Spatiotemporal Variability of Flash Drought in the Continental United States

Kyle Lesinger[1] and Di Tian[1]

[1]Auburn University

November 26, 2022

Abstract

Flash droughts are a recently recognized extreme climate phenomena that occur at the subseasonal timescale and develop with sudden onset and rapid intensity, which have significant socio-environmental impacts on agriculture, ecosystem, and water resources. However, the spatial and temporal variability of flash droughts in the continental United States (CONUS) are still not well understood. In this study, we characterize flash drought events using a novel evaporative demand flash drought (EDFD) index as well as a soil moisture flash drought (SMFD) index at the weekly timescale between September 1981 and December 2018. Hierarchical clustering divided CONUS into different clusters where SMFDs occur synchronously over space and time. The results show that flash droughts occur in all seasons and regions in CONUS with increasing trends in EDFDs (0.07 $>$ tau $>$ 0.28), but not equal trends in SMFDs (-0.12 $>$ tau $>$ 0.08). Periodic short-term behavior between EDFDs and SMPDs was identified in all clusters but more importantly long-term oscillatory behavior is identified between the two indexes in all clusters except the Northwest US. Our research into the spatiotemporal variability of flash droughts using both the EDFD index and SMPD index displays that CONUS is still at risk for increased flash drought events in the future to come.

Spatiotemporal Variability of Flash Droughts in the Continental United States

Kyle Lesinger and Dr. Di Tian
Auburn University
Department of Crop, Soil, & Environmental Sciences

Background

- Flash droughts are droughts that occur with a rapid onset and intensification and can be initiated by optimal conditions of high temperature and cloud-limited skies, low precipitation, high wind speed, high vapor pressure deficit, low humidity, or associated land-atmosphere feedbacks which drive drought severity[1]. These droughts can develop in as little as 2-8 weeks and can adversely impact agriculture, municipal water resources, or ecosystem health.
- The 2012 United States Midwest flash drought went from moderate to extreme drought conditions across nearly half of the country within two months and cost agricultural sectors nearly $34 billion in losses and over 120 lives were lost in the associated summer heatwave[2] (see Fig. 1).

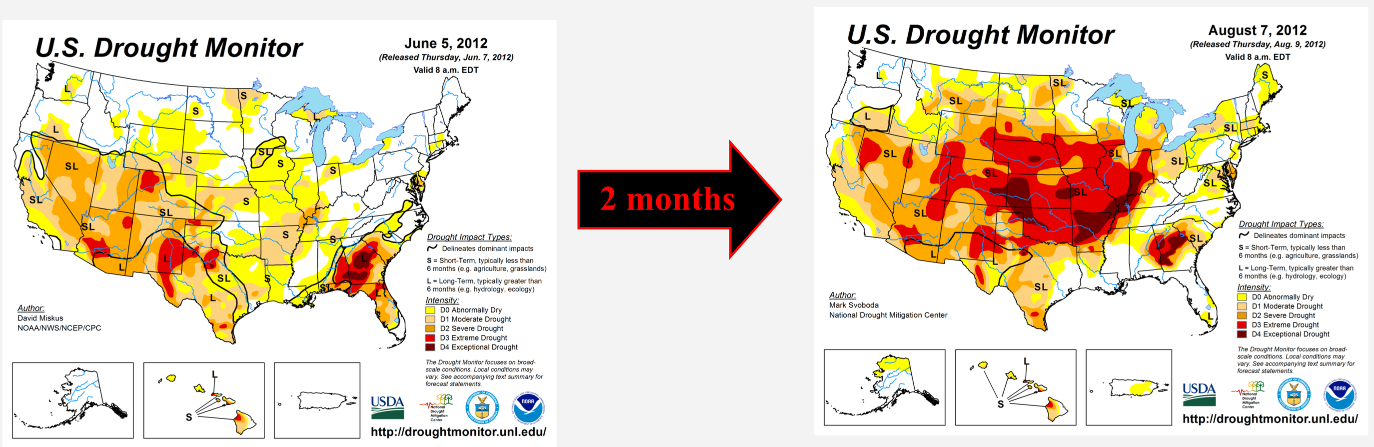


Fig. 1. Flash drought progression across the United States over the two month period June 5—August 7, 2012.

