



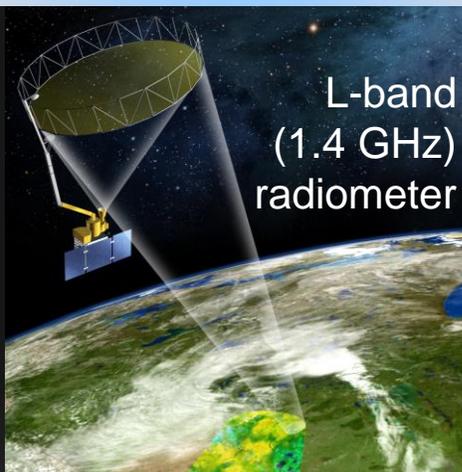
Systematic Errors in Simulated L-Band Brightness Temperature in the SMAP Level-4 Soil Moisture Analysis

Rolf Reichle, Qing Liu,
M. Bechtold, W. Crow, G. De Lannoy, A. Fox, J. Kimball, & R. Koster

SMAP Level-4 Soil Moisture (L4_SM)



SMAP Tb observations
36-km brightness temperatures

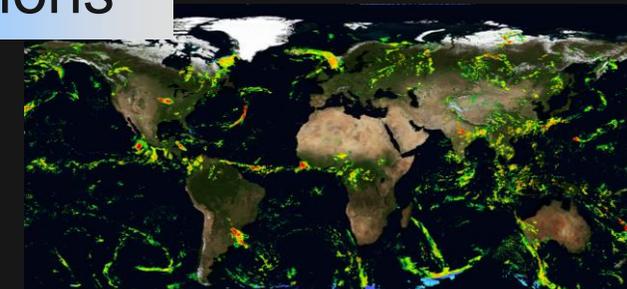


L-band
(1.4 GHz)
radiometer

GEOS NWP
surface
meteorology

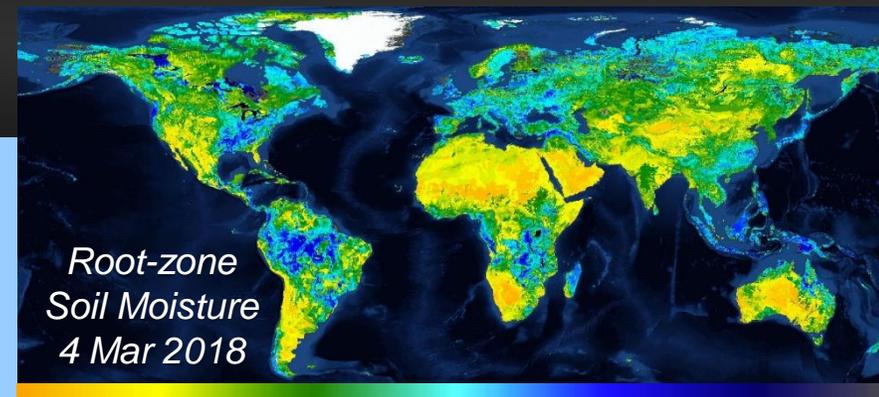
IMERG & CPC
precipitation
observations

*GEOS
Catchment Model
(9 km)*



*Ensemble data
assimilation*

L4_SM Product
9-km, 3-hourly, global,
2.5-day latency



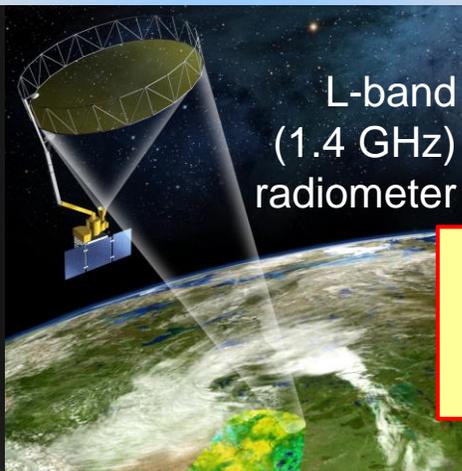
*Root-zone
Soil Moisture
4 Mar 2018*



SMAP Level-4 Soil Moisture (L4_SM)



SMAP Tb observations
36-km brightness temperatures

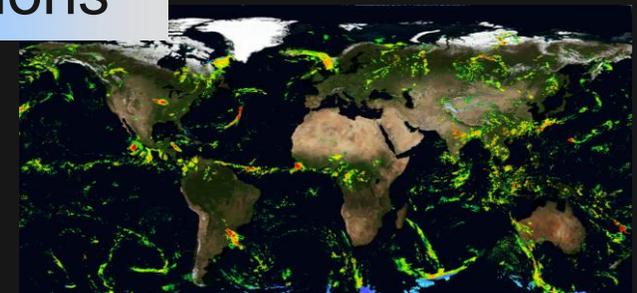


Soil moisture corrections derived from observed-minus-simulated Tb diffs.

GEOS NWP surface meteorology

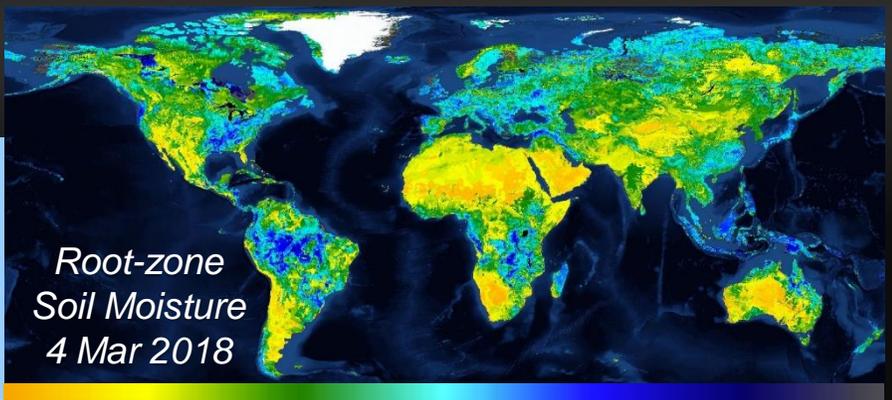
IMERG & CPC precipitation observations

GEOS Catchment Model (9 km)



