# Incorporating land surface observations into reanalyses: NASA's MERRA-2 and beyond.

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Rolf Reichle, Qing Liu, Randy Koster
Amal El Akkraoui, Ricardo Toddling,
and many others.

CDAW2016, Toulouse, 21 Oct 2016.

GMAO

# GMAO Land DA Coupling Progression

| | COUPLED (Land/Atmosphere) | OFFLINE (Land Only) |
|---|---|---|
| 2009 | MERRA | |
| 2012 | | MERRA-Land<br>Observed precipitation over land |
| 2015 | MERRA-2<br>inc. observed precipitation over land | |
| .<br>2015 | | EnKF LDAS:<br>+SMAP L4 soil moisture product (assim of L-band $T_B$, obs. precip.)<br>+Research activities (assim. of SM, $T_B$, LST, TWS, SWE, SCF, …) |
| | Integrated Earth System Analysis inc LDAS | |

# MERRA-2 and Observed Precipitation

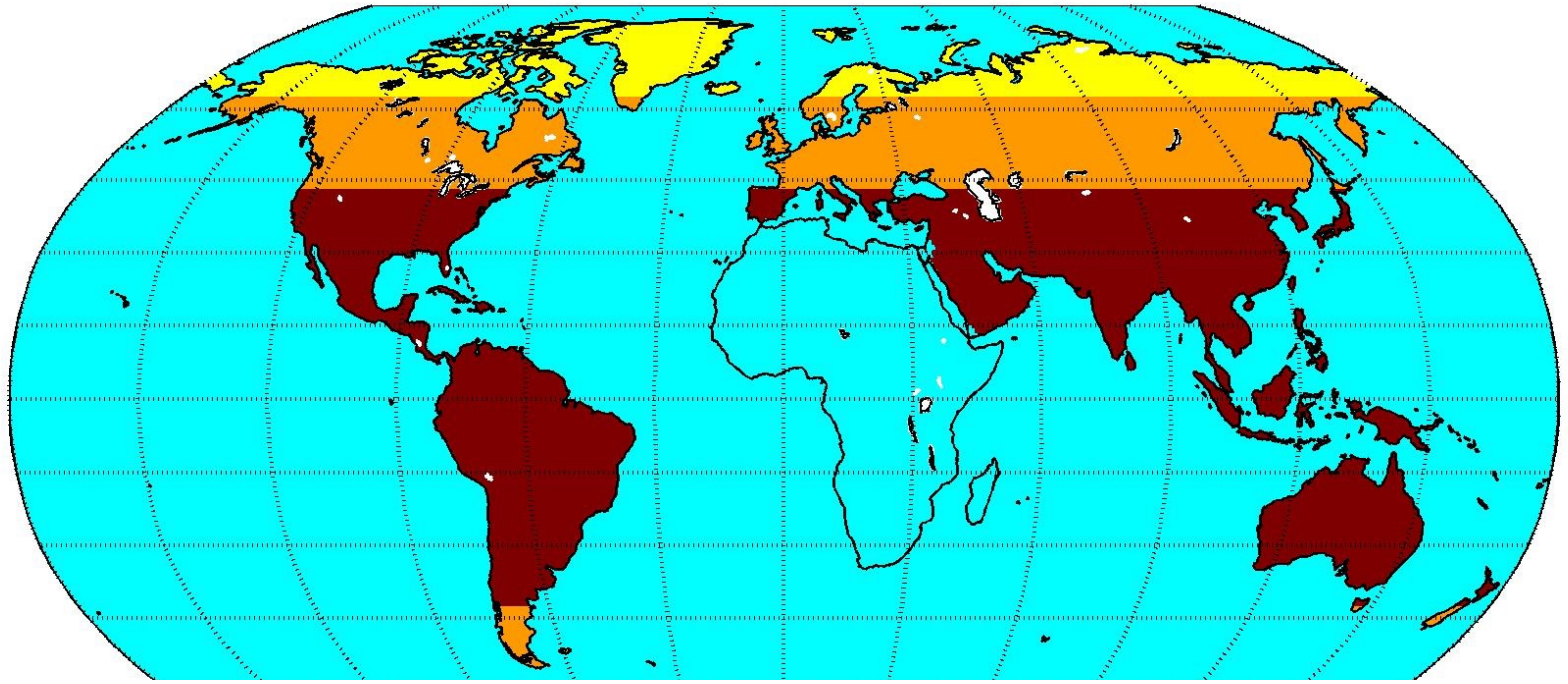
# Precipitation Corrections in MERRA-2

- In MERRA-2, observed precipitation is directly inserted at the land surface
  - Precipitation is the main driver of land surface hydrology
  - Intent is to improve land surface moisture storage, preventing model precipitation errors from feeding back to the atmosphere

- The precipitation correction approach in MERRA-2 was refined from that used in MERRA-Land
  - Note: MERRA-Land and MERRA-2 also include minor, but important, land surface model updates

# Precipitation Corrections in MERRA-2

**MERRA-Land used CPCU precipitation for all land.**
**In MERRA-2, precip. is corrected in 4 regimes:**



**Oceans* & Africa:**
**Pentad, 2.5° satellite+gauge data (CMAP/GPCP2.1).**

**Low & mid latitude land ( |lat|< 42.5°) except Africa:**
**Daily, 0.5° gauge data (CPCU).**

**Mid & high latitude land (42.5° < |lat| < 62.5°):**
**Linear tapering from CPCU at 42.5° to MERRA-2/AGCM-generated precipitation at 62.5°.**

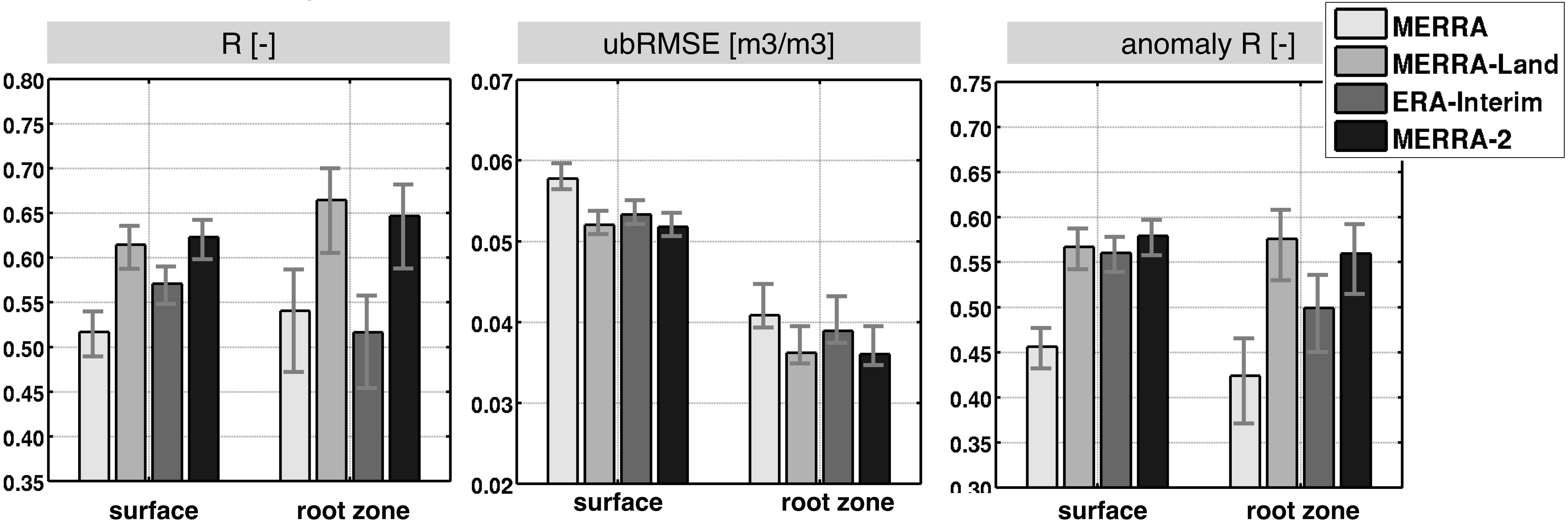
**High latitude land (|lat| > 62.5°):**
**MERRA-2/AGCM-generated (no correction).**

Reichle and Liu, NASA GMAO TM 2014

*In MERRA-2, corrected precip. also modulates aerosol wet deposition.

