Soil Moisture Active Passive (SMAP) Project:
Calibration and Validation for the L2/3_SM_P Version 4 and L2/3_SM_P_E Version 1 Data Products

Citation:

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1 EXECUTIVE SUMMARY

During the post-launch Cal/Val Phase of SMAP there are two objectives for each science product team: 1) calibrate, verify, and improve the performance of the science algorithms, and 2) validate accuracies of the science data products as specified in the L1 science requirements according to the Cal/Val timeline. This report provides analysis and assessment of the SMAP Level 2 Soil Moisture Passive (L2SMP) Version 4 and the L2SMP Enhanced (L2SMP_E) Version 1 data products. The SMAP Level 3 Soil Moisture Passive (L3SMP, L3SMP_E) products are simply a daily composite of the L2 half-orbit files. Hence, analysis and assessment of the L2SMP and L2SMP_E products can also be considered to cover the L3SMP and L3SMP_E products.

Products have now been expanded to include soil moisture retrievals for the PM (ascending) passes in addition to the original L2SMP AM (descending) passes. In addition, enhanced products (L2SMP_E) based upon interpolated brightness temperatures posted on a 9 km grid are now available. Each of these products was separately assessed.

Assessment methodologies utilized include comparisons of SMAP soil moisture retrievals with *in situ* soil moisture observations from core validation sites (CVS) and sparse networks, and intercomparison with products from ESA's Soil Moisture Ocean Salinity (SMOS) mission. The primary assessment methodology was based on CVS comparisons using established metrics and time series plots. These metrics include unbiased root mean square error (ubRMSE), bias, and correlation. The ubRMSE captures time-random errors, bias captures the mean differences or offsets, and correlation captures phase compatibility between data series.

SMAP L2SMP supports a total of five alternative retrieval algorithms. Of these, the Single Channel Algorithm–H polarization (SCA-H), Single Channel Algorithm–V polarization (SCA-V), and Dual Channel Algorithm (DCA) are the most mature and are the focus of this assessment. These same retrieval algorithms were also used in L2SMP_E.

The first step in this assessment was the comparison of the L2SMP AM Version 4 products to the CVS and sparse network observations. CVS results indicated that the SCA-V provided the best overall performance with an ubRMSE of 0.037 m^3/m^3, bias of -0.014 m^3/m^3 and correlation of 0.828. These metrics exceed the SMAP mission requirements and those of the SMOS products. Assessment of L2SMP Version 4 AM utilizes a somewhat different set of CVS than Version 3 (one CVS dropped out while a new CVS was added). A comparison of Version 3 and Version 4 metrics indicates that there was very little difference in the results. Some of this small difference could also be associated with the longer period of record (11 vs 19 months). Sparse network results were similar. The overall conclusion is that the L2SMP AM product is stable and meeting mission requirements (the L2SMP AM soil moisture shall meet or exceed an accuracy of 0.040 m^3/m^3 ubRMSE over land in the absence of frozen ground, permanent snow/ice, or dense vegetation). The combination of CVS and sparse networks, intercomparison with products from ESA's Soil Moisture Ocean Salinity (SMOS) mission, and recent triple colocation analyses have contributed to a better understanding of the performance uncertainties. The assessment now includes 19 months of intercomparisons, and two papers have been published/accepted in peer-reviewed journals [1, 2]. These analyses satisfy the basic criteria established by the Committee on Earth Observing Satellites (CEOS) for Stage 3 validation.

Version 4 now provides a L2SMP PM product in addition to the AM. This new product was assessed following the same procedures used for L2SMP AM. Results indicate that the L2SMP PM also meets the mission requirements. However, when compared to the L2SMP AM, there was a small degradation in the metrics that is likely related to increased bias resulting from the difficulty in normalizing for land surface temperature during the PM observing time of SMAP. Other algorithm assumptions that hold true for the AM retrievals might be less valid for the PM data (more Faraday rotation, less hydraulic/thermal uniformity, etc.) and contribute a small amount of error as well.

The L2SMP_E are posted at 9 km but the contributing domain (i.e. primary spatial area contributing to the radiometer brightness temperature response) is approximately 33 km. New 33 km CVS areas were identified in order to assess the performance of the new product; all ground measurements of soil moisture within the 33 km domain were used and compared to the SMAP retrieved soil moisture at each CVS. Recognizing that users may simply choose to use the data at the posted scale, the soil moisture retrieval performance was also assessed using yet another set of CVS defined for 9 km areas. Sparse network comparisons were also performed for the L2SMP_E. SMOS comparisons were not performed with the 9 km L2SMP_E data due to the mismatch of postings. While the period of observation available for assessment is the same as the L2SMP, the maturity of the L2SMP_E product is not and is currently at CEOS Stage 2.

Version 1 of the L2SMP_E, both AM and PM, were also assessed using the CVS and sparse networks. Both AM and PM products meet the mission requirements while the L2SMP_E exhibit a slightly higher bias for the PM data. SCA-V had the best overall metrics. The differences between the performance of the L2SMP_E and the equivalent L2SMP were very small. No further quantitative inference should be made since the metrics are based on different spatial domains.

Finally, recognizing that it is a common practice for users to apply products posted at a particular grid size (here 9 km) as an estimate of the soil moisture for that cell rather than the contributing domain (33 km), the impact of this assumption was assessed. For the subset of CVS that satisfied established criteria, the impact on the metrics was very small when compared to the L2SMP_E assessments for 33 km contributing areas. This result is encouraging but may not be reliable in more heterogeneous regions.

Overall conclusions in this assessment:

- *L2SMP performance is stable and continues to meet the SMAP Project requirements.*
- *The SCA-V continues to outperform the alternative algorithms.*
- *The L2SMP AM performance is slightly better than L2SMP PM. This result is not unexpected and is associated with land surface temperature and other conditions during ascending passes.*
- *L2SMP_E AM performance is almost identical with L2SMP AM when evaluated using 33 km contributing domains.*
- *L2SMP_E performance assessed using 9 km contributing domains is almost the same as using 33 km contributing domains.*
- *The L2SMP product has now achieved CEOS Validation Stage 3. L2SMP_E is at CEOS Validation Stage 2.*

2 OBJECTIVES OF CAL/VAL

During the post-launch Cal/Val (Calibration/Validation) Phase of SMAP there are two objectives for each science product team:

- Calibrate, verify, and improve the performance of the science algorithms, and
- Validate accuracies of the science data products as specified in Level 1 science requirements according to the Cal/Val timeline.

The process is illustrated in Figure 2.1. In this Assessment Report the progress of the Level 2 Soil Moisture Passive Team in addressing these objectives is described. The approaches and procedures utilized follow those described in the SMAP Cal/Val Plan [3] and Algorithm Theoretical Basis Document for the Level 2 & 3 Soil Moisture (Passive) Data Products [4].

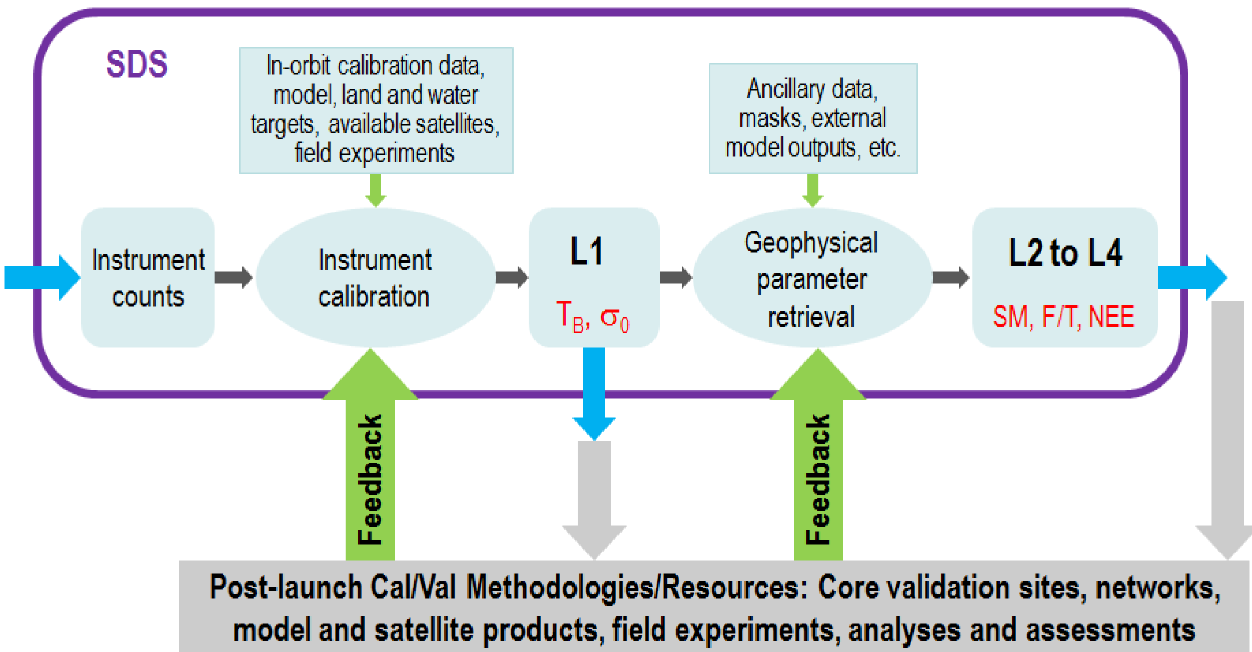


Figure 2.1. Overview of the SMAP Cal/Val Process.

SMAP established a unified definition base in order to effectively address the mission requirements. These are documented in the SMAP Handbook/ Science Terms and Definitions [5], 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 L2SMP Team adopted the same soil moisture retrieval accuracy requirement for the fully validated L2SMP data (0.040 m^3/m^3) that is listed in the L1 Mission Requirements Document [6] for the active/ passive soil moisture product.

In assessing the maturity of the L2SMP (and L2SMP_E) products, the team considered the guidance provided by the Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV) [7]:

- 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.

For the current L2SMP Version 4 data release, the team has completed Stage 3. This was accomplished by using CVS combined with sparse networks and SMOS intercomparisons over 19 months by publishing the assessment results in a peer-reviewed journal [1] and by a more robust assessment of uncertainty using the Triple Colocation technique with the sparse network data [2]. The L2SMP_E Version 1 is a new product and is currently in Stage 2 with some broader assessment provided by the sparse networks. Details of the assessments are provided in Section 8. The Cal/Val program will continue through the CEOS stages over the SMAP mission life span with the goal of achieving Stage 4.

3 EXPECTED PERFORMANCE OF L1 RADIOMETER DATA AND IMPACT ON L2SMP AND L2SMP_E

The L2SMP soil moisture retrievals are based on Version 3 of the radiometer Level 1B and 1C brightness temperature data [http://nsidc.org/data/smap/smap-data.html]. An assessment of data quality and calibration is available at NSIDC [http://nsidc.org/data/docs/daac/smap/sp_l1b_tb/index.html], from which the material in this section is drawn. The data meet the noise equivalent delta temperature (NEDT) and geolocation requirements with margin (see Table 3.1). The Version 3 calibration includes a revised thermal model for the instrument reflector. The inclusion of the new thermal model required a recalibration of the instrument, which resulted in a change in comparison to SMOS. Global average brightness temperature comparisons over land areas are 2 K lower than SMOS (mean difference at top of the atmosphere after Faraday rotation correction was applied). A future but small change in reflector or radome emissivity (predicted for the next major T_B data release, likely in 2017) will subtly modify this bias. Calibration drift is less than ±0.1 K relative to the global ocean, much improved over Version 1 and 2 data. Previously observed fore-aft differences in L1C_TB due to antenna sidelobe contamination and radio frequency interference (RFI) still remain. Asymmetric antenna sidelobes create fore-aft differences of several K along coastlines. A similar effect is possible in highly heterogeneous land areas, especially those with mixed land and water. Finally, RFI behavior is similar as before: conditions in the Americas and Europe are good with poorer conditions in Asia. In summary, the radiometer calibration is very stable over time, and changes in agreement with SMOS are consistent with intentional calibration changes in SMAP data. The noise and geolocation performance meet requirements with margin. Excellent performance should be expected over homogeneous land surfaces.

Table 3.1. Version 3 Characteristics of SMAP L1 Radiometer Data

Parameter		**Mission Requirement**
NEDT	1.1 K	< 1.6 K[1]
Geolocation accuracy	2.7 km	< 4 km
Land SMAP/SMOS bias (H pol)	-2.65 K	n/a
Land SMAP/SMOS bias (V pol)	-2.71 K	n/a

It is a challenge to validate brightness temperatures over land targets due to the heterogeneity of the land surface. SMOS L1 brightness temperature provides an opportunity to check the consistency in brightness temperature between the two L-band missions. SMOS has in general benefitted from more extensive Cal/Val activities than SMAP due to its relative longevity in operational data acquisition (SMOS launched in November 2009). SMOS observations at the top of the atmosphere were reprocessed to 40^{o} incidence angle (after applying the Faraday rotation correction). SMAP L1B observations were co-located with reprocessed SMOS observations (less than 30 min difference). The current L1B radiometer data (R13080) were compared with the most recent SMOS L1B data (version 620) for this analysis.

[1]An NEDT of 1.6 K for a single-look L1B_TB footprint is equivalent to an NEDT of 0.51 K on a 30 x 30 km grid (Table 2.1 in SMAP Radiometer Error Budget, JPL D-61632 [8]). When combined with other error terms in the L1 radiometer error budget, the current single-look footprint NEDT of 1.1 K should result in an NEDT of less than 0.51 K on a 30 x 30 km grid. If all other error sources are within the requirements, this level of NEDT (< 0.51 K) should result in a total radiometric uncertainty of less than 1.3 K as required in the L2SMP error budget.

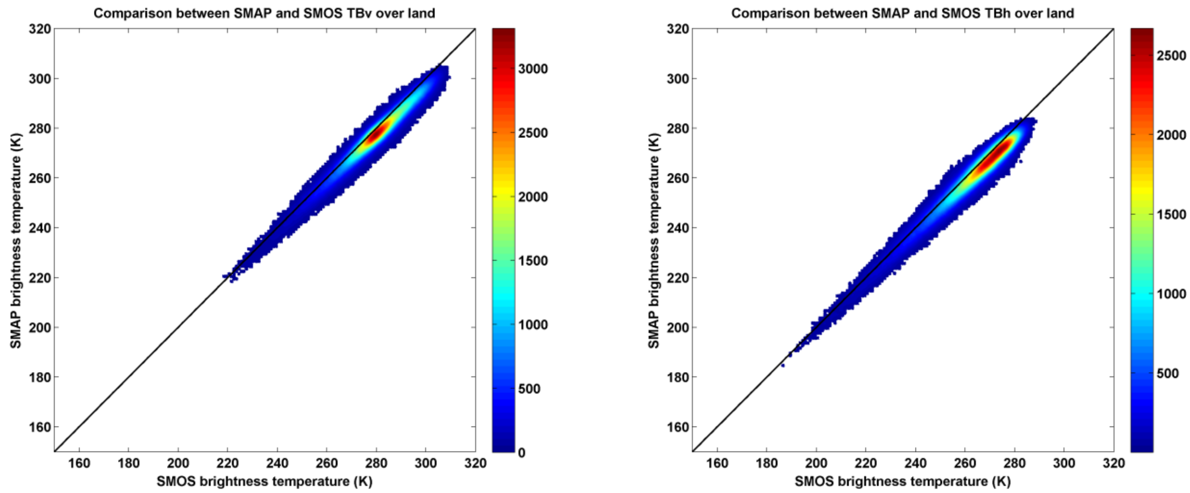


Figure 3.1 Density plot of the L1 brightness temperature comparison (top of the atmosphere) between SMAP (R13080) and SMOS (version 620) observations over land targets for V-pol (left) and H-pol (right).

Table 3.2. Summary statistics of the brightness temperature comparison between SMOS (version 620) and SMAP (R13080) for May 5, 2015-October 31, 2016.

		RMSD (K)	**R**	**Bias [SMAP-SMOS] (K)**	**ubRMSD (K)**
H pol	Land	4.34	0.9775	-2.65	3.44
	Ocean	2.45	0.7061	0.08	2.45
	Overall	2.92	0.9994	-0.60	2.86
V pol	Land	4.21	0.9745	-2.71	3.22
	Ocean	2.57	0.7679	0.57	2.51
	Overall	2.98	0.9994	-0.25	2.97

Figure 3.1 shows the density plot of the brightness temperature (top of the atmosphere) comparison between SMOS and SMAP over land targets for V-pol and H-polarization. SMOS and SMAP observations show a very strong correlation over land targets (Table 3.2). SMAP observations show a colder T_B bias (about 2 K) as compared to SMOS for both polarizations. Most of the RMSD can be attributed to the bias between the two satellites. Global average brightness temperature comparisons over ocean areas with SMOS are quite favorable indicating less than 0.4 K mean bias at top of the atmosphere. Efforts will be made to address these differences in T_B calibration and to develop a consistent L-band brightness temperature dataset between SMOS and SMAP missions. The impact of these T_B differences on soil moisture comparisons between the two satellites is more complex because the two missions use different soil moisture algorithms and ancillary datasets.

