

# SMAP MISSION STATUS AND PLAN

Simon H. Yueh<sup>1</sup>, Dara Entekhabi<sup>2</sup>, Peggy E. O'Neill<sup>3</sup>, Jared K. Entin<sup>4</sup>, and Mark Garcia<sup>1</sup>

<sup>1</sup>Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA

<sup>2</sup>The Massachusetts Institute of Technology, Cambridge, Massachusetts, USA

<sup>3</sup>NASA Goddard Space Flight Center, Greenbelt, MD, USA

<sup>4</sup>NASA Headquarters, Washington, DC, USA

## ABSTRACT

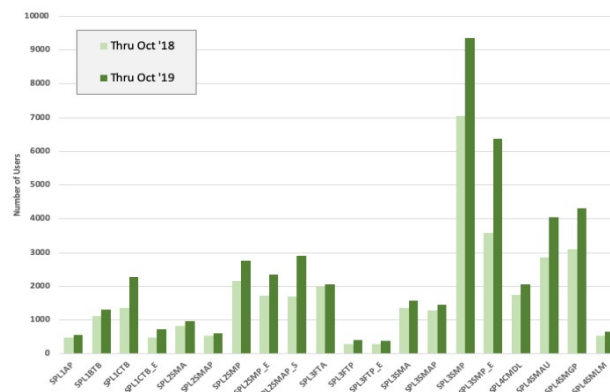
The National Aeronautics Space Administration's (NASA's) Soil Moisture Active Passive (SMAP) mission will be completing its first extension phase in August 2020. The uncertainty of SMAP soil moisture products is  $\leq 0.04 \text{ m}^3/\text{m}^3$ . During the first extension phase, SMAP data have been used to advance our understanding of water, energy and carbon cycles. Significant progress has also been made to transition the use of SMAP data to operational communities. In particular, the United States Air Force (USAF) and United States Department of Agriculture (USDA) Foreign Agriculture Service (FAS) have included SMAP data in their operational forecast systems. The SMAP project has been performing a recalibration of radiometer data using four years of cold sky maneuver data. The recalibrated data and updated soil moisture and freeze/thaw products will be presented during the meeting. The SMAP project is preparing an extension proposal to continue the data acquisition and processing activities for another three years (2021-2023) and also identifying additional activities for 2024-2026. We will describe the activities for the second extension phase, including plans for SMAPVEX20 and '22 field campaigns.

**Index Terms**— NASA Soil Moisture Active Passive, soil moisture, water cycle

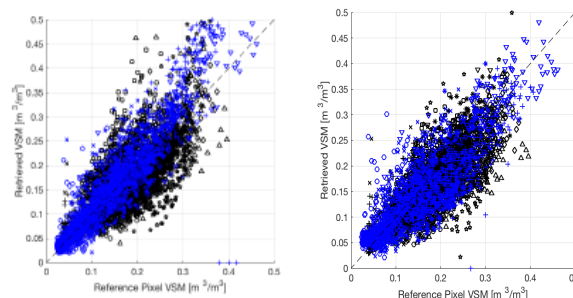
## 1. INTRODUCTION

NASA's Soil Moisture Active Passive (SMAP) mission [1] has been operating for more than four years since 2015. Examples of scientific investigations and applications can be found on the SMAP project website (<https://smap.jpl.nasa.gov>). The observatory and radiometer have been operating flawlessly except for about one month in mid 2019 due to a spacecraft anomaly, putting the spacecraft into safe mode and hence no data collection. The anomaly was successfully resolved after some spacecraft software updates and resets.