# Soil Moisture v. In Situ Observations

Comparison to obs. from ~100 SCAN sites in CONUS, 2002-2014

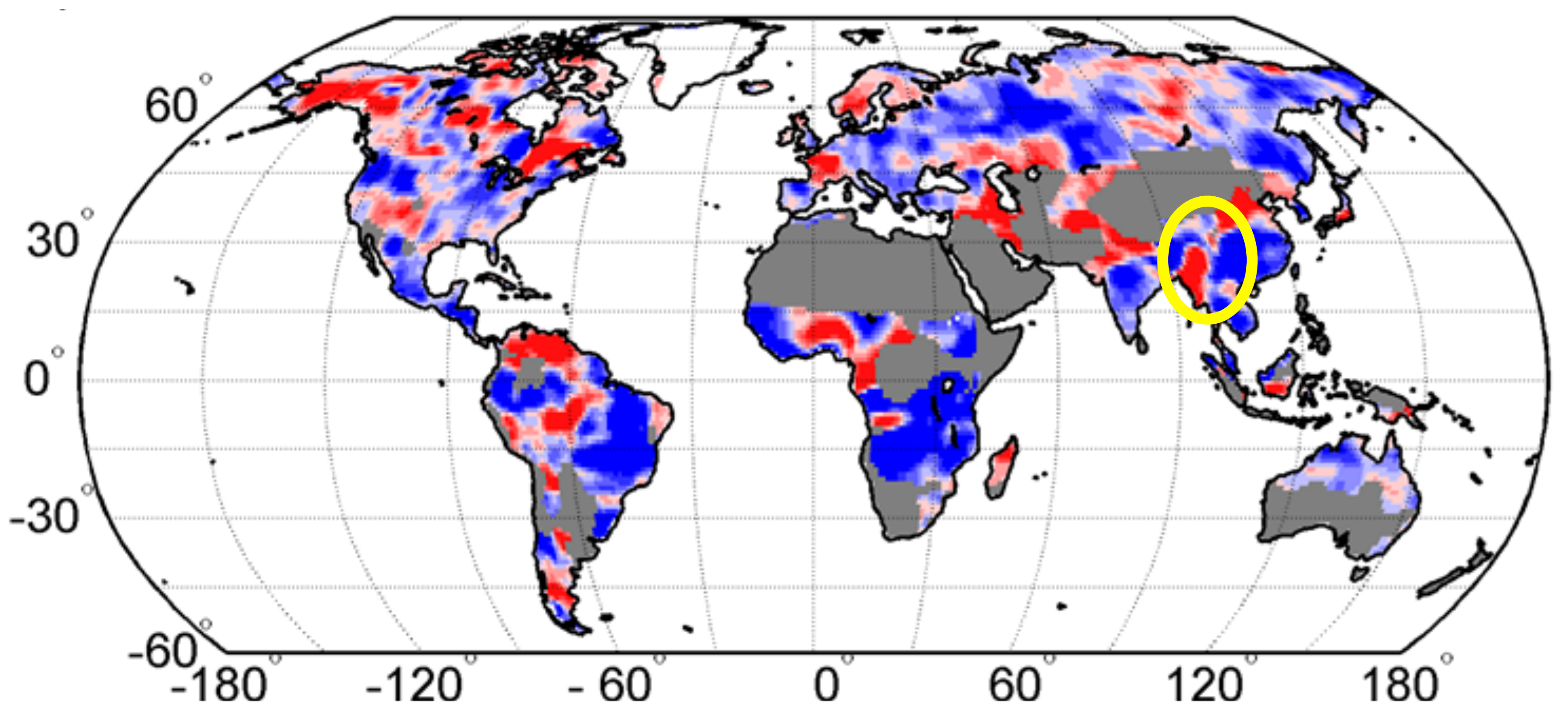


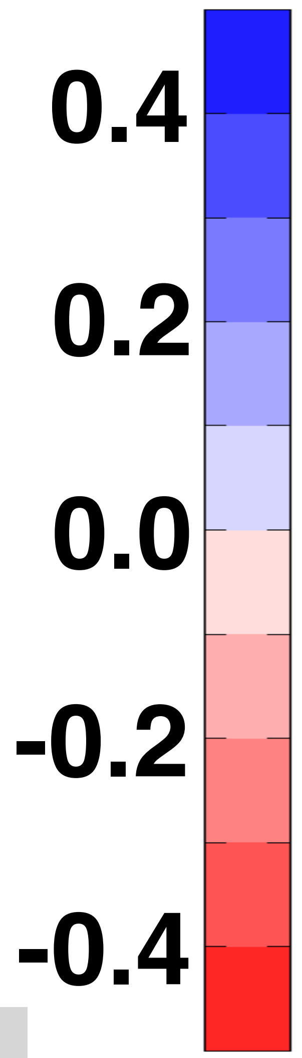

**Use of observed precipitation in MERRA-2 and MERRA-Land is associated with significantly higher soil moisture skill.**

# Terrestrial Water Storage Skill v. GRACE

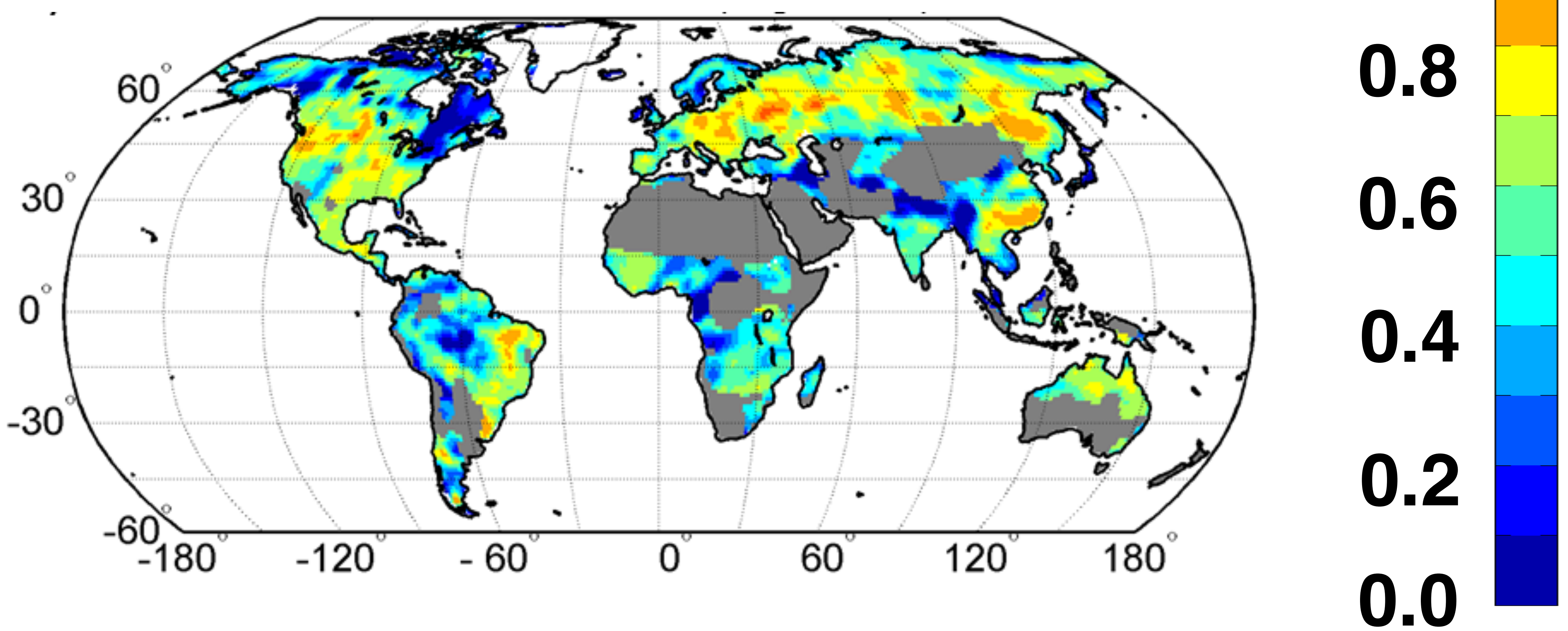
R = Correlation of monthly anomalies from the seasonal cycle, 2003-2015.

