Level 4 Soil Moisture Version 2 & Version 3

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SMAP Cal/Val Workshop #8
20 June, 2017, Amherst

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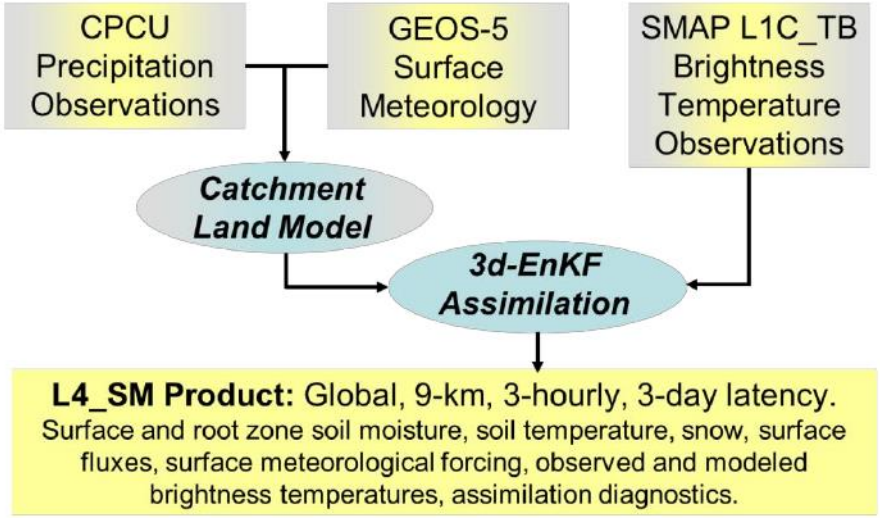
(3) Science Systems and Applications

Outline

1. The L4_SM product
2. Updates in Version 3
3. Assimilation diagnostics
4. In situ validation
5. Summary

L4_SM Algorithm and Product



- Merging of model information and SMAP observations
  → soil moisture estimates with complete vertical, horizontal and temporal coverage
- Available for April 2015 - present
- Science Version ID: Vv2030 (current), **Vv3030 (to be released July 2017)**

L4_SM Version 3 – Algorithm and Product Changes

- Only minor changes to land model and forcing for SMAP period (April 2015 – present)
  → mean L4_SM soil moisture mostly unchanged between Version 2 and 3
  (Objective was to avoid recalibration of L4_C algorithm)

- Updated model-only simulation (NRv4.1; 2000 - 2017)
  → forcing data for pre-SMAP (2000-2014) and SMAP periods are more coherent
  → improved soil moisture percentile output

- Augmented brightness temperature (Tb) scaling factors using:
  - 6 years of SMOS v6 Tbs where available
  - 2 years of SMAP Version 3 Tbs elsewhere

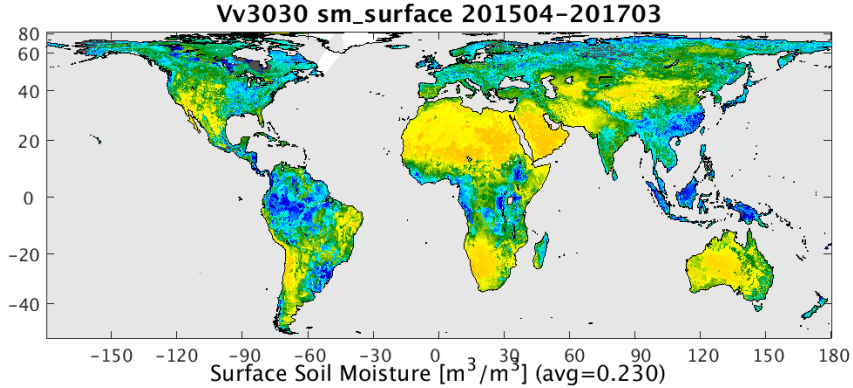
  → more SMAP observations are assimilated

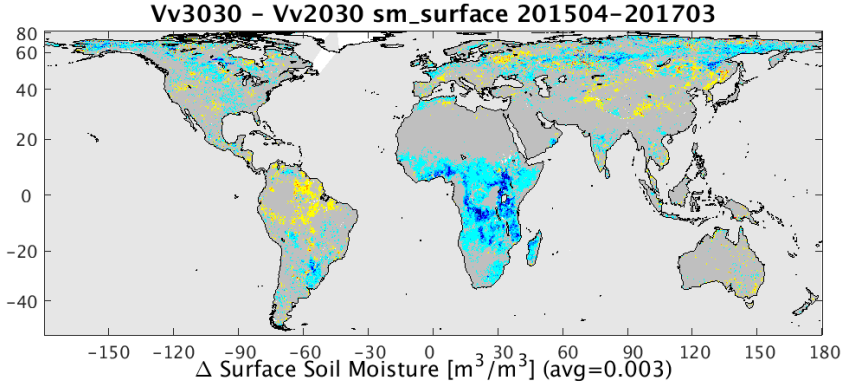
L4_SM Product Validation

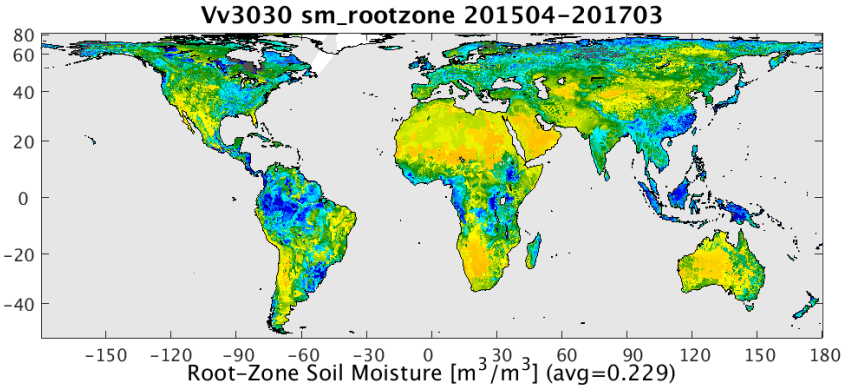
Validation Period: 1 Apr 2015 – 31 Mar 2017

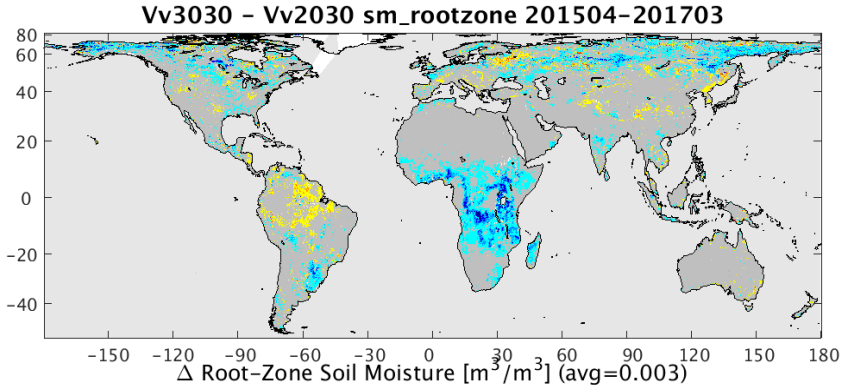
NRv4 is reference (model-only simulation) for Vv2030
NRv4.1 is reference (model-only simulation) for Vv3030

L4_SM Version 3 – Product Climatology

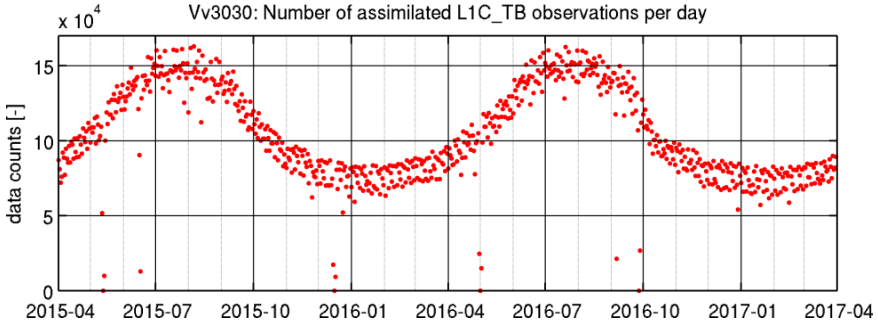


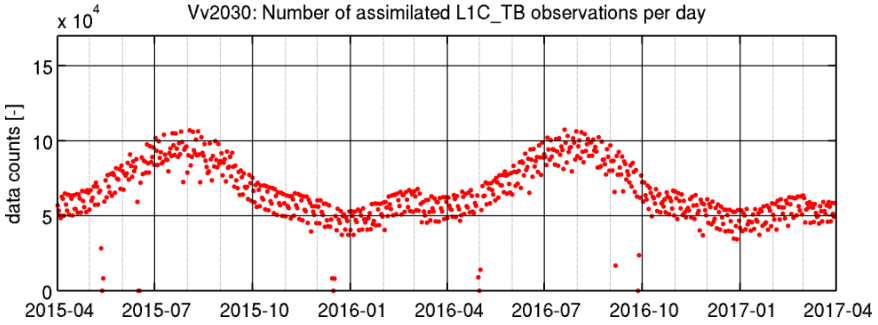


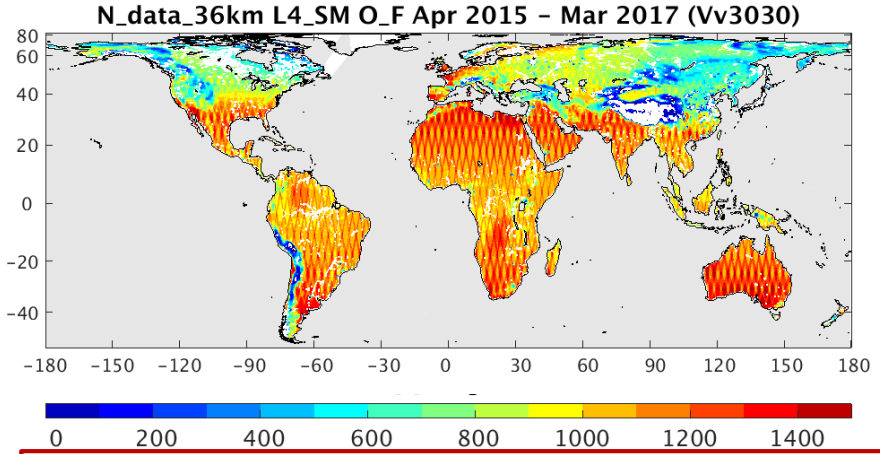


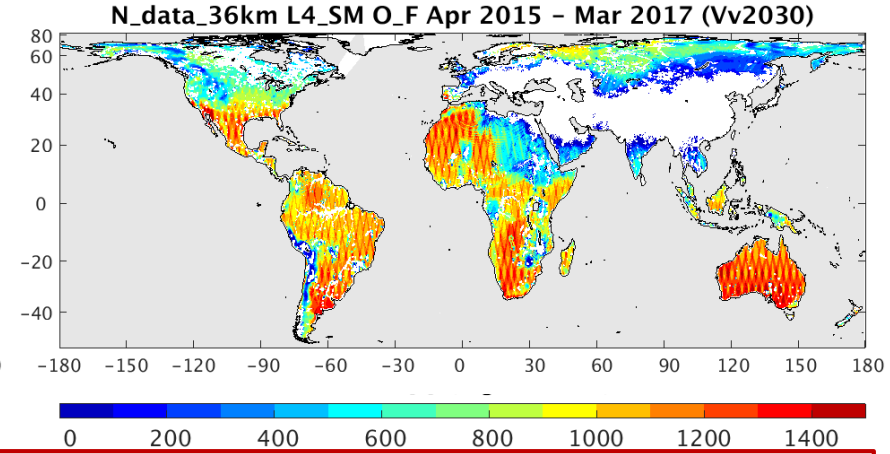


Assimilation Diagnostics – Data Count



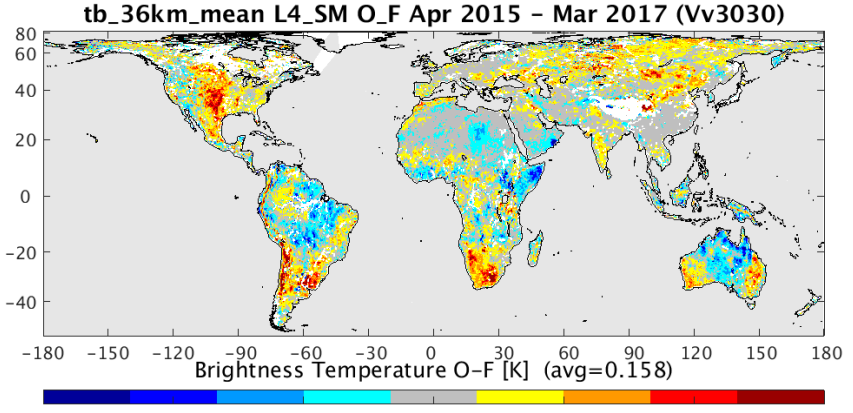


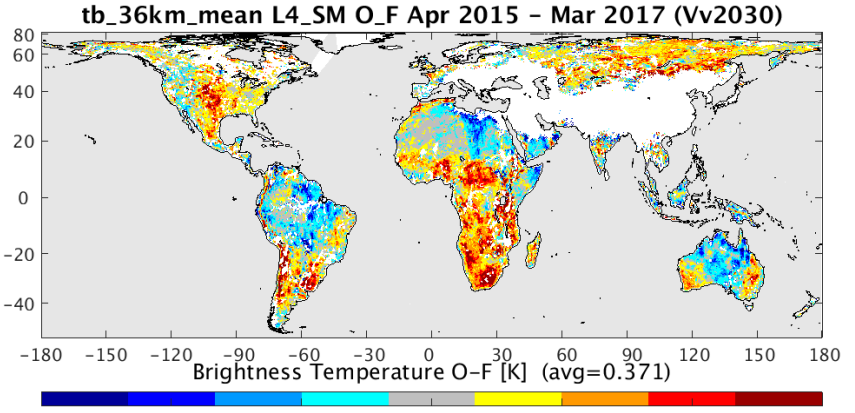


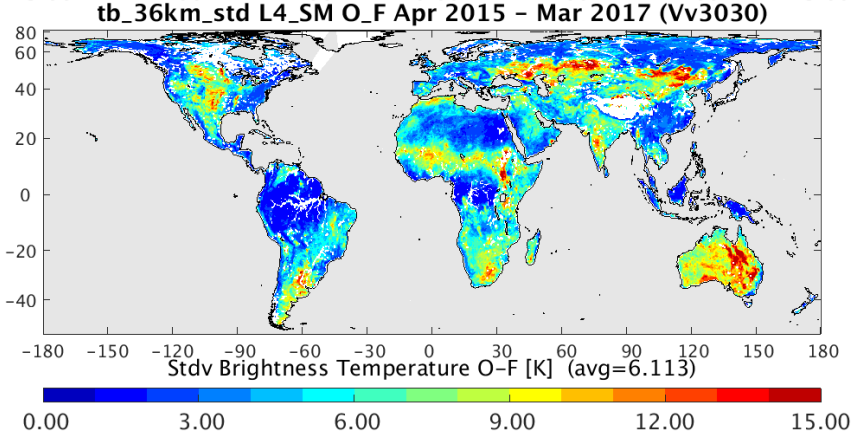


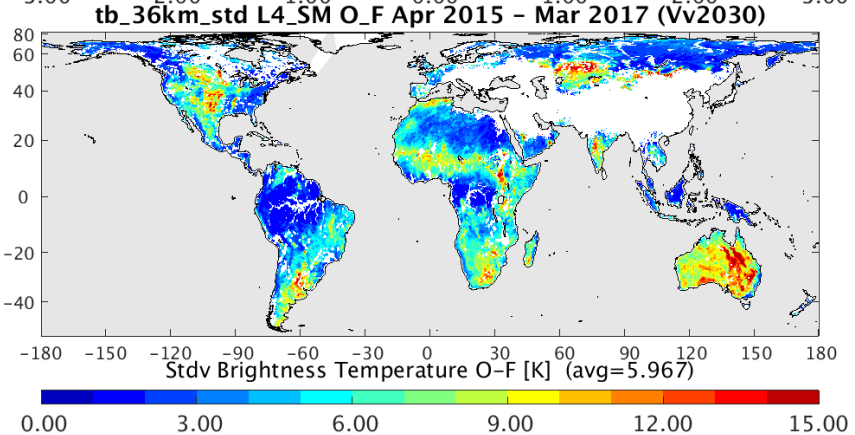
Version 3 assimilates ~59% more SMAP observations than version 2 (~100,000 observations per day)

Assimilation Diagnostics – Observations minus Forecast (O-F)

