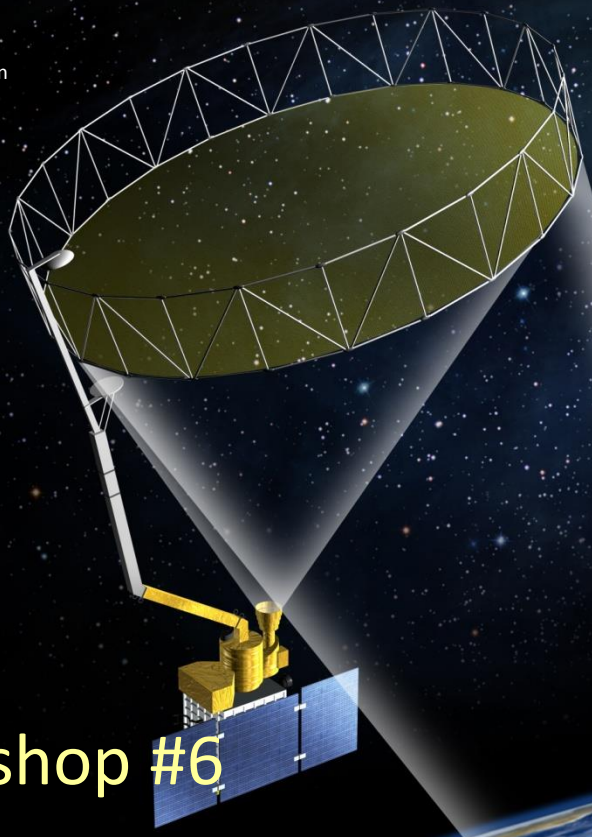
National Aeronautics and Space Administration



Soil Moisture Active Passive Mission

SMAP

L2SMP Algorithm Team Report

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Cal/Val Workshop #6

Sep 1-3, 2015

Columbia, MD

Outline

1. Product Overview & Development

1. Processing Flowchart & Algorithm Options

1. Major Post-launch Algorithm Improvements

1. Cal/Val Methodologies & Stages

1. Beta-Level Release & Performance Assessment

1. Outlook Towards Validated Release

1. Conclusion

Product Overview & Development

- **Product Attributes**
  - Radiometer-only soil moisture retrieval in the top 5 cm of soil
  - Global coverage in 2-3 days
  - Posted on 36 km global cylindrical EASE Grid 2.0 projection
  - 6:00 am descending half orbits (6:00 pm under evaluation)

- **Post-launch Development**
  - SW worked almost immediately upon receiving ‘first light’
  - In routine production and Cal/Val evaluation since Mar 31, 2015
  - Early beta release by mid-Sep 2015

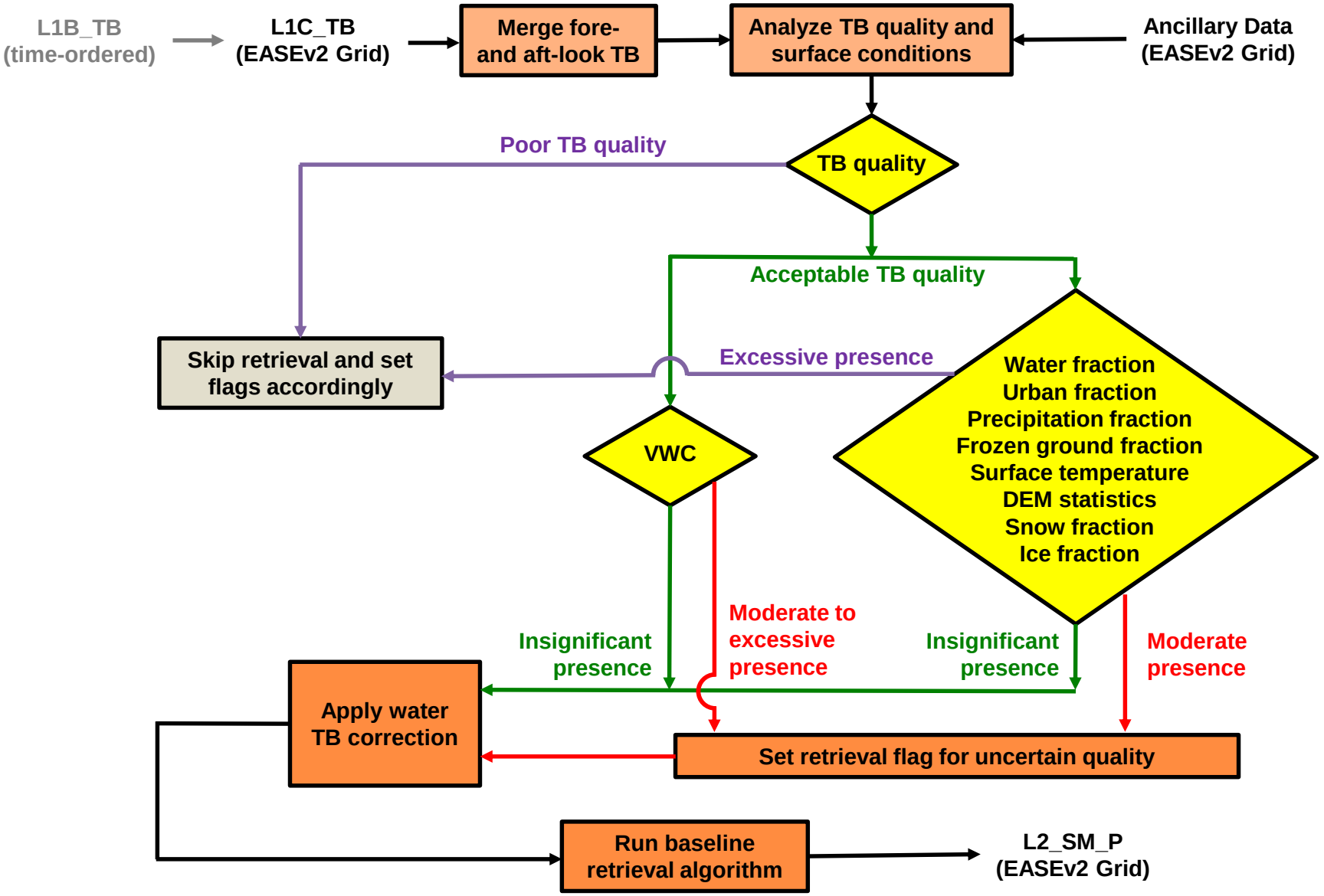
- **Product Contents**
  - Retrieved soil moisture (m^3/m^3) using baseline and option algorithms
  - T_B, dynamic ancillary data, quality flags, etc. (next page)

Product Overview & Development

Output fields fall into 4 categories: (1) Time/Geolocation, (2) Instrument, (3) Retrieval, and (4) Ancillary Data

