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NASA SOIL MOISTURE ACTIVE PASSIVE MISSION STATUS AND SCIENCE HIGHLIGHTS

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ABSTRACT

The Soil Moisture Active Passive (SMAP) observatory was launched January 31, 2015, and its L-band radiometer and radar instruments became operational during April 2015. This paper provides a summary of the quality assessment of its baseline soil moisture and freeze/thaw products as well as an overview of new products. The first new product explores the Backus Gilbert optimum interpolation based on the oversampling characteristics of the SMAP radiometer. The second one investigates the disaggregation of the SMAP radiometer data using the European Space Agency's Sentinel-1 C-band synthetic aperture radar (SAR) data to obtain soil moisture products at about 1 to 3 km resolution. In addition, SMAP's L-band data have been found useful for many scientific applications, including depictions of water cycles, vegetation opacity, ocean surface salinity and hurricane ocean surface wind mapping. Highlights of these new applications will be provided.

Index Terms— Soil moisture, radiometer, radar, microwave remote sensing

1. INTRODUCTION

Soil moisture is a primary state variable of hydrology and the land portion of the water cycle. In diverse Earth and environmental science disciplines, this state variable is either an initial condition or a boundary condition of relevant hydrologic models. Applications such as weather forecasting, and modeling and forecasting of climate variability and change, agricultural productivity, water resources management, drought prediction, flood area mapping, and ecosystem health monitoring all require information on the status of soil moisture. The outcomes from these applications all have direct impacts on the global environment and human society. Measuring surface soil moisture with the required accuracy and resolution (spatial and temporal) is imperative to fulfill the needs of these and other applications.

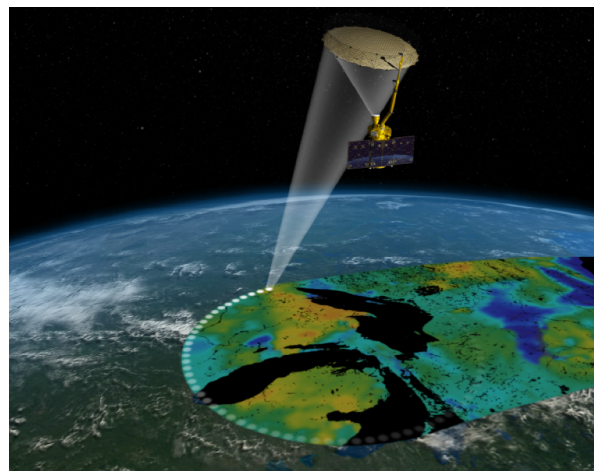

Figure 1. SMAP's conical scanning instrument produces a swath width of 1000 km to enable global coverage in 3 days.

The NASA Soil Moisture Active Passive (SMAP) Mission was recommended as the one of the tier 1 missions in the National Research Council's (NRC) Decadal Survey Report, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond [1]*. The key science requirements of the SMAP mission are to provide accurate soil moisture and freeze/thaw classification for hydrology and carbon cycle studies.

SMAP mission design uses an L-band radar and an L-band radiometer for concurrent, coincident measurements integrated as a single observation system [2]. The radiometer and radar share one common antenna reflector, which is a 6-m mesh deployable antenna. The antenna design is based on the offset parabola reflector design with one antenna feed to produce the antenna beam pointing at an incidence angle of about 40 degrees on the earth surface (Fig. 1). The mesh antenna together with the feed is positioned on a spinning assembly with a conical scanning rate of about 14 rotations per minute. The resulting swath width is about 1000 km, which allows global coverage every 3 days.

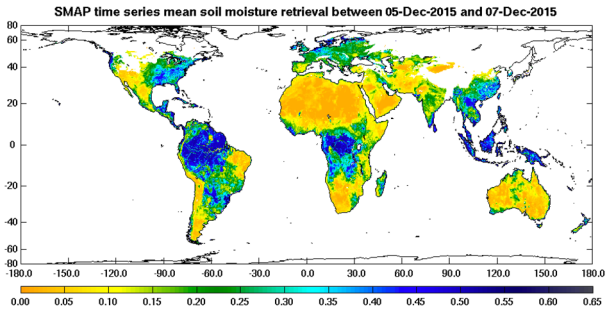

Figure 2. A three-day composite of the soil moisture derived from the vertically polarized brightness temperatures acquired by the SMAP radiometer and the frozen ground (white) during Dec 5-7, 2015.

