SOIL MOISTURE DATA PRODUCT GENERATED FROM NASA SMAP OBSERVATIONS WITH NOAA ANCILLARY DATA

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ABSTRACT

NASA Soil Moisture Active/Passive (SMAP) satellite was launched on January 31st, 2015 and has been providing level-1B radiometer brightness temperature (L1B-TB) data with an official latency of 12 hours since April 2015. The primary application users of the SMAP radiometer observations include numerical weather prediction operations that require shorter data latency (e.g. less than 6 hours). With slightly simplified algorithms of the L1B-TB data, NASA SMAP project is also providing near real time (NRT) L1B-TB data to NOAA operational users with a latency ranging from 2-6 hours. With this latency NOAA NWP models could use most of those SMAP half-orbit data that arrives within the 6 hour cut-off time limit. Before a radiance data assimilation capability for NOAA NWP models is developed, NOAA NESDIS is retrieving soil moisture from the NRT L1B-TB data through its Soil Moisture Product System (SMOPS) and makes surface soil moisture directly available for assimilation into the NWP models with the shortest possible turn-around time. Unlike using NASA GEOS model surface and soil temperature and multi-year average vegetation index data, SMOPS soil moisture retrieval algorithm uses the surface temperature data from operational Global Forecast System (GFS) and the vegetation index (NDVI) data from the near real time Suomi-NPP VIIRS observations. This paper introduce the structure of SMOPS, the soil moisture retrieval algorithm for SMAP data, and validation of the soil moisture data products against in the situ soil moisture measurements collected from the Soil Climate Analysis Networks of US Department of Agriculture and the Tibetan Soil Moisture Networks of Chinese Academy of Sciences. The soil moisture data retrieved from SMAP NRT TB data through SMOPS are also evaluated against the NASA official SMAP Level 2/3 soil moisture products. Preliminary validation results indicate that the SMAP soil moisture product from the SMAP NRT TB data and NESDIS SMOPS has similar quality to the NASA official products, but has shorter latency which may be critical to NOAA NWP operations.

Index Terms— satellite soil moisture, SMAP, SMOPS

1. INTRODUCTION

Soil moisture is one of the critical land surface state variables that control the exchanges of water, energy and trace gases between land surface and the atmosphere. It is required for the initialization of numerical weather, climate, hydrological and ecological prediction models because of its impact on the accuracy of these predictions [1, 2]. To obtain the best global soil moisture observational data, NASA launched the Soil Moisture Active/Passive (SMAP) satellite mission on January 31st, 2015 and high quality L-band radiometer observations and soil moisture retrievals have become available since April 2015 [3]. However, most of these products may not meet the latency requirement for NOAA numerical weather and flash flood forecast operations. The primary application users of the SMAP radiometer observations include numerical weather prediction operations that require shorter data latency (e.g. less than 6 hours). With slightly simplified algorithms of the L1B-TB data, NASA SMAP project is also providing near real time (NRT) L1B-TB data to NOAA operational users with a latency ranging from 2-6 hours. With this latency NOAA NWP models could use most of those SMAP half-orbit data that arrives within the 6 hour cut-off time limit. Before a radiance data assimilation capability for NOAA NWP models is developed, NOAA NESDIS is retrieving soil moisture from the NRT L1B-TB data through its Soil Moisture Product System (SMOPS) and makes surface soil moisture directly available for assimilation into the NWP models with the shortest possible turn-around time. In the following sections, the SMOPS and the soil moisture retrieval algorithm are briefly introduced. Then the retrieval and validation results are presented.

