



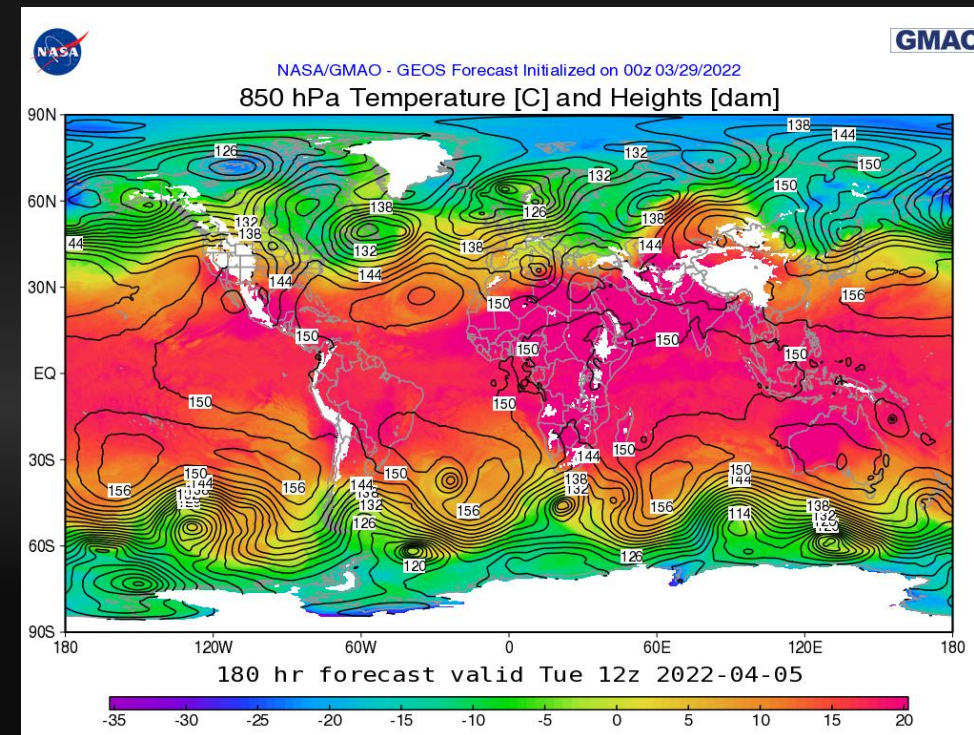
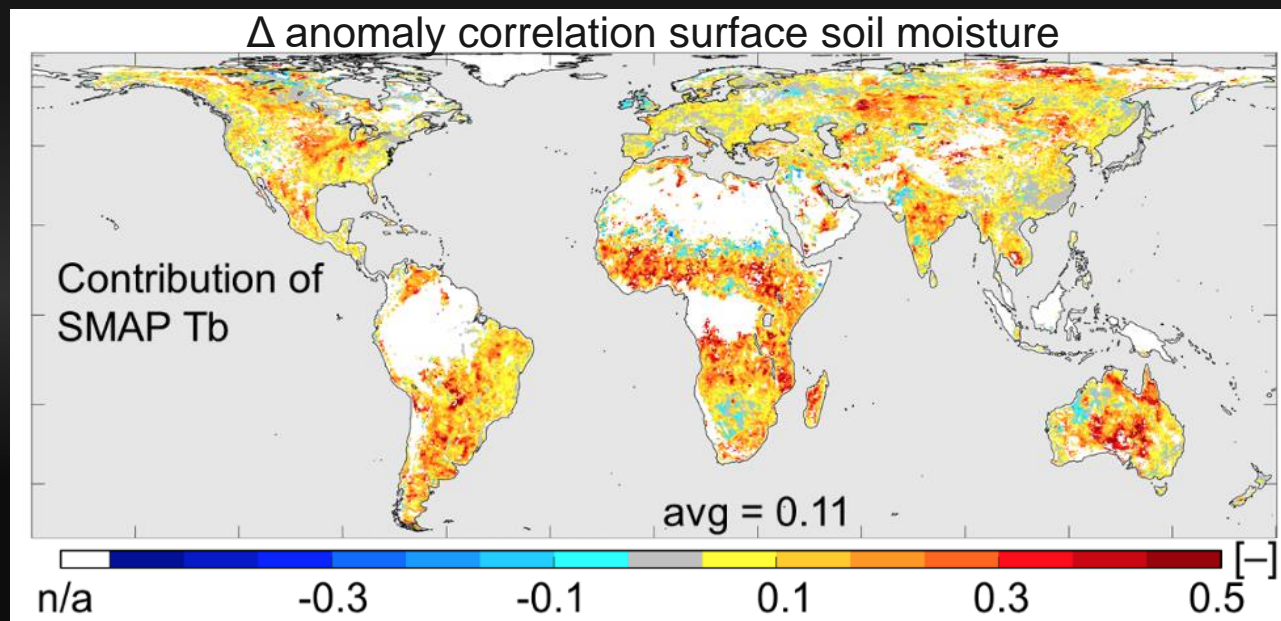
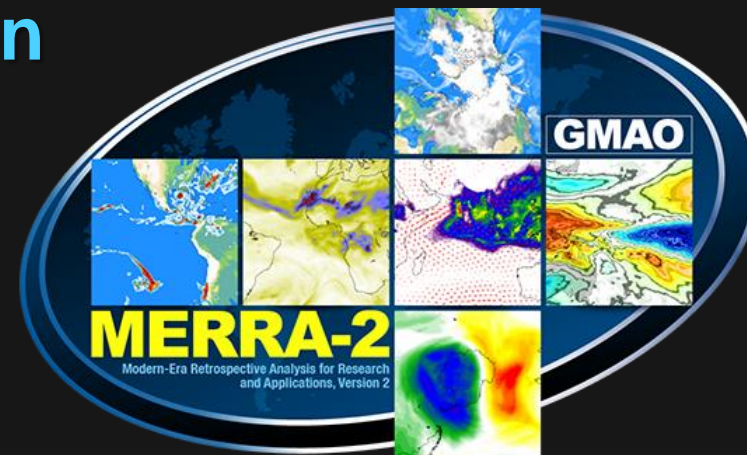
Assimilation of SMAP L-band Radiances Improves Near-Surface Atmospheric Humidity and Temperature in the GEOS Weather Analysis and Forecasting System

Rolf Reichle, Sara Zhang, Qing Liu, Clara Draper,
Jana Kolassa, and Ricardo Todling

Background and Motivation

Goddard Earth Observing System (GEOS) products:

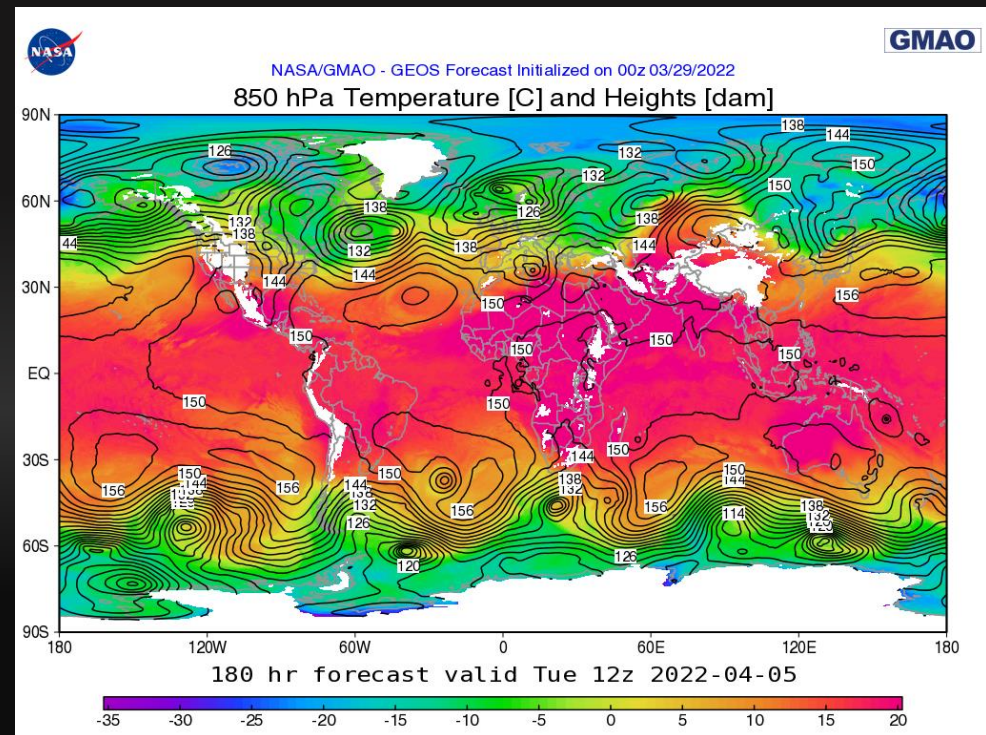
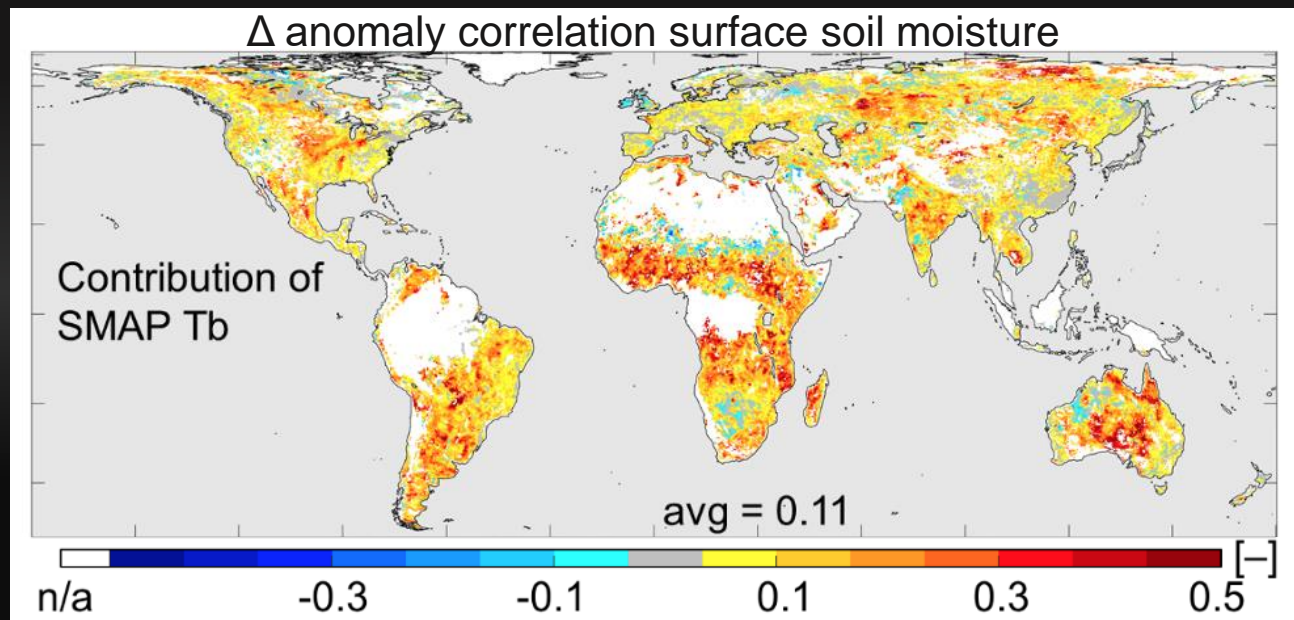
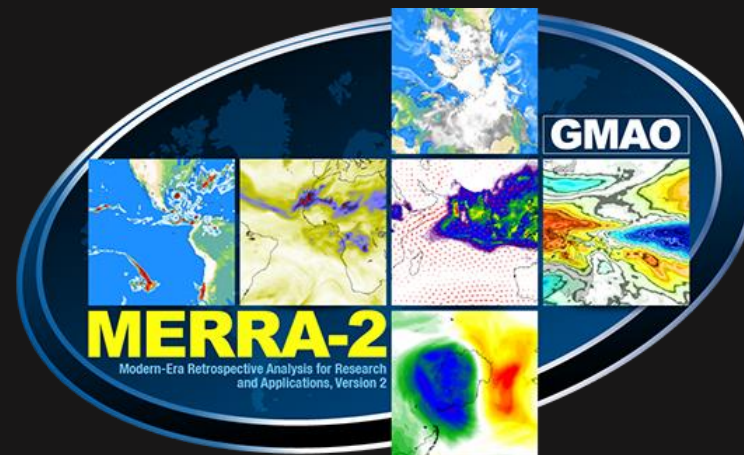
- Reanalysis
- Weather analysis and prediction (no land analysis)
- SMAP Level-4 Soil Moisture (land-only!)



Objective

Goddard Earth Observing System (GEOS) products:

- • Reanalysis
- • Weather analysis and prediction (no land analysis)
- SMAP Level-4 Soil Moisture (land-only!)



Development Overview

Draper and Reichle 2019 (MWR):

- First GEOS Land-Atmosphere DAS (LADAS)
- ~GEOS 5.12.4 (MERRA-2) model and ADAS (3D-Var)
- SMOS and ASCAT soil moisture retrieval assimilation (1D-EnKF)
- Experiment: MJJA 2013 at 0.5 deg

Reichle et al. 2021 (IEEE):

- GEOS 5.26.4 in 3D-Var configuration
- SMAP radiance (Tb) assimilation as in SMAP L4_SM (3D-EnKF; Reichle et al. 2019)
- Experiment: JJA 2017 at 0.5 deg

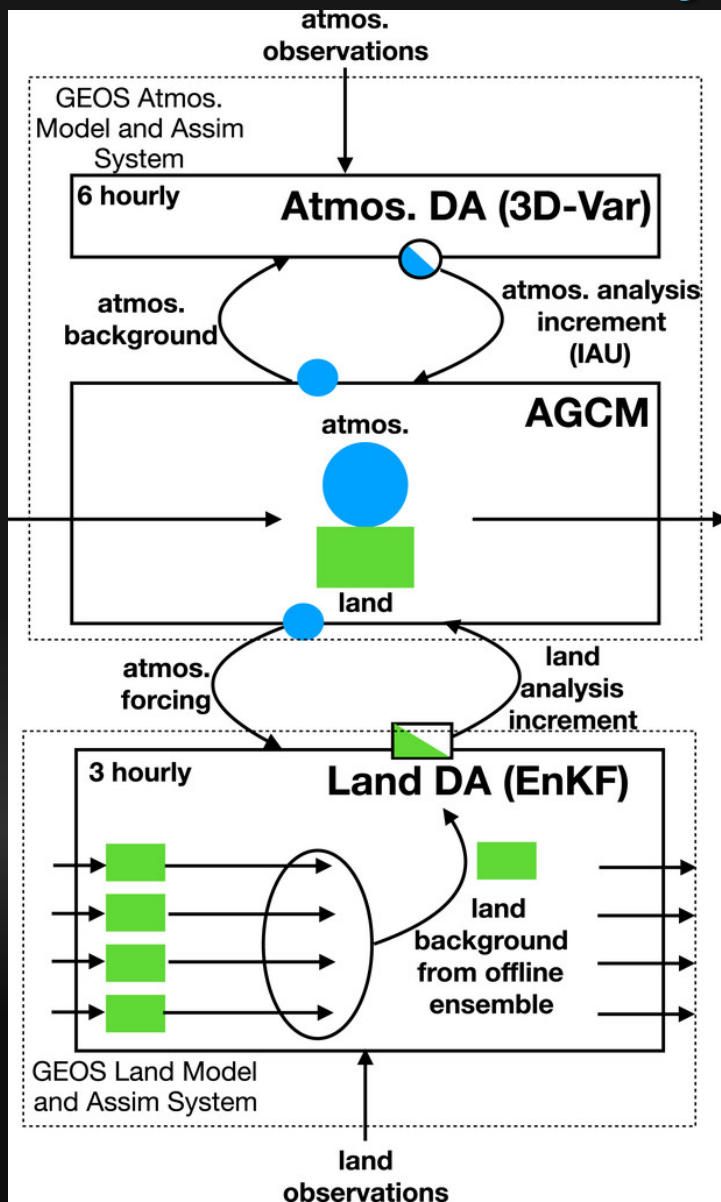
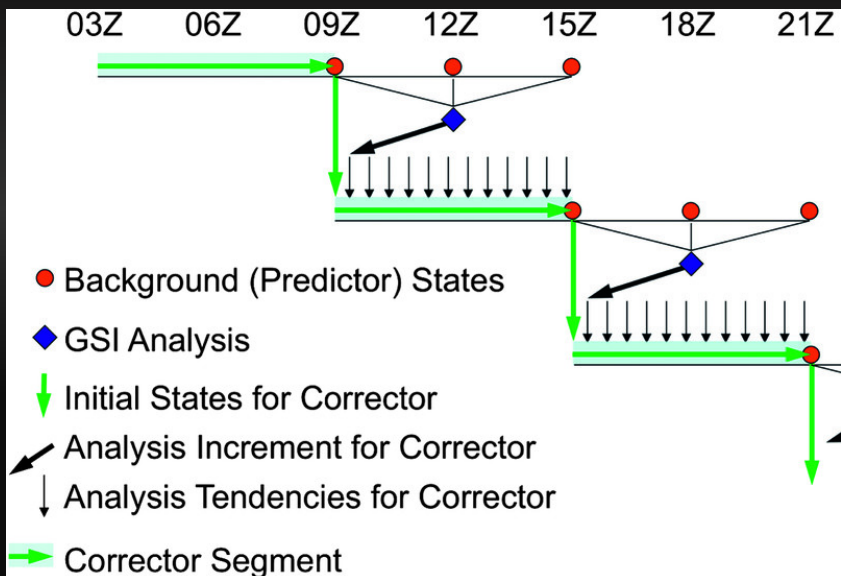
Recently:

- GEOS 5.29.x in 4D-Hybrid-EnVar configuration
- SMAP radiance (Tb) assimilation as in SMAP L4_SM (3D-EnKF)
- Experiment: JJA 2017 at 0.5 deg (incl. forecasts)

Land-Atmosphere Data Assimilation System (LADAS)

ADAS (3D-Var):

- Predictor:** 6-hour AGCM forecast from previous cycle.
- Atmospheric analysis (GSI):** Compute atmospheric analysis increments.
- Corrector:** Re-integrate 6-hour segment with atmos. corrections.



