The Soil Moisture Active and Passive Mission (SMAP): Science and Applications

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***Abstract*—The Soil Moisture Active and Passive mission (SMAP) will provide global maps of soil moisture content and surface freeze/thaw state. Global measurements of these variables are critical for terrestrial water and carbon cycle applications. The SMAP observatory consists of two multipolarization L-band sensors, a radar and radiometer, that share a deployable-mesh reflector antenna. The combined observations from the two sensors will allow accurate estimation of soil moisture at hydrometeorological (10 km) and hydroclimatological (40 km) spatial scales. The rotating antenna configuration provides conical scans of the Earth surface at a constant look angle. The wide-swath (1000 km) measurements will allow global mapping of soil moisture and its freeze/thaw state with 2-3 days revisit. Freeze/thaw in boreal latitudes will be mapped using the radar at 3 km resolution with 1-2 days revisit. The synergy of active and passive observations enables measurements of soil moisture and freeze/thaw state with unprecedented resolution, sensitivity, area coverage and revisit.**

I. INTRODUCTION

The Soil Moisture Active and Passive (SMAP) mission is one of the first two missions initiated by NASA in February 2008 in response to recommendations by the U.S. National Research Council Committee on Earth Science and Applications from Space in 2007 [1]. SMAP is scheduled for launch in early 2013. The SMAP observatory is designed to make simultaneous active (radar) and passive (radiometer) measurements in the 1.2-1.4 GHz range (L-band) from a sun-synchronous low-earth orbit. Measurements will be obtained across a 1000-km swath using conical scanning at a constant incidence angle of 40°. The radar resolution varies from 1-3 km over the outer 70% of the swath to about 30 km near the center of the swath. The radiometer resolution is 40 km across the entire swath. The SMAP mission will provide soil moisture data products at hydrometeorology (10 km) and hydroclimatology (40 km) scales with 3-day global revisit using combined information from both the radiometer and the radar measurements. Soil-vegetation freeze/thaw products in boreal latitudes will be provided at 3 km resolution with 1-2 day revisit. SMAP builds on concept development and risk-reduction studies carried out for the earlier Hydros ESSP mission [2]. The SMAP mission is managed for NASA by the Jet Propulsion Laboratory with participation by the Goddard Space Flight Center.

II. SOIL MOISTURE AND FREEZE/THAW APPLICATIONS

SMAP will provide global maps of land surface soil moisture and freeze-thaw state. Global measurements of these variables are critical for terrestrial water and carbon cycle applications. These measurements will enable science and applications users to:

- Understand processes that link the terrestrial water, energy and carbon cycles
- Estimate global water and energy fluxes at the land surface
- Quantify net carbon flux in boreal landscapes
- Enhance weather and climate forecast skill
- Develop improved flood prediction and drought monitoring capabilities

Soil moisture controls the partitioning of available energy into sensible and latent heat fluxes across regions where the evaporation regime is (at least intermittently) water-limited, as opposed to energy-limited. Fluxes of sensible heat and moisture at the base of the atmosphere influence the evolution of weather, hence soil moisture is often a significant factor in the performance of atmospheric models. Numerical Weather Prediction (NWP) and seasonal climate prediction figure prominently among the applications that drive soil moisture measurement requirements. Soil moisture retrievals are used in forecast initializations for these applications. Given the persistence of soil moisture anomalies, the initialized soil moisture can influence land fluxes and thus simulated weather or climate for days to months into the forecast. In this context the metric used to define the soil moisture measurement requirements is influenced by the need to capture the control of soil moisture over land-atmosphere interactions in atmospheric models.

