Soil Moisture Active Passive (SMAP) Mission

Science Data Calibration and Validation Plan

Tom Jackson
United States Department of Agriculture

Andreas Colliander
Jet Propulsion Laboratory, California Institute of Technology

John Kimball
University of Montana

Rolf Reichle
NASA Goddard Space Flight Center

Wade Crow
United States Department of Agriculture

Dara Entekhabi
Massachusetts Institute of Technology

Peggy O'Neill
NASA Goddard Space Flight Center

Eni Njoku
Jet Propulsion Laboratory, California Institute of Technology

JULY 6, 2012
JPL D-52544

Jet Propulsion Laboratory
California Institute of Technology

CONTENTS

1 INTRODUCTION AND SCOPE

1.1 Purpose

This document describes the plan for calibrating and validating Level 1 through Level 4 science data products of the Soil Moisture Active and Passive (SMAP) Mission. The SMAP Calibration and Validation (Cal/Val) Plan is the basis for implementation of the detailed set of calibration and validation activities that take place during the SMAP mission lifetime.

1.2 Scope and Objectives

SMAP is one of four missions recommended by the National Research Council's Committee on Earth Science and Applications from Space for launch in the 2010 to 2013 period [1]. 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 that include hydrology, climate, and carbon cycle, and the meteorological, agricultural, environmental, and ecological applications communities.

SMAP mission science requirements are contained in the Level 1 science requirements document: Science Requirements and Mission Success Criteria (SRMSC) [2]. Included in this document are requirements for accuracy, spatial resolution, and temporal revisit for the soil moisture and freeze/thaw measurements, and mission duration, for both baseline and minimum missions (Section 2.2). Also stated in the SRMSC is the requirement that a Calibration and Validation Plan be developed and implemented to minimize and assess random errors and spatial and temporal biases in the soil moisture and freeze/thaw estimates, and that the SMAP validation program shall demonstrate that SMAP retrievals of soil moisture and freeze/thaw state meet the stated science requirements.

The SMAP Cal/Val Plan 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 scope of the Cal/Val plan is the set of activities that enable the pre-and post-launch Cal/Val objectives to be met.

- The Pre-Launch objectives of the Cal/Val program are to:
  - 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.
- The Post-Launch objectives of the Cal/Val program are to:
  - Verify and improve the performance of the science algorithms;
  - Validate the accuracy of the science data products.

1.3 Roles and Responsibilities

The SMAP Cal/Val Plan is developed and implemented by the SMAP Cal/Val Team, which includes members of the Science Definition Team (SDT), the Core and Contributing Validation Sites, and members of the Project Science and Science Data System staff at JPL and GSFC. The SMAP Cal/Val Plan will be developed taking into consideration a broad range of inputs and contributions from the U.S. and international communities, including Cal/Val plans of other microwave remote sensing missions related to the hydrology and ecology disciplines.

1.4 Document Overview

Section 1 provides introductory information on scope and contents.
Section 2 provides an overview of SMAP science objectives, data products, and mission operations.
Section 3 provides an overview of methodology relevant to the SMAP calibration and validation planning.
Section 4 presents the requirements for the Cal/Val activities identified by the science products and their ATBDs.
Section 5 describes details of planned pre-launch SMAP Cal/Val activities.
Section 6 describes details of planned post-launch SMAP Cal/Val activities.
Section 7 describes international Cal/Val coordination, including data availability, access, and exchange.
Section 8 describes the SMAP SDT Cal/Val Working Group.
Section 9 provides a list of references and sites for further information.

1.5 Cal/Val Program Deliverables

The deliverables of SMAP Cal/Val Program fall in the following six categories:

(1) SMAP Science Cal/Val Plan document;
(2) Implementation plans for identified pre- and post-launch field campaigns;
(3) Reports documenting results, archival, and analyses of pre-launch field campaigns and data acquisitions;
(4) Beta Release and Validation report for L1 data accompanying archived data (at IOC plus three and six months, respectively);
(5) Beta Release and Validation report for L2-L3 data accompanying archived data (at IOC plus three and twelve months, respectively);
(6) Validation report for L4 data (accompanying archived data at post-IOC plus twelve months).

2 SCIENCE AND MISSION OVERVIEW

2.1 Science Objectives

SMAP is a spaceborne Earth observation mission designed to measure surface soil moisture and freeze/thaw state (together termed the hydrosphere state). SMAP hydrosphere state measurements will yield a data set that 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

The SMAP mission is designed to validate a space-based measurement approach that could be used for future systematic hydrosphere state monitoring missions.

2.2 Science Requirements

The SMAP Level 1 science requirements are the basis for achieving the science objectives of the mission. These requirements are described in the Level 1 Science Requirements and Mission Success Criteria (SRMSC) document [2].

2.2.1 Measurements

The Level 1 'Baseline' and 'Minimum' SMAP science requirements are summarized in Table 2-1. The requirements are derived from science assessments, reviewed in a series of NASA and community workshops [3]. The requirements rationales are summarized in SMAP Science Document [4]. Note that for practical reasons the 10 km resolution requirement was translated to 9 km grid resolution for Level 2 through L4 soil moisture products.

The requirements listed in Table 2-1 are to be met over land areas identified by the regions shown in Figure 2-1 and Figure 2-2.

Table 2-1. SMAP Level 1 Science Requirements Summary

Requirement	Baseline Mission		Minimum Mission	
	Soil Moisture	Freeze/ Thaw	Soil Moisture	Freeze/ Thaw
Resolution	10 km	3 km	10 km	10 km
Refresh Rate	3 days	2 days[(1)]	3 days	3 days[(1)]
Accuracy	0.04 m^3/m^3[(2)]	80%[(3)]	0.06 m^3/m^3[(2)]	70%[(3)]
Duration	36 months		18 months	

[(1)]North of 45°N Latitude
[(2)] volumetric water content, standard deviation (1-sigma)
[(3)] % classification accuracy (binary: Freeze or Thaw)

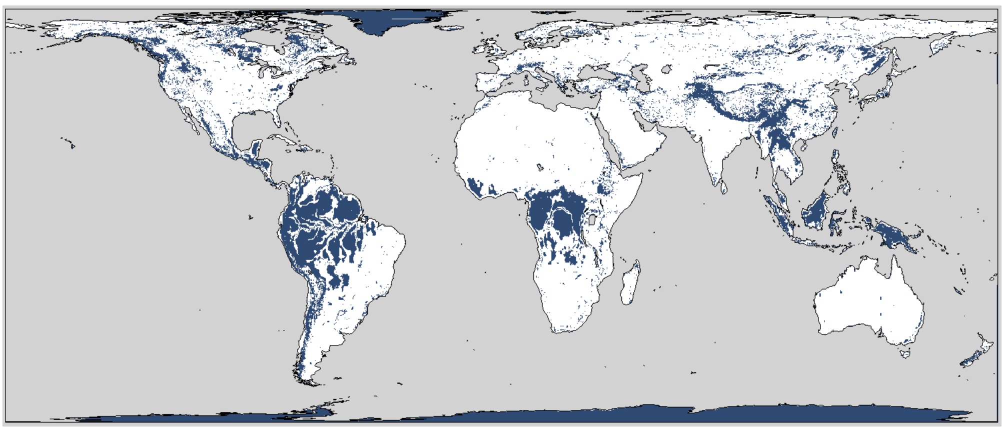


Figure 2-1. Regions of coverage (white areas) where soil moisture requirements are to be met.

Figure 2-2. Regions of coverage (white areas) where freeze/thaw requirements are to be met.

2.2.2 Data Delivery

SMAP requirements are that the SMAP project shall begin the first release of validated Level 0 and Level 1 instrument data products (Section 2.4) to the public no later than six months after the end of the In-Orbit Check-out (IOC) phase (Section 2.6). Before releasing the first version of the validated data, a beta data product version will be released.

Similarly, no later than twelve months after the end of the IOC phase the SMAP project shall begin the first release of validated Level 2 to Level 4 geophysical data products to the public. Before releasing the first version of the validated data, beta data product version will be released. The final processed mission data set shall be available for delivery to the public within one month after the end of the mission (Level 3 Mission System Requirements).

2.3 Mission Implementation Approach

2.3.1 Requirements Flow-Down

The SMAP Level 1 requirements are traced to Level 2 science requirements as shown in Table 2-2.

Table 2-2. SMAP Requirements Traceability Matrix

Science Objectives	Scientific Measurement Requirements	Instrument Functional Requirements	Mission Functional Requirements
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: ~0.04 m^3/m^3 accuracy in top 5 cm for vegetation water content < 5 kg m^{-2}; Hydrometeorology at 10 km; Hydroclimatology at 40 km	L-Band Radiometer: Polarization: V, H, U; Resolution: 40 km; Relative accuracy*: 1.5 K L-Band Radar: Polarization: VV, HH, HV; Resolution: 10 km; Relative accuracy*: 0.5 dB for VV and HH Constant incidence angle** between 35° and 50°	Data Center data archiving and distribution. Validation program. Integration of data products into multisource land data assimilation.
	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: 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 Global, 3-4 day revisit; Boreal, 2 day revisit	Swath Width: 1000 km Minimize Faraday rotation (degradation factor at L-band)	Orbit: 670 km, circular, polar, sun-synchronous, ~6am/pm equator crossing
	Observation over a minimum of three annual cycles	Minimum three-year mission life	Three year baseline mission***

* Includes precision and calibration stability, and antenna effects
** Defined without regard to local topographic variation
*** After completion of the in-orbit check-out phase

2.3.2 Measurement Approach

The SMAP measurement configuration is shown in Figure 2-3. Key features of the system are provided in Table 2-3.

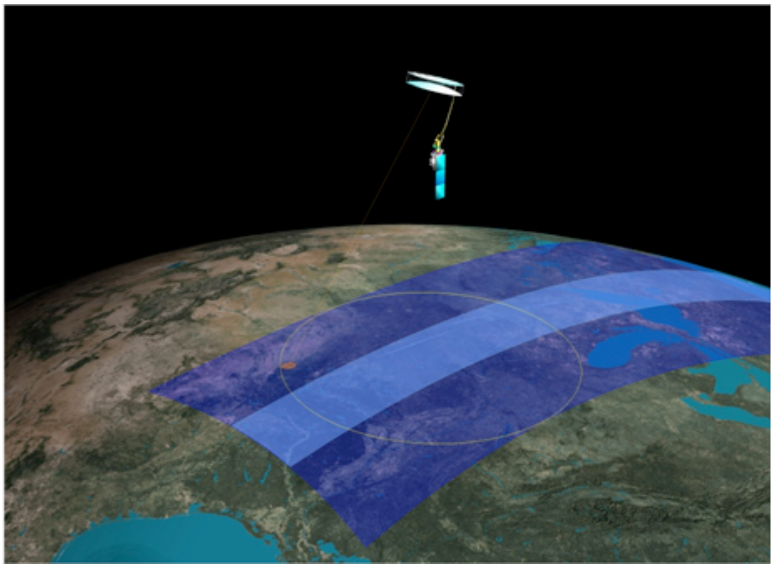


Figure 2-3. SMAP measurement system indicating conical scan and wide swath.

Table 2-3. Key Measurement System Characteristics

Radar:
- L-band (1.26 GHz); HH, VV, HV
- High resolution, moderate accuracy soil moisture
- Freeze/thaw state detection
- 3 km SAR resolution
- 30 x 6 km real-aperture resolution

Radiometer:
- L-band (1.4 GHz); H, V, U
- Moderate resolution, high accuracy soil moisture
- 40 km resolution

Shared Antenna:
- 6-m diameter deployable mesh antenna
- Conical scan at 14.6 rpm
- Constant incidence angle of 40 degrees

Orbit:
- Sun-synchronous, 6 am/pm orbit
- 670 km altitude
- 1000 km-wide swath
- Swath and orbit enable 2-3 day revisit

Mission Operations:
- 3-year baseline mission

2.4 Science Data Products

The SMAP science requirements will be met by generating the data products listed in Table 2-4. The data products will be generated by the SMAP Science Data System (SDS) (Section 2.5).

Science software for the data products will be developed using a set of algorithms described in the Algorithm Theoretical Basis Documents (ATBDs). There will be one ATBD for each science data product.

Table 2-4. List of SMAP Science Data Products.

Data Product Short Name	Short Description	Spatial Resolution	Grid Spacing	Latency*
L1A_Radar	Radar raw data in time order	NA	NA	12 hours
L1A_Radiometer	Radiometer raw data in time order	NA	NA	12 hours
L1B_S0_LoRes	Low resolution radar σ_o in time order	5x30 km	NA	12 hours
L1B_TB	Radiometer T_B in time order	40 km	NA	12 hours
L1C_S0_HiRes	High resolution radar σ_o (half orbit, gridded)	1x1 km to 1x30 km	1 km	12 hours
L1C_TB	Radiometer T_B (half orbit, gridded)	40 km	36 km	12 hours
L2_SM_A**	Soil moisture (radar, half orbit)	3 km	3 km	24 hours
L2_SM_P	Soil moisture (radiometer, half orbit)	40 km	36 km	24 hours
L2_SM_A/P	Soil moisture (radar/radiometer, half orbit)	9 km	9 km	24 hours
L3_F/T_A	Freeze/thaw state (radar, daily composite)	3 km	3 km	36 hours
L3_SM_A**	Soil moisture (radar, daily composite)	3 km	3 km	36 hours
L3_SM_P	Soil moisture (radiometer, daily composite)	40 km	36 km	36 hours
L3_SM_A/P	Soil moisture (radar/radiometer, daily composite)	9 km	9 km	36 hours
L4_SM	Soil moisture (surface & root zone)	9 km	9 km	7 days
L4_C	Carbon net ecosystem exchange (NEE)	9 km	1 km	14 days

* SMAP L2 science requirements. Mean latency under normal operating conditions. The SMAP project will make a best effort to reduce these latencies

** Research products (archival at discretion of project)

Implementation of this Cal/Val Plan will provide documented assessments of the random errors and regional biases in the science data products, and verification that the accuracies of the soil moisture and freeze/thaw estimates of these products meet the SMAP mission science requirements and objectives.

2.5 Science Data System (SDS)

The functional architecture of the SMAP Science Data System is shown in Figure 2-4. The SDS supports Cal/Val, by providing analysis tools that enable generation and assessment of quality indicators from specified products and by accommodating special data processing needs. External ancillary data including Cal/Val data from field campaigns, in situ networks, and special target data sets provided by the Science Team are ingested into the Cal/Val Database on SDS Testbed (see Section 5.4.2) and SDS Life-of-Mission (LOM) storage. Initially, the SDS science product data processing is done with the prelaunch parameter sets and algorithms. Derivation of new sets of processing parameters and their evaluation are performed using the SDS Testbed. The SDS supports both the Cal/Val phase and the routine observations phase (see Section 2.6), which involve extended monitoring and data evaluations through the life of the mission.

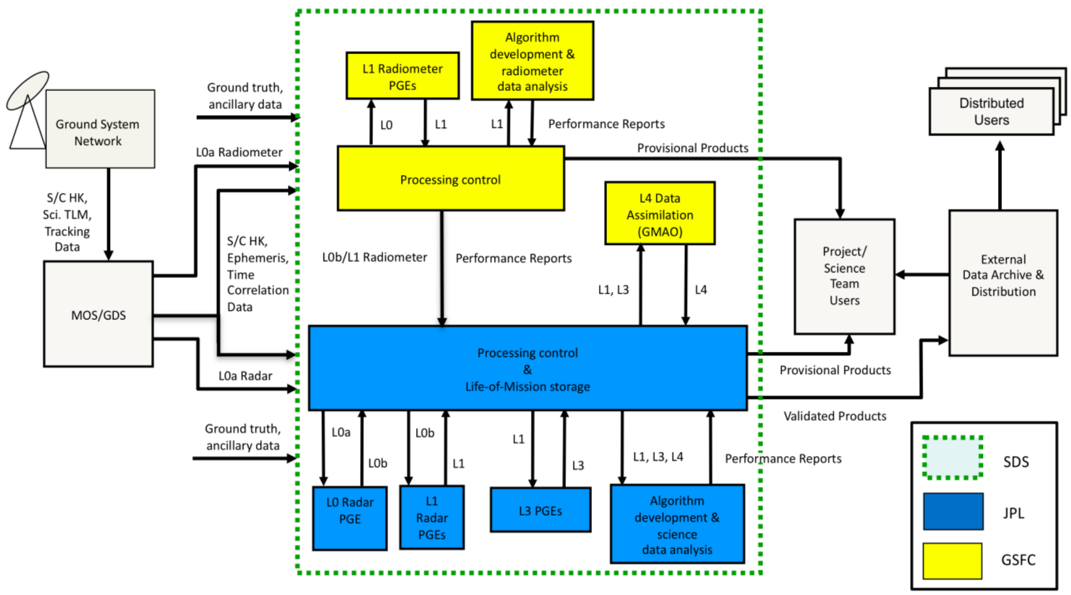


Figure 2-4. SMAP Science Data System Architecture

2.6 Mission Operations

The SMAP *Science Observation Phase (SOP)* follows the 90-day *In-Orbit Check-out (IOC) phase*, and extends for the duration of the science mission (baseline three years). During the SOP, routine global data coverage and low-loss data delivery are provided to meet the primary science mission objectives.

The first part of the SOP is the *Calibration and Validation (Cal/Val) Phase*, which extends for twelve months after IOC and includes intensive sensor calibration, special field campaigns, data acquisitions, intensive analysis and performance evaluation of the science algorithms and data product quality.

The *Routine Observations Phase* follows the Cal/Val Phase, during which routine science data processing and data quality assessments will be performed. Continued Cal/Val activities will occur during this phase but are focused primarily on monitoring and fine-tuning the quality of the science data products. This may lead to Science Team recommendations for algorithm upgrades and reprocessing if they are necessary and within the available mission resources.

2.6.1 Calibration and Validation (Cal/Val) Phase

The first part of the Science Observation Phase will be devoted to a period of Calibration and Validation of the L0-L4 data products.

During the Cal/Val phase, the Science Team evaluates the accuracy and quality of the data products generated by the SDS, following the protocols stated in the Cal/Val plan. The L0 and L1 product Cal/Val will include verifying that the geolocated brightness temperatures and radar backscatter values align to known terrestrial features such as coastlines, islands and other significant topographical features. Natural targets with relatively stable microwave and known characteristics (such as cold sky, tropical forest, and ice sheets) will be used to assess the precision and calibration bias stability of the instrument. This activity validates instrument pointing, radiometer and radar operation, and the L0 and L1 data processing. During L0-L1 Cal/Val, terrestrial radio frequency interference (RFI) in the instrument data will be evaluated to confirm the effectiveness of both flight system and ground processing mitigations. The L2-L4 Cal/Val will include validation using terrestrial in situ sensor data, airborne microwave sensor data, special field campaign in situ data collections, comparisons with other mission sensor data, such as the European Space Agency's (ESA's) Soil Moisture and Ocean Salinity (SMOS) mission and the NASA Aquarius mission, numerical model output data, and data assimilation approaches.

SMAP is required to begin delivering calibrated and validated L1 science products to a NASA-designated and funded Data Center within six months after the completion of IOC. The beta release of L1 data products is to be delivered 3 months after IOC. Validated L2-L4 science products are required to be available for delivery to the Data Center within twelve months after the IOC. The beta release of L2 data products is to be delivered 3 months after IOC At the end of the L0-L1 and L2-L4 calibration activities, the previously collected data will be reprocessed using the calibrated/validated algorithms, so that they become part of a consistently processed total mission data set. The Data Center is responsible for permanent archiving and public distribution of the SMAP data products.

2.6.2 Routine Observations Phase

During the Routine Observations Phase, the instrument and science data product performances are regularly monitored for long-term trend analysis and re-calibration. The trend analyses will be based on comparisons of the science data products against routinely available data from in situ networks and calibration monitoring sites. Derivation of new sets of processing parameters and algorithm upgrades will be done and implemented on the SDS as directed by the Science Team. The total number of supported reprocessing of the mission data is three.

3 OVERVIEW OF VALIDATION METHODOLOGY

3.1 Background

In developing the Cal/Val plan for SMAP there are precedents and experiences that can be utilized. The Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV) [5] has established standards that may be used as a starting point for SMAP. The Land Products Sub-Group [6] has expressed the perspective that "A common approach to validation would encourage widespread use of validation data, and thus help toward standardized approaches to global product validation. With the high cost of in situ data collection, the potential benefits from international cooperation are considerable and obvious".

Cal/Val has become synonymous in the context of remote sensing with the suite of processing algorithms that convert raw data into accurate and useful geophysical or biophysical quantities that are verified to be self-consistent. Another activity that falls in the gray area is vicarious calibration, which refers to techniques that make use of natural or artificial sites on the surface of the Earth for the post-launch calibration of sensors.

A useful reference in developing a validation plan is the CEOS Hierarchy of Validation [6]:

- Stage 1: Product accuracy is assessed from a small (typically < 30) set of locations and time periods by comparison with in-situ or other suitable reference data.
- Stage 2: Product accuracy is estimated over a significant set of locations and time periods by comparison with reference in situ or other suitable reference data. Spatial and temporal consistency of the product and with similar products has been evaluated over globally representative locations and time periods. Results are published in the peer-reviewed literature.
- Stage 3: Uncertainties in the product and its associated structure are well quantified from comparison with reference in situ or other suitable reference data. Uncertainties are characterized in a statistically robust way over multiple locations and time periods representing global conditions. Spatial and temporal consistency of the product and with similar products has been evaluated over globally representative locations and periods. Results are published in the peer-reviewed literature.
- Stage 4: Validation results for stage 3 are systematically updated when new product versions are released and as the time-series expands.

A validation program would be expected to transition through these stages over the mission life span.

The SMAP mission is linked by common L-band frequency with the SMOS, Aquarius, ALOS-2 and SAOCOM missions, and by its soil moisture products with the GCOM-W and NPOESS (or its successors) missions (operating at C-band and higher frequencies). All of these missions could be generating soil moisture products at the same time; therefore, SMAP will attempt to cooperate in their validation activities to improve the efficiency and robustness of its Cal/Val.

3.2 Definitions

In order for the Calibration/Validation Plan to effectively address the mission requirements, a unified definition base has to be developed. The SMAP Cal/Val Plan uses the same source of terms and definitions as the SMAP Level 1 and Level 2 requirements. These are documented in the SMAP Science Terms and Definitions document [7], where Calibration and Validation are defined as follows:

- *Calibration*: The set of operations that establish, under specified conditions, the relationship between sets of values or quantities indicated by a measuring instrument or measuring system and the corresponding values realized by standards.

- *Validation:* The process of assessing by independent means the quality of the data products derived from the system outputs

The L2 product requirements are interpreted in [8] for computing the validation quality metric.

Before releasing validated products the mission is required to release beta products (see Section 2.6.1). The maturity of the products in the beta release is defined as follows:

- Early release used to gain familiarity with data formats.
- Intended as a test bed to discover and correct errors.
- Minimally validated and still may contain significant errors
- General research community is encouraged to participate in the QA and validation, but need to be aware that product validation and QA are ongoing.
- Data may be used in publications as long as the fact that it is beta quality is indicated by the authors. Drawing quantitative scientific conclusions is discouraged. Users are urged to contact science team representatives prior to use of the data in publications, and to recommend members of the instrument teams as reviewers
- The estimated uncertainties will be documented.
- May be replaced in the archive when an upgraded (provisional or validated) product becomes available.

3.3 Validation Methods, Resources and Data Availability

A valuable lesson learned in global land imaging has been that validation is critical for accurate and credible product usage. It must be based on quantitative estimates of uncertainty for all products. For satellite-based retrievals, this should include direct comparison with independent correlative measurements. The assessment of uncertainty must also be conducted and presented to the community in normally used metrics in order to facilitate acceptance and implementation. SMAP will utilize a wide range of methodologies in calibrating and validating the mission science products, these include;

- In situ networks
- Tower- and aircraft-based SMAP instrument simulators
- Homogeneous targets
- Satellite products
- Model-based products
- Field experiments

Some of these methodologies will be better suited to a specific product than others. Matching these to SMAP products will be addressed in later sections of the Cal/Val Plan. The following section discusses each of these techniques in more detail.

Another important consideration in developing the Cal/Val Plan is that SMAP will provide global products. Therefore, product validation should be representative of a wide range of global climate and vegetation conditions. Obviously the logistics and potential costs of conducting a fully comprehensive program may be beyond the capabilities available. Success will require partnerships that leverage ongoing programs, both within the U.S. and internationally.

3.3.1 In Situ Networks

In situ soil moisture, surface and air temperature, surface flux, and additional land surface characteristics 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 AMSR, PALSAR, SMOS, and Aquarius.

The characteristics of an ideal in situ validation resource for SMAP will depend upon the product. However, the following features apply to all;

1. Represents a spatial domain approximately the size of the retrieval footprint (3, 9, and 36 km). Since in situ observations typically represent an area much smaller than the satellite product, this means that scaling must be addressed using multiple sample sites that satisfy statistical criteria or with an alternative technique.
2. Includes numerous domains in a variety of climate/geographic regions.
3. Provides data in near real time with public availability.
4. Has the potential for continued operation.
5. Includes a wide range of related meteorological measurements.

The L2 through L4 soil moisture products share common features (measurements of soil moisture); however, the requirements of the L3_FT_A and L4_C are different from these and each other. Therefore, each will be discussed separately.

Another important consideration for SMAP Cal/Val implementation (which will utilize data from a variety of observing programs with varying objectives) is establishing global consistency in the correlative data. In the case of freeze-thaw, there are many potential sites but much of the data will come from operational meteorological observatories that have well established standards. For Net Ecosystem CO2 Exchange (NEE), most of the data come from national and international surface flux observing networks. Although there are a limited number of these sites, collaboration has resulted in standards for the relevant variables. The most problematic in situ observations are those of soil moisture. Almost every soil moisture installation and network has some variation in its instrumentation and design that must be taken into consideration. As a result, the SMAP project has devoted more time and attention to resolving issues associated with soil moisture observations than with FT and NEE, which have established standards. Additional details for soil moisture, freeze-thaw, and related resources are provided in the following sections.

3.3.1.1 Product Requirements and Preliminary Review of Resources

3.3.1.1.1 Soil Moisture

Based upon the SMAP mission requirements, in addition to the list of characteristics above, an ideal in situ soil moisture resource would include verified surface layer (5 cm soil depth) as well as the 0-100 cm profile observations. An initial survey of available resources conducted in 2008 (Appendix A) indicated that very few could meet the requirements for an ideal validation site and that the overall number of sites was limited.

The resources identified in the survey can be grouped into two distinct categories;

- *Sparse networks* that provide only one (or possibly a few) site within a satellite footprint.
- *Dense networks* that provide multiple sampling sites within a spatial domain matching a SMAP product footprint.

Sparse networks are often operational and satisfy data latency and availability requirements. At the time of the initial survey, the only dedicated soil moisture program was the Soil Climate Analysis Network (SCAN) [9] operated by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service. Covering almost every state in the U.S. (Figure 3-1), SCAN satisfied many of the requirements mentioned above with two exceptions; they are single point measurements with no supporting scaling studies and have not been rigorously verified.

Figure 3-1. SCAN (red dots) and CRN (blue dots)

Another example of a sparse network is the Oklahoma Mesonet http://www.mesonet.org/ that provides soil moisture and a wide range of other variables at over 90 stations in the state of Oklahoma. In the case of the Oklahoma Mesonet, there are also issues with the real time and public availability of the data. Over the past few years, the National Oceanic and Atmospheric Administration (NOAA) has implemented a network, Climate Reference Network (CRN) http://www.ncdc.noaa.gov/crn/, which shares many of the features of SCAN (> 100 sites in the U.S.) and includes a wide range of additional measurements (Figure 3-1).

We also found that there were a few programs that did provide soil moisture observations that were very close to ideal for SMAP validation. Most of these are these were developed to support satellite validation projects. Examples include the USDA ARS Research Watersheds initiated for AMSR-E [10, 11], Mongolia[12], and the Murrumbidgee sites in Australia [13].

3.3.1.1.2 Freeze-Thaw

Freeze-thaw (FT) in situ validation resources should include the reference (2 m height) air temperature and vegetation (stem and canopy) temperature with high temporal fidelity (daily or better) sampling and representation over the observed range of climate, terrain, land cover and vegetation biomass conditions. As noted for soil moisture, these measurements should also satisfy the general requirements listed above. Unlike soil moisture, basic air temperature observations are available from all operational meteorological networks and are subject to international standards. In addition, air temperature is not expected to exhibit as much spatial variability as soil moisture.