LADAS:

- As in ADAS.
- Add land analysis (EnKF) to produce soil moisture increments.
- Add soil moisture corrections.

Atmosphere and land analysis are weakly coupled through model physics.

Same general approach with 4D-Hybrid-EnVar (but need two LDAS instances).

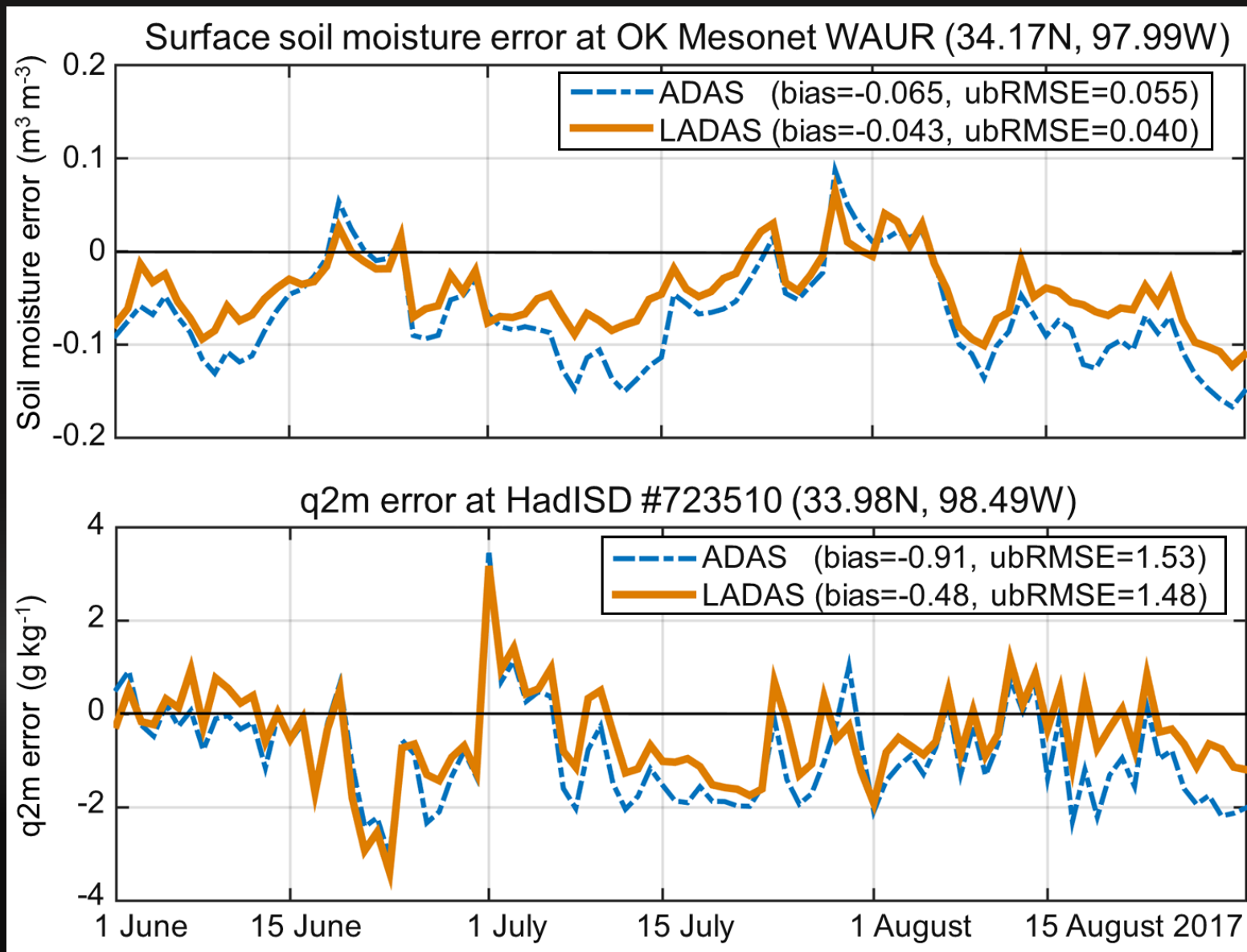


Notation for Results Slides

“ADAS” ≡ CTRL (no SMAP assim.)

“LADAS” ≡ Experiment (with SMAP assim.)

Impact on Screen-Level Specific Humidity (q_{2m})

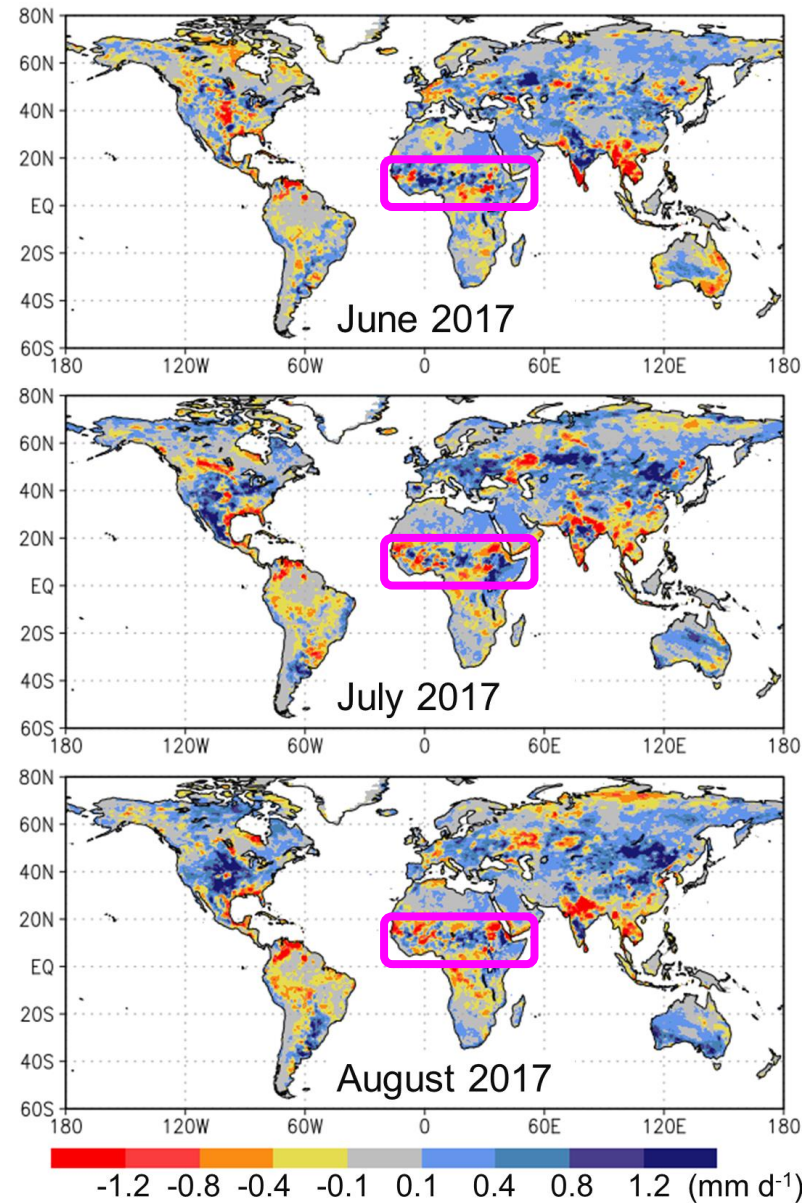


Reichle
et al.
2021

Improved soil
moisture translates
into improved q_{2m} .

Soil Moisture Analysis Increments

Monthly Mean Profile Soil Moisture Increments



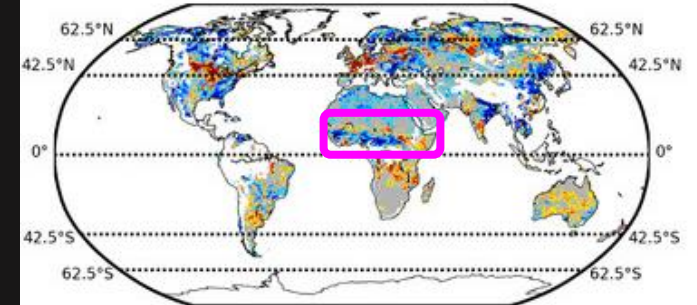
Reichle et al. 2021

Consistent with L4_SM diagnostics.

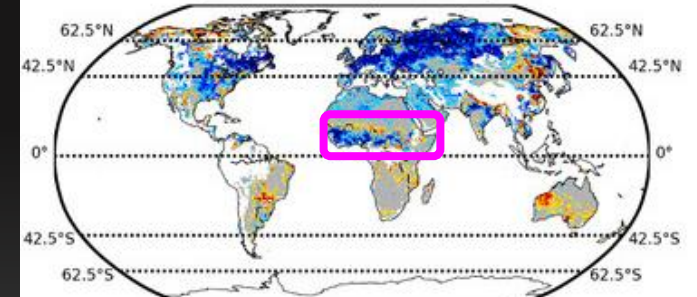
More spatio-temporal variability than seen in (Draper & Reichle 2019).

Draper & Reichle 2019 SMOS+ASCAT DA for 2013

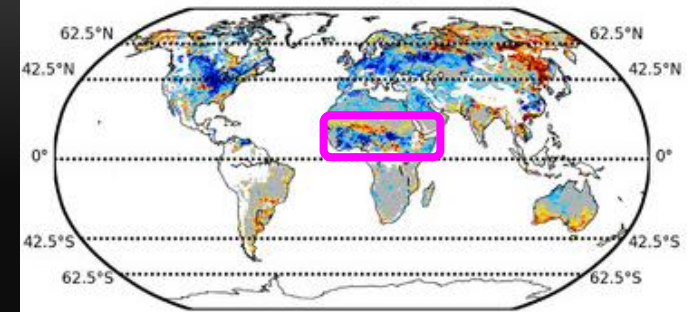
e) Mean SM incr Jun [mm/day]



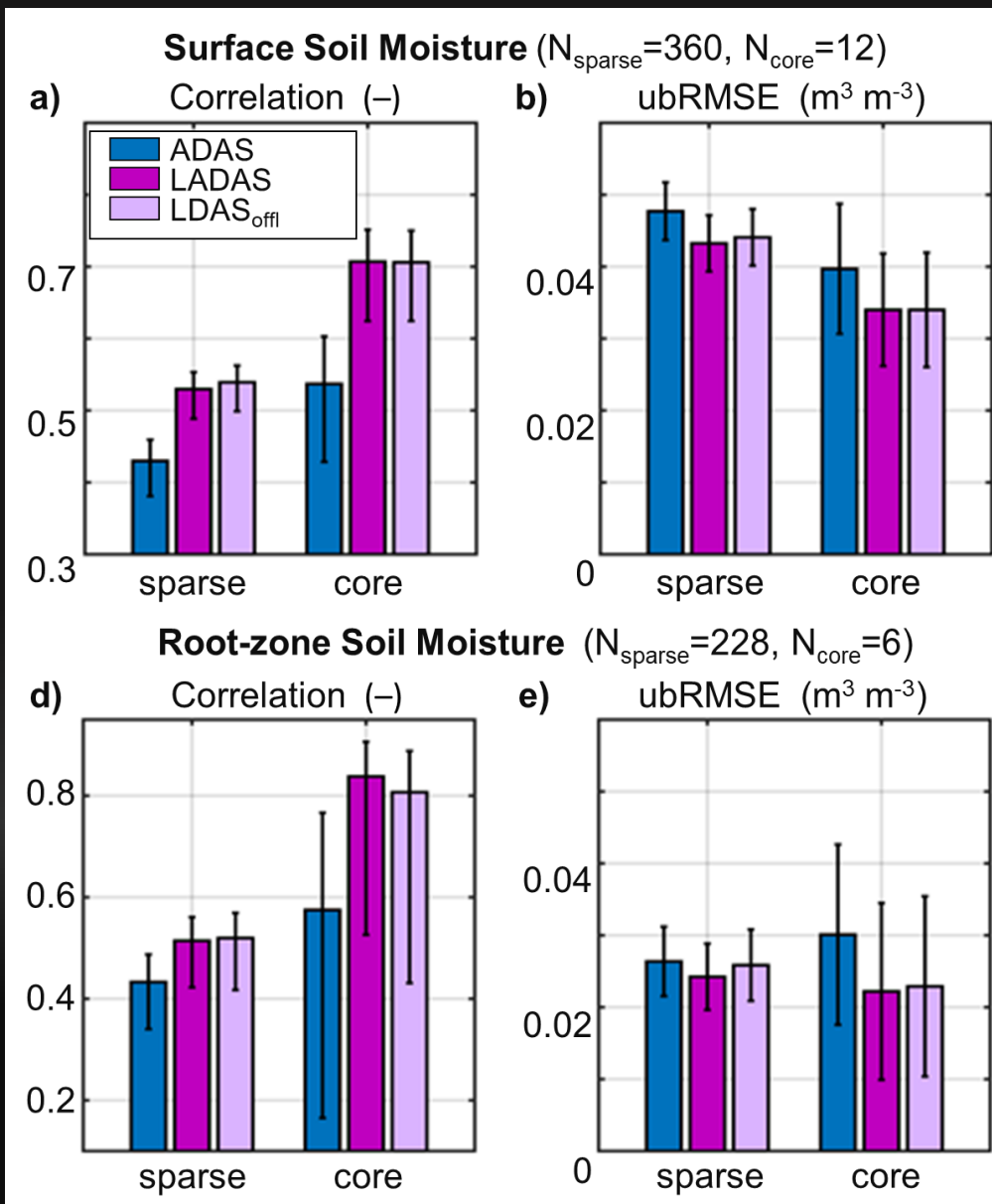
g) Mean SM incr Jul [mm/day]



i) Mean SM incr Aug [mm/day]



