The Soil Moisture Active Passive Mission: Overview and Status

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Abstract

NASA's Soil Moisture Active Passive (SMAP) mission, scheduled for launch in November 2014, will provide global maps of soil moisture every 2-3 days. SMAP soil moisture observations will yield significantly improved estimates of water, energy and carbon transfers between the land and atmosphere. Soil moisture control of these fluxes is a key factor in atmospheric models used for weather forecasts and climate projections. Soil moisture measurements are of importance for flood prediction, drought monitoring, and human health. In addition, observations of soil moisture and freeze/thaw timing in boreal latitudes can help reduce uncertainties in quantifying the global carbon balance. To make these measurements SMAP utilizes an L-band radar and an L-band radiometer sharing a rotating 6-meter mesh reflector antenna. The radar and radiometer instruments will operate onboard the SMAP spacecraft in a 685 km Sun-synchronous near-polar orbit, viewing the surface at a constant 40-degree incidence angle with a 1000-km swath width. Data from the instruments will yield global maps of soil moisture and freeze/thaw state at 10 km and 3 km resolutions respectively, every two to three days.

1. Introduction

Soil moisture is a primary state variable of hydrology and the water cycle over land. 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 skillful modeling and forecast 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. The National Research Council's (NRC) Decadal Survey Report, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*, was released in 2007. NASA announced in early 2008 that SMAP would be one of the first two new Earth science missions to be developed in response to the NRC Decadal Survey report.

The SMAP mission is being developed by NASA's Jet Propulsion Laboratory, which is building the spacecraft, the instrument (except for the radiometer), and the science processing system. NASA Goddard Space Flight Center is providing the L-band radiometer and Level 4 science processing. The Canadian Space Agency (CSA) is also a mission partner to provide critical support to science and calibration/validation (pre- and post-launch). SMAP will be launched from Vandenberg Air Force Base in California on a Delta-II launch vehicle, and will be placed into a polar sun synchronous orbit with a 685 km altitude. Figure 1 shows the configuration of the SMAP observatory. The L-band SAR and radiometer share a 6-m mesh deployable offset fed reflector antenna that rotates at 14 rpm to provide high spatial resolution with a 1000 km measurement swath that enables global coverage every 2-3 days. Major challenges that have been and are being addressed by SMAP include: (1) mitigation of L-band radio frequency interference to both radiometer and SAR measurements from terrestrial and other spaceborne sources; (2) use of a mesh reflector antenna for L-band radiometry measurements; (3) dynamics and control of a relatively large spinning payload by a comparatively small spacecraft bus; and (4) cost effective adaptation of an existing avionics architecture to accommodate the unique demands of a high data volume SAR.

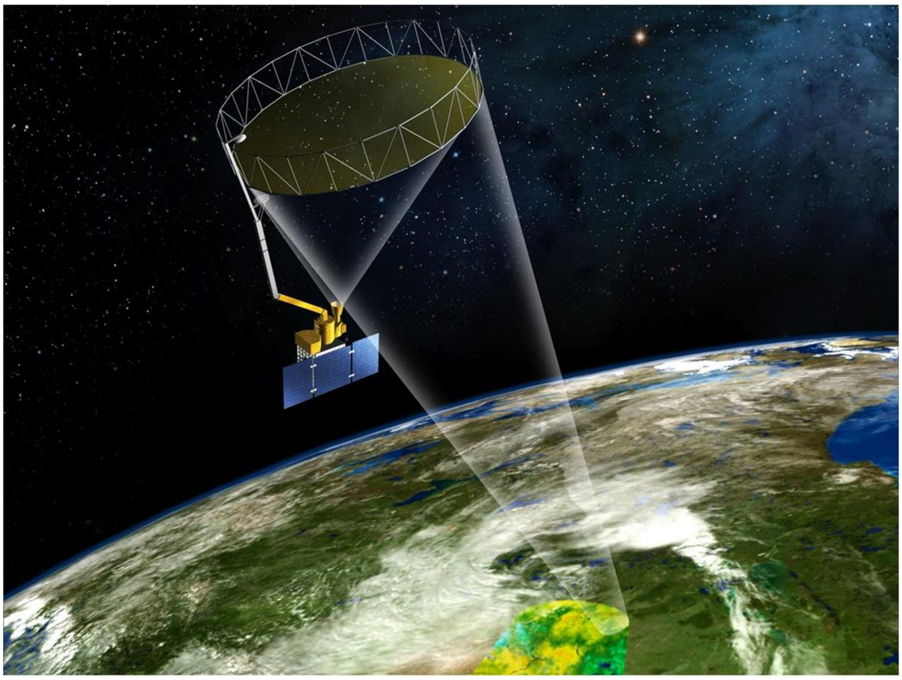

Figure 1. The SMAP observatory is a dedicated spacecraft with a rotating 6-m lightweight deployable mesh reflector. The radar and radiometer share a common antenna feed.

