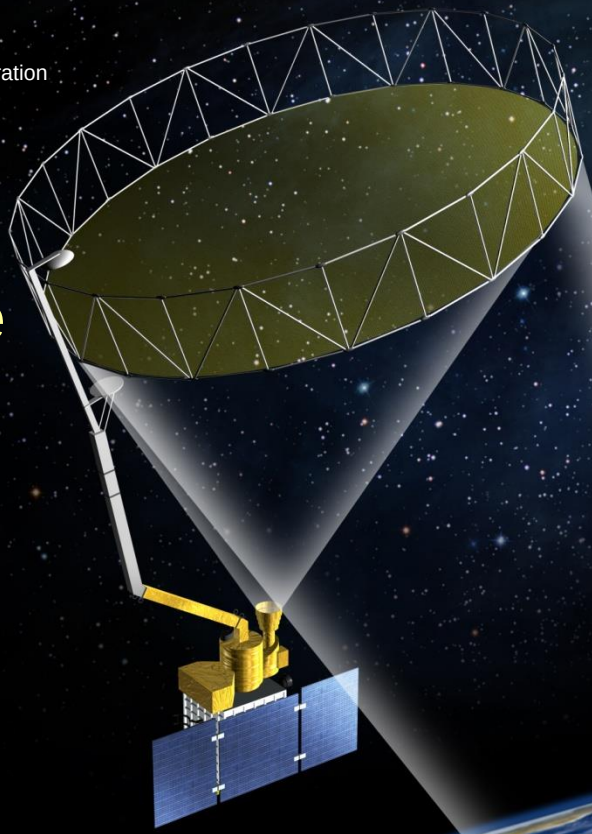
National Aeronautics and Space Administration

Soil Moisture Active Passive Mission

SMAP



SMAP Enhanced Passive Soil Moisture Products

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SMAP Canada Workshop
May 16-17, 2017
University of Guelph
Ontario, Canada

Outline

- SMAP Data Product Status
- Enhanced Passive Soil Moisture Product
- Validation strategy
- Assessment
- Conclusion

SMAP Data Product Status

Products in **boldface** are or will be in routine operational production

Product	Description	Gridding (Resolution)	Latency	Data Type
L1A_Radiometer	**Radiometer Data in Time Order**	**-**	**12 hrs**	Instrument Data
L1A_Radar	Radar Data in Time Order	-	12 hrs	
L1B_TB	**Radiometer T_B in Time Order**	**(36 x 47 km)**	**12 hrs**	
L1B_S0_LoRes	Low Resolution Radar σ_0 in Time Order	(5 x 30 km)	12 hrs	
L1C_S0_HiRes	High Resolution Radar σ_0 on EASE Grid 2.0	1 km (1 – 3 km)	12 hrs	
L1C_TB	**Radiometer T_B on EASE Grid 2.0**	**36 km**	**12 hrs**	
L1C_TB_E (★)	**Radiometer T_B on EASE Grid 2.0 (Enhanced)**	**9 km**	**12 hrs**	
L2_SM_A	Soil Moisture (Radar)	3 km	24 hrs	Science Data (Half-Orbit)
L2_SM_P	**Soil Moisture (Radiometer)**	**36 km**	**24 hrs**	
L2_SM_P_E (★)	**Soil Moisture (Radiometer, Enhanced)**	**9 km**	**24 hrs**	
L2_SM_AP	Soil Moisture (Radar + Radiometer)	9 km	24 hrs	
L2_SM_SP (★★)	**Soil Moisture (Sentinel Radar + Radiometer)**	**3 km**	**Best effort**	
L3_FT_A	Freeze/Thaw State (Radar)	3 km	50 hrs	Science Data (Daily Composite)
L3_FT_P	**Freeze/Thaw State (Radiometer)**	**36 km**	**50 hrs**	
L3_FT_P_E (★)	**Freeze/Thaw State (Radiometer, Enhanced)**	**9 km**	**50 hrs**	
L3_SM_A	Soil Moisture (Radar)	3 km	50 hrs	
L3_SM_P	**Soil Moisture (Radiometer)**	**36 km**	**50 hrs**	
L3_SM_P_E (★)	**Soil Moisture (Radiometer, Enhanced)**	**9 km**	**50 hrs**	
L3_SM_AP	Soil Moisture (Radar + Radiometer)	9 km	50 hrs	
L4_SM	**Soil Moisture (Surface and Root Zone)**	**9 km**	**7 days**	Science Value-Added
L4_C	**Carbon Net Ecosystem Exchange (NEE)**	**9 km**	**14 days**	

