SPECIAL SMAP COLLECTION

Connecting NASA Science and Engineering with Earth Science Applications

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ABSTRACT

The National Research Council (NRC) recently highlighted the dual role of NASA to support both science and applications in planning Earth observations. This article reports the efforts of the NASA Applied Sciences Program and NASA Soil Moisture Active Passive (SMAP) mission to integrate applications with science and engineering in prelaunch planning. The SMAP Early Adopter program supported the prelaunch applied research that comprises the SMAP Special Collection of the *Journal of Hydrometeorology*. This research, in turn, has resulted in unprecedented prelaunch preparation for SMAP applications and critical feedback to the mission to improve product specifications and distribution for postlaunch applications. These efforts have been a learning experience that should provide direction for upcoming missions and set some context for the next NRC decadal survey.

1. Introduction

The NASA Earth Science Division (ESD) has a primary mission to develop a scientific understanding of Earth's system and its response to natural or human-induced changes. Implicit to this is the ESD goal to design and launch missions with sound system engineering while balancing cost and complexity. A classic example is the NASA Landsat program, which provides the longest continuous space-based record of Earth's land in existence (Irons et al. 2012). ESD is further dedicated to promoting the use of NASA mission products and information in decision-making activities for societal benefit, often termed applications. It is commonly the case in mission planning to emphasize science and engineering in the prelaunch efforts and to delay consideration of applications until after launch. The integration of applications into prelaunch mission planning, with examples from the Soil Moisture Active Passive (SMAP) mission, is the theme of this Special Collection and the topic of this article.

Innovative applications of NASA Earth science data are fostered by the ESD Applied Sciences Program (ASP), which provides support to integrate applications needs into mission planning. The ASP capacity building efforts focus on activities with state and local governments and developing countries to improve capabilities and workforce applying Earth observations.

The work of ASP received recent support from the National Research Council's (NRC) decadal survey (National Research Council 2007). The NRC offered a 10-yr outlook

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TABLE 1. SMAP data product, description, spatial resolution, and latency. SMAP will make a best effort to reduce the data latencies beyond those shown in this table. In the second column, σ_o refers to radar backscatter and T_B refers to brightness temperature.

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
L2_SM_P	Soil Moisture (Radiometer)	36 km	24 hrs	(Half-Orbit)
L2_SM_AP	Soil Moisture (Radar + Radiometer)	9 km	24 hrs	
L3_FT_A	Freeze/Thaw State (Radar)	3 km	50 hrs	Science Data
L3_SM_A	Soil Moisture (Radar)	3 km	50 hrs	(Daily Composite)
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
L4_C	Carbon Net Ecosystem Exchange (NEE)	9 km	14 days	Value-Added

* Over outer 70% of swath.
** The SMAP Project will make a best effort to reduce the data latencies beyond those shown in this table.

to prioritize research and missions and identified more than a dozen new space missions for NASA and NOAA based on an assessment of applications meeting societal needs. NRC went further to state that ‘‘broadened community participation and improved means for dissemination and use of information are all required’’ (National Research Council 2007, p. 23).

One of the first missions recommended by the NRC decadal survey is the SMAP mission, which is scheduled for launch in January 2015 (Entekhabi et al. 2010). The SMAP mission is designed to provide global soil moisture and freeze–thaw measurements from space for applications in fields of weather, climate, drought, flood, agricultural production, human health, and national security (Table 1). The range of applications is defined partly by the spatial resolution and latency of the SMAP products, ranging from ~1 to 3 km for the synthetic aperture radar (SAR) data (L1C_S0_HiRes) to the 39 km × 47 km radiometer data, nominally referred to as 40-km resolution (L1B_TB). This is distinct from the gridding resolution, where, for example, the L1C_TB product is resampled on a 36-km Earth grid and will have spatial resolution ~10% greater than the L1B_TB data. The high resolution of the radar is critical for accurate determination of freeze–thaw state (L3_F/T_A), and the low-resolution radiometer measurements are key to deriving the soil moisture product (L2_SM_P). The radar and radiometer measurements are combined to generate a midresolution product (L2_SM_A/P) that optimizes the resolution and accuracy attributes of the radar and radiometer. The satellite orbit provides an exact 8-day revisit with optimum coverage of global land area at 3-day average intervals. Product latency is defined as time from data acquisition by instrument to availability in the designated archive. The latencies provided in Table 1 are median values under normal operating conditions, with a stated commitment to make a best effort to reduce these latencies to maximize applications.

During the SMAP design and development, the SMAP project (responsible for the SMAP mission, including the SMAP Science Team) is required to define potential applications that can be supported with existing SMAP data requirements. The SMAP project and NASA ASP have taken extraordinary steps to promote applications as well as sound system engineering in the definition, design, and development phases of the SMAP mission. These efforts, and particularly the SMAP Early Adopter program, have been a learning experience that should provide direction for upcoming missions.