All acquired and processed radiometer-related data have been distributed through the National Snow and Ice Data Center (NSIDC). The number of data users is significant for all products, in particular the Level 3 gridded soil moisture



**Figure 1:** Number of SMAP data users by product (courtesy of NSIDC).

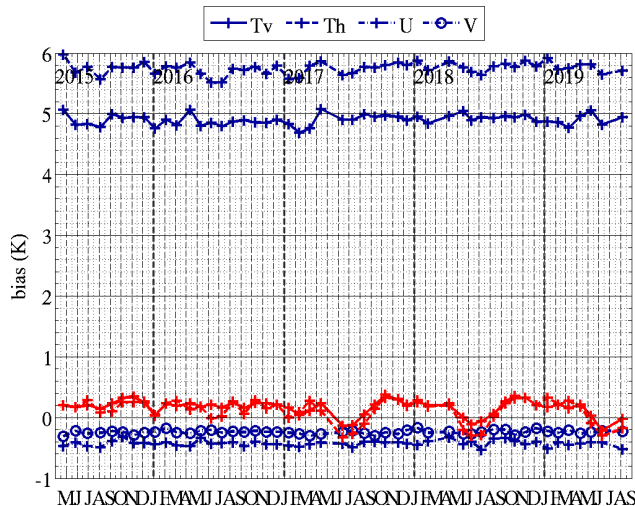


**Figure 2:** SMAP soil moisture retrievals versus *in situ* data from core Cal/Val sites. SCA-V (left panel) and current DCA (right panel). Different symbols represent data from different core cal/val sites.

product (Fig. 1), reaching more than 8000. The SMAP-Copernicus Sentinel-1 active-passive soil moisture product (L2SMAP\_S) [2] has also been gaining attention with more than 1700 users at the end of October 2018 and reached close to 3000 in October 2019.

## 2. SMAP DATA AND APPLICATIONS

The error assessment of SMAP soil moisture products was made by comparison with *in situ* data from 12 core calibration and validation sites. Each core Calibration/Validation (cal/val) site has several *in situ* sensors deployed within the



**Figure 3:** Difference (bias) in SMAP brightness temperature acquired from cold sky maneuvers and estimation by an end-to-end brightness temperature model from 2015-2019. Blue curves for version 3 TB. Version 3 TV (blue solid, +), TH (blue dashed, +), third Stokes (circle), and fourth Stokes (short dashes, +). Version 4 TV (red solid, +) and TH (red dashes, +). There was a drop of about 0.5 K during eclipse in V4 data. (Courtesy of D. LeVine and E. Dinnat)

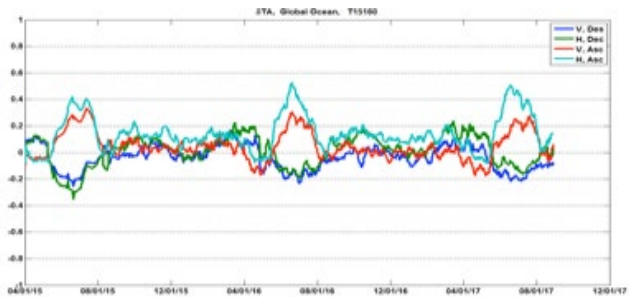
corresponding 36 km Equal Area Scalable Earth (EASE) grid. The data from all individual sensors were averaged for comparison with each SMAP’s soil moisture retrieval for the baseline Single Channel Algorithm-Vertical polarization (SCA-V) [3] and the Modified Dual Channel Algorithm (MDCA) [4]. The SMAP soil moisture versus *in situ* data are illustrated in Fig. 2.

*Table 1. SMAP soil moisture uncertainty estimated using data from core Cal/Val sites. The RMSD is computed using the scatter illustrated in Fig. 2 and represents the root-square-sum of in situ and SMAP uncertainties.*

	SCA-V	DCA
RMSD (SMAP-in-situ)	0.051	0.052
In-situ Uncertainty	0.039	0.039
SMAP Uncertainty	0.033	0.034

The Root-Mean-Square-Difference (RMSD) between SMAP and core Cal/Val site data is about 0.05 (Table 1). We have also completed an assessment of the uncertainty of in-situ data, which is about 0.039, accounting for the spatial scaling, vertical profiling and calibration error of in-situ sensors. The resulting SMAP retrieval error is therefore better than  $0.04 \text{ m}^3/\text{m}^3$ .

