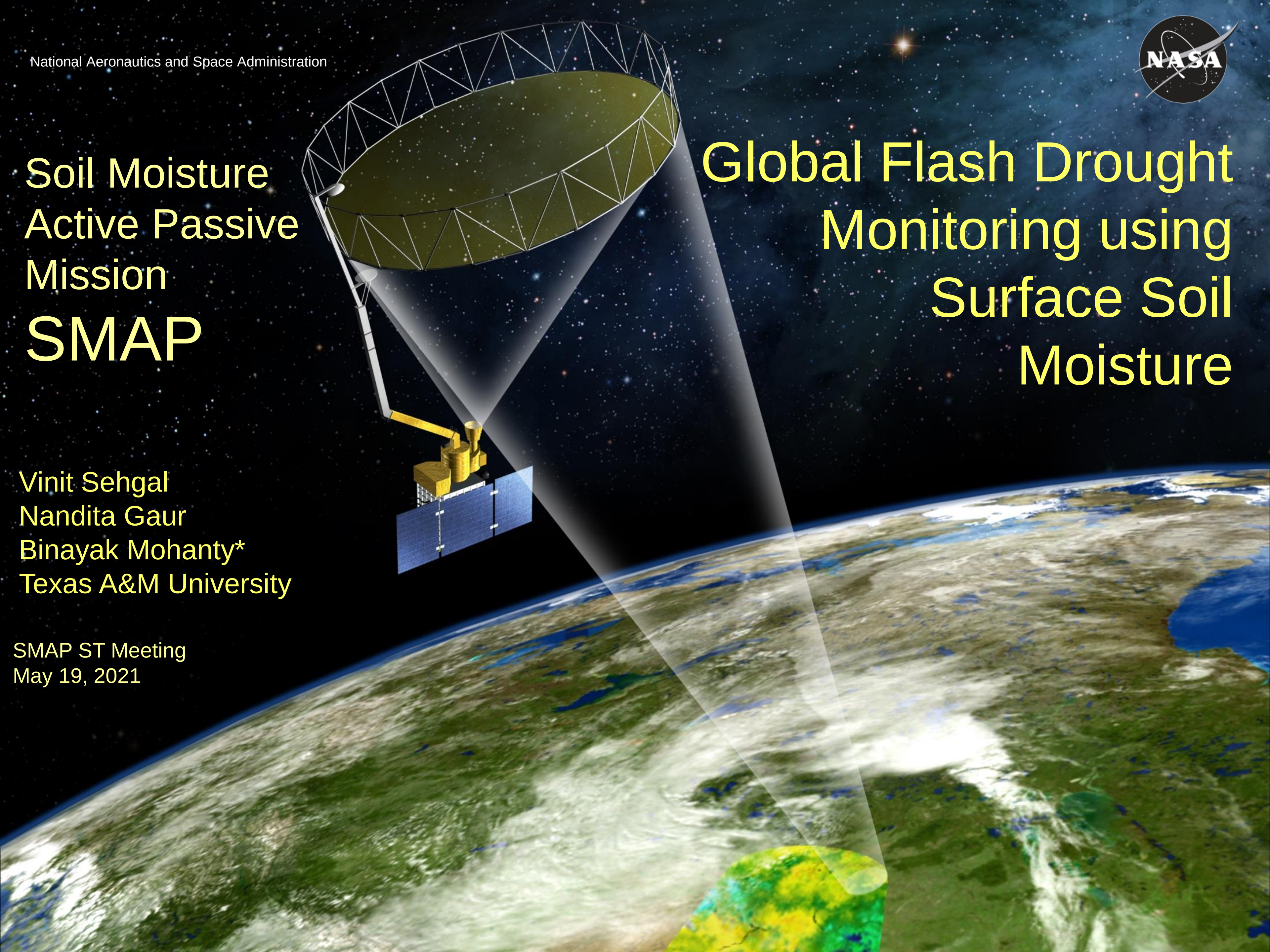


National Aeronautics and Space Administration

Soil Moisture Active Passive Mission

SMAP

Global Flash Drought Monitoring using Surface Soil Moisture

Vinit Sehgal
Nandita Gaur
Binayak Mohanty*
Texas A&M University

SMAP ST Meeting
May 19, 2021

Challenges in Drought Monitoring using Soil Moisture

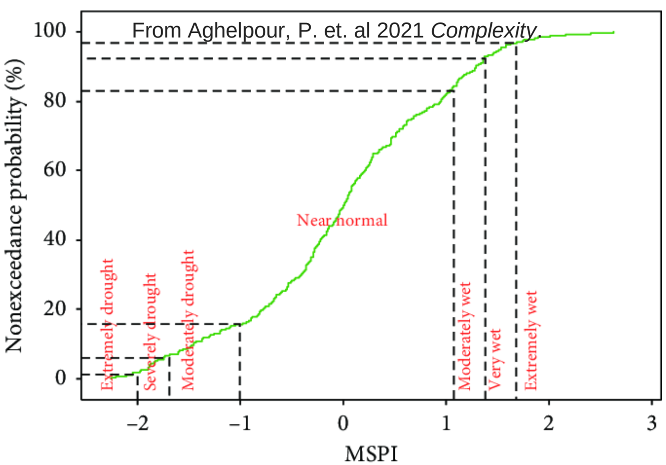
A robust flash drought monitoring using ϑ_{RS} must account for:

- ❑ Short observation record of SMAP
- ❑ Non-linear geophysical controls over ϑ_{RS} dynamics
- ❑ Emergent meteorological drivers of flash droughts

Percentile Approach

Use standardized soil moisture percentiles to estimate drought stress

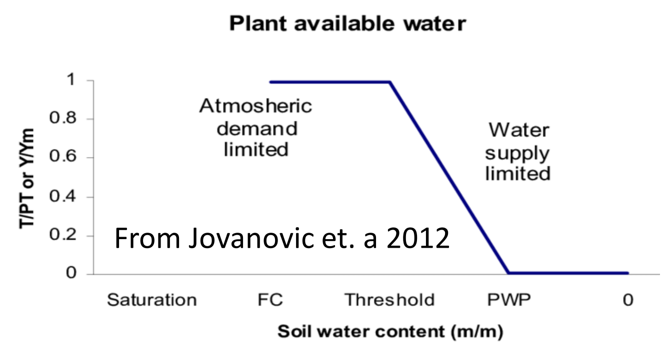
- Requires long-term dataset
- Bias-correction required spatial and temporally consistent model outputs
- Long-term data is not available from RS-SM platforms



Plant Available Water Approach

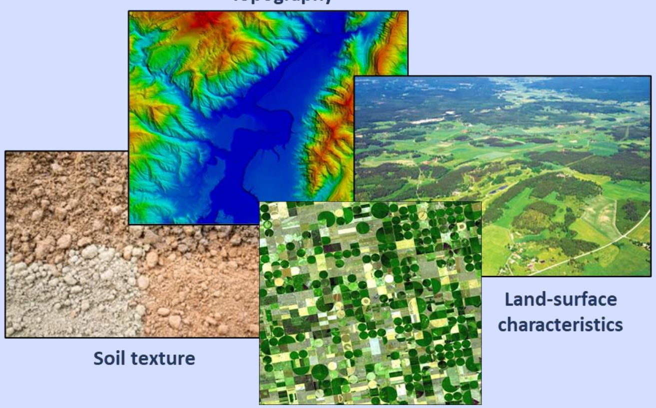
The relative fraction of available water content compared to the maximum (plant) available water is used as an indicator of drought stress