3.1 Description of the L1BTB_E

Given the relatively high sampling density of the SMAP radiometer in the across-track direction, the SMAP radiometer data present an opportunity to provide additional data at a similar sampling density through sophisticated and well-established interpolation techniques. Among these techniques is the Backus-Gilbert (BG) interpolation technique [20, 21]. This technique uses the antenna pattern of the sensor to apply optimal weightings to available data points to interpolate for additional data points at locations other than the original sampling locations. Since this technique had been successfully applied to spaceborne radiometer data, it was adopted by SMAP as the baseline technique to create an interpolated T_B product – the enhanced L1BTB product – at a 9 km grid resolution. Details of this new algorithm approach can be found in the SMAP Algorithm Theoretical Basis Document: Enhanced L1B_TB_E Radiometer Brightness Temperature Data Product, SMAP Project, JPL D-56287 [22].

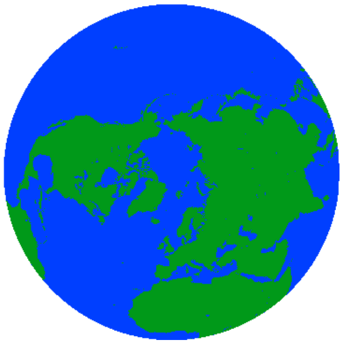
Operationally, the BG interpolation technique is first applied to the standard L1BTB product, resulting in an intermediate product known as L1BTB_E, which contains interpolated T_B data based on the original time-ordered T_B observations in the standard L1BTB product. The interpolated T_B data are available at a 9 km grid resolution in three different EASE Grid 2.0 projections: (1) global cylindrical projection, (2) north polar azimuthal projection, and (3) south polar azimuthal projection. The L1BTB_E data in global cylindrical projection form the basis for the subsequent L1CTB_E processing (Section 3.2) and L2SMP_E processing (Section 4).

Since the BG interpolation technique is not expected to alter the calibration of the input standard L1BTB data, the L1BTB_E is expected to inherit the same calibration characteristics of the standard L1BTB product.

3.2 Description of the L1CTB_E

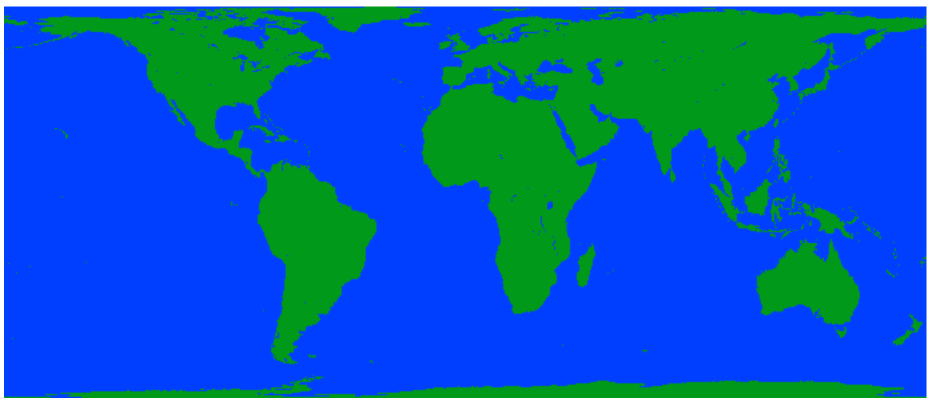
Within the SMAP operational processing environment, the intermediate L1BTB_E product described above must be converted to a certain format before the interpolated T_B data can be used for subsequent Level 2 passive soil moisture retrieval. To this end a dedicated processor was developed. In essence, this processor reduces the many vast two-dimensional arrays in L1BTB_E into a smaller number of one-dimensional arrays needed for passive soil moisture retrieval. The resulting L1CTB_E data files contain the same interpolated T_B data fields on the same 9 km EASE Grid 2.0 projections as in the L1BTB_E data files, but are a lot smaller in size for faster processing and data transfer.

By design the L1CTB_E product exhibits identical data fields and internal data organization as the standard L1CTB product, with the exception that the grid resolution of L1CTB_E is now specified based on the 9 km EASE Grid 2.0 projections on global and polar grids as shown in Fig. 3.3. Only the T_B data on the global grid will be used for passive soil moisture retrieval in Level 2 processing.



(a) North polar azimuthal projection
Array dimensions: 2000 rows by 2000 columns
(Figure credited to NSIDC)

(b) South polar azimuthal projection
Array dimensions: 2000 rows by 2000 columns
(Figure credited to NSIDC)



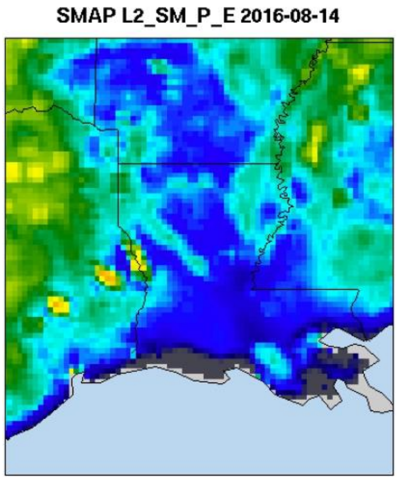
(c) Global cylindrical projection
Array dimensions: 1624 rows by 3856 columns
(Figure credited to NSIDC)

Figure 3.3 The 9 km EASE Grid 2.0 on (a) north polar azimuthal projection, (b) south polar azimuthal projection, and (c) global cylindrical projection.

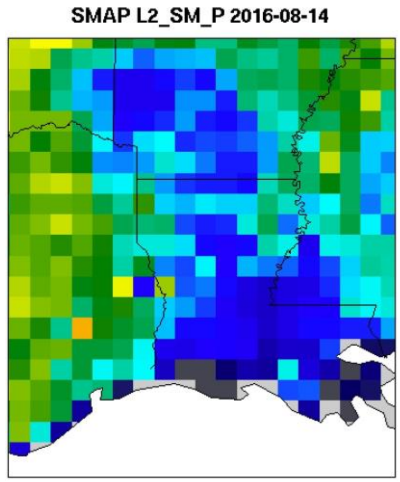
3.3 Description of the L2SMP_E

The fine grid resolution (9 km) of L1CTB_E provides a convenient basis to produce passive soil moisture retrieval at the same fine grid resolution. Operationally this is achieved by leveraging the same soil moisture inversion algorithms used for the standard 36 km L2SMP product to the enhanced 9 km L2SMP_E product. Instead of performing passive soil moisture retrieval one 36 km grid cell at a time as in the standard product, retrieval is performed one 9 km grid cell at a time in the enhanced product.

The above processing results in available soil moisture retrieval data points at a higher spatial density by virtue of T_B interpolation at a 9 km grid resolution in L1BTB_E. It is important to note that the L2SMP_E processing does not improve the native resolution (~36 km) of the original T_B measurements acquired by the SMAP radiometer. The enhanced L2SMP_E exhibits the same native resolution as the standard L2SMP; it only posts soil moisture retrieval data points on a finer grid using the BG interpolation methodology that takes advantage of the radiometer oversampling on orbit. A visual comparison of a daily snapshot between the enhanced L2SMP_E and the standard L2SMP during the Louisiana flood (Aug 12–16, 2016) is shown in Fig. 3.4.



(a) Enhanced Passive Soil Moisture Product



(b) Standard Passive Soil Moisture Product

Figure 3.4: Compared with the current standard L2SMP soil moisture product in (b), the enhanced L2SMP_E soil moisture product in (a) demonstrates a more detailed distribution of surface soil moisture and shows spatial features more clearly than with the standard product.

The development and production of the enhanced L2SMP_E will be discussed in Section 7 of this report.

4 ALTERNATIVE L2SMP ALGORITHMS

The current L2SMP contains soil moisture retrieval fields produced by the baseline and several optional algorithms. Inside an L2SMP granule the *soil_moisture* field is the one that links to the retrieval result produced by the currently-designated baseline algorithm. At present, the operational L2SMP Science Production Software (SPS) produces and stores soil moisture retrieval results from the following five algorithms:

1. Single Channel Algorithm V-pol (SCA-V)
2. Single Channel Algorithm H-pol (SCA-H)
3. Dual Channel Algorithm (DCA)
4. Microwave Polarization Ratio Algorithm (MPRA)
5. Extended Dual Channel Algorithm (E-DCA)

Given the results to date from the L2SMP Cal/Val analyses, the SCA-V algorithm continues to deliver slightly better performance overall than the alternative algorithms. For this reason, the SCA-V will continue to be the operational baseline algorithm for this release of L2SMP data. Throughout the rest of the SMAP mission, the choice of the operational algorithm of the product will be evaluated on a regular basis as analyses of new observations and Cal/Val data become available or if significant improvements can be achieved by algorithm modifications.

All five algorithms operate on the same zeroth-order microwave emission model commonly known as the *tau-omega* model. In essence, this model relates brightness temperatures (SMAP L1 observations) to soil moisture (SMAP L2 retrievals) through ancillary information (e.g. soil texture, soil temperature, and vegetation water content) and a soil dielectric model. The algorithms differ in their approaches to solve for soil moisture from the model under different constraints and assumptions. Of these, the Single Channel Algorithm–V polarization (SCA-V), Single Channel Algorithm–H polarization (SCA-H), and Dual Channel Algorithm (DCA) are the most mature and are the focus of this assessment. Below is a concise description of these three algorithms. Further details are provided in [4].

4.1 Single Channel Algorithm V-pol (SCA-V)

In the SCA-V, the vertically polarized T_B observations are converted to emissivity using a surrogate for the physical temperature of the emitting layer. The derived emissivity is corrected for vegetation and surface roughness to obtain the soil emissivity. The Fresnel equation is then used to determine the dielectric constant from the soil emissivity. Finally, a dielectric mixing model is used to solve for the soil moisture given knowledge of the soil texture. [Note: The software code includes the option of using different dielectric models. Currently, the software switch is set to the Mironov model [9]]. Analytically, SCA-V attempts to solve for one unknown variable (soil moisture) from one equation that relates the vertically polarized T_B to soil moisture. Vegetation information is provided by a 13-year climatological data base of global NDVI and a table of *tau-omega* parameters based on land cover.

4.2 Single Channel Algorithm H-pol (SCA-H)

The SCA-H is similar to SCA-V in that the horizontally polarized T_B observations are converted to emissivity using a surrogate for the physical temperature of the emitting layer. The derived emissivity is corrected for vegetation and surface roughness to obtain the soil emissivity. The Fresnel equation is then used to determine the dielectric constant. Finally, a dielectric mixing model is used to obtain the soil moisture given knowledge of the soil texture. Analytically, SCA-H attempts to solve for one unknown variable (soil moisture) from one equation that relates the horizontally polarized $T_\mathbf{B}$ to soil moisture.

Vegetation information is provided by a 13-year climatological data base of global NDVI and a table of *tau-omega* parameters based on land cover.

4.3 Dual Channel Algorithm (DCA)

In the DCA, both the vertically and horizontally polarized T_B observations are used to solve for soil moisture and vegetation optical depth. The algorithm iteratively minimizes a cost function (Φ^2) that consists of the sum of squares of the differences between the observed and estimated T_Bs:

$$\min \Phi^2_{DCA} = (T^{obs}_{B,v} - T^{est}_{B,v})^2 + (T^{obs}_{B,h} - T^{est}_{B,h})^2 \tag{1}$$

In each iteration step, the soil moisture and vegetation opacity are adjusted simultaneously until the cost function attains a minimum in a least square sense. Similar to SCA-V and SCA-H, ancillary information such as effective soil temperature, surface roughness, and vegetation single scattering albedo must be known *a priori* before the inversion process. DCA permits polarization dependence of coefficients in the forward modeling of T_B observations. As currently implemented for the validated release, the H and V parameters are set the same. During ongoing Cal/Val activities leading up to the next release of the L2SMP data, implementing polarization dependence for the *tau-omega* model parameters will be investigated.

5 METHODOLOGIES USED FOR L2 CAL/VAL

Validation is critical for accurate and credible product usage, and must be based on quantitative estimates of uncertainty. For satellite-based retrievals, validation 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.

During mission definition and development, the SMAP Science Team and Cal/Val Working Group identified the metrics and methodologies that would be used for L2-L4 product assessment. These metrics and methodologies were vetted in community Cal/Val Workshops and tested in SMAP pre-launch Cal/Val rehearsal campaigns. The methodologies identified and their general roles are:

- Core Validation Sites: Accurate estimates of products at matching scales for a limited set of conditions
- Sparse Networks: One point in the grid cell for a wide range of conditions
- Satellite Products: Estimates over a very wide range of conditions at matching scales
- Model Products: Estimates over a very wide range of conditions at matching scales
- Field Campaigns: Detailed estimates for a very limited set of conditions

In the case of the L2SMP data products, all of these methodologies can contribute to product assessment and improvement.

5.1 Validation Grid (VG)

The scanning radiometer on SMAP provides elliptical footprint observations across the scan. The orientation of this ellipse varies across the swath, and on successive passes a point on the ground might be observed with very different azimuth angles. A standard assumption in using radiometer observations is that the signal is dominated by the energy originating within the 3 dB (half-power) footprint (ellipse). The validity of this contributing area assumption will depend upon the heterogeneity of the landscape.

A major decision was made for SMAP to resample the radiometer data to an Earth-fixed grid at a resolution of 36 km. This facilitates temporal analyses and the disaggregation algorithm planned for the AP product. It ignores azimuth orientation and some contribution beyond the 3 dB footprints mentioned above, although the SMAP L1B_TB data do include a sidelobe correction. An important point is that T_Bs on the Earth-fixed 36 km grid are used in the retrieval of soil moisture, and it is the soil moisture for these 36 km grid cells that must be validated and improved.

The standard SMAP processor provides L2 surface (0-5 cm) soil moisture using only the radiometer (passive) data posted on a 36 km EASE2 Grid. The standard SMAP grid was established without any acknowledgement of where the CVS might be located. In addition, the CVS were established in most cases to satisfy other objectives of the Cal/Val Partners. One of the criteria for categorizing a site as a CVS is that the number of individual *in situ* stations (N) within the site is large (target is $N \geq 9$ for 36 km). It was observed when examining the distribution of points at a site that in many cases only a few points fell in any specific standard grid cell. Therefore, it was decided that special SMAP validation grids (VGs) would be established for validation assessment that would be tied to the existing SMAP 3 km standard grid but would allow the shifting of the 36 km grids at a site to fully exploit N being as large as possible (i.e, the validation grid would be centered over the collection of *in situ* points at a given CVS to the extent possible). The process of the validation grid processing is illustrated in Figure 5.1.

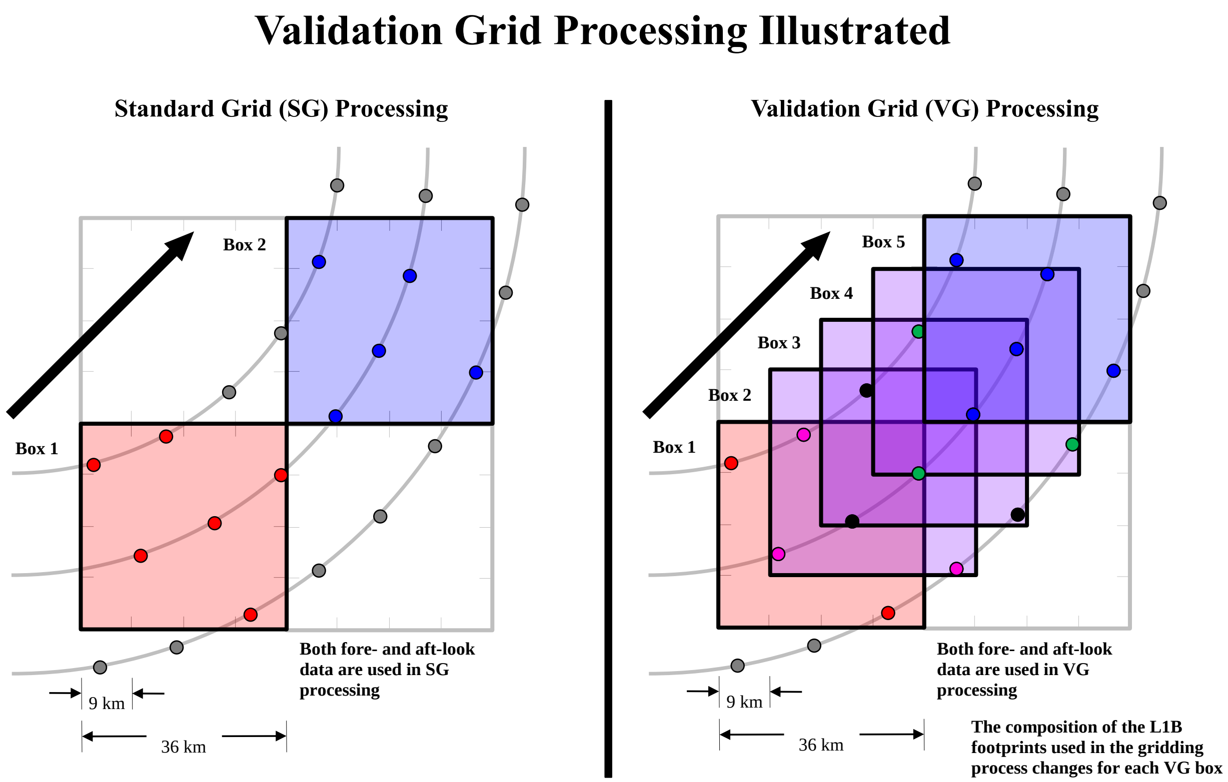


Figure 5.1. Illustration of validation grid processing. The EASE GRID2 boxes are shifted by 3 km increments (although 9 km shifts are shown for clarity) to allow a better geographical match with the *in situ* validation sites.

Computationally the L2 and L3 VG products are the same as the standard product. The selection of the VGs for each site was done by members of the SMAP Algorithm Development Team and Science Team. As noted, the 3 km grid does not change. The selection of the VGs also considered avoiding or minimizing the effects of land features that were not representative of the sampled domain or were known problems in retrieval (e.g., non-representative terrain, large water bodies, etc.).