★ Radiometer-based enhanced products were released in Dec 2016

SMAP Radiometer Data Product

- SMAP: **S**oil **M**oisture **A**ctive **P**assive
  - L-band (1.4 GHz) radar and radiometer for global mapping of soil moisture and F/T state
  - Radiometer in good health, though radar stopped working in July 2015
  - On orbit since Jan 31, 2015, returning more than 2 years of radiometer data
  - Soil moisture retrieval accuracy reached 0.04 m^3/m^3 (ubRMSE) over non-frozen land surfaces that are free of excessive snow, ice, mountainous terrain, and dense vegetation coverage
  - Recent releases in December, 2016:
    - SPL2SMP_E (verison 1): Enhanced 9 km passive soil moisture product
    - SPL2SMP (version 4): Standard 36 km passive soil moisture product (both AM & PM)
    - Product and documentation available on https://nsidc.org/data/smap/data_versions

Enhanced Passive Soil Moisture Product

- E in SPL2SMP_E:
  - An enhanced version of standard SPL2SMP

    [a] finer grid resolution – analogy: go from SD to HD in TV "resolution"

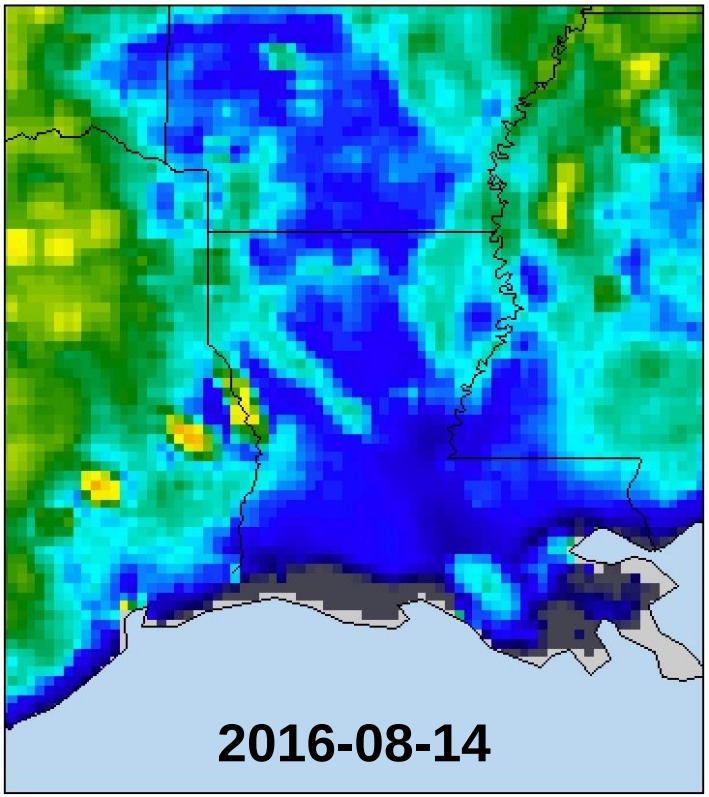
    [b] native resolution – comparable to SMAP radiometer FOV
- Achieve finer grid resolution through
  - Backus-Gilbert optimal interpolation on 9 km EASE Grid 2.0 (three projections)
- Same inversion algorithms and ancillary data as L2/3_SM_P

	Enhanced Product	Standard Product
Grid Posting	9 km	36 km
Ancillary Data Grid Posting	3 km	3 km
Contributing Inversion Domain	33 km	36 km
LTDN / LTAN	6:00 am and 6:00 pm	6:00 am and 6:00 pm
Granularity	Half orbit	Half orbit
Primary Input	Enhanced 9 km L1C_TB_E	Standard 36 km L1C_TB
Baseline Algorithm	V-pol Single Channel Algorithm	V-pol Single Channel Algorithm

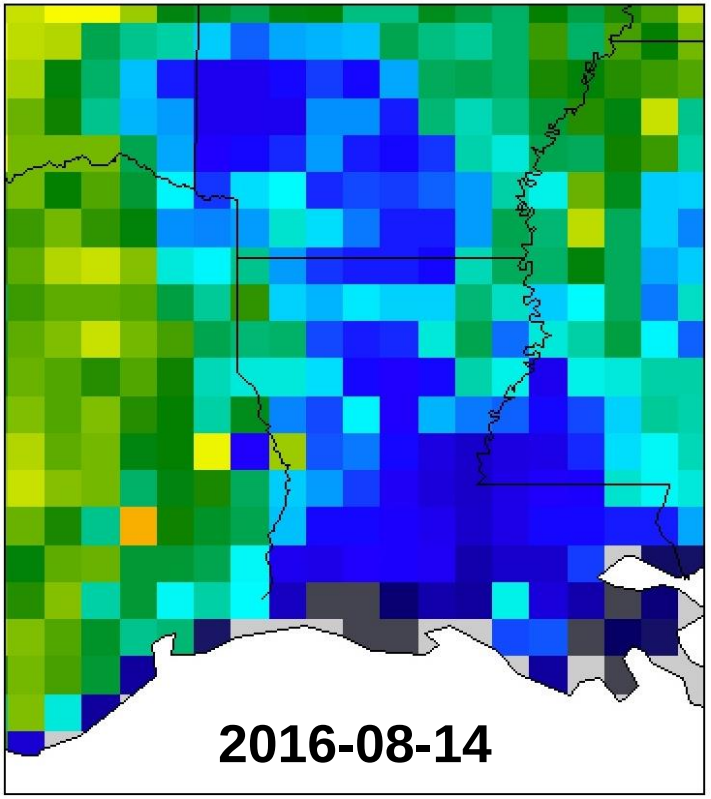
Enhanced Passive Soil Moisture Product

soil moisture mapping during the 2016 Louisiana flood

Enhanced SMAP
Passive Soil Moisture Product
(9 km grid resolution)