- Requires estimates of field capacity and wilting point
- Errors, bias and scale issues in PTF-based estimates.
- Doesn't account for non-linear dynamic geophysical controls of SM dynamics

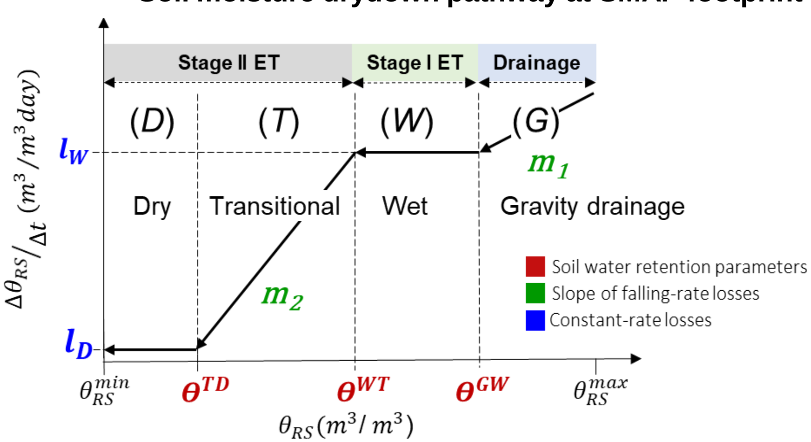


Global SMAP Drydown Patterns

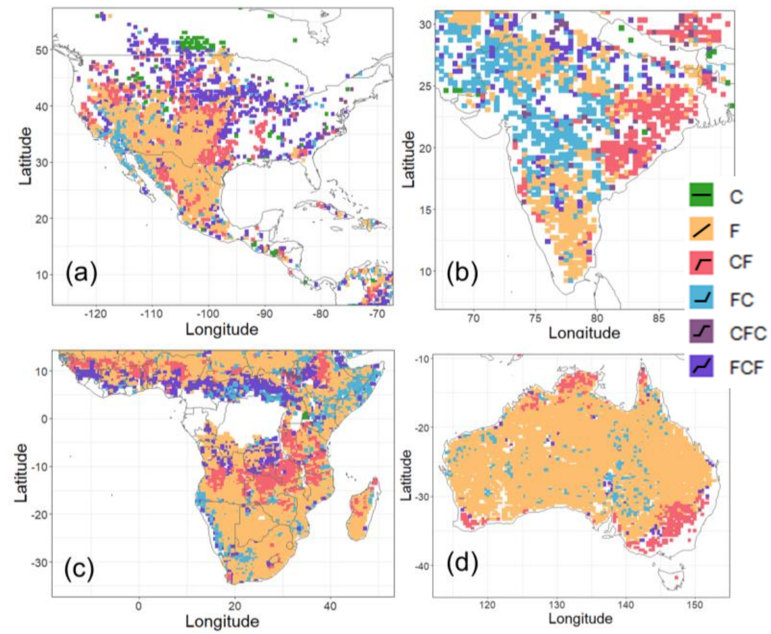
The drying patterns of SMAP soil moisture (θ_{RS}) change spatially and temporally under heterogenous non-linear geophysical controls:



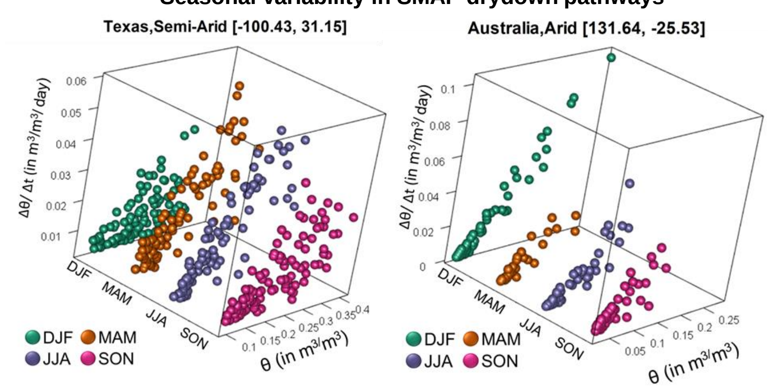
Soil moisture drydown pathway at SMAP footprint



