Texas A&M University

High-Resolution Global Flash Drought Monitoring at a 9km Footprint Using Satellite Remote Sensing

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BAEN 491

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Contents

Abstract

Flash droughts are an increasingly common phenomenon that continue to threat agriculture, land management, and water security. Global flash drought monitoring plays a crucial role in understanding flash drought development and minimizing its negative effects. We developed a global, near-real time flash drought monitor using satellite surface soil moisture (θ_{RS}) from NASA's Soil Moisture Active Passive (SMAP) satellite at a 36-km resolution, called FLASH (Flash drought Assessment using SMAP Hydrology). Data observed from SMAP allows daily flash drought outlooks to be generated at a global scale with only a 2-day delay. FLASH is a successful proof-of-concept, providing global Flash Drought Stress Index (FDSI) calculations by combining rate of soil moisture (SM) drydown and SM stress, derived from SM information at satellite footprint-scale. However, FLASH operates at a coarse 36-km resolution and uses conservative data filtering, which limits its spatial coverage and resolution. We developed FLASH 2.0 to mitigate these limitations and expand the FLASH program's applications. FLASH 2.0 was developed using enhanced SM data from SMAP to operate at a 16x finer resolution of 9-km. This scale required calculations of all SM parameters and FDSI calculations through TAMU's High Performance Research Computing (HPRC). In addition, we utilize more liberal data filters to improve spatial coverage of SM parameters by ~20% compared to FLASH 1.0. Increased spatial coverage is most prominent in moderately vegetated regions such as croplands and grasslands. Enhanced global flash drought monitoring allows for more effective resource management over greater areas, while more effectively accounting for spatial heterogeneities in the governing drivers of terrestrial hydrology, as well as increasing its relevance to localities due to its significant improvement in resolution. This research supplements complementary efforts in estimation of effective "on ground" precipitation, qualifying land-surface heterogeneity, and enhancement of flood forecasting.

Introduction

Flash droughts are characterized by rapid intensification of drought conditions to severe levels over large areas, caused by atypically stressful temperatures, winds, or a lack of precipitation. Flash droughts pose a significant threat to resource and land management as they can develop in as short at 2 to 4 weeks of anomalous weather. Despite, their short development time, flash droughts can result in catastrophic losses for agricultural industry and water security, accounting for several billions of dollars in damages. Although other drought monitors exist, FLASH was created as the first global flash drought monitor and differentiates itself from other drought monitors by combining both observed soil and climatological factors with short-term environmental stresses to generate drought classification.

Existing drought monitors have several limitations that FLASH 2.0 seeks to bridge. FLASH 2.0 is directly compared with the following indices: Evaporative Demand Drought Index (EDDI, Hobbins et al., 2016), Vegetation Health Index (VHI, F. Kogan, 2002), and Standardized Precipitation Evapotranspiration Index (SPEI, Vicente-Serrano, Beguería, et al., 2010) for comparison with FDSI at daily, weekly and monthly timesteps respectively. EDDI measures the atmospheric evaporative demand relative to the climatological mean over a minimum 1-week aggregated timescale at a 12.5km spatial resolution. EDDI effectively captures environmental stress and is a strong reference point for SMS. USDM provides a holistic view of drought development using numerical models, climate, and weather, and hydrological indices and is widely used in socioeconomic and agricultural assessment and policymaking. Although we are particularly interested in the development of flash droughts, USDM is the benchmark for drought monitoring in the US and captures drought development using a wide array of methods that offer a good touchstone for comparison. VHI utilizes Normalized Vegetation Index and brightness temperature to estimate vegetative stress due to anomalous weather patterns and decreasing SM. VHI operates on a 7-day global composite at 4-km spatial resolution. These drought monitors have pushed forward scientific and industrial applications, but are limited by revisit time, latency, and resolution. FLASH 2.0 features a short 2-3 day revisit time, 2 day latency, and 9-km spatial resolution. No other drought monitor can produce high resolution drought outlooks at the frequency and timeliness as FLASH 2.0. This high frequency, resolution, and timely observation increases FLASH's application to resource management and allows FLASH to increase its impact in other applications such as "on ground" precipitation estimation.

