Assimilation of satellite soil moisture for improved atmospheric reanalyses

Clara Draper
NOAA PSD / CU CIRES Boulder, CO, USA
Rolf Reichle
NASA GSFC GMAO, Greenbelt, MD, USA

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Draper & Reichle, MWR (2019)

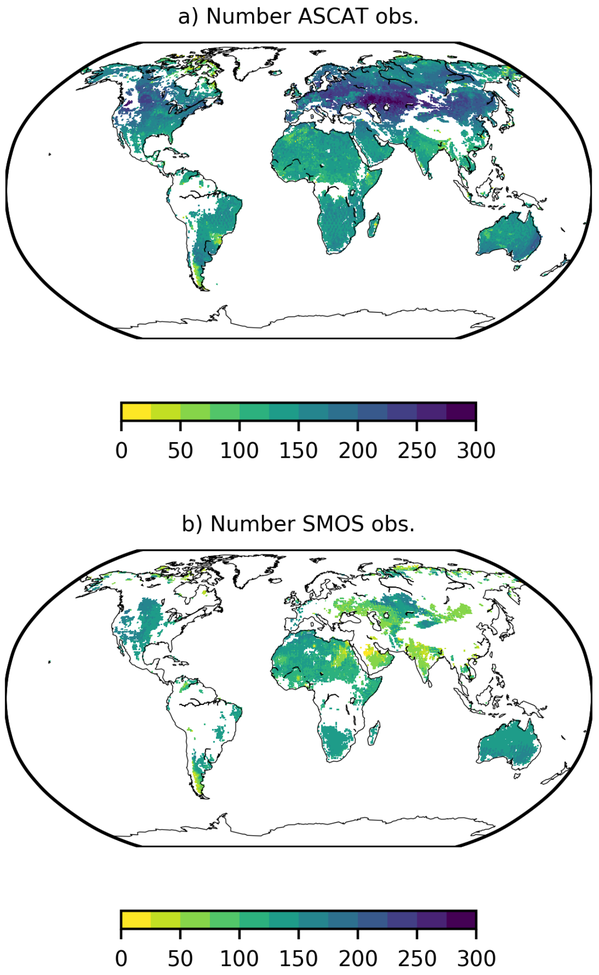
Experiment Design

- Wish to test whether assimilating surface soil moisture improves NASA GMAO's Earth system reanalysis

- Use an EnKF assimilation of satellite soil moisture into a system similar to MERRA-2, from April - August, 2013:

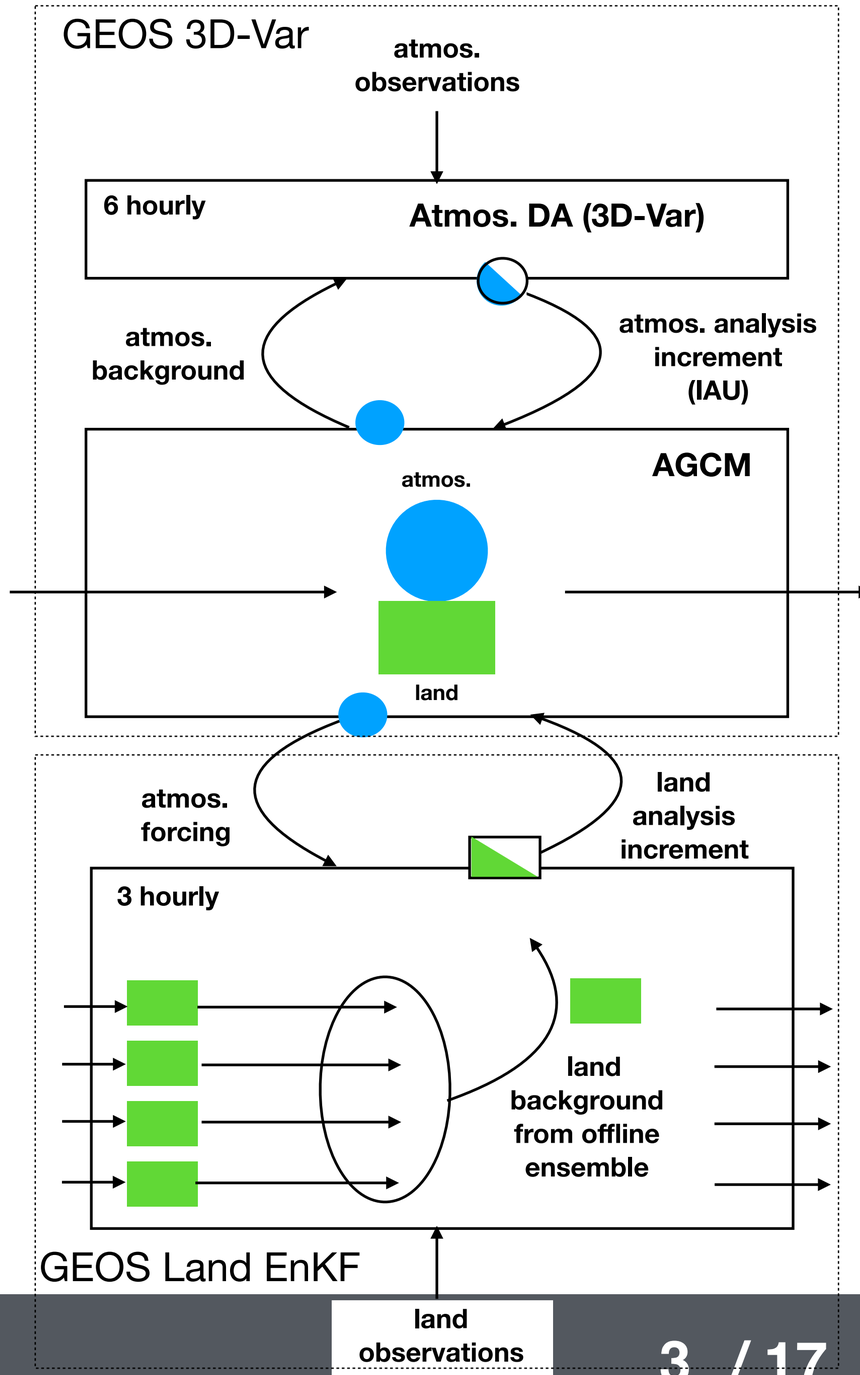
  1. <u>AGCM-DAatmos:</u>
  Same AGCM, atmospheric DA system, and assimilated observations as MERRA-2

  2. <u>AGCM-DAland/atmos</u>:
  As above, plus assimilate ASCAT & SMOS surface soil moisture to update model profile soil moisture