6 L2SMP REFINEMENTS IN VERSION 4

- *Expanded Assessment Period*: For the previous validated (Version 3) data release report, the analysis time period was April 1, 2015 - February 29, 2016. The start date was based on when the radiometer data were judged to be stable following instrument start-up operations. The end date was based upon the closing date of the Version 3 release report. The current assessment report expands the time period from April 1, 2015 through October 31, 2016, which provides a more robust 19-month assessment.
- *Changes in the 36 km CVS*: One site, Kyeamba,(Australia) was dropped due to problems with the *in situ* data that resulted in too few points being available. A new site in Denmark (HOBE) was added.
- *Improved Quality Control of CVS Data*: The *in situ* data downloaded from the Cal/Val Partners is now run through an improved automatic quality control before determining the upscaled soil moisture values for each grid cell. This process can result in the removal of stations that then requires modification of the upscaling function.
- *L2SMP produced for both AM and PM passes.* The standard soil moisture product is now available for 6:00 PM ascending half-orbit granules in addition to the 6:00 AM descending half-orbit granules that have been the baseline dataset since the early beta release of the product in September 2015. The availability of soil moisture retrieval from 6:00 PM ascending half-orbit granules significantly shortens the time it takes for SMAP to provide gapless global coverage than with 6:00 AM descending half-orbit granules alone.
- *SMAP Radiometer Freeze-Thaw Product Used for Flagging*. The radiometer-based freeze/thaw state detection algorithm, now a SMAP product, reports surface freeze/thaw state as frozen ground or non-frozen ground condition in the surface quality flag and retrieval quality flag data fields in the product. Previously this information was limited to geographical regions at latitudes of 45°N and above when the SMAP radar was still operational. With the global availability of T_B data from the SMAP radiometer, it is now possible to transfer the output of the new radiometer-based freeze/thaw detection state algorithm to the soil moisture product.
- *First Assessment of the L2SMP_E products.* The new soil moisture products posted at 9 km were assessed for both 33 km and 9 km contributing domains.

7 DESCRIPTION OF THE L2SMP_E PRODUCTS

As described in Section 3.1, the Backus-Gilbert interpolation technique applied to the standard L1BTB results in the production of L1BTB_E (Section 3.2) and L1CTB_E (Section 3.3). Both products contain the same interpolated T_B data (albeit in different data organization schemes) at a 9 km grid resolution on the EASE Grid 2.0 projection.

As the standard L1CTB radiometer product is the input to the standard L2SMP soil moisture product, the enhanced L1CTB_E plays the same role of input to the enhanced L2SMP_E soil moisture product. The development of L2SMP_E was drawn heavily from the development of L2SMP in that the same baseline and candidate geophysical inversion algorithms developed for L2SMP were reused for L2SMP_E. Because the input and output specifications between the two soil moisture products are almost identical, the resulting software codes of the two products are also almost identical. While the L2SMP processor retrieves one 36 km grid cell at a time, the L2SMP_E processor retrieves one 9 km grid cell at a time. The L2SMP_E processor thus runs the same computation steps of the L2SMP processor but does so more frequently by a factor of $(36/9)^2$ or 16, resulting in half-orbit L2SMP_E granules that are about 16 times larger in data volume compared with their L2SMP counterparts. The final L2SMP_E soil moisture retrieval data are posted on a 9 km Earth-fixed grid based on the EASE Grid 2.0 global cylindrical projection as two-dimensional arrays of 1624 rows and 3856 columns. Even though the projection is two-dimensional, the data in the product files are expressed as one-dimensional arrays to save space and to maintain the same data format as the standard L2SMP soil moisture product for consistency.

7.1 AM and PM Soil Moisture Retrieval

Historically it has been a common practice among satellite soil moisture data product developers to utilize both AM and PM radiometer data to produce the corresponding soil moisture half-orbit granules. Among these examples are SMMR, Aqua/AMSR-E, WindSat, Aquarius, GCOM-W/AMSR2, and SMOS. It is generally anticipated that soil moisture retrieval derived from the PM data may not be as optimal as soil moisture retrieval derived from the AM data, as (1) the thermal gradient along the vertical soil profile is often more uniform and (2) soil temperature and canopy temperature are more similar to each other during AM hours than PM hours. These considerations had been well documented in the SMAP Passive Soil Moisture Product ATBD [4]. They also formed the basis for the SMAP project to focus only on the AM soil moisture product whose performance was evaluated during the one-year post-launch cal/val activities.

Even though the two considerations above are well grounded, it was realized a data product derived from PM radiometer data would bring along tremendous benefits to the users. At a small expense of degradation in retrieval performance (i.e., a larger ubRMSE and bias, as described more fully in Sections 8.1 and 8.2), a PM soil moisture product, along with the current AM soil moisture product, would significantly shorten the time it takes for SMAP to provide gapless global coverage. In addition, the availability of soil moisture retrieval during dawn and dusk hours provides a way to study and model diurnal variability of soil moisture at many locations over the globe on a near daily basis.

Operationally, the same procedures applied to the standard L2SMP product for AM and PM soil moisture retrieval production are also applied to the enhanced L2SMP_E product. The procedures involve pairing up the input T_B granules in AM or PM time stamps with the corresponding dynamic ancillary data. Identical geophysical inversion codes are then applied to both AM and PM radiometer data to produce the corresponding soil moisture products. Table 7.1 describes the availability of the AM and PM data for L2SMP and L2SMP_E throughout the various data releases mandated by the SMAP Project.

Table 7.1. Passive soil moisture product based on AM radiometer data have been operationally produced and released since Sept 2015. The Dec 2016 release marked the first release to have AM- and PM-based passive soil moisture data available to the public.

	Early Beta Release (2015/09)	Beta Release (2015/11)	Validated Release (2016/04)	Current Release (2016/12)
L2SMP AM	√	√	√	√
L2SMP PM	x	x	x	√
L2SMP_E AM	x	x	x	√
L2SMP_E PM	x	x	x	√

Each one of the above four product collections was assessed using the same 19 months of *in situ* data over core validation sites and sparse soil moisture networks.

7.2 Grid Posting and Contributing Domain

The SMAP radiometer is a conically scanning instrument at a constant incidence angle of 40º from nadir. The combination of full-360º fore and aft observations results in a dense sampling pattern. The SMAP reflector rotation rate, combined with the instrument integration time, results in over-sampling in the along-scan direction. Figure 7.1 illustrates the sampling pattern of the SMAP radiometer from an actual half-orbit L1BTB granule.

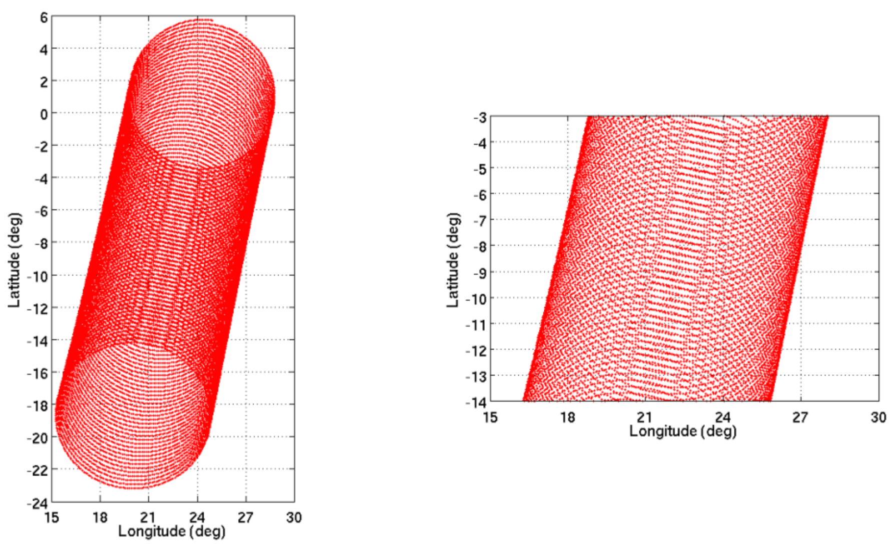


Figure 7.1: Sampling pattern of the SMAP radiometer as reported in the ephemeris data of an actual half-orbit L1BTB granule (left). A closer inspection (right) of the actual sampling locations reveals that over-sampling is achieved in the along-scan direction by virtue of the rotation rate of the SMAP reflector and the integration time of the radiometer.

Given the above sampling density, it is possible to compute the distribution of the shortest distance (L_{min}) between any given sampling location and its nearest neighbor. Such a distribution of L_{min} enables estimation of the minimum grid spacing needed in the mapping of time-ordered T_B data onto an Earth-fixed grid. With the sampling locations shown on the right-hand side of Fig. 7.1, the corresponding distribution of L_{min} is shown in Fig. 7.2.

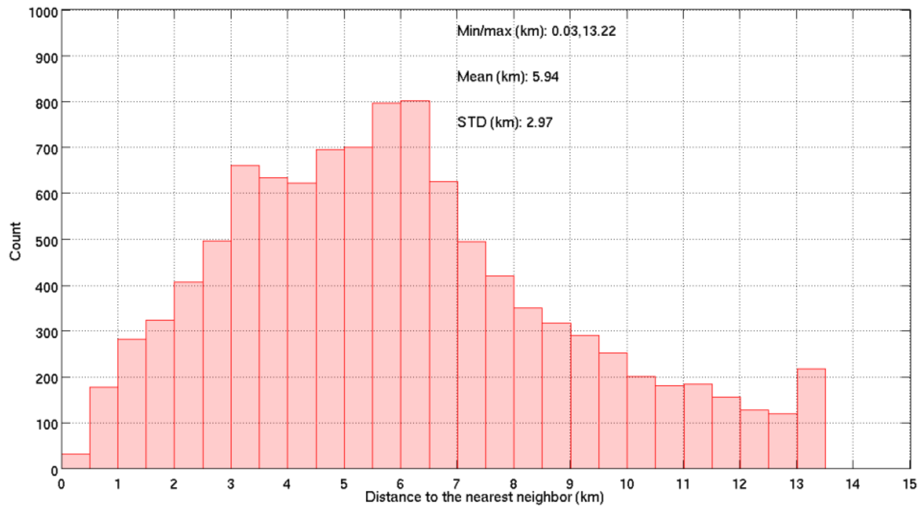


Figure 7.2. Distribution of the shortest distance (L_{min}) between any given sampling location and its nearest neighbor. Based on the actual sampling locations as reported in the ephemeris data of an actual half-orbit L1BTB granule, the mean L_{min} was found to be about 6 km with a standard deviation of about 3 km.

The distribution of L_{min} indicates that with a grid resolution chosen to be one standard deviation above the mean (6 km + 3 km = 9 km), about 83.58% of the original time-ordered L1BTB data points can be uniquely mapped onto a 9 km Earth-fixed grid using the nearest-neighbor interpolation method. This percentage goes up if there are more than one point involved in an alternate interpolation scheme such as the BG interpolation technique. As it turns out, the six-point scheme considered by the current BG implementation in L1CTB_E is adequate to provide full (i.e., 100%) mapping of the original time-ordered L1BTB data points onto a 9 km grid without resulting in empty grid cells.

Note that an L1CTB_E on a 9 km grid would also enable the reuse of resources originally invested for the SMAP Active/Passive Soil Moisture Product that was disabled after the failure of the SMAP radar in July 2015. Because such a 9 km grid is also perfectly nested within the 36 km grid used by the standard L2SMP soil moisture product, high-resolution ancillary data intended for L2SMP can be subsetted to accommodate the new contributing domain of the enhanced L2SMP_E soil moisture product.

Based on the above considerations, a global Earth-fixed grid of 9 km grid resolution was chosen to represent the enhanced L1CTB_E as the primary input to the enhanced L2SMP_E soil moisture product. Since the native resolution of the enhanced L1CTB_E – even after BG interpolation – remains approximately the same as the 3-dB spatial resolution (~36 km) of the original SMAP radiometer, it is important in the subsequent soil moisture inversion process that a proper contributing domain be chosen to accurately reflect the actual spatial extent observed by the radiometer. The relationship between grid resolution and contributing domain is illustrated in Fig. 7.3.

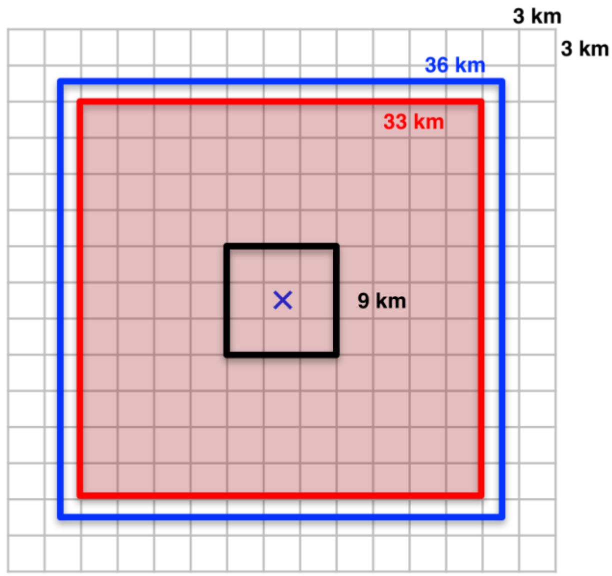
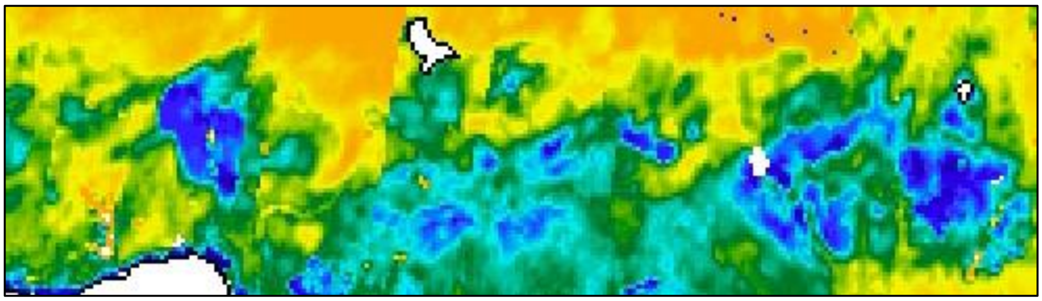


Figure 7.3. In L2SMP_E development, the input L1CTB_E is posted at a 9 km grid resolution (black box). Even though the interpolated T_B value in L1CTB_E is on a 9 km grid, the actual spatial extent that it represents corresponds to the 3-dB spatial resolution (~36 km, blue box) of the original SMAP radiometer. Since the finest resolution of the underlying ancillary data needed by L2SMP_E is 3 km, a contributing domain of 33 km (red box) was chosen to approximate the spatial extent covered by the radiometer. Here the spatial extent of the radiometer is approximated as a square for simplicity in code implementation.

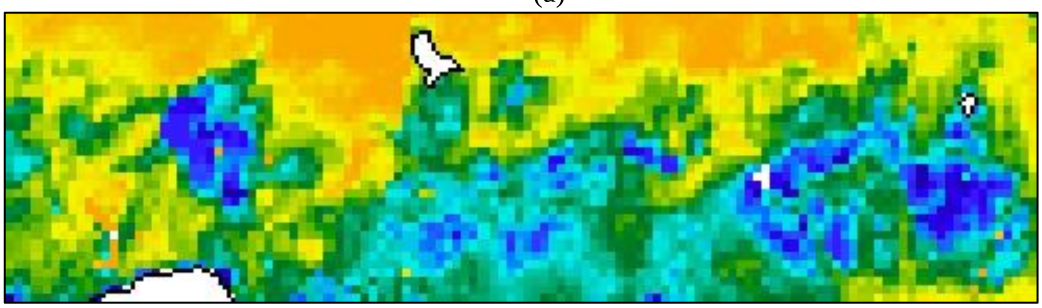
In L2SMP_E development, the input L1CTB_E is posted at a 9 km grid resolution (black box). Even though the interpolated T_B value in L1CTB_E is on a 9 km grid, the actual spatial extent that it represents corresponds to the 3-dB spatial resolution (~36 km, blue box) of the original SMAP radiometer. Since the finest resolution of the underlying ancillary data needed by L2SMP_E is 3 km, a contributing domain of 33 km (red box) was chosen to approximate the spatial extent covered by the radiometer. In future L2SMP_E development when ancillary data at a grid resolution finer than 3 km are available, the contributing domain can be made to match more closely with the native resolution of the radiometer. A comparison in input/output product specifications between the enhanced L2SMP_E and the standard L2SMP soil moisture products is given in Table 7.2, followed by a visual comparison along the desert-forest transition region in Africa in Fig. 7.4.

Table 7.2. Comparison between the enhanced L2SMP_E and the standard L2SMP. The two products are quite similar to each other in input product specifications, output product specifications, and the underlying codes for soil moisture inversion.

	L2SMP_E (Dec 2016 Release)	L2SMP (Dec 2016 Release)
Native Resolution	36 km	36 km
Grid Posting	9 km	36 km
Ancillary Data Grid Posting	3 km	3 km
Contributing Domain	33 km	36 km
Granularity	6:00 AM and 6:00 PM	6:00 AM and 6:00 PM
Primary Input	9 km L1CTB_E	36 km L1CTB
Baseline Algorithm	SCA-V	SCA-V



(a)



(b)

Figure 7.4 Comparison between the (a) enhanced L2SMP_E and the (b) standard L2SMP along the desert-forest transition region in Africa. Compared with the standard product, the enhanced product demonstrates a more detailed distribution of surface soil moisture and shows spatial features more clearly than with the standard product. Note that while the native resolution of the two products are comparable, the improvement of the enhanced product comes from interpolation using data that could have been more fully explored in the standard product.

