Improving the SMAP Level-4 Soil Moisture Product

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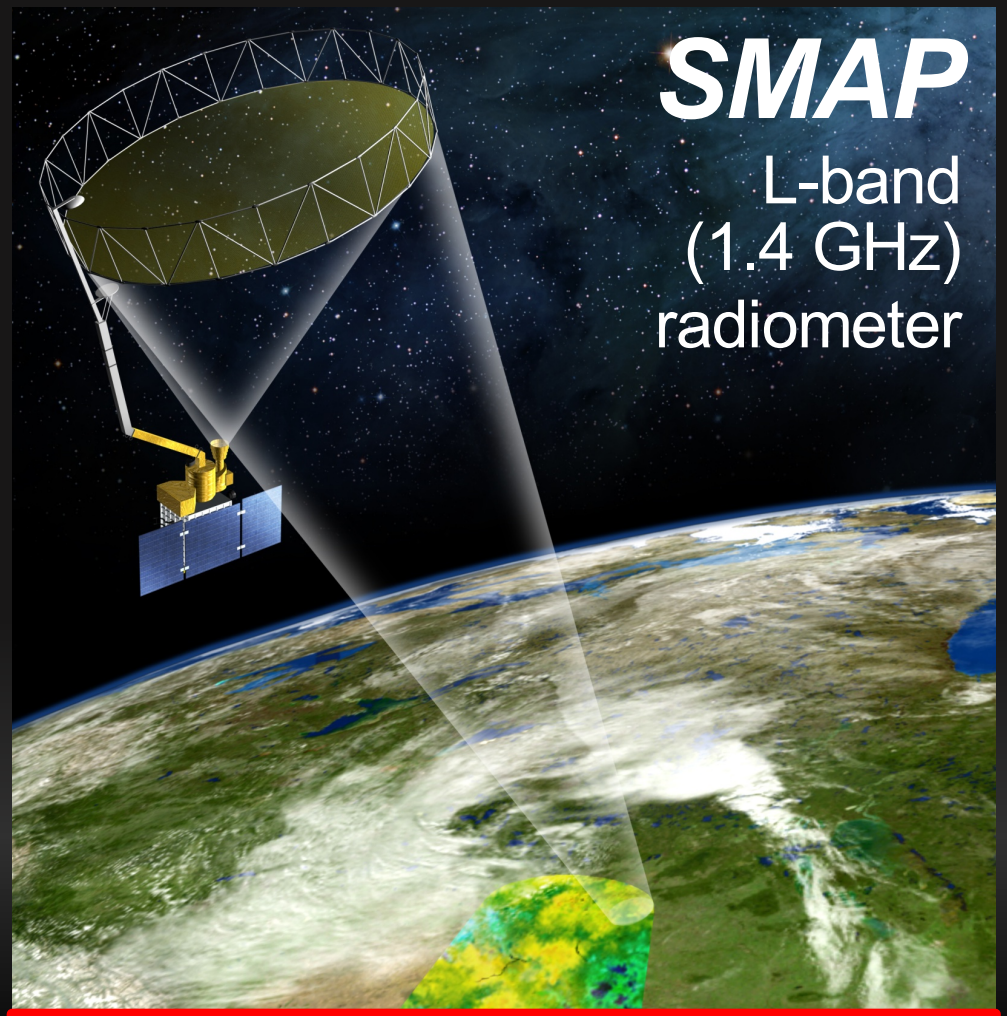
Outline

1. Motivation and Overview
2. In Situ Validation
3. Assimilation Diagnostics
4. Summary and Outlook

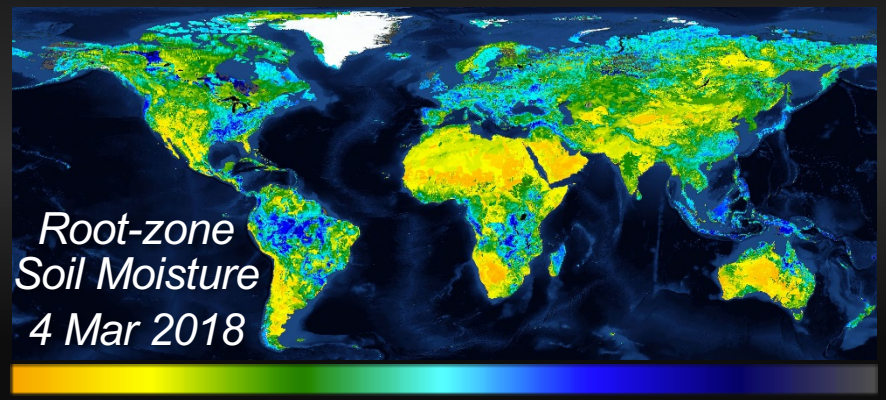
Motivation



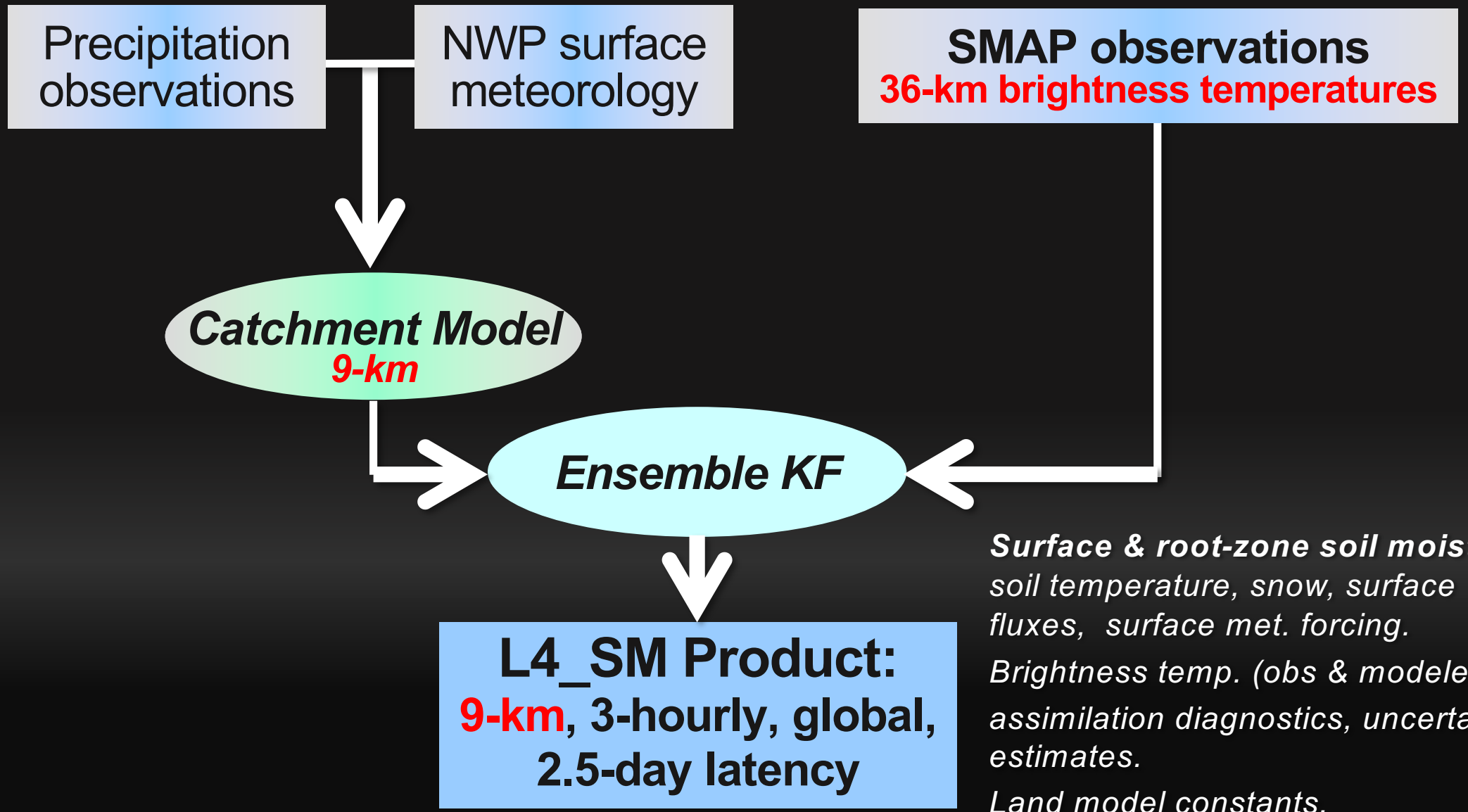
Sensitive only to surface soil moisture (~0-5 cm)

Key Objectives of the Level-4 Soil Moisture (L4_SM) product:

1. **"Root-zone" soil moisture (0-100 cm)**
2. **Spatially & temporally complete**



Algorithm Overview



Surface & root-zone soil moisture, *soil temperature, snow, surface fluxes, surface met. forcing.*

Brightness temp. (obs & modeled), assimilation diagnostics, uncertainty estimates.

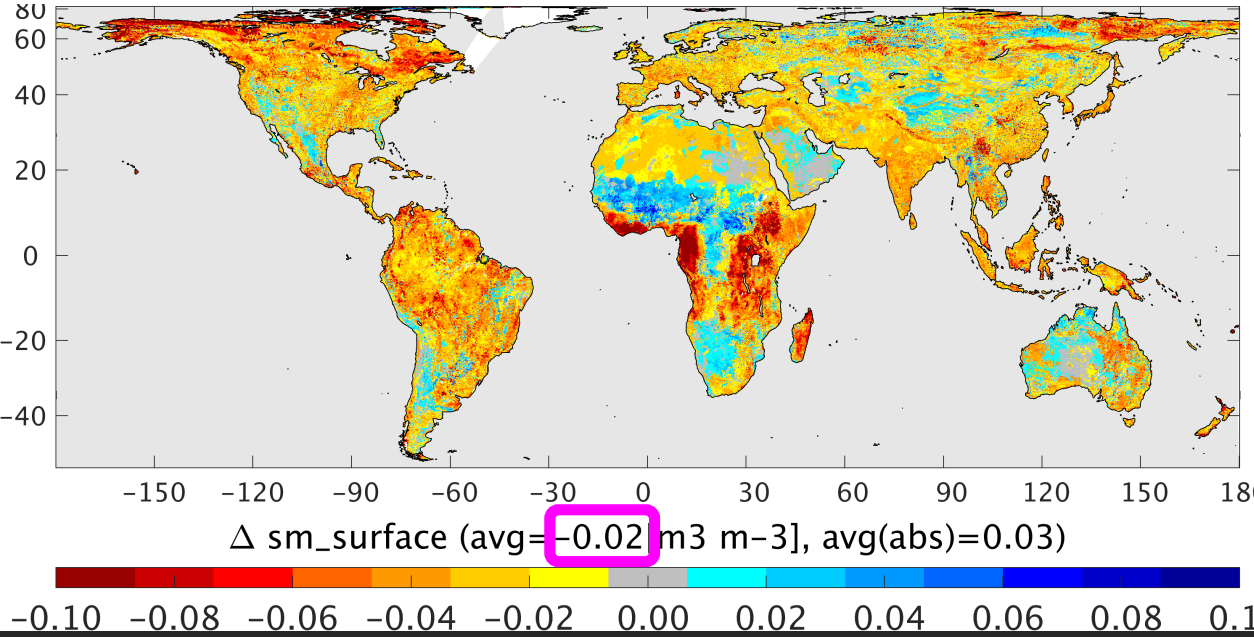
Land model constants.

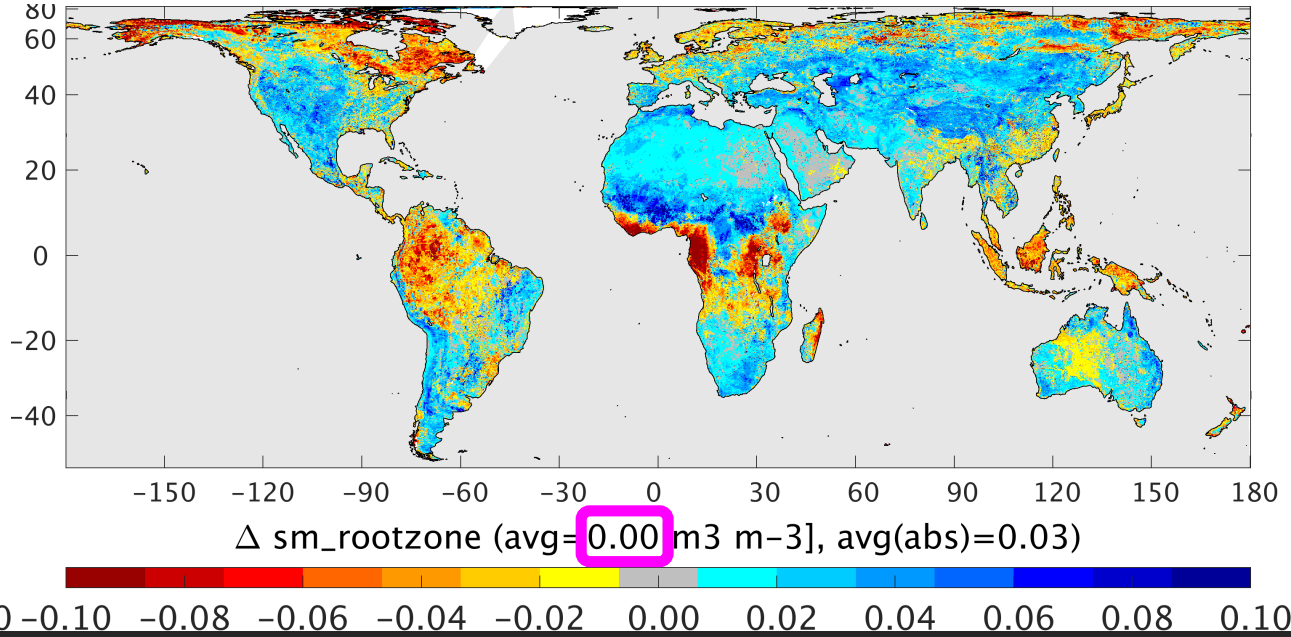
Key Changes in Version 4

Category	Description
Ancillary data	Improved land cover (MODIS+Geoland), topography (SRTM) and veg. height (Lidar).
	Longer L-band & forcing time series to derive model climatology and Tb scaling parameters.
	New SMAP Tb calibration (3-4 K over land!).
	Rescaled background precipitation to GPCP climatology (Africa, high latitudes).
Model	Reduced upward recharge of surface soil moisture under non-equilibrium conditions.
	Revised treatment of surface energy balance (impact on surface soil temperature).
Analysis	Removed “catchment deficit” from EnKF state vector.
Metadata	Added “projection coordinates” for improved interoperability (ArcGIS, OPeNDAP).

