The SMAP and Copernicus Sentinel 1A/B Microwave Active-Passive High Resolution Surface Soil Moisture Product and its Applications

Authors: *Narendra N. Das[1], Dara Entekhabi[2], Scott Dunbar[1], Mario Chaubell[1], Thomas Jagdhuber[3], Andreas Colliander[1], Simon Yueh[1], P. E. O'Neill[4],*

[1]Jet Propulsion Laboratory, California Institute of Technology
[2]Massachusetts Institute of Technology, Cambridge, MA, USA
[3]German Aerospace Center, Microwaves and Radar Institute, Oberpfaffenhofen, Germany
[4]Goddard Space Flight Center, NASA, Greenbelt, MD, USA

ABSTRACT

SMAP project released a new enhanced high-resolution (3km and 1 km) soil moisture active-passive product. This product is obtained by combining the SMAP radiometer data and the Sentinel-1A and -1B Synthetic Aperture Radar (SAR) data. The approach used for this product draws heavily from the heritage SMAP active-passive algorithm. Modifications in the SMAP active-passive algorithm are done to accommodate the Copernicus Program's Sentinel-1A and -1B multi-angular C-band SAR data. Assessment of the SMAP and Sentinel active-passive algorithm has been conducted and results show feasibility of estimating surface soil moisture at high-resolution in regions with low vegetation density (~< 3 kg m^{-2}). A new version of this product is released to public in May 2018. This high resolution (3 km and 1 km) soil moisture product with reasonable accuracy of 0.05 m^3/m^3 is useful for agriculture, flood mapping, watershed/rangeland management, and ecological/hydrological applications.

Index Terms— soil moisture, microwave remote sensing, active-passive algorithm, SMAP, and Sentinel-1A and -1B

1. INTRODUCTION

The SMAP active-passive soil moisture product (L2SMAP) [1] was discontinued on July 7th, 2015 due to malfunction in the SMAP radar. The active-passive algorithm developed for the SMAP mission is also capable to work with different combinations of coarse resolution passive microwave (L-/C-band radiometer) and high resolution active microwave (L-/C-band SAR) observations, provided they meet certain criteria. This feature of the microwave active-passive algorithm enables us to work on an Enhanced SMAP-Sentinel high resolution soil moisture product. The importance of such high-resolution (3 km) soil moisture product is in many geophysical applications.

2. THE SMAP-SENTINEL HIGH RESOLUTION SOIL MOISTURE PRODUCT

The heritage SMAP single-look angle L-band active-passive algorithm [1] is modified to accommodate the Sentinel multi-angular and higher frequency C-band SAR data. The most important change is in the method to compute two algorithm parameters. In the heritage SMAP active-passive algorithm, a seasonal time series regression was done between the SMAP brightness temperature and the SMAP SAR co-pol observations for computing the algorithm parameter. It is not possible to create such seasonal time series between the SMAP radiometer-based brightness temperature and the temporally sparse Sentinel SAR co-pol observations because the revisit interval of the Sentinel overpass is very coarse (6 to12 days). Also the Sentinel data have variable look angles. Therefore, we used a snapshot approach [2] to compute the algorithm parameter. This approach does not need a time series and can provide the algorithm parameter whenever there is an overlap (within 24 hours) of the SMAP radiometer brightness temperature and the Sentinel SAR data. The parameters incorporate the effects of changes in look-angle as well.

The SMAP-Sentinel active-passive algorithm used in the high resolution product is shown in Eq. 1:

$$T_{B_p}(M_j) = \left[\frac{T_{B_p}(C)}{Ts} + \beta'(C)\cdot\{[\sigma_{pp}(M_j) - \sigma_{pp}(C)] + \Gamma\cdot[\sigma_{pq}(C) - \sigma_{pq}(M_j)]\}\right]\cdot Ts \quad (1)$$

where, Ts [K] is the effective surface temperature of the top ~5 cm of the soil profile. The parameter Γ [-] is estimated the same way as in the heritage SMAP active-passive algorithm, however, in a linear scale. The snapshot $\beta'(C)$ is shown in Eq. 2:

$$\beta'(C) = \frac{\frac{T_{B_p}(C)}{Ts} - (\gamma + (1-\omega)\,(1-\gamma))}{|S_{pp}(M_j)|^2 - \mu_{pp-pq}\cdot|S_{pq}(M_j)|^2} \quad (2)$$