Ensemble data assimilation

L4_SM Product
9-km, 3-hourly, global, 2.5-day latency

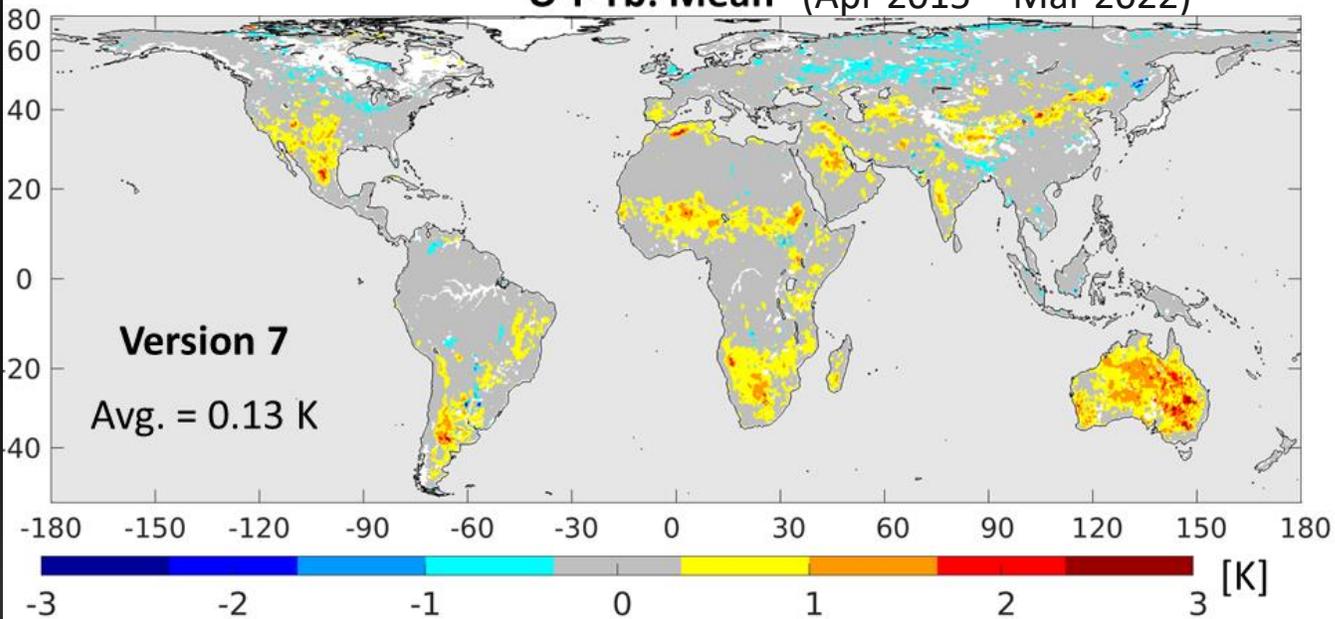


Tb O-F Residuals



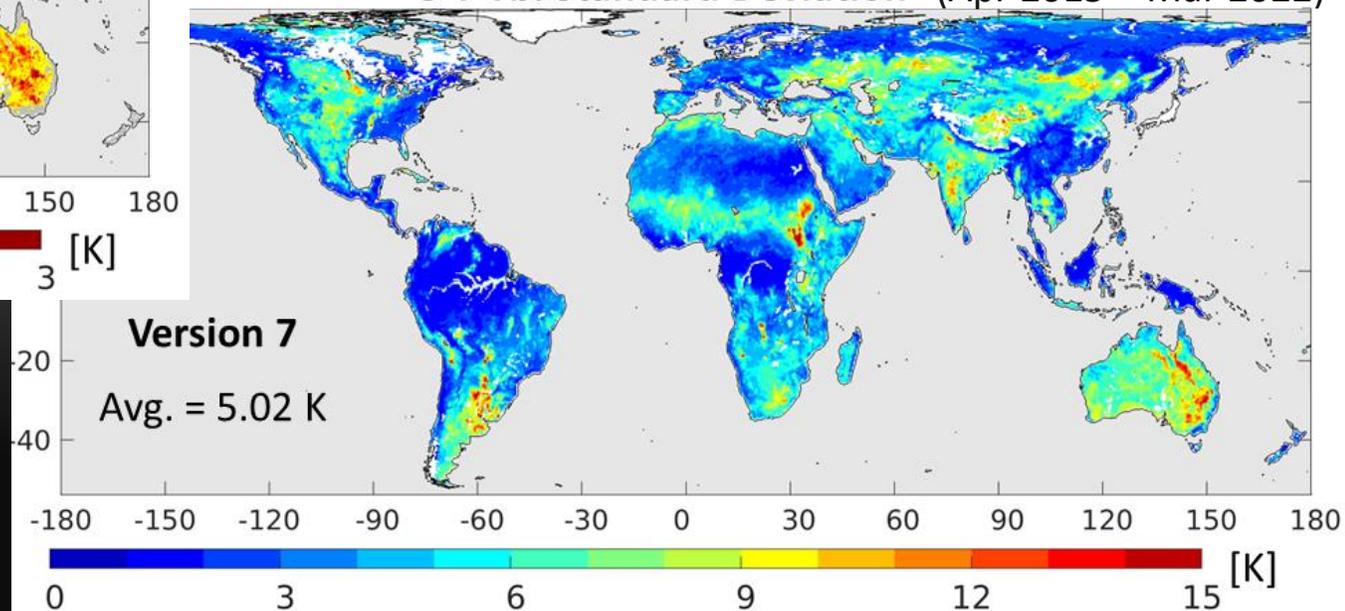
Tb O-F residuals can independently verify short-term forecasts of simulated Tb.

O-F Tb: Mean (Apr 2015 – Mar 2022)



Long-term mean and stdv generally well behaved.

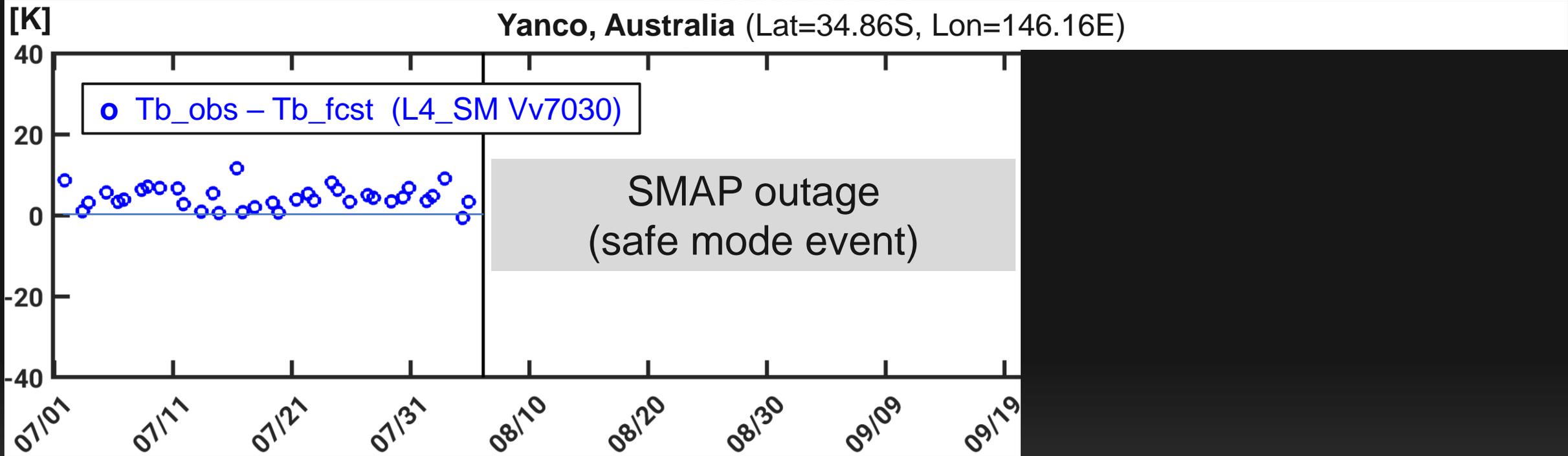
O-F Tb: Standard Deviation (Apr 2015 – Mar 2022)



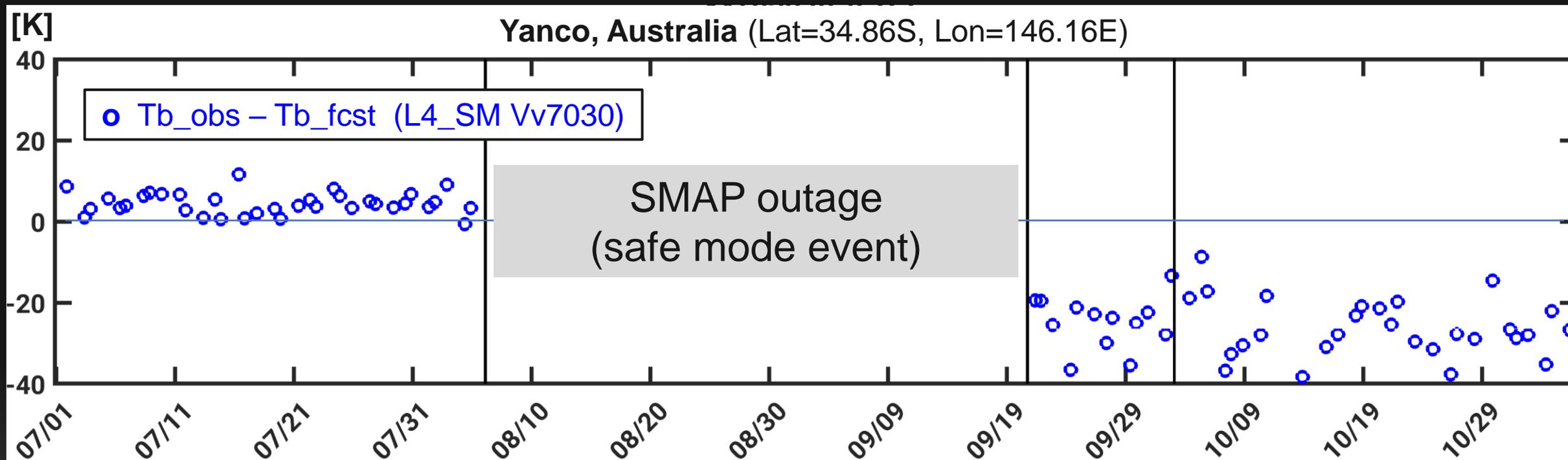
Tb O-F Residuals (July 2022)