8 ASSESSMENTS

In this section several assessments and intercomparisons are presented. First, the standard L2SMP AM (Version 4) is examined for the expanded time period and new set of CVS. Changes from the previous assessment (Version 3) will be noted if they occur. This serves as a baseline. Following this the new L2SMP PM is assessed and compared to the baseline. These assessments utilize CVS, sparse network, and SMOS comparisons.

The next assessment looks at the L2SMP_E (AM and PM) assuming that the contributing domain is 33 km. CVS and sparse network results will be compared to the L2SMP to determine whether or not there is any impact associated with the use of the new 33 km CVS versus using the validation grids. SMOS comparisons are also presented. Finally, the L2SMP_E will also be assessed assuming (erroneously) that the contributing domain is 9 km. These results will be compared to those obtained for a 33 km domain to assess the impact of this assumption. Only CVS are used in this task.

8.1 L2SMP AM

8.1.1 Core Validation Sites

The primary validation for the L2SMP soil moisture is a comparison of retrievals at 36 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 (CVS) in the SMAP Calibration/Validation Plan [3].

In situ data are critical in the assessment of the SMAP products. These comparisons provide error estimates and a basis for modifying algorithms and/or parameters. A robust analysis will require many sites representing diverse conditions. However, there are relatively few sites that can provide the type and quality of data required. SMAP established a Cal/Val Partners Program in order to foster cooperation with these sites and to encourage the enhancement of these resources to better support SMAP Cal/Val. The current set of sites that provide data for L2SMP are listed in Table 8.1.

Not all of the sites in Table 8.1 have reached a level of maturity that would support their use as CVS. In some cases this is simply a latency problem that will be resolved in time. Prior to initiating the beta-release assessments, the L2SMP and Cal/Val Teams reviewed the status of all sites to determine which sites were ready to be designated as CVS. This process was repeated prior to both the validated release (Version 3) and the current assessment (Version 4), with the addition of new screening procedures for *in situ* data. The basic process is as follows:

- Develop and implement the validation grid
- Assess the site for conditions that would introduce uncertainty
- Determine if the number of points is large enough to provide reliable estimates
- Assess the geographic distribution of the *in situ* points
- Determine if the *in situ* instrumentation has been either (1) widely used and known to be well-calibrated or (2) calibrated for the specific site in question
- Perform quality assessment of each point in the network
- Establish a scaling function (default function is a linear average of all stations)
- Conduct pre-launch assessment using surrogate data appropriate for the SMAP L2SMP product (i.e. SMOS soil moisture)
- Review any supplemental studies that have been performed to verify that the network represents the SMAP product over the grid domain

The current CVS for the L2SMP are marked with an asterisk in Table 8.1. A total of 15 CVS were used in this assessment. Each of these should have at least 9 points (ground *in situ* measurement stations); however, exceptions are made if the site has a well-established scaling and calibration function. The status of candidate sites will continue to be reviewed periodically to determine if they should be classified as CVS and used in future assessments, which did occur in this assessment. Note that the table includes comments on sites that are used for some of the L2SMP_E analyses discussed later.

The *in situ* data downloaded from the Cal/Val Partners is run through an automatic quality control (QC) before determining the upscaled soil moisture values for each pixel (grid cell). The QC is implemented largely following the approach presented in [11]. The procedure includes checks for missing data, out of control values, spikes, sudden drops, and physical temperature limits. Additionally, the physical temperature is checked to be above 4°C because many sensors experience change in behavior at colder temperatures. In several cases the sites include stations that do not perform as expected, or at all, during the comparison period. These stations are removed from consideration altogether, and a new configuration is set for the site accounting for only the stations that produce a reasonable amount of data over the comparison period. Consequently, the upscaling functions for these sites are also based on the remaining set of stations.

The key tool used in L2SMP CVS analyses is illustrated by Figure 8.1. These charts are updated as changes are made to L1 data, L2 algorithms, or in preparation for periodic reviews with Cal/Val Partners. It includes a time series plot of *in situ* and retrieved soil moisture as well as flags that were triggered on a given day, an XY scatter plot of SMAP retrieved soil moisture compared to the average *in situ* soil moisture, and the quantitative statistical metrics. It also shows the CVS site distribution. When the *in situ* values are marked with a magenta color instead of red, it means that the *in situ* quality flag is raised. Several alternative algorithms and the SMOS soil moisture product are also displayed (SMOS L2 v551 was used for April 1-May 4, 2015 and SMOS L2 v621 was used for May 5, 2015-October 31, 2016). These plots are carefully reviewed and discussed by the L2SMP Team and Cal/Val Partners on a periodic basis. Systematic differences and anomalies are identified for further investigation. This particular site (HOBE) was selected for illustration because it was relatively new in the assessment process.

All sites are then compiled to summarize the metrics and compute the overall performance. Table 8.2 gives the overall results for the current L2SMP AM Version 4 validated data set. The combined scatter plots associated with these results are shown in Figure 8.2. These metrics and plots include the removal of questionable-quality and retrieval-flagged data.

The key results for this assessment are summarized in the SMAP Average results row in Table 8.2. First, all algorithms have about the same ubRMSE, differing by 0.007 m^3/m^3, and exceed or are very close to the SMAP mission goal of 0.04 m^3/m^3. Second, the correlations are also very similar. For both of these metrics, the SCA-V has slightly better values. More obvious differences among the algorithms were found in the bias, with the SCA-V having a slight dry bias and DCA having a slightly smaller wet bias.

Based upon the metrics and considerations discussed, the SCA-V has been selected to continue as the operational baseline algorithm for this release (Version 4). As a longer period of observations builds and additional CVS are added, the evaluations will be repeated on a periodic basis.

For guidance in expected performance, the SMOS soil moisture products for each site over the same time period were analyzed. Summary statistics are included in Table 8.2. For the CVS analyzed here, SMAP SCA-V outperforms SMOS for all meterics, although they are generally of the same order of magnitude.

Also shown in Table 8.2 are the metric averages from the L2SMP Version 3 assessment, which was limited to AM retrievals. Note that in addition to a change in the period of record associated with Version 4 there are two changes in the CVS used (Kyeamba was dropped and HOBE was added). Comparing the two versions, the ubRMSE decreased for all algorithms by a small amount and R increased. There was a slight increase in the bias for the SCA-V. Overall, the algorithms appear to be stable over time.

Table 8.1. SMAP Cal/Val Partner Sites Providing L2SMP Validation Data

Site Name	Site PI	Area	Climate regime	IGBP Land Cover
Walnut Gulch[1,2]	M. Cosh	USA (Arizona)	Arid	Shrub open
Reynolds Creek[1,2]	M. Cosh	USA (Idaho)	Arid	Grasslands
Fort Cobb[1,2]	M. Cosh	USA (Oklahoma)	Temperate	Grasslands
Little Washita[1,2]	M. Cosh	USA (Oklahoma)	Temperate	Grasslands
South Fork[1,2]	M. Cosh	USA (Iowa)	Cold	Croplands
Little River[1,2]	M. Cosh	USA (Georgia)	Temperate	Cropland/natural mosaic
TxSON[1,2]	T. Caldwell	USA (Texas)	Temperate	Grasslands
Millbrook	M. Temimi	USA (New York)	Cold	Deciduous broadleaf
Kenaston[1,2]	A. Berg	Canada	Cold	Croplands
Carman[1,2]	H. McNairn	Canada	Cold	Croplands
Monte Buey[1,2]	M. Thibeault	Argentina	Arid	Croplands
Bell Ville	M. Thibeault	Argentina	Arid	Croplands
REMEDHUS[1,2]	J. Martinez	Spain	Temperate	Croplands
Valencia[2]	E. Lopez-Baeza	Spain	Arid	Woody Savannas
Twente[1]	Z. Su	Netherlands	Cold	Cropland/natural mosaic
HOBE[1,2]	F. Udall	Denmark	Temperate	Croplands
Kuwait	H. Jassar	Kuwait	Temperate	Barren/sparse
Niger	T. Pellarin	Niger	Arid	Grasslands
Benin	T. Pellarin	Benin	Arid	Savannas
Naqu	Z. Su	Tibet	Polar	Grasslands
Maqu	Z. Su	Tibet	Cold	Grasslands
Ngari	Z. Su	Tibet	Arid	Barren/sparse
MAHASRI[1]	J. Asanuma	Mongolia	Cold	Grasslands
Yanco[1,2]	J. Walker	Australia	Arid	Croplands
Kyeamba	J. Walker	Australia	Temperate	Croplands
1=CVS used in L2SMP and L2SMPE assessment. 2=CVS used in L2SMPE assessment at 9-km				

It should be noted that a small underestimation bias should be expected when comparing satellite retrievals to *in situ* soil moisture sensors during drying conditions. Satellite L-band microwave signals respond to a surface layer of a depth that varies with soil moisture (this depth is taken to be ~0-5 cm for average soils under average conditions). The *in situ* measurement is centered at 5 cm and measures a layer from ~ 3 to 7 cm. For some surface conditions and climates, it is expected that the surface will be slightly drier than the layer measured by the *in situ* sensors. For example, Adams et al. [12] reported that a mean difference of 0.018 m^3/m^3 existed between the measurements obtained by inserting a probe vertically from the surface versus horizontally at 5 cm for agricultural fields in Manitoba, Canada. Drier conditions were obtained using the surface measurement and this difference was more pronounced for mid- to dry conditions and minimized during wet conditions.

A review of the individual CVS indicates that several sites (South Fork, Little River, and Carman) have much larger bias values. Of these, South Fork and Carman also have large ubRMSE, which may suggest error sources that cannot be accounted for with the current algorithm/parameter approach. The low ubRMSE and high R for Little River indicates that there is a strong relationship that might be correctable. Two other sites have high ubRMSE and low bias values (Twente and Monte Buey).

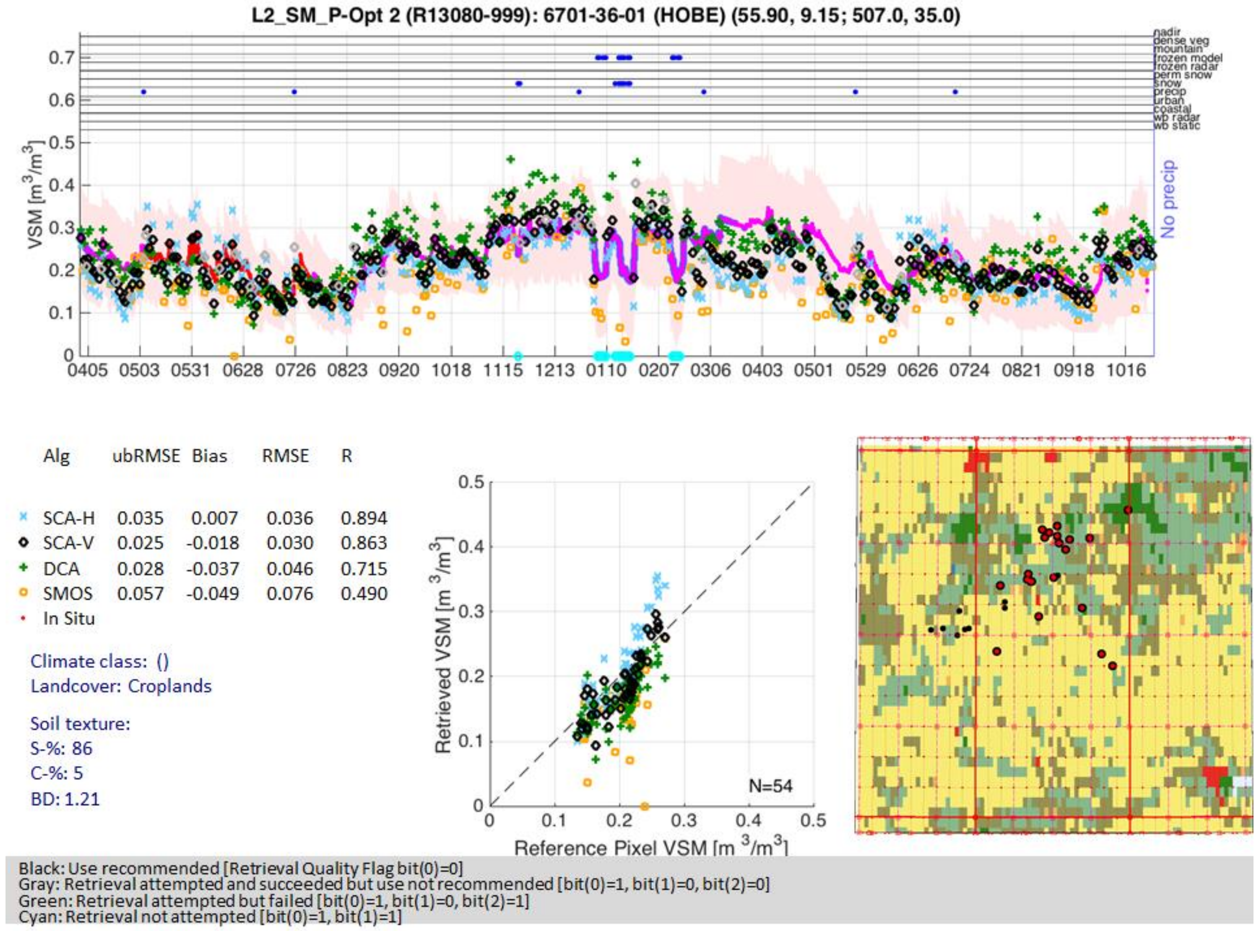


Figure 8.1. L2SMP Assessment Tool Report for the HOBE Network, Denmark.

Table 8.2. SMAP L2SMP Version 4 CVS Assessment for Descending (AM) Overpasses

CVS	ubRMSE (m^3/m^3)			Bias (m^3/m^3)			RMSE (m^3/m^3)			R			N		
	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA
Reynolds Creek	0.042	0.040	0.054	-0.066	-0.032	-0.006	0.079	0.051	0.055	0.643	0.698	0.680	132	147	146
Walnut Gulch	0.024	0.026	0.040	-0.026	-0.004	0.017	0.035	0.026	0.044	0.708	0.787	0.771	145	188	179
TxSON	0.028	0.028	0.034	-0.061	-0.011	0.065	0.068	0.030	0.073	0.944	0.946	0.888	183	183	181
Fort Cobb	0.032	0.028	0.044	-0.071	-0.040	0.001	0.078	0.049	0.044	0.857	0.879	0.818	259	259	259
Little Washita	0.024	0.022	0.042	-0.057	-0.021	0.034	0.062	0.031	0.054	0.908	0.921	0.852	269	269	268
South Fork	0.061	0.054	0.058	-0.077	-0.066	-0.050	0.098	0.085	0.077	0.585	0.612	0.551	206	209	209
Little River	0.032	0.026	0.037	0.055	0.095	0.153	0.064	0.098	0.157	0.908	0.912	0.783	278	278	278
Kenaston	0.036	0.026	0.041	-0.060	-0.035	0.006	0.070	0.044	0.041	0.766	0.810	0.524	149	149	149
Carman	0.092	0.058	0.052	-0.086	-0.086	-0.076	0.126	0.104	0.092	0.478	0.602	0.519	158	160	160
Monte Buey	0.072	0.051	0.043	-0.023	-0.018	-0.028	0.076	0.054	0.051	0.791	0.877	0.669	98	109	111
REMEDHUS	0.034	0.037	0.048	-0.030	-0.014	0.001	0.045	0.040	0.048	0.911	0.895	0.867	194	190	182
Twente	0.065	0.051	0.050	0.006	0.021	0.038	0.065	0.055	0.063	0.877	0.885	0.805	262	266	267
HOBE	0.035	0.025	0.028	0.007	-0.018	-0.037	0.036	0.030	0.046	0.894	0.863	0.715	54	54	54
MAHASRI	0.033	0.039	0.038	-0.007	-0.008	-0.005	0.033	0.040	0.038	0.713	0.681	0.682	85	67	71
Yanco	0.046	0.04	0.043	0.004	0.026	0.044	0.046	0.048	0.061	0.963	0.966	0.950	176	178	176
SMAP L2SMP Average V4	0.044	0.037	0.043	-0.033	-0.014	0.010	0.065	0.052	0.063	0.796	0.822	0.738			
SMOS L2SMP Average V4	0.051			-0.024			0.072			0.713					
SMAP L2SMP Average V3	*0.045*	*0.039*	*0.043*	*-0.033*	*-0.010*	*0.016*	*0.067*	*0.054*	*0.061*	*0.786*	*0.820*	*0.758*			
SMOS L2SMP Average V3	*0.048*			*-0.023*			*0.066*			*0.750*					