2. NESDIS SOIL MOISTURE PRODUCT SYSTEM

There are several satellite missions/sensors that have land surface soil moisture sensing capabilities, such as the ASCAT on the operational MetOp-A and B satellites of EUMETSAT, the SMOS of ESA, WindSat of NRL, AMSR2 of JAXA, GMI on NASA GPM, and NASA SMAP. In order to seamlessly and conveniently provide the soil moisture observations from these satellites to NOAA operational numerical weather prediction and other users, NOAA NESDIS has developed the Soil Moisture Operational Product System (SMOPS). Figure 1 shows the main data flows of SMOPS. It basically has four data processing streams: 1) ingest and convert soil moisture data files from product provider to SMOPS internal common format if they are available in order for them to be used in SMOPS output; 2) retrieve soil moisture from brightness temperature data files if soil moisture retrievals are not available or do not meet latency requirement; 3) blend and output all available soil moisture retrieval files into either 6 hours or daily product files for users within the 6 hour or the current day time period; 4) blend and output the daily product files for archive data users two days after the current date.

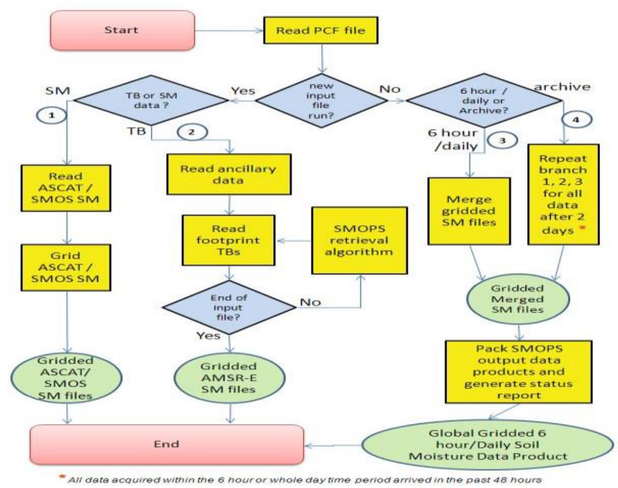

Figure 1. Data Flow Chart of the NESDIS Soil Moisture Operational Product System (SMOPS)

For retrieving soil moisture from SMAP NRT L1B-TB data, the second data processing stream will be used and retrieval algorithm is introduced as follows.

3. SOIL MOISTRUE RETRIEVAL ALGORITHM

Based on the following commonly called tau-omega microwave emission model [4], several types of algorithms have been developed to retrieve soil moisture from microwave radiometer observations [5].

$$T_{Bp} = T_s\, e_{r,p} \exp(-\tau_p/\cos\theta) + T_c\,(1-\omega_p)\,[1-\exp(-\tau_p/\cos\theta)]\,[1+R_{r,p}\exp(-\tau_p/\cos\theta)]. \quad (1)$$

The subscript p refers to polarization (v or h) and subscript r stands for rough surface, T_s is the soil effective temperature, T_c is the vegetation temperature, τ_p is the nadir vegetation opacity, ω_p is the vegetation single scattering albedo, and $R_{r,p}$ is the soil reflectivity. The rough surface soil reflectivity is related to the soil emissivity by $e_{r,p} = (1 - R_{r,p})$, and ω_p, $R_{r,p}$ and $e_{r,p}$ are values at the radiometer incident angle of θ=40°. $R_{r,p}$ is related to smooth surface soil reflectivity R_s through the soil roughness parameter h so that $R_s = R_r \exp(h \cos^2\theta)$ without notification for polarization. Vegetation opacity τ_p was computed from vegetation water content (VWC or W) by multiplying it with an empirical parameter b, that is, $\tau_p = bW$ while W is usually computed from a vegetation index (e.g. the normalized difference vegetation index-NDVI). Among the most widely used algorithm, the soil moisture single channel algorithm (SCA) [6] assumes $T_c = T_s$, and uses the H-pol T_B observations, along with ancillary data, to determine T_s and W. Since the impact of ω_p on brightness T_B is small compared with that of W, the SCA algorithm in [6] assumes $\omega_p = 0$. Consequently, Eq. (1) can be simplified as (now without polarization indication)

$$T_B = T_S[1 - R_r \exp(\frac{-2bW}{\cos\theta})] \quad (2)$$

When h is known, the value of R_s and subsequently the real part of the soil dielectric constant can be obtained by inverting (2) from T_B. Surface soil moisture can then be retrieved using a soil dielectric mixing model such as [7].