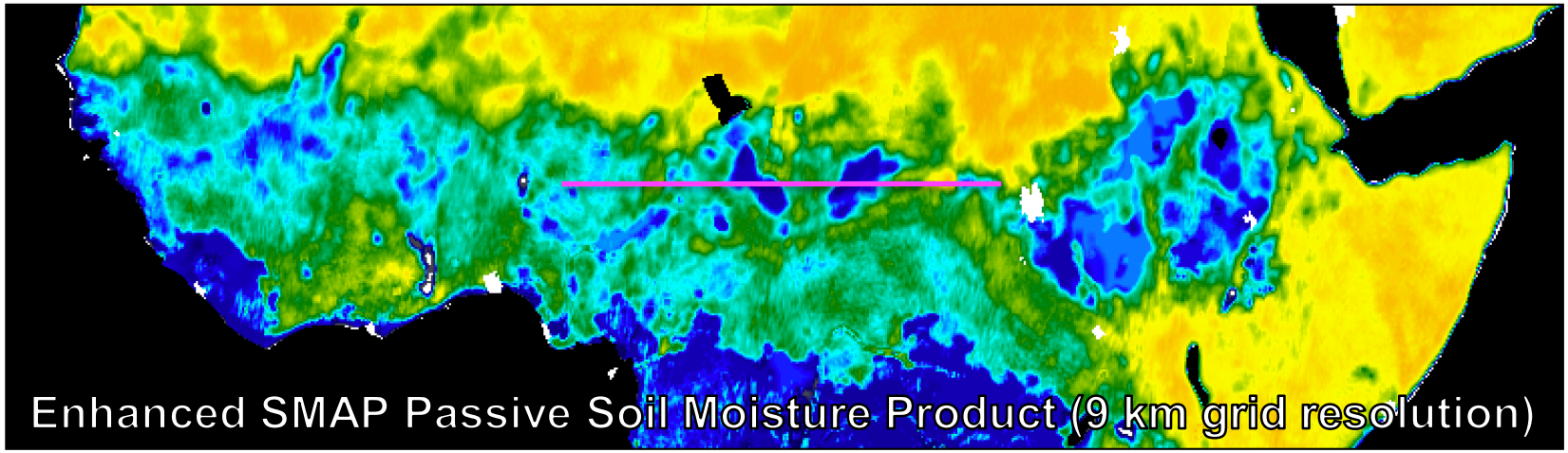


Standard SMAP
Passive Soil Moisture Product
(36 km grid resolution)