Time/Geolocation	Instrument	Retrieval	Ancillary Data
Time in J2000 seconds	Water-corrected TBH	Soil moisture (SCA-H)	Surface flag
Time in ASCII text	Water-corrected TBV	Soil moisture (SCA-V)	VWC
EASEv2 row index	TB3	Soil moisture (DCA)	TSOIL
EASEv2 column index	TB4	Soil moisture (MPRA)	Static water fraction
EASEv2 grid center latitude	TBH quality flag	Soil moisture (E-DCA)	Radar water fraction
EASEv2 grid center longitude	TBV quality flag	Retrieval quality flag (SCA-H)	Radar F/T fraction
EASEv2 grid centroid latitude	TB3 quality flag	Retrieval quality flag (SCA-V)	Top 3 IGBP
EASEv2 grid centroid longitude	TB4 quality flag	Retrieval quality flag (DCA)	Top 3 IGBP fraction
Incidence angle		Retrieval quality flag (MPRA)	
		Retrieval quality flag (E-DCA)	
		tau (SCA-H) from NDVI	
		tau (SCA-V) from NDVI	
		tau (DCA)	
		tau (MPRA)	
		tau (E-DCA)	

Processing Flowchart



Algorithm Options

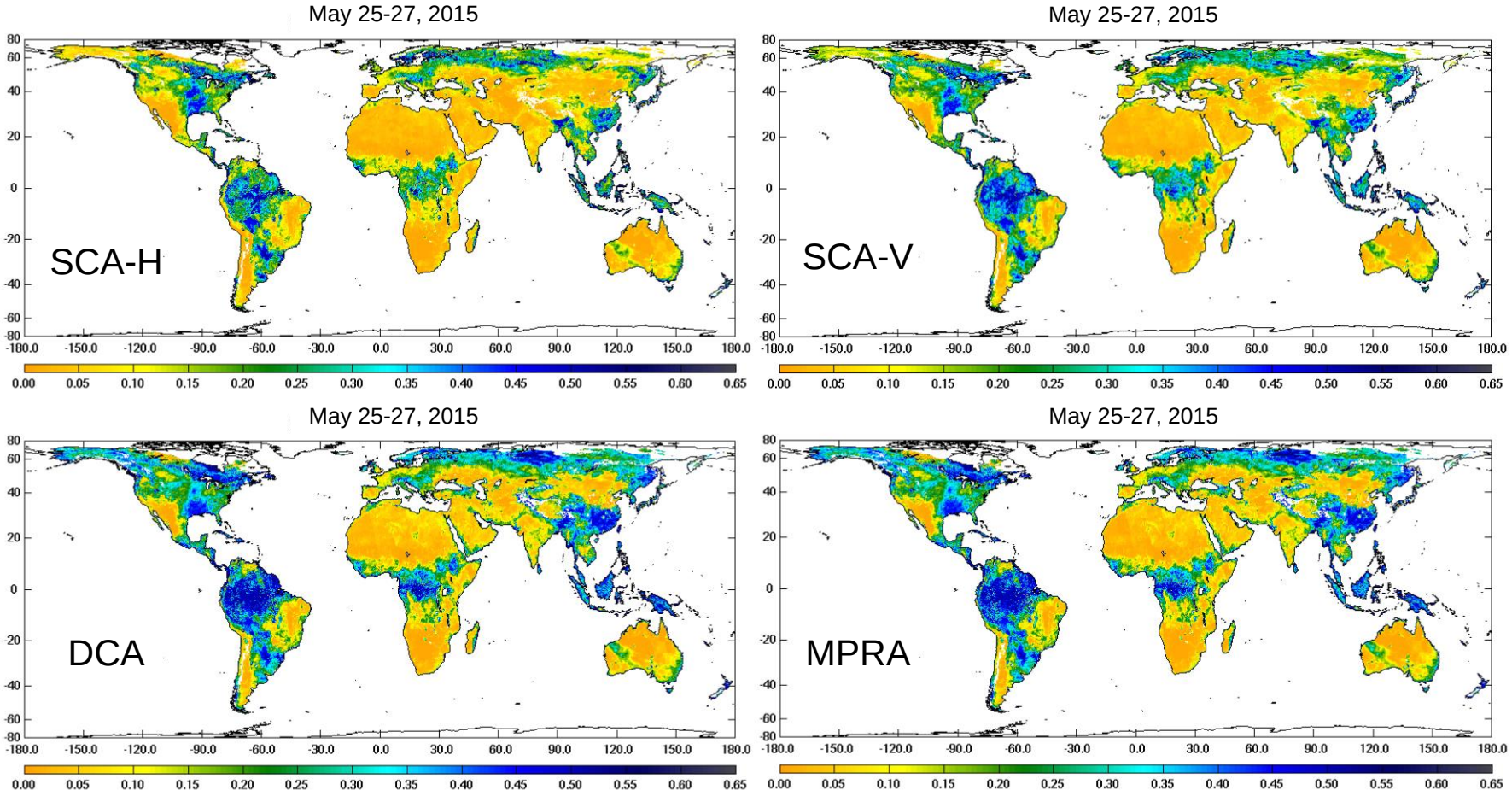
Algorithms	Status	Input Fields	Output Field(s)
Single Channel Algorithm (SCA-H)	Baseline (pre-launch)	TBH, soil temperature, soil texture, NDVI	soil moisture
Single Channel Algorithm (SCA-V)	Baseline (beta-release)	TBV, soil temperature, soil texture, NDVI	soil moisture
Dual Channel Algorithm (DCA)	Option	TBH, TBV, soil temperature, soil texture	soil moisture, tau
Microwave Polarization Ratio Algorithm (MPRA)	Option	TBH, TBV, soil temperature, soil texture	soil moisture, tau
Extended Dual Channel Algorithm (E-DCA)	Option	TBH, TBV, soil temperature, soil texture	soil moisture, tau

Single Channel Algorithms (SCA-H or SCA-V): Use T_{BH} or T_{BV} to retrieve soil moisture after correction for surface temperature, vegetation water content, and surface roughness using ancillary data

Dual Channel Algorithms (DCA or E-DCA): Use T_{BH} and T_{BV} to retrieve soil moisture and VOD by iteratively minimizing a cost function that computes the difference between computed and observed T_B's

Microwave Polarization Ratio Algorithm (MPRA): Use a microwave polarization difference index and emissivity to retrieve soil moisture and VOD based on LPRM formulation; τ_c and ω are assumed to be the same for H and V polarizations

Algorithm Options



All algorithms show similar and expected global geographical patterns of soil moisture; quantitative differences being investigated in ongoing Cal/Val

Major Post-launch Algorithm Improvements

- **Improved T_{eff} formulation**
  - Pre-launch: T_{eff} = ½ (TSURF + TSOIL1) resulted in several problems:
    - Cold bias compared with *in situ* data from CVS and sparse network
    - Dry bias or non-convergence in soil moisture retrieval
  - Post-launch: T_{eff} = TSOIL2 + (TSOIL1 – TSOIL2) × 0.246 (based on Choudhury)
    - Better agreement with *in situ* observations from CVS and sparse network
    - Smaller dry bias in soil moisture retrieval (more work still needed)
  - Additional GEOS-5 temperature data brought in to support new T_{eff} formulation

- **Improved flagging of retrieval quality**
  - Surface conditions, centroid distance, revised screening thresholds, etc

- **Beta-release baseline algorithm**
  - Single Channel Algorithm (V-pol)

Cal/Val Methodologies

The SMAP Science Team and Cal/Val Working Group identified a number of methodologies that would be used for L2-L4 product assessment:

- **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

Cal/Val Stages

On CEOS defintion of Cal/Val maturity level, the L2SMP team has completed Stage 1 and is moving towards Stage 2.