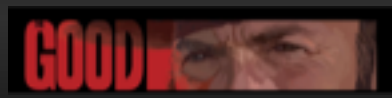
Soil Moisture Climatology (Apr 2015 – Mar 2018)

Version 4 minus Version 3





- Version 4 surface soil moisture slightly drier in most regions because of reduced upward recharge.
- No change in global average root zone soil moisture.
- Changes in Africa and high latitudes owing to rescaling of GEOS precip. to GPCPv2.2 climatology.



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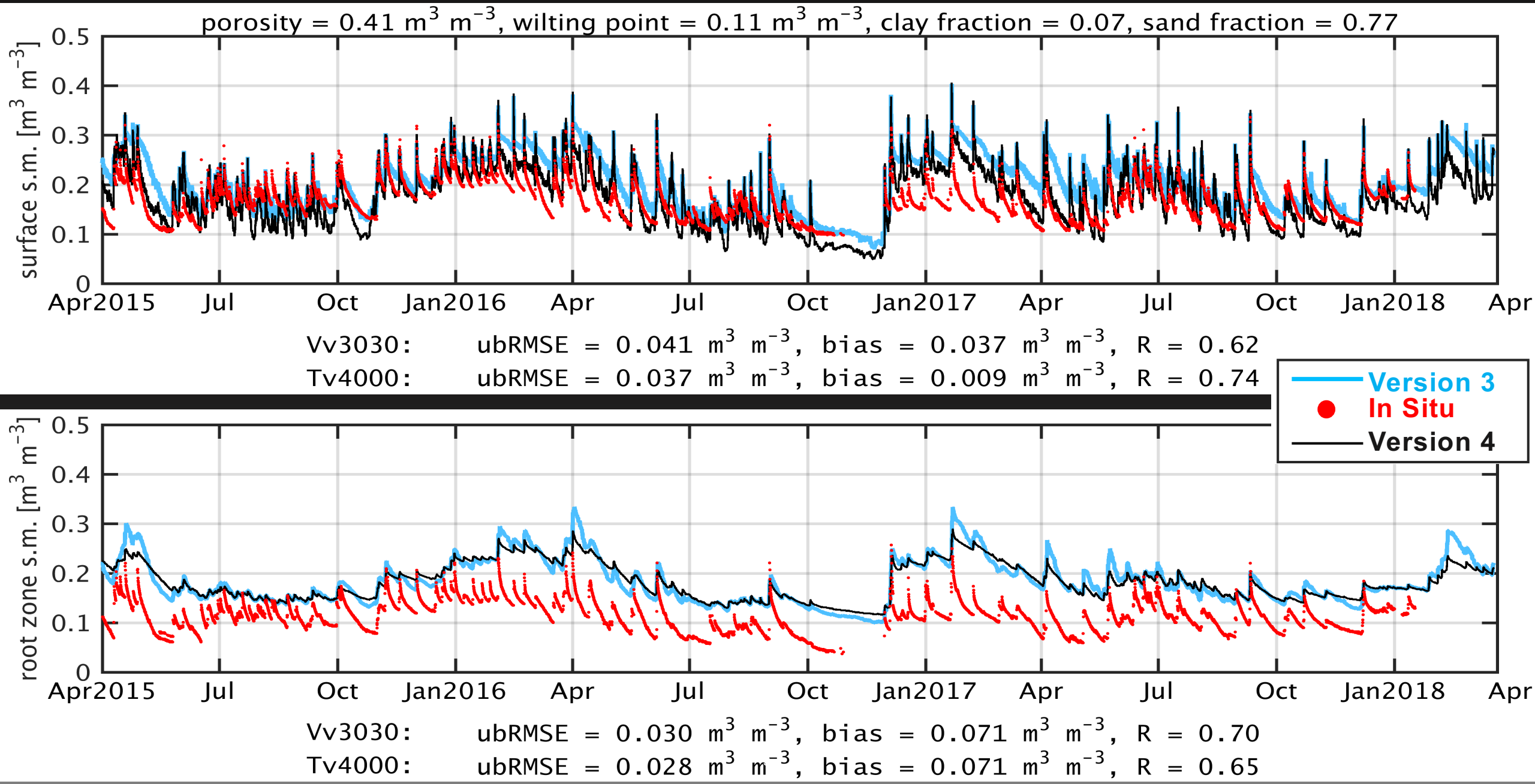
In Situ Validation

- Validation period: Apr 2015 – Mar 2018 (3 years) – unless noted otherwise

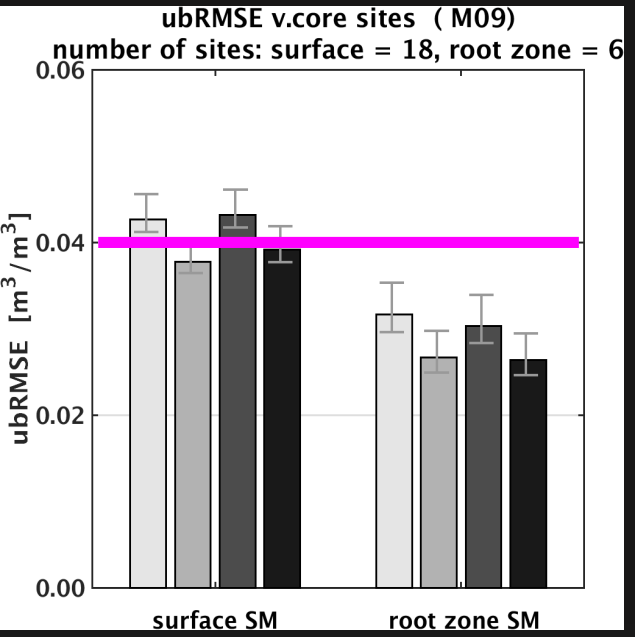
- Core sites provide locally dense in situ networks in 18 watersheds.
- Sparse networks provide point-scale measurements at hundreds of locations.

- Compare to model-only simulation (without assimilation of SMAP Tbs):
  - NRv4.1 is model for Version 3.
  - NRv7.2 is model for Version 4.

33 km Core Site at Little River, Georgia, USA

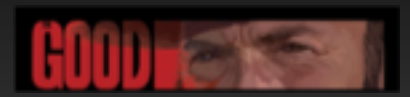


Soil Moisture Skill

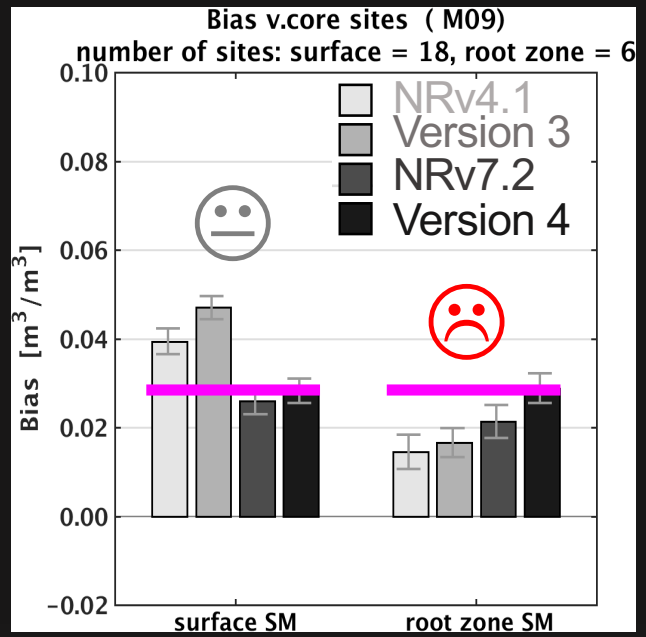


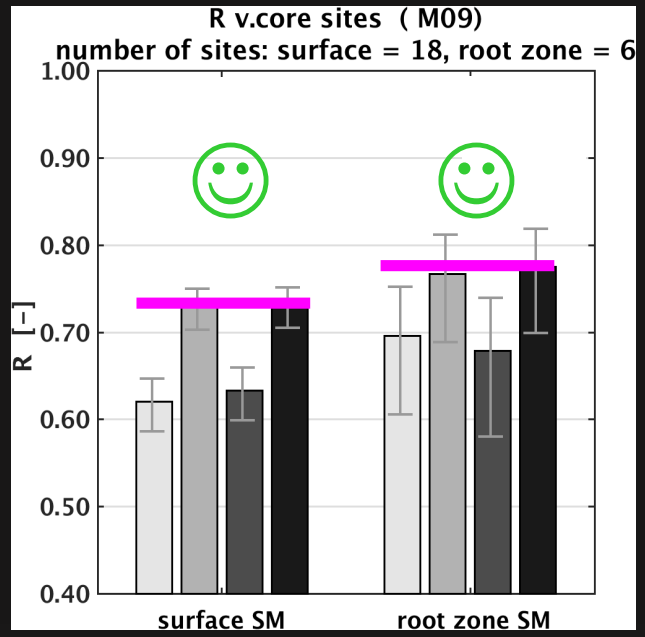
NRv4.1
Version 3
NRv7.2
Version 4

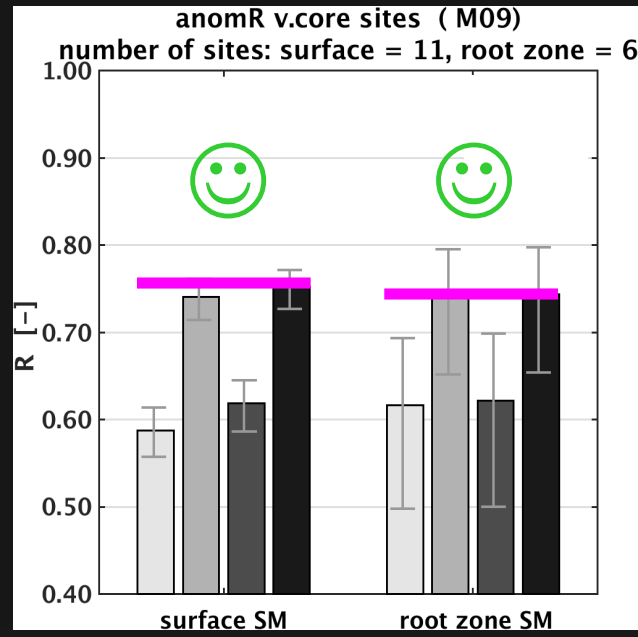
- Both versions meet accuracy requirement (ubRMSE < 0.04 m^3/m^3).



Soil Moisture Skill







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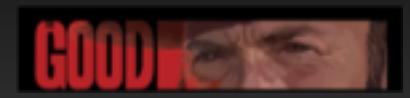
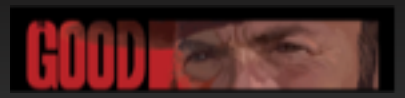
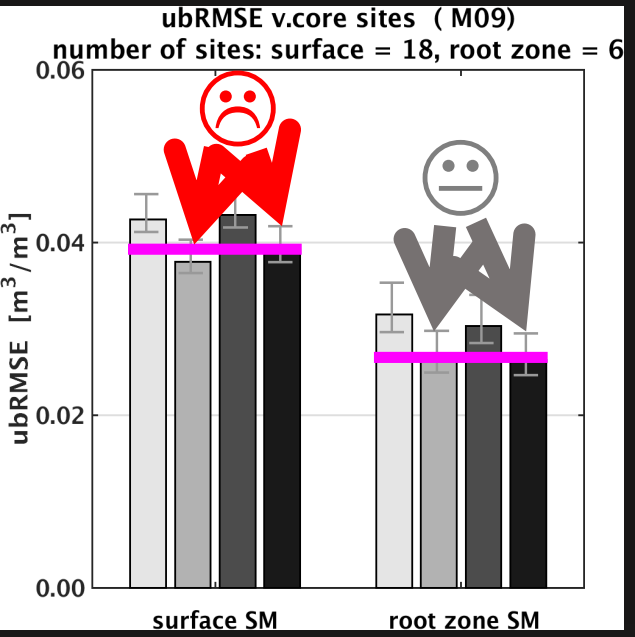
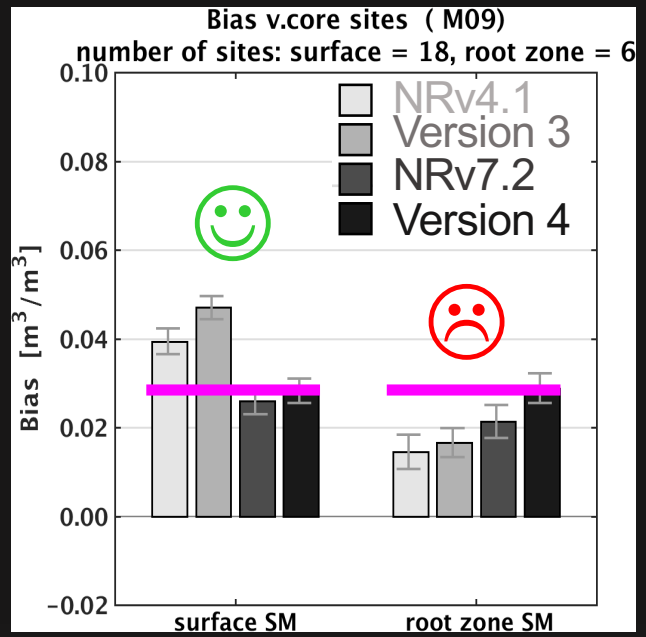


