

Multivariate Evaluation of Flash Drought Across the United States using the Flash Drought Intensity Index

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Drought Classifications

- Drought is a naturally feature of the climate system that refers to a water deficit
 - Meteorological drought – precipitation deficits
 - Agricultural drought – impacts of soil moisture on vegetation
 - Hydrological drought – surface and ground water deficits
 - Socioeconomic drought – impacts on availability of economic goods
 - Ecological drought – impacts on natural ecosystems
 - Snow drought – below-normal snowpack
 - Flash drought – drought that develops quickly over a few weeks

Flash Drought Characteristics

- Drought is usually thought of as being a slowly-developing climate phenomenon; however, its onset can be very rapid
- Rapid drought development is most likely when extreme weather anomalies remain over the same area for several weeks or more
 - Below normal rainfall, hot temperatures, strong winds, low humidity, and sunny skies can lead to rapid drawdown in root zone soil moisture
 - This can lead to the rapid emergence of agricultural and ecological drought conditions even when rainfall departures are not large
- Can have a larger impact than a conventional drought because there is less time to prepare for its adverse effects

Why Are Flash Droughts Important?

- Many high-impact flash drought events in recent years, both in the U.S. and globally

- Flash droughts occur most often during the growing season
- Can lead to rapid browning and potential death of plants
- Lower crop yields, less forage for livestock, and larger and more intense wildfires

Marena, OK Phenocam - 01 July 2012



Flash drought

Marena, OK Phenocam - 11 August 2012



Marena, OK Phenocam - 01 July 2014



Normal year

Marena, OK Phenocam - 11 August 2014



NOAA



Samantha Powers

Multivariate Drought Indicators

- For this study, we chose to use:
 - Evaporative Stress Index (satellite-based ET)
 - 0-40 cm soil moisture from NLDAS-2 Noah
 - Evaporative Demand Drought Index (evaporative demand)
 - SPI and SPEI (precipitation-based metrics)
 - U.S. Drought Monitor (expert-based, multivariable analysis)
 - Combined flash drought indicator (all variables, except for USDM)
- CONUS climatology covering the 2001-2021 growing seasons

Motivation for a Flash Drought Intensity Index

- Most studies identify flash droughts based on rapid intensification, but do not assess its magnitude or the subsequent drought severity
- Critical limitation because impacts are closely tied not only to how quickly drought conditions develop but by how severe they become
- Would events such as the 2012 U.S. flash drought be considered exceptionally severe if heavy rainfall had rapidly terminated drought conditions at the end of the rapid intensification period (thereby preventing long-term drought conditions)?
- Important to consider both rate of intensification and subsequent drought severity when assessing flash drought characteristics

Flash Drought Intensity Index (FDII)

- FDII explicitly accounts for rapid rate of intensification (FD-INT) and the resultant drought severity (DRO-SEV)
- Can be computed using percentiles or standardized change anomalies
- Intensification and severity components computed relative to baseline values that represent minimum requirements for flash drought
- Minimum intensification rate equivalent to a -0.85 standardized change anomaly over a 3-week period ($\Delta\text{CHA-BASE}=-0.85$; $\Delta\text{T-BASE}=3$)
- FDII framework accommodates flash drought development over a range of time scales by searching for the maximum intensification over 2-to-7-week time periods

$$\text{FD-INT} = \left(\frac{\Delta\text{CHA-OBS}}{\Delta\text{T-OBS}} \right)_{\max} \cdot \left(\frac{\Delta\text{T-BASE}}{\Delta\text{CHA-BASE}} \right)$$

Flash Drought Intensification (FD-INT)

Standardized Anomalies

(a) DCHA-OBS DT-OBS	-0.85	-1.00	-1.25	-1.50	-1.75	-2.00
2 weeks	1.27	1.50	1.88	2.25	2.62	3.00
3 weeks	0.00	1.00	1.25	1.50	1.75	2.00
4 weeks	0.00	0.00	0.00	1.12	1.31	1.50
5 weeks	0.00	0.00	0.00	0.00	1.05	1.20
6 weeks	0.00	0.00	0.00	0.00	0.00	1.00
7 weeks	0.00	0.00	0.00	0.00	0.00	0.00