Tb O-F Residuals (Jul-Sep 2022)



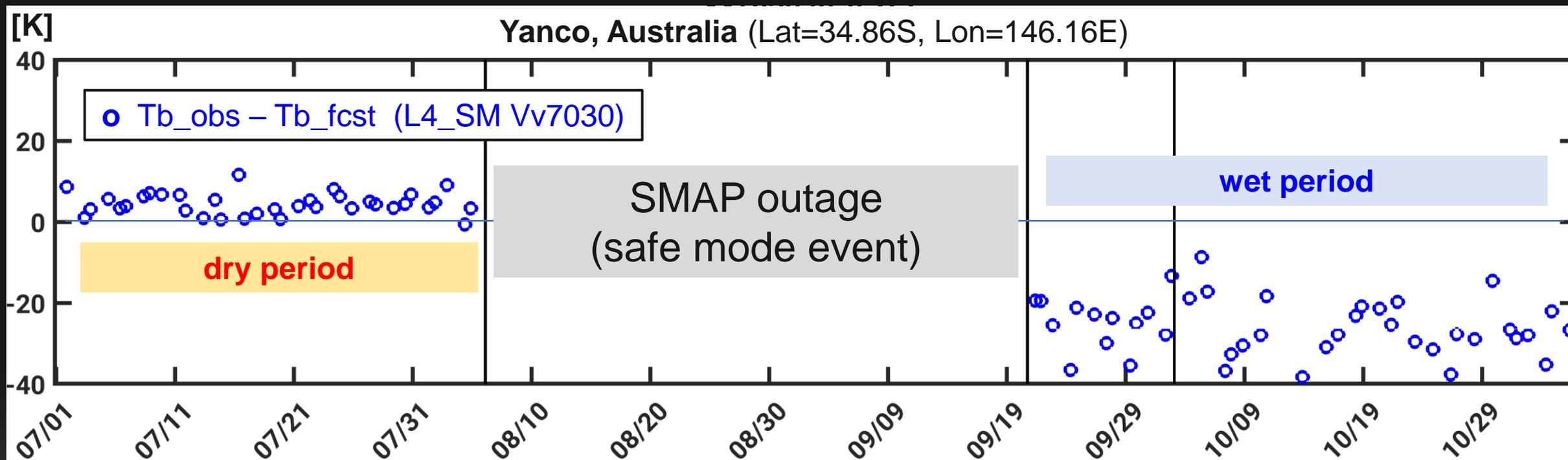
Tb O-F Residuals (Jul-Oct 2022)



Large offset in Tb O-F residuals after SMAP outage.

Soil moisture looks reasonable (not shown).

Tb O-F Residuals (Jul-Oct 2022)



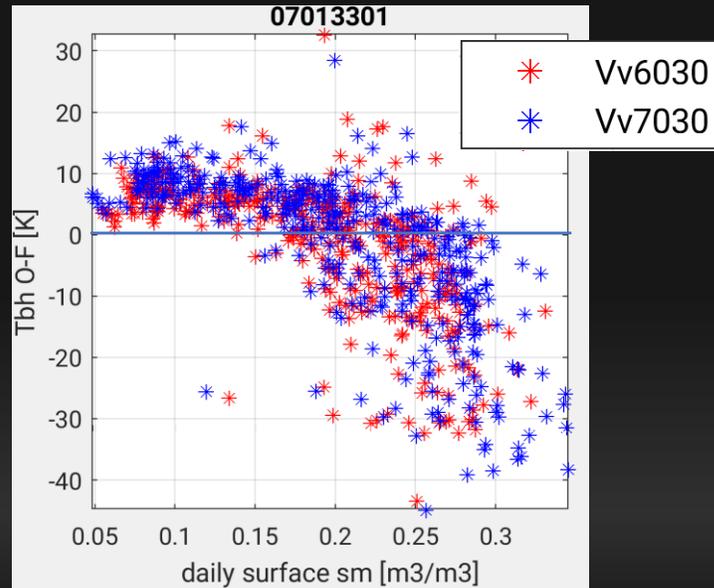
Large offset in Tb O-F residuals after SMAP outage.

Soil moisture looks reasonable (not shown).

Tb O-F Residuals (Apr 2015-Mar 2021)



Yanco (Australia)



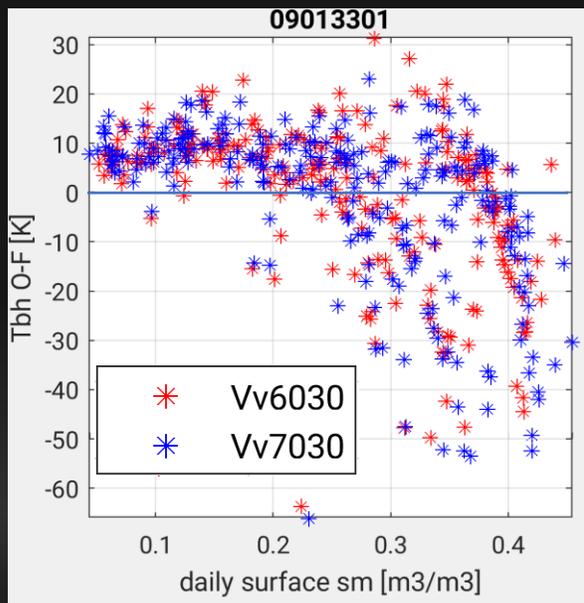
Tb O-F residuals depend
on soil moisture?!?!

Applies to H- and V-pol
and both Versions 6 & 7.

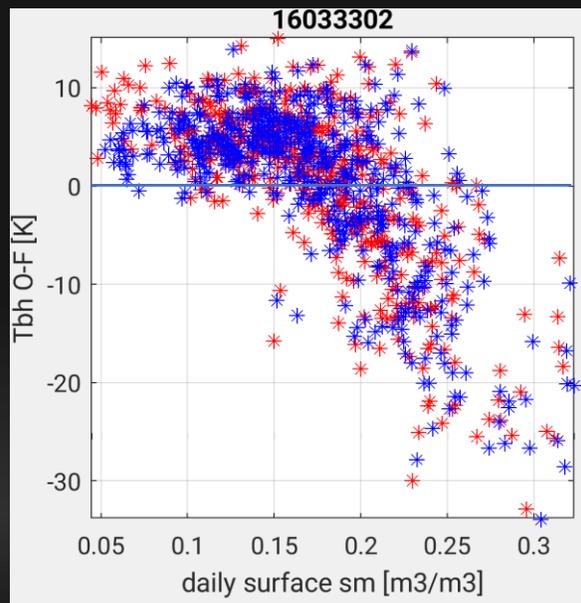
Tb O-F Residuals



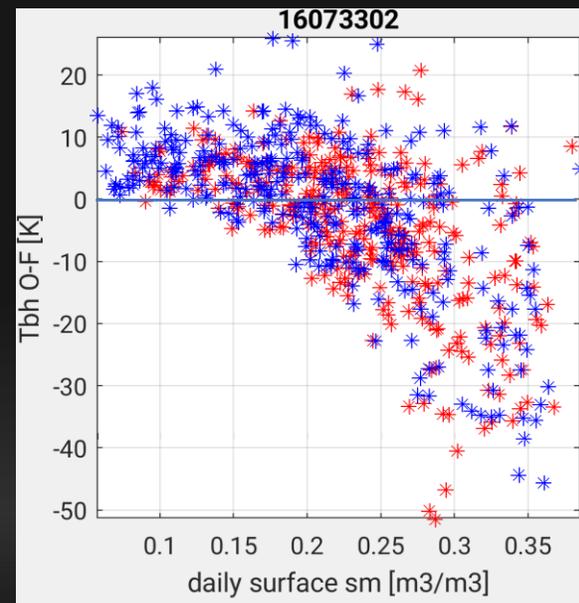
Carman
(Manitoba)