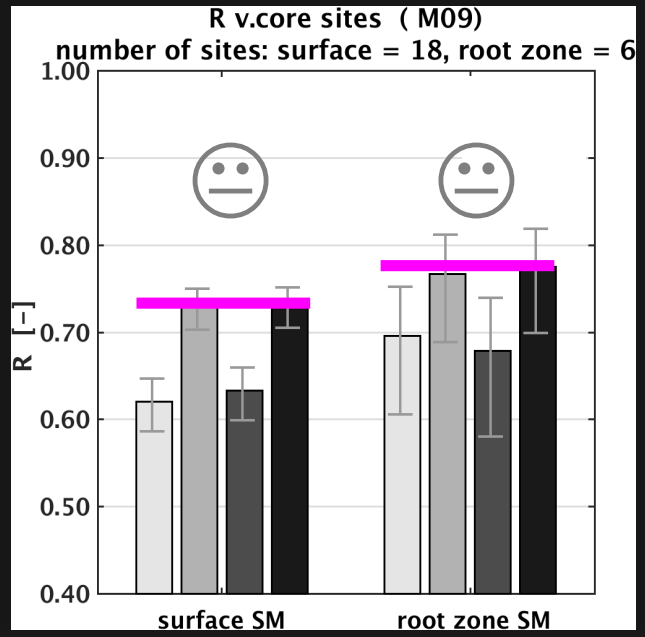


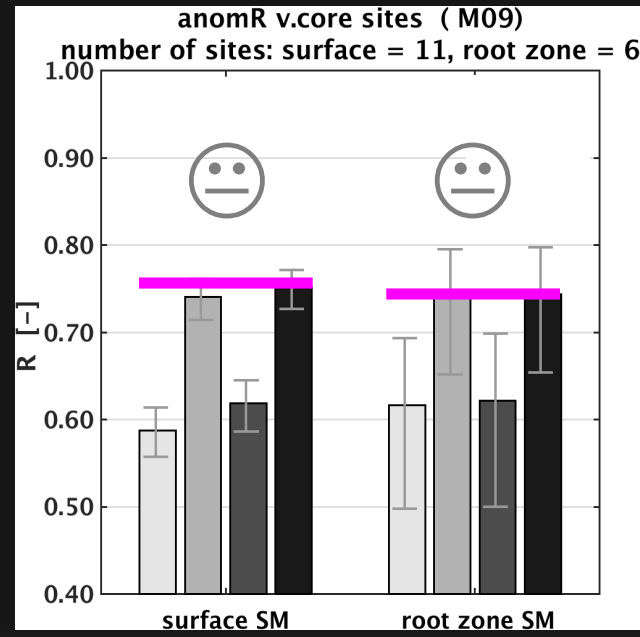
- Compared to model-only estimates (NR[x]), ubRMSE and correlation metrics in both versions are improved.

Soil Moisture Skill









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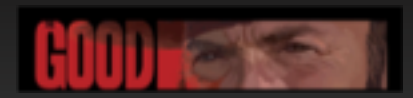
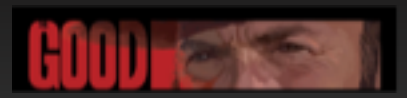
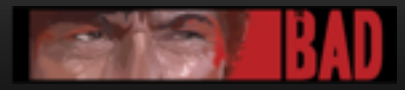


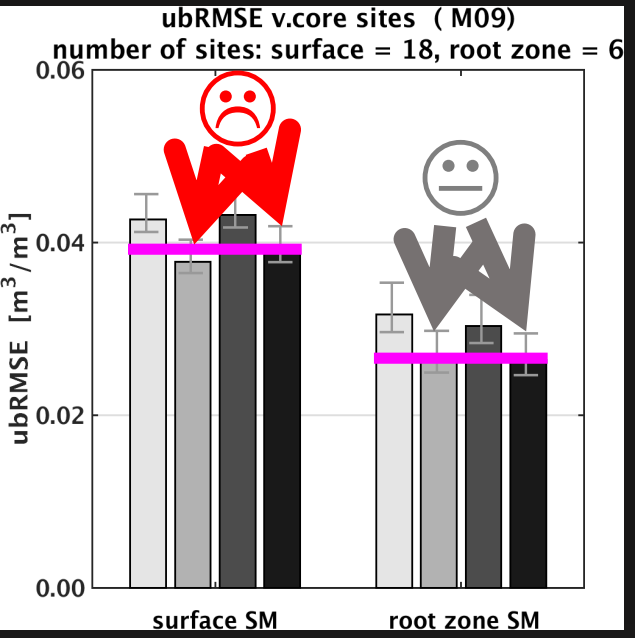


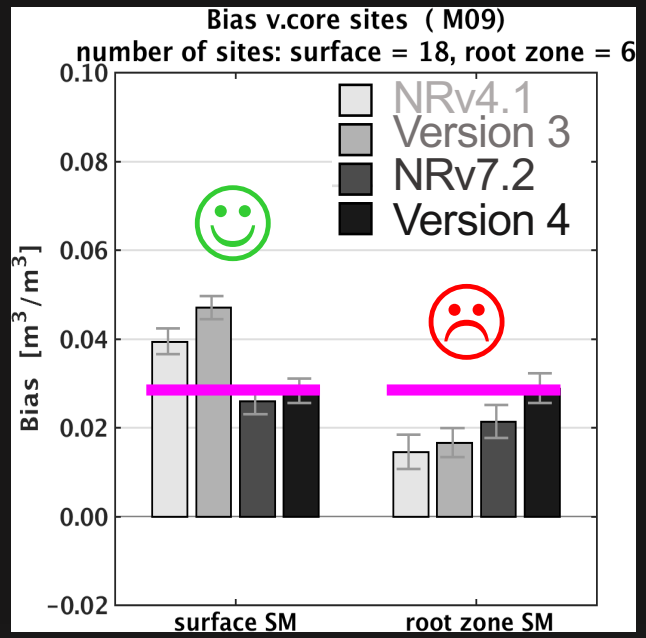
- Compared to model-only estimates (NR[x]), ubRMSE and correlation metrics in both versions are improved.
- Surface soil moisture ubRMSE slightly larger in Version 4 than in Version 3.

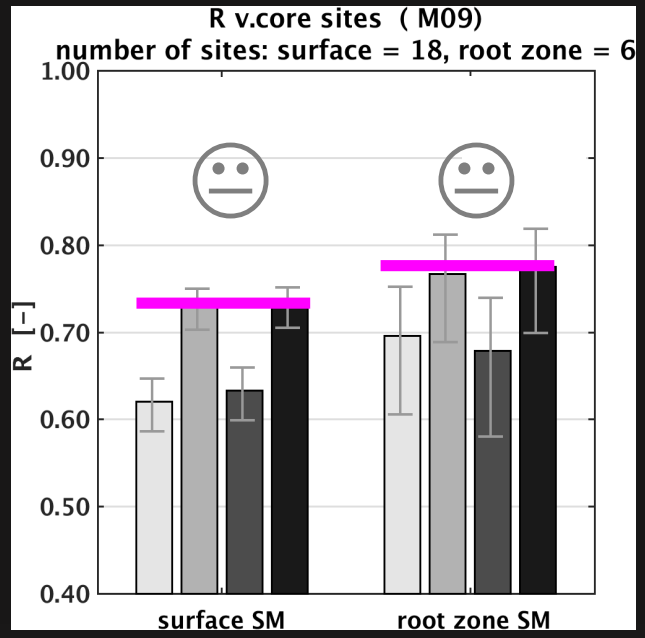


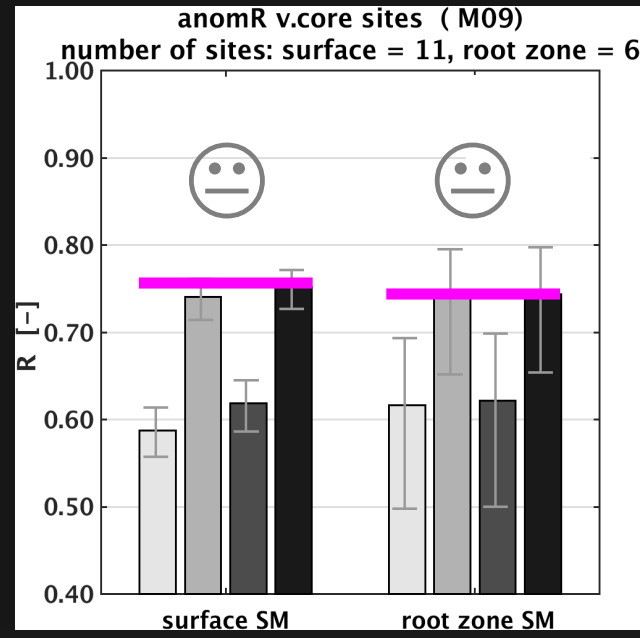
- Surface soil moisture bias smaller in Version 4 than in Version 3, but opposite holds for root zone bias.
- Correlation metrics unchanged between versions.

