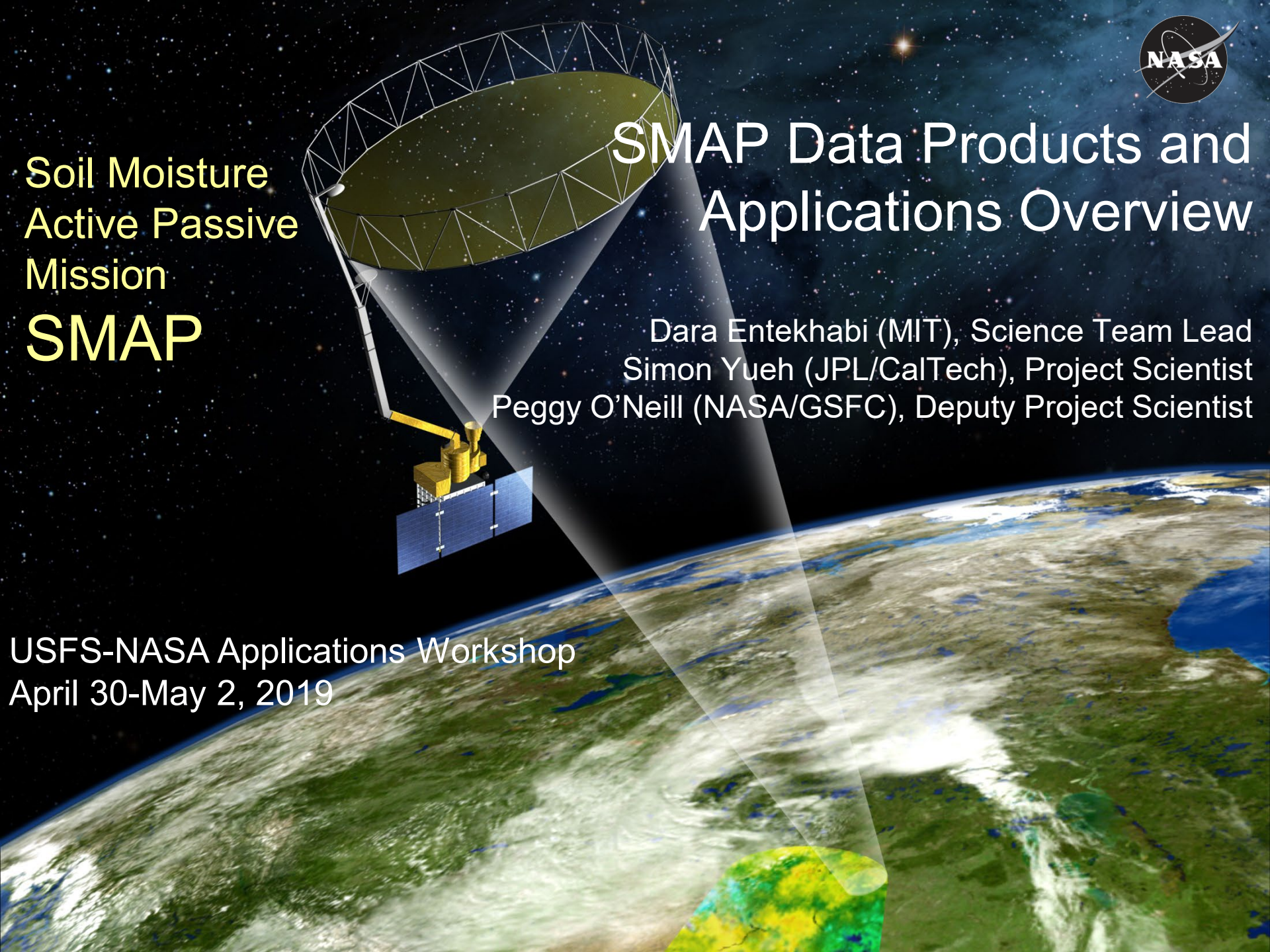


Soil Moisture  
Active Passive  
Mission  
**SMAP**

# SMAP Data Products and Applications Overview

Dara Entekhabi (MIT), Science Team Lead  
Simon Yueh (JPL/CalTech), Project Scientist  
Peggy O'Neill (NASA/GSFC), Deputy Project Scientist

USFS-NASA Applications Workshop  
April 30-May 2, 2019

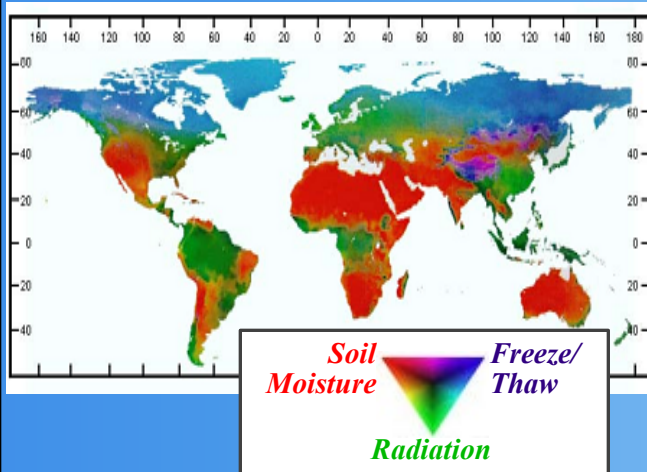


# SMAP Program-Level Requirements (PLRA)



## Science Returns

Understand Processes that Link the Terrestrial Water, Energy, and Carbon Cycles

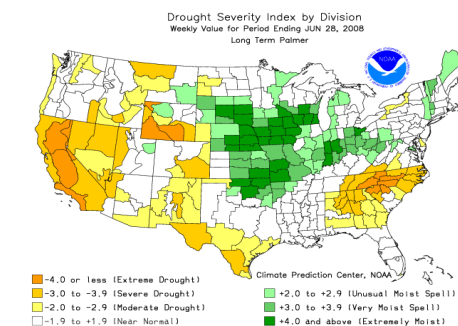
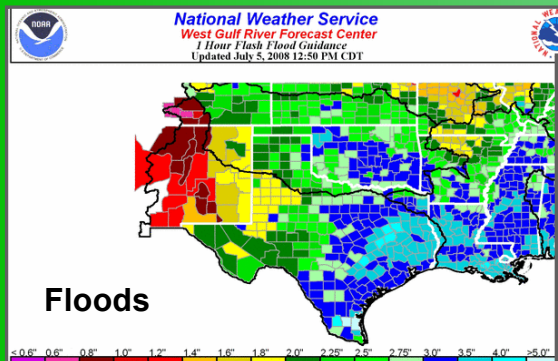


1. Estimate global surface water and energy fluxes
2. Quantify net carbon flux in boreal landscapes
3. Reduce uncertainty of climate model projections



L-band (~21 cm; All-Weather; Canopy Penetration; Sensing Depth)

