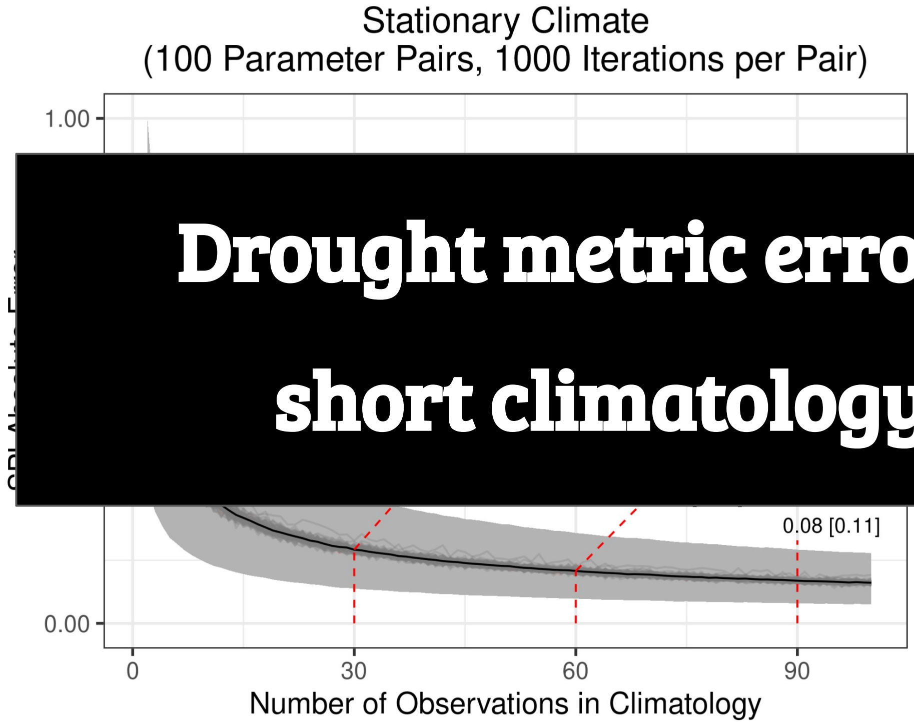
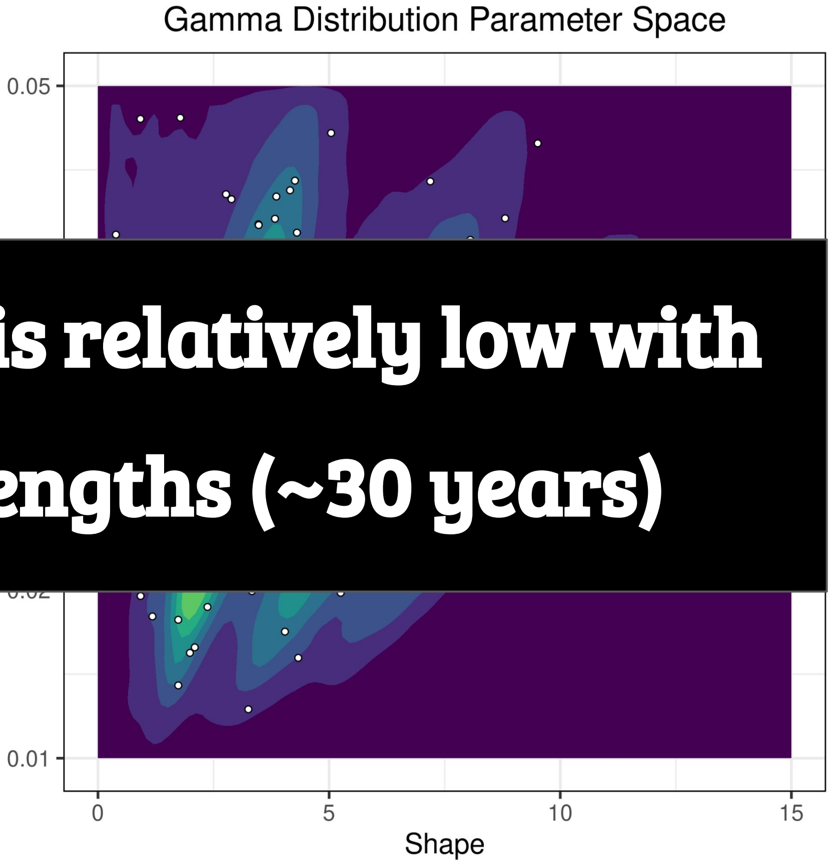
Is This Parameter Specific?