Enhanced Passive Soil Moisture Product

soil moisture variability along transect



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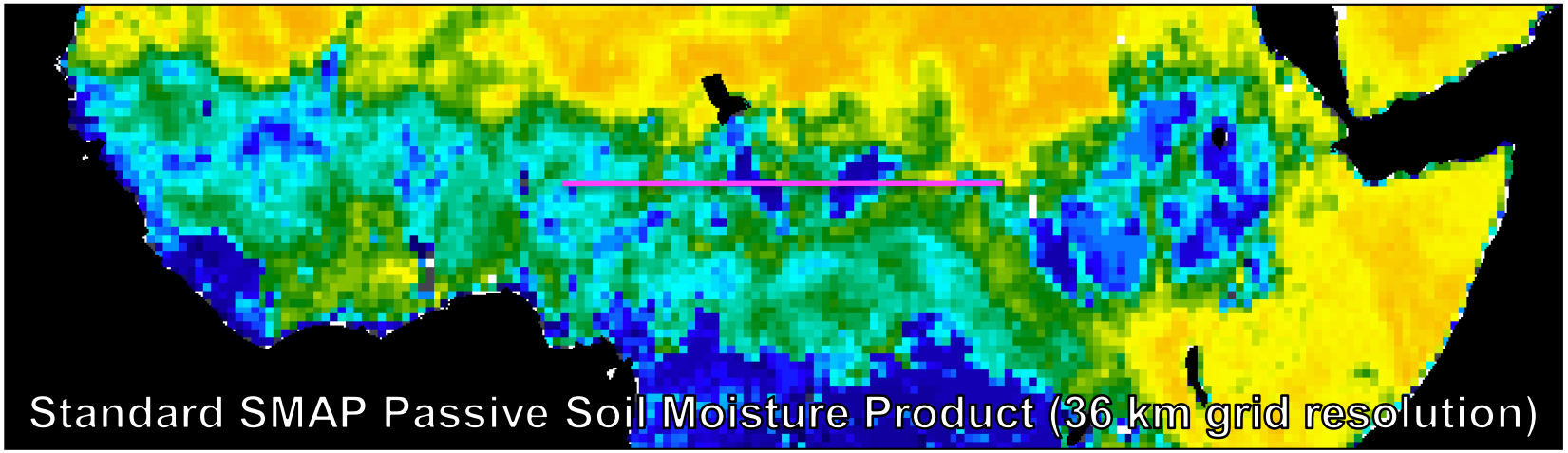
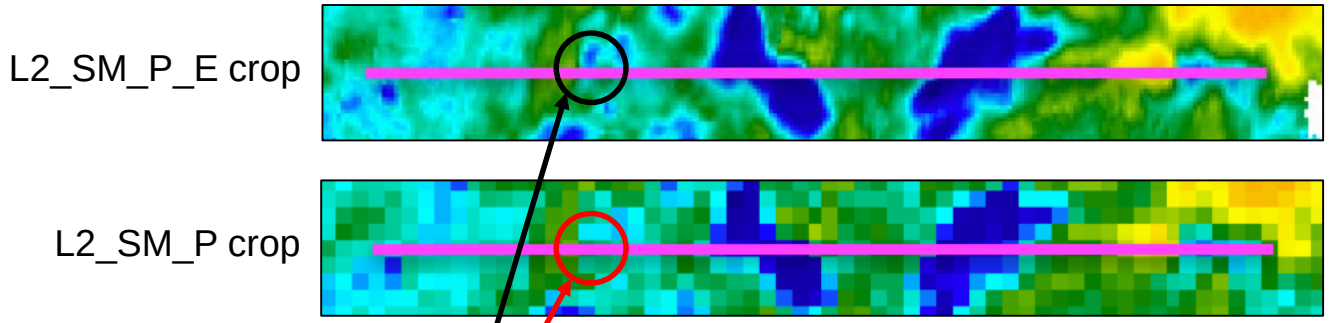


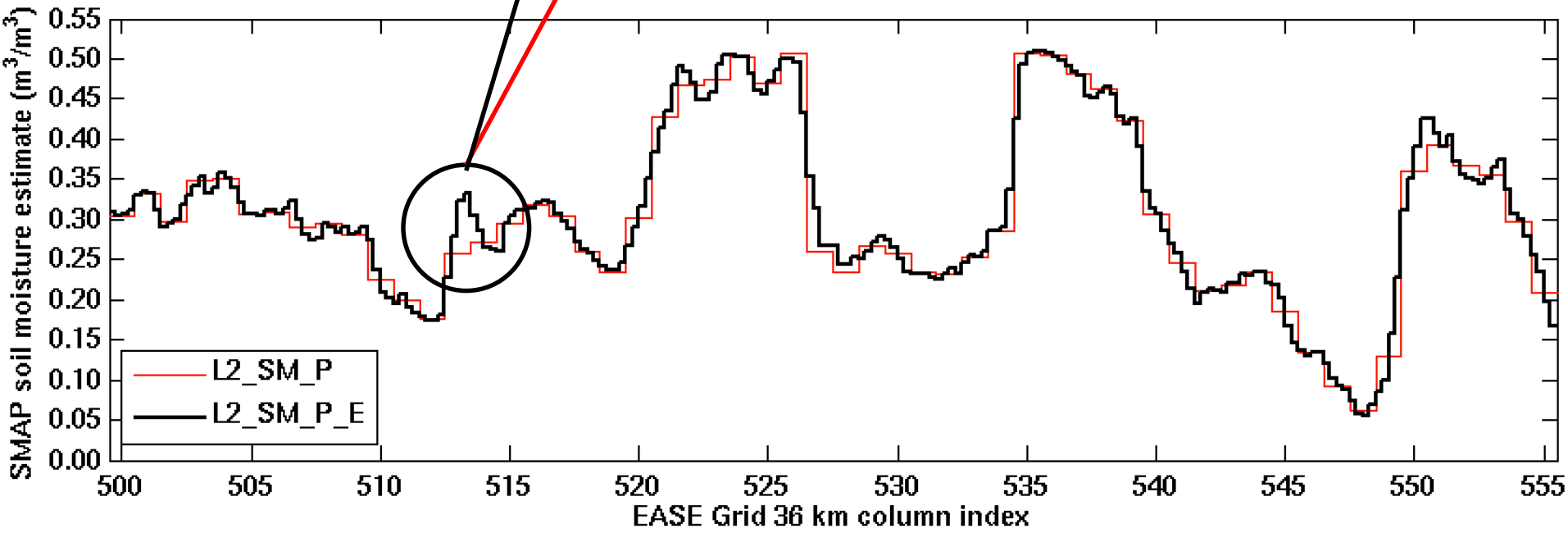
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65