Although standard meteorological networks can be used for validation of FT, there is a need for some observations using dense networks with additional surface measurements. Networks and sites identified in the preliminary survey are summarized in Appendix A. Almost all of these are sparse networks.

3.3.1.1.3 Net Ecosystem Exchange

Surface flux towers are the primary requirement for validating the L4 C product. As noted for soil moisture, these measurements should also satisfy the general requirements listed above. Surface flux observations are typically available from national and international cooperating networks with agreed upon standards for instrumentation and data distribution. Surface flux observations are representative of a larger footprint and rarely include multiple towers within spatial domains relevant to SMAP sampling.

3.3.1.1.4 Sparse Networks

There are additional data sets available that may be utilized if possible. For soil moisture, there are two emerging resources; COSMOS and NEON. Both are currently being implemented and/or calibrated. Another valuable public domain resource is the International Soil Moisture Network (ISMN) [14]. This effort is currently supported by the European Space Agency and is building up its database. Both historic and current in situ soil moisture data from around the globe are being archived into an integrated database with quality controls. The SMAP Cal/Val Team will collaborate with the ISMN on an informal basis; however, continued support for this effort through the life of SMAP should be promoted.

The ongoing Cal/Val efforts of other satellite missions, specifically GCOM-W and SMOS, support in situ soil moisture observing networks that will remain operational through the SMAP project life. Specific examples include the GCOM-W Mongolia and the SMOS supported Valencia, Spain networks. In addition to the networks mentioned above, there are a number of others that exist or will come into existence..

Freeze-thaw validation can utilize data from standard meteorological stations, which for the most part are in the public domain and do not require the intensive verification. However, a scaling methodology must be developed if these data are to be of value for SMAP. It should be noted that temperatures do not exhibit the spatial variability of soil moisture and that the matching scale is 3 km. The WMO network (Table 3-1, Figure 3-3) is of value because it provides a central source for global observations. Additional resources included the landscape temperature profile measurements from Alaska Ecological Transect (ALECTRA) sites and SNOTEL.

For the NEE (L4_C) a major in situ validation resource is the FLUXNET, which is in the public domain. However, there may be issues in using these data related to standardization. It is also anticipated that the NEON sites will provide high quality surface flux data with supporting verification and scaling studies.

Furthermore, Table 3-1 indicates that there are a substantial number of additional number of sparse networks available for validation.

Table 3-1. Additional Public Domain or Potential SMAP In Situ Validation Resources

Network Name	Country or Region	No. Sites	Type	Products	Website or Other Reference
WMO global surface weather station network	Global	9000+	Sparse	FT	http://www.ncdc.noaa.gov/cgi-bin/res40.pl
Alaska Ecological Transect (ALECTRA)	Alaska	9	Sparse	FT	kyle.mcdonald@jpl.nasa.gov
FLUXNET	Global	500+	Sparse	C	http://www.fluxnet.ornl.gov/fluxnet/index.cfm
Coordinated Energy and Water Cycle Observation Project (CEOP)	Global	13	Sparse	SM	http://www.ceop.net/
National Ecological Observatory Network (NEON)	USA	20	Sparse	SM, C	http://neoninc.org/
COsmic-ray Soil Moisture Observing System (COSMOS)	USA	50+	Sparse	SM	http://cosmos.hwr.arizona.edu/
SNOTEL	Western USA	750	Sparse	SM	http://www.wcc.nrcs.usda.gov/snow/
ARM-SGP	Oklahoma /Kansas	31	Sparse	SM, C	http://www.arm.gov/sites/sgp
Illinois Climate Network	Illinois	19	Sparse	SM	http://www.sws.uiuc.edu/warm/datatype.asp
International Soil Moisture Network (ISMN)	Global	TBD	TBD	SM	http://www.ipf.tuwien.ac.at/insitu/

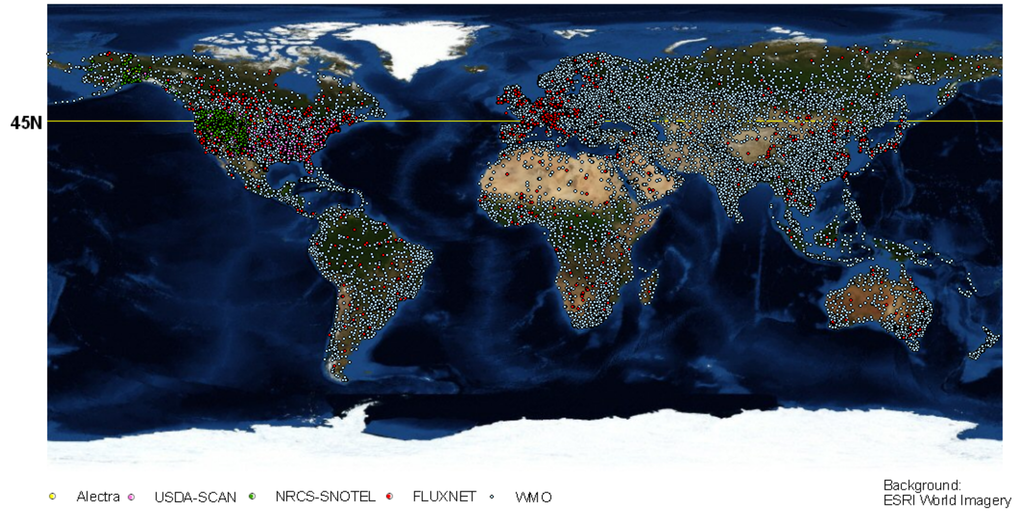


Figure 3-3. World Meteorological Organization's (WMO) global meteorological observation station network (the white dots) with ALECTRA, USDA-SCAN, NRCS-SNOTEL, FLUXNET networks (see Table 9-1 and 3-2). Note that the WMO sites cannot be used directly for comparison with satellite products since they do not measure soil moisture or freeze/thaw state.

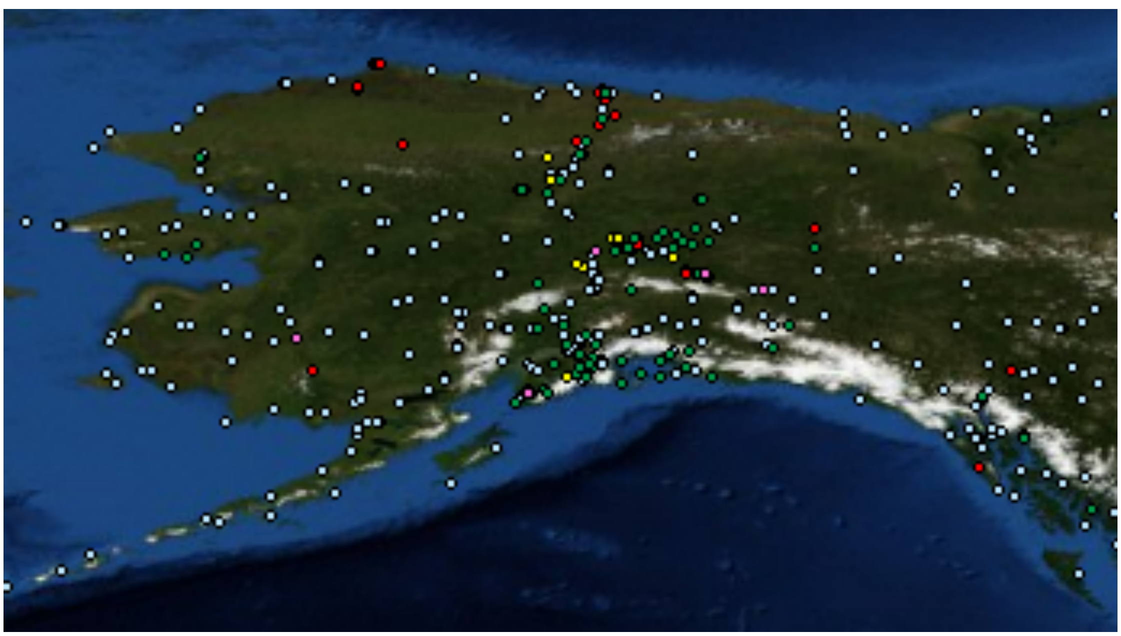


Figure 3-2. ALECTRA network stations (the yellow dots) with FLUXNET (red dots), SNOTEL (green dots), SCAN (pink dots) and WMO (white dots) network sites in Alaska.

3.3.1.2 Scaling Methodologies and Heterogeneity

In situ observations are usually made point-wise and the problem in using point measurements for the validation of a measurement over a sizeable footprint is the representativeness of those point measurements with respect to the footprint measurement. In order to use the point measurements for the validation of the footprint measurement a scaling methodology must be used.

One approach that has been successfully used is temporal, or rank, stability, since the method is based on investigating which measurement point of an area gives the most stable response for the variable over time and then that measurement is used to represent the area [15], [16]. This method may be enhanced with ancillary data to improve the estimation of the temporally stable point.

Statistical tools can be used to characterize the sampling points to establish reliability to the scaling process. One example of this approach, called statistical replication, is presented in [17]. Finally, a number of different scaling approaches have been developed that leverage information from a land surface model simulation of soil moisture fields. Examples include the use of a distributed land surface model to capture the relationship between field-scale (800-m) soil moisture and a coarse-scale (40-km) areal average [18] and applying land surface modeling within a triple collocation strategy (see Section 3.3.5) to estimate random sampling errors in coarse-scale soil moisture estimates obtained from sparse ground-based observations [19]. Additional scaling approaches are being developed, as described in a later section that may lead to a solution [20].

In testing and validating these methods tower and airborne observations are crucial to characterize the field sites and regions where the scaling is supposedly going to take place. Especially, when the land cover introduces additional heterogeneity over the area, having a remotely sensed reference for the surface parameters is even more critical in the process of translating the point measurements to the satellite footprint scale.

3.3.2 Tower and Aircraft-based Radiometers and Radars

Tower-based and airborne microwave sensors play important roles in Earth remote sensing. Tower-based systems can provide continuous observations of relatively small areas. Smaller footprints are very useful in controlled condition experiments, which are vital in advancing our understanding of microwave emission and scattering. These observations provide the basis of models and algorithms. Tower sensors are also the most efficient means of obtaining temporal information. Phenomena ranging from minutes (infiltration) to days (evapotranspiration) or weeks (crop growth) can be observed.

Airborne sensor systems complement tower observations by providing an intermediate spatial scale that links to the satellite footprint. Understanding the scaling of the basic sensor measurement (i.e. brightness temperature and radar backscatter) as well as the geophysical variable that is being retrieved (i.e. soil moisture and freeze/thaw status) is critical to satellite-based remote sensing. These platforms facilitate the observation of a wide range of target features and facilitate experimental sample replication, which are logistically difficult with towers. Airborne systems are valuable in the demonstration and verification of algorithms and applications in that they can be used to map a spatial domain.

An important aspect that needs to be considered is the calibration of the instruments and their compatibility with the satellite configuration. During the pre-launch stage of the SMAP project, highly accurate and representative data sets are necessary for algorithm refinement.

To support SMAP Cal/Val, a survey of existing and planned L-band tower and airborne instruments, and synergistic mission data, was conducted by the SMAP Science Definition Team (SDT) Cal/Val Working Group. Information was provided by the groups operating each sensor system. The results are provided in Table 3-3. Some systems may not be included due to lack of response to the survey or lack of knowledge by the SDT of their existence. These can be identified and added in a future update. For a full list of participants in the survey, see [21].

It should be noted that the number of stand-alone passive tower systems is much greater than the available combined systems. This is largely the result of activities related to SMOS, which is a passive system and has supported a significant program in this area. Also, there is a relatively large data base of experimental passive observations. There are fewer relevant radar data sets and very few combined active/passive. The most valuable system to SMAP would provide the combined observations.

Table 3-2. Existing L-band Tower and Aircraft-based Sensors [21]

Tower Systems	Airborne Systems
Combined Passive and Active	**Combined Passive and Active**
ComRAD	*PALS*
VLR2	*PLMR/PLIS*
Passive	*CAROLS/STORM*
TMRS-3	*RadSTAR2*
UFLMR	*PSR/L: LAIS*
ISMR	**Passive**
SWAMP	*2D-STAR*
TSMR	*AMIRAS*
JULBARA	*HUT-2D*
RADOMEX	*EMIRAD-2*
LAURA	*IROE*
ELBARA	*Radius/Ranet*
EMIRAD-1	*MAPIR*
PLR	*LDCR*
LNIR	*ECMR*
MERITXEL	**Active**
PAU	*UAVSAR*
Active	*E-SAR*
MOSS	*Pi-SAR*
UMS	
HPS	

Recommendations to the SMAP Project were made following earlier SDT and Cal/Val Working Group meetings concerning actions to insure instrumentation that would provide the data needed to support Cal/Val. These included improving the quality and operations of the tower-based ComRAD and adding scanning capability for PALS. Both of these have been initiated.

3.3.3 Utilization of Homogenous Targets

Homogeneous areas over the Earth's surface are especially interesting for the calibration and validation of instruments and algorithms, primarily Level 1 products. These areas, in principle, have good representativeness for point measurements and they are easy to model, primary resulting from the lack of heterogeneity within the footprint. Naturally, the areas have to be homogeneous over the entire footprint of the instrument: in the case of SMAP this means tens of kilometers for the diameter of the area. Additionally, the larger the homogeneous area, the more likely it is that the antenna main beam and the side lobes will measure the same target, which increase the accuracy. Furthermore, it is very desirable that the area is temporally stable (particularly at the overpass time). The observed stability of the target depends on the stability of the source medium over the penetration depth, which is determined by the measurement frequency of the instrument.

Examples of homogeneous areas are ocean surfaces, thick ice sheets and glaciers, deserts and large rain forests. Since SMAP observes at L-band, the large penetration depth may make the ice sheets more attractive [22]-[24] and rain forests less attractive [23],[24] regions in terms of stability when compared to their use with higher frequencies. Antarctica has proven useful in recent studies [26], [27], [28]. The targets need to be characterized as to whether they will be used in the calibration and/or validation. For example, if the target is a vicarious stability reference it is adequate just to know how stable the target is over time, but if it is used as an absolute reference then exact a priori knowledge of the emission and scattering properties need to be known.

An additional homogeneous and well characterized target is the Cosmic Microwave Background (CMB) of space, which needs to be complemented with a map of celestial objects to account for their emission at L-band.

3.3.4 Synergistic Satellite Observations

Observations by other satellite instruments both before and after launch can be utilized for calibration and validation of SMAP. For pre-launch calibration and validation the primary role of spaceborne observations will be the testing of algorithms, using Level 1 products to produce SMAP Level 2 and 3. Level 2 products (soil moisture) from these missions can be used to evaluate the SMAP algorithm performance. For post-launch calibration and validation the alternative mission observations will provide products that can be compared with those from SMAP.

The following lists some of the most relevant satellite products that could be used before and/or after the launch for SMAP calibration and validation (responsible agency and launch year in parenthesis):

- SMOS (ESA, 2009): Global L-band horizontal and vertical polarization brightness temperature and surface soil moisture; pre-launch and post-launch
- ALOS PALSAR (JAXA, 2006): Multiple resolution backscatter product based on L-band SAR; pre-launch
- MetOp ASCAT (ESA, 2006) and Sentinal-1 (ESA, 2013): Soil moisture index based on C-band backscatter; pre-launch and post-launch
- Aquarius (NASA/CONAE, 2011): Simultaneous L-band brightness temperature and backscatter; experimental soil moisture product; pre-launch and post-launch
- GCOM-W AMSR-2 (JAXA, 2012): Soil moisture product based on C- and X-band brightness temperature; pre-launch and post-launch
- SAOCOM (CONAE, 2015): Backscatter and soil moisture products based on L-band SAR; pre-launch and post-launch
- ALOS-2 PALSAR (JAXA, 2012): Multiple resolution backscatter product based on L-band SAR; possibly pre-launch and post-launch

These satellite programs measure either brightness temperature or backscatter at L-band (Aquarius provides both) and/or produce a soil moisture product from their observations. The options and the value of these other satellites depend largely on the overlap of the mission with SMAP. However, for example, in the case of SMOS the measurements of brightness temperature will be extremely valuable, even if the data are limited to the pre-launch period, because they represent the first L-band brightness temperature measurements from space. The use of SMOS will be described in greater detail in a following section.

Cross-calibration exercises between different satellite instruments have been successfully carried out improving the quality of the time series created by the instruments in question (e.g. [29]-[30]). For inter-comparisons between the satellites, the product accuracy requirements of the other missions are of significance. The most relevant inter-comparison mission is SMOS (since it is L-band and has a soil moisture product at the same spatial resolution), which has soil moisture accuracy requirements equivalent to SMAP.

The limitations of this type of comparison are the quality of the alternative product, differences in overpass days, and accounting for system differences affecting the soil moisture product. In the case of GCOM-W, which is planned for a 01:30 am / 01:30 pm overpass time, confusion factors would include data at a different time of day (from the SMOS/SMAP overpass time of 06:00 am) and contributing depth issues associated with GCOM-W's C-band frequency [31]. The SMAP team will actively participate in the validation of these alternative products during the SMAP pre-launch period, which will provide us with knowledge of the quality of both the SMOS and GCOM-W soil moisture.

3.3.5 Model-based Validation Approaches

Validation based on land surface modeling and data assimilation will be used to complement in situ based validation. As discussed in previous sections, validation against in situ observations is difficult because the observation sites span limited geographic regions and environmental settings and is complicated by the mismatch between the point-scale of the in situ measurements and the distributed (order of km) scale of the SMAP data products. Hydrological land surface models and data assimilation approaches provide continuous (in space and time) soil moisture products that match the spatial support of SMAP soil moisture products. Model-based validation can start immediately upon launch and thereby offers a key advantage for meeting the ambitious IOC+12-month validation deadline.

Several Numerical Weather Prediction (NWP) centers (including ECMWF, NCEP, and NASA/GMAO) routinely produce operational or quasi-operational soil moisture fields at a scale comparable to the SMAP radiometer product. These data products rely on the assimilation of a vast number of atmospheric observations (and select land surface observations) into General Circulation Models (GCM's). Although there are many caveats that need to be considered in using these data, they are readily available and they are consistent with the atmospheric forcing (precipitation and radiation) and land use information that determine the spatial and temporal patterns in soil moisture fields. Moreover, surface temperature from at least one NWP system will be used in the generation of the SMAP L2_SM_P data product. Output from these systems is necessary for the application the validation activities described below. In this context, NWP data may be used directly or as forcing inputs to more customized hydrological modeling systems. It is expected that investigators will be performing more rigorous evaluations of these model products now that SMOS is producing routine soil moisture information. These ongoing studies will benefit SMAP by quantifying the performance and identifying the optimal product for comparison.

In the simplest case, land surface models (either imbedded in a NWP system or in off-line mode) can be used to generate soil moisture products at larger (basin-wide and continental) scales using land surface and meteorological forcing data sets that are independent of the SMAP remote sensing data. The resulting soil moisture fields can then be compared with the remotely sensed soil moisture product at validation sites over diurnal and seasonal cycles. These model-derived soil moisture fields can also be used to extend the comparisons to larger space and time domains than available from in situ observations. Model-based soil moisture fields can also be used to derive brightness temperature and backscatter using forward modeling. These estimates can be valuable in validating the Level 1 SMAP products.

3.3.5.1 Land surface modeling comparisons

In the simplest case, land surface models (either imbedded in a NWP system or in off-line mode) can be used to generate soil moisture products at larger (basin-wide and continental) scales using land surface and meteorological forcing data sets that are independent of the SMAP remote sensing data. The resulting soil moisture fields can then be compared with the remotely sensed soil moisture product at validation sites over diurnal and seasonal cycles. These model-derived soil moisture fields can also be used to extend the comparisons to larger space and time domains than available from in situ observations.

The inherent uncertainty in any model-based soil moisture product is an obvious limitation to such a validation approach. However, recent work has extended the application of so-called "Triple Collocation" (TC) approaches to soil moisture validation activities [32], [19], [33]. These approaches are based on cross-averaging three independently-acquired estimates of soil moisture to estimate the magnitude of random error in each product. One viable product-triplet is the use of passive-based remote sensing, active-based remote sensing and a model-based soil moisture product [32], [33]. If successfully applied, TC can correct model versus SMAP soil moisture comparisons for the impact of uncertainty in model product. However, TC cannot provide viable bias information and therefore only assesses the random error contribution to total RMSE. Note that TC can also be applied to reduce the impact of sampling error when upscaling sparse in situ measurements during validation against ground-based soil moisture observations (see Section 3.3.1.2).

3.3.5.2 Data assimilation approaches

The development of land surface modeling and data assimilation tools for SMAP synergistically provides an important framework for the supplemental calibration and validation of SMAP data products as well as the option to generate Level 4 data products.

An ensemble-based data assimilation system (such as that under development for SMAP; Section 5.6.6) produces internal diagnostics that will be used to indirectly validate its output. One such diagnostic consists of the "innovations" (or "observation-minus-forecast" residuals) that contrast the model-based forecast values directly with the observations. The assimilation system also produces corresponding error estimates. Specifically, the statistics of appropriately normalized innovations will be examined ([34]; see also discussion of adaptive filtering in Section 4.1.2 of the L4_SM ATBD [35]). Through minor customizations of the assimilation system, this approach can be applied to brightness temperature as well as soil moisture retrievals.

Data assimilation and land surface modeling systems also provide an opportunity to convert the impact of soil moisture information into a more readily-measurable quantity. For example, [36] develops and verifies a quasi-global soil moisture evaluation system that effectively substitutes rain gauge measurements for ground-based soil moisture observations. The approach is based on evaluating the correlation coefficient between antecedent rainfall error and analysis increments (i.e. the net addition or subtraction of modeled soil water accompanying the assimilation of a single soil moisture estimate) that are produced by a land data assimilation system. This correlation coefficient provides a reliable linear metric for the ability of a given soil moisture product to accurately characteristics soil moisture anomalies. The use of rain observations as a source of verification expands potential soil moisture validation locations from isolated sites (Figure 1) to much broader regions in which rain-gauge measurements are available for retrospective analysis. [37] uses a similar methodology to assess the added utility of assimilating AMSR-E soil moisture retrievals for root-zone soil moisture monitoring in the presence of uncertain precipitation forcing into a land surface model.

3.3.6 Field Experiments

Field experiments serve a valuable role during pre-launch by providing diverse but controlled condition data that can be used for developing algorithms, establishing algorithm parameterization, and defining validation site scaling properties. Post-launch airborne field experiments can be used, for example, to Level 1 product validation, resolve fine resolution features over validation sites for more accurate comparison with the satellite products, and increase the temporal fidelity of remote sensing measurements over the validation sites.

Field experiments that address microwave soil moisture algorithm issues and/or applications are listed in Table 3-3. The experiments also complement pre-launch (and post-launch) studies with SMOS, Aquarius, and ALOS PALSAR data. Table 3-3 also lists the launch dates of these relevant satellites. Experiments indicated in red address SMAP algorithm issues specifically. Additional details on each campaign are provided in Section 5.5.

Table 3-3. Field Experiments and Satellite Launches

Year \ Quarter	1	2	3	4
2008			SMAPVEX08	
2009				*SMOS*
2010		CanEx-SM10 SMAPEx 1		SMAPEx 2
2011		*Aquarius* SMAPVEX11	SMAPEx 3	
2012	*GCOM-W*		SMAPVEX12	
2013		CARVE	CARVE	
2014	*ALOS-2*	CARVE	CARVE	*SMAP*
2015	*SAOCOM*	SMAPVEX15		

4 CALIBRATION AND VALIDATION REQUIREMENTS OF SMAP PRODUCTS

The SMAP data products are listed earlier in Section 2 (Table 2-4). Assessing whether the requirements of these products are met is the primary objective of the Cal/Val Plan. The requirements for the algorithms, i.e. ATBDs, flow down from the product requirements (see Section 2.3.1). In the ATBDs, each product algorithm team identifies what calibration and validation activities are needed to meet the product requirements. These activities then become another set of requirements for the Cal/Val Plan. This Chapter focuses on detailing the requirement defined by the ATBDs, and the subsequent Chapters describe how the Cal/Val Program addresses these requirements together with the other mission requirements. Note that in order to maintain the consistency in this process all central terms and definitions used in requirement documents, ATBDs, and this document follow the definitions given in [7].

4.1 Level 1 - Sensor Products

Level 1 SMAP science products are the calibrated sensor outputs (brightness temperature and radar backscatter). The accuracy of these products depends on the pre-launch calibration model and the calibration algorithm and coefficients applied in the post-launch processing.

Table 4-1 shows the Level 1 products, their requirements for spatial resolution and accuracy, and associated pre-launch and post-launch Cal/Val requirements. Products L1B_TB [38] and L1C_TB [39] are time-ordered and swath- and Earth-gridded (collocated with radar) brightness temperatures, respectively. Products L1B_S0_LoRes and L1C_S0_HiRes [40] are the low resolution (real aperture) and high resolution (synthetic aperture) radar cross-sections, respectively.

Separate calibration documents will be produced for the sensors. The pre-launch calibration of the radiometer is described in [41].

Table 4-1. Level 1 products and associated Cal/Val requirements. The columns are divided for product type; spatial resolution of the instrument output for L1B_TB, L1B_S0, L1C_S0 and grid resolution for L1C_TB; accuracy for horizontal and vertical polarization, and for 3rd Stokes parameter of radiometer and HV-combination of radar; and pre-launch and post-launch Cal/Val requirements.

Level 1	Reso	Accuracy		Information and data required for performing Cal/Val	
Products	[km]	H/V	3/ HV	Pre-Launch	Post-Launch
L1B_TB [38]	40	1.3 K	-	• High-level output coaxial noise source with 0.3 K accuracy (to be modified from existing source called RATS) • Polarimetric coaxial noise source (existing source called CNCS [42]) • L-band warm blackbody (for feed horn) with return loss > 35 and thermal stability of 0.2°C (existing) • L-band LN2-cooled blackbody with 1 K accuracy (existing) • Controlled thermal environment • Antenna pattern and reflector emission verified by antenna team [1]	• Pre-launch calibration parameters • Sky TB map for CSC (accuracy TBD K) • Ocean and land target RTM with overall 0.4 K uncertainty • Geolocation: Antenna pointing information; ocean RTM; coastlines • Faraday rotation: IRI and IGRF databases; Aquarius and SMOS values; Rotation angles from astronomers, geostationary satellites and GPS satellites • Atmospheric correction: global temperature and humidity profiles • Antenna pattern correction: Nominal antenna pattern; Antenna pointing information; SMAP TB Forward Simulator [2,3] • Aquarius radiometer brightness temperatures • SMOS radiometer brightness temperatures • Aircraft-based observations during field campaigns
L1C_TB [39]	36	1.3 K	-	• C-band AMSR-E data over Florida region; • Prototype SMAP-like data set from the Testbed over Florida region	• SMAP L1B and L1C data over TBD locations, where the grids coincide with time ordered locations;
L1B_S0 [40]	30	1 dB	1.5 dB	• TBD	• Sky TB map for CSC (accuracy TBD); • Pre-launch calibration parameters; • Established uniform, isotropic, stable Earth targets; • Data from contemporaneous radars (Aquarius, PALSAR, UAVSAR, SAOCOM, etc.); • Aircraft-based observations during field campaigns • Receive only data acquisition (for RFI)
L1C_S0 [40]	3	1 dB	1.5 dB	• TBD	• L1B_S0; • Checks for scalloping…
(1) The radiometer development, implementation and calibration is the responsibility of GSFC. The antenna development, implementation, testing and characterization is the responsibility of JPL.					

(2) SMAP Brightness Temperature (TB) Forward Simulator: based on ocean and land surface radiative transfer model (RTM). The simulator includes the following sources and effects included:

- Solar direct, reflected
- Lunar direct, reflected
- Galactic direct, reflected
- Land, atmosphere, ocean
- Faraday rotation
- Antenna sidelobes

(3) Assumptions in current error budget

- Earth sidelobe scene known to 6 K
- Cross-pol TB known to 2 K
- Space scene known to 1 K
- Solar flux known to 20 s.f.u.

4.2 Level 2 and 3 - Geophysical Products

Level 2 products contain derived geophysical parameters (soil moisture, freeze/thaw) whose accuracy depends on the accuracy of the input Level 1 sensor data, ancillary data, and the Level 2 geophysical retrieval algorithms.