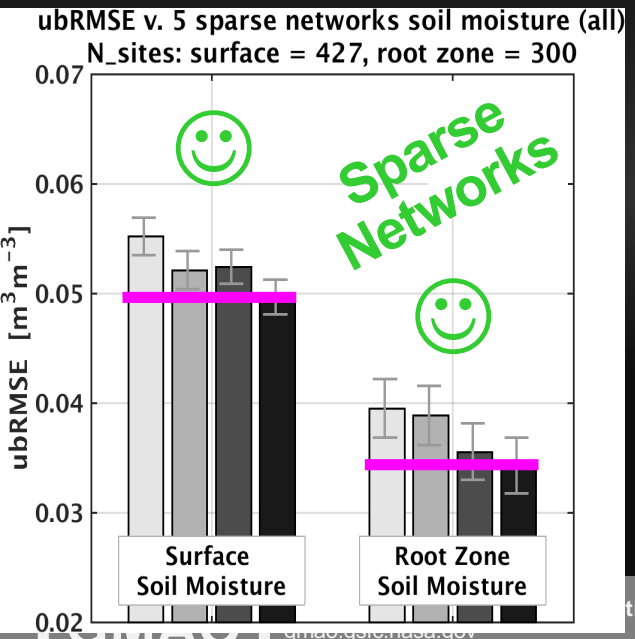
Soil Moisture Skill

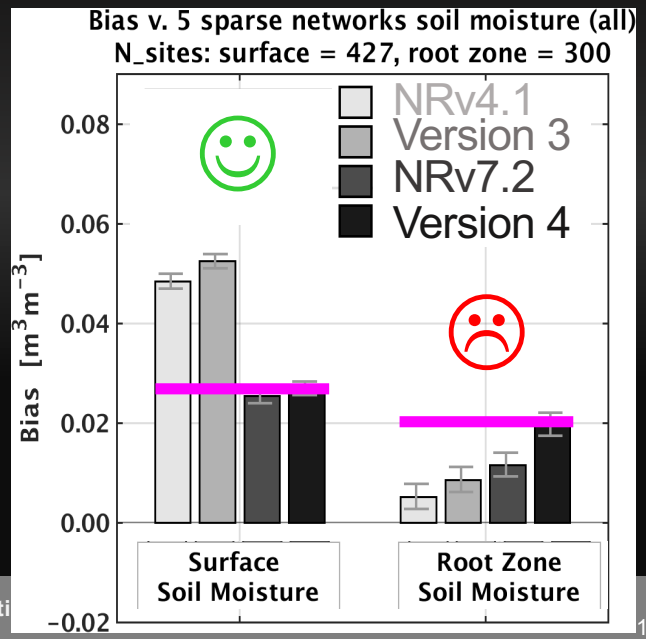


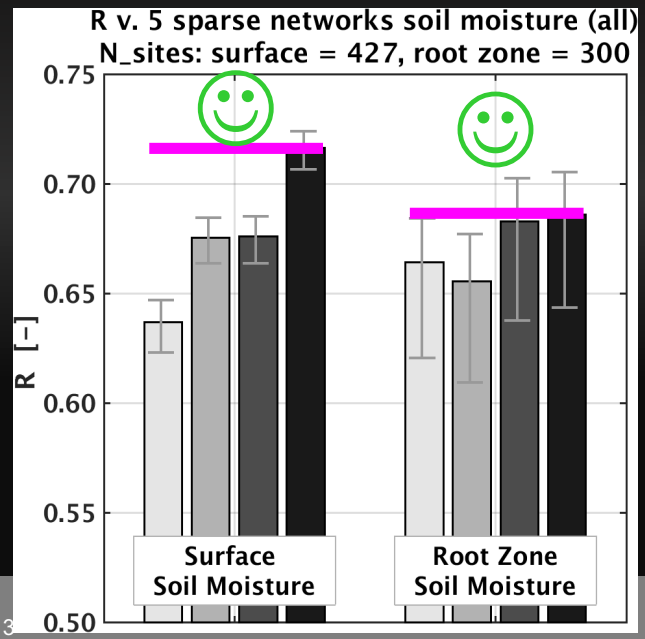


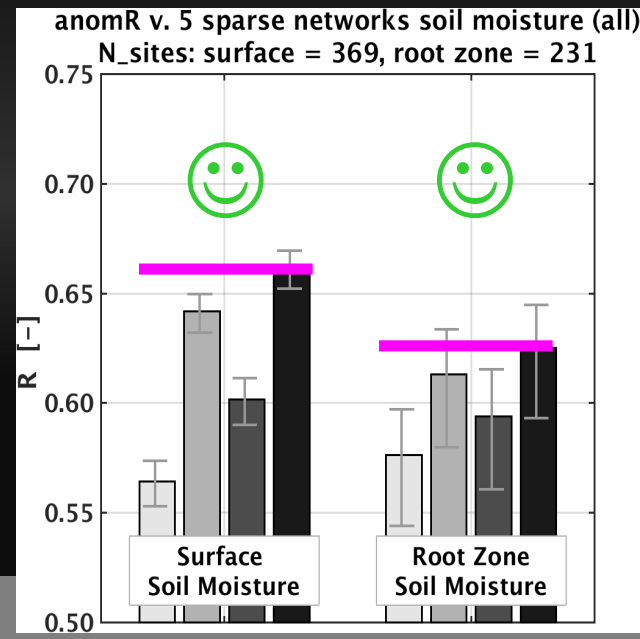




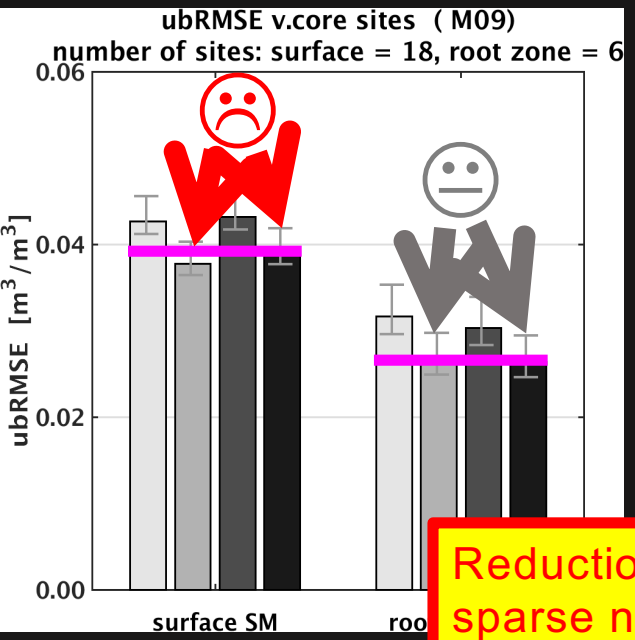


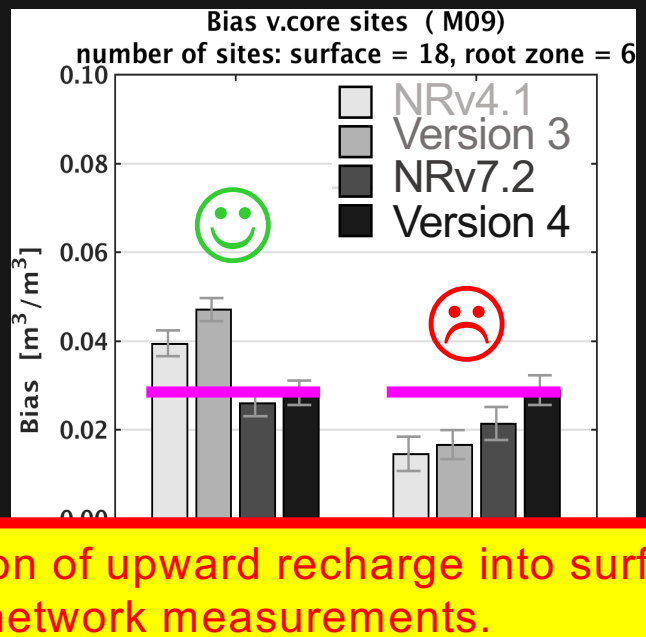


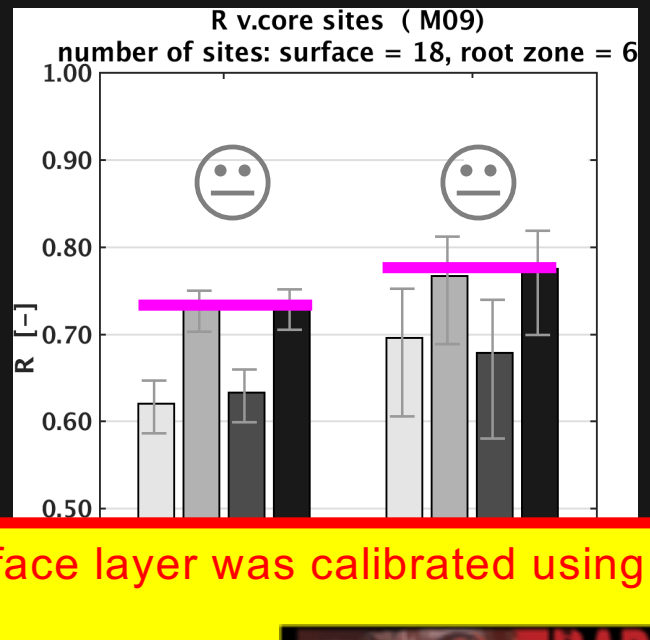


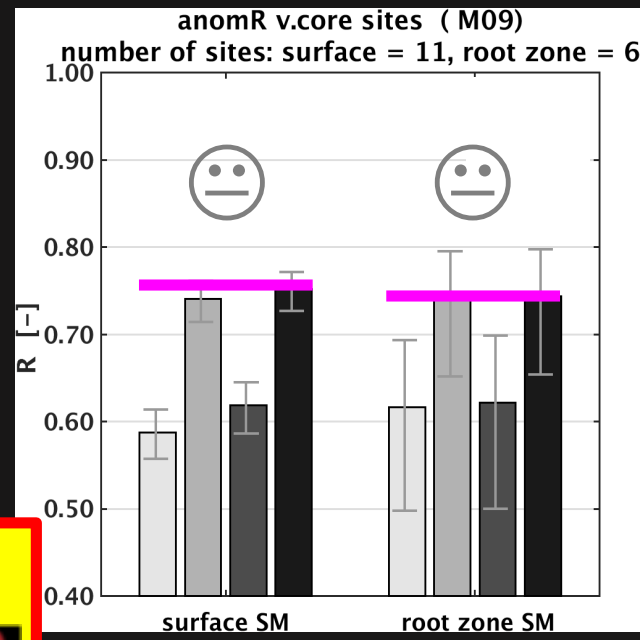


Soil Moisture Skill

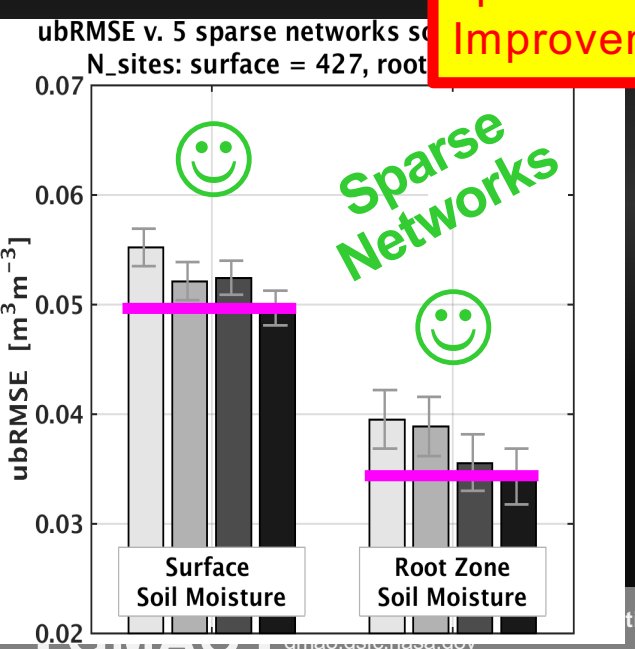


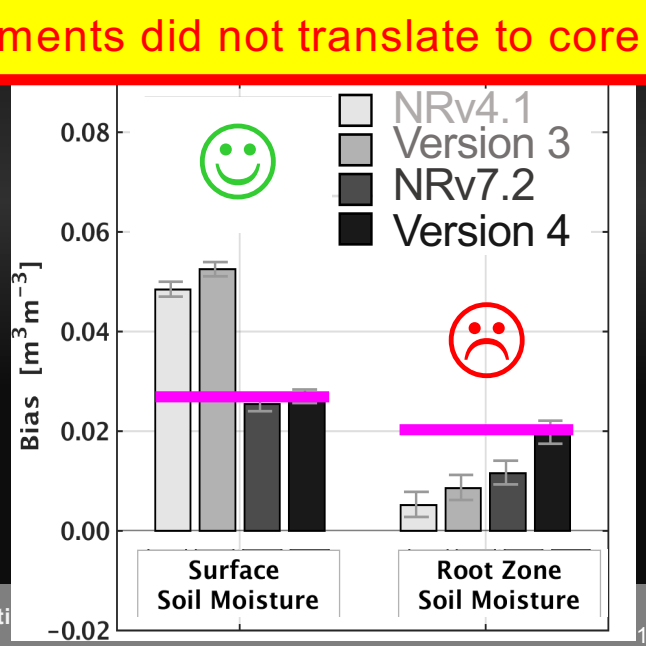


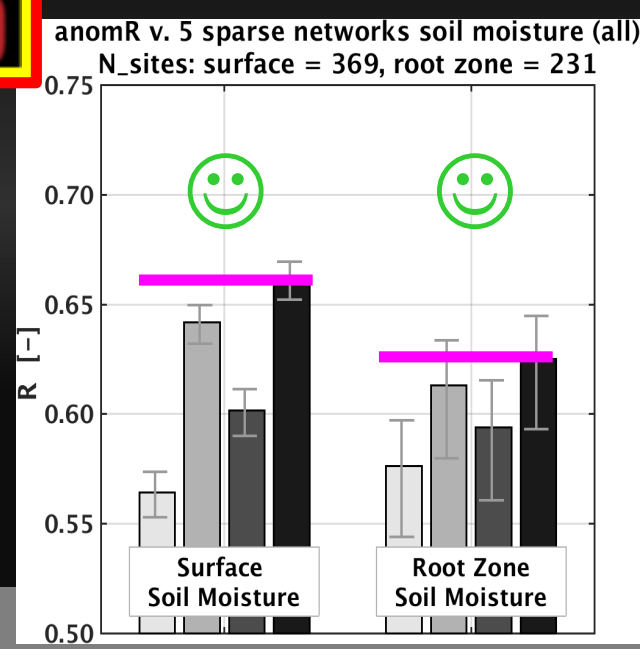




Reduction of upward recharge into surface layer was calibrated using sparse network measurements.
Improvements did not translate to core site metrics.



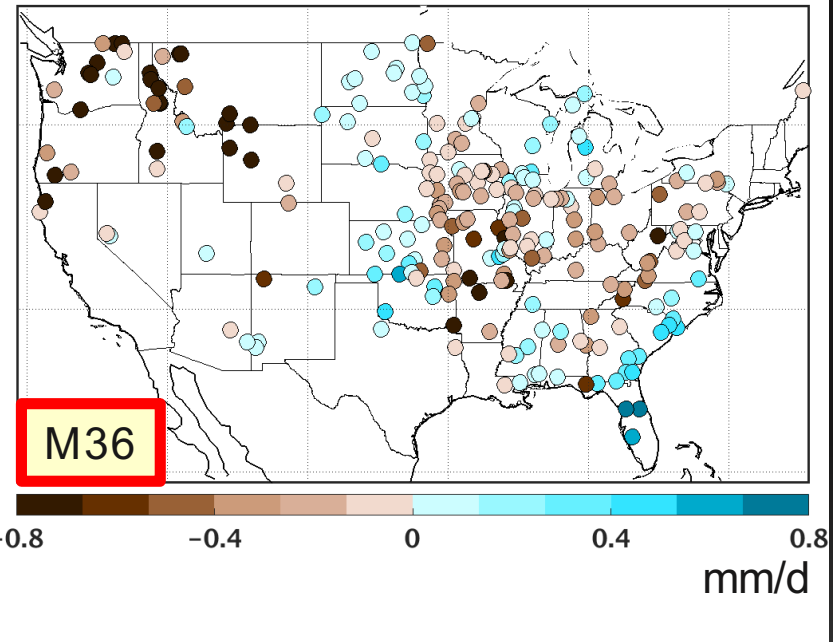




Runoff Validation

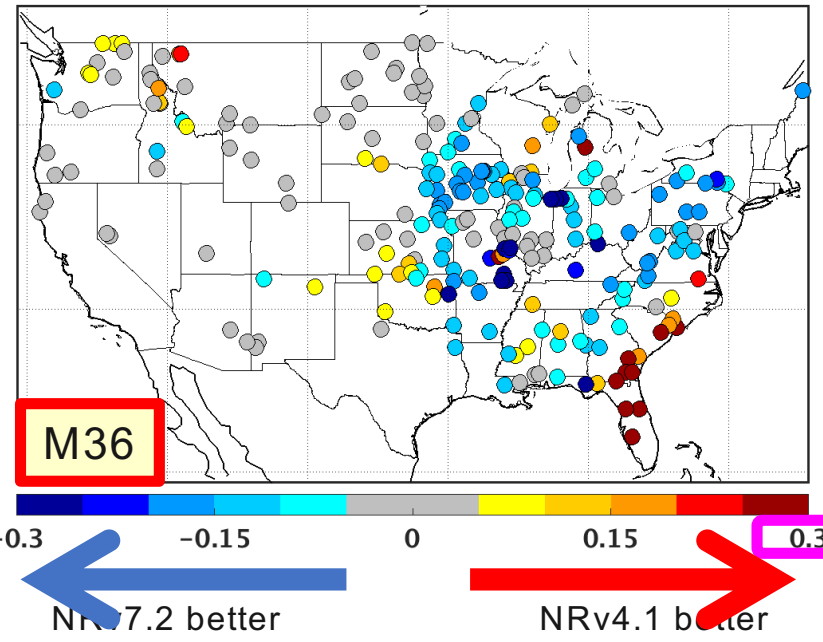
Bias (NRv7.2)