## Applications Returns

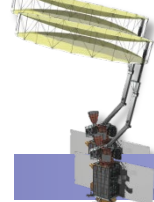


4. Enhance weather forecasts
5. Improve flood prediction and drought monitoring

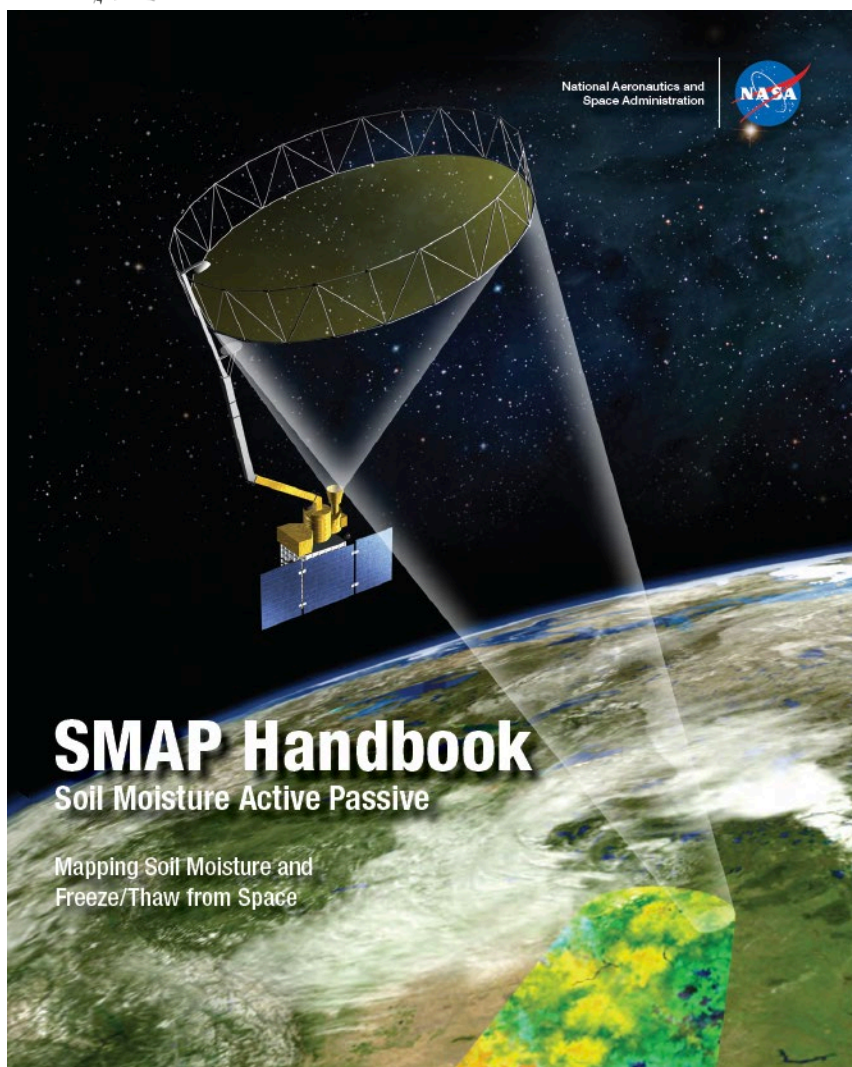
6m conically scanning (14 rpm) antenna for 1000 km swath

Global coverage every 2-3 days





# SMAP Mission Concept



L-band instruments share 6 [m] light-weight deployable mesh reflector.

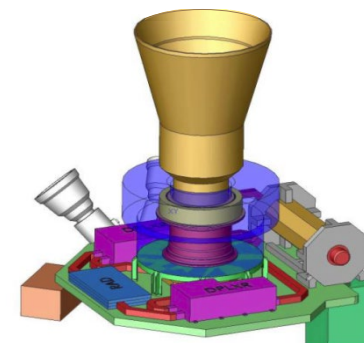
- 1.2 GHz Radar 1-3 km (30% nadir gap)  
HH, VV and HV (Failed; 2 Months of Data)
- 1.4 GHz Radiometer at 40 km (-3 dB)  
H, V, 3<sup>rd</sup> and 4<sup>th</sup> Stokes

Conical scan, fixed incidence angle at 40°

Contiguous 1000 km swath 2-3 days revisit

Sun-synchronous 6am/6pm orbit (680 km)

Launched January 2015

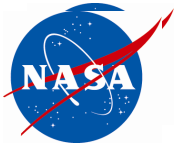


Electronic Version at <http://smap.jpl.nasa.gov/Imperative/>

Now being updated with bibliography of SMAP peer-reviewed publications (1500+) and select science highlights



# Prime-Mission Status and Statistics Summary



Mission Parameter	Mission Status (thru April 2019)
Data volume	~960 TB data
Operating time	~40,000 hours
Number of orbits	~24,000
Antenna revolutions	~32M
L1 median latency	~4 hours
L2 median latency	~12 hours
Near-Real-Time (NRT) median latency	~80% within 3 hours



# SMAP Products Status\*



1. SMAP radiometer has been operating for more than 4 years
  - Completed prime mission in June 2018
  - Next senior review in 2020 for extension through 2026
2. SMAP L1-L4 products distributed through NSIDC
3. SMAP-Copernicus Sentinel-1 active-passive hi-res (3-km and 1-km 6 to 12 days) soil moisture
4. Near-Real-Time (NRT) brightness temperature and soil moisture
5. New vegetation optical depth (VOD) product

# Current SMAP L1-L4 Data Product Table



Product Type	Product description	Gridding	Granule Extent
L1B_TB	Geolocated, calibrated brightness temperature in time order	36 km	Half Orbit
L1B_TB_E	Backus-Gilbert interpolated, calibrated brightness temperature in time order	9 km	Half Orbit
L1C_TB	Geolocated, calibrated brightness temperature on EASE2 grid	36 km	Half Orbit
L1C_TB_E	Backus-Gilbert interpolated, calibrated brightness temperature on EASE2 grid	9 km	Half Orbit
L2_SM_P	Radiometer soil moisture	36 km	Half Orbit
L2_SM_P_E	Radiometer soil moisture	9 km	Half Orbit
L2_SM_SP	SMAP radiometer/Copernicus Sentinel-1 soil moisture	3 km	Sentinel-1 A/B
L3_SM_P	Daily global composite radiometer soil moisture	36 km	Daily - Global
L3_SM_P_E	Daily global composite radiometer soil moisture	9 km	Daily - Global
L3_FT_P	Daily composite freeze/thaw state	36 km	Daily - Global
L3_FT_P_E	Daily composite freeze/thaw state	9 km	Daily - Global
L4_SM	Surface and Root Zone soil moisture	9 km	3 hours - Global
L4_C	Carbon Net Ecosystem Exchange	9 km	Daily – North of 45 N
L1B_TB_NRT	Near Real Time Geolocated, calibrated brightness temperature in time order	36 km	Half Orbit
L2_SM_P_NRT	Near Real Time Radiometer soil moisture	36 km	Half Orbit

# Current SMAP L1-L4 Data Product Table



Product Type	Product description	Gridding (resolution)	Granule Extent
L1B_TB	Geolocated, calibrated brightness temperature in time order	36 km	Half Orbit
<b>L1B_TB_E</b>	<b>Backus-Gilbert interpolated, calibrated brightness temperature in time order</b>	<b>9 km (36 km)</b>	<b>Half Orbit</b>
L1C_TB	Geolocated, calibrated brightness temperature on EASE2	36 km	Half Orbit
L1C_TB_E	Backus-Gilbert interpolated, calibrated brightness temperature on EASE2 g	9 km	Half Orbit
L2_SM_P	Radiometer soil moisture	36 km	Half Orbit
<b>L2_SM_P_E</b>	<b>Radiometer soil moisture</b>	<b>9 km (36 km)</b>	<b>Half Orbit</b>
<b>L2_SM_SP</b>	<b>SMAP radiometer/Copernicus Sentinel-1 soil moisture</b>	<b>3 km (1 km)</b>	<b>Sentinel-1A/B</b>
L3_SM_P	Daily global composite radiometer soil moisture	36 km	Daily - Global
L3_SM_P_E	Daily global composite radiometer soil moisture	9 km	Daily - Global
L3_FT_P	Daily composite freeze/thaw state	36 km	Daily - Global
L3_FT_P_E	Daily composite freeze/thaw state	9 km	Daily - Global
L4_SM	Surface and Root Zone soil moisture	9 km	3 hours - Global
L4_C	Carbon Net Ecosystem Exchange	9 km	Daily >45 N
<b>L1B_TB_NRT</b>	<b>Near Real Time Geolocated, calibrated brightness temperature in time order</b>	<b>36 km</b>	<b>Half Orbit</b>
<b>L2_SM_P_NRT</b>	<b>Near Real Time Radiometer soil moisture</b>	<b>36 km</b>	<b>Half Orbit</b>

# SMAP R16 Release Algorithm Updates



Products	Algorithm/Product Changes
L1B_TB/E	<ol style="list-style-type: none"><li>1. Radiometer re-calibration</li><li>2. More rigorous land/waterbody un-mixing</li></ol>
L2_SM_P/E	<ol style="list-style-type: none"><li>1. Revised effective soil temperature used in SM retrieval</li><li>2. AM and PM retrievals</li><li>3. Vegetation Optical Depth (VOD) retrievals</li></ol>
L2_SM_SP	<ol style="list-style-type: none"><li>1. Pre-filtering of high-res (20m) s0 to remove/mitigate urban areas</li><li>2. 3 km and 1 km weekly soil moisture</li></ol>