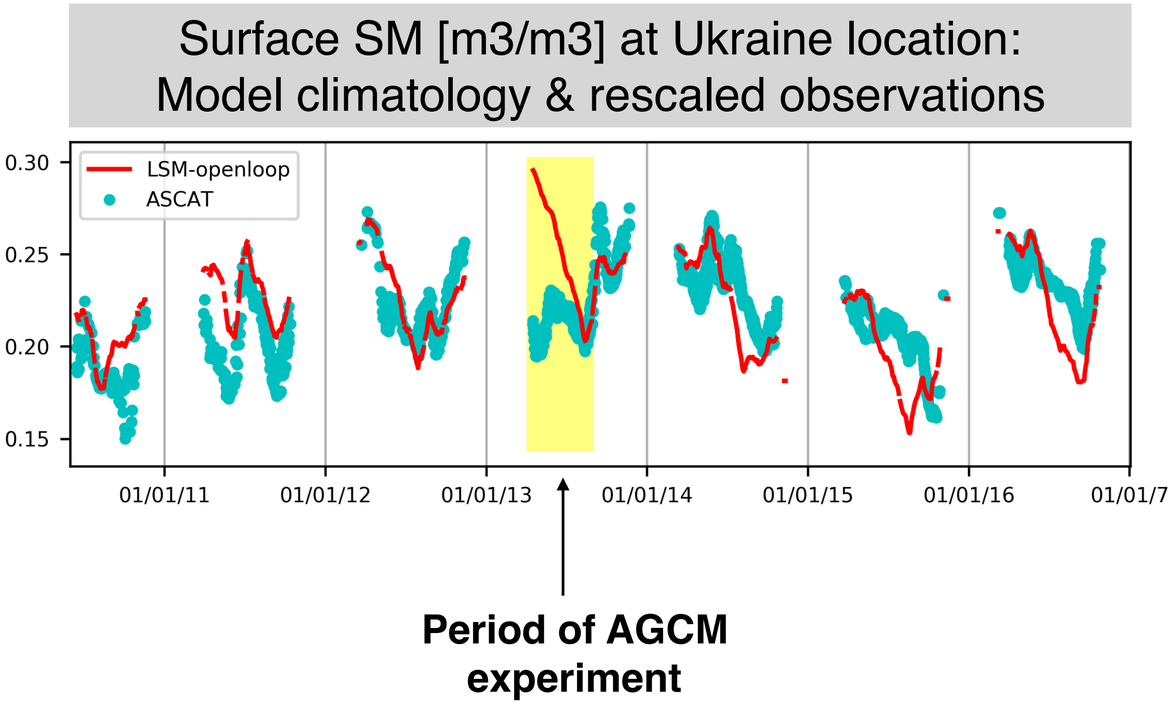


The GEOS Coupled Land/ Atmosphere DA

- Atmospheric DA is GEOS 3D-Var (as in MERRA-2)
- Land DA is GEOS EnKF (developed by Rolf Reichle)
  - Land ensemble is run offline, using atmospheric forcing updated at every assimilation cycle
- Weakly coupled: no observations or error covariances directly shared between land and atmosphere DA, but information is shared in subsequent forecast step



Bias Correction of the Satellite Soil Moisture

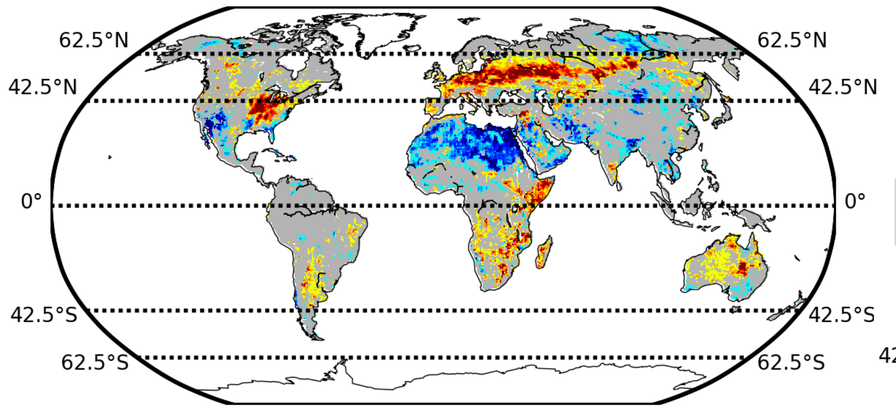


- The ASCAT/SMOS observations were ‘bias-corrected’ prior to assimilation, by rescaling them to match the climatology (mean, variance, …) of the model soil moisture *using the maximum available time period, of 6.5 years*

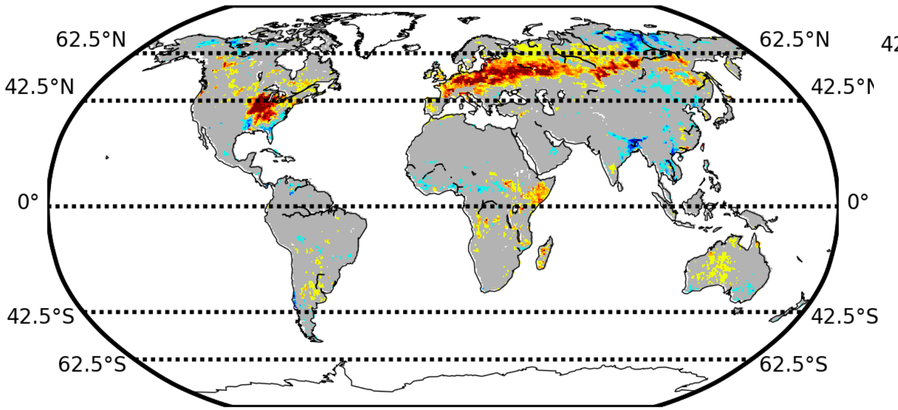
- Allows the assimilation to correct for model errors with inter-annual time scales

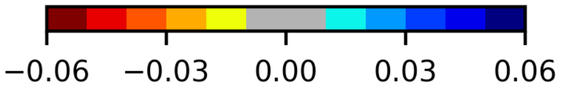
Impact on the model (mean differences in June)

Surface Soil Moisture (0-5cm) [m3/m3]