4. ANCILLARY DATA SETS

To invert Eq. (2) for soil moisture the following ancillary data have to be accurately provided: 1) NDVI for estimating W; 2) surface type for the parameters used to estimate W from NDVI; 3) Surface temperature T_s in Eq. (2); 4) soil texture data required in the soil dielectric mixing model.

Different from the SCA used in NASA SMAP official soil moisture product, we are using the near real time NDVI from the visible infrared imaging radiometer suite (VIIRS) of Suomi National Polar-orbiting Partnership (S-NPP) satellite, instead of the multi-year average of NDVI from MODIS observations used in the NASA SMAP SCA [3]. NRT NDVI is expected to better reflect the vegetation situation when the SMAP T_B is acquired. To account for the linearity of NDVI impact on microwave emission from different scale land surface, the approach in [8] is used to aggregate VIIRS 1km scale NDVI to SMOPS 25km.

The parameters used to estimate W from NDVI is similar to NASA SMAP SCA algorithm, including the global surface type map derived from NASA MODIS data.

Surface temperature data are extracted from output of NOAA NCEP Global Forecast System (GFS) which is the operational numerical weather prediction model for almost all US and global weather forecasts by NOAA. The Ts data corresponding to the exact local time of SMAP overpass or when SMAP T_B is acquired have to be interpolated from GFS output at several different times.

The static soil texture maps from Food and Agriculture Organization of United Nations used in this study are the same as used in SMOPS described in SMOPS ATBD [9].

Figure 2 shows the example of the SMAP TB, NDVI, and Ts data for June 6th of 2015.

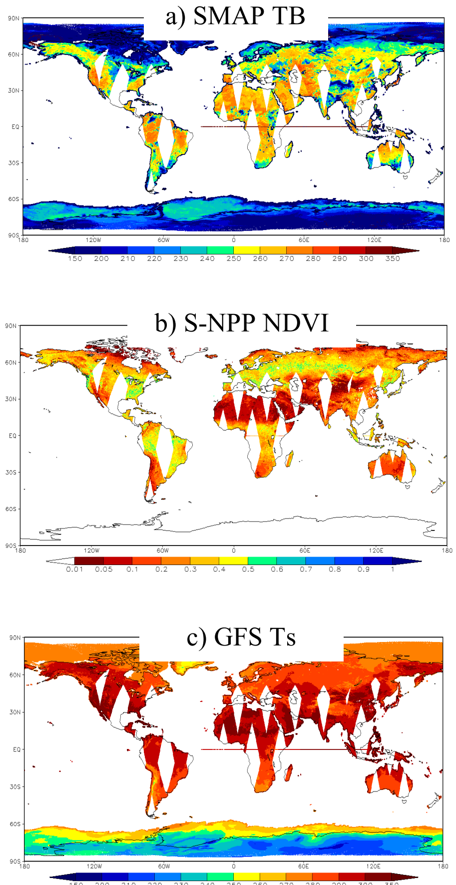

Figure 2. Data for retrieving soil moisture from SMAP TB observations using the Single Channel Algorithm: a) SMAP T_B; b) S-NPP NDVI; c) NCEP GFS T_s.

5. RETRIEVAL RESULTS

Using the currently implemented computer code of SMOPS and the above stated data sets, global soil moisture for each day can be retrieved. Figure 3 is an example for June 26th, 2015. Although this is a very preliminary result of directly using the SMOPS, the global pattern of the retrieved soil moisture map looks reasonable. We'll further adjust the parameters of the retrieval algorithm within SMOPS for SMAP and present more complete results in the full paper and the presentation to IGARSS.

6. VALIDATION OF THE RETRIEVALS

The soil moisture retrievals from SMAP NRT L1B-TB observations since April 2015 will be evaluated against soil moisture in situ measurements from the USDA Soil Climate Analysis Networks (SCAN) and three Tibetan Soil Moisture Networks of Chinese Academy of Sciences. The retrievals are currently evaluated with NASA SMAP L2/3 products.