Methodology

Calculation of FDSI

FDSI is calculated from two SM-derived variables: relative rate of drydown (RRD) and soil moisture stress (SMS). As seen in *Figure 1*, soil moisture drydown, approximated by a piecewise-linear curve, is dictated by soil parameters derived from SM observations that determine when soil enters a different hydrological regime. These parameters capture the hydrological regime soil will be in based on the current season, soil type, and other climatological factors. SMS captures short-term environmental factors such as extreme temperatures or high winds. These two factors are combined to generate FDSI values for each pixel and can be used to measure the onset, intensification, and sustenance of a flash drought for a given region.

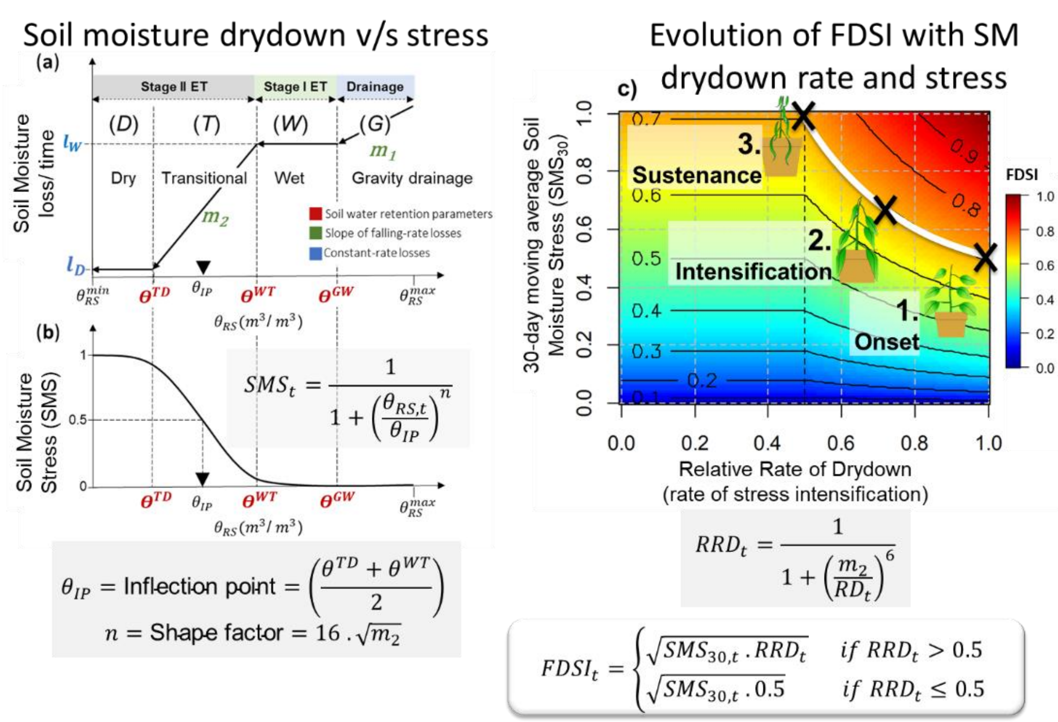

Figure 1. Soil Moisture Drydown, SMS, and FDSI Plots

Expansion of FLASH

FLASH 1.0 has proven its utility but the impact of its applications is limited by its coverage and resolution. FLASH 1.0 omitted all data that was observed in spatial pixels with vegetative water content (VWC) greater than $5kg/m^2$. This limited coverage in moderately and densely vegetated areas such as grass lands and forests. FLASH 2.0 seeks to recover some of this area by relaxing the data filters by including data up to $7kg/m^2$ VWC. This change increases the spatial coverage and is primarily evident in warmer climates during summer months due to the increase in vegetation coverage as illustrated in *figure 2*. The second major advancement in FLASH 2.0 is a 16x finer spatial resolution from 36-km to 9-km. The development of 9km-scale soil parameter and FDSI values was possible by leveraging global SM observations from NASA's SMAP Level 3 Enhanced–9km dataset from March 31, 2015 to May 15, 2021 (O'Niell, 2021). Relaxing data filters and computing FDSI at 9km increased spatial coverage by 20%, varying by season as indicated in *figure* 3. Firstly, all data is collected in swaths by SMAP which requires a global dataset to be collected over the course of 2-3 days. After the data set is collected, all missing values are linearly interpolated at a 2-day interval. All parameters are computed and then interpolated at a 1-day interval to compute SMS, RRD, and FDSI for each pixel. One key difference in this process compared to FLASH 1.0 is that several statistical outliers were identified that were not present at 36-km. These outliers were trimmed out of the dataset based on an interquartile range. This final, statistically trimmed dataset is deployed onto public data access platforms.

