Soil Moisture Active Passive Mission
SMAP

Global Flash Drought Monitoring using Surface Soil Moisture

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Challenges in Drought Monitoring using Soil Moisture

A robust flash drought monitoring using $\theta_{RS}$ must account for:
- Short observation record of SMAP
- Non-linear geophysical controls over $\theta_{RS}$ 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

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From Aghelpour, P. et. al 2021

From Jovanovic et. a 2012
The drying patterns of SMAP soil moisture ($\theta_{RS}$) change spatially and temporally under heterogeneous non-linear geophysical controls:

- Global SMAP Drydown Patterns
- Spatial variability in drydown form
- Seasonal variability in SMAP drydown pathways

Soil moisture drydown pathway at SMAP footprint:

- $l_D$: Soil water retention parameters
- $l_W$: Slope of falling-rate losses
- $m_1$: Constant-rate losses

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.

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

**Flash Drought Stress Index (FDSI)**

**FDSI is based on two components:**

A) **Soil Moisture Stress**
   Measure of drought stress in soil
   
   \[ SMS_t = \frac{1}{1 + \left( \frac{\theta_{IP}}{\theta_{RS,t}} \right)^n} \]
   
   30-day rolling mean
   
   \[ SMS_{30,t} = \sum_{i=t}^{t-29} SMS_i / 30 \]
   
   Inflection point
   
   \[ \theta_{IP} = \left( \frac{\theta^{TD} + \theta^{WT}}{2} \right) \]
   
   Shape factor
   
   \[ n = 12 \cdot \sqrt{m_2} \]

B) **Relative Rate of Drydown**
   Rate of drought intensification
   
   \[ RRD_t = \frac{1}{1 + \left( \frac{m_2}{RD_t} \right)^6} \]
   
   \[ RD_t = \text{rate of drydown based on SM observations for } t \text{ to } t-29. \]

Nonlinear relationship of FDSI with SMS\(_{30}\) and RRD

\[
FDSI_t = \begin{cases} 
\sqrt{SMS_{30,t} \cdot RRD_t} & \text{if } RRD_t > 0.5 \\
\sqrt{SMS_{30,t} \cdot 0.5} & \text{if } RRD_t \leq 0.5 
\end{cases}
\]

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Evolution of Flash Drought

Strenance

- 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

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Intensification

- SM recedes with sustained RRD >0.5.

Onset

- SMS$_{30}$ is normal
- High RRD causes rapid loss of SM as time progresses.
Overestimation of Drought Severity by SMS\textsubscript{PTF}

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

Overestimation of high-severity droughts.
2017 Flash Drought in the Northern Great Plains

No drought stress
Onset of drought
Intensification
Sustenance of drought
Offset

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

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.
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 $\theta_{RS}$ 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).