U.S. Drought Monitor

(b) DCHA-OBS DT-OBS	2	3	4	5
2 weeks	3.00	4.50	6.00	7.50
3 weeks	2.00	3.00	4.00	5.00
4 weeks	1.50	2.25	3.00	3.75
5 weeks	1.20	1.80	2.40	3.00
6 weeks	1.00	1.50	2.00	2.50
7 weeks	0.00	1.29	1.71	2.14



- FD-INT increases for larger changes occurring over shorter time periods

Flash Drought Intensity Index (FDII)

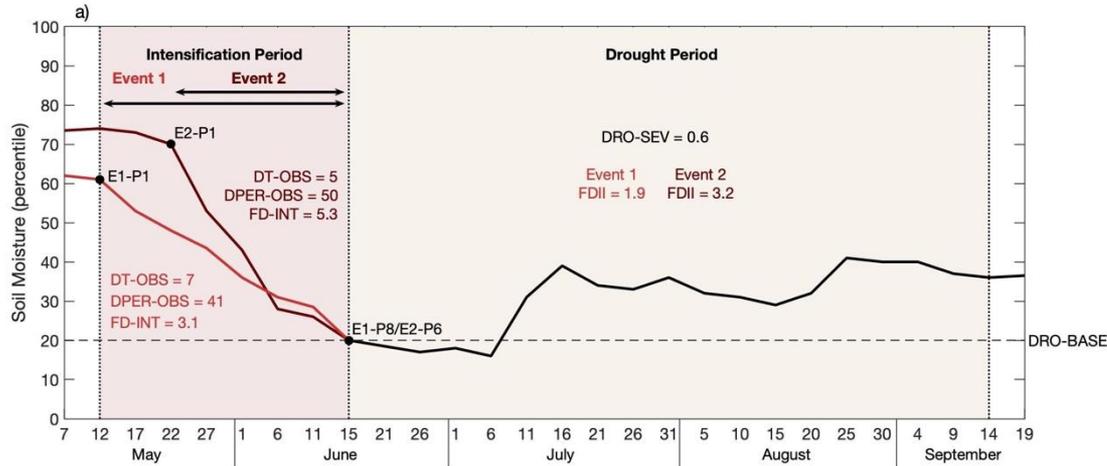
- After computing FD-INT, need to determine drought severity (DRO-SEV)
- Data from next 13 weeks following end of rapid intensification are used to represent long-term impacts of flash drought
- Variable must fall below -0.85 (DRO-BASE) for at least four consecutive weeks, but can rise above it within the 13-week period
- Allows us to consider drought severity over a range of time scales

$$\text{DRO-SEV} = \frac{1}{\text{nw}} \sum_{n=1}^{\text{nw}} (\text{DRO-BASE} - \text{DRO-OBS}(n))$$

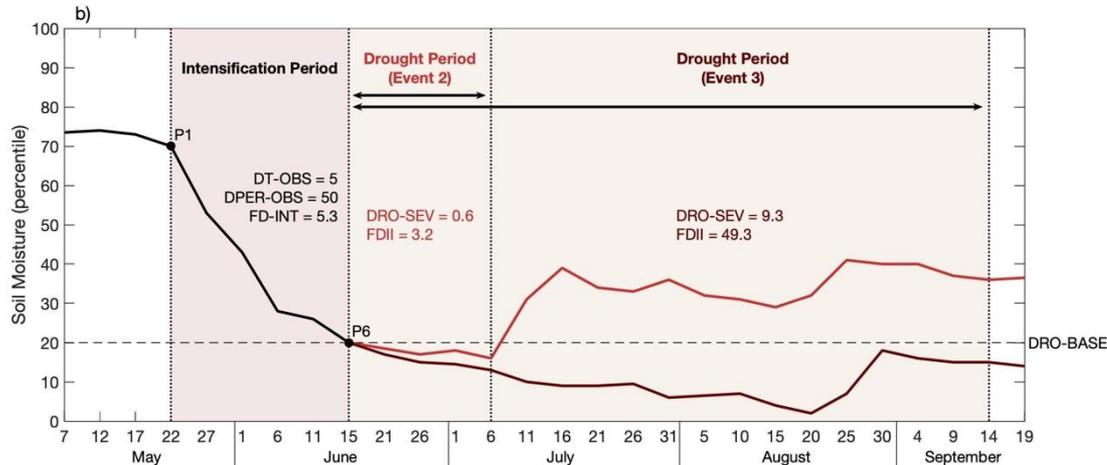
- FDII is computed as the product of the FD-INT and DRO-SEV terms