In Situ Soil Moisture Validation



Reichle
et al.
2021

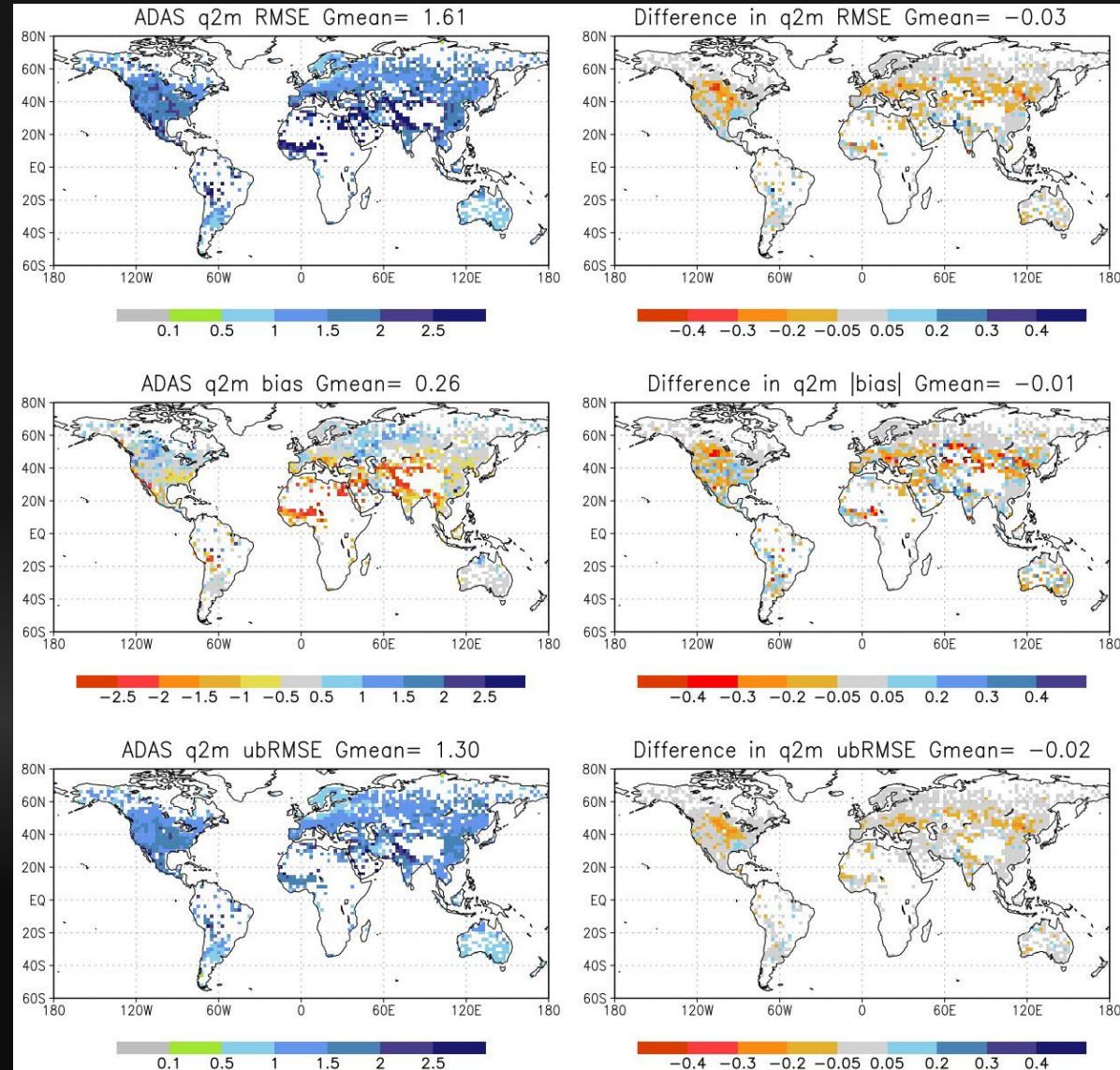
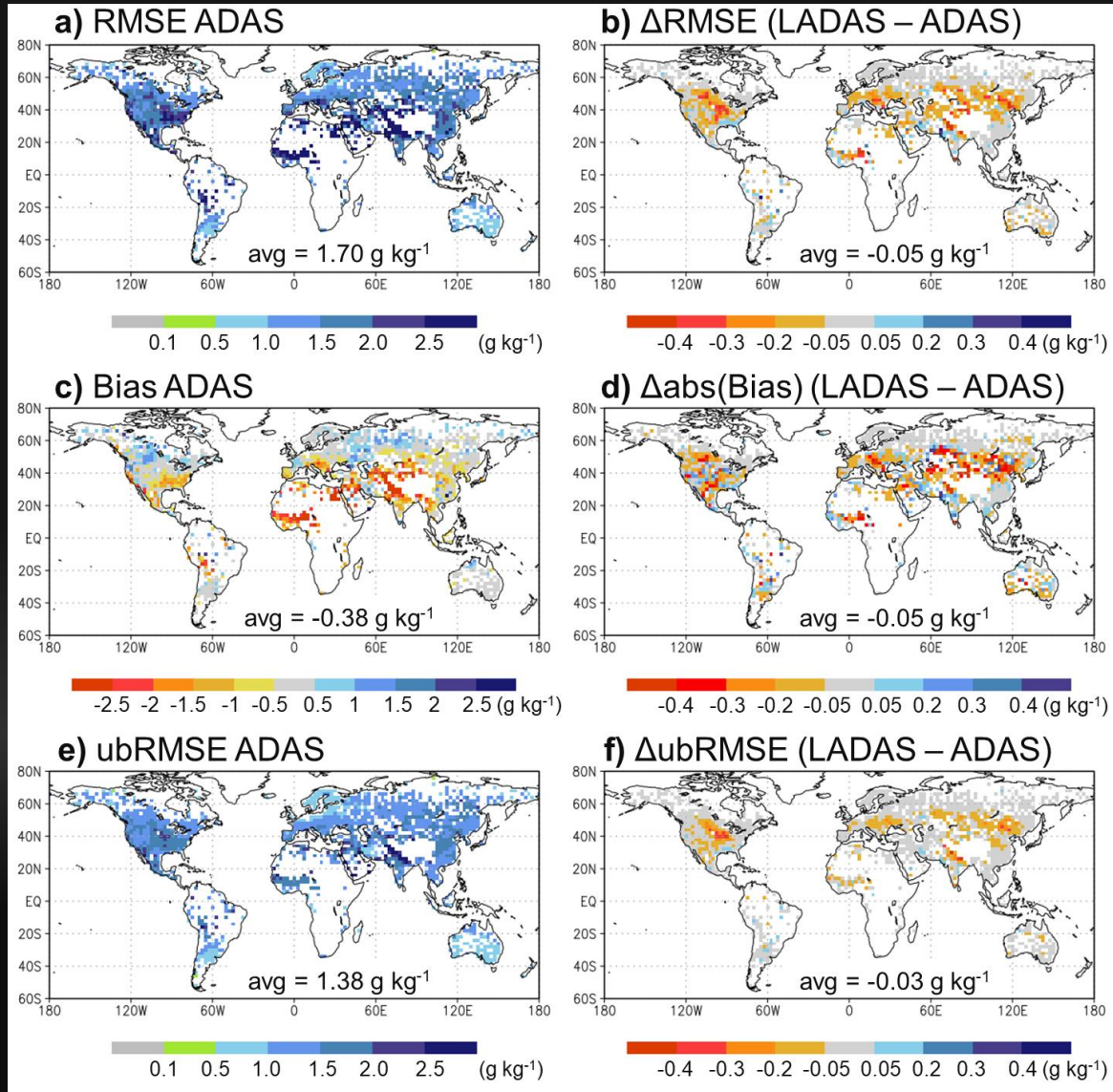
Soil moisture skill improvements over ADAS (consistent with L4_SM improvements over land model-only simulation).

Improvements statistically significant for surface soil moisture correlation.

Screen-Level Humidity (q2m) vs. HadISD

3D-Var (Reichle et al. 2021)

4D-Hybrid-EnVar (in prep)

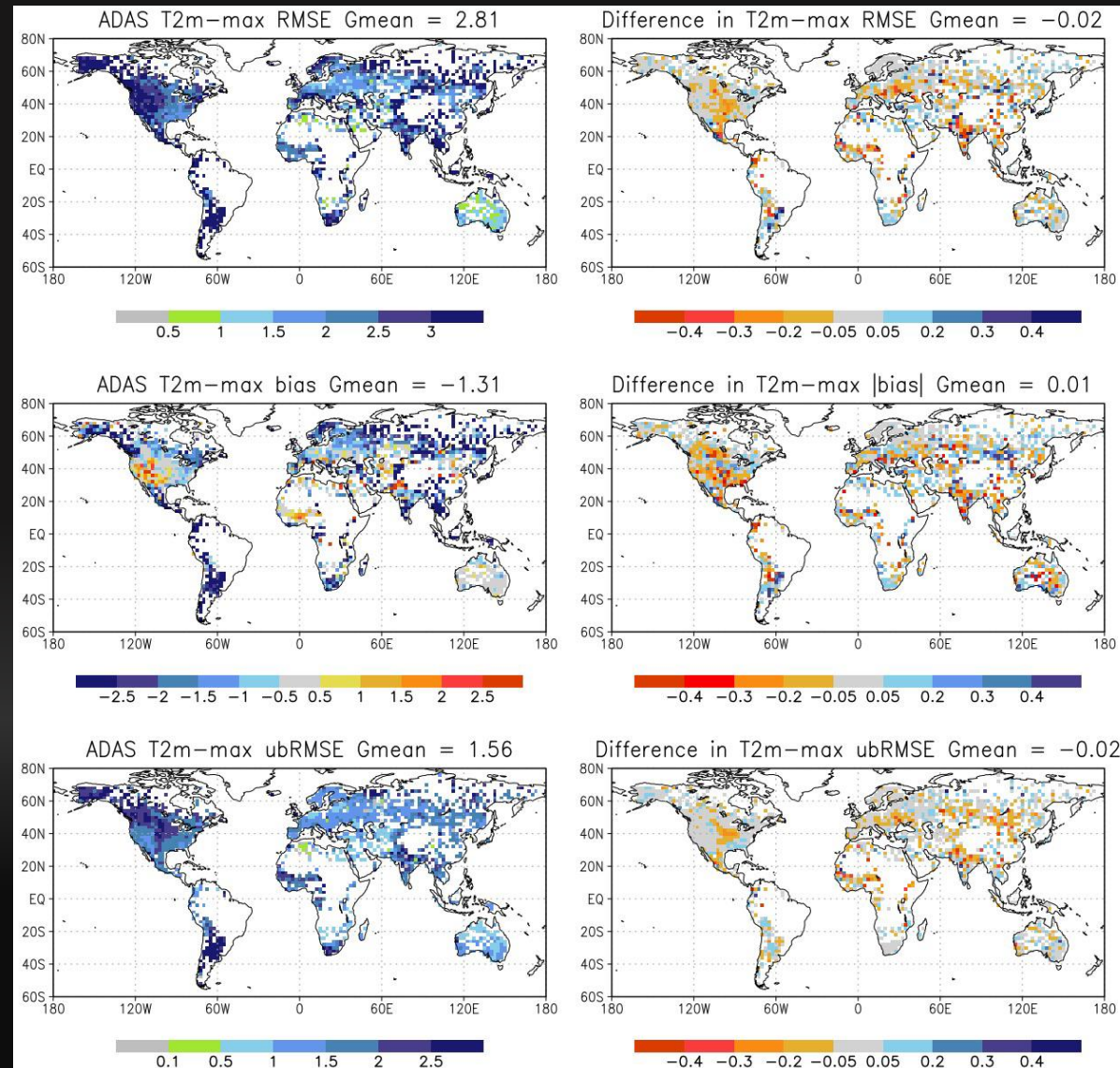
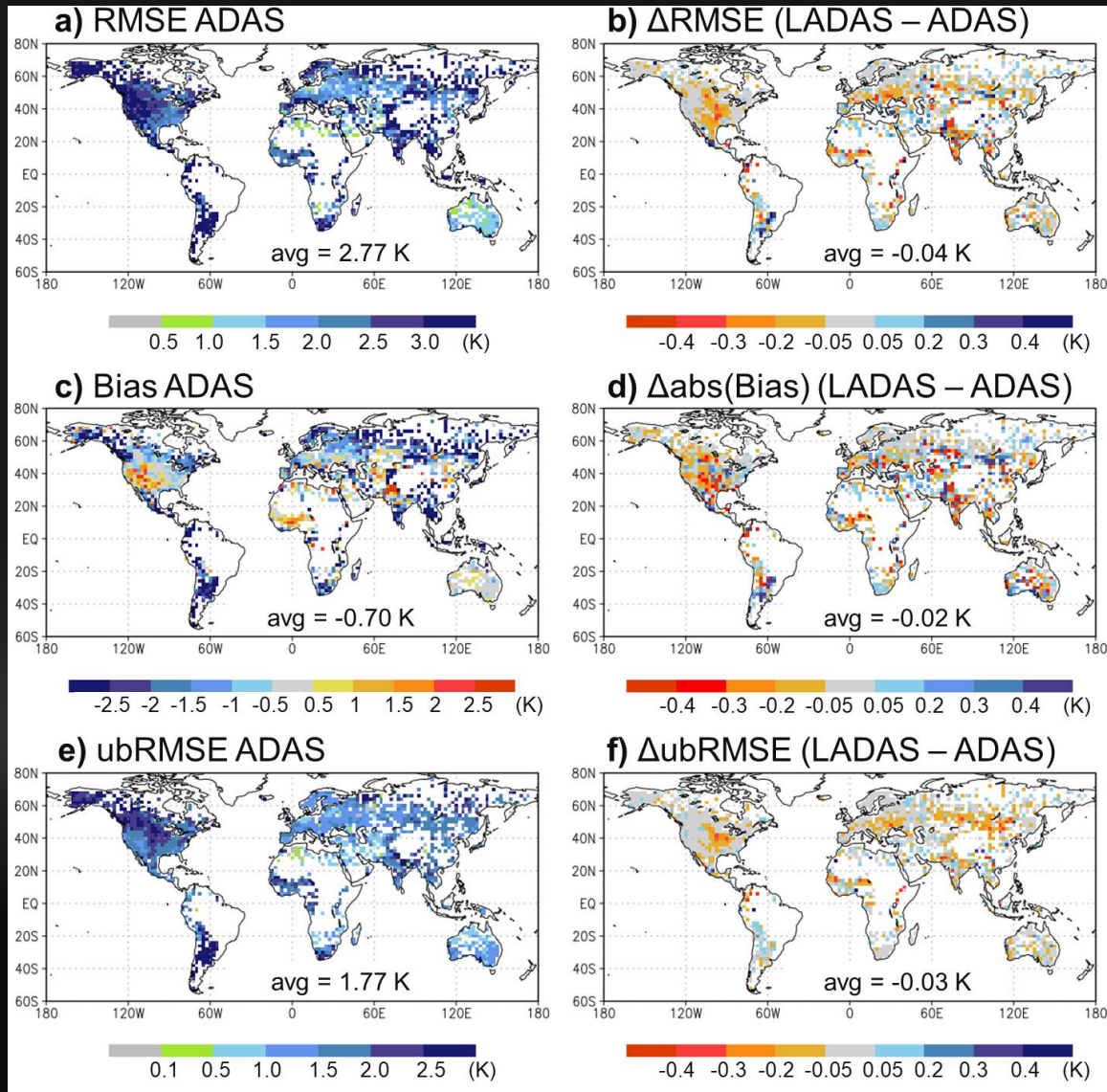


Screen-Level Daily Max Air Temperature (T_{2m_max}) vs. GHCN



3D-Var (Reichle et al. 2021)

4D-Hybrid-EnVar (in prep)