CEOS Definition of Cal/Val Maturity Levels	Methodologies	Team Progress
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.	Core validation sites, Field Campaigns	
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.	Sparse Networks, Satellite and Model Products	
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.		

Beta-Level Release

Given the observed preliminary performance of L2SMP, the project decided to pursue an early beta-level release (around mid-Sept) of the product for two purposes:

1. Enable access to larger science and application communities
2. Help users get familiar with L2SMP's data before its validated release in 2016

The evidences of the observed preliminary performance were presented in the Beta-Level L2/3_SM_P Assessement Report (JPL D-93981):

Soil Moisture Active Passive (SMAP) Project

Calibration and Validation for the L2/3_SM_P

Beta-Level Data Products

Beta-Level Performance Assessment

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) product specifically for the beta release. The SMAP Level 3 Soil Moisture Passive (L3SMP) product is simply a daily composite of the L2SMP half-orbit files. Hence, analysis and assessment of the L2SMP product can be considered to cover the L3SMP product also.

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 inter-comparison with products from ESA's Soil Moisture Ocean Salinity (SMOS) mission. These analyses meet the criteria established by the Committee on Earth Observing Satellites (CEOS) Stage 1 validation, which supports beta release of the data based on a limited set of core validation sites. The sparse network and SMOS analyses address Stage 2 by expanding to regional and global assessment.

Preliminary analyses showed that a few refinements were required in the passive soil moisture retrieval algorithms. One was related to the physical temperature used for normalizing brightness temperature and the other was the application of the precipitation flag. Both of these modifications involved the ancillary GMAO (GSFC's Global Modeling and Assimilation Office) model forecast data.

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 the beta release assessment.

The primary assessment methodology was based on CVS comparisons using metrics and time series plots. These analyses indicated that the SCA-V had better unbiased root mean square errors (ubRMSE), bias, and correlation R than SCA-H, and SCA-H had better ubRMSE and correlation R than DCA. DCA had the lowest bias of all the algorithms (essentially zero bias). The differences in performance metrics between the three algorithms were relatively small (generally to the third decimal place). Based upon these results, it is recommended that the SCA-V be adopted as the baseline algorithm for the beta release. The overall ubRMSE of the SCA-V is 0.041 m^3/m^3, which is approximately the mission requirement. [Note that the documented mission accuracy requirement is in units of cm^3/cm^3, which is mathematically identical to m^3/m^3.]

Comparisons with sparse network *in situ* data are subject to upscaling issues and were not used as a primary methodology for performance assessment. However, the results from over 300 sparse network sites mirrored the CVS results. Intercomparisons with SMOS retrievals serve as a means of assessing global performance, considering that SMOS provides a mature product. SMOS products were first assessed against data from the CVS, which showed similar levels of performance to SMAP. Global inter-comparisons of SMOS to SMAP retrievals showed good agreement over most land cover types but indicated significant differences over forest covers.

This report notes several limitations in the beta-release calibration which will be addressed in the coming year prior to release of the validated data. These issues include optimization of algorithm parameters, performance over very dense vegetation, and upscaling effects. In addition, the methodologies will expand prior to validated data release to include nearly double the number of CVS, model-based inter-comparisons, and the results of several intensive field experiments. Despite these remaining areas, the beta-release L2SMP product is of sufficient level of maturity and quality that it can be approved for distribution to and used by the larger science and application communities. This beta release also presents an opportunity to enable users to gain familiarity with the parameters and data formats of the product prior to full validation.

"… the beta-release L2SMP product is of sufficient level of maturity and quality that it can be approved for distribution to and used by the larger science and application communities." (p.3, Assessment Report)

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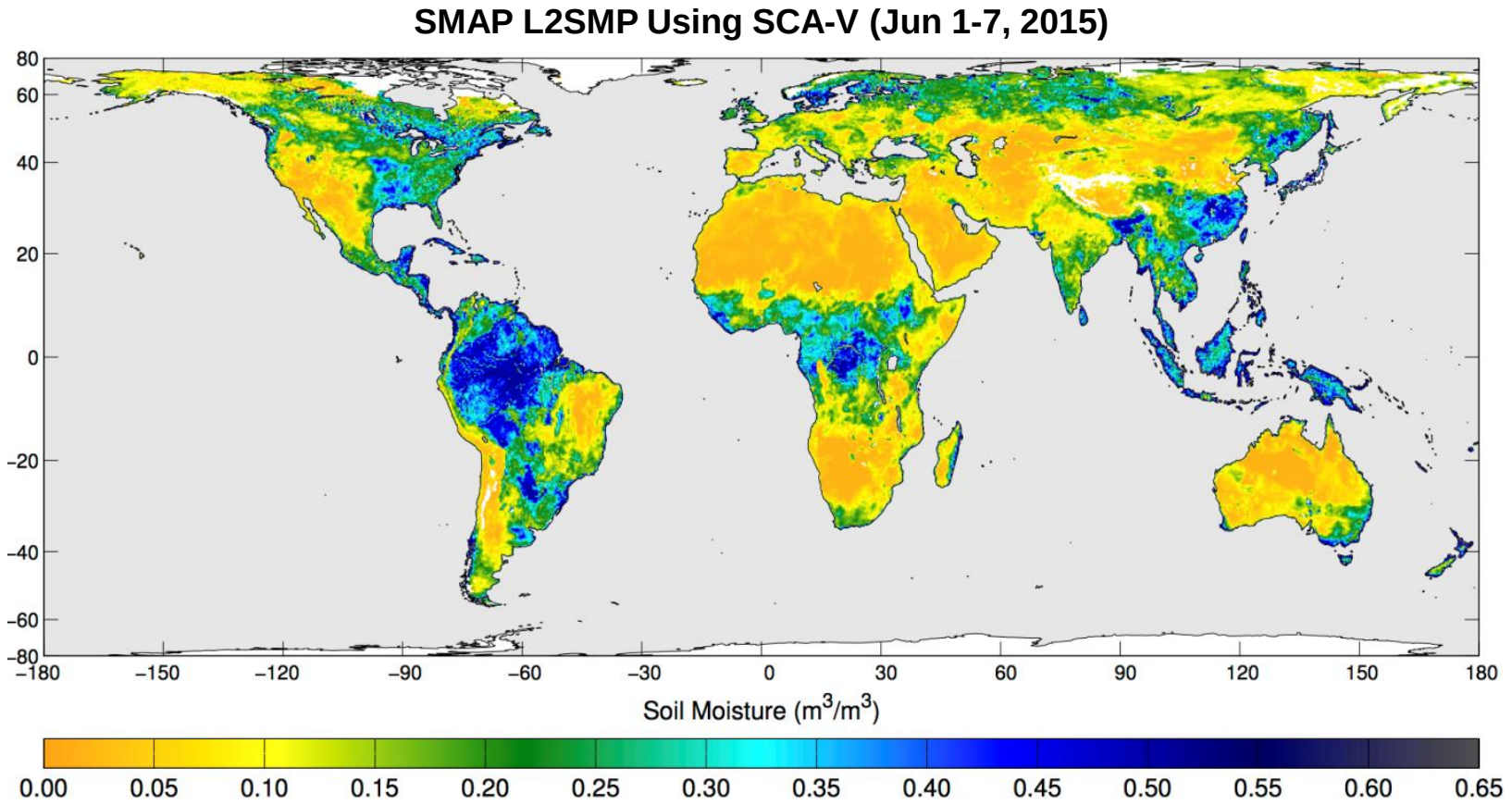
Beta-Level Performance Assessment

Global Pattern



"*… The regions that are expected to be very dry (i.e., the Sahara desert) and wet (i.e., the Amazon Basin) reflect the expected levels of retrieved soil moisture.*" (p.15, Assessment Report)

Beta-Level Performance Assessment

Regional Pattern

3 Killed in Floods After 300 mm of Rain in New South Wales, Australia

21 April 2015

Storms across the Sydney Metropolitan, Central and Mid North Coast, Hunter and Illawarra areas of New South Wales, Australia have brought widespread destruction and raging floods.