$$\text{FDII} = \text{FD-INT} * \text{DRO-SEV}$$

Flash Drought Schematic

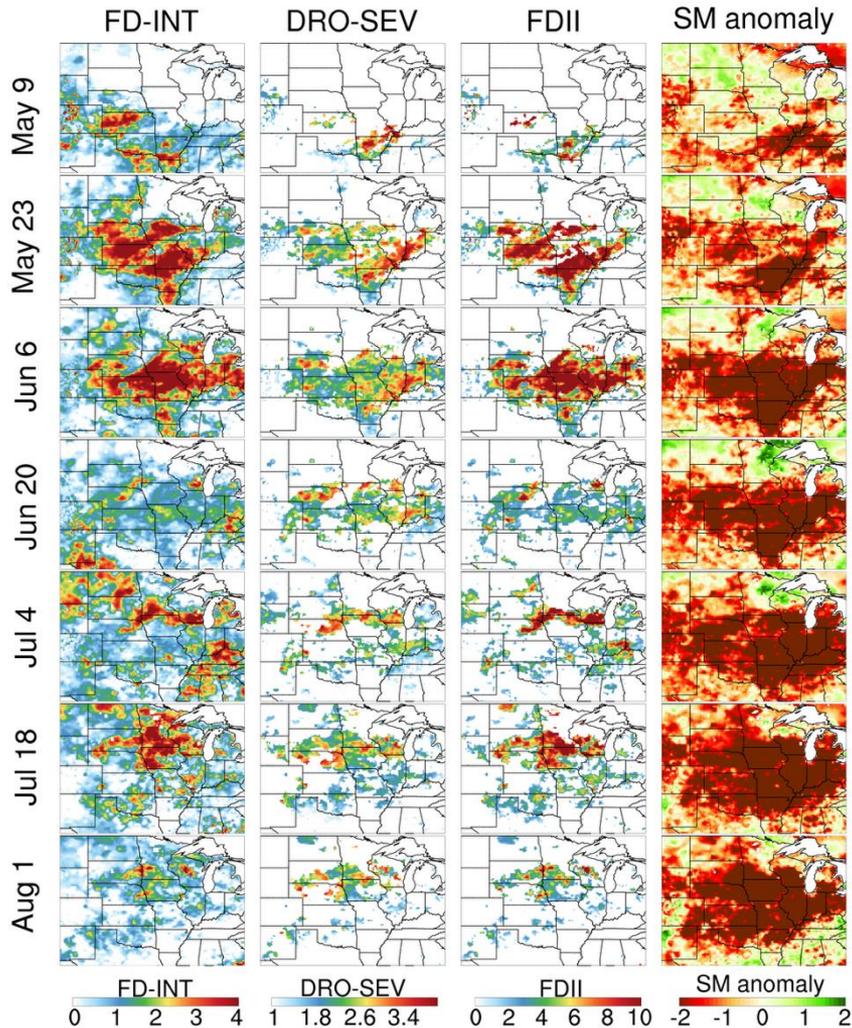


- Impact on FDII due to different intensification rates (FD-INT)
- Event 2 has larger FDII because FD-INT was larger