III. Measurement Approach

Soil moisture and freeze/thaw state will be estimated using combined passive and active low-frequency microwave measurements of the Earth's surface. The spatial resolution and L-band operating frequency requirements dictate that a large antenna aperture be used. SMAP is efficiently configured to share an antenna reflector and feed system. Fig. 1 shows the configuration of the SMAP radar and radiometer instrument approach. The baseline antenna design employs a single feedhorn with dual-polarization capability at frequencies of 1.41 GHz (radiometer) and 1.26 and 1.29 GHz (radar). The lightweight mesh deployable antenna has a fixed off-nadir look angle and rotates about the nadir axis to make conical scans of the surface. This provides a constant incidence angle across a wide swath, which is advantageous in that angular variations are minimized across the swath. Data mapping, interpretation, and retrieval algorithms can benefit significantly from this approach.

The requirement for global coverage and constant diurnal sampling leads to the selection of a near-polar, sun-synchronous orbit. A series of trade studies was performed to select the optimum combination of orbit altitude and antenna parameters to simultaneously meet the 2-3 day temporal revisit requirement and the instrument spatial resolution requirements. The nominal SMAP altitude was selected to be 670 km. At this altitude, a six-meter diameter antenna, scanning to provide a total swath of 1000 km, is required to meet the measurement requirements (see Table 1).

The spatial resolution of the radiometer measurement is determined by the dimensions of the antenna beam "footprint" projected on the Earth's surface. To obtain the required 3 km and 10 km resolution for the freeze/thaw and soil moisture products the radar will employ pulse compression in range and Doppler discrimination in azimuth to sub-divide the antenna footprint. This is equivalent to the application of synthetic aperture radar (SAR) techniques to the conically scanning radar case. Due to squint angle effects, the achievable spatial resolution varies across the swath. High-resolution products will not be obtained within a 300-km band of the swath centered on the nadir track.

In order to minimize range/Doppler ambiguities with the baseline antenna and viewing geometry, separate carrier frequencies are used for each polarization (1.26 GHz for H-Pol and 1.29 GHz for V-Pol). An additional channel measures the HV cross-pol return. This frequency separation approach allows both polarization channels to be operated simultaneously with the same timing. However, since the two polarizations use separate frequencies, it is not possible to measure simultaneously all the parameters of the scattering matrix.

Figure 1. The SMAP large-aperture rotating antenna configuration provides for simultaneous low-frequency (L-band) radar and radiometer measurements across a wide swath.

IV. Science and Applications

Both radiometer and radar L-band measurements have been shown to be sensitive to soil moisture in the surface layer (0 to 5 cm). Under vegetated conditions, radiometric retrieval algorithms currently provide more accurate soil moisture estimates. The radar measurements on the other hand are capable of higher spatial resolution and provide sub-pixel roughness and vegetation information. Hence, the combination of simultaneous radar and radiometer data can enhance the resolution capability and accuracy of the soil moisture estimates. The inclusion of radar is also critical for the determination of freeze/thaw state at the required resolution. Table 2 lists the data products that will be generated by the SMAP mission. A comprehensive validation, science, and applications program will be implemented, and all data will be made available publicly through a designated NASA archive. The SMAP mission will yield many societal benefits, including numerous applications that are described below.

Weather & Climate Forecasting. Soil moisture variations affect the evolution of weather and climate over continental regions. Initialization of numerical weather prediction and seasonal climate models with accurate soil moisture information enhances their prediction skills and extends their skillful lead-times. Improved seasonal climate predictions will benefit climate-sensitive socioeconomic activities, including water management, agriculture, and fire, flood and drought hazards monitoring.