Spatial variability in drydown form

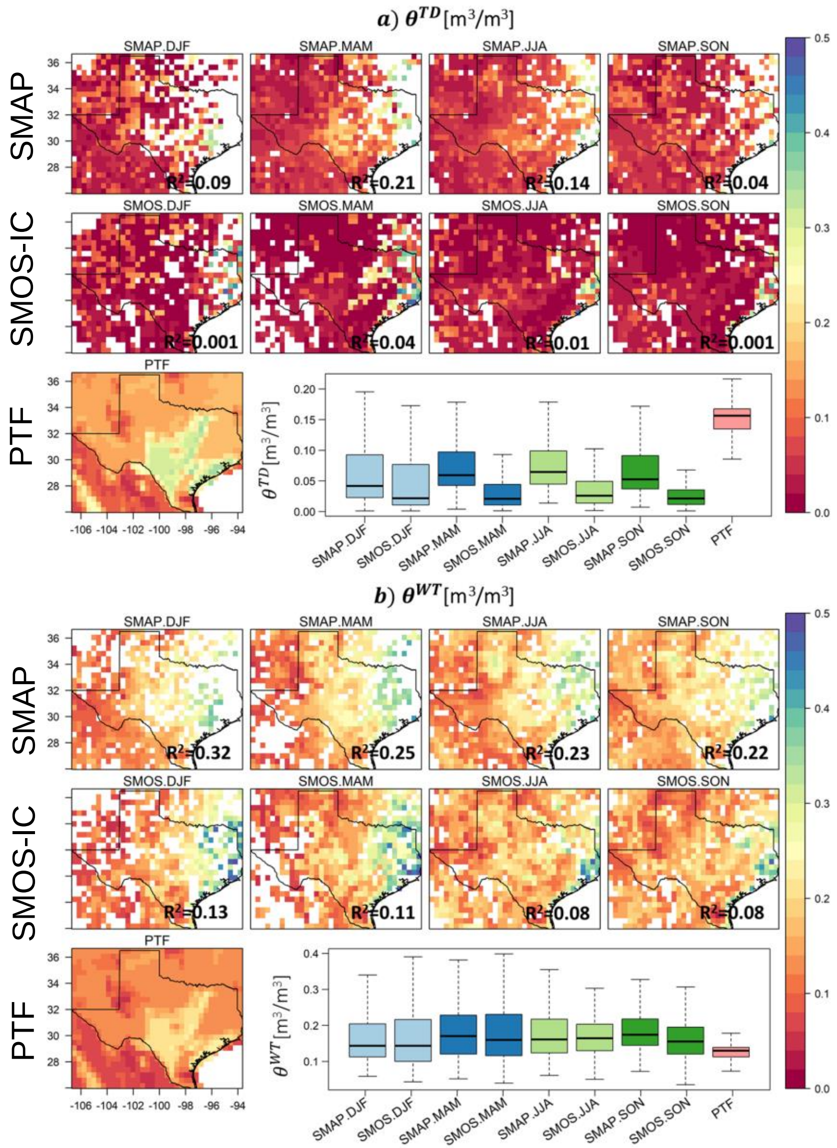


Seasonal variability in SMAP drydown pathways



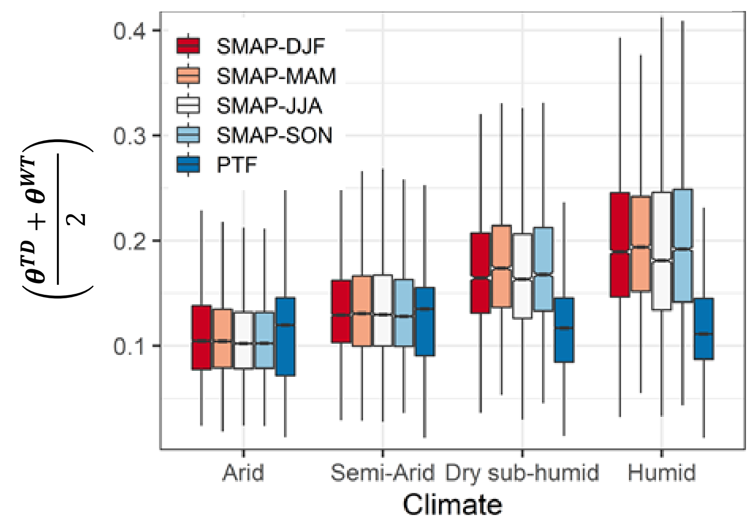
Sehgal, V., Gaur, N. and Mohanty, B.P., Global Surface Soil Moisture Drydown Patterns. ***Water Resources Research***, p.e2020WR027588.

SMAP v/s PTF-based SWRPs



Due to the influence of nonlinear geophysical controls, effective drydown parameters from SMAP and SMOS-IC show difference wrt wilting point and critical point estimates using Saxton and Rawls 2005 PTF and soil texture from Harmonized World Soil Database.

Climate-wise comparison of global SMAP and PTF-based estimates



The difference between SMAP and PTF-based estimates of SWRPs is higher in humid and sub-humid regions due to dominant influence of vegetation.

Sehgal, V., Gaur, N. and Mohanty, B.P., Global Surface Soil Moisture Drydown Patterns. ***Water Resources Research***, p.e2020WR027588.

Flash Drought Stress Index (FDSI)

FDSI is based on two components:

A) Soil Moisture Stress
Measure of drought stress in soil

$$SMS_t = \frac{1}{1 + \left(\frac{\theta_{RS,t}}{\theta_{IP}}\right)^n}$$

30-day rolling mean

$$SMS_{30,t} = \sum_{i=t}^{t-29} SMS_i \Big/ 30$$

Inflection point

$$\theta_{IP} = \left(\frac{\boldsymbol{\theta^{TD}} + \boldsymbol{\theta^{WT}}}{2}\right)$$

Shape factor

$$n = 12 . \sqrt{\boldsymbol{m_2}}$$

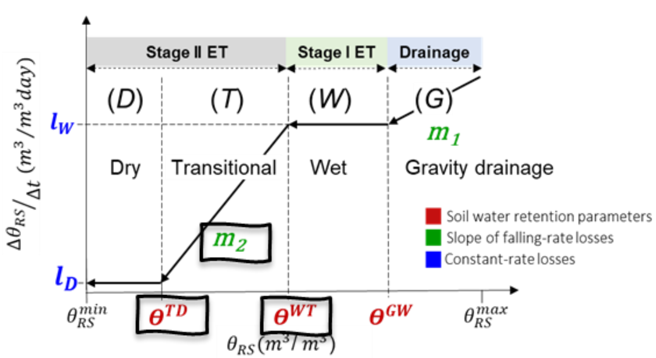
B) Relative Rate of Drydown
Rate of drought intensification

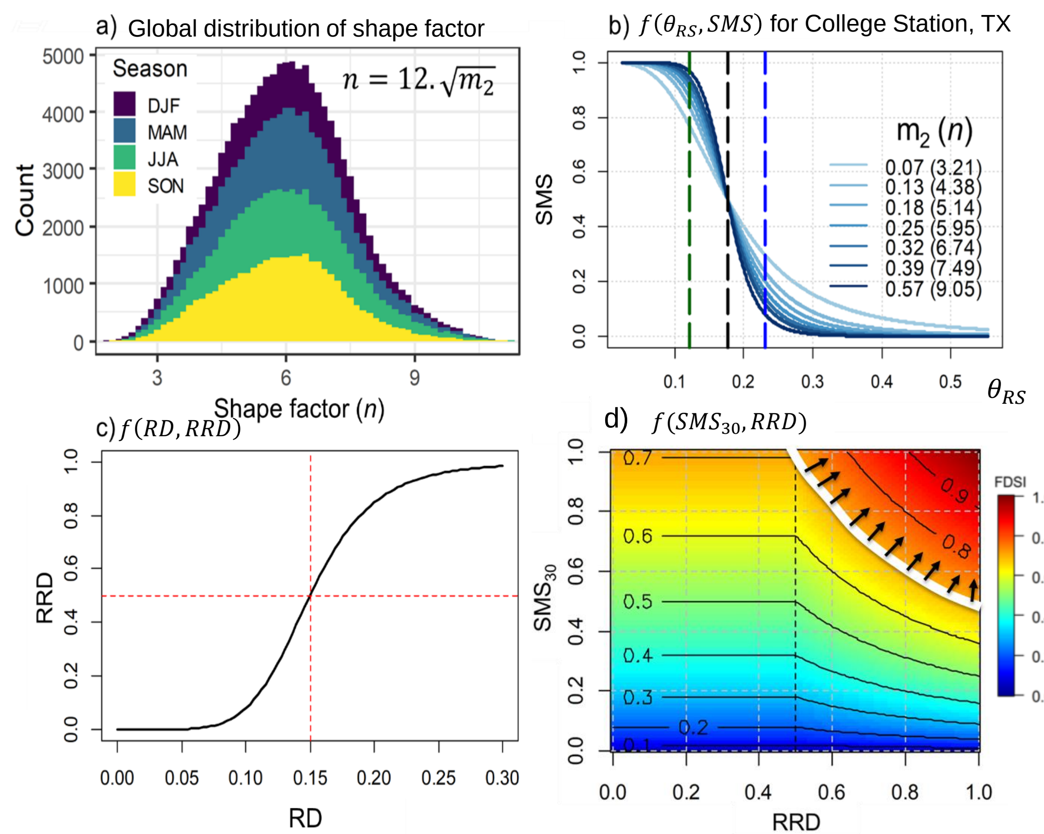
$$RRD_t = \frac{1}{1 + \left(\frac{m_2}{RD_t}\right)^6}$$

RD_t= rate of drydown based on SM observations for *t* to *t*-29.

Nonlinear relationship of FDSI with SMS_{30} and RRD

$$FDSI_t = \begin{cases} \sqrt{SMS_{30,t} \,.\, RRD_t} & if\ RRD_t > 0.5 \\ \sqrt{SMS_{30,t} \,.\, 0.5} & if\ RRD_t \le 0.5 \end{cases}$$





Sehgal, V., Gaur, N. and Mohanty, B.P. "**Global Flash Drought Monitoring using Surface Soil Moisture.**" Under review, WRR (2021).