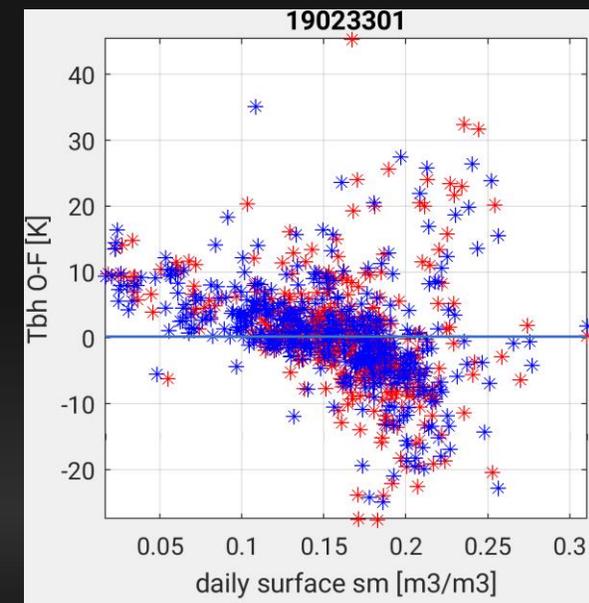
Ft Cobb
(OK)



South Fork
(IA)



Monte Buey
(Argentina)



Applies elsewhere (although not everywhere).

First Attempt to Fix the Problem



The L4_SM algorithm assimilates departures from the mean seasonal cycle of Tb:

$$\text{"O-F"} = (\text{Tb_obs} - \langle \text{Tb_obs} \rangle) - (\text{Tb_model} - \langle \text{Tb_model} \rangle)$$

Additionally scale with seasonally varying (time series) stdv of Tb ("assimilate Z-scores"):

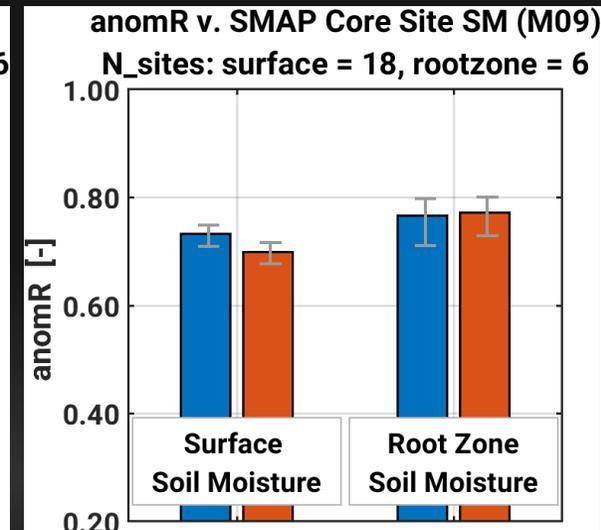
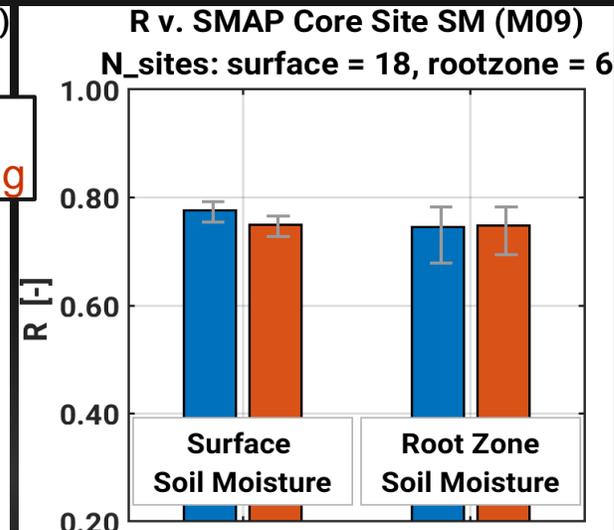
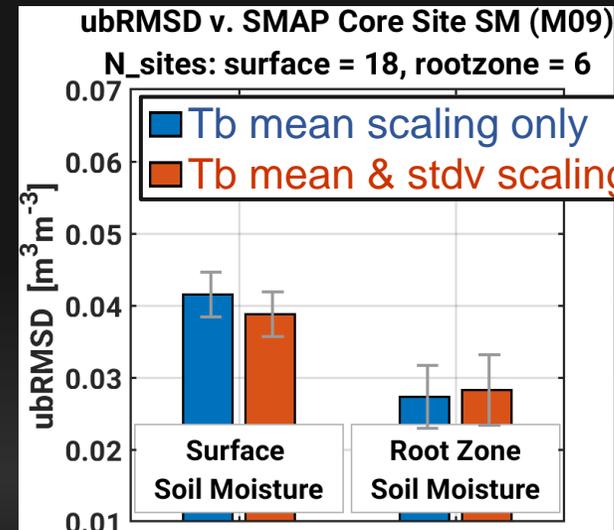
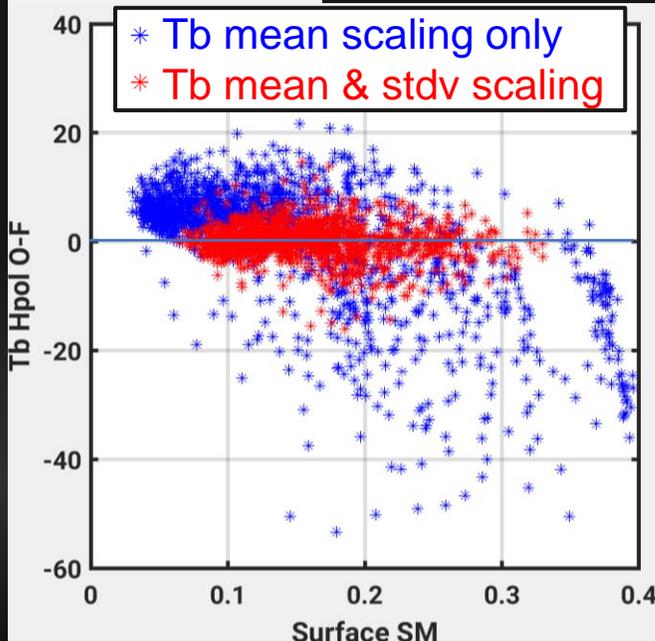
$$\text{"O-F"} = (\text{Tb_obs} - \langle \text{Tb_obs} \rangle) / \text{stdv}[\text{Tb_obs}] - (\text{Tb_model} - \langle \text{Tb_model} \rangle) / \text{stdv}[\text{Tb_mod}]$$

First Attempt to Fix the Problem

Also scaling the stdv of Tb:

- Eliminates systematic error in Tb O-F but reduces soil moisture dynamic range (less obs impact).
- Reduces ubRMSD for surface soil moisture at core sites but also degrades correlation metrics.