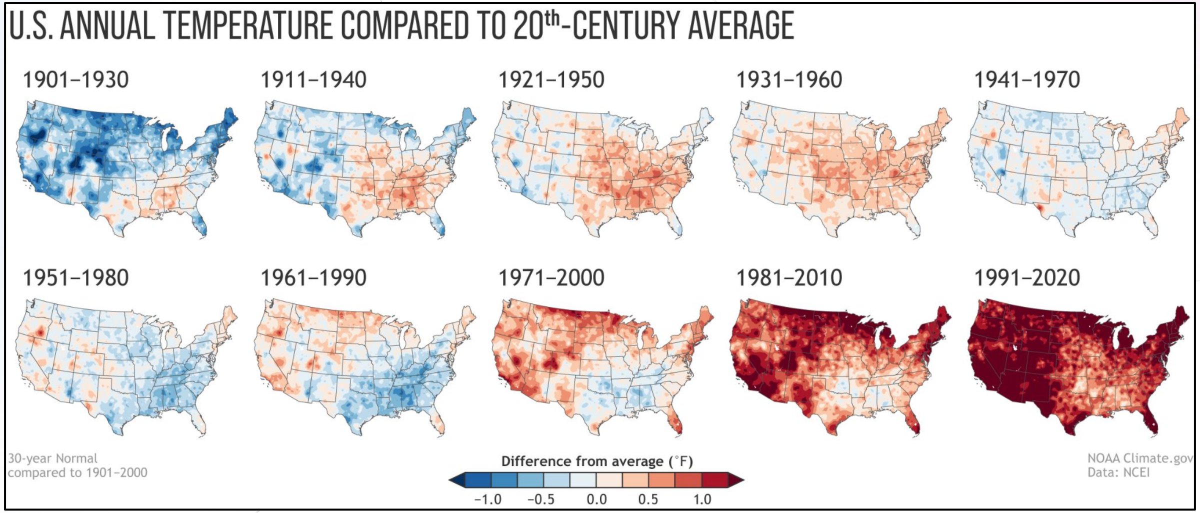




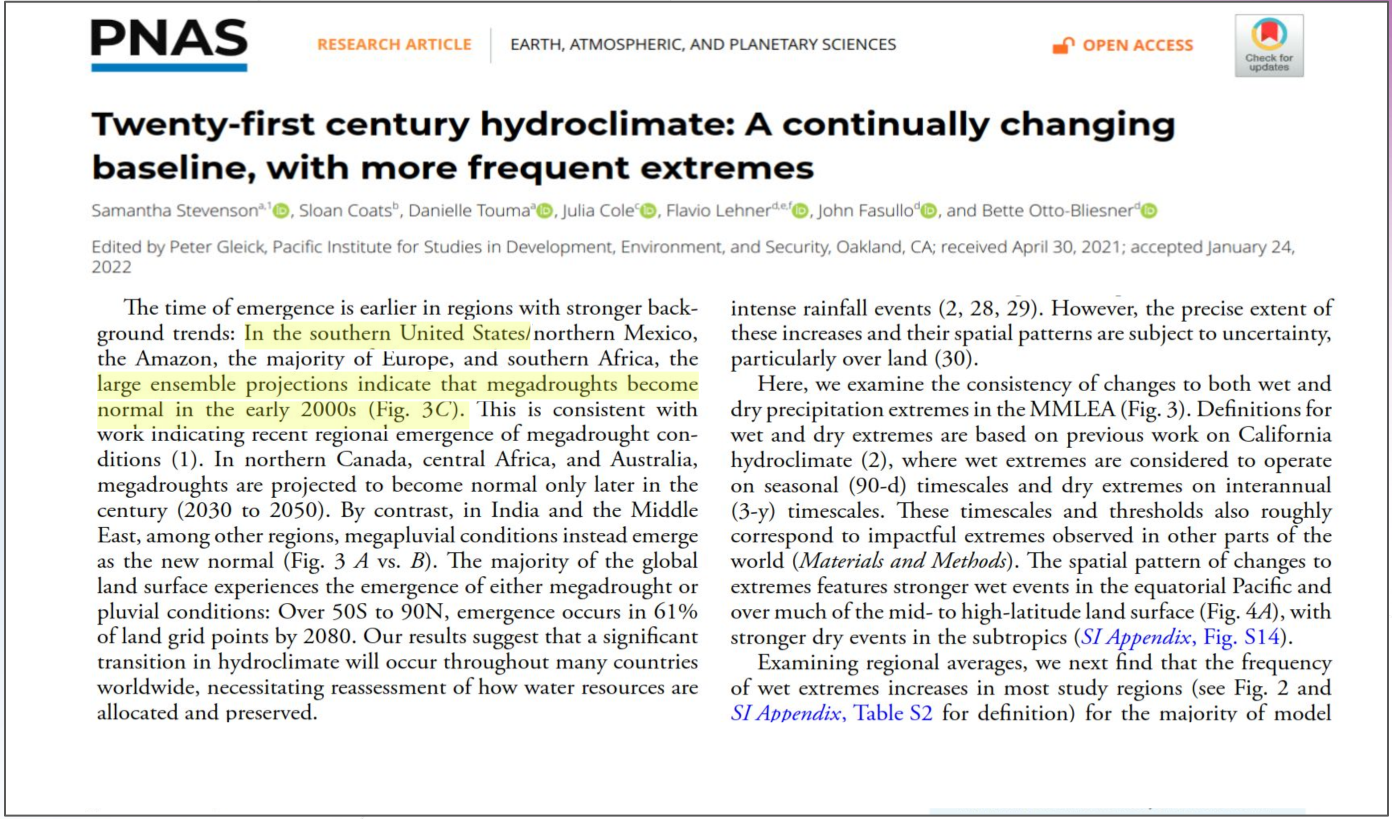
Drought metric error is relatively low with short climatology lengths (~30 years)

Climate change and reference periods — Why do we care?

