In Situ Validation of the Soil Moisture Active Passive (SMAP) Satellite Mission

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Abstract-SMAP is a new NASA mission proposed for 2014 that would provide a number of soil moisture and freeze/thaw products. The soil moisture products span spatial resolutions from 3 to 40 km. In situ soil moisture observations will be one of the key elements of the validation program for SMAP. Data from the currently available soil moisture observing sites are not adequate and will require improvement if they are to be useful. Problems include i) a lack of standardization of instrumentation and installation and ii) the disparity in spatial scale between the point-scale in situ data (a few centimeters) and the coarser satellite products. SMAP has initiated activities to resolve these issues for some of the existing resources. The other challenge to soil moisture validation is the need to expand the number of sites and their geographic distribution. SMAP is attempting to increase the number of sites and their value in validation through collaboration. An overview of SMAP validation and specific issues and solutions involving in situ observations will be described.

Keywords: Soil moisture, validation, in situ, microwave

1. OVERVIEW OF SMAP CAL/VAL

Soil Moisture Active Passive (SMAP)* is a proposed NASA satellite being planned for launch in 2014 (Entekhabi et al., 2010). SMAP will provide global measurements of surface soil moisture and freeze/thaw state. The high accuracy, resolution, and global coverage provided by SMAP measurements will serve science and applications. Disciplines include hydrology, climate, and carbon cycle, and the meteorological, agricultural, environmental, and ecological communities. SMAP will achieve its objectives by combining L-band passive and active microwave observations. Here we will only discuss the soil moisture component of the mission. SMAP will build from previous missions that include SMOS (Kerr et al., 2010) and Aquarius (LeVine et al., 2010). The new contribution of SMAP is a significantly higher resolution global 9 km soil moisture product. There is the potential that this could be improved to 3 km for some regions if efforts to develop robust radar algorithms are successful.

The SMAP mission science requirements include specifications on accuracy, spatial resolution, and temporal revisit for the soil moisture measurements, and mission duration, for both a baseline and a minimum mission. The requirements also call for a validation plan that minimizes and assesses random errors and spatial and temporal biases in the estimates.

*The SMAP mission has not been formally approved by NASA. The decision to proceed with the mission will not occur until the completion of the National Environmental Policy Act (NEPA) process. Material in this paper related to SMAP are being made available for information purposes only.

The SMAP Cal/Val Plan (Jackson et al., 2010) includes pre-launch and post-launch activities starting in Phase A and continuing after launch and commissioning through the end of the mission (Phase E). The objectives in these phases are:

- Pre-Launch:
  - Acquire and process data with which to calibrate, test, and improve models and algorithms used for retrieving SMAP science data products;
  - Develop and test the infrastructure and protocols for post-launch validation; this includes establishing an in situ observation strategy for the post-launch phase.
- Post-Launch:
  - Verify and improve the performance of the science algorithms;
  - Validate the accuracy of the science data products.

To satisfy these objectives, four types of resources will be utilized; 1) in situ observations, 2) products from related satellite observing systems, 3) model products, and 4) field campaigns. Since SMAP is currently in the early pre-launch phase (Phase B), the major concerns of Cal/Val are on providing data sets for algorithm development and establishing the infrastructure for in situ validation. Several recent activities that the project has initiated involving in situ observations and field experiments will be described.

2. ROLE OF IN SITU OBSERVATIONS IN SMAP SOIL MOISTURE VALIDATION

In situ soil moisture observations will be important in validating science products from the SMAP mission. These data will also be valuable throughout the development phase of the mission to support field campaigns, modeling, and synergistic studies using currently available satellite systems such as SMOS and Aquarius. Of particular value to SMAP are existing resources that are expected to continue through its life span in orbit (2014 through 2017).

An ideal in situ soil moisture resource would include a verified surface layer observation (5 cm soil depth), the 0-100 cm profile moisture, a spatial domain approximately the size of the retrieval footprint (3, 10, and 40 km) with replication of measurements, real time availability on a public server, and additional meteorological measurements with coverage over numerous domains in a variety of climate/geographic regions. Few currently available resources meet all these requirements, especially as stand-alone networks.

Recognizing the limitations of the project resources and the characteristics of the existing in situ observing networks, SMAP initiated several activities that would lead to a more accurate and robust in situ observing component of its soil moisture product validation. These activities, described below, have included i) establishing an in situ sensor testbed to facilitate the integration of data provided by different sensors and installation, ii) initiating an evaluation of scaling techniques, and iii) developing a program for collaboration.

2.1. In Situ Sensor Testbed (ISST)

A testbed was established to test and calibrate various soil moisture probes provided by different manufacturers, which utilize different measurement techniques.. Specifically, the SMAP In Situ Sensor Testbed (ISST) will provide answers to the following set of questions: (1) How do different soil moisture sensors perform given the same hydrologic inputs of rainfall and evaporation? (2) How do different sampling intervals impact the soil moisture estimates, given instantaneous measurements versus time averaged measurements? (3) How do the orientations of installation influence the data record and effectiveness of the sensor? (4) How can networks which measure soil moisture by different fundamental methods (capacitance, FDR, TDR, reflectometry) be compared to a standard of thermo-gravimetric validation? (5) How the measurements from different sensors with different sampling scales, particularly the COSMOS and GPS systems, of soil moisture monitoring, compare given the variation in scale of measurement? Answering these questions is important for establishing a standard for soil moisture measurement at in situ sites across the globe.