Mean = -0.016 mm/d (N=237)



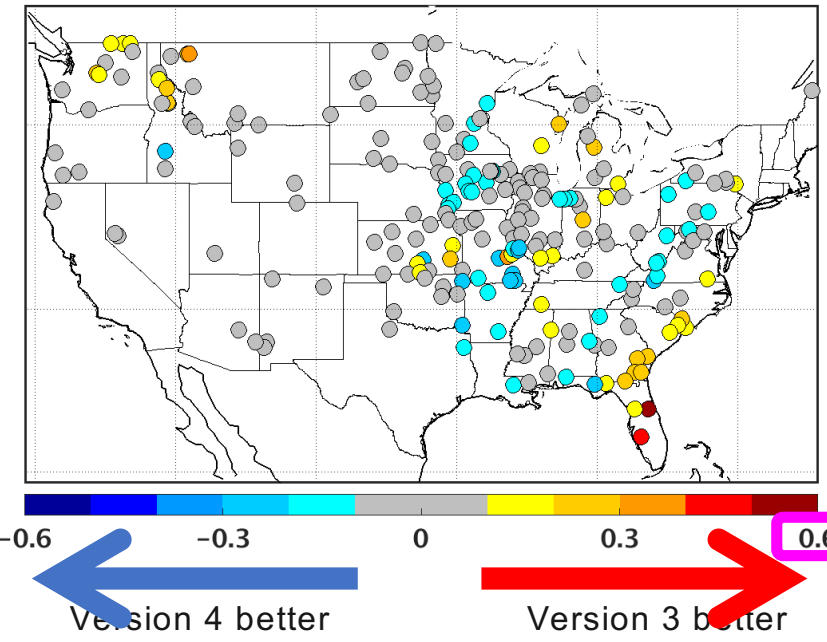
Skill diff: NRv7.2 minus NRv4.1

Mean = -0.034 mm/d (N=237)

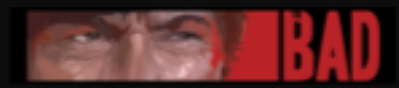


Skill diff: Tv4000 minus Vv3030

Mean = -0.002 mm/d (N=232)



- On average, the model generates too little runoff.
- Mean runoff is better in NRv7.2 than NRv4.1.
- Model improvements do not translate into better Version 4 product.



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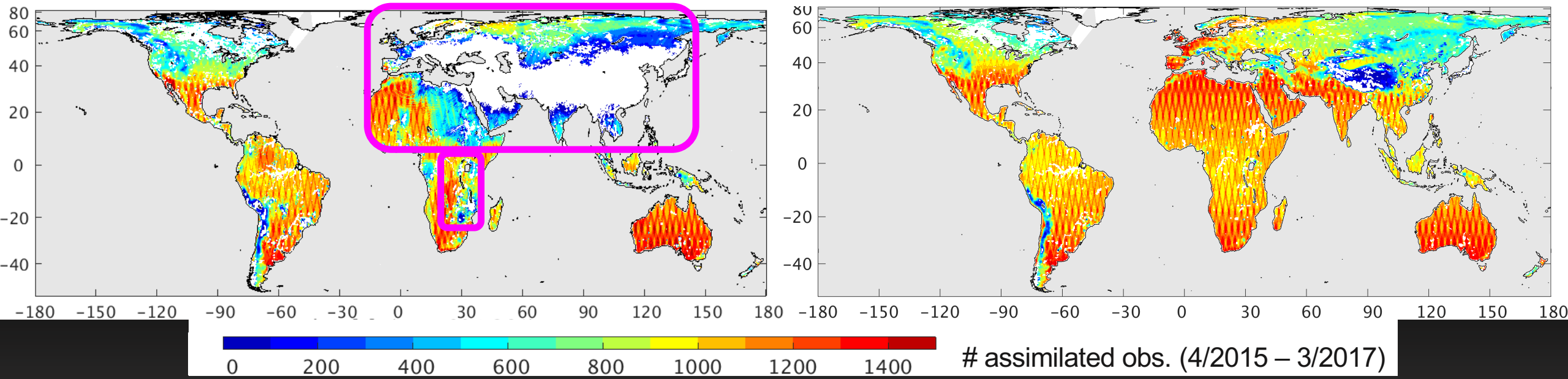
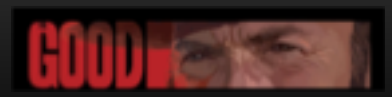
Number of Assimilated SMAP L1C_TB Observations

Version **2** – Tb scaling with SMOS only

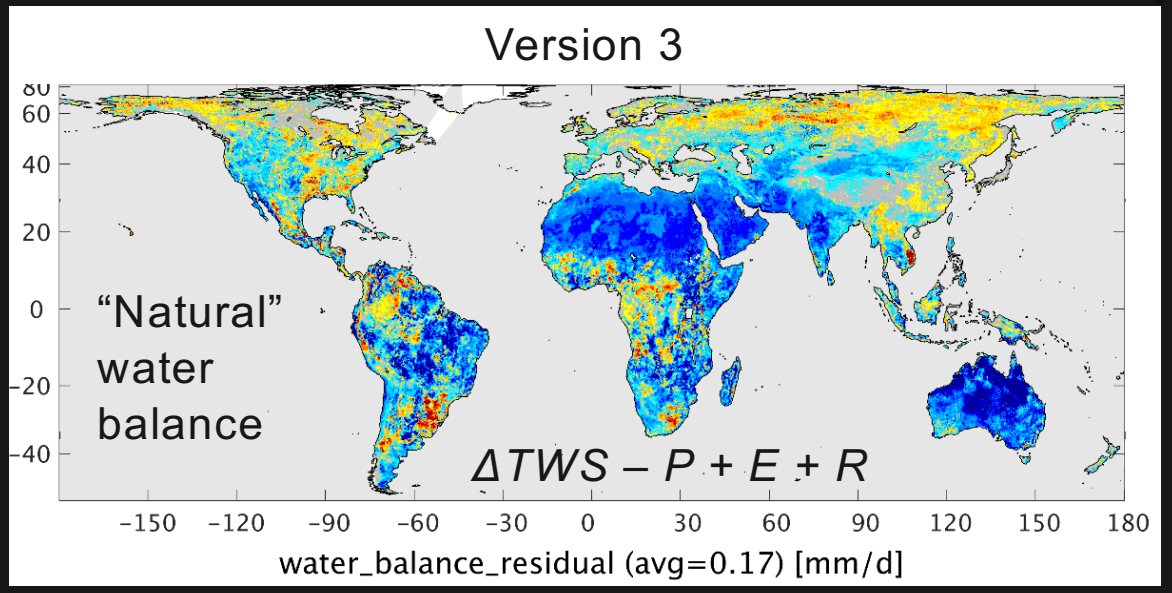
Version 4 – Tb scaling with SMOS & SMAP

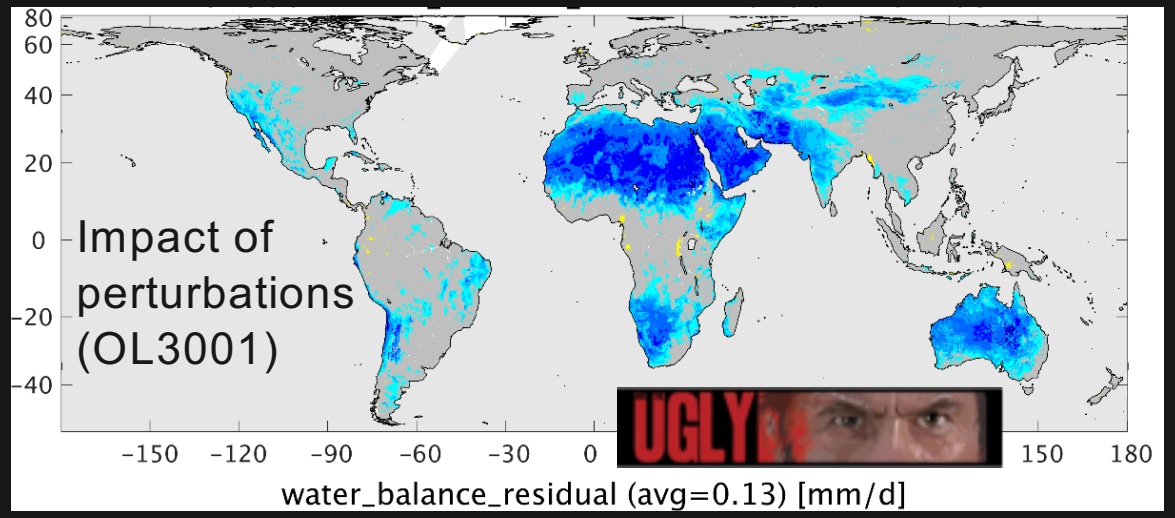


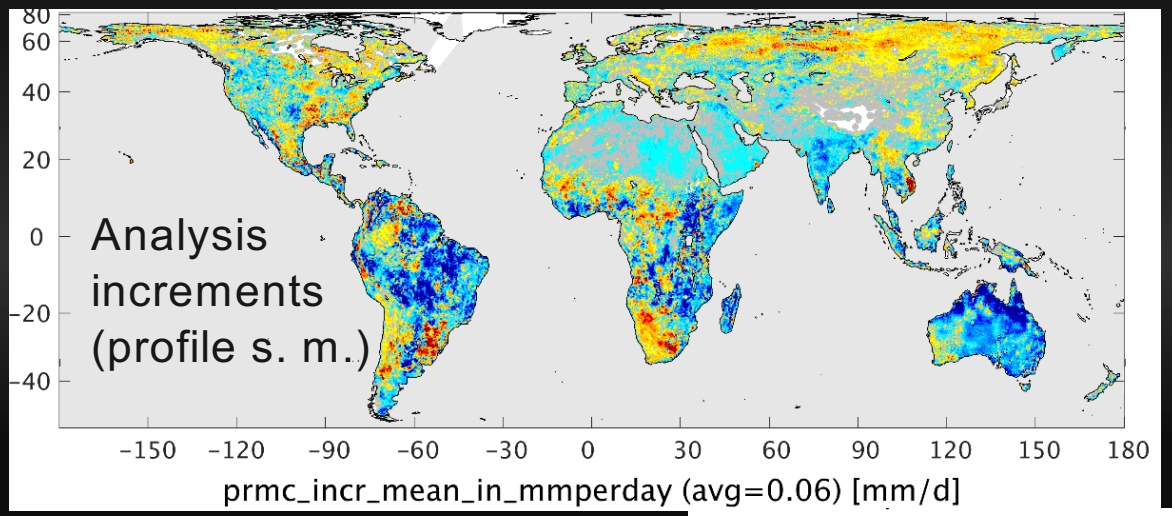
Beginning with Version 3, brightness temperature scaling parameters are based on SMAP data where SMOS climatology is unavailable due to RFI.

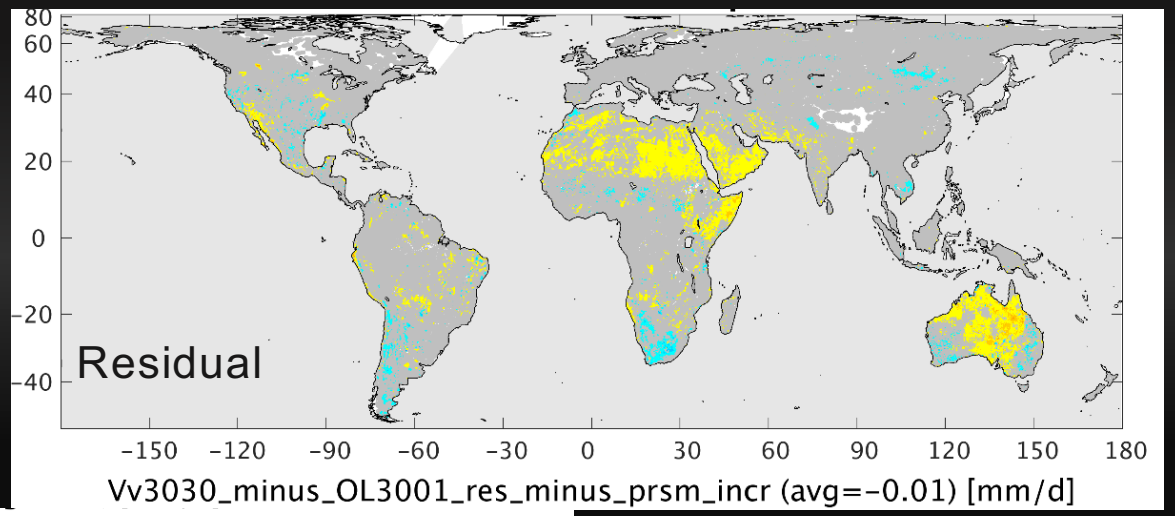


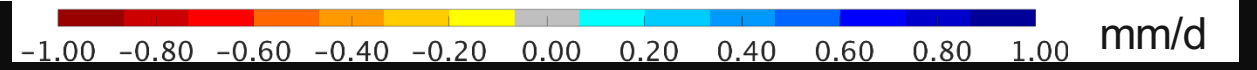
Water Balance (Apr 2015 – Mar 2017)