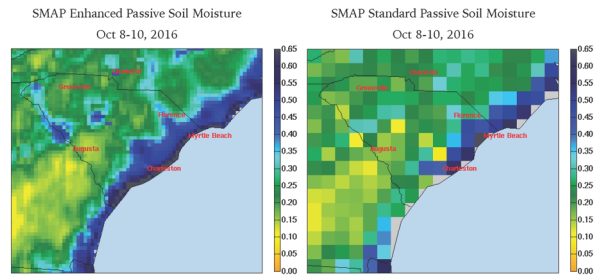

Figure 3. SMAP enhanced (left) and standard (right) radiometer soil moistures during Oct 8-10, 2015. After radiometer enhancement processing the SMAP enhanced passive soil moisture is able to reveal finer spatial details of the variability of surface soil moisture. Much of the coastal region in South Carolina exhibited surface soil moisture in excess of 0.40 m^3/m^3.

The SMAP radiometer resolution is ~40 km, while the SMAP L-band SAR provided backscatter measurements at higher resolution (~ 1 to 3 km). The accuracy of the radar was limited for soil moisture sensing, however, by the higher sensitivity of radar to surface roughness and vegetation scattering. The SMAP project has been collaborating with the European Union's Sentinel-1 project to use the Sentinel-1 C-band radar data as a replacement of the SMAP radar data.

2. ASSESSMENT OF SCIENCE PERFORMANCE

The SMAP instruments have been calibrated using the data from other satellites and external targets. The calibration of SMAP radiometer's noise diode was achieved using the ocean targets and cold sky. Cross-comparison with the European Space Agency's Soil Moisture and Ocean Salinity (SMOS) radiometer data over land and ocean surfaces indicates an excellent agreement of about 1 K. The radiometric calibration of the radar was performed using the data from the Japanese Phased Array type Synthetic Aperture Radar (PALSAR). Independent assessment was performed by comparison with the Aquarius radar model function for ocean surfaces and indicated an agreement of about 0.5 dB for all polarizations. The calibrated Level 1 radar data have been released through the Alaska Satellite Facility (ASF) and the radiometer data through the National Snow and Ice Data Center (NSIDC).

The excellent calibration of radiometer and radar data has allowed the production and early release of L2/3/4 soil moisture and L3 freeze/thaw validated products through NSIDC. Figure 2 provides a global image of the soil moisture derived from the radiometer data on a 36 km grid. The data depict dry soil moisture surfaces in the western United States, Sahara, Middle East and central Australia. Wetter soil due to precipitation is evident in the Southern United States, the pampas regions in South America, Congo River basin and South East Asia.

The freeze/thaw products were also generated using the radiometer data at a spatial resolution of 36 km. The algorithm is based on the threshold of the data normalized by the minimum level of radiometer polarization ratios in winter and maximum in summer. Figure 2 illustrates the areas classified as frozen ground by white during Dec 5-7, 2015. The locations of frozen ground are clearly within the expectation.

3. NEW SCIENCE PRODUCTS

One of SMAP's key science requirements is to produce soil moisture products at a spatial resolution of better than 10 km for hydrometeorology applications. This was to be achieved by using the high-resolution radar data to disaggregate brightness temperatures on 9 km resolution grids. Unfortunately, the SMAP radar transmitter ceased operation on July 7, 2015. Since then the SMAP project has been conducting two tasks to produce new soil moisture products based on radiometer data. One of the tasks takes advantage of the oversampling characteristics of the SMAP radiometer data along scan and along track based on the Backus Gilbert (BG) optimum interpolation algorithm [3]. The other task will match up the SMAP radiometer data and Sentinel-1's C-band SAR data, and will then apply the SMAP Active-Passive (AP) algorithm to produce the higher resolution soil moisture products. These two tasks will produce complementary products; the BG will lead to a global product on a sampling grid resolution of 9 km, while the SMAP/Sentinel-1 AP algorithm will produce soil moisture with resolution as high as 1 km, but only for regions where the Sentinel-1 data are available and the vegetation biomass is low enough.

Figure 3 provides an illustration of the soil moisture derived from the brightness temperature optimally

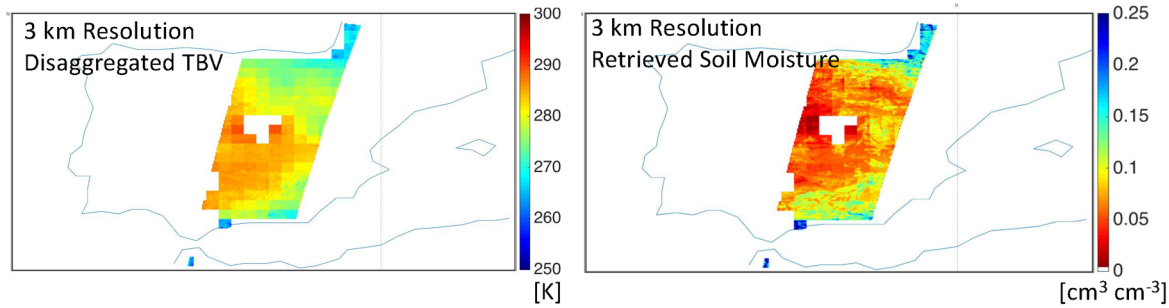

Figure 4. Disaggregated SMAP radiometer data using the Sentinel-1 radar data and resulting soil moisture at a spatial resolution of 3 km over Spain on August 19,2015.