- Drought is a relative phenomena, in space and in time
  - Without a shifting reference frame some places may eventually be in perpetual drought (or water “surplus”)
- Shifting reference frames in climate science are common
  - Critical to describe realistic expectations of climate variability



Have we already shifted to the new normal for drought?



PNAS RESEARCH ARTICLE | EARTH, ATMOSPHERIC, AND PLANETARY SCIENCES OPEN ACCESS

Twenty-first century hydroclimate: A continually changing baseline, with more frequent extremes

Samantha Stevenson[a,1], Sloan Coats[b], Danielle Touma[a], Julia Cole[c], Flavio Lehner[d,e,f], John Fasullo[d], and Bette Otto-Bliesner[d]

Edited by Peter Gleick, Pacific Institute for Studies in Development, Environment, and Security, Oakland, CA; received April 30, 2021; accepted January 24, 2022

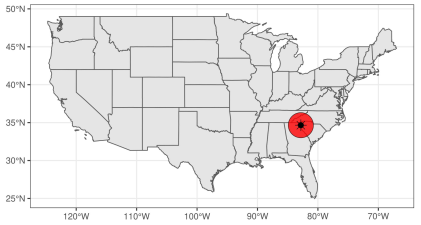
The time of emergence is earlier in regions with stronger background trends: In the southern United States/northern Mexico, the Amazon, the majority of Europe, and southern Africa, the large ensemble projections indicate that megadroughts become normal in the early 2000s (Fig. 3*C*). This is consistent with work indicating recent regional emergence of megadrought conditions (1). In northern Canada, central Africa, and Australia, megadroughts are projected to become normal only later in the century (2030 to 2050). By contrast, in India and the Middle East, among other regions, megapluvial conditions instead emerge as the new normal (Fig. 3 *A* vs. *B*). The majority of the global land surface experiences the emergence of either megadrought or pluvial conditions: Over 50S to 90N, emergence occurs in 61% of land grid points by 2080. Our results suggest that a significant transition in hydroclimate will occur throughout many countries worldwide, necessitating reassessment of how water resources are allocated and preserved.

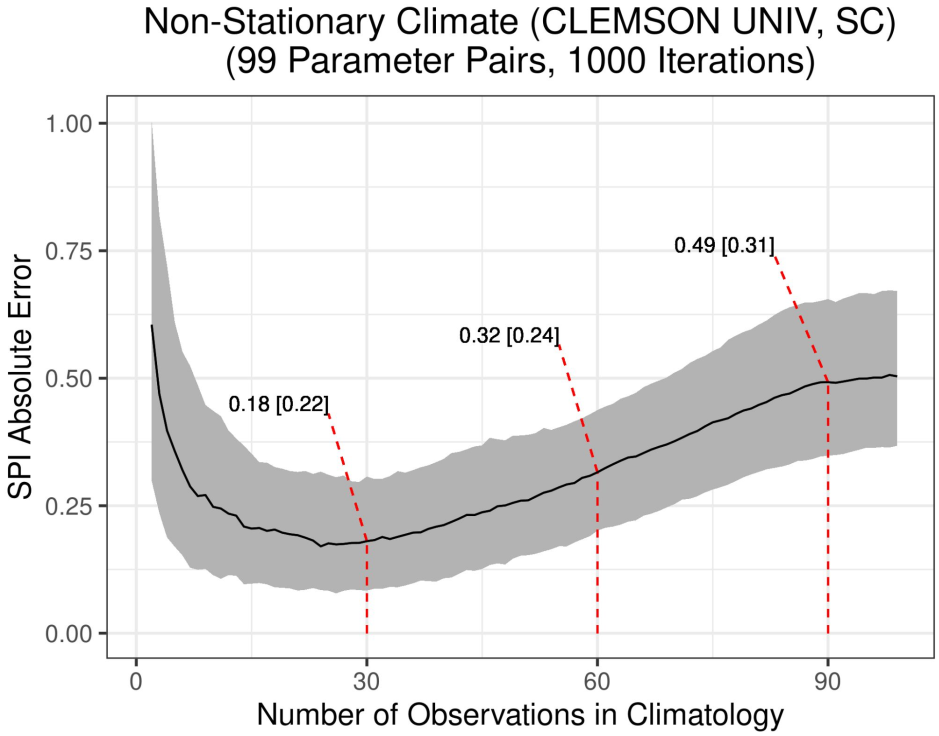
intense rainfall events (2, 28, 29). However, the precise extent of these increases and their spatial patterns are subject to uncertainty, particularly over land (30).