Enhanced Passive Soil Moisture Product

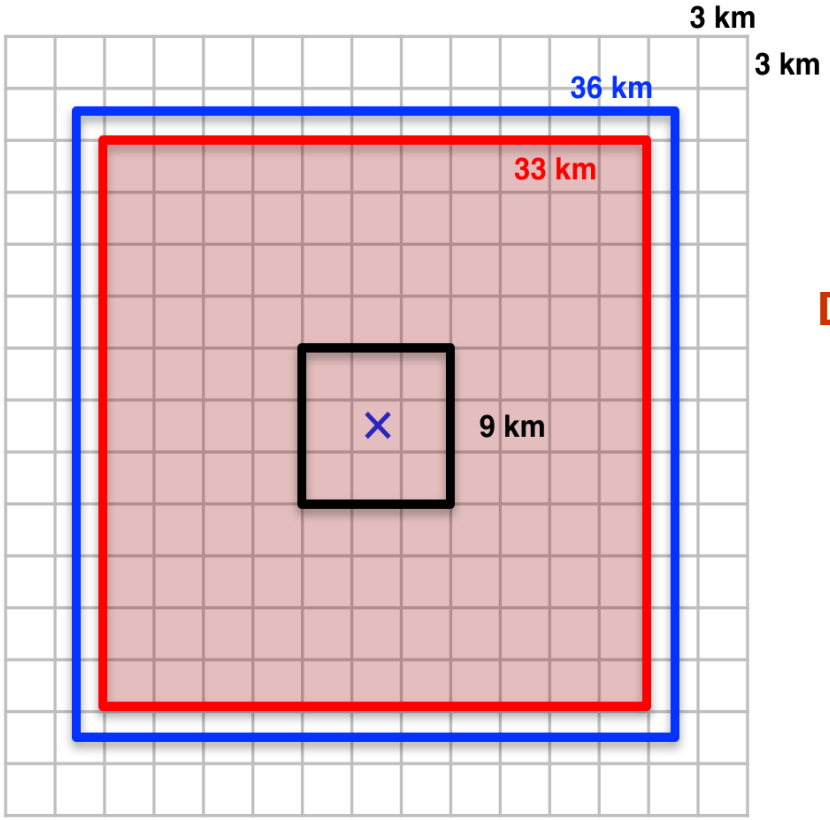
soil moisture variability along transect

The enhanced product displays more visible spatial features than the standard product. An example is shown in the highlighted area where the enhanced product captures a peak but the standard product doesn't.





Validation Strategy



L2SMP_E Contributing Domain is 33 km

- L2SMP_E data posted on 9 km EASE Grid 2.0 (black box)
- Assessed at 33 km scale (red box) to match SMAP radiometer FOV (blue box) as much as possible
- Individual CVS *in situ* data rescaled to accommodate these dimensions

Part 1: Assessment of L2SMP_E

in situ data from core validation sites

Core Validation Sites

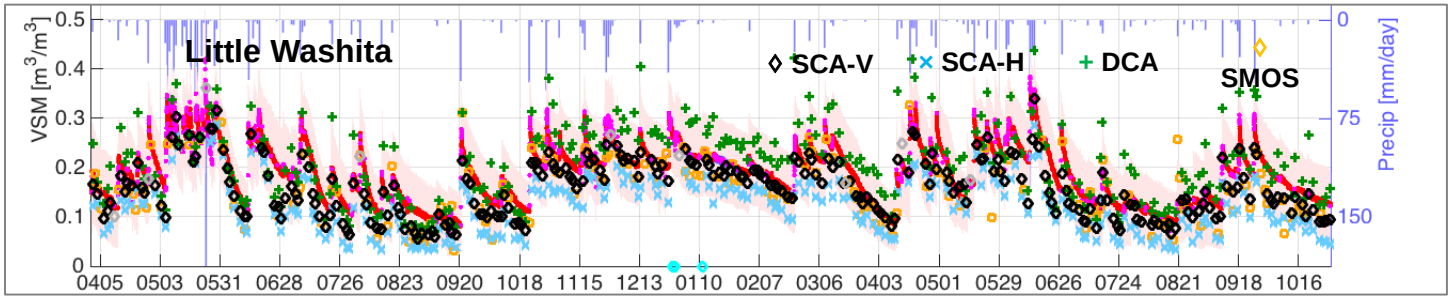
CVS Name	Site PI	Area	Climate Regime	IGBP Land Cover
Walnut Gulch[1,2]	M. Cosh	USA (Arizona)	Arid	Shrub open
Reynolds Creek[1,2]	M. Cosh	USA (Idaho)	Arid	Grasslands
Fort Cobb[1,2]	M. Cosh	USA (Oklahoma)	Temperate	Grasslands
Little Washita[1,2]	M. Cosh	USA (Oklahoma)	Temperate	Grasslands
South Fork[1,2]	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
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
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
MAHASRI[1]	J. Asanuma	Mongolia	Cold	Grasslands
Yanco[1,2]	J. Walker	Australia	Arid	Croplands