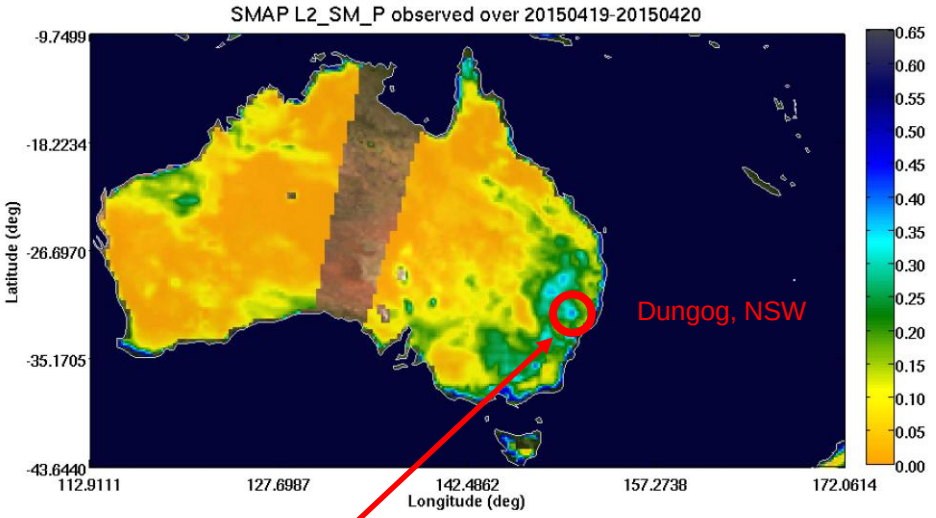
With strong winds of up to 100 kmh, the storms downed trees and left as many as 200,000 homes without power.

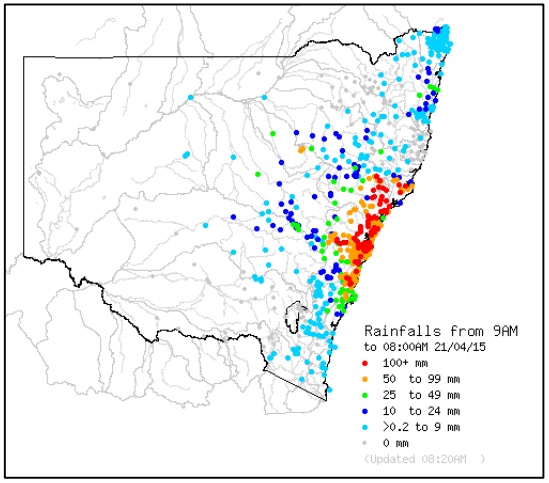
The storms also dumped over 300 mm of rain in some areas in a short period, resulting in raging flash floods across Sydney, Newcastle, Hunter Valley and surrounding areas.

NSW Premier Mike Baird is asking people to be patient as emergency crews deal with life-threatening situations. He also urged people to start to head home from work, with weather conditions expected to worsen.

One of the worst affected towns is Dungog, where at least 3 people are thought to have died, with further reports of another person still missing. Australia Bureau of Meteorology say that 312 mm of rain has fallen in Dungog in the last 24 hours.

Source here.





Beta-Level Performance Assessment

Core/Candidate Validation Sites

Site Name	Site PI	Area	Climate Regime	IGBP Land Cover
Walnut Gulch*	M. Cosh	USA (Arizona)	Arid	Shrub open
Reynolds Creek**	M. Cosh	USA (Idaho)	Arid	Grasslands
Fort Cobb*	M. Cosh	USA (Oklahoma)	Temperate	Grasslands
Little Washita*	M. Cosh	USA (Oklahoma)	Temperate	Grasslands
South Fork*	M. Cosh	USA (Iowa)	Cold	Croplands
Little River*	M. Cosh	USA (Georgia)	Temperate	Cropland/natural mosaic
TxSON*	T. Caldwell	USA (Texas)	Temperate	Grasslands
Millbrook	M. Temimi	USA (New York)	Cold	Deciduous broadleaf
Kenaston*	A. Berg	Canada	Cold	Croplands
Carman***	H. McNairn	Canada	Cold	Croplands
Monte Buey*	M. Thibeault	Argentina	Arid	Croplands
Bell Ville	M. Thibeault	Argentina	Arid	Croplands
REMEDHUS*	J. Martinez	Spain	Temperate	Croplands
Twente	Z. Su	Holland	Cold	Cropland/natural mosaic
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	JAXA	Mongolia	Cold	Grasslands
Yanco*	J. Walker	Australia	Arid	Croplands
Kyeamba*	J. Walker	Australia	Temperate	Croplands
*=CVS used in assessment, **=Reynolds Creek, the length of record was too short due to snow cover, and ***=Carman was removed by a water body flag associated with Lake Manitoba.				

The status of candidate validation sites will be periodically reviewed to determine if they should be classified as CVS. A total of 11 CVS were used in this assessment.

Beta-Level Performance Assessment

Core Validation Sites

CVS provide the primary means to assess L2SMP's performance in Stage 1 validation. Together these sites provide:

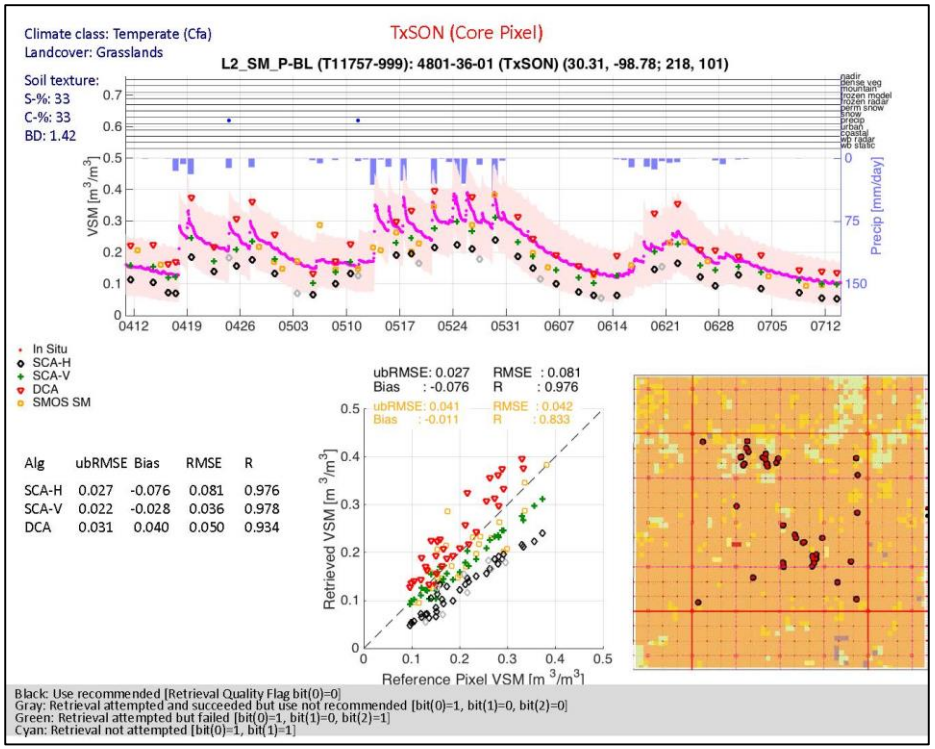
- Ground-based *in situ* observations that have been verified as providing a spatial average of soil moisture at 36 km scale
- Error estimates and a basis for modifying algorithms and/or parameters
- Representative metrics over diverse surface and land cover conditions

The Validation Grid (VG) processing was applied to L2SMP for more accurate alignment between observation and inversion domains

Beta-Level Performance Assessment

Core Validation Sites

Example 1: L2SMP and *in situ* data comparison at TxSON, TX

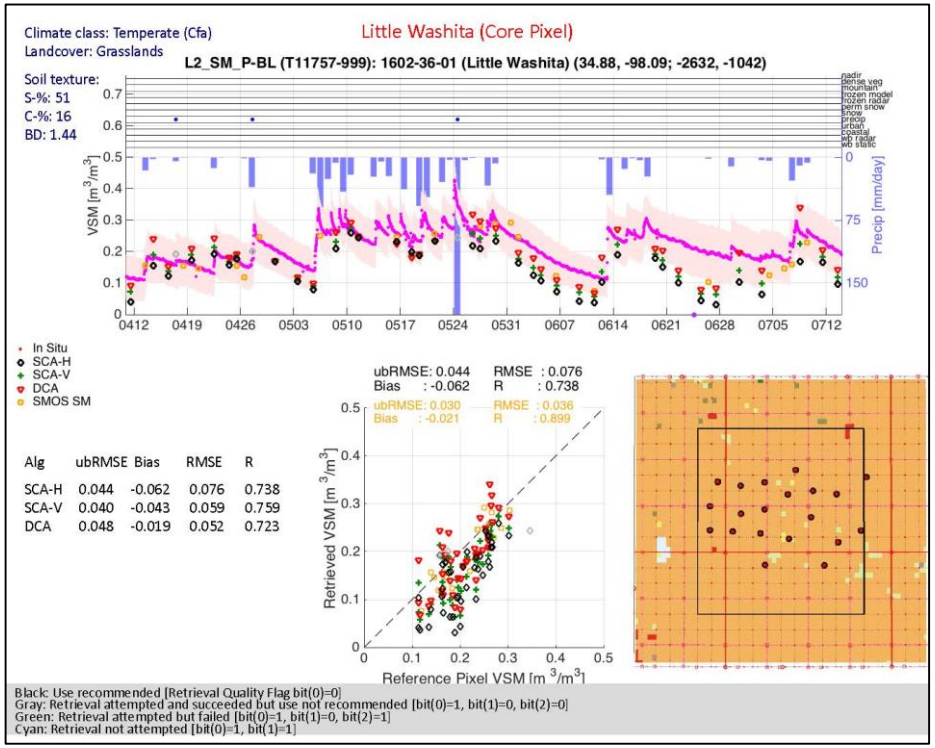


"*The outstanding feature of this site is the high correlation, over 0.9, achieved for all options. Both SMOS and SCA-V have similar patterns.*" (p.27, Assessment Report)

Beta-Level Performance Assessment

Core Validation Sites

Example 2: L2SMP and *in situ* data comparison at Little Washita, OK

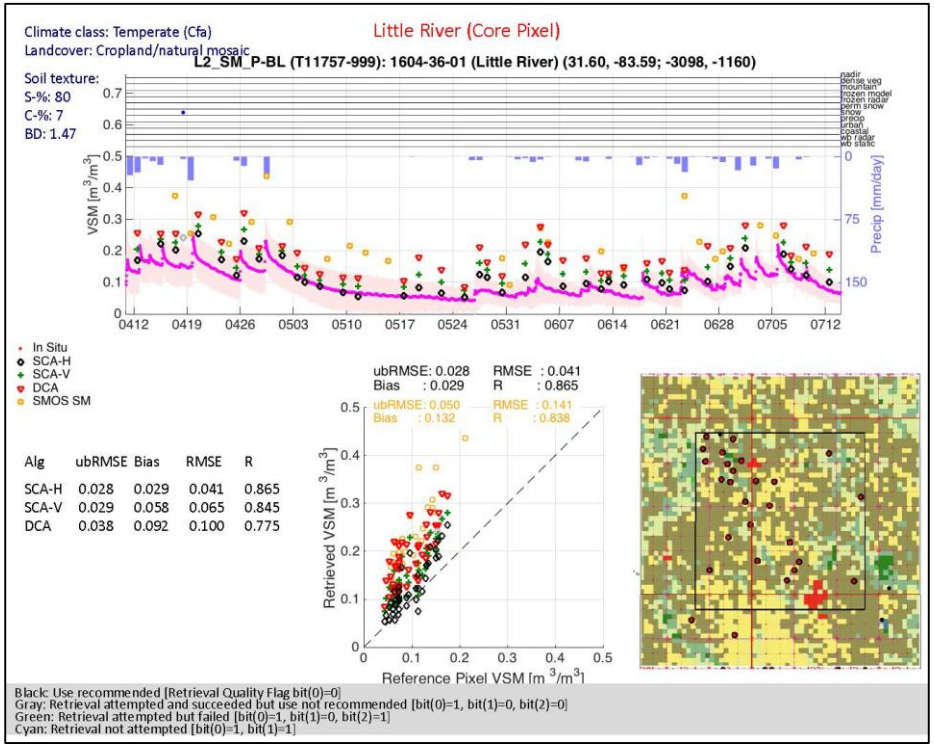


"The use of the DCA, as applied in SMAP, offers only a small improvement beyond the SCA-V. This suggests that the SMAP vegetation climatology approach is working in this region and time period." (p.26, Assessment Report)

Beta-Level Performance Assessment

Core Validation Sites

Example 3: L2SMP and *in situ* data comparison at Little River, GA



"Regardless of the ubRMSE and bias, all algorithms have high correlations. The results for Little River illustrate that there may be inherent performance limitations in some algorithms under specific conditions." (p.26, Assessment Report)

