National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Drought Cascades in the Hydrologic Cycle: A Set of Case Studies from Remote Sensing

Alireza Farahmand[1], JT Reager[1]

1) NASA Jet Propulsion Laboratory, California Institute of Technology

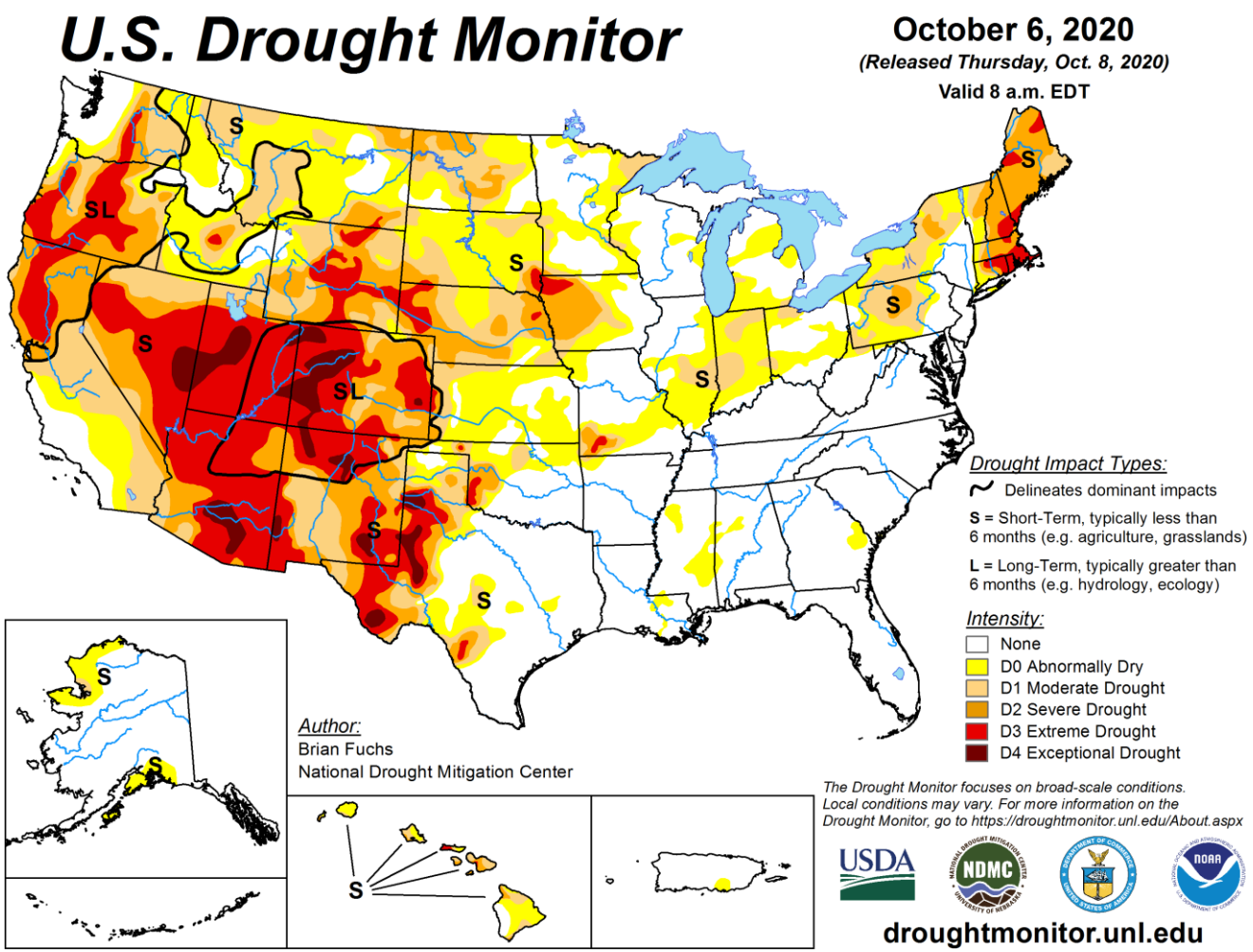
AIRS STM October 15rd 2020

Drought and Environment

2012 Midwest drought