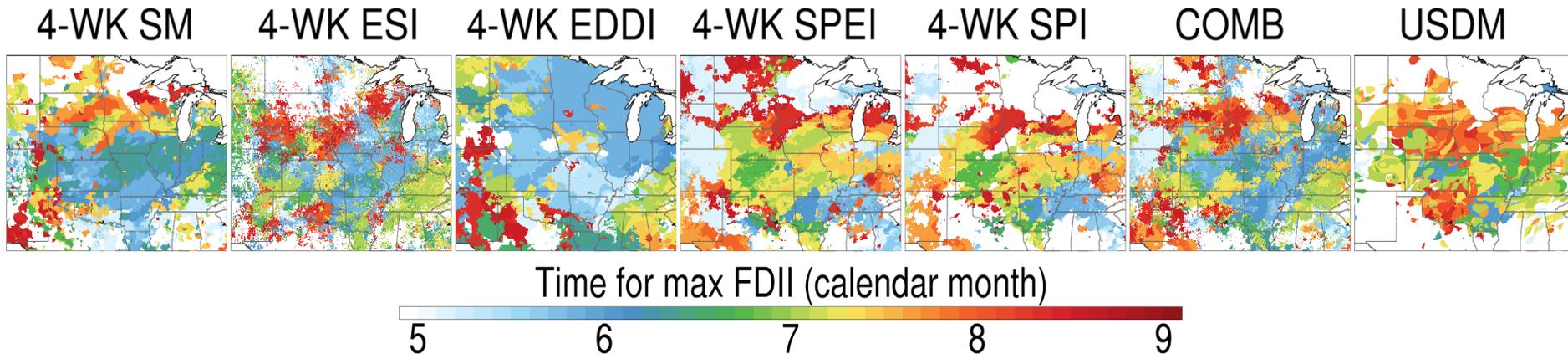
- Impact on FDII due to different drought severity (DRO-SEV)
- Event 3 has larger FDII because DRO-SEV was larger

2012 U.S. Flash Drought



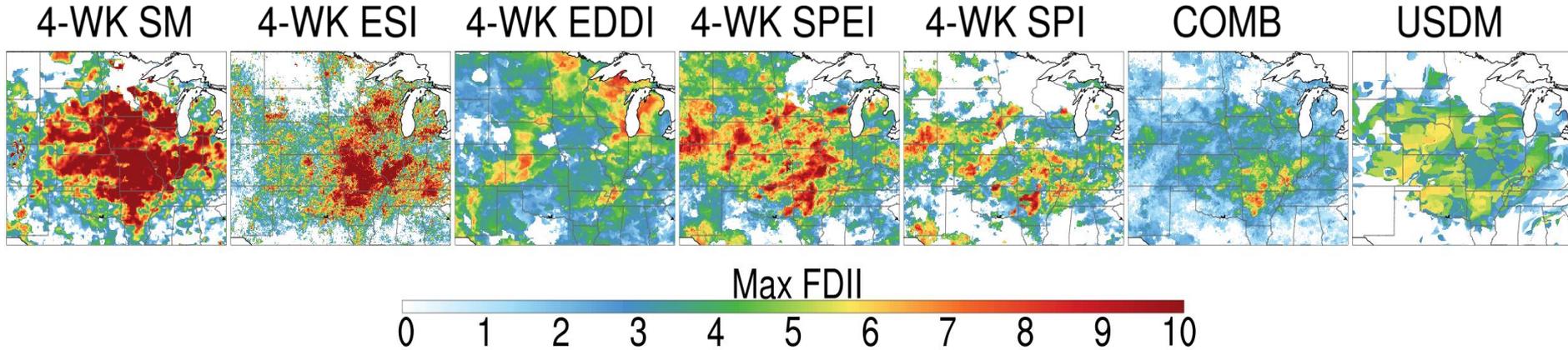
- FD-INT indicates conditions were rapidly deteriorating across south-central U.S. on May 9th
- Spatial extent of FDII is less than FD-INT because drought conditions had not yet developed in some locations
- Spatial extent of FDII was maximized on June 6th when rapid intensification and drought was most widespread
- New areas of flash drought developed further north during July