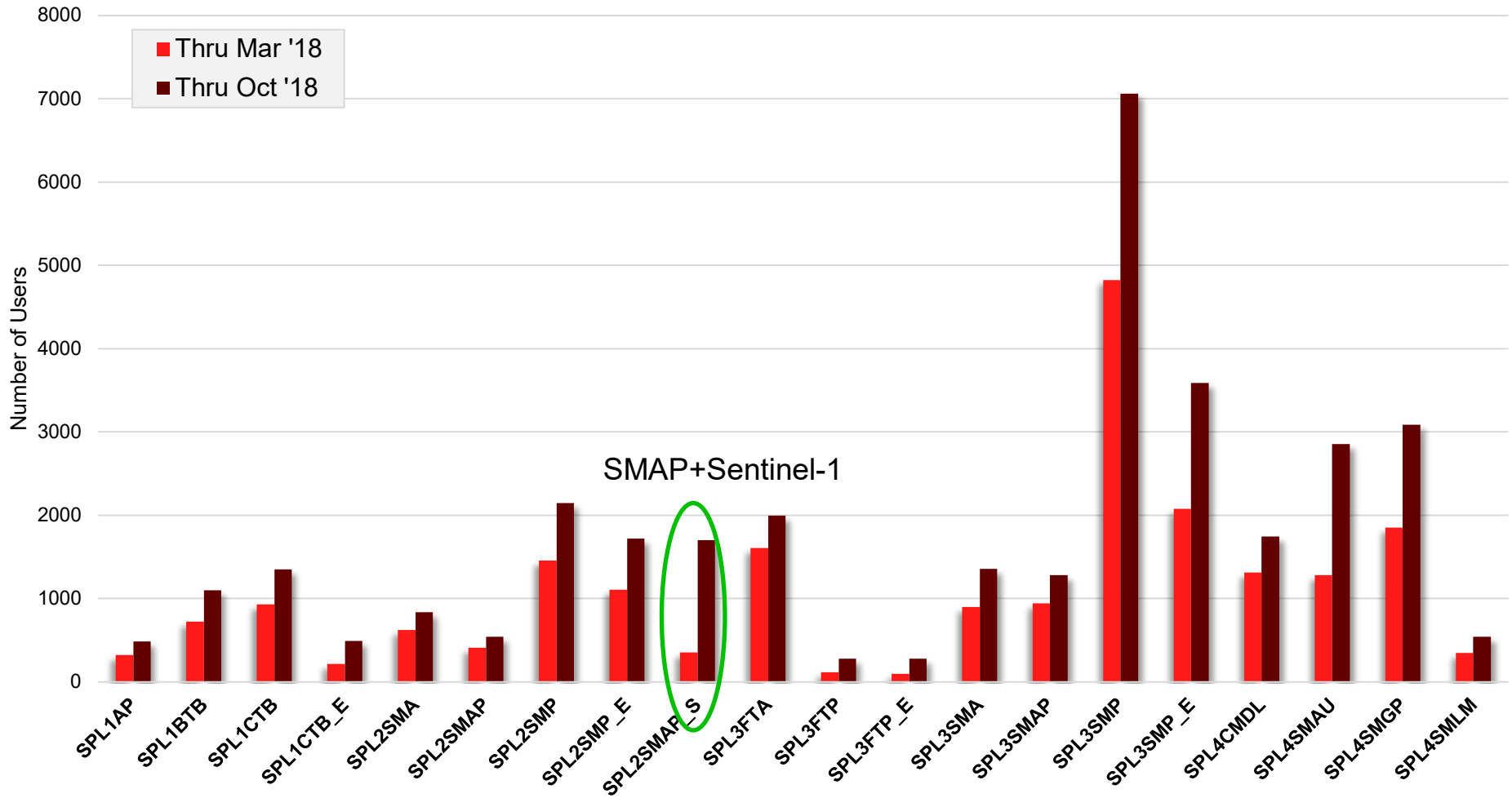


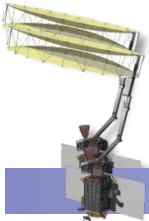


# NSIDC Distribution Statistics



Number of **users** of SMAP data all-time by **product**





## What data subsetting, reformatting, and reprojection services are available for SMAP data?

The following table describes the data subsetting, reformatting, and reprojection services that are currently available for SMAP data via the [NASA Earthdata Search](#) tool.

Short name	Title	Subsetting		Reformatting						Reprojection*
		Parameter	Spatial	GeoTIFF	ASCII	netCDF-3	netCDF-4	KML	HDF-EOS5	

## How to Import SMAP HDF Data Into ArcGIS

This How To guide, **relevant only to ESRI ArcMap10.5 and later versions**, will outline the steps to follow in order to properly project and visualize global\*\* SMAP L3 and L4 HDF data in ArcGIS. However, if you are running ArcMap10.4.1, there is a [patch available for download](#) that will allow you to follow the instructions below after installation. If you are working in older versions of ArcMap, the best course of action is to utilize [NASA's Earthdata Search](#) tool to order SMAP data in GeoTIFF format. If you are in need of guidance for the Earthdata tool, please see our [video tutorial](#) showing you how to search for and order SMAP data. This example (using [SPL4SMG](#))

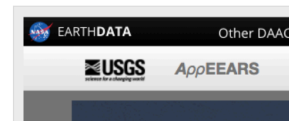
### 1. Create a File Geodatabase

Begin ArcMap10.5 with a blank map. Open the Catalog pane and Right Click on some folder connection > New > File Geodatabase

## How to extract point and area samples of SMAP data using AppEEARS

This step-by-step tutorial demonstrates how to access SMAP data using the Application for Extracting and Exploring Analysis Ready Samples (AppEEARS). AppEEARS allows users to obtain and display point and area data using spatial, temporal, and layer subsets. SMAP data from NSIDC that are accessible in AppEEARS include the complete time series of **SPL3SMP**, **SPL3SMP\_E**, **SPL3FTP**, **SPL4CMDL**, **SPL4SMGP** (31 March 2015 to current). Time series data are plotted on several graphs within the interface and can also be downloaded in .csv (point data) or GeoTiff and NetCDF (area data) formats.

Step 1: Access the AppEEARS interface, <https://lpdaacsvc.cr.usgs.gov/appeears/>. An Earthdata login is required.



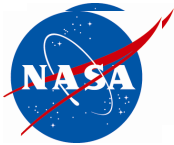
## How do I access data using OPeNDAP?

Data can be programmatically accessed using NSIDC's OPeNDAP Hyrax server, allowing you to reformat and subset data based on parameter and array index. For more information on OPeNDAP, including supported data sets and known issues, please see our OPeNDAP documentation: <https://nsidc.org/api/opendap/>

Last updated: 10 January 2018

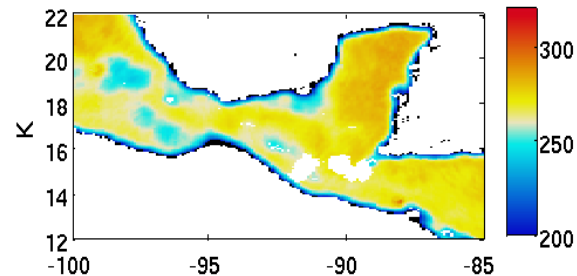
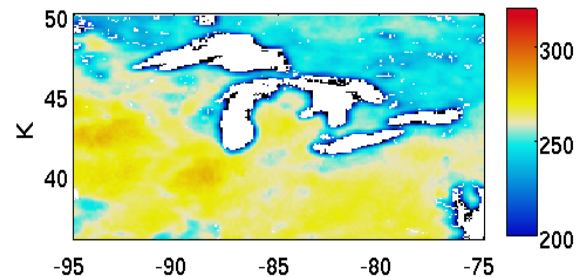
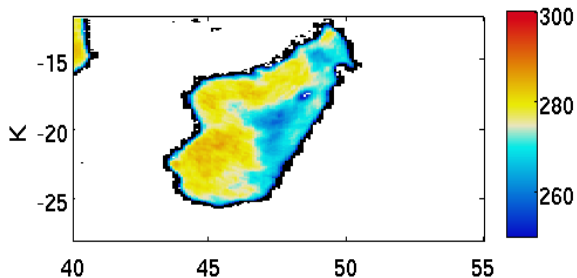