2018 California Wildfire

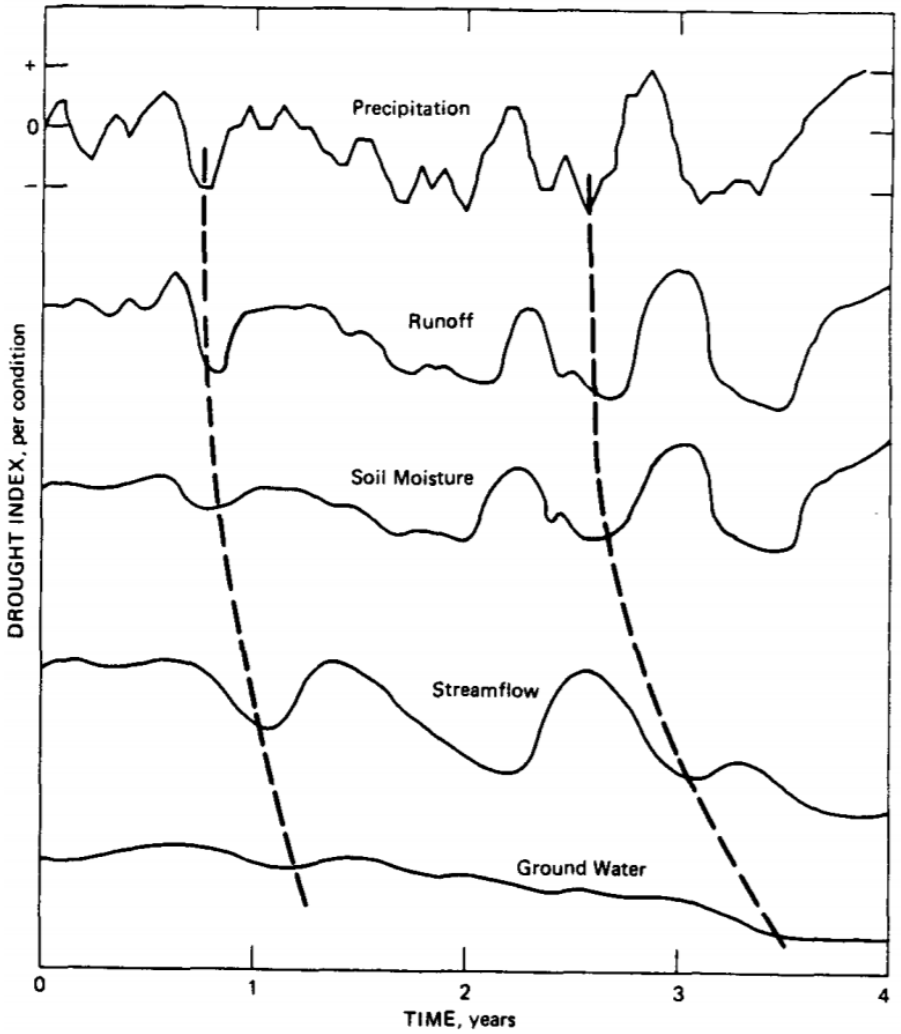
Drought and Environment



Drought Types

- *Meteorological: precipitation deficit*
  - ✓ SPI: Standardized Precipitation Index
- *Agricultural: soil moisture deficit*
  - ✓ SSI: Standardized Soil Moisture Index
- *Hydrological: Shortage of surface or sub-surface water supplies*
  - ✓ GRACE-DSI: GRACE-Drought Severity Index