1 = CVS used in L2_SM_P and L2_SM_P_E assessment
2 = CVS used in L2_SM_P_E assessment at 9 km

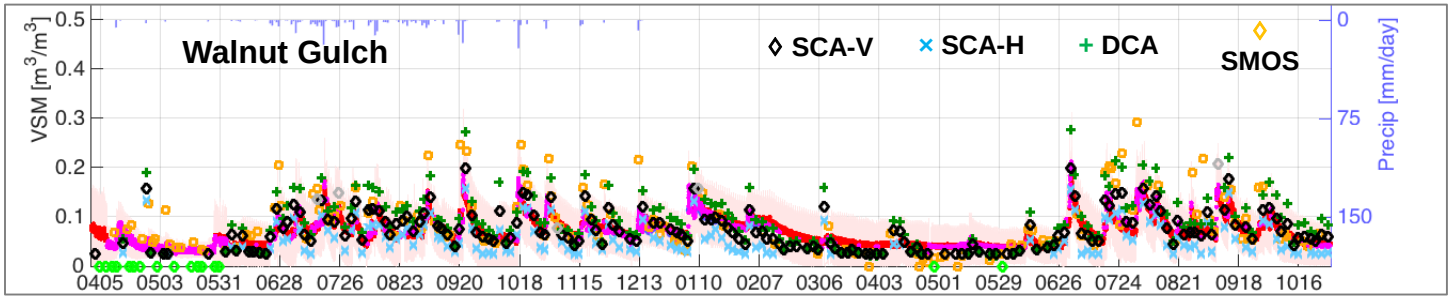
Part 1: Assessment of L2SMP_E

in situ data from core validation sites

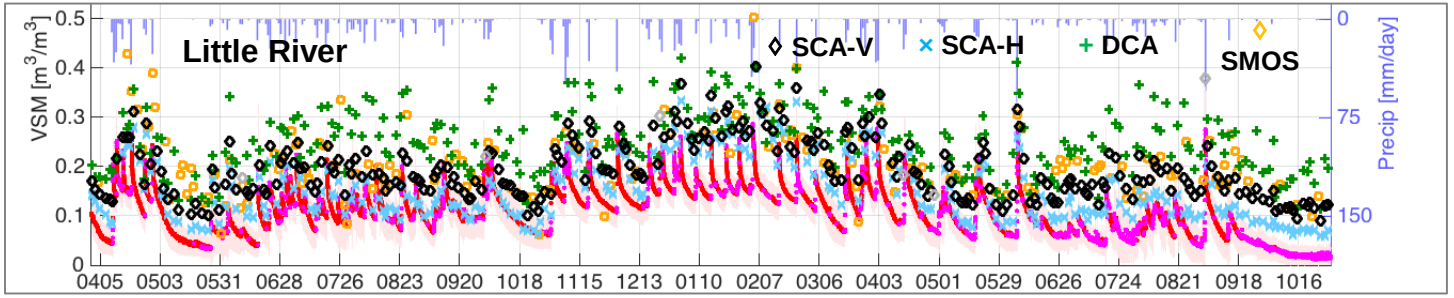
ubRMSE	0.022 m^3/m^3
Bias	-0.027 m^3/m^3
Corr	0.920



ubRMSE	0.024 m^3/m^3
Bias	0.011 m^3/m^3
Corr	0.813



ubRMSE	0.028 m^3/m^3
Bias	0.087 m^3/m^3
Corr	0.887



- Overall SMAP retrieval compares well with *in situ* data scaled to match satellite FOV
- Certain sites (e.g. Little River) exhibit moderate bias despite good correlation
- SCA-V delivers the best performance

Part 1: Assessment of 6:00 AM L2SMP_E

in situ data from core validation sites

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
Enhanced → L2_SM_P_E SMAP average vs 33 km *in situ*	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 vs 33 km *in situ*	0.051			-0.023			0.072			0.698					
Standard → L2_SM_P SMAP average vs 36 km *in situ*	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 vs 36 km *in situ*	0.051			-0.024			0.072			0.713					

- Enhanced L2SMP_E shows comparable performance as standard L2SMP
- Both products exceeded SMAP mission objective (retrieval accuracy ~ 0.040 m^3/m^3 or better)