# Waterbody/Land Un-Mixing

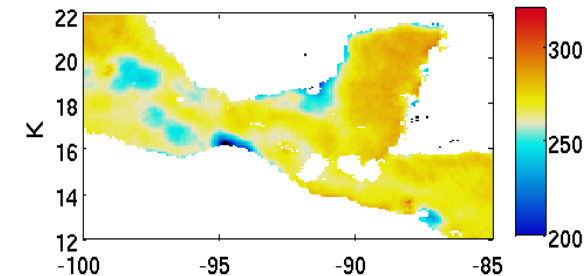
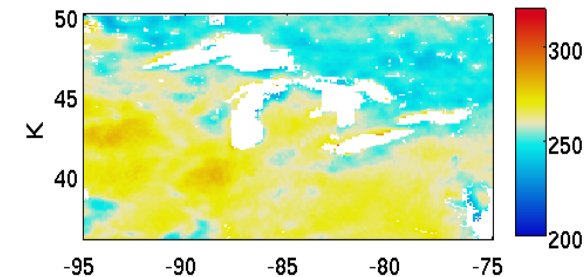
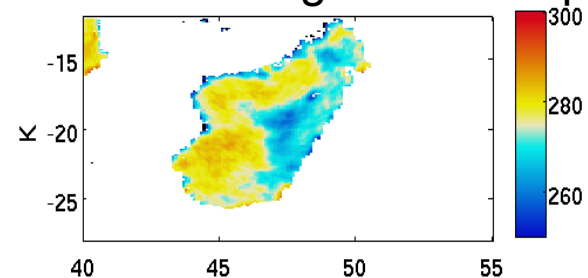


Data near coastlines (~100 km) significantly improved.

Uncorrected SMAP data



Corrected land brightness temperature



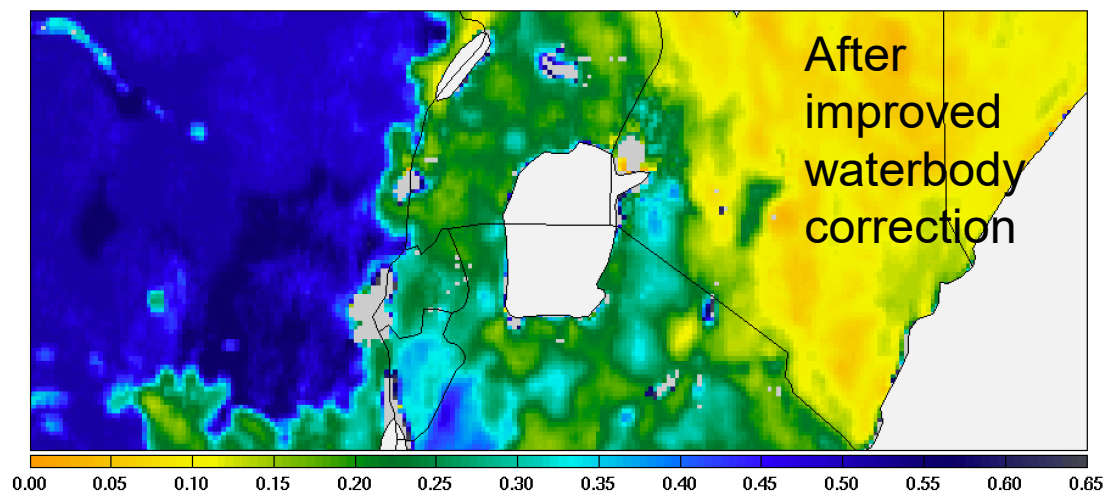
Similar algorithm applied to reduce land contamination on data over oceans/lakes



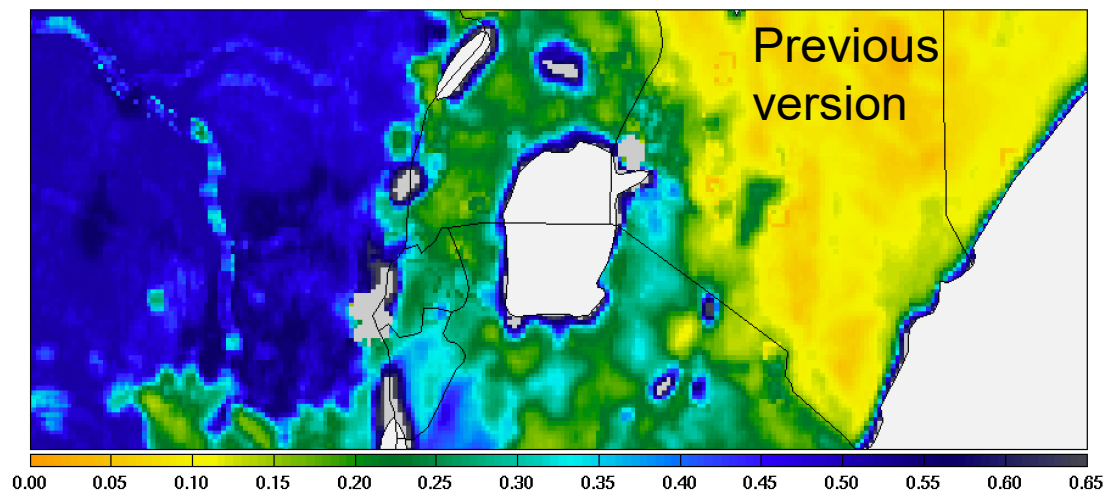
# Waterbody Correction of Soil Moisture Near Coasts

2017/03 6:00 am L2\_SM\_P\_E with antenna pattern TB water correction

OAS version of SMAP soil moisture between 2017-03-01 and 2017-03-01 in m<sup>3</sup>/m<sup>3</sup>



2017/03 6:00 am L2\_SM\_P\_E without antenna pattern TB water correction

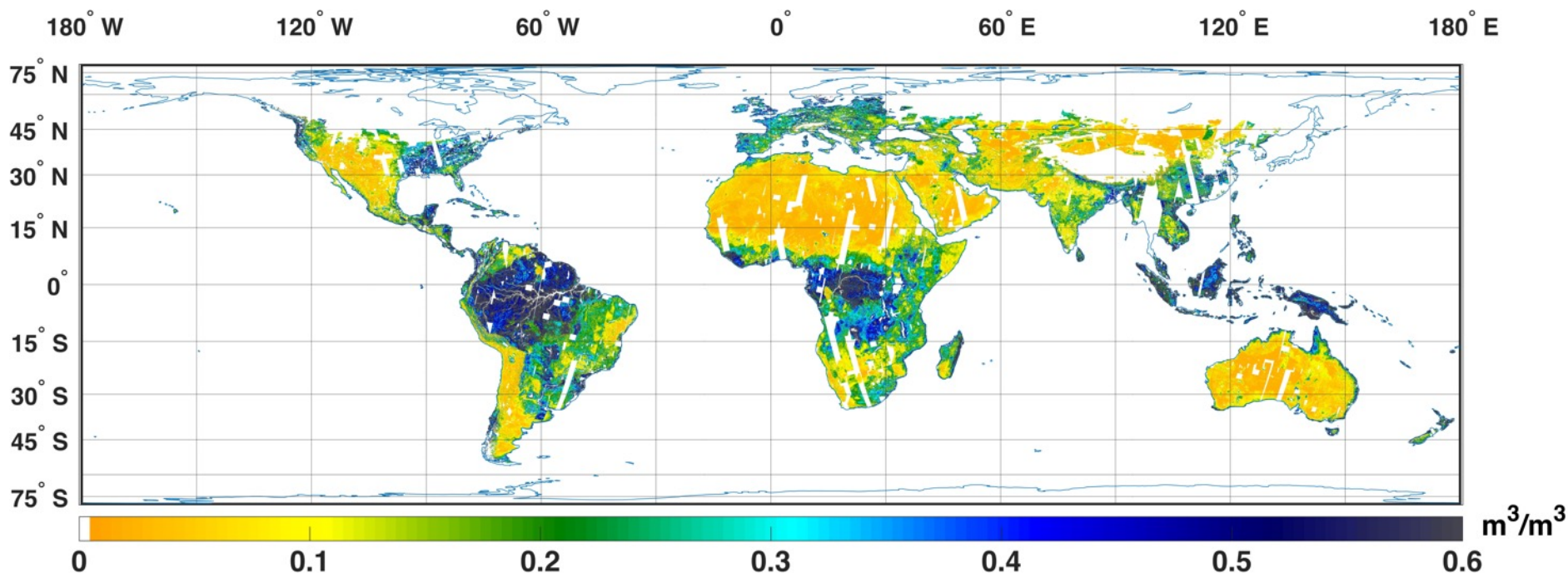




# SMAP/Copernicus Sentinel-1 Soil Moisture Product



- Leverage the SMAP active-passive algorithm
- Use the Copernicus Sentinel-1A/1B data as the surrogate
- Reach nearly global coverage every week to 12 days since March 2017
- Limited to low-vegetation ( $< \sim 3 \text{ kg m}^{-2}$ )