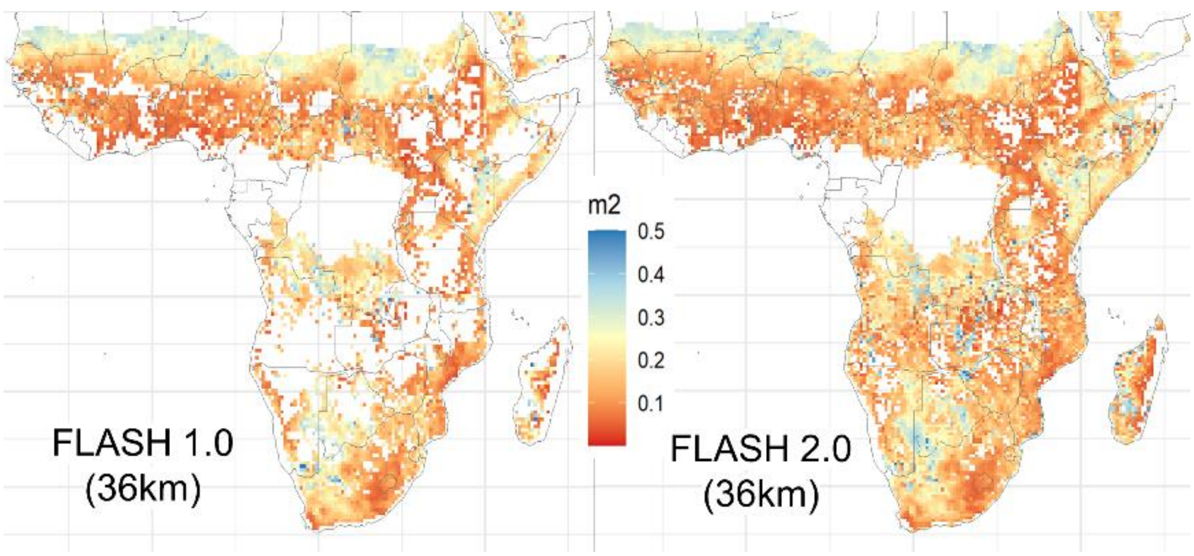

Figure 2. Comparison of m2 land area coverage from FLASH 1.0 (36km) to FLASH 2.0 (36km) in Sub Saharan Africa during the JJA triplet

