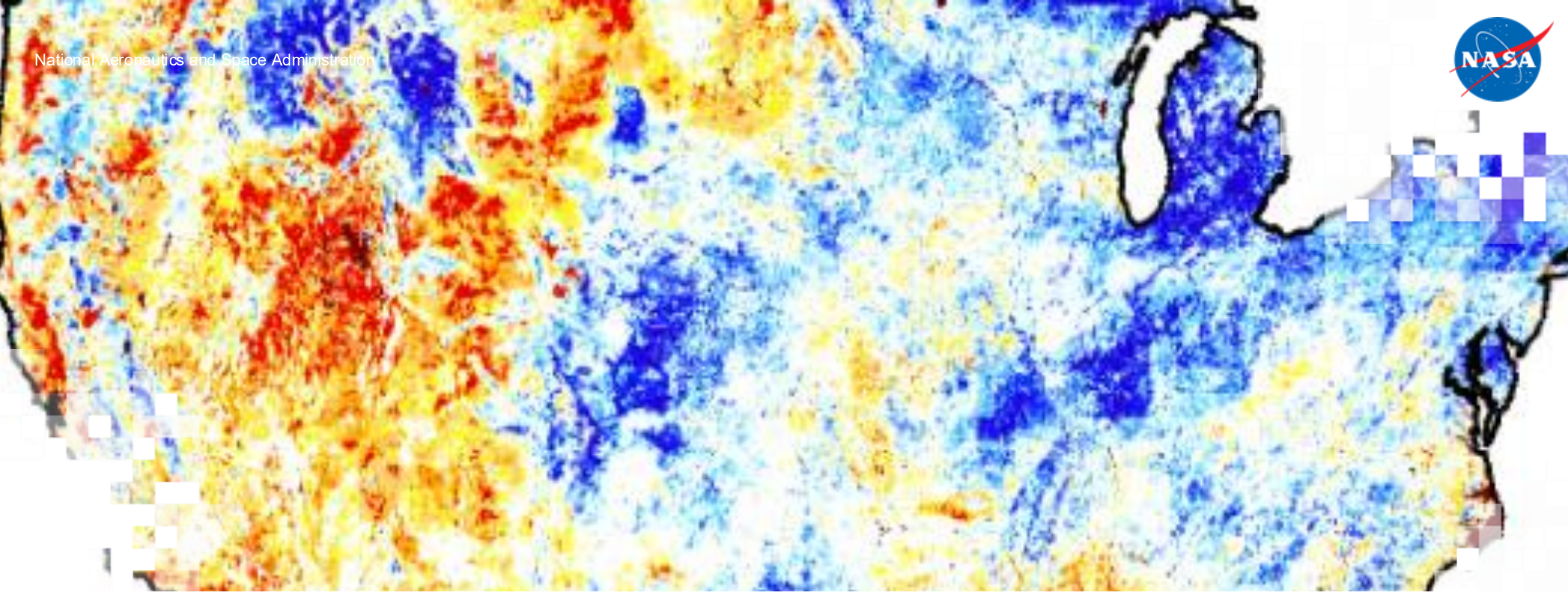




Agricultural Flash Drought Detection using Solar-Induced Fluorescence (SIF) and Soil Moisture Data

Session 2: Flash Drought Detection and Prediction

Nicholas Parazoo (JPL/Caltech), Jacqueline Ryan (JPL/Caltech)

September 29, 2026

Training Outline

Session 1

Introduction to
Flash Drought
Monitoring using SIF
and Soil Moisture

Sep. 24, 2026

Session 2

Flash Drought
Detection and
Prediction

Sep. 29, 2026

Homework

Opens Sep. 29 – Due Oct. 20, 2026 – Posted on Training Webpage

A certificate of completion will be awarded to those who attend all live parts and complete the homework assignment(s) before the given due date.



Prerequisites

- [Fundamentals of Remote Sensing](#)
- [Use of Solar Induced Fluorescence and LIDAR to Assess Vegetation Change and Vulnerability](#)
- [Solar Induced Fluorescence \(SIF\) Observations for Assessing Vegetation Changes Related to Floods, Drought, and Fire Impacts](#)

Session 1 – Instructors

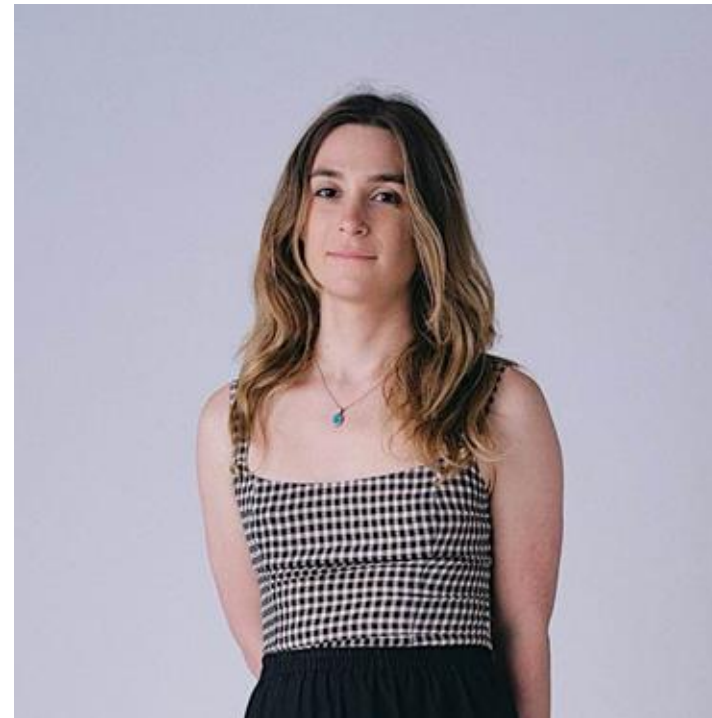
Erika Podest

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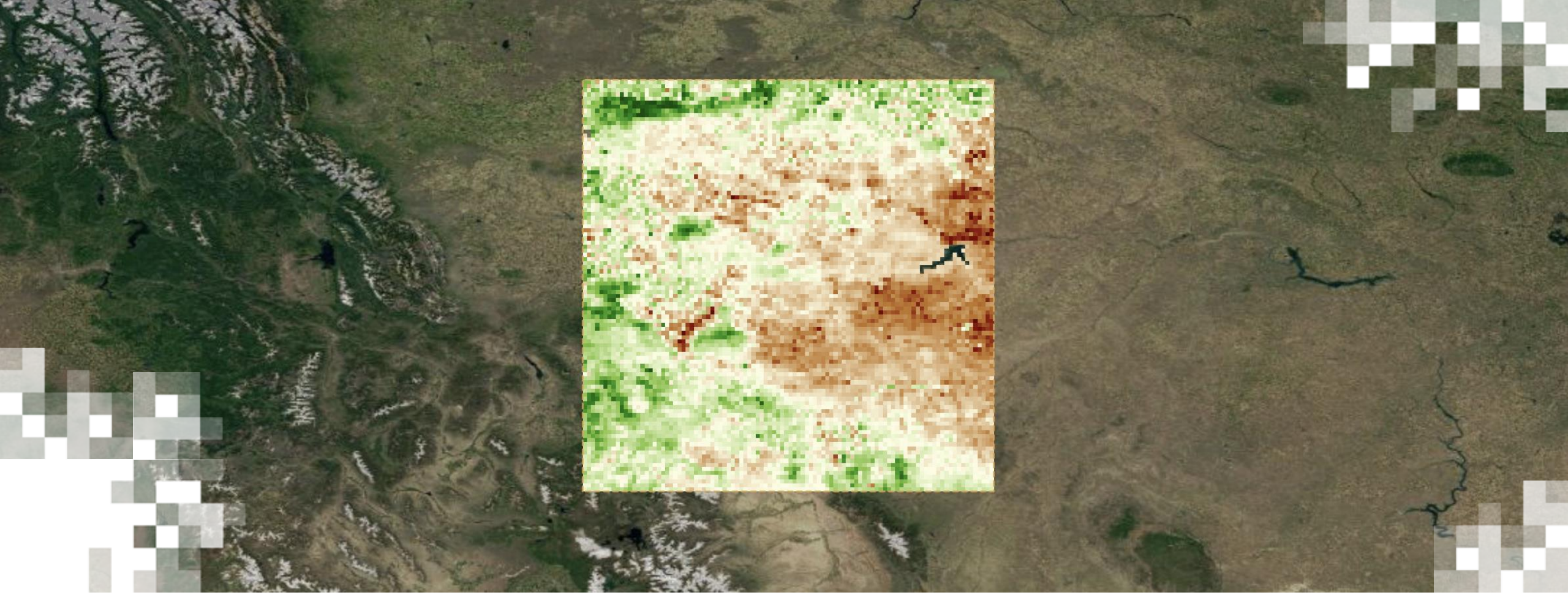
Session 2 Objectives

By the end of Session 2, participants will be able to:

- Synthesize Solar-Induced Fluorescence Rapid Change Index (SIF-RCI) time series data for a selected region using a provided Jupyter Notebook.
- Retrieve and manipulate SMAP Soil Moisture (SM) and land process model-based Soil Water Deficit Index (SWDI) time series and compare with SIF-RCI time series data using a provided Jupyter Notebook.
- Compare the implications of different methods for flagging and identifying flash droughts in real-world scenarios.

How to Ask Questions

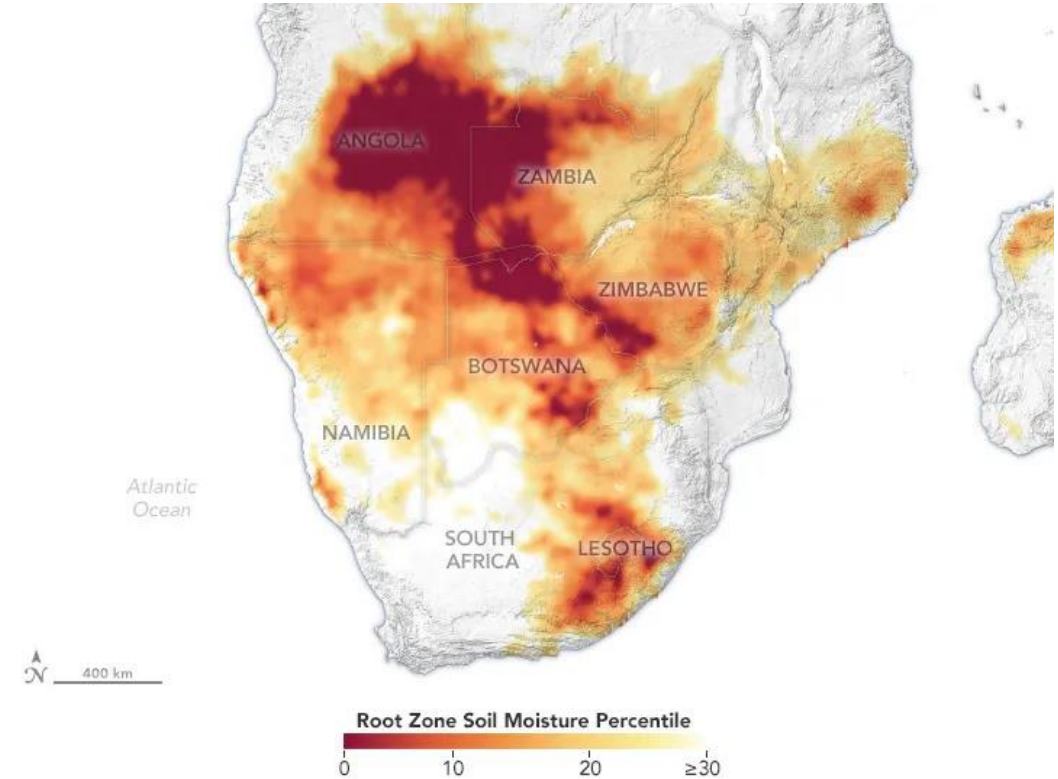
- Please write your questions in the Questions box and we will answer them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to respond all the questions during the Q&A session after the webinar.
- The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.



Session 2: Flash Drought Detection and Prediction

Session 2 Objectives

- Review why SIF and Soil Moisture are used together for detecting flash drought
- Create SIF-RCI and SWDI time series in new regions and time periods
- South African Flash Drought of 2023-2024
- Compare different rules for detecting and identifying flash droughts
- Explore other data sources for flash drought early warning



Estimates of Root Zone Soil Moisture in Southern Africa for March 2024.
Credit: NASA FEWS NET, Emily Cassidy



Review – Agricultural Drought

- A period of declining **soil moisture** with impacts to crop yield, regardless of surface water resources
- Distinct from **meteorological drought**, which is a lack of precipitation over a period of time
- Why is this difference important?
 - Severe precipitation deficit is frequently absent during flash drought events
 - Crops do not behave like wildland ecosystems; they're typically not native plants and they have different water requirements from the environments they are growing in
 - A thirsty crop may fail during a relatively mild precipitation deficit due to high evaporative demand



Alfalfa fields in the Imperial Valley of California, United States. Located in an extremely arid desert, agriculture in this region is reliant on irrigation, so farmers here do not care much about precipitation. Credit: JacobSA2019, CC BY-SA 4.0



Why do we need Root Zone Soil Moisture (RZSM)?

Catchment Model:

- SRFEXC: Surface Moisture Exceeding Equilibrium
- RZEXC: Root Zone Moisture Exceeding Equilibrium
- D: Root Zone Depth

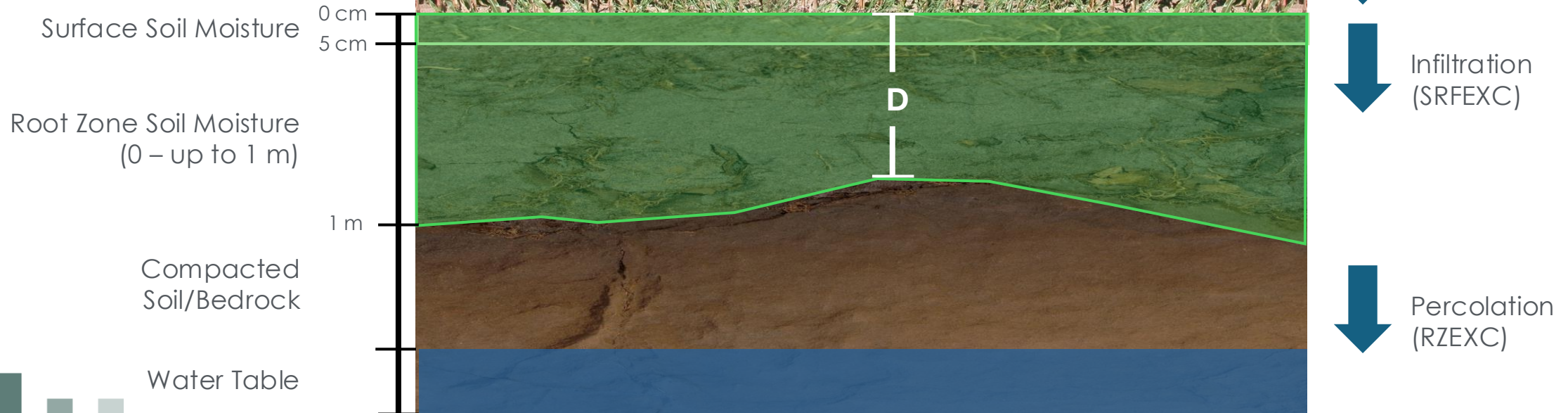


Photo Credits: Gilles Ayotte (Maize crop), Spaargaren (soil monolith). Photos used under CC-BY-SA 4.0



Root Zone Soil Moisture is a water “bank account.”