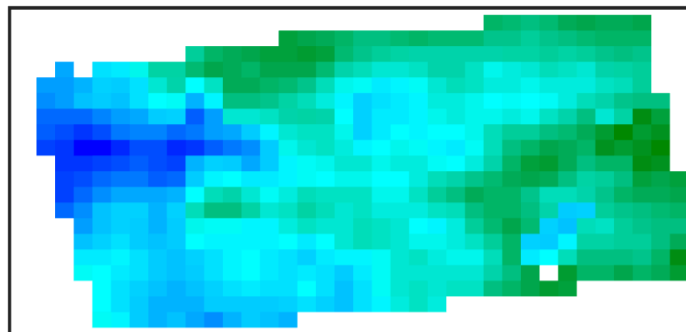
**SMAP-Sentinel-1 Multi-Platform Soil Moisture Global Coverage, 12-day Cycle, April 1st - 12th, 2018**



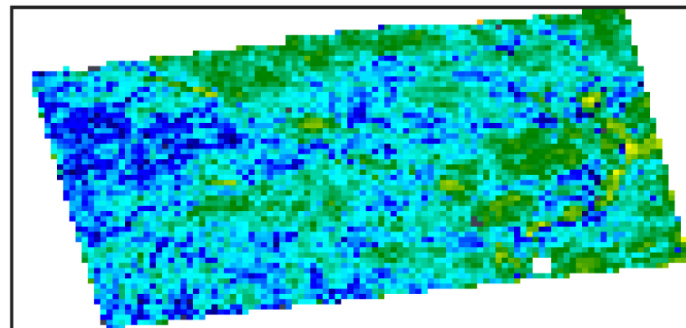
# Sample Soil Moisture Maps



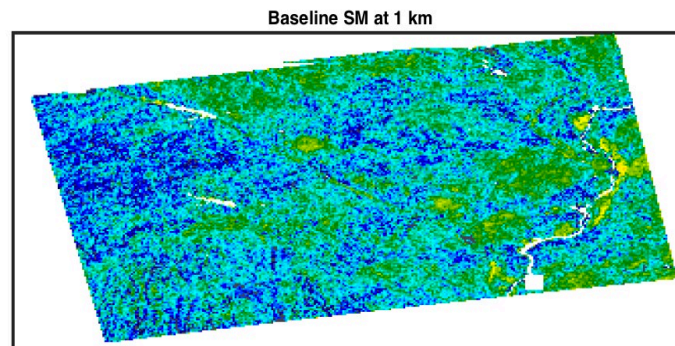
5<sup>th</sup> May 2018  
Southern Iowa



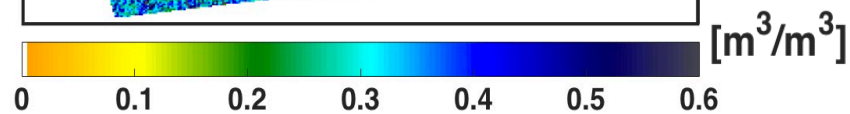
L3\_SM\_P\_E  
Gridded  
at 9 km

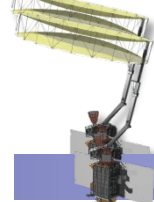


L2\_SM\_SP  
at 3 km



L2\_SM\_SP  
At 1 km





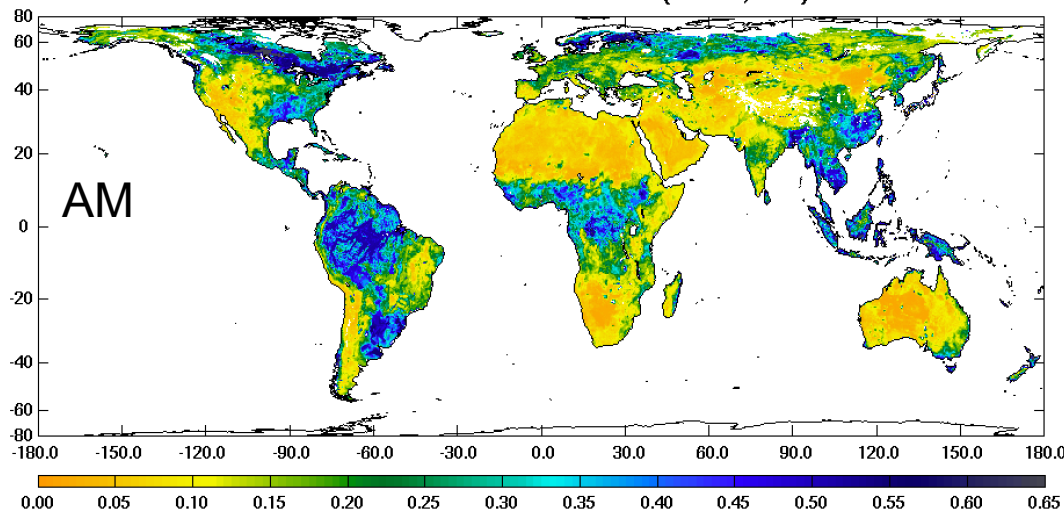
# L2 Product

## SMAP Radiometer Soil Moisture

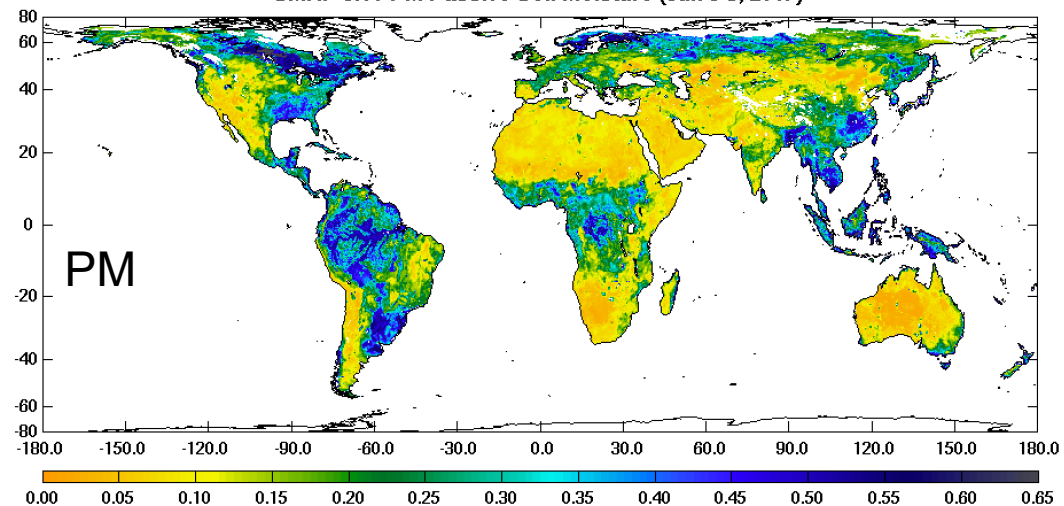


- PM has achieved similar performance as AM at core cal/val sites
- Use of AM and PM data together leads to an average revisit of 1.5 days

SMAP 6:00 AM Passive Soil Moisture (Jun 3-5, 2017)



SMAP 6:00 PM Passive Soil Moisture (Jun 3-5, 2017)



	ubRMSE [m <sup>3</sup> m <sup>-3</sup> ]	Bias [m <sup>3</sup> m <sup>-3</sup> ]	Correlation
AM	0.038	-0.001	0.814
PM	0.036	-0.002	0.818