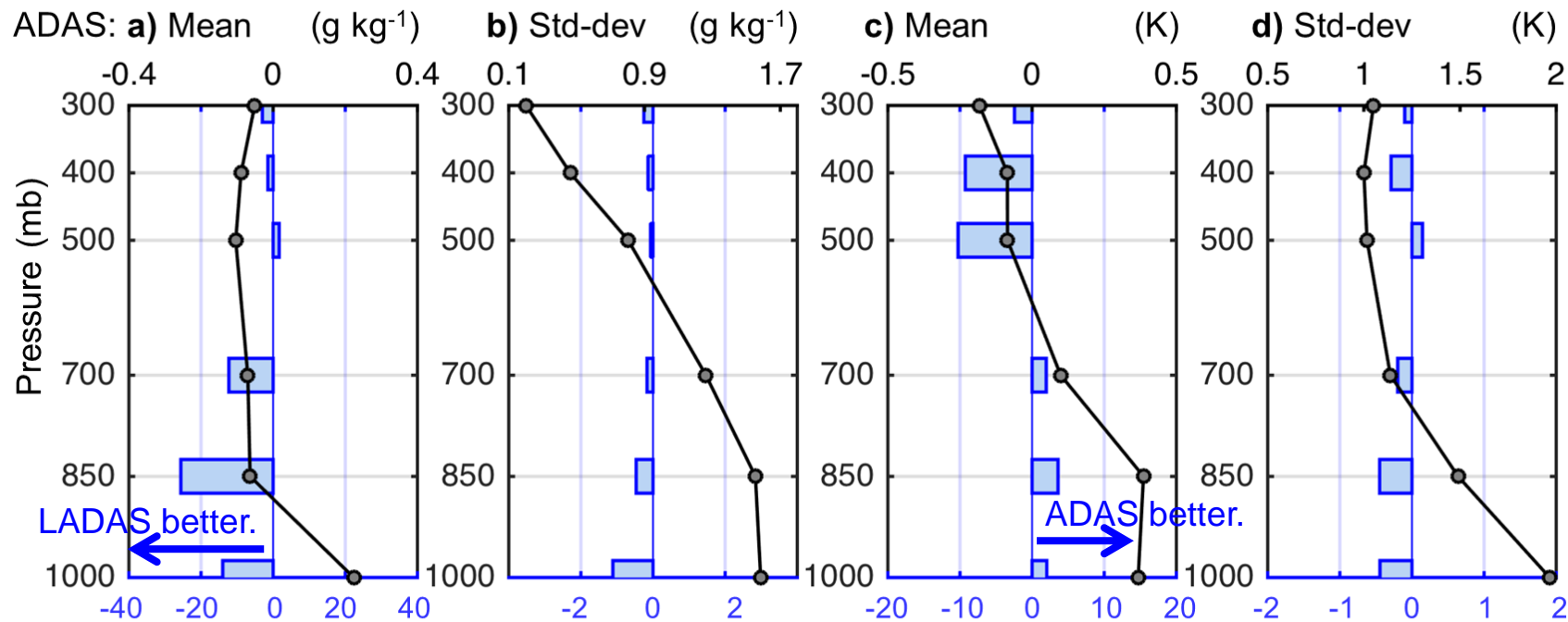


Atmospheric Profiles

OmF Specific Humidity

OmF Air Temperature

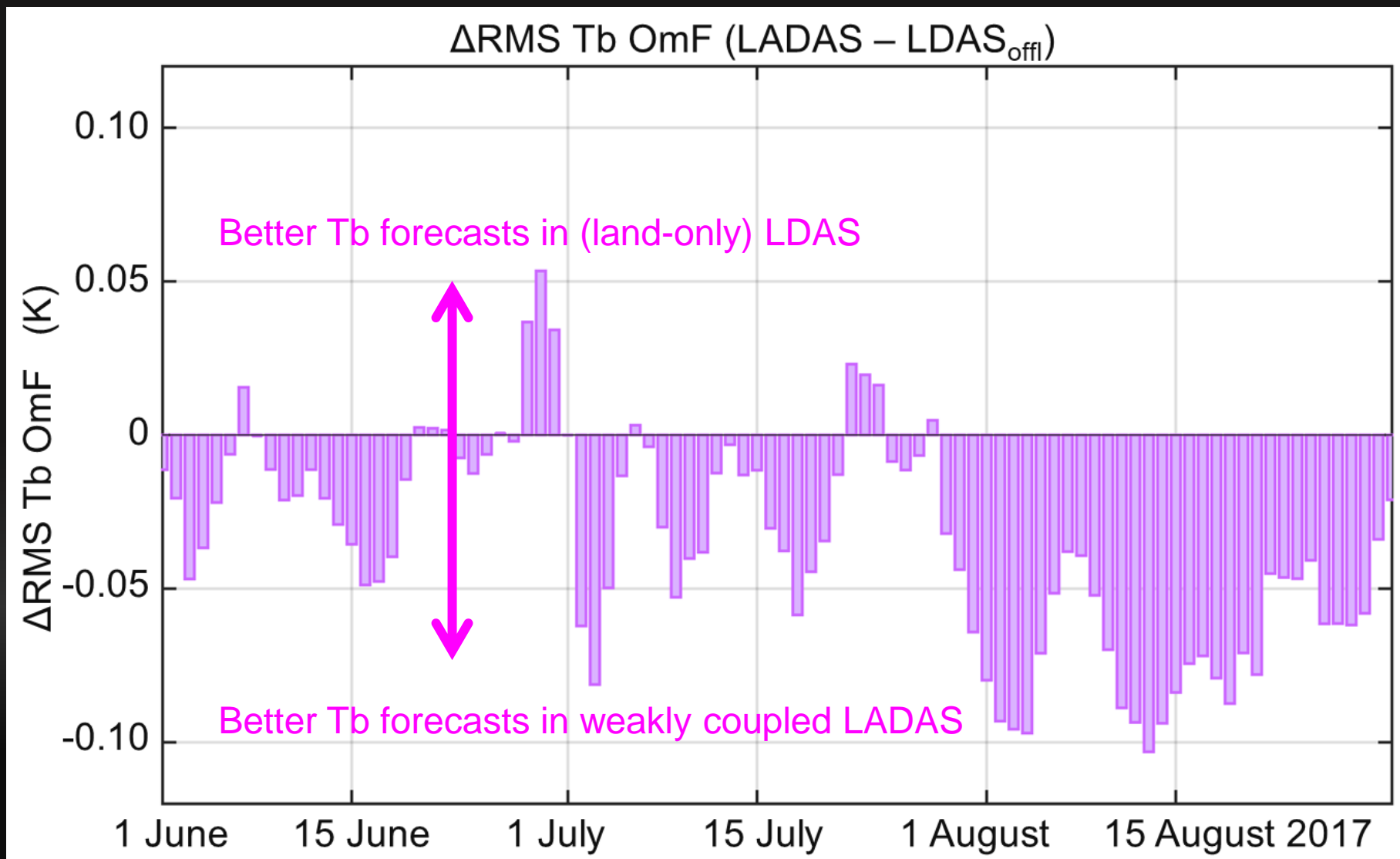
Reichle
et al.
2021



O-minus-F stats
for radiosondes
over continental
land.

Improvements in
specific humidity
extend into the
lower troposphere
(below ~700 mb).

Weakly-coupled LADAS vs. land-only LDAS



Reichle
et al.
2021

Weakly coupled system
improves land surface
forcing!

4D-Hybrid-EnVar LADAS and CTRL vs ECMWF (Jun 21-Aug 31, 2017)

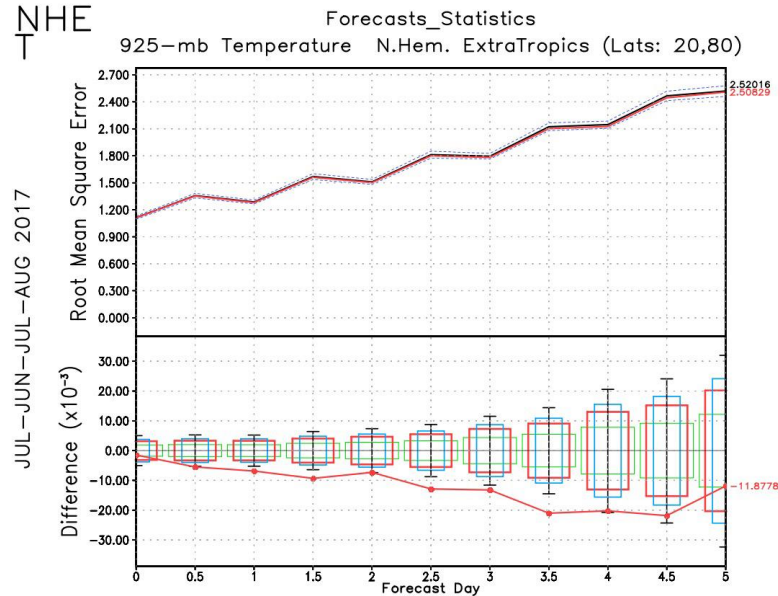
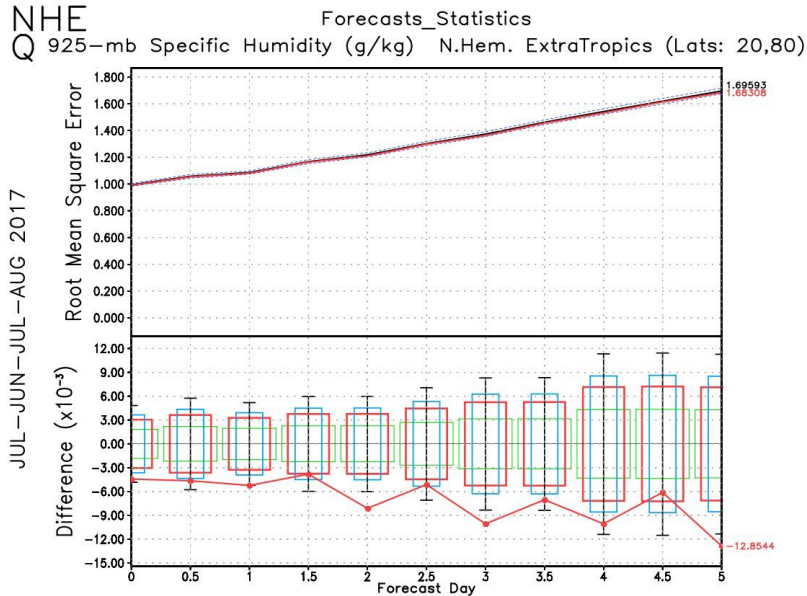
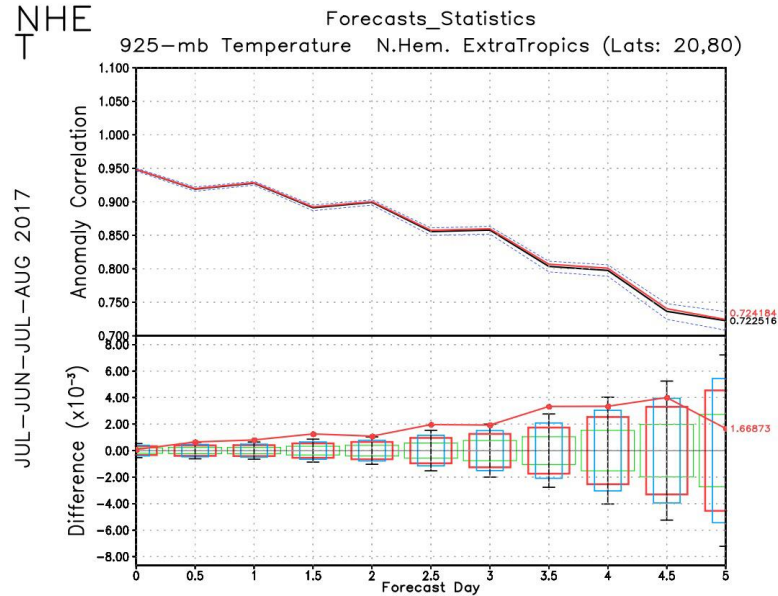
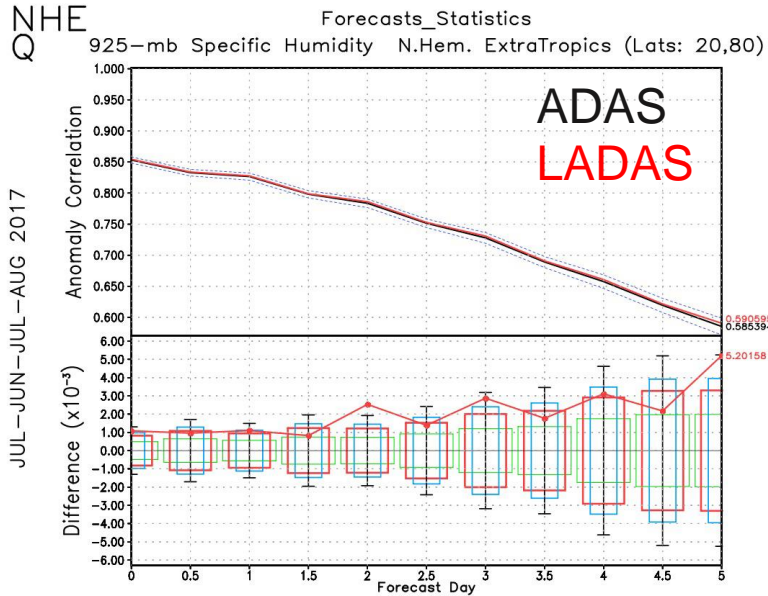


Variable	Pressure Level	NH					SH					Tropics														
		COR					RMS					COR					RMS									
Forecast Day		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Geopotential Height	10																									
	70																									
	100																									
	250																									
	500																									
	700																									
SLP	850																									
	1000																									
Specific Humidity	10																									
	70																									
	100																									
	250																									
	500																									
	700																									
Temperature	850																									
	10																									
	70																									
	100																									
	250																									
	500																									
U-Wind	700																									
	850																									
	10																									
	70																									
	100																									
	250																									
V-Wind	500																									
	700																									
	850																									
	10																									
	70																									
	100																									

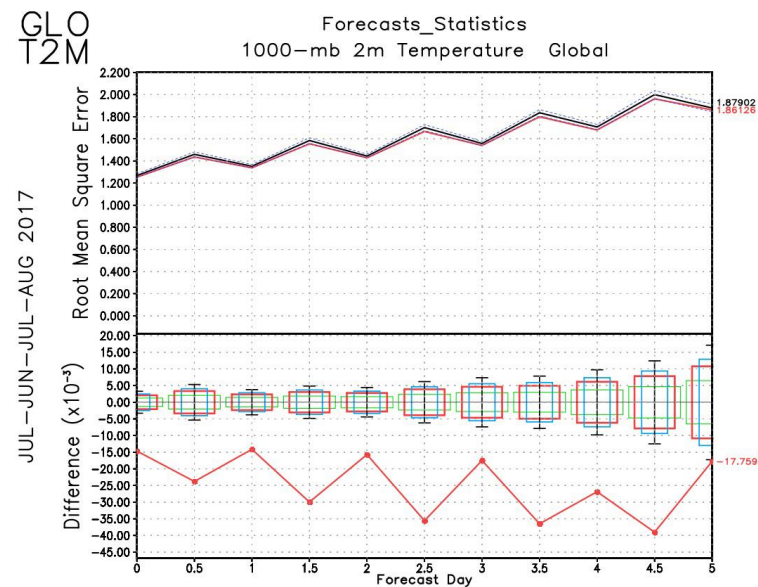
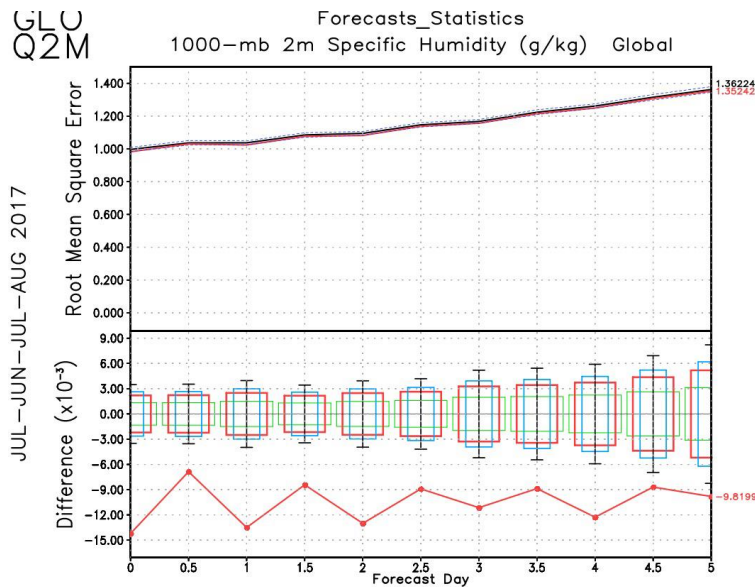
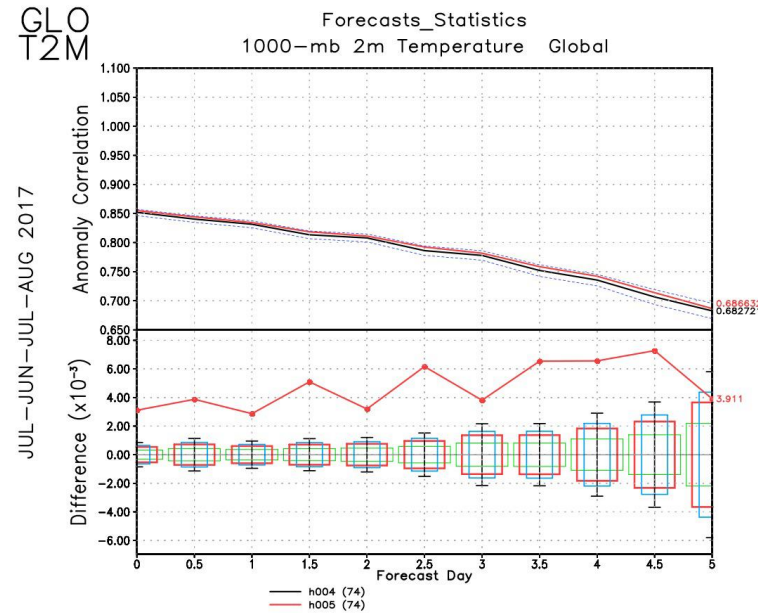
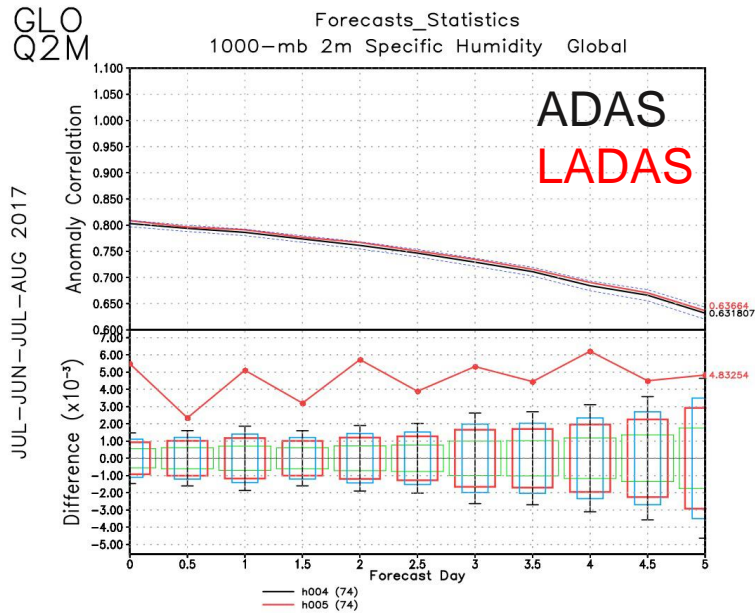
Standard GEOS score card does not get close to the surface...