Motivation

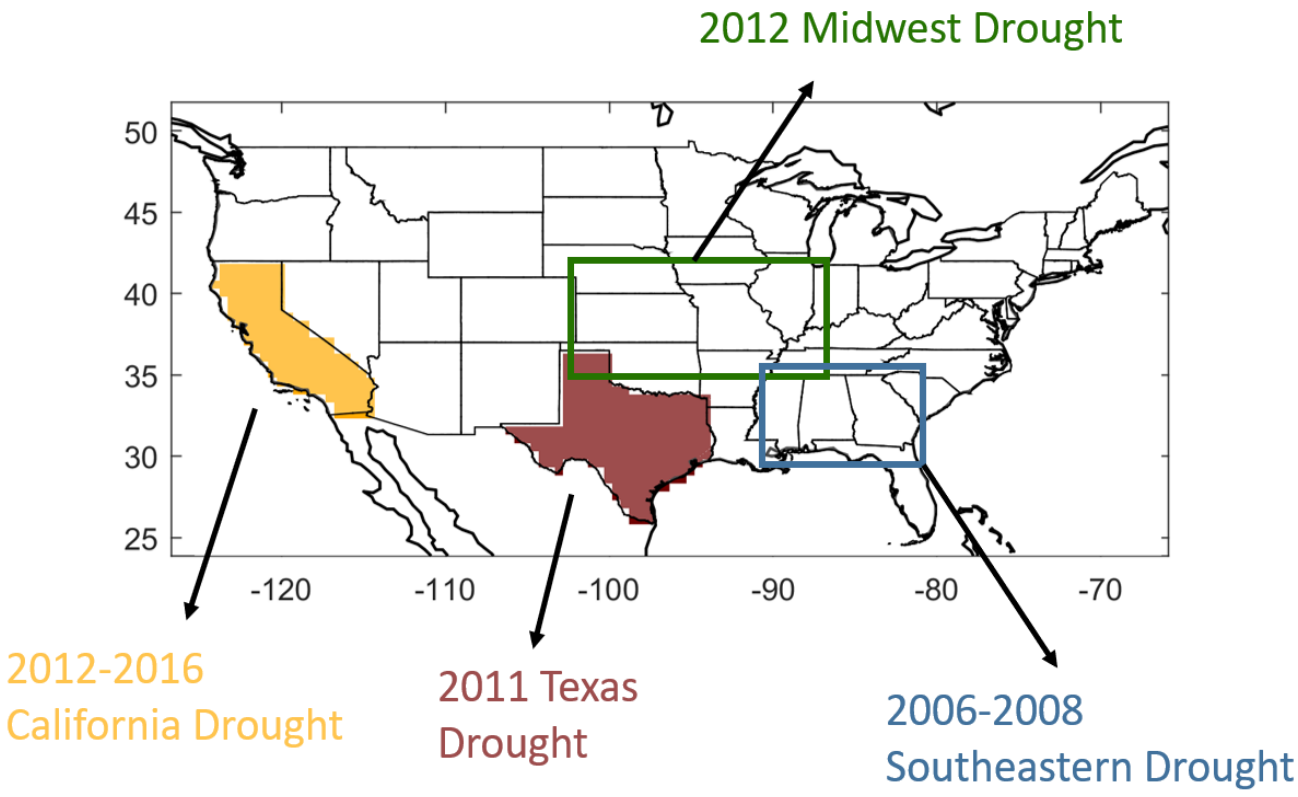


Changnon 1987

- Drought signals in Illinois
- Drought signal is transferred with delay from precipitation to soil moisture and groundwater
- Smoother and increased persistent with depth in soil column

Case Studies

- Use remote sensing to look at larger spatial scales
- Investigate the cascading phenomenon across multiple major droughts



Data Inputs

- Monthly AIRS *Vapor Pressure Deficit (VPD)*
  - Derived from Temperature and Relative Humidity
- Monthly Climate Hazards Center InfraRed Precipitation with Station data (CHIRPS) *Precipitation (P)*
- Monthly GRACE *Terrestrial Water Storage (TWS)*
- Monthly MERRA reanalysis *Soil Moisture (SM)*