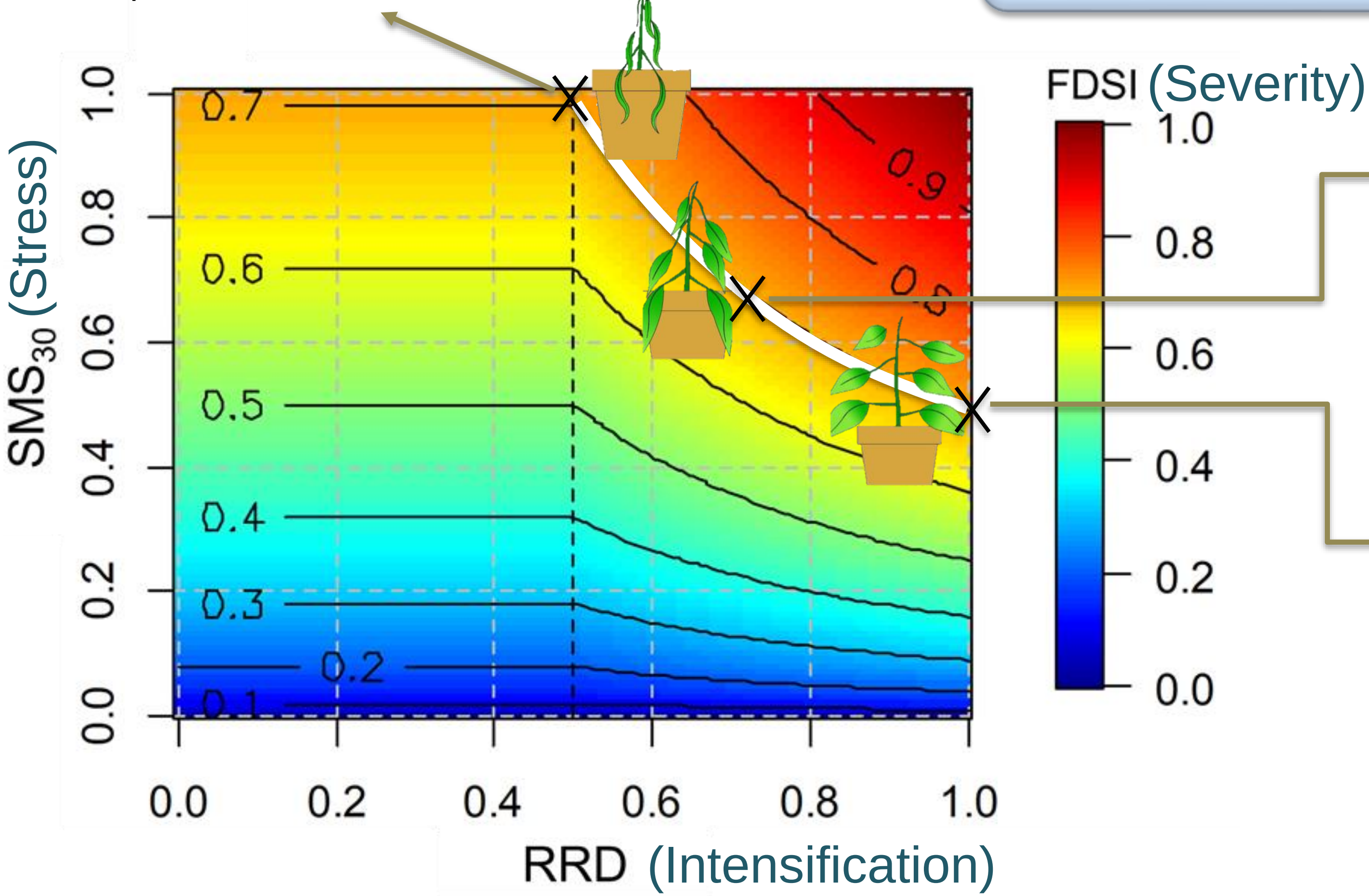
Evolution of Flash Drought

Sustenance

- ❑ Long term SM stress desiccates soil
- ❑ SMS_{30} reaches peak, while RRD decreases with increased matric potential in the soil

Nonlinear relationship of FDSI with SMS_{30} and RRD

$$FDSI_t = \begin{cases} \sqrt{SMS_{30,t} \, . RRD_t} & if \ RRD_t > 0.5 \\ \sqrt{SMS_{30,t} \, .0.5} & if \ RRD_t \leq 0.5 \end{cases}$$



Intensification

- ❑ SM recedes with sustained RRD >0.5.

Onset

- ❑ SMS_{30} is normal
- ❑ High RRD causes rapid loss of SM as time progresses.

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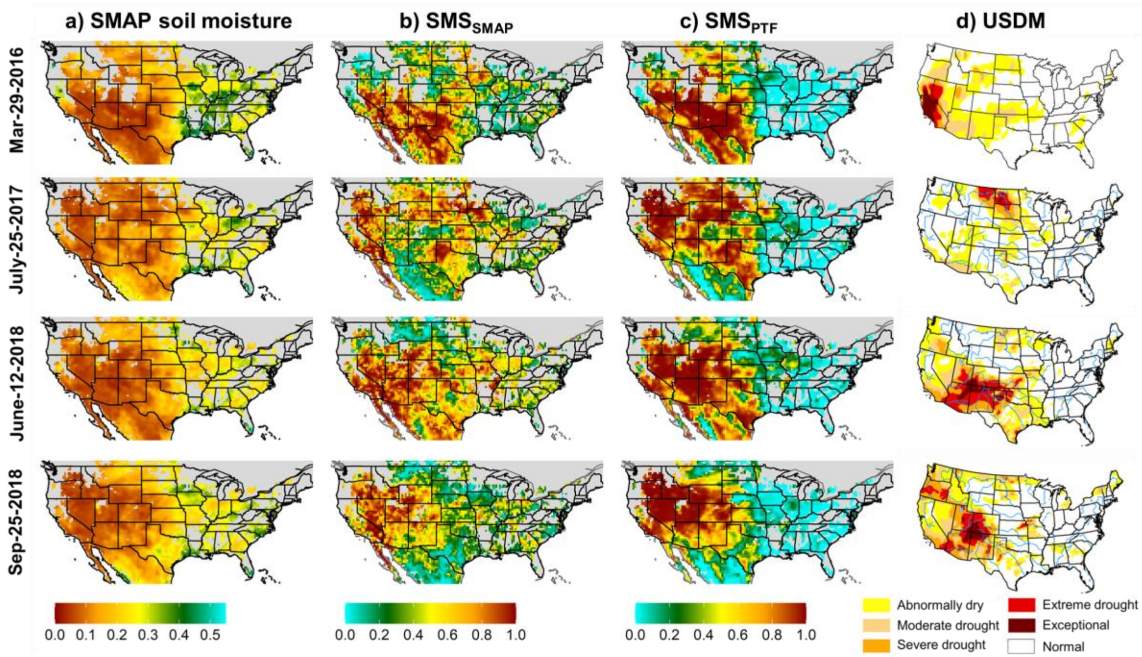
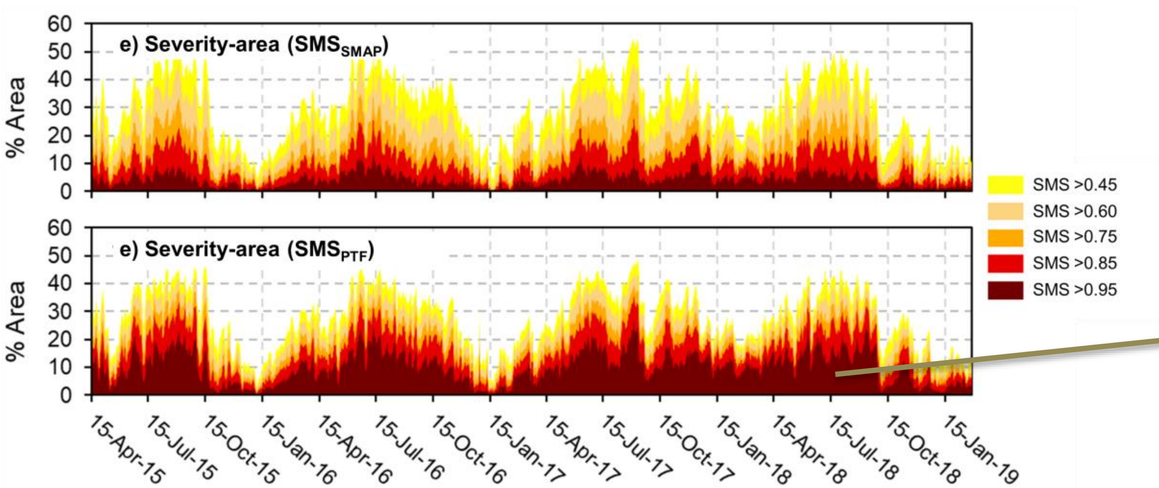
Overestimation of Drought Severity by SMS_{PTF}