2012 Flash Drought – Month with Maximum FDII



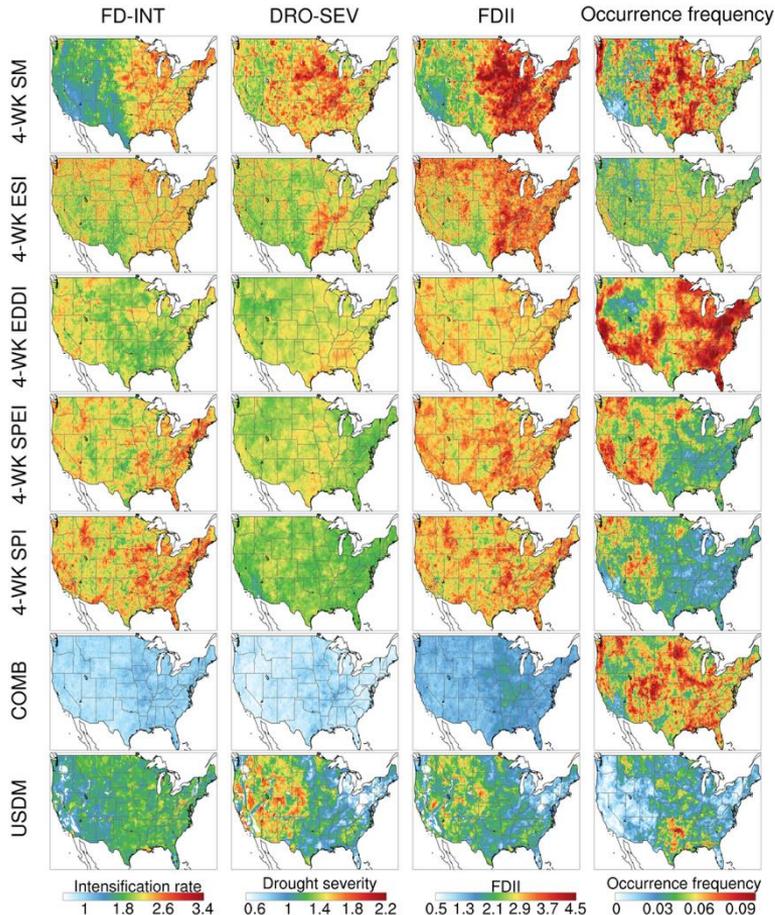
- All indicators except for EDDI exhibit a general northward progression of the max FDII
- Timing differences for maximum FDII between indicators
- COMB indicator shows that the flash drought started in the mid-Mississippi River Valley in early May and then spread northwestward

2012 Flash Drought – Maximum FDII



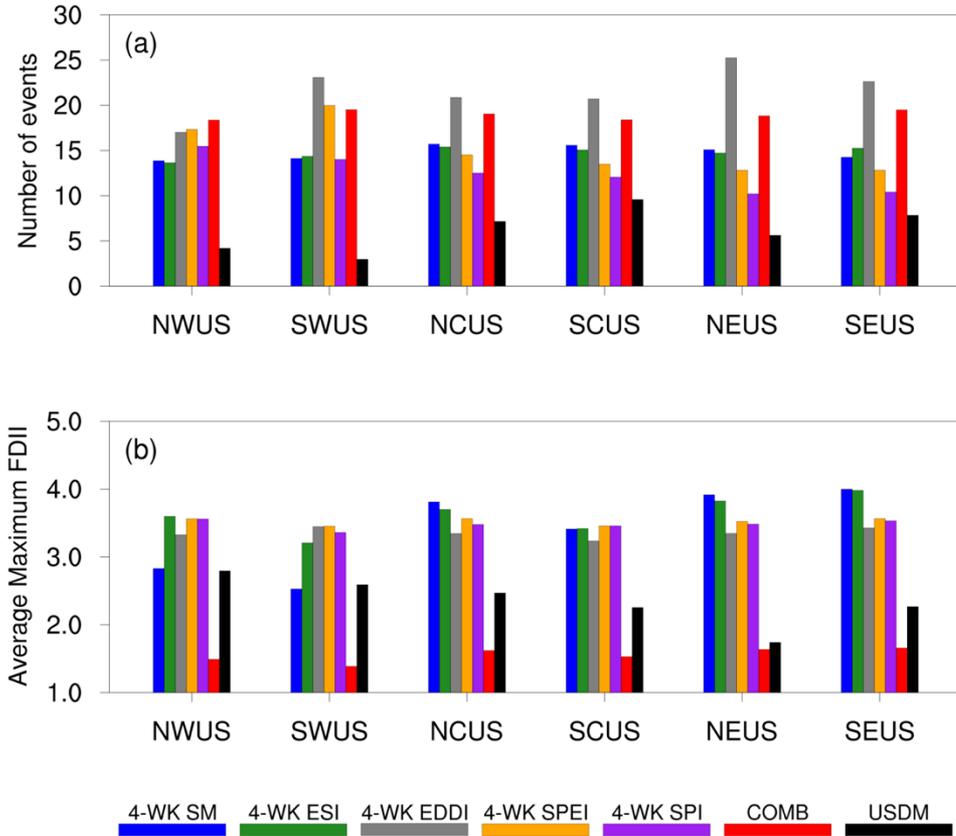
- Large differences in spatial extent and magnitude of maximum FDII
- Indicators depicting land surface conditions had especially rapid intensification and drought severity when compared to the meteorological drivers
- Results show why it is good to use more than one indicator to evaluate flash droughts