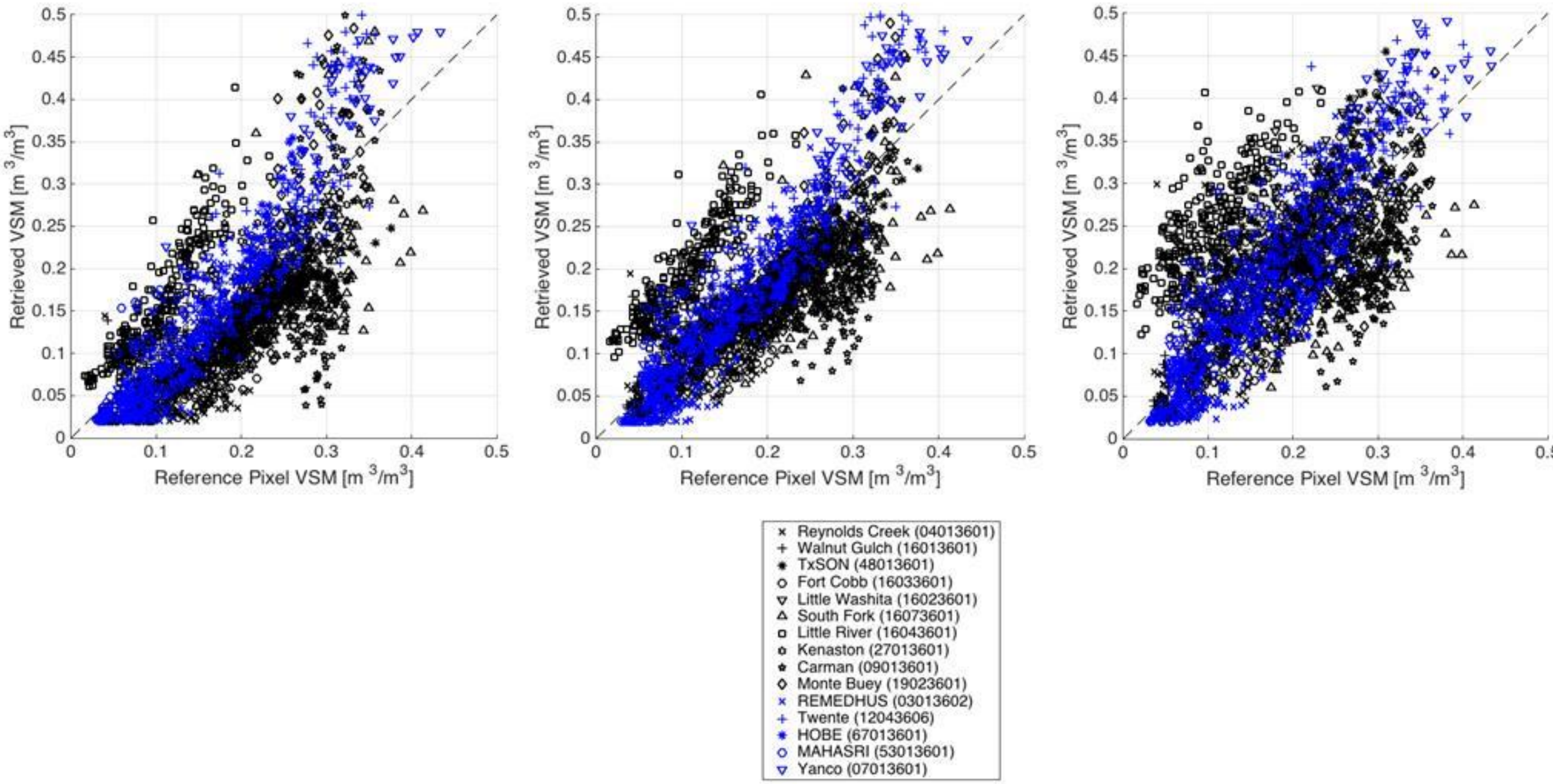


Figure 8.2. Scatterplot of SMAP L2SMP Version 4 CVS Assessment for Descending (AM) Overpasses (SCA-H left panel, SCA-V middle panel, and DCA right panel).

8.1.2 Sparse Networks

The intensive network CVS validation described above can be complemented by sparse networks as well as by new/emerging types of soil moisture networks. The current set of networks being utilized by SMAP are listed in Table 8.3.

The defining feature of these networks is that the measurement density is low, usually resulting in one point per SMAP footprint. These observations cannot be used for validation without addressing two issues: verifying that they provide a reliable estimate of the 0-5 cm surface soil moisture layer and that the one measurement point is representative of conditions across the entire SMAP footprint.

SMAP has been evaluating methodologies for upscaling data from these networks to SMAP footprint resolutions. A key element of the upscaling approach is Triple Colocation that combines the *in situ* data and SMAP soil moisture product with another independent source of soil moisture, likely to be a model-based product. A paper on the first Triple Colocation results for SMAP is currently in press [2].

Although limited by upscaling, sparse networks do offer many sites in different environments and are typically operational with very low latency. They are very useful as a supplement to the limited number of CVS.

Table 8.3 Sparse Networks Providing L2SMP Validation Data

Network Name	PI/Contact	Area	No. of Sites
NOAA Climate Reference Network (CRN)	M. Palecki	USA	110
USDA NRCS Soil Climate Analysis Network (SCAN)	M. Cosh	USA	155
GPS	E. Small	Western USA	123
COSMOS	M. Zreda	Mostly USA	53
SMOSMania	J. Calvet	Southern France	21
Pampas	M. Thibeault	Argentina	20
Oklahoma Mesonet	-	Oklahoma, USA	140
MAHASRI	J. Asanuma	Mongolia	13

The sparse network metrics are summarized in Table 8.4 (SMAP in green columns and SMOS in blue columns). Because of the larger number of sites, it is possible to also examine the results based upon the IGBP land cover classification used by SMAP. The reliability of the analyses based upon these classes will depend upon the number of sites available (N).

Overall, the relative performance of the algorithms based on ubRMSE is similar to that obtained from the CVS. The sparse network values are higher for ubRMSE and bias and lower for R, which is expected due to the significant change in scale between a point and the grid product. When comparing Version 4 AM to Version 3 AM, the bias values increased for the two SCA algorithms while the DCA bias was the same as with the CVS. Considering the many caveats that must be considered in making sparse network comparisons, the algorithm performance is still good. This result provides additional confidence in the previous conclusions based on the CVS. The SCA-V has the best overall ubRMSE and correlation while the DCA has the lowest bias.

Interpreting the results based on land cover is more complex. There are no clear patterns associated with broader vegetation types. The ubRMSE values for SCA-V are all between 0.020 and 0.065 m^3/m^3. Categories with larger bias values are grasslands and croplands. Forest results are based on single sites and should not be generalized. The larger ubRMSE and bias for grasslands and croplands needs to be addressed.

Figure 8.3 is a scatterplot of the SCA-V observed versus estimated for several different products that will be discussed in this report. Focusing on Figure 8.3a for the L2SMP AM Version 4, the distribution reflects the summary metric discussed above.

SMOS (Level 2 UDP) metrics are also included in Table 8.4 (in blue columns) as supporting information. It should be noted that while SMOS retrievals are based on a different land cover classification scheme (ECOCLIMAP), this does not have any impact on the comparisons shown, which compares the soil moisture retrievals to the *in situ* observations for the points that fall into these categories. Overall, the SMOS products are showing a higher bias and ubRMSE than the SCA-V. They also increased slightly from the Version 3 analysis.

Table 8.4. SMAP L2SMP Version 4 Sparse Network Assessment for Descending (AM) Overpasses

	ubRMSE(m^3/m^3)				Bias (m^3/m^3)				RMSE (m^3/m^3)				R				*N*
IGBP Class	SCA-H	SCA-V	DCA	SMOS	SCA-H	SCA-V	DCA	SMOS	SCA-H	SCA-V	DCA	SMOS	SCA-H	SCA-V	DCA	SMOS	
Evergreen needleleaf forest	0.043	0.042	0.054	0.062	-0.041	0.026	0.159	-0.127	0.059	0.050	0.168	0.141	0.477	0.481	0.411	0.430	1
Evergreen broadleaf forest																	
Deciduous needleleaf forest																	
Deciduous broadleaf forest	0.063	0.041	0.041	0.079	-0.011	-0.002	0.013	-0.224	0.063	0.041	0.043	0.237	-0.134	0.119	0.507	0.412	1
Mixed forest	0.058	0.058	0.061	0.055	-0.044	-0.009	0.038	-0.054	0.073	0.059	0.072	0.077	0.745	0.742	0.698	0.752	1
Closed shrublands																	
Open shrublands	0.037	0.039	0.051	0.057	-0.046	-0.013	0.027	-0.011	0.066	0.056	0.071	0.069	0.543	0.551	0.546	0.463	40
Woody savannas	0.055	0.049	0.056	0.079	-0.020	0.017	0.073	-0.055	0.083	0.077	0.104	0.126	0.723	0.743	0.658	0.585	20
Savannas	0.032	0.032	0.038	0.044	-0.045	-0.028	-0.018	-0.031	0.066	0.056	0.056	0.059	0.886	0.886	0.884	0.866	3
Grasslands	0.050	0.049	0.056	0.063	-0.074	-0.041	0.003	-0.049	0.096	0.076	0.078	0.091	0.686	0.699	0.673	0.601	236
Permanent wetlands																	
Croplands	0.076	0.065	0.069	0.080	-0.048	-0.034	-0.010	-0.049	0.117	0.100	0.095	0.119	0.561	0.603	0.554	0.553	62
Urban and built-up																	
Crop/Natural vegetation mosaic	0.061	0.051	0.057	0.079	-0.039	-0.011	0.036	-0.121	0.087	0.076	0.091	0.174	0.546	0.606	0.585	0.532	22
Snow and ice																	
Barren/Sparse	0.018	0.020	0.028	0.033	-0.010	0.014	0.052	0.005	0.032	0.036	0.064	0.041	0.587	0.555	0.484	0.595	7
SMAP L2SMP Average V4	**0.053**	**0.050**	**0.057**	**0.066**	**-0.061**	**-0.031**	**0.010**	**-0.049**	**0.093**	**0.077**	**0.081**	**0.099**	**0.643**	**0.663**	**0.633**	**0.576**	**393**
SMAP L2SMP Average V3	***0.051***	***0.048***	***0.056***	***0.062***	***-0.060***	***-0.030***	***0.011***	***-0.039***	***0.093***	***0.076***	***0.082***	***0.091***	***0.655***	***0.674***	***0.640***	***0.619***	***402***
Average is based upon all sets of observations, not the average of the land cover category results.																	

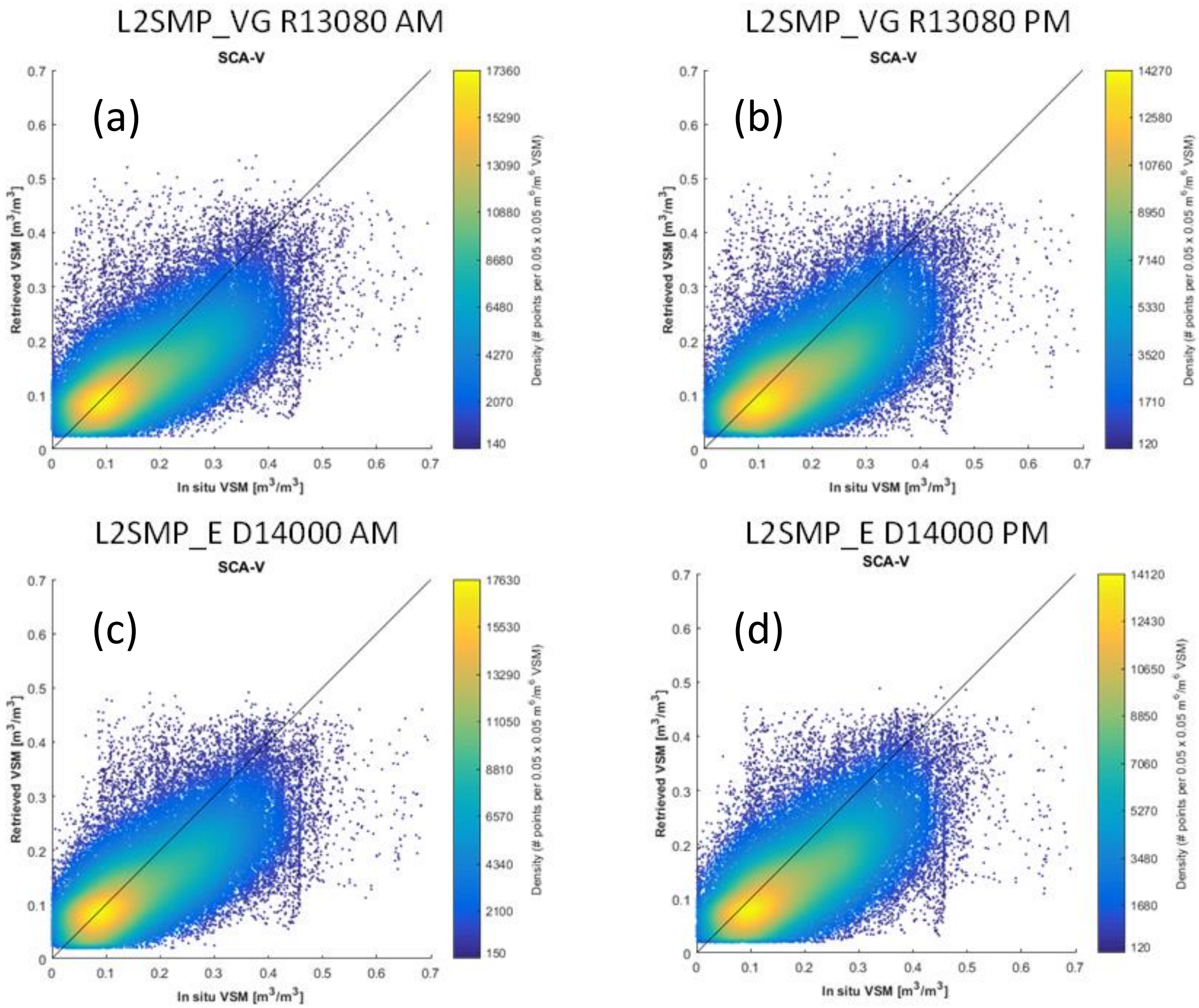


Figure 8.3. Scatterplots of the Sparse Network *In Situ* Observations and SMAP Retrievals: (a) L2SMP AM Version 4, (b) L2SMP PM Version 4), (c) L2SMP_E AM Version 1, and (d) L2SMP_E PM Version 1.

8.2 L2SMP PM

8.2.1 Core Validation Sites

The L2SMP Version 4 provides soil moisture retrievals based upon the PM (ascending) data as well as the standard AM (descending) passes. The PM product was not included initially because it was anticipated that many of the assumptions of the soil moisture retrieval algorithms used for the AM product would be violated at the nominal 6 PM time of observation. However, some early results from the SMOS mission suggested that the additional error associated with 6 PM retrievals may not be as large as expected.

Table 8.5 summarizes the performance metrics for the PM retrievals. The relative performance of the algorithms remains the same as for the AM retrievals; SCA-V has the lowest ubRMSE and highest R. The DCA has the lowest bias. Therefore, the SCA-V is the current baseline algorithm for both the AM and PM soil moisture products.

As might be expected considering land surface temperature issues and other algorithm issues, there was an increase in the ubRMSE and bias for all algorithms accompanied by a decrease in R. Most of these changes in metrics were small. The SCA-V PM ubRMSE of 0.039 m^3/m^3 still meets the mission requirement.

The increase in bias for SCA-V was present for all the CVS. An underestimation of the appropriate land surface temperature would result in an underestimation of soil moisture. Another factor that could contribute to the underestimation is near surface drying that is larger in the PM period than the AM and not reflected in the *in situ* observations measured at a deeper depth. Faraday rotation is also larger at 6 PM than at 6 AM.

8.2.2 Sparse Networks

Table 8.6 summarizes the sparse networks analysis for the L2SMP PM product. The results support the conclusions reached using the CVS; the SCA-V has the best performance metrics. Comparing the summary metrics for Version 4 to Version 3, the ubRMSE increased by very small amounts. Bias increased and R decreased. Figure 8.3b shows the SCA-V results and the increased negative bias is apparent when compared to Figure 8.3a.