4.2.1 Metrics

The soil moisture accuracy requirements will be satisfied by the L2 and L3_soil moisture products at the corresponding horizontal resolution. Specifically, the requirement implies that for the selected validation areas (see Sections 5.6.4 and 5.6.5) for which validating in situ observations are available from verified sites, the SMAP surface (0-5 cm) soil moisture products must satisfy RMSE<0.04 m^3/m^3 (after removal of long-term mean bias) in the case of active/passive and passive products and RMSE<0.06 m^3/m^3 (after removal of long-term mean bias) in the case of the active product.

The L3 freeze/thaw product will provide estimates of land surface freeze/thaw state expressed as a binary (frozen or thawed) condition. The baseline L3 freeze/thaw product will be provided for land areas north of 45 degrees north latitude with a mean classification accuracy of 80% at 3 km spatial resolution and 2-day average temporal fidelity. The accuracy of the L3 product is determined by comparison of the freeze/thaw state map to selected (see Sections 5.6.4 and 5.6.5) in situ temperature measurement networks within northern (≥45°N) vegetated land areas for the baseline product.

4.2.2 Information and Data Required for Cal/Val

Table 4-2 shows the Level 2/3 products, their requirements for spatial resolution, accuracy, and revisit time, and the associated Cal/Val requirements. Products L2_SM_P [43], L2_SM_A [44] and L2_SM_AP [45] are soil moisture products (top 5 cm of soil), based on radiometer-only, radar-only, and combined radar-radiometer data, respectively. Product L3_FT_A [46] is the freeze/thaw state product, based on radar data only.

Table 4-2. Level 2/3 products and associated Cal/Val requirements. The columns are divided by product type; grid resolution; accuracy requirement of the product; revisit time; pre-launch and post-launch Cal/Val requirements.

Level 2/3 Products	Grid [km]	Acc.	Rep [d]	Information and data required for performing Cal/Val: Pre-Launch	Post-Launch
L2_SM_P [43]	36	0.04 m^3/m^3	3	• Ancillary data sets needed by baseline and option algorithms; • Global Testbed (GloSim) retrieval simulations using synthetic observation conditions; • Field experiment data (SGP99, SMEX02, CLASIC, SMAPVEX08, CanEx-SM10, SMAPVEX12) for surface SM[1]; • SMOS brightness temperature and soil moisture products, ancillary data and validation products	• Algorithm parameterization established; • In situ core validation sites[2]; • Field experiments[1]; • In situ sparse networks; • SMOS, GCOM-W and ASCAT soil moisture products; • Independent hydrologic model outputs
L2_SM_A [44]	3	0.06 m^3/m^3 (TBC)	3	• Ancillary data sets needed by baseline and option algorithms; • Global Testbed (GloSim) retrieval simulations using synthetic observation conditions; • Field experiment data (SGP99, SMEX02, CanEx-SM10, SMAPVEX12 tower-based campaigns) for surface SM[1,1b]; • Satellite (PALSAR) data	• Algorithm parameterization established; • In situ core validation sites[2]; • Field experiments[1]; • In situ sparse networks; • ALOS-2 and SAOCOM soil moisture products; • Independent hydrologic model outputs;
L2_SM_A/P [45]	9	0.04 m^3/m^3	3	• Ancillary data sets needed by baseline and option algorithms; • Global Testbed (GloSim) retrieval simulations using synthetic observation conditions; • SGP99, SMEX02, CLASIC, SMAPVEX08, SMAPVEX12 data sets; • Multi-scale and long-duration airborne field experiment[1] data capturing temporal soil moisture and diversity of land cover type	• Algorithm parameterization established; • In situ core validation sites[2]; • Field experiments[1]; • In situ sparse networks; • Independent hydrologic model outputs;

L3_FT_A [46]	3	80 %	2	• Ancillary data sets needed by baseline and option algorithms; • Global Testbed (GloSim) retrieval simulations using synthetic observation conditions • Testbed simulations with in situ sparse networks (NRCS Snotel, SCAN, FLUXNET, ALECTRA, WMO) frozen/non-frozen status and SMOS and PALSAR; • SMOS, PALSAR, PALS time series data over test regions; • Field experiments over complex terrain and land cover [3];	• Algorithm parameterization established; • In situ sparse networks (NRCS Snotel, SCAN, FLUXNET, ALECTRA, WMO) frozen/non-frozen status; • Field experiments (e.g. PALS) with in situ sparse network sites (e.g. FLUXNET)

(1) Surface soil moisture (SM) experiments have the following baseline requirements (subsite is a part of the experiment domain, such as a field):

- The soil moisture in the top 5 cm can be determined with dielectric probes with point location specific calibration through bulk density and thermo-gravimetric core sampling, which yields sample uncertainty no more than 0.04 m^3/m^3.
- The spatial sampling of surface SM is done following the methodology established for that specific location
- The soil texture is to be determined for each sampling point specifically through bulk density core samples.
- The land cover is classified according to the classes used for the SMAP products.
- The vegetation is classified according to the classes used for the SMAP products.
- The vegetation water content measurements are calibrated through destructive thermo-gravimetric sampling.
- Soil temperature is determined at each sampling point. Site specific meteorological state is determined for air temperature and precipitation.

Some geophysical input parameters have greater impact on the radar soil moisture error (as opposed to the radiometer soil moisture) than others (such as roughness, and information on vegetation geometric and dielectric properties (see L2_SM_A ATBD for the complete list)). Therefore, these information should be available from the pre-launch field experiments to develop the algorithms. The procedures for doing this need to be established in the pre-launch phase. Furthermore, radar is more sensitive to the incidence and azimuth angle of the measurement than radiometers primarily because of the high spatial resolution of radar needs to be considered in the experiments.

(2) In situ core validation sites (meaning an intense measurement site with established scaling from point measurements to satellite footprint) used in the post-launch soil moisture validation need to satisfy the following requirements:

- The soil moisture measured must provide an estimate of the state of the top 5 cm with well defined uncertainty brackets
- For L2_SM_A, surface roughness measurements at appropriate time & spatial scales are highly desired.
- The spatial sampling of the site must be such that a defined resolution scaling scheme can be applied.

(3) In situ frozen/non-frozen status will be determined as a composite ensemble of vegetation, soil and air temperature measurements where available, and will be compared to coincident footprint scale L3 freeze/thaw measurements for areas of the globe where seasonally frozen temperatures are a major constraint to hydrological and ecosystem processes. The fulfillment of the requirements will be assessed by comparing SMAP freeze-thaw classification results and in situ frozen or non-frozen status. The in situ resource should provide a strategy for spatial up-scaling of in situ measurements commensurate with the 3 km spatial scale of the satellite retrieval. Attention should be given to landscape heterogeneity within the scope of the validation site or sites in the up-scaling strategy.

Measurements supporting freeze-thaw Cal/Val activities should meet the following minimum requirements:

- Measurement of surface (screen height) air temperature
- Measurement of surface (up to 10 cm depth) and profile (up to 1 m depth) soil temperatures
- Measurement of vegetation temperature (when significant vegetation present)
- In situ temperature measurements should be sufficient to characterize the variability in local microclimate heterogeneity within a spatial scale compatible with the SMAP freeze-thaw product.
- To provide uniformity across sites, the local land cover of the site should be consistent with a global (IGBP-type) land cover classification
- Each land cover class within the validation site should be captured within the suite of temperature measurements such that the local vegetation and land cover heterogeneity is represented.
- Measurements should have sufficient temporal fidelity to capture seasonal and diurnal temperature and freeze-thaw patterns.

Desired methods for measuring air, soil, and vegetation temperatures include thermocouple type measures of physical temperatures and thermal IR type measurements of surface “skin” temperatures with consistent and well documented accuracy and error sources over a large (e.g. -30°C to 40°C) temperature range.

4.3 Level 4 - Geophysical Products

Level 4 products contain geophysical parameters whose accuracies depend on the accuracies of the input Level 1 and Level 2-3 data products, other input data, and the model and assimilation technique.

4.3.1 Metrics

The soil moisture accuracy requirements will be satisfied by the L4_soil moisture product at the 9 km horizontal resolution. Specifically, the requirement implies that for the selected validation areas (see Sections 5.6.4 and 5.6.5) for which validating in situ observations are available from verified sites, the SMAP surface (0-5 cm) and root-zone soil moisture products must satisfy RMSE<0.04 m^3/m^3 (after removal of long-term mean bias).

The net ecosystem exchange (NEE) estimates from the L4_C product will be validated at 9 km resolution against the selected in situ observations from flux towers (see Sections 5.6.4 and 5.6.5). Specifically, the requirement will be satisfied if the median RMSE against the validation is less than 30 gC/(m^2/yr).

4.3.2 Information, data and processing required for Cal/Val

Table 4-3 shows the two Level 4 products, their requirements for spatial resolution, accuracy, revisit time, and the associated Cal/Val requirements. L4_SM [35] is a surface and root-zone soil moisture product, and L4_C [47] is a net ecosystem exchange (NEE) product.

Table 4-3. Level 4 products and associated Cal/Val requirements. The columns are divided by product type; grid resolution; accuracy requirement of the product; revisit time; pre-launch and post-launch Cal/Val requirements.

Level 4	Grid	Acc.	Rep	Information and data required for performing Cal/Val	
Products	[km]		[d]	Pre-Launch	Post-Launch
L4_SM [35]	9	0.04 m^3/m^3	3	• Testbed simulations; • Satellite observations (SMOS, Aquarius, PALSAR); • In situ core sites and sparse networks; • Internal data assimilation diagnostics	• Surface SM: see Level 2; • Root-zone SM: Contributing Validation Sites (SCAN, CEOP, Oklahoma Mesonet, USCRN, GPS, COSMOS); • Precipitations observations; • Internal data assimilation diagnostics
L4_C [47]	9	30 $gC/m^2/yr$	3	• Satellite data (e.g. MOD17 product); • GEOS-5; • In situ CO2 eddy flux (e.g. FLUXNET) • Internal data assimilation diagnostics	• SMAP L4 SM; • In situ CO2 eddy flux (e.g. FLUXNET) [1]

(1) The accuracy of the L4_C outputs, including NEE and component carbon fluxes will be established in relation to in situ tower eddy flux CO_2 measurements and associated carbon budgets within regionally dominant vegetation classes following established protocols. The fulfillment of the NEE requirement will be assessed by comparing SMAP L4_C NEE output with in situ measurement-based CO_2 flux estimates.

In order for a flux tower to be useful for NEE validation, it has to provide at minimum the following measurements:

- Continuous daily (cumulative 24-hr) estimates of gross primary production (GPP), ecosystem respiration (R_{eco}), and NEE with well defined and documented accuracy, including both systematic and random errors;
- Relatively homogeneous land cover and vegetation conditions within an approximate 10 km x 10 km footprint commensurate with the resolution of the SMAP L4_C product;
- To provide uniformity across sites, the local land cover of the site should be compatible with a global (IGBP-type) land cover classification;
- The local site should have a minimum level of supporting meteorological measurements including air temperature and humidity, surface (≤10 cm depth) soil moisture and soil temperature, precipitation, and snow depth (if present); these measurements should be continuously monitored and sufficient to capture local microclimate heterogeneity within the tower footprint.
- The local site should have a minimum level of supporting biophysical inventory measurements including surface (≤10 cm depth) soil organic carbon stocks, vegetation stand age class, land use, and disturbance history.

4.4 Prioritization of Geophysical Algorithm Risk-Reduction Issues

Table 4-4 summarizes algorithm issues that influence accuracies of the Level 2/3 and geophysical retrieval algorithms. The entries are based on the Level 2/3 ATBDs for the soil moisture and freeze/thaw algorithms. The tables provide a focus for prioritization of pre-launch Cal/Val activities in addressing areas of risk-reduction in the algorithm development.

The table rows list algorithm issues, while the columns list the four Level 2/3 products. Filled dots in the table mean that the issue needs more input data (such as field experiment data, improved data source or processing, etc.) to bring the product retrieval algorithm to the required level. Empty dots mean that new input data would be useful for improving the product but is not strictly necessary to have confidence that the product requirements can be met. Vacant cell means that there is no issue with respect to the product in question.

Based on Table 4-4 it can be concluded that most important issues to be addressed in the algorithm development are performance of the time series method, heterogeneity within the pixel, resolution scaling of the measurement, effects of the topography, and effects of different land cover types. Additionally, the mitigation of the RFI in the measurements is a major concern. Regarding the quality of the ancillary data soil moisture and VWC require the most attention. Also the masks of dense vegetation, mountain area and urban areas need further development.

Table 4-4. Level 2 Algorithm Issues and Prioritization

	Level 2/3 Product			
Issues	**SM P**	**SM A**	**SM A/P**	**FT**
Algorithm questions				
Algorithm selection	○	•	•	○
Time series performance		•	•	•
Heterogeneity	•	•	•	•
Azimuthal dependency		•	○	○
Resolution scaling	•	•	•	○
Topography effects	•	•	•	•
Separability soil and vegetation				•
Vegetation types	•	•	•	○
RFI mitigation	•	•	•	○
Ancillary data				
Soil temperature	•	○	•	
Vegetation temperature	○	○	○	
Soil texture	○	○	○	○
Roughness	○	•	○	○
VWC	•	•	•	○
Dense vegetation mask	•	•	•	•
Mountain mask	•	•	•	•
Land cover mask	•	•	•	•
Urban area mask	•	•	•	•
Water body mask	○	○	○	○
Freeze/snow mask	○	○	○	
● - New input required				
○ - New input useful but not required				
Vacant - Not an issue				

5 PRE-LAUNCH ACTIVITIES

5.1 Overview

During the pre-launch period there are a variety of activities that fall under calibration and validation. These mainly involve calibration, algorithm development and evaluation, and establishing the infrastructure and methodologies for post-launch validation.

Requirements for Cal/Val related to specific SMAP data products have been identified by the respective science algorithm teams in their Algorithm Theoretical Basis Documents (ATBDs) and these will likely be added to over time. The ATBDs are developed in Phases A and B of the mission so that the production processing algorithms can be coded and tested in Phase C/D. Pre-launch activities will include development of the calibration procedures and algorithms for the SMAP radar and radiometer (Level 1 products), development of surface soil moisture and freeze-thaw state algorithms (Level 2-3 products), and development of a surface to root-zone soil moisture product and carbon exchange product (Level 4 products).

Pre-launch instrument calibration will include modeling, analysis, simulations, and laboratory and test-facility measurements. Algorithm development for all products will include testbed simulations, laboratory and test-facility data, field campaigns, exploitation of existing in situ and satellite data, and utilization of instrument and geophysical models. Controlled-condition tower and aircraft experiments using SMAP measurement prototypes, and utilization of e.g. SMOS, Aquarius and PALSAR satellite data and model products, will be included. This Section details these activities.

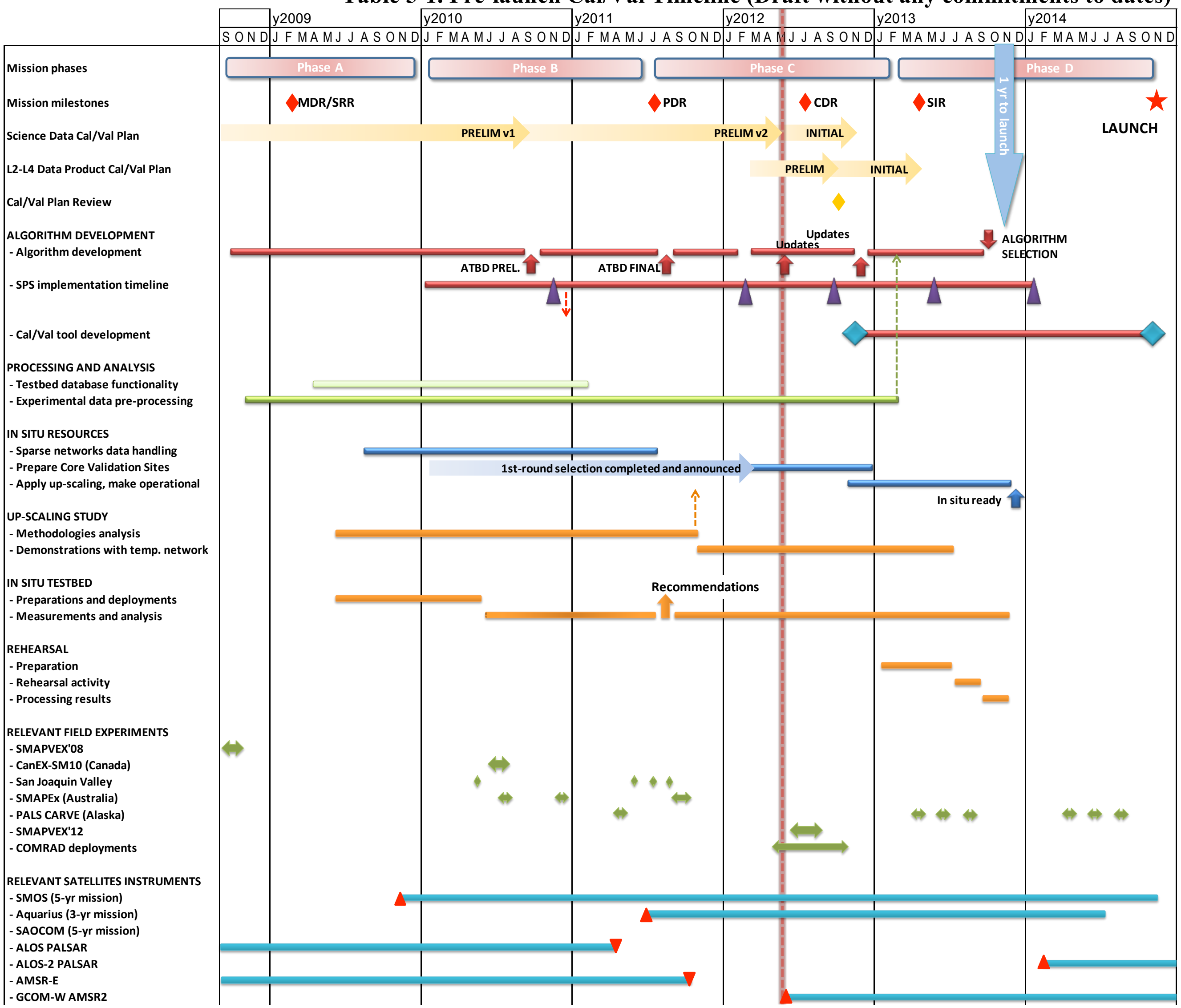
5.2 Pre-Launch Cal/Val Timeline

Table 5-1 shows a draft timeline for pre-launch Cal/Val activities. The timeline shows key Cal/Val activities and related project schedule items. The timeline includes the project phases and algorithm and software delivery schedules. The table also indicates timing of field campaigns. The final versions of algorithm ATBDs are due well before CDR, however, it is expected that the algorithms and their parameterization will evolve throughout the pre-launch phase. The algorithm selection will take place little over one year before the launch in order to accommodate the finalization of the algorithm implementation and testing before the launch.

A timeline for preparation/data acquisition of in situ sites and networks is shown in the bottom part of the table. Some of the in situ sites are involved in the pre-launch field campaigns, and some in both pre- and post-launch campaigns, providing linkage between pre- and post-launch algorithm development, calibration and validation.

The operation of other relevant satellites is indicated on the last rows of the table, to show their general availability and opportunities for coordinated cal/val activities.

Table 5-1. Pre-launch Cal/Val Timeline (Draft without any commitments to dates)



5.3 Algorithm Issues

5.3.1 Sensor Algorithms

This Section provides a summary of the instrument pre-launch development, test and calibration activities (see [41] for detailed radiometer pre-launch calibration plan), which are essential to meeting the Level 1 product requirements.

5.3.1.1 Radiometer Brightness Temperature

The production of SMAP brightness temperatures is divided between producing the time-ordered calibrated brightness temperatures from the instrument output and gridding the brightness temperature to Earth grid.

5.3.1.1.1 Instrument Calibration

The radiometer pre-launch calibration is required to initialize the calibration algorithm, fill in specific thermal states of the thermal model, help post-launch calibration separate effects, and verify performance (reflector by analysis only). The objectives of the radiometer pre-launch calibration activities are to:

- provide initial values of calibration parameters (needed to run L1A and L1B algorithms and to meet performance requirements);
- provide temperature correction coefficients (needed to refine calibration parameters values once on orbit);
- provide full characterization of instrument behavior before launch, and
- show compatibility with the requirements and post-launch calibration scheme.

The calibration algorithm will be based on an analytical model describing the end-to-end system architecture employing parameters whose values are obtained from testing of the sub-systems. For sub-system level testing and characterization a noise source will be utilized. A heritage noise source (RATS) from Aquarius radiometer development can be utilized with some modifications. This noise source will also be utilized to verify the calibration repeatability requirement of 0.3 K. For verifying 3rd and 4th Stokes parameter functionality the Correlated Noise Calibration Standard (CNCS) will be utilized [42]. The radiometer calibration algorithm and parameters will be verified at the feed horn aperture through observation of the external references (the pre-launch calibration accuracy requirement is 2 K). A load cooled with liquid Nitrogen (LN2) will be used for the feed horn level verification (an LN2-load with 1 K brightness temperature uncertainty is available from Aquarius radiometer test campaign). The performance analysis, simulation and test conditions will be based on on-orbit environment scenarios.

The emissivity of the antenna reflector and the pattern of the antenna beam will be characterized in the pre-launch phase. These will be important calibration parameters affecting directly to the accuracy of the brightness temperature measurement and only partial verification/correction can be carried out from the orbit after the launch. The emissivity is determined using a sample of a mesh identical to the one used for the entire reflector. Due to the relatively low operating frequency the emissivity is projected to be very small, which is critical in mitigation of the effect of the changes in the physical temperature of the reflector. The antenna pattern is determined through a measurement of the feed horn pattern and the pattern of a 1-to-10 scale model of the reflector (TBC).

Additionally, in preparation for the post-launch calibration and validation activities, the suitability of several homogeneous areas on Earth's surface are investigated for use as external calibration references. The brightness temperature knowledge of these target areas need to allow calibration of the radiometer stability to 0.4 K. Potential target areas are Dome-C and Marie-Byrd in Antarctica and calm ocean surfaces (see Section 3.3.3). Studies predict 0.1 K stability for Dome-C and Marie-Byrd over an annual cycle [27], [28]. Dome-C area is being evaluated by European Space Agency's tower measurements [27]. An analysis using the tower and satellite data will be carried out to confirm the stability of Dome-C Radiative Transfer Model (RTM). Aquarius measurements over ocean buoys will be analyzed to establish the performance of the RTM over ocean surfaces. Also other regions will be investigated during the pre-launch activities. The Aquarius and SMOS L-band radiometer missions will provide new information on the suitability of all these regions.

A forward simulator will be developed to generate SMAP measured brightness temperatures. The simulator utilizes the hydrological modeling capabilities developed for SMAP (Section 5.4.1) and employs land and ocean surface parameters to calculate the Earth surface emission. The simulator will account for direct and reflected solar, lunar, galactic and CMB radiation; direct and reflected land, ocean and atmosphere radiation; Faraday rotation, and antenna pattern with sidelobes. The simulator will also include a radiometer model to simulate the behavior of the radiometer in the expected orbital conditions. The simulator will be used to study both radiometer calibration algorithm and geophysical algorithm performance. In the post-launch phase the simulator will be utilized for the correction of the antenna pattern and the evaluation of the RFI detection algorithms.

5.3.1.1.2 Data Gridding

The baseline for the L1C_TB data product is for processing to a swath based grid co-registered with the L1C_S0_HiRes grid and processing to an Earth-fixed grid co-registered with L1C_S0_HiRes grid. Prototype SMAP-like data sets will be generated using simulated and actual satellite data (AMSR-E data scaled appropriately). These data will be used to study errors in adopting different gridding parameters - cell resolution, interpolation radius and weights. Gridding effects are especially noticeable at high contrast boundaries such as coastlines and lakes; therefore, Florida coastlines (TBC) will be used as a focus for these studies.

5.3.1.2 Radar Backscatter Cross Section

Radar pre-launch Cal/Val activities include characterization of the radar and its components. The purpose is to show the compatibility of the hardware with the requirements and also to support the post-launch calibration. These tests include among others propagation measurements, radiometric calibration of the receivers and characterization of the internal calibration procedures of the radar. Furthermore, performance analysis and simulations will be carried out based on instrument model and on-orbit environment scenarios. For the preparation of the post-launch external calibration suitable Earth targets will be surveyed. These targets are required to be large, uniform, isotropic, well-characterized and stable in order to be useful in the calibration process.

5.3.2 Geophysical Algorithms

5.3.2.1 Soil Moisture

Procedures will be developed to test the performance of the various candidate retrieval algorithms and quantify the expected error attributes of the ancillary data inputs. This information will assist in the selection of a baseline retrieval algorithm and in the generation of an error budget for the soil moisture products. The ancillary data will be available as part of SMAP SDS Testbed (see Section 5.4) and available for algorithm testing. The quality of this data will be assessed before evaluating its impact on the algorithm performance. A memo has been prepared to describe each ancillary data source and the justification for its selection over other potential sources.

Of primary concern for the brightness temperature-based algorithms is the error in the effective soil temperature, since it requires the most frequent (daily) updates. The latency of the soil temperature input data is also important – currently NCEP produces a 6-hour temperature product, while ECMWF and GEOS/GMAO produce a 3-hour product. As part of the ancillary data preparation for ingestion into the soil moisture processing, a local 6 am soil temperature will be generated by interpolating in time between the closest available information.

Issues concerning the accuracy of vegetation parameterizations will be addressed in the context of ongoing field campaigns. These field experiments are expected to add to the growing database of historical information on microwave-vegetation relationships.

Existing ground and airborne radiometer and radar measurements will be used with the associated ground truth data to compare the accuracy of the various algorithms with each other. In general, the comparisons will involve the following steps:

- Inversion Accuracy: In this activity, each algorithm will be used to invert the same set of observational sensor data, and the results will be compared to in situ data. Since the range of surfaces for which measured airborne sensor data exist is limited, a model will be used to establish a database that covers the global surface soil moisture and roughness properties including RMS height, correlation length, and the forms of the correlation functions. The various retrieval algorithms will then be tested against this database to establish their accuracy, and the ranges of surface parameters over which they are applicable. This activity will be carried out on SDS Testbed as described in Section 5.4.1.

- The PALS airborne sensor (see Appendix B.1) L-band backscatter and brightness temperature fields are available at constant incidence angle as flight lines. PALS measurements were made in the SGP99, SMEX02, CLASIC 2007 and SMAPVEX08 experiments. Although the radar and radiometer measurements are not at different resolutions, gridding and re-sampling can be performed to mimic SMAP instrument sampling. The UAVSAR (and earlier AIRSAR) airborne L-band backscatter data, collected in SMEX02 and CanEx-SM10 experiments, can also be utilized. UAVSAR offers fine resolution data that could be used for mimic SMAP instrument with PALS brightness temperature when measured coincidentally.

- SMOS brightness temperature based SMAP L2_SM_P soil moisture retrieval. The result will be compared to in situ sites and SMOS soil moisture products. A similar exercise will be carried out with Aquarius once it has been commissioned.

- The global backscatter measurements carried out by Aquarius will be compared with the values obtained using L2_SM_A data cubes to adjust the parameters of the forward model.

Before the SMAP launch, the hydrological modeling and data assimilation tools developed for SMAP (including the L4_SM algorithm) will be tested globally, to the extent possible, with satellite observations from the precursor missions discussed in Section 3.3.4. Among the pre-cursor missions, SMOS, the first passive microwave sensor operating at L-band, plays a key role. In each case, the outcome of the tests will be assessed by validating the assimilation estimates against in situ observations from existing networks and field experiments and by ensuring the consistency of internal diagnostics (see Post-launch validation). Existing long term networks include SCAN, USCRN and FLUXNET networks in the North America region.

Additional development and testing for the SMAP hydrological modeling and assimilation tools will be conducted in the context of Observing System Simulation Experiments (OSSE's; see also section 4.1.4 of the L4_SM ATBD [35]).