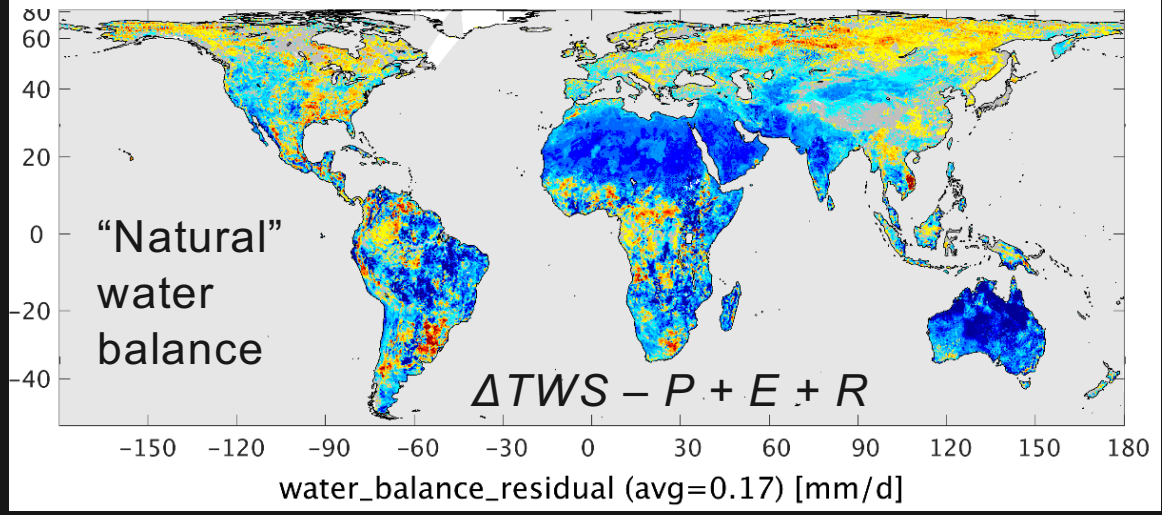


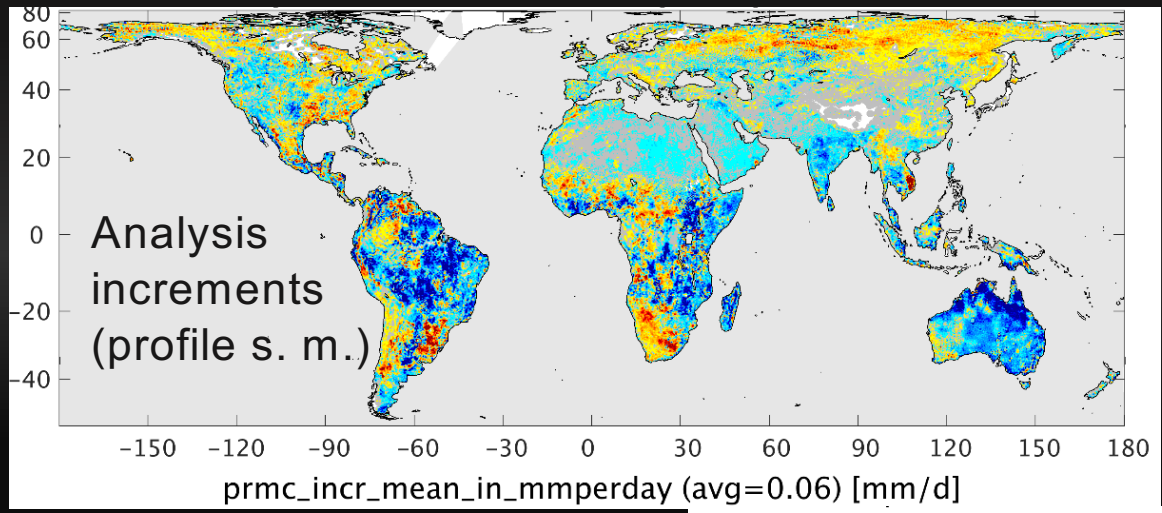


Water balance (nearly) closes after considering analysis increments and impact of perturbations.

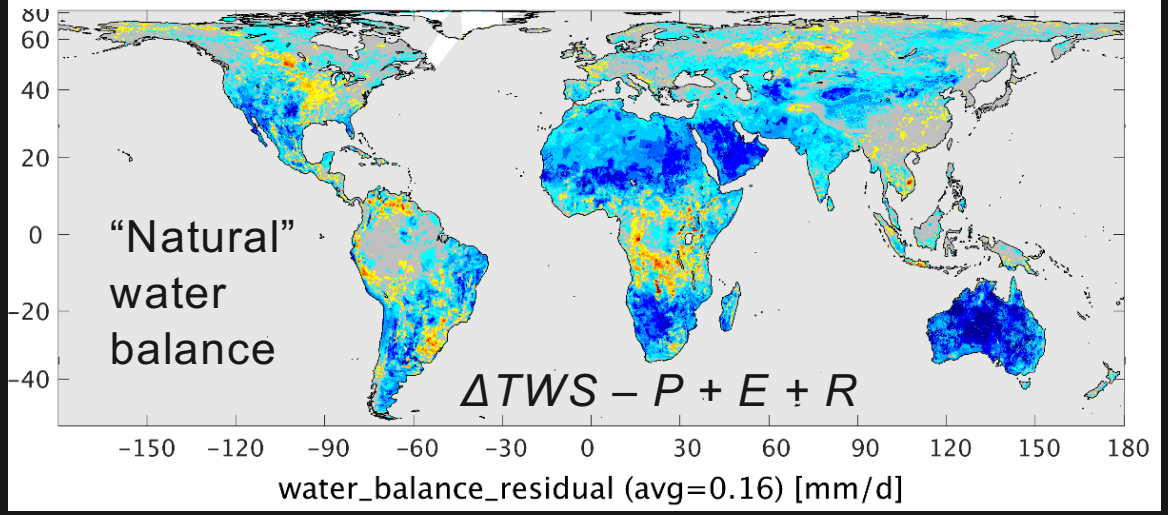
Water Balance (Apr 2015 – Mar 2017)

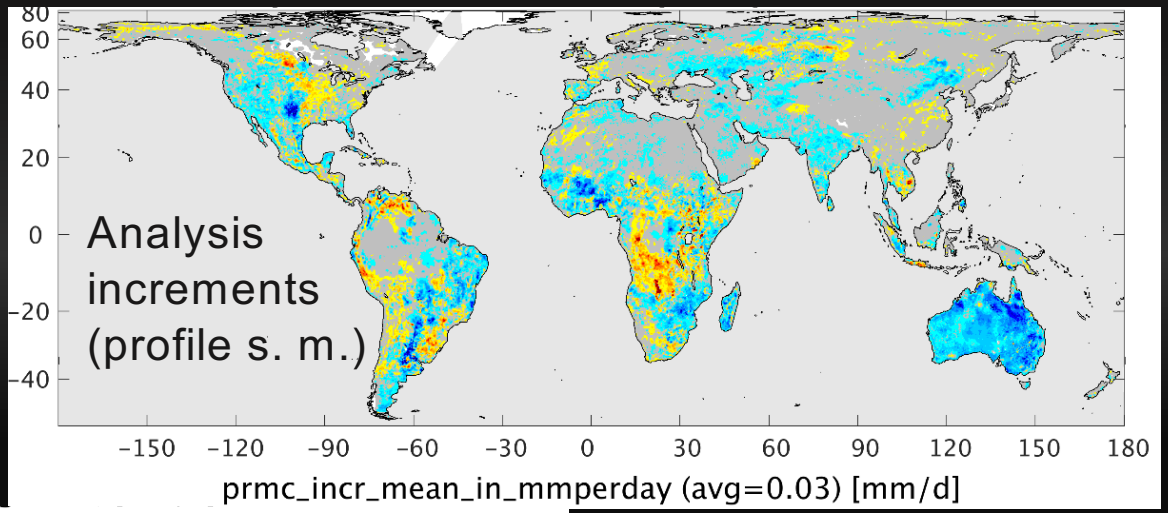
Version 3

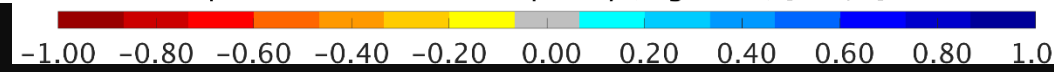




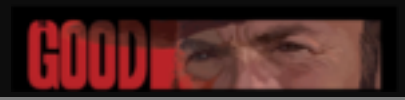
Version 4



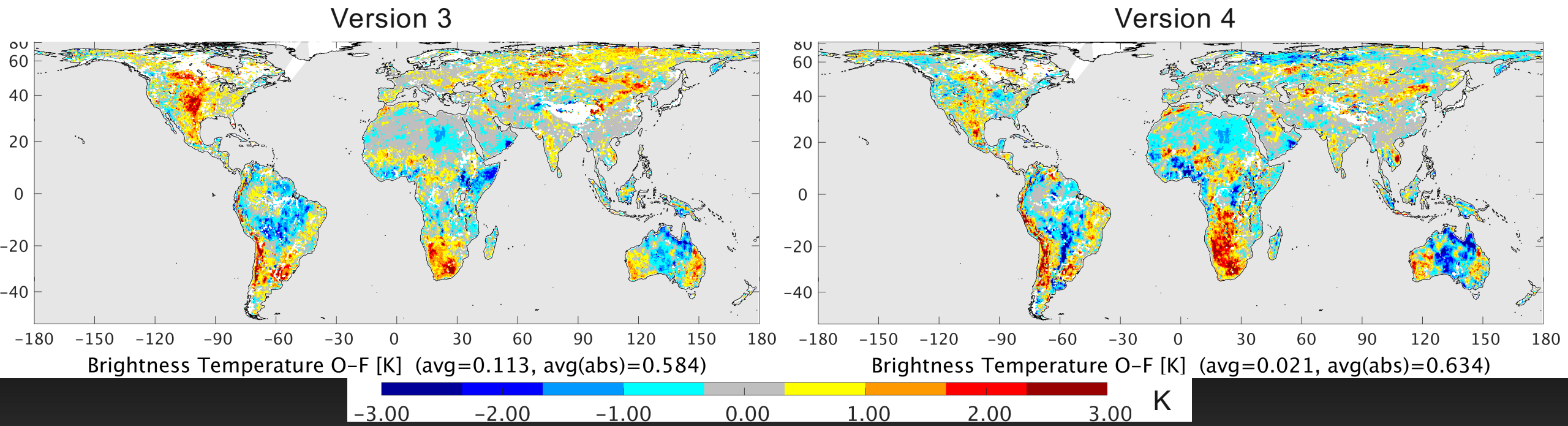




Version 4 has smaller “natural” imbalance and smaller profile s. m. increments than Version 3.

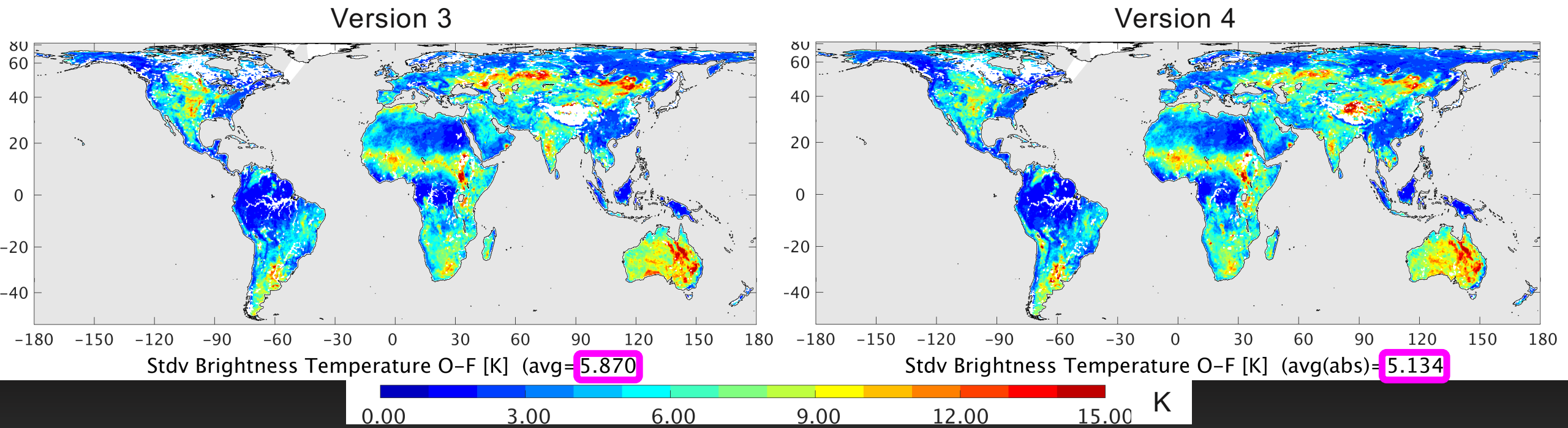


Mean O-F

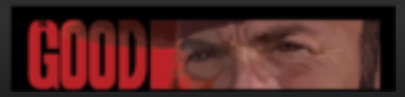


- Version 4 is nearly bias-free in global average, but has slightly larger typical bias magnitude.