Deposits

Precipitation

+water

Withdrawals

Evapotranspiration*

-water

Infiltration (below RZ)

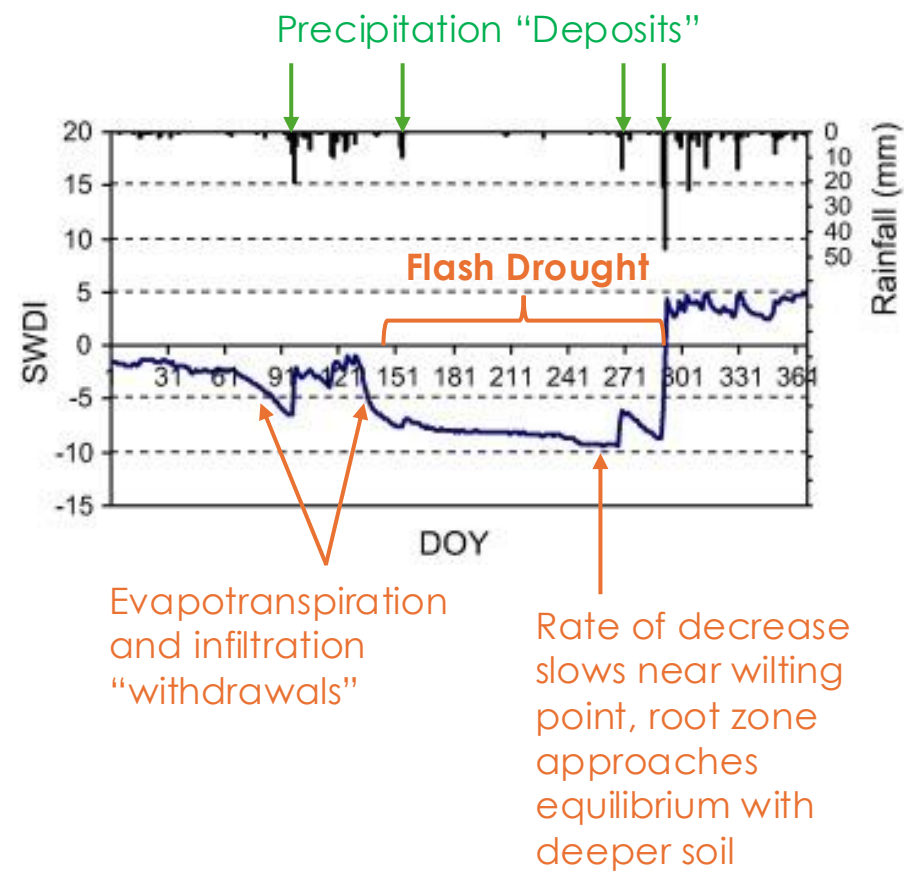
-water

Root Zone Soil Moisture

Available Water

*Evapotranspiration is correlated with Temperature (T_a) and Vapor Pressure Deficit (VPD)

In comparison, **surface** soil moisture is like a recent transaction history – it doesn't tell us about the **total** water content available to vegetation.



Source (right): Martínez-Fernández et al., 2015



Why use Soil Water Deficit Index (SWDI) in place of RZSM?

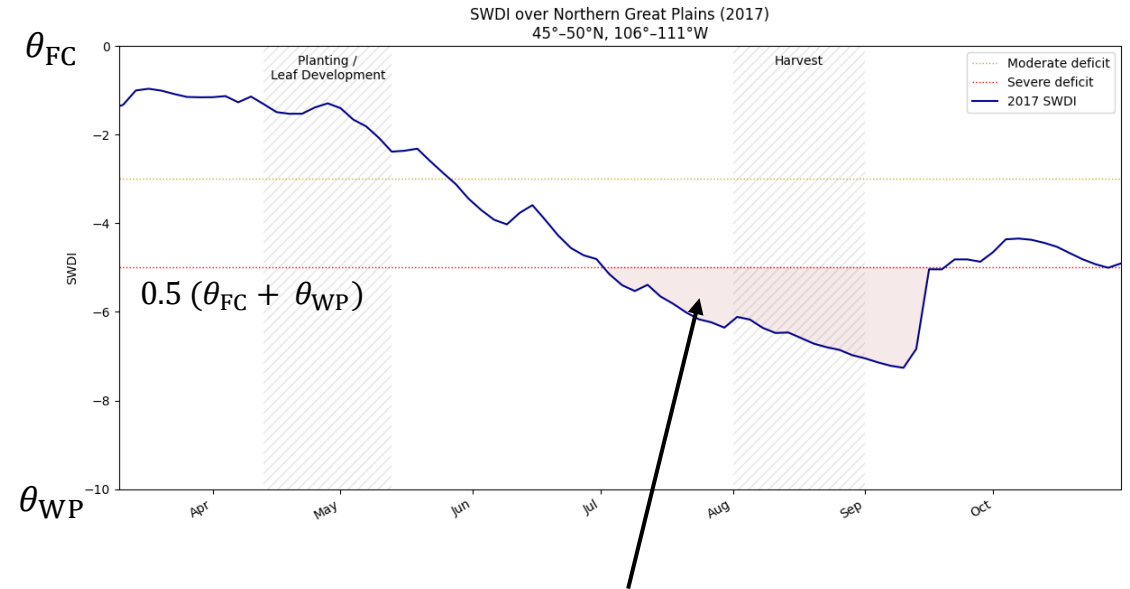
- Remember:

$$\text{SWDI} = \frac{\theta - \theta_{\text{FC}}}{\theta_{\text{FC}} - \theta_{\text{WP}}} * 10$$

- When using the SMAP L4 data's catchment model constants, we also need to calculate θ_{FC} per spatial grid cell:

$$\theta_{\text{FC}} = \frac{\text{cdcr2}}{d_{\text{pr}} * \rho_{\text{w}}}$$

- This effectively divides out the bias in the RZSM estimate, allowing for creation of ensemble SWDI if multiple model sources are available.
- Key Criticism:** Thresholds of SWDI (e.g., $\text{SWDI} \leq -5$ is severe drought) are only physical meaningful if you trust θ_{FC} and θ_{WP} .



Is $\text{SWDI} \leq -5$ a severe soil moisture deficit in reality? It depends on the accuracy of our constants!

θ = Root Zone Soil Moisture

θ_{FC} = Field Capacity, the “wet” extreme for the soil

θ_{WP} = Wilting Point, the “dry” extreme for the soil

cdcr2 = Column Water Capacity (in kg/m^2)

d_{pr} = Depth of Soil Profile (D from earlier diagram)

ρ_{w} = Density of Water (in kg/m^3)

Source: Martínez-Fernández et al., 2015, Reichle et al., 2025 [ATBD]

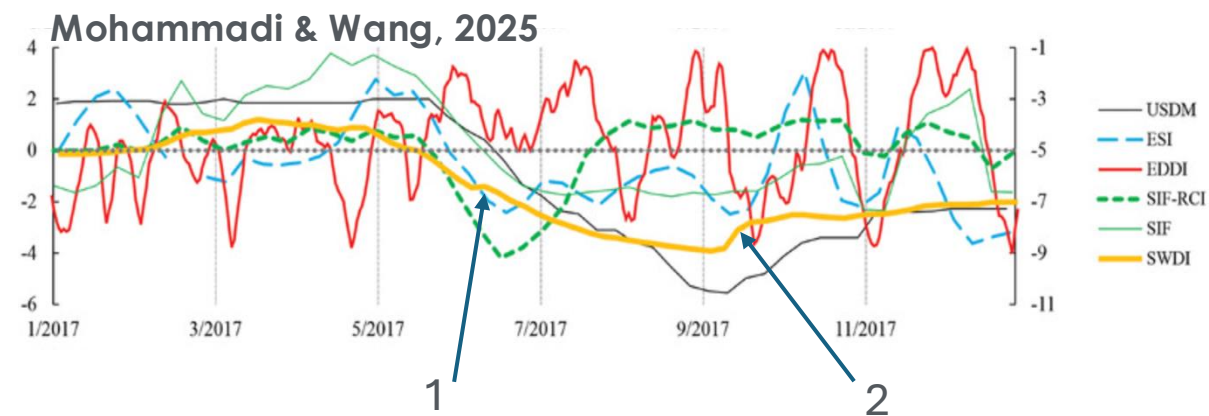
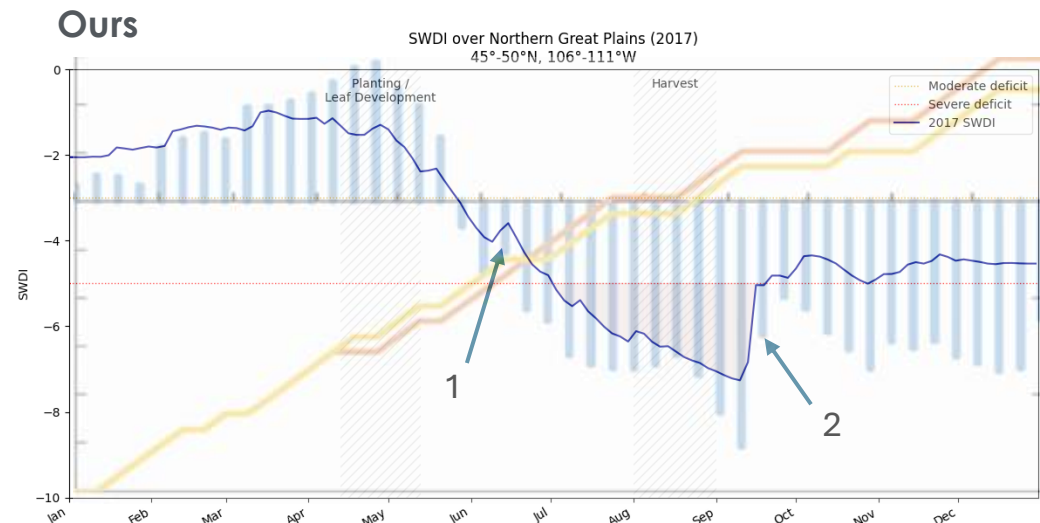
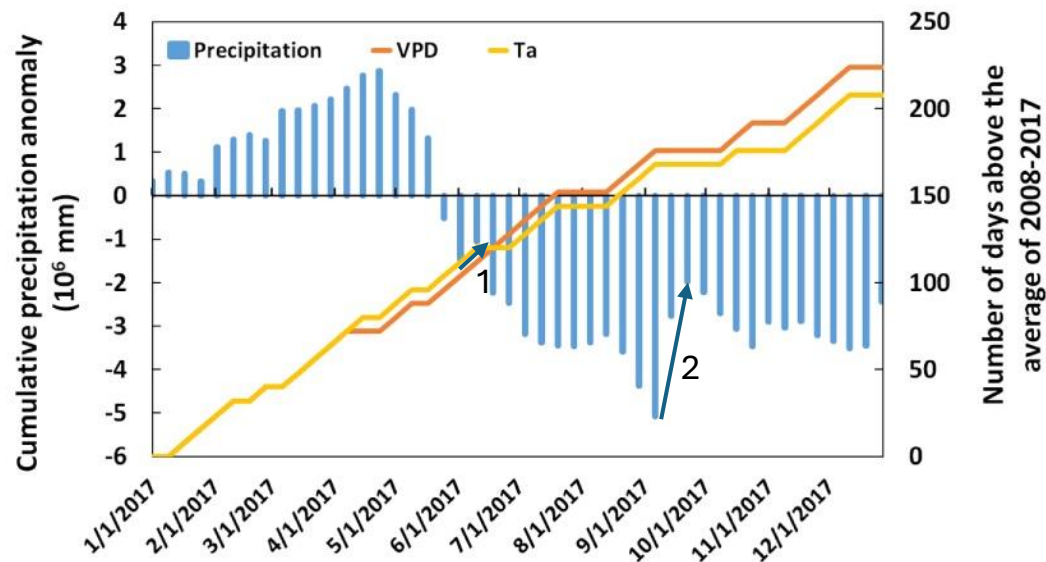


Comparing SWDI to Precipitation, ET, and Other Metrics

Returning to 2017 Flash Drought from Part 1, let's see if notable precipitation events are reflected in independent estimates of SWDI:

1. June minor precipitation
2. September major precipitation

Reference: Precipitation (and VPD/Ta) from He et al., 2019

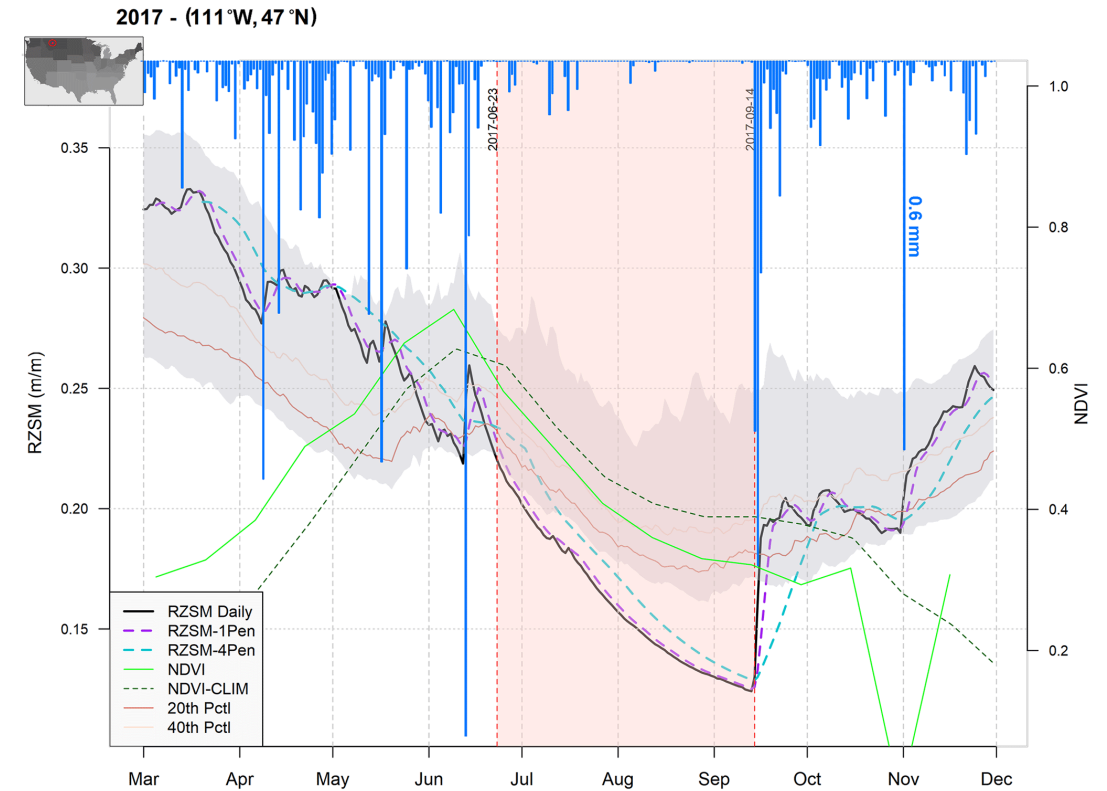
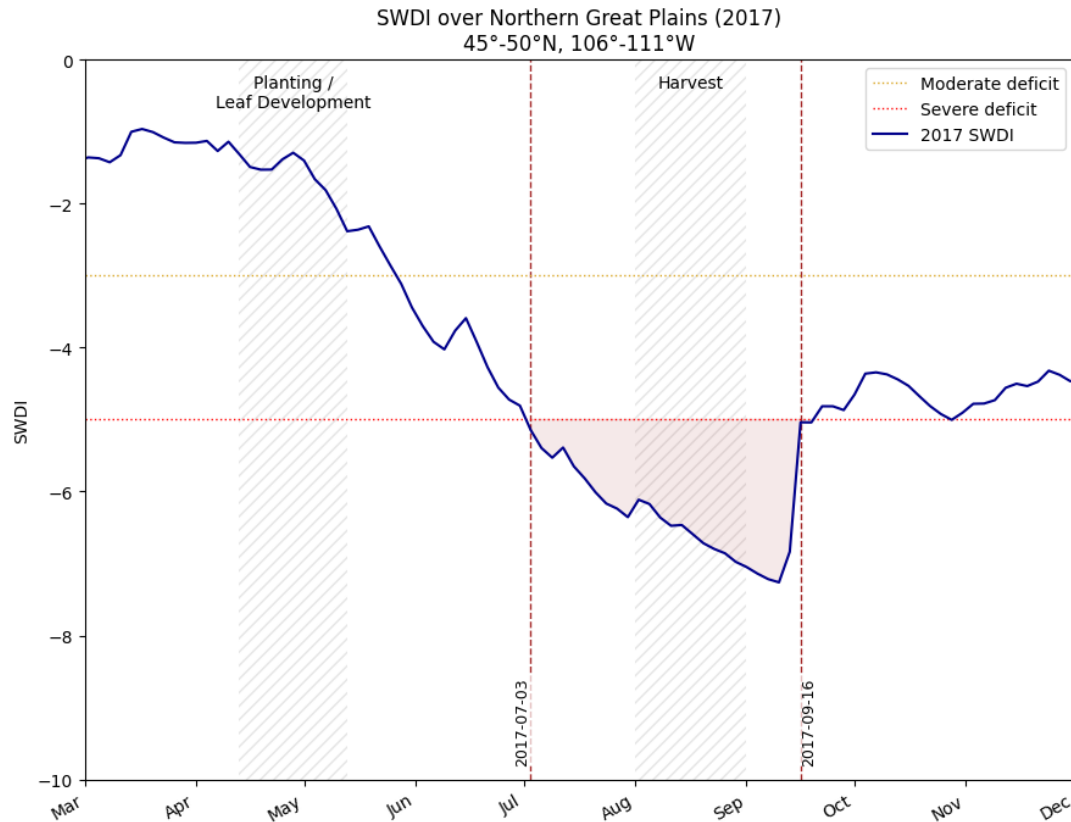


ESI and EDDI are not providing much diagnostic information in this case.

Source: He et al., 2019 (bottom left). Mohammadi and Wang, 2025 (bottom right).



Comparing SWDI to Precipitation, ET, and Other Metrics



In this approach, Osman et al. define FD as occurring when:

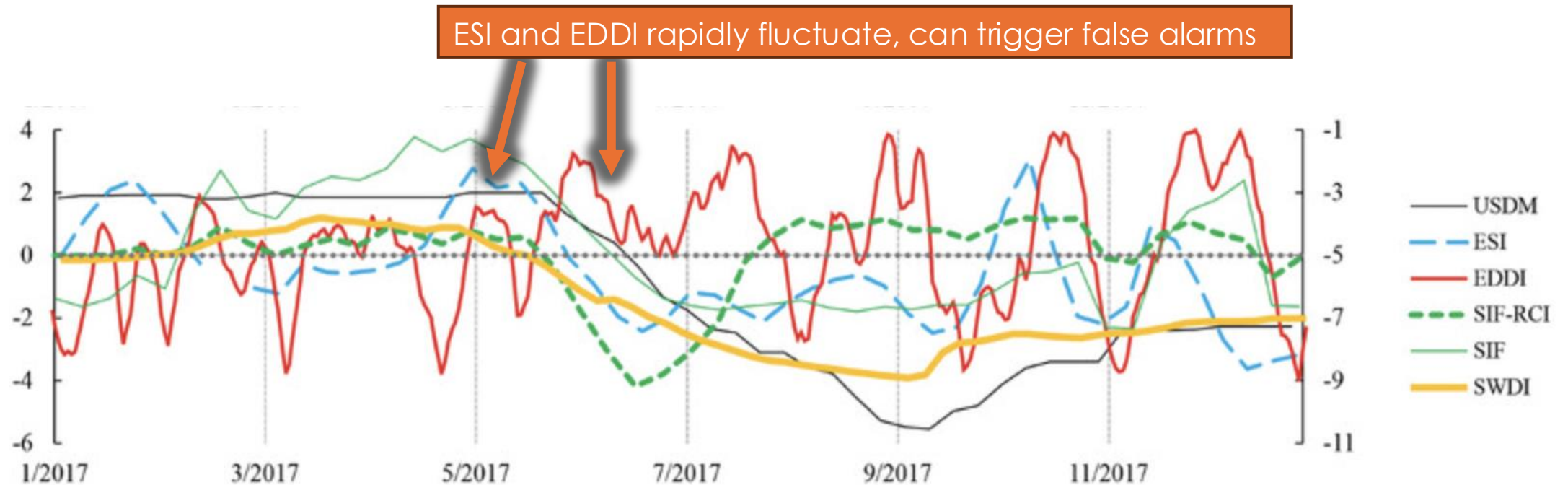
1. The 5-day moving average (RZSM-1Pen) falls below the 20-day moving average (RZSM-5Pen) for at least 4 consecutive 5-day time steps.
2. At the time step that passes rule 1, RZSM is below the 20th percentile from the 1979-2018 climatological record.

Source: Osman et al., 2021 (right)



Why Flash Drought Excludes Precipitation and Evapotranspiration

- Precipitation deficit (traditional drought) alone lacks relevance
- Drought via ET is more sophisticated:
 - Within ERA5 model, Provides ESI or EDDI, Available from VPD and Temperature

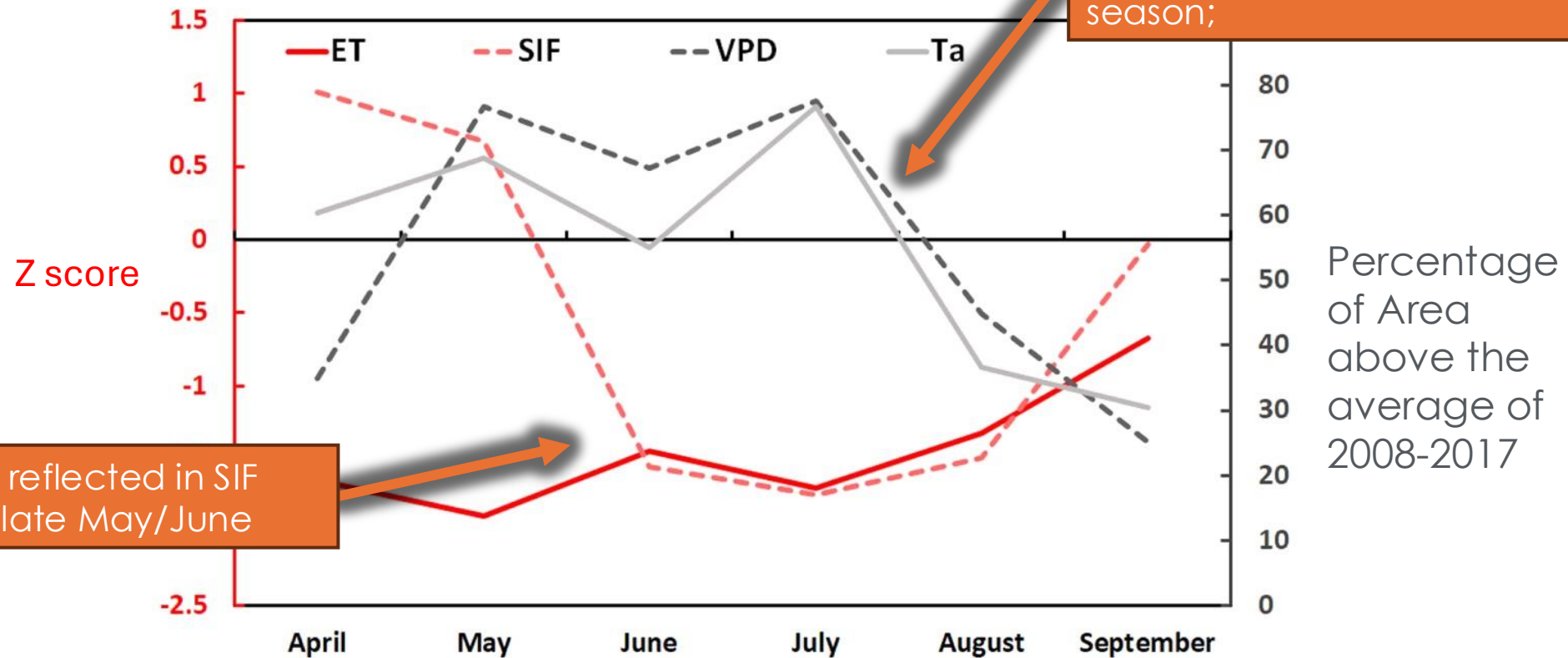


Source: Mohammadi and Wang, 2025



Why Flash Drought Excludes Precipitation and Evapotranspiration?

Theory: RZSM is more holistic (depends on precip, ET)



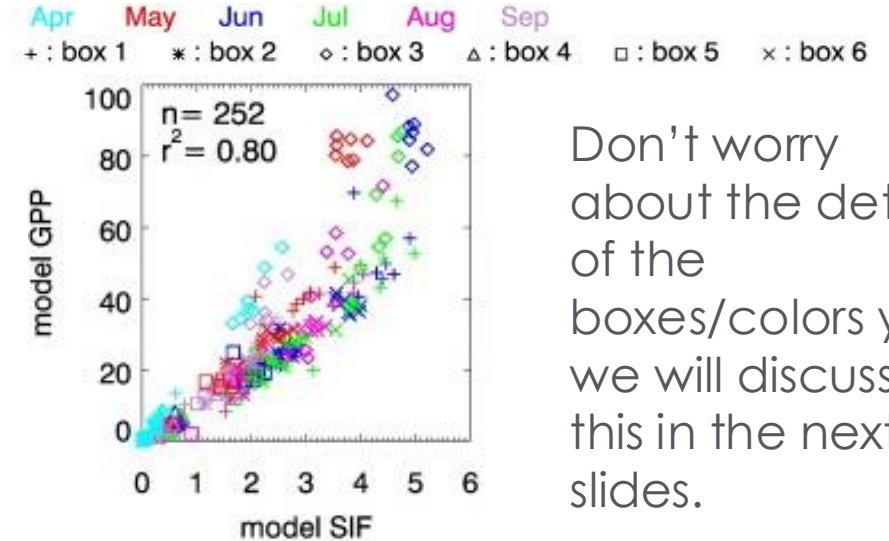
Source: He et al., 2019

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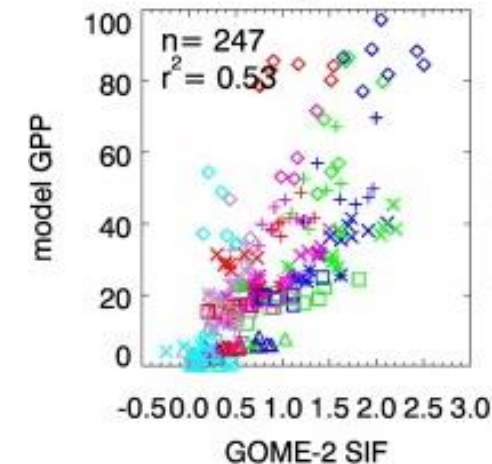


The Case for SIF in Agricultural Drought Monitoring

- To determine **agriculturally impactful drought**, we want a measurement that:
 - Is highly correlated with photosynthetic function
 - Responds rapidly and linearly to stress
 - Does not require *in situ* measurements or rely solely on models
- Gross Primary Productivity (GPP) is a direct measure of photosynthetic function, but **can't be measured from space (SIF can!)**.
- Flux towers measure GPP *in situ*; otherwise, must be modeled.
- Yoshida et al., 2015 studies a 2010 Russian flash drought by comparing GOME-2 SIF to MODIS NDVI, model GPP, and tower-based GPP.
- **SIF and GPP are linearly correlated, and the study found the correlation was stronger in croplands & grasslands.**



Don't worry about the details of the boxes/colors yet, we will discuss this in the next slides.