- Flash droughts are identified by rapid increases in evaporative demand (ED) or rapid decreases in soil moisture (SM) which can indicate evaporative, water, and/or heat stress but no study has comprehensively assessed interannual variability and association between flash drought severity and large-scale oscillation activity.
- The objectives of this study are to a.) understand spatial patterns of flash droughts b.) identify the temporal patterns within each CONUS region, and c.) understand the association between severe flash droughts and large-scale oscillations. This research methodology can increase our understanding of flash drought variability and knowledge of impacts from large-scale patterns may be helpful for informing long-term forecast of flash drought.

Data

Table 1. Description of datasets used to identify the spatiotemporal variability of flash droughts.

Data Source	Temporal Resolution	Spatial Resolution	Variable(s)	Notes
Evaporative Demand Drought Index (EDDI)	Daily-Monthly*	0.125°	Evaporative Demand	*Multi-scalar index
SMERGEv2.0	Daily	0.125°	Soil Moisture	0-40cm root-zone soil moisture (RZSM) depth
gridMET	Daily	~ 4km	T_{avg}, Precip., PET	Blended gridded PRSIM and NLDAS-2 data
GLEAM	Daily	0.25°	Evapotranspiration (ET)	Includes actual ET, soil ET, and transpiration

Table 2. Oscillations analyzed identify regional associations between severe flash drought activity and different oscillation phases.

Oscillation	Abbr.	Area of Classification	Classification Methods
El Niño Southern Oscillation	ENSO	Pacific Ocean	Sea-surface temperature (SST) anomalies exceed +/- 0.4°C for six months (El Nino/La Nina respectively). ENSO- = La Niña, ENSO+ = El Niño
Atlantic Multidecadal Oscillation	AMO	Atlantic Ocean	Higher/Lower than average SSTs (AMO+ positive and AMO- negative respectively.)
North Atlantic Oscillation	NAO	Atlantic Ocean	Strong Azores high and Icelandic low—NAO+ Weak Azores high and Icelandic high—NAO-
Pacific Decadal Oscillation	PDO	Pacific Ocean	Cooler waters in Pacific Basin—PDO+ Warmer waters in Pacific Basin—PDO-
Arctic Oscillation	AO	Mid– to High–Latitudes of NH	Lower than average pressure over Arctic—AO+ Higher than average pressure over Arctic—AO-
Madden-Julian Oscillation	MJO	Indian Ocean/ Pacific Ocean	Eastward moving 'pulse' of cloud and rain measured by RMM indexes—cloud and wind measurements.

Methodology

Flash Drought Identification

- Definition 1 → **Evaporative Demand Flash Drought (EDFD)**: 50% increase in EDDI over 2 weeks and sustained for another 2 weeks.
- Definition 2 → **Soil Moisture Percentile Drop (SMPD)**: Decrease in soil moisture from above the 40th to below the 20th percentile in 3 weeks or less.

Hierarchical Agglomerative Clustering

- Finding grid cells experiencing similar flash drought conditions over time.

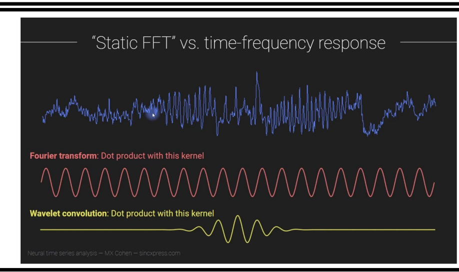
Jaccard Similarity

$$J(A,B) = \frac{|A \cap B|}{|A \cup B|}$$

\+ **Ward's Minimum Variance Method**

Wavelet Analysis

- Time series converted into time-frequency space.



Conditional Probability

$$P(Flash\ drought \mid Oscillation) = \frac{P(Flash\ drought \cap Oscillation)}{P(Oscillation)} \times 50{,}000 \text{ simulations}$$