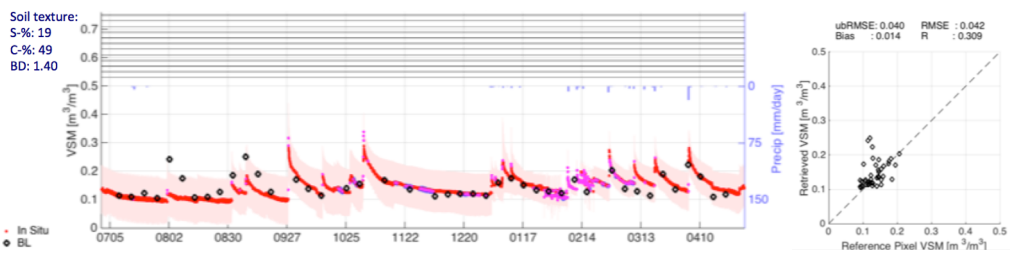

Figure 5. Left panel provides a time series comparison of high resolution (3 km) soil moisture derived from combined SMAP radiometer and Sentinel-1 radar data over the SMAP cal/val site in Valencia, Spain. The scatter of SMAP/Sentinel-1 soil moisture against in situ is provided in the right panel.

interpolated using BG interpolation algorithm. The interpolation was carried out on the Equal-Area Scalable-2 Earth Grid (EASE-2) at 9 km resolution. The soil moisture image derived from the BG data provides more detailed features than the standard soil moisture product (Fig. 3).

The AP soil moisture algorithm for combined SMAP radiometer/Sentinel-1 radar data is being implemented for operational processing. The Sentinel-1 SAR data was used to disaggregate the SMAP radiometer data obtained from the BG algorithm. Fig. 4 illustrates the disaggregated brightness temperature and soil moisture at a spatial resolution of 3 km for the SMAP Cal/Val site in Valencia, Spain. About 50 revs of collocated SMAP radiometer and Sentinel-1 radar data acquired from July 2015 to April 2016 were used to retrieve the soil moisture at a spatial resolution of 3 km. Time series comparison of the SMAP/Sentinel-1 soil moisture with in situ data over the Valencia Cal/Val site was reasonable with a Root Mean Square Difference (RMSD) of about 4% (Fig. 5)

5. SCIENCE APPLICATIONS

In spite of the loss of SMAP radar in July, the SMAP radiometer has been performing very well. The radiometer soil moisture products have been used to monitor the severe flooding caused by heavy rainfall in Texas in May-June and in South Carolina in early October 2015 due to hurricane Matthew (Fig. 3).

The calibrated radiometer data have also generated several new science products, including the vegetation opacity (Fig. 6). The SMAP vegetation opacity agreed qualitatively well with the land cover map and independent LIDAR vegetation height measurement. The change of vegetation opacity has a good correlation with the crop growth and harvest periods in South Fork, Iowa.

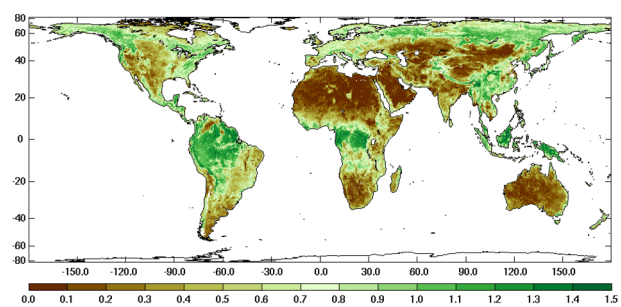

Figure 6. Vegetation opacity derived from the SMAP dual-polarized brightness temperature during Aug 23-25, 2016 is related to the water content in the vegetation and can be used to track the vegetation growth and crop harvests.

The SMAP radiometer has been operating over ocean surfaces as well. The ocean data have been used to retrieve the sea surface salinity (SSS) (Fig. 7) [4] and extreme ocean surface wind speed during hurricanes [5].