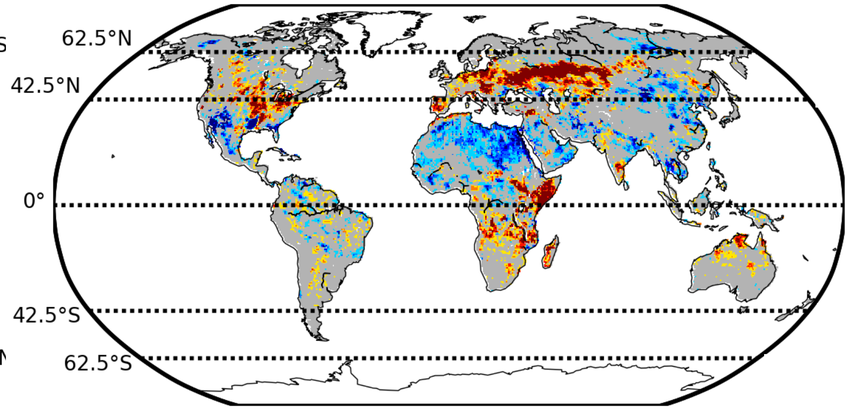


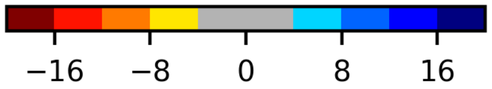
Root-zone Moisture (0-1.0m) [m3/m3]



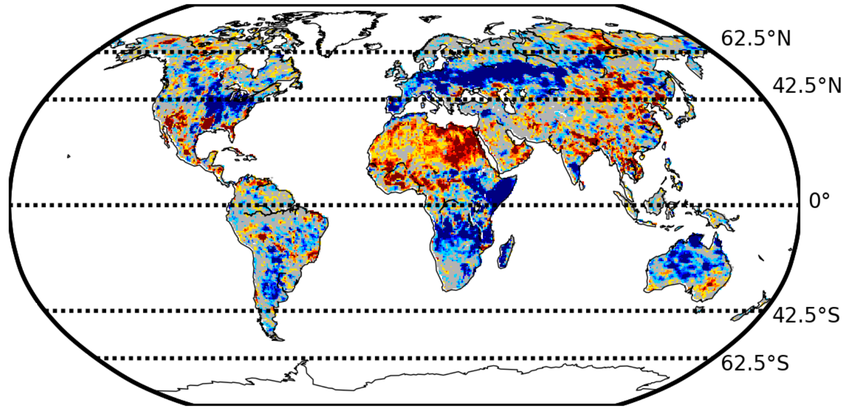


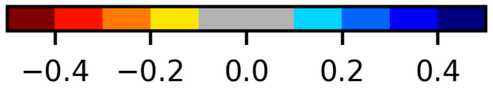
Latent heating [W/m2]





Daily Max T2m [K]

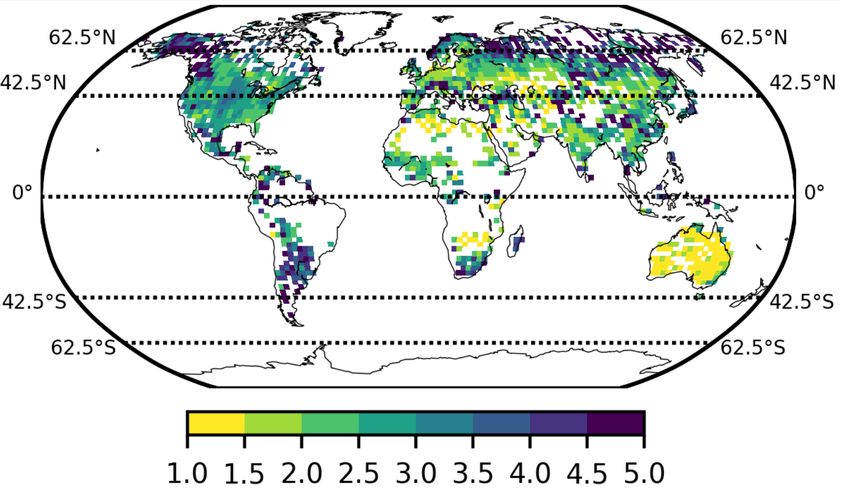




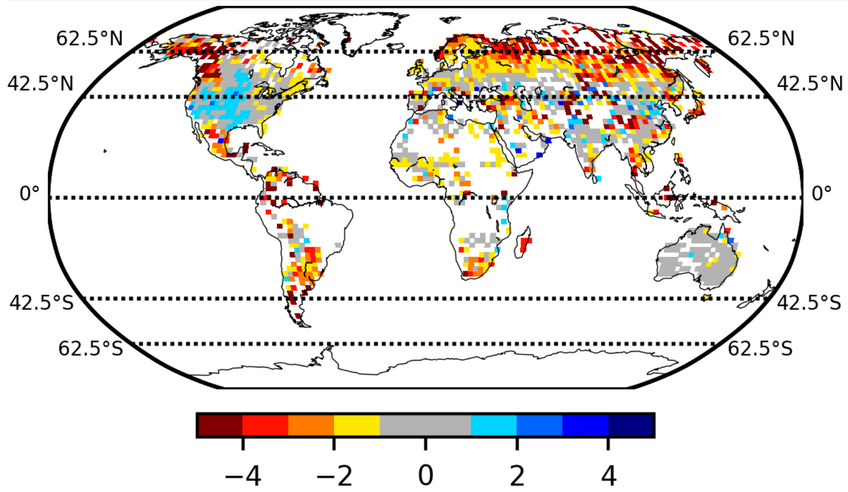
- Soil moisture DA induces relatively large changes in surface heat partition (hence, T2m, precipitation, boundary layer height)

Daily Max. T2m Skill (vs. GHCN obs) 14Apr-31Aug 2013

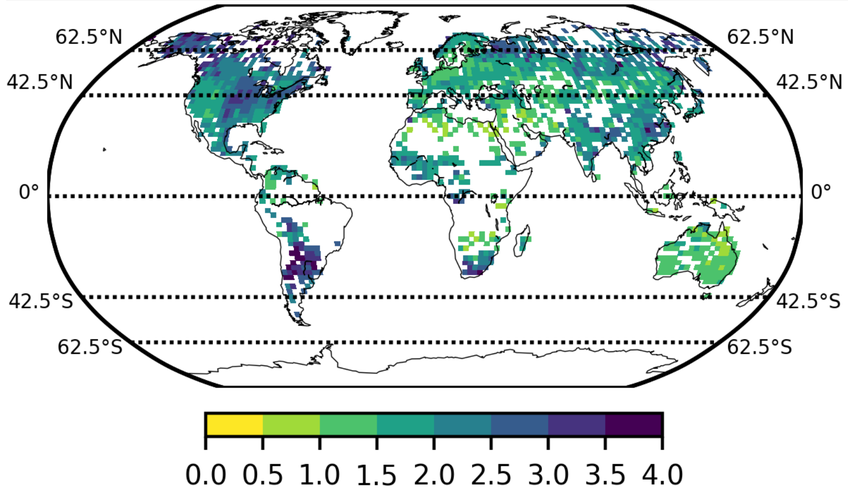
RMSE AGCM-DAatmos [K]