Beta-Level Performance Assessment

Core Validation Sites

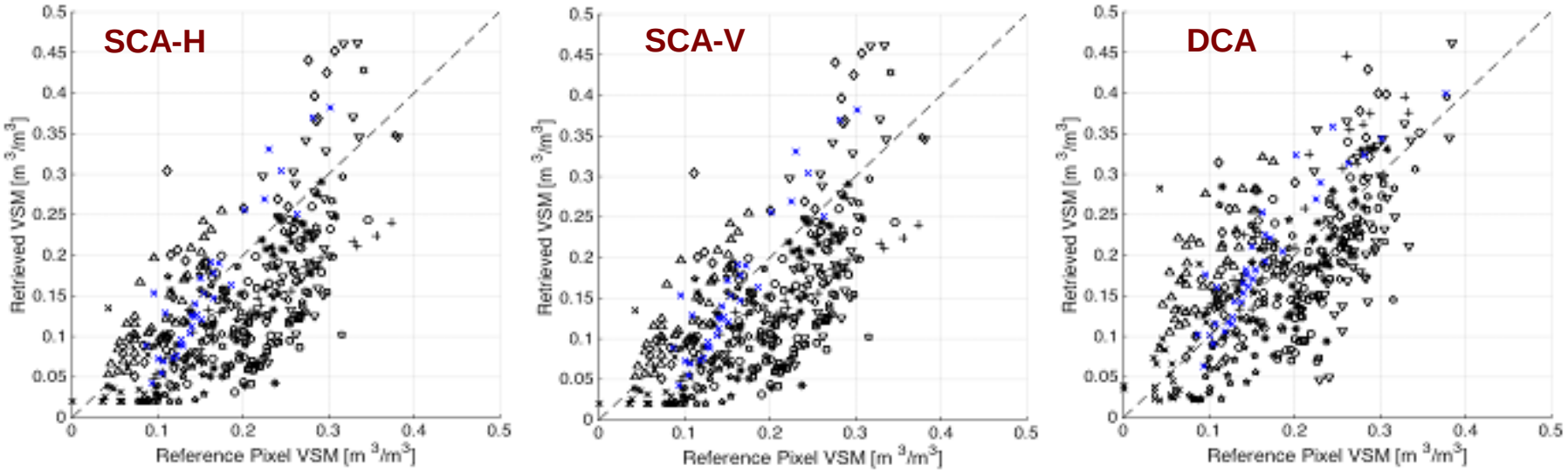
L2SMP Beta-Level CVS Assessment

	ubRMSE (m^3/m^3)			Bias (m^3/m^3)			RMSE (m^3/m^3)			R		
Sites	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA
Walnut Gulch	0.036	0.036	0.053	-0.025	-0.001	0.018	0.044	0.036	0.057	0.183	0.403	0.415
TxSON	0.027	0.022	0.031	-0.076	-0.028	0.040	0.081	0.036	0.050	0.976	0.978	0.934
Fort Cobb	0.046	0.042	0.051	-0.058	-0.043	-0.026	0.074	0.061	0.057	0.733	0.736	0.654
Little Washita	0.044	0.040	0.048	-0.062	-0.043	-0.019	0.076	0.059	0.052	0.738	0.759	0.723
South Fork	0.082	0.079	0.072	-0.055	-0.051	-0.058	0.099	0.095	0.093	0.693	0.718	0.532
Little River	0.028	0.029	0.038	0.029	0.058	0.092	0.041	0.065	0.100	0.865	0.845	0.775
Kenaston	0.022	0.021	0.035	-0.134	-0.109	-0.075	0.136	0.111	0.082	0.813	0.869	0.860
Monte Buey	0.052	0.043	0.046	-0.070	-0.049	-0.017	0.087	0.065	0.049	0.760	0.763	0.665
REMEDHUS	0.040	0.041	0.053	-0.059	-0.042	-0.027	0.071	0.059	0.059	0.690	0.727	0.692
Yanco	0.068	0.058	0.053	0.020	0.031	0.040	0.071	0.066	0.067	0.875	0.862	0.827
Kyeamba	0.043	0.036	0.035	0.001	0.017	0.031	0.043	0.040	0.047	0.948	0.959	0.923
SMAP Average	**0.044**	**0.041**	**0.047**	**-0.044**	**-0.024**	**0.000**	**0.075**	**0.063**	**0.065**	**0.752**	**0.784**	**0.727**
SMOS Average	**0.043**			**-0.014**			**0.065**			**0.796**		
Averages are based on the values reported for each CVS												

Beta-Level Performance Assessment

Core Validation Sites

L2SMP Beta-Level CVS Assessment



"*... First, all algorithms have about the same ubRMSE, differing by 0.006 m^3/m^3, and are very close to the SMAP mission goal of 0.04 m^3/m^3 ... Based upon the metrics and considerations discussed, it is recommended that the SCA-V be used as the baseline algorithm for the beta release.*" (p.26, Assessment Report)

Beta-Level Performance Assessment

Sparse Networks

Despite their low measurement density, Sparse Neworks provide *in situ* observations over more diverse surface and land cover conditions than what CVS alone could provide

Network Name	PI	Coverage	Number of Sites	Status
NOAA Climate Reference Network (CRN)	M. Palecki	US	110	Implemented
USDA Soil Climate Analysis Network (SCAN)	M. Cosh	US	155	Implemented
GPS	E. Small	Western US	123	Implemented
COSMOS	-	Mostly US	53	Implemented
SMOSMania	J. Calvet	Southern France	21	Implemented
OZNet-Murrumbidgee	J. Walker	Australia	7	
Oklahoma Mesonet	C. Fiebrich	US (Oklahoma)	120	
Pampas	M. Tiebault	Argentina	20	
South Africa	J. Qu	South Africa	18	

- Triple Co-location (TC) is used to upscale observations to SMAP footprint resolutions

Beta-Level Performance Assessment

Sparse Networks

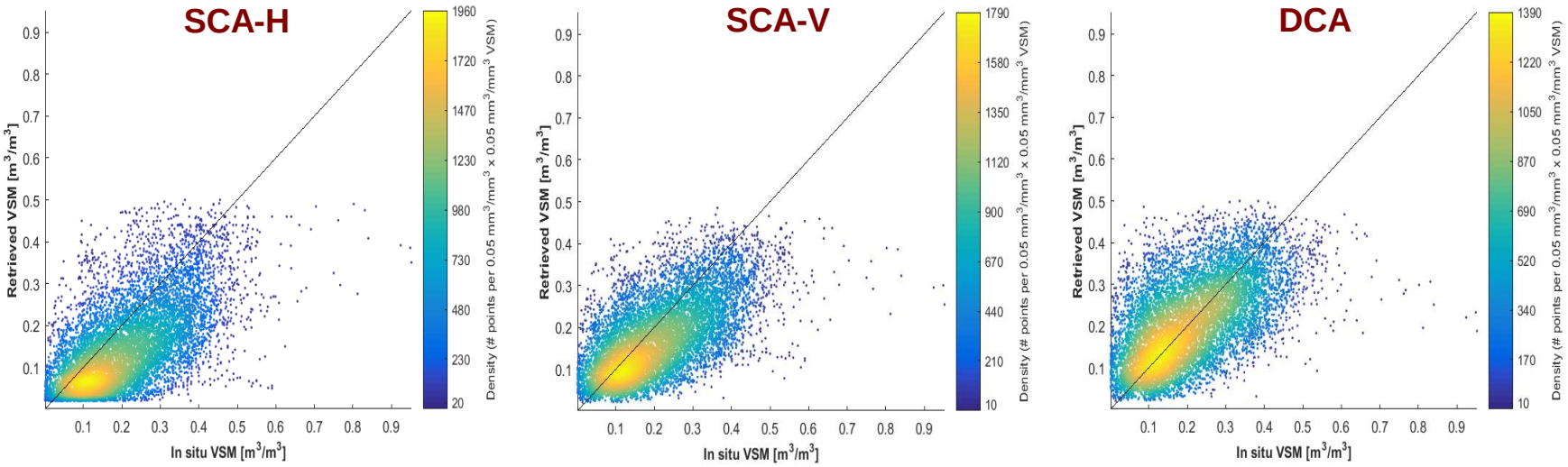
L2SMP Beta-Level Sparse Networks Assessment