2. SMAP Early Adopter program

The SMAP applications program is a pioneering plan to engage SMAP end users and to build broad support for SMAP applications through prelaunch activities. At the first SMAP Applications Workshop in 2009, over 150 scientists, engineers, managers, and potential users came together to identify an array of SMAP applications and to compile a list of potential users to form the inclusive SMAP Applications Working Group (AppWG). The AppWG comprises a wide breadth of users interested in SMAP products for applications, but it does not provide the depth of user involvement required to help guide scientific priorities and prepare for postlaunch application. Consequently, the SMAP Early Adopter program was conceived. Early adopters were formally defined as

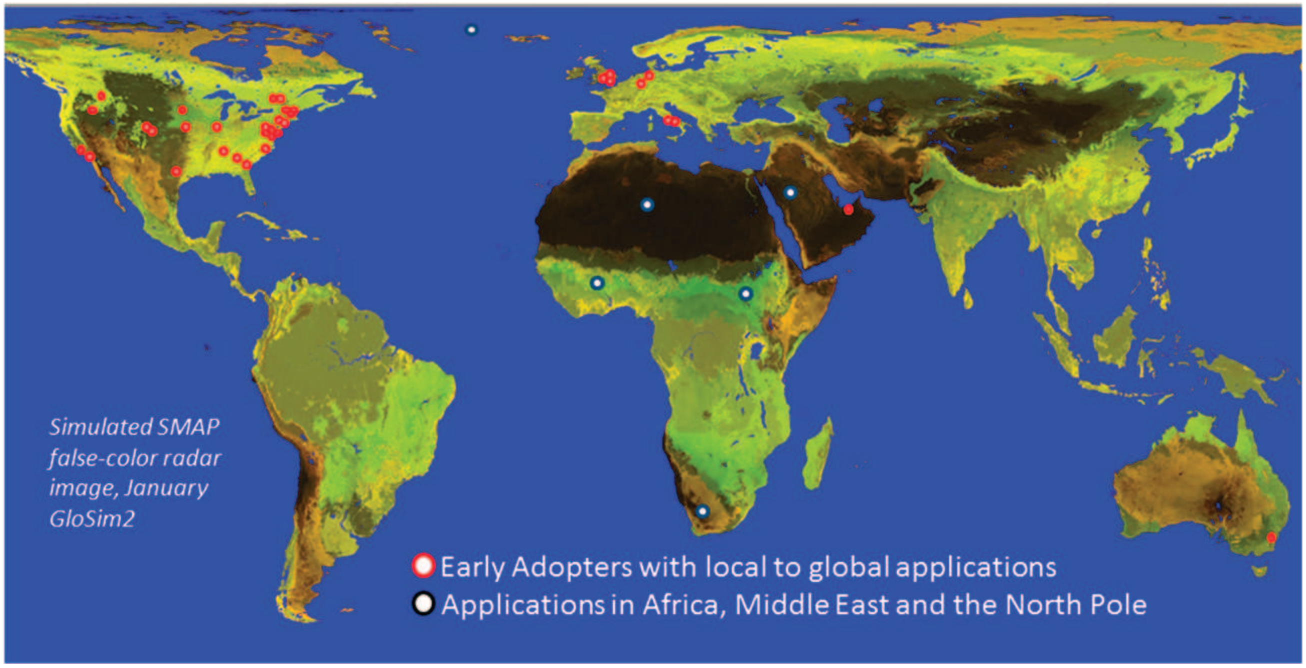

FIG. 1. A simulated image of SMAP radar data scaled backscatter triplets in the order VV, HH, and HV to a 24-bit color map and overlain with the locations of 37 early adopters conducting applied research over local-to-global domains, and specific applications in Africa, the Middle East, and the North Pole.

those users who have a direct or clearly defined need for SMAP-like data and who are planning to apply their own resources to demonstrate the utility of SMAP data for their particular system or model. The goals of the SMAP Early Adopter program are to 1) facilitate feedback on SMAP products prelaunch and 2) accelerate the use of SMAP products postlaunch. The SMAP Early Adopter program is a nonfunded activity for projects to be completed with quantitative metrics designed to benefit the user and the SMAP project.

From the AppWG of 270 members in 2011, 15 users were self-nominated for the SMAP Early Adopter program and 7 were selected as the first round of early adopters. In a second round in 2012, 13 nominations were received and another 11 early adopters were selected. Since then, the nomination process has been open and 19 more early adopters have been selected. At the time of this writing, the AppWG has almost 600 members and there are a total of 37 early adopters with several proposals pending decision (Fig. 1). The selection criteria include a good end-user connection, a high chance of success, reasonable metrics, maximum return on SMAP project investment, a high-impact application, and a basic understanding of SMAP products. Furthermore, selection is designed to create a set of early adopters covering diverse topics and societal needs, using diverse SMAP products, and representing a diverse geography. The proposals are reviewed by representatives of the SMAP project and NASA, termed the SMAP Applications Team.