2. Mission Description

The baseline science requirement for SMAP is to provide estimates of soil moisture in the top 5 cm of soil with an error of no greater than 0.04 cm^3 cm^{-3} volumetric (one sigma) at 10 km spatial resolution and 3-day average intervals over the global land area excluding regions of snow and ice, frozen ground, mountainous topography, open water, urban areas, and vegetation with water content greater than 5 kg m^{-2} (averaged over the spatial resolution scale). The mission is additionally required to provide estimates of surface binary freeze/thaw state in the region north of 45N latitude, which includes the boreal forest zone, with a classification accuracy of 80% at 3 km spatial resolution and 2-day average intervals. The L-band radiometer provides 'passive' measurements of the microwave emission from the upper soil with a spatial resolution of 40 km, and is more sensitive to near-surface soil moisture and less sensitive to the effects of surface roughness and vegetation than the radar. The L-band radar makes 'active' backscatter measurements of the surface, and the ground processing system performs the synthetic aperture radar processing to achieve a spatial resolution of 3 km across about 70 percent of the swath in its high-resolution mode. Utilizing a combination of the active and passive data sets provides greater accuracy and spatial resolution in measuring moisture in the upper 5 cm of soil than is possible with either of the individual instruments alone. The radar data also provide information on the frozen/thawed state of the soil, which is important to understanding the length of the vegetation growing season and the contribution of the boreal forests to the global carbon balance.

SMAP has a 40-month mission timeline based on a launch date in November 2014. Four mission phases are defined to simplify description of the different periods of activity during the mission. These phases are the launch, commissioning, science observation, and decommissioning. The launch phase is the period of transition that takes the observatory from the ground, encapsulated in the launch vehicle fairing, to its initial free flight in the injection orbit. The commissioning phase, sometimes known as in-orbit checkout (IOC), is the period of initial operations that includes checkout of the spacecraft subsystems, maneuvers to raise the observatory into the science orbit, deployment and spin-up of the instrument boom and reflector, and checkout of the full observatory. Commissioning will be completed within 90 days. The science observation phase is the period of near-continuous instrument data collection and return, extending from the end of the commissioning phase for three years. The observatory is maintained in the nadir attitude, except for brief periods when propulsive maneuvers are required to maintain the orbit and for periodic radiometer calibrations that require briefly viewing cold space. During the first year of science acquisition, a period of calibration and validation of the science data products is conducted. This includes field campaigns and intensive *in situ* data acquisitions, data analysis, and performance evaluations of the science algorithms and data product quality. These activities continue at a lower level for the remainder of the science observation phase for the purpose of monitoring and fine-tuning the quality of the science data products. During science operations, the mission must return an average volume of 135 GB per day of science data to be delivered to the science data processing facility. Finally, at the end of its useful life, the observatory is maneuvered to a lower disposal orbit and decommissioned to a functional state that prevents interference with other missions.

3. Data Products

The SMAP baseline data products are listed in Table 1. Level 1B and 1C data products are calibrated and geolocated instrument measurements of surface radar backscatter cross-section and brightness temperatures. Level 2 products are geophysical retrievals of soil moisture on a fixed Earth grid based on Level 1 products and ancillary information; the Level 2 products are output on a half-orbit basis. Level 3 products are daily composites of Level 2 surface soil moisture and freeze/thaw state data. Level 4 products are model-derived value-added data products of surface and root zone soil moisture and carbon net ecosystem exchange that support key SMAP applications and more directly address the driving science questions. There are three Level 2 soil moisture products resulting from the radar and radiometer data streams. L2_SM_A is a high-resolution research-quality soil moisture product that is mostly based on the radar measurements and is posted at 3 km. L2_SM_P is soil moisture derived from the radiometer brightness temperature measurements and is posted at 36 km. L2_SM_AP is a combination active and passive (radar and radiometer) product that produces soil moisture estimates at 9 km resolution.