Part 1: Assessment of 6:00 PM L2SMP_E

in situ data from core validation sites

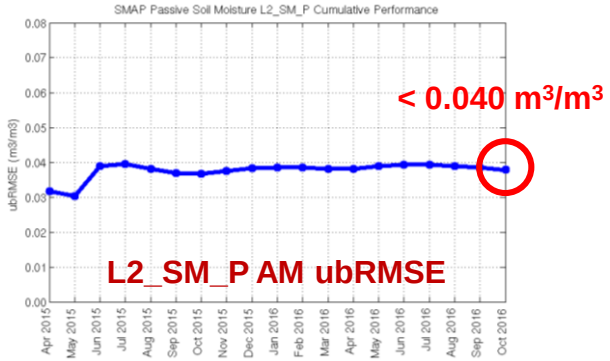
CVS	ubRMSE (m^3/m^3)			Bias (m^3/m^3)			RMSE (m^3/m^3)			R			N		
	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA	SCA-H	SCA-V	DCA
Reynolds Creek	0.046	0.042	0.060	-0.075	-0.042	-0.005	0.088	0.059	0.060	0.452	0.651	0.630	79	106	96
Walnut Gulch	0.027	0.029	0.042	-0.031	-0.019	-0.000	0.041	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
Enhanced → L2_SM_P_E SMAP average vs 33 km *in situ*	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 vs 33 km *in situ*	0.052			-0.029			0.071			0.721					
Standard → L2_SM_P SMAP average vs 36 km *in situ*	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 vs 36 km *in situ*	0.053			-0.028			0.072			0.710					

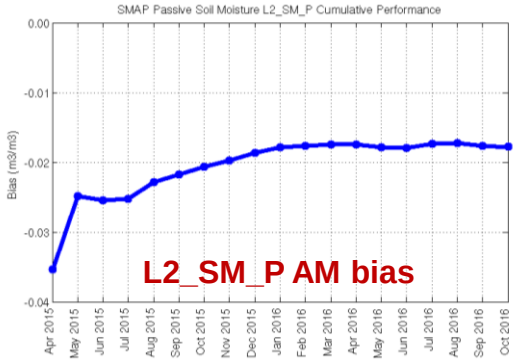
- Enhanced L2SMP_E shows comparable performance as standard L2SMP
- Both products exceeded SMAP mission objective (retrieval accuracy ~ 0.040 m^3/m^3 or better)

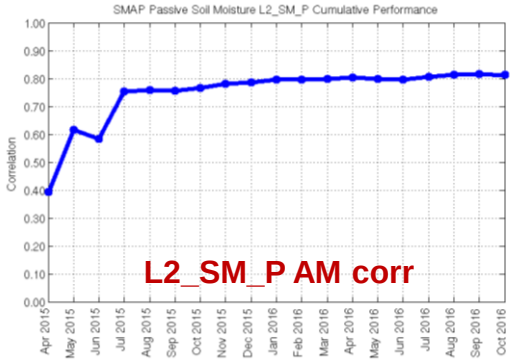
Cumulative Retrieval Performance

in situ data from core validation sites

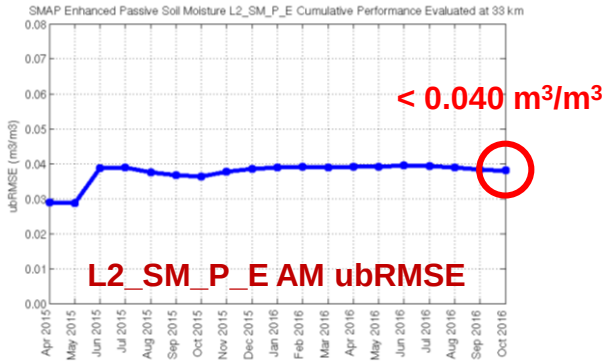
Standard Passive Soil Moisture Product

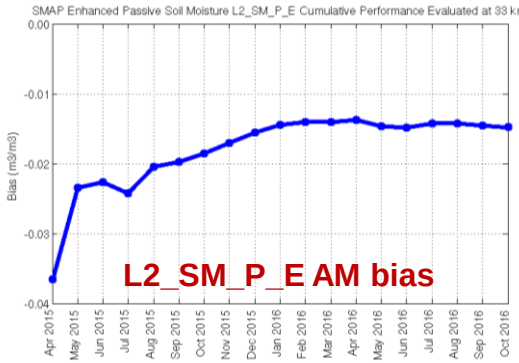


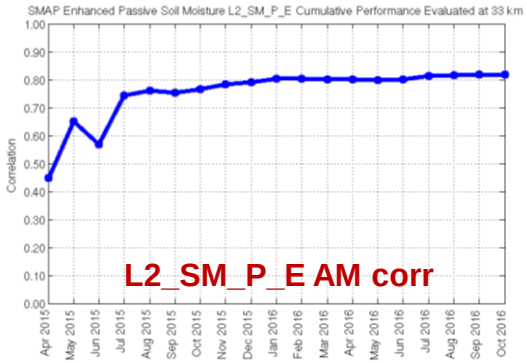




Enhanced Passive Soil Moisture Product







- Passive soil moisture product demonstrates stable performance about 4–5 months into cal/val
- Metrics generally improved over time; however, some asymptotic limits apparently reached

Part 2: Assessment of L2SMP_E

in situ data from sparse networks

Sparse Networks

Sparse Network Name	Site 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

OPTIONAL

Part 2: Assessment of L2SMP_E

in situ data from sparse networks

6:00 AM

IGBP Class	ubRMSD (m^3/m^3)				Bias (m^3/m^3)				RMSD (m^3/m^3)				R				N
	SCA-H	SCA-V	DCA	SMOS	SCA-H	SCA-V	DCA	SMOS	SCA-H	SCA-V	DCA	SMOS	SCA-H	SCA-V	DCA	SMOS	
ENF	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	0.430	1
MXF	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
OSH	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	0.460	38
WSV	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
SAV	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
GRS	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
CRP	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
MOS	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
BAR	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	0.620	6
L2_SM_P_E SMAP average	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
L2_SM_P SMAP average	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.