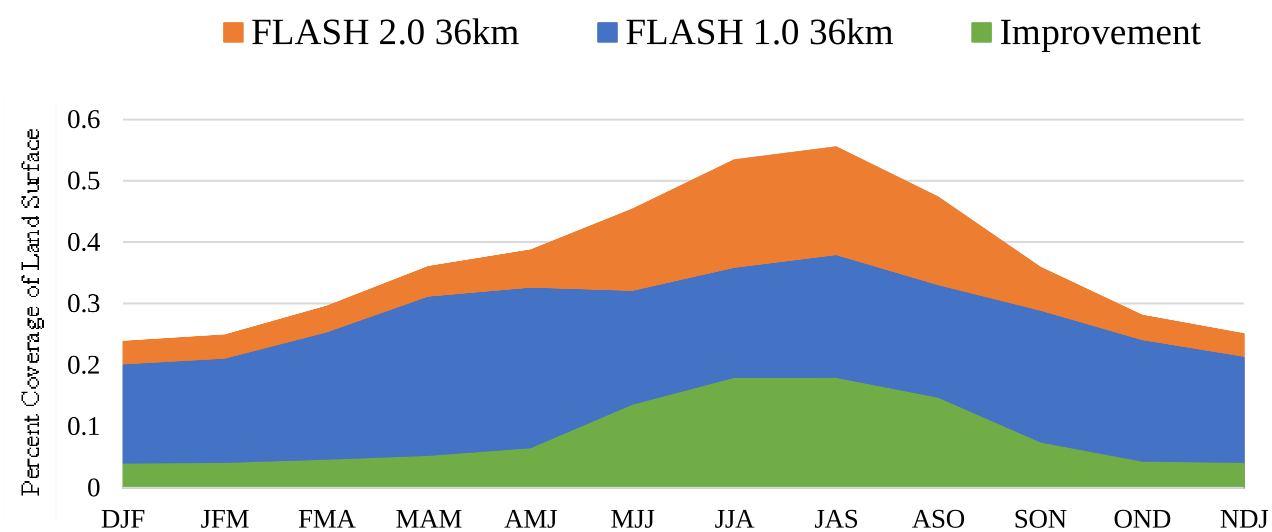

Figure 3. Percent of global coverage of FLASH 1.0 and FLASH 2.0

High Performance Computing Resources for FLASH 2.0

The 9-km resolution dramatically increased the size of the data set compared to the 36-km resolution and required that all soil parameters were calculated using the above process in parallel on TAMU's HPRC. 9-km SM data was used to generate SM parameters at a global scale on a 2-day interval consistent with SMAP observational intervals. Global data is segmented into the 41 IPCC regions (Iturbide, 2020) and computed on a seasonal basis (3 month rolling window) using distributed computing on HPRC. Combined with SMAP observations, RRD and SMS are computed in parallel on a 1-day interval using linear interpolation. Finally, RRD and SMS are combined to generate FDSI at each region at published individually.