Table 8.5. SMAP L2SMP Version 4 CVS Assessment for Ascending (PM) Overpasses

CVS	ubRMSE (m^3/m^3)			Bias (m^3/m^3)			RMSE (m^3/m^3)			R			N		
	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA
Reynolds Creek	0.054	0.047	0.069	-0.091	-0.060	-0.035	0.106	0.076	0.078	0.380	0.619	0.497	88	147	101
Walnut Gulch	0.027	0.032	0.047	-0.043	-0.029	-0.009	0.051	0.043	0.047	0.678	0.711	0.657	155	205	169
TxSON	0.024	0.024	0.032	-0.057	-0.017	0.033	0.062	0.030	0.046	0.937	0.937	0.906	201	201	201
Fort Cobb	0.037	0.033	0.045	-0.075	-0.056	-0.033	0.084	0.065	0.056	0.834	0.855	0.793	258	262	259
Little Washita	0.027	0.026	0.041	-0.053	-0.028	0.003	0.060	0.038	0.041	0.910	0.914	0.851	267	267	266
South Fork	0.053	0.048	0.062	-0.087	-0.091	-0.082	0.102	0.103	0.103	0.664	0.697	0.587	221	221	221
Little River	0.034	0.028	0.040	0.053	0.083	0.121	0.063	0.087	0.128	0.912	0.897	0.727	208	208	208
Kenaston	0.036	0.026	0.045	-0.061	-0.048	-0.024	0.071	0.054	0.051	0.806	0.834	0.566	181	181	181
Carman	0.090	0.053	0.051	-0.104	-0.113	-0.109	0.138	0.125	0.120	0.376	0.538	0.481	164	165	165
Monte Buey	0.067	0.047	0.047	0.001	-0.023	-0.053	0.067	0.052	0.071	0.868	0.870	0.635	88	96	97
REMEDHUS	0.041	0.046	0.052	-0.036	-0.028	-0.001	0.055	0.054	0.052	0.861	0.853	0.776	165	176	140
Twente	0.070	0.055	0.049	0.013	0.010	0.004	0.071	0.056	0.049	0.890	0.907	0.861	301	308	309
HOBE	0.037	0.032	0.035	0.006	-0.020	-0.041	0.038	0.038	0.054	0.784	0.735	0.585	55	55	55
MAHASRI	0.028	0.041	0.037	-0.020	-0.017	-0.015	0.034	0.044	0.040	0.710	0.595	0.636	67	28	35
Yanco	0.059	0.052	0.051	0.005	0.013	0.014	0.059	0.053	0.053	0.966	0.966	0.942	203	206	202
SMAP L2SMP PM Average V4	0.046	0.039	0.047	-0.037	-0.028	-0.015	0.071	0.061	0.066	0.772	0.795	0.700			
SMOS L2SMP PM Average V4	0.053			-0.028			0.072			0.710					
SMAP L2SMP AM Average V4	*0.044*	*0.037*	*0.043*	*-0.033*	*-0.014*	*0.010*	*0.065*	*0.052*	*0.063*	*0.796*	*0.822*	*0.738*			
SMOS L2SMP AM Average V4	*0.051*			*-0.024*			*0.072*			*0.713*					

Table 8.6. SMAP L2SMP Version 4 Sparse Network Assessment for Ascending (PM) Overpasses

	ubRMSE (m^3/m^3)				**Bias (m^3/m^3)**				**RMSE (m^3/m^3)**				**R**				***N***
IGBP Class	SCA-H	SCA-V	DCA	SMOS	SCA-H	SCA-V	DCA	SMOS	SCA-H	SCA-V	DCA	SMOS	SCA-H	SCA-V	DCA	SMOS	
Evergreen needleleaf forest	0.048	0.047	0.070	0.050	-0.064	-0.003	0.092	-0.095	0.080	0.047	0.115	0.107	0.422	0.443	0.424	0.585	1
Evergreen broadleaf forest																	
Deciduous needleleaf forest																	
Deciduous broadleaf forest	0.064	0.035	0.039	0.082	0.011	0.003	0.002	-0.175	0.065	0.035	0.039	0.193	-0.286	0.049	0.576	0.449	1
Mixed forest	0.056	0.055	0.058	0.056	-0.045	-0.020	0.009	-0.047	0.072	0.059	0.059	0.073	0.749	0.764	0.732	0.753	1
Closed shrublands																	
Open shrublands	0.040	0.042	0.052	0.058	-0.057	-0.028	0.003	-0.006	0.075	0.062	0.066	0.073	0.450	0.444	0.429	0.426	41
Woody savannas	0.055	0.050	0.056	0.078	-0.017	0.008	0.040	-0.042	0.084	0.078	0.092	0.111	0.732	0.736	0.651	0.623	20
Savannas	0.035	0.036	0.041	0.047	-0.045	-0.039	-0.034	-0.023	0.067	0.063	0.062	0.073	0.893	0.885	0.879	0.841	3
Grasslands	0.051	0.051	0.059	0.062	-0.079	-0.054	-0.023	-0.043	0.100	0.085	0.082	0.089	0.661	0.664	0.629	0.612	236
Permanent wetlands																	
Croplands	0.074	0.065	0.070	0.078	-0.041	-0.041	-0.035	-0.046	0.117	0.104	0.101	0.113	0.573	0.603	0.552	0.547	62
Urban and built-up																	
Crop/Natural vegetation mosaic	0.058	0.050	0.059	0.080	-0.032	-0.018	0.006	-0.107	0.084	0.077	0.086	0.158	0.522	0.616	0.632	0.535	22
Snow and ice																	
Barren/Sparse	0.020	0.022	0.031	0.038	-0.018	0.000	0.029	0.011	0.036	0.038	0.056	0.049	0.548	0.489	0.410	0.44	7
SMAP L2SMP PM Average V4	**0.053**	**0.051**	**0.059**	**0.065**	**-0.063**	**-0.043**	**-0.016**	**-0.043**	**0.097**	**0.083**	**0.084**	**0.095**	**0.618**	**0.629**	**0.595**	**0.578**	**394**
SMAP L2SMP AM Average V4	***0.053***	***0.050***	***0.057***	***0.066***	***-0.061***	***-0.031***	***0.010***	***-0.049***	***0.093***	***0.077***	***0.081***	***0.099***	***0.643***	***0.663***	***0.633***	***0.576***	***393***
Average is based upon all sets of observations, not the average of the land cover category results.																	

8.3 L2SMP_E Assessed at 33 km

8.3.1 Core Validation Sites

The new L2SMP_E Version 1 is assessed using the same approach as that employed for L2SMP. The major difference between this and L2SMP is that this product is assessed using a different set of CVS. Because it is possible to now provide a retrieval for every SMAP 9 km grid cell, where feasible, the need for using the validation grid (as used for L2SMP) is not expected to be as important an issue in performing validation. It should be noted that the validation grid allowed centering the retrieval on any 3 km grid, whereas L2SMP_E process can only be centered on a 9 km grid. Thus the ability to match the *in situ* network to the grid may be more restrictive for L2SMP_E. Each available CVS was reviewed to identify the 9 km grid cell that satisfied the CVS criteria for the new 33 km contributing domain. Therefore, the mix/weighting of *in situ* stations and grid center will be different between the CVS sets used for the two products.

The CVS results are summarized in Tables 8.7 and 8.8 for the AM and PM overpasses, respectively. The best algorithm choice remains the SCA-V and the ubRMSE meets/exceeds the SMAP mission requirements. When compared to the L2SMP retrievals, the differences in the metrics are negligible. These results indicate that the L2SMP_E products can be used in place of L2SMP without loss of accuracy.

8.3.2 Sparse Networks

The sparse network results are summarized in Tables 8.9 and 8.10 for the AM and PM overpasses, respectively. Comparing the overall metrics for the L2SMP products to the L2SMP_E products, the results are nearly identical and therefore support the CVS analysis.

Table 8.7. SMAP L2SMP_E Version 1 33 km CVS Assessment for Descending (AM) Overpasses

CVS	ubRMSE (m^3/m^3)			Bias (m^3/m^3)			RMSE (m^3/m^3)			R			N		
	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA
Reynolds Creek	0.039	0.040	0.057	-0.059	-0.023	0.007	0.071	0.046	0.058	0.572	0.598	0.558	86	97	96
Walnut Gulch	0.021	0.024	0.038	-0.011	0.011	0.035	0.024	0.026	0.052	0.759	0.813	0.800	93	118	115
TxSON	0.031	0.032	0.041	-0.064	-0.015	0.056	0.071	0.036	0.069	0.935	0.921	0.827	153	153	152
Fort Cobb	0.032	0.028	0.045	-0.086	-0.056	-0.017	0.091	0.062	0.048	0.858	0.883	0.817	244	247	247
Little Washita	0.023	0.022	0.042	-0.062	-0.027	0.026	0.066	0.035	0.050	0.911	0.920	0.837	246	246	245
South Fork	0.062	0.054	0.054	-0.071	-0.062	-0.050	0.094	0.082	0.074	0.597	0.646	0.637	159	162	162
Little River	0.034	0.028	0.041	0.048	0.087	0.144	0.059	0.092	0.150	0.871	0.887	0.755	229	229	229
Kenaston	0.034	0.022	0.040	-0.064	-0.040	-0.001	0.072	0.046	0.040	0.808	0.854	0.515	145	145	145
Carman	0.094	0.056	0.053	-0.087	-0.088	-0.077	0.128	0.104	0.093	0.463	0.611	0.535	157	158	158
Monte Buey	0.075	0.051	0.042	-0.022	-0.020	-0.025	0.078	0.055	0.049	0.754	0.840	0.724	126	135	137
REMEDHUS	0.037	0.042	0.054	-0.024	-0.007	0.010	0.044	0.042	0.055	0.897	0.872	0.837	197	196	189
Twente	0.072	0.056	0.056	0.003	0.013	0.028	0.072	0.057	0.063	0.888	0.885	0.784	238	242	241
HOBE	0.048	0.036	0.063	0.004	-0.009	-0.012	0.048	0.037	0.064	0.700	0.863	0.789	104	104	104
MAHASRI	0.032	0.036	0.036	-0.009	-0.006	-0.006	0.033	0.037	0.037	0.736	0.728	0.730	139	102	116
Yanco	0.051	0.043	0.045	0.000	0.020	0.035	0.051	0.048	0.057	0.960	0.964	0.943	170	172	170
SMAP Average L2SMP_E	0.046	0.038	0.047	-0.034	-0.015	0.010	0.067	0.054	0.064	0.781	0.819	0.739			
SMOS Average L2SMP_E	0.051~~2~~			-0.023~~11~~			0.071~~67~~			0.698~~748~~					
SMAP Average L2SMP	*0.044*	*0.037*	*0.043*	*-0.033*	*-0.014*	*0.010*	*0.065*	*0.052*	*0.063*	*0.796*	*0.822*	*0.738*			
SMOS Average L2SMP	*0.051*			*-0.024*			*0.072*			*0.713*					

Table 8.8. SMAP L2SMP_E Version 1 33 km CVS Assessment for Ascending (PM) Overpasses

CVS	ubRMSE (m^3/m^3)			Bias (m^3/m^3)			RMSE (m^3/m^3)			R			N		
	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA
Reynolds Creek	0.046	0.042	0.060	-0.075	-0.042	-0.005	0.088	0.059	0.060	0.452	0.651	0.630	79	106	96
Walnut Gulch	0.027	0.029	0.042	-0.031	-0.019	-0.000	0.041	0.034	0.042	0.622	0.676	0.631	102	165	141
TxSON	0.028	0.028	0.033	-0.058	-0.018	0.031	0.065	0.034	0.045	0.930	0.929	0.893	178	178	178
Fort Cobb	0.039	0.035	0.046	-0.087	-0.069	-0.046	0.096	0.077	0.065	0.811	0.846	0.778	240	251	245
Little Washita	0.027	0.026	0.042	-0.057	-0.032	0.000	0.063	0.041	0.042	0.909	0.910	0.835	259	259	258
South Fork	0.053	0.045	0.061	-0.084	-0.087	-0.074	0.099	0.098	0.095	0.710	0.764	0.668	172	171	171
Little River	0.036	0.029	0.041	0.050	0.078	0.115	0.062	0.083	0.122	0.885	0.872	0.683	193	193	193
Kenaston	0.033	0.027	0.052	-0.065	-0.051	-0.024	0.073	0.057	0.057	0.833	0.828	0.515	186	186	186
Carman	0.087	0.049	0.051	-0.102	-0.109	-0.101	0.134	0.120	0.113	0.406	0.594	0.505	161	162	162
Monte Buey	0.075	0.052	0.046	0.007	-0.019	-0.050	0.075	0.056	0.067	0.848	0.874	0.722	107	113	113
REMEDHUS	0.041	0.045	0.055	-0.029	-0.018	0.006	0.050	0.048	0.056	0.856	0.857	0.781	168	184	156
Twente	0.068	0.052	0.051	0.006	0.001	-0.001	0.069	0.052	0.051	0.897	0.903	0.834	272	274	274
HOBE	0.046	0.042	0.069	0.003	-0.013	-0.019	0.046	0.044	0.071	0.711	0.844	0.811	106	106	106
MAHASRI	0.032	0.038	0.037	-0.017	-0.018	-0.017	0.036	0.042	0.041	0.747	0.700	0.706	110	79	82
Yanco	0.060	0.053	0.052	0.004	0.011	0.013	0.060	0.054	0.054	0.966	0.966	0.940	201	203	199
SMAP Average L2SMP_E	0.047	0.039	0.049	-0.036	-0.027	-0.011	0.070	0.060	0.066	0.772	0.814	0.729			
SMOS Average L2SMP_E	0.052			-0.029~~16~~			0.071~~68~~			0.721~~50~~					
SMAP Average L2SMP	*0.046*	*0.039*	*0.047*	*-0.037*	*-0.028*	*-0.015*	*0.071*	*0.061*	*0.066*	*0.772*	*0.795*	*0.700*			
SMOS Average L2SMP	0.053			-0.028			0.072			0.710					

Table 8.9. SMAP L2SMP_E Version 1 Sparse Network Assessment for Descending (AM) Overpasses

	ubRMSD (m3/m3)				**Bias (m3/m3)**				**RMSD (m3/m3)**				**R**				***N***
IGBP Class	SCA-H	SCA-V	DCA	SMOS	SCA-H	SCA-V	DCA	SMOS	SCA-H	SCA-V	DCA	SMOS	SCA-H	SCA-V	DCA	SMOS	
Evergreen needleleaf forest	0.040	0.039	0.052	0.062	-0.033	0.033	0.166	-0.127	0.052	0.051	0.174	0.141	0.498	0.530	0.515	0.43	1
Evergreen broadleaf forest																	
Deciduous needleleaf forest																	
Deciduous broadleaf forest																	
Mixed forest	0.059	0.060	0.068	0.055	-0.037	-0.003	0.045	-0.054	0.070	0.060	0.081	0.077	0.609	0.591	0.541	0.752	1
Closed shrublands																	
Open shrublands	0.038	0.039	0.050	0.056	-0.041	-0.008	0.032	-0.010	0.063	0.055	0.075	0.068	0.516	0.523	0.513	0.46	38
Woody savannas	0.054	0.049	0.061	0.081	-0.017	0.021	0.078	-0.063	0.088	0.080	0.112	0.134	0.709	0.717	0.596	0.541	16
Savannas	0.032	0.032	0.040	0.044	-0.043	-0.026	-0.016	-0.031	0.063	0.055	0.056	0.059	0.877	0.875	0.869	0.866	3
Grasslands	0.051	0.051	0.059	0.062	-0.076	-0.042	0.003	-0.049	0.098	0.079	0.080	0.091	0.667	0.675	0.637	0.596	224
Permanent wetlands																	
Croplands	0.077	0.066	0.071	0.078	-0.047	-0.033	-0.009	-0.050	0.117	0.101	0.097	0.117	0.569	0.602	0.541	0.553	54
Urban and built-up																	
Crop/Natural vegetation mosaic	0.063	0.056	0.066	0.079	-0.044	-0.015	0.033	-0.124	0.095	0.084	0.101	0.176	0.722	0.761	0.643	0.536	20
Snow and ice																	
Barren/Sparse	0.018	0.021	0.030	0.032	-0.015	0.006	0.035	0.002	0.034	0.033	0.051	0.040	0.648	0.596	0.522	0.62	6
Average L2SMP_E AM	**0.054**	**0.051**	**0.060**	**0.065**	**-0.062**	**-0.032**	**0.010**	**-0.049**	**0.095**	**0.079**	**0.084**	**0.098**	**0.642**	**0.654**	**0.608**	**0.572**	**363**
Average L2SMP AM	***0.053***	***0.050***	***0.057***	***0.066***	***-0.061***	***-0.031***	***0.010***	***-0.049***	***0.093***	***0.077***	***0.081***	***0.099***	***0.643***	***0.663***	***0.633***	***0.576***	***393***

Average is based upon all sets of observations, not the average of the land cover category results.

Table 8.10. SMAP L2SMP_E Version 1 Sparse Network Assessment for Ascending (PM) Overpasses

	ubRMSD (m3/m3)				**Bias (m3/m3)**				**RMSD (m3/m3)**				**R**				***N***
IGBP Class	SCA-H	SCA-V	DCA	SMOS	SCA-H	SCA-V	DCA	SMOS	SCA-H	SCA-V	DCA	SMOS	SCA-H	SCA-V	DCA	SMOS	
Evergreen needleleaf forest	0.047	0.046	0.067	0.050	-0.057	0.006	0.115	-0.095	0.074	0.047	0.133	0.107	0.442	0.461	0.429	0.585	1
Evergreen broadleaf forest																	
Deciduous needleleaf forest																	
Deciduous broadleaf forest																	
Mixed forest	0.057	0.053	0.051	0.056	-0.040	-0.011	0.029	-0.047	0.070	0.054	0.059	0.073	0.687	0.740	0.771	0.753	1
Closed shrublands																	
Open shrublands	0.040	0.042	0.053	0.057	-0.051	-0.022	0.009	-0.005	0.070	0.058	0.067	0.071	0.485	0.468	0.441	0.421	39
Woody savannas	0.051	0.047	0.058	0.080	-0.012	0.015	0.053	-0.045	0.086	0.079	0.098	0.114	0.745	0.750	0.625	0.584	16
Savannas	0.033	0.035	0.040	0.047	-0.043	-0.034	-0.029	-0.023	0.063	0.058	0.058	0.073	0.890	0.871	0.861	0.841	3
Grasslands	0.051	0.051	0.059	0.062	-0.079	-0.053	-0.020	-0.043	0.101	0.085	0.082	0.088	0.663	0.667	0.632	0.609	224
Permanent wetlands																	
Croplands	0.075	0.065	0.070	0.076	-0.037	-0.037	-0.030	-0.047	0.117	0.103	0.100	0.111	0.579	0.610	0.560	0.547	54
Urban and built-up																	
Crop/Natural vegetation mosaic	0.061	0.055	0.065	0.079	-0.033	-0.017	0.009	-0.112	0.089	0.083	0.093	0.160	0.723	0.761	0.659	0.544	20
Snow and ice																	
Barren/Sparse	0.019	0.022	0.031	0.036	-0.022	-0.005	0.018	0.004	0.038	0.035	0.045	0.045	0.577	0.516	0.443	0.453	6
Average L2SMP_E PM	**0.053**	**0.051**	**0.059**	**0.065**	**-0.063**	**-0.041**	**-0.012**	**-0.043**	**0.097**	**0.083**	**0.084**	**0.094**	**0.639**	**0.645**	**0.601**	**0.575**	**364**
Average L2SMP PM	***0.053***	***0.051***	***0.059***	***0.065***	***-0.063***	***-0.043***	***-0.016***	***-0.043***	***0.097***	***0.083***	***0.084***	***0.095***	***0.618***	***0.629***	***0.595***	***0.578***	***394***
Average is based upon all sets of observations, not the average of the land cover category results.																	