5.3.2.2 Freeze/Thaw

Freeze/thaw algorithm performance will be assessed using the SMAP SDS Algorithm Testbed (see Section 5.4.1) and available L-band microwave remote sensing datasets within the SMAP freeze/thaw domain, including satellite based observations from PALSAR and SMOS, and relatively fine scale remote sensing and biophysical data from in situ towers and airborne field campaigns, e.g. PALS (see Appendix B.1) and CARVE experiment (see Appendix C.1).

The algorithm results will be evaluated across regional gradients in climate, land cover, terrain and vegetation biomass through direct comparisons to existing surface biophysical measurement network observations including air/soil/vegetation temperature, snow depth and snow water-equivalent and eddy covariance CO_2 exchange. The relationship between the algorithm freeze/thaw state and the in situ sampling data will be established. Major focus areas include relations between the local/solar timing of satellite AM and PM overpasses and diurnal variability in local surface temperature and freeze/thaw state dynamics; the spatial and temporal distribution and stability of L-band radar backscatter under frozen and non-frozen conditions, and the effects of sub-grid scale land cover and topographic heterogeneity on the aggregate freeze/thaw signal within the sensor footprint.

Biophysical measurements from in situ station measurement networks will be used to drive physical models within the SMAP algorithm testbed for spatial and temporal extrapolation of land surface dielectric and radar backscatter properties and associated landscape freeze/thaw dynamics. These results will be compared with field campaign measurements and satellite based retrievals of these properties. Model sensitivity studies will be conducted to assess L3_FT algorithm and freeze/thaw classification uncertainties in response to uncertainties in sensor sigma-0 error and terrain and land cover heterogeneity within the sensor FOV.

5.3.2.3 Carbon Flux

Calibration and validation of the L4_C algorithms and products will involve model sensitivity studies in relation to observed variability in northern environmental conditions and uncertainties in satellite based GPP (e.g. MOD17) and L4_SM inputs (i.e., surface soil moisture and soil temperature). Model sensitivity studies will be conducted by perturbing input parameters within their respective ranges of uncertainty independently and in combination, and documenting L4_C algorithm responses.

Initialization and calibration of model parameters and initial SOC pools will be conducted prior to launch using available satellite GPP time series (e.g. MODIS MOD17) and long-term daily soil moisture and temperature inputs from the GMAO LIS. The accuracy of algorithm inputs and outputs will be established in relation to in situ CO_2 eddy flux measurements from regional tower networks (e.g., FLUXNET) and surface meteorological observations from regional weather stations following previously developed methods [48], [49], [50], [51]).

Calibration and optimization of L4_C algorithm parameters will be conducted using daily time series carbon fluxes from northern CO_2 eddy covariance flux towers (e.g. FLUXNET) representing regionally dominant vegetation classes. Monte Carlo Markov Chain (MCMC) optimization will be applied to minimize an objective function weighted by the observation error and model error covariance matrices by adjusting model decomposition rate constants and initial SOC pool sizes. Smaller values of the objective function are associated with more informative model-data configurations and resulting posterior distributions that allow for significance testing. The initial rate constants and SOC pools will be derived from regional soil inventories and published field studies, and compared with optimized parameter values. The initial SOC pools will also be compared to those estimated for steady state and average climate conditions and using optimized rate constants. This approach will provide quantitative and uncertainty estimates of the L4_C outputs relative to the tower observations.

5.4 SMAP SDS Testbed Role

SMAP Science Data System (SDS) Testbed will be utilized for algorithm development and testing, storing calibration and validation data, and carrying out calibration and validation of algorithms and products.

5.4.1 Testbed Simulations and Analysis

Simulation of retrieval algorithm performance is an important part of the algorithm development and pre-launch Cal/Val activities. The goals of the simulations are:

1) the identification of algorithm operational and performance issues over global diversity with the specified ancillary data, and
2) the parameterization and validation of the algorithms.

For meeting the first goal, simulated global observations with orbital instrument sampling are carried out on SMAP SDS Testbed. Figure 5-1 shows a schematic diagram on the processing flow on the testbed for science algorithm testing. The forward models of the instrument measurements include land surface model (Model Truth) and instrument characteristics (Orbit/Data Simulation, which feeds to Simulated Level 1 products). The retrieval algorithms are implemented as they would be on the operational system (Science Processing Prototype). The ancillary data identified in the ATBDs are made available on the testbed for full end-to-end retrieval algorithm runs.

For meeting the second goal actual, observational data is used on the testbed. This data will include coincidental in situ (Validation Data in Figure 5-1) and tower-based, airborne and spaceborne measurement data (Field Campaign Observations). The observational data is to cover wide range of diversity in terms of land cover conditions. The observations are reformatted to correspond to the Level 1 instrument data so that they can be fed to the same retrieval algorithms in the Science

Processing Prototype as in the case of the global simulations. The use of the same processing establishes a critical link between the global simulations and actual observational data. The field campaign data sets are complemented with ancillary data of similar quality as that specified for the algorithms in the ATBDs of the products.

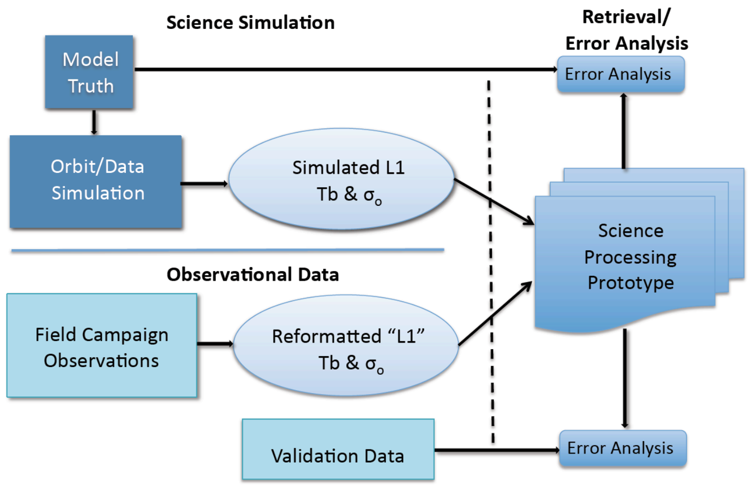


Figure 5-1: Diagram of the processing flow on the testbed for algorithm testing; both simulated orbit and land surface model data and actual observational data can be used as basis of the algorithm performance assessments.

5.4.2 Cal/Val Data Repository

SMAP Cal/Val Data Repository resides on the SMAP SDS Testbed. It contains the experimental data used for pre- and post-launch calibration and validation. The data from the utilized field experiments (see Sections 5.5 and 6.4), selected core sites (see Sections 5.6.4.3) and sparse in situ networks (see Section 5.6.5.3) will be ingested into the repository.

In the post launch phase the key feature of the repository is to allow automatic download and up-scaling of data from the selected in situ resources to the database for expedient processing against the SMAP products.

5.5 Pre-Launch Field Campaign Activities

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 resolving any outstanding (soil moisture) SMAP algorithm issues.

5.5.1 Remote Sensing Instrumentation Considerations

In the planning of the campaigns, the availability of the supporting airborne and tower-based instruments must be considered. Since its inception, the SMAP Cal/Val Plan has supported the development of several key resources that included the tower-based active/passive ComRAD, the airborne PALS instrument and the airborne UAVSAR (see Appendix B). Over the past few years these instruments have been enhanced to improve the quality and utility of the data provided. In the case of ComRAD these improvements have include the antenna, calibration, and autonomous operation. For PALS, the major modifications proposed were the ability to scan, which facilitates mapping large domains, and additional RFI mitigation components.

An additional complexity facing SMAP for using PALS is that the instrument is being heavily utilized by the CARVE project between 2011 and 2015 (see Appendix C.1). Due to the CARVE deployments the utilization of PALS has to be planned accounting for CARVE needs.

With regard to the modification of PALS to a scanning configuration (PALScan), a decision has been made to postpone the possible installation until after SMAPVEX12. There is a problem with using the current position of PALS in the Twin Otter aircraft (which is the only aircraft available for SMAPVEX12 campaign) that necessitates moving the instrument to the front of the plane. The implementation of this option has proven to be very time consuming and costly and therefore not elected. In the future, depending on the availability of other aircrafts, the implementation of PALScan will be reconsidered.

Furthermore, time is required to evaluate the tradeoffs in efficiency and cost of the scanning versus non-scanning acquisition modes as well as aircraft options in the future. There are operating altitude constraints on the PALS radar, minimum of ~1000 m and a maximum of ~4000 m, which limit swath width. This fact combined with constraints on aircraft speed, to provide integration time and beam overlap, reduce the benefits of higher and/or faster flying aircraft.

A tower-based L-band radar-radiometer ComRAD (see Appendix B.3) will be available for deployments to gather stationary coincidental active and passive data.

5.5.2 Field Campaigns

5.5.2.1 SMAPVEX08 (East Coast, USA)

SMAPVEX08 was the first field campaigns dedicated to resolving SMAP algorithm issues took place on the East coast of US in the fall of 2008 ([52],[53]). In addition to the addressing open algorithm issues, the campaign had a major focus on questions related to RFI. Data from this campaign will be archived at the SMAP DAAC.

5.5.2.2 CanEx-SM10 (Canada)

NASA flew the airborne UAVSAR instrument in conjunction with the Canadian L-band radiometer as part of the CanEx-SM10 SMOS soil moisture validation field experiment in Saskatchewan territory in June 2010 ([54], [55]). The campaign included airborne radiometer measurements at additional frequencies and in situ sampling over four individual SMOS pixels (see Section 7.1.2 for more details). Data from this campaign is currently archived at the University of Sherbrooke and will also be archived at the SMAP DAAC.

5.5.2.3 SMAPEx 1-3 (Australia)

The University of Melbourne and Monash University in Australia conducted three field campaigns in 2010 and 2011 designed to specifically address SMAP soil moisture algorithm issues ([56], [57]). The campaigns included coincidental radiometer and radar measurement, which will provide contributions to the data set available for the development of the active/passive soil moisture algorithm (see Section 7.1.1 for more details).

5.5.2.4 San Joaquin Valley Experiment (West Coast, USA)

The UAVSAR instrument will be deployed for San Joaquin Valley experiment on several days in 2010-2011 ([58],[59]). 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 relative rare opportunity to gather data from this type of landscape.

5.5.2.5 SMAPVEX11 (Oklahoma, USA)

The CARVE instrument was deployed to Oklahoma City for several days with the primary objective of calibrating an atmospheric sensor over the DOE SGP site near Lamont. During this period, several flights were conducted over the recently installed SMAP Marena Oklahoma In Situ Sensor Testbed (MOISST). Conditions were very dry. As part of the campaign, concurrent PALS and COSMOS Rover data were acquired over spatial domains near Marena and the Little Washita Watershed.

5.5.2.6 CARVE Opportunities (Alaska, USA)

Appendix C.1 summarizes the highlights of the CARVE (Carbon Arctic Reservoir Vulnerability Experiment) investigation, which utilizes the PALS instrument (see Appendix B.1) to make L-band passive and active airborne measurements over many regions in Alaska. The deployment of PALS on Twin Otter is based out of Fairbanks, Alaska. The three campaigns are going to be executed annually in 2012 through 2014 (possibly 2015). The campaign provides an opportunity for SMAP to gather data over boreal landscapes, which is the focus of the investigation. In principle, the CARVE observation could be augmented by denser in situ observations and more frequent over-flights.

5.5.2.7 ComRAD Deployments

NASA GSFC ComRAD (Combined Radar/Radiometer System) truck-based instrument [60] is going through a major upgrade improving its scan mechanism and antenna performance. The upgraded system will be tested in field conditions in the Fall 2011. After the performance has been validated under field conditions the instrument will be deployed in Maryland at the OPE3 study site. The observations will include at least two crop types at the site. In addition to continuous observations over an extended period, the campaign will include enhanced observation to study the effects of morning dew on the soil moisture retrieval. Additional long deployments are being planned (the SMAP ISST (see Section 5.6.2) site is one of the considered locations).

5.5.2.8 SMAPVEX12

A major soil moisture experiment SMAPVEX12 is being planned for summer 2012 to address the remaining algorithm issues before the launch. The SMAP L1/L2 algorithm teams were asked to identify issues that could be addressed in a field campaign and these are summarized in Table 5.2. The general approach for organizing the campaign is to collaborate with the Canadian Space Agency. Planning is currently underway. General elements of the campaign include; sites near Winnipeg Canada, a 45-day study period with airborne and ground-based observations beginning in early June, PALS and UAVSAR coverage. This experiment has been carefully planned to satisfy the science requirements of SMAP.

The design of SMAPVEX12 is driven by the following;

- Algorithm Development: As identified in Table 5-2, the location, land cover types, season and duration of the campaign are driven by the outstanding algorithm issues. At the moment the most significant soil moisture algorithm issues include retrieval under dense vegetation conditions, and changing vegetation, for all soil moisture algorithms; time series approach performance for L2_SM_A and L2_SM_A/P, and diversity of the land cover of the available data for all soil moisture algorithms. These would steer the campaign towards the later portion of the growing season with a relatively long duration.
- Validation Site Up-Scaling: The site selected for the SMAPVEX12 campaign will take place over one of the SMAP validation core sites. The airborne measurements over the site will be used to establish the up-scaling of the site, and also as input for the up-scaling methodology of all core sites.

Table 5-2. Summary of Algorithm Requirements for SMAPVEX12 and Field Campaigns

Product	Needs	Targets	Compatibility with Tower Campaign	Compatibility with Aircraft Campaign
L1	Observations that contribute to RFI studies	Most acquired opportunistically especially in transit flights. Some repeat observations of previously observed areas to observe RFI changes are desirable; Include enhanced backends to enable RFI characterization. Attempt to route transit flights when possible over known L-band RFI sources. Limited tests of broadcast of controlled source to aircraft. Observations outside US would be useful … collaborations with international researchers needed.	Low	High
L2_SM_P	Parameterizing vegetation	Crops-wheat, other and light forest or shrub	Medium	High
	Intercompare soil dielectric models	Homogeneous bare soil or low-vegetation regions. Desirable to have simultaneous tower and aircraft TB observations to assess (a) degree of sub-footprint heterogeneity and (a) calibration intercomparison between tower and aircraft	High	Medium

		TB observations.		
L2_SM_AP	Concurrent AP observations to establish relationships	Should include a range of conditions and cover types over an extended period	Medium	High
	SMAP scaled observations to validate algorithm		Low	High
L2_SM_A	Time series of radar observations	Data cube categories. *Some vegetation types have fairly well understood allometric relationships between VWC and geometry, such as grass (and wheat before the grain-forming period). For these vegetation, extensive veg characterization is not needed and aircraft campaigns are useful.	High	High*
	Transient water body detection	Water body ground truth will be necessary.	Low	High

5.6 Infrastructure Development for Validation

As mentioned earlier, a major activity during the pre-launch phase of the SMAP mission is developing the infrastructure needed to conduct post-launch validation in an efficient manner. During the earlier stages of developing the SMAP Cal/Val Plan, Table 5-3 was developed to summarize the methodologies that would be used in Cal/Val and outstanding issues associated with these.

Of these issues three demanded immediate actions by SMAP if they were going to be resolved. These all involved the in situ observations; 1) inter-calibration between different sensors used in different in situ networks, 2) up-scaling of the point-wise in situ measurement to the SMAP footprint scale, and 3) increasing the number and quality of the core validation sites. These efforts will be described in subsequent sections.

For implementing the calibration and validation program SMAP will form designated groups based on their role in the Cal/Val process. The SMAP Cal/Val Team consists of SMAP Cal/Val Partners, SMAP Science Team and SMAP Project Team. The investigators, including those of Core Validation Sites and Contributing Validation sites, selected for working on the SMAP calibration and validation issues form the group called SMAP Cal/Val Partners. Core Validation Sites are in situ sites which have been selected based on very strict requirements (see Section 5.6.4) and Contributing Validation Sites are in situ sites which do not fulfill all the requirements of the Core Validation Sites but are nevertheless seen as very important for the SMAP calibration and validation activities (see Section 5.6.5).

Table 5-3. Overview of the SMAP Cal/Val Methodologies

Methodology	Role	Issues	Actions
Core Validation Sites	Accurate estimates of products at matching scales for a limited set of conditions	Calibration Comparability Limited number	In Situ Testbed DCL
Sparse Networks	One point in the grid cell for a wide range of conditions	Calibration Comparability Up-scaling	In Situ Testbed Scaling methods DCL
Satellite Products	Estimates over a very wide range of conditions at matching scales	Validation Comparability Continuity	Validation Studies CDF Matching
Model Products	Estimates over a very wide range of conditions at matching scales	Validation Comparability	Validation Studies
Field Experiments	Detailed estimates for a very limited set of conditions	Resources Schedule Conflicts	Simulators Partnerships Communication

5.6.1 Comments on In Situ Soil Moisture Measurement

In situ measurement and scaling of soil moisture presents many challenges. As a result, there are a wide range of measurement techniques and protocols that have been adopted in practice. The value of an observing program to SMAP validation will depend upon (a) the quality of the measurements, (b) how the measurement relates to the validation criteria (in particular the depths and scales), and (c) the availability of the data in a timely manner. The following discussion focuses on the first two issues.

Although the providers of in situ data are likely to have conducted an assessment of the quality of their measurements, if adequate calibration has not been conducted the SMAP project will cooperate in implementing an assessment before using the data for validation.

In situ resources that will be the most relevant for SMAP soil moisture calibration and validation would provide an estimate of the volumetric soil moisture over the surface 5 cm and the 100 cm depth of soil. In general, this will involve two steps: 1) establishing that the sensor provides the equivalent of the volumetric soil moisture that would be obtained using a reference standard, and 2) if the sensor does not actually measure the defined layer, providing verification that the sensor values are well correlated to the mission product depths (0-5 and 0-100 cm). It should be noted that the 0-5 cm measurement is the highest priority and that this measurement is logistically easier to obtain and verify than the 0-100 cm depth measurement.

The recommended reference standard for characterizing volumetric soil moisture is the thermo-gravimetric (usually shortened to gravimetric) measurement method (Chapter 3.1.2.1 in [62]). This technique is time consuming to implement operationally; therefore, it is usually only used for calibration of sensors and in field campaigns. The soil moisture in a known volume (cm^3) is characterized by weighing, then drying, and weighing again to obtain the mass of water (gm). With a specific density of 1 cm^3/gm for water, the result is the volumetric soil moisture (cm^3/ cm^3).

Most sensor manufacturers provide a calibration function for converting the sensor signal to soil moisture (some do not actually provide volumetric soil moisture but an alternative variable such as moisture-tension). These calibrations are often based on limited laboratory studies and are often soil type specific; thus requiring site characterization for a more accurate estimate. Some operational networks have conducted supplemental laboratory analyses to improve their products. An advantage of laboratory calibration is that a full range of soil moisture can be examined.

An alternative, or in some cases a complement, to laboratory calibration is site-specific calibration. The advantage of a site-specific calibration is that it incorporates soil type correction and peculiarities associated with the installation. As described later, it can also be used to correct for measurement depth differences. Disadvantages include repetitive site visits to capture a range of conditions and potential impacts from destructive sampling. Also, his approach is much easier to implement for surface layer measurements than the full profile.

The most straightforward way to provide both items above is to sample the 0-5 cm soil layer using a volume extraction method, such as a ring coring tool.

The other aspect that must be considered regarding the use of in situ observations for SMAP validation is how the measurement relates to the depths defined in validation criteria, Each type of sensor measures a different volume and different networks utilize different installation protocols that can result in incompatibility. SMAP is supporting studies, specifically the In Situ Sensor Testbed described in a later section, to provide a basis for normalizing these different methods and protocols, especially if it becomes the SMAP Projects responsibility to do so.

Performing a site-specific calibration against a standard of gravimetric measurement of the 0-5 cm soil layer (and 0-100 cm if possible) is the recommended protocol for calibration and normalizing an in situ network for integration into the SMAP validation data base.

5.6.2 Soil Moisture In Situ Sensor Testbed (SMAP-ISST)

A testbed will be established to test and calibrate various soil moisture probes provided by different manufacturers [61]. 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 gravimetric validation? (5) How can 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 in situ sites across the globe.

The site has been selected to be Marena in Oklahoma and it will be managed by Oklahoma State University (OSU) Range Research Station. The Oklahoma Mesonet MARE site is located 400 m from the site and two NOAA CRN stations are located nearby. The landscape of the site is characterized as rangeland and pasture. OSU Dept. Plant and Soil Science will provide additional local support.

The site consists of 4 separate sets of installations situated around Subsite A so they have radially increasing distance from Subsite A. Figure 5-2 shows the locations of the subsites: Subsite C is at a distance of 100 m, Subsite B at 200 m, Subsite D at 300 m and Mesonet MARE site additionally at a distance of 400 m from Subsite A.

Each subsite has a set of soil moisture sensors. Table 5-2 shows which sensors are installed at which subsite, number of sensors at each subsite and depths of the installations at those subsites. Passive Distributed Temperature Sensor System is installed between Subsites A and B. For investigation of the effect of the sampling interval each sensor is sampling with enhanced one-minute interval for five minutes every hour. Additionally, the vegetation water content, surface roughness and soil characteristics will be determined for the domain over the course of the experiment.

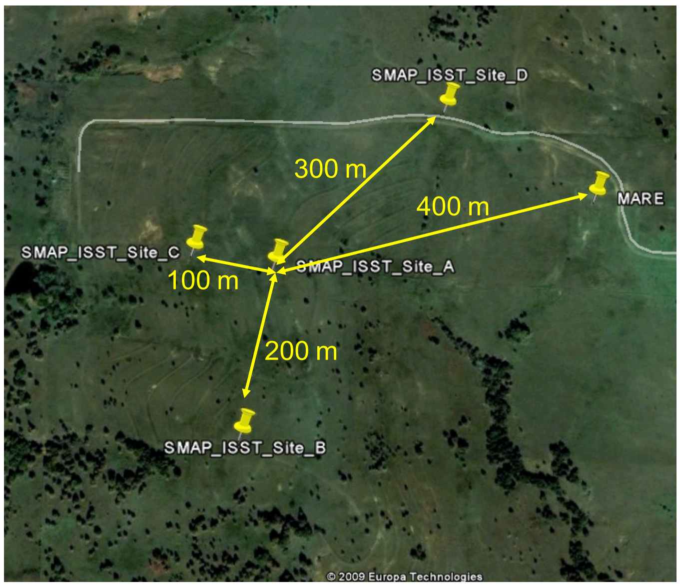


Figure 5-2. Geographic configuration of the SMAP ISST and its subsites.

Table 5-2. Soil moisture sensor types, subsites where they are installed, number of sensors per subsite, and depths of installations at those subsites.

Configuration	Sites	No.	Depths [cm]
Stevens Water Hydra Probes	A,B,C,D	6	2.5, 5, 10, 20, 50, 100
Delta-T Theta Probes	A,B,C,D	5	5, 10, 20, 50, 100
Decagon EC-TM probes	A,B,C,D	5	5, 10, 20, 50, 100
Sentek EnviroSMART	A,B,C,D	4	10 , 20, 50, 100
Acclima Sensor	A,B,C,D	5	5, 10, 20, 50, 100
Campbell CS 229-L heat dissipation sensors (OK Mesonet)	A,B,C,D	5	5, 10, 20, 50, 100
Campbell CS615/CS616 TDRs	A,B,C,D	5	5, 10, 20, 50, 100
Passive Distributed Temperature Sensor (DTS) System	A-B	1	10 cm
GPS reflectometers	A, C, D	1	
COSMOS system	A	1	
Climate Reference Network Station	B, D	6	2.5, 5
Traditional TDR System	A	4	5, 10, 50, 100
ASSH System (Mongolia)	A	TBD	

5.6.3 Soil Moisture Up-Scaling Study

As discussed in Section 3.3.1.2 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 is to define a standard methodology on how to transfer point-wise ground measurements of in situ resources to SMAP footprint scale. There is a SDT working group focused on providing systematic scaling guidelines for the SMAP Cal/Val program. This effort has resulted in a paper "Upscaling sparse ground-based soil moisture observations for the validation of coarse-resolution satellite soil moisture products" [20].

The pre-launch schedule in Table 5-1 shows the tentative timeline for these activities. The details of the methodology summary and the deployments of the temporary stations will be described as plans advance.

5.6.4 Core Validation Sites

The most explicit requirements were set out for soil moisture Core Validation Sites;

- Depths: Minimum 0-5 cm, desirable 0-5 and 0-100 cm
- Sensors that have been calibrated to volumetric soil moisture using the thermo-gravimetric method (verification)
- A dense network of sensors (Minimum 6, desired 15) over a SMAP grid cell or footprint
  - Acceptable: Scaling using an established alternative technique
  - Desirable: Three nested levels of extent (3, 9, and 36 km)
- Supporting studies to establish the representativeness of the network using more intensive sampling
- Data available in near real time to the validation team
- Supporting information on soils, vegetation, and meteorology
- Operational by 2013 with infrastructure support through 2017
- Formal arrangement with the SMAP project

Overall the highest priority in situ resources for SMAP Cal/Val are the Core Validation Sites. The scientific objective of these sites is to provide in situ observations that can be used to estimate soil moisture and/or freeze thaw accurately at the spatial resolution of the SMAP geophysical data products, while satisfying all the other requirements described in subsequent sections. An essential requirement is that the design includes multiple measurement locations within a footprint-sized site that would provide a statistically reliable estimate. Furthermore, estimates of ground-truth sampling error must accompany the product area mean values.

Gaining access to resources located outside the U.S. is also considered. Depending upon the launch date of SMAP; the seasonal variations between the northern and southern hemispheres may impact the usefulness of some regions in validation. However, data access (included latency) and verification of calibration and scaling must be satisfied. Networks that cannot provide near-real time data will be of minor value in validation.

These sites will also be the focus of intensive ground and aircraft field campaigns to further verify scaling (see Section 6.4). Validation core sites have been an important component of previous efforts to use remote sensing to estimate soil moisture (AMSR-E, SMOS) and other land parameters.

5.6.4.1 General Requirements for Core Sites

The following minimum criteria are desired for a core validation site:

- Accessible to researchers
- Has existing infrastructure including access and utilities
- Heritage of scientific studies to build from
- Long term commitment by the sponsor/host
- An area that is homogeneous or has a uniform mixture of land covers at the product scale
- Represents an extensive or important biome
- Complements the overall set of sites

In situ methods provide point observations and each point is orders of magnitude different from satellite grid products. A variety of techniques can be used to establish the scaling of the points and grids (see Section 3.3.1.2). Each participating validation site will have associated a description of the methods that will be used to scale its in situ measurements up to a SMAP grid cell size. The data from each core site will be automatically downloaded to the SMAP Cal/Val Database (see Section 5.4.2).

5.6.4.2 Selection Process for Core Validation Sites

Based upon the discussion above, it was apparent that existing resources alone could not provide all the information needed to conduct SMAP validation. Most of the readily available resources were sparse and lacked an explicit scaling to SMAP grid cell spatial resolutions. When combined with variations between instruments and installations, it would be difficult to conduct the analyses necessary for global consistency. There were a few candidate dense networks; however, even these would need to adapt to the spatial scales of SMAP.

Increasing the number and improving the quality of in situ observations available to SMAP was identified as a significant issue by the Cal/Val Working Group and actions were initiated to address these problems. One specific action taken was to release a NSPIRES Dear Colleague Letter (DCL) for In Situ Validation. This announcement solicited responses that involved no exchange of funds, allowed international participation, provided guidance and minimum requirements, and applied to all types of in situ observations including ground-based SMAP simulators.

In the process of preparing for the DCL, the SMAP project chose to follow the approach used in previous satellite validation programs (MODIS, AMSR-E, and SMOS) and to establish a set of Core Validation Sites (CVS). The scientific objective of these sites is to provide very high quality in situ observations that can be used to estimate soil moisture, freeze-thaw, or NEE accurately at the spatial resolution of the L2-L4 products. Linking the in situ observations to the SMAP product grid sizes is a key aspect of the CVS. It was suggested that it is highly desirable that the CVS design included multiple sites that would provide a statistically reliable estimate; however, the use of an established alternative method for scaling would be considered, especially for sparse networks. In the case of sparse networks, if the basic data provided has been verified, the SMAP project can collaborate on alternative scaling methods. These sites would be the focus of intensive ground and aircraft field campaigns to further verify scaling. Extensive ancillary data sets would be established to support algorithm development and implementation at multiple scales and water, energy, and carbon models and other synergistic science.