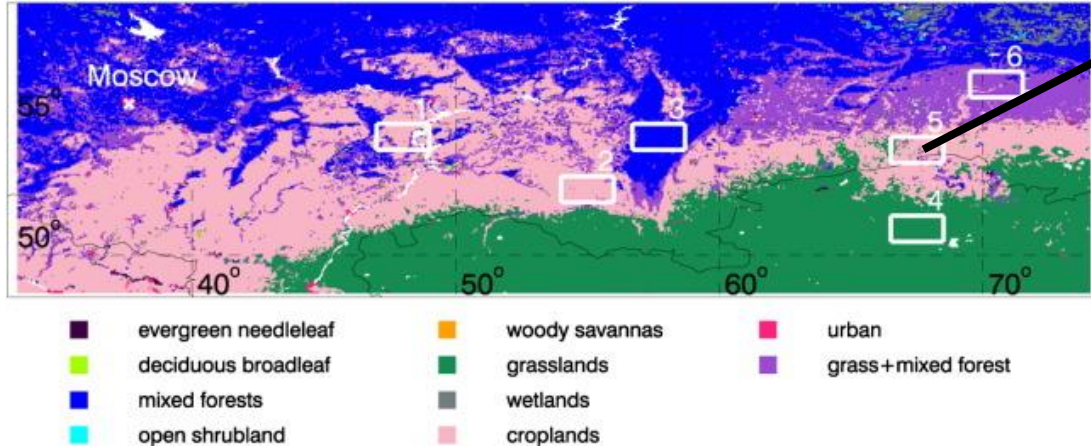
Note the linear relationship between SIF and GPP.

Source: Yoshida, et al., 2015

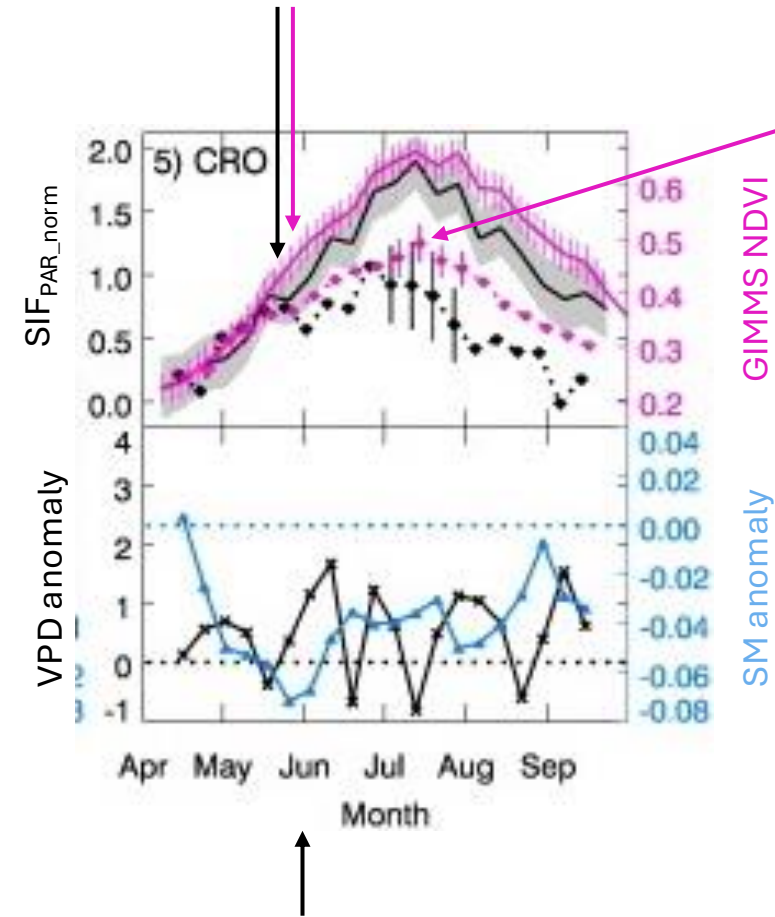


SIF vs. NDVI and Other Vegetation Indices

- SIF showed a rapid decline during autumn senescence compared to NDVI
- This rapid decline had better agreement with tower-based GPP measurements
- SIF shows more sensitivity to stress = advantage in drought early warning (compared to NDVI)



SIF (black dots) and NDVI (magenta dots) go below climatological mean (solid lines) around the same time over cropland (CRO) but note more rapid decline in SIF



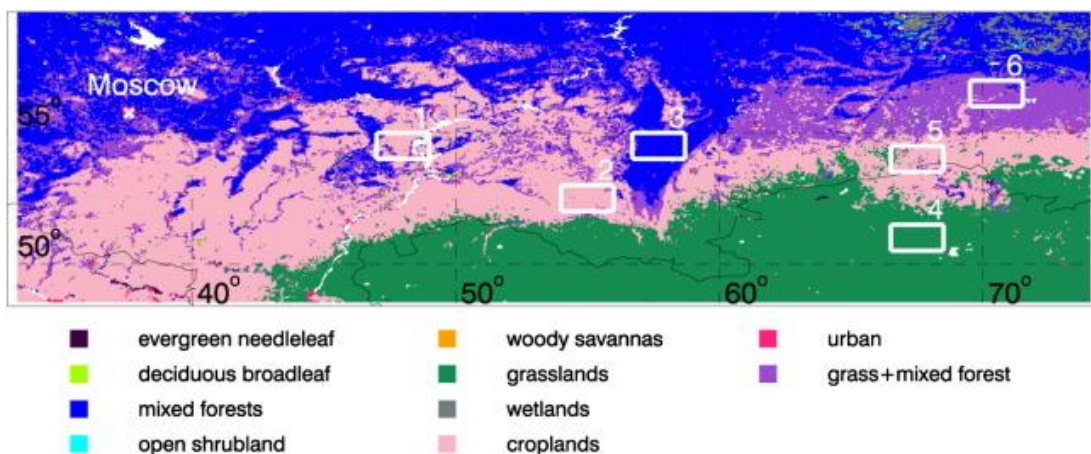
NDVI curve is generally "smoother," doesn't respond as quickly to changes in SM and VPD anomaly

Positive VPD anomaly = drier air, higher ET, worsens drought and causes SIF to fall further below clim. mean



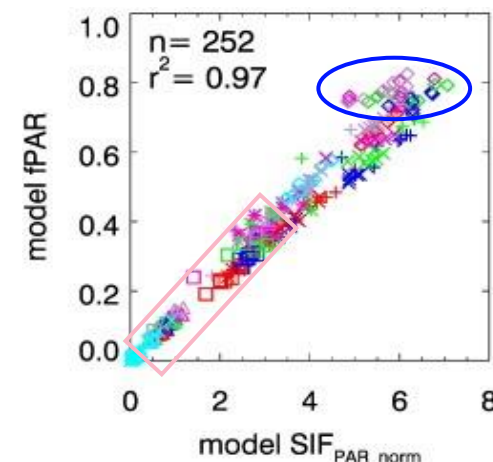
SIF vs. NDVI and Other Vegetation Indices

- SIF is sensitive to fraction of Photosynthetically Absorbed Radiation (fPAR) and photosynthetic yield (Θ_f)
- Drought causes declines in fPAR and Θ_f
- More acute in grasslands and croplands
- NDVI is based on reflectance, which also responds to stress by a reduction in energy absorption, but more slowly than SIF, on the order of days

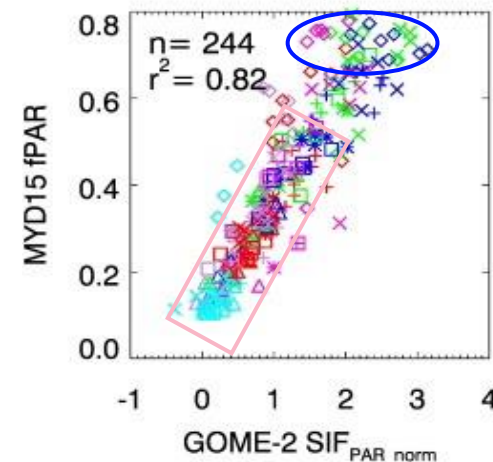


Source: Yoshida et al., 2015

Apr May Jun Jul Aug Sep
+: box 1 * : box 2 ◊ : box 3 △ : box 4 □ : box 5 × : box 6



Mixed Forest (◊, ×) shows more spread from linear trend compared with croplands & grasslands (+, △, □)

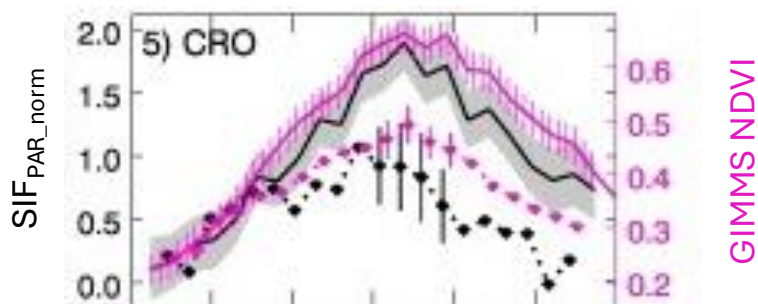


This implies that **SIF responds to stress more linearly over cropland.**

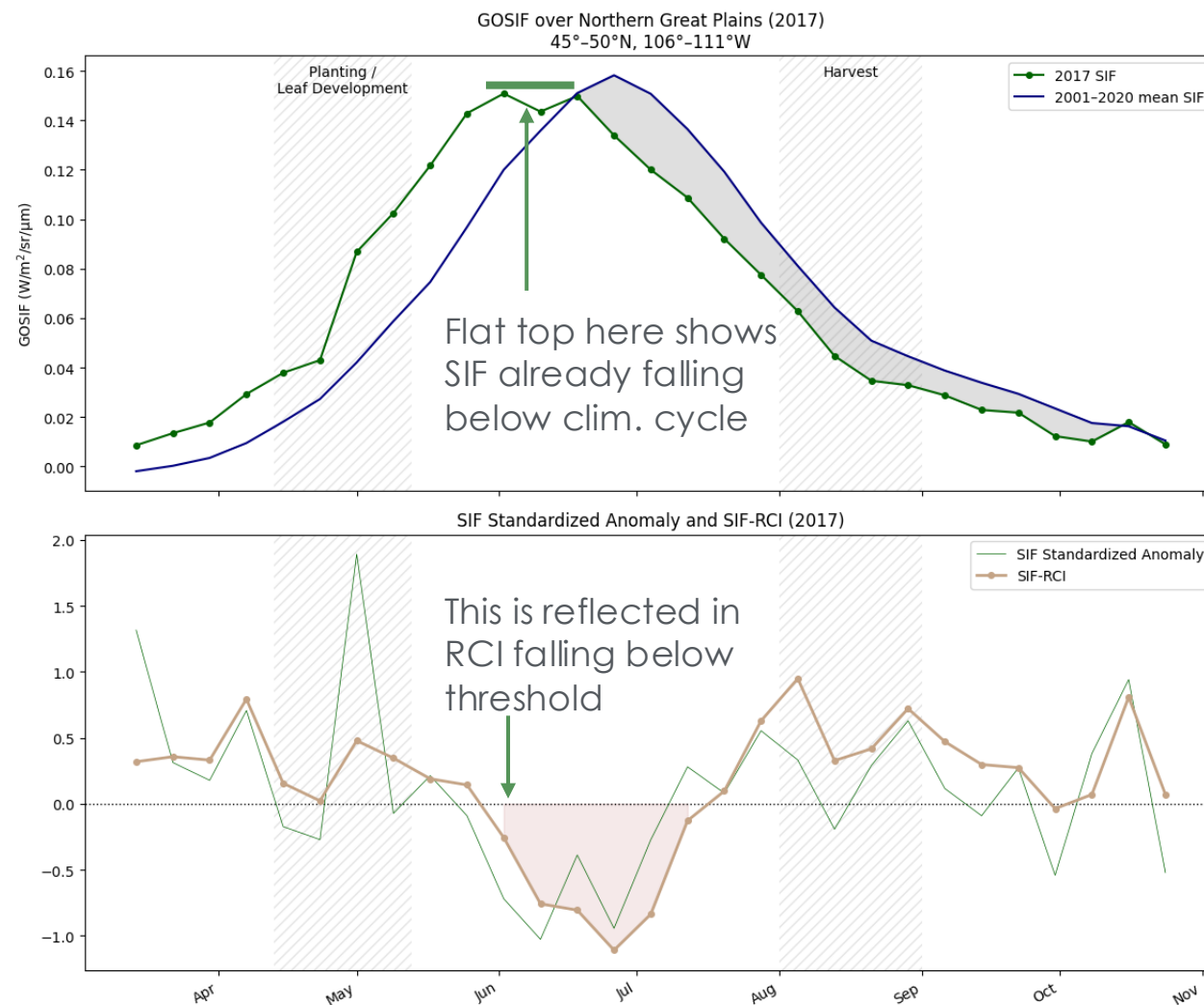


Why do we use SIF-RCI in place of SIF?

- To detect agriculturally impactful drought, we want to quantify **departure from the normal growing season cycle**.
- When we look at a simple time series of SIF (like the example below from Yoshida et al., 2015), how would we decide when a SIF anomaly becomes agriculturally impactful?
- Don't just want to detect when we fall below clim. mean, but specifically when the cumulative anomaly becomes impactful.