Delta R, MERRA-2 minus MERRA (avg=0.11)

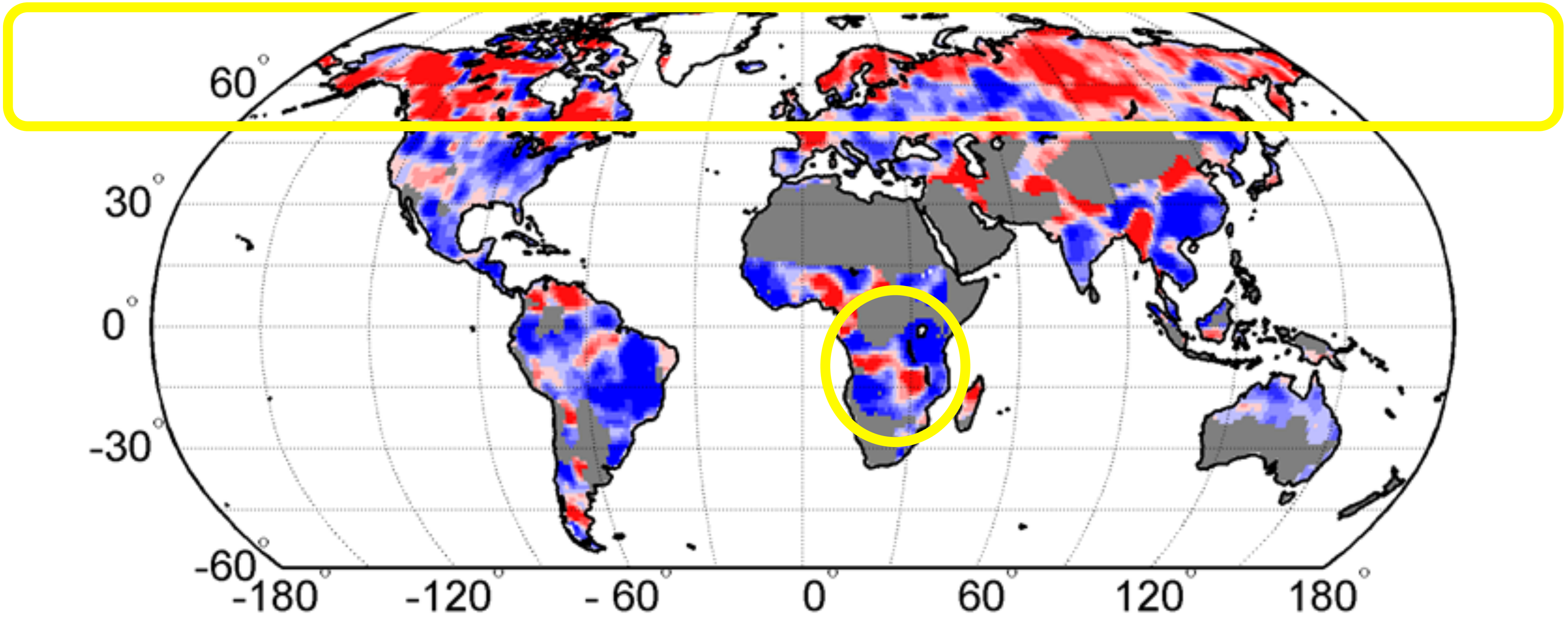



R, MERRA-2 (avg=0.52)




Delta R, MERRA-Land minus MERRA (avg=0.03)