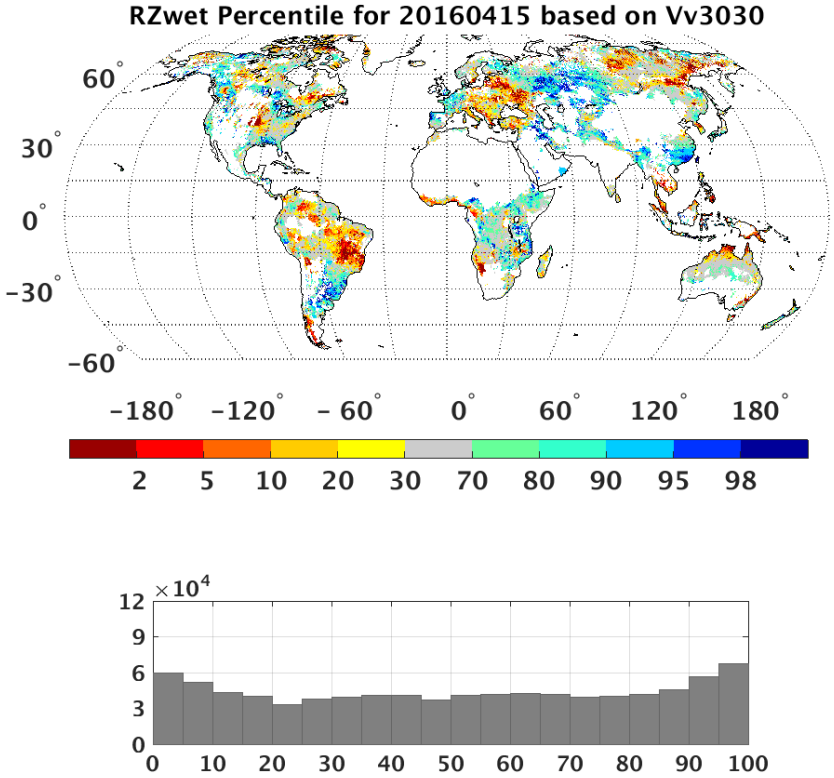


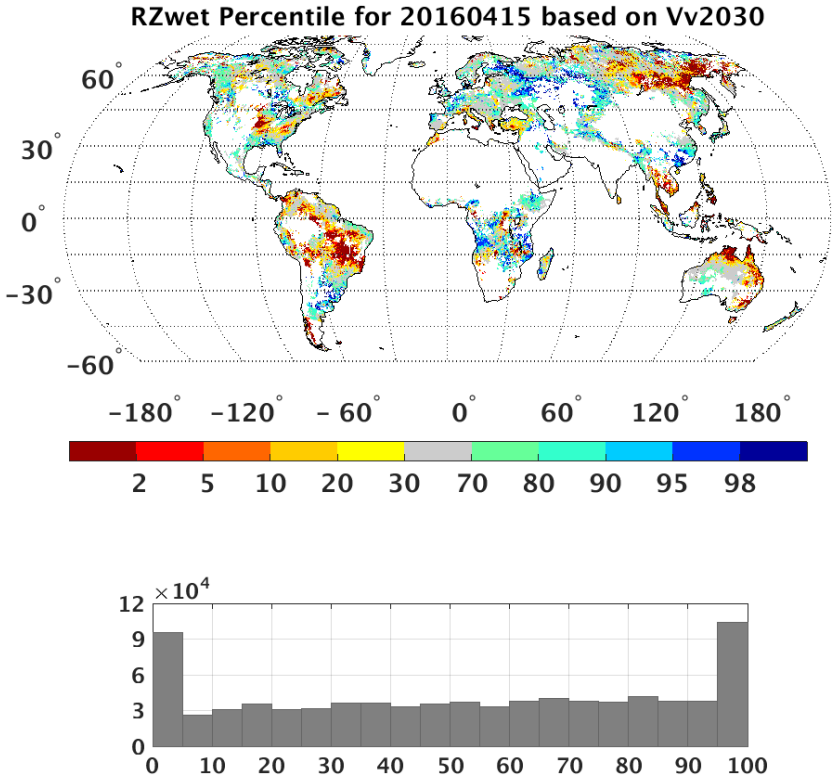






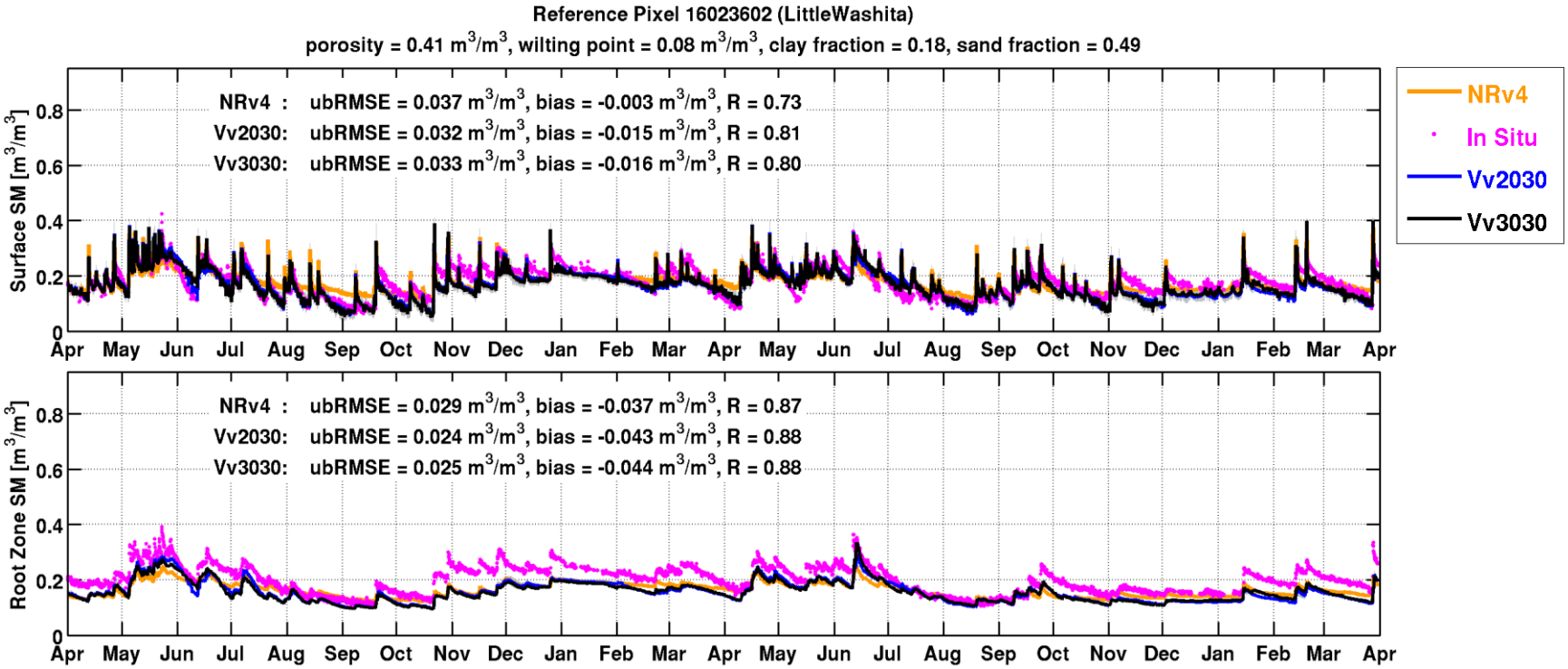
Assimilation Diagnostics – Soil Moisture Percentiles





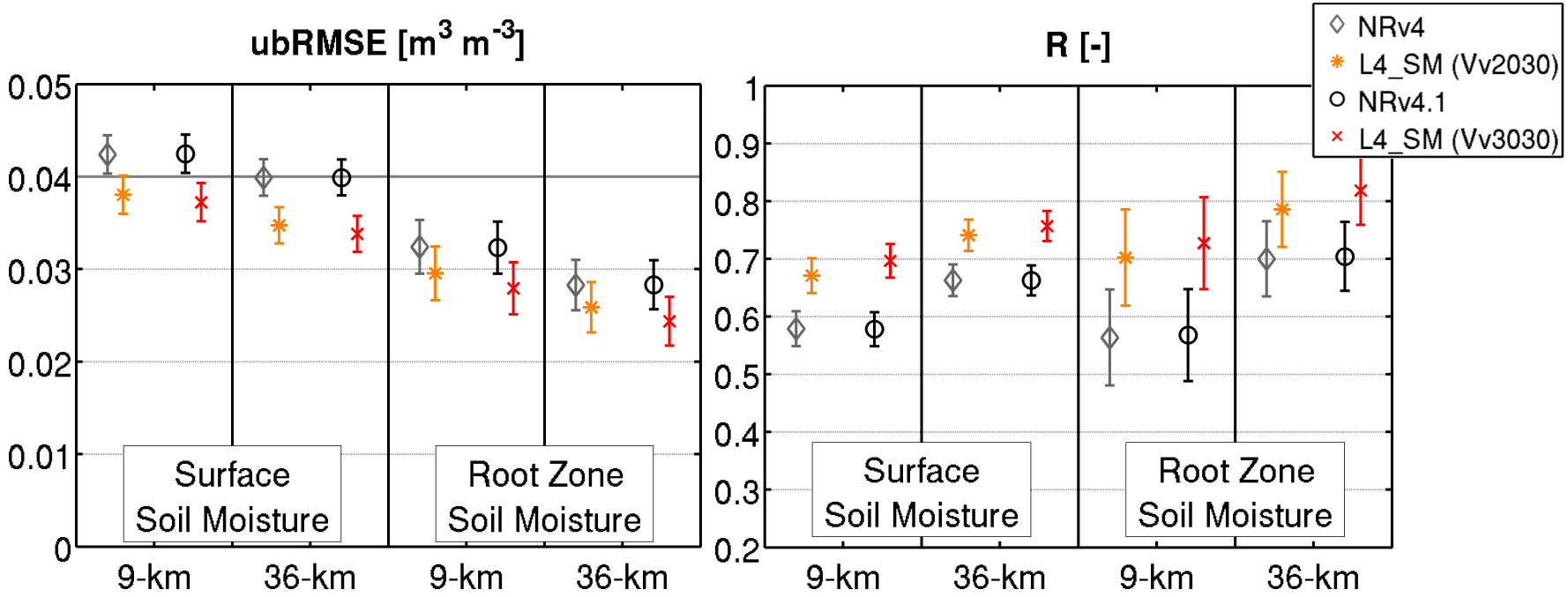
→ Less unrealistic extremes in Version 3

Validation – Core Sites



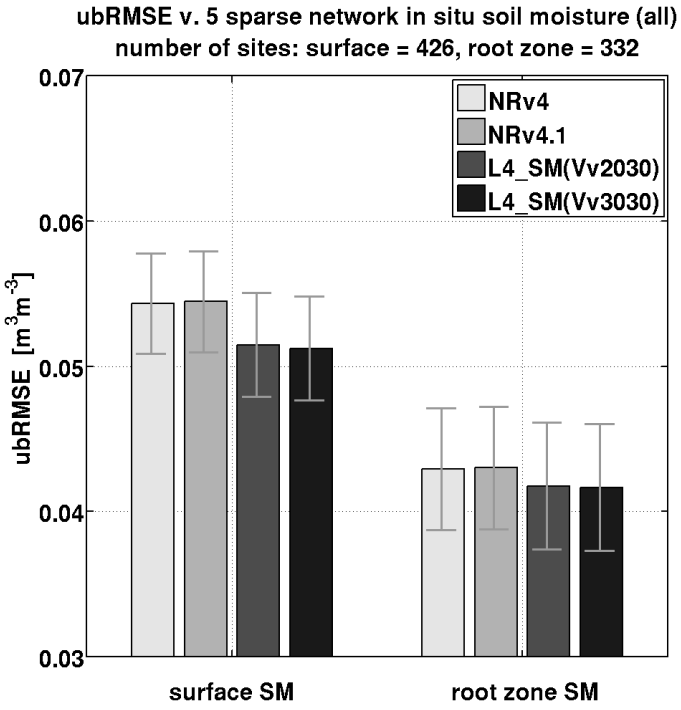
- Version 2 & 3 are consistent and agree well with in situ measurements

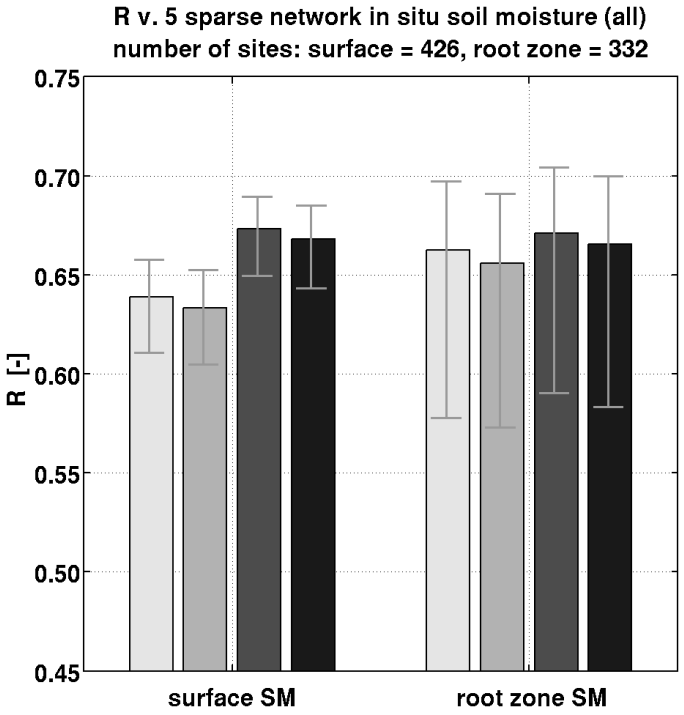
Validation – Core Sites



- NRv4 and NRv4.1 have nearly identical skill
- Version 3 has slightly (but not significantly) better ubRMSE and R skill than Version 2
- **Both versions meet the accuracy requirement**

Validation – Sparse Networks





- Version 3 has slightly (but not significantly) worse R skill than Version 2 (likely a result of the worse skill of NRv4.1)

Summary

- Validation shows that L4_SM data products meet accuracy requirements

Version 3 updates:

- Only minor changes to land model and forcing
- Updated model-only simulation for better estimate of soil moisture climatology
- Updated brightness temperature (Tb) scaling factors

Impact of Version 3 updates:

- Version 3 assimilates ~59% more data than Version 2
- The data assimilation diagnostics are slightly better in Version 3
- The root zone soil moisture percentiles (in particular the extremes) are more realistic in Version 3
- The skill vs. in situ observations is the same (within error bars) for both versions (with slightly higher skill of Version 3 at core sites)

L4_SM Version 3 – Status and Schedule

Task	Date
Software delivery	15 Apr 2017
Testing & verification	18 Apr 2017
Reprocessing	10 May 2017
Forward-processing	On-going
NSIDC User Guide	7 Jun 2017 (draft)
Presentation to ADT	13 Jun 2017
Validation document	TBD
Transfer to NSIDC	In progress
Public release	Mid-July

Current Operational Product Status -- SMAP Streams Only

GSFC local time: 20170613 07:44:24 ET UTC: 20170613 11:44:24 Z

JOB NAME	STATUS	RUNNING	COMPLETED
SMAP Nature v03	Nominal	20170611	06/10/2017
SPL4C Vv2043 002	Nominal	20170602	06/01/2017
SPL4SM Vv2030 002	Nominal	20170611	06/10/2017
SPL4SM Vv3030 003	Nominal	20170611	06/10/2017

L4_SM Version 3 – Model Changes

*Catchment model & forcing for 2015-present **unchanged**, except:*

- *Albedo no longer inferred from net shortwave forcing.*
  (Matters only if snow cover differs between NR and GEOS-5 NWP system providing forcing.)
- *Late-look CPCU precipitation data (minor impact).*

→ Expect ~identical climatology for Version 2 and 3 during SMAP period.

(Objective was to avoid recalibration of L4_C algorithm.)

Updated model-only simulation (NRv4.1):

- *GEOS-**5.12** RP/FP-IT forcing (2000-2014)*
  (NRv4 used GEOS-5.9 RP/FP-IT forcing.)

→ Better matches GEOS-5 FP forcing during SMAP ops period.

Updated soil moisture climatology based on 16-years of NRv4.1:

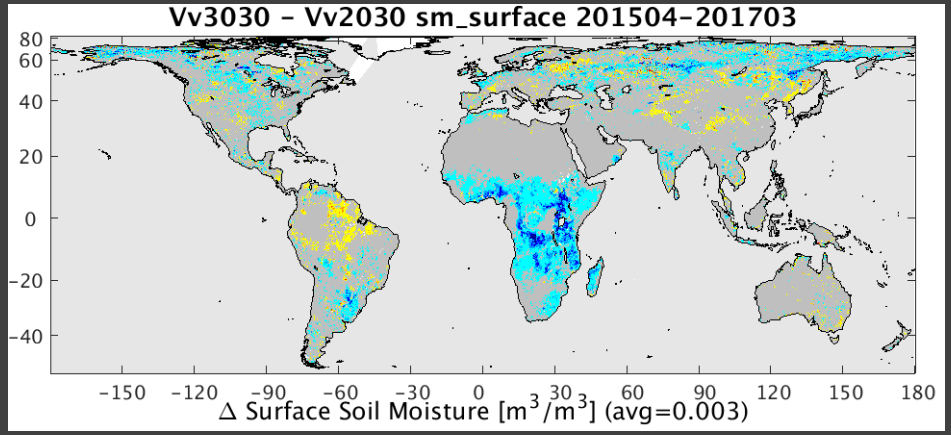
→ Expect better soil moisture percentile output.