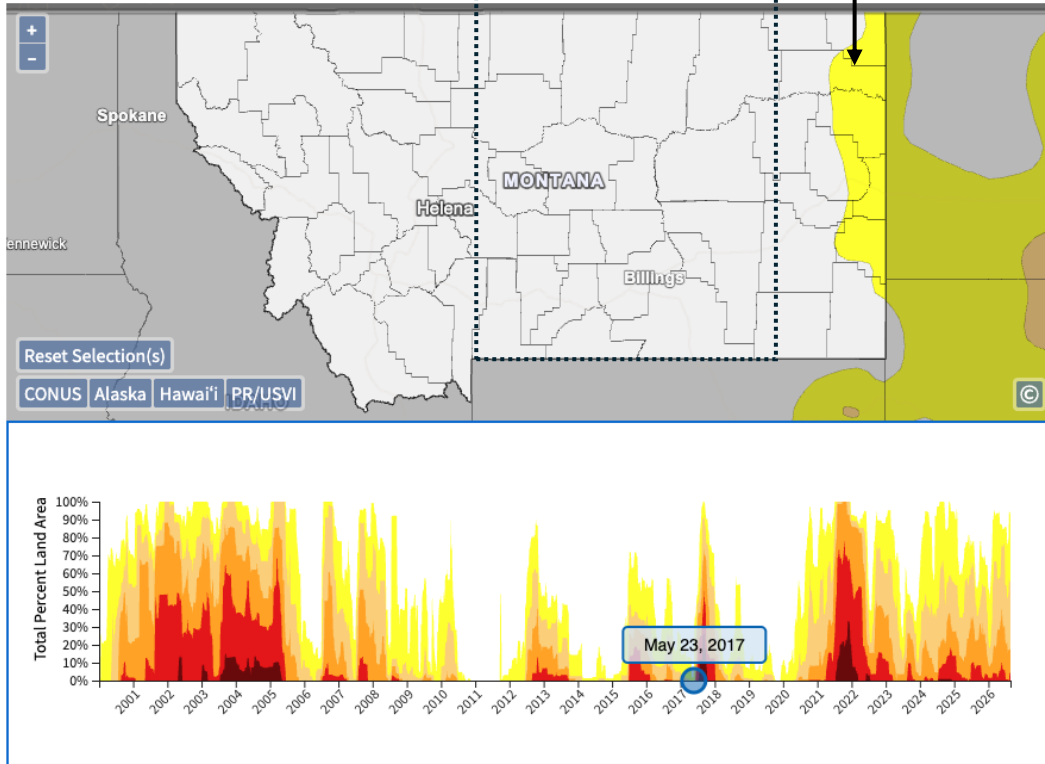


Source (Left): Yoshida et al., 2015

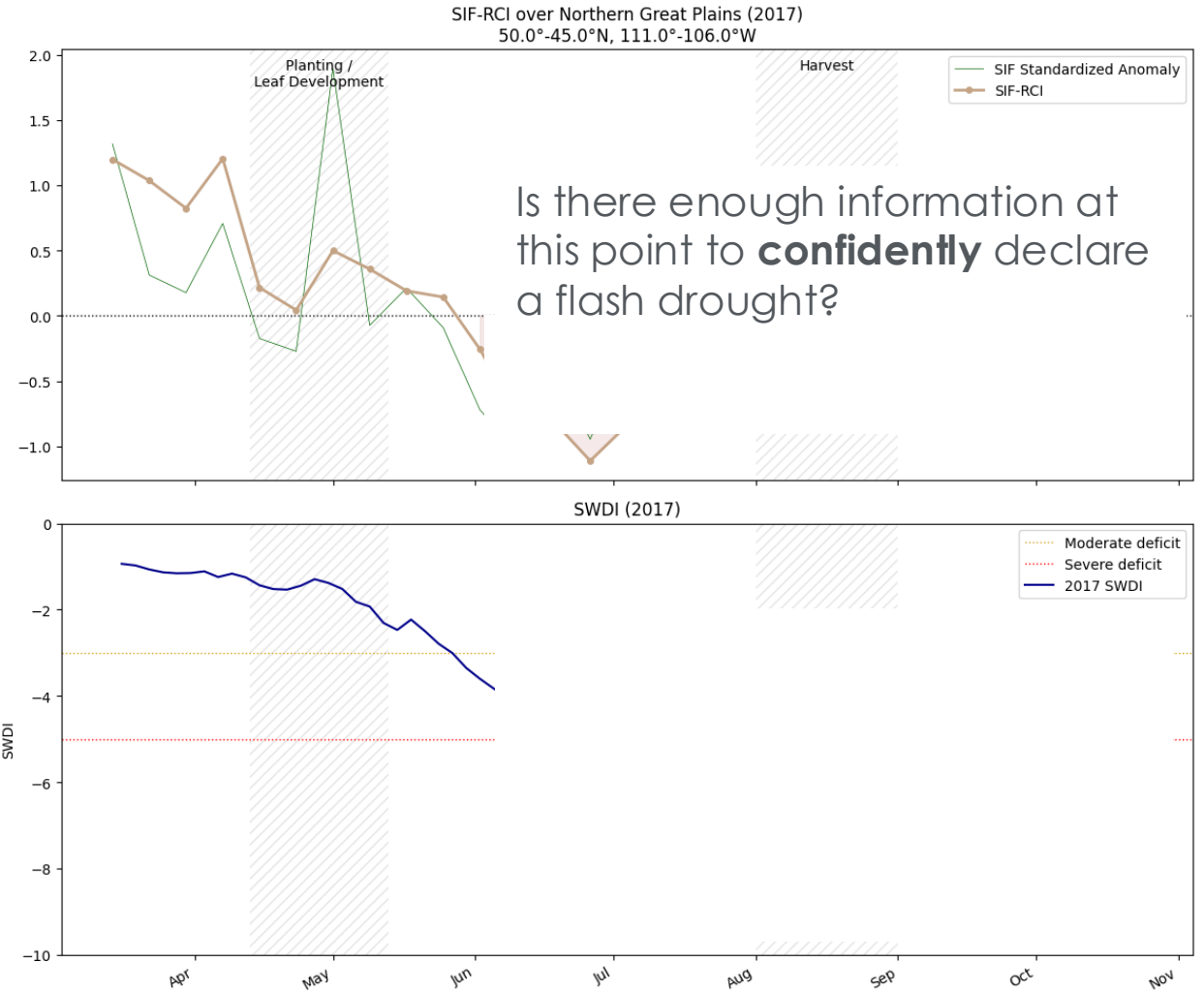


Flash Drought Onset in Northern Great Plains: 2 June 2017

D0 – Abnormally Dry



Arguably, it's "unfair" to compare the May 23 USDM to the June 2 SIF-RCI and SWDI. USDM is released every 2-weeks, so if we were using all available information on June 2, this would be the most recent USDM we have.



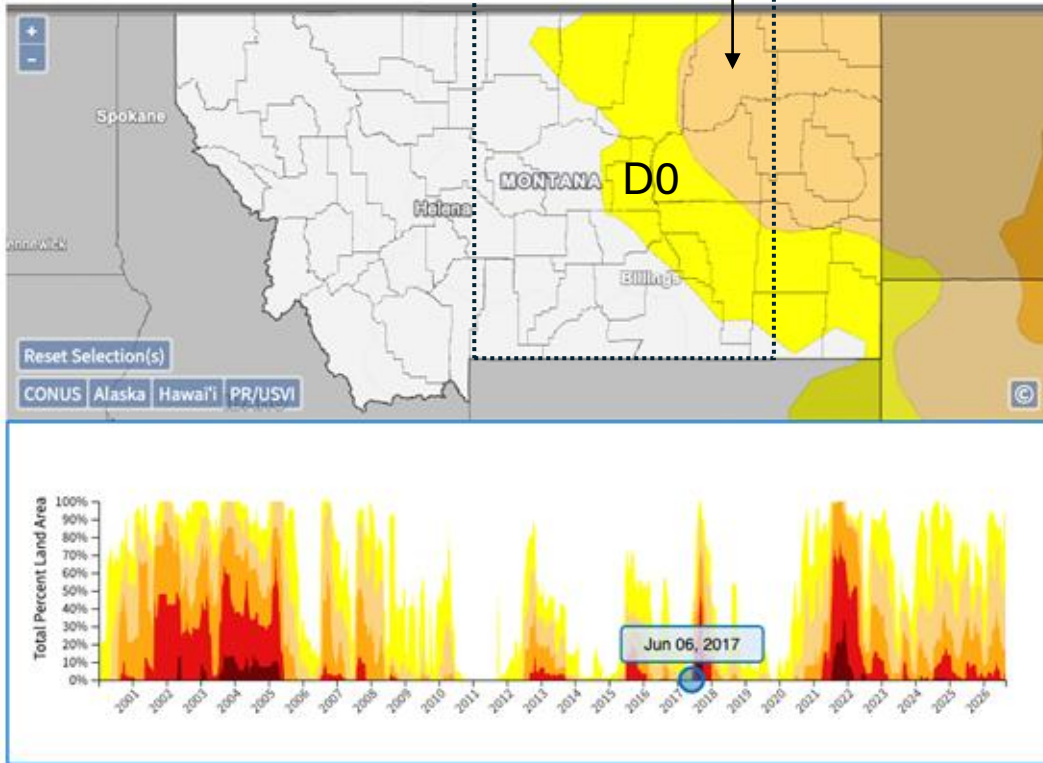
Source (Left): NOAA, USDA, National Drought Mitigation Center [Accessed 28 August 2026]

NASA ARSET – Agricultural Flash Drought Detection using SIF and Soil Moisture Data: Part 2

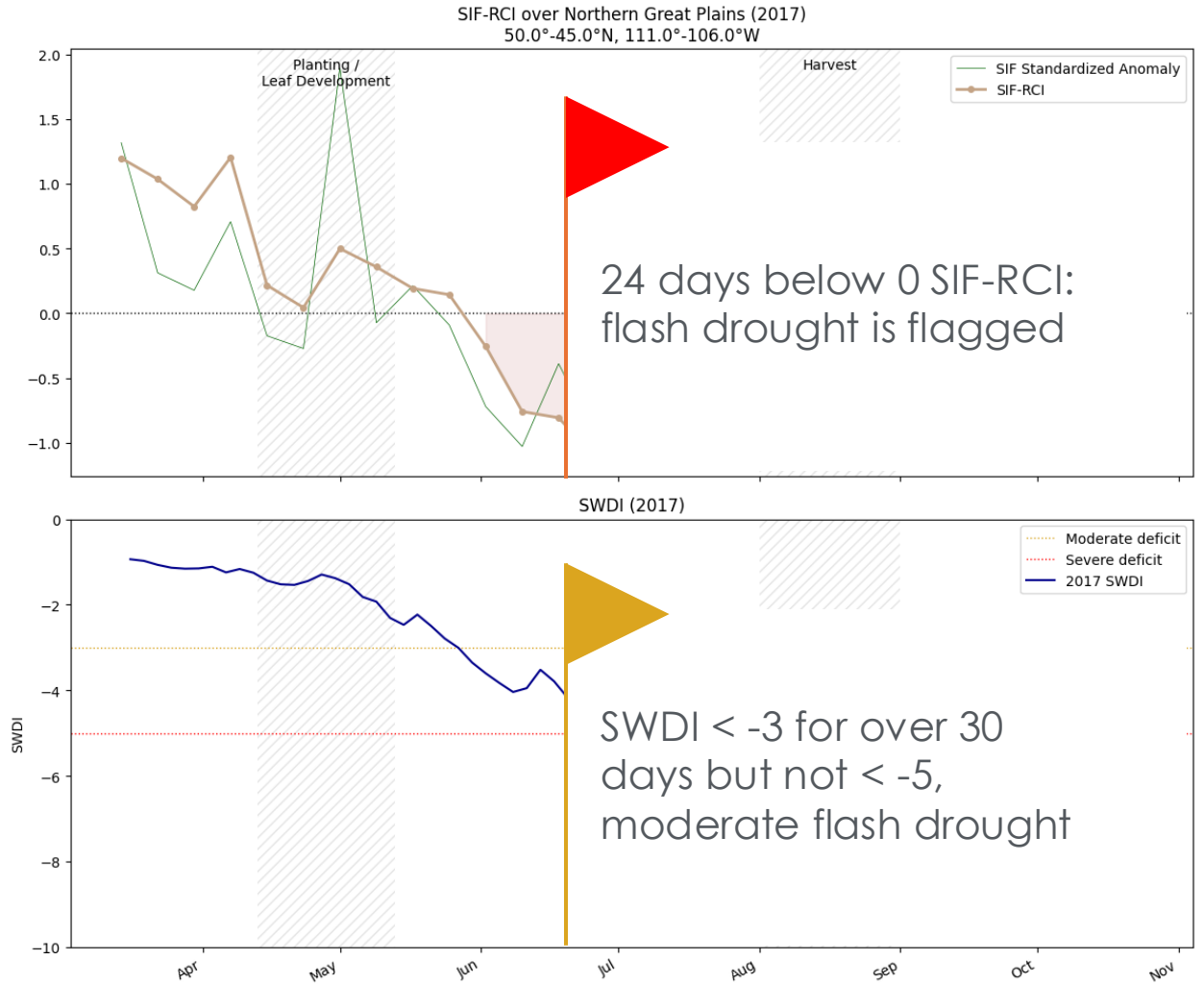


Flash Drought Onset in Northern Great Plains: 18 June 2017

D1 – Moderate Drought



By 20 June 2017, a new USDM was released showing a significant worsening of the drought, but the two-week cadence is important. Having 3-day (SWDI) and 8-day (SIF-RCI) time series allows us to have more time steps for decision making.



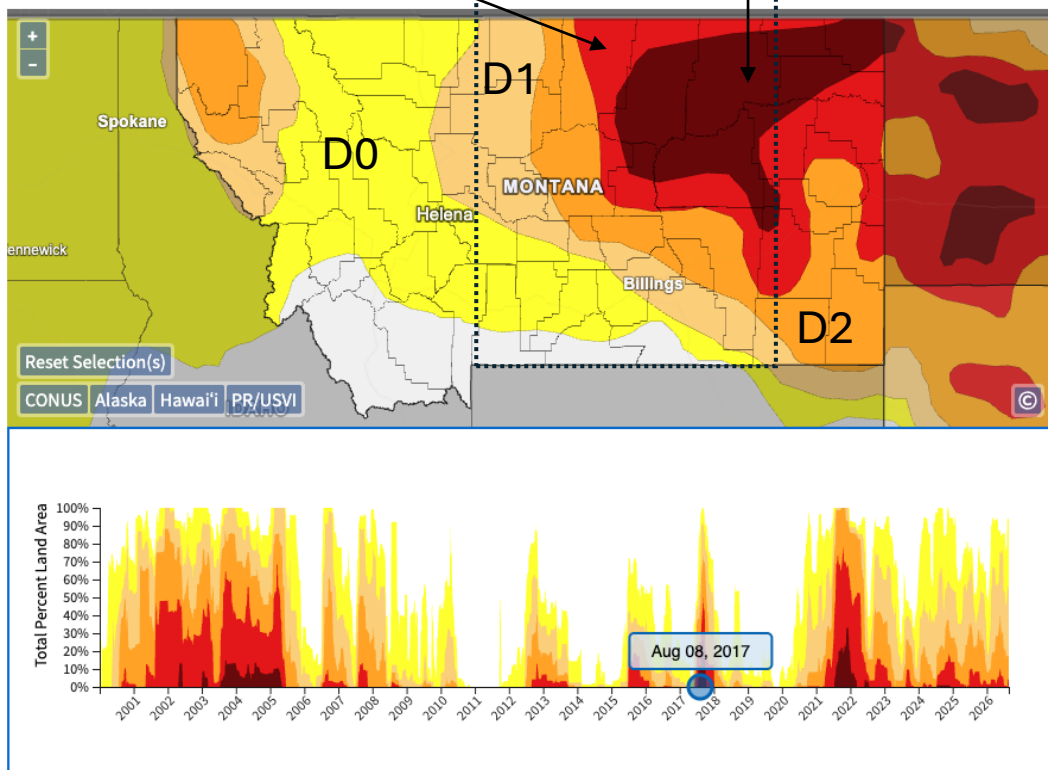
Source (Left): NOAA, USDA, National Drought Mitigation Center [Accessed 28 August 2026]

NASA ARSET – Agricultural Flash Drought Detection using SIF and Soil Moisture Data: Part 2