SMAP has been producing near real time (NRT) data products with a short latency; about 85% of data is available within 3 hours. The data have been assimilated into the Land Information System (LIS) at the Goddard Space Flight Center



**Figure 4:** Difference between SMAP and an ocean radiative transfer for ascending and descending passes in V4 data. There was an overcorrection for the ascending passes during eclipse while the data over descending passes remain lower than expected. (Courtesy of J. Peng)

(GSFC). The GSFC LIS is used in the United States Air Force (USAF) Weather Forecast system. USAF has made the use of SMAP NRT soil moisture operational since December 2019.

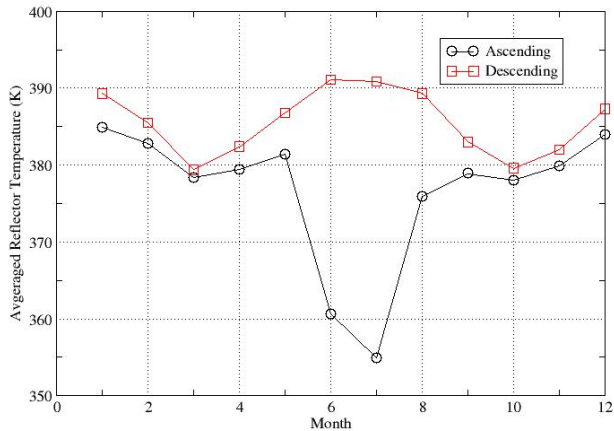
LIS has other users. The US Army uses the LIS-Air Force soil moisture analysis for mobility and flood potential assessments. The US Department of Agriculture (USDA) Foreign Agriculture Service (FAS) makes food security assessments and has included SMAP data in their operational forecast systems (<https://ipad.fas.usda.gov/cropexplorer/>).

The USDA National Agriculture Statistics Service (NASS) is producing analysis based on SMAP’s Level 4 soil moisture products for their users, and is planning to release the first version of the application for operational testing in April 2020. The data are being used for NASS modeling research via implemented web services. More information can be found at: <https://cloud.csiss.gmu.edu/smap/>.

SMAP soil moisture is also being assessed by the National Drought Mitigation Center (NDMC) for drought monitoring. NDMC has been creating SMAP-based maps every week from Dec 2016 onwards (3 years), except for the weeks when the SMAP data were not available.

### 3. ACTIVITIES FOR IMPROVEMNT

To further improve the quality of SMAP data, the project has revisited the radiometer calibration to resolve two issues. One was indicated in the current version of the radiometer soil moisture algorithm and is related to the adjustment of radiometer brightness temperatures over land surfaces, and the other one concerns the overcorrection of cold sky brightness temperatures. Additional efforts involve improving the SMAP algorithm over regions with relatively high vegetation water content ( $>5 \text{ kg}/\text{m}^2$ ). We have been planning two field campaigns with airborne radiometer flights and intensive in-situ samplings of soil moisture and vegetation properties. The first one will be carried out in 2020 with two campaign periods, and the second one is being



**Figure 5:** The expected average physical temperature of the SMAP reflector for ascending and descending passes.

planned for 2022 with a site to be determined in the Boreal regions.

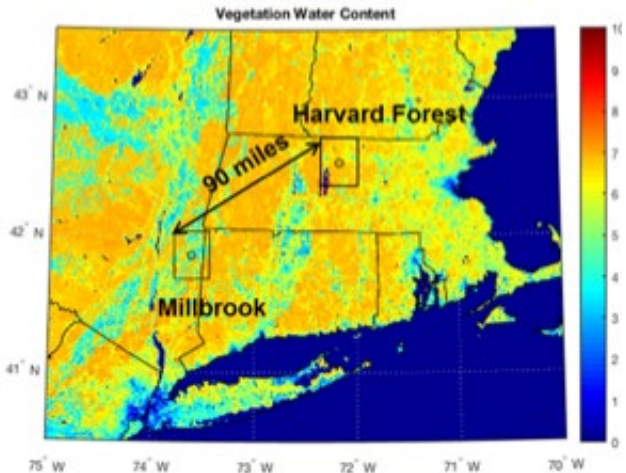
### 3.1. Radiometric Calibration

The SMAP Version 4 (V4) calibrated radiometer brightness temperatures were released in August 2019 (<http://nsidc.org/data/search/#keywords=smap/sortKeys=score,,desc/facetFilters=%257B%257D/pageNumber=1/itemsPerPage=25>). The values of V4 calibration parameters, including antenna reflector emissivity, radiometer noise diode and internal reference loads, were tuned using the data acquired over sea surfaces and two years of cold sky (CS) maneuver data [5].