Yanco, Australia



(Results may be unreliable b/c of a minor bug in test setup. Would need to re-run to find out.)

Second Attempt to Fix the Problem



Improve the L-band radiative transfer model (RTM), a.k.a. the “tau-omega” model?
Or at least make it more self-consistent?

L4_SM V7 uses select microwave RTM parameters from SMAP L2 retrievals:

- Soil roughness
- Scattering albedo
- Seasonally varying climatology of vegetation opacity

However, differences in the RTM parameterizations remain...

Tau-Omega Model: L2 vs L4



	L2 DCA Retrievals (R17, R18)	L4_SM Version 7
Soil dielectric mixing model	Mironov	Wang & Schmugge
Rough surface reflectivity: $r_{p,rough} = \text{polmix}_p \cdot \exp(-h \cdot \cos^x \theta)$ $\text{polmix}_p = [Q \cdot r_{p,smooth} + (1 - Q) \cdot r_{q,smooth}]$	$x = 2$ $Q = 0.1771 \cdot h$	$x = \text{fn}(\text{land cover, pol.})$ $Q = 0$ (<u>no</u> polarization mixing)
Effective physical temperature	$T_{eff} = K \cdot [T_{soil2} + C \cdot (T_{soil1} - T_{soil2})]$ $C = 0.246$ (6am) $C = 1$ (6pm) $K = 1.007$ (!!!) T_{soil1}, T_{soil2} from GEOS-FP	$T_{eff} = T_{soil1}$
Soil texture	SoilsGrid250m	HWSDv2.1, STATSGO, FAO

Tau-Omega Model: L2 vs L4



	L2 DCA Retrievals (R17, R18)	L4_SM Version 7
Soil dielectric mixing model	Mironov	Wang & Schmugge
Rough surface reflectivity: $r_{p,rough} = \text{polmix}_p \cdot \exp(-h \cdot \cos^x \theta)$ $\text{polmix}_p = [Q \cdot r_{p,smooth} + (1 - Q) \cdot r_{q,smooth}]$	$x = 2$ $Q = 0.1771 \cdot h$	$x = \text{fn}(\text{land cover, pol.})$ $Q = 0$ (<u>no</u> polarization mixing)
Effective physical temperature	$T_{eff} = K \cdot [T_{soil2} + C \cdot (T_{soil1} - T_{soil2})]$ $C = 0.246$ (6am) $C = 1$ (6pm) $K = 1.007$ (!!!) T_{soil1}, T_{soil2} from GEOS-FP	$T_{eff} = T_{soil1}$
Soil texture	SoilsGrid250m	HWSDv2.1, STATSGO, FAO Tried clay fraction from SoilsGrid250m. → No change.

Tau-Omega Model: L2 vs L4



	L2 DCA Retrievals (R17, R18)	L4_SM Version 7
Soil dielectric mixing model	Mironov	Wang & Schmugge
Rough surface reflectivity: $r_{p,rough} = \text{polmix}_p \cdot \exp(-h \cdot \cos^x \theta)$ $\text{polmix}_p = [Q \cdot r_{p,smooth} + (1 - Q) \cdot r_{q,smooth}]$	$x = 2$ $Q = 0.1771 \cdot h$	$x = \text{fn}(\text{land cover, pol.})$ $Q = 0$ (<u>no</u> polarization mixing)
Effective physical temperature	$T_{eff} = K \cdot [T_{soil2} + C \cdot (T_{soil1} - T_{soil2})]$ $C = 0.246$ (6am) $C = 1$ (6pm) $K = 1.007$ (!!!) T_{soil1}, T_{soil2} from GEOS-FP	$T_{eff} = T_{soil1}$
Soil texture	SoilsGrid250m	HWSDv2.1, STATSGO, FAO

Tau-Omega Model: L2 vs L4



	L2 DCA Retrievals (R17, R18)	New RTM
Soil dielectric mixing model	Mironov	Mironov
Rough surface reflectivity: $r_{p,rough} = \text{polmix}_p \cdot \exp(-h \cdot \cos^x \theta)$ $\text{polmix}_p = [Q \cdot r_{p,smooth} + (1 - Q) \cdot r_{q,smooth}]$	$x = 2$ $Q = 0.1771 \cdot h$	$x = 2$ $Q = 0.1771 \cdot h$
Effective physical temperature	$T_{eff} = K \cdot [T_{soil2} + C \cdot (T_{soil1} - T_{soil2})]$ $C = 0.246$ (6am) $C = 1$ (6pm) $K = 1.007$ (!!!) T_{soil1}, T_{soil2} from GEOS-FP	$T_{eff} = T_{soil1}$
Soil texture	SoilsGrid250m	HWSDv2.1, STATSGO, FAO

Third Attempt to Fix the Problem



Scale soil moisture inputs to microwave RTM:

$$\text{SFMC}_{\text{RTM}} = a * \text{SFMC}_{\text{Catchment}} + b \quad (1)$$

where a and b are derived from Catchment and L2-retrieved soil moisture.

Global 36-km resolution (M36) results shown next for:

OLv7 = L4_SM V7 Open Loop (M36)