The agreement between the SMAP early adopters, the SMAP project, and NASA ASP is that the early adopter will engage in applied research that will enable integration of SMAP data in the application after launch. In turn, the SMAP project will provide early adopters with simulated SMAP data products via a NASA Distributed Active Archive Center (DAAC) and/or prelaunch calibration and validation (cal–val) data from SMAP field campaigns, modeling, and synergistic studies. The cal–val data include large-area, multiday coverage of specific sites with the airborne Passive–Active L- and S-Band (PALS) sensor and the Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) deployed in support of SMAP field campaigns.

This is a challenge to early adopters because they are expected to provide feedback to the SMAP project and prepare for assimilation of SMAP products postlaunch, all without any data from the soon-to-be-launched SMAP mission. Nonetheless, early adopters came forward to propose research that was both beneficial to themselves and the mission, as described in this Special Collection.

SMAP Early Adopter research

The SMAP early adopters are a diverse group of scientists, engineers, managers, and entrepreneurs representing applications in a broad range of areas (Table 2). Some early adopters had been involved with the SMAP mission for years, and others were only recently introduced to SMAP. Yet, the tasks they proposed to fulfill their

TABLE 2. Early adopters, project contacts, and applied research topics. Many early adopters cross multiple applications. Early adopters are defined as those groups and individuals who have a direct or clearly defined need for SMAP-like soil moisture or freeze–thaw data and who are planning to apply their own resources (funding, personnel, facilities, etc.) to demonstrate the utility of SMAP data for their particular system or model. The goal of this designation is to accelerate the use of SMAP products after launch of the satellite.

Early adopter principal investigator(s) and institution contact(s)	Applied research topic
Weather and climate forecasting	
Stephane Bélair, Meteorological Research Division, Environment Canada (EC)*; SMAP contact: Stephane Bélair	Assimilation and impact evaluation of observations from the SMAP mission in EC's environmental prediction systems
Lars Isaksen and Patricia de Rosnay, ECMWF*; SMAP contact: Eni Njoku	Monitoring SMAP soil moisture and brightness temperature at ECMWF
Xiwu Zhan, Michael Ek, John Simko, and Weizhong Zheng, NOAA/NCEP, NOAA/NESDIS*; SMAP contact: Randy Koster	Transition of NASA SMAP research products to NOAA operational numerical weather and seasonal climate predictions and research hydrological forecasts
Michael Ek, Marouane Temimi, Xiwu Zhan, and Weizhong Zheng, NOAA/NCEP, NOAA/NESDIS, CUNY*; SMAP contact: Chris Derksen	Integration of SMAP freeze–thaw product line into the NOAA/NCEP weather forecast models
John Galantowicz, AER*; SMAP contact: John Kimball	Use of SMAP-derived inundation and soil moisture estimates in the quantification of biogenic greenhouse gas emissions
Jonathan Case, Clay Blankenship, and Bradley Zavodsky, NASA Short-Term Prediction Research and Transition Center (SPoRT)**; SMAP contact: Molly Brown	Data assimilation of SMAP observations, and impact on weather forecasts in a coupled simulation environment
Droughts and wildfires	
Jim Reardon and Gary Curcio, U.S. Forest Service*; SMAP contact: Dara Entekhabi	The use of SMAP soil moisture data to assess the wildfire potential of organic soils on the North Carolina coastal plain
Chris Funk, Amy McNally, and James Verdin, USGS and University of California, Santa Barbara*; SMAP contact: Molly Brown	Incorporating soil moisture retrievals into the FEWS NET Land Data Assimilation System (FLDAS)
Brian Wardlow and Mark Svoboda, Center for Advanced Land Management Technologies, National Drought Mitigation Center**; SMAP contact: Narendra Das	Evaluation of SMAP soil moisture products for operational drought monitoring: potential impact on the U.S. Drought Monitor
Uma Shankar, Institute for the Environment, University of North Carolina at Chapel Hill**; SMAP contact: Narendra Das	Enhancement of a bottom-up fire emissions inventory using Earth observations to improve air quality, land management, and public health decision support
Floods and landslides	
Fiona Shaw, Global Analytics, Willis Group*; SMAP contact: Robert Gurney	A risk identification and analysis system for insurance; eQUIP suite of custom catastrophe models, risk rating tools, and risk indices for insurance and reinsurance purposes
Rafael Ameller, StormCenter Communications, Inc.*; SMAP contact: Randy Koster	SMAP for enhanced decision making
Kashif Rashid and Emily Niebuhr, United Nations World Food Programme*; SMAP contact: Eni Njoku	Application of a SMAP-based index for flood forecasting in data-poor regions
Konstantine Georgakakos, Hydrologic Research Center**; SMAP contact: Narendra Das	Development of a strategy for the evaluation of the utility of SMAP products for the Global Flash Flood Guidance Program of the Hydrologic Research Center
Steven Quiring, Texas A&M University**; SMAP contact: Dara Entekhabi	Hurricane power outage prediction
Luca Brocca, Research Institute for Geo-Hydrological Protection, Italian Dept. of Civil Protection**; SMAP contact: Dara Entekhabi	Use of SMAP soil moisture products for operational flood forecasting: data assimilation and rainfall correction
Agricultural productivity	
Catherine Champagne, AAFC*; SMAP contact: Stephane Bélair	Soil moisture monitoring in Canada
Zhengwei Yang and Rick Mueller, NASS, USDA*; SMAP contact: Wade Crow	U.S. national cropland soil moisture monitoring using SMAP
Amor Ines and Stephen Zebiak, IRI, Columbia University*; SMAP contact: Narendra Das	SMAP for crop forecasting and food security early warning applications