Results and Discussion

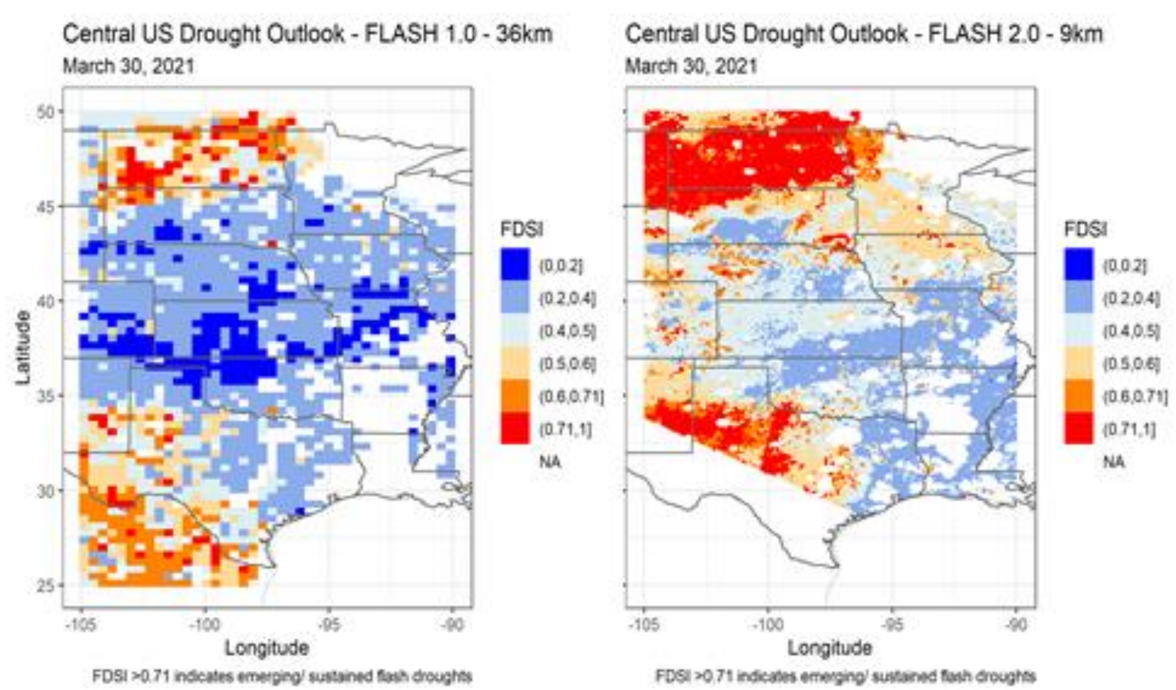

Figure 4. Comparison of FDSI FLASH 1.0 and FLASH 2.0

Preliminary results suggest that the 9-km footprint and relaxed data filters can offer significant improvements to the current FLASH program including ~20% increase in global coverage and a 16x finer resolution. These two factors will be able to greatly increase FLASH's relevance to local communities and ordinances by providing higher resolution data to inform decisions regarding water and resource management. As indicated in *figure 4*, FLASH 2.0 consistently overestimates FDSI values compared to the validated FLASH 1.0. This is thought to be caused by additional statistical outliers that were not captured in FLASH 1.0 due to the more conservative data filters ($5kg/m^2$ vs $7kg/m^2$ VWC) and increase in resolution. As each pixel is much smaller at 9km, outliers are much more dominant. Geographic regions where outliers may be more prominent (edges of bodies of water or transitions into vegetated areas) are more dominant in their representation at the much finer resolution. After investigation, SMS calculations appear to be the cause of FDSI inflation. As pictured in *figure 5*, SMS appear to be very high and continues to be during nearly all times of year and as expected, has a very high correlation with areas of high FDSI values. This is particularly evident in arid and semi-arid regions as very large regions have SMS values that are very close to 1 which is high enough to result in FDSI values greater than 0.71 which indicates that the area is under a flash drought. Not only does this result in high FDSI values but will also prolong the time an area appears to be experiencing a flash drought as the role of RRD is less prominent. Despite this inflation, FLASH 2.0 can still capture general trends which indicates that the methodology is sound but requires additional adjustments to hyperparameters. As FLASH 2.0 computational hyperparameters are finalized, we plan to enable FLASH to generate beyond a static time frame and expand into near-real-time computation. Beyond the time range we have already generated data for we plan to be able to generate data daily with a 2-day latency period utilizing daily data streams from SMAP. FLASH 1.0 already has this capability and we will be using its structure, illustrated in *figure 5*, as a model for FLASH 2.0 operationalization with the additional step of distributed processing on HPRC. Data will continue to be updates in near-real-time and made available to all users free of charge to further scientific innovation and industry knowledge.

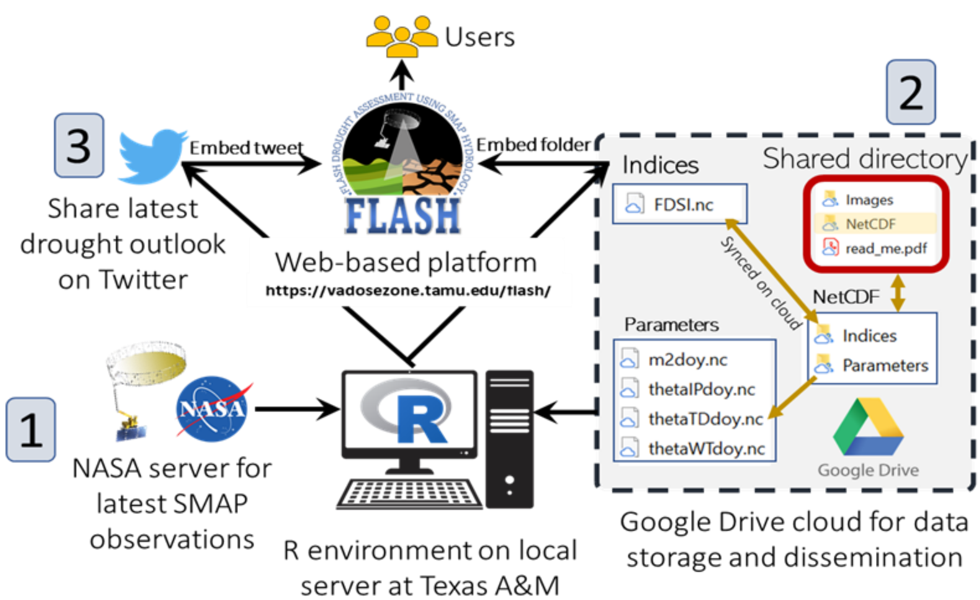

Figure 5. Operational Workflow for the FLASH System

Conclusion

The coverage and resolution improvements implemented into FLASH 2.0 are very promising. The transition to a 9km resolution dramatically improves the applicability of this product for all users below the regional level. With soil moisture drydown and its associated parameters computed at 9km applications such as on ground precipitation within watersheds is much more practical. The 9km resolution can effectively capture the edges of watersheds and is fine enough for applications for localities. Once filtering steps are finalized, data validation against leading drought and stress monitors such as Evaporative Demand Drought Index will be performed and evaluated. When this is completed, FLASH 2.0 can be operationally launched with global computation and daily updates from incoming SMAP observations. The process of upgrading FLASH's resolution and coverage serves as a model for future upgrades and expansion as remote sensing technology increases in coming years. With each resolution increase of FLASH comes several more applications that can be directly applied to users in addition to the emerging science. Resolutions at 9km and finer are approaching high relevance to individuals in agricultural industry and property management as they can apply the insights provided by FDSI and other products for water, crop, and fire risk management.

References

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Appendix A – TAMUS Pathways Student Research Symposium Poster

Enhancing Near-Real-Time Global Flash Drought Monitoring with High Resolution Satellite Soil Moisture

Aidan Brown[1*], Sara Antonijevic[2], Vinit Sehgal[3], Binayak P. Mohanty[4]

Presenter Aidan Brown

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❑ WHAT ARE FLASH DROUGHTS?