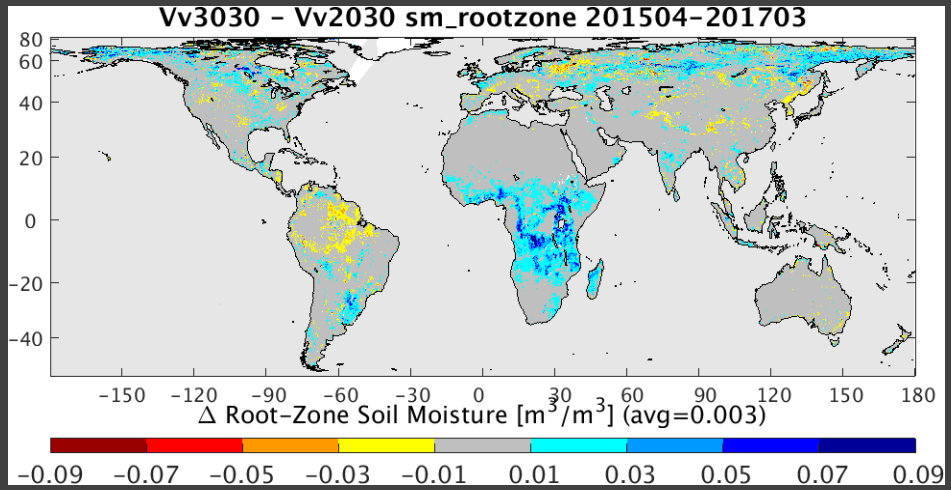
Soil Moisture Climatology

Differences in Africa are because of differences in Tb scaling parameters.

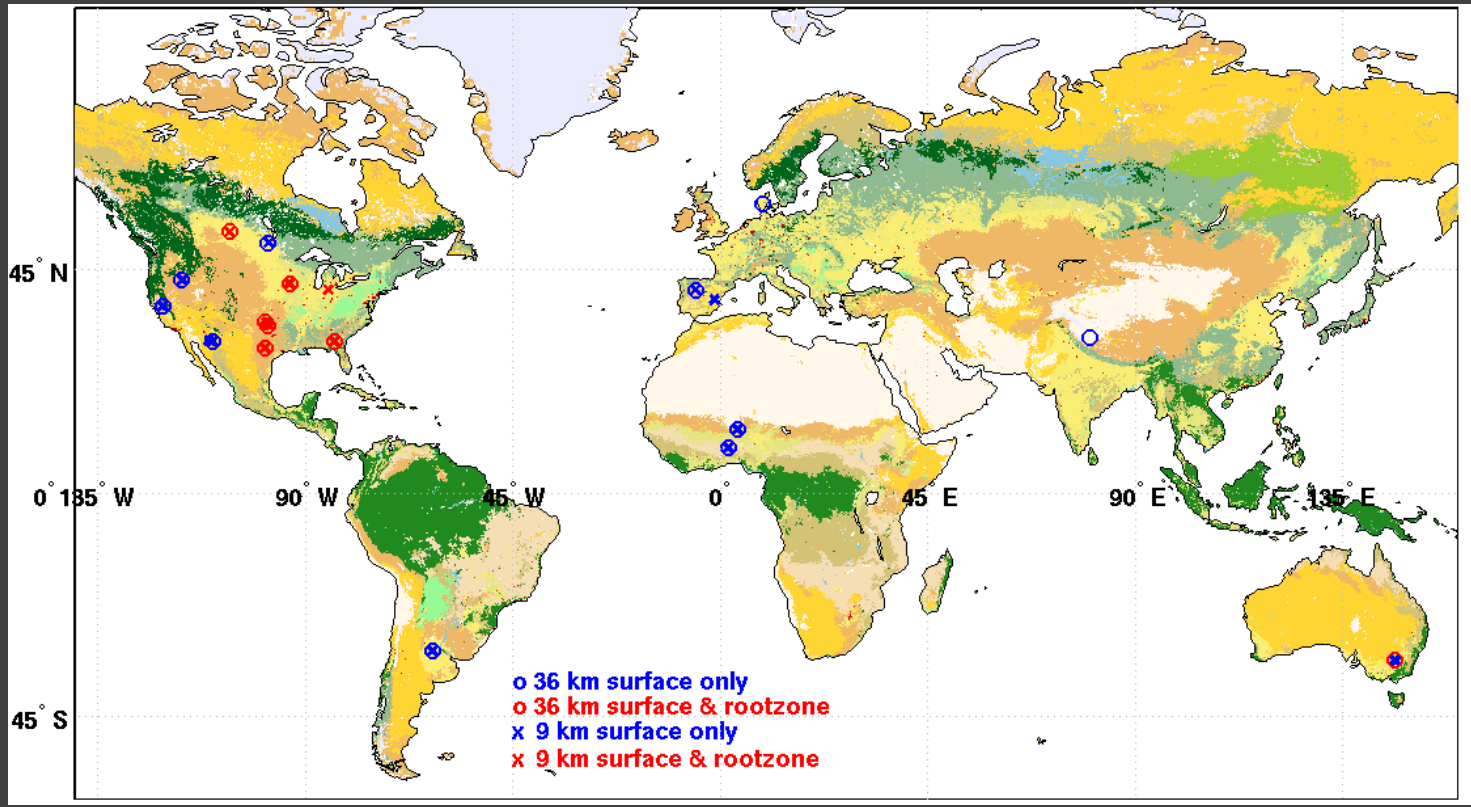
In Africa, precipitation is not corrected, and SMOS-derived scaling parameters are based on model Tbs obtained with different precipitation and other forcing inputs.

Note that in Africa, mean O-F and mean surface soil moisture increments are better in Vv3030 than in Vv2030 (see below).



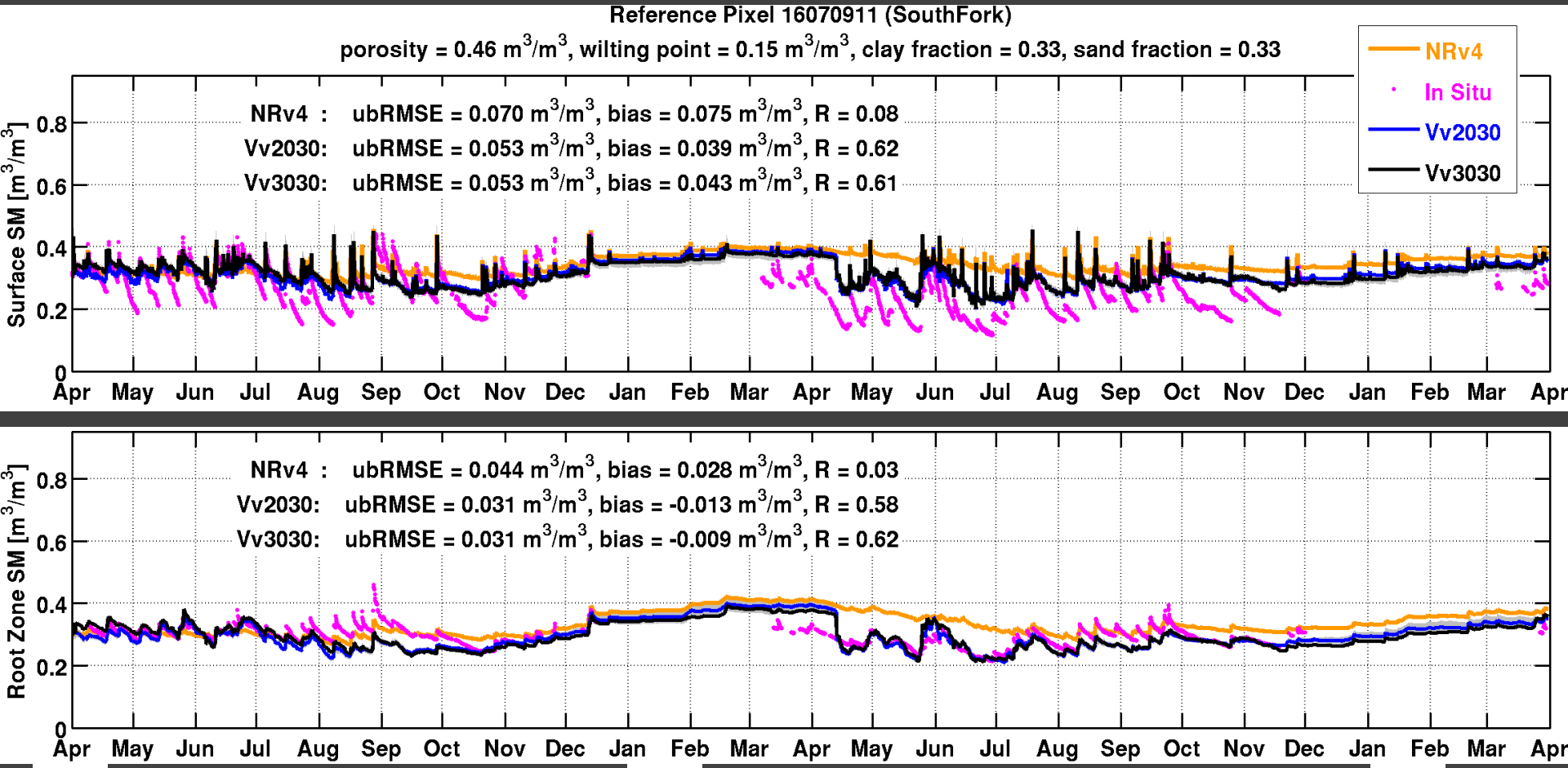


Core Sites

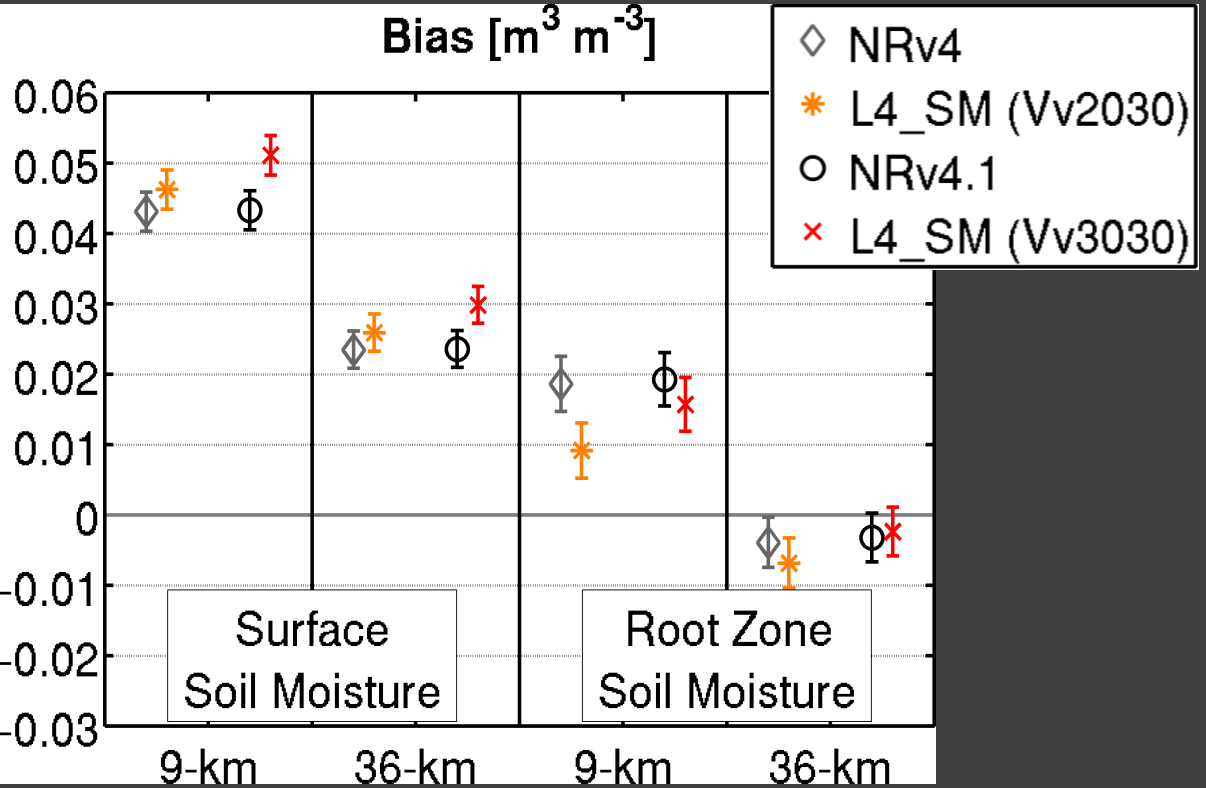


	Surface soil moisture		Root zone soil moisture		Surface Soil Temperature (6am)		Surface Soil Temperature (6pm)	
Horizontal scale	36 km	9 km	36 km	9 km	36 km	9 km	36 km	9 km
Number of different core sites	17	17	7	6	14	12	14	13
Number of reference pixels	17	26	7	9	14	21	14	22

Core Sites


Reference Pixel 16070911 (SouthFork)
porosity = 0.46 m3/m3, wilting point = 0.15 m3/m3, clay fraction = 0.33, sand fraction = 0.33
NRv4
In Situ
Vv2030
Vv3030
NRv4 : ubRMSE = 0.070 m3/m3, bias = 0.075 m3/m3, R = 0.08
Vv2030: ubRMSE = 0.053 m3/m3, bias = 0.039 m3/m3, R = 0.62
Vv3030: ubRMSE = 0.053 m3/m3, bias = 0.043 m3/m3, R = 0.61
Surface SM [m3/m3]
0
0.2
0.4
0.6
0.8
Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr
NRv4 : ubRMSE = 0.044 m3/m3, bias = 0.028 m3/m3, R = 0.03
Vv2030: ubRMSE = 0.031 m3/m3, bias = -0.013 m3/m3, R = 0.58
Vv3030: ubRMSE = 0.031 m3/m3, bias = -0.009 m3/m3, R = 0.62
Root Zone SM [m3/m3]
0
0.2
0.4
0.6
0.8
Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr
2015
2016
2017

Core Sites



- *NRv4 and NRv4.1 have same skill.*
- *Vv3030 bias slightly (but not significantly) worse than Vv2030.*
- *Soil temperature skill unchanged between Vv2030 and Vv3030 (extra slides).*

Sparse Networks

Changes from submitted JHM paper:

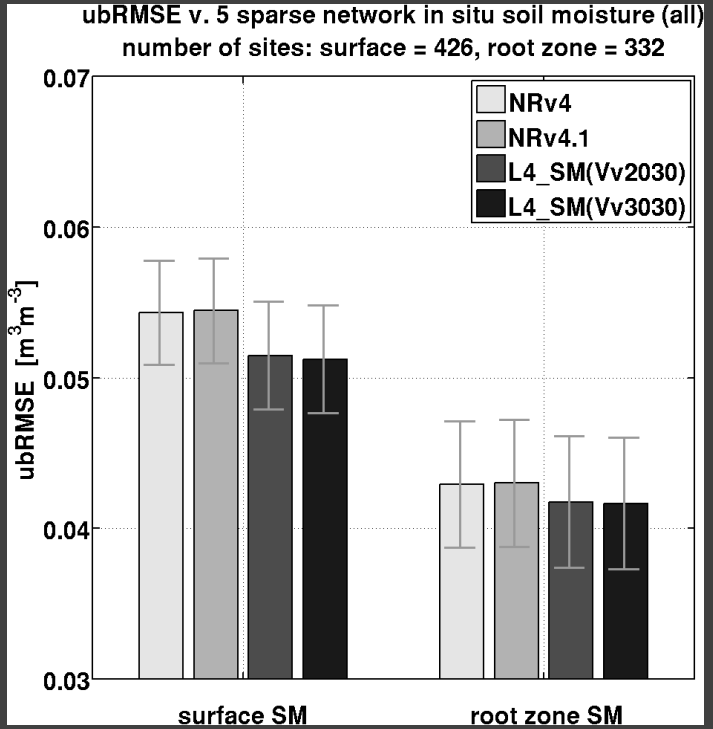
Validation Period: *1 Apr 2015 – 31 Mar 2017*

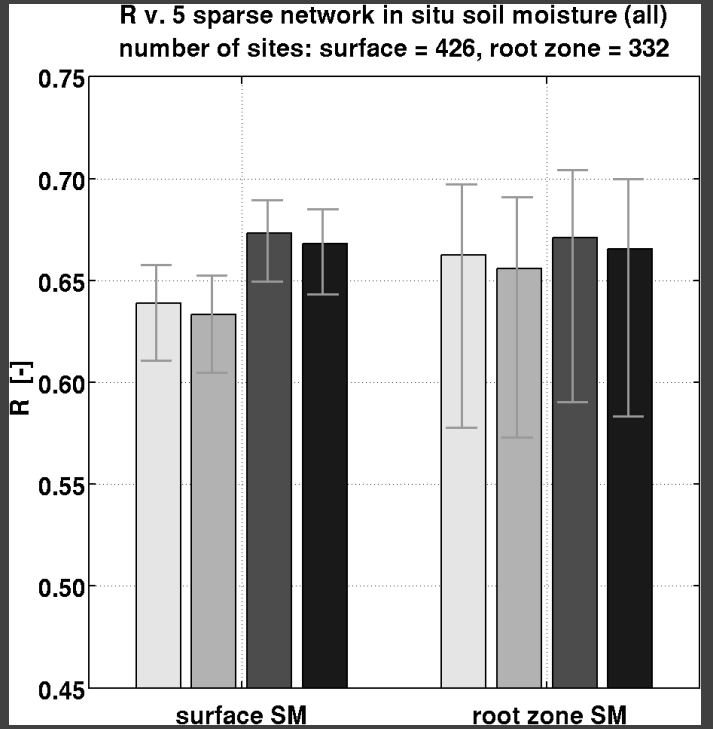
Added SMOSMANIA network: *surface 20*
root zone 21