8.4 L2SMP_E Assessed at 9 km

8.4.1 All Core Validation Sites

The contributing domain for the L2SMP_E is approximately 33 km. This is defined as being centered on a specific 9 km grid cell (posting). It is intended that the data be interpreted as an estimate of the surface soil moisture over a box which is 33 km on each side. However, it is a common (though incorrect) practice for users to assume that the posted grid data represent the surface soil moisture over the 9 km grid cell. Therefore, the impact of making this assumption on the metrics was assessed. In order to do this, all 9 km grids with at least five *in situ* sites (four at well-characterized CVS) were identified. These sites are summarized in Table 8.11. In some cases there were multiple 9 km CVS at a location and in others, no 9 km box was viable. *In situ* averages were computed based upon these boxes and compared to the L2SMP_E values. In order not to bias the results, the values for each location with multiple boxes (i.e. Walnut Gulch) were first averaged. These averages were then combined with the sites having only a single 9 km CVS to determine the overall averages for the metrics.

The matched CVS results for the AM and PM passes are shown in Tables 8.11 and 8.12, respectively. When compared to the 33 km assessment, the ubRMSE and bias increased slightly and R decreased (SCA-H ubRMSE AM decreased slightly). The conclusion that could be made is that for this set of CVS, interpreting posting as resolution does not have much impact.

Caution should be taken in interpreting this portion of the assessment. It is possible that the impact of assuming that the values represent 9 km domains, as opposed to 33 km, may be associated with the relative homogeneity of many of the CVS. In addition, a radiometer measurement is a nonlinear integrated response over a footprint. The contribution from the region near its center may play a more dominant role in determining the brightness temperature (or soil moisture). In more heterogeneous domains the results might be different.

8.4.2 Matched Core Validation Sites

As noted above, a different set of CVS were used for the 33 km and 9 km assessments of the L2SMP_E. Regardless of the fact that the results are nearly the same, an additional assessment was conducted using only sites at which co-located 33 km and 9 km CVS could be identified (an adequate number of *in situ* points distributed over the domain).

The results for the AM passes for 33 km and 9 km are shown in Tables 8.13 and 8.14. Figures 8.15 and 8.16 show the corresponding PM results. These results support the conclusions from above that there is not much difference in the performance metrics.

Table 8.11. SMAP L2SMP_E Version 1 9 km CVS Assessment for Descending (AM) Overpasses

CVS	ubRMSE (m^3/m^3)			Bias (m^3/m^3)			RMSE (m^3/m^3)			R			N		
	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA
Reynolds Creek	0.038	0.039	0.065	-0.084	-0.047	-0.008	0.092	0.061	0.066	0.693	0.733	0.694	43	46	46
Walnut Gulch (35)	*0.022*	*0.026*	*0.042*	*-0.009*	*0.011*	*0.035*	*0.024*	*0.028*	*0.054*	*0.753*	*0.817*	*0.787*	*85*	*116*	*110*
Walnut Gulch (36)	*0.029*	*0.030*	*0.043*	*-0.033*	*-0.007*	*0.018*	*0.044*	*0.031*	*0.046*	*0.615*	*0.678*	*0.657*	*107*	*140*	*134*
Walnut Gulch (37)	*0.024*	*0.024*	*0.036*	*-0.010*	*0.015*	*0.043*	*0.026*	*0.029*	*0.056*	*0.739*	*0.798*	*0.791*	*91*	*107*	*103*
Walnut Gulch (38)	*0.023*	*0.022*	*0.035*	*-0.021*	*0.004*	*0.026*	*0.031*	*0.022*	*0.044*	*0.741*	*0.835*	*0.814*	*98*	*129*	*122*
Walnut Gulch (avg)	0.025	0.026	0.039	-0.018	0.006	0.031	0.031	0.028	0.050	0.712	0.782	0.762			
TxSON (02)	*0.024*	*0.023*	*0.038*	*-0.046*	*0.005*	*0.077*	*0.051*	*0.023*	*0.086*	*0.929*	*0.933*	*0.867*	*189*	*189*	*186*
TxSON (11)	*0.033*	*0.032*	*0.039*	*-0.049*	*0.004*	*0.082*	*0.059*	*0.032*	*0.090*	*0.943*	*0.940*	*0.875*	*177*	*177*	*176*
TxSON (avg)	0.029	0.028	0.039	-0.048	0.005	0.080	0.055	0.028	0.088	0.936	0.937	0.871			
Fort Cobb	0.029	0.025	0.037	-0.072	-0.040	0.002	0.078	0.047	0.037	0.887	0.915	0.870	226	228	228
Little Washita	0.029	0.029	0.049	-0.034	0.001	0.050	0.045	0.029	0.070	0.858	0.852	0.754	162	162	162
South Fork	0.063	0.056	0.058	-0.086	-0.078	-0.065	0.107	0.095	0.087	0.594	0.637	0.604	166	169	169
Little River	0.033	0.028	0.041	0.063	0.103	0.163	0.071	0.106	0.168	0.873	0.885	0.735	221	221	221
Kenaston (01)	*0.042*	*0.032*	*0.049*	*-0.062*	*-0.036*	*0.007*	*0.074*	*0.048*	*0.049*	*0.719*	*0.744*	*0.405*	*163*	*163*	*163*
Kenaston (02)	*0.033*	*0.029*	*0.051*	*-0.102*	*-0.078*	*-0.040*	*0.107*	*0.083*	*0.064*	*0.826*	*0.825*	*0.458*	*157*	*157*	*157*
Kenaston (03)	*0.040*	*0.032*	*0.049*	*-0.069*	*-0.043*	*0.001*	*0.080*	*0.054*	*0.049*	*0.716*	*0.762*	*0.469*	*149*	*149*	*149*
Kenaston (avg)	0.038	0.031	0.050	-0.078	-0.052	-0.011	0.087	0.062	0.054	0.754	0.777	0.444			
Carman	0.091	0.057	0.058	-0.077	-0.077	-0.064	0.119	0.095	0.086	0.431	0.585	0.562	144	146	146
Monte Buey	0.085	0.064	0.051	-0.027	-0.024	-0.037	0.089	0.068	0.063	0.829	0.851	0.593	92	102	103
REMEDHUS	0.039	0.043	0.053	-0.024	-0.006	0.013	0.046	0.043	0.055	0.880	0.861	0.825	200	200	197
Valencia	0.030	0.036	0.064	-0.066	-0.010	0.056	0.072	0.037	0.085	0.579	0.490	0.395	92	93	93
HOBE	0.044	0.034	0.051	0.016	-0.010	-0.028	0.047	0.035	0.058	0.742	0.692	0.346	60	60	60
Yanco (03)	*0.061*	*0.054*	*0.055*	*-0.022*	*-0.002*	*0.018*	*0.064*	*0.054*	*0.057*	*0.899*	*0.904*	*0.892*	*192*	*192*	*191*
Yanco (04)	*0.059*	*0.047*	*0.042*	*0.000*	*0.014*	*0.023*	*0.059*	*0.049*	*0.048*	*0.931*	*0.952*	*0.953*	*175*	*179*	*187*
Yanco (avg)	0.060	0.051	0.049	-0.011	0.006	0.021	0.062	0.052	0.053	0.915	0.928	0.923			
SMAP L2SMP_E Average (9 km)	0.045	0.039	0.050	-0.039	-0.016	0.014	0.071	0.056	0.073	0.763	0.780	0.670			
SMAP L2SMP_E Average (33 km)	*0.046*	*0.038*	*0.047*	*-0.033*	*-0.014*	*0.010*	*0.067*	*0.054*	*0.064*	*0.783*	*0.819*	*0.742*			

Table 8.12. SMAP L2SMP_E Version 1 9 km CVS Assessment for Ascending (PM) overpasses

CVS	ubRMSE (m^3/m^3)			Bias (m^3/m^3)			RMSE (m^3/m^3)			R			N		
	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA
Reynolds Creek	0.054	0.051	0.078	-0.104	-0.074	-0.034	0.118	0.090	0.085	0.281	0.551	0.440	36	49	41
Walnut Gulch (35)	*0.031*	*0.035*	*0.050*	*-0.022*	*-0.009*	*0.013*	*0.038*	*0.036*	*0.051*	*0.590*	*0.639*	*0.620*	*98*	*142*	*129*
Walnut Gulch (36)	*0.037*	*0.038*	*0.050*	*-0.055*	*-0.042*	*-0.024*	*0.066*	*0.057*	*0.055*	*0.436*	*0.500*	*0.478*	*118*	*199*	*176*
Walnut Gulch (37)	*0.030*	*0.029*	*0.042*	*-0.031*	*-0.013*	*0.003*	*0.043*	*0.032*	*0.042*	*0.626*	*0.711*	*0.666*	*112*	*185*	*162*
Walnut Gulch (38)	*0.032*	*0.035*	*0.048*	*-0.036*	*-0.022*	*-0.005*	*0.048*	*0.041*	*0.048*	*0.527*	*0.588*	*0.558*	*100*	*141*	*131*
Walnut Gulch (avg)	0.033	0.034	0.048	-0.036	-0.022	-0.003	0.049	0.042	0.049	0.545	0.610	0.581			
TxSON (02)	*0.024*	*0.025*	*0.042*	*-0.040*	*0.001*	*0.052*	*0.046*	*0.025*	*0.067*	*0.912*	*0.908*	*0.855*	*197*	*197*	*197*
TxSON (11)	*0.026*	*0.025*	*0.032*	*-0.043*	*-0.002*	*0.048*	*0.050*	*0.025*	*0.057*	*0.937*	*0.936*	*0.900*	*189*	*189*	*188*
TxSON (avg)	0.025	0.025	0.037	-0.042	-0.001	0.050	0.048	0.025	0.062	0.925	0.922	0.878			
Fort Cobb	0.031	0.027	0.038	-0.072	-0.051	-0.027	0.079	0.058	0.046	0.860	0.893	0.841	223	232	229
Little Washita	0.036	0.035	0.042	-0.030	-0.007	0.016	0.047	0.036	0.045	0.851	0.837	0.758	165	165	164
South Fork	0.054	0.051	0.068	-0.098	-0.102	-0.090	0.112	0.114	0.113	0.698	0.703	0.574	181	180	180
Little River	0.038	0.031	0.042	0.066	0.093	0.131	0.076	0.098	0.137	0.900	0.875	0.663	194	194	194
Kenaston (01)	*0.044*	*0.043*	*0.068*	*-0.051*	*-0.034*	*-0.004*	*0.067*	*0.055*	*0.068*	*0.682*	*0.569*	*0.189*	*224*	*224*	*224*
Kenaston (02)	*0.033*	*0.031*	*0.058*	*-0.103*	*-0.089*	*-0.062*	*0.108*	*0.094*	*0.085*	*0.822*	*0.798*	*0.488*	*209*	*209*	*209*
Kenaston (03)	*0.036*	*0.033*	*0.059*	*-0.069*	*-0.054*	*-0.026*	*0.078*	*0.063*	*0.065*	*0.786*	*0.777*	*0.418*	*188*	*188*	*188*
Kenaston (avg)	0.038	0.036	0.062	-0.074	-0.059	-0.031	0.084	0.071	0.073	0.763	0.715	0.365			
Carman	0.093	0.054	0.057	-0.081	-0.096	-0.093	0.123	0.110	0.109	0.343	0.503	0.416	139	140	140
Monte Buey	0.067	0.060	0.054	-0.017	-0.031	-0.064	0.069	0.068	0.084	0.852	0.777	0.420	88	99	99
REMEDHUS	0.043	0.045	0.055	-0.034	-0.021	0.001	0.055	0.050	0.055	0.827	0.841	0.764	163	180	157
Valencia	0.029	0.032	0.055	-0.075	-0.021	0.036	0.080	0.038	0.066	0.400	0.392	0.343	87	88	88
HOBE	0.043	0.034	0.042	0.014	-0.018	-0.041	0.045	0.039	0.059	0.713	0.659	0.395	58	58	58
Yanco (03)	*0.067*	*0.062*	*0.059*	*-0.025*	*-0.016*	*-0.014*	*0.072*	*0.064*	*0.061*	*0.911*	*0.911*	*0.892*	*219*	*223*	*223*
Yanco (04)	*0.074*	*0.061*	*0.046*	*0.002*	*0.009*	*0.001*	*0.074*	*0.062*	*0.046*	*0.918*	*0.953*	*0.952*	*174*	*190*	*192*
Yanco (avg)	0.071	0.062	0.053	-0.012	-0.004	-0.007	0.073	0.063	0.054	0.915	0.932	0.922			
SMAP L2SMP_E Average (9 km)	0.047	0.041	0.052	-0.042	-0.029	-0.011	0.076	0.064	0.074	0.705	0.729	0.597			
SMAP L2SMP_E Average (33 km)	*0.047*	*0.039*	*0.049*	*-0.036*	*-0.027*	*-0.011*	*0.070*	*0.060*	*0.066*	*0.772*	*0.814*	*0.729*			

Table 8.13. SMAP L2SMP_E Version 1 Matched 33 km CVS Assessment for Descending (AM) Overpasses

CVS	ubRMSE (m^3/m^3)			Bias (m^3/m^3)			RMSE (m^3/m^3)			R			N
	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	
Walnut Gulch (35)	*0.021*	*0.024*	*0.038*	*-0.011*	*0.011*	*0.035*	*0.024*	*0.026*	*0.052*	*0.759*	*0.813*	*0.800*	*118*
Walnut Gulch (36)	*0.021*	*0.024*	*0.039*	*-0.022*	*0.006*	*0.035*	*0.030*	*0.024*	*0.053*	*0.798*	*0.807*	*0.782*	*86*
Walnut Gulch (37)	*0.021*	*0.024*	*0.038*	*-0.031*	*-0.006*	*0.022*	*0.037*	*0.024*	*0.044*	*0.790*	*0.812*	*0.796*	*108*
Walnut Gulch (38)	*0.021*	*0.023*	*0.038*	*-0.007*	*0.013*	*0.037*	*0.022*	*0.027*	*0.053*	*0.781*	*0.850*	*0.835*	*137*
Walnut Gulch (avg)	0.021	0.024	0.038	-0.018	0.006	0.032	0.028	0.025	0.051	0.782	0.821	0.803	
TxSON (02)	*0.033*	*0.032*	*0.041*	*-0.050*	*0.000*	*0.067*	*0.060*	*0.032*	*0.079*	*0.909*	*0.910*	*0.844*	*227*
TxSON (11)	*0.031*	*0.031*	*0.042*	*-0.066*	*-0.015*	*0.064*	*0.073*	*0.034*	*0.077*	*0.933*	*0.926*	*0.831*	*148*
TxSON (avg)	0.032	0.032	0.042	-0.058	-0.008	0.066	0.067	0.033	0.078	0.921	0.918	0.838	
Fort Cobb	0.032	0.028	0.045	-0.086	-0.056	-0.017	0.091	0.062	0.048	0.858	0.883	0.817	247
South Fork	0.062	0.054	0.054	-0.071	-0.062	-0.050	0.094	0.082	0.074	0.597	0.646	0.637	162
Kenaston	0.034	0.022	0.040	-0.064	-0.040	-0.001	0.072	0.046	0.040	0.808	0.854	0.515	145
HOBE	0.048	0.036	0.063	0.004	-0.009	-0.012	0.048	0.037	0.064	0.700	0.863	0.789	104
Yanco (03)	*0.054*	*0.048*	*0.051*	*-0.001*	*0.019*	*0.040*	*0.054*	*0.052*	*0.065*	*0.920*	*0.923*	*0.908*	*185*
Yanco (04)	*0.068*	*0.060*	*0.060*	*0.014*	*0.036*	*0.043*	*0.069*	*0.070*	*0.074*	*0.946*	*0.957*	*0.892*	*159*
Yanco (avg)	0.061	0.054	0.056	0.007	0.028	0.042	0.062	0.061	0.070	0.933	0.940	0.900	
SMAP Average Matched 33 km	0.041	0.036	0.048	-0.041	-0.020	0.008	0.066	0.049	0.061	0.800	0.846	0.757	

Table 8.14. SMAP L2SMP_E Matched 9 km CVS Assessment for Descending (AM) Overpasses