Rapid intensification of drought conditions to **severe** levels over **large areas**, caused by atypically stressful temperatures, winds, lack of precipitation, or both.

❑ Effects of Flash Droughts

Rapid death of crops and soil degradation

Notable Flash Droughts:
Fall 2019: Southeastern USA
Summer 2017: Northern Plains ($2.6 billion loss[1])
2012 Central USA ($34.5 billion loss[1])

[1] NIDIS-Flash-Drought-Workshop-Report-2021

What FLASH provides

- ❑ FDSI estimates (NetCDF)
- ❑ Latest map
- ❑ 14-day drought outlook
- ❑ Parameters for FDSI

Notable features

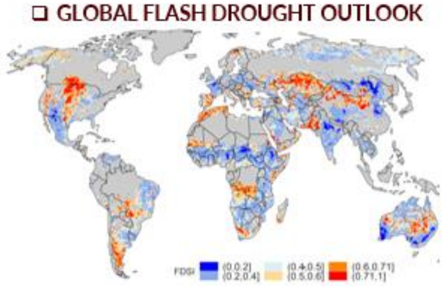
- ❑ Updated Daily
- ❑ Low latency of 2 days
- ❑ Free & open-source tools

F.L.A.S.H.

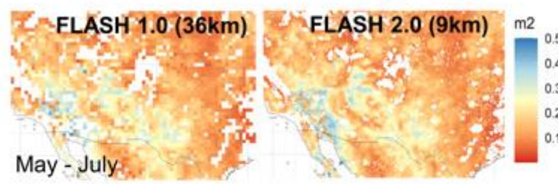
FLash Drought **A**ssessment using **S**MAP **H**ydrology

An **operational** platform for **global near-real-time** flash drought monitoring

❑ GLOBAL FLASH DROUGHT OUTLOOK

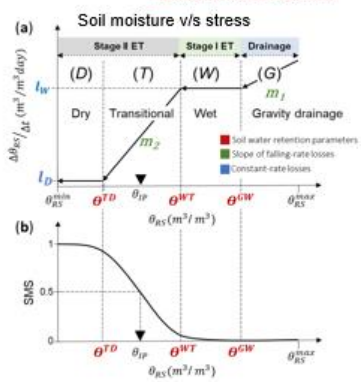


❑ IMPROVED RESOLUTION IN FLASH 2.0



- 16x improvement from 36km to 9km footprint
- Improved representation of sub-grid land-surface heterogeneity

❑ METHODOLOGY



Inflection point

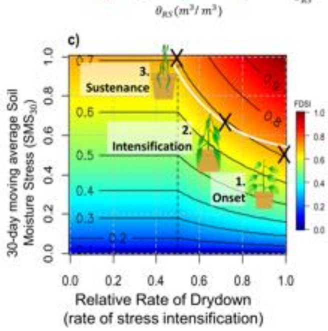
$$\theta_{IP} = \left(\frac{\theta^{TD} + \theta^{WT}}{2}\right)$$

Shape factor

$$n = 16 . \sqrt{m_2}$$

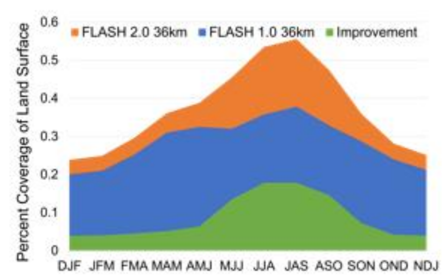
Intensification

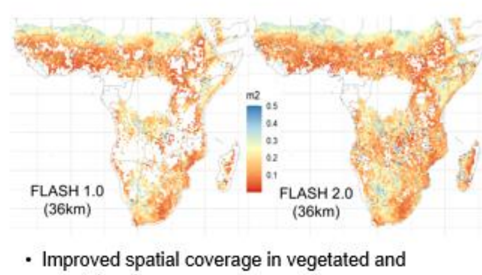
$$RRD_t = \frac{1}{1 + \left(\frac{m_2}{RD_t}\right)^6}$$



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

❑ IMPROVED COVERAGE IN FLASH 2.0





- Improved spatial coverage in vegetated and coastal regions

❑ REFERENCE

Sehgal, V., Gaur, N. and Mohanty, B.P., 2021. Global Flash Drought Monitoring using Surface Soil Moisture. *Water Resources Research*

Appendix B – TAMU Student Research Week Poster