✓ Spatial Resolution: 0.5°

✓ Data Length: 2003-2017

Methodology

- Derive standardized scores for VPD, P, SM, and TWS

$$DI_{ij} = \frac{x_{ij} - \bar{x}_j}{\sigma_j}$$

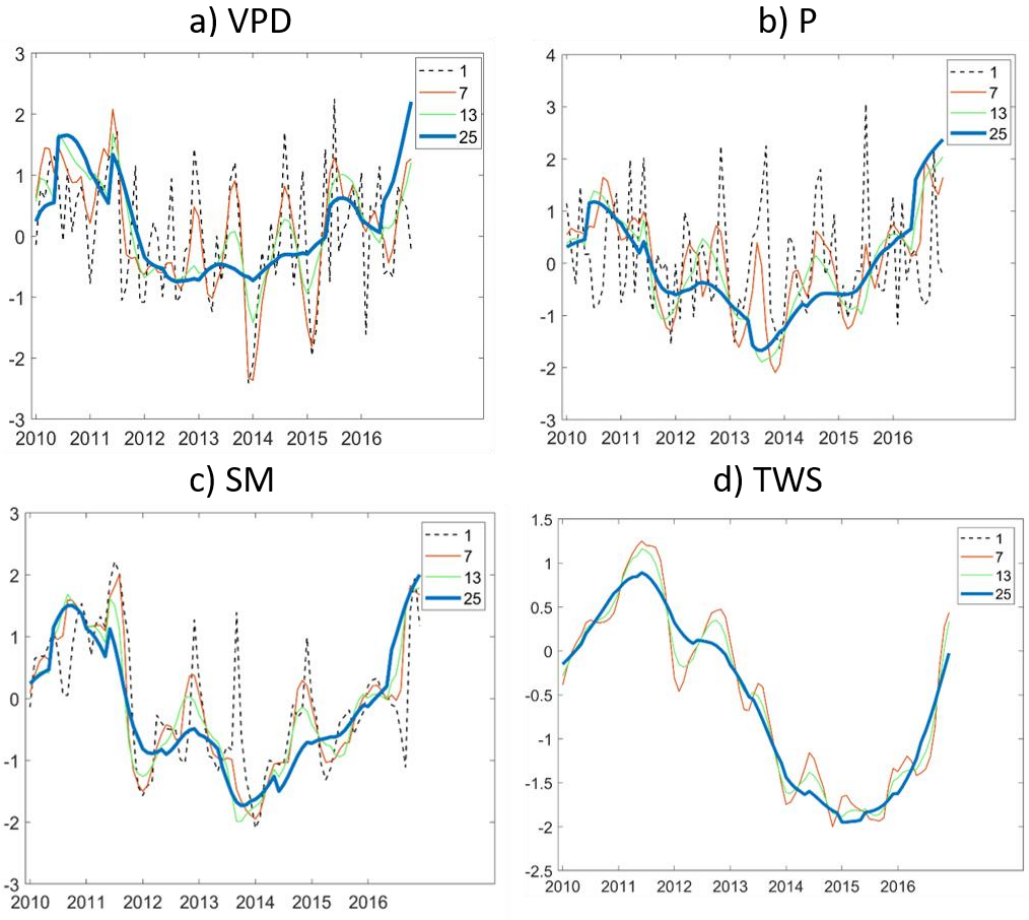
IF DI > 0 ⟹ Wet

IF DI < 0 ⟹ Dry

DI_{ij}	Drought Indicator of month j for year i
x_{ij}	variable of month j for year i
$\bar{x}$	mean variable for month j
σ_j	standard deviation of precipitation for month j