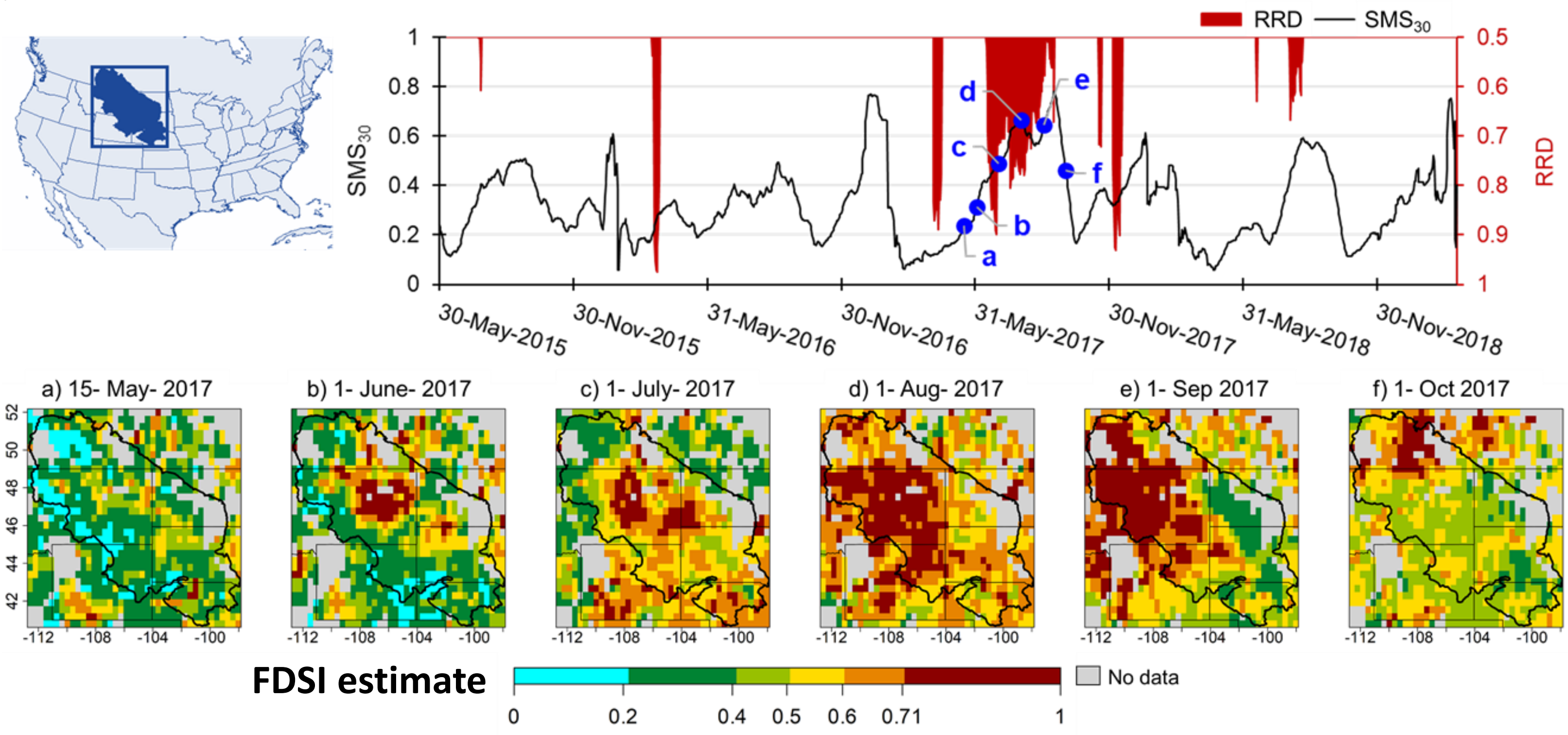


Lack of temporal adaptability to changing land surface conditions in PTF-based parameters, SMS_{PTF} overestimates drought severity.



Overestimation of high-severity droughts.