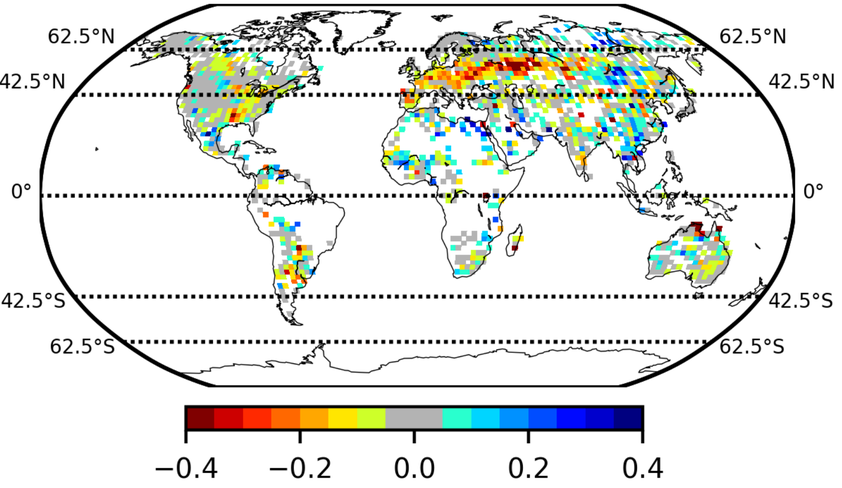
Bias AGCM-DAatmos [K]

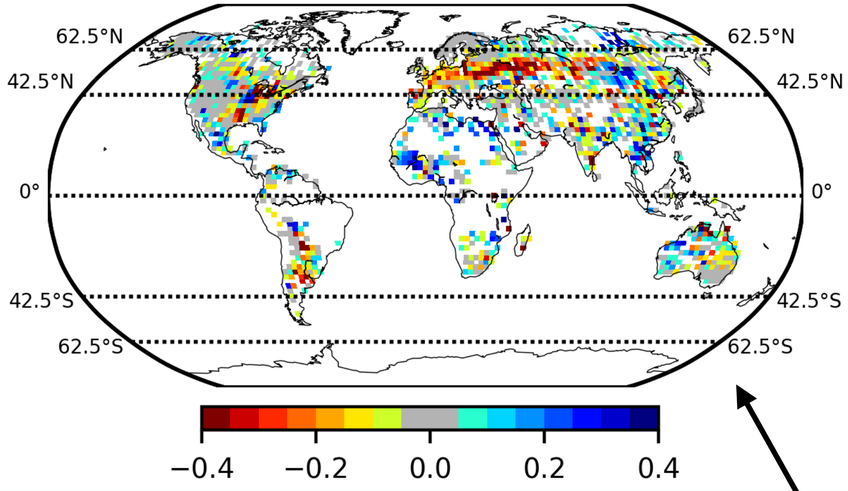


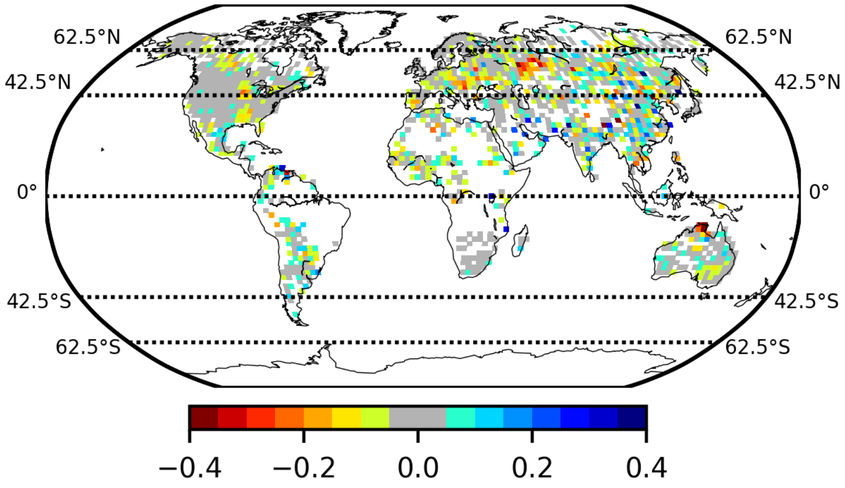
ubRMSE AGCM-DAatmos [K]



Change from Soil Moisture Assim (AGCM-DAland/atmos - AGCM-DAatmos)







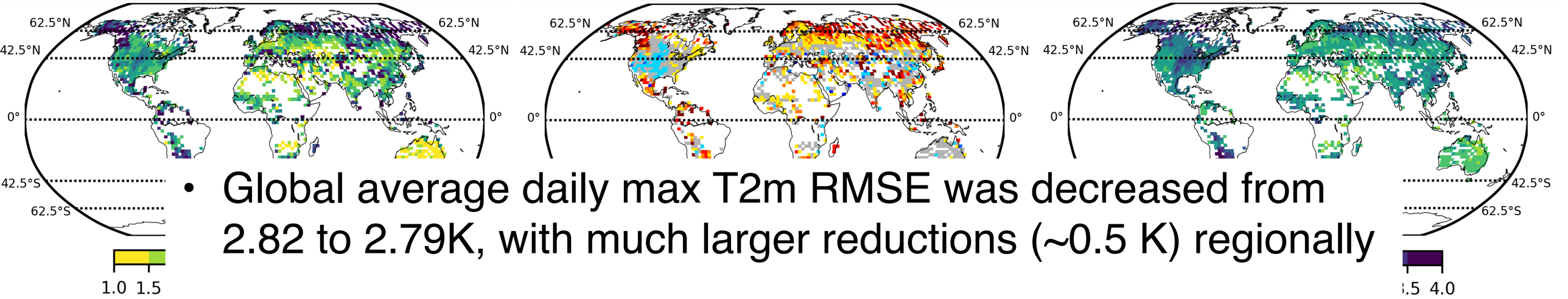
Change in abs(bias)

Daily Max. T2m Skill (vs. GHCN obs) 14Apr-31Aug 2013

RMSE AGCM-DAatmos [K]