Added SCAN sites: *surface 5*
root zone 14

Network	Area	Sensor Depths (cm)	N	
			Surface Soil Moisture	Root Zone Soil Moisture
SCAN	USA	5, 10, 20	135	129
USCRN	USA	5, 10, 20	111	87
OK Mesonet	Oklahoma	5, 25, 60	42	18
OzNet	Australia	4, 45	118	77
SMOSMANIA	France	5, 20	20	21
All Networks			***426***	***332***

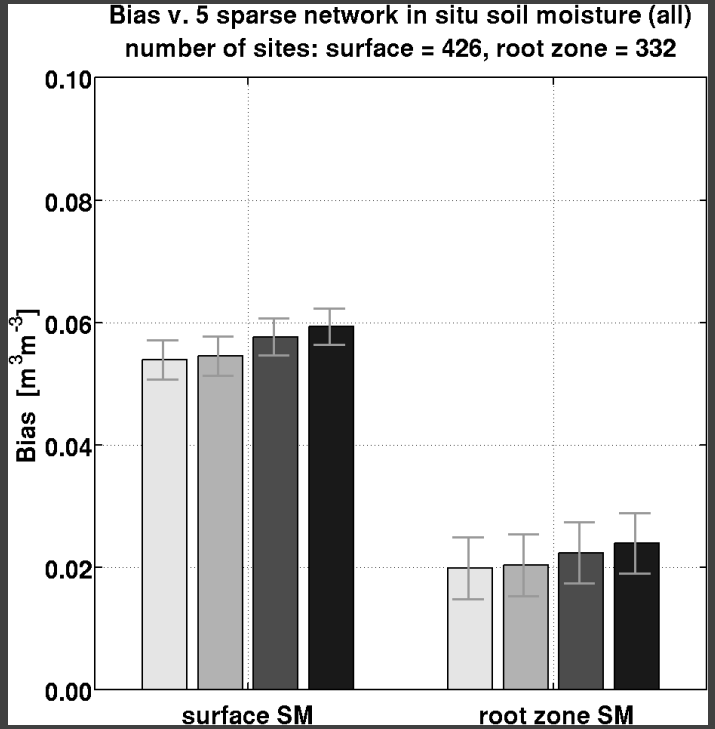
Sparse Networks

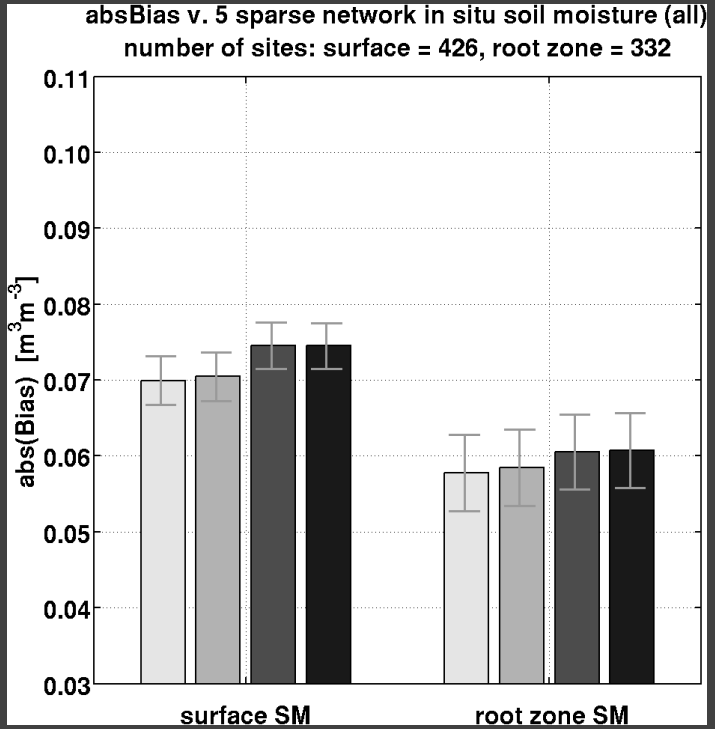




Vv3030 has slightly (but not significantly) worse R skill than Vv2030 because NRv4.1 is slightly worse than NRv4.

Sparse Networks

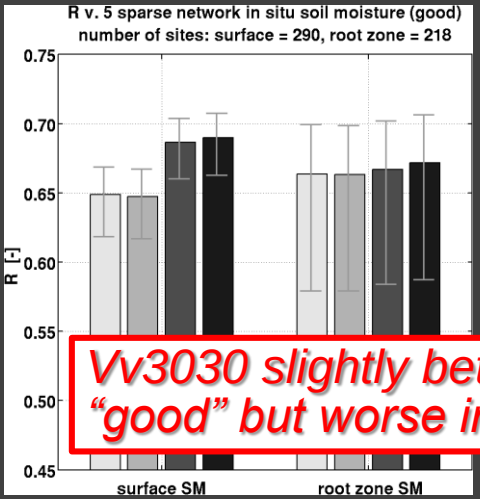


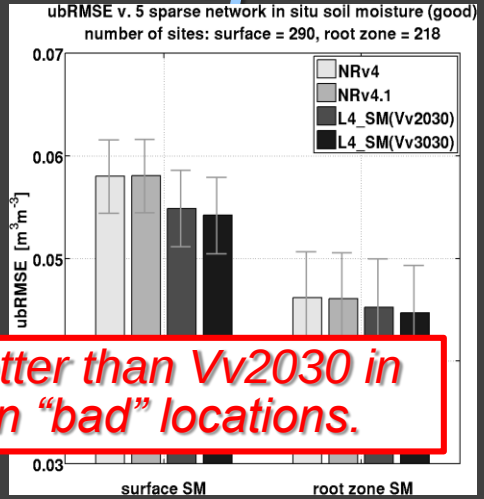


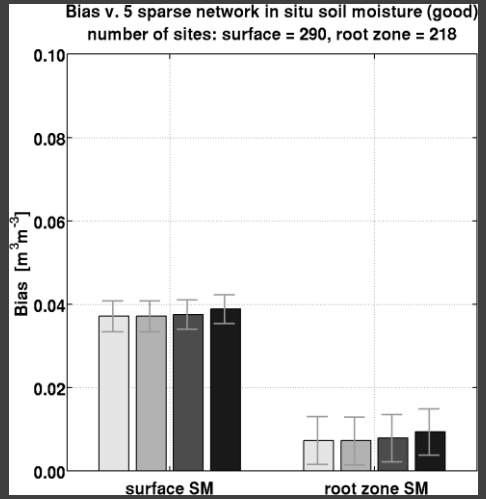
Vv3030 has slightly (but not significantly) worse bias than Vv2030, partly because NRv4.1 is slightly more biased than NRv4.

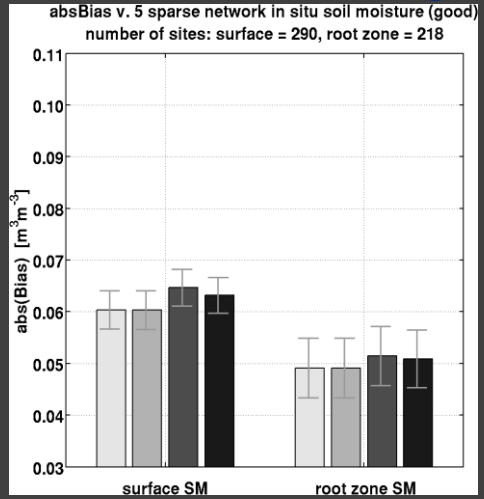
GMAO

Sparse Networks

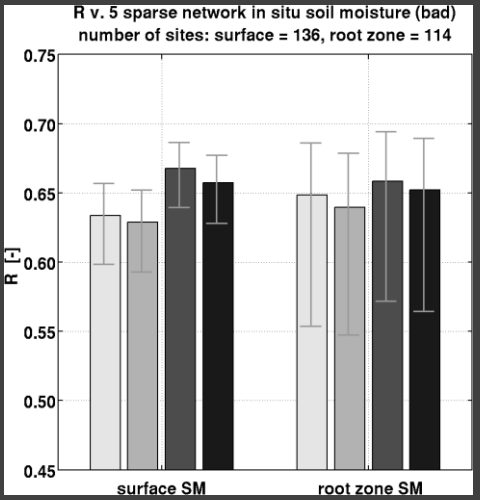


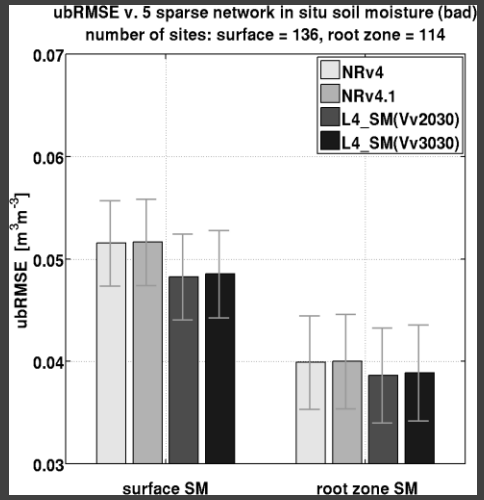


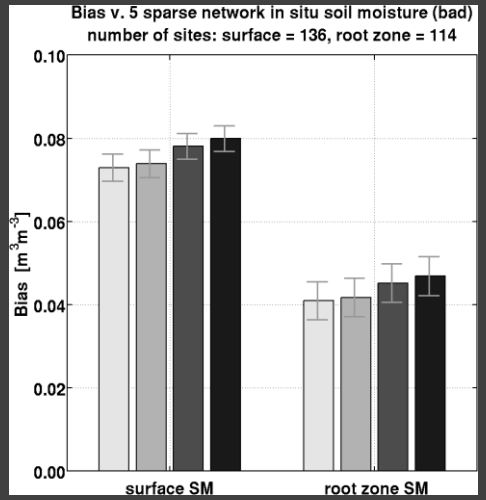


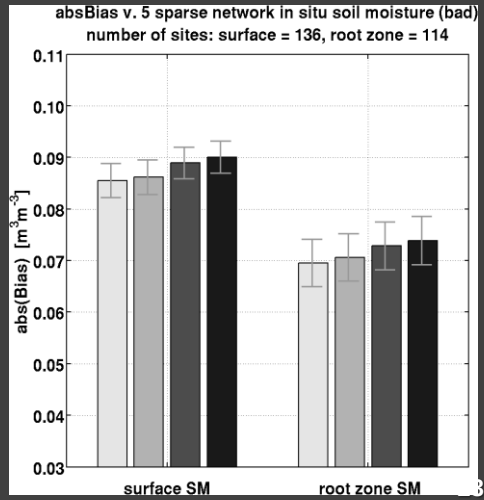


Vv3030 slightly better than Vv2030 in "good" but worse in "bad" locations.