Multivariate Flash Drought Climatology



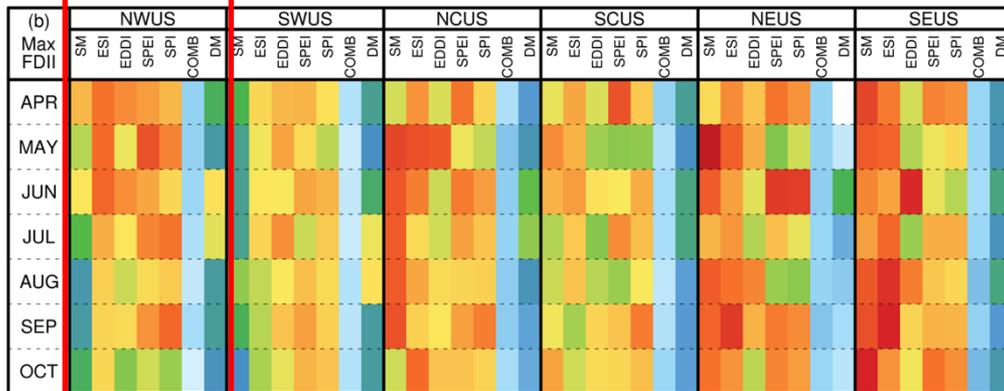
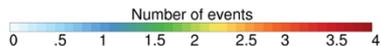
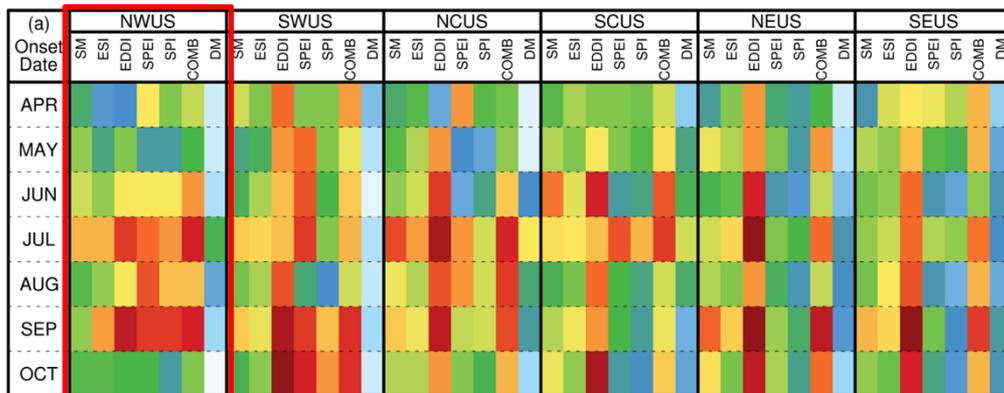
- Rapid decreases in soil moisture and ESI are more likely in humid areas with more vegetation
- Relatively large FD-INT for SPI and SPEI show that precipitation deficits can develop quickly, but it is difficult to maintain those large deficits
- EDDI has the highest flash drought occurrence across most of the U.S.
- COMB FD-INT, DRO-SEV, and FDII are much smaller than the single-variable indicators
- COMB FDII indicates that the strongest multivariate flash droughts occur across the central and southeastern U.S.