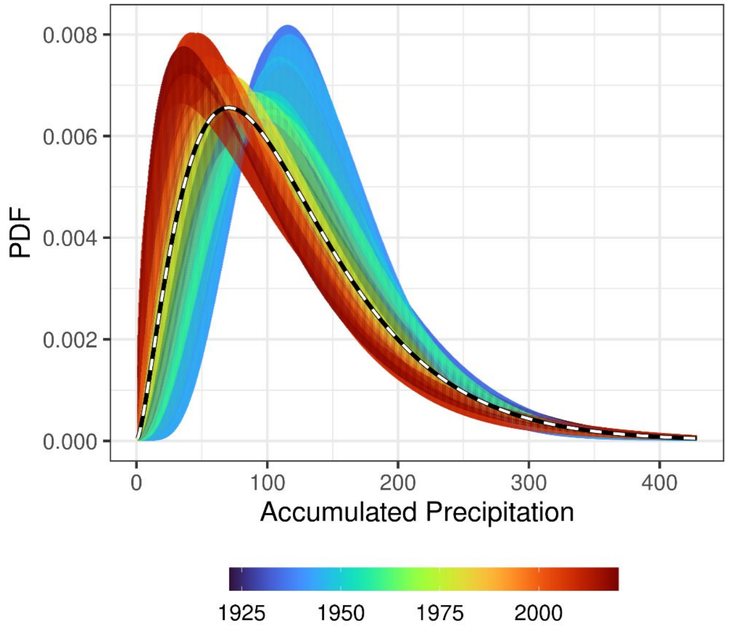
Here, we examine the consistency of changes to both wet and dry precipitation extremes in the MMLEA (Fig. 3). Definitions for wet and dry extremes are based on previous work on California hydroclimate (2), where wet extremes are considered to operate on seasonal (90-d) timescales and dry extremes on interannual (3-y) timescales. These timescales and thresholds also roughly correspond to impactful extremes observed in other parts of the world (*Materials and Methods*). The spatial pattern of changes to extremes features stronger wet events in the equatorial Pacific and over much of the mid- to high-latitude land surface (Fig. 4*A*), with stronger dry events in the subtropics (*SI Appendix*, Fig. S14).

Examining regional averages, we next find that the frequency of wet extremes increases in most study regions (see Fig. 2 and *SI Appendix*, Table S2 for definition) for the majority of model

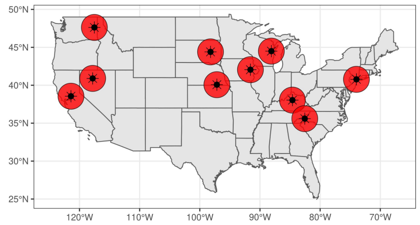
Drought Metric Error (Non-Stationary)