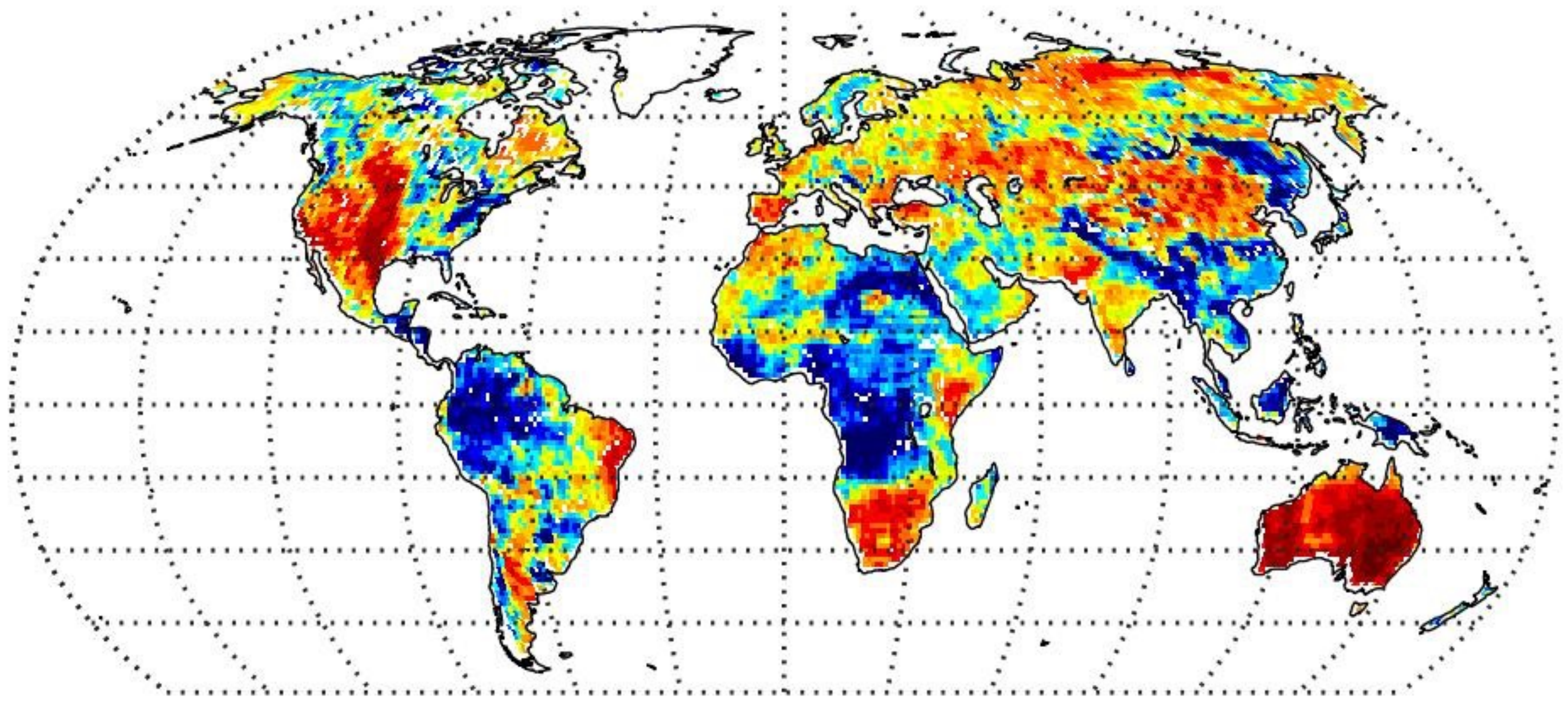

**Use of observed precipitation improves the TWS anomalies, compared to GRACE.**

**Many of the differences relate to known problems in precipitation.**

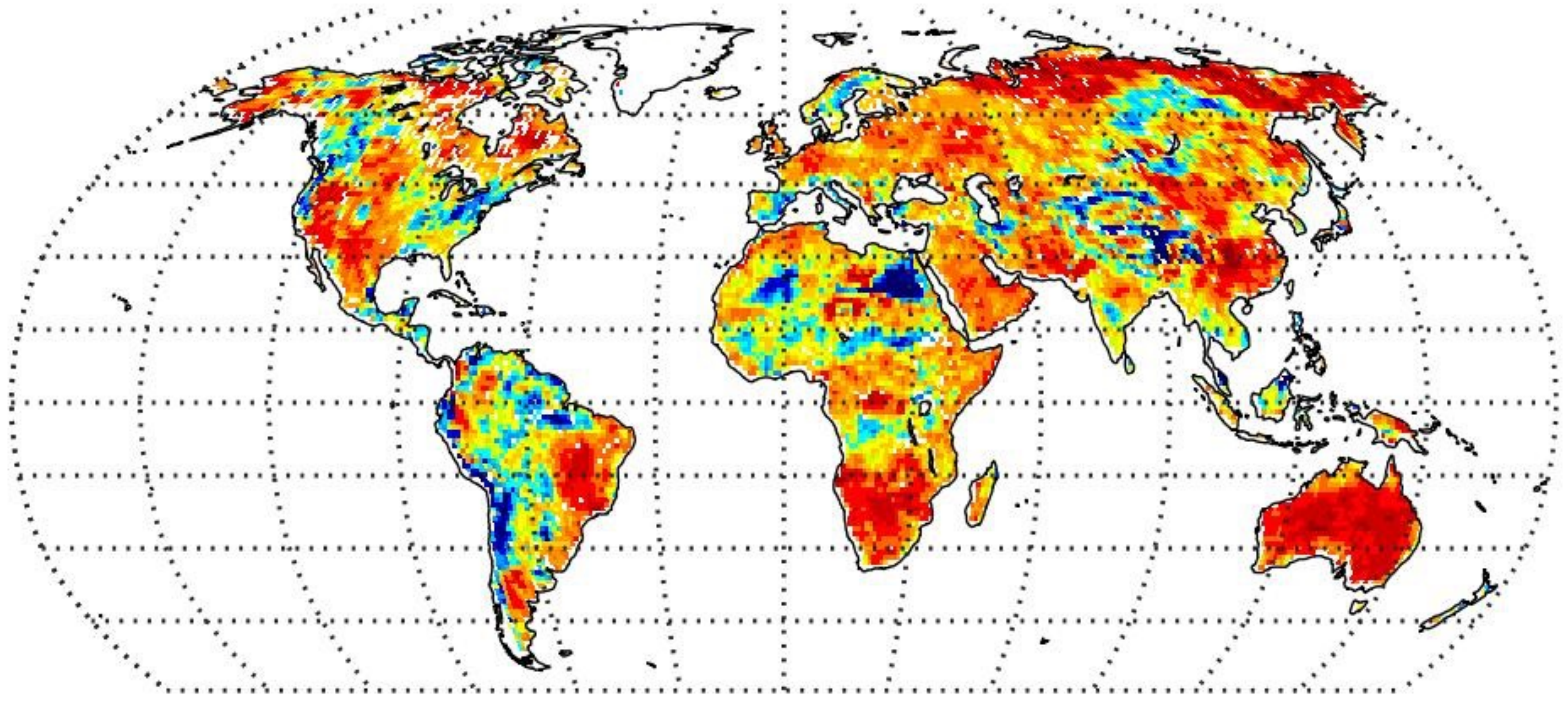
c/o M. Girotto.

# Latent Heat Fluxes

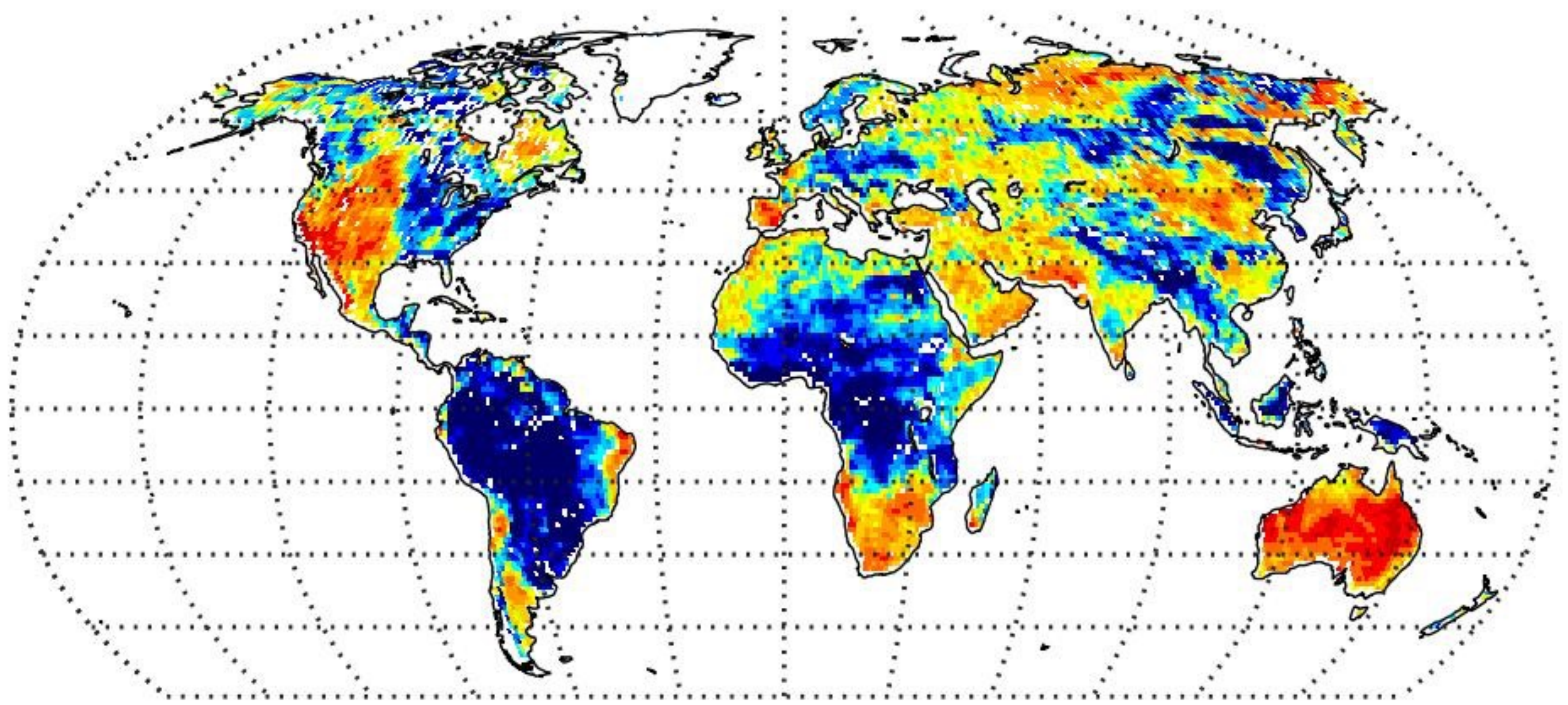
R, MERRA-2 v. GLEAM LH [-]