Results

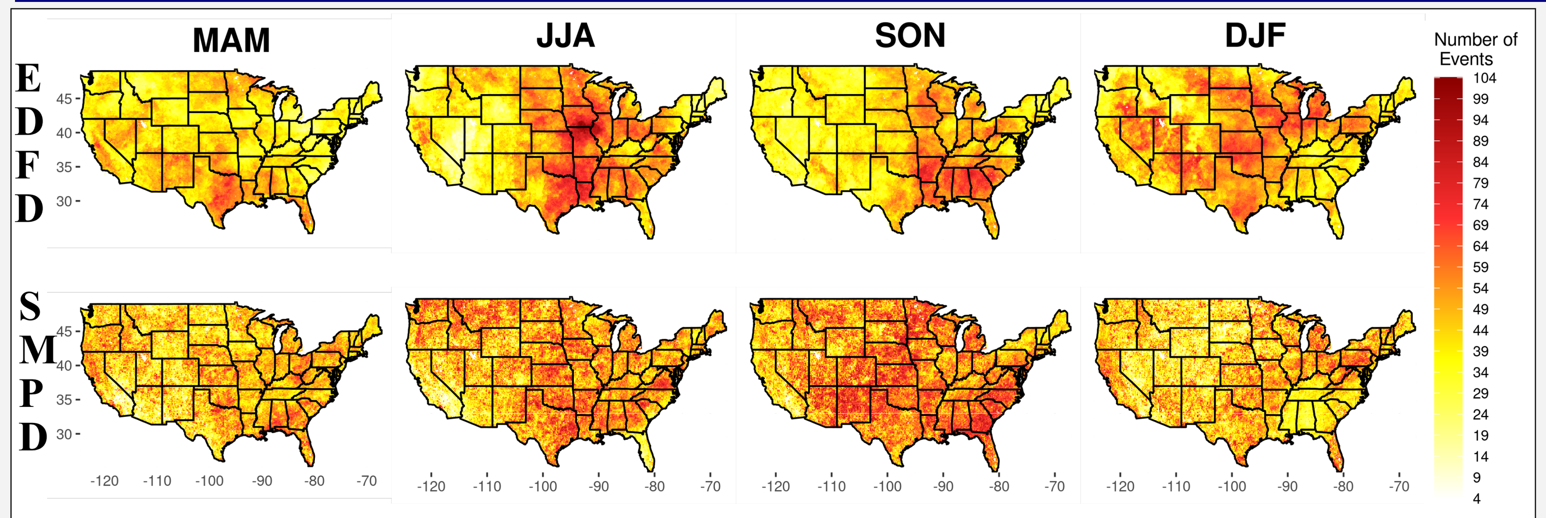


Fig. 2. Seasonal distribution of evaporative demand (EDFD) and soil moisture (SMPD) flash drought events between 1981-2018. All