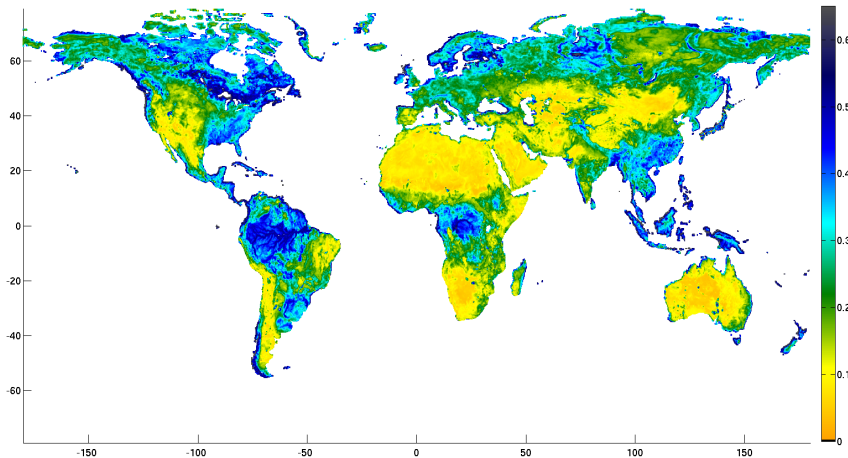
L2SMP\_E at Core Cal/Val Sites

# SMAP Dual Channel Algorithm for Soil Moisture and Vegetation Optical Depth

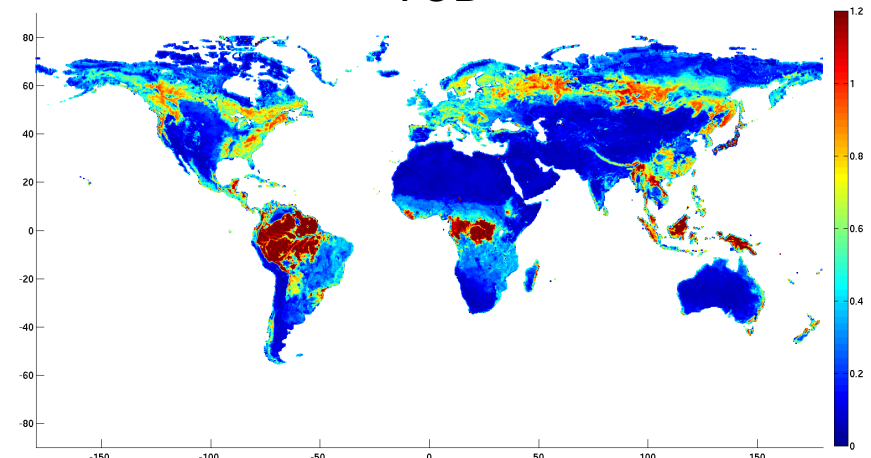


SMAP dual-channel algorithm can retrieve soil moisture and vegetation optical depth from dual-polarized brightness temperatures

Soil Moisture



VOD



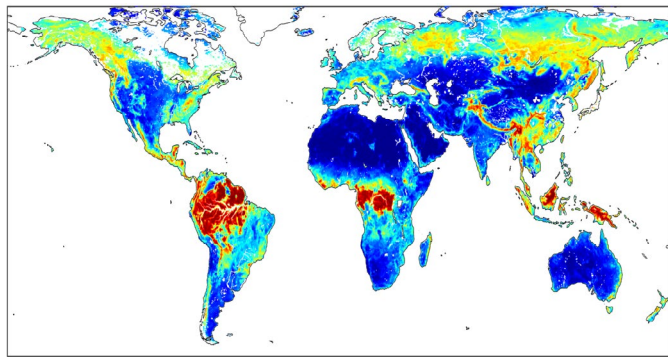
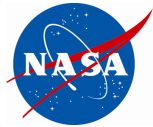
Improved Q-H-Omega parameterization leads to significant improvement in DCA performance, close to Baseline SCAV

	ubRMSE [m <sup>3</sup> m <sup>-3</sup> ]	Bias [m <sup>3</sup> m <sup>-3</sup> ]	Correlation
<b>Baseline SCA-V</b>	0.037	-0.006	0.805
<b>New-DCA</b>	0.039	-0.005	0.746

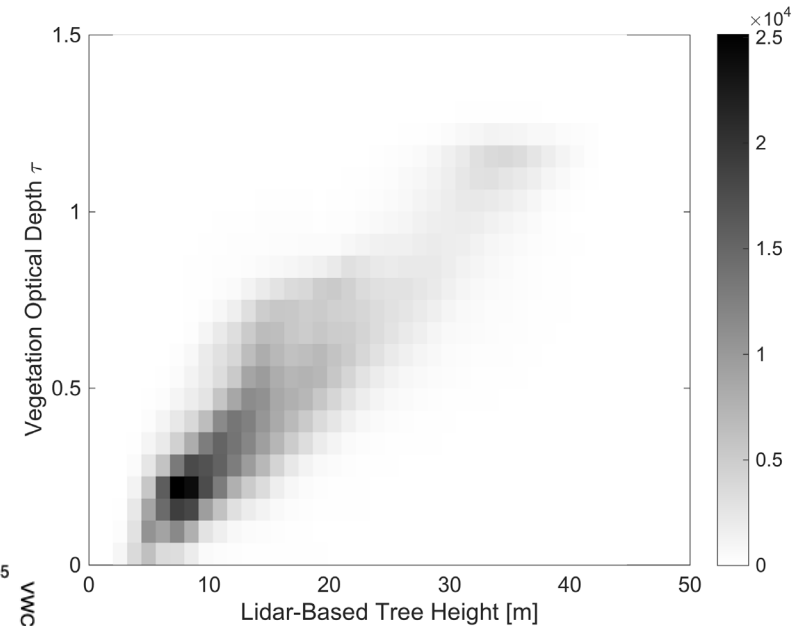
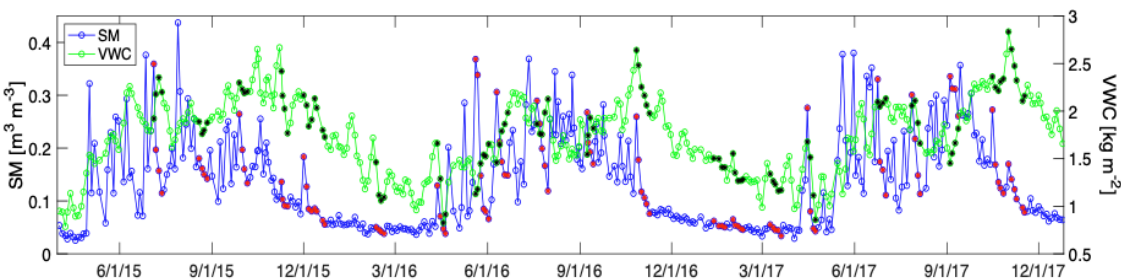
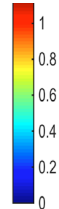
At Core Cal/Val Sites