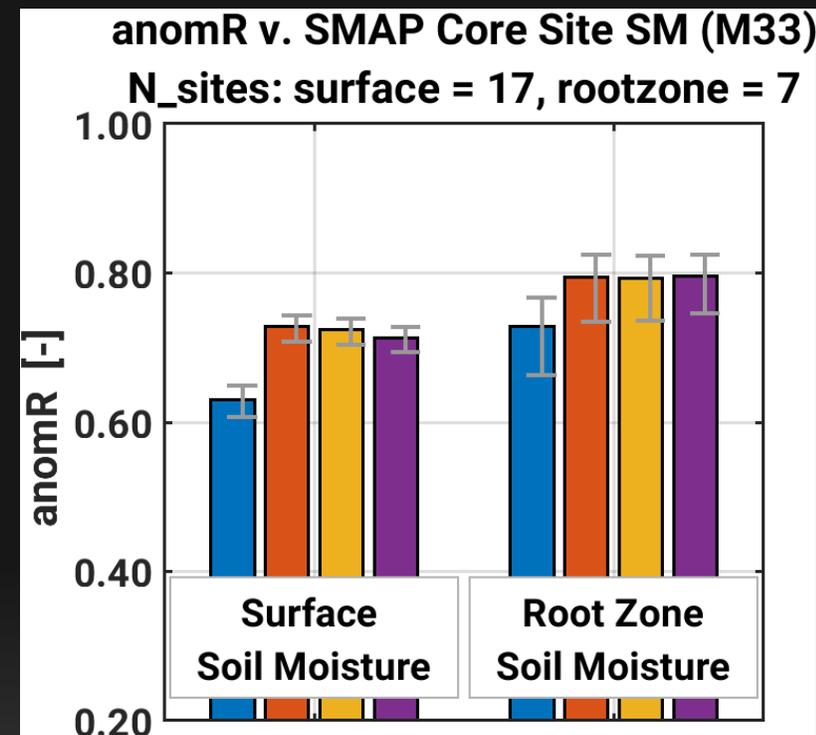
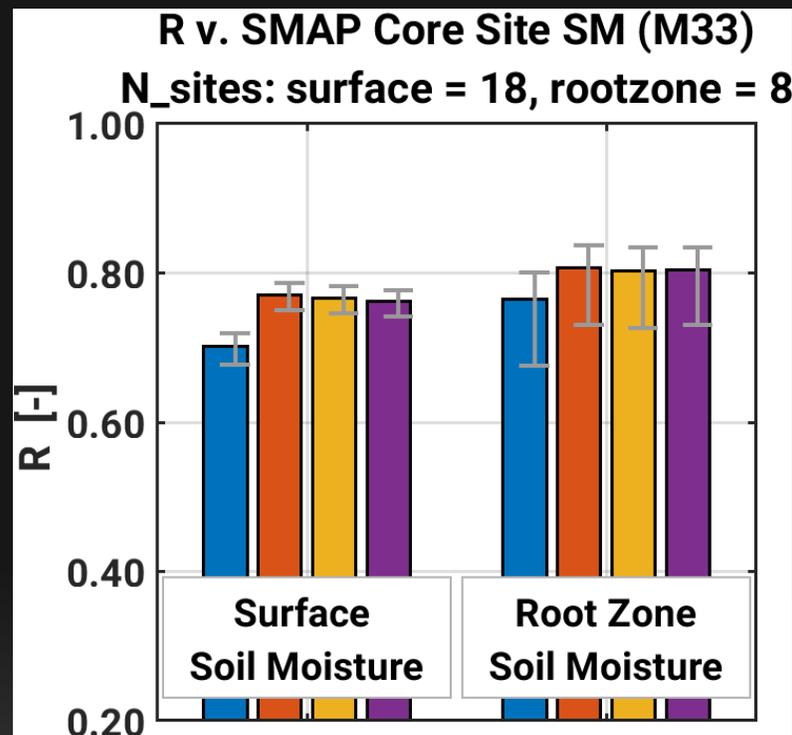
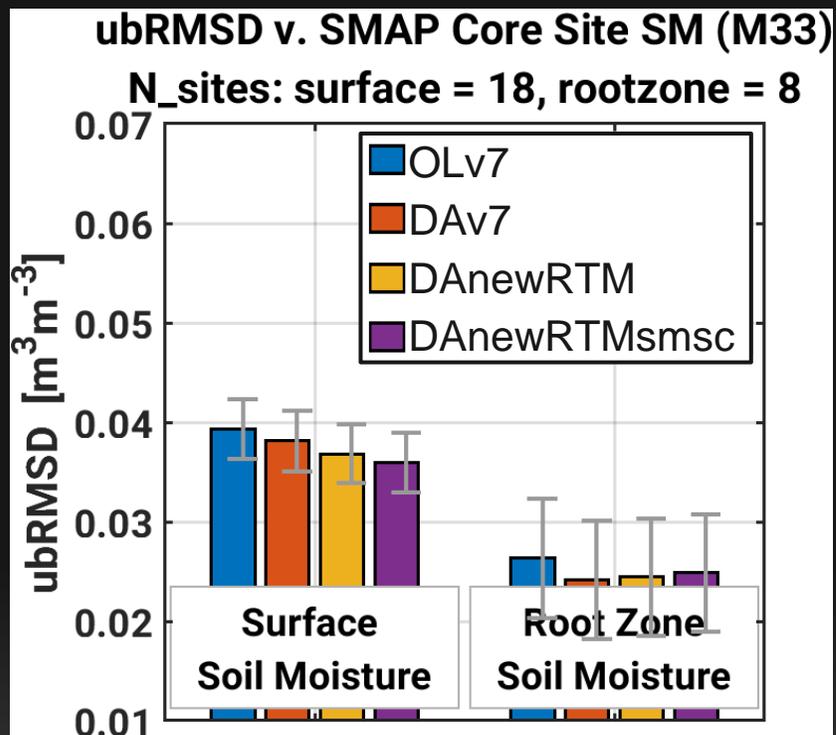
DAv7 = L4_SM V7 (M36)

DAnewRTM = As in DAv7 but with revised RTM (Mironov, rough reflectivity params)

DAnewRTMsmc = As in DAnewRTM plus scaling of soil moisture inputs to RTM as in (1)

All DA experiments have custom Tb scaling parameters. Mean Tb scaling only (no Tb stdv scaling).

Core Site Validation (M33)



New RTM improves surface soil moisture ubRMSD with minimal loss of skill in correlation and root-zone soil moisture ubRMSD.

Scaling soil moisture inputs to RTM further improves surface soil moisture ubRMSD but more noticeably degrades correlation and root-zone soil moisture ubRMSD.

Sparse Network Validation (USCRN, SCAN, ...)

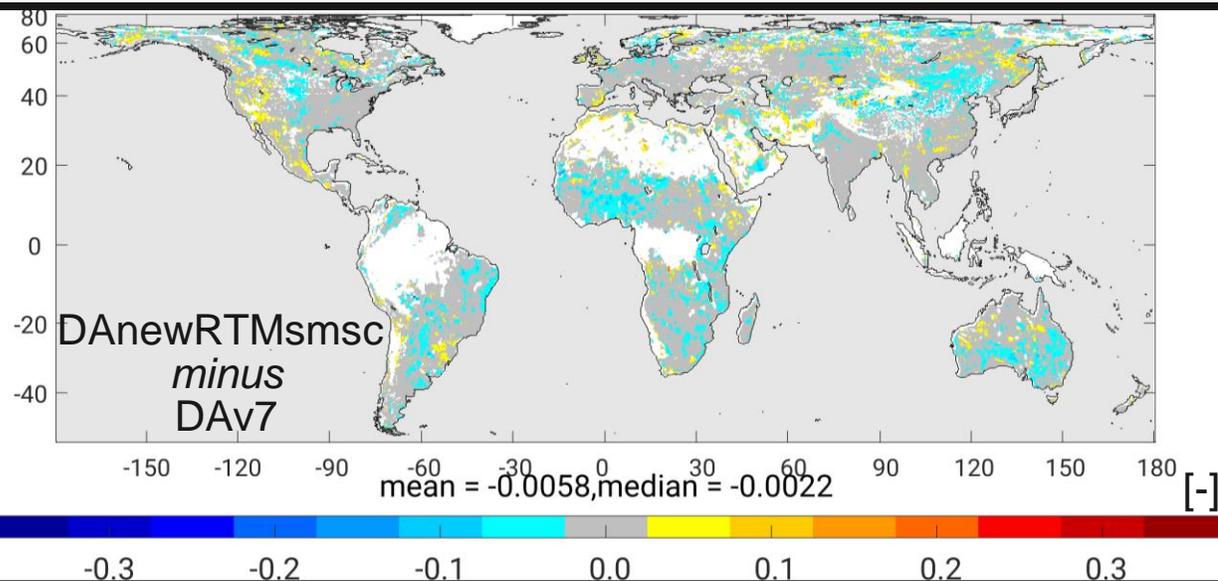
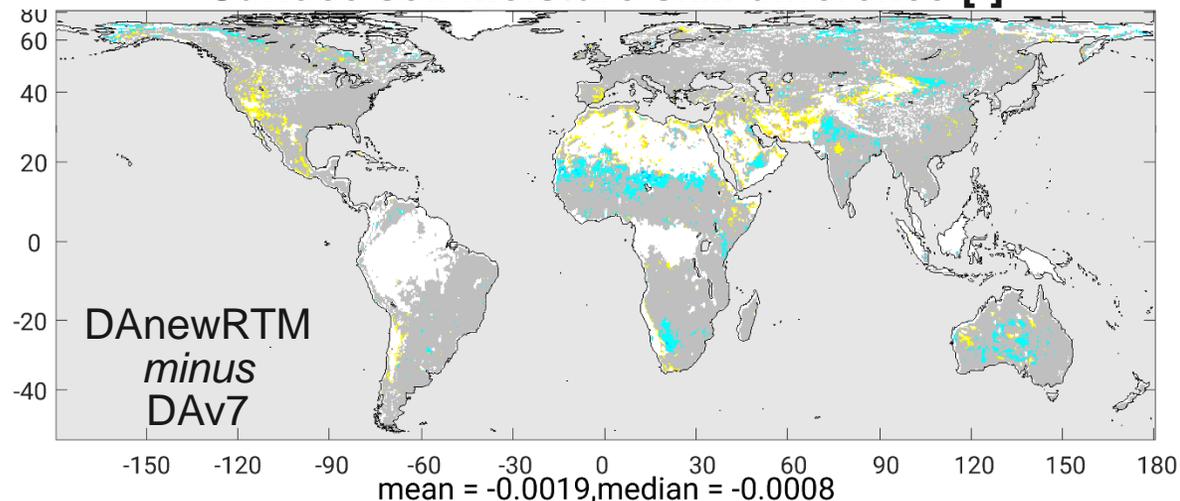


- At sparse networks, new microwave RTM has neutral impact on skill w.r.t. L4_SM V7 (not shown).
- Possible explanations:
 - L2 system calibrated to core site locations.
 - “Good” results at core sites are just luck of sampling from few sites.