5.6.4.3 List of potential SMAP Core Validation Sites

Over thirty responses were received and the resulting selections are summarized in Table 5-3 and Figure 5-3. These included good geographic coverage and were mostly focused on soil moisture. Additional details on these sites are being compiled and will be included in the Cal/Val Plan when available.

Table 5-3. The list of selected Cal/Val Partners for potentially establishing SMAP Core Validation Sites.

Site/Network	PI Last name	Location	Type	L2 SM	L3 FT	L4 SM	L4 C	L1
USDA ARS Research Watershed Networks	M. Cosh	USA (6)	Dense	x				
Reynolds Creek Experimental Watershed	M. Seyfried	Idaho	Dense	x		x		
SoilSCAPE Wireless Network	M. Moghaddam	California	Dense	x		x		
Soil moisture and freeze/thaw network in the Northeast	M. Temimi	New York	Dense	x		x		
Saskatchewan and Ontario Soil Moisture Networks	A. Berg	Canada (2)	Dense	x		x		
Agri-Food Canada In Situ Networks	H. McNairn	Canada (2)	Dense	x		x		
Mexican Riverine Ecosystem	J. Ramos Hernandez	Mexico	Dense	x		x		
Murrumbidgee Catchment Core Validation Site	J. Walker	Australia	Dense	x		x		x
Kuwait Desert Terrain	K. Al Jassar	Kuwait	Dense	x				x
Twente NL and Tibeten Plateau Sites	Z. Su	Netherlands and Tibet (4)	Dense	x		x		
Argentina Forest and Agricultures	H. Karszenbaum	Argentina	Dense	x		x		
Argentina SAOCOM Sites	M. Thibeault	Argentina	Dense	x				
Mpala Hydrological Observatory, Kenya	K. Caylor	Kenya	Dense	x		x	x	
REMEDHUS	J. Martinez-Fernandez	Spain	Dense	x		x		
TERENO	C. Montzka	Germany	Dense	x				x
HOAL	W. Dorigo	Austria	Dense	x		x		
VASKAS	M. Zribi	Tunisia	Dense	x		x		

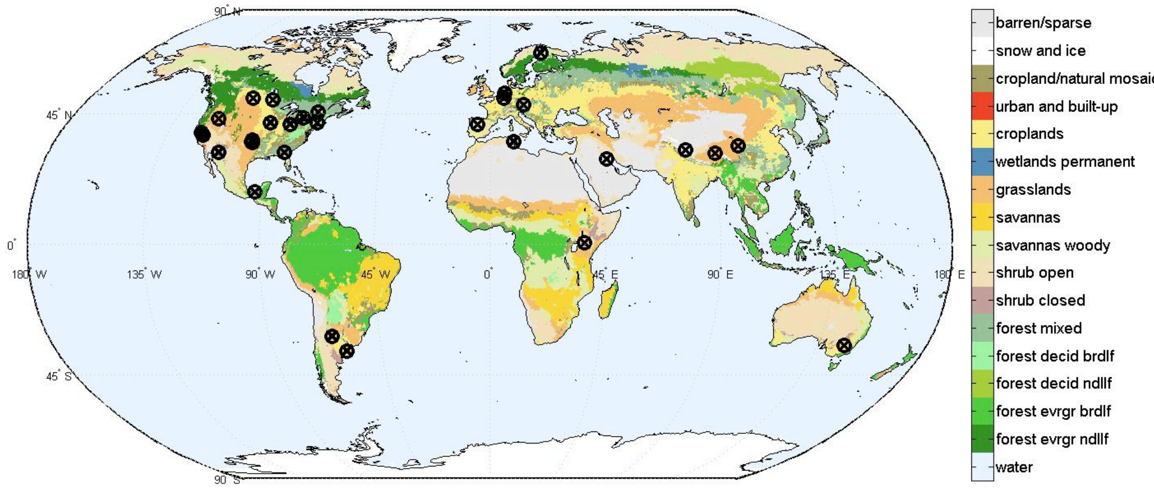


Figure 5-3. The selected Cal/Val Partners for potentially establishing SMAP Core Validation Sites.

5.6.5 Contributing Validation Sites

Contributing Validation Sites are in situ sites which do not fulfill all the requirements of the Core Validation Sites but are nevertheless seen as very important for the SMAP calibration and validation activities. The reason is that the Core Validation Sites do not cover entire global geophysical diversity.

5.6.5.1 General Requirements for Contributing Validation Sites

The following minimum criteria are desired for Contributing Validation Sites utilized in the calibration and validation efforts:

- Accessible to researchers
- Long term commitment by the sponsor/host
- Available in a timely manner
- Compatible with the validation requirements in terms of depths, etc.

In situ methods provide point observations and each point is orders of magnitude different from satellite grid products. A variety of techniques can be used to establish the scaling of the points and grids (see Section 3.3.1.2). Each participating validation site will have associated a description of the methods that will be used to scale in situ measurements up to a SMAP grid cell size. Additionally, whenever there is doubt about the validity of a data point or a part of the time series, the measurements in question will be excluded and that no data be filled in or interpolated.

5.6.5.2 Selection Process

The sparse in situ networks (see Section 3.3.1) for SMAP product validation are selected based on availability, quality and need for coverage. This means that all network data available to SMAP Project will be considered, and they will be prioritized based on the quality and coverage area. The selected data will be automatically downloaded to SMAP Cal/Val Database (see Section 5.4.2) for further processing. The ATBD requirements for the soil moisture sparse networks (Sections 4.2 and 4.3) are augmented by the general requirements given above (Section 5.6.5.1).

5.6.5.3 List of Contributing Validation Sites

Table 5-4lists the sparse networks selected as described in Section 5.6.5.2 above.

Table 5-4. The list of selected partners for establishing SMAP Contributing Validation Sites.

Site/Network	PI Last name	Location	Type	L2 SM	L3 FT	L4 SM	L4 C	L1
SMOSMANIA	JC Calvet	France	Sparse	x				
SCAN	G. Schaefer	USA	Sparse	x		x		
CRN	M. Palecki	USA	Sparse	x		x		
GPS Interferometric Reflectometry Network	E. Small	Western USA	Sparse	x				
Southern Sierra Critical Zone Observatory	J. Hopmans	California	Sparse	x		x	x	
Sodankylä-Pallas	J. Pulliainen	Finland	Sparse	x	x	x	x	

There are new technologies being evaluated (COSMOS, GPS) that could provide distributed soil moisture information. The details of these new approaches are still being developed. SMAP is participating in the evaluation of these new technologies as part of the ISST investigation (see Section 5.6.2) that is assessing both the verification of the relevant depth of measurement of these methods and scaling to SMAP footprints.

USDA Soil Climate Analysis Network (SCAN) NOAA Climate Reference Network (CRN) GPS Network (~100 of the points will be used)

Figure 5-4. Map of some SMAP Contributing Validation Sites.

Additionally, several groups have indicated that they will support SMAP Cal/Val with tower- and aircraft-based observations of brightness temperature and soil moisture. These collaborators are summarized in Table 5-5.

Table 5-5. SMAP Cal/Val Team L-band Tower and Aircraft-based Sensors.

Group	Tower Instruments	Aircraft Instruments
NASA GSFC	Active and Passive (ComRAD)	
JPL		Active and Passive (PALS)
JPL		Active (UAVSAR)
University of Monash, Australia		Active (PLIS) and Passive (PLMR)
University of Julich, Germany	Passive (Julbara)	Active (?) and Passive (PLMR)
SAOCOM		Active
CREST	Passive	
University of Florida	Active and Passive	
Kuwait University	Active and Passive	

5.6.6 Model-based validation

Validation based on land surface modeling and data assimilation will be used to complement in situ based validation (Section 3.3.5). Calibration and validation tools using hydrological modeling and data assimilation are under development at the NASA/GMAO based on the existing and proven NASA GEOS-5 Earth system modeling and data assimilation framework. The development of these tools is highly synergistic with the development of the Level 4 algorithms. The customization of the GEOS-5 land modeling and assimilation component for SMAP includes the use of the SMAP EASE grid and the capability to assimilate SMAP data products into the system. The SMAP data assimilation system will include the capability to assimilate brightness temperature, soil moisture retrievals, and/or freeze/thaw retrievals. Consequently, the assimilation system can be used for supplemental validation of the L1 brightness temperature, L2 soil moisture, and L3 freeze-thaw products in the context of the assimilation-based validation tools discussed in section 3.3.5.2.

A preliminary version of the customized system has already been used to generate a Nature Run for SMAP on the global and North America domains (data delivered in March 2011), thereby enabling the generation of synthetic SMAP data products that are important for the outreach by the SMAP Applications Working Group to future SMAP data users.

6 POST-LAUNCH ACTIVITIES

6.1 Overview

In the post-launch period the calibration and validation activities will address directly the measurement requirements for the L1-L4 data products. Each data product has quantifiable performance specifications to be met over the mission lifetime, with calibration and validation requirements addressed in their respective ATBDs.

Post-launch calibration and validation activities are divided into four main parts following the IOC phase after launch:

(1) Release of beta (or provisional) versions of L1 and L2 products

(2) Six-month sensor product Cal/Val phase, after which delivery of validated L1 products to the public archive will begin.

(3) Twelve-month geophysical product Cal/Val phase, after which delivery of validated L2 through L4 products to the public archive will begin.

(4) Extended monitoring phase (routine science operations) lasting for the remainder of the science mission. During this period, additional algorithm upgrades and reprocessing of data products can be implemented if found necessary (e.g., as a result of drifts or anomalies discovered during analysis of the science products).

6.2 Post-Launch Cal/Val Timeline

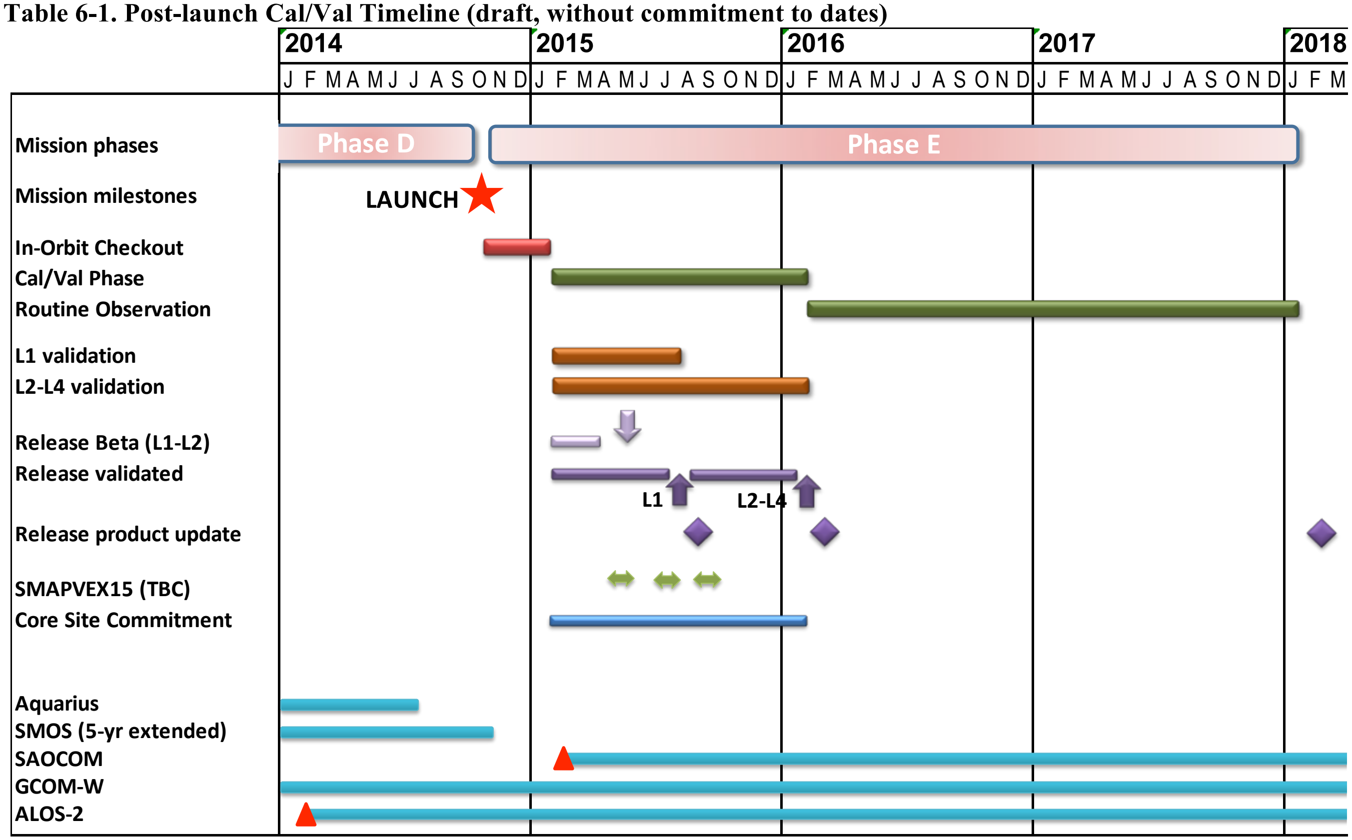
Table 6-1 shows the draft timeline (placeholders, and without commitment to dates) for the Cal/Val in the post-launch phase (Phase E). The timeline shows the key Cal/Val activities and relevant project schedule items. Phase E of the mission is divided into the IOC phase, Science Cal/Val phase, and Routine Operations phase as discussed in Section 2.6. This is reflected at the top of the table. In the Cal/Val Phase there are two important milestones: (1) release of validated L0 and L1 data, and (2) release of validated L2 through L4 data.

In situ validation sites, networks and field campaigns are the core of the science product cal/val in the post-launch phase. The table highlights the operation and occurrence of these.

Coordination of post-launch Cal/Val and Science Data System (SDS) activities is important since the SDS produces the science products, provides storage and management of Cal/Val data, provides data analysis tools, and performs reprocessing and metadata generation of algorithm and product versions. The Level 2 requirements state that the cumulative mission science data shall be reprocessed up to three times (if necessary) to improve the data quality and that the final reprocessing shall be used to generate consistently-processed set for the complete mission one month after the end of prime (3-year) science mission. The table shows placeholders for these milestones.

Finally, the table displays other relevant satellite missions taking place simultaneously with the SMAP mission.

Table 6-1. Post-launch Cal/Val Timeline (draft, without commitment to dates)



6.3 Mission Products

The specific approaches that will be used to calibrate and validate the SMAP Mission Products are described in the following sections. The methodologies for the L1 or Geophysical Products are slightly different than those used for the Science Products.

6.3.1 Sensor Products

6.3.1.1 Radiometer Brightness Temperature

The calibration approach of the SMAP radiometer requires that the absolute calibration is done on orbit after launch. The specific objectives of the radiometer post-launch calibration and validation activities are following:

- Provide any necessary tuning of pre-launch calibration, including bias removal, and set calibration-related parameters that can only be determined on-orbit
- Calibrate drifts in the measured brightness temperature
- Validate instrument performance i.e. determine radiometer performance figures
- Validate brightness temperature product i.e. determine overall uncertainty
- Validate brightness temperature gridding to Earth grid

The following subsections break these objectives down to separable components of the radiometer operation and calibration.

6.3.1.1.1 Geolocation

Standard geolocation techniques which have been previously developed and inherited from other missions (e.g. QuikSCAT, AIRS) are carefully documented in existing documents. These algorithms account for spacecraft position, pointing, and attitude; antenna scan angle; curvature of Earth and measurement timing.

The baseline geolocation will be established based on the space craft ephemeris and the nominal scan geometry. The measured brightness temperatures will be utilized in several ways to refine the baseline. Flat targets, such as large open ocean regions, can be used to determine pitch and roll bias utilizing the measured brightness temperature over the full 360° scan. The scan cone angle can also be solved and used to adjust the nominal cone angel. Alignment of coastlines and water bodies can be used to determine the best fit of the two-dimensional brightness temperature image vs. known geography. Coastline crossings can be also be utilized but the scan position needs to be addressed (as opposed to the case of fixed beam instruments such as Aquarius). Finally, the radiometer geolocation can be compared against the SAR geolocation, which, however, needs to account for the latency in the processing.

6.3.1.1.2 Faraday Rotation Correction

The validation of the Faraday rotation correction will be accomplished by comparing the estimated Faraday rotation with the Faraday rotation obtained from ionosphere electron density (International Reference Ionosphere (IRI) database) and magnetic field data (International Geomagnetic Reference Field (IGRF) database). The rotation angle can also be compared with the estimation by

SMOS [63]. This validation will be particularly important for calibration data collected over the ocean, where 3rd Stokes parameter is generated both by Faraday rotation and by the azimuthal asymmetry of ocean wave fields, although ocean-generated third Stokes parameter is expected to be less than 1K.

6.3.1.1.3 Atmospheric Correction

The effect of atmosphere is expected to be very small at L-band. Nevertheless, a correction will be applied to the brightness temperature measurement. The atmospheric correction will be carried out by applying global temperature and humidity profiles (from forecast data) to radiative transfer model of standard clear-sky case, at least over ocean. Over land an application of path delay measured by other microwave instruments is considered to improve accuracy.

6.3.1.1.4 Antenna Pattern Correction

The SMAP Brightness Temperature Forward Simulator (see Section 5.3.1.1) will be used to calculate an estimate of the effect of the sidelobes on the brightness temperature. The method will be validated utilizing known scenes.

6.3.1.1.5 RFI and Post-Launch Calibration

For validation of RFI mitigation, RFI detection flags will be compared with known RFI sites (such as FAA radars) and aircraft underpasses. The SMAP brightness temperature product will be compared with brightness temperature products of the Aquarius and SMOS missions (at about 40° incidence angle) and also the RFI detection flags will be compared with the RFI records generated by Aquarius and SMOS. RFI mitigation can also be validated by comparing soil moisture retrieval quality measures to RFI detection flags; poor retrieval quality could be due to missed RFI.

6.3.1.1.6 Absolute Calibration and Drift Monitoring and Correction

After applying the corrections listed in the previous paragraphs, the Cal/Val activities listed in Table 6-2 will be implemented. Post-launch absolute calibration and drift correction of the radiometer is centered on the measurements of three external targets: Cosmic Microwave Background (CMB), ocean and Antarctica ice sheets. By applying these reference targets the absolute error and drift of the brightness temperature measurements is corrected to less than 0.4 K (this requires that the radiometer is to be calibrated with accuracy of better than 2 K in the pre-launch phase, see Section 5.3.1.1.1). The radiometer will acquire data in high data rate mode (RFI detection) over the external calibration targets in order to calibrate all sub-channels for optimal RFI detection and removal.

The CMB is measured in Cold Sky Calibration (CSC) maneuver. In CSC the instrument is pointed at the galactic pole. The maneuver will be carried out monthly (TBC). The exact maneuver type (tipping, inertial hold, etc) is under study. The effect of the thermal changes during the maneuver will also be evaluated and accounted for. The absolute accuracy of the aggregate CMB and galactic source models are on the order of 0.1 K, the brightness temperature of CMB being at 2.73 K level.

The ocean target is a bounded geographical area specified by latitude and longitude limits (an area in Southeast Pacific has been preliminary identified). In order to have accurate value for the brightness temperature over the ocean target a radiative transfer model (RTM) will be developed (utilizing experience from Aquarius). The RTM will exploit buoy measurements (such as TOGA-TAO and ARGO arrays) and regional averages based on environmental reanalysis models to obtain accurate input values for physical temperature, wind, salinity etc. The RTM will account for surface roughness, atmospheric effects, reflections of celestial objects, etc. where applicable. The performance of the RTM of the target area will be confirmed in pre-launch activities (see Section 5.3.1.1.1). The absolute accuracy of the ocean target RTM is expected to be better than 0.4 K with better relative accuracy (for stability monitoring). However, achieving this accuracy would mean discarding of data obtained during less than ideal conditions (e.g. high winds). The expected brightness temperature is in 80-150 K range depending mostly on the polarization and ocean temperature.

Table 6-2. SMAP Cal/Val Methodologies and Their Roles in the L1B_TB Product Validation

Methodology	Data Required	Importance	Metrics
External Targets	Grid Cell averages for each overpass	Primary	RMSE, SDEV, Drift
Satellite Products	TB matchups with SMOS and Aquarius	Primary	Relative RMSE, SDEV, Drift, spatial and temporal correlation
Model Products	Antarctic, ocean, and cold space expected TBs	Primary	RMSE, SDEV, Drift, spatial and temporal correlation
Field Experiments	Aircraft- and ground-based radiometer measurements	Secondary	Spatial and temporal variability of sites

The Antarctica ice sheets contain areas with seasonally highly stable L-band brightness temperature. Especially the area around the Dome-C on eastern Antarctica has been under study and this region has been preliminary identified as a calibration target (a latitude and longitude mask has been specified around Dome-C). Intensive ground based studies at L-band suggest that the stability would be in the order of 0.1 K. The Dome-C site is equipped with meteorological measurements but the RTM from snow and ice layers need more development before absolute accuracies at levels better than 1 K can be reliably achieved. An option to increase the absolute accuracy would be continuous ground based measurements of the brightness temperature, which would then be up-scaled to footprint size. See Section 5.3.1.1.1 for the pre-launch activities to develop the accuracy of the Antarctica target. The brightness temperature level of the Antarctica is around 200 K.

The calibration data from the ocean and Antarctica targets will be acquired on every overpass. For Antarctica this means almost every orbit. The ocean target will be measured a few times a day. In comparison to the CSC maneuver, which is carried out monthly (TBC), the observation frequency of the terrestrial calibrations targets is very high. Hence, the calibration strategy involves two elements: activity related to the proximity of CSC maneuvers and activity related to the frequent observations of the terrestrial calibration targets between CSC maneuvers.

The absolute calibration of the brightness temperature measurements is determined around the CSC events. The CSC observation together with the observations of the terrestrial targets (within one day of the CSC maneuver (TBC)) is used to find the best fit between calibration parameters and the targets. In this case the CSC value is fixed and the radiometer calibration parameters are adjusted. However, through analysis of the measurements of the terrestrial calibration targets it may be possible that also the RTM parameters of the terrestrial targets are adjusted to find the best fit.

Between the CSC events the RTM parameters of the terrestrial calibration targets remain fixed and the RTM values are used to monitor the stability of the radiometer, detect any drifts and correct for them. It is important to note that when monitoring the stability of the radiometer the absolute value of the target is not essential as long as the changes of the target, if any, are known. Therefore, although the absolute accuracy of the RTM values for the terrestrial targets may not always meet the requirement, they should meet the requirement in the sense of stability.

There is a feedback from Level 2 product validation to Level 1 product validation. The observations over the Level 2 validation site are used to detect any systematically behaving biases which could possibly be attributed to the radiometer calibration parameters rather than Level 2 retrieval algorithm parameterization.

Inter-satellite calibration will also be employed if other L-band radiometer instruments will be available, such as SMOS and Aquarius. The process for utilizing these observations is TBD.

The process described above counts as the calibration and validation activity of the brightness temperature and is intended 1) to ensure that the L1B_TB product meets its requirement and 2) to provide the performance characteristics of the L1B_TB product.

6.3.1.1.7 Validation of Gridding

The accuracy of the gridding algorithms will be evaluated by viewing coastlines, islands, and inland lakes.

6.3.1.2 Radar Backscatter Cross Section

The post-launch calibration goals for the radar measured backscatter cross section are to remove channel-to-channel and pixel-to-pixel biases to the required accuracy and to remove the absolute bias to the required accuracy. The goal of the cross section validation is to show that the requirements of L1_S0_LoRes and L1_S0_HiRes have been met and also to use this information to optimize the accuracy of the final cross section products. Table 6-3 summarizes the methodologies that will be utilized.

The post-launch external calibration of the radar receive and transmit operation consists of several components. It is expected that man-made targets are insufficient to complete the calibration. This is due to the fact that the pixel size is too large for corner reflectors (however, they are cheap and may be helpful in geo-location validation) and the transponder accuracy is insufficient. Instead, the CSC maneuver and pre-launch calibration parameters are used for the receiver characterization and statistical analysis of large, uniform, isotropic and well-characterized, stable scenes (such as Amazon) are applied. Additionally, cross-calibrations with other contemporaneously flying radars are used. These possibly include ALOS-2, Aquarius and UAVSAR measurements over distributed targets and over targets where these comparison sensors can be calibrated with corner reflectors. Furthermore, calibrations based on natural targets have been demonstrated be very accurate. For example, JPL Ku-Band scatterometers removed channel-to-channel and pixel-to-pixel biases to 0.2 dB, and JERS-1 demonstrated that Amazon is stable to less than 0.2 dB at L-Band. The polarimetric backscatter reciprocity can also be utilized in the calibration. Finally, active mode data integrity checks can be carried out using BFPQ statistics, spectrum check, zero range delay check, and internal loop-back measurements can be processed to look for proper chirp operation and check transmit power stability.

Table 6-3. SMAP Cal/Val Methodologies and Their Roles in the L1B/C_S0 Product Validation

Methodology	Data Required	Importance	Metrics
Stable Emission Targets	Radar cross section only data + system parameter matchups w/observed or modeled Tb	Secondary	RMSE, SDEV, Drift vs. spatial/temporal range
Stable Scattering Targets	Amazon reference area radar observations over time	Primary	SDEV, Drift vs. time, channel, cross-track position
Satellite Products	σ^o cross-calibration with (PALSAR,JERS, Aquarius) over the Amazon	Primary	Minimize biases
Geolocation by Shoreline Fitting	Known shoreline maps vs. highest resolution radar map	Primary	Mean displacement along/cross track
Swath Oriented Artifact Detection	Full-Res swath image over isotropic targets (Amazon, Ice)	Primary	Visible swath oriented discontinuities

For calibrating the SAR image formation, checks for scan oriented brightness variation (scalloping) indicating antenna, attitude, and/or ephemeris offsets will be carried out. The processing parameters can be tweaked and attitude from the radar data can be derived as needed.

In terms of mitigating the RFI problem occasional receive only data collections will be carried out in order to survey the RFI conditions and flag problematic areas.

6.3.2 Geophysical Products

This Section describes the post-launch calibration and validation of the geophysical products, L2-L4. Note that the Cal/Val of L2 soil moisture products automatically calibrates and validates the L3 soil moisture products, since they are just compilations of L2 products.

6.3.2.1 Soil Moisture Passive (L2/3_SM_P)

Table 6-4 summarizes the methodologies that will be used to validate L2/3_SM_P. Each of these was described previously. The primary validation will be a comparison of retrievals at 40 km with ground-based observations that have been verified as providing a spatial average of soil moisture at this scale, the CVS (see Section 5.6.3). However, other types of observations or products will contribute to post-launch validation. The following subsections describe these in more detail.

Table 6-4. SMAP Cal/Val Methodologies and Their Roles in the L2/3_SM_P Product Validation

Methodology	Data Required	Importance	Metrics
Core Validation Sites	Grid Cell averages for each overpass	Primary	RMSE, Bias, Correlation
Contributing Validation Sites	Spatially scaled grid cell values for each overpass	Secondary: Pending results of scaling analyses	RMSE, Bias, Correlation
Satellite Products	Orbit-based match-ups Key targets	Primary: Pending assessments and continued operation	RMSD, Bias, Correlation
Model Products	Orbit-based match-ups Key targets	Secondary	RMSD, Bias, Correlation
Field Experiments	Detailed estimates for a very limited set of conditions	Primary	RMSE, Bias, Correlation

6.3.2.1.1 Core Validation Sites

As noted previously, the baseline validation (Stage 1) for the L2_SM_P soil moisture will be a comparison of retrievals at 40 km with ground-based observations that have been verified as providing a spatial average of soil moisture at the same scale, referred to as Core Validation Sites (Section 5.6.4). Many of these sites have been used in AMSR-E and SMOS validation [47-50]. Some of these sites will also be the focus of intensive ground and aircraft field campaigns to further verify the accuracy of the collected data.

The footprint-scale soil moisture estimates of Core Validation Sites will be compared against the SMAP L2_SM_P products to produce RMSE assessment of the accuracy of the product over these sites.

6.3.2.1.2 Contributing Validation Sites

The intensive network validation described above can be complemented by sparse networks as well as by new/emerging types of networks included in the Contributing Validation Sites (see Section 5.6.5). Due to the scaling issues of most of these networks discussed in Section 5.6.5 the data are more likely to be used as part of the statistical triple co-location analysis [32], [33] opposed to exact comparisons of in situ value and the product..