TABLE I. SMAP SCIENCE MEASUREMENT AND INSTRUMENT FUNCTIONAL REQUIREMENTS

Science Measurement Requirements	**Instrument Functional Requirements**
Soil Moisture: ~±0.04 m^3m^{-3} volumetric accuracy in top 2-5 cm for vegetation water content < 5 kg m^{-2}; Hydrometeorology at ~10 km; Hydroclimatology at ~40 km	L-Band Radiometer (1.41 GHz): Polarization: V, H, U Resolution: 40 km Relative accuracy: 1.5 K L-Band Radar (1.26 GHz): Polarization: VV, HH, HV Resolution: 10 km Relative accuracy: 0.5 dB (VV and HH) Constant incidence angle between 35° and 50°
Freeze/Thaw State: Capture freeze/thaw state transitions in integrated vegetation-soil continuum with two-day precision, at the spatial scale of landscape variability (~3 km).	L-Band Radar (1.26 GHz): Polarization: HH Resolution: 3 km Relative accuracy: 0.7 dB (1 dB per channel if 2 channels are used) Constant incidence angle between 35° and 50°
Sample diurnal cycle at consistent time of day (~6am/6pm); Global, ~3 day revisit; Boreal, ~2 day revisit	Swath Width: ~1000 km Minimize Faraday rotation (degradation factor at L-band)
Observation over minimum of three annual cycles	Minimum three-year mission life

Drought. Soil moisture strongly affects plant growth and hence agricultural productivity, especially during conditions of water shortage and drought. At present there is no global in situ network for soil moisture monitoring. Global estimates of soil moisture and plant water stress must be derived from models. These model predictions (and hence drought monitoring) can be greatly enhanced through assimilation of space-based soil moisture observations.

Floods & Landslides. Soil moisture is a key variable in water related natural hazards such as floods and landslides. High resolution observations of soil moisture will lead to improved flood forecasts, especially for intermediate to large watersheds where most flood damage occurs. The surface soil moisture state is key to partitioning of precipitation into infiltration and runoff. Soil moisture in mountainous areas is one of the most important determinants of landslides. Hydrologic forecast systems initialized with mapped high-resolution soil moisture fields will therefore open up new capabilities in operational flood forecasting.

Agricultural Productivity. SMAP will provide information on water availability for estimating plant productivity and potential yield. The availability of direct observations of soil moisture from SMAP will enable significant improvements in operational crop productivity and water stress information systems, by providing realistic soil moisture observations as inputs for agricultural prediction models.

Human Health. Improved seasonal soil moisture forecasts using SMAP data will directly benefit famine early warning systems particularly in sub-Saharan Africa and South Asia, where hunger remains a major human health factor and the population harvests its food from rain-fed agriculture in highly monsoonal (seasonal) conditions. Indirect benefits will also be realized as SMAP data will enable better weather forecasts that lead to improved predictions of heat stress and virus spreading rates. Better flood forecasts will lead to improved disaster preparation and response. SMAP will also benefit the emerging field of landscape epidemiology (aimed at identifying and mapping vector habitats for human diseases such as malaria) where direct observations of soil moisture can provide valuable information on vector population dynamics.

V. SUMMARY

Global monitoring of soil moisture and freeze/thaw state with SMAP will improve our understanding of the linkages between the water, energy and carbon cycles. It will also lead to improvements in weather forecasts, flood and drought forecasts, and predictions of agricultural productivity. Additional enabled science and applications could include climate prediction, sea ice, salinity, surface winds, human health, and defense applications. SMAP is currently under going mission development with an expected launch in 2013.

TABLE II. SMAP DATA PRODUCTS

L1B_S0_LoRes	Low Resolution Radar σ^o in Time Order
L1C_S0_HiRes	High Resolution Radar σ^o on Earth Grid
L1B_TB	Radiometer T_B in Time Order
L1C_TB	Radiometer T_B on Earth Grid
L3_SM_HiRes	Radar Soil Moisture on Earth Grid
L3_F/T_HiRes	Freeze/Thaw State on Earth Grid
L3_SM_40km	Radiometer Soil Moisture on Earth Grid
L3_SM_A/P	Radar/Radiometer Soil Moisture on Earth Grid (10km)
L4_GPP	Gross Primary Productivity on Earth Grid
L4_4DDA	Soil Moisture Model Assimilation on Earth Grid
L1B_S0_LoRes	Low Resolution Radar σ^o in Time Order

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