Anomaly R Skill Differences (IVs ASCAT)



Surface soil moisture skill difference [-]

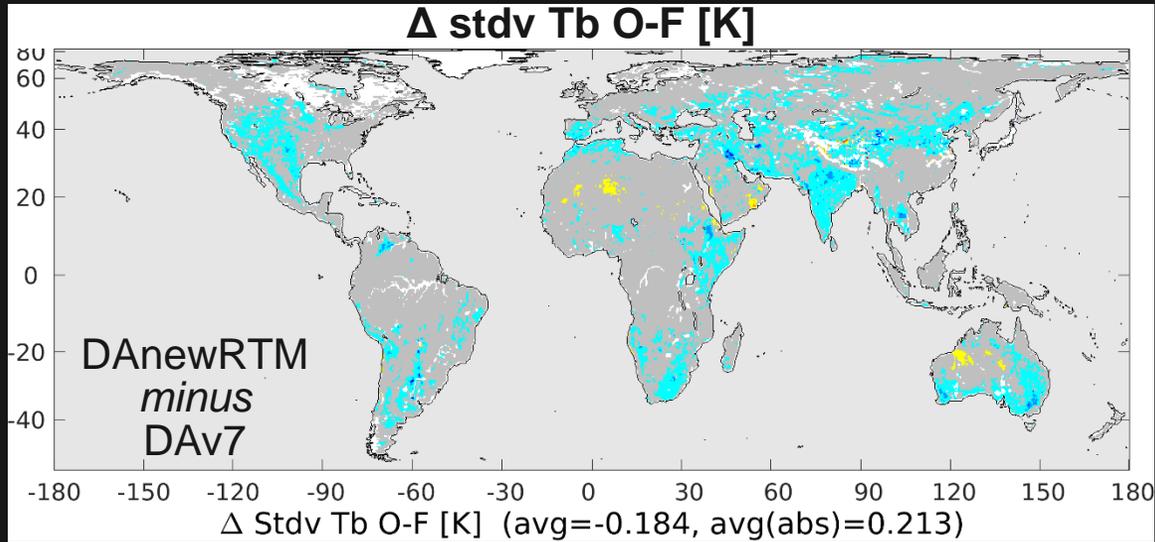


New RTM does not change skill compared to L4_SM V7.

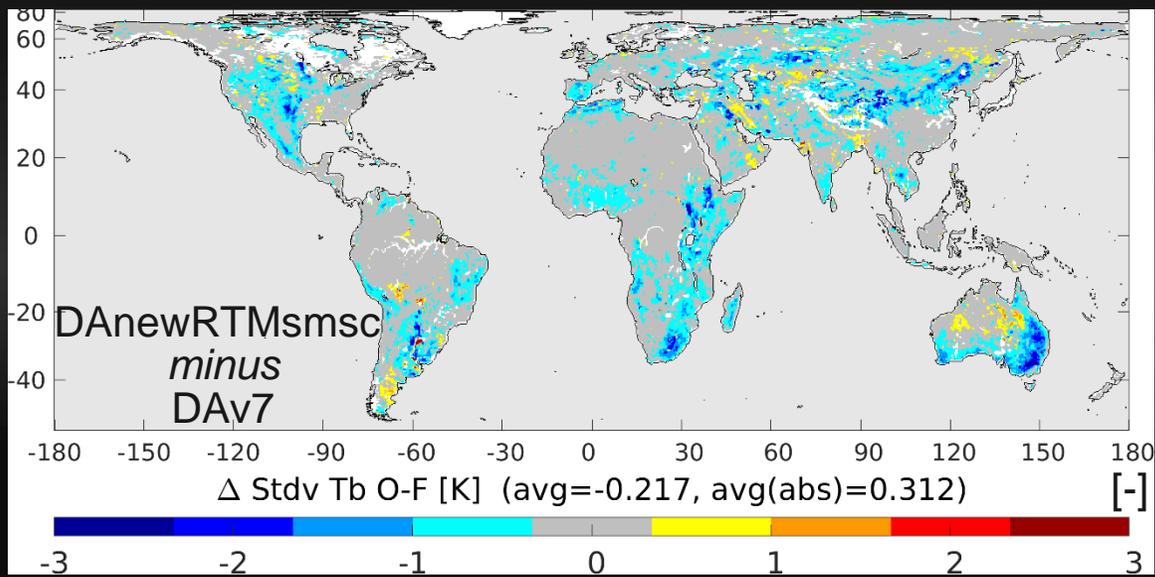
Similar result with additional scaling of soil moisture inputs to RTM.

Same results with straight difference in R values vs ASCAT (as opposed to IVs).

Stdv Tb O-F



- New RTM improves stdv of Tb O-F residuals by 0.2 K w.r.t. L4_SM V7.

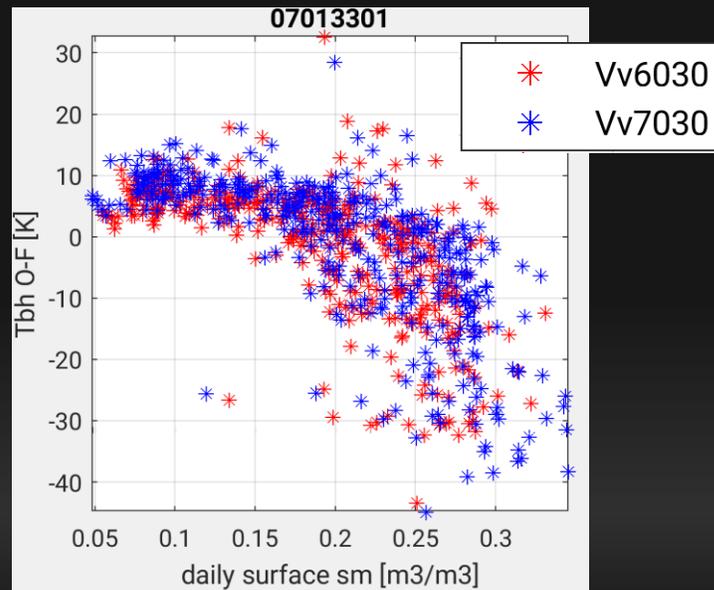


- On balance, similar result with scaling of soil moisture inputs to RTM.