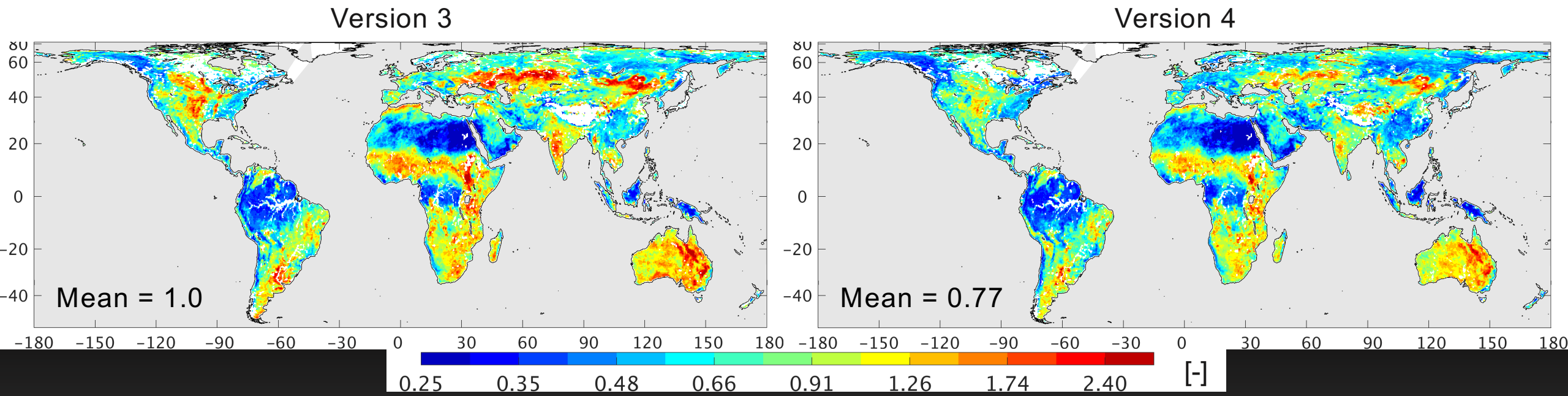
Std-dev O-F



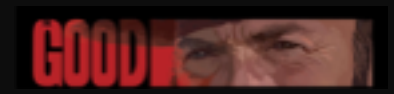
- Version 4 better able to forecast Tb (possibly helped by better obs).



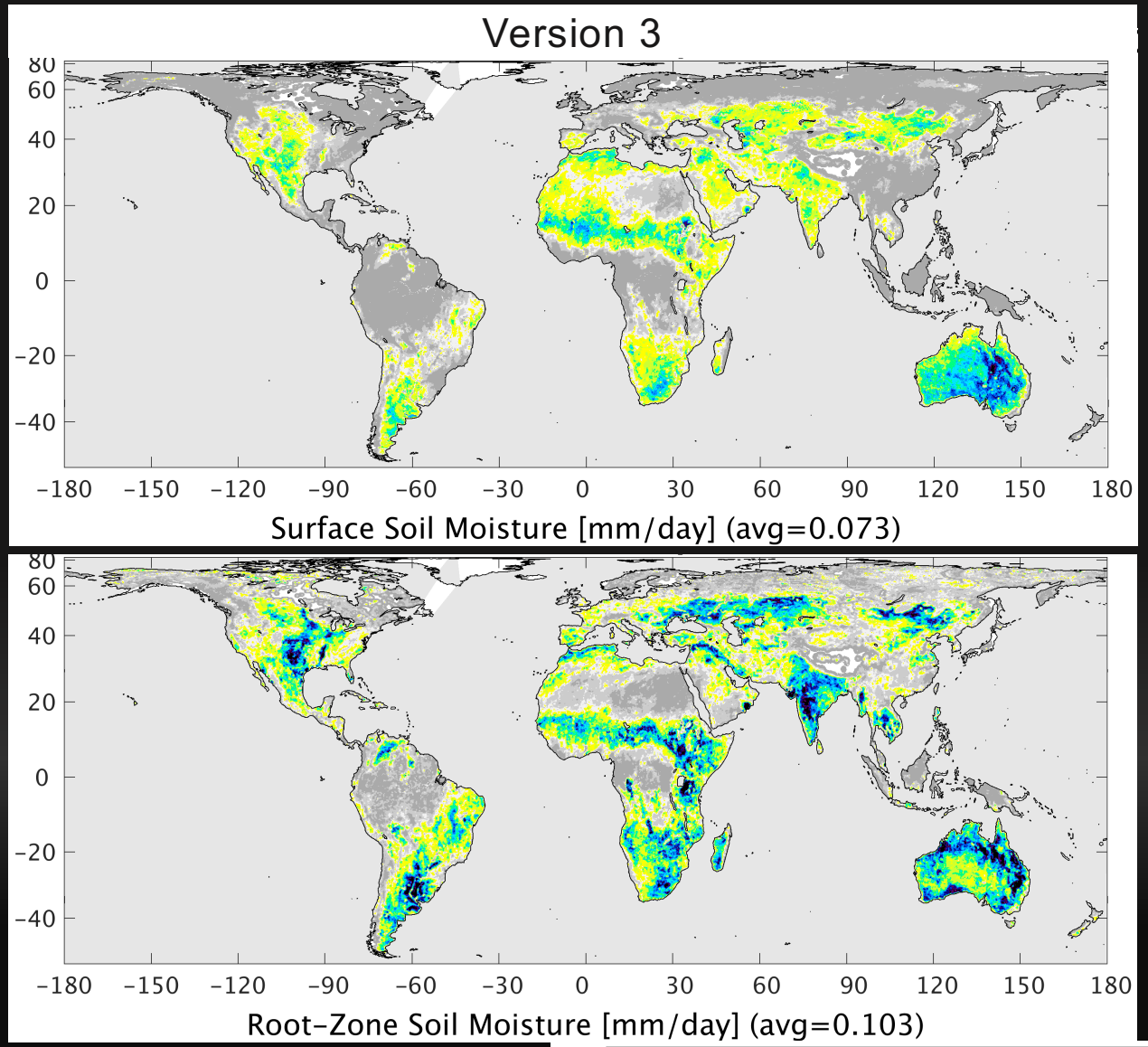
Std-dev Normalized O-F



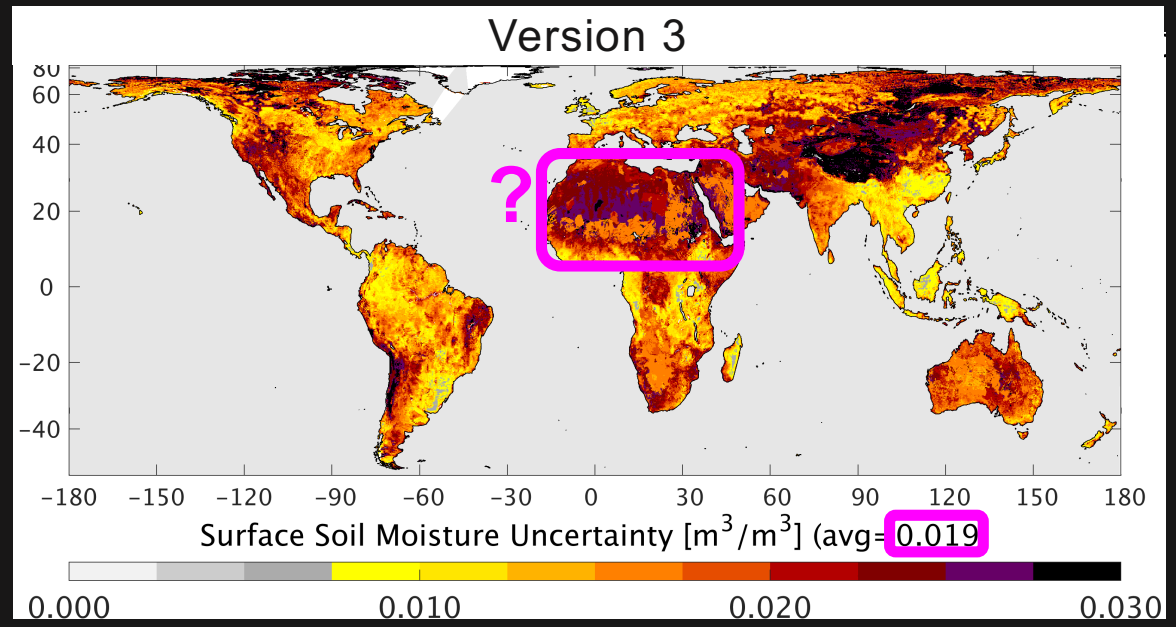
- Normalize O-Fs with (assumed) error std-devs supplied to the analysis.
- Version 4 better (less under-estimation) in regions where Tb analysis impacts soil moisture.
- Version 4 worse (more over-estimation) in forested regions (where Tb provides less information on soil moisture).