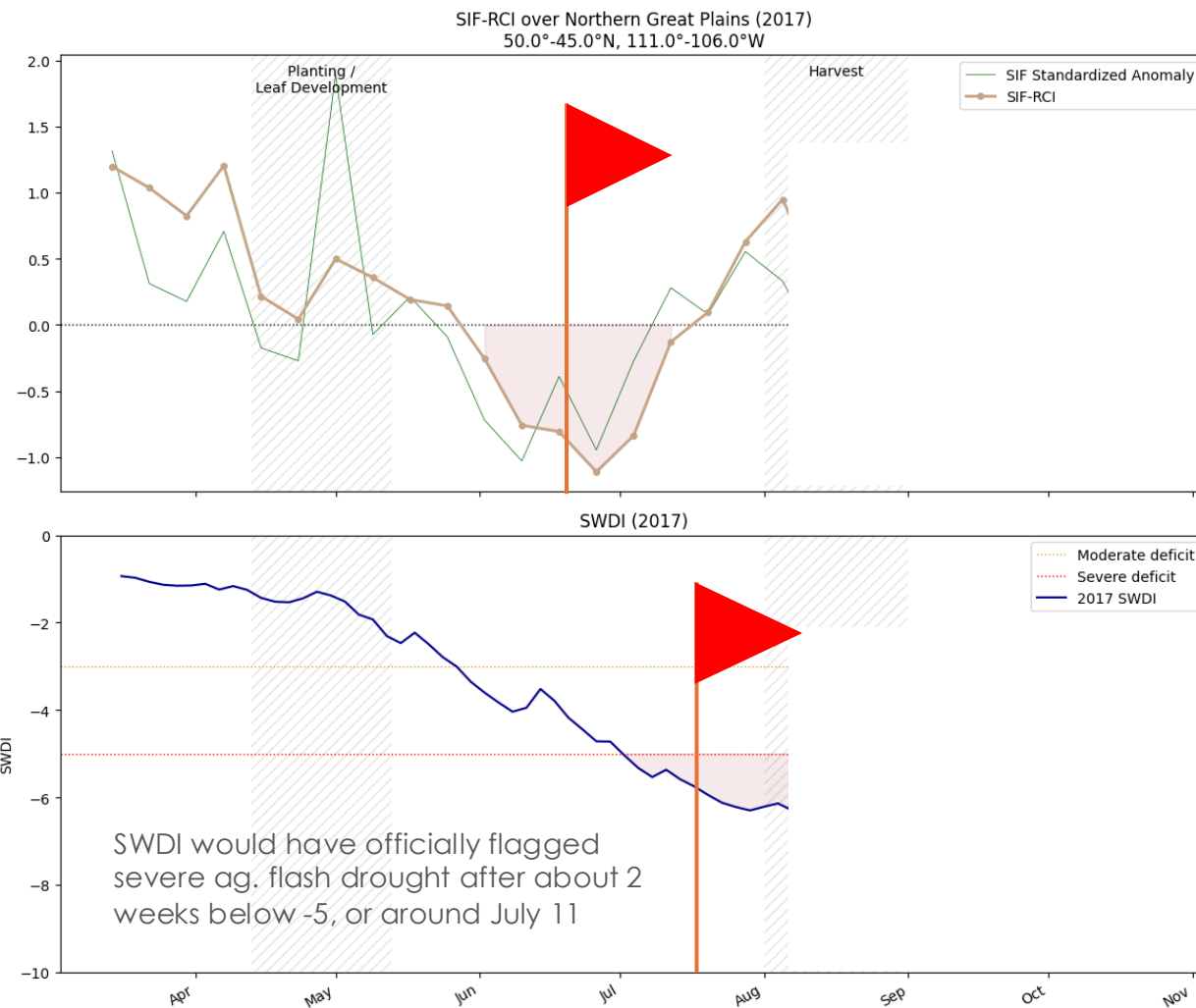


Flash Drought Onset in Northern Great Plains : 8 August 2017

D3 – Extreme Drought D4 – Exceptional Drought



By early August, the wheat fields were drying down, and harvest season was beginning. Farmers were aware by this point that a drought was underway, and the crop damage had already been done. Within another month, wildfires were breaking out across the state.



Source (Left): NOAA, USDA, National Drought Mitigation Center [Accessed 28 August 2026]

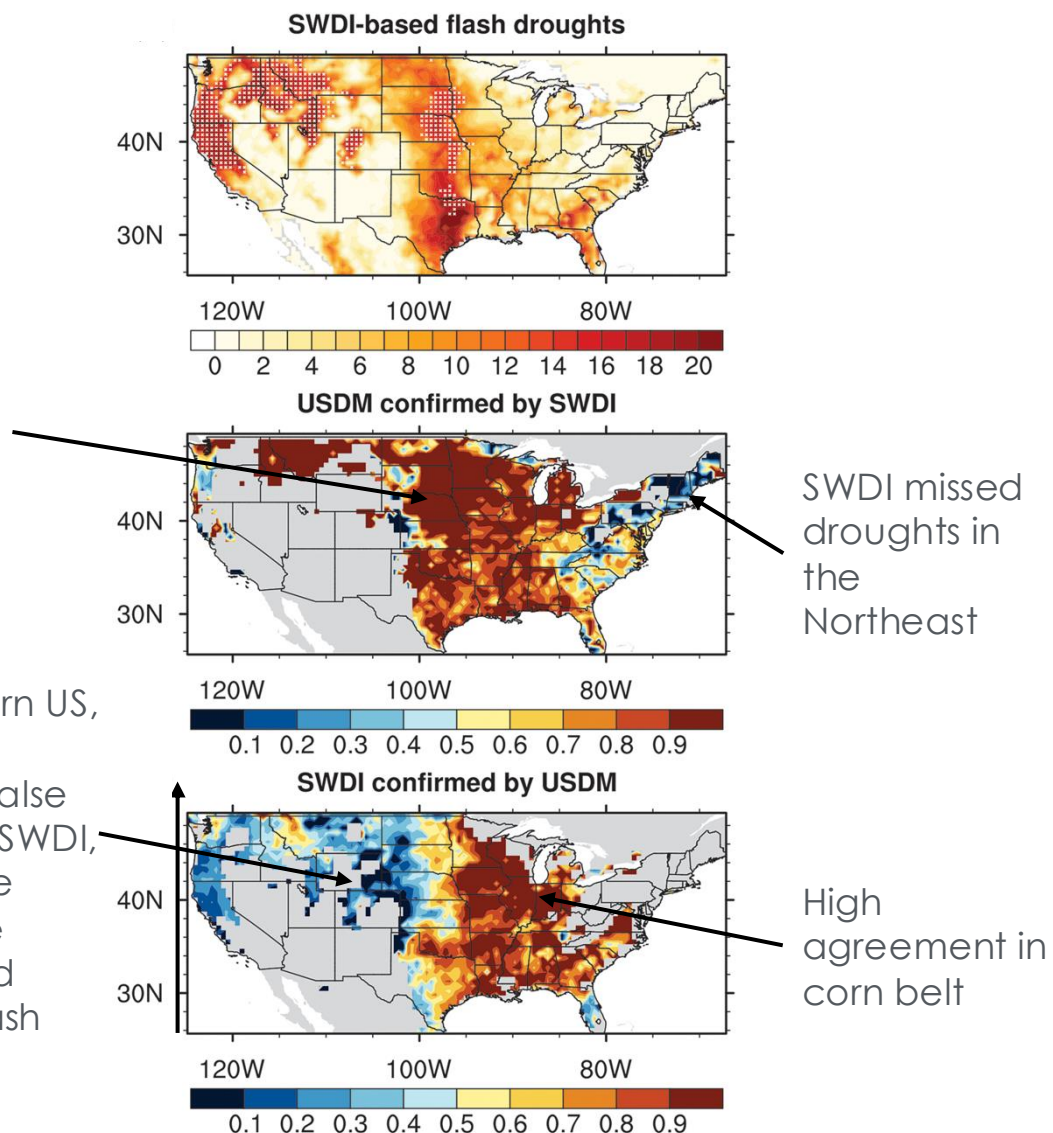
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SIF-RCI and SWDI Together

In most of the country, SWDI is detecting all the droughts that the USDM is.

In the Western US, these aren't necessarily false positives for SWDI, but could be cases where USDM missed impactful flash droughts.



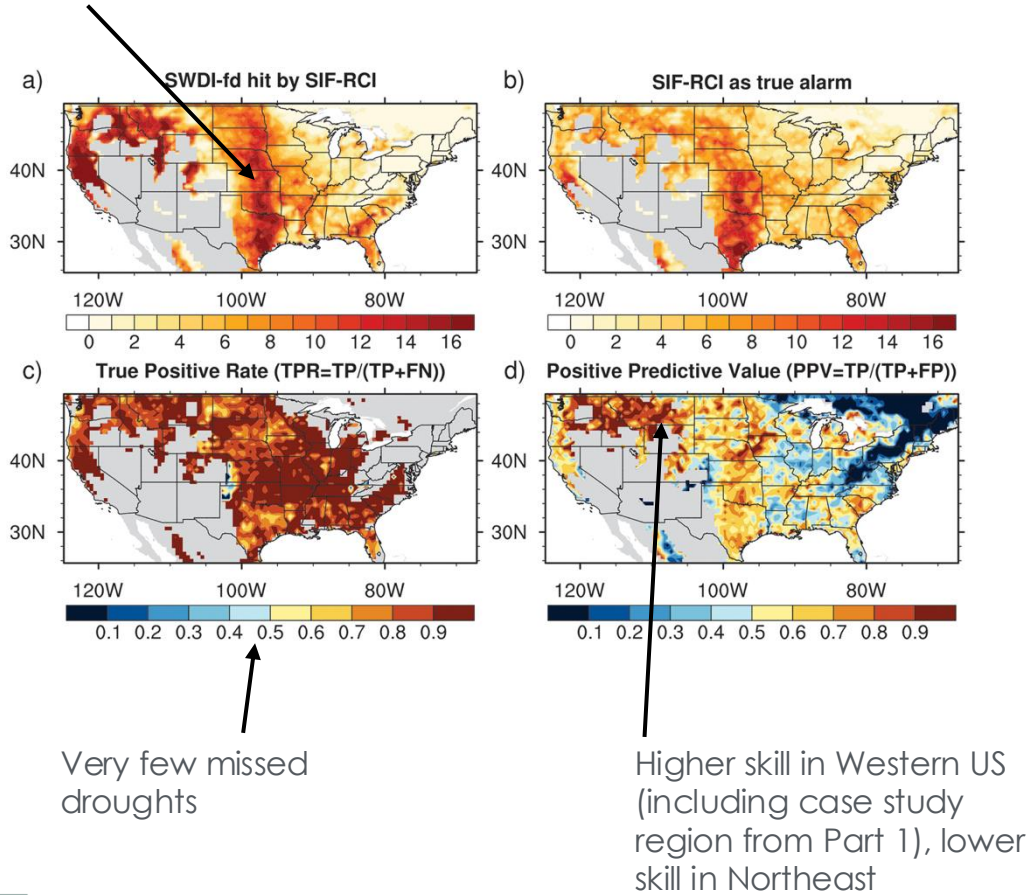
Source: Mohammadi and Wang, 2025

- In Mohammadi and Wang, 2025, the researchers studied the effectiveness of SWDI and SIF-RCI (among other metrics) in terms of their ability to provide early warning of flash drought in the US.
- The US Drought Monitor (USDM) is a baseline for predictive skill.
 - Since everyone has access to the USDM, if the metrics are not at least as skillful as the USDM, then there is no benefit.
 - Can the metrics achieve a time advantage over USDM? *The study showed that they can.*
- Researchers looked at inventory of flash droughts from 2001-2019 (see figure).
- The “goal” would be for SWDI and SIF-RCI to confirm all the droughts declared by USDM **and** detect flash droughts that the USDM didn't.



SIF-RCI and SWDI Together

Darker Red = more cases where SIF-RCI and SWDI predict flash drought simultaneously



- Again, it's not enough to just detect all the droughts that existing readily available data can. We must show that these metrics provide an **early warning**.
- In this study, early warning means SIF-RCI spent 24 consecutive days below -0.5 and did so before or at most 16 days after SWDI indicated FD.
- In the Western US (mostly croplands and grasslands), more than 70% of the SIF-RCI early warning signals were confirmed as flash droughts.
- 80% of SWDI flash droughts had an associated negative SIF anomaly.
- In cases where SIF-RCI alone had lower predictive skill, this can be due to SIF anomaly being associated with environmental factors other than drought:
 - Storm Damage
 - Flooding
 - Conventional Drought

Source: Mohammadi and Wang, 2025

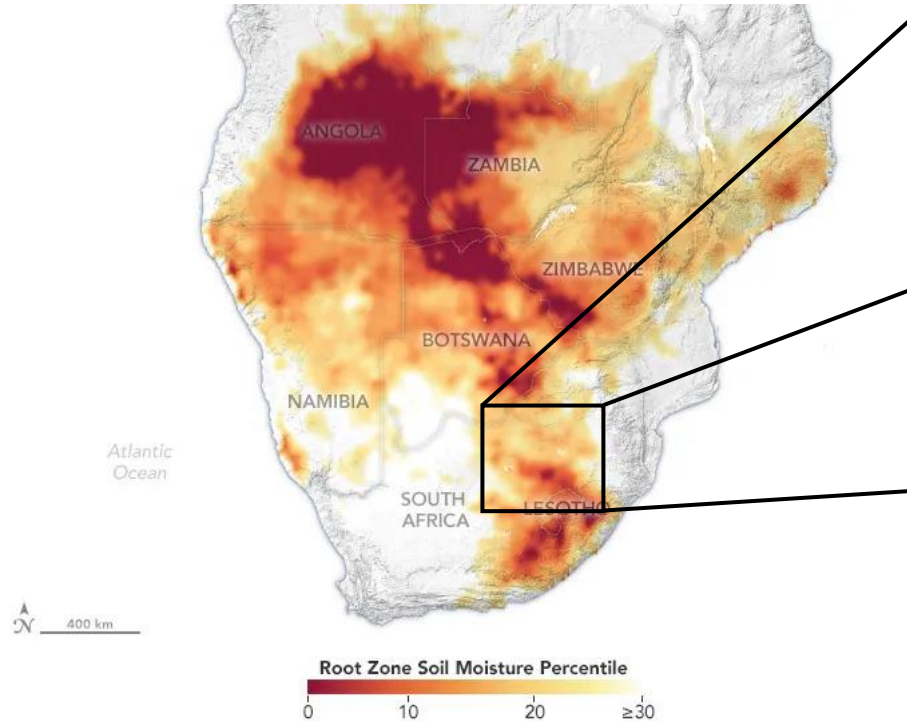
NASA ARSET – Agricultural Flash Drought Detection using SIF and Soil Moisture Data: Part 2



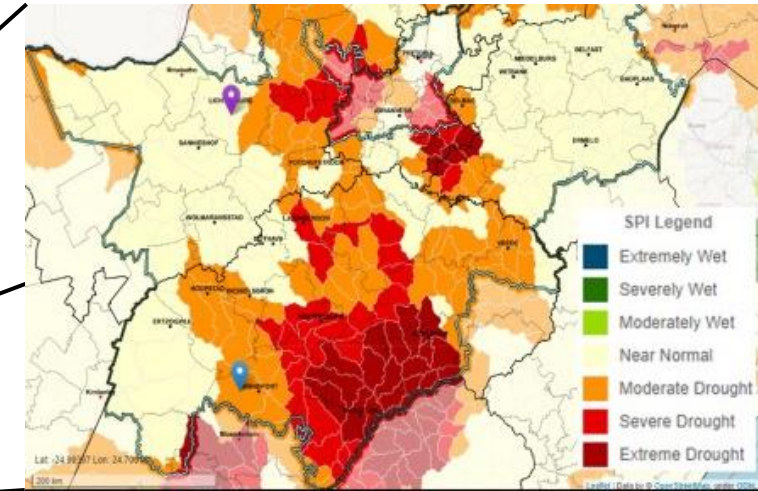
Case Study: South African Flash Drought of 2023-2024

- Malherbe et al., 2025 examined a summer flash drought in the 2023/2024 growing season in South Africa, although event extended across much of Southern Africa
- Region studied has rain-fed cropland with maize (corn) as the primary grain
- Event lasted two and a half months but had significant impact on grain yields due to timing
- In the Jupyter notebook for Part 2, we will compare the effectiveness of our SIF-RCI + SWDI technique to the method used by the researchers.