TABLE 2. (*Continued*)

Early adopter principal investigator(s) and institution contact(s)	Applied research topic
Jingfeng Wang, Rafael Bras, Aris Georgakakos, and Husayn El Sharif, Georgia Institute of Technology*; SMAP contact: Dara Entekhabi	Application of SMAP observations in modeling energy–water–carbon cycles and its impact on weather and climatic predictions
Curt Reynolds, Foreign Agricultural Service, USDA*; SMAP contact: Wade Crow	Enhancing USDA's global crop production monitoring system using SMAP soil moisture products
Alejandro Flores, Boise State University**; SMAP contact: Dara Entekhabi	Data fusion and assimilation to improve applications of predictive ecohydrologic models in managed rangeland and forest ecosystems
Barbara S. Minsker, University of Illinois and sponsored by John Deere, Inc.**; SMAP contact: Wade Crow	Comprehensive, large-scale agriculture and hydrologic data synthesis
Lynn J. Torak, Georgia Water Science Center, USGS**; SMAP contacts: Dara Entekhabi and Vanessa Escobar	Downscaling SMAP soil moisture data to improve crop production and efficient use of energy and water resources and to assess water availability in the Apalachicola–Chattahoochee–Flint watershed
Human health	
Hosni Ghedira, Masdar Institute, United Arab Emirates*; SMAP contact: Dara Entekhabi	Estimating and mapping the extent of Saharan dust emissions using SMAP-derived soil moisture data
Kyle McDonald and Don Pierson, CUNY and CUNY Remote Sensing of Earth Science and Technology (CREST) Institute, New York City Dept. of Environmental Protection*; SMAP contact: Erika Podest	Application of SMAP freeze–thaw and soil moisture products for supporting management of New York City's potable water supply
James Kitson, Andrew Walker, and Cameron Hamilton, Yorkshire Water, United Kingdom**; SMAP contacts: Robert Gurney and Vanessa Escobar	Using SMAP L-2 soil moisture data for added value to the understanding of land management practices and its impact on water quality
Luigi Renzullo, CSIRO, Australia**; SMAP contact: Jeff Walker	Preparing the AWRA system for the assimilation of SMAP data
National security	
John Eylander and Susan Frankenstein, Cold Regions Research and Engineering Laboratory (CRREL), U.S. Army Engineer Research and Development Center (ERDC)*; SMAP contact: Susan Moran	U.S. Army ERDC SMAP adoption for U.S. Army Corps of Engineers civil and military tactical support
Gary McWilliams, George Mason, Li Li, Andrew Jones, and Maria Stevens, Army Research Laboratory; Geotechnical and Structures Laboratory, ERDC; NRL; and Colorado State University*; SMAP contact: Susan Moran	Exploitation of SMAP data for Army and Marine Corps mobility assessment
Kyle McDonald, CUNY**; SMAP contact: Simon Yueh	Integration of SMAP datasets with the NRL environmental model for operational characterization of cryosphere processes across the North Pole land–ocean domain
Georg Heygster, Institute of Environmental Physics, University of Bremen, Germany**; SMAP contact: Simon Yueh	SMAP-Ice: Use of SMAP observations for sea ice remote sensing
Lars Kaleschke, Institute of Oceanography, University of Hamburg, Germany**; SMAP contact: Simon Yueh	Migration from SMOS to SMAP for cryosphere and climate application
Jerry Wegiel, Air Force Weather Agency Headquarters (AFWA HQ)**; SMAP contact: Peggy O'Neill	Optimization of NASA's Land Information System (LIS) at AFWA HQ
General	
Srini Sundaram, Agrisolum Limited, United Kingdom**; SMAP contacts: Robert Gurney and Vanessa Escobar	Application of SMAP data products in Agrisolum, a big data social agritech platform
Thomas Harris and Dave Hulslander, Exelis Visual Information Solutions**; SMAP contact: Barry Weiss	Utilization of SMAP Products in ENVI, IDL, and SARscape (products L1–L4)
Kimberly Peng, Africa Soil Information Service and Center for International Earth Science Network**; SMAP contact: Eric Wood	Input generator for digital soil mapping

* Early adopters selected in 2011–12 agreed to engage in prelaunch research that will enable integration of SMAP data after launch in their application, complete the project with quantitative metrics prior to launch, and take a lead role in SMAP applications research, meetings, workshops, and related activities.