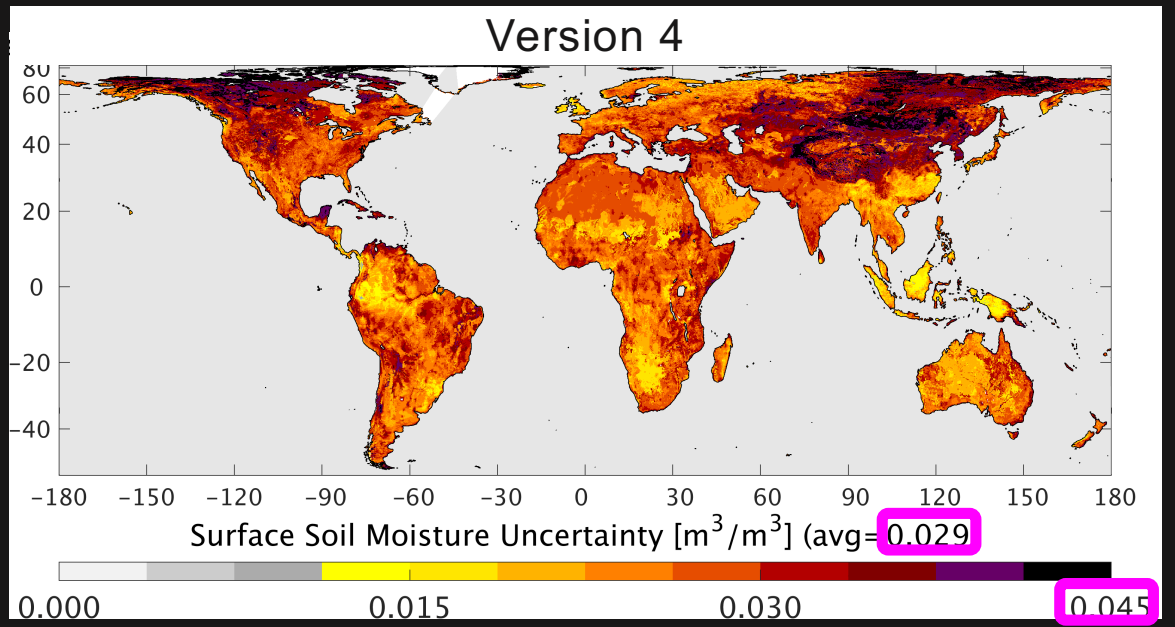


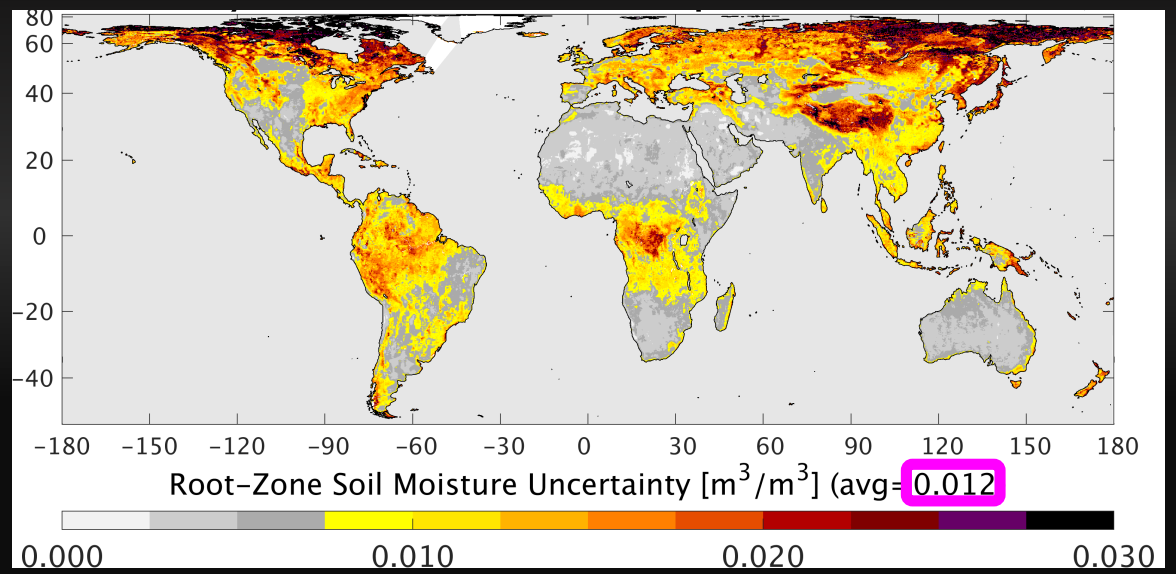
Std-dev Increments

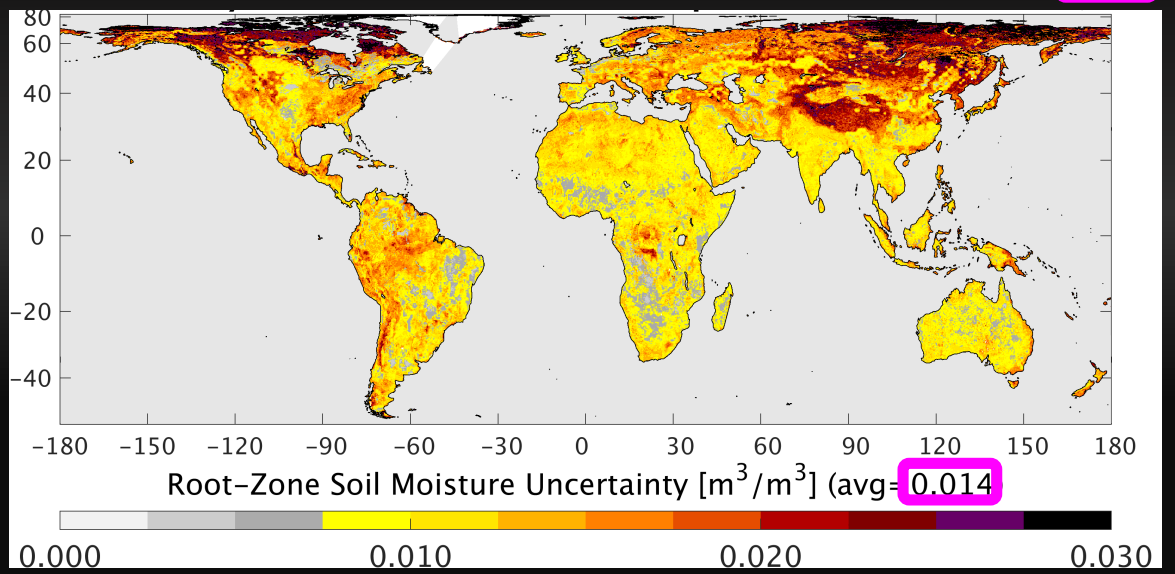


Uncertainty Estimates

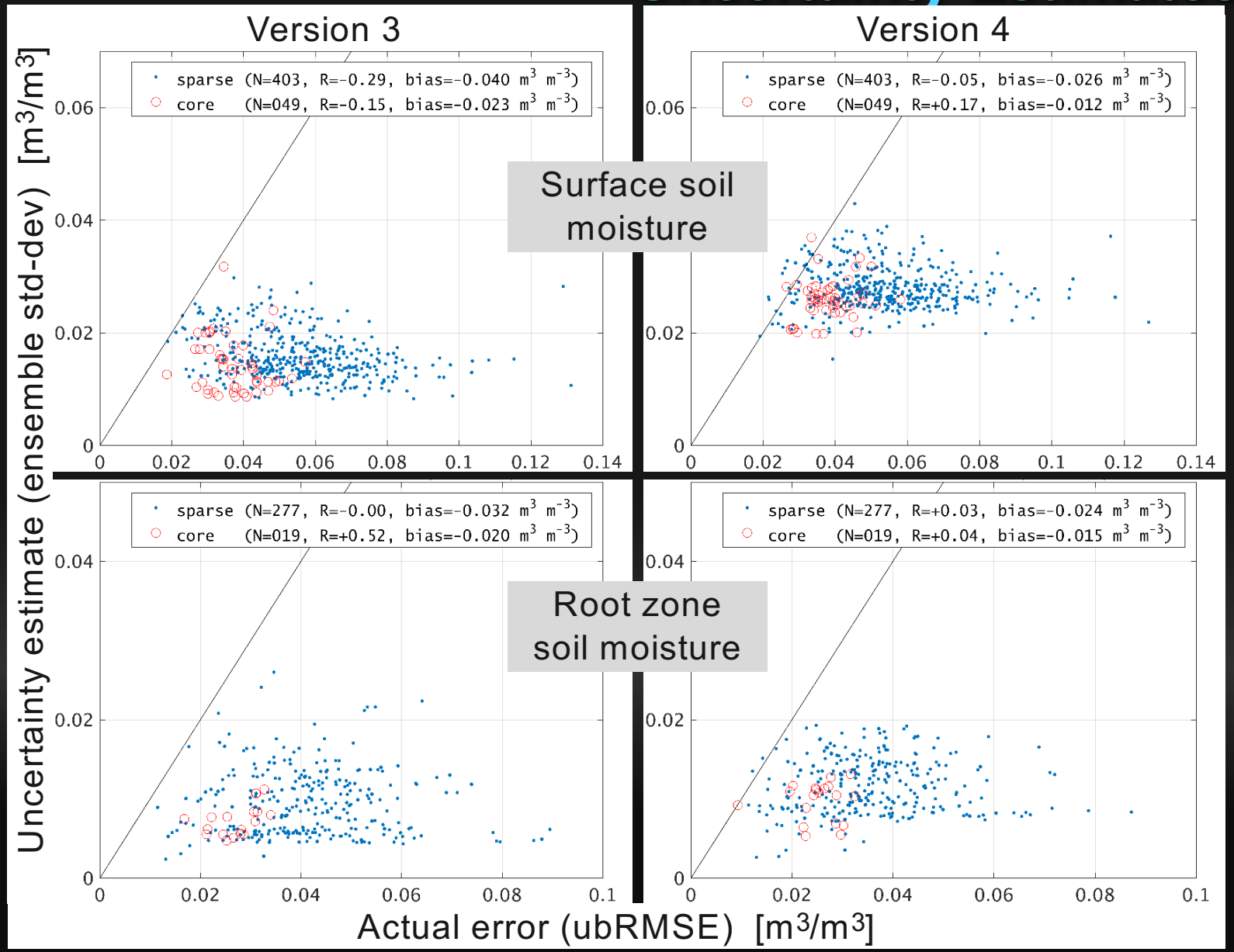








Uncertainty Estimates

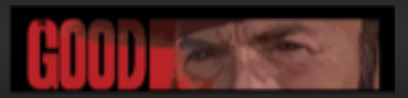


L4_SM provides uncertainty estimates ("ensemble std-dev") for surface and root-zone soil moisture.

These estimates should characterize the actual errors in the L4_SM product ("ubRMSE").

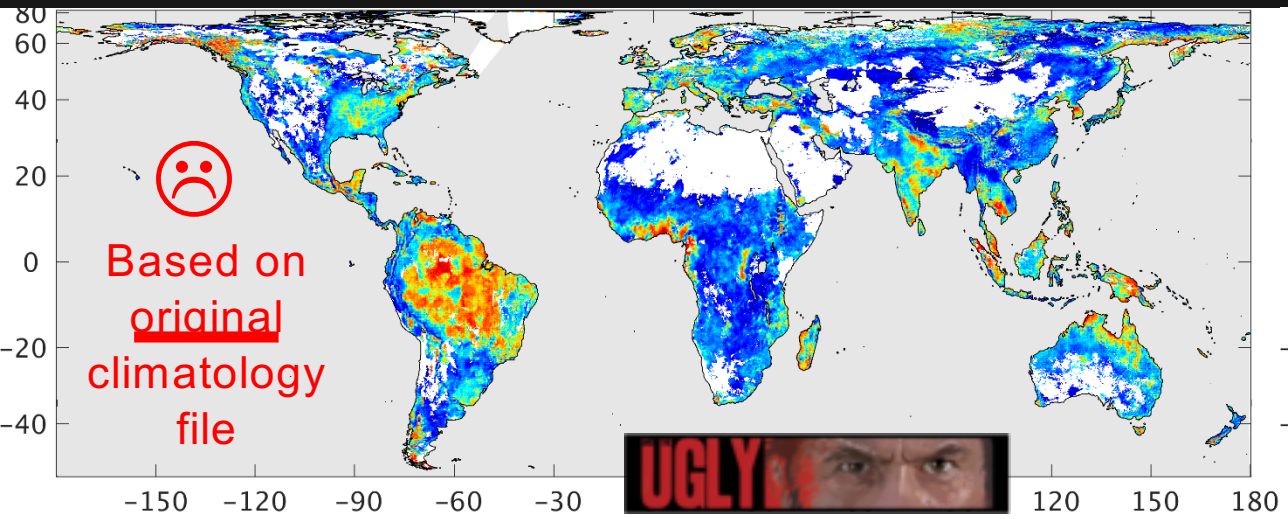
Version 4 uncertainty estimates:

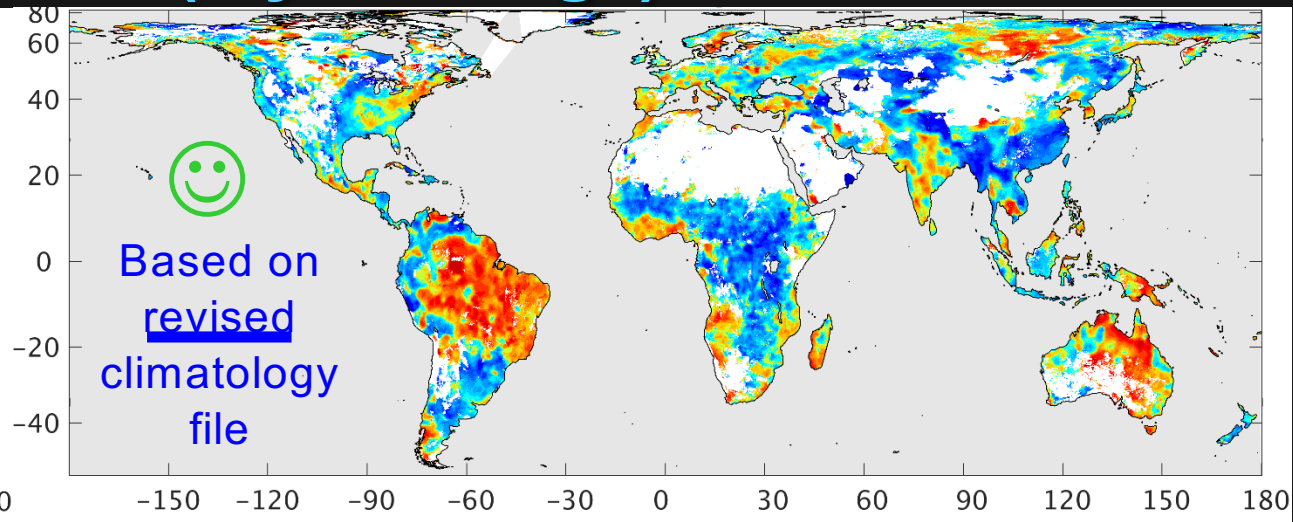
- better capture the average ubRMSE than in Version 3



- but are still not (spatially) correlated with ubRMSE.

Root Zone Percentiles (3-yr average)





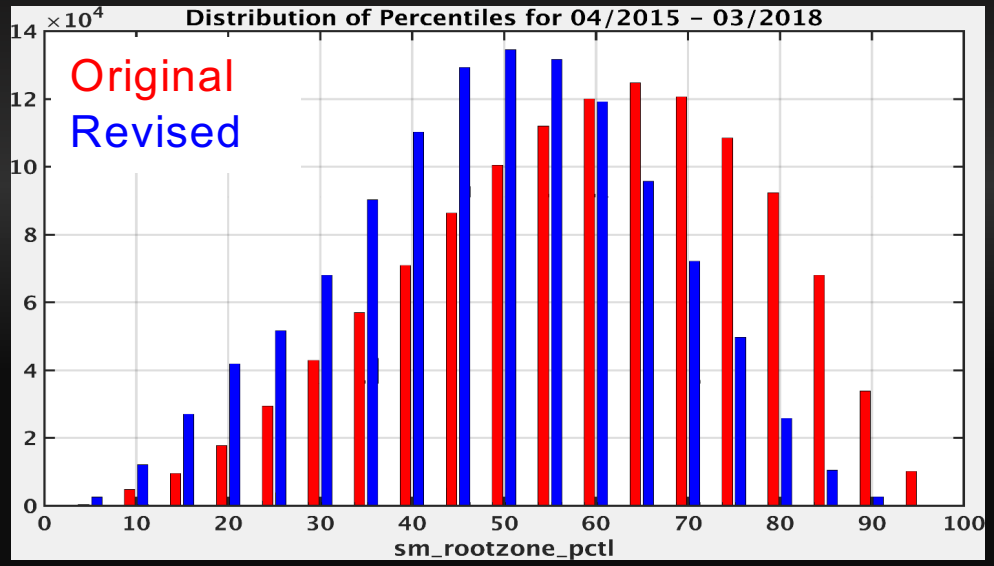
0 12 25 38 50 62 75 88 100 %

Original climatology file is based on NRv7.2 only.

Revised climatology file is adjusted for 3-yr seasonally varying mean difference between Version 4 and NRv7.2a (forced with MERRA-2 during SMAP period).

This corrects for:

1) the discontinuity between retrospective (MERRA-2) and current (GEOS FP) forcing, and
2) the effect of ensemble perturbations.



Summary

The L4_SM algorithm assimilates SMAP brightness temperature (Tb) observations into the NASA Catchment model using a distributed (3d) EnKF.

The L4_SM product provides global, 9-km, 3-hourly estimates with ~2.5-day latency.

The L4_SM algorithm now also assimilates SMAP Tbs in RFI-prone regions.

The L4_SM soil moisture meets accuracy requirements (ubRMSE<0.04 m^3 m^{-3}).

Compared to Version 3, Version 4 has:

- slightly larger surface soil moisture ubRMSE,
- generally drier surface soil moisture and larger differences in Africa and high-lats,
- larger surface s. m. increments and smaller root-zone and profile s. m. increments,
- improved Tb model forecasts (smaller O-F std-dev),
- better representation of actual errors in North American and Eurasian plains,
- larger (more realistic) uncertainty estimates,
- still no correlation between uncertainty estimates and actual errors,
- no improvement in runoff skill.

Perturbations make up non-negligible fraction of water balance in desert regions.

L4_SM Caveats and Future Work

Mismatch in layer depths (L4_SM: 0-5 cm; in situ: ~3-7 cm) and in situ measurement errors adversely impact the validation and result in over-estimated ubRMSE values.

Preliminary reprocessing stream (using L1C Tb test inputs) should complete in July.

Future work:

- Repeat reprocessing (by November 2018) using re-derived Tb scaling parameters based on published L1C Tb reprocessed data and microwave RTM parameters calibrated to NRv7.2.
- Explore assimilation of enhanced resolution and/or water-corrected Tbs.