6.3.2.1.3 Satellite Products

Depending upon mission timing and life, it is possible that both SMOS and JAXA's GCOM-W will be producing global soil moisture products at the same time as SMAP (see Section 3.3.4). Both of these products are at the same nominal spatial resolution as the SMAP L2_SM_P soil moisture and are supported by validation programs, which should be mature by the SMAP launch date.

Post-launch soil moisture product comparisons with SMOS and GCOM-W are a very efficient means of validation over a wide range of conditions. If confidence in these products is high, they will provide a good resource for Stage 2 SMAP validation.

Post-launch validation will consist of comparisons between the SMAP / SMOS / GCOM-W soil moisture estimates that include:

- Core Validation Sites (Section 5.6.4)
- Extended homogeneous regions
- Global maps

For the core validation sites and extended homogeneous regions, statistical comparisons will be conducted (Root Mean Square Difference, RMSD, will be used instead of RMSE because the alternative satellite products are not considered to be "ground truth").

Comparisons will be initiated as soon as SMAP soil moisture products become available; however, a sufficient period of record that includes multiple seasons will be necessary before any firm conclusions can be reached. It should also be noted that only dates when both satellites cover the same ground target at the same time will be useful. The overlap of the swaths will vary by satellite. The morning (and evening) orbits of SMAP and SMOS cross (the SMOS 6 am overpass is ascending while the SMAP 6 am overpass is descending). Obviously, coverage of a specific site by both satellites will be infrequent.

Although data collected over the CVS will be of the greatest value, the Contributing Validation sites with concurrent satellite observations will also be useful, especially for regions that are relatively homogeneous in terms of land cover/vegetation and soils. One example would be the Sahara region.

Another role for the satellite products is in providing a synoptic perspective. Global image comparisons will be used to identify regions and / or time periods where the soil moisture products from the different satellites diverge.

Assessments will be conducted periodically throughout the SMAP post-launch period to assess, monitor, and possibly correct bias offsets between SMAP products and SMOS/GCOM-W products. In order to fully exploit SMOS/GCOM-W soil moisture products for SMAP validation, it will be necessary for SMAP team members to participate in the assessment and validation of these products and to secure access to the data through ESA and JAXA.

6.3.2.1.4 Model-based Products

In the simplest case, land surface models (either imbedded in a Numerical Weather Prediction (NWP) system or in off-line mode) can be used to generate soil moisture products at larger (basin-wide and continental) scales using land surface and meteorological forcing data sets that are independent of the SMAP remote sensing data. As in the case of satellite products, the resulting soil moisture fields can then be compared with the remotely sensed soil moisture product at validation sites (or synoptically) over diurnal and seasonal cycles. These model-derived soil moisture fields can also be used to extend comparisons to larger space and time domains than available from in situ observations, thus supporting Stage 2 validation. Of all the SMAP soil moisture products, only the L2_SM_P matches the typical spatial resolution of the NWP products. An advantage of the model-based products is that they produce a synoptic global product every day, which means that more frequent comparisons to SMAP and ground-based observations are possible.

Several Numerical Weather Prediction (NWP) centers (including ECMWF, NCEP, and NASA/GMAO) routinely produce operational or quasi-operational soil moisture fields at a scale comparable to the SMAP radiometer product that could be used in SMAP validation. [This is distinct from the GMAO generation of the SMAP L4_SM surface and root zone soil moisture product which uses an ensemble Kalman filter (EnKF) to merge SMAP observations with soil moisture estimates from the NASA Catchment land surface model.] The NWP-derived data products rely on the assimilation of a vast number of atmospheric observations (and select land surface observations) into General Circulation Models (GCMs). Although there are many caveats that need to be considered in using these data, they are readily available and they are consistent with the atmospheric forcings (precipitation and radiation) and land use information that determine the spatial and temporal patterns in soil moisture fields.

There is significant inherent uncertainty in any model-based soil moisture product since this is not one of the NWP primary variables. In addition, the models typically simulate a thicker surface soil layer than the layer that dominates the satellite measurement. Little effort has put so far into validating the soil moisture products of these models. Therefore, while these model products are useful, they must be used very carefully. As a result, they are considered to be a secondary resource for validating L2_SM_P soil moisture.

6.3.2.1.5 Field Experiments

Post-launch field experiments will play an important role in a robust validation of the L2_SM_P data product (see also Section 3.3.6). These experiments provide critical information that can be used to independently assess the contributions of radiometer calibration, algorithm structure and parameterization, and scaling on performance. Field experiments require numerous elements that include ground and aircraft resources, which involve many participants and associated financial support. However, they provide moderate-term intensive measurements of soil moisture and other surface characteristics at SMAP footprint scales.

While it is desirable to acquire such information as soon as possible after launch, the uncertainties of the actual launch date, the relationship of the launch date to the season, and the logistics of allocating fiscal year resources require that such commitments be conservative. Therefore, the field experiments should be scheduled for some time post-launch and used as part of the more robust validation of the SMAP products. Based on an October 2014 launch, one major extended post-launch field campaign which should include one or core validation sites (such as Oklahoma) is scheduled for summer 2015.

6.3.2.1.6 Combining Techniques

Recent work has extended the application of the "Triple Collocation" (TC) approach to soil moisture validation activities [32], [33]. These approaches are based on cross-averaging three independently-acquired estimates of soil moisture to estimate the magnitude of random error in each product. One viable product-triplet is the use of passive-based remote sensing, active-based remote sensing and a model-based soil moisture product [33], [36]. If successfully applied, TC can correct model versus SMAP soil moisture comparisons for the impact of uncertainty in the model product. However, TC cannot provide viable bias information and, therefore, only assesses the random error contribution to total RMSE. Note that TC can also be applied to reduce the impact of sampling error when up-scaling sparse in situ measurements during validation against ground-based soil moisture observations.

6.3.2.2 Soil Moisture Active (L2/3_SM_A)

The baseline validation will be a comparison of retrievals at 3 km with ground-based observations that have been verified as providing a spatial average of soil moisture at this scale (see Section 5.6.3). However, as indicated in Table 6-5, there are other types of observations or products will contribute to post-launch validation. The validation approach of the L2_SM_A product follows that of the L2_SM_P: the scaling issue is only adjusted to the finer 3-km resolution and there are some issues which require different amount of attention due to the different observing instrument (radar as opposed to radiometer). The following subsections discuss the use of the various methodologies.

Table 6-5. SMAP Cal/Val Methodologies and Their Roles in the L2/3_SM_A Product Validation

Methodology	Data Required	Importance	Metrics
Core Validation Sites	Grid Cell averages for each overpass	Primary	RMSE, Bias, Correlation
Contributing Validation Sites	Spatially scaled grid cell values for each overpass	Secondary: Pending results of scaling analyses	RMSE, Bias, Correlation
Satellite Products	Orbit-based match-ups Key targets and CVS	Secondary: Pending assessments and continued operation	RMSD, Bias, Correlation
Model Products	Orbit-based match-ups Key targets and CVS	Secondary	RMSD, Bias, Correlation
Field Experiments	Detailed estimates for a very limited set of conditions	Primary	RMSE, Bias, Correlation

6.3.2.2.1 Core and Contributing Validation Sites

The usefulness of soil moisture in situ networks for satellite product validation was described in Section 3.3.1. In terms of utilization of in situ core sites and the sparse networks the L2_SM_A product validation follows mostly the approach of the L2_SM_P product. However, the scaling process of the point measurements (see Section 3.3.1.2) has different parameters, since the pixel size of the L2_SM_A product is only 3 km (see Section 5.6.3). The lists of soil moisture Core and Contributing Validation Sites are presented in Sections 5.6.4 and 5.6.5.3, respectively.

The footprint-scale soil moisture estimates from the Core and Contributing Validation Sites will be compared with the radar-based soil moisture products. In this process the model based techniques described in 3.3.5.1 will be used to minimize the up-scaling errors, broaden the temporal and spatial domain of the validation and to provide more insight into the parameters of the hydrological cycle at the network locations. First comparisons will be made before the release of the beta release. The full comparison and evaluation will be completed by the end of Cal/Val Phase. The comparison between the in situ estimates and the product will also be used to refine the algorithm and its parameterization.

The validation metric (mean of site-specific RMSE, see [8]) is determined separately for sparse networks and core sites due to their different up-scaling properties.

As explained in Section 3.3.5.2, the land surface data assimilation framework will be utilized for retrieving additional performance metrics (innovation statistics) for the soil moisture product and also for the exercise where the in situ soil moisture observations are substituted for ground-based measurements of rain rate, which enables the utilization of rain gauge networks with large coverage.

6.3.2.2.2 Satellite and Model Products

The utility of other satellite products for the validation of a SMAP product was described in Section 3.3.4. Radar cross section measured by ALOS PALSAR (or ALOS-2) and SAOCOM may be obtained to test the algorithms. The resolutions of these radars are very high, which can be utilized in the validation of the mitigation of pixel heterogeneity effects. However, care must be taken regarding the various polarimetric modes and incidence angles of PALSAR and SAOCOM. Assessments will be conducted to estimate, monitor, and correct bias offsets between SMAP products and ALOS-2 and SAOCOM products over the validation sites.

The first tests against SAOCOM soil moisture products will be performed by the end of Cal/Val Phase, and the monitoring will continue as long as these products are available. They are not a priority for the beta release.

6.3.2.2.3 Field Experiments

The role of the airborne field experiments for satellite product validation was described in Section 3.3.6. Similarly as in the case of L2_SM_P the field experiments provide critical information that can be used to independently assess the contributions of radar calibration, algorithm structure and parameterization, and scaling on performance for the L2_SM_A product validation. They provide moderate-term intensive measurements of soil moisture and other surface characteristics at L2_SM_A pixel scales. However, due to the relatively small pixel size of the L2_SM_A product the significance of the airborne field experiments in terms of scaling properties of a pixel is not as disparate as in the case of L2_SM_P (36-km pixel).

SMAPVEX15 is planned to include airborne radar observations. While SMAPVEX15 is scheduled as soon as possible after launch, the uncertainties of the actual date, the relationship to the season, and other logistics require that time-wise commitments for utilization of the campaign data be conservative. Therefore, SMAPVEX15 and other potential field experiments shall be used as part of the more robust validation of the SMAP products. SMAPVEX15 and other post-launch field campaigns are discussed more in Section 6.4. The analysis will focus on matching up airborne observation with satellite products and produce RMSE on product scale and also regarding variability within the product footprint.

The field experiment data will be processed and analyzed for the final validation report. The beta release will not include results from the field experiments not only due to the processing time but also due to the timing of the campaign which cannot be guaranteed to take place within three months after completion of the IOC.

6.3.2.2.4 Combining Different Validation Sources

Each abovementioned validation component produces a separate quantified validation result. The primary, and most emphasized, value is given by the core sites, which is complemented by the result from the sparse networks to add coverage and diversity of validation conditions. The field campaign results will be used to augment this value by giving additional insight to the breakdown of error sources in in situ measurements and scaling process.

The role of other satellite products is to establish the product relative to these products and will not directly add to the validity of the product. Additionally, the land surface data assimilation framework will be used to obtain innovation statistics as an additional performance metric.

The beta release will include only assessment based on selection of core sites and sparse networks. The validation release will include input from all validation sources.

6.3.2.3 Soil Moisture Active/Passive (L2/3_SM_AP)

The baseline validation will be a comparison of retrievals at 9 km with ground-based observations that have been verified as providing a spatial average of soil moisture at this scale. However, as shown in Table 6-6, other types of observations or products will contribute to the post-launch validation. The validation approach of the L2_SM_AP product takes into account the validation efforts of both L2_SM_P and L2_SM_A, as L2_SM_AP combines both radiometer and radar measurements for retrieval. The following subsections discuss use of long term measurement networks, field experiments, utilization of other satellite products and hydrological modeling.

Table 6-6. SMAP Cal/Val Methodologies and Their Roles in the L2/3_SM_A/P Product Validation

Methodology	Data Required	Importance	Metrics
Core Validation Sites	Grid Cell averages for each overpass (time-continuous)	Primary	RMSE, Bias, Anomaly Correlation
Contributing Validation Sites	Spatially scaled grid cell values for each overpass (time-continuous)	Secondary: Pending results of scaling analyses	RMSE, Bias, Anomaly Correlation
Satellite Products	Orbit-based match-ups Key targets for GPM, SMOS, GCOM-W	Secondary: Pending assessments and continued operation	Pattern matching, Correlation
Model Products	Global model outputs (ECMWF, NCEP, GMAO, Merra)	Secondary	Correlation
Field Experiments	Detailed estimates for a very limited set of conditions	Primary	RMSE, Bias, Correlation

6.3.2.3.1 Core and Contributing Validation Sites

The utility of soil moisture in situ networks for satellite product validation was described in Section 3.3.1. The utilization of in situ dense sampling sites and sparse networks for the L2_SM_AP product validation mostly follows the approach of the L2_SM_P product. However, the scaling process of the point measurements has different parameters, since the pixel size of the L2_SM_AP product is only 9 km and the pixel is formed by a combination of 36 km radiometer pixels and 3 km radar pixels. The lists of soil moisture Core and Contributing Validation Sites are presented in Sections 5.6.4 and 5.6.5.3, respectively.

The footprint-scale soil moisture estimates from the Core and Contributing Validation Sites will be compared with the radiometer-based soil moisture products. In this process the model based techniques described in 3.3.5.1 will be used to minimize the up-scaling errors, broaden the temporal and spatial domain of the validation and to provide more insight into the parameters of the hydrological cycle at the network locations. First comparisons will be made before the release of the beta release. The full comparison and evaluation will be completed by the end of Cal/Val Phase. The comparison between the in situ estimates and the product will also be used to refine the algorithm and its parameterization.

The validation metric (mean of site-specific RMSE, see [8]) is determined separately for sparse networks and core sites due to their different up-scaling properties.

As explained in Section 3.3.5.2, the land surface data assimilation framework will be utilized for retrieving additional performance metrics (innovation statistics) for the soil moisture product and also for the exercise where the in situ soil moisture observations are substituted for ground-based measurements of rain rate, which enables the utilization of rain gauge networks with large coverage.
Satellite and Model-based Products

The utility of other satellite products for the validation of a satellite product was described in Section 3.3.4. The testing of the L2_SM_AP directly with other satellite data products is limited due to the unique nature of combining L-band radiometer and L-band radar with synthetic aperture processing. However, it may be possible to carry out some algorithm level tests by combining data from L-band radiometers (such as SMOS) and L-band radar (such as ALOS-2) flying on different platforms. The direct comparisons of soil moisture products on a 9-km scale can be carried out against SAOCOM by aggregating its soil moisture products.

The first tests against these other satellite products will be performed by the end of Cal/Val Phase, and the monitoring will continue as long as these products are available. They are not a priority for the beta release.

6.3.2.3.2 Field Experiments

The role of the airborne field experiments for satellite product validation was described in Section 3.3.6. Similarly as in the case of L2_SM_P the field experiments provide critical information that can be used to independently assess the contributions of radar and radiometer calibration, algorithm structure and parameterization, and scaling on performance for the L2_SM_AP product validation. They provide moderate-term intensive measurements of soil moisture and other surface characteristics at L2_SM_AP pixel scales. The collection of field experiment data is combined for all soil moisture algorithms to campaigns occurring as has been laid out for L2_SM_P in Section 6.3.2.1.5 and summarized in Section 6.4.

SMAPVEX15 is planned to include combined airborne radar and radiometer observations. While SMAPVEX15 is scheduled as soon as possible after launch, the uncertainties of the actual date, the relationship to the season, and other logistics require that time-wise commitments for utilization of the campaign data be conservative. Therefore, SMAPVEX15 and other potential field experiments shall be used as part of the more robust validation of the SMAP products. SMAPVEX15 and other post-launch field campaigns are discussed more in Section 6.4. The analysis will focus on matching up airborne observation with satellite products and produce RMSE on product scale and also regarding variability within the product footprint.

The field experiment data will be processed and analyzed for the final validation report. The beta release will not include results from the field experiments not only due to the processing time but also due to the timing of the campaign which cannot be guaranteed to take place within three months after completion of the IOC.

6.3.2.3.3 Combining Different Validation Sources

Each abovementioned validation component produces a separate quantified validation result. The primary, and most emphasized, value is given by the core sites, which is complemented by the result from the sparse networks to add coverage and diversity of validation conditions. The field campaign results will be used to augment this value by giving additional insight to the breakdown of error sources in in situ measurements and scaling process.

The role of other satellite products is to establish the product relative to these products and will not directly add to the validity of the product. Additionally, the land surface data assimilation framework will be used to obtain innovation statistics as an additional performance metric.

The beta release will include only assessment based on selection of core sites and sparse networks. The validation release will include input from all validation sources.

6.3.2.4 Freeze/Thaw State (L3_FT_A)

The baseline validation will be a comparison of freeze/thaw state retrievals with ground-based observations that have been verified as providing a spatial average of freeze/thaw state at this scale. However, as shown in Table 6-7, other types of observations or products will contribute to the post-launch validation. The following subsections discuss the use of long-term measurement networks and field experiments.

Table 6-7. SMAP Cal/Val Methodologies and Their Roles in the L3_FT Product Validation

Methodology	Data Required	Importance	Metrics
Core Validation Sites	Grid Cell averages for each overpass	Primary	RMSE, Bias, Correlation
Contributing Validation Sites	Spatially scaled grid cell values for each overpass	Primary: Pending results of scaling analyses	RMSE, Bias, Correlation
Satellite Products	ALOS II PALSAR, ASCAT, SMOS, AMSR-E	Secondary: Pending assessments and continued operation	RMSD, Bias, Correlation
Model Products	MERRA	Secondary	RMSD, Bias, Correlation
Field Experiments	Detailed estimates for a very limited set of conditions	Secondary	RMSE, Bias, Correlation

6.3.2.4.1 Core and Contributing Validation Sites

Success criteria for the L3_FT_A product will be assessed relative to in situ network measurements of frozen and non-frozen status for northern (≥45°N) biophysical monitoring stations within the major land cover and climate regimes. The lists of Core and Contributing Validation Sites are presented in Sections 5.6.4 and 5.6.5.3, respectively.

In situ frozen/non-frozen status will be determined as a composite ensemble of vegetation, soil and air temperature measurements, and will be compared to coincident footprint scale L3 freeze/thaw measurements. The fulfillment of the requirements will be assessed by comparing SMAP freeze/thaw classification results and in situ frozen or non-frozen status.

The full comparison and evaluation of the L3 freeze/thaw product accuracy will be completed by the end of the mission Cal/Val Phase. The comparison between the in situ temperature observations and the freeze/thaw product will also be used to refine the classification algorithm and its parameterization.

6.3.2.4.2 Satellite and Model-based Products

TBD

6.3.2.4.3 Field Experiments

Additional L3 freeze/thaw validation activities may involve field campaigns using relatively fine scale airborne (e.g., PALS) and tower based L-band remote sensing in conjunction with detailed biophysical measurements from in situ station networks (e.g., FLUXNET). Particular focus areas for these activities include examining sub-grid scale spatial heterogeneity in radar backscatter and freeze/thaw characteristics within the SMAP footprint; verifying spatial and temporal stability in L-band radar backscatter for reference frozen and non-frozen conditions; verifying linkages between L3 freeze/thaw dynamics, vegetation productivity and seasonal patterns in land-atmosphere CO_2 exchange. The results of these validation activities may then be used to refine pre-launch algorithms and ancillary data sets to improve L3 freeze/thaw product accuracy.

6.3.2.4.4 Combining Different Validation Sources

Each abovementioned validation component produces a separate quantified validation result. The primary, and most emphasized, value is given by the core sites, which is complemented by the result from the sparse networks to add coverage and diversity of validation conditions. The field campaign results will be used to augment this value by giving additional insight to the breakdown of error sources in in situ measurements and scaling process.

6.3.2.5 Soil Moisture Data Assimilation Product (L4_SM)

The overall approach that will be used to validate L4_SM is summarized in Table 6-8. For certain applications, such as the initialization of soil moisture reservoirs in atmospheric forecasting systems, the absolute error in the soil moisture estimates is not necessarily relevant [64] . Since scaling of soil moisture data is required prior to their use in model-based applications, time-invariant biases in the moments of the L4_SM product become meaningless. For model applications, the temporal correlation of soil moisture estimates with independent observations is therefore a more relevant validation metric. By focusing on the correlation metric, evaluation problems stemming from the inconsistency between point and area-averaged quantities are, to some extent, ameliorated. Reference [65] provides a detailed discussion of the relationship between RMSE and correlation metrics.

Table 6-8. SMAP Cal/Val Methodologies and Their Roles in the L4_SM Product Validation

Methodology	Data Required	Importance	Metrics
Core Validation Sites	Observed grid cell averages (time-continuous)	Primary	Anomaly correlation, RMSE, Bias,
Contributing Validation Sites	Observed values (time-continuous)	Primary	Anomaly correlation
Satellite Products	Orbit-based match-ups (SMOS, ASCAT,…)	Secondary: Pending assessments and continued operation	Anomaly correlation, RMSD, Bias,
Model Products	Global modeling and data assimilation systems (ECMWF, NCEP, …..)	Primary	Anomaly correlation, Assimilation diagnostics, RMSD, Bias,
Field Experiments	Detailed estimates for a very limited set of conditions	Secondary	Anomaly correlation, RMSE, Bias,

6.3.2.5.1 Validation with In Situ Observations

Validation of the *surface* soil moisture estimates from the L4_SM product against in situ observations will be identical to that of the L2_SM_A/P surface soil moisture product, including validation against measurements from dedicated field experiments (Section 6.3.2.3).

The *root zone* soil moisture estimates of the L4_SM product will be validated with in situ observations from Core and Contributing Validation Sites which are listed in Sections 5.6.4 and 5.6.5.

Land surface flux, surface temperature, and other estimates from the L4_SM product will be evaluated against in situ observations as much as possible but will be considered research products. The availability of land surface flux data for validation is very limited. A comparably large collection of such data is provided free of charge by the Coordinated Energy and Water Cycle Observations Project (CEOP; http://www.ceop.net) and FLUXNET (http://fluxdata.org). These measurements will be used to validate the research products to the extent possible. From 1 October 2002 through 31 December 2004, for example, 24 CEOP reference sites, located mostly in Kansas and Oklahoma, provide hourly surface flux data that is sufficient for validation.

6.3.2.5.2 Validation with Data Assimilation Approaches

Relative to the coverage of the satellite and model soil moisture estimates, few in situ data are available. The validation of the L4_SM product based on in situ observations (Section 6.3.2.5.1) will thus be complemented with model-based validation approaches. Specifically, the soil moisture data assimilation system produces internal diagnostics that will be used to indirectly validate its output (Section 3.3.5.2). Specifically, the statistics of appropriately normalized innovations will be examined (; see also discussion of adaptive filtering in Section 4.1.2 of the L4_SM ATBD). Moreover, we will use also use independent precipitation observation as described in Section

3.3.5.2 to evaluate the surface and root zone soil moisture increments that are produced by the L4_SM algorithm.

6.3.2.6 NEE Product (L4_C)

The overall approach that will be used to validate L4_C is summarized in Table 6-9. The statistical methods and domains of validity envisaged for testing the L4_C algorithms and for demonstrating that their performance meets the SMAP science requirements will involve direct comparisons between model outputs and tower eddy covariance CO_2 flux measurements from available FLUXNET tower sites representing the dominant global biome types [66]. Similar protocols have been successfully implemented for validating the MODIS MOD17 GPP products ([48], [67], [68], [69]). The L4_C performance and error budgets will also be determined through model perturbation and sensitivity analyses spanning the range of observed northern environmental conditions and using model input accuracy information. If the L4_C algorithms are implemented within the GMAO assimilation framework, this will enable robust error tracking and quantification of the value of SMAP inputs relative to L4_C calculations derived solely from unconstrained model reanalysis inputs. The model reanalysis framework will also enable L4_C products to be generated well before initiation of the SMAP data stream and will provide a standard from which improved model calculations using SMAP derived inputs can be assessed.

Table 6-9. SMAP Cal/Val Methodologies and Their Roles in the L4_C Product Validation.

Methodology	Data Required	Importance	Metrics
Core Validation Sites	Observed grid cell averages (time-continuous)	Primary	Correlation, RMSE, Bias,
Contributing Validation Sites	Observed values (time-continuous)	Primary	Correlation
Satellite Products	Orbit-based match-ups (SMOS, ALOS-2…)	Secondary: Pending continued operation	Anomaly correlation, RMSD, Bias,
Model Products	Site and global modeling systems , model inversions (Carbontracker)	Primary	Sensitivity diagnostics, correlation, RMSD, Bias,
Field Experiments	Detailed estimates for a very limited set of conditions	Secondary	Correlation, RMSE, Bias,

L4_C model parameters and initial SOC pool sizes will be determined prior to launch through model simulations and sensitivity studies using GMAO LIS assimilation based soil moisture and temperature inputs and MODIS GPP inputs over the observed range of Northern Hemisphere (≥45 °N) variability. These estimates will be refined post-launch following initiation of the SMAP data stream and associated production of the input GMAO L4_SM fields. If the L4_C algorithms are implemented within the GMAO assimilation framework, the value of SMAP inputs will be quantified relative to L4_C NEE calculations derived solely from unconstrained model reanalysis inputs.

The accuracy of the L4_C outputs, including NEE and component carbon fluxes for GPP and R_{tot} will be also be established in relation to in situ CO_2 eddy flux measurements and associated carbon budgets from available tower network observations (e.g., FLUXNET) within regionally dominant vegetation classes following established protocols (e.g. [48], [50]).

The fulfillment of the NEE requirement will be assessed by comparing SMAP L4_C NEE output with FLUXNET NEE estimates.

6.4 Dedicated Post-Launch Field Campaigns

The purpose of the post-launch field campaigns is to provide critical information needed for the validation of the products. Each product identified a strategy for the validation in the preceding sections and whether field campaigns are required to carry out this strategy. This section presents a summary of coordinated efforts which answer these needs of each product.

Field experiments typically require considerable coordination between different groups, such as the project team, SDT working groups, government agencies, research institutions and universities. This imposes relatively long lead time for the planning of campaigns and may affect the timing of the campaign. At the same time, the field campaigns need to be finished well before the end of the Cal/Val Phase to leave time for processing and analysis. Moreover, there is also optimum seasonal timing to carry out soil moisture and freeze/thaw state field campaigns.

6.4.1 SMAPVEX15

A field campaign dedicated to calibration and validation of SMAP soil moisture products is planned to be carried out in North-America after the completion of IOC (but no later than IOC+8 months to allow time for data processing and analysis before the end of the Cal/Val Phase) depending on the launch date.

Considering the launch date of November 2014 (which would mean the end of IOC in February 2015) the campaign would be carried out in the May to October timeframe in 2015 to coincide with favorable season for soil moisture validation. The location of the campaign is to be determined but it will be carried out over one or several of the soil moisture core validation sites in North America (see Section 5.6.4).

The airborne instrumentation will include at least an airborne L-band radar and radiometer; possibly PALS and UAVSAR (see Appendices B.1 and B.2). Post-launch field campaigns will require the rapid mapping of spatial domains on the scale of the SMAP products (up to 36 km) concurrent with satellite overpasses. In general, this will require coverage within a one-hour time window in order to minimize the effects of naturally occurring geophysical changes. In addition, several geographic domains will be required. These requirements make it critical that the airborne simulator be an efficient mapping instrument installed on an aircraft platform with higher speed and possibly altitude capabilities than have been available in pre-launch campaigns. Planning for this campaign will have to be coordinated with CARVE and AirMOSS projects (see Appendices C.1and C.2), which utilize these airborne resources as well. Alternative resources should be identified for potential risk mitigation.

The aim of the campaign is to capture a range of soil moisture and vegetation conditions and this is accounted for in the timing and planning of the location of the campaign. One potential design is shown in Figure 6.1.

The in situ sampling needs to account for the different sensitivities of the radiometer and radar algorithms on different surface and vegetation components. Since the radar is more sensitive to these parameters, the requirements of the radar-based algorithms are driving the design.