** Early adopters selected from 2013 onward agreed to engage in research that will enable integration of SMAP data after launch in their application and to provide feedback to the SMAP project upon request concerning their experience in using the data.

commitment had much in common. Many early adopters proposed to create in-house capacity to download, visualize, and manipulate SMAP data based on the simulated product formats available from the DAAC. For example, the U.S. Department of Agriculture (USDA) National Agricultural Statistical Service (NASS) is updating their Vegetation Condition Explorer (VegScape) to provide visualization of SMAP products in service to U.S. agriculture (http://nassgeodata.gmu.edu/VegScape/). Others proposed an exploratory marketing survey of existing clients to determine economic metrics, client profitability, and the level of client comfort with satellite products. The Global Analytics sector of the Willis Group is exploring the concept of merging NASA satellite data into existing systems for flooding reinsurance companies at different scales, and StormCenter Communications, Inc. proposed to determine the best SMAP products for the emergency management community and decide how these SMAP data products should be presented.

The majority of early adopters proposed applied research that would provide fundamental knowledge of how soil moisture and freeze–thaw information could be used for decision making. In some cases, this took the form of data-denial experiments to determine how soil moisture information improves the accuracy of climate-informed models. An increase in accuracy of soil moisture analyses used for numerical weather prediction was achieved by combining improved precipitation forcing and assimilation of L-band brightness temperatures in the Canadian Land Data Assimilation System (Carrera et al. 2014, manuscript submitted to *J. Hydrometeor.*). The Institute for Climate and Society (IRI) at Columbia University tested a data assimilation framework for forecasting yields of grain crops in Africa and reported the potential to detect irrigation applications otherwise not possible through model simulations (Ines et al. 2013; Das et al. 2014, manuscript submitted to *J. Hydrometeor.*). The European Centre for Medium-Range Weather Forecasts (ECMWF) is involved, among other research, in an analysis of a time series of soil moisture products for global trend analysis (Albergel et al. 2013). Using data from the U.S. Drought Monitor provided by the National Drought Mitigation Center, a study reported that assimilation of soil moisture information in a land surface model provided improvement in spatial patterns of drought estimates (Kumar et al. 2014b). New hydrologic data assimilation techniques have been developed to optimally merge information contained in simultaneous active–passive retrievals of surface soil moisture (Chen et al. 2014). Such techniques can potentially form the basis for integrating SMAP data products into next-generation streamflow forecasting systems. Results from these and other studies will elucidate which products will be most appropriate for these activities (given the spatial resolution, frequency/timing, and ease of integration into systems) and the efficiencies that can be achieved.

Because SMAP-simulated data are not suitable for testing the absolute accuracy of SMAP applications, it is being used by early adopters to study the relative impact of introducing soil moisture into some applications. For example, military maneuver planning in data-sparse regions has traditionally been based solely on climate data and a rough estimate of soil type. Early adopters associated with the U.S. Army and Marine Corps are testing the ingestion of SMAP-simulated data into military maneuver planning and ground vehicle mobility predictions (Frankenstein et al. 2015). Early adopters working with USGS as part of the Famine Early Warning Systems Network (FEWS NET) found that a water requirement satisfaction index could be reformulated to take advantage of a SMAP-like product to improve crop yield estimates (McNally et al. 2015). Simulated L-band microwave measurements have been used to assess the economic utility of these observations for drought and risk assessments by factoring in both science and societal impacts (Kumar et al. 2014a). Simulated data similar to SMAP products were used in agricultural models to show the usefulness of soil moisture for crop yield estimation at sites where the full time sequence of precipitation and other critical weather variables were not available or subject to measurements errors (El Sharif et al. 2014, manuscript submitted to *J. Hydrometeor.*) and the increase in streamflow forecast skill achievable through improved soil moisture estimation (Koster et al. 2014).

Using observations related to SMAP cal–val experiments, early adopters are verifying soil moisture and freeze–thaw analyses at a scale, resolution, and/or accuracy comparable to SMAP products. Environment Canada played a key role in the design of the SMAP Validation Experiments in 2010 and 2012 (CanEx-SM10 and SMAPVEX12), not only to assess the improvement in Canadian environmental analysis and prediction systems using SMAP-like data, but also to prepare operational program and policy users for exploitation and assimilation of SMAP products, once available (Magagi et al. 2013; McNairn et al. 2015). In the Cold Land Processes Experiment, combining the active and passive measurements like those planned for SMAP resulted in decreased errors in estimates of snow water equivalent and underlying soil freeze–thaw state (Bateni et al. 2013). The long-term soil moisture measurements of the USDA Soil Climate Analysis Network (SCAN) were used to better understand the impact of a changing climate on soil moisture for more efficient resource management and better-informed policy decisions (Hottenstein et al. 2015).