- ▲ far better, significant (99.99% confidence)
- △ better, significant (99% confidence)
- ⊞ slightly better, significant (95% confidence)
- no significant difference
- ⊞ slightly worse, significant (95% confidence)
- ▽ worse, significant (99% confidence)
- ▼ far worse, significant (99.99% confidence)

4D-Hybrid-EnVar LADAS and CTRL vs ECMWF (925 mb, NH)



4D-Hybrid-EnVar LADAS and CTRL vs ECMWF (Screen-Level, Global)

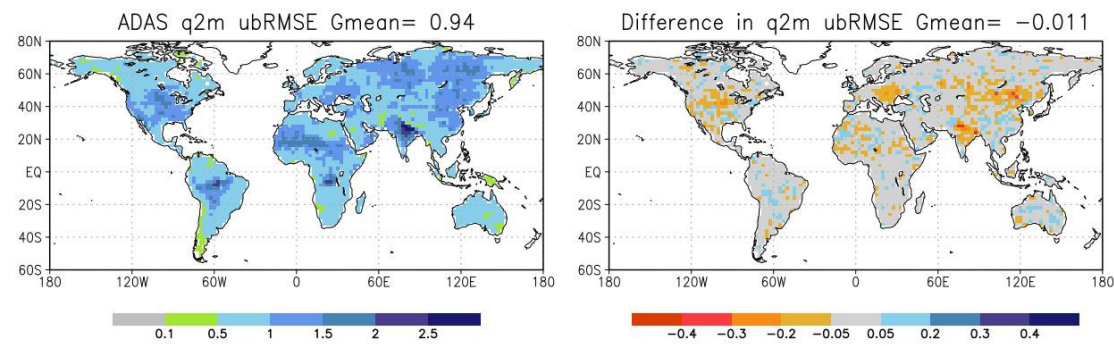
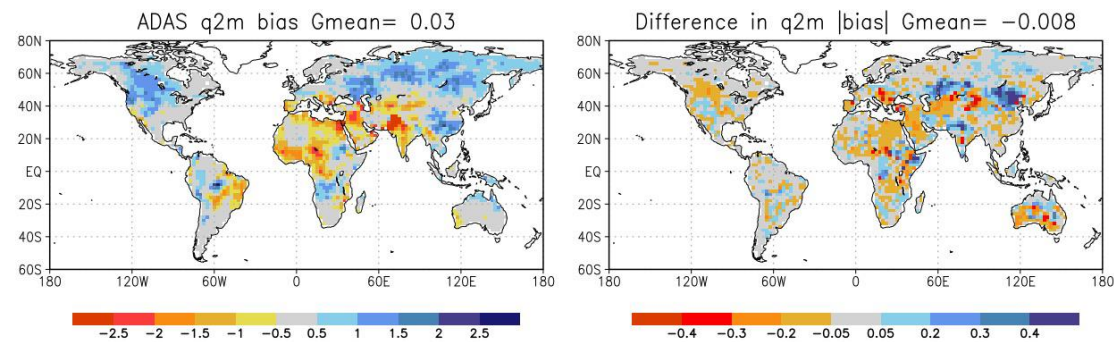
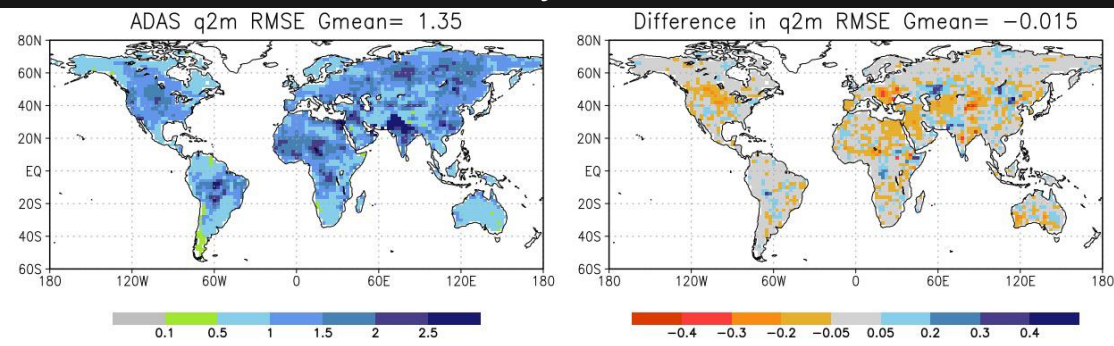
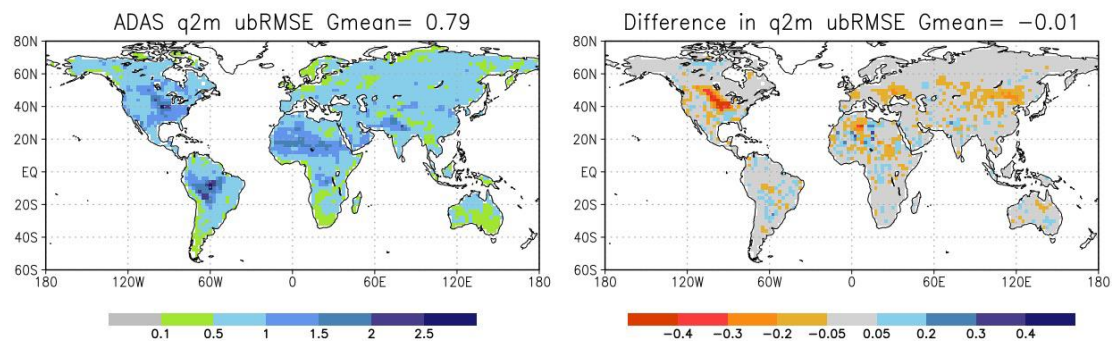
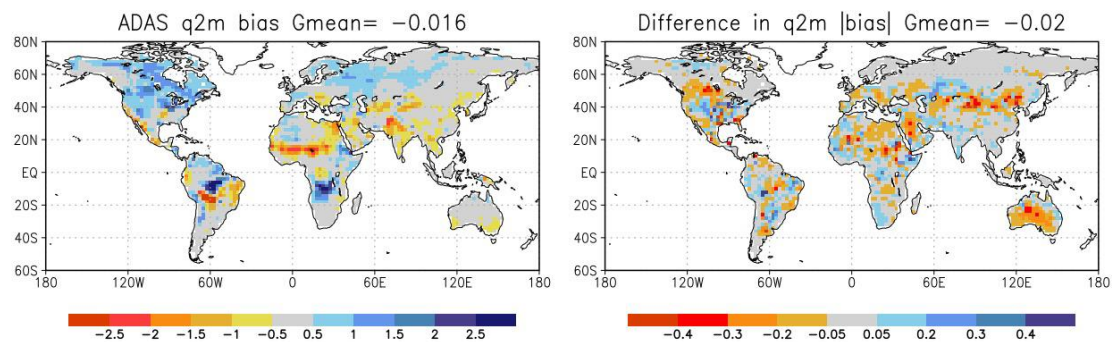
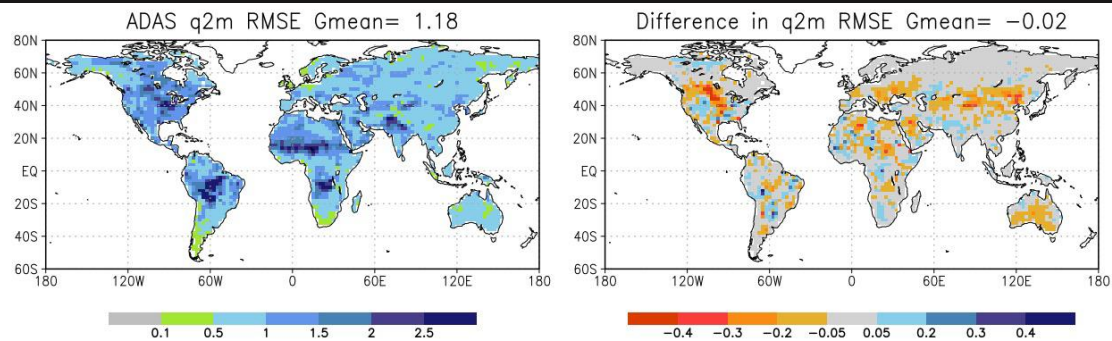


Screen-Level Specific Humidity (q_{2m}) vs. ECMWF



Analysis (0z)

2.5-day Forecast

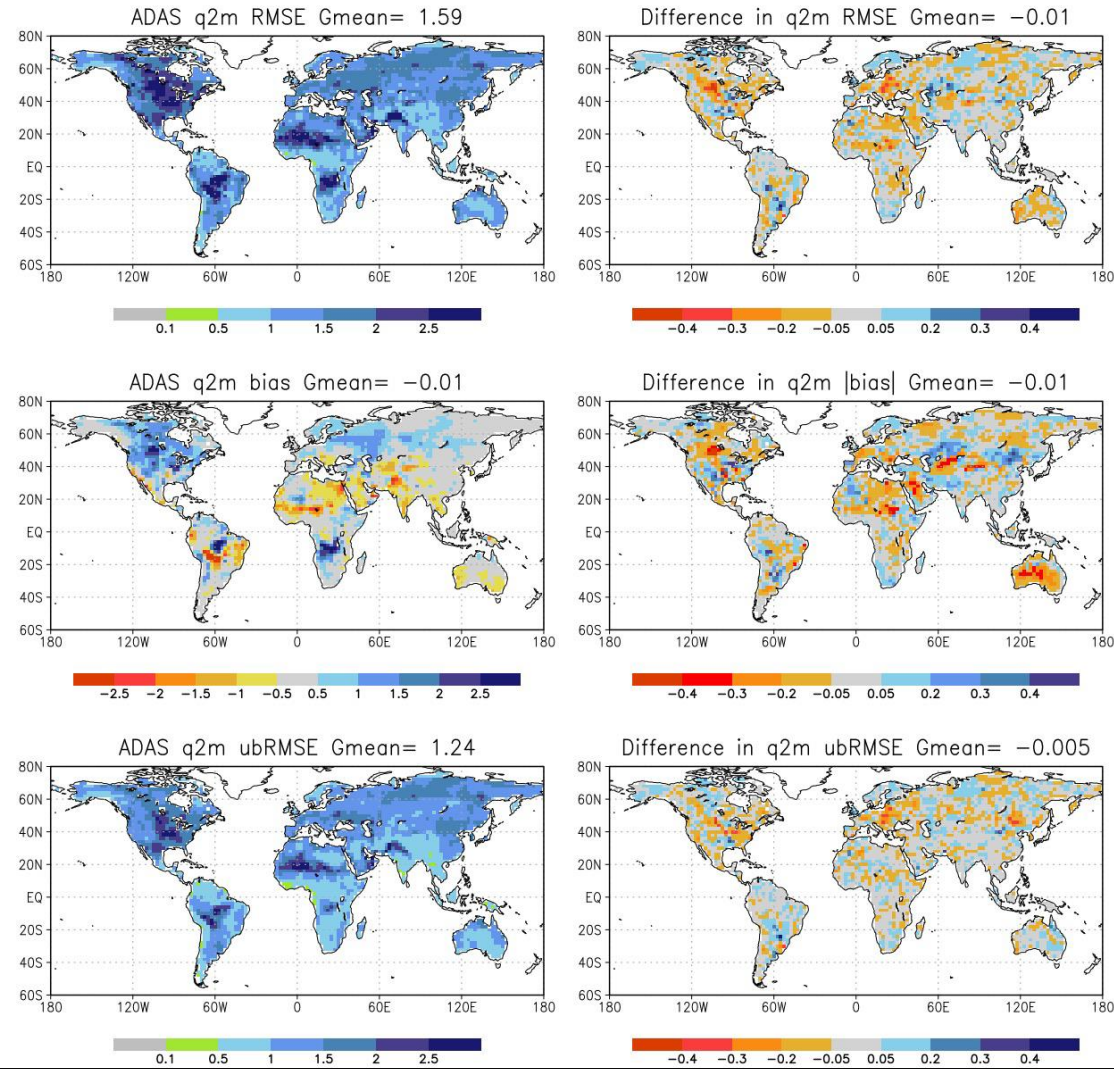
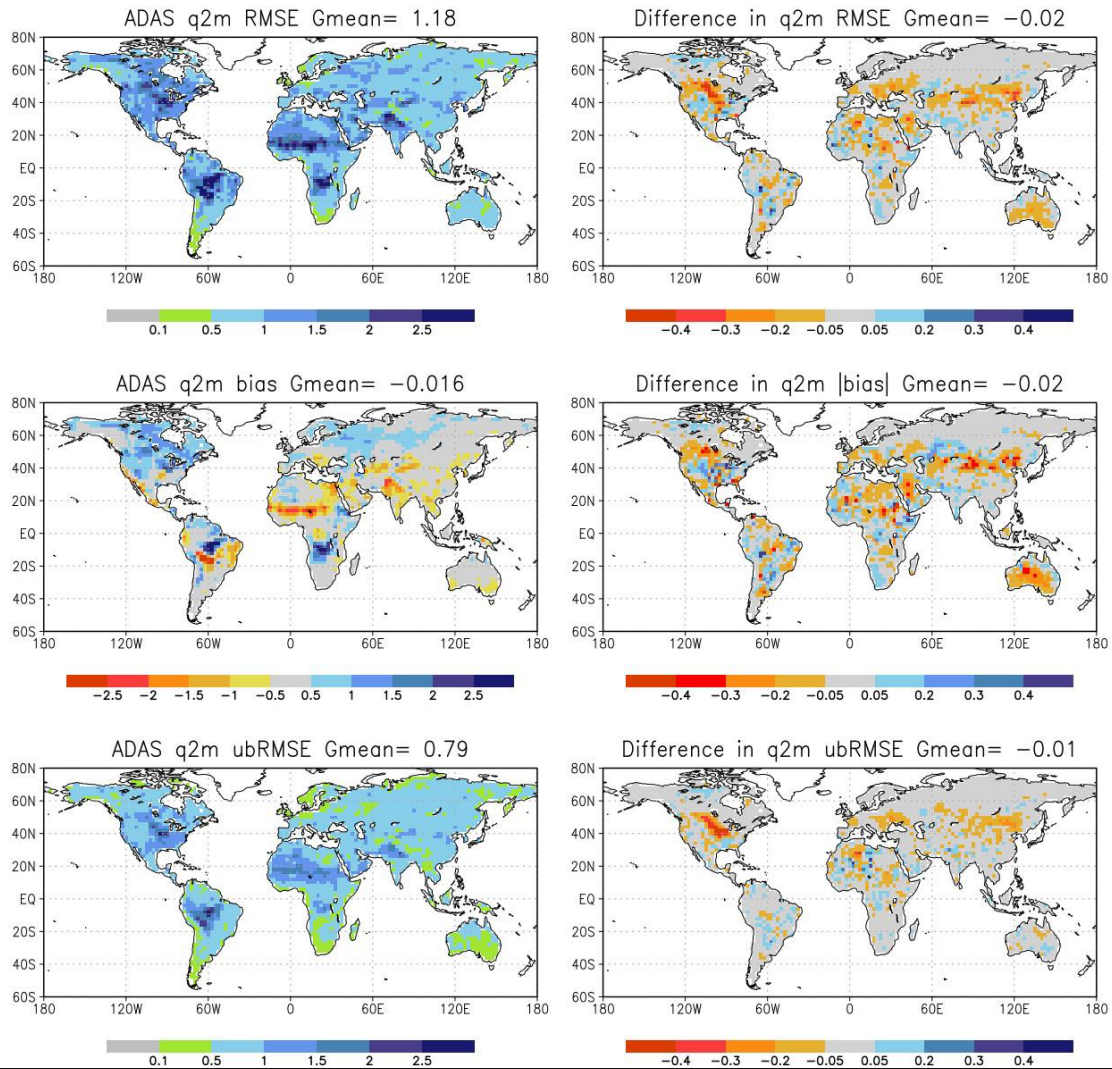


Screen-Level Specific Humidity (q2m) vs. ECMWF



Analysis (0z)