2017 Flash Drought in the Northern Great Plains



No drought stress — a

Onset of drought — b
Record low PCP, high Temp*

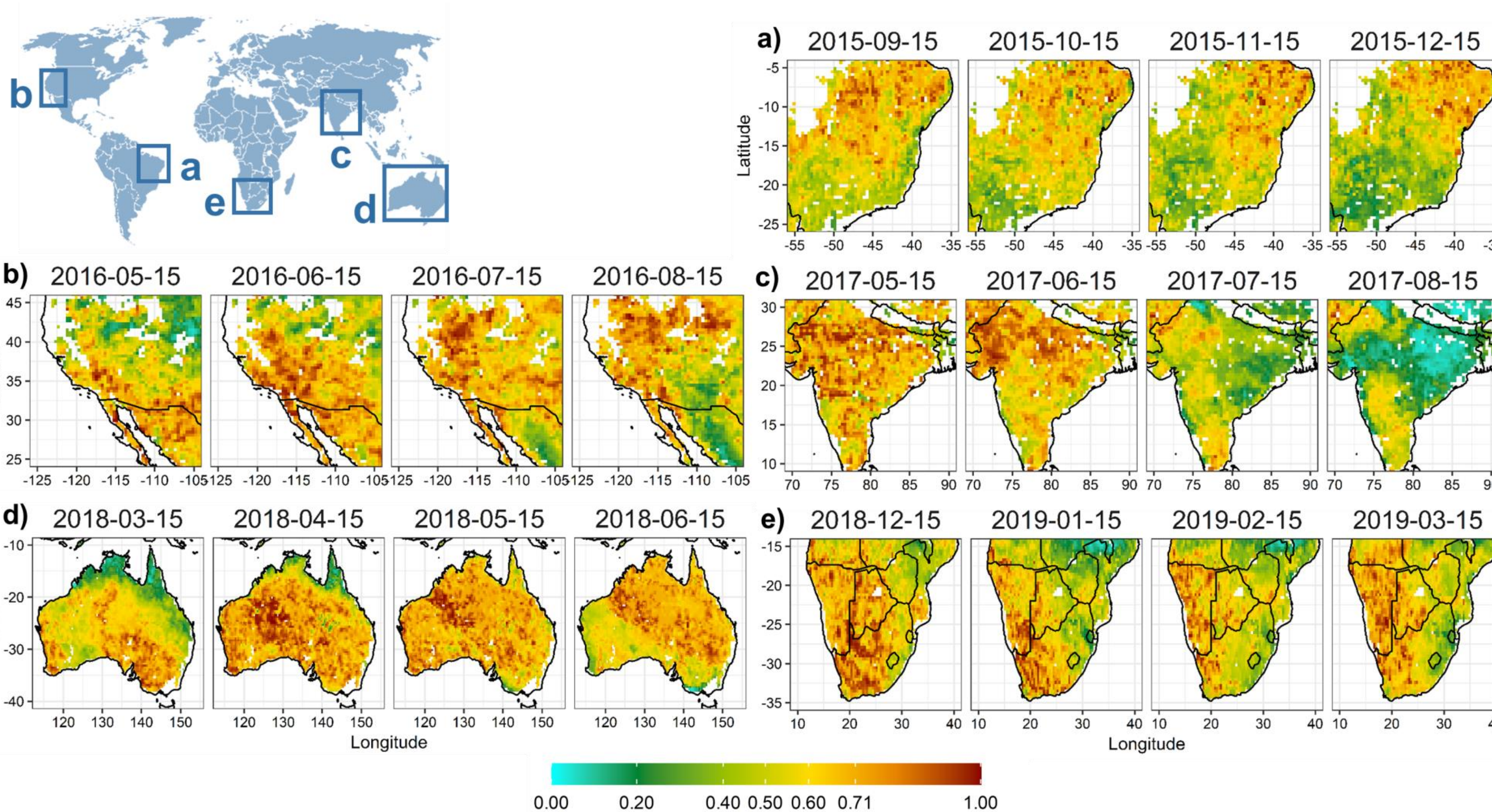
Intensification — c
High Temp, high winds*

Sustenance of drought — d, e

Offset — f

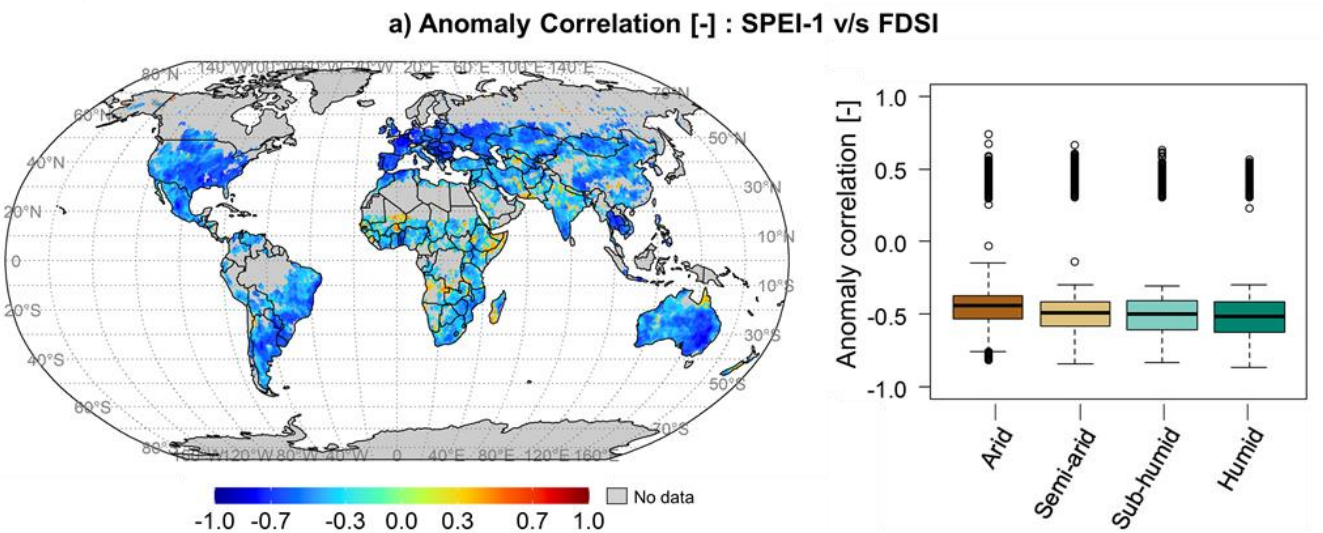
*(Mo & Plettenmaier, 2020; Osman et al., 2020; Pendergrass et al.,2020)

Snapshots of Global Drought Monitoring Using FDSI

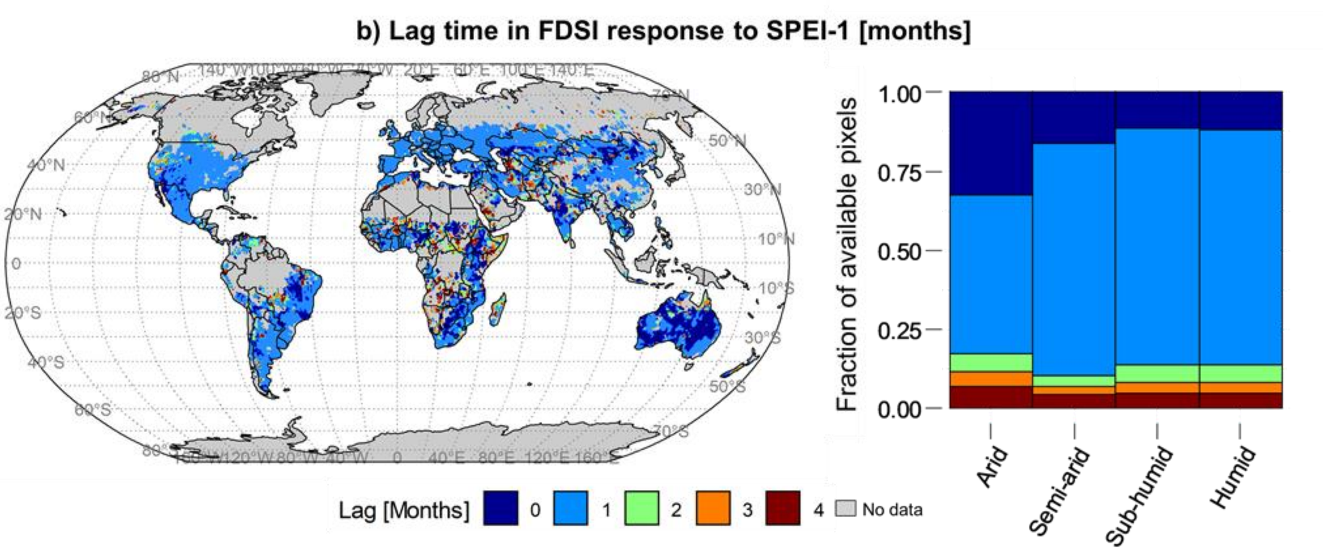


(a) Sustained drought conditions in Northeastern Brazil, (b) sustained drought in the Western U.S.(c) Drought recovery with advancing monsoon in the Indian peninsula (d) Intensification of drought severity in Northern Australia (e) Sustained dry conditions in Southern Africa