Early adopters have taken advantage of soil moisture observations derived from other orbiting sensors including the EUMETSAT Advanced Scatterometer (ASCAT), NASA Advanced Microwave Scanning Radiometer (AMSR), and the European Space Agency (ESA) Soil Moisture and Ocean Salinity (SMOS) mission. Though ASCAT, AMSR, and SMOS observations differ from SMAP products in spatial resolution, surface penetration, accuracy, and processing, they have been useful for SMAP applied research. The Masdar Institute study of dust emission in the Middle East showed that as SMOS observations of soil moisture increased, the aerosol optical thickness decreased to a threshold moisture content above which no dust emission took place. Agriculture and Agri-Food Canada (AAFC) is developing a system to integrate multisensor soil moisture data (through data intercalibration) to allow seamless use of AMSR, SMOS, and SMAP for agroclimate risk monitoring and reporting (Champagne et al. 2015). In preparing the Australian Water Resources Assessment (AWRA) system for the assimilation of SMAP data, Renzullo et al. (2014) reported that AMSR and ASCAT-derived soil moisture products improved root-zone soil moisture estimation. Satellite soil moisture measurements were used for estimating rainfall on a global scale with ASCAT, SMOS, and AMSR data to improve rainfall estimates for hydrologic applications (Brocca et al. 2014). Atmospheric and Environmental Research, Inc. (AER) created their own simulated SMAP-like daily inundation maps using AMSR for Earth Observing System (AMSR-E) data while controlling for sensitivity to permanent and transient inundation to quantify greenhouse gas emissions.

Several early adopters are conducting applied research to combine data from multiple NASA missions to a single application. For example, the City University of New York (CUNY) is working with the Naval Research Laboratory (NRL) to merge the SMAP freeze–thaw product with NASA ICESat-2 measurements of ice thickness and extent to enhance the Navy's associated operational applications. In a study of the impact of drought on crop yields, AMSR soil moisture measurements and the MODIS leaf area index product were assimilated in a crop model to show the impact of both surface and subsurface drought on crop yields, emphasizing the importance of the SMAP root-zone soil moisture product (Mishra et al. 2015).

3. Lessons learned

The SMAP Early Adopter program is a major initiative of the NASA Applied Sciences Program. The focus of this program is to facilitate the application of satellite mission products by operational users. The science data users are engaged early in the mission design and development processes of Earth science satellite missions, allowing for better preparation for eventual data delivery and the development of rapid and useful response products. The SMAP Early Adopter program not only benefits the SMAP project, but more generally, responds to 2007 NRC call to broaden community participation and improve means for dissemination and use of NASA information.

TABLE 3. Elements of demand and supply that enabled community participation in the SMAP mission planning and continuity of engagement through launch.

Early adopter demand
• A critical need that can only be met with the SMAP products
• Responsibility for a mandate that requires SMAP-like data
• A high degree of creative vision for what is possible with SMAP products
• Institutional support to prepare for launch
SMAP project supply
• Product algorithms defined
• Test bed production of simulated products
• Cal–val experiments underway, with archived data
• DAACs preparing for SMAP product access
• SMAP Applications Plan in place
• Opportunities for funding
Continuity of engagement by the SMAP project
• SMAP project contacts for early adopters from ST, SDS, and DAACs
• Quarterly teleconferences to share latest SMAP information
• SMAP applications workshops and tutorials with early adopter participation
• An outreach video to make early adopters the face of the mission
• This special collection in the *Journal of Hydrometeorology* on early adopter prelaunch research
• Quad charts providing feedback to the SMAP project

a. *Community participation in NASA missions*

There is much to be learned from the makeup of the early adopters and the circumstances that led to their interest in NASA mission products. A common distinction of all early adopters is that they had one or more of the following characteristics (Table 3):

1) A critical need that can only (or best) be met with the SMAP product. For example, assimilating SMAP soil moisture information into the USDA NASS has the potential to replace qualitative user surveys for a substantial savings to the NASS budget.
2) Responsibility for a mandate that required SMAP-like data. For example, EC, ECMWF, and NOAA are responsible for weather and climate predictions at the national and continental scale and need accurate soil moisture information to initialize their models.
3) A high degree of creative vision for what is possible with SMAP information. For example, the Willis

Group has not used satellite data in the past, but it is exploring the role of SMAP products with their clients.

4) Institutional support to prepare for launch. Funding for early adopter research has taken many forms, including internal funding and related grants.

These are some of the characteristics that define a pull organization representing the demand for NASA mission products.