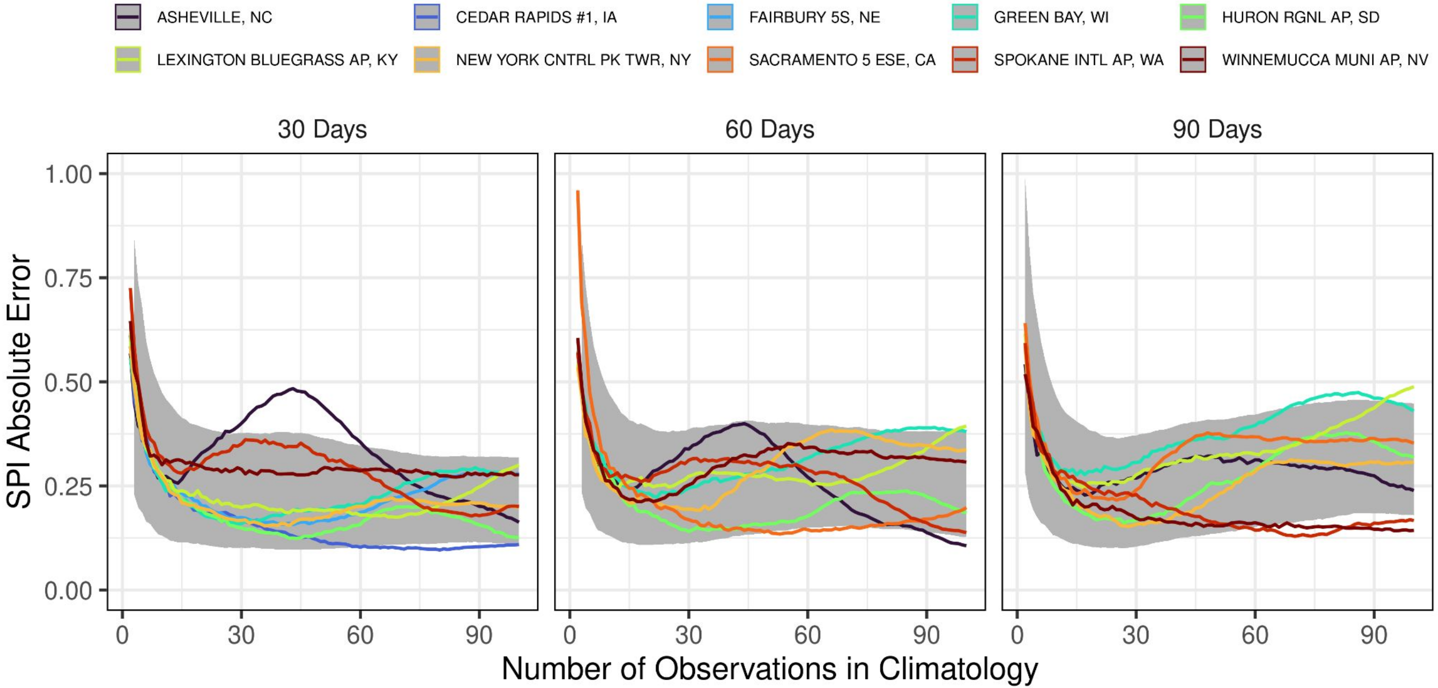




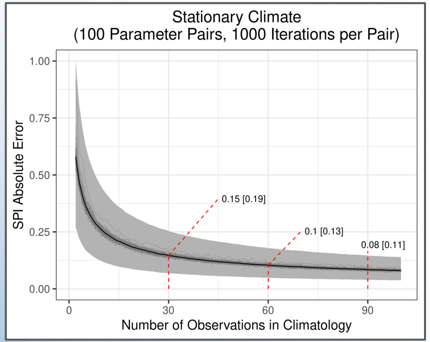


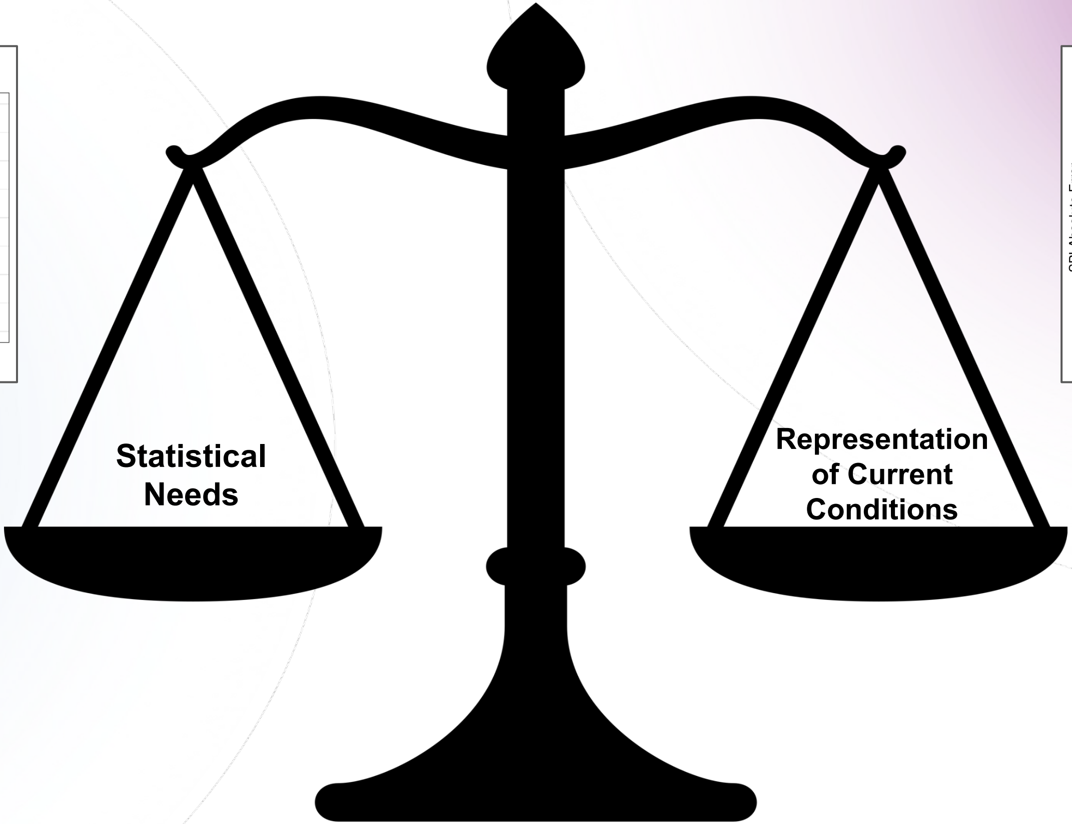
Error is Site and Timescale Specific





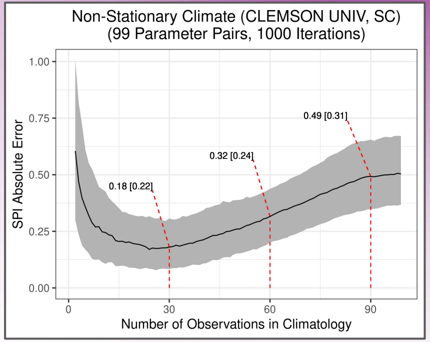
Adaptive Drought Assessment Requires Balance