Root Zone Soil Moisture
March 2024



Standardized Precipitation Index
(SPI) January – March 2024



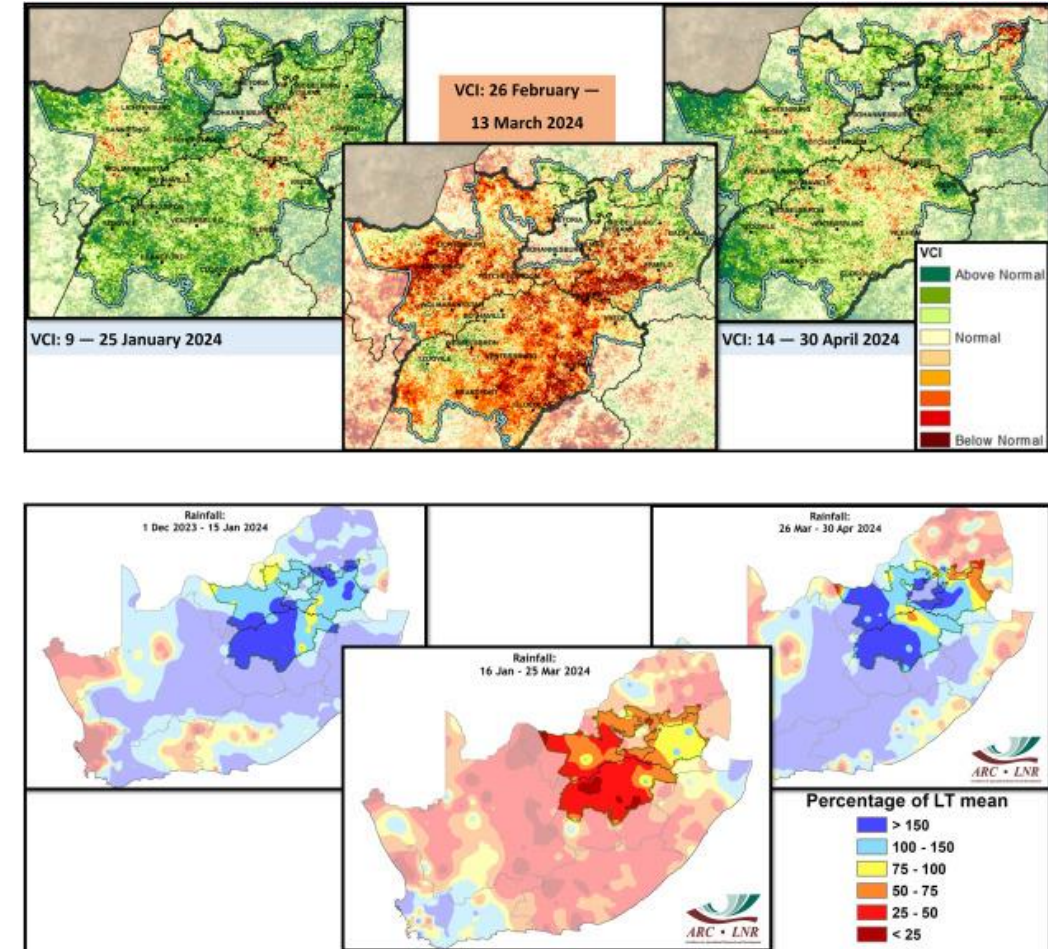
RZSM is correlated with long-term SPI, but recall earlier discussion: what do we gain by using RZSM?

Source: FEWS NET/Emily Cassidy (*left*), Malherbe et al., 2025 (*right*)



Case Study: South African Flash Drought of 2023-2024

- South Africa provides an agricultural drought early warning system (ADEWS) that integrates various indicators:
 - SPI (Precipitation) from local weather stations
 - Vegetation Condition Index (VCI) from MODIS VIIRS
 - Percentage of Annual Seasonal Greenness (PASG)
 - 0.25° SM from GRACE and GRACE-FO where available
- VCI is derived from NDVI and is conceptually similar to SWDI.
- PASG is also an NDVI-based indicator but considers cumulative trend.
- Most countries already have a vested interest in detecting and predicting drought and will have existing techniques.
- We must show that there is an advantage to using our technique: can we detect the flash drought early without detecting false alarms?



Source: Malherbe et al., 2025



Deciding When to Declare Flash Drought

- There are no hard and fast rules for flagging a flash drought, every paper uses a different definition.
- We will use rules based on Mohammadi and Wang since their technique is the basis for ours.
- Initial Rules:
 - 30-day moving average SWDI decreases by 2 points and $\text{SWDI} \leq -5$ for at least 12 days (4 time steps)
 - $\text{SIF-RCI} \leq -0.5$ for at least 24 days (3 time steps)
- The notebook assesses case studies using these rules and then compares them to the USDM (for Northern Great Plains) and ADEWS (for Free State) to see if they are “good enough.”
- Is it justifiable to change the rules for detection? How can different rules be compared across numerous cases?



The Crop Calendar

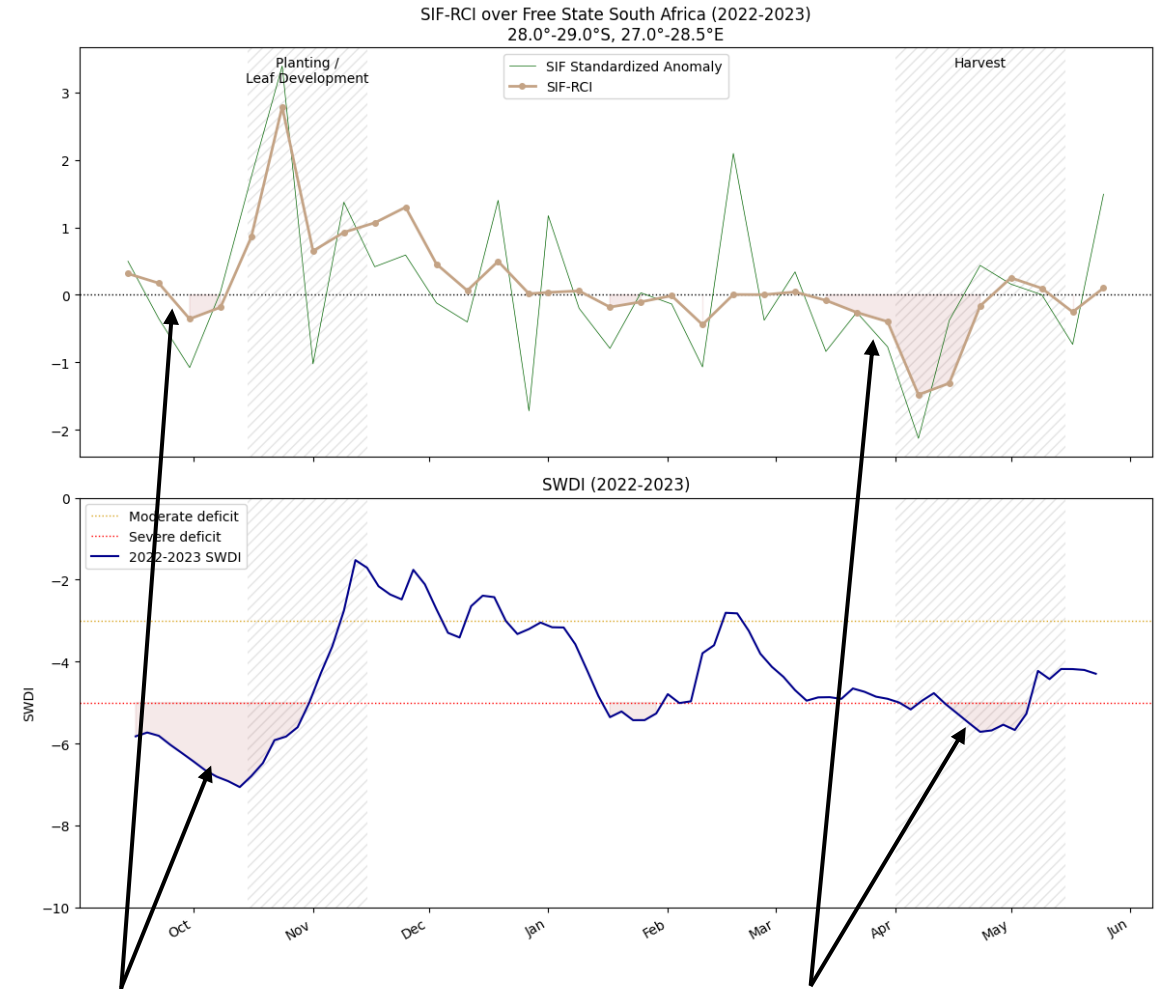
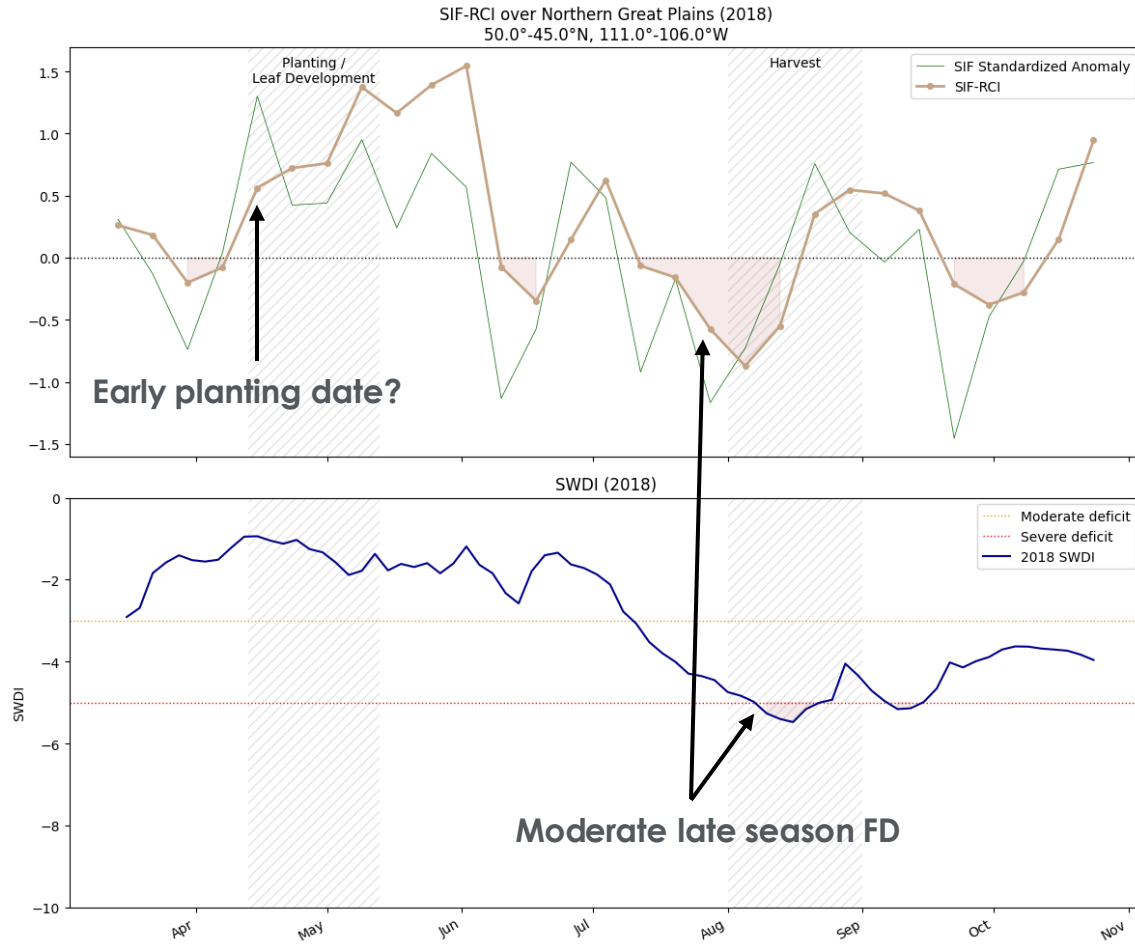


Dent corn is harvested dry, so these maize plants have already been dead for 4-8 weeks. If the crop was healthy during the growing season, would a late season “flash drought” matter? Credit: Carl Young, CC BY-SA 4.0

- Our technique uses planting and harvest windows for assessing agricultural impact
- This is more than just a plot decoration: arguably, **a flash drought is only impactful if it occurs during the growing season.**
- A flash drought outside the growing season or during crop senescence may have no impact on yields.
- In fact, you may often see negative SIF anomaly during senescence! Early planting → early senescence.
- In the US, the USDA provides crop calendar guidelines for each state: <https://esmis.nal.usda.gov/publication/usual-planting-and-harvesting-dates-us-field-crops>
- Unfortunately, there is no single, universal source for crop calendars outside the US.



The Crop Calendar in Practice



Does an early spring FD impact the growing season if SIF and SM recover?