5-day Forecast

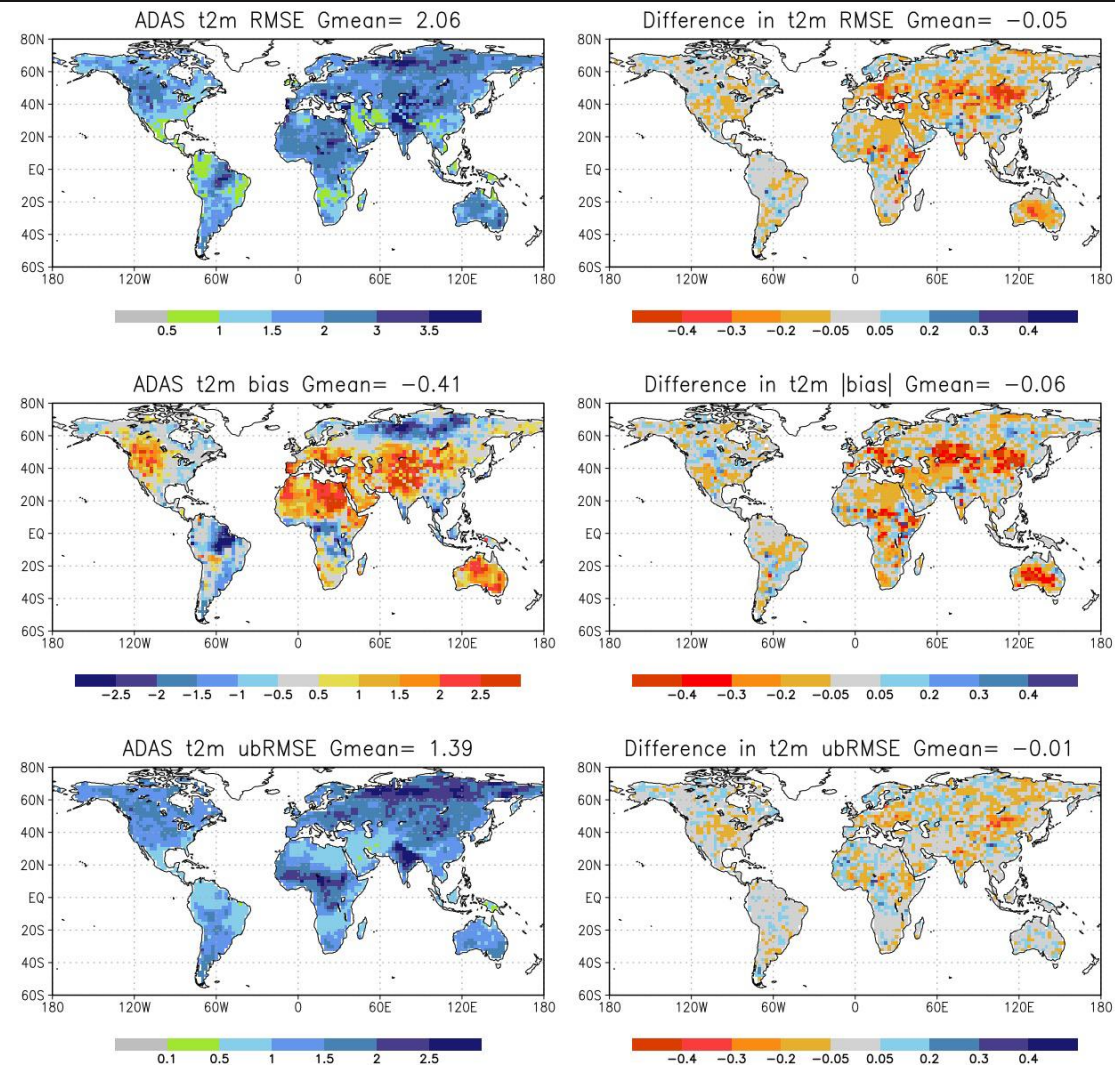
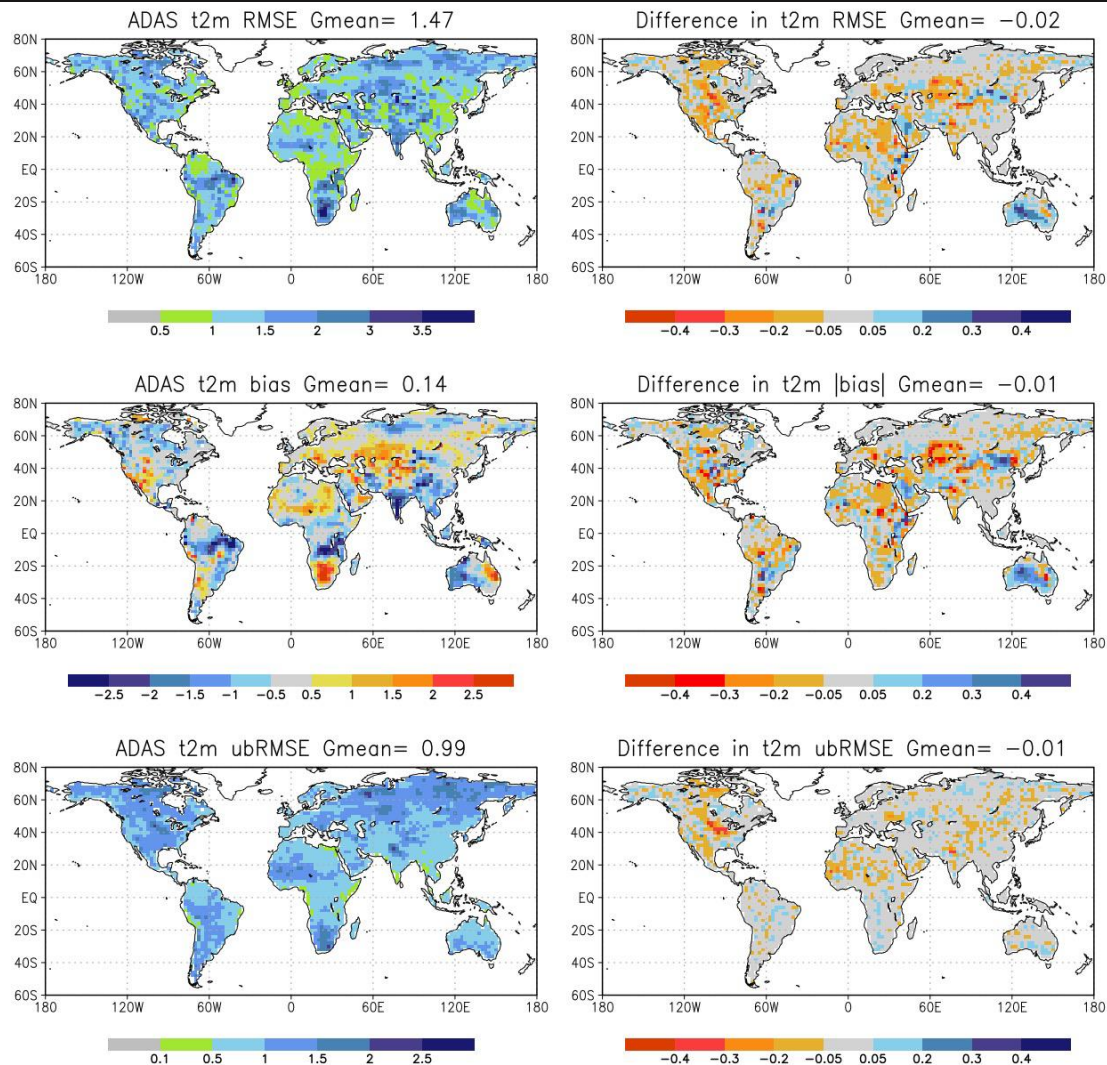


Screen-Level Air Temperature (T2m) vs. ECMWF



Analysis (0z)

2.5-day Forecast

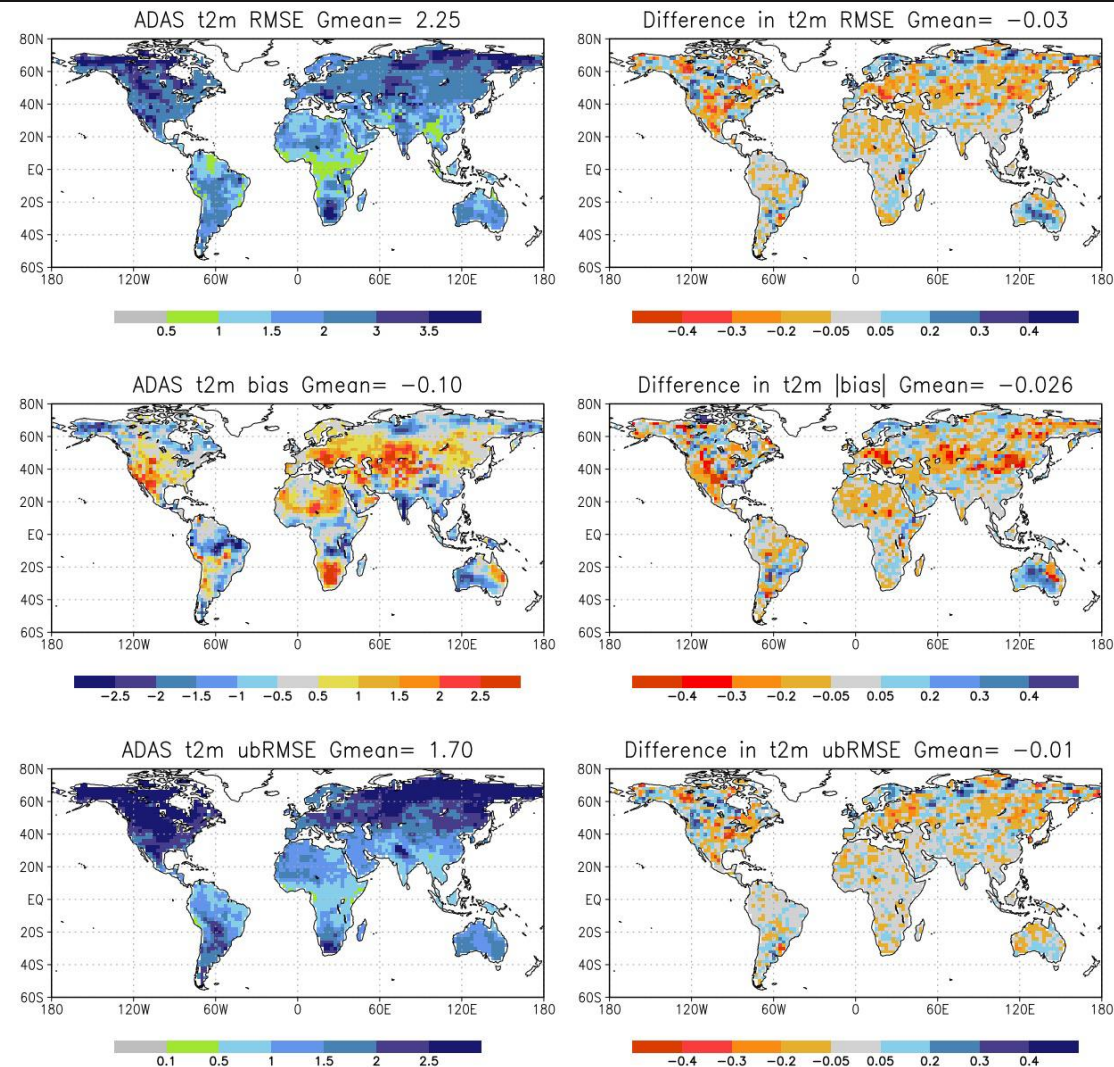
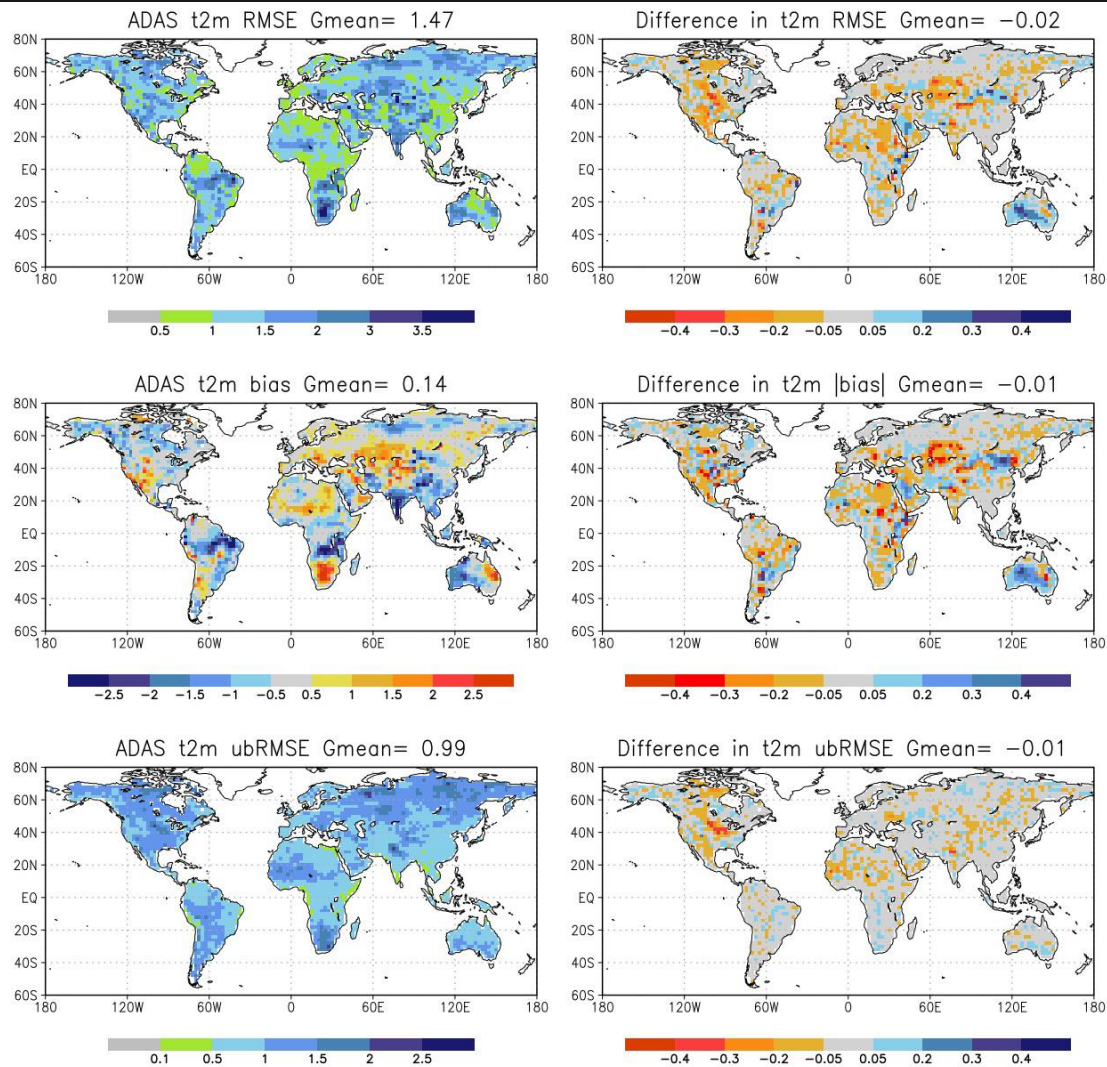


Screen-Level Air Temperature (T2m) vs. ECMWF



Analysis (0z)

5-day Forecast



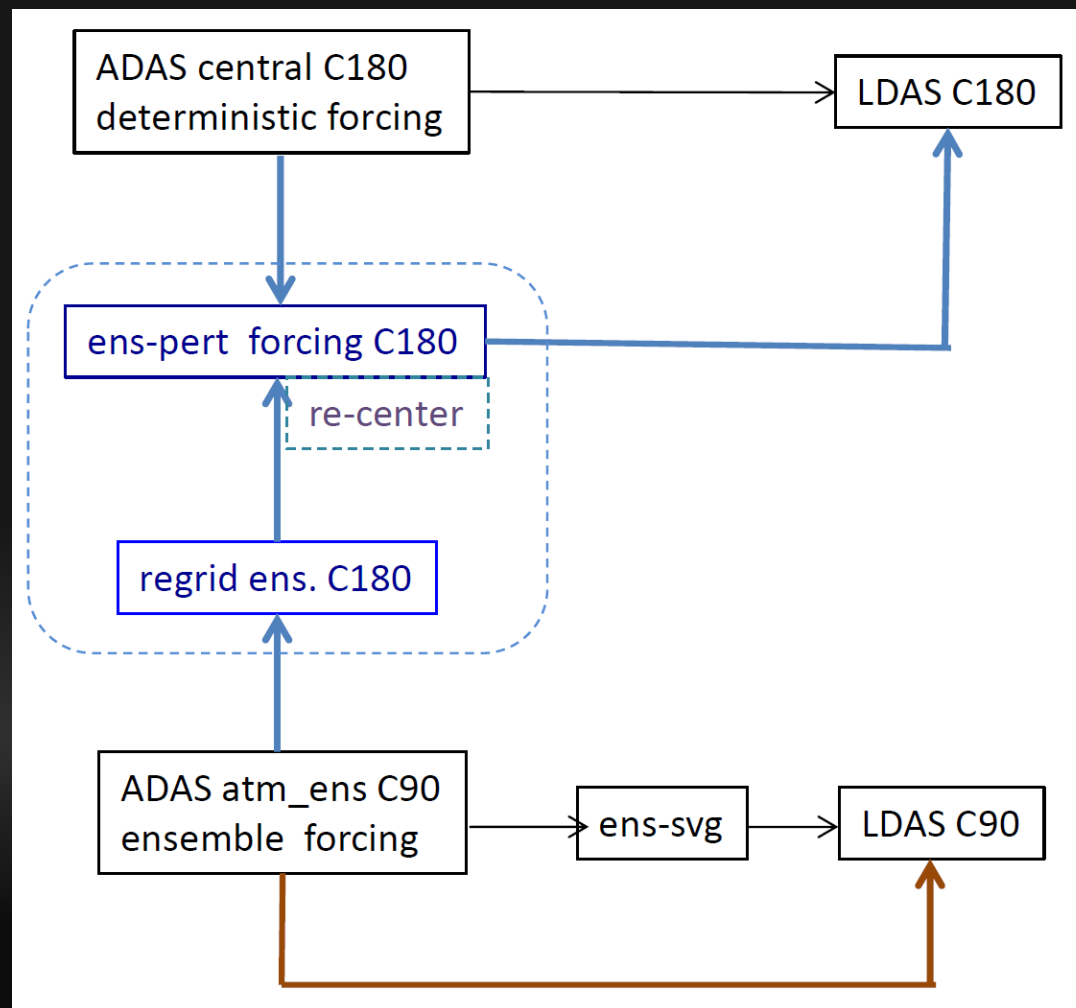
Current Work and Next Steps

- Conducting 4D-Hybrid-EnVar experiments at 0.25 deg resolution for SMAP Tropical Cyclone project.
- Adding screen-level verification into standard package for die-off curves and score card.
- Connecting ADAS and LDAS ensembles.
- Investigate surface turbulent flux estimates.
- Include and verify in formal “X” experiment for system development.
- Add plumbing for near-real time SMAP Tb.
- Test in “parallel” operations.