R, ERA-Interim v. GLEAM LH [-]



R, MERRA v. GLEAM LH [-]




R = Correlation of monthly anomalies from the seasonal cycle.

| Average | GLOBAL | | 27 sites | |
|---|---|---|---|---|
| | GLEAM | MTE | Fluxnet -2015 | |
| | LH | LH | LH | SH |
| MERRA | 0.40 | 0.30 | 0.22 | 0.40 |
| MERRA-Land | 0.47 | 0.31 | 0.29 | 0.28 |
| MERRA-2 | 0.50 | 0.34 | 0.31 | 0.39 |
| ERA-Interim | 0.62 | 0.44 | 0.28 | 0.46 |

**MERRA-2 improved both where LH is moisture-limited (improved precip.), and where it is not (model parameter updates).**

# Feedback of Obs Precip to the Atmosphere

Correlation between summer precip (Jun+Jul) & model $T^{2m}$ (Jul)


**Strong relationship between anomalies in precipitation seen by the land, and subsequent modeled T2m**

# MERRA-2 Summary

- MERRA-2 includes first use of observations in a GMAO reanalysis land surface, through direct insertion of observed precipitation
  - Generally, improves soil moisture and TWS, leading to improved surface turbulent fluxes, and possibly $T^{2m}$
  - Some instances of degraded land surface hydrology (e.g., Myanmar), often associated with changes in rainguage network
    - In future: complement with soil moisture assimilation
- Compared to offline land reanalysis (MERRA-Land), MERRA-2 provides more internally consistent land and atmospheric states
- (Not shown) Use of observed precip. allows consistent spin-up of land initial conditions for reanalysis streams
    - MERRA-2 has spin-up discontinuities in high-lats, where observed precip was not used (and model precip. is higher than expected)

# Future Coupled Land/Atmosphere DA

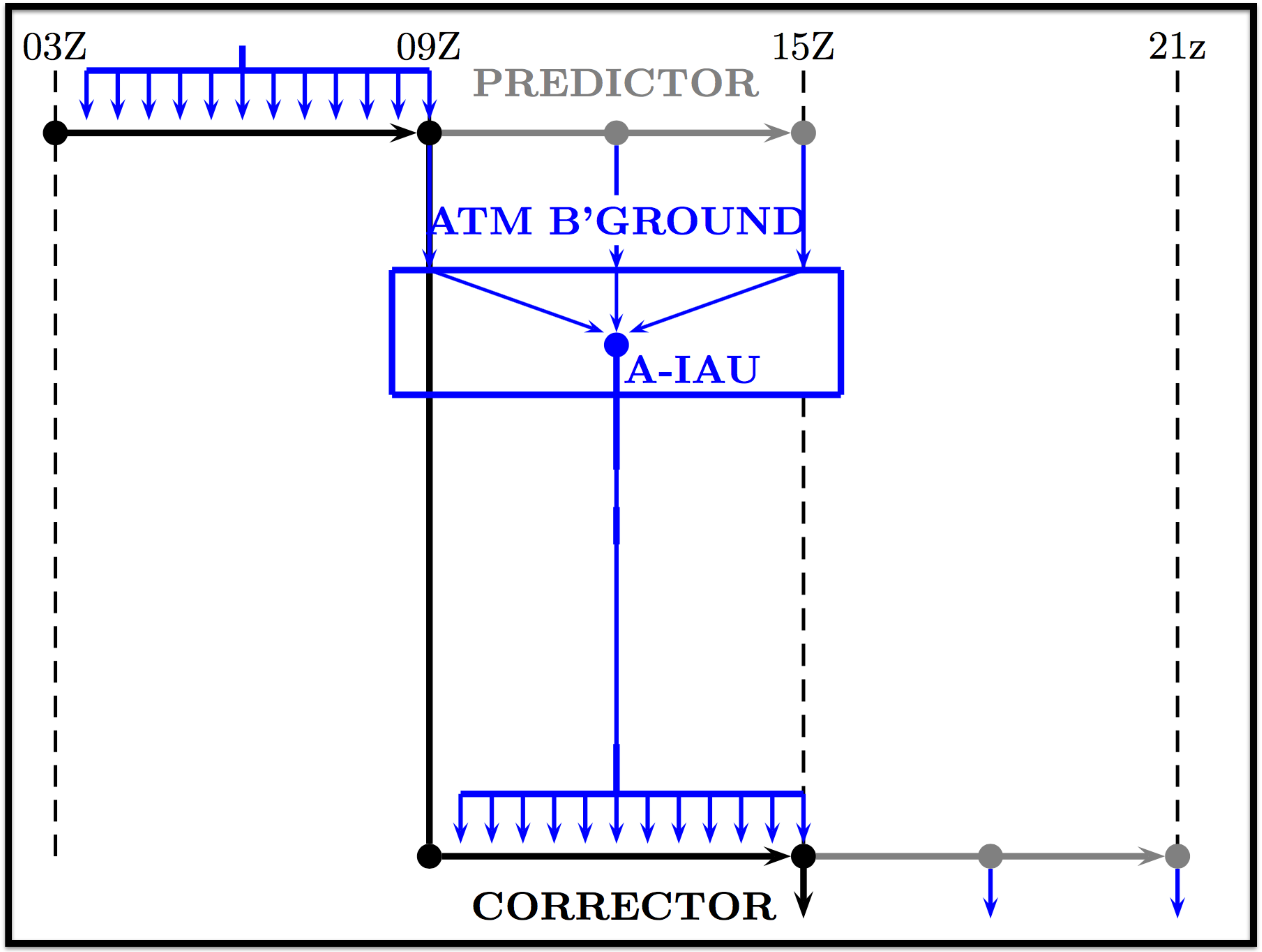
# LDAS in the Integrated Earth System Analysis

- IESA will use the weakly coupled GEOS-5 Land/Atmosphere DA (LA-DAS)
  - LDAS: GMAO Land EnKF
  - ADAS: Currently GEOS-5 3D-Var
    (Hybrid 3D-Var now operational at GMAO)