However further analysis of CS data appears to suggest that there was an overcorrection to the reflector loss in the V4 data (Fig. 4), while there was no such similar drop in the former release, Version 3 (V3) data [6]. Separating the data from ascending and descending passes shows that there appears to be an overcorrection for the ascending pass data during eclipse, while the data for descending passes remain lower than expected (Fig. 4).

Because of the seasonal change of relative angle between SMAP’s orbital plane and the beta angle of the Sun, it is expected that the average physical temperature of SMAP’s reflector for descending orbits should rise from March to May, further increase over eclipse season (May-August), and then reduce to minimum around October (Fig. 5). The temporal variation of residual  $T_B$  indicated in Fig. 4 is inconsistent with the temperature changes, further suggesting residual calibration errors in the V4 data although the values are small ( $\sim 0.6$  K or less).

Additionally, we found that the V4 calibration led to an increase of  $T_B$  over land surfaces by about 2-3 K from V3, and hence an ad hoc positive adjustment of 2% was introduced to the land surface effective temperature from the Global Modeling and Assimilation Office (GMAO), which



**Figure 6:** SMAPVEX20 campaign sites located at the Harvard Forest in Massachusetts and Millbrook, New York.

was used as ancillary data for retrieval of soil moisture from the V4 brightness temperatures.

To address these issues, we have been performing detailed analyses and sensitivity studies to understand the uncertainty of parameter estimation [5]. The current findings suggest that the parameter calibration depends largely on whether the radiometer reference load temperature ( $T_{RL}$ ) is returned. Should there be no changes to the values of  $T_{RL}$  determined by pre-launch thermal-vacuum calibration tests, then only minor perturbations need to be introduced to the values of other radiometer calibration parameters and the 2% ad hoc adjustment to the land surface effective temperature from GMAO will not be required. In addition, comparative analysis on collocated data from the European Space Agency (ESA) Soil Moisture Ocean Salinity mission indicates reasonable agreement between the brightness temperatures from the two missions. The expected SMAP  $T_B$  biases against SMOS over land surfaces are summarized in Table 2 based on the most recent calibration estimation. The SMAP Version 5 radiometer calibration is planned to be finalized in March 2020.

*Table 2. SMAP-SMOS TB difference over land surfaces for different versions. V4 biases high against SMOS, while V3 biases low. The future version (preliminary V5) is expected to bias low, but closer to SMOS than V3.*

Version	V (K)	H (K)
V3	-2.71	-2.65
V4	0.67	1.64
Preliminary V5	-1.4	-0.8

### 3.2. SMAP Field Campaigns

The objectives of field campaigns are to extend the algorithm performance for regions with higher vegetation

water content ( $>5 \text{ kg/m}^2$ ) and Boreal regions, where organic soil is present.

We have been planning an extensive field program in 2020 (SMAPVEX20), including space (SMAP and Sentinel-1), airborne (JPL Passive Active L-band System), ground-based radiometers and *in situ* soil moisture and vegetation observations. Two campaign sites located at the Harvard Forest in Massachusetts and Millbrook in New York have been selected (Fig. 6). The SMAPVEX20 data will also be used to advance the science investigations relating the soil moisture to vegetation water usage.

The second campaign will be targeting retrievals across Boreal forests (primarily coniferous). One-fifth of the global land biomes are boreal forests but they contain a disproportionate one-third of the land's stored carbon. Water-limitation and drought-enhanced fires release large amounts of this carbon, adding to perturbations of the global carbon cycle. This is a particularly difficult environment for satellite soil moisture retrievals. Due to the lack of validation sites in such forested areas, the SMAP team is planning a field campaign in 2022 (SMAPVEX22) to add quantitative evidence for the SMAP soil moisture and vegetation water content products over these regions. The campaign includes temporarily-installed ground stations with PALS aircraft overflights coincident with SMAP overpasses.