	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	0.048	0.058	0.067	-0.101	-0.064	-0.015	-0.133	0.124	0.093	0.090	0.162	0.669	0.675	0.661	0.498	10
Evergreen broadleaf forest																	
Deciduous needleleaf forest																	
Deciduous broadleaf forest	0.051	0.038	0.043	0.064	-0.053	-0.018	0.041	-0.145	0.124	0.093	0.094	0.166	0.047	0.295	0.598	0.075	6
Mixed forest	0.048	0.044	0.053	0.059	-0.035	0.007	0.074	-0.086	0.092	0.081	0.107	0.139	0.459	0.531	0.588	0.435	12
Closed shrublands																	
Open shrublands	0.033	0.035	0.047	0.049	-0.052	-0.021	0.017	-0.014	0.074	0.066	0.078	0.078	0.334	0.349	0.348	0.348	44
Woody savannas	0.042	0.042	0.056	0.060	-0.048	-0.002	0.070	-0.069	0.098	0.092	0.129	0.120	0.674	0.663	0.497	0.423	24
Savannas	0.030	0.032	0.039	0.044	-0.064	-0.038	-0.021	-0.038	0.098	0.090	0.098	0.078	0.814	0.768	0.656	0.569	7
Grasslands	0.044	0.044	0.054	0.053	-0.091	-0.057	-0.013	-0.045	0.108	0.087	0.083	0.087	0.671	0.674	0.647	0.652	156
Permanent wetlands																	
Croplands	0.066	0.057	0.060	0.069	-0.049	-0.047	-0.040	-0.064	0.119	0.110	0.113	0.127	0.643	0.669	0.584	0.585	56
Urban and built-up																	
Crop/Natural vegetation mosaic	0.052	0.047	0.053	0.073	-0.023	-0.001	0.033	-0.073	0.081	0.073	0.084	0.140	0.652	0.712	0.643	0.509	33
Snow and ice																	
Barren/Sparse	0.019	0.020	0.029	0.048	-0.059	-0.026	0.043	-0.017	0.067	0.054	0.074	0.065	0.522	0.520	0.456	0.397	9
Average	**0.046**	**0.044**	**0.053**	**0.058**	**-0.067**	**-0.038**	**0.001**	**-0.052**	**0.101**	**0.087**	**0.091**	**0.103**	**0.605**	**0.623**	**0.583**	**0.547**	**357**
Average is based upon all sets of observations, not the average of the land cover category results.																	

Beta-Level Performance Assessment

Sparse Networks

L2SMP Beta-Level Sparse Networks Assessment

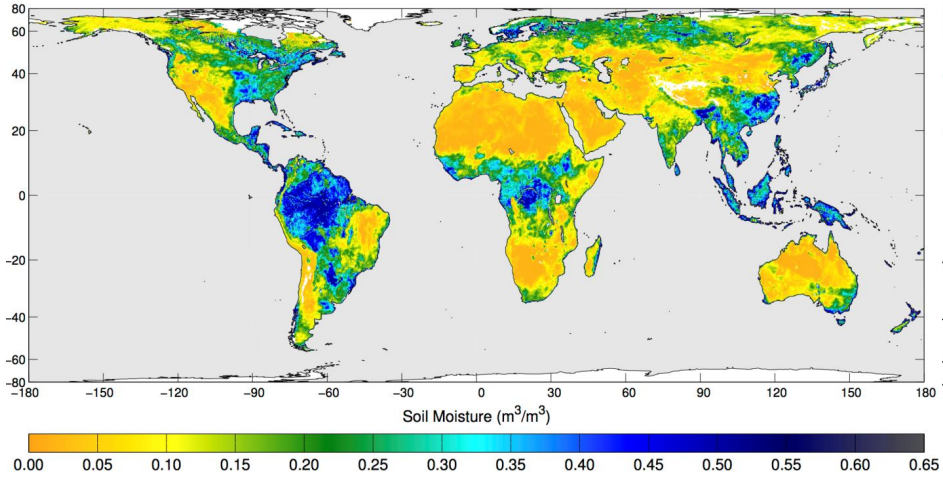


"… Overall, the ubRMSE and bias values are similar to those obtained from the CVS. This result provides additional confidence in the previous conclusions based on the CVS … the SCA-V has the best overall ubRMSE and correlation while the DCA has the lowest (near zero) bias. These are the same results observed for the CVS." (p.30, Assessment Report)

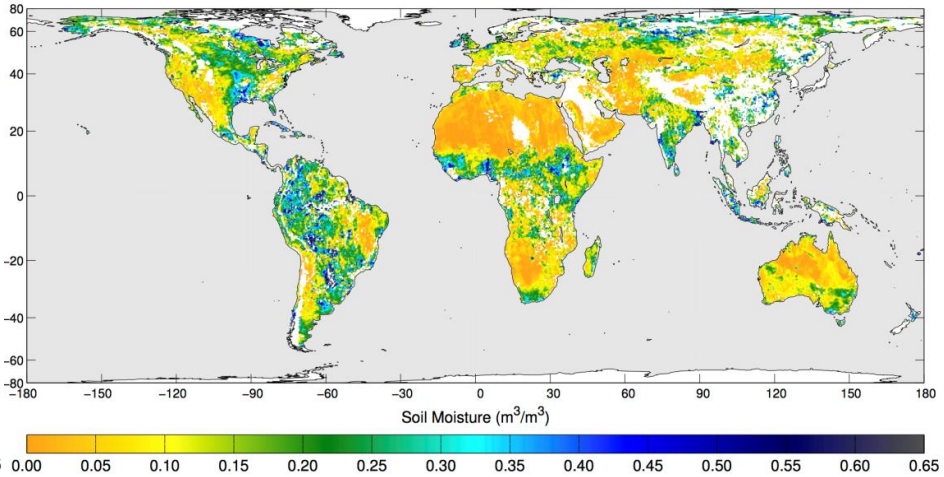
Beta-Level Performance Assessment

Satellite Intercomparison

SMAP 6:00 am L2SMP (Jun 1-7, 2015)



SMOS 6:00 am L3 (Jun 1-7, 2015)



"… Some features are similar (i.e., the Sahara), but there are some very obvious differences between the soil moisture from the two missions. The other significant difference is that the SCA-V algorithm predicts higher soil moisture in forested domains." (p.14, Assessment Report)

"… SMAP predicts lower soil moisture values for most categories than SMOS." (p.33, Assessment Report)

More quantitative results to be presented in the ***Satellite-based Products in SMAP L2-L4 Cal/Val*** presentation by T. Jackson/M. Burgin tomorrow.