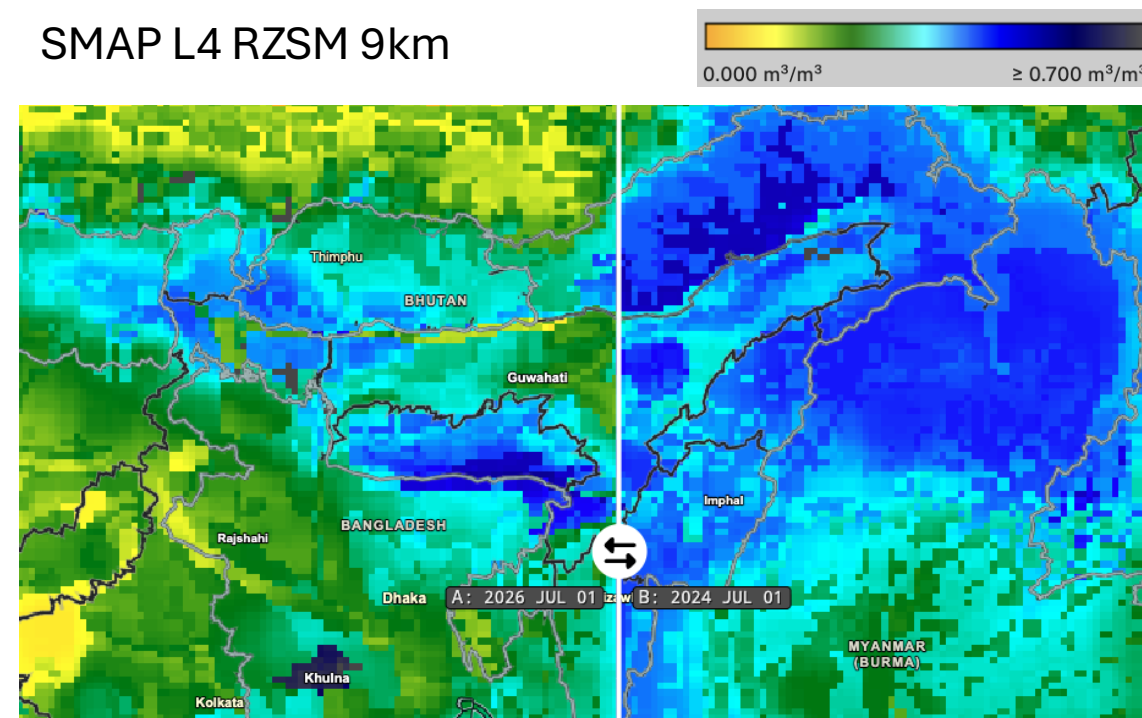
What about an FD during the harvest?



Extending the Technique

- Our two indicators are floating point, so we can categorize droughts based on severity.
- There is no current rigorous drought severity definition based on SIF-RCI and SWDI.
- Theoretically, it is possible to create a global map of the two metrics like the map of SIF anomaly we looked at in the Part 1 notebook.
- Could assess predictive skill of different detection rules (like $SWDI < -5$ for 14 days or $SIF-RCI < 0$ for 24 days).
- That level of analysis is beyond the scope of this course.
- For small scale studies, you should be able to follow these steps:
 1. Pick your region of interest
 2. Research the main crop types and the crop calendar
 3. Input the values for your region into the Part 2 notebook

SMAP L4 RZSM 9km

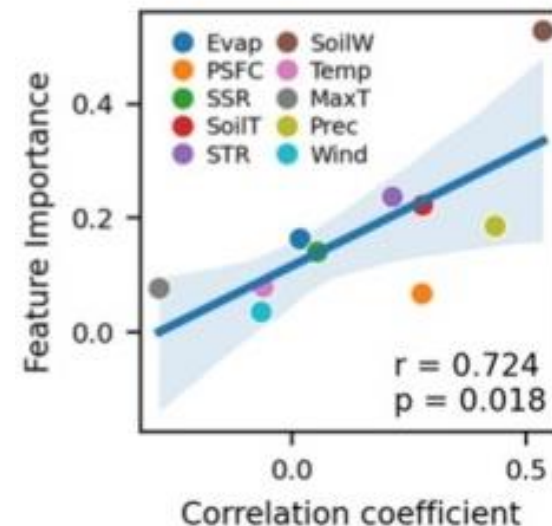


SMAP L4 Root Zone Soil Moisture shows a notable anomaly over Eastern India developing from June 2026 into July. The right side of the map shows the 2024 RZSM for comparison purposes. Will this event be considered a flash drought in retrospect? Credit: SMAP/NASA/JPL-Caltech

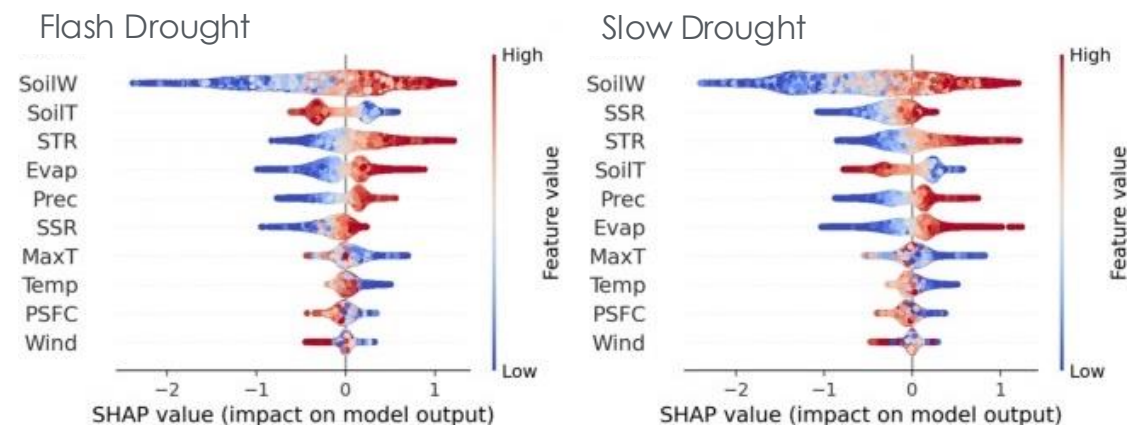


Extending the Technique: Prediction

- More sophisticated approaches examine the trajectory of SM.
- Tang et al., 2026 trained a Convolutional Neural Network (CNN) with spatiotemporal context to detect flash droughts.
- CNN was used to predict soil moisture using ERA5 model data.
- Using SHAP values, the authors were able to attribute the causality of various drivers of drought used in the model.
- Surface Thermal Radiation (STR) or downward longwave radiation emerged as a key predictor, at least in humid regions.
- Model forecasts can be incorporated to provide greater lead time.



Evap: Evaporation
PSFC: Surface pressure
SSR: Surface net solar radiation
SoilT: Soil temperature
STR: Surface net thermal radiation
SoilW: Soil water content
Temp: 2m mean temperature
MaxT: 2m max temperature
Prec: Precipitation
Wind: 10m wind speed

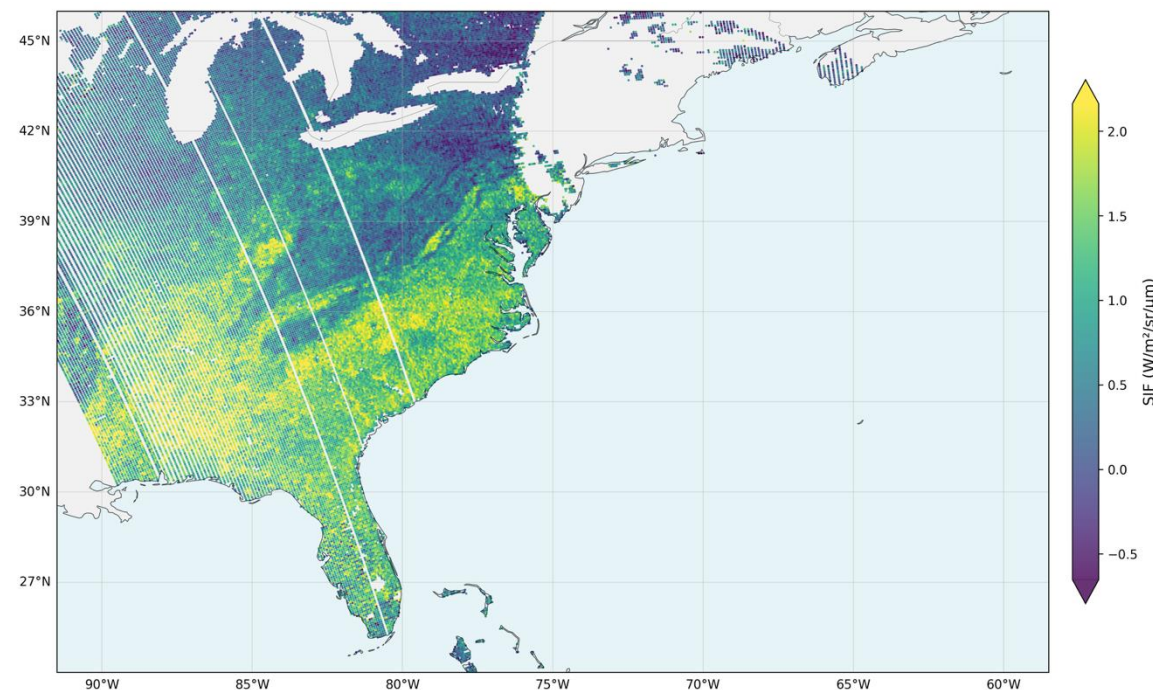


Source: Tang et al., 2026



Other Sources of SIF Data

- You may be excited to try out this technique on present-day data – one small problem: GOSIF data is not forward processed.
- GOSIF processing code is not currently open-source.
- **Option 1:** TROPOMI SIF (5km x 7.5km)
- **Option 2:** Use NDVI or EVI from VIIRS (500m/pixel, 8-day temporal) or Harmonized Landsat Sentinel (HLS) (30m/pixel, 16-day temporal) and convert to an RCI time series
- **Coming Soon:** The ESA Flex mission will measure SIF at 300 m resolution with a 27-day revisit time (to be useful for applied science like this, the data will need to be assimilated with a medium resolution imager like VIIRS, similar to GOSIF).
- NASA is working to provide a publicly accessible, forward processed gap-filled SIF product derived from OCO-2 and OCO-3.



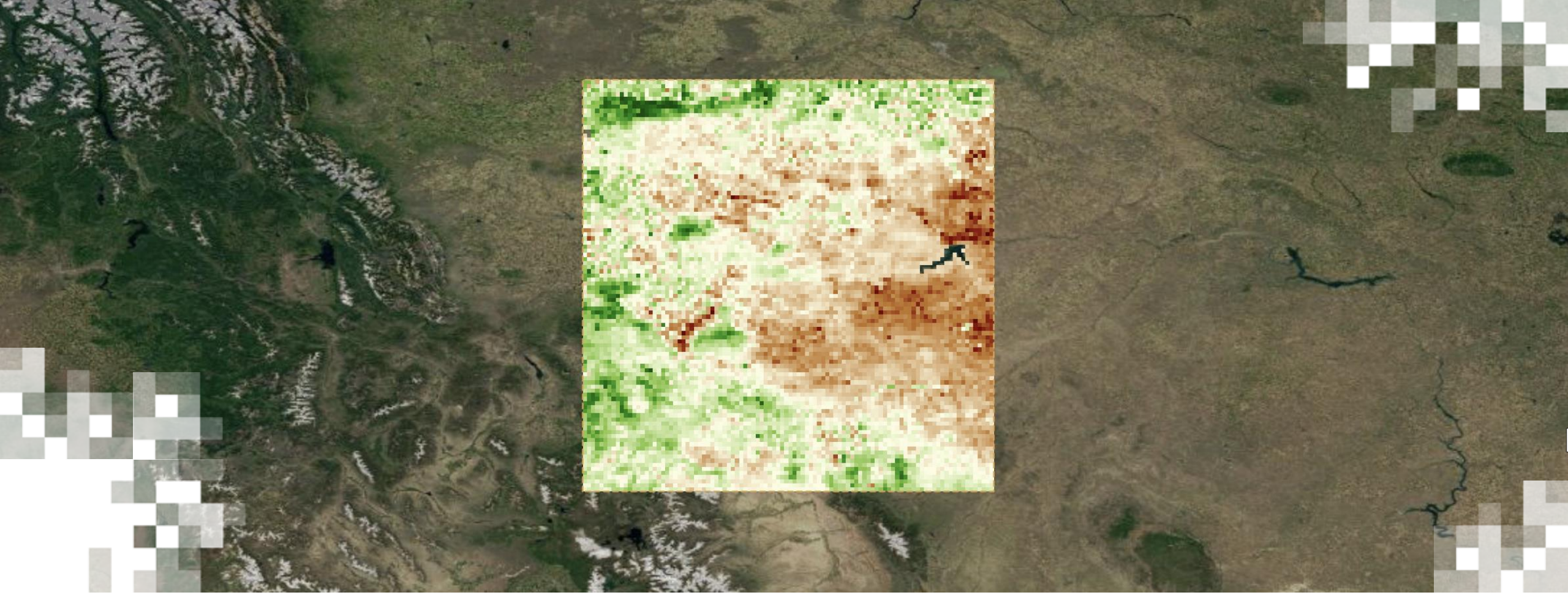
Subdaily TROPOMI SIF swath over the Eastern US for April 30, 2018. Converting entire observational record to a regularly gridded dataset would take considerable work. Credit: Copernicus/ESA (data), own work (plot)



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Session 2: Summary

Summary

- Flash drought is characterized by a rapid decline in plant-available water that can significantly reduce crop productivity, even when precipitation deficits are relatively small.
- Root Zone Soil Moisture (RZSM) is a more meaningful indicator of crop water availability than surface soil moisture because it represents the water accessible to plant roots.
- Soil Water Deficit Index (SWDI) standardizes RZSM, enabling comparisons across regions and identifying periods of significant soil moisture stress.
- SIF provides a direct measure of photosynthetic activity and responds more rapidly to vegetation stress than traditional greenness indices such as NDVI.
- Combining SWDI and SIF-RCI provides complementary information on soil water availability and crop physiological response, improving confidence in flash drought detection.
- Joint analysis of SWDI and SIF-RCI can provide earlier detection of agriculturally impactful flash droughts than traditional drought monitoring approaches in many regions.
- Detection criteria should consider crop calendars so that drought is evaluated during periods when crops are actively growing and vulnerable to stress.
- The workflow demonstrated in the Jupyter Notebook can be adapted to new regions, crop types, and growing seasons using local crop calendars and regional data.
- Future improvements may incorporate machine learning, additional environmental variables, and new satellite observations to further improve flash drought prediction and early warning.



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