# Mapping Coverage With 2-3 Days Dynamics



VOD

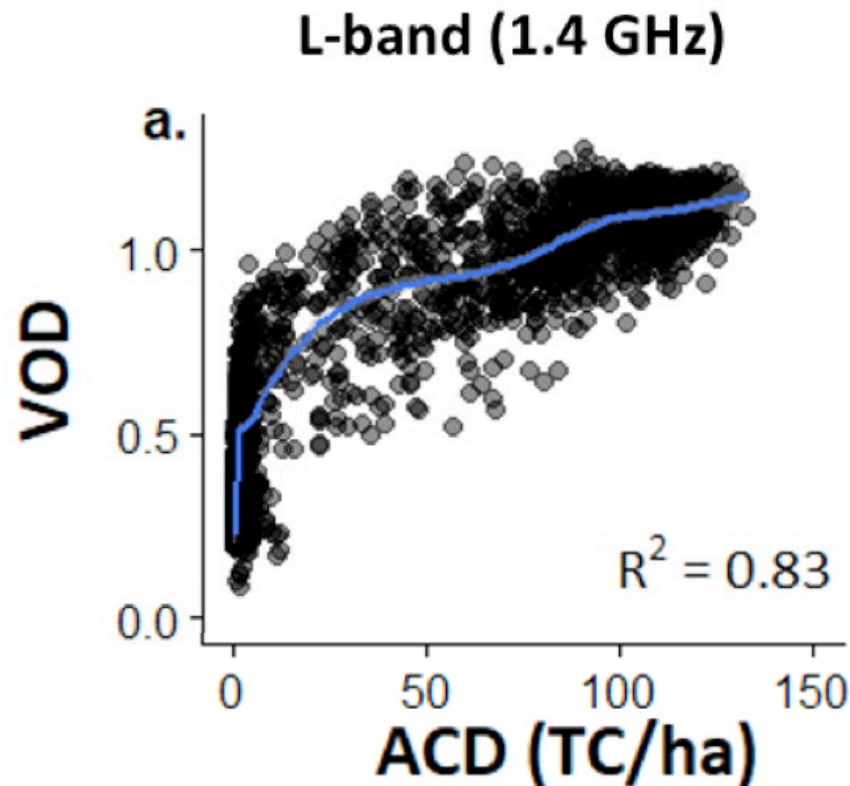
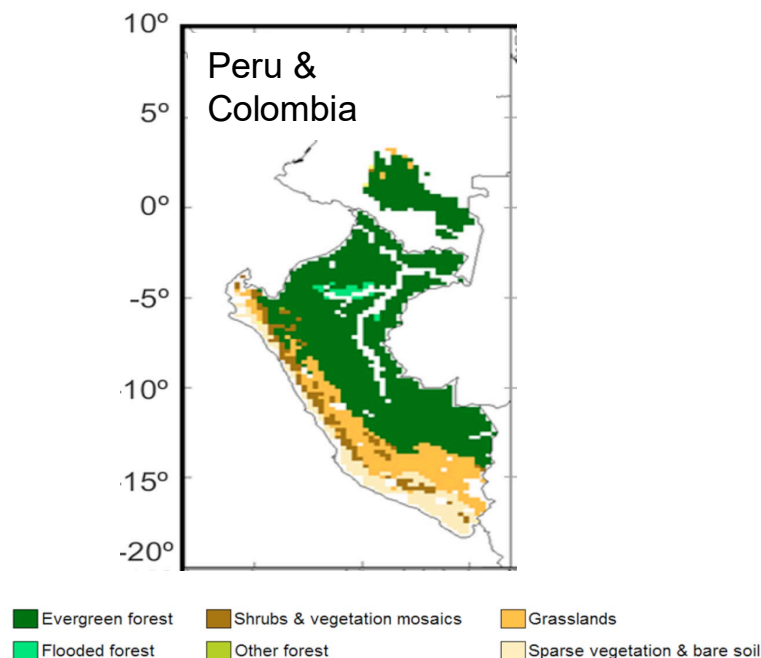


Potential for assessments of:

- Fuel load
- Dryness and ignition hazard
- Tree mortality
- Carbon stocks



# Above-Ground Biomass



Above-Ground Carbon Density (ACD) from  
Carnegie Airborne Observatory  
Asner et al., 2014, PNAS, 111.

Chaparro Duveiller Piles Cescatti, Vall-llossera, 2019: Sensitivity of L-band passive microwaves to carbon stocks in American tropical forests: a comparison to higher microwave frequencies and optical data, *RSE*.



# Summary

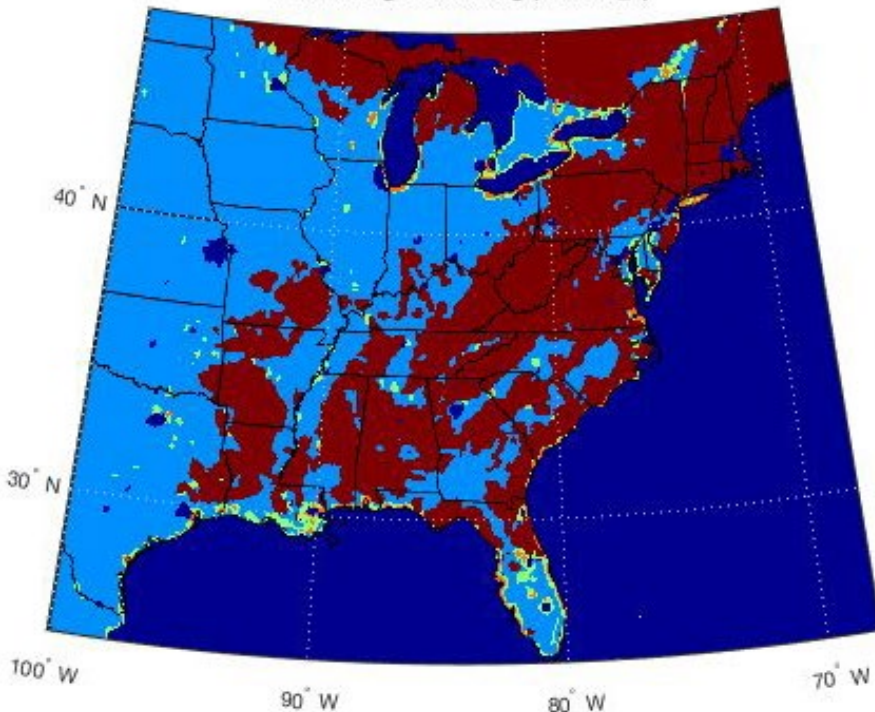


- SMAP radiometer has been operating for more than 4 years
- All products meet requirements
- Added products:
  - Near Real Time (NRT)
  - SMAP-Sentinel-1A/B soil moisture 3 km and 1 km
  - Dynamic vegetation biomass mapping (2015+, available June 2019)
- Airborne field experiment SMAPVEX19 in 2019



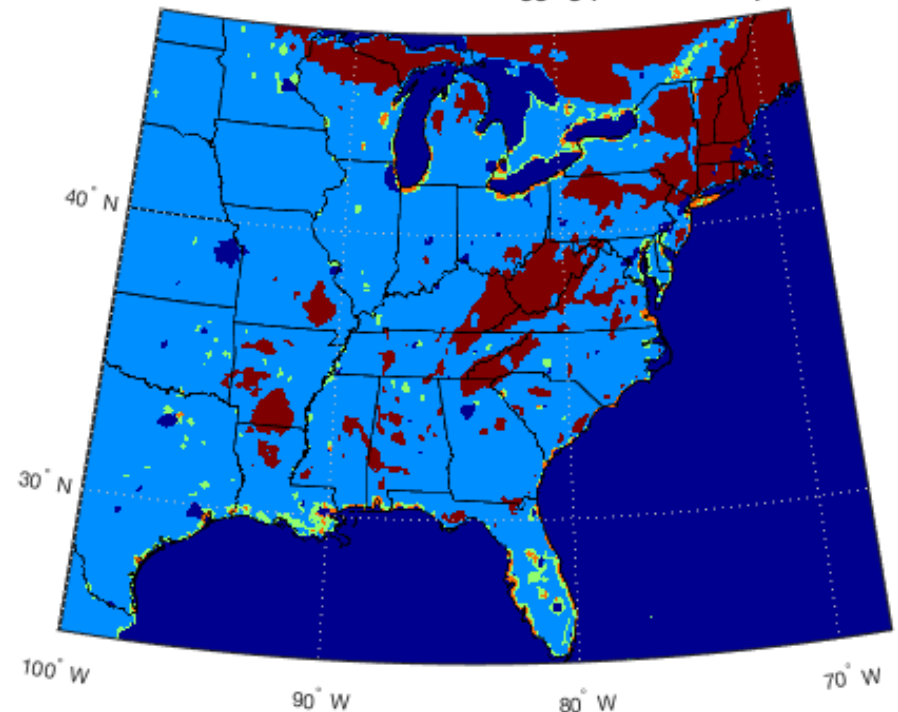
Resolving soil moisture under mixed pixel conditions (similar to Millbrook) will allow “unmasking” of majority of dense vegetation flag in the Eastern US

Dense Vegetation Flag (L2SMP\_E)



**Current flag**  
 $<5 \text{ [kg m}^{-2}\text{]}$

Mixed Pixels Omitted from Flagging (threshold 70%)



**Mixed pixels resolved**  
 $<70\%$  forest fraction





# What and How SMAP Products Can Support USFS Management Needs?\*



## Surface soil moisture (radiometer-only):

Temporal:	2-3 days mapping
Spatial:	9 km posting (36 km resolution)
Accuracy:	At least 5 levels of discrimination within dynamic range
Domain:	Direct sensing of top ~ 5 cm (indicative of top tens of cm)

## Surface soil moisture (radar-radiometer):

Temporal:	6-12 days mapping
Spatial:	3 km and 1 km resolution
Accuracy:	Same for non-forested
Domain:	Same

Soil moisture is a time-integrated measure of landscape moisture conditions relevant for:

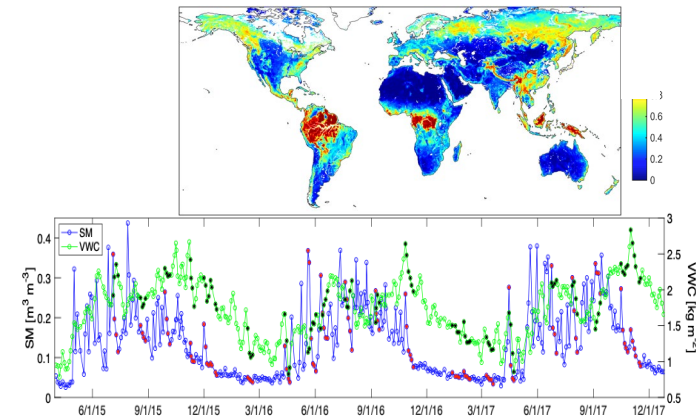
1. Forest and rangeland monitoring
2. Hazards assessments

# What Existing/Future Product(s) Do You Think Most Relevant to USFS Management Needs?\*



Vegetation Optical Depth  
(related to wet+dry biomass [ $\text{kg m}^{-2}$ ]):

Temporal: 2-3 days mapping  
Spatial: 9 km posting (36 km resolution)



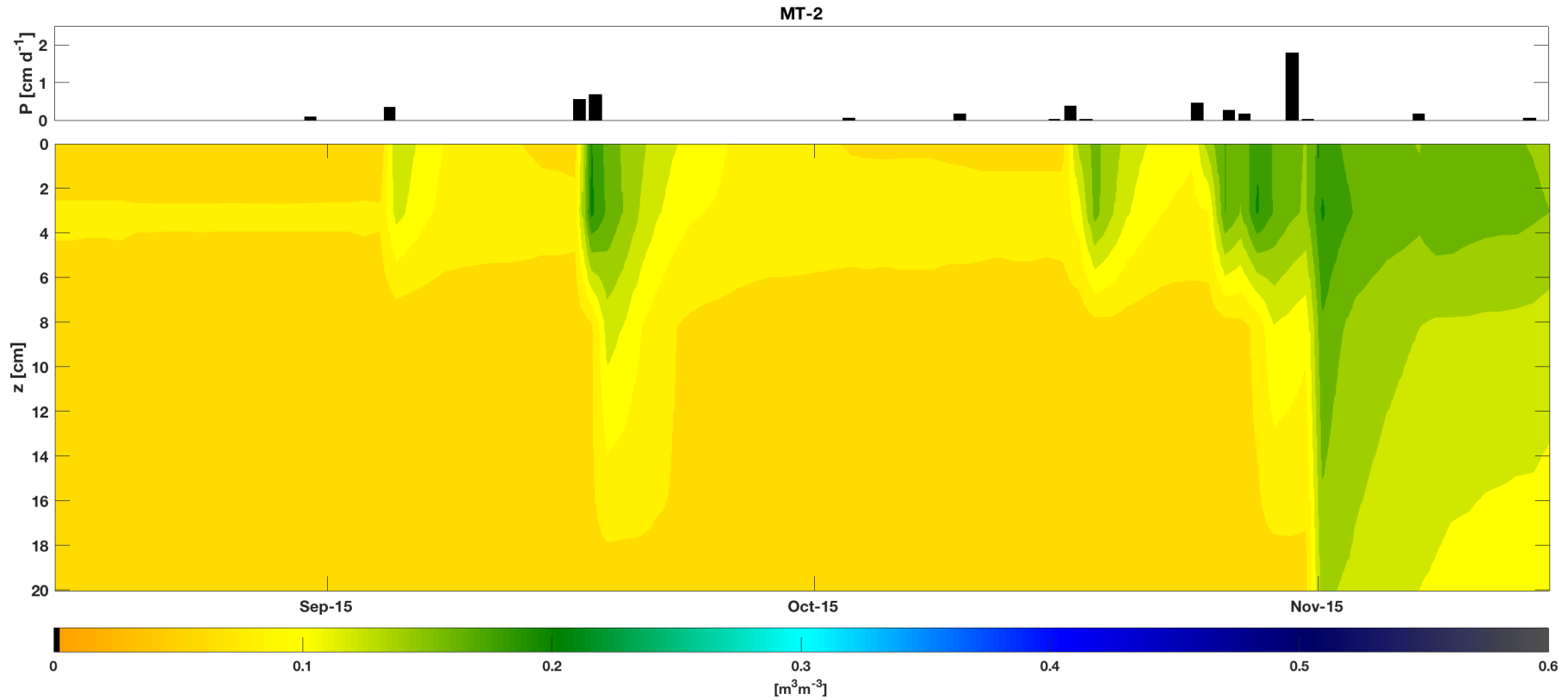
Potential application in assessing:

1. Fuel load
2. Dryness and ignition hazard
3. Tree mortality
4. Carbon stocks

Backup Slides



# Surface-Subsurface Coupling





# Landscape Water Balance Closure is Represented by the Combination of SMAP and GPM Data



**Problem:** Landscape water balance cannot be closed using available observations

The landscape water budget is:

$$\Delta z \frac{d\theta}{dt} = P - ET(\theta) - D(\theta) \quad [\text{mm day}^{-1}]$$

Equivalent to

$$\frac{d\theta}{dt} = \frac{P}{\Delta z} - E \left[ -\frac{\Delta\theta^-}{\Delta t_{obs}} \middle| \theta \right] \quad [\text{day}^{-1}]$$

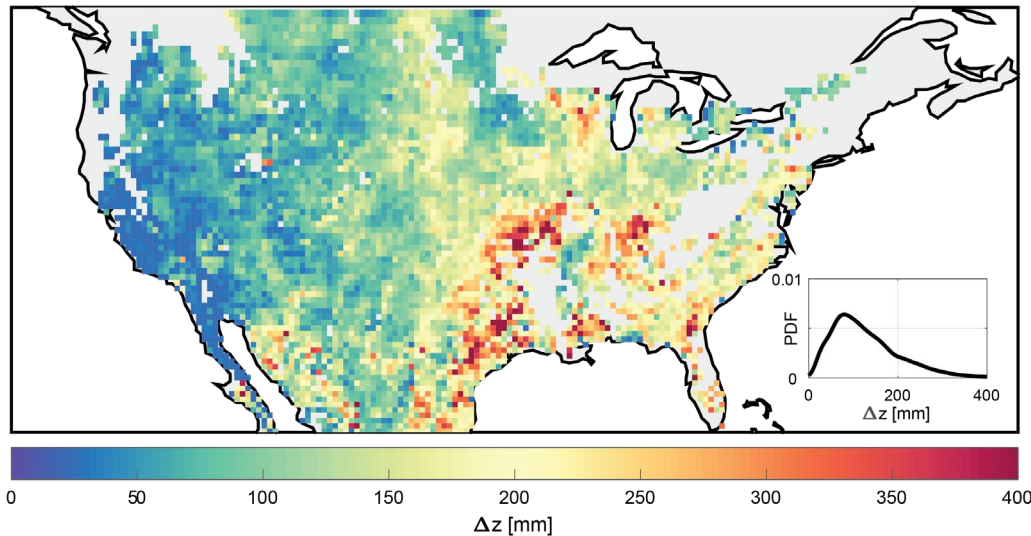
The functional form of the landscape moisture loss is approximated by the expectation  $E[ \ ]$  of dry-down SMAP rate  $\frac{\Delta\theta^-}{\Delta t_{obs}}$  conditioned on the soil moisture state  $\theta$ :

$$L(\theta) = E \left[ -\frac{\Delta\theta^-}{\Delta t_{obs}} \middle| \theta \right]$$

**Finding:** The characteristic hydrologic depth  $\Delta z$  that

- tracks the dynamics of landscape water balance,
- closes the water budget

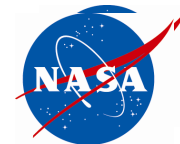
is identifiable with only precipitation ( $P$  from GPM) and soil moisture ( $\theta$  and  $\Delta\theta$  from SMAP)



**Impact:** Taken together, soil moisture and precipitation define a closed landscape water budget. Together they define a landscape storage that is deeper than the sensing depth of surface soil moisture.

Akbar, Gianotti, Haghighi, McColl, Salvucci, Entekhabi, 2018: Hydrological storage length scales represented by remote sensing estimates of soil moisture and precipitation, *Water Resources Research*.

# SMAP-Sentinel AM Average Revisit [Days]



Average Revisit Time in days for 2016.10-2017.09