The SMAP soil moisture, freeze/taw state and SSS provide a synergistic view of water cycle. For example, Fig. 7 illustrates the transition of freeze/thaw state, change of soil moisture near the pole and SSS in the Arctic Ocean from April to October in 2015 and 2016. In April, most parts of Alaska, Canada, and Siberia remained frozen. Melt onset started in May. Alaska, Canada, and a big part of Siberia have become thawed at the end of May; some freshwater discharge could be found near the mouth of Mackenzie in 2016, but not in 2015. The soil moisture appeared to be higher in the Ob and Yenisei river basins in Siberia in 2015. As a result, freshwater discharge was more widespread in the Kara Sea near the mouths of both rivers in June 2015 than in 2016. The North America and Siberia have become completely thawed in July. After June, the freshwater discharge from other rivers into the Arctic, indicated by blue, also became visible. The freeze-up started in September and the high latitude regions in North America and Eurasia became frozen. Comparing the spread of freshwater in August 2015 and 2016 suggests that there was more discharge from Ob and Yenisei in 2015, which appeared to correspond to a higher soil moisture content in the Ob and Yenisei basins. In contrast, Mackenzie appeared to have more discharge in September 2016.

6. ACKNOWLEDGEMENT

The work described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration. The authors would like to acknowledge the contributions by the SMAP team members on the Cal/Val effort and the figures presented in the article.

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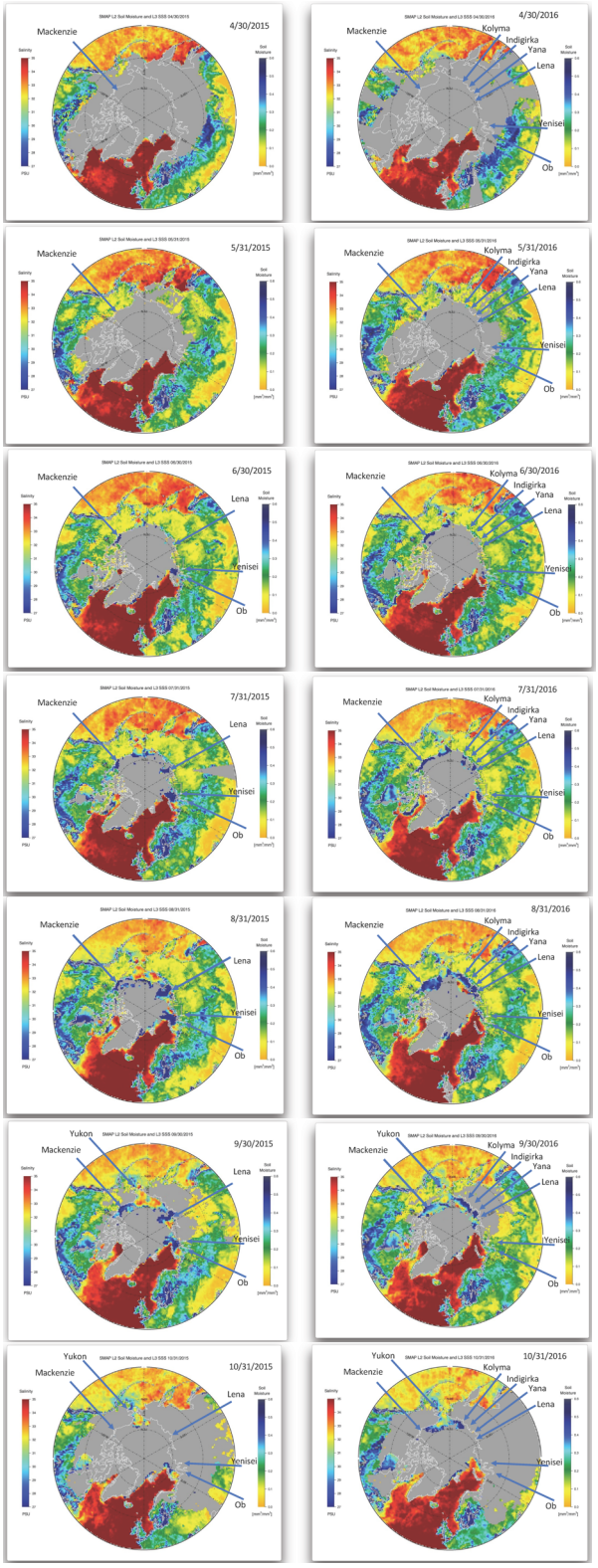

Figure 7. SMAP freeze/thaw state, soil moisture, and sea surface salinity from May to October in 2015 (left column) and 2016 (right column).