Flash Drought Climatology – Regional Analysis



- Large differences between regions and indicators
- EDDI has the most flash droughts, but their maximum FDI is generally lower than the other indicators
- Fewest flash droughts are found in each region when using the USDM
- COMB has the second or third most events but the smallest average FDI
- Central U.S. is not a hotspot in the COMB data set despite its reputation as a prime area for flash drought

Seasonal Flash Drought Climatology



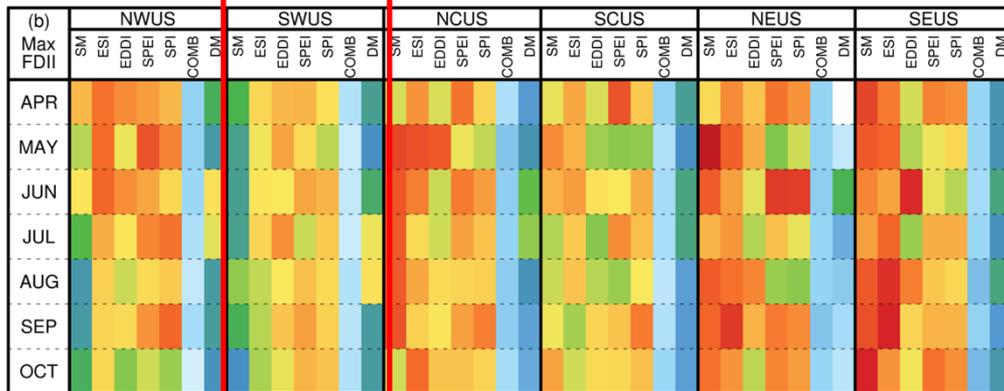
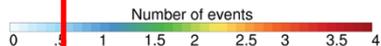
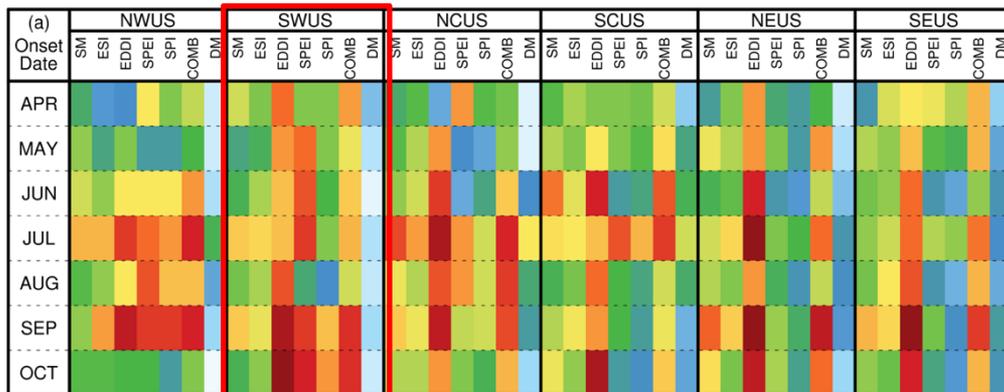
- **Northwestern U.S.**

- Flash drought onset most often during the first half of the growing season in soil moisture, but is more likely in mid-summer to early fall in other indicators

- Early season events tend to be stronger based on the max FDII

- Flash droughts that begin in the spring are more likely to persist and intensify during the summer due to climatologically drier weather