#### 4. SUMMARY

The SMAP mission has been acquiring data for close to five years and will be completing its first extension phase in summer 2020. The accuracy of retrieved volumetric soil moisture has consistently been at or better than  $0.04 \text{ m}^3/\text{m}^3$  for regions with vegetation water content less than  $5 \text{ kg/m}^2$ . Further improvement has been made to the calibration of the radiometer so that the data can have an improved impact on ocean applications, such as sea surface salinity and extreme ocean winds, which require a much higher calibration accuracy. We are also planning field campaigns to improve data products over regions with a higher vegetation water content to further strengthen the use of SMAP data for understanding the interaction of water and vegetation. The second mission extension proposal for an additional 3 years, being evaluated by NASA, will allow SMAP to acquire close to 10 years of data.

#### 5. ACKNOWLEDGEMENT

Part of this work is carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. The technical data, including graphs and tables, presented in this article were generated by SMAP team members.

#### 6. REFERENCES

- [1] D. Entekhabi, E. G. Njoku, P. E. O'Neill, K. H. Kellogg, W. T. Crow, W. N. Edelstein, J. K. Entin, S. D. Goodman, T. J. Jackson, J. Johnson, J. Kimball, J. R. Piepmeier, R. D. Koster, N. Martin, K. C. McDonald, M. Moghaddam, S. Moran, R. Reichle, J. C. Shi, M. W. Spencer, S. W. Thurman, L. Tsang, and J. Van Zyl, The Soil Moisture Active Passive (SMAP) Mission, Proceedings of IEEE, Vol. 98, No. 5, pp. 704-716, May 2010.
- [2] Das, N., S. Dunbar, A. Colliander, M. Chaubell, S. Yueh, D. Entekhabi, T. Jagdhuber, P. E. O'Neill, W. Crow, F. Chen, Algorithm Theoretical Basis Document SMAP-Sentinel L2 Radar/Radiometer (Active/Passive) Soil Moisture Data Products, Release V.3, Jet Propulsion Laboratory Document D-104870, October 2019.
- [3] Chan, S. K., Bindlish, R., O'Neill, P., Jackson, T., Njoku, E., Dunbar, S., Chaubell, J., Piepmeier, J., Yueh, S., and Entekhabi, D., Development and assessment of the SMAP enhanced passive soil moisture product, Remote Sensing of Environment, Volume: 204 Pages: 931-941, Jan 2018.
- [4] J. Chaubell, S. Chan, F. Chen, A. Colliander, S. Dunbar, D. Entekhabi and S. Yueh, "Improved SMAP Dual-Channel Algorithm for the Retrieval of Soil Moisture," IEEE Trans. Geoscience and Remote Sens., accepted for publication, 2019.
- [5] Peng, J., S. Misra, J. Piepmeier, E. Dinnat, S. Yueh, T. Meissner, D. LeVine, K. Shelton, A. Freedman, S. Dunbar, R. Dunbar, S. Chan, R. Bindlish, G. De Amici, P. Mohammed, L. Hong, D. Hudson, and T. Jackson, "Soil Moisture Active/Passive (SMAP) L-Band Microwave Radiometer Post-Launch Calibration Upgrade," IEEE. J. Selected Topics in Applied Earth Observations and Remote Sensing, Vol. 12, No. 6, pp. 1647-1657, June 2019, doi: 10.1109/JSTARS.2019.2902492
- [6] Peng, J., Misra, S., Piepmeier, J.R., Dinnat, E. P., Hudson, D., Le Vine, D. M., De Amici, G., Mohammed, P. N., Bindlish, R., and Yueh, S. H., "Soil Moisture Active/Passive L-Band Microwave Radiometer Postlaunch Calibration," IEEE Trans. Geosci. Remote Sens., Vol. 55, No. 9, pp. 5339-5354, doi: 10.1109/TGRS.2017.2705342, Sept. 2017