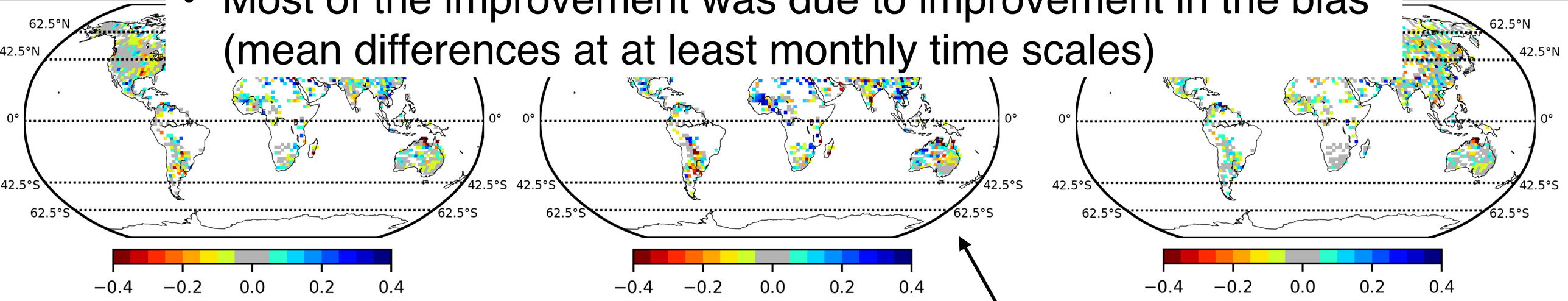
Bias AGCM-DAatmos [K]

ubRMSE AGCM-DAatmos [K]



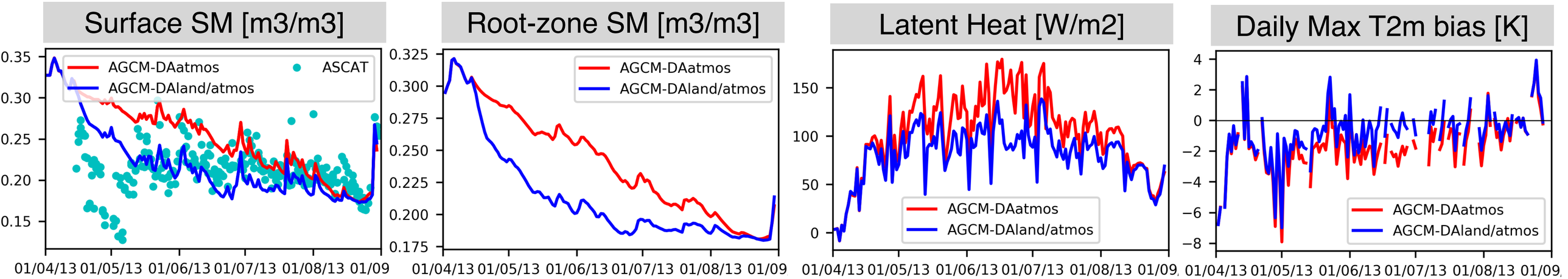
- Global average daily max T2m RMSE was decreased from 2.82 to 2.79K, with much larger reductions (~0.5 K) regionally

- Most of the improvement was due to improvement in the bias (mean differences at at least monthly time scales)



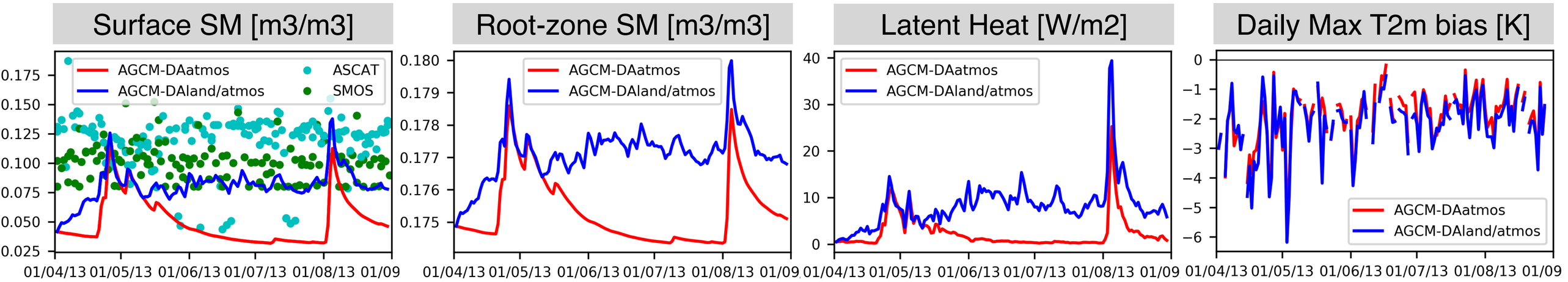
Change in abs(bias)

Example Timeseries: Ukraine



- Location representative of region spanning western Europe across southern Russia, with reduced T2m RMSE
- T2m RMSE reduced from 2.32 to 1.78 K
- The soil moisture assimilation dried the model soil moisture, decreasing latent heating (and increasing sensible heating), and reducing the cool bias

