THE SOIL MOISTURE ACTIVE/PASSIVE MISSION (SMAP)

Dara Entekhabi[1], Eni Njoku[2], Peggy O'Neill[3], Michael Spencer[2], Tom Jackson[4], Jared Entin[5], Eastwood Im[2], Kent Kellogg[2]

[1]Massachusetts Institute of Technology, Cambridge, MA 02139
[2]California Institute of Technology, Jet Propulsion Laboratory, Pasadena, CA 91109-8099
[3]NASA Goddard Space Flight Center, Greenbelt MD 20771
[4]USDA ARS Hydrology and Remote Sensing Lab, Beltsville, MD 20705
[5]NASA Headquarters, Washington DC 20546

ABSTRACT

The Soil Moisture Active/Passive (SMAP) mission will deliver global views of soil moisture content and its freeze/thaw state that are critical terrestrial water cycle state variables. Polarized measurements obtained with a shared antenna L-band radar and radiometer system will allow accurate estimation of soil moisture at hydrometeorological scale (10 km) and hydroclimatological scale (40 km) resolutions. The sensors will share a feed and a deployable light-weight mesh reflector that will make 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 measurements enables global soil moisture mapping with unprecedented resolution, sensitivity, area coverage, and revisit. This paper outlines the science objectives of the SMAP mission and provides an overview of the measurement approach and data products.

Index Terms— Soil Moisture, Freeze/Thaw, Water Cycle, Sensors and Systems, Missions

1. INTRODUCTION

The Soil Moisture Active and Passive (SMAP) mission is one of four first-tier missions recommended by the U.S. National Research Council Committee on Earth Science and Applications from Space in 2007 [1]. SMAP was selected by NASA as a directed mission in FY 2008, and 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 wide swath (1000 km) using conical scanning at a constant incidence angle (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].

SMAP is a directed mission with an established budget profile and target launch date in early 2013. The SMAP project is managed for NASA by the Jet Propulsion Laboratory, with participation by the Goddard Space Flight Center. SMAP builds on the heritage and risk-reduction activities of the NASA ESSP Hydros mission.

2. SOIL MOISTURE AND FREEZE-THAW APPLICATIONS

SMAP will provide measurements of the land surface soil moisture and freeze-thaw state with near-global revisit coverage in 2-3 days. 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 capability

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). Since the fluxes of sensible heat and moisture at the base of the atmosphere influence the evolution of weather, soil moisture is often a significant factor in the performance of atmospheric models. Among the applications that drive soil moisture measurement requirements Numerical Weather Prediction (NWP) models and seasonal climate prediction figure prominently. For these applications, soil moisture retrievals are used in forecast initialization; in effect, 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 that is used to define soil moisture measurement requirements is influenced by the need to capture soil moisture's control over land-atmosphere interactions in atmospheric models.

3. EARTH SCIENCE DECADAL SURVEY

The 2007 National Research Council's Earth Science Decadal Survey – formally published as Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond [1] - was a study commissioned by NASA, NOAA, and USGS to provide consensus recommendations to guide the agencies' space-based Earth observation programs in the coming decade. Many factors involving both scientific advance and societal benefit were considered in the process. In the end, the NRC report recommended the Soil Moisture Active/Passive (SMAP) mission to observe soil moisture and freeze/thaw for weather and water cycle processes for implementation in the first of three phases (2010-2013). Later in July 2007, NASA Headquarters convened a series of workshops to further investigate each of the missions recommended for near-term implementation and initiated further review of the mission concepts that had been recommended. Several key conclusions resulted from the SMAP workshop:

- There is a stable set of instrument measurement requirements for SMAP that are traceable to science requirements for soil moisture/freeze-thaw.
- The baseline SMAP instrument design is capable of satisfying the science measurement requirements.
- Significant heritage exists from design and risk-reduction work performed during Hydrosphere State (Hydros) mission formulation and other technology development activities [2]. This heritage includes studies addressing science applications and algorithms, antenna rotation dynamics, antenna RF performance, and RFI mitigation techniques.
- Heritage and lessons learned can be leveraged from the Aquarius project. This includes both the L-Band radiometer and radar electronics.
- There are no technology "show-stoppers," and SMAP formulation is positioned to begin where Hydros left off.