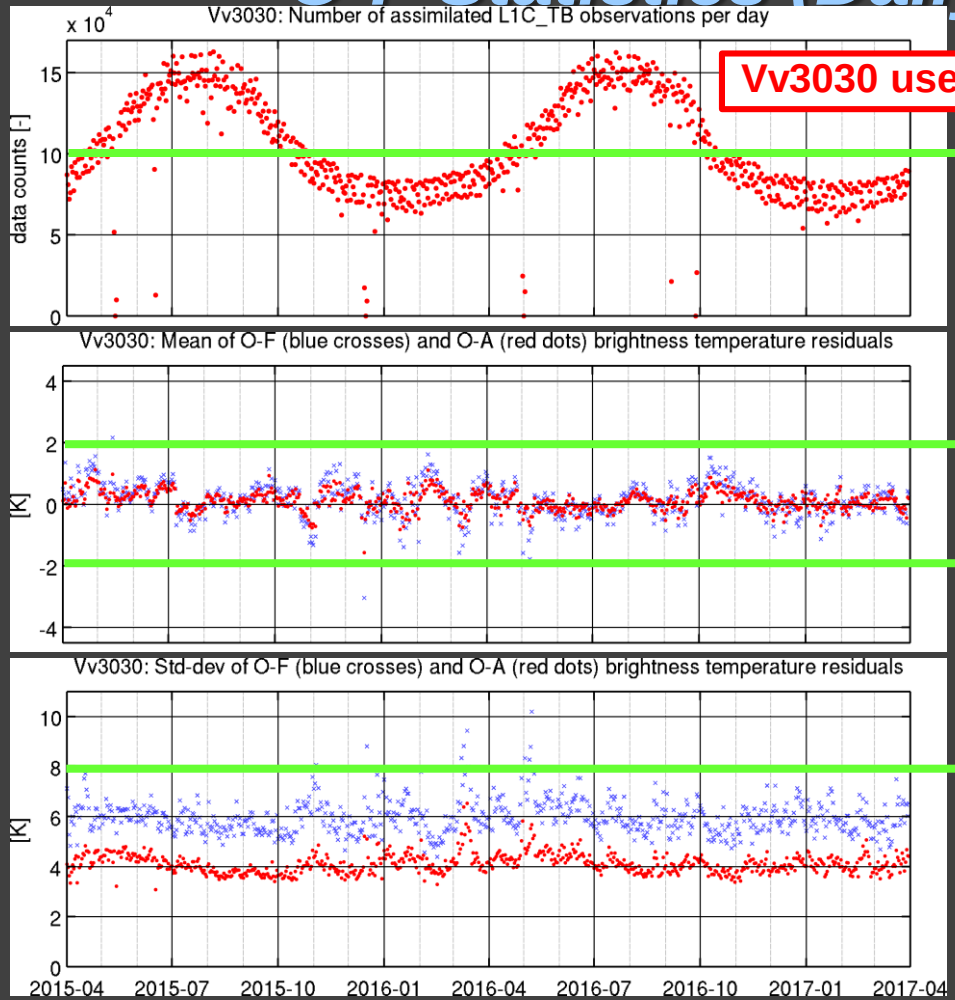


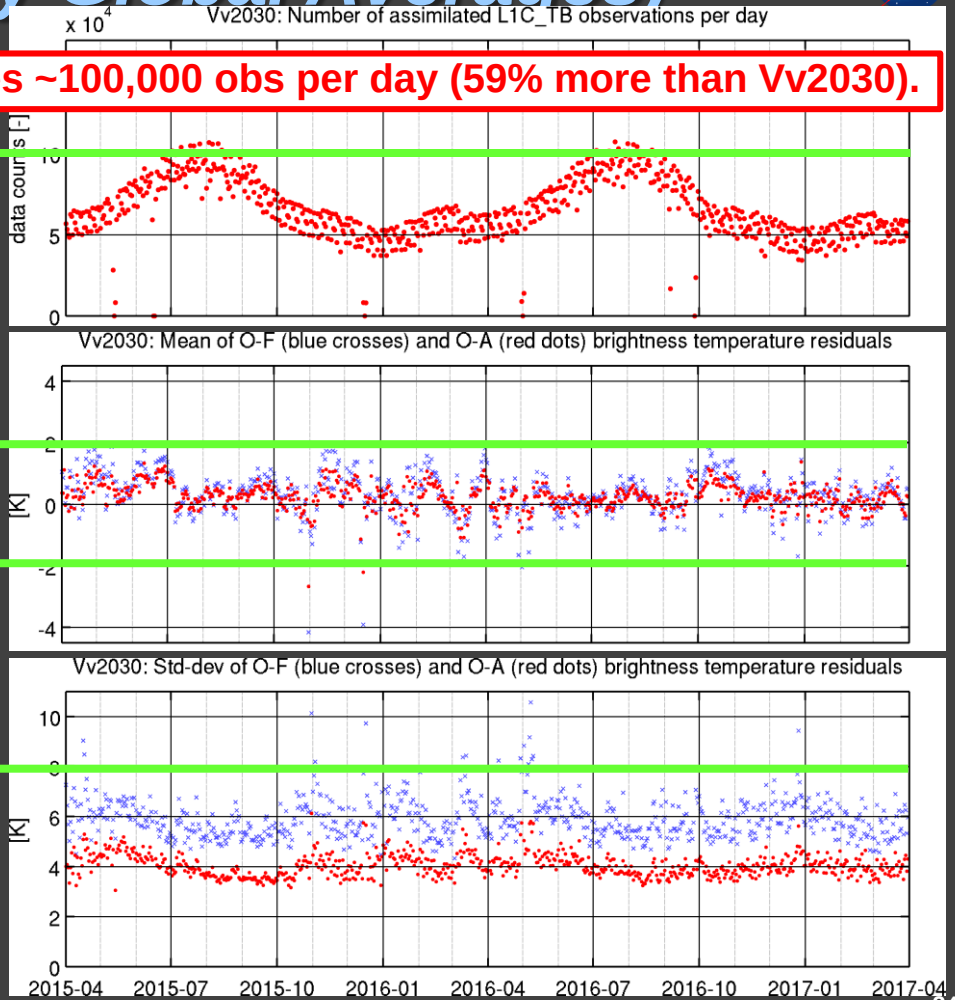






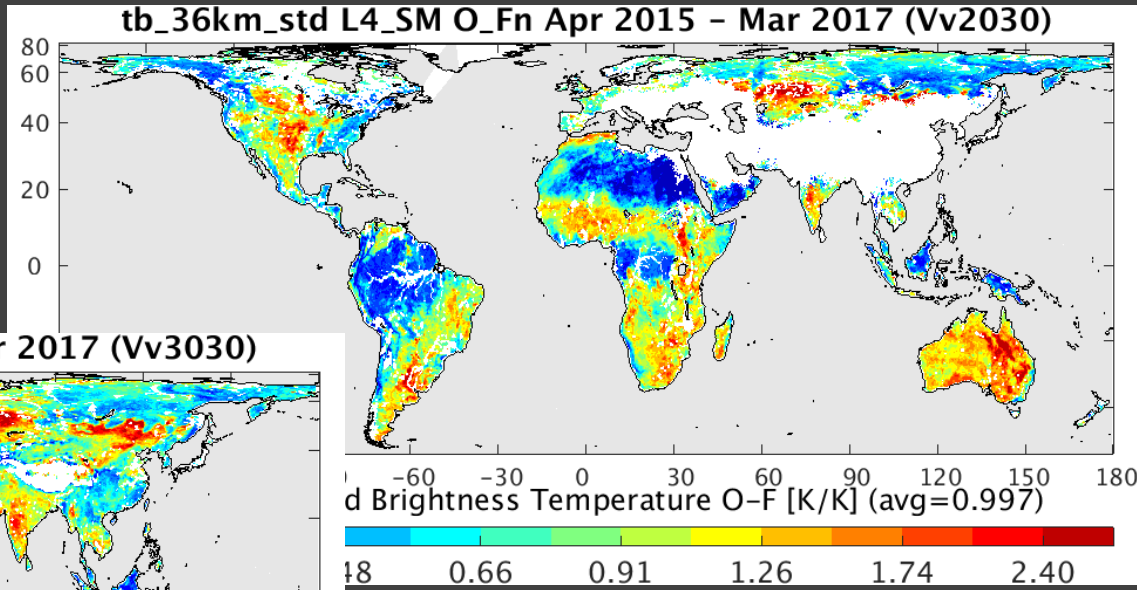
O-F Statistics (Daily Global Averages)

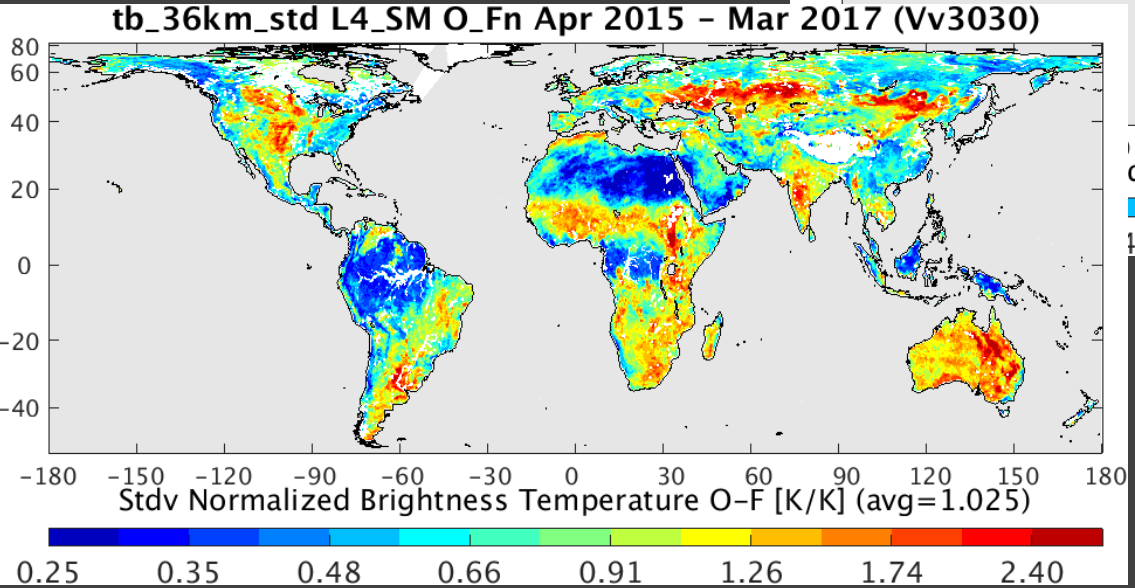




Vv3030 uses ~100,000 obs per day (59% more than Vv2030).