Tb O-F Residuals (Apr 2015-Mar 2021)

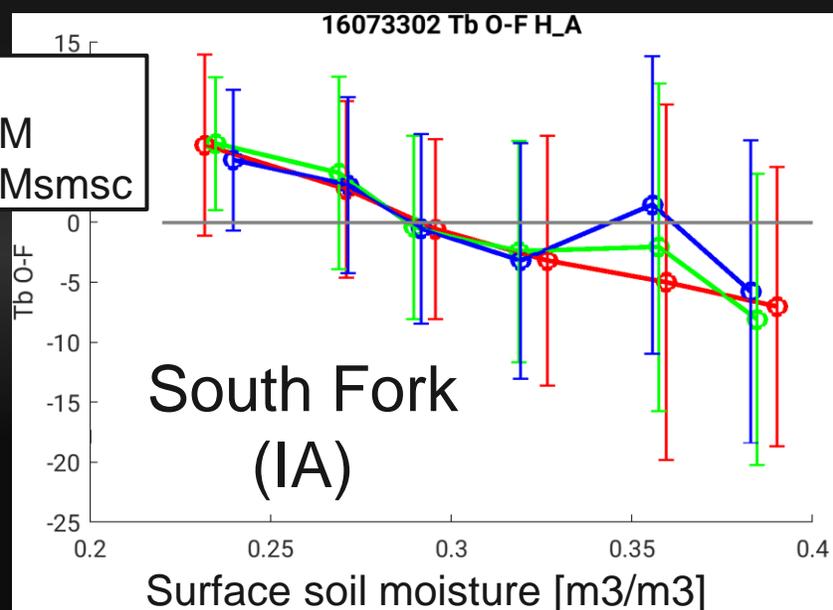
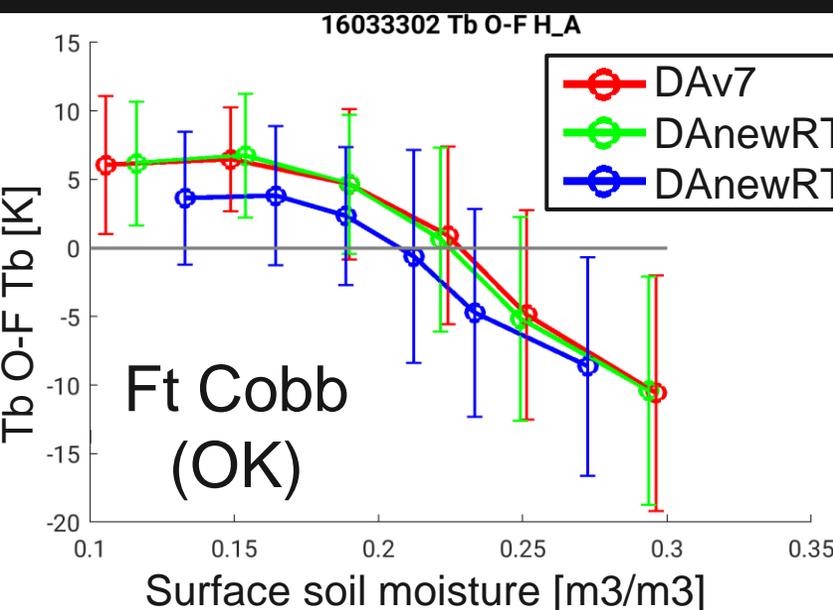
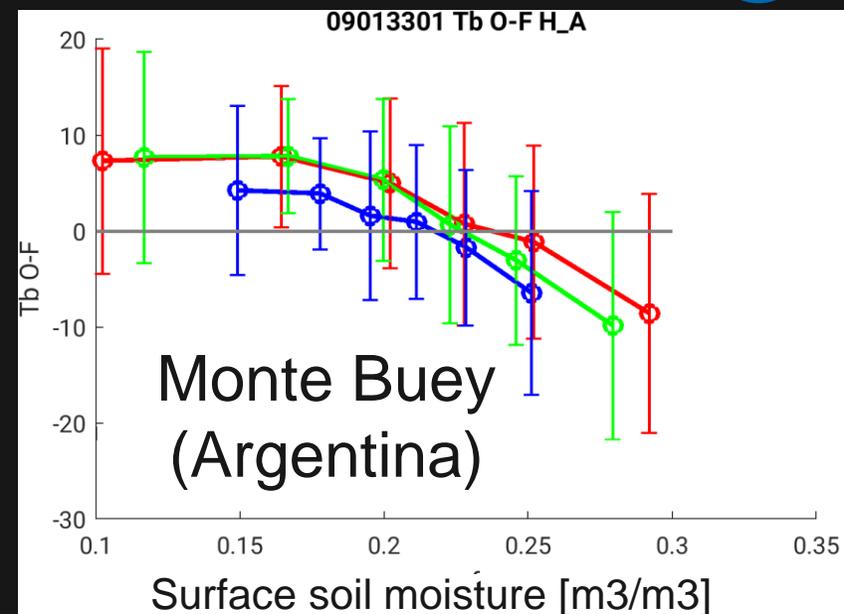
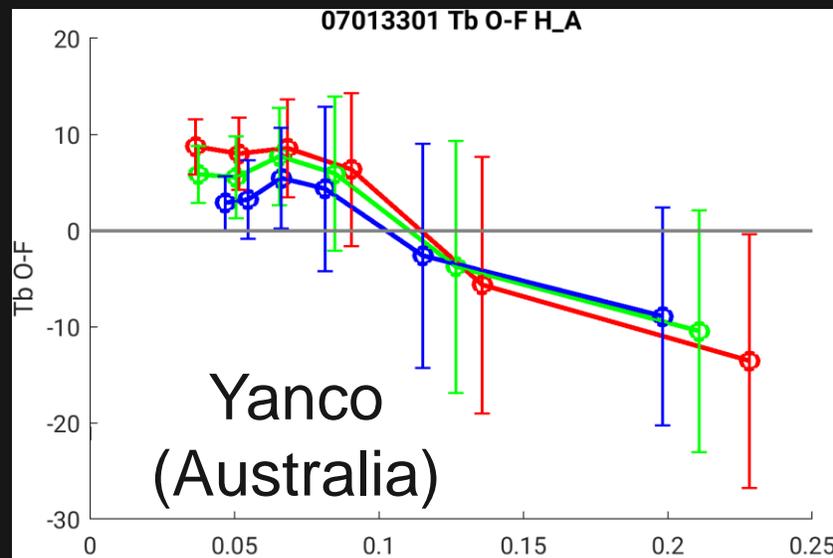
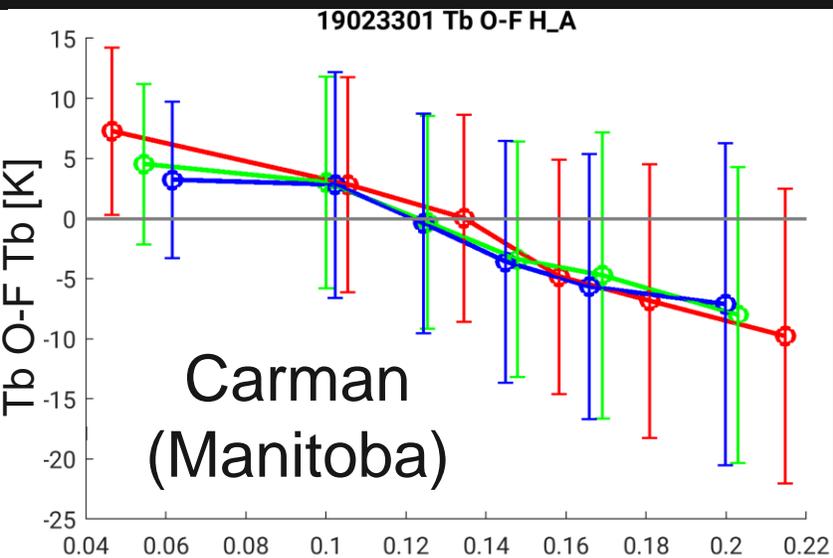


Yanco (Australia)



Tb O-F residuals depend
on soil moisture?!?!

Tb O-F Residuals



New RTM and soil moisture scaling slightly reduce (but by no means eliminate) the systematic error in Tb O-F residuals.

Note impact on soil moisture dynamic range.

Summary



- Soil moisture scaling depends on L2 retrievals and appears invasive for relatively little benefit.
- For L4_SM Version 8, plan to switch RTM to Mironov and the L2 parameters for rough reflectivity.
- To do:
 - Verify results with small-domain M09 data assimilation (in progress).
 - GEOSIdas release with RTM changes.
 - Keep working to eliminate systematic error in Tb O-F residuals.