Example Timeseries: Algeria

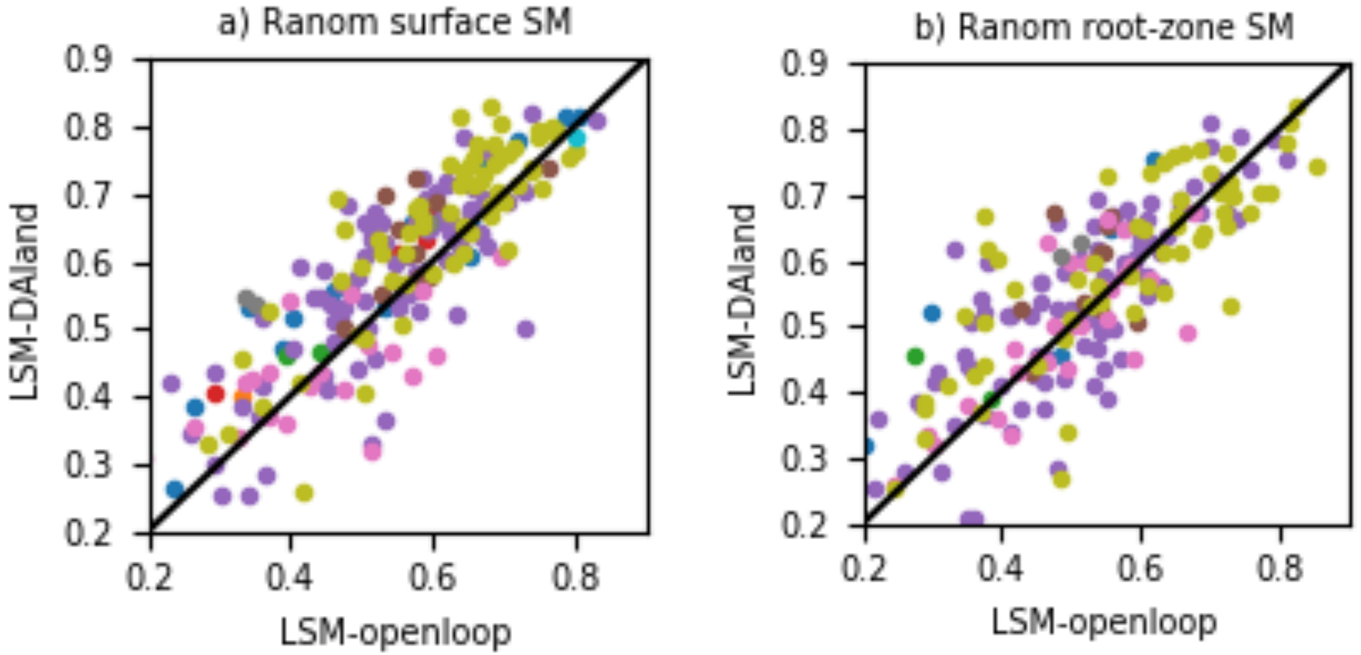


- Location representative of region across Sahara, where the assimilation wetted the model near-surface soil moisture, and increased latent heating by 5-15 W/m2
- T2m RMSE increased from 2.05 to 2.31 K
- Near surface soil moisture does not converge to obs.: instead assimilation persistently added small increments to the near-surface soil moisture, which are then evaporated
- Over time, a problematic volume of moisture is added to the system (enough to affect global circulation?)
  - Highlights importance of checking for serially correlated assimilation increments

Implications for evaluating SM DA

- In a preliminary offline DA experiment, assimilating ASCAT and SMOS SM slightly (but significantly) improved fit to ground-based soil moisture observations
  - "Fit" is measured using daily anomaly correlation, as is standard when evaluating model (or satellite) soil moisture with ground-based obs.

Correlation of daily anomalies from the seasonal cycle, at 215 sites



Mean Ranom
OL: 0.54, DA: 0.58

Mean Ranom
OL: 0.51, DA: 0.54

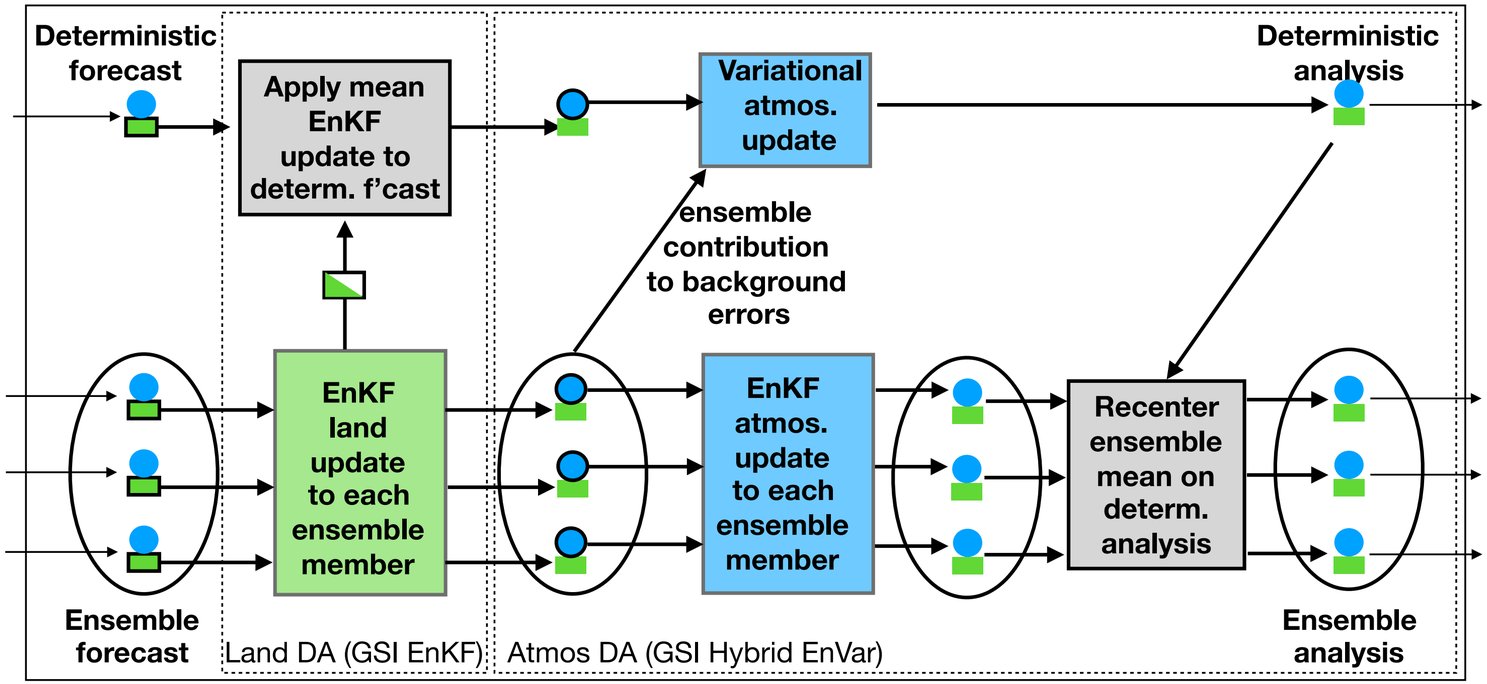
- Improvements to T2m support conclusion that soil moisture was improved
  - But these improvements are at longer time scales than usually evaluated for soil moisture. Should we re-think this?

Experiment Conclusions

- Assimilating satellite soil moisture decreased the global average daily max T2m RMSE from 2.82 to 2.79K, with much larger reductions (~0.5 K) regionally
  - Do not expect uniform improvement, since T2m only sensitive to soil moisture where latent heating is moisture limited
  - Improvement in T2m due to improvement in biases at monthly-plus scales, rather than day-to-day variability

- Based on these experiments, recommend assimilating satellite soil moisture into GMAO's future reanalyses
  - Will require updating the GMAO LA-DAS from the MERRA-2 3DVar used here to the 4DVar Hybrid