flash drought events are at least two weeks long.

Spatial and Temporal Variability

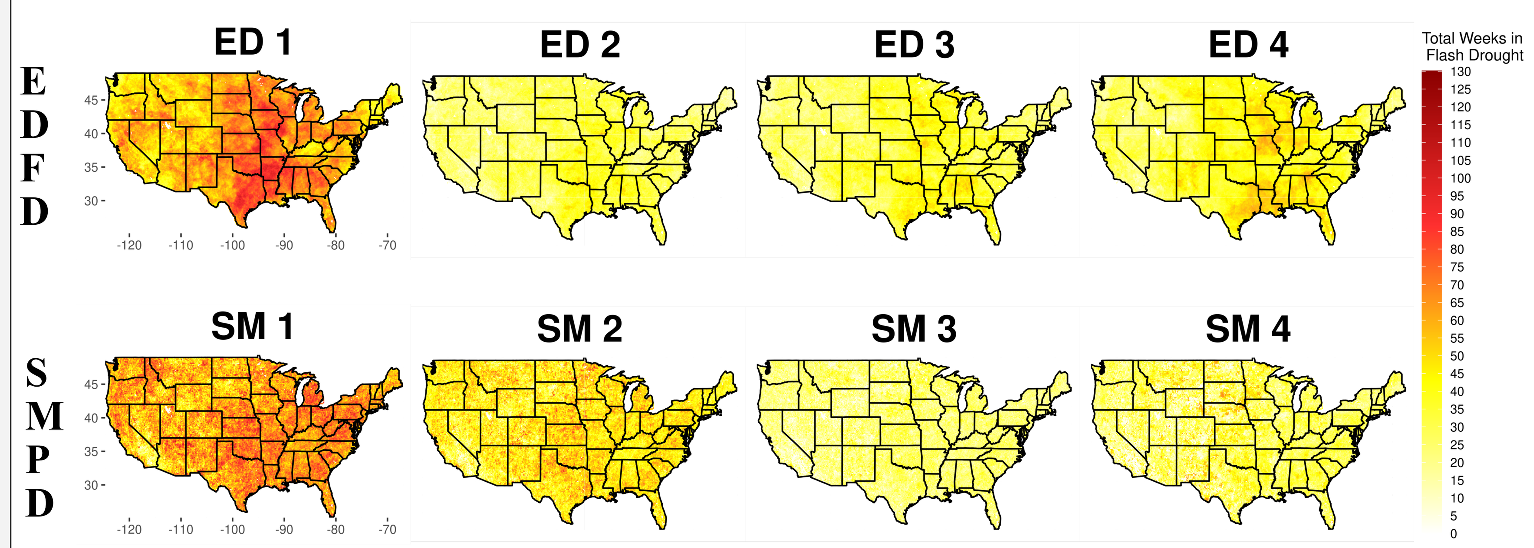
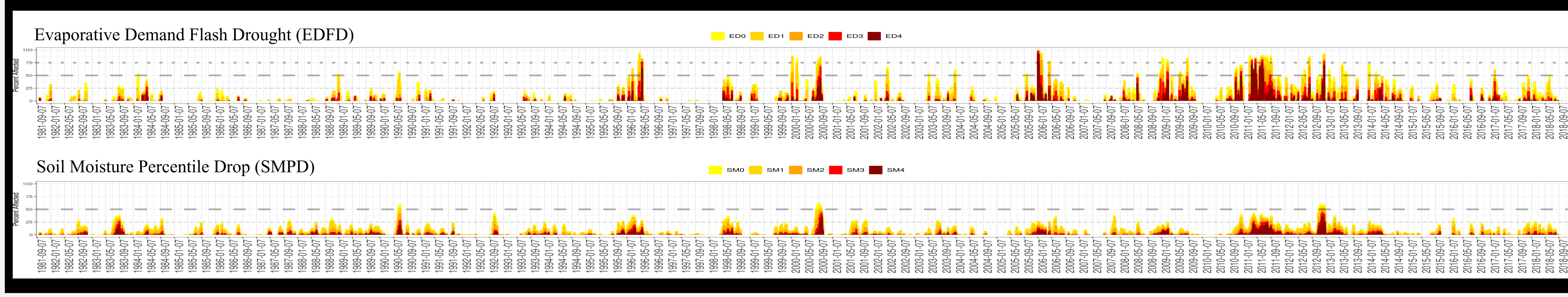