EXTRA SLIDES

Connect ADAS and LDAS Ensembles



Experiment Setup

Reichle et al. 2021

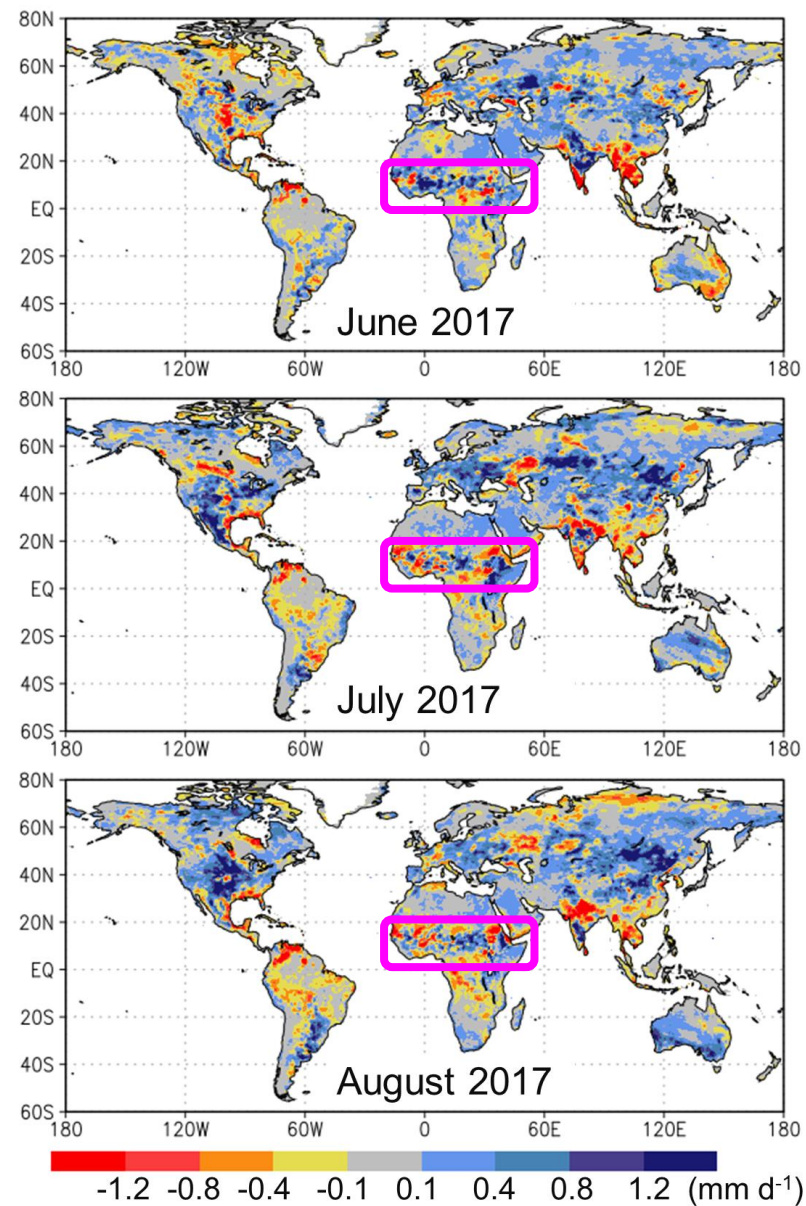
- GEOS ADAS version 5.26.4 (ca. 2020):
 - AGCM: ½-deg resolution, 72 levels (to 0.01 hPa)
 - Atmos. analysis: GSI, 3D-Var
- Land analysis (as in L4_SM Version 4):
 - 3d-EnKF
 - SMAP L1C_TB
 - Seasonally-varying Tb scaling
- Experiment period: JJA 2017 (LADAS init. Apr 1)
- Validation:
 - SMAP core validation sites
 - Sparse networks
 - HadISD q2m
 - GCHN T2m
 - Radiosonde observations

Draper & Reichle 2019

- GEOS ADAS version 5.12.4 (ca. 2014):
- Land analysis:
 - 1d-EnKF
 - SMOS + ASCAT s.m. retrievals
 - Cdf-matching (impose obs seasonal cycle)
- Experiment period: MJJA 2013
- Validation:
 - ~~SMAP core validation sites~~
 - Sparse networks
 - HadISD q2m
 - GCHN T2m
 - ~~Radiosonde observations~~

Soil Moisture Analysis Increments

Monthly Mean Profile Soil Moisture Increments

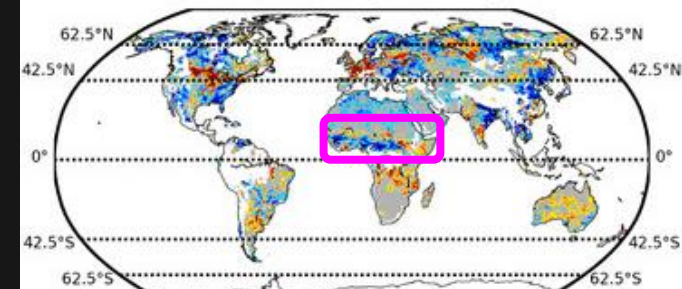


Consistent with L4_SM diagnostics.

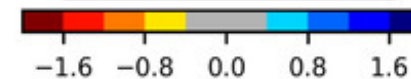
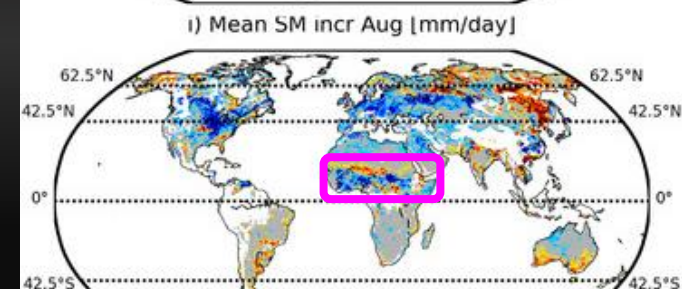
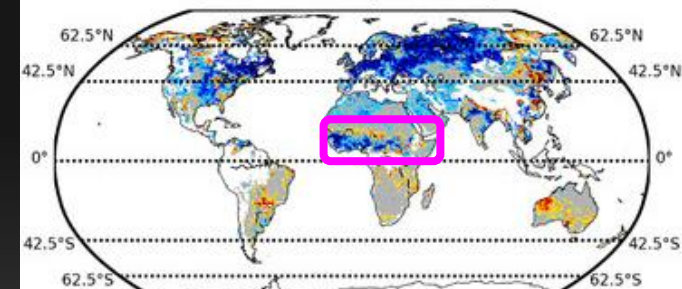
Somewhat more spatio-temporal variability than seen in (Draper & Reichle 2019).

Draper & Reichle 2019 SMOS+ASCAT DA for 2013

e) Mean SM incr Jun [mm/day]

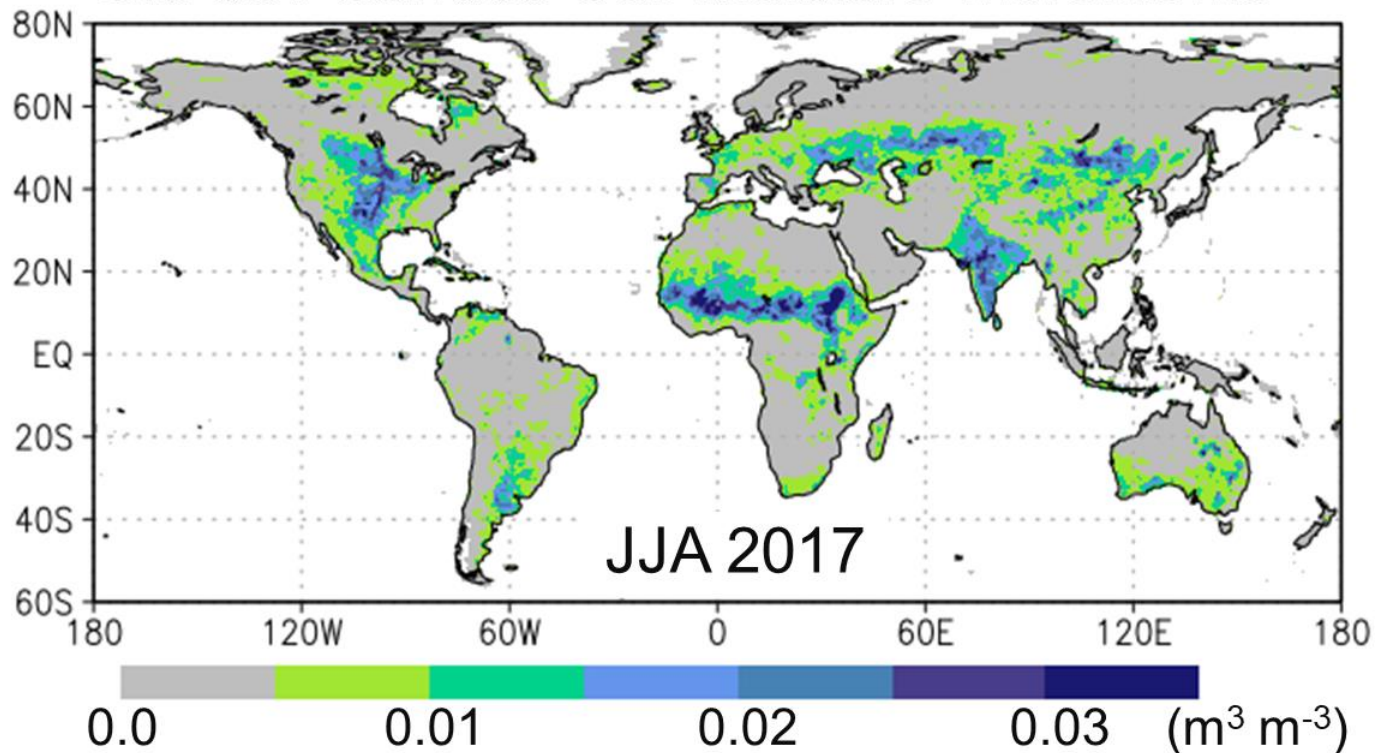


i) Mean SM incr Aug [mm/day]

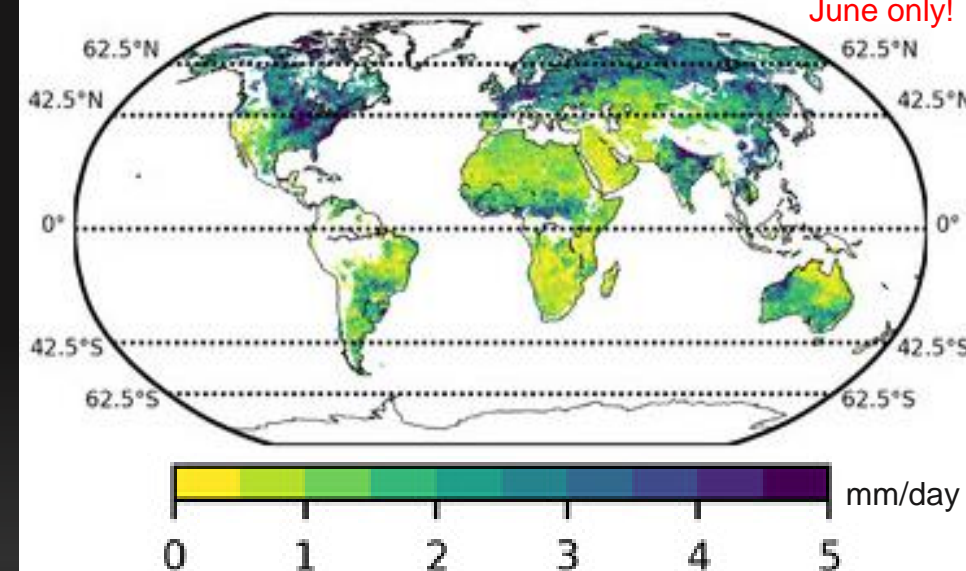


Soil Moisture Analysis Increments

Std-dev Surface Soil Moisture Increments



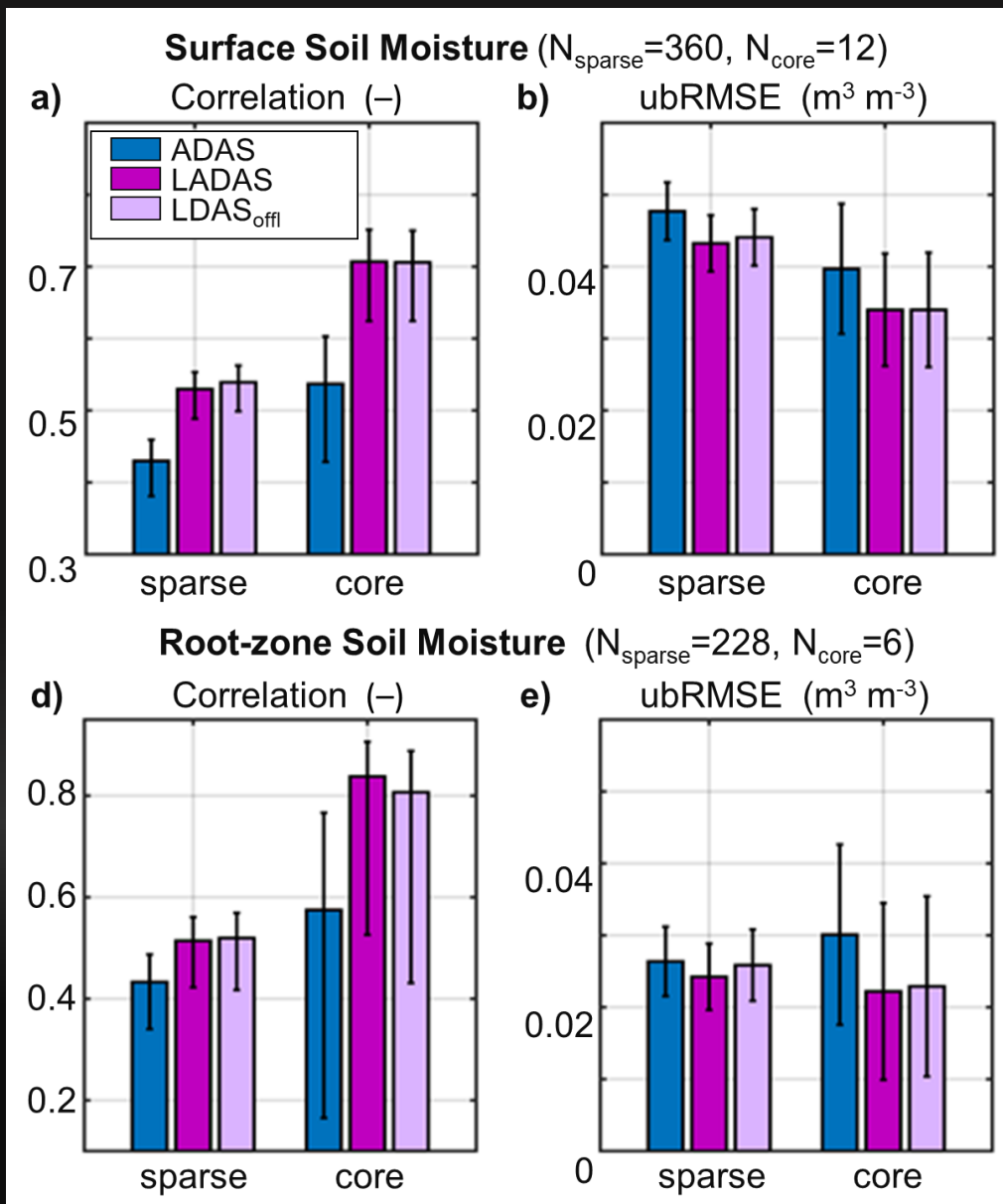
Draper & Reichle 2019
SMOS+ASCAT DA for 2013 Profile s.m.!
t) Stdev SM incr Jun [mm/day] Different units!
June only!