Outlook Towards Validated Release

- **CEOS Cal/Val maturity level**
  - Completed Stage 1 and begun Stage 2 (global assessment with an annual data record)
- **Additional CVS expected**
  - Some sites (Mongolia, Tibet) provide data only once a year due to their remoteness
- **Additional sparse networks expected**
  - Efforts underway to bring in the Oklahoma Mesonet data
- **Triple co-location robustness improvement expected**
  - Longer data record (> 1 year) would improve inference from sparse network comparison
- **Precipitation flag improvement**
  - GMAO precipitation to be compared with GPM to ensure proper flagging of retrieval
- **Potential retrieval errors**
  - Ancillary data: T_{eff}, soil texture, land cover, VWC parameterization
  - Modeling: dielectric model, model coefficients and their polarization dependence
- **Optimal model calibration**
  - Model coefficients to be determined by the forward model constrained in time and space

Conclusion

- **L2SMP's prompt reach to beta-level quality credited to**
  - Cal/Val partners
  - Cal/Val tools developed and refined in previous Cal/Val rehearsal campaigns
  - Benefits from SMOS/Aquarius data availability
  - High-quality radiometer data (e.g. relatively free of RFI)

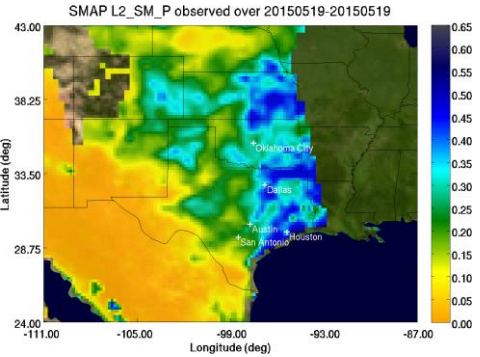
- **Beta-level L2SMP to be available from NSIDC by mid-Sept**
  - Data documentation (PSDs, User Guide, Assessment Report, etc) ✓
  - Data production (Mar 31 – Aug 18) completed ✓

- **Current L2SMP approaching accuracy requirement (0.04 m^3/m^3) based on**
  - Similar patterns of performance metrics from CVS and Sparse Networks
  - SCA-V recommended as interim post-launch baseline algorithm; all algorithms to be vetted in ongoing Cal/Val activities
  - Further improvement expected upon more rigorous model calibration

Backup

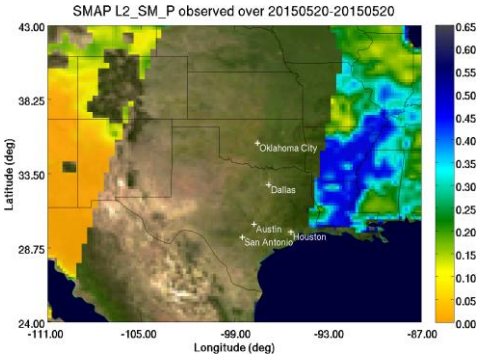
Beta-Level Performance Assessment

Regional Pattern



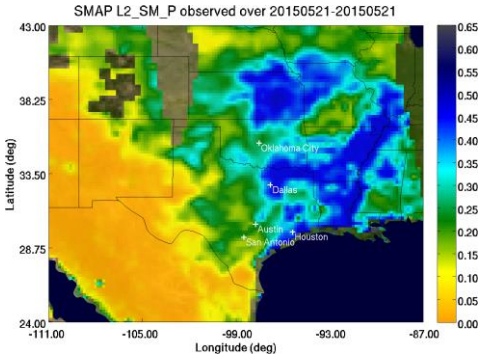
May 19, 2015

Eastern TX began with high soil moisture (due to prior rainfall)



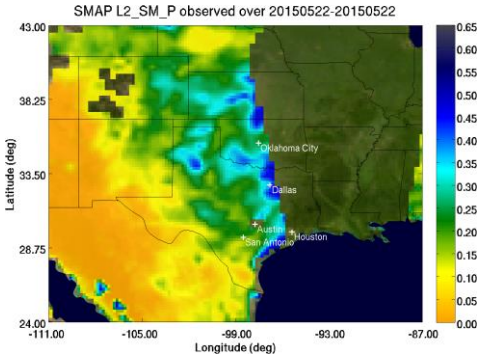
May 20, 2015

Heavy rainfall began over AR and LA



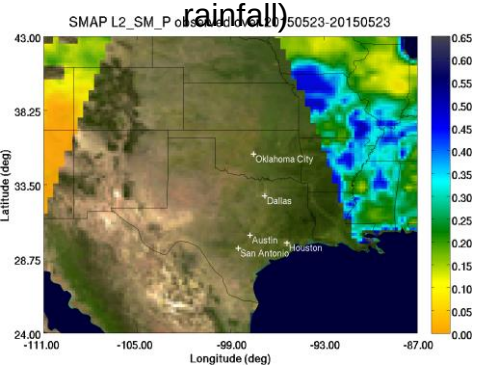
May 21, 2015

Rainfall continued to intensify



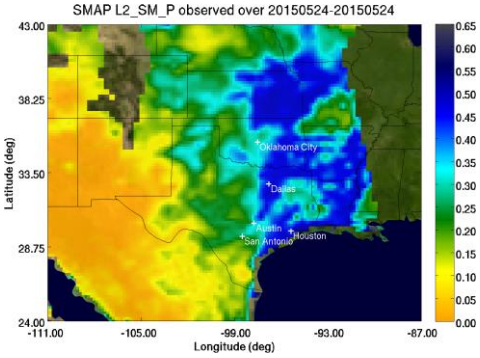
May 22, 2015

Limited swath coverage



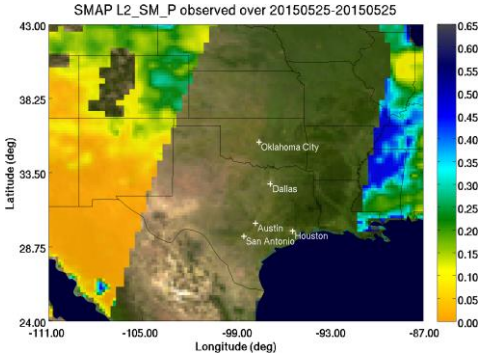
May 23, 2015

Limited swath coverage



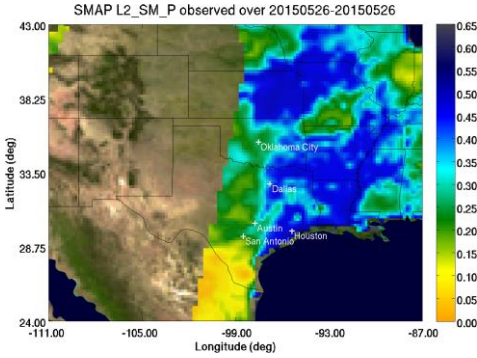
May 24, 2015

Heavy rainfall causing widespread flash flood and river overflow



May 25, 2015

Limited swath coverage



May 26, 2015

High soil moisture observed throughout KS, OK, TX, AR, MO, MS and LA