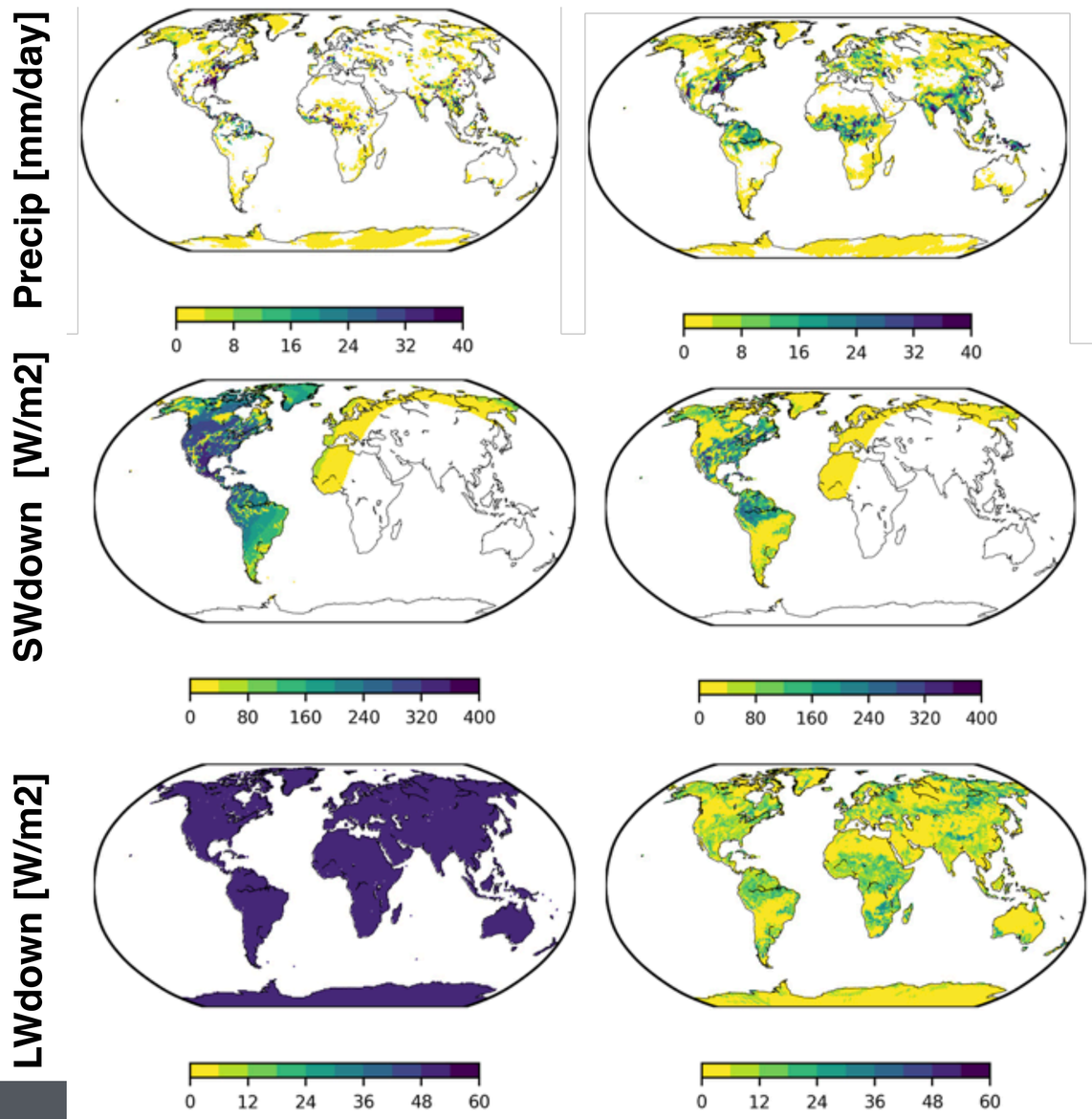
Update to EnVar atmos. DA (at NOAA ESRL)



- The NASA/NOAA GSI atmospheric DA is now a hybrid EnVar
- Update the LADAS to make use of the atmospheric ensemble from the hybrid (moving towards strongly coupled DA)

Update to EnVar atmos DA

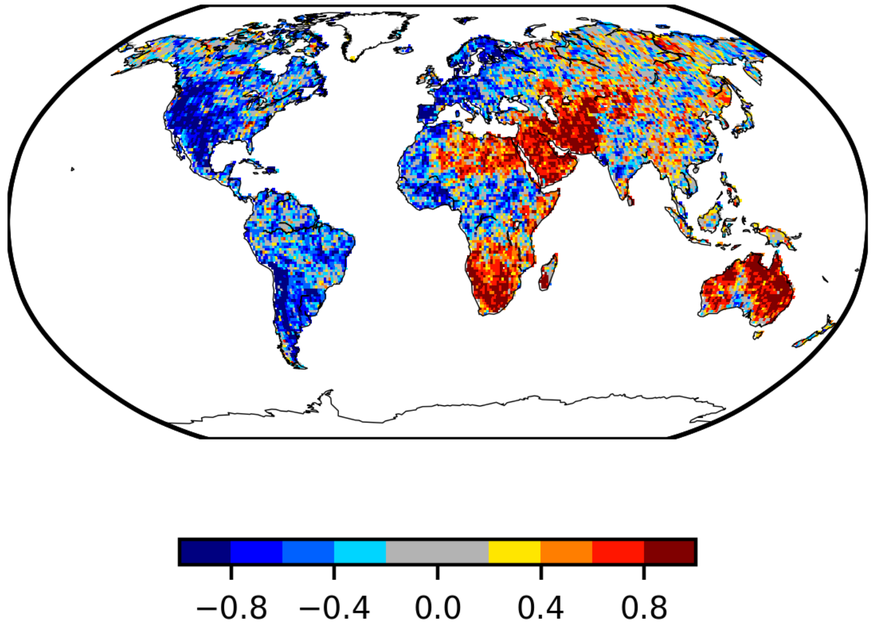
- Atmospheric ensemble underestimates model uncertainty in/ near the land surface
  - Spread in atmospheric fields that force surface appears OK
  - Currently no perturbations to the land model and/or states



Update to EnVar atmos DA

- Added perturbations to soil states in the GFS ensemble
  - Currently SPPT of soil moisture
  - Produces reasonable spread in soil moisture and temperature, and 2-m T, q
  - GFS has unexpected night-time +ve relationship between soil moisture and temperature.
  - Traced to Noah LSM physics, expected to be fixed with update to Noah-MP

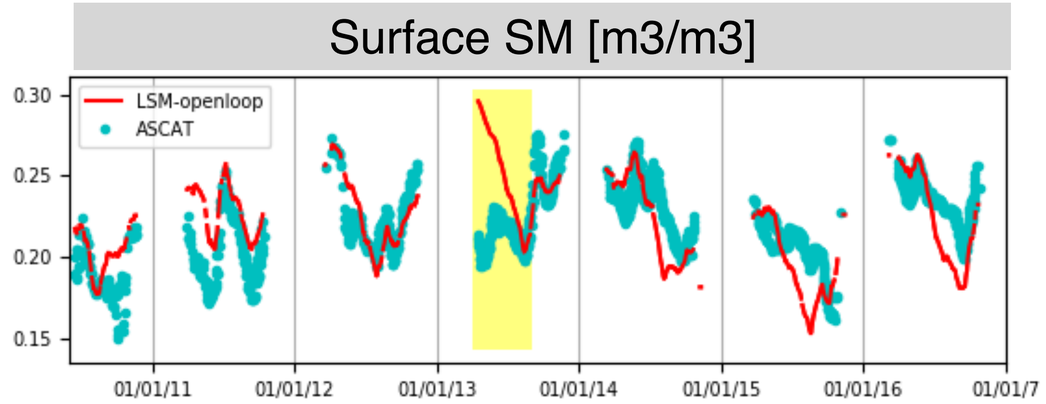
GFS Ensemble correlation sm1, T2m [00 UTC]