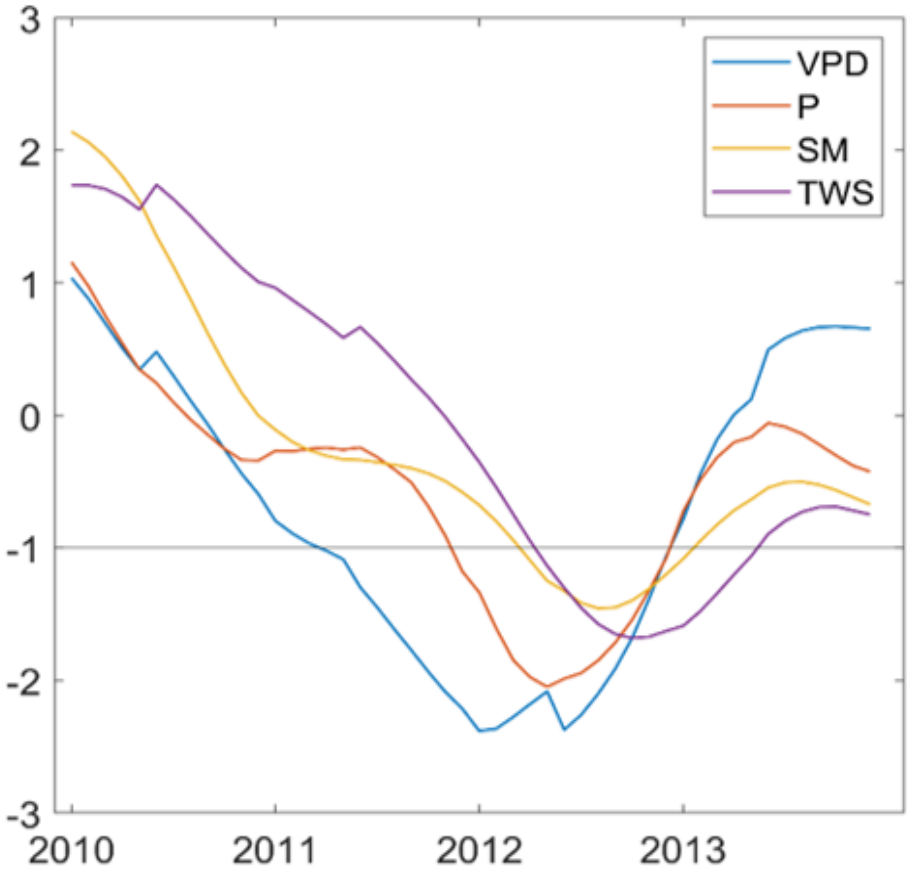
Time scale selection

Different smoothing scales for all variables



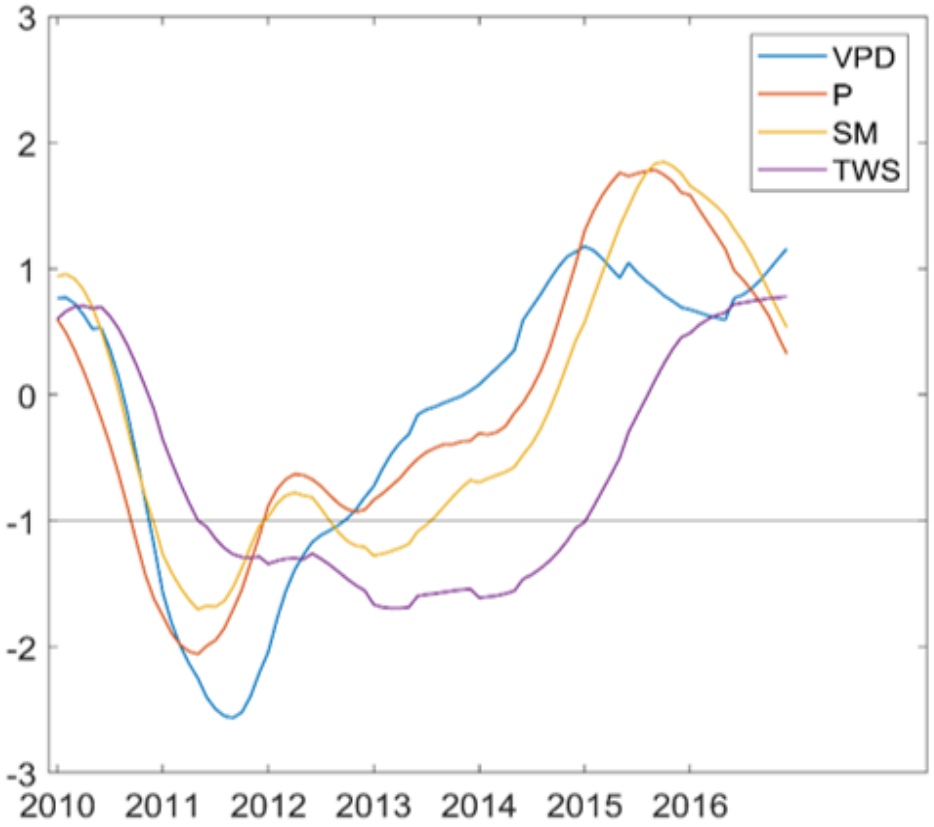
- 25-month scale appears to exhibit the drought signals more clearly