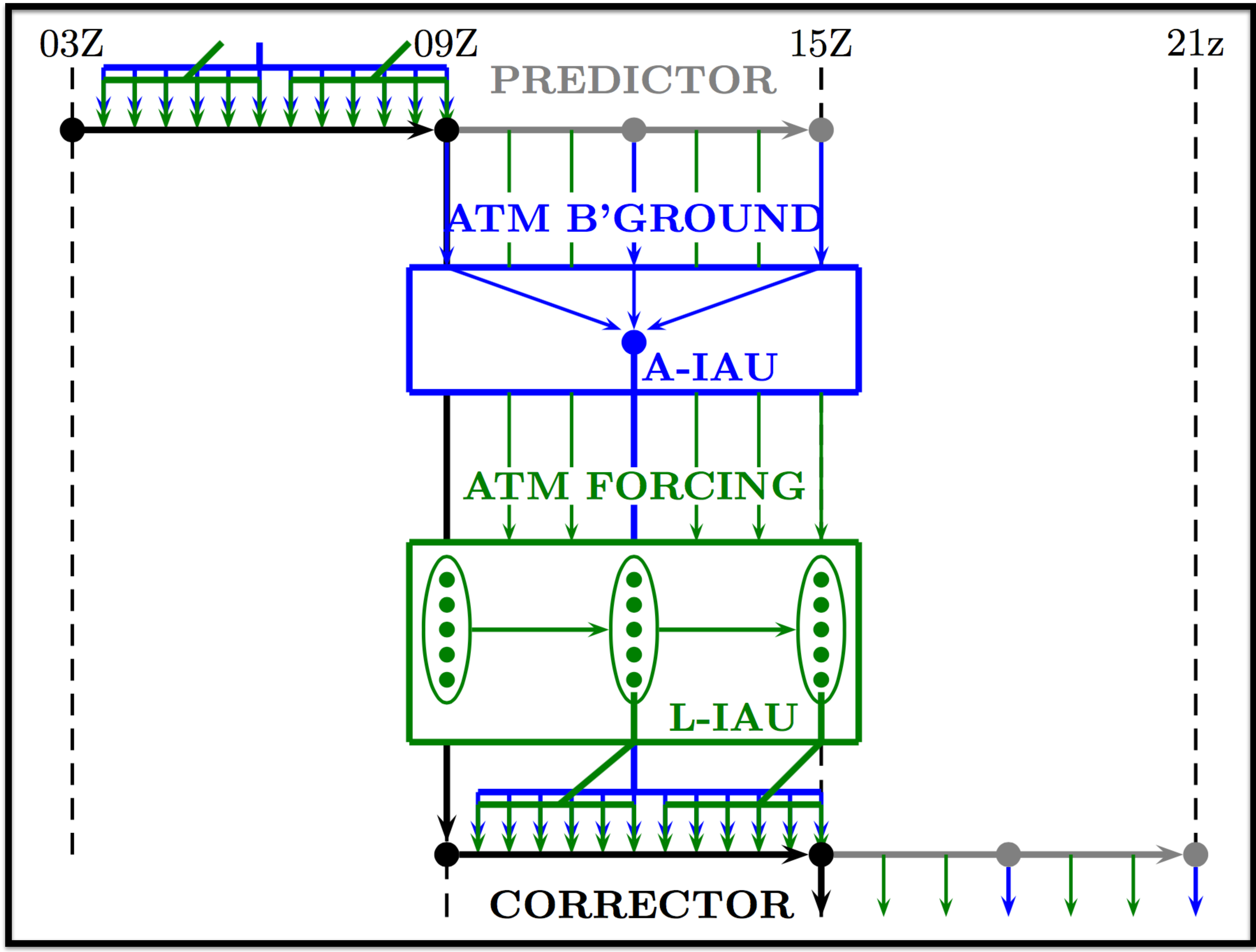
- Initial effort:
  - Soil moisture retrievals: ASCAT, LPRM AMSR-E (&AMSR2?)
  - Snow cover fraction (IMS), and snow depth (ground-based)
- Secondary effort:
  - LST &/or LH, direct insertion of cloud/radiation at land surface, vegetation, radiance assimilation