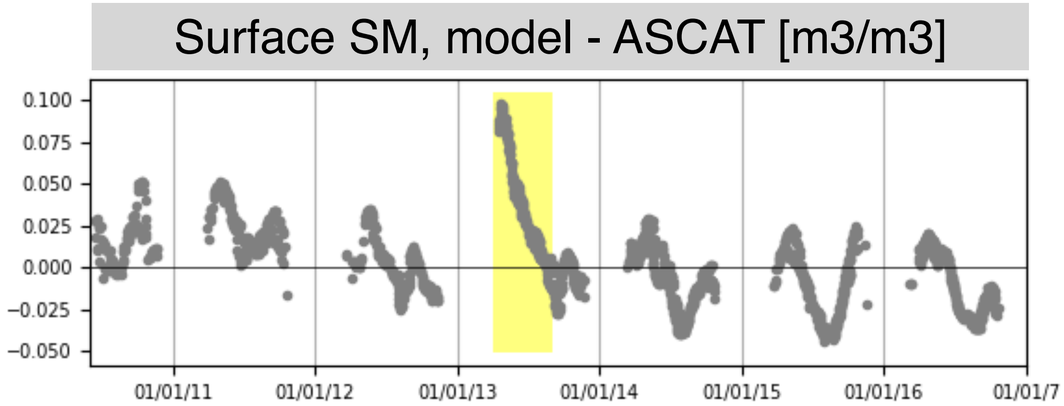


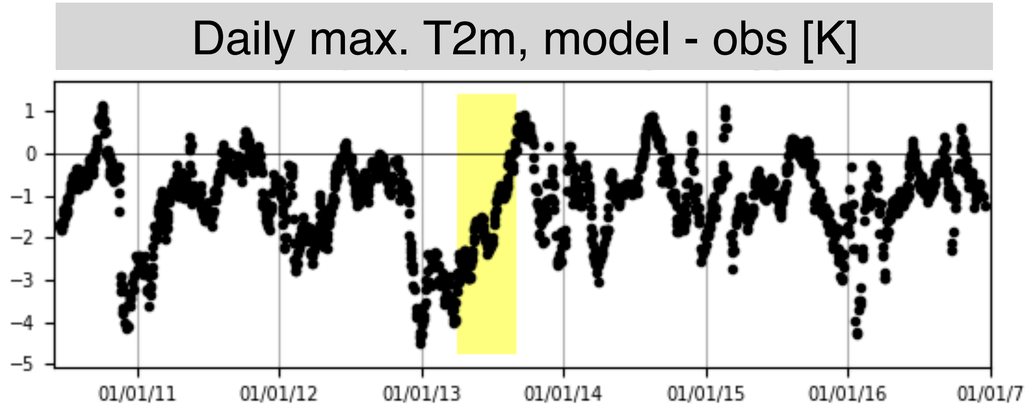
Thanks for Listening

clara.draper@noaa.gov

Example Timeseries: Ukraine

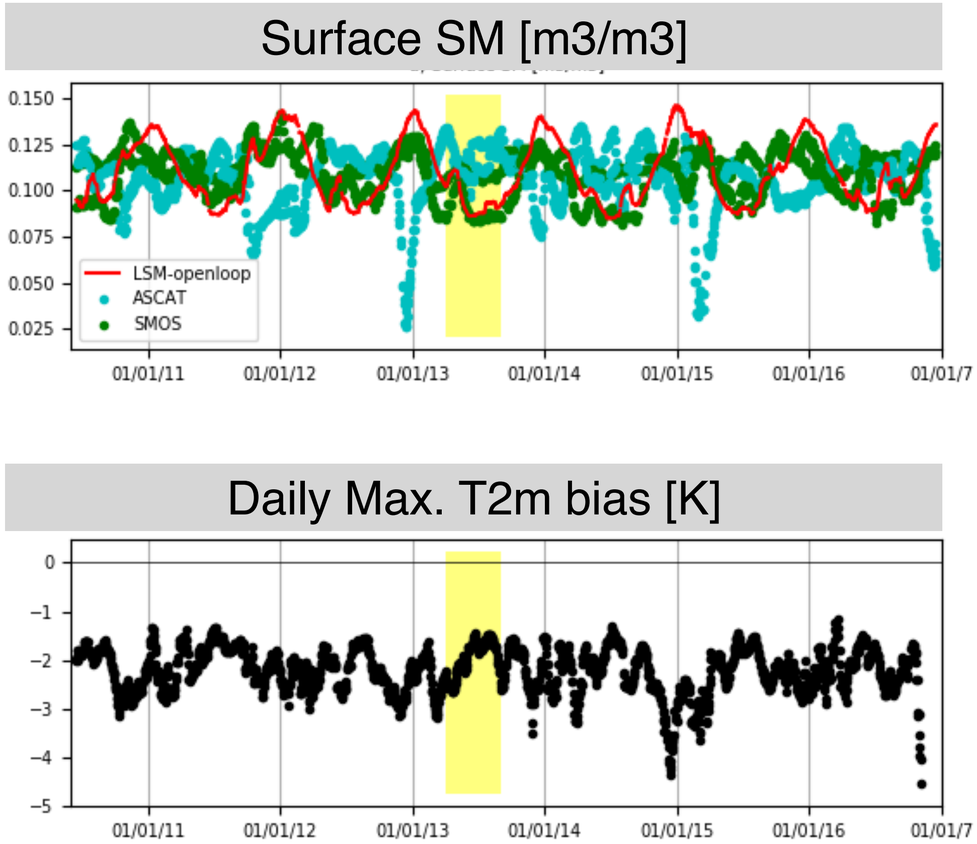






- The model was unusually wet during the AGCM experiment period
- Coincided with unusual cool bias in T2m
- ASCAT assimilation correctly detected this wet bias, to reduce the T2m bias

Example Timeseries: Algeria



- Extremely arid regions are unlikely to benefit from assimilating soil moisture
- Satellite soil moisture does not look realistic
- Given very low temporal variability, observation signal-to-error ratio will be very low
- In future, screen out arid (low variability) regions

- Also, for land DA into AGCMs, check for serially correlated assimilation increments