Statistical Needs

Representation of Current Conditions



Methods, Data and Analysis

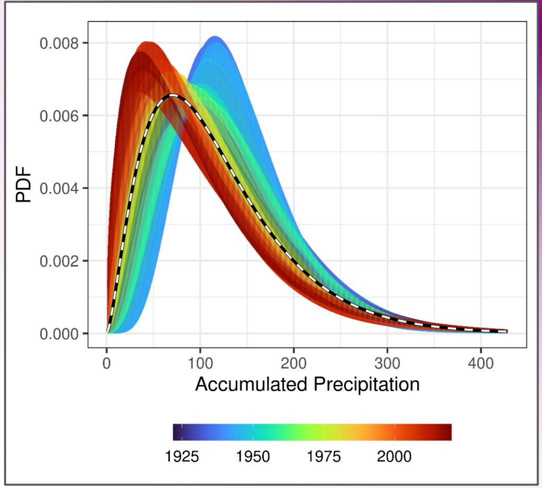
Question #2: Do long climatology lengths bias drought assessment?

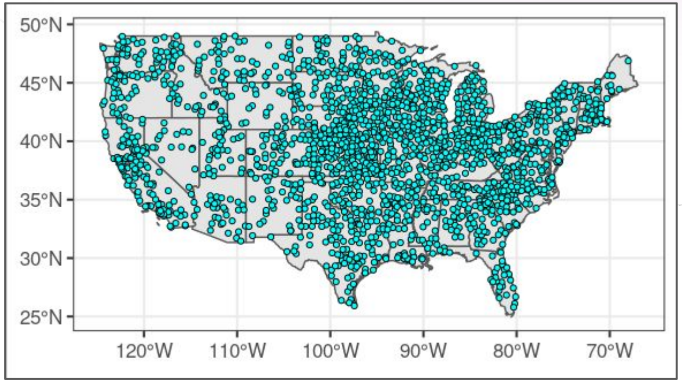
Method: Compute daily time series of SPI using different reference periods

- Longest (Period of Record) climatologies versus contemporary 30 year climatologies

Sites: 1934 GHCN sites with > 70 years of <u>complete</u> rainfall time series

- Daily SPI for June 1st - August 31st, 1991-2020
- Total of 4,907,001 probability distributions

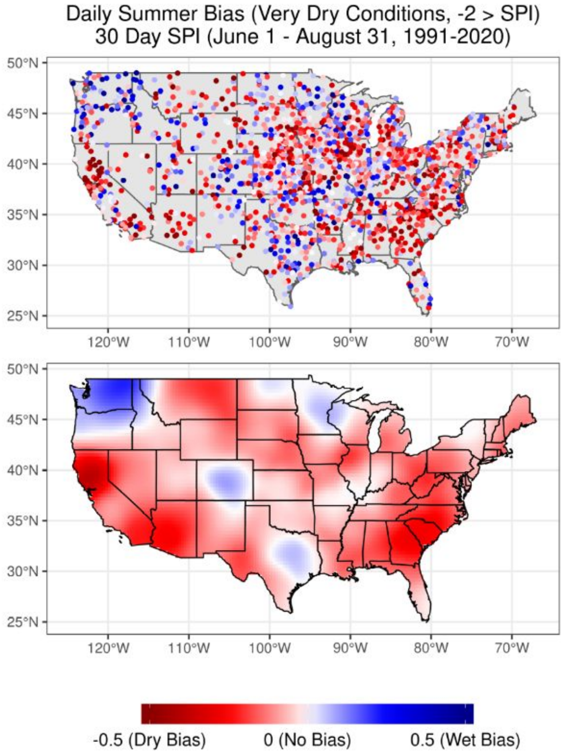




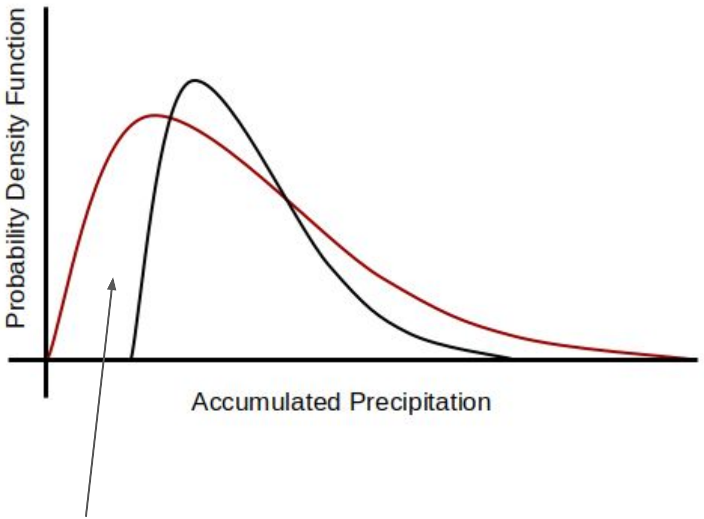
Drought metric bias due to climate change