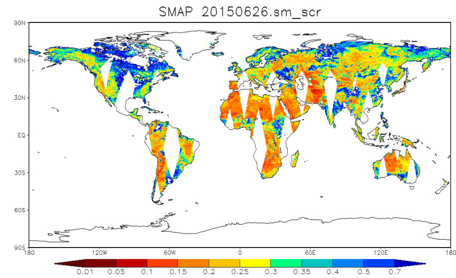

Figure 3. Global soil moisture retrieved from NASA SMAP near real time L1B TB observations using NOAA ancillary data sets.

7. SUMMARY AND CONCLUSIONS

To promptly provide soil moisture observations from NASA SMAP satellite radiometer observations, NOAA NESDIS is implementing the single channel algorithm to retrieve soil moisture from SMAP NRT L1B-TB data using NOAA near real time ancillary data. The SMAP NRT L1B-TB data has a latency of 1-5 hours shorter than the official SMAP L1B-TB data. The retrieval process through NOAA SMOPS using NOAA ancillary data for the retrieval algorithm has a turn-around time of less than 30 minutes, which may result in that most SMAP half-orbit data files could be used by NOAA NCEP numerical weather prediction operations. Preliminary test of the SMOPS for SMAP data processing is producing reasonable results. Further tuning and evaluation are going on currently. Comprehensive retrieval and validation results will be presented.

8. ACKNOWLEDGMENT

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9. REFERENCES

[1] F. Chen, T. Warner, and K. Manning, 2001: Sensitivity of Orographic Moist Convection to Landscape Variability: A Study of the Buffalo Creek, Colorado, Flash Flood Case of 1996. *J. Atmos. Sci*., 58, 3204–3223.

[2] R. D. Koster and 22 others. 2010. Contribution of land surface initialization to subseasonal forecast skill: First results from a multi-model experiment. *GEOPHYSICAL RESEARCH LETTERS*, VOL. 37, L02402, doi:10.1029/2009GL041677, 2010.

[3] S. Chan and 33 others. 2016. Assessment of the SMAP Level 2 Passive Soil Moisture Product. *IEEE Transactions on Geoscience and Remote Sensing*. In Review.

[4] T. Mo, B.J. Choudhury, T.J. Schmugge and J.R. Wang. “A model for microwave emission from vegetation covered fields”, J. Geophys. Res. Vol 87(C13), pp. 11,229-11237. December 20, 1982.

[5] P. O’Neill, M. Owe, B. Gouweleeuw, E. Njoku, JC Shi, and E. Wood, “Hydros soil moisture retrieval algorithms: status and relevance to future missions”, *Proceedings of IEEE Geoscience and Remote Sensing Symposium 2006*, Denver, Colorado, Vol. I, pp. 436-439, July 2006.

[6] T.J. Jackson, “Measuring surface soil moisture using passive microwave remote sensing,” *Hydrol. Process,* vol. 7, pp.139-152, 1993.

[7] M.C. Dobson. F. T. Ulaby, M. T. Hallikainen, and M. A. El-Rayes, “Microwave dielectric behaviour of wet soil-Part II: Dielectric mixing models,” *IEEE Trans. Geosci. Remote Sensing*, vol. GE-23, no. 1, pp. 35-46, Jan. 1985.

[8] X. Zhan, W.T. Crow, T.J. Jackson and P.E. O’Neill, “Improving Spaceborne Radiometer Soil Moisture Retrievals With Alternative Aggregation Rules for Ancillary Parameters in Highly Heterogeneous Vegetated Areas,” IEEE Geosci. Remote Sens. Lett., vol. 5, no. 2, pp. 261-265. April 2008.

[9] X. Zhan, J. Liu, L. Zhao and K. Jensen. 2013. Soil Moisture Operational Product System (SMOPS) Algorithm Theoretical Basis Document (ATBD). NOAA NESDIS Center for Satellite Applications and Research. College Park, MD. Pp. 60. August 8, 2011.