Midwest Drought



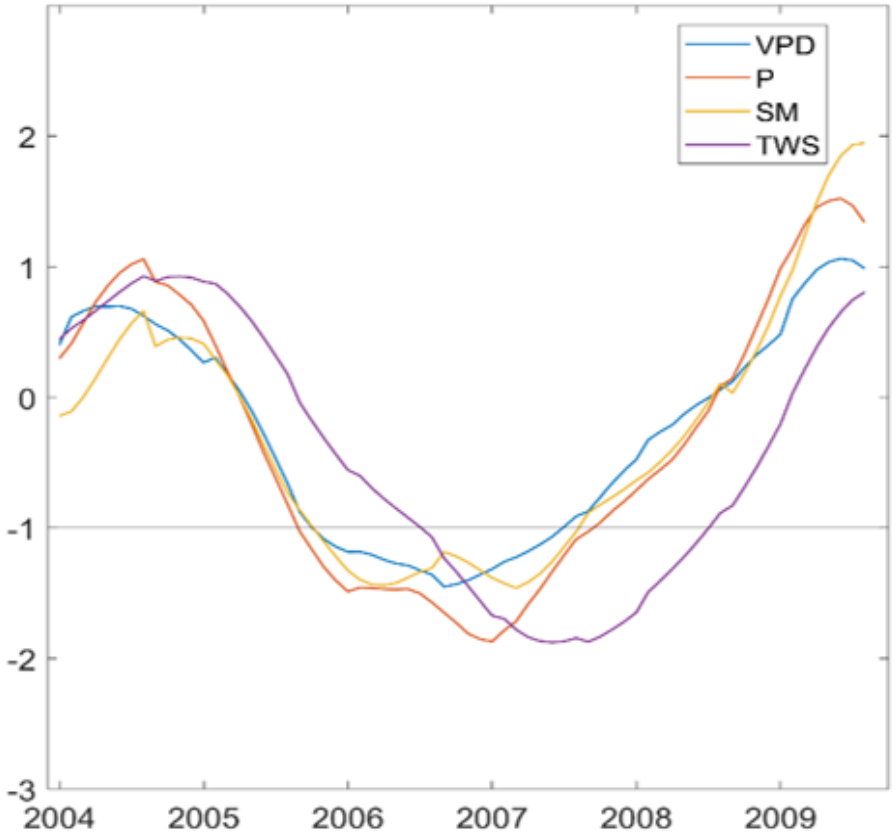
- Flash drought with onset determined by VPD
- Largely dominated by extreme deficit of VPD and Precipitation
- Relatively smaller impacts on TWS and particularly SM