Fig. 3. Total number of weeks in flash drought for drought intensity categories. Drought intensity increases from left to right. Category 1 (i.e., ED 1) is drought present and conditions above the 80th percentile, Category 2 is 90th, Category 3 is 95th, and Category 4 is 98th percentile.

South Region Weekly Time Series for Evaporative Demand and Soil Moisture Flash Drought Cluster Coverage



Results

Clustering

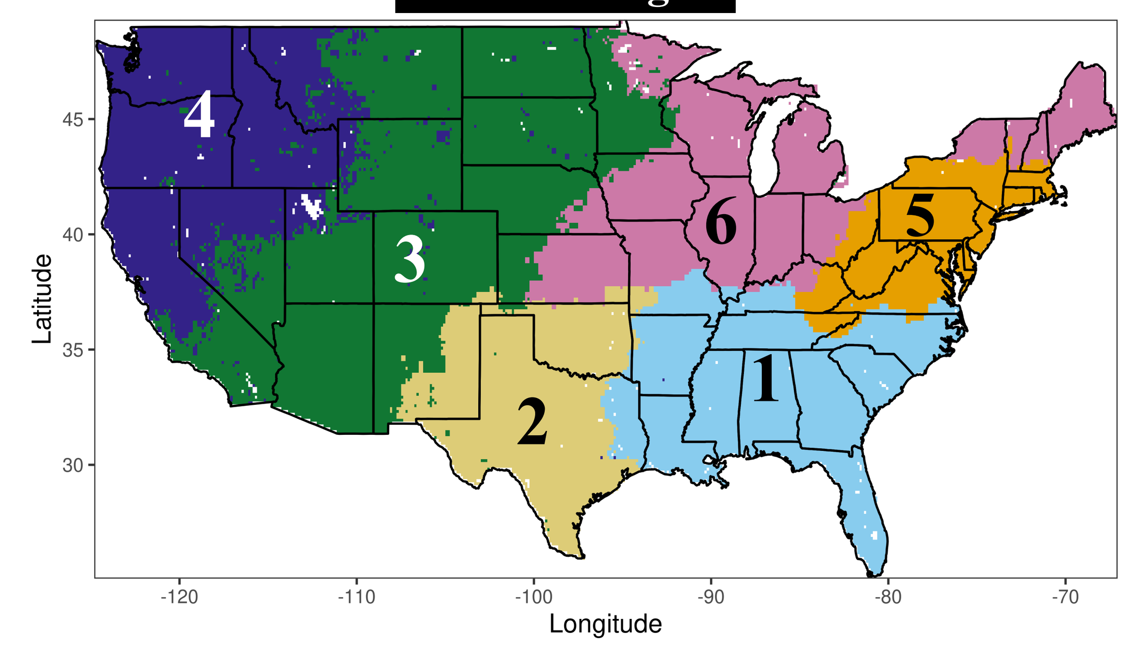


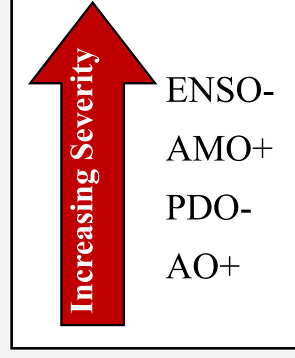
Fig. 4. Six SMPD clusters generated after hierarchical agglomerative clustering using ward's minimum variance method.

Trends

Cluster Number	Cluster Name	EDFD	SMPD	RZSM	EDDI	PET	ET	Tavg	Precip.
1	Southeast	0.28***	0.02	-0.05**	0.19***	0.06***	0.03	0.03	0.01
2	South	0.19***	0.05**	-0.03	0.1***	0.05**	-0.01	0.03	-0.02
3	West	0.15***	0.08***	-0.05*	0.14***	0.03*	-0.02	0.03	0
4	Northwest	0.07***	0.01	-0.09***	0.17***	0.04*	-0.01	0.03*	-0.02
5	Northeast	0.21***	-0.12***	0.02	0.16***	0.03	0.03	0.03	0.03
6	Upper Midwest	0.24***	0.02	-0.05***	0.25***	0.03*	0.03	0.02	0.03*

Table 3. Mann-Kendall cluster trends results for each CONUS region. Positive trends are colored red and negative trends are colored blue. Significance values are placed beside each trend value with (*** = $p < 0.001$) and (** = $p < 0.01$) and (* = $p < 0.05$).

Major oscillations impacting flash drought severity:



Conditional Probability

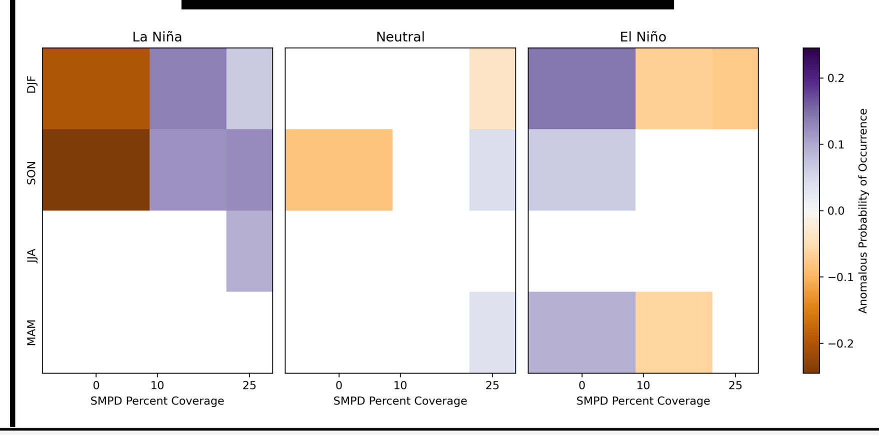


Fig 5. Southeast cluster probability of flash drought severity conditioned on both season and ENSO phases. All colored values are significant at the 90% confidence level. Purple indicates higher probabilities of occurrence and orange indicates lower probabilities.

Conclusions

- Flash droughts can occur anywhere in the United States and occur most often during the warm season (Mar.-Nov.). Severe flash droughts are highly associated with large-scale oscillations such as La Niña (ENSO-) and during AMO+ phases.
- Flash drought definitions that only rely on evaporative demand may overestimate actual drought conditions, multiple definitions are optimal.
- The South and West regions have increasing soil moisture flash drought trends because of strong land-atmosphere coupling when soil moisture is low. These regions also have decreasing precipitation trends and increasing evaporative demand trends which may contribute to future flash drought events.

References
[1]NCEI. U.S. Billion Dollar Weather and Climate Disasters. https://www.ncdc.noaa.gov/billions/. Accessed date 5 May 2021.
[2]Pendergrass et al. (2020). Flash Droughts Present a New Challenge for Subseasonal-to-Seasonal Prediction. Nature Climate Change. https://doi.org/10.1038/s41558-020-0709-0. s