Comparing daily drought metric bias from 1991-2020

$\text{BIAS} = \text{SPI}_{POR} - \text{SPI}_{1991\text{-}2020}$ (Period of Record [POR] represents >70 years)



Daily Summer Bias (Very Dry Conditions, -2 > SPI)
30 Day SPI (June 1 - August 31, 1991-2020)



Drought metric bias due to climate change

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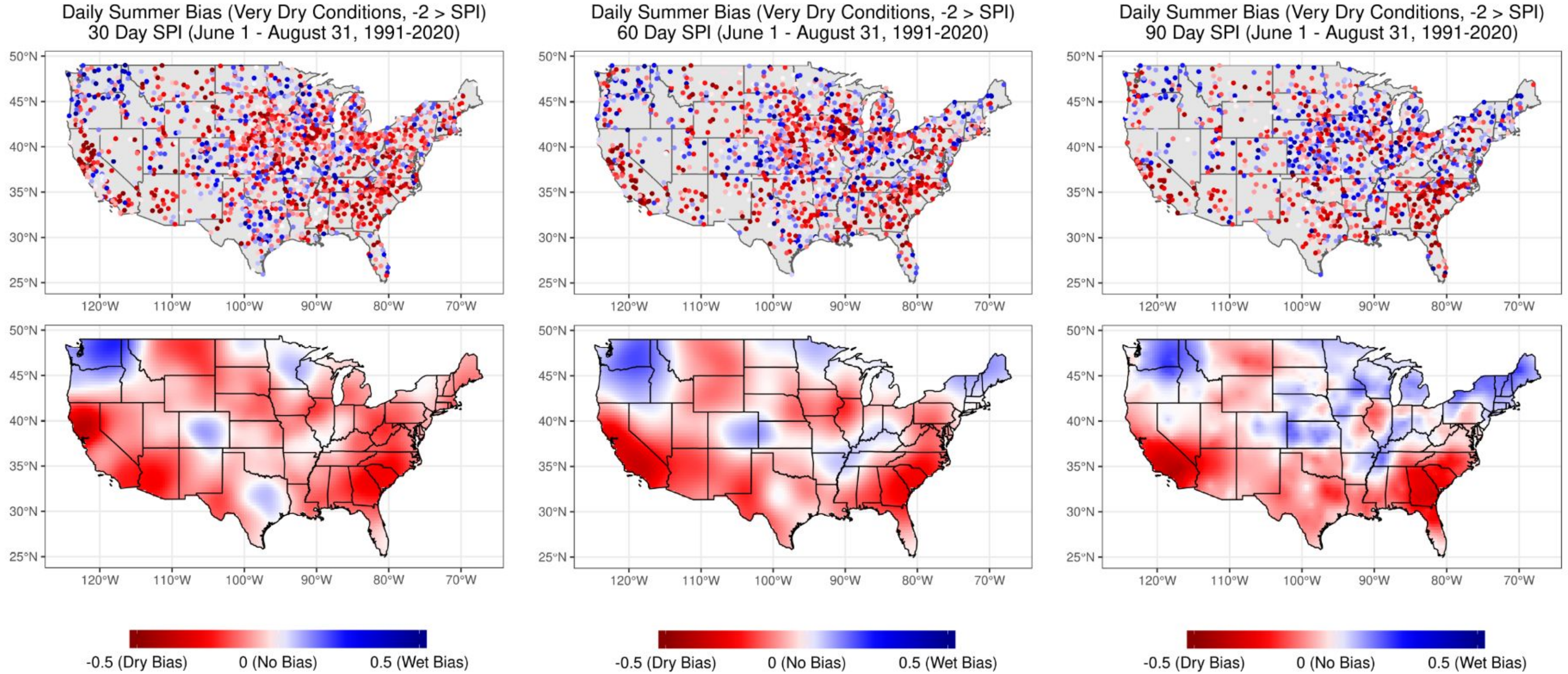