CVS	ubRMSE (m^3/m^3)			Bias (m^3/m^3)			RMSE (m^3/m^3)			R			N		
	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA
Walnut Gulch (35)	*0.022*	*0.026*	*0.042*	*-0.009*	*0.011*	*0.035*	*0.024*	*0.028*	*0.054*	*0.753*	*0.817*	*0.787*	*85*	*116*	*110*
Walnut Gulch (36)	*0.029*	*0.030*	*0.043*	*-0.033*	*-0.007*	*0.018*	*0.044*	*0.031*	*0.046*	*0.615*	*0.678*	*0.657*	*107*	*140*	*134*
Walnut Gulch (37)	*0.024*	*0.024*	*0.036*	*-0.010*	*0.015*	*0.043*	*0.026*	*0.029*	*0.056*	*0.739*	*0.798*	*0.791*	*91*	*107*	*103*
Walnut Gulch (38)	*0.023*	*0.022*	*0.035*	*-0.021*	*0.004*	*0.026*	*0.031*	*0.022*	*0.044*	*0.741*	*0.835*	*0.814*	*98*	*129*	*122*
Walnut Gulch (avg)	0.025	0.026	0.039	-0.018	0.006	0.031	0.031	0.028	0.050	0.712	0.782	0.762			
TxSON (02)	*0.024*	*0.023*	*0.038*	*-0.046*	*0.005*	*0.077*	*0.051*	*0.023*	*0.086*	*0.929*	*0.933*	*0.867*	*189*	*189*	*186*
TxSON (11)	*0.033*	*0.032*	*0.039*	*-0.049*	*0.004*	*0.082*	*0.059*	*0.032*	*0.090*	*0.943*	*0.940*	*0.875*	*177*	*177*	*176*
TxSON (avg)	0.029	0.028	0.039	-0.048	0.005	0.080	0.055	0.028	0.088	0.936	0.937	0.871			
Fort Cobb	0.029	0.025	0.037	-0.072	-0.040	0.002	0.078	0.047	0.037	0.887	0.915	0.870	226	228	228
South Fork	0.063	0.056	0.058	-0.086	-0.078	-0.065	0.107	0.095	0.087	0.594	0.637	0.604	166	169	169
Kenaston	0.033	0.029	0.051	-0.102	-0.078	-0.040	0.107	0.083	0.064	0.826	0.825	0.458	157	157	157
HOBE	0.044	0.034	0.051	0.016	-0.010	-0.028	0.047	0.035	0.058	0.742	0.692	0.346	60	60	60
Yanco (03)	*0.061*	*0.054*	*0.055*	*-0.022*	*-0.002*	*0.018*	*0.064*	*0.054*	*0.057*	*0.899*	*0.904*	*0.892*	*192*	*192*	*191*
Yanco (04)	*0.059*	*0.047*	*0.042*	*0.000*	*0.014*	*0.023*	*0.059*	*0.049*	*0.048*	*0.931*	*0.952*	*0.953*	*175*	*179*	*187*
Yanco (avg)	0.060	0.051	0.049	-0.011	0.006	0.021	0.062	0.052	0.053	0.915	0.928	0.923			
SMAP Average Matched 9 km	0.040	0.035	0.046	-0.046	-0.027	0.000	0.070	0.052	0.062	0.802	0.817	0.691			
SMAP Average Matched 33 km	0.041	0.036	0.048	-0.041	-0.020	0.008	0.066	0.049	0.061	0.800	0.846	0.757			

Table 8.15. SMAP L2SMP_E Version 1 Matched 33 and 9 km CVS Assessment for Ascending (PM) Overpasses

CVS	ubRMSE (m^3/m^3)			Bias (m^3/m^3)			RMSE (m^3/m^3)			R			N
	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	
Walnut Gulch (35)	*0.027*	*0.029*	*0.042*	*-0.031*	*-0.019*	*0.000*	*0.041*	*0.034*	*0.042*	*0.622*	*0.676*	*0.631*	*165*
Walnut Gulch (36)	*0.023*	*0.027*	*0.041*	*-0.045*	*-0.031*	*-0.015*	*0.051*	*0.042*	*0.043*	*0.652*	*0.684*	*0.651*	*130*
Walnut Gulch (37)	*0.027*	*0.030*	*0.044*	*-0.052*	*-0.038*	*-0.021*	*0.058*	*0.049*	*0.049*	*0.664*	*0.690*	*0.644*	*154*
Walnut Gulch (38)	*0.026*	*0.029*	*0.043*	*-0.024*	*-0.012*	*0.003*	*0.036*	*0.031*	*0.043*	*0.662*	*0.696*	*0.650*	*165*
Walnut Gulch (avg)	0.026	0.029	0.043	-0.038	-0.025	-0.008	0.047	0.039	0.044	0.650	0.687	0.644	
TxSON (02)	*0.028*	*0.028*	*0.041*	*-0.050*	*-0.010*	*0.038*	*0.057*	*0.030*	*0.056*	*0.907*	*0.905*	*0.860*	*224*
TxSON (11)	*0.026*	*0.026*	*0.036*	*-0.059*	*-0.018*	*0.033*	*0.064*	*0.032*	*0.049*	*0.925*	*0.921*	*0.870*	*166*
TxSON (avg)	0.027	0.027	0.039	-0.055	-0.014	0.036	0.061	0.031	0.053	0.916	0.913	0.865	
Fort Cobb	0.039	0.035	0.046	-0.087	-0.069	-0.046	0.096	0.077	0.065	0.811	0.846	0.778	251
South Fork	0.053	0.045	0.061	-0.084	-0.087	-0.074	0.099	0.098	0.095	0.710	0.764	0.668	171
Kenaston	0.033	0.027	0.052	-0.065	-0.051	-0.024	0.073	0.057	0.057	0.833	0.828	0.515	186
HOBE	0.046	0.042	0.069	0.003	-0.013	-0.019	0.046	0.044	0.071	0.711	0.844	0.811	106
Yanco (03)	*0.060*	*0.056*	*0.054*	*-0.006*	*0.004*	*0.008*	*0.061*	*0.056*	*0.055*	*0.935*	*0.934*	*0.916*	*216*
Yanco (04)	*0.081*	*0.070*	*0.059*	*0.027*	*0.033*	*0.024*	*0.085*	*0.078*	*0.063*	*0.955*	*0.962*	*0.913*	*186*
Yanco (avg)	0.071	0.063	0.057	0.011	0.019	0.016	0.073	0.067	0.059	0.945	0.948	0.915	
SMAP Average Matched 33 km	0.042	0.038	0.052	-0.045	-0.034	-0.017	0.071	0.059	0.063	0.797	0.833	0.742	

Table 8.16. SMAP L2SMP_E Matched 9 km CVS Assessment for Ascending (PM) Overpasses

CVS	ubRMSE (m^3/m^3)			Bias (m^3/m^3)			RMSE (m^3/m^3)			R			N		
	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA
Walnut Gulch (35)	*0.031*	*0.035*	*0.050*	*-0.022*	*-0.009*	*0.013*	*0.038*	*0.036*	*0.051*	*0.590*	*0.639*	*0.620*	*98*	*142*	*129*
Walnut Gulch (36)	*0.037*	*0.038*	*0.050*	*-0.055*	*-0.042*	*-0.024*	*0.066*	*0.057*	*0.055*	*0.436*	*0.500*	*0.478*	*118*	*199*	*176*
Walnut Gulch (37)	*0.030*	*0.029*	*0.042*	*-0.031*	*-0.013*	*0.003*	*0.043*	*0.032*	*0.042*	*0.626*	*0.711*	*0.666*	*112*	*185*	*162*
Walnut Gulch (38)	*0.032*	*0.035*	*0.048*	*-0.036*	*-0.022*	*-0.005*	*0.048*	*0.041*	*0.048*	*0.527*	*0.588*	*0.558*	*100*	*141*	*131*
Walnut Gulch (avg)	0.033	0.034	0.048	-0.036	-0.022	-0.003	0.049	0.042	0.049	0.545	0.610	0.581			
TxSON (02)	*0.024*	*0.025*	*0.042*	*-0.040*	*0.001*	*0.052*	*0.046*	*0.025*	*0.067*	*0.912*	*0.908*	*0.855*	*197*	*197*	*197*
TxSON (11)	*0.026*	*0.025*	*0.032*	*-0.043*	*-0.002*	*0.048*	*0.050*	*0.025*	*0.057*	*0.937*	*0.936*	*0.900*	*189*	*189*	*188*
TxSON (avg)	0.025	0.025	0.037	-0.042	-0.001	0.050	0.048	0.025	0.062	0.925	0.922	0.878			
Fort Cobb	0.031	0.027	0.038	-0.072	-0.051	-0.027	0.079	0.058	0.046	0.860	0.893	0.841	223	232	229
South Fork	0.054	0.051	0.068	-0.098	-0.102	-0.090	0.112	0.114	0.113	0.698	0.703	0.574	181	180	180
Kenaston	0.033	0.031	0.058	-0.103	-0.089	-0.062	0.108	0.094	0.085	0.822	0.798	0.488	209	209	209
HOBE	0.043	0.034	0.042	0.014	-0.018	-0.041	0.045	0.039	0.059	0.713	0.659	0.395	58	58	58
Yanco (03)	*0.067*	*0.062*	*0.059*	*-0.025*	*-0.016*	*-0.014*	*0.072*	*0.064*	*0.061*	*0.911*	*0.911*	*0.892*	*219*	*223*	*223*
Yanco (04)	*0.074*	*0.061*	*0.046*	*0.002*	*0.009*	*0.001*	*0.074*	*0.062*	*0.046*	*0.918*	*0.953*	*0.952*	*174*	*190*	*192*
Yanco (avg)	0.071	0.062	0.053	-0.012	-0.004	-0.007	0.073	0.063	0.054	0.915	0.932	0.922			
SMAP Average Matched 9 km	0.041	0.038	0.049	-0.050	-0.041	-0.026	0.073	0.062	0.067	0.782	0.788	0.668			
SMAP Average Matched 33 km	0.042	0.038	0.052	-0.045	-0.034	-0.017	0.071	0.059	0.063	0.797	0.833	0.742			

8.5 Summary

Three alternative L2SMP retrieval algorithms were evaluated using three methodologies in preparation for this release. The algorithms included the Single Channel Algorithm–H Polarization (SCA-H), Single Channel Algorithm–V Polarization (SCA-V), and Dual Channel Algorithm (DCA). Assessment methodologies were Core Validation Sites (CVS), sparse networks, and intercomparisons with SMOS.

For the current validated release (Version 4) of L2SMP, the goal was to update the previous assessment based primarily on CVS comparisons using metrics and time series plots. This assessment was supported by global assessments using sparse networks and SMOS intercomparisons. These analyses indicated that the SCA-V had better unbiased root mean square error and correlation than the SCA-H or DCA. Differences were relatively small, generally third decimal level. Based on the results, it is recommended that the SCA-V be continued as the operational baseline algorithm for this release. The overall ubRMSE of the SCA-V is 0.037 m^3/m^3, which is better than the mission requirement.

Sparse network comparisons are more difficult to interpret due to upscaling but provide many more locations than the CVS. The analyses conducted here supported the conclusion reached in the CVS assessment, and contributed to reaching Stage 3 validation through Triple Colocation analyses of uncertainties. The sparse network data also allowed the evaluation of performance based on land cover.

SMAP CVS and sparse network retrievals were compared to SMOS. These analyses supported the conclusions of prior assessments that the L2SMP currently performs better.

The analyses described above were repeated for the new L2SMP PM products. Similar results with a small degradation of performance, primarily increased underestimation bias, were obtained.

The new L2SMP_E Version 1 product was assessed using CVS chosen specifically to exploit the new posting (9 km) and contributing domain (33 km) of the product. Results were essentially the same as those obtained in the L2SMP Version 4 analyses, which suggests that the new product is as reliable as L2SMP. Even though the period of record is the same, the L2SMP_E has not been subjected to broad scrutiny and therefore it should be considered to be at CEOS Stage 2.

Finally, recognizing that it is common practice for users to apply products posted at a particular grid size (here 9 km) as an estimate of the soil moisture for that cell rather than the contributing domain(33 km), the impact of this assumption was assessed. For the subset of CVS that satisfied established criteria, the impact was very small.

9 OUTLOOK AND FUTURE PLANS

Satellite passive microwave retrieval of soil moisture has been the subject of intensive study and assessment for the past several decades. Over this time there have been improvements in the microwave instruments used, primarily in the availability of L-band sensors on orbit. However, sensor resolution has remained roughly the same over this period, which is actually an achievement considering the increase in sensor wavelength from X band to C band to L band over the years. With spatial resolution in the 25-50 km range, there will always be heterogeneity within the satellite footprint that will influence the accuracy of the retrieved soil moisture as well as its validation. Precipitation types and patterns are one of the biggest contributors to this heterogeneity. As a result, one should not expect that the validation metric ubRMSE will ever approach zero except in very homogeneous domains. In contrast, bias tends to be indicative of a systematic error, possibly related to algorithm parameterization and model structure. High quality data are needed to discover and address these systematic errors. Some issues that should be considered during the remaining SMAP primary mission include:

- *Moving toward a Stage 3 validated product for L2SMP_E.* Stage 3 validation is characterized by a more rigorous analysis and longer time periods: "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."

- *Increasing the number of CVS.* There are several candidate calibration/validation sites that may yet qualify as CVS. Several will require additional time for further development (Millbrook, Kuwait, Bell Ville). In addition, with the assumption of a 9 km contributing domain, it may be easier to expand to more sites.

- *Evaluate the impacts of algorithm structure and components on retrieval.* There are some aspects of soil moisture retrieval algorithms that are used because they facilitate operational soil moisture retrieval. One of these simplifying aspects is the use of the Fresnel equations that specify that conditions in the microwave contributing depth are uniform. While there is ample evidence that this is true in most cases, it should be recognized that this assumption is a potential source of error – some effort should be made to evaluate when and where it limits soil moisture retrieval accuracy. Another assumption is that a single dielectric mixing model applies under all conditions globally. Any of the commonly-used dielectric models is highly dependent on the robustness of the data set used in its development. The impact of this assumption on retrieval error needs further evaluation. Another consideration in the current DCA is the assumption of equality of the vegetation parameters for the H and V polarizations. This assumption does simplify retrieval but it is not valid for all categories of vegetation.

- *Optimization of algorithm parameters.* The current release retains the same set of algorithm parameters used previously in SMAP Data Versions 2 and 3 (beta and validated release). Because the current algorithm parameters do not vary in time, they are likely to be inadequate for producing accurate retrieval results in agricultural areas where there is often high temporal variability of vegetation amount, land cover heterogeneity, and terrain roughness due to tillage. Initial attempts with spatio-temporal optimization of algorithm parameters have resulted in modest gains in retrieval performance at CVS. Full implementation of the optimization results would require more rigorous validation involving sparse network comparison in addition to CVS comparison, as well as a significant redesign of the current SMAP operational processing codes. It is anticipated that the benefits of using optimal coefficients will be demonstrated in future releases of the L2SMP product, along with other improvements.

- *Possible subdivision of crop land cover class into distinct crop subclasses.* Another source of error is SMAP's use of a single IGBP land cover class to cover the great variety of global crops. One area of future work will examine the possibility of subdividing the single crop class into a number of distinct subclasses (e.g., corn, soybeans, wheat, rice) with appropriate parameterization which would better represent the main global crop structural categories. Due to the latency problem in acquiring up-to-date crop maps, this issue is not likely to be addressed until the final bulk reprocessing of SMAP data.

- *Incorporating field campaign results into algorithm assessments and improvements.* Several SMAP field campaigns were conducted in 2015 and 2016. Results from these field campaigns will be used in future assessments and algorithm improvements. There are many steps involved in this process: acquisition, quality control, pre-processing, integration of ground observations and precipitation, aircraft soil moisture estimation, model-based mapping, and finally SMAP product comparisons. It is expected that the results of the Iowa and Manitoba campaigns in 2016 will be of great value in resolving the significant error in soil moisture retrievals at these CVS (South Fork and Carmen).

- *Implementing model-based products as an assessment and algorithm improvement tool*. Model intercomparisons are one of the methodologies proposed for SMAP L2SMP. There are several readily available products that include the GMAO Nature Run, ECMWF, NCEP, and a Canadian Met Office product. One problem faced when using some of these model products is the depth of their surface layer, which is typically thicker than the 5 cm layer assumed by SMAP to apply to the surface satellite retrievals. Preliminary assessments suggest that model responses may be dampened relative to satellite estimates. Some effort is required to further evaluate the use of model products in assessing and validating SMAP products. The greatest contribution that the model-based assessments might make to validation is providing a basis for upscaling several candidate validation sites that are interesting but lack enough points or have an unbalanced distribution of points to qualify as a core site. These potential sites include Tabasco, St. Joseph's, Tonzi Ranch, Valencia, Tereno, Kuwait, Benin, and Ngari.

- *Precipitation flag improvement.* Satellite observations made shortly after (or during) a rain event can be difficult to interpret and use in validation. A wet surface will dominate what the radiometer observes, which may be much wetter than at the 5 cm depth of an *in situ* sensor (due to the lag time for the wetting front to infiltrate down to the *in situ* sensor depth). Smaller precipitation events may be more problematic than larger events that wet a thicker surface layer. The divergence in these satellite observations will also be dependent on antecedent conditions (i.e., rain on a very dry soil). At the present time the GMAO model precipitation forecast for the three hours preceding a SMAP overpass at a given site is used. There is evidence that this approach is not adequate and that a longer time window might be necessary. However, achieving a longer time window for the SMAP precipitation flag will require additional/alternative processing of the GMAO data. Additionally, a comparison between using GMAO forecast model data and the GPM blended satellite data for the SMAP precipitation flag should also be done.

- *Improvement of retrievals over forests.* Dense forests (where VWC > 5 kg/m^2) typically exceed the currently accepted threshold for accurate soil moisture retrieval. SMAP provides a flagged retrieval over forests, and the spatial extent of these flagged areas is quite large. At this point there is no supporting validation of the L2SMP soil moisture retrieved for forest areas, and as discussed above, the SMAP forest retrievals are quite different from SMOS. While extending accurate soil moisture retrievals to forests would likely be very beneficial to a variety of end users of the data, the SMAP team has little confidence in the accuracy and the appropriateness of the current baseline retrieval approach for soil moisture retrieval in forests. Future efforts to improve these retrievals should include both a careful evaluation of alternative algorithms and improving validation resources through a combination of CVS, temporary networks, and field campaigns.

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