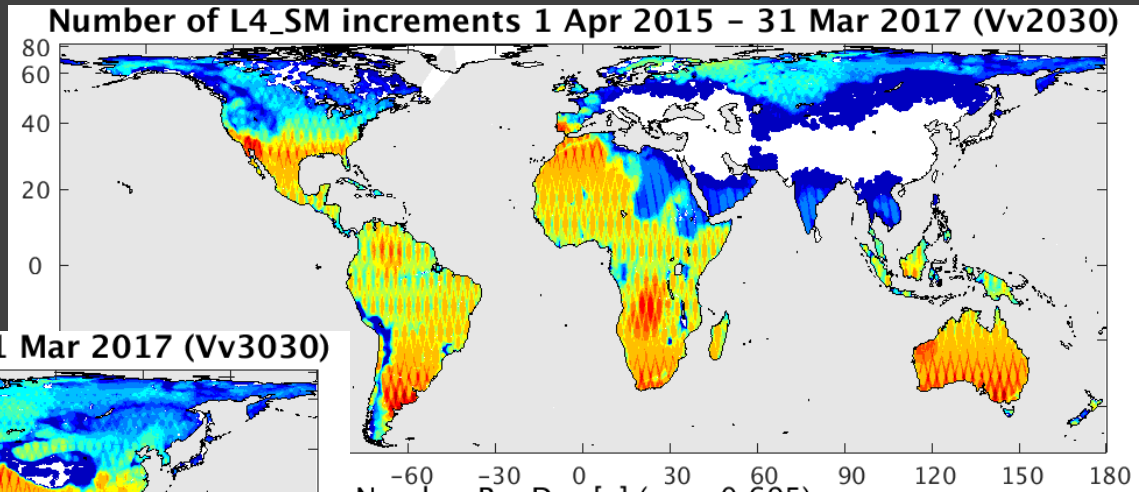
Std-dev Normalized O-F

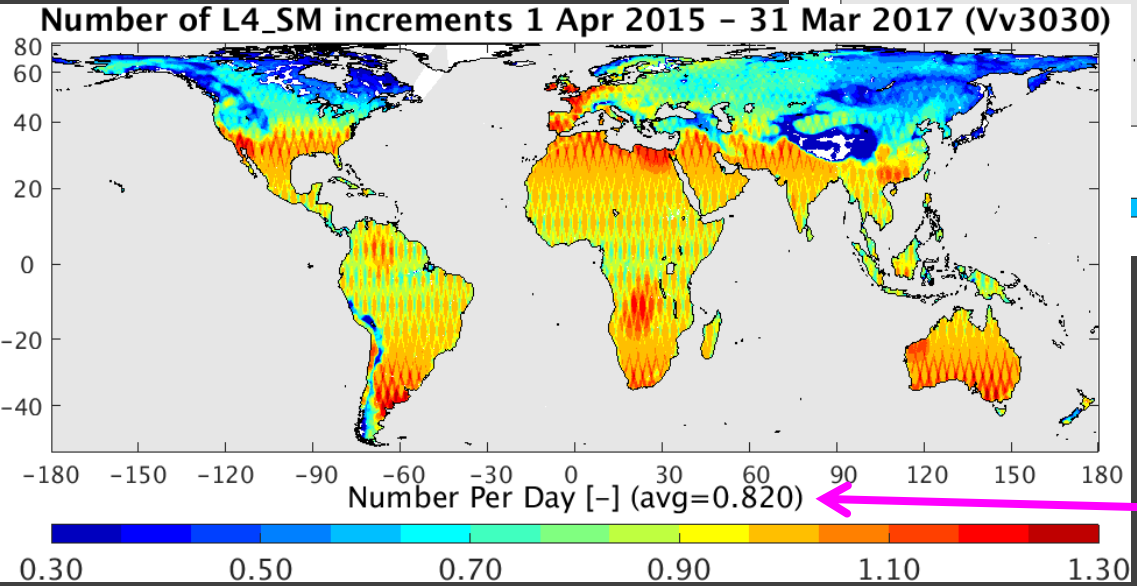




GMAO

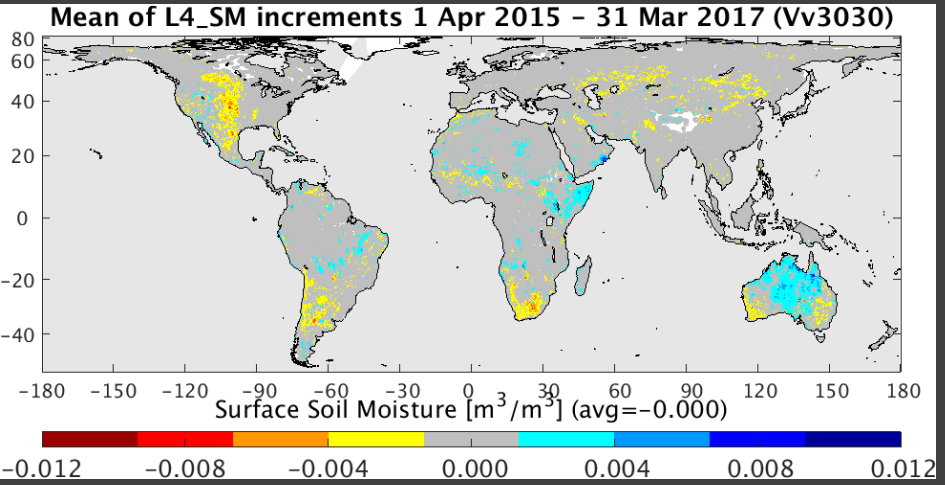
Number of Increments

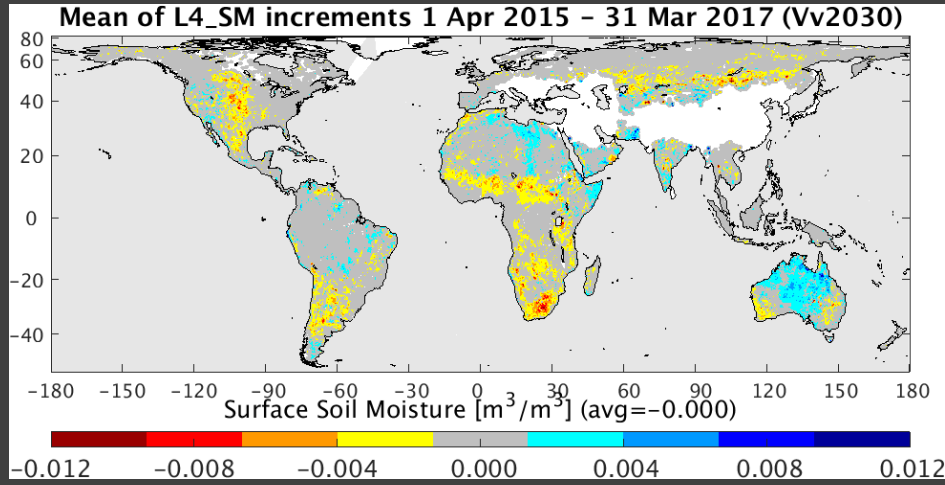


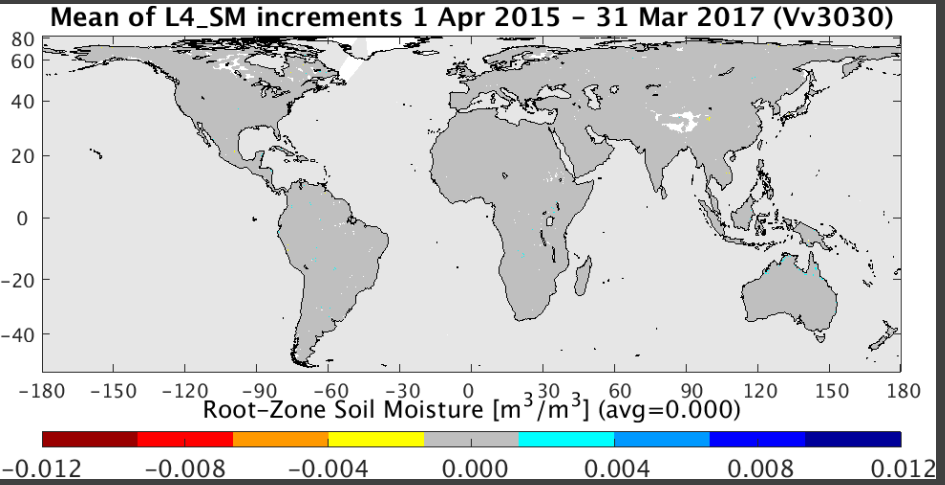


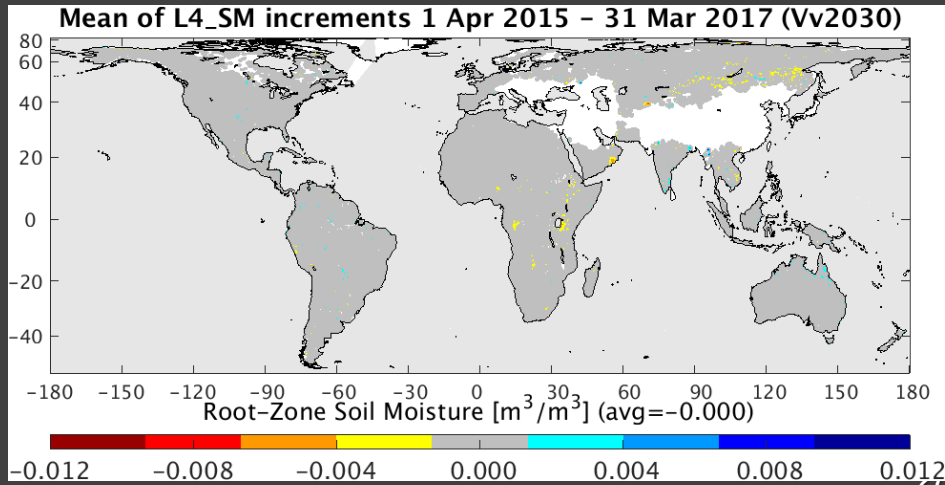
Averages exclude no-data regions

Mean Increments

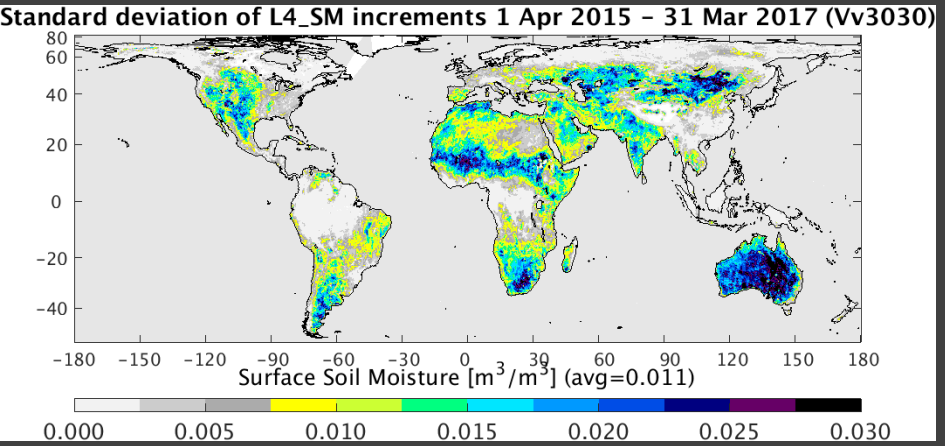


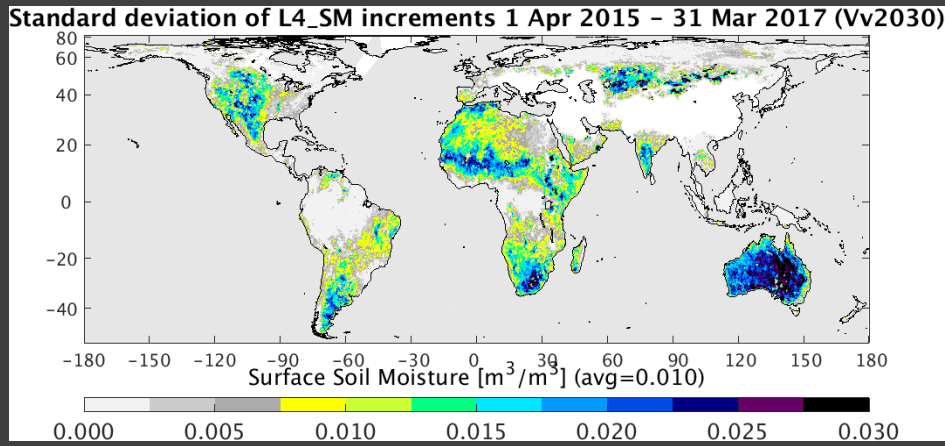


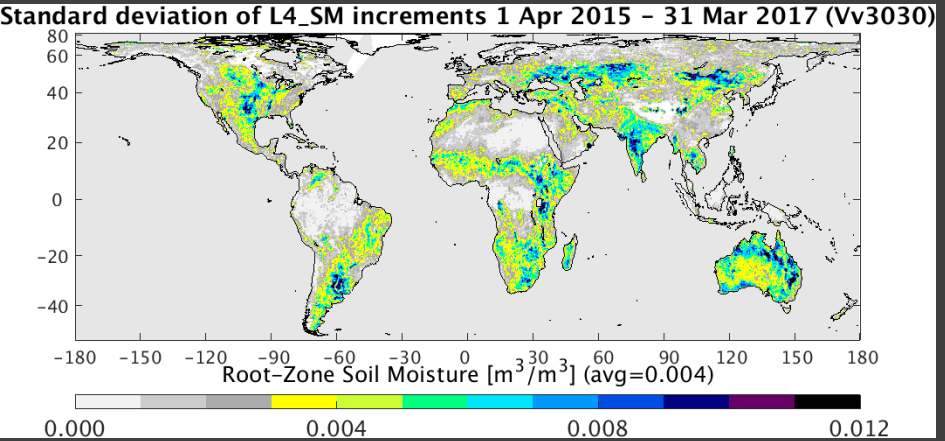


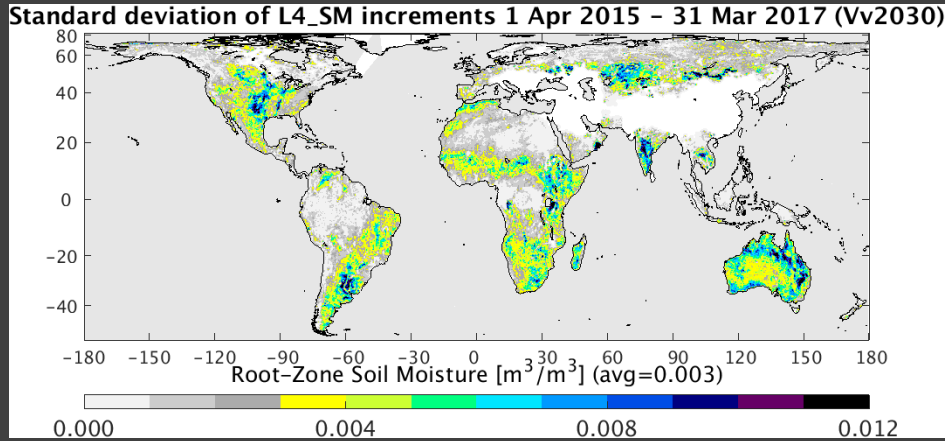


Std-dev Increments

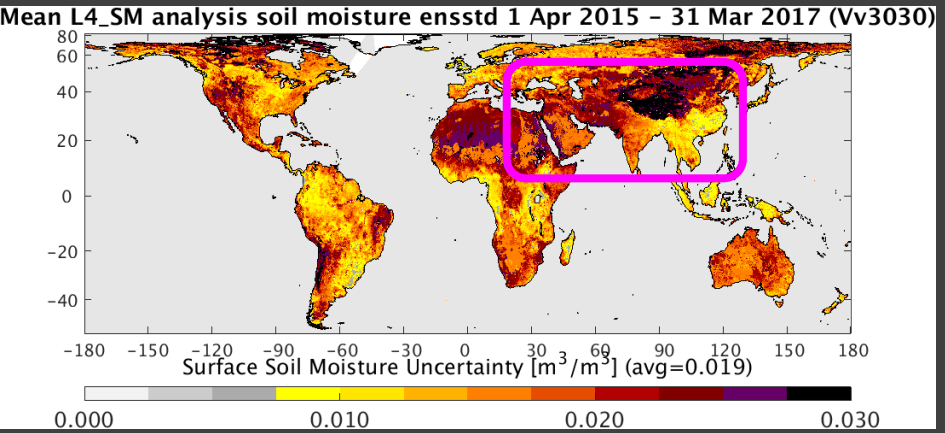


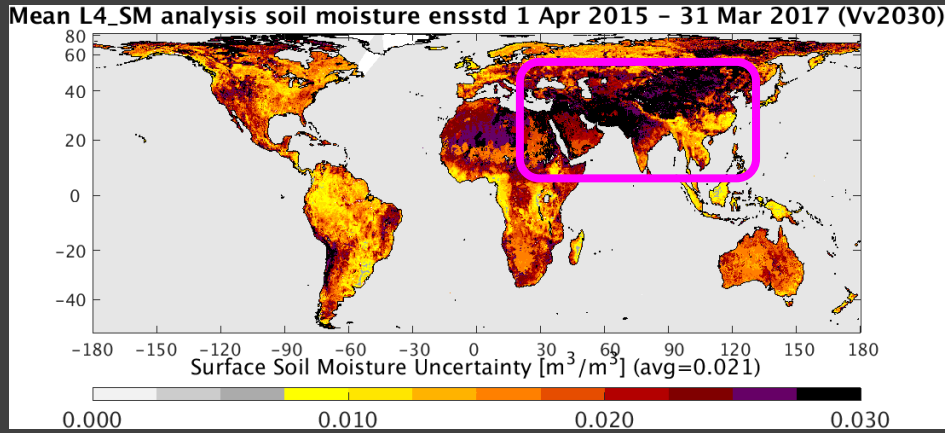


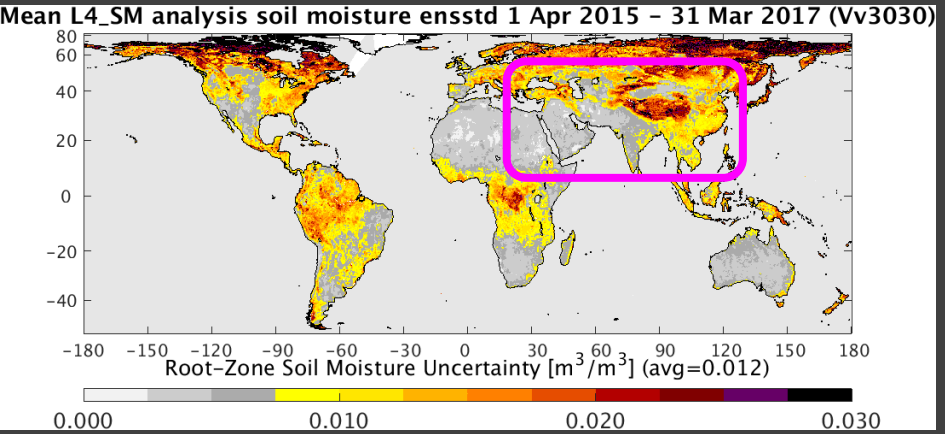


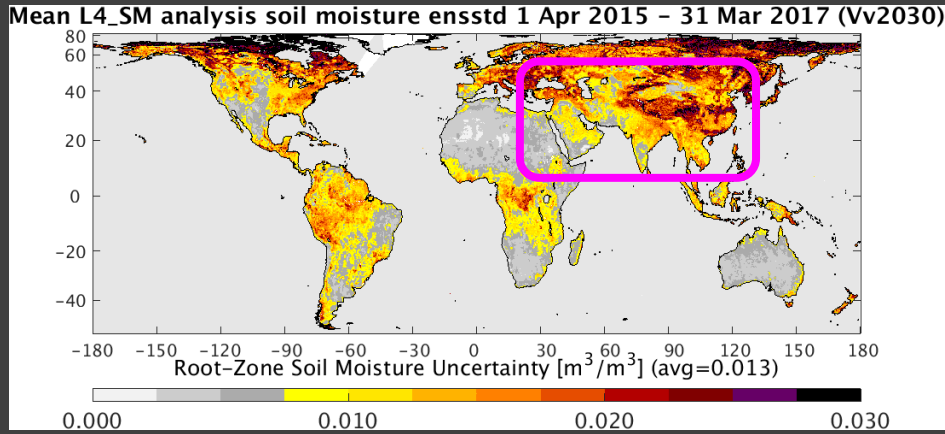


Uncertainty Estimates



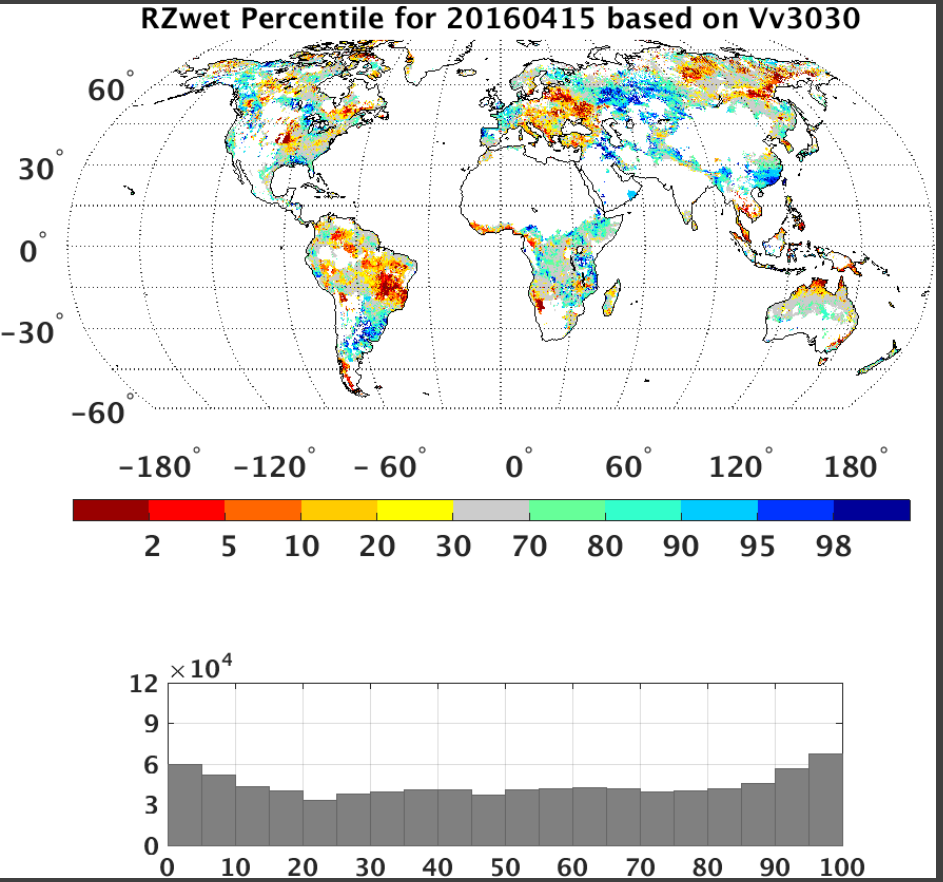


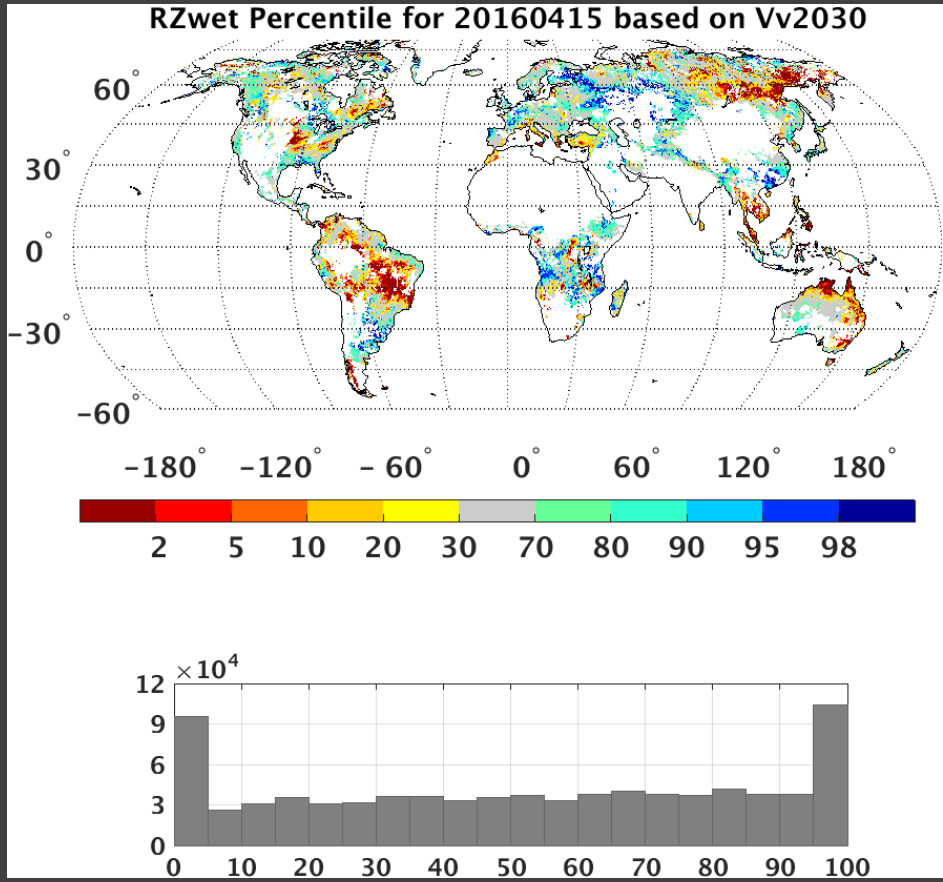




Vv3030 has lower estimated uncertainty areas where Vv2030 did not use SMAP obs.