6:00 PM

IGBP Class	ubRMSD (m^3/m^3)				Bias (m^3/m^3)				RMSD (m^3/m^3)				R				N
	SCA-H	SCA-V	DCA	SMOS	SCA-H	SCA-V	DCA	SMOS	SCA-H	SCA-V	DCA	SMOS	SCA-H	SCA-V	DCA	SMOS	
ENF	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
MXF	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
OSH	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
WSV	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
SAV	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
GRS	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
CRP	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
MOS	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
BAR	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
L2_SM_P_E SMAP average	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
L2_SM_P SMAP average	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.

- Enhanced L2_SM_P_E shows decent ubRMSD and correlation over sparse networks
- Same trends of relative merits among algorithm options as indicated in CVS analysis

OPTIONAL

Conclusion

- **Enhanced L2_SM_P_E:**
  - Uses L1C_TB_E on 9 km as input
  - Provides diurnal monitoring ability with AM and PM data
  - Uses identical ancillary data and inversion algorithm as standard L2_SM_P
  - Reveals enhanced visual features otherwise concealed due to blockiness in standard L2_SM_P

- **Assessment using *in situ* data indicates:**
  - Standard product attains an ubRMSE of 0.037 m^3/m^3 (AM being the best case)
  - Enhanced product attains an ubRMSE of 0.038 m^3/m^3 (AM being the best case)
  - AM retrieval slightly more accurate than PM retrieval
  - SCA-V delivers more accurate retrieval than other option algorithms

- **Stable cumulative retrieval performance**:
  - ubRMSE has been staying near or below 0.040 m^3/m^3

Backup

SMAP Data Product Status

Product assessment publications (published and under-review):

On enhanced product (SPL2SMP_E)

- **Chan**, S., R. Bindlish, P. O'Neill, T. Jackson, E. Njoku, S. Dunbar, J. Chaubell, J. Piepmeier, S. Yueh, D. Entekhabi, A. Colliander, F. Chen, M. H. Cosh, T. Caldwell, J. Walker, A. Berg, H. McNairn, M. Thibeault, J. Martínez-Fernández, F. Uldall, M. Seyfried, D. Bosch, P. Starks, C. Holifield Collins, J. Prueger, R. van der Velde, J. Asanuma, M. Palecki, E. E. Small, M. Zreda, J. Calvet, W. T. Crow, and Y. Kerr (**2017**): **Development and Assessment of the SMAP Enhanced Passive Soil Moisture Product**, *Remote Sensing of Environment*, under review.

On standard product (SPL2SMP)

- **Chan**, S., R. Bindlish, P. O'Neill, E. Njoku, T. Jackson, A. Colliander, F. Chen, M. Mariko, S. Dunbar, J. Piepmeier, S. Yueh, D. Entekhabi, M. Cosh, T. Caldwell, J. Walker, X. Wu, A. Berg, T. Rowlandson, A. Pacheco, H. McNairn, M. Thibeault, J. Martinez-Fernandez, A. Gonzalez-Zamora, M. Seyfried, D. Bosch, P. Starks, D. Goodrich, J. Prueger, M. Palecki, E. Small, M. Zreda, J. Calvet, W. Crow, Y. Kerr (**2016**): **Assessment of the SMAP Passive Soil Moisture Product**, *IEEE Transactions on Geoscience and Remote Sensing*, 54(8), pp. 4994–5007.

On enhanced and standard products (SPL2SMP_E and SPL2SMP)

- **Jackson**, T., P. O'Neill, E. Njoku, S, Chan, R. Bindlish, A. Colliander, F. Chen, M. Burgin, S. Dunbar, J. Piepmeier, M. Cosh, T. Caldwell, J. Walker, X. Wu, A. Berg, T. Rowlandson, A. Pacheco, H. McNairn, M. Thibeault, J. Martínez-Fernández, Á. González-Zamora, M. Seyfried, D. Bosch, P. Starks, D. Goodrich, J. Prueger, Z. Su, R. van der Velde, J. Asanuma, M. Palecki, E. Small, M. Zreda, J. Calvet, W. Crow, Y. Kerr, S. Yueh, and D. Entekhabi (**2016**): **Calibration and Validation for the L2/3_SM_P Version 4 and L2/3_SM_P_E Version 1 Data Products**, [Online]. Available: https://nsidc.org/data/smap/data_version