where, ω [-] is the effective single scattering albedo, $\gamma = e^{-\tau/\cos\theta}$ [-] is the vegetation loss term, and θ_i [rad] is the incidence angle. The nadir vegetation opacity τ [-] is related to the physical characteristics of the vegetation layer, such as the vegetation water content (VWC). $|S_{pp}(M_j)|^2$ is co-polarized backscatter, where $|S_{pp}(M_j)|^2 \equiv \sigma_{pp}(M_j)$, and $|S_{pp}(M_j)|^2$ is cross-polarized backscatter, where $|S_{pq}(M_j)|^2 \equiv \sigma_{pq}(M_j)$. μ_{pp-pq} is the same as Γ of (1), except using a linear regression of backscattering coefficients ($\sigma_{pp}(M_j)$ [-], $\sigma_{pq}(M_j)$ [-]) at fine scale (3 km) within each coarse-resolution TB grid cell ($T_{B_p}(C)$). The parameters $\beta'(C)$ and μ_{pp-pq} depend on the look-angles of the radiometer and the SAR respectively through the brightness temperature and SAR data used to estimate them. Detailed derivation of (2) is elaborated in [2]. In a nutshell, $\beta'(C)$ is formed by eliminating surface reflectivity between emission and backscatter equations. This physically-based Equation (2) to retrieve $\beta'(C)$ also accounts for the effects of vegetation/roughness on emission as well as on backscatter. This approach to derive physically-based $\beta'(C)$ does not require any time series of $T_{B_p}(C)$ and $\sigma_{pp}(C)$. For evaluation of $\beta'(C)$ retrieved in snapshot approach, a comparison was made with $\beta(C)$ derived from the time series purely obtained from data of the SMAP mission. Both approaches converge with the $\beta'(C)$ values almost similar to $\beta(C)$ except over locations were the time series do not have significant correlations, i.e., the dynamic range of $T_{B_p}(C)$ and $\sigma_{pp}(C)$ is not observed, especially over very arid regions.

We used more than 3 years (May, 2015 to Oct, 2018) of the SMAP L-band radiometer data and the Sentinel-1A/1B C-band SAR data to produce the SMAP-Sentinel combined soil moisture product at 3 km spatial resolution [3]. The global coverage using SMAP and Sentinel-1A and -1B data from active and passive algorithm is shown in Fig. 1. However, it is expected that the global coverage and the revisit interval will further improve with more acquisitions from Sentinel 1B as convey by the European Space Agency.

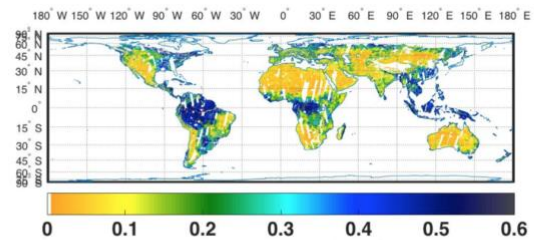

Figure 1: Soil moisture retrievals at 3 km spatial resolution from the SMAP and Sentinel-1A and -1B data between 1th May 2017 and 12th May 2017.

The SMAP-Sentinel combined product cannot match the spatial coverage and revisit interval of the SMAP-only combined product, however, the spatial resolution obtained from the SMAP-Sentinel combined product is higher. Figure 2 shows the comparison of SMAP radiometer-only product (L2SMP_E) and SMAP-Sentinel combination (L2SMSP).

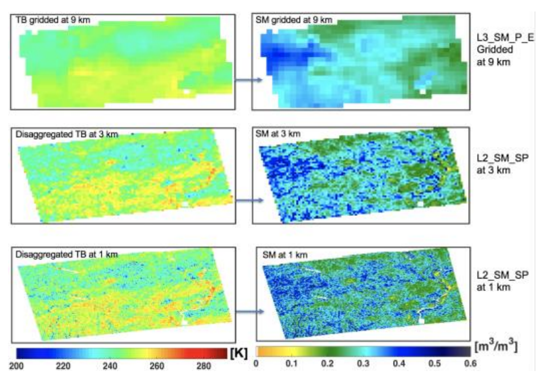

Figure 2: Example of an L2SMSP granule from Southern for date 5th May, 2018, showing enhancement of spatial details of soil moisture retrievals through application of the L2SMSP algorithm.