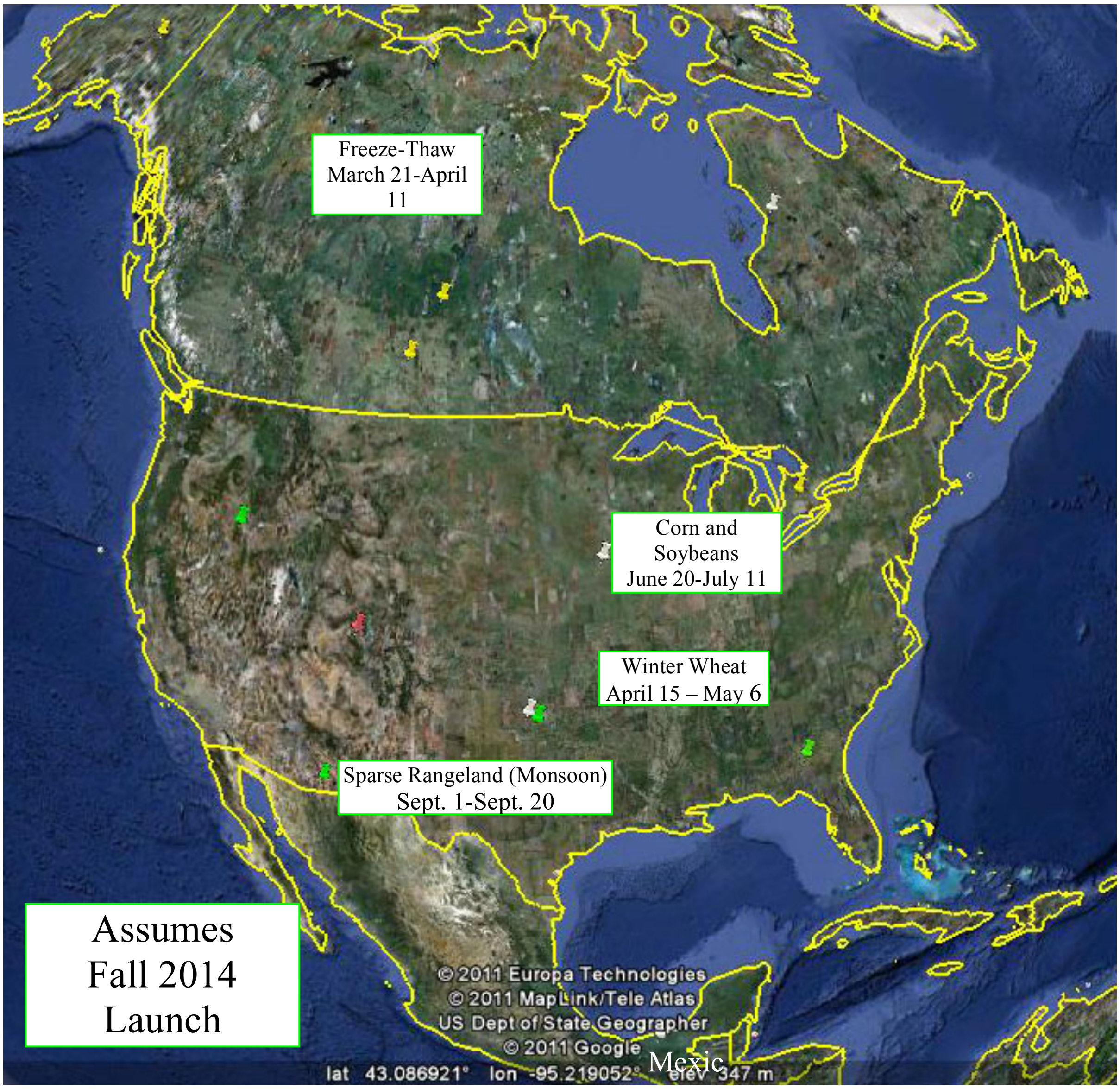


Figure 6.1 Example of a Possible SMAPVEX15 design.

7 INTERNATIONAL COLLABORATION

This Section summarizes projects and associated observing networks have already made commitments to supporting the SMAP Cal/Val program.

International collaboration in SMAP Cal/Val consists of in situ observations in the Core Validation Site program (after selection) or sparse networks, field campaigns that provide pre- and/or post-launch sensor and geophysical observations, and satellite-based observations and products. Satellite program interactions are described in Appendix D. The plans for in situ observations have been discussed previously; therefore, only the field experiment and satellite elements are described here.

7.1 Pre-Launch Field Campaigns

7.1.1 SMAPEx campaigns in Australia in 2010-2011

The University of Melbourne and University of Monash, under support from the Australian Research Council, carried out field experiments with airborne passive and active L-band instrumentation, which contributes to the pre-launch algorithm development of SMAP [56],[57]. The campaigns are called Soil Moisture Active Passive Experiments (SMAPEx). The campaigns took place in July 2010, December 2010 and September 2011. The objective of the campaigns is to develop algorithms for accurate high resolution soil moisture mapping under Australian conditions that will subsequently be used by SMAP.

The concept for the study is to obtain SMAP simulator data in each of the four seasons to build a robust data set for grazing and agricultural land covers. The length of each campaign is one week. Figure 7-1 shows the location and ground truth sites of the planned study region. The Yanco area lies within the Murrumbidgee catchment in southeast Australia.

The study site has been used in previous campaigns and in situ sites provide continuous observations of soil moisture. The site instrumentation has been modified to match up with the multiple scales required for validation of all SMAP soil moisture products and as result it also matches the Core Validation Site requirements described in Section 5.6.4. During the field campaign intensive ground-based sampling is conducted to support the algorithm development studies as well as providing calibration and scaling information on the in situ network.

The airborne microwave instruments to be used in the campaign will include Polarimetric L-band Multibeam Radiometer (PLMR) and Polarimetric L-band Imaging Synthetic Aperture Radar (PLIS). The configuration allows simultaneous radiometer footprints of 1 km and radar footprints of 10 m when flown at flying altitude of 3000 m.

The ground observations will be publicly available at a website of the University of Melbourne [57]. Data from the airborne instruments will be made available to the SMAP validation community.

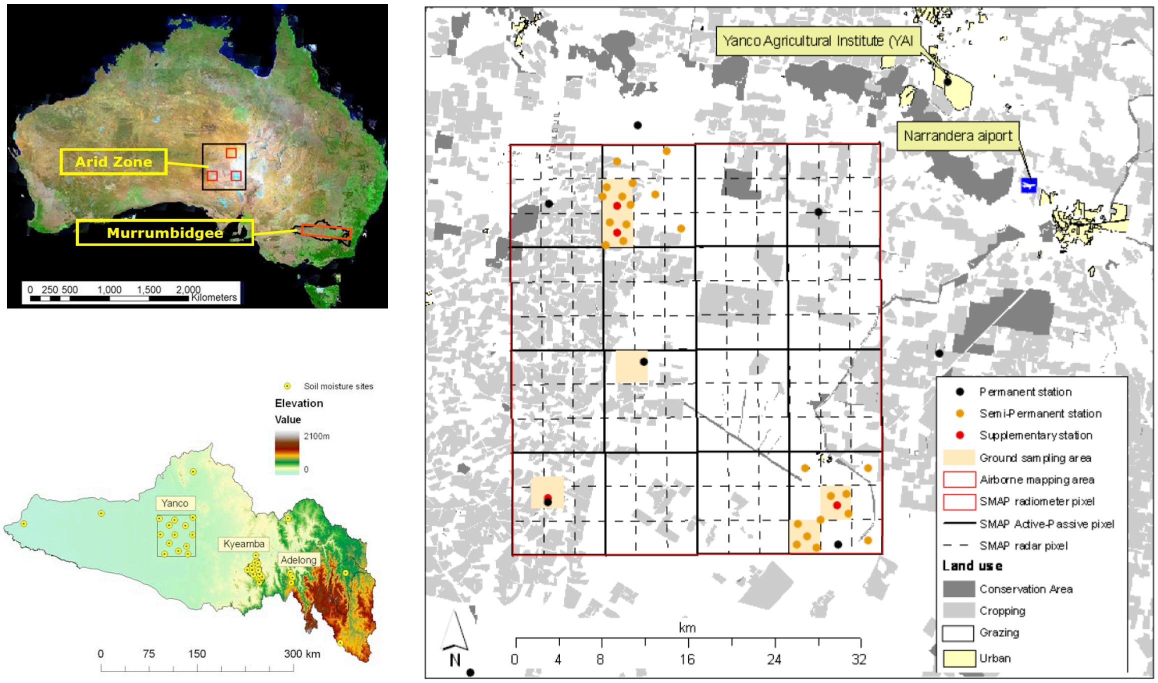


Figure 7-1. Australia and the location of the Murrumbidgee catchment (upper left), the location of the Yanco study region in the Murrumbidgee catchment (lower left) and the Yanco study area with the locations of continuous soil moisture monitoring and intensive ground sampling sites with expected SMAP grid (on the right).

7.1.2 CanEx-SM10 (Canada)

The Canadian Space Agency is a partner in the SMAP project and as part of its collaboration is providing support to Canadian institutions to collect both in situ and field campaign data for algorithm development and validation. The first activity was a soil moisture field campaign named Canadian Experiment for Soil Moisture 2010 (CanEx-SM10) that was carried out in Saskatchewan, Canada, from June 2 to June 16, 2010 [54],[55]. This was an enhancement of a planned effort to contribute to the validation of Soil Moisture and Ocean Salinity (SMOS) soil moisture estimation and brightness temperature products. Additional ground and aircraft observations were added to support the pre-launch soil moisture algorithm calibration and validation of SMAP over agricultural and forested sites. The specific objectives were:

- Comparative analysis of L-Band microwave data along with field measurements;
- Development of soil moisture retrieval algorithms from passive and active microwave data (SMOS, RADARSAT-2, ALOS-PALSAR, L-Band airborne data from EC's radiometer and NASA's UAVSAR);
- Scaling methodologies for SMOS coarse resolution data,
- Calibration and scaling of two potential Core Validation Sites including two nested in situ soil moisture networks, and
- Assimilation of SMOS data in land surface systems to improve land surface initial conditions provided to environmental forecast models.

Two experiment sites were selected for the campaign. One is an agricultural area located in the south of Saskatoon, near Kenaston, Saskatchewan and the second is a forested area located at about

100 km north-east of Prince Albert, Saskatchewan (see Figure 7-2). They are located at about 300 km from each other. Measurements from these two sites provide analysis of soil moisture over large areas of very different types of soil and vegetation.

Ground sampling over the experiment sites included intensive soil moisture, vegetation and roughness measurements. Additionally, enhanced vegetation sampling was carried out at the BERMS site. Longer term in situ measurements were initiated over the BERMS site to establish the scaling of the limited permanent sites. At the Kenaston site, there were two nested networks, one operated by EC and the other by the University of Guelph, which matched many of the criteria for a Core Validation Site.

Simultaneous with the ground measurements and SMOS overpasses, aircraft campaigns were conducted over the Kenaston and BERMS sites. The airborne microwave instruments included an L-band radiometer from Environment Canada on the Canadian NRC Twin Otter and an L-band synthetic aperture (UAVSAR) on NASA G-III aircraft (see Appendix B.2).

The campaign focused first on the Kenaston site over a period of about two weeks including 6 days of flights with the radiometer and radar and 1 day of flights with the radar only. At the end of the campaign, one day of sampling including both radiometer and radar over the BERMS site.

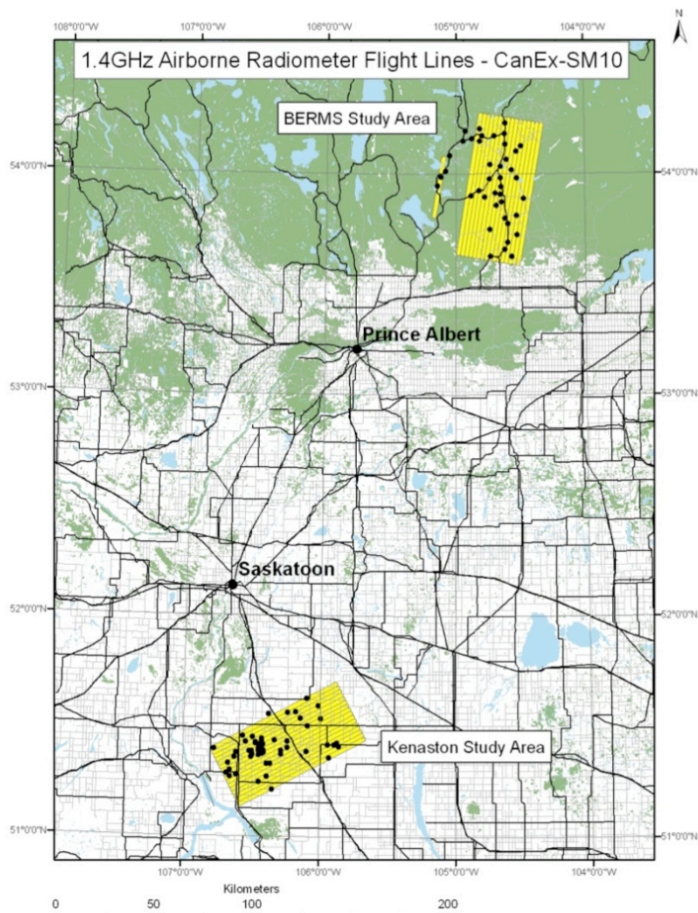


Figure 7-2. CanEx-SM10 experiment sites.

7.1.3 Post-Launch Field Campaigns

It is anticipated that the collaborations described above for pre-launch will continue into post-launch; however, no details have been developed at this stage.

7.2 Satellite Data

7.2.1 SMOS

ESA provides data from missions such as SMOS through an ongoing proposal process. The SMAP project has subscribed Level 1C product over land (L-band brightness temperature on Earth grid) and Level 2 soil moisture product with necessary ancillary data products through this process. The data is utilized to support algorithm pre-launch development, calibration and validation and preparation to post-launch calibration and validation activities.

7.2.2 GCOM-W

JAXA has provided data from its missions to NASA in the past. At the present, there are ongoing discussions between NASA and JAXA that are specifically related to GCOM-W that include the AMSR-2 instrument. If these are not formalized by the time of the GCOM-W launch, the SMAP project will attempt to establish scientific collaboration directly in order to acquire soil moisture products. It is also possible that the current NASA AMSR-E program algorithms may be adapted for GCOM-W to continue this data stream.

7.2.3 SAOCOM

SAOCOM will provide data to groups based upon a proposal process. CONAE released a pre-launch announcement of opportunity that the SMAP project responded to. When the post-launch announcement of opportunity is released, the SMAP project will submit a proposal for the acquisition of data to support Cal/Val.

8 SMAP SDT CALIBRATION & VALIDATION WORKING GROUP

The SMAP project initiated Working Groups (WGs) as a means to enable broad science participation in the SMAP mission. The working groups are led by Science Definition Team (SDT) members and provide forums for information exchange on issues related to SMAP science and applications goals and objectives. A specific WG was created to support SMAP Cal/Val. Community participation and contributions to the Cal/Val Working Group (CVWG) will contribute to designing the Cal/Val program and generating a plan. It provides a mechanism for engaging key people and teams that can contribute to resolving pre-launch algorithm issues, infrastructure for validation, and the post-launch validation.

Cal/Val involves all mission products; from sensor data to L4 value added. Supporting these involves a wide range of elements including in situ, tower and aircraft simulators, satellite observations, model and surrogate variables, and field campaigns. As a result the CVWG requires the participation of a large and diverse group of scientists and disciplines.

Some aspects of SMAP Cal/Val are unique to SMAP while others would be enhanced through coordination with other satellite mission Cal/Val programs, for example those of SMOS and GCOM-W. The CVWG provides one mechanism for engaging scientists and activities involved in these missions and leveraging their resources.

CVWG activities are carried out mainly through emails and teleconferences. The primary forum for interaction will be a series of Cal/Val Workshops conducted at key points during the pre-launch and post-launch phases (approximately every eighteen months).

Workshops to Date

June 9-11, 2009 (Oxnard, CA). This workshop was organized jointly by the SMAP CVWG and the SMAP Algorithm Working Group (AWG). The workshop was open to the science community and attracted approximately 80 attendees, including international participants from Europe, Asia, and Australia. The workshop provided a forum for the science community to review the status of algorithm development for SMAP data products and to provide input to the development of the science data calibration and validation plan. Overview presentations covered the SMAP science objectives and requirements, project status, the measurement system, the science data system, and the algorithm testbed. Presentations were also given on each of the data product algorithms, and participants had the opportunity to provide feedback on the algorithm plans and to make brief presentations of their own work on related algorithm topics. In the calibration and validation portion of the workshop, presentations described the major in situ soil moisture networks and measurement techniques including the U.S. Department of Agriculture Soil Climate Analysis Network (SCAN), National Oceanic and Atmospheric Administration Climate Reference Network (CRN), Oklahoma Mesonet, U.S. Department of Agriculture/Agricultural Research Service watersheds, Cosmic- ray Soil Moisture Observing System (COSMOS), Global Positioning System (GPS), and others. The workshop presentations can be viewed through the Algorithms & Cal/Val Workshop link on the SMAP Web page [70].

May 3-5, 2011 (Oxnard, CA). During the pre-launch phase, the focus of Cal/Val is on contributing to algorithm development and establishing the infrastructure for post-launch validation. As a result of the preliminary Cal/Val plan and previous workshop involving the science community, activities were initiated to support the objectives of Cal/Val. These included field campaigns to provide specific data sets for the algorithm teams, developing tower and aircraft-based simulators, and developing and implementing methods for integrating the diverse in situ resources available for validation. As part of this workshop, results to date will be reviewed and additional requirements identified. These activities include additional field campaigns. Specific topics to be addressed at the workshop include:

- New programmatic commitments in the NASA aircraft program will impact SMAP field campaign planning and need to be integrated.
- SMOS will have been in operation for over one-year. Lessons learned in its Cal/Val program will benefit SMAP planning.
- A robust in situ Cal/Val program will require partnerships with a variety of research groups and programs around the world. A mechanism for achieving this and agreement on standards must be established. To support this topic, the members of the GEWEX International Soil Moisture Working Group, the CEOP Land Products Validation-Soil Moisture Group, and the International Soil Moisture Network will be invited to participate in the workshop.

The participation of the broad science community and the plans and decisions arising from discussions of these issues will have significance for identifying research needs and allocating resources. Details are available at [71].

9 REFERENCES

[1] Committee on Earth Science and Applications from Space: A Community Assessment and Strategy for the Future, "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond", National Research Council, 2007.

[2] Science Requirements and Mission Success Criteria, SMAP Mission.

[3] "SMAP Science Workshop", Arlington, VA, July 9-10, 2007; "SMAP Open Meeting at IGARSS 2008", Boston, MA, July 6, 2008; "Microwave Land Hydrology Workshop", Oxnard, CA, October 20-22, 2008.

[4] D. Entekhabi, E. Wood, "Science Rationale for SMAP Baseline and Minimum Missions", Version 2, SMAP Science Transition Team, June 6, 2008.

[5] WWW: Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV): http://calvalportal.ceos.org/CalValPortal/welcome.do

[6] WWW: Land Products Sub-Group of Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV): http://lpvs.gsfc.nasa.gov

[7] SMAP Science Terms and Definitions, Draft, 2010.

[8] R. Reichle et al., "Skill Metrics for Validation of SMAP Data Products", SMAP SDT Memo, April 13, 2010.

[9] G. L. Schaefer, M. H. Cosh, and T. J. Jackson, "The USDA Natural Resources Conservation Service Soil Climate Analysis Network (SCAN)," Journal of Atmospheric and Oceanic Technology, vol. 24, pp. 2073-2077, 2007.

[10] T. J. Jackson, M. Cosh, R. Bindlish, P. Starks, D. Bosch, M. Seyfried, D. Goodrich, S. Moran, and J. Du, "Validation of Advanced Microwave Scanning Radiometer Soil Moisture Products," IEEE Trans. Geosci. Rem. Sens., vol. 48, no. 12, pp. 4256 – 4272, 2010.

[11] T. J. Jackson, R. Bindlish, M. H. Cosh, T. Zhao, P. J. Starks, D. D. Bosch, M. Seyfried, M. S. Moran, D. C. Goodrich, Y. H. Kerr, and D. Leroux, "Validation of Soil Moisture and Ocean Salinity (SMOS) Soil Moisture Over Watershed Networks in the U.S.," IEEE Trans. Geosci. Rem. Sens., Vol. 50, No. 5, pp. 1530-1543, 2012.

[12] S. Peischl, J. Walker, C. Rüdiger, N. Ye, Y. Kerr, E. Kim, R. Bandara, R. and M. Allahmoradi, "The AACES Field Experiments: SMOS Calibration and Validation Across the Murrumbidgee River Catchment", Hydrology and Earth System Sciences Discussions, Vol. 9:, pp. 2763-2795, 2012

[13] I. Kaihotsu, T. Koike, T. Yamaanaka, H. Fuji, T. Ohta, K. Tamagawa, D. Oyunbataar, and R. Akiyama, "Validation of Soil Moisture Estimation by AMSR‐E in the Mongolian Plateau," Journal of the Remote Sensing Society of Japan, Vol. 29, No. 1, pp. 271‐281, 2009.

[14] W. A. Dorigo, W. Wagner, R. Hohensinn, S. Hahn, C. Paulik, M. Drusch, S. Mecklenburg, P. Van Oevelen, A. Robock, and T. J. Jackson, "The International Soil Moisture Network: A Data Hosting Facility for Global In Situ Soil Moisture Measurements," Hydrology and Earth System Sciences, Vol. 15, pp. 1675-1698, 2011.

[15] Vachaud, G., A. Passerat De Silans, P. Balabanis, M. Vauclin, "Temporal Stability of Spatially Measured Soil Water Probability Density Function", Soil Science Society of America J., Vol. 49 No. 4, pp. 822-828, 1985.

[16] Cosh, M. H., T. J. Jackson, R. Bindlish, J. H. Prueger, "Watershed Scale Temporal and Spatial Stability of Soil Moisture and Its Role in Validating Satellite Estimates", Remote Sensing of Environment, Vol. 92, pp. 427-435, 2004.

[17] Famiglietti, J. S., D. Ryu, A. A. Berg, M. Rodell, T. J. Jackson, "Field Observations of Soil Moisture Variability Across Scales", Water Resources Research Vol. 44, W01423, 2008.

[18] Crow, W. T, D. Ryu, J. S. Famiglietti, “Upscaling of Field-Scale Soil Moisture Measurements Using Distributed Land Surface Modeling”, Remote Sensing of Environment, Vo. 28, pp. 1-14, 2005.

[19] Miralles, D.G., W.T. Crow and M.H. Cosh, "A technique for estimating spatial sampling errors in coarse-scale soil moisture estimates derived from point-scale observations," Journal of Hydrometeorology, 11(6), 1404-1410,10.1175/2010JHM1285.1, 2010.

[20] W. T. Crow, A. A. Berg, M. H. Cosh, A. Loew, B. P. Mohanty, R. Panciera, P. de Rosnay, D. Ryu, and J. P. Walker, “Upscaling Sparse Ground-Based Soil Moisture Observations for the Validation of Coarse-Resolution Satellite Soil Moisture Products,” Rev. Geophys., Vol. 50, RG2002, doi:10.1029/2011RG000372, 2012.

[21] P. O’Neill, T. Jackson, D. Entekhabi, E. Njoku, “Survey of L-Band Tower and Airborne Sensor Systems Relevant to Upcoming Soil Moisture Missions”, IEEE Geosci. Remote Sensing Society Newsletter, June 2009.

[22] N. Floury, M. Drinkwater, O. Witasse, “L-band Brightness Temperature of Ice Sheets in Antarctica: Emission Modeling Ionospheric Contribution and Temporal Stability”, Proc. IEEE International Geoscience and Remote Sensing Symposium 2002, Toronto, Canada, June 24-28, 2002.

[23] R. G. Kennett, and F. K. Li, “Seasat Over-Land Scatterometer Data, Part II: Selection of Extended Area Land-Target Sites For the Calibration of Spaceborne Scatterometers”, IEEE Trans. Geosci. Remote Sens., Vol. 27, No. 6, 1989.

[24] S. Brown, C. Ruf, “On-Orbit Microwave Blackbody Calibration Using Regions of Dense Vegetation”, Proc. IEEE International Geoscience and Remote Sensing Symposium 2003, Toulouse, France, July 21-25, 2003.

[25] L. B. Kunz, and D. G. Long, “Calibrating SeaWinds and QuikSCAT Scatterometers Using Natural Land Targets”, IEEE Geosci. Remote Sens. Letters, Vol. 2, No. 2, 2005.

[26] M. Drinkwater, M. Brogioni, G. Macelloni, P. Pampaloni, and E. Santi, “DOME-C Multi-frequency Microwave Characterization and Related Campaign Activities”, 7th SMOS Workshop (http://earth.esa.int/smos07), Frascati, Italy, October 29-31, 2007.

[27] S. Paloscia, G. Macelloni, M. Brogioni, S. Pettinato, M. Drinkwater, A. Crepaz, “DOMEX-2: Long Time-Stability of L-Band Emission at Dome-C Antarctica”, SMOS Validation & Retrieval Team Readiness Review Workshop (http://earth.esa.int/smos09/), Lisbon, Portugal, March 11-13, 2009.

[28] S. Misra, and S. Brown, “Modeling of Microwave Emissions from the Marie-Byrd Antarctic Region: A Stable Calibration Target in the L-band”, Presentation at Jet Propulsion Laboratory, California Institute of Technology, August 26, 2010.

[29] R., Atlas, R. N. Hoffman, J. Ardizzone, M. Leidner, and J. C. Jusen, “A New Cross-Calibrated, Multi Ocean Surface Wind Product”, Proc. IEEE International Geoscience and Remote Sensing Symposium 2008, Boston, MA, USA, July 6-11, 2008

[30] J. Liu, X. Zhan, T. J. Jackson, “Soil Moisture Retrieval from WindSat Using the Single Channel Algorithm Toward a Blended Global Soil Moisture Product from Multiple Microwave Sensors”, Proc. SPIE 2008, Vol. 7085, 2008.

[31] T. Jackson, “SMAP Soil Moisture Overpass Time Considerations,” SMAP Workshop Report, NASA, 2007.

[32] K. Scipal, T. Holmes, R. de Jeu, V. Naeimi, W. Wagner, “A Possible Solution for the Problem of Estimating the Error Structure of Global Soil Moisture Data Set”, Geophys. Res. Let., Vol. 35, 2008.

[33] W. A. Dorigo, K. Scipal, R. Parinussa, Y. Liu, W. Wagner, R. de Jeu, and V. Naeimi, “Error Characterisation of Global Active and Passive Microwave Soil Moisture Datasets,” Hydrol. Earth Syst. Sci., 14, 2605-2616, 2010.