Still, that was not enough to bring early adopters to the SMAP project; demand needed to be matched by supply (Table 3). When the SMAP Early Adopter program was initiated, the SMAP project had several programs and datasets in place that attracted early adopters. The SMAP mission was in phase C (design and development), so the SMAP hardware, algorithms, and products were clearly defined. The algorithm theoretical basis documents (ATBDs) were drafted, and the SMAP Science Data System (SDS) test bed was in place to make high-fidelity simulated data products available (listed in Table 1). The Alaska Satellite Facility (ASF) and the National Snow and Ice Data Center (NSIDC) DAACs had been selected for the SMAP mission and were preparing for SMAP product visualization and access. Some SMAP-sponsored field campaigns were completed and others were ongoing, with field data archived to the DAAC within months of the experiment. The NSIDC DAAC utilized its established systems to make SMAP-simulated products and cal–val data accessible to early adopters. The SMAP Science Definition Team had already engaged users related to SMAP products, algorithms, and cal–val through the SMAP working groups. In addition to this maturity of SMAP science and engineering, the SMAP Applications Plan was also in place. The SMAP project secured a SMAP Applications Coordinator to plan workshops, tutorials, and focus sessions providing mission information to potential users (Brown et al. 2013).

With this state of the mission, early adopters considering a proposal could rely on access not only to simulated SMAP products and cal–val data, but also to assistance from the SMAP Science Team (ST), the SMAP Applications Coordinator, the SDS, and the DAACs. It was this high level of support that convinced early adopters they could invest their time and funds on a worthwhile project. Further, on both sides of the early adopter agreement, expectations were clear. The SMAP project was aware that most early adopters were constrained by the requirement to expend their own resources for this activity, without additional funding from NASA. The early adopters were aware that the primary goal of the SMAP project was to design and launch the mission, and applications needs would be accommodated within that constraint. Clearly defined expectations on both sides were attractive to both early adopters and mission planners.

b. *Success of community participation in NASA mission*

By definition, a successful early adopter will complete a planned (or contingent) project with quantitative metrics that are beneficial to both themselves and the mission. Assuming the early adopter has one or more of the characteristics listed above (1–4), the success of the proposed activity is arguably based on only one thing—continuity of engagement by the SMAP project.

Continuity of engagement by the SMAP project is designed to develop the early adopters and the project into a single community with the functioning of a team. At quarterly teleconferences of early adopters and the SMAP project, we share the latest SMAP information, answer questions, and arrange for early adopters to share latest research results with web-enabled presentations. The early adopters are included in planning and presentations at annual SMAP Applications workshops and tutorials. Recently, an outreach video was produced with interviews of early adopters to inspire new SMAP users and cultivate broad community support for the SMAP mission (https://smap.jpl.nasa.gov/applications/). In this way, the early adopters have become the face of the mission at most events.

Continuity of engagement in the SMAP Early Adopter program before launch is a mix of opportunities and responsibilities. For early adopters, opportunities included the SMAP Special Collection published in the *Journal of Hydrometeorology*, and responsibilities included reports in the form of quad charts outlining objectives, methods, status, schedule, and issues, which allowed the project to be responsive to feedback and problems. The SMAP project had the opportunity to receive valuable feedback from early adopters' research and was responsible for providing timely responses to their needs. The SMAP project response to early adopters' requests is organized to be most effective for the early adopter and least burdensome to the SMAP project. Each early adopter is coupled with a SMAP Science Team Contact who provides personal help when necessary (Table 2). Specific contacts for the early adopters have been identified related to SMAP algorithms, the SDS, and the DAACs. The SDS and DAAC contacts have been particularly important because a complete understanding of, and easy access to, data are key to early adopters' success. By spreading the load across the whole project, it is not a massive effort to accommodate the needs of the early adopters.

Given that continuity of engagement has been identified here as the key to success, the importance of funding cannot be overlooked and deserves mention. The SMAP Early Adopter program is a nonfunded activity. Early adopters sign an agreement with the SMAP project and NASA ASP to apply their own resources to demonstrate the utility of SMAP data for their particular system or model. In some cases, being a part of the SMAP Early Adopter program has influenced funding for early adopters in the form of internal support and external grants. This emphasis on self-funded research ensures that the organizations that become early adopters are motivated to incorporate SMAP data and are not required to go through a peer-review research proposal process that often is not a priority for these organizations.

c. *Applications value in mission planning*

Much of the benefit of the SMAP Early Adopter program to the SMAP project was covered by previous discussion, including the fundamental knowledge published in this Special Collection. In fact, it is too early to tell what the benefits will be. The SMAP Early Adopter program will be evaluated with qualitative and quantitative metrics after launch. For now, anecdotal feedback dominates the description of the application value to the mission, as do specific complaints. A few examples are given here.

1) HOW HAVE EARLY ADOPTERS BENEFITED NASA AND THE SMAP PROJECT?

The applied research by AER on the use of SMAP-derived inundation and soil moisture estimates in the quantification of biogenic greenhouse gas emissions is a good example for describing benefits of the SMAP Early Adopter program. The feedback to the SMAP project is that the SMAP 3-day revisit reduced local uncertainty in inundation algorithms, a long time series is needed to calibrate empirical inundation algorithms, and maps of permanent wetlands and water bodies are needed to optimize models using soil moisture. Similarly, the National Drought Mitigation Center applied research-provided guidance to the SMAP project about the type of soil moisture anomaly metrics that need to be summarized for drought monitoring applications. Applied research by the Department of Defense provided information on how latency is related to errors in prediction of Army and Marine Corps mobility assessment.