4. 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. In microwave remote sensing the antenna in large part determines the measurement resolution and accuracy. The radiometer and radar resolution requirements at L-Band require that a relatively large antenna aperture must be used. SMAP is efficiently configured to share antenna reflector and feed. Fig. 1 shows the configuration of the SMAP radar and radiometer instrument approach with shared antenna subsystems.

The baseline feed assembly design employs a single smooth-wall horn, capable of dual-polarization and dual frequency (radiometer frequency at 1.41 GHz, and the radar frequencies at 1.26 and 1.29 GHz). The light-weight mesh deployable antenna rotates about the nadir axis to make conical scans of the surface. The resulting measurements across the wide swath are at a constant incidence angle. This is highly 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 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 high-resolution products will not be obtained within the 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, and a polarizer is used in the current baseline design.

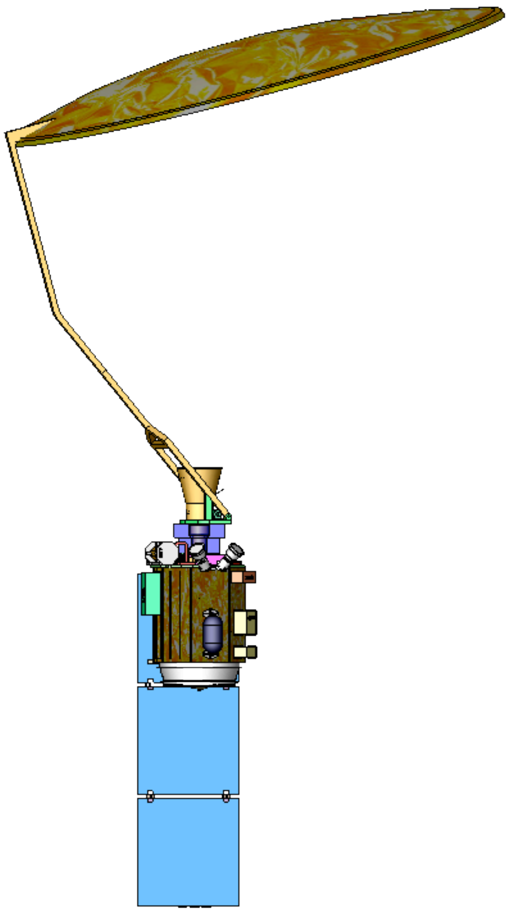

Figure 1: The SMAP mission approach to simultaneous low-frequency microwave active radar and passive radiometer measurements across a wide swath.

Table 1. SMAP Preliminary Mission Requirements	
Scientific Measurement Science Requirements	**Instrument Functional Instrument Instrument 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 land-scape 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

5. DATA PRODUCTS

Both radiometer and radar L-band measurements have been shown to be sensitive to soil moisture in the surface (0 to 5 cm) layer. In order to minimize the impact of vegetation on the soil parameter retrievals, both active and passive SMAP measurements will be obtained at L-Band frequency. Under vegetated conditions, radiometric retrieval algorithms currently provide more accurate soil moisture estimates. The radar measurements, on the other hand, are capable of a 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. SMAP observations will be acquired for a period of three years after launch. A comprehensive validation, science, and applications program will be implemented, and all data will be made available publicly through the NASA archive centers.

Table 2. SMAP Data Products	
Data Product	**Description**
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

6. 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.

7. REFERENCES

[1] National Research Council, 2007: Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond, 400 pages.

[2] Entekhabi, D., Njoku, E., Houser, P., Spencer, M., Doiron, T., Smith, J., Girard, R., Belair, S., Crow, W., Jackson, T., Kerr, Y., Kimball, J., Koster, R., McDonald, K., O'Neill, P., Pultz, T., Running, S., Shi, J.C., Wood, E. and van Zyl, J., 2004, The Hydrosphere State (HYDROS) mission concept: An Earth system pathfinder for global mapping of soil moisture and land freeze/thaw, IEEE Transactions on Geoscience and Remote Sensing, 42(10), 2184-2195.