Root-Zone Soil Moisture in Percentile Units





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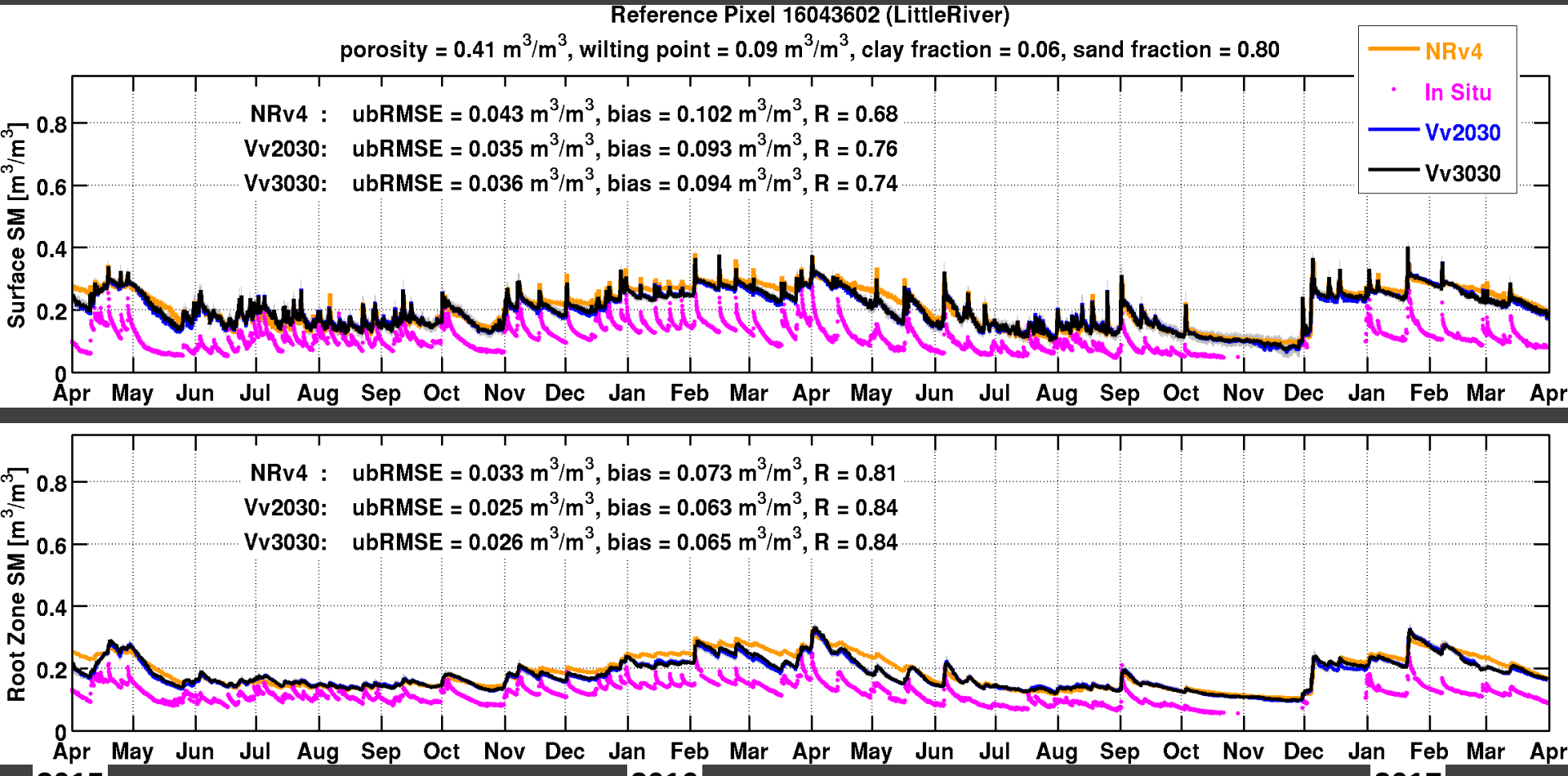
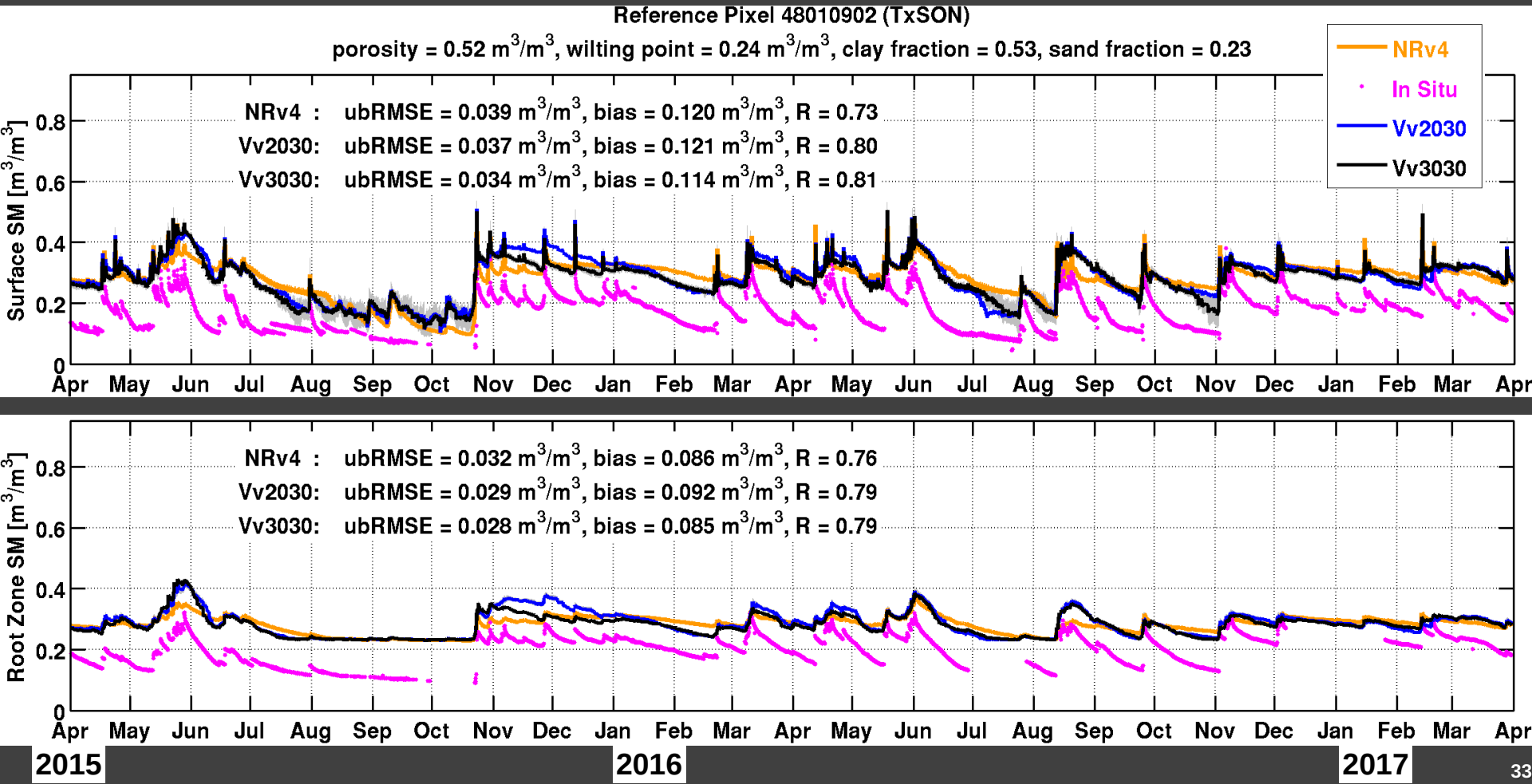
Summary

- *Validation conducted for 2-year period (Apr 2015 – Mar 2017).*
- *L4_SM Vv**3**030 assimilates ~59% more SMAP obs. than Vv**2**030 because 2 years of SMAP information was used to fill in the Tb scaling parameters where RFI makes SMOS unavailable.*
- *Skill vs. in situ obs. is the same (within error bars) for Vv**3**030 & Vv**2**030, with Vv**3**030 slightly better vs. core site obs. Vv**3**030 meets accuracy requirement.*
- *Vv**3**030 has slightly better O-F and increments statistics than Vv**2**030.*
- *Root zone soil moisture in percentiles is more consistent for Vv**3**030 than Vv**2**030.*
- *Vv**3**030 system reports range check failures that were present but missed previously. Range check failures occur very occasionally, most of them owing to interpolation details in the precipitation corrections algorithm.*
- *Vv**3**030 also includes the following minor fixes:*
  - *Used late-look CPCU precipitation data during reprocessing.*
  - *Used R**14** L1C_TB through 6 Dec 2016, with bad half-orbits excluded.*

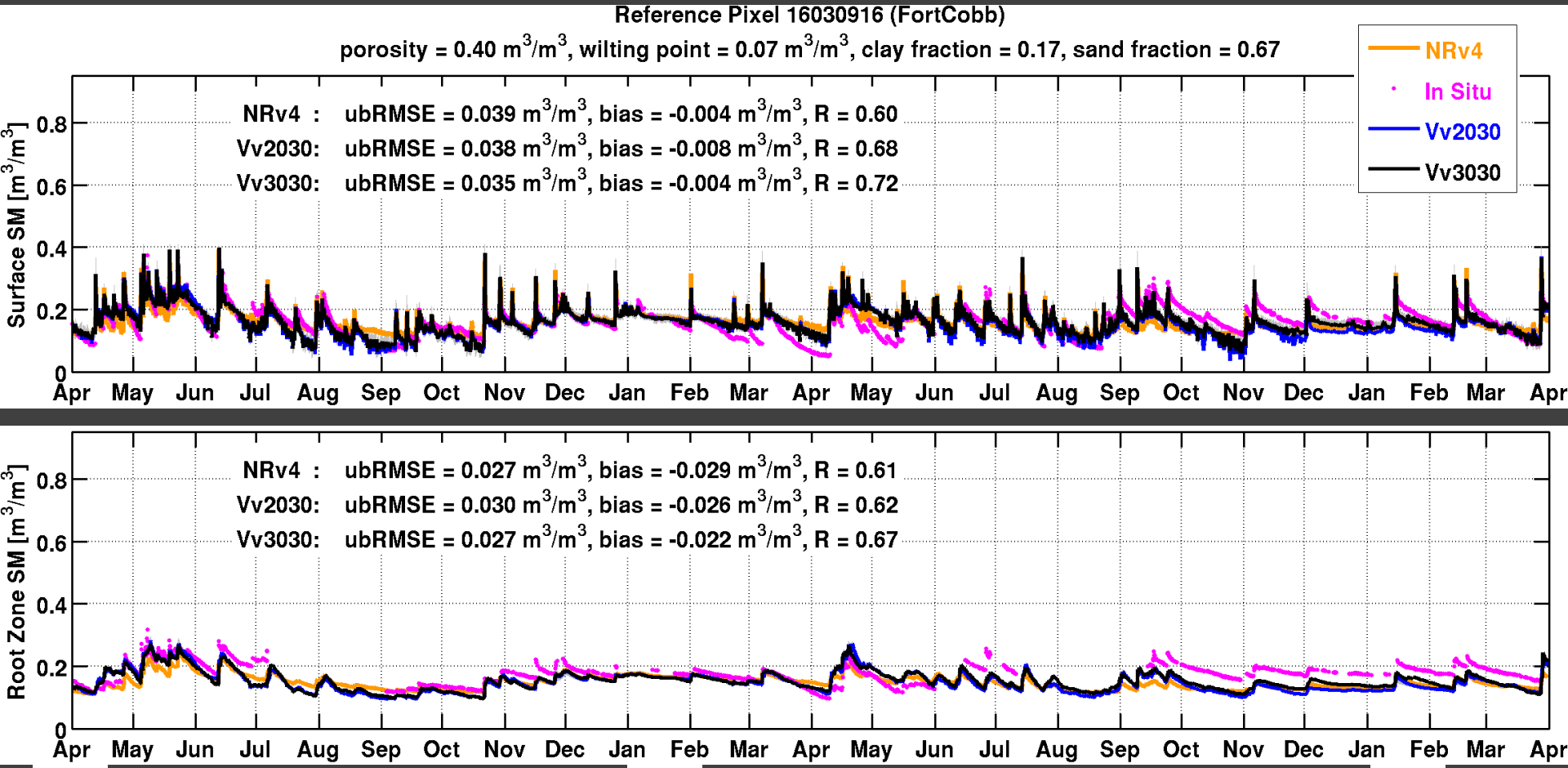
Core Sites


Reference Pixel 16043602 (LittleRiver)
porosity = 0.41 m3/m3, wilting point = 0.09 m3/m3, clay fraction = 0.06, sand fraction = 0.80
NRv4
In Situ
Vv2030
Vv3030
NRv4 : ubRMSE = 0.043 m3/m3, bias = 0.102 m3/m3, R = 0.68
Vv2030: ubRMSE = 0.035 m3/m3, bias = 0.093 m3/m3, R = 0.76
Vv3030: ubRMSE = 0.036 m3/m3, bias = 0.094 m3/m3, R = 0.74
Surface SM [m3/m3]
0
0.2
0.4
0.6
0.8
Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr
NRv4 : ubRMSE = 0.033 m3/m3, bias = 0.073 m3/m3, R = 0.81
Vv2030: ubRMSE = 0.025 m3/m3, bias = 0.063 m3/m3, R = 0.84
Vv3030: ubRMSE = 0.026 m3/m3, bias = 0.065 m3/m3, R = 0.84
Root Zone SM [m3/m3]
0
0.2
0.4
0.6
0.8
Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr
2015
2016
2017

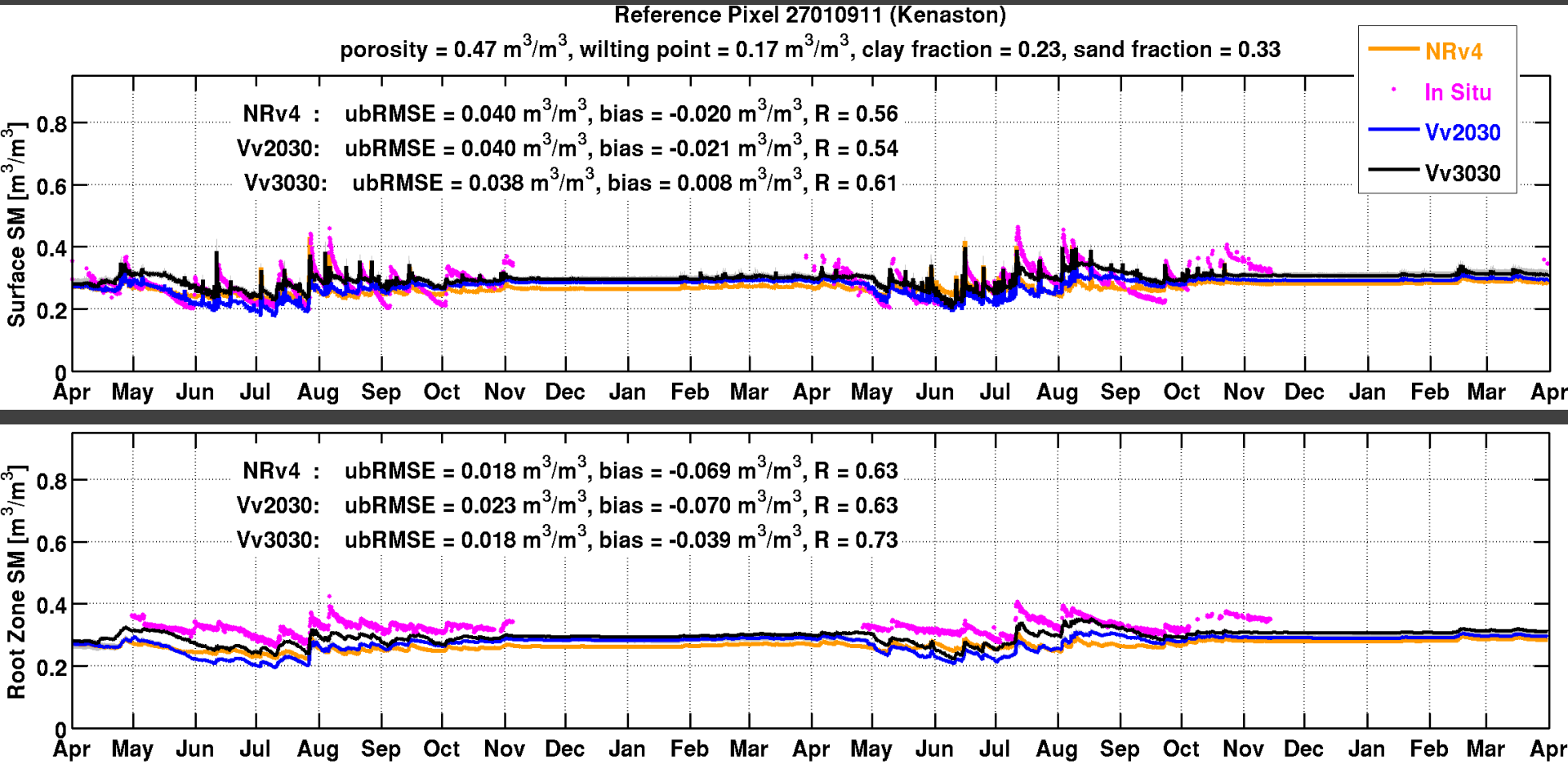
Core Sites


Reference Pixel 48010902 (TxSON)
porosity = 0.52 m3/m3, wilting point = 0.24 m3/m3, clay fraction = 0.53, sand fraction = 0.23
NRv4
In Situ
Vv2030
Vv3030
NRv4 : ubRMSE = 0.039 m3/m3, bias = 0.120 m3/m3, R = 0.73
Vv2030: ubRMSE = 0.037 m3/m3, bias = 0.121 m3/m3, R = 0.80
Vv3030: ubRMSE = 0.034 m3/m3, bias = 0.114 m3/m3, R = 0.81
Surface SM [m3/m3]
NRv4 : ubRMSE = 0.032 m3/m3, bias = 0.086 m3/m3, R = 0.76
Vv2030: ubRMSE = 0.029 m3/m3, bias = 0.092 m3/m3, R = 0.79
Vv3030: ubRMSE = 0.028 m3/m3, bias = 0.085 m3/m3, R = 0.79
Root Zone SM [m3/m3]
0
0.2
0.4
0.6
0.8
Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr
2015
2016
2017