Texas Drought



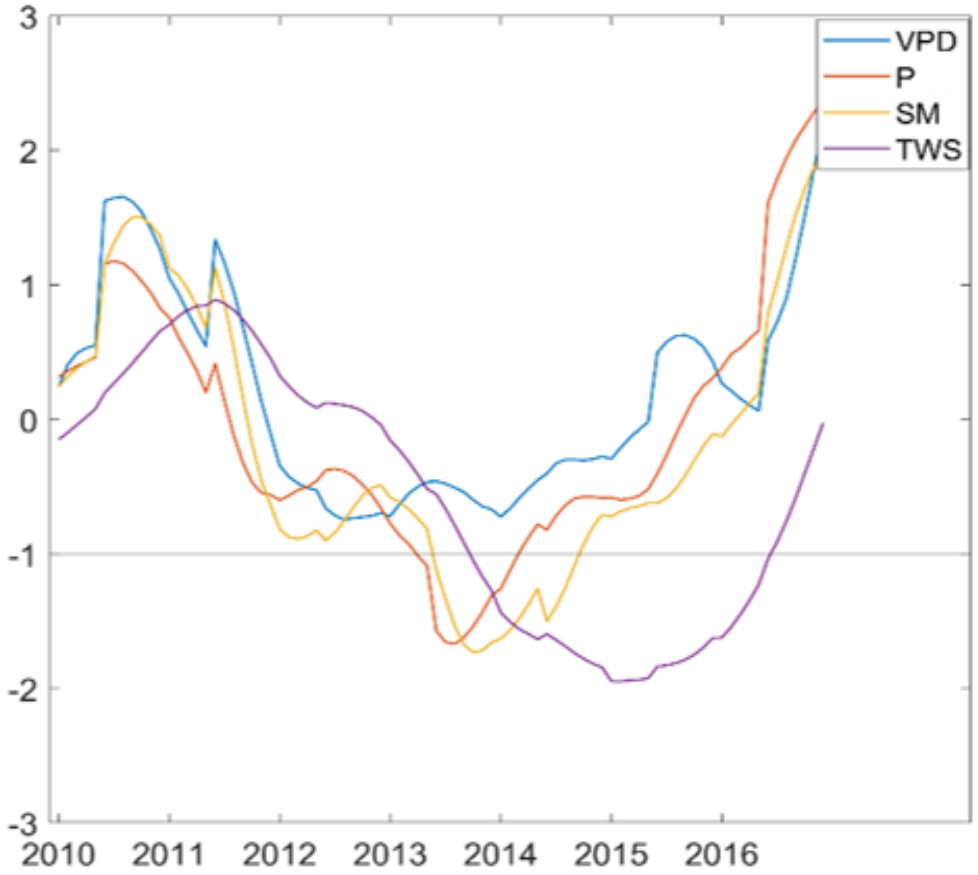
- Also initiated by anomalously high VPD and low Precipitation
- Precipitation leads the onset
- Prolonged period of 24 months stress on water storage

Southeastern Drought



- Dominated by the precipitation deficit with relatively large impacts on TWS
- Precipitation leads the onset

California Drought



- Initiated by Precipitation deficit and dominated by extreme deficits in TWS
- VPD does not show drought signals for this event

Drought Cascade

- Onset, termination, and timing of minimum are transferred with delay from P to SM and to TWS

- VPD onset and timing of minimum are on average 1.3 months earlier than precipitation

All Events			
Index	**Onset (month)**	**Termination (month)**	**Timing of Minimum (month)**
VPD	-1.3	19.7	-1.3
P	0	16	0
SM	2.5	22.5	1.8
TWS	7.5	36	12.3

Drought Cascade

- SM signals are smoother and longer than P
- However, severity of P and SM similar

- TWS intensity stronger than SM as TWS records entire water storage
- TWS duration and severity signals larger than other variables

All Events			
Index	**Maximum Intensity**	**Duration (month)**	**Severity**
VPD	-2.1	21	-34.7
P	-2	16	-24.8
SM	-1.6	20	-24.4
TWS	-1.8	28.5	-43

Summary

- We looked at the development of four major drought events of Midwest, Southeastern, Texas, and California using remote sensing information
- We used four variables of vapor pressure deficit (VPD), precipitation, terrestrial water storage, and soil moisture
- Results indicate that a cascading pattern may exist between precipitation, soil moisture and terrestrial water storage
- VPD appears to not exhibit a straight relationship with the rest of the variables
- However, VPD strength in detecting drought onset can be seen
- Future studies could include additional events and further remote sensing variables such as NDVI and Evapotranspiration