# Coupling in the GEOS-5 LA-DAS

**ADAS**

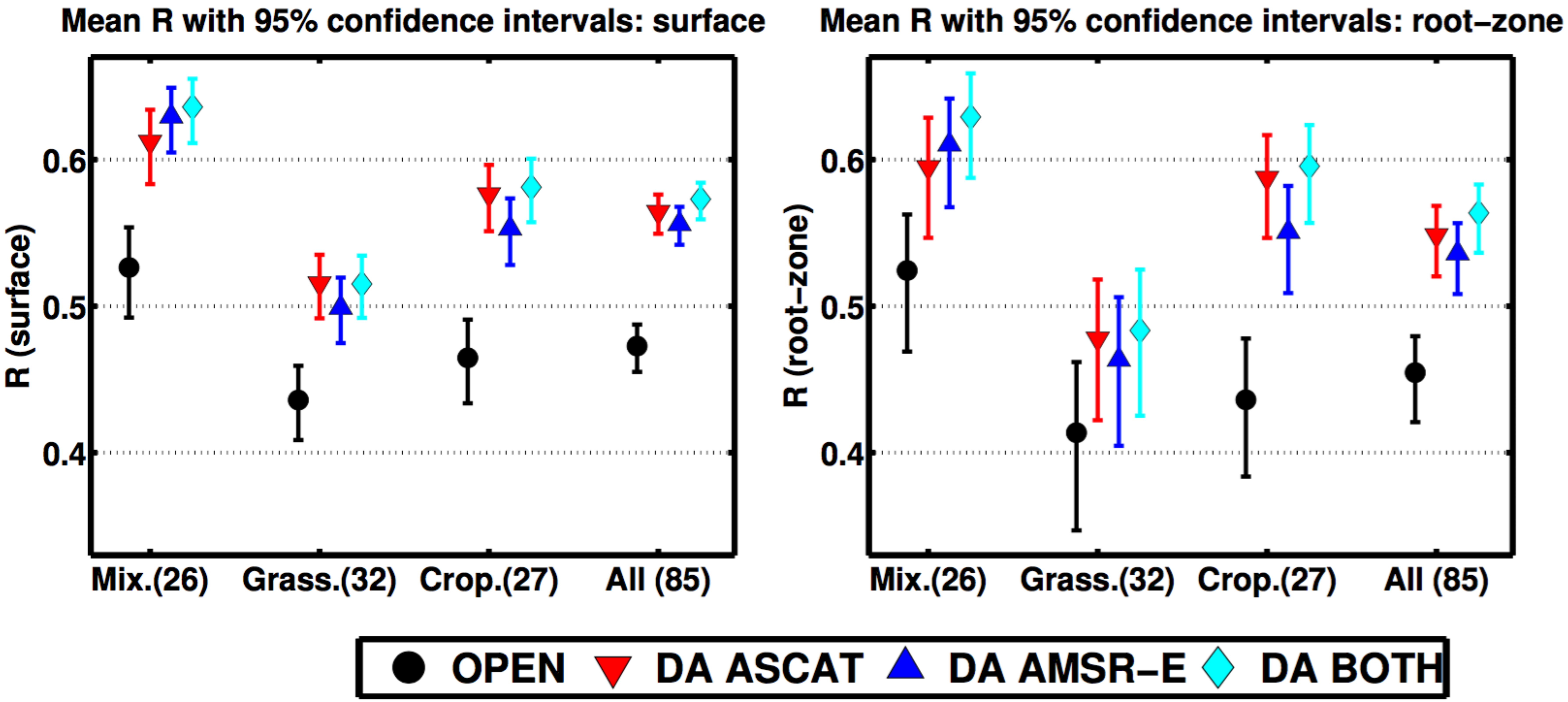



**LA-DAS**



# Soil Moisture Retrieval Assimilation (Offline)

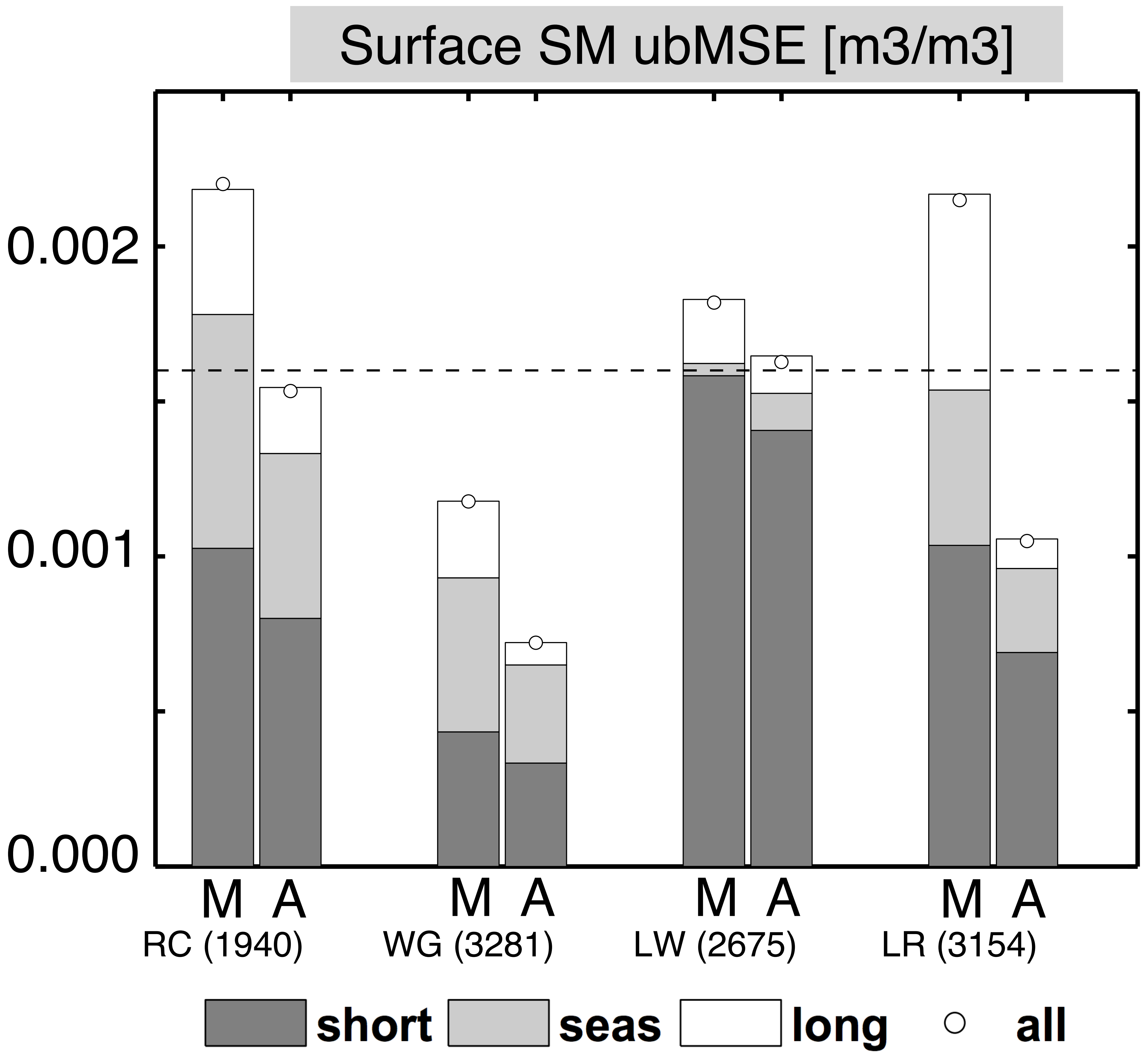
Correlation of daily anomalies from the seasonal cycle, at 85 sites




**Assimilation of 3.5 years of ASCAT and AMSR-E shows significant improvements, compared to ground-based observations from the Murrumbidgee (Aus) and SCAN/ SNOTEL (US) networks**

Draper et al, GRL 2012.

# Soil Moisture Retrieval Assimilation (Offline)




Assimilation of 9 years of AMSR-E soil moisture

**Ability to improve subseasonal soil moisture (short) is well established.**

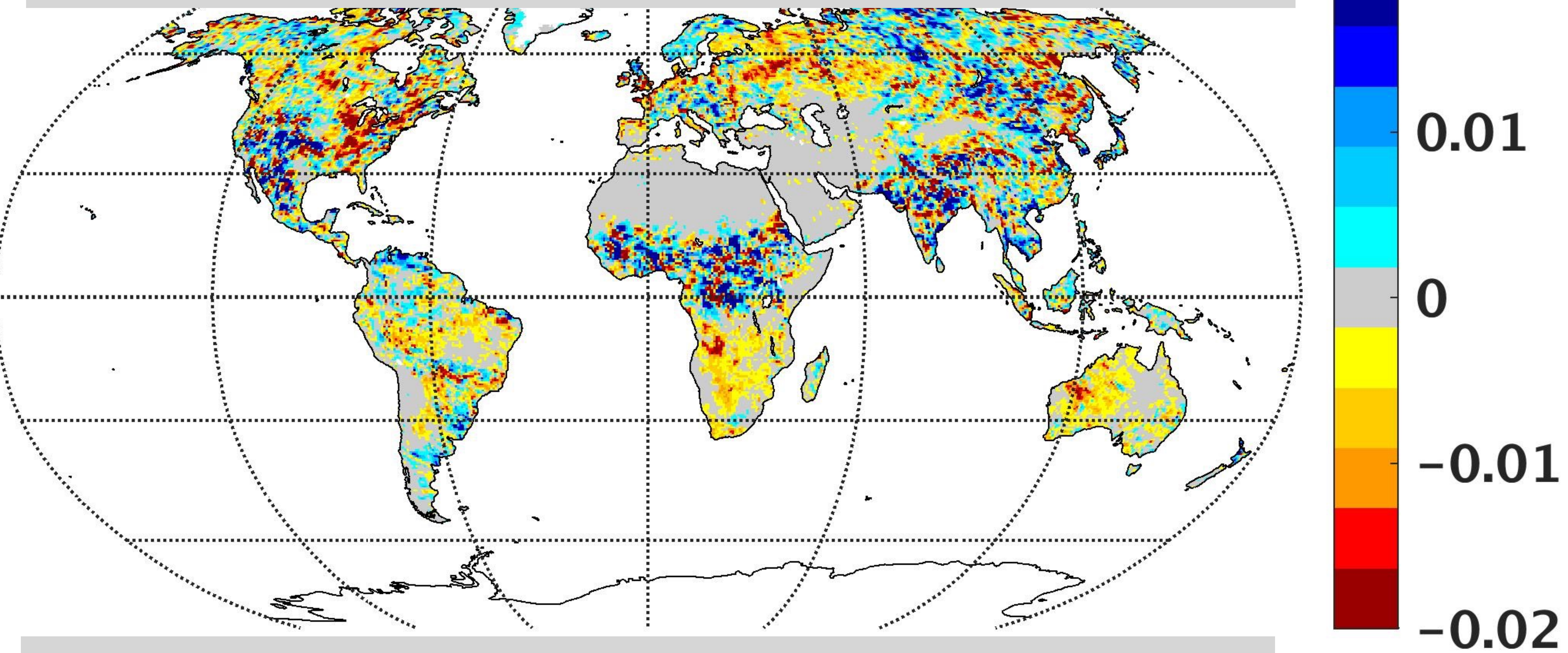
**Assimilating a sufficiently long data record can also improve interannual soil moisture (long).**