Global Validation: Standardized Precipitation-Evapotranspiration Index (SPEI-1) v/s FDSI



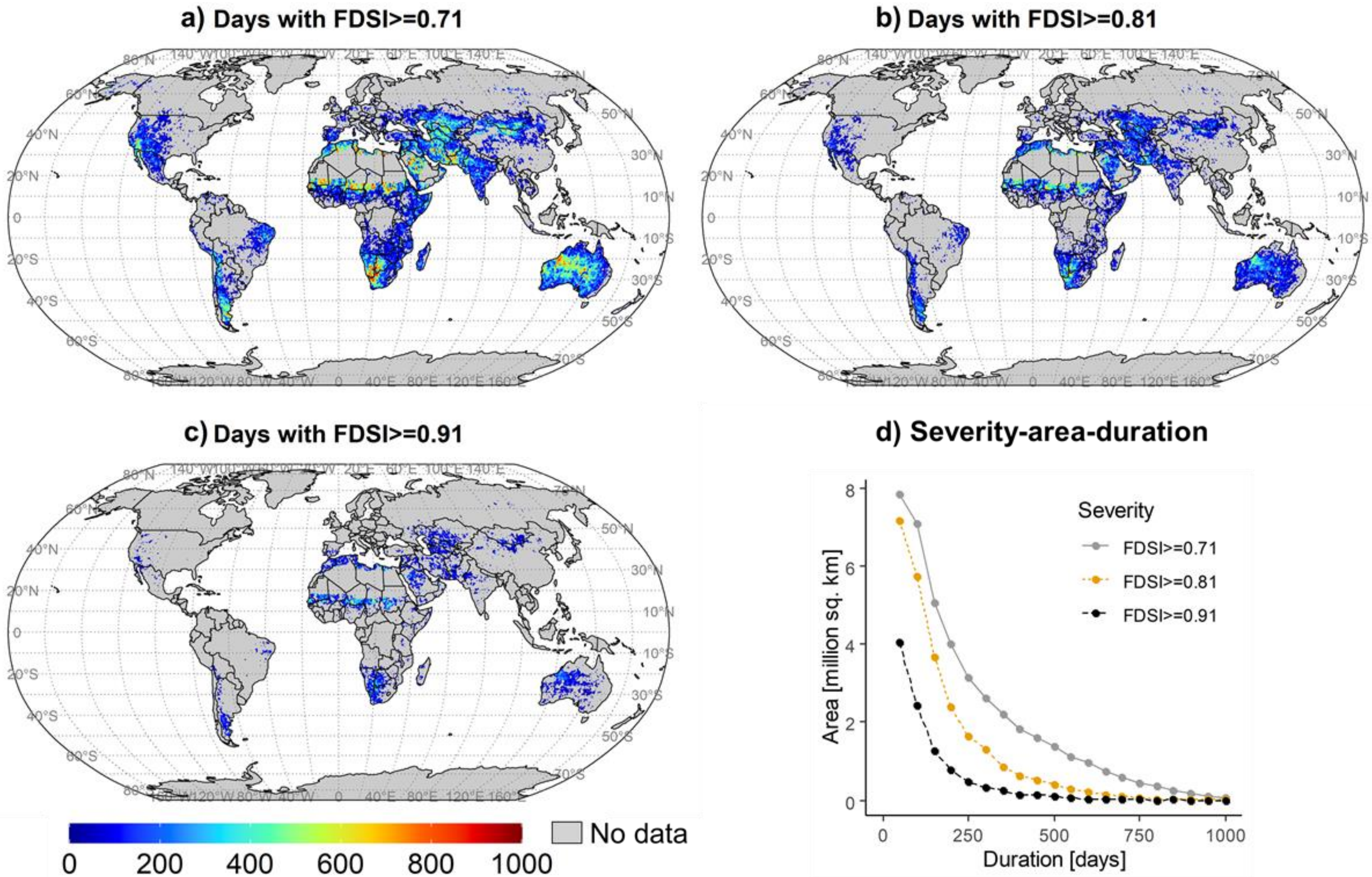
- Strong relationship between FDSI and SPEI-1 with 0-1-month lag is observed for most part of the globe.



- Weaker AC for arid regions due to underestimation of hydrometeorological variability (temporal) under extreme and/or sustained dry conditions.

Time lagged Anomaly Correlation (AC) quantifies the linear relationship (strength and timescale) between trigger and response variables. The formulation of AC follows that of Pearson's correlation coefficient; except, the coefficient is computed using temporal anomalies of the dataset.