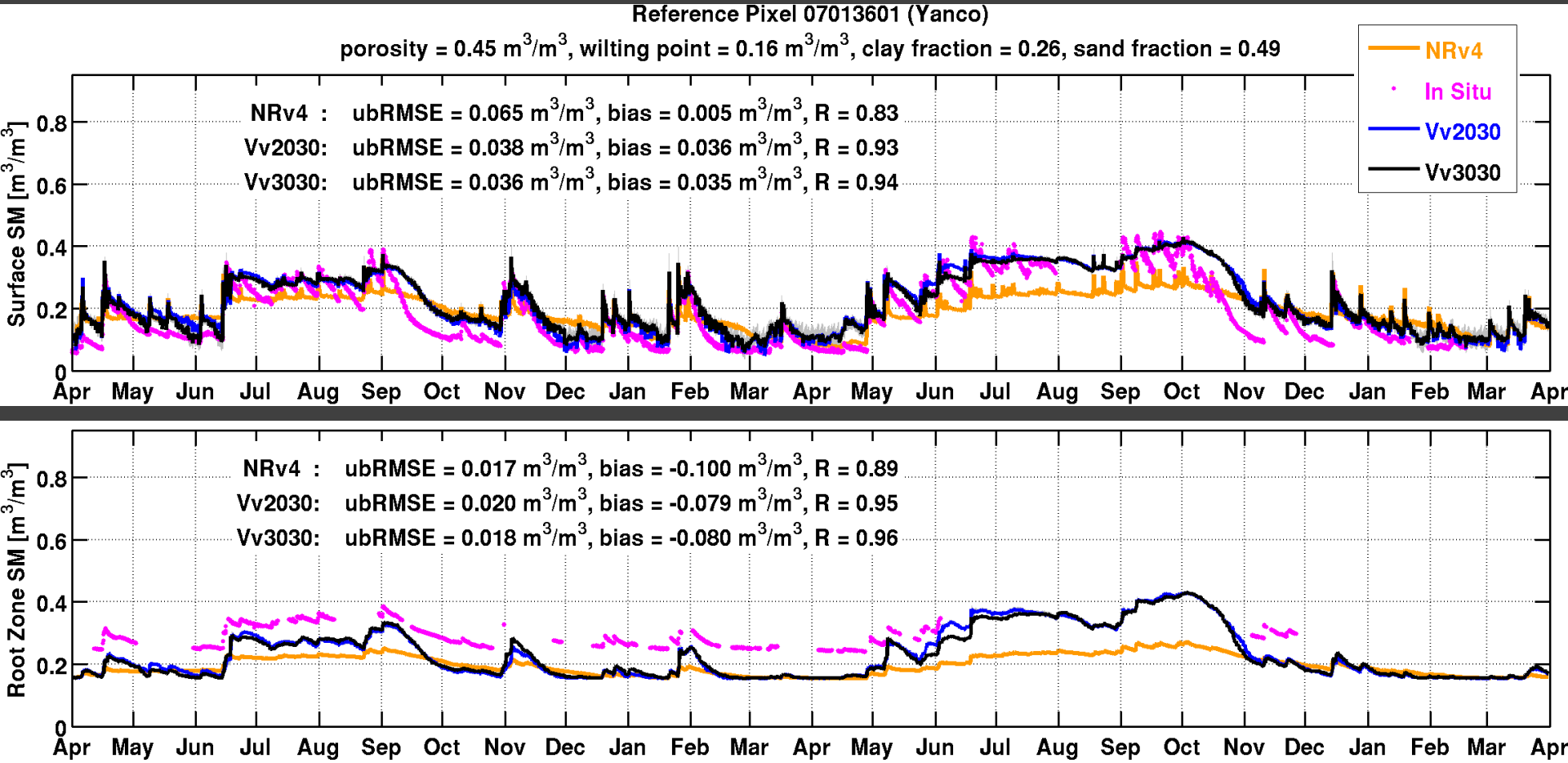
Core Sites


Reference Pixel 16030916 (FortCobb)
porosity = 0.40 m3/m3, wilting point = 0.07 m3/m3, clay fraction = 0.17, sand fraction = 0.67
NRv4
In Situ
Vv2030
Vv3030
NRv4 : ubRMSE = 0.039 m3/m3, bias = -0.004 m3/m3, R = 0.60
Vv2030: ubRMSE = 0.038 m3/m3, bias = -0.008 m3/m3, R = 0.68
Vv3030: ubRMSE = 0.035 m3/m3, bias = -0.004 m3/m3, R = 0.72
Surface SM [m3/m3]
0
0.2
0.4
0.6
0.8
Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr
NRv4 : ubRMSE = 0.027 m3/m3, bias = -0.029 m3/m3, R = 0.61
Vv2030: ubRMSE = 0.030 m3/m3, bias = -0.026 m3/m3, R = 0.62
Vv3030: ubRMSE = 0.027 m3/m3, bias = -0.022 m3/m3, R = 0.67
Root Zone SM [m3/m3]
0
0.2
0.4
0.6
0.8
Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr
2015
2016
2017

Core Sites


Reference Pixel 27010911 (Kenaston)
porosity = 0.47 m3/m3, wilting point = 0.17 m3/m3, clay fraction = 0.23, sand fraction = 0.33
NRv4
In Situ
Vv2030
Vv3030
NRv4 : ubRMSE = 0.040 m3/m3, bias = -0.020 m3/m3, R = 0.56
Vv2030: ubRMSE = 0.040 m3/m3, bias = -0.021 m3/m3, R = 0.54
Vv3030: ubRMSE = 0.038 m3/m3, bias = 0.008 m3/m3, R = 0.61
Surface SM [m3/m3]
0
0.2
0.4
0.6
0.8
Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr
NRv4 : ubRMSE = 0.018 m3/m3, bias = -0.069 m3/m3, R = 0.63
Vv2030: ubRMSE = 0.023 m3/m3, bias = -0.070 m3/m3, R = 0.63
Vv3030: ubRMSE = 0.018 m3/m3, bias = -0.039 m3/m3, R = 0.73
Root Zone SM [m3/m3]
0
0.2
0.4
0.6
0.8
Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr
2015
2016
2017

Core Sites


Reference Pixel 07013601 (Yanco)
porosity = 0.45 m3/m3, wilting point = 0.16 m3/m3, clay fraction = 0.26, sand fraction = 0.49
NRv4
In Situ
Vv2030
Vv3030
NRv4 : ubRMSE = 0.065 m3/m3, bias = 0.005 m3/m3, R = 0.83
Vv2030: ubRMSE = 0.038 m3/m3, bias = 0.036 m3/m3, R = 0.93
Vv3030: ubRMSE = 0.036 m3/m3, bias = 0.035 m3/m3, R = 0.94
Surface SM [m3/m3]
0
0.2
0.4
0.6
0.8
Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr
NRv4 : ubRMSE = 0.017 m3/m3, bias = -0.100 m3/m3, R = 0.89
Vv2030: ubRMSE = 0.020 m3/m3, bias = -0.079 m3/m3, R = 0.95
Vv3030: ubRMSE = 0.018 m3/m3, bias = -0.080 m3/m3, R = 0.96
Root Zone SM [m3/m3]
0
0.2
0.4
0.6
0.8
Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr
2015
2016
2017

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Core Sites

		Horiz. Scale	Number of Core Sites	Number of Reference Pixels	ubRMSE [m^3m^{-3}]			Bias [m^3m^{-3}]			R [-]		
					NRv4	**L4_SM**	95% Conf. Interval	NRv	**L4_SM**	95% Conf. Interval	NR	**L4_SM**	95% Conf. Interval
Vv3030 / NRv4.1	**Surface Soil Moisture**	9 km	17	26	0.042 m^3m^{-3}	**0.037 m^3m^{-3}**	0.002 m^3m^{-3}	0.043 m^3m^{-3}	**0.051 m^3m^{-3}**	0.003 m^3m^{-3}	0.58	**0.70**	0.03
		36 km	*17*	*17*	*0.040 m^3m^{-3}*	***0.034 m^3m^{-3}***	*0.002 m^3m^{-3}*	*0.024 m^3m^{-3}*	***0.030 m^3m^{-3}***	*0.003 m^3m^{-3}*	*0.66*	***0.76***	*0.03*
	Root Zone Soil Moisture	9 km	6	9	0.032 m^3m^{-3}	**0.028 m^3m^{-3}**	0.003 m^3m^{-3}	0.019 m^3m^{-3}	**0.016 m^3m^{-3}**	0.004 m^3m^{-3}	0.57	**0.73**	0.08
		36 km	*7*	*7*	*0.028 m^3m^{-3}*	***0.024 m^3m^{-3}***	*0.003 m^3m^{-3}*	*-0.003 m^3m^{-3}*	***-0.002 m^3m^{-3}***	*0.003 m^3m^{-3}*	*0.70*	***0.82***	*0.06*
	Surface Soil Temperature (6am)	9 km	12	21	1.7 K	**1.6 K**	0.3 K	-2.5 K	**-1.8 K**	0.3 K	0.98	**0.98**	0.01
		36 km	*14*	*14*	*1.6 K*	***1.5 K***	*0.2 K*	*-2.5 K*	***-1.7 K***	*0.3 K*	*0.97*	***0.98***	*0.01*
	Surface Soil Temperature (6pm)	9 km	13	22	1.8 K	**1.8 K**	0.3 K	0.2 K	**-1.2 K**	0.3 K	0.98	**0.98**	0.01
		36 km	*14*	*14*	*1.8 K*	***1.7 K***	*0.2 K*	*-0.4 K*	***-1.8 K***	*0.3 K*	*0.97*	***0.97***	*0.01*
Vv2030 / NRv4	**Surface Soil Moisture**	9 km	17	26	0.042 m^3m^{-3}	**0.038 m^3m^{-3}**	0.002 m^3m^{-3}	0.043 m^3m^{-3}	**0.046 m^3m^{-3}**	0.003 m^3m^{-3}	0.58	**0.67**	0.03
		36 km	*17*	*17*	*0.040 m^3m^{-3}*	***0.035 m^3m^{-3}***	*0.002 m^3m^{-3}*	*0.023 m^3m^{-3}*	***0.026 m^3m^{-3}***	*0.003 m^3m^{-3}*	*0.66*	***0.74***	*0.03*
	Root Zone Soil Moisture	9 km	6	9	0.032 m^3m^{-3}	**0.030 m^3m^{-3}**	0.003 m^3m^{-3}	0.019 m^3m^{-3}	**0.009 m^3m^{-3}**	0.004 m^3m^{-3}	0.56	**0.70**	0.08
		36 km	*7*	*7*	*0.028 m^3m^{-3}*	***0.026 m^3m^{-3}***	*0.003 m^3m^{-3}*	*-0.004 m^3m^{-3}*	***-0.007 m^3m^{-3}***	*0.004 m^3m^{-3}*	*0.70*	***0.79***	*0.06*
	Surface Soil Temperature (6am)	9 km	12	21	1.7 K	**1.6 K**	0.3 K	-2.5 K	**-1.8 K**	0.3 K	0.98	**0.98**	0.01
		36 km	*14*	*14*	*1.6 K*	***1.6 K***	*0.2 K*	*-2.5 K*	***-1.7 K***	*0.3 K*	*0.97*	***0.97***	*0.01*
	Surface Soil Temperature (6pm)	9 km	13	22	1.8 K	**1.7 K**	0.3 K	-0.1 K	**-1.1 K**	0.3 K	0.98	**0.98**	0.01
		36 km	*14*	*14*	*1.8 K*	***1.7 K***	*0.2 K*	*-0.5 K*	***-1.7 K***	*0.3 K*	*0.97*	***0.97***	*0.01*

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Sparse Networks

Sparse Network Subset	Surface Soil Moisture										Root Zone Soil Moisture									
		ubRMSE [m^3m^{-3}]			Bias [m^3m^{-3}]			R [-]				ubRMSE [m^3m^{-3}]			Bias [m^3m^{-3}]			R [-]		
	Number of sites	NRv4.1	*L4_SM Vv3030*	95% Conf. Interval	NRv4.1	*L4_SM Vv3030*	95% Conf. Interval	NRv4.1	*L4_SM Vv3030*	95% Conf. Interval	Number of sites	NRv4.1	*L4_SM Vv3030*	95% Conf. Interval	NRv4.1	*L4_SM Vv3030*	95% Conf. Interval	NRv4.1	*L4_SM Vv3030*	95% Conf. Interval
Forests (IGBP 1-5)	45	0.059	*0.056*	±0.007	0.100	*0.101*	±0.005	0.62	*0.64*	±0.04	39	0.048	*0.045*	±0.007	0.056	*0.059*	±0.006	0.63	*0.64*	±0.09
Open shrublands (IGBP 7)	27	0.040	*0.035*	±0.004	0.013	*0.028*	±0.004	0.69	*0.74*	±0.04	20	0.031	*0.027*	±0.008	-0.001	*0.010*	±0.006	0.65	*0.68*	±0.11
Woody savannas (IGBP 8)	31	0.062	*0.056*	±0.008	0.047	*0.045*	±0.007	0.55	*0.61*	±0.08	26	0.048	*0.043*	±0.015	0.041	*0.036*	±0.019	0.60	*0.63*	±0.21
Grasslands (IGBP 10)	177	0.053	*0.051*	±0.006	0.037	*0.048*	±0.005	0.66	*0.68*	±0.03	130	0.040	*0.042*	±0.009	-0.008	*0.002*	±0.010	0.72	*0.68*	±0.10
Croplands (IGBP 12)	94	0.057	*0.054*	±0.005	0.034	*0.036*	±0.005	0.60	*0.65*	±0.03	71	0.045	*0.044*	±0.006	0.016	*0.019*	±0.008	0.63	*0.65*	±0.08
Urban/built-up (IGBP 13)	4	0.075	*0.068*	±0.023	0.060	*0.049*	±0.017	0.49	*0.59*	±0.13	3	0.051	*0.049*	±0.026	0.087	*0.079*	±0.020	0.61	*0.62*	±0.34
Crop/natural (IGBP 14)	41	0.058	*0.055*	±0.004	0.039	*0.035*	±0.004	0.63	*0.67*	±0.04	38	0.046	*0.043*	±0.005	0.010	*0.006*	±0.005	0.63	*0.66*	±0.08
Barren/sparse (IGBP 16)	2	0.033	*0.028*	±0.005	0.004	*0.014*	±0.004	0.60	*0.69*	±0.08	1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SCAN	135	0.053	*0.051*	±0.003	0.031	*0.033*	±0.003	0.60	*0.63*	±0.03	129	0.043	0.041	±0.004	-0.005	-0.002	±0.004	0.61	0.62	±0.07
USCRN	111	0.054	*0.051*	±0.004	0.064	*0.068*	±0.003	0.65	*0.69*	±0.02	87	0.044	0.041	±0.004	0.034	0.036	±0.004	0.70	0.70	±0.06
OZNet-Murrumbidgee	42	0.075	*0.062*	±0.024	0.006	*0.036*	±0.027	0.75	*0.85*	±0.11	18	0.031	0.055	±0.062	-0.091	-0.055	±0.078	0.71	0.75	±0.55
OK Mesonet	118	0.066	*0.059*	±0.013	0.003	*-0.001*	±0.015	0.52	*0.64*	±0.10	77	0.046	0.046	±0.035	-0.022	-0.023	±0.053	0.63	0.63	±0.36
SMOSMANIA	20	0.058	*0.051*	±0.017	0.040	*0.043*	±0.016	0.58	*0.65*	±0.16	21	0.049	0.044	±0.025	0.048	0.050	±0.038	0.57	0.62	±0.38
Inside mask	290	0.058	*0.054*	±0.004	0.037	*0.039*	±0.004	0.65	*0.69*	±0.02	218	0.046	*0.045*	±0.005	0.007	*0.009*	±0.006	0.66	*0.67*	±0.06
Outside mask	136	0.052	*0.049*	±0.004	0.074	*0.080*	±0.003	0.63	*0.66*	±0.03	114	0.040	*0.039*	±0.005	0.042	*0.047*	±0.005	0.64	*0.65*	±0.06
Average (all sites)	**426**	**0.054**	***0.051***	**±0.004**	**0.055**	***0.059***	**±0.003**	**0.63**	***0.67***	**±0.02**	**332**	**0.043**	***0.042***	**±0.004**	**0.020**	***0.024***	**±0.005**	**0.66**	***0.67***	**±0.06**

GMAO

Sparse Networks

Vv3030 Vv2030

Sparse Network Subset	Skill difference (L4_SM minus NRv4.1)						Skill difference (L4_SM minus NRv4)					
	Surface			Root Zone			Surface			Root Zone		
	ubRMSE	abs(bias)	R	ubRMSE	abs(bias)	R	ubRMSE	abs(bias)	R	ubRMSE	abs(bias)	R
Forests (IGBP 1-5)	-0.003	0.001	0.015	-0.003	0.0033	0.01	-0.003	0.000	0.014	-0.003	0.0022	0.01
Open shrublands (IGBP 7)	-0.005	0.015	0.055	-0.004	0.0083	0.04	-0.005	0.016	0.046	-0.004	0.0111	0.00
Woody savannas (IGBP 8)	-0.005	-0.003	0.052	-0.005	-0.0056	0.03	-0.005	-0.007	0.047	-0.006	-0.0103	0.02
Grasslands (IGBP 10)	-0.001	0.011	0.025	0.003	-0.0061	-0.04	-0.002	0.009	0.043	0.003	-0.0085	-0.04
Croplands (IGBP 12)	-0.004	0.002	0.054	0.000	0.0031	0.02	-0.003	-0.002	0.041	0.001	0.0002	0.00
Urban/built-up (IGBP 13)	-0.008	-0.012	0.101	-0.002	-0.0085	0.01	-0.007	-0.018	0.108	0.000	-0.0148	0.00
Crop/natural (IGBP 14)	-0.004	-0.005	0.037	-0.003	-0.0042	0.04	-0.003	-0.003	0.039	-0.003	-0.0033	0.04
Barren/sparse (IGBP 16)	-0.005	0.011	0.092				-0.006	0.012	0.089			
SCAN	-0.002	0.003	0.034	-0.001	-0.0031	0.01	-0.002	0.000	0.031	-0.002	-0.0003	0.00
USCRN	-0.003	0.004	0.031	-0.003	0.0020	0.01	-0.003	0.002	0.034	-0.002	0.0004	0.00
OZNet-Murrumbidgee	-0.013	0.030	0.094	0.024	-0.0354	0.03	-0.012	0.034	0.091	0.025	-0.0394	0.03
OK Mesonet	-0.007	-0.001	0.118	0.000	0.0006	0.00	-0.006	0.004	0.107	0.002	0.0044	-0.03
SMOSMANIA	-0.007	0.003	0.071	-0.004	0.0020	0.05	-0.006	0.008	0.054	-0.004	0.0069	0.03
Inside mask	-0.004	0.002	0.043	-0.001	0.0022	0.01	-0.003	0.000	0.038	-0.001	0.0005	0.00
Outside mask	-0.003	0.006	0.029	-0.001	0.0052	0.01	-0.003	0.005	0.034	-0.001	0.0042	0.01
Average (all sites)	-0.003	0.005	0.035	-0.001	0.0036	0.01	-0.003	0.004	0.034	-0.001	0.0025	0.01