Seasonal Flash Drought Climatology



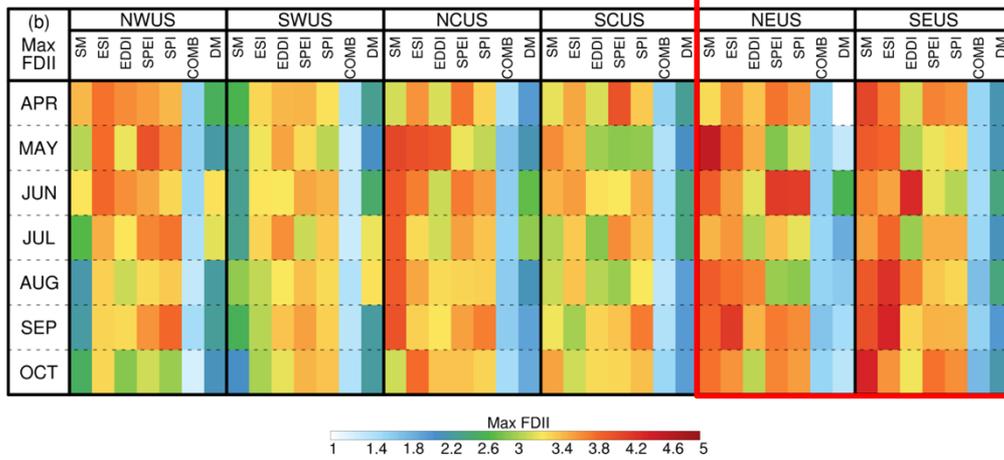
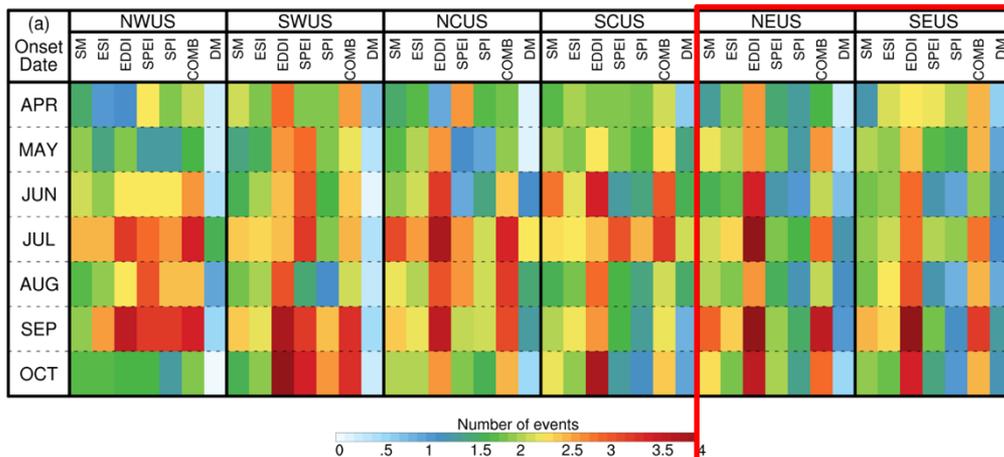
- **Southwestern U.S.**

- Flash drought onset occurs most often from July to October with a secondary maximum in April

- Flash droughts can develop at any time of the year according to the SPEI and EDDI

- Seasonal pattern indicates that flash droughts are often associated with poor summer monsoons that lead to flash drought onset during the latter half of summer

Seasonal Flash Drought Climatology



- Eastern U.S. regions
- Lack a distinct seasonal cycle in flash drought occurrence
- Notable feature is the high number of EDDI flash droughts relative to the other indicators
- Flash droughts tend to be more severe when their onset is during the first half of the growing season
- Severe ESI and soil moisture flash droughts also occur later in the year

Conclusions

- Large differences in flash drought occurrence and severity depending upon which drought monitoring indicators are used to compute the FDII
- Precipitation indicators identified more flash droughts across the western U.S. whereas indicators of vegetation moisture stress had more events in the central and eastern U.S
- Severity of SPI and SPEI flash droughts was more strongly influenced by how quickly the precipitation deficits developed than by the size of the subsequent deficits
- Evaluation of the SM and ESI data sets revealed a longitudinal gradient in intensification rates, with larger values in the central and eastern U.S.
- A distinct seasonal cycle in flash drought occurrence was evident in the western and central U.S. regions but was not as apparent in the eastern U.S.

References and Contact Info

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