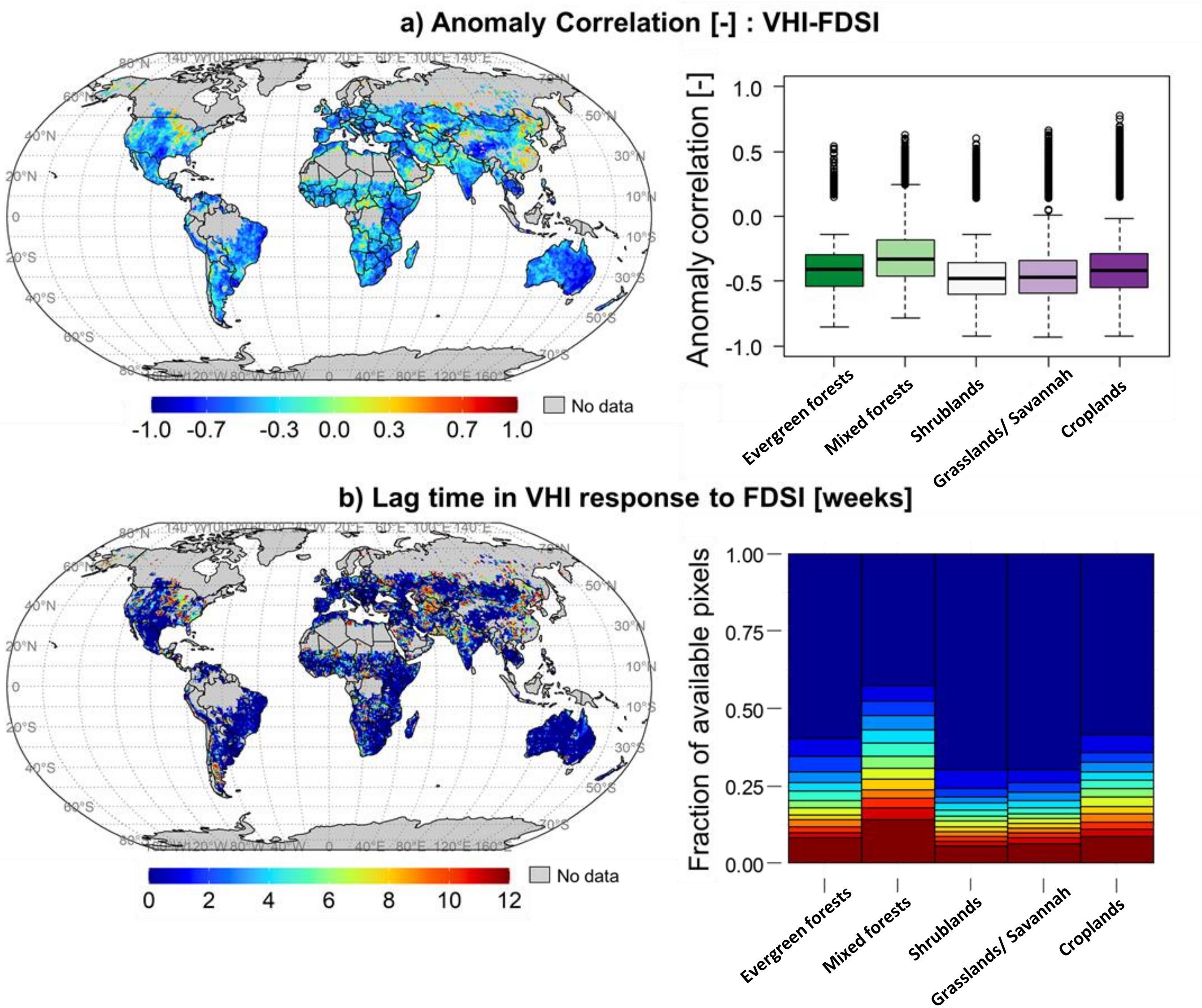
Global Hotspots of Flash Droughts



Several global hotspots of flash droughts are observed, predominantly, in global drylands – Western US, Sahel, large parts of India, Northeastern Brazil, and Central Asia due to strong land-atmospheric interactions and high atmospheric moisture demand in these regions.

Sehgal, V., Gaur, N. and Mohanty, B.P. "**Global Flash Drought Monitoring using Surface Soil Moisture**." Under review, WRR (2021).

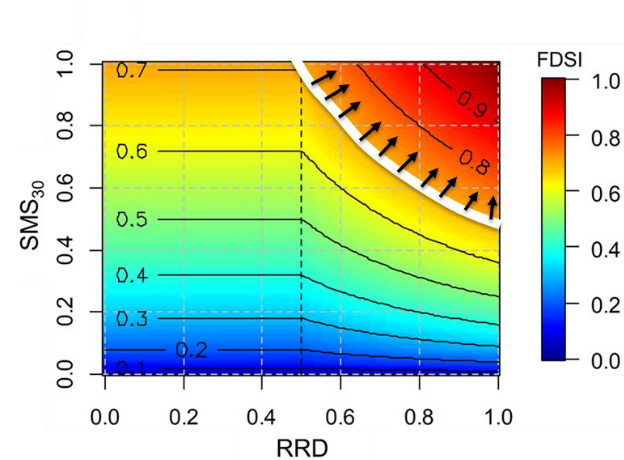
Predicting Global Vegetation Health (VHI)

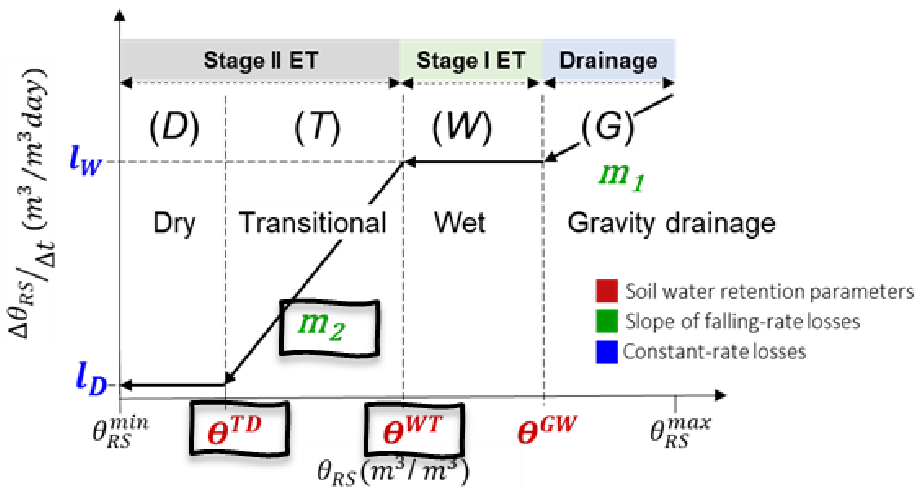


- ❑ Strong linear relationship between FDSI and AVHRR-Vegetation Health Index (VHI) for large parts of the world.
- ❑ Grassland and savannah vegetation show intense competition for moisture are sensitive to short-term deficits (0-1 week) in the SM.
- ❑ Mixed forests respond weekly to short-term meteorological variability low due to access to SM in the deeper rootzone profile.

Conclusion

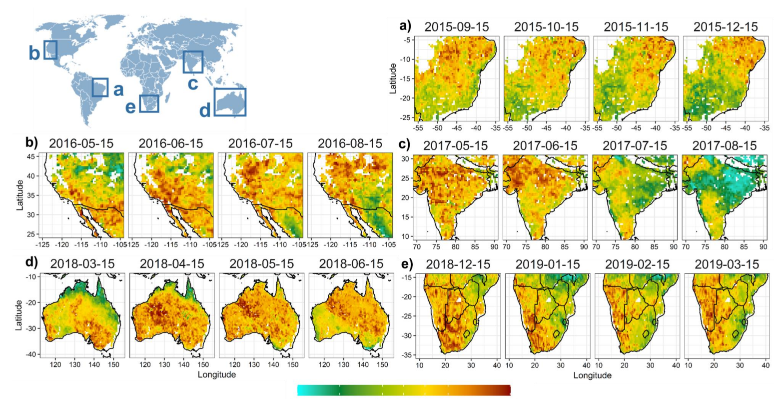
- A new index, FDSI, is developed as a non-linear, bivariate function of SMS and RRD to quantify the coupled impact of severity and intensification rate of flash droughts.





- Use of footprint-scale seasonal drydown parameters of θ_{RS} provide sensitivity to FDSI to the temporal variability in the subgrid-scale land-surface heterogeneity and soil-vegetation-climate interactions.

- Readily available parameters and purely data-driven method facilitates an easy implementation of this study into a real-time, operational framework, advancing global (flash) drought monitoring capabilities.



Appendix

Global FDSI rasters and associated parameters are freely available through Zenodo (a public, open-source repository)

zenodo

Search | Upload | Communities

February 24, 2021

Dataset | Open Access

Global estimates of drought stress in soils using SMAP

Sehgal, Vinit; Gaur, Nandita; Mohanty, Binayak

This resource provides the global estimates of Flash Drought Stress Index (FDSI) from 31st Match 2015 through 19th March 2019 at a daily time-step at 36-km spatial resolution. FDSI non-linearly combines Soil Moisture Stress (SMS, drought stress) and the Relative Rate of Drydown (RRD, drought stress intensification rate). SMS and RRD are developed using SMAP θ_{RS} (March 2015-2019) and footprint-scale seasonal soil water retention parameters and land-atmospheric coupling strength. The value of FDSI ranges between (0, 1) with values >0.71 indicates flash drought conditions. For details, the readers are referred to the **read.me.pdf**.

The authors acknowledge the funding support from NASA SMAP projects (NNX16AQ58G, 80NSSC20K1807). We thank the Texas A&M High-Performance Research Computing (https://hprc.tamu.edu/) for providing computing resources for this research.

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