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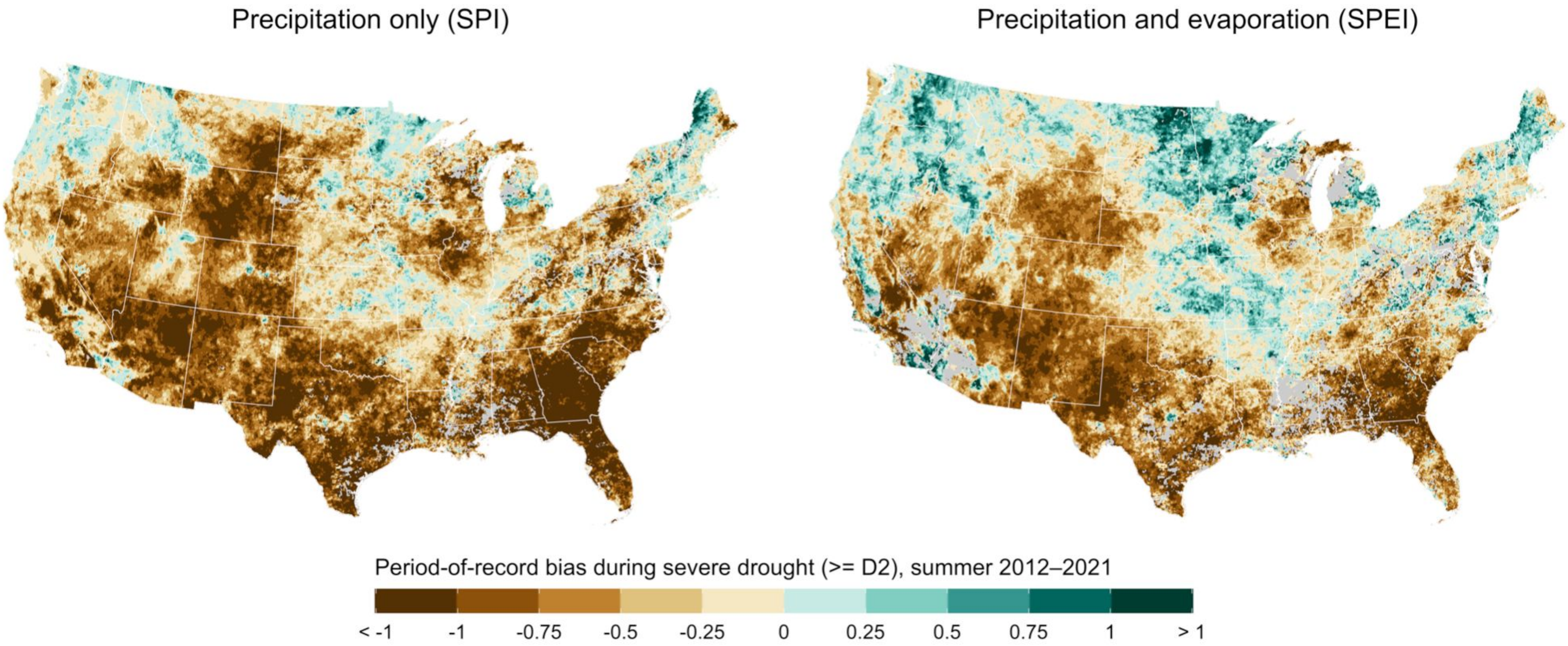
Drought Assessment and Climate Change
Zachary Hoylman, Kyle Bocinsky & Kelsey Jencso
Montana Climate Office
NIDIS Joint DEWs (Omaha, NE - 10/13/2022)

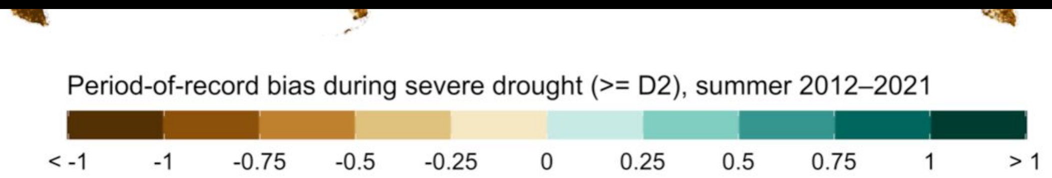
Drought bias exceeds +/-1 class during severe drought



Drought bias exceeds +/-1 class during severe drought

Recommendations?

- Leverage the 30 year “normals” concept in drought assessments
- Align drought assessment with contemporary conditions
- Develop targeted climate adaptation programs where drought is changing



Precipitation only (SPI)

Precipitation and evaporation (SPEI)

Period-of-record bias during severe drought (>= D2), summer 2012–2021

Drought monitoring impacted by aridification

- Under stationary assumptions, **drought severity is exaggerated in locations that are experiencing aridification**, and underrepresented in locations that are getting wetter.
- **This concept applies to other metrics commonly used in drought assessment.**
- Shifting to 30-year drought climatologies achieves the following goals:
    a. Drought assessment will better reflect “current day” drought risk to affected communities;
    b. Greater standardization across datasets with differing periods of record;
    c. Better accounting for climate change into the future.

nature COMMUNICATIONS

ARTICLE

Check for updates

https://doi.org/10.1038/s41467-022-30316-5

OPEN

Drought assessment has been outpaced by climate change: empirical arguments for a paradigm shift

Zachary H. Hoylman[1,2]✉, R. Kyle Bocinsky[1,3] & Kelsey G. Jencso[1,2]

Thank You!

Zachary Hoylman

zachary.hoylman@umontana.edu