[34] R. H. Reichle, R. D. Koster, P. Liu, S. P. P. Mahanama, E. G. Njoku, and M. Owe, "Comparison and Assimilation of Global Soil Moisture Retrievals from AMSR-E and SMMR", J. Geophys. Res., Vol. 112, D09108, 2007.
[35] R. Reichle et al., "L4_SM ATBD", Preliminary, September 15, 2010.
[36] W. T. Crow, D.G. Miralles and M.H. Cosh, "A quasi-global evaluation system for satellite-based surface soil moisture retrievals," IEEE Transactions on Geoscience and Remote Sensing, 48(6), 2516-2527, 10.1109/IGARSS.2008.4779051, 2010.
[37] J. Bolten, W. T. Crow, X. Zhan, T. J. Jackson, and C. A. Reynolds, "Evaluating the Utility of Remotely Sensed Soil Moisture Retrievals for Operational Agricultural Drought Monitoring", IEEE J. Selected Topics Applied Earth Obs. Remote Sens., Vol. 3, No. 1, pp. 57-66, 2010.
[38] J. J. Piepmeier et al., "L1B_TB ATBD", Preliminary, September 15, 2010.
[39] E. Njoku et al., "L1C_TB ATBD", Preliminary, September 15, 2010.
[40] R. West et al., "L1B_S0_LoRes and L1C_S0_HiRes ATBD", Preliminary, September 15, 2010.
[41] D. Hudson, J. Peng, "SMAP Radiometer (minus reflector) Pre-Launch Calibration Plan", NASA Goddard Space Flight Center, September 8, 2010.
[42] J. Peng, C. S. Ruf, "Calibration Method for Fully Polarimetric Microwave Radiometers Using the Correlated Noise Calibration Standard", IEEE Trans. Geosci. Remote Sens., Vol. 46, No. 10, October 2008.
[43] P. O'Neill et al, "L2/3_SM_P ATBD", Preliminary, September 15, 2010.
[44] J. van Zyl et al, "L2/3_SM_A ATBD", Preliminary, September 15, 2010.
[45] D. Entekhabi et al., "L2/3_SM_AP ATBD", Preliminary, September 15, 2010.
[46] K. McDonald et al., "L3_FT_A ATBD", Preliminary, September 15, 2010.
[47] J. Kimball et al., "L4_C ATBD", Preliminary, September 15, 2010.
[48] F. A. Heinsch, M. Zhao, S.W. Running, J.S. Kimball, R.R. Nemani, et al., "Evaluation of Remote Sensing Based Terrestrial Productivity From MODIS Using Regional Tower Eddy Flux Network Observations", IEEE Trans. Geosci. Remote Sens., Vol. 44, No. 7, pp. 1908-1925, 2006.
[49] L. A. Jones, J.S. Kimball, K.C. McDonald, S.K. Chan, E.G., Njoku, and W.C. Oechel, "Satellite Microwave Remote Sensing Of Boreal And Arctic Soil Temperatures from AMSR-E", IEEE Trans. Geosci. Remote Sens., Vol. 45, No. 7, pp. 2004–2018, 2007.
[50] J. S. Kimball, L.A. Jones, K. Zhang, F.A. Heinsch, K.C. McDonald, and W.C. Oechel, "A Satellite Approach To Estimate Land-Atmosphere CO2 Exchange for Boreal And Arctic Biomes Using MODIS and AMSR-E", IEEE Trans. on Geosci. Remote Sens., Vol. 47, No. 2, pp. 569-587, 2009.
[51] K. Zhang, J.S. Kimball, M. Zhao, W.C. Oechel, J. Cassano, and S.W. Running, "Sensitivity of Pan-Arctic Terrestrial Net Primary Productivity Simulations To Daily Surface Meteorology from NCEP/NCAR and ERA-40 Reanalyses", J. Geophys. Res. - Biogeosciences, Vol. 112, G01011, pp. 1–14, 2007.
[52] T. Jackson, "Soil Moisture Active Passive Validation Experiment 2008 (SMAPVEX08) Experiment Plan", September 4, 2008.
[53] WWW: Soil Moisture Active Passive Validation Experiment 2008 (SMAPVEX08), http://smap.jpl.nasa.gov/science/Validation/SMAPVEX08/
[54] R. Magagi, "Canadian Experiment for Soil Moisture 2010 (CanEx-SM10) Experiment Plan", May 28, 2010.
[55] WWW: Canadian Experiment for Soil Moisture 2010 (CanEx-SM10), http://pages.usherbrooke.ca/canexsm10/
[56] R. Panciera, "Soil Moisture Active Passive Experiments 2010-2011 (SMAPEx) Experiment Plan", June 2010.

[57] WWW: Soil Moisture Active Passive Experiments 2010-2011 (SMAPEx), http://www.smapex.monash.edu.au/

[58] T. Jackson, "San Joaquin Valley Field Campaign (UAVSAR / Soil Moisture) Experiment Plan", April 29, 2010.

[59] WWW: San Joaquin Valley Field Campaign , http://smap.jpl.nasa.gov/science/Validation/SJV/

[60] P. E. O'Neill, R. H. Lang, M. Kurum, K. R. Carver, and C. Utku, "Multisensor Microwave Remote Sensing of NASA's Combined Radar/Radiometer (Comrad) System," in Proc. MicroRad'06, San Juan, Puerto Rico, pp. 50–54, Feb. 2006.

[61] M. Cosh, "SMAP In Situ Sensor Testbed Experiment Plan", United States Department of Agriculture, January 22, 2010.

[62] J. H. Dane, C. Topp, "Methods of Soil Analysis. Part 4. Physical Methods", Soil Science Society of America Book Series, Vol. 5, 2002.

[63] S. Yueh, "Estimates of Faraday Rotation with Passive Microwave Polarimetry for Microwave Remote Sensing of Earth Surfaces", IEEE Trans. Geosci. Remote Sens., Vol. 38, No. 5, September 2000.

[64] Crow, W. T., R. D. Koster, R. H. Reichle, and H. O. Sharif, "Relevance of time-varying and time-invariant retrieval error sources on the utility of spaceborne soil moisture products", Geophys. Res. Lett., Vol. 32, No. 24, Art. No. L24405, 2005.

[65] D. Entekhabi, R. H. Reichle, W. T. Crow, and R. D. Koster, Performance metrics for soil moisture retrievals and applications requirements, Journal of Hydrometeorology, in preparation, 2009.

[66] D. Baldocchi, "Breathing of the terrestrial biosphere: lessons learned from a global network of carbon dioxide flux measurement systems", Austr. J. Bot., Vol. 56, pp. 1–26, 2008.

[67] S. R. Running, D.D. Baldocchi, D.P. Turner, S.T. Gower, P.S. Bakwin, and K.A. Hibbard, "A global terrestrial monitoring network integrating tower fluxes, flask sampling, ecosystem modeling and EOS satellite data", Remote Sensing of Environment, Vol. 70, pp. 108–128, 1999.

[68] D. Baldocchi, E. Falge, L. Gu, R. Olson, D. Holinger, S. Running, et al., "FLUXNET: A new tool to study the temporal and spatial variability of ecosystem-scale carbon dioxide, water vapor, and energy flux densities", Bulletin of the American Meteorological Society, Vol. 82, pp. 2415-2434, 2001.

[69] D.P. Turner, W.D. Ritts, W.B. Cohen, S.T. Gower, S.W. Running, M. Zhao, M.H. Costa, A.A. Kirschbaum, J.M. Ham, S.R. Saleska, and D.E. Ahl., "Evaluation of MODIS NPP and GPP products across multiple biomes", Remote Sensing of Environment, Vol. 102, pp. 282-292, 2006.

[70] WWW: SMAP Algorithms and Cal/Val Workshop, June 9-11, 2009, Oxnard, CA, USA, http://smap.jpl.nasa.gov/science/workshops/index.cfm?FuseAction=ShowNews&NewsID=18&newsTypeID=2

[71] WWW: SMAP Cal/Val Workshop #2, May 3-5, 2011, Oxnard, CA, USA, http://smap.jpl.nasa.gov/science/workshops/index.cfm?FuseAction=ShowNews&NewsID=65&newsTypeID=2

[72] W. Wilson, S. Yueh, S. Dinardo, S. Chazanoff, A. Kitiyakara, F. Li, Y. Rahmat-Samii, "Passive Active L- and S-Band (PALS) Microwave Sensor for Ocean Salinity and Soil Moisture Measurements", IEEE Trans. Geosci. Remote Sens., Vol. 39, No. 5, May 2001.

[73] S. Yueh, S. Dinardo, S. Chan, E. Njoku, T. Jackson, R. Bindlish, J. Johnson, J. Piepmeier, C. Ruf, "PALS-ADD and Airborne Campaigns to Support Soil Moisture and Sea Surface Salinity Missions", Proc. IEEE IGARSS'09, Cape Town, South-Africa, 12-17 July 2009.

[74] S. Delwart, "SMOS Validation and Retrieval Plan", http://earth.esa.int/category/index.cfm?fcategoryid=42&S_ID=39, European Space Agency, 2007.

Appendix A: Review of Resources

Table 9-1. Summary of possible Cal/Val Resource Networks (name of the network, the network coverage region, number of sites in the networks, whether the network is part of the International Soil Moisture Network (ISMN) database [14], and the website of the network).

Network Name	Country or Region	No. Sites	ISMN	Website or Other Reference
WMO global surface weather station network	Global	9000+		http://www.ncdc.noaa.gov/cgi-bin/res40.pl
Alaska Ecological Transect (ALECTRA)	Alaska	9		kyle.mcdonald@jpl.nasa.gov
FLUXNET	Global	500+		http://www.fluxnet.ornl.gov/fluxnet/index.cfm
Coordinated Energy and Water Cycle Observations Project (CEOP)	Global	13		http://www.ceop.net/
Chinese Ecosystem Research Network (CERN)	China	31		http://www.cern.ac.cn/0index/index.asp
Soil Climate Analysis Network (SCAN)	USA+	141		http://www.wcc.nrcs.usda.gov/scan/
Climate Research Network (CRN)	USA+	144		http://www.ncdc.noaa.gov/oa/climate/uscrn/
National Ecological Observatory Network (NEON)	USA	20		http://neoninc.org/
SNOTEL	Western USA	750		http://www.wcc.nrcs.usda.gov/snow/
Oklahoma Mesonet	Oklahoma	127		http://www.mesonet.org/
ARM-SGP	Oklahoma/Kansas	31		http://www.arm.gov/sites/sgp
Illinois Climate Network (ICN)	Illinois, USA	19	X	http://www.sws.uiuc.edu/warm/datatype.asp
High Plains Regional Climate Center (HPRCC)	Nebraska, USA	53		http://www.hprcc.unl.edu/awdn/soilm/index.php ?action=More+About+This+Project
Mongolia Validation (GCOM-W)	Mongolia	14		http://monsoon.t.u-tokyo.ac.jp/camp-i/
Little Washita (ARS)	Oklahoma, USA	20		http://www.ars.usda.gov/main/site_main.htm?modecode=62-18-05-20
Fort Cobb (ARS)	Oklahoma, USA	15		http://www.ars.usda.gov/main/site_main.htm?modecode=62-18-05-20
Little River (ARS)	Georgia, USA	29		http://www.ars.usda.gov/main/site_main.htm?modecode=66-02-05-00
Walnut Gulch (ARS)	Arizona, USA	21		http://www.ars.usda.gov/main/site_main.htm?modecode=53-42-45-00
Reynolds Creek (ARS)	Idaho, USA	15		http://www.ars.usda.gov/main/site_main.htm?modecode=53-62-00-00
Walnut Creek (ARS)	Iowa, USA	9		http://www.ars.usda.gov/Main/site_main.htm?modecode=36-25-15-00
Sonora	Mexico	14		http://vivoni.asu.edu/sonora/www/pages/hydromet.html
Saskatchewan	Canada	16		aberg@uoguelph.ca
Kenaston	Canada	24		brenda.toth@ec.gc.ca
Ontario	Canada	26		aberg@uoguelph.ca
REMEDHUS-Salamanca	Spain	23	X	http://campus.usal.es/~hidrus/
Valencia Anchor Site	Spain	11		http://www.uv.es/elopez/?21
SMOSMANIA	France	12	X	http://www.hymex.org/
Upper Danube Basin	Germany	10	X	alexander.loew@zmaw.de
Yanco	Australia	13	X	http://www.oznet.org.au/
Kyeamba	Australia	14	X	http://www.oznet.org.au/
Goulburn	Australia	20	X	http://www.oznet.org.au/
Adelong Creek	Australia	5	X	http://www.oznet.org.au/
Mumbridgee	Australia	7	X	http://www.oznet.org.au/
West Africa	Africa	TBD		TBD
South African Weather Service	South Africa	TBD		TBD
La Plata Basin	Argentina	TBD		TBD

Appendix B: Supporting Instrumentation for Cal/Val

This Appendix describes some airborne and ground-based instruments which may play a key role in SMAP Calibration and Validation Program in both pre- and post-launch phases

B.1 PALS

The PALS (Passive and Active L- and S-band) instrument is an airborne L-band radiometer which includes both radiometer and radar operating both at L- and S-band. The instrument has been deployed on different platforms including C-130 and Twin Otter aircrafts. The nominal viewing angle of the instrument is 40° [72]. The most recent configuration with a light-weight relative small-size microstrip antenna has been deployed on Twin Otter, see Figure C-9-1.

Figure C-9-1. Twin Otter with the PALS and the light-weight relative small-size microstrip antenna installed (the antenna pointing backwards at the bottom aft in the fuselage).

The PALS have been utilized for soil moisture field experiment multiple times in the past. These campaigns included SGP99 in Oklahoma in 1999; SMEX02 in Iowa in 2002; CLASIC in Oklahoma in 2007, and SMAPVEX08 in Maryland in 2008. The configuration of the instrument changed from campaign to campaign, but the performance parameters remained the same throughout all campaigns. Table C-9-2 summarizes the performance parameters. In SGP99 and SMEX02 PALS flew on a C-130 aircraft operated by NCAR. In CLASIC and SMAPVEX08 (see Section 5.5.2.1) it flew on a Twin Otter (DHC-6) aircraft. In SGP99 and SMEX02 PALS was using a horn antenna with 13° beamwidth, but in CLASIC and SMAPVEX08 the next generation design incorporated a lightweight microstrip antenna (which allowed the installation to the Twin Otter) with 20° beamwidth. Additionally, in SMAPVEX08 PALS was flown with an Agile Digital Detector (ADD) for RFI mitigation [73].

In order to facilitate cost-effective characterization of large spatial domains for Cal/Val, the SMAP Cal/Val Working Group and the SDT recommended that the sensor be modified to include scanning. This effort was initiated and should be completed in the near future.

Table C-9-2. Characteristics of PALS instrument (different antenna configurations have been deployed for different campaigns).

Passive	Frequency	1.413 GHz
	Polarization	V, H, +45, -45
	Calibration stability	1 K (bias); 0.2 K (stability)
Active	Frequency	1.26 GHz
	Polarization	VV, HH, VH, HV
	Calibration accuracy	<2 dB (bias); 0.2 dB (stability)
Antenna (SGP99, SMEX02)	Half Power Beamwidth	12° (passive); 13° (active)
	Beam efficiency	92%
	Directivity	23.4 dB
	Polarization isolation	>20 dB
Antenna (CLASIC, SMAPVEX08)	Half Power Beamwidth	20° (passive); 23° (active)
	Beam Efficiency	94%
	Directivity	18.5 dB
	Polarization isolation	> 35 dB

B.2 UAVSAR

The UAVSAR instrument is a reconfigurable, polarimetric L-band synthetic aperture radar (SAR) specifically designed to acquire airborne repeat track SAR data for differential interferometric measurements. The radar was designed to be operable on a UAV (Uninhabited Aerial Vehicle), but it is currently implemented on a NASA Gulfstream III. Figure C-9-2 shows a photo of the Gulfstream III aircraft with the UAVSAR instrument installed in the belly pod.

Figure C-9-2. The UAVSAR instrument in the belly pod of NASA Gulfstream III aircraft.

The radar is fully polarimetric, with a range bandwidth of 80 MHz, and will support a ~20 km range swath, which translates to an incidence angle range of 25°-65°. The system operates nominally at 45,000 ft (13800 m). Using precision real-time GPS and a sensor controlled flight management system the system will be able to fly predefined paths with great precision. The performance of the flight control system requires the flight path to be within a 10 m diameter tube about the desired flight track. The accuracy of the measured radar cross-section is 1 dB without calibration targets (corner reflectors) in the vicinity of the experiment area and 0.1 dB with calibration targets. Table C-9-3 summarizes the relevant parameters of the UAVSAR instrument.

Table C-9-3. Relevant parameters of the UAVSAR instrument.

Parameter	Value
Frequency	L-band (1.26 GHz)
Bandwidth	80 MHz
Resolution, Range	1.8 m
Resolution, Azimuth	0.6 m
Resolution, Product	6 m
Accuracy	1 dB / 0.1 dB
Polarization	Full Quad-Polarization
Antenna Type	Phased Array
Antenna Dimensions	0.5 m range/1.5 azimuth
Polarization Isolation	<-20 dB
Waveform	Nominal Chirp/Arbitrary Waveform
Swath	25° - 65° off nadir

B.3 ComRAD

The ComRAD instrument is a truck-mounted L-band radiometer and radar developed by NASA Goddard Space Flight Center and George Washington University, see Figure C-9-3 [60]. The instrument utilizes a parabolic dish antenna for both passive and active measurements. The mounting allows wide scanning in both elevation and azimuth directions and measurements from height of about 20 m. Table C-9-4 shows some characteristic parameters of the ComRAD instrument.

Figure C-9-3. ComRAD.

Table C-9-4. Parameters of ComRAD.

Passive	Frequency	1.413 GHz
	Polarization	V, H
	Accuracy	1 K
Active	Frequency	1.25 GHz
	Polarization	VV, HH, VH, HV
	Accuracy	?
Antenna	Half Power Beamwidth	12° (passive); 13° (active)
	Gain	19.5 dB
	Polarization isolation	~20 dB

The Cal/Val Working Group and SDT suggested that modifications of ComRAD would be needed in order to collect the type of data needed for algorithm development and validation. Key requirements were the ability to operate autonomously over extended periods of time and improving the reliability of the radiometer calibration. As a result, the ComRAD team initiated system improvements, including a new antenna. These are expected to be completed by the Spring/Summer of 2011.

Appendix C: Field Experiments of Opportunity

This Appendix describes field campaigns planned outside SMAP domain that may, however, provide opportunity for acquiring valuable data from SMAP science calibration and validation point of view. At this time, some of the recent selections under the NASA ESSP Venture-class Science Investigations Program may have positive or negative impacts of the SMAP Cal/Val Plan. Details of these projects are being developed and the SMAP Cal/Val Working Group will be looking for opportunities to exploit these.

C.1 CARVE

The Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE) is designed to understanding of Arctic ecosystems, linkages between the Arctic hydrologic and terrestrial carbon cycles, and the feedbacks from fires and thawing permafrost. The PI is Charles Miller. The key mission parameters are:

Aircraft	Twin Otter
Instruments	Passive-Active L-band (PALS), FTS, ISGA
Region	Alaska (Fairbanks base of operation)
Mission	Conduct three a year over fixed flight lines each year 2011-2015. Flights will take place in mid April (not in 2011), June and August. Each will require about 2 weeks. Between flights, the instruments and aircraft will be left in Fairbanks (without a crew). The aircraft would be available in each of these 6 week periods.
Flight Lines	Set, waiting on details (see Figure D-9-4)
Other	Need resolution of time line and flight lines

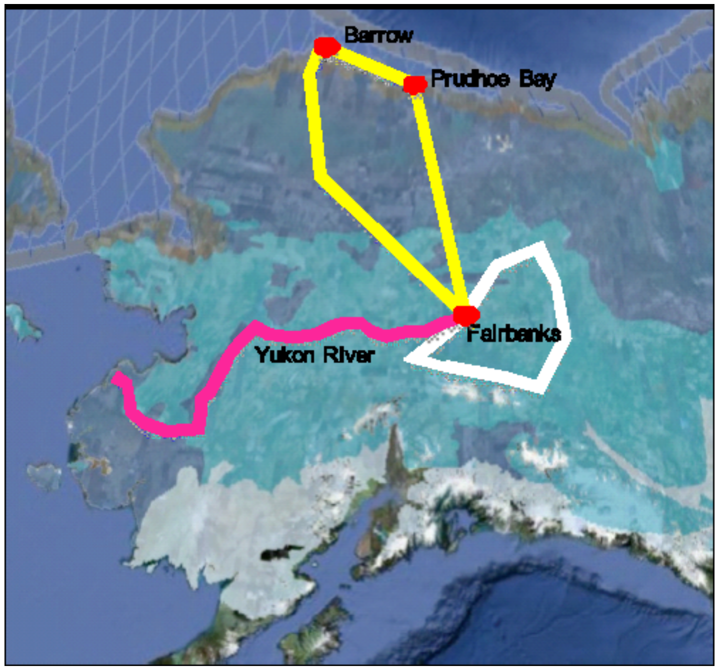


Figure D-9-4. CARVE flight plans. Colors indicate continuous (dark blue), discontinuous (light blue), sporadic (gray), and subsea (hatched) permafrost regimes. Each colored loop represents a single day's flight path. The gold flight path is anchored by flights over 5 flux towers which will be used for validation. (Provided by S. Dinardo)

C.2 AirMOSS

Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS) Mahta Moghaddam (PI, UofM). Addresses key questions: 1. How does root zone soil moisture, and its landscape heterogeneity, control the regional carbon fluxes? 2. How is this control quantified via estimates of root zone soil moisture at spatial (100-1000m) and temporal (daily to weekly) sampling?

Aircraft	NASA G-III
Instruments	Polarimetric UHF synthetic aperture radar, 280-440 MHz band capability, 80 MHz total bandwidth (capability for both split spectrum and contiguous). Radar to fit inside a G-3 pod
Region	Survey major biomes in North America
Mission	Visit 9 flux tower sites, three times for temperate & boreal sites, twice for arid/semiarid, once for tropical sites; each time complete 3 surveys over 7-10days. 3 seasons (depends) over 3 years; Mid-March to Mid-April; Mid-June to Mid-July, and first 2 weeks of October.
Flight Lines	Set, waiting on details (see Figure D-9-5)
Other	Updated estimates indicate that the instrument will be ready for June 2012. Sites may change.

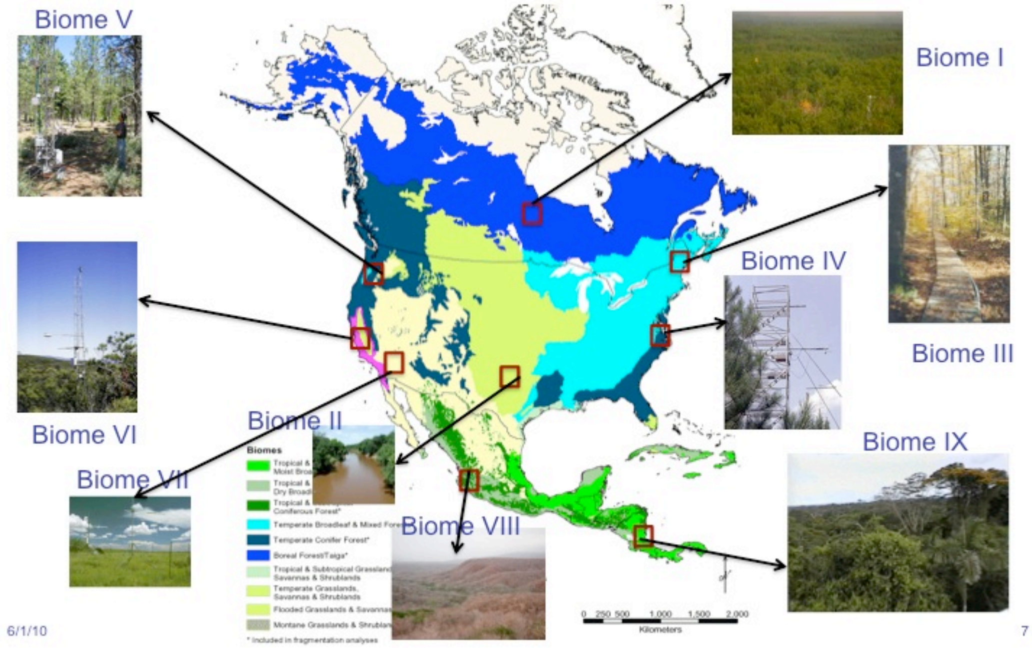


Figure D-9-5. AirMOSS study sites. (Provided by M. Moghaddam).

Appendix D: Cal/Val Programs of Other Soil Moisture Missions

There are other soil moisture missions in operation or in development during the SMAP pre- and post-launch phases (see Section 0). This Appendix highlights the key features of the cal/val programs of European Space Agency's (ESA) SMOS mission, Japan Aerospace Exploration Agency's (JAXA) GCOM-W mission, and Argentinean Space Agency's (CONAE) SAOCOM mission.

D.1 SMOS Soil Moisture Cal/Val Program

SMOS (Soil Moisture and Ocean Salinity) is European Space Agency's Earth observation satellite mission focused on measurement of soil moisture sea surface salinity utilizing L-band radiometry. The resolution of the soil moisture product of the mission is about 40 km and the revisit time 2-3 days. The performance requirement of 0.04 cm^3/cm^3 coincides with that of SMAP. SMOS will measure each pixel at multiple incidence angles and this multi-incidence angle information will be exploited to retrieve soil moisture and other geophysical variables.

The SMOS Validation and Retrieval Team (SVRT) Plan was developed from the responses to the call for proposals to conduct calibration and validation activities for SMOS [74]. Following the SMOS AO Review Panel Meeting held in ESA ESTEC 9-10 June 2005, 39 proposals were accepted on the basis of their potential contribution for calibrating and validating SMOS products. These proposals form the basis of the SVRT Plan. Activities included in situ soil moisture measurement, ground- and aircraft-based microwave radiometer measurements, satellite inter-comparisons, and model products.

Figure E-1 provides the locations of the selected validation sites.

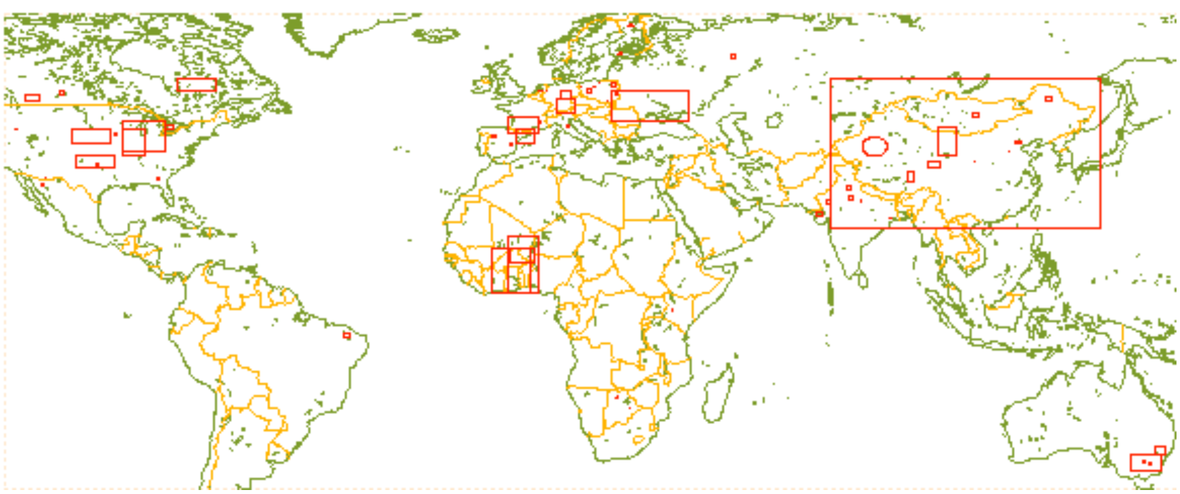


Figure E-1. Locations of SMOS soil moisture validation sites.

The SVRT plan recommended measurement protocols for the soil moisture validation sites that included being at least 100 km away from any coastline. The validation sites are responsible for up-scaling observations and for being compliant with the measurement protocols.

In addition to the sites selected through this process, SMOS supports several "anchor" sites. These sites in Spain, Germany, and Australia were designed to provide much more extensive ground based observations including multiple sites within a SMOS footprint. Airborne campaigns were conducted over these sites prior to launch to characterize both the radiometric and geophysical variables and post-launch campaigns will also be conducted.

In order to support both the satellite instrument calibration, site scaling, and algorithm refinement the SMOS mission developed ground- and aircraft-based L-band radiometers that will be deployed at the anchor sites as well as other sites selected through a competitive process.

In order to provide an accessible long term resource to support the analysis of SMOS products and those from future sensors, datasets comprising SMOS products and correlative data from in-situ or models are held within a dedicated SMOS cal/val campaign database.

SMOS SVRT is ongoing and SMAP project and SDT members actively participate. The SMAP project will maintain these relationships and expand them as needed.

D.2 AMSR-2 Soil Moisture Cal/Val Program

JAXA will support the Cal/Val of its GCOM-W AMSR-2 program using sites that it supports in Asia and from proposals submitted to announcements of opportunities. The validation sites are typically well characterized and provide data in regions of the world that complement the core activities of NASA and ESA missions. Some of these such as the Mongolia site have long-term observations initiated for AMSR and AMSR-E.

Members of the SMAP SDT currently participate in the AMSR-2 Cal/Val program and will continue this effort. The SMAP project will establish agreements with JAXA/GCOM-W as needed to facilitate the exchange of data for Cal/Val.

D.3 SAOCOM Soil Moisture Cal/Val Program

As part of its SAOCOM program, CONAE will provide a high resolution validated soil moisture product from L-band radar backscatter. Both the backscatter measurements and soil moisture will be of value to SMAP Cal/Val. CONAE is currently supporting projects to validate soil moisture from Aquarius. They plan to establish in situ validation sites for SAOCOM; however, details are not available at this time. CONAE has also developed an aircraft-based L-band SAR that will support pre-launch algorithm development and post-launch validation.

The SMAP project and SDT have submitted a proposal to the CONAE SAOCOM announcement of Opportunity for pre-launch collaboration and will extend this in the follow on announcements.