The site has been developed in Marena, Oklahoma. The landscape of the site is characterized as rangeland and pasture. The site consists of four separate sets of installations situated around a central location. Each subsite has a full set of soil moisture sensors for replication. In addition to these in situ observations, intensive campaigns using thermo-gravimetric soil sampling and vegetation sampling is ongoing to facilitate calibration and scaling.

2.2. Evaluation of Scaling Methodologies: Matching Sparse Points to Coarse Resolution Footprints

Up-scaling is a key issue in utilization of in situ measurements for calibration and validation. Therefore, one of the pre-launch cal/val objectives for SMAP is to define a standard methodology for transferring point-wise ground measurements of in situ resources to SMAP footprint scales. A working group has been established to conduct a systematic assessment of techniques. To start, the working group is producing a white paper summary (Crow et al., 2011) with analysis of methodologies summarized in a public white paper put together by the working group. The white paper provides a review of currently available techniques for either (1) reducing the up-scaling error associated with characterizing a SMAP footprint using sparse, ground-based, surface soil moisture observations or (2) estimating the magnitude of soil moisture up-scaling error so that it can be compensated for in direct comparisons between SMAP soil moisture retrievals and sparse, ground-based observations. This analysis will be complemented and verified with a temporary in situ network deployed around selected measurement points. Furthermore, the field campaigns will contribute by providing high-resolution (compared to the satellite footprint) airborne mapping of the footprint scale in situ resources, which adds an intermediate step to the up-scaling analysis.

2.3. Engaging Partners in In Situ Validation

As stated earlier, ground-based or in situ observations are one of the resources that will be employed in SMAP validation. Establishing, calibrating, and maintaining a robust and globally distributed network of in situ instrumentation will be essential to the success of the SMAP Cal/Val program. Recognizing the breadth of issues involved in acquiring these data, the SMAP project will attempt to achieve its objective through partnerships with complementary operational and research programs around the globe. This will include in situ soil moisture, surface and air temperature, CO^2 flux and land surface characteristics observations and in addition, aircraft and/or tower-based L-band microwave measurements taken as part of an ongoing measurement program at these in situ sites are welcome, especially data from instrument systems currently deployed in support of SMOS.

A no-cost solicitation for participation in the calibration and validation Cal/Val program SMAP through contributions that include in situ observations supporting SMAP mission products was issued by NASA with a closing date of March 1, 2011. Specific guidelines and general requirements were provided in the solicitation. Selected teams will enter into a partnership arrangement in which the partner provides SMAP with timely information for assessing mission performance and product quality. In return, SMAP will provide mission products to the partners during the SMAP Cal/Val phase, prior to general public release of the data, as well as over the entire mission life.

3. FIELD CAMPAIGNS

In order to provide observational data for algorithm development, parameterization and validation, field campaigns employing in situ, tower-based, airborne, and spaceborne measurement systems will be utilized. In addition to activities designed in collaboration with SMAP, data from experiments sponsored by other missions and activities will be exploited if possible. This section summarizes pre-launch campaigns which have components matching the SMAP algorithm pre-launch needs. This set of campaigns will ensure that required data is available to complete the pre-launch validation of algorithms. Of particular significance is the SMAPVEX12 experiment, which is a campaign dedicated to resolve any outstanding (soil moisture) SMAP algorithm issues. Post-launch field campaigns will be carried out as well.

3.1. SMAPVEX08 (East Coast, USA)

SMAPVEX08 was the first field campaign dedicated to resolving SMAP algorithm issues. This experiment took place on the East coast of US in the fall of 2008. In addition to the addressing open algorithm issues, the campaign had a major focus on questions related to radiofrequency interference (RFI).

3.2. CanEx-SM10 (Canada)

NASA flew the airborne UAVSAR instrument in conjunction with the Canadian CanEx-SM10 SMOS soil moisture validation field experiment in Saskatchewan province in June 2010. The campaign included airborne radiometer measurements and in situ sampling over four individual SMOS pixels.

3.3. SMAPEx (Australia)

The Universities of Melbourne, Monash and Adelaide in Australia organized an experiment designed to observe agricultural conditions during different seasons. These campaigns included coincident radiometer and radar measurements with ground observations to support the development of the active/passive soil moisture retrieval and downscaling algorithms. Two campaigns were successfully completed in July and December 2010. A final campaign is planned for September 2011.

3.4. San Joaquin Valley Experiment (West Coast, USA)

The UAVSAR instrument will be deployed for San Joaquin Valley experiment on several days in 2010-2011. The primary objective of the experiment is to develop Vegetation Water Content (VWC) retrieval from optical remote sensing instruments. However, the experiment lends itself also for investigation of the effects of different types of vegetation on the radar-based soil moisture retrieval algorithm, since the experiment includes the UAVSAR instrument. The experiment sites include canopies of almond and pistachio trees (in addition to wheat and cotton), which provide a rare opportunity to gather data for these types of landscapes.

3.5. SMAPVEX12

A major field campaign dedicated to calibration and validation of SMAP soil moisture products is planned to be carried out in North-America during 2012. The location and design of this campaign will be resolved at a workshop in May 2011. The airborne instrumentation will include at least airborne L-band radar and radiometer; possibly PALS and UAVSAR. This campaign will also serve as a dry run for the post-launch validation in 2015.

CONCLUSIONS

The key elements of the soil moisture product calibration and validation of NASA's SMAP mission in pre- and post-launch phases were outlined. The currently on-going activities include an In Situ Sensor Testbed, ground-truth up-scaling investigation, engagement of partners for in situ validation, and conducting field campaigns. These activities address issues related to algorithm development and calibration, and establishment of post-launch validation infrastructure which are the key objectives at this stage of the SMAP Cal/Val activities.

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