Table 1. SMAP Data Products

Product	Description	Gridding (Resolution)	Latency**	
L1A_Radiometer	Radiometer Data in Time-Order	-	12 hrs	Instrument Data
L1A_Radar	Radar Data in Time-Order	-	12 hrs	
L1B_TB	Radiometer T_B in Time-Order	(36×47 km)	12 hrs	
L1B_S0_LoRes	Low-Resolution Radar σ_o in Time-Order	(5×30 km)	12 hrs	
L1C_S0_HiRes	High-Resolution Radar σ_o in Half-Orbits	1 km (1−3 km)[#]	12 hrs	
L1C_TB	Radiometer T_B in Half-Orbits	36 km	12 hrs	
L2_SM_A	Soil Moisture (Radar)	3 km	24 hrs	Science Data (Half-Orbit)
L2_SM_P*	Soil Moisture (Radiometer)	36 km	24 hrs	
L2_SM_AP*	Soil Moisture (Radar + Radiometer)	9 km	24 hrs	
L3_FT_A*	Freeze/Thaw State (Radar)	3 km	50 hrs	Science Data (Daily Composite)
L3_SM_A	Soil Moisture (Radar)	3 km	50 hrs	
L3_SM_P*	Soil Moisture (Radiometer)	36 km	50 hrs	
L3_SM_AP*	Soil Moisture (Radar + Radiometer)	9 km	50 hrs	
L4_SM	Soil Moisture (Surface and Root Zone)	9 km	7 days	Science Value-Added
L4_C	Carbon Net Ecosystem Exchange (NEE)	9 km	14 days	

 # Over outer 70% of swath.
** The SMAP Project will make a best effort to reduce the data latencies beyond those shown in this table.
*** Product directly addresses the mission L1 science requirements.**

SMAP measurements provide direct sensing of soil moisture in the top 5 cm of the soil column. However, several of the key applications targeted by SMAP require knowledge of root zone soil moisture in the top 1 m of the soil column, which is not directly measured by SMAP. As part of its mission, the SMAP project will produce model-derived value-added Level 4 data products to fill this gap and provide estimates of root zone soil moisture that are informed by and consistent with SMAP surface observations. Such estimates are obtained by merging SMAP observations with estimates from a land surface model in a data assimilation system. The land surface model component of the assimilation system is driven with observations-based meteorological forcing data, including precipitation, which is the most important driver for soil moisture. The model also encapsulates knowledge of key land surface processes, including the vertical transfer of soil moisture between the surface and root zone reservoirs. Finally, the model interpolates and extrapolates SMAP observations in time and in space, producing 3-hourly estimates of soil moisture at a 9 km resolution. The SMAP L4_SM product thus provides a comprehensive and consistent picture of land surface hydrological conditions based on SMAP observations and complementary information from a variety of sources. The L4_C algorithms utilize daily soil moisture and temperature inputs with ancillary land cover classification and vegetation gross primary productivity (GPP) inputs to compute the net ecosystem exchange (NEE) of carbon dioxide with the atmosphere over global vegetated land areas (with an emphasis on boreal areas north of 45N latitude). Carbon NEE is a fundamental measure of the balance between carbon uptake by vegetation and carbon losses through autotrophic and heterotrophic respiration. SMAP data products will be archived at the National Snow and Ice Data Center and the Alaska Satellite Facility.

5. Applications

SMAP initiated an applications program to engage SMAP end users and build broad support for SMAP applications through a transparent and inclusive process. The sub-goals of the program are to: (1) Develop a community of users and decision makers that understand SMAP capabilities and are interested in using SMAP products in their applications; (2) Reach out to users that are unfamiliar with SMAP capabilities but have the potential to benefit from SMAP products in their applications; (3) Provide information about SMAP applications to the broad science community to build support for SMAP applications; (4) Facilitate feedback between SMAP user communities and the SMAP Mission and Science Definition Teams; (5) Identify 'Early Adopters' who will partner with SMAP to optimize their use of SMAP products before launch as part of SMAP testbed and SMAP calibration/validation activities.

The SMAP Early Adopter Program was developed in 2010 to facilitate feedback on SMAP products pre-launch, and accelerate the use of SMAP products post-launch. Early Adopters engage in pre-launch research that enable integration of SMAP data after launch in their application. The program provided specific non-financial support to Early Adopters who committed to engage in pre-launch applied research with quantitative metrics. Twenty-one Early Adopters have been selected to date.
(http://smap.jpl.nasa.gov/science/wgroups/applicWG/EarlyAdopters/).

6. Acknowledgment

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