Many early adopters provided information to the DAACs about the data format that would be most useful for applications. For example, the NSIDC DAAC added the easy-to-read Keyhole Markup Language (KML) format as a standard product based on specific early adopter requests. Experience proved that including the DAAC as early as possible in the process of mission planning boosted prelaunch interest in the mission and supported prelaunch applied research. In fact, including the DAAC in the SMAP Early Adopter program is key to success because 1) early adopters have easy access to data with the same interface they will use postlaunch; 2) the DAAC has a longer run-up to prepare the mission interface using simulated products, with prelaunch guidance from both the project and the users; and 3) the SMAP project and NASA ASP receive valuable prelaunch feedback on mission products and formats for user applications.

The early adopters also provide an intangible benefit to the SMAP project in the form of local perspective on a global mission. Though many early adopters work at the continental scale, they have users at the local scale. These are the user's users who provide information to the project on small, perhaps overlooked anomalies. Many of the early adopters have progressed so far in their value-added products that the SMAP project sees them as providers themselves with a set of users. For example, Exelis Visual Information Solutions has developed commercial software for their users to project SMAP level 1–3 (L1–L3) products with other data in the IDL MAP and IMAGE functions.

2) HOW HAS THE SMAP EARLY ADOPTER PROGRAM BENEFITED EARLY ADOPTERS?

The SMAP Early Adopter program is expected to prepare users for postlaunch application of SMAP products. Of the 18 early adopters selected in the first rounds of nominations in 2011 and 2012, 8 have tested the ingestion of SMAP-simulated data into their operational systems and 9 submitted applied research results to this Special Collection. Of the 12 early adopters selected in 2013 and 2014, 3 have already tested the ingestion of SMAP-simulated data, and 2 have completed sufficient applied research to offer guidance to the project. Of the 37 early adopters, 12 have adapted their systems to ingest SMOS data for testing the utility of SMAP-like products in their operations. Two national soil moisture monitoring agencies—Canada's AAFC and USDA NASS—have developed operational prototypes for integrating SMAP soil moisture products into existing monitoring programs, and several other early adopters expect to have prototype systems in place by launch. These examples, and the applied research reported here, are tangible metrics of the value of providing SMAP-simulated and cal–val data to users prelaunch. Based on these deliverables, it is clear that the 2011/12 early adopters have met and exceeded prelaunch expectations, and the 2013+ early adopters are making progress and contributing to the mission.

4. Path forward

Considering this momentum and contribution to NASA and the SMAP project, a plan is now in place to continue the SMAP Early Adopter program from launch through the life of the mission (termed phase E or the Operations Phase). Phase E activities are partly determined by the schedule for SMAP cal–val and product release. During the first 3 months after launch (i.e., the in-orbit commissioning), the instruments may only be operating intermittently and no science data will be available for the user community. Corresponding with the SMAP plan for calibration and validation, the product release to the general public via the DAAC is phased so that Beta L1 products are available 6 months after launch, Beta L2–L4 products and validated L1 products are available 9 months after launch, and validated L2–L4 products are available 15 months after launch.

The SMAP project will continue to provide SMAP-simulated data to early adopters through the NSIDC DAAC until SMAP Beta products are released to the general public via the DAAC. In phase E, early adopter proposals will be reviewed with the same rigorous selection criteria and process that has been in place prelaunch, as described previously. Under very limited circumstances, access to pre-Beta-release products will be provided to select early adopters during the period before Beta products are released to the general public via the ASF and NSIDC DAACs. The selection process will be based on an early adopter request to be reviewed by the SMAP Applications Team on a case-by-case basis.

A report on the SMAP Early Adopter program and contributions of case studies, statistics of use, and a description of the expansion of the community using SMAP data will be submitted for the Senior Review after the end of the primary 3-yr science mission. The early adopters will play a role in the report by 1) providing feedback to the project on the usefulness of the data and the SMAP Early Adopter program and 2) participating in cost–benefit research conducted by the project (Brown and Escobar 2014).

5. Concluding remarks

The NASA Applied Sciences Program is committed to engaging users in the planning for future Earth-observing satellites, envisioning potential applications early on, and further enhancing the value of each satellite mission. The SMAP project and NASA ASP have made an effort to go beyond exploratory science and system engineering in mission planning by including users in prelaunch research. The result has been an unprecedented prelaunch preparation for SMAP applications ranging from client surveys to prototype visualization software and operational systems. This work put faces to the general societal issues originally identified by the NRC Decadal Survey in their recommendation of the SMAP mission. The applied research results presented in this Special Collection provide a jump start to application of SMAP products that will begin soon after launch.

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