The L2SMSP shows more detailed features with higher dynamic range than L2SMP_E that has more spatial averaging. The regional trends in the two fields are similar.

The advantage of the SMAP-Sentinel based product is high spatial resolution because unlike the SMAP SAR (~3 km) the Sentinel SAR observations have very high resolution of (~50 meters). For the SMAP-Sentinel combined product, the Sentinel-1A and -1B SAR observations are preprocessed at JPL and aggregated to 1 km resolution that helps to reduce the speckle. It is planned to provide the SMAP-Sentinel product at two different resolutions (3 km and 1 km). Beta assessment of the L2SMSP product shows less variability than the SMAP-only combined product. This is expected because of the higher sensitivity of microwave C-band for the vegetation and roughness as compared to the microwave L-band SAR observations.

3. ASSESSMENT OF THE SMAP-SENTINEL HIGH RESOLUTION SOIL MOISTURE DATA

The assessment and validation of the L2SMSP data is done using two different approaches: a) comparing the disaggregated brightness temperature from (1) against the high resolution brightness temperature acquired during airborne experiments; and b) comparison of the L2SMSP retrieved soil moisture against the in situ soil moisture observations from the core cal/val sites (CVS).

The validation assessment of the L2SMSP product shows significant contributions of the Sentinel 1 SAR data in capturing the finer spatial details that is otherwise not visible in the coarse resolution L2SMP_E product. In the second assessment, the L2SMSP high resolution (3 km) data when compared against the CVS sites shows an unbiased root mean square error (RMSE) of ~0.05 m^3/m^3 of soil moisture. The CVS sites at 3 km resolution is limited in number, therefore, we used the CVS sites at 9 km resolution. The coinciding nine 3 km retrievals are averaged to obtain 9 km soil moisture from the L2SMSP data and then evaluated against the 9 km CVS sites. The statistics shows an unbiased RMSE of 0.036 m^3/m^3. of soil moisture, that meets the L1 accuracy standards set for the SMAP mission.

4. DISCUSSION

The latest release of the L2SMSP product was done in May, 2018 [3]. The data is hosted in the NASA DAAC at the National Snow and Ice Data Center (NSIDC). Future release of the L2SMSP data is expected in the end of 2019 timeframe, and some improvement is expected in the L2SMSP data due to following steps: i)We plan to include more recent and current ancillary information and updated tau-omega parameters for different landcovers. This will improve the quality and accuracy of the high resolution soil moisture retrievals in the L2SMSP products; ii) We also plan to conduct more rigorous analysis of the L2SMSP algorithm parameters to understand further its behavior and evolution over variety of geophysical surface conditions and how this understanding can help to improve the accuracy of the parameters in the L2SMSP disaggregation algorithm (2); and iii) With the improved acquisition strategy of the Sentinel 1A and 1B at Interferometric Wide (IW) swath mode in ascending and descending orbits, the global coverage of the Sentinel 1 data is also expected to improve to nearly ~6 days revisit over the select regions of the world.

In the current form, the latest released L2SMSP product shows promise. The high resolution (3 km) features of soil moisture data from the SMAP-Sentinel combined product has capability to improve the performance of many geophysical applications, especially in agriculture and flooding.

5. REFERENCES

[1] Das, N. N., D. Entekhabi, E. Njoku, J. Shi, J. Johnson, and A. Colliander, Tests of the SMAP combined radar and radiometer algorithm using airborne field campaign observations and simulated data, IEEE Transactions on Geoscience and Remote Sensing, vol. 52, pp. 2018–2028, 2014

[2] T. Jagdhuber, D. Entekhabi, N.N. Das, M. Link, C. Montzka, S. Kim, and S. Yueh, “Microwave Covariation Modelling and Retrieval for the Dual-Frequency Active-Passive Combination of Sentinel-1 and SMAP,” Proc. of IGARSS 2017, July 23-28, Fort Worth, 2017.

[3] N. N. Das, D. Entekhabi, S. Kim, S. Yueh, R.S. Dunbar, and A. Colliander, “SMAP/Sentinel-1 L2 Radiometer/Radar 30-Second Scene 3 km EASE-Grid Soil Moisture,” Version 1. Boulder, Colorado USA. *NASA National Snow and Ice Data Center Distributed Active Archive Center*. doi: http://dx.doi.org/10.5067/ 9UWR1WTHW1WN, 2017.

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