Largest impact from SMAP in transition zones between wet and dry climates (consistent with L4_SM).

Pattern quite different from that seen in (Draper & Reichle 2019).

In Situ Soil Moisture Validation



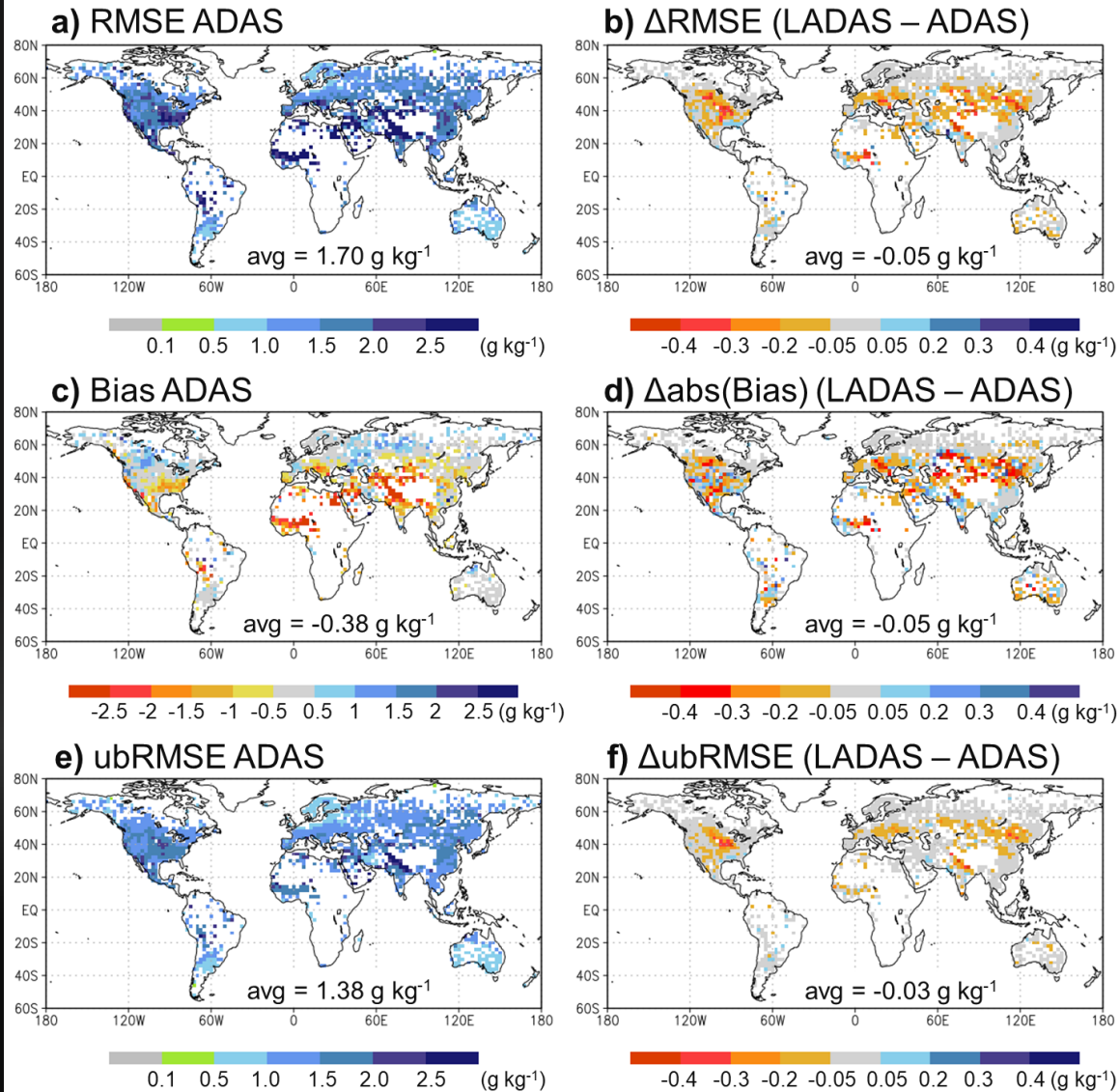
Soil moisture skill improvements over ADAS (consistent with L4_SM improvements over land model-only simulation).

Improvements statistically significant for correlation.

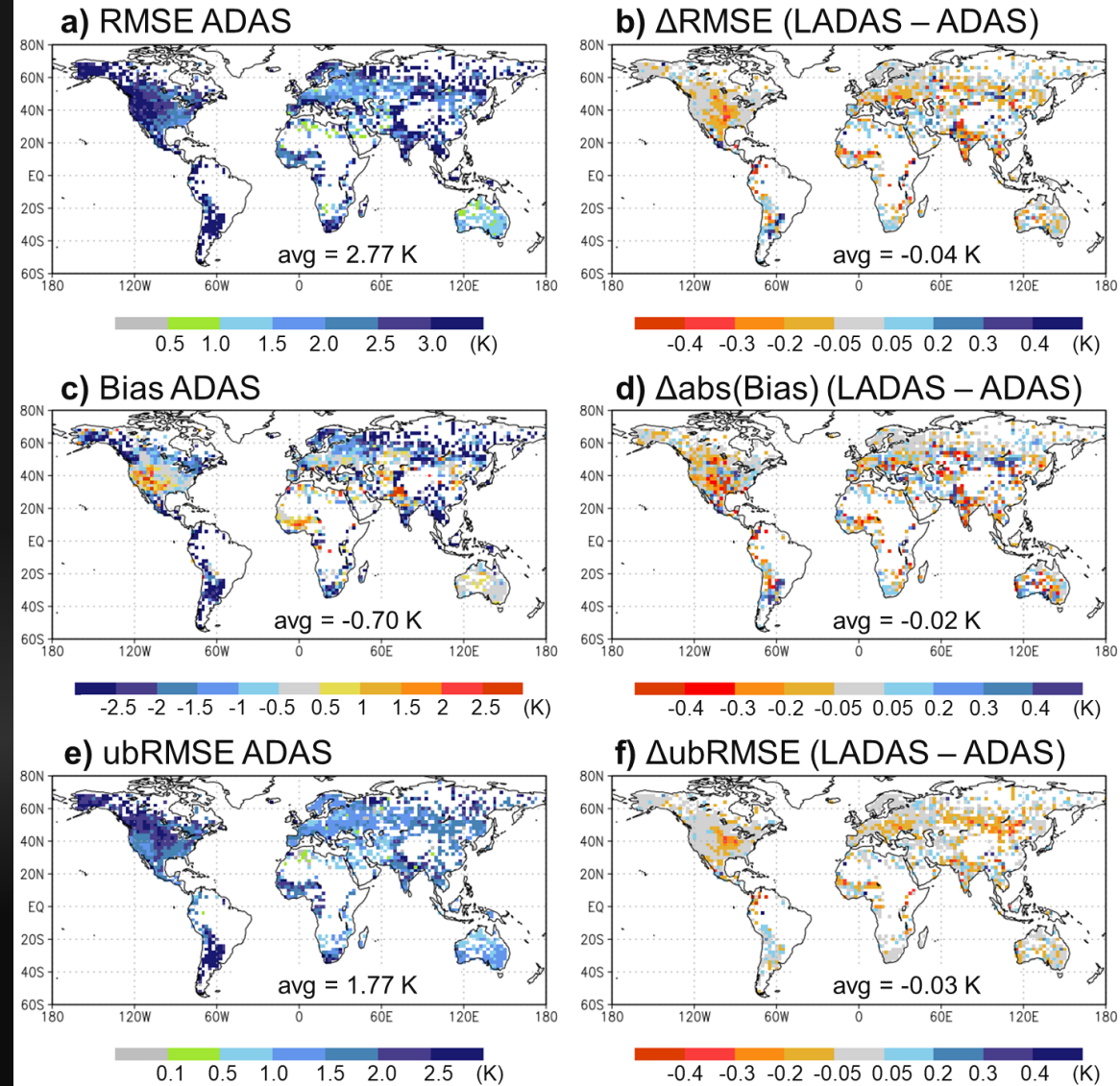
Screen-Level Humidity and Air Temperature



q2m metrics vs. HadISD



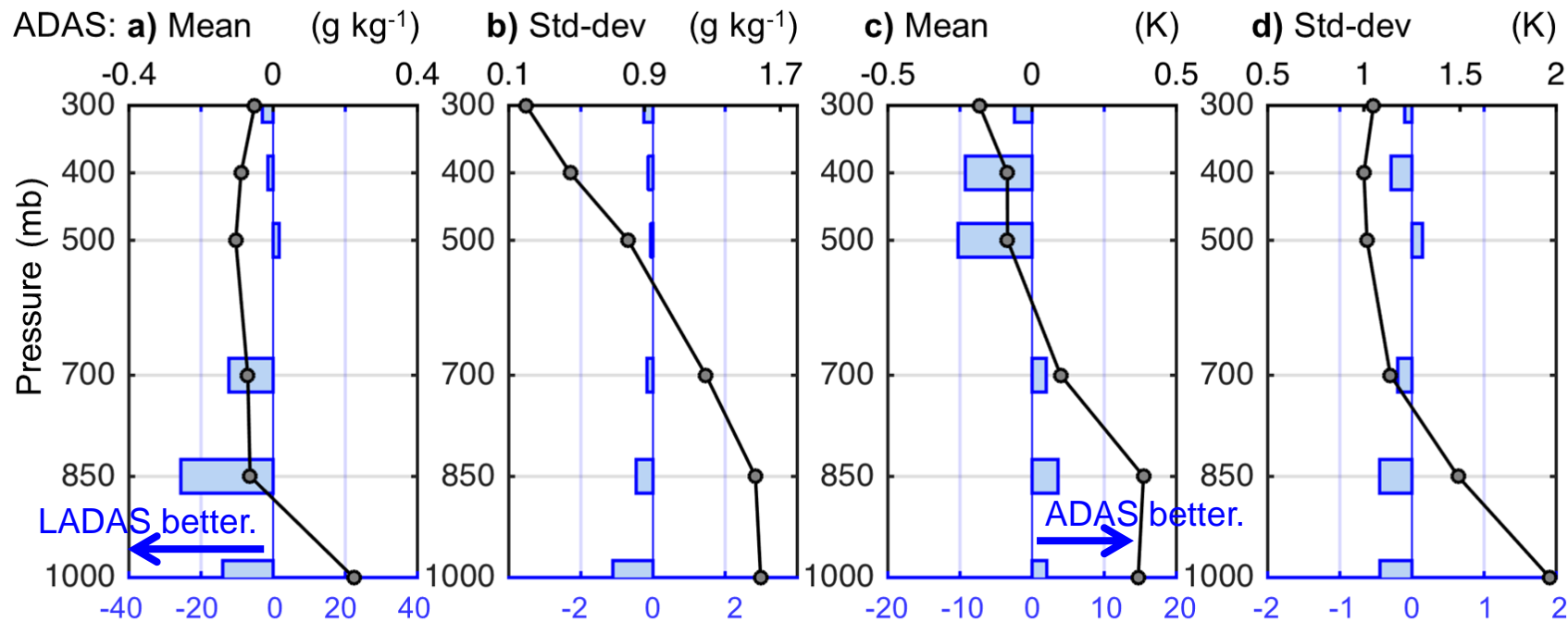
T2m_{max} metrics vs. GHCN



Atmospheric Profiles

OmF Specific Humidity

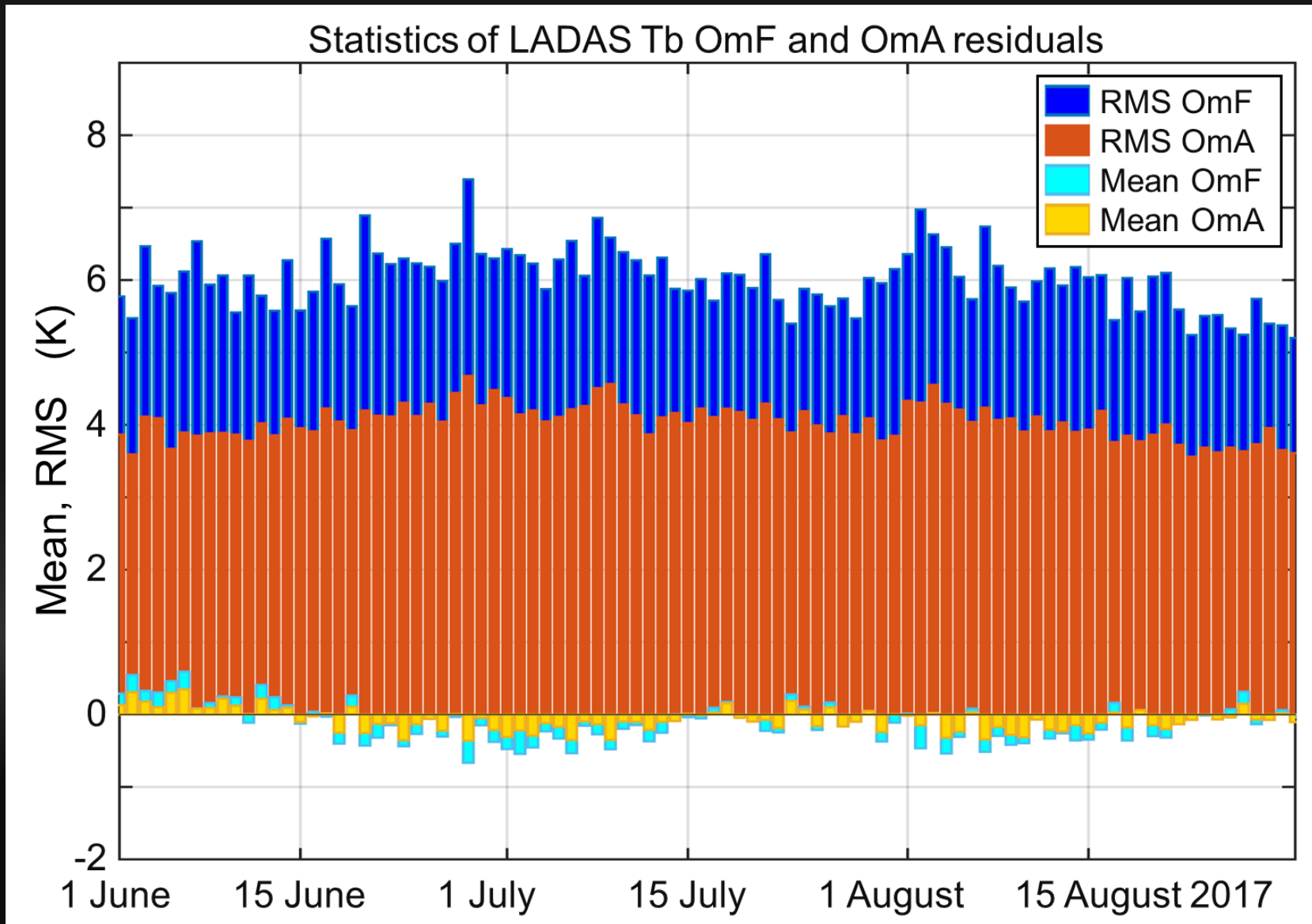
OmF Air Temperature



O-minus-F stats for radiosondes over continental land.

Improvements in specific humidity extend into the lower troposphere (below ~700 mb).

SMAP Tb Assimilation Diagnostics



Consistent with Tb
assimilation diagnostics
in L4_SM



4D-Hybrid-EnVar LADAS and CTRL vs ECMWF (850 mb, NH)