**For reanalysis, suggests improvements to important long term events, such as drought.**

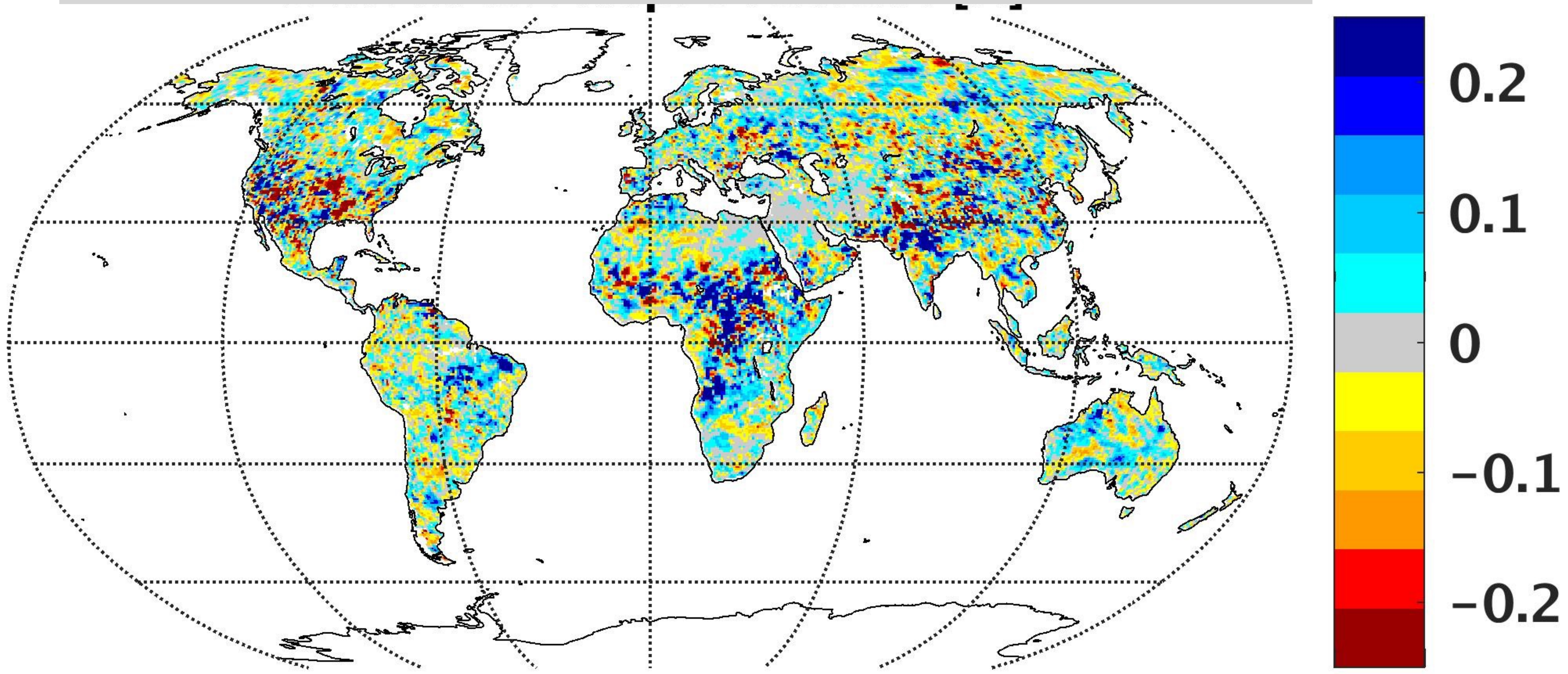
Draper and Reichle, HESS, 2015.

# Soil Moisture Retrieval Assimilation (Coupled)

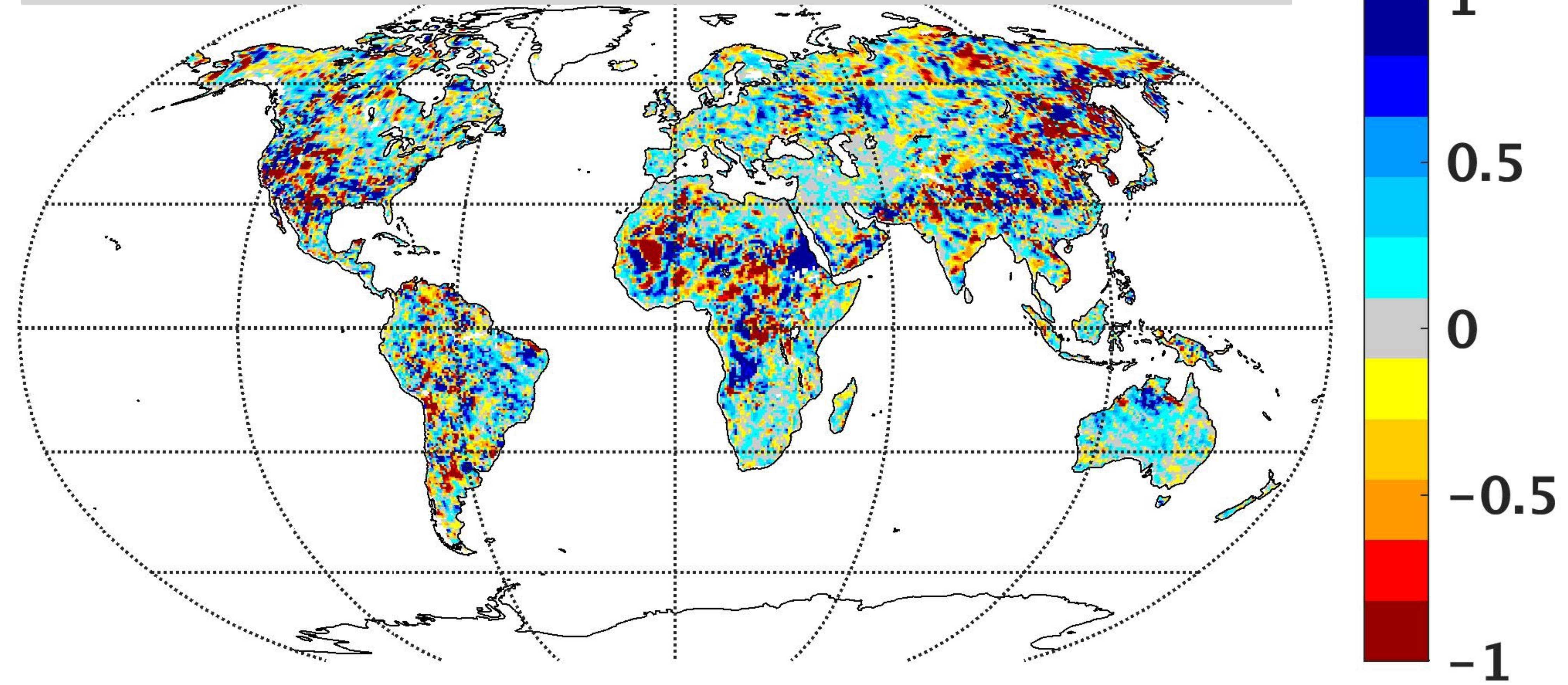
20140801: LA-DAS - ADAS Rootzone SM [m3/m3]




Delta $T^{2m}$ JAS, RMSE [K]
ADAS - LA-DAS




20140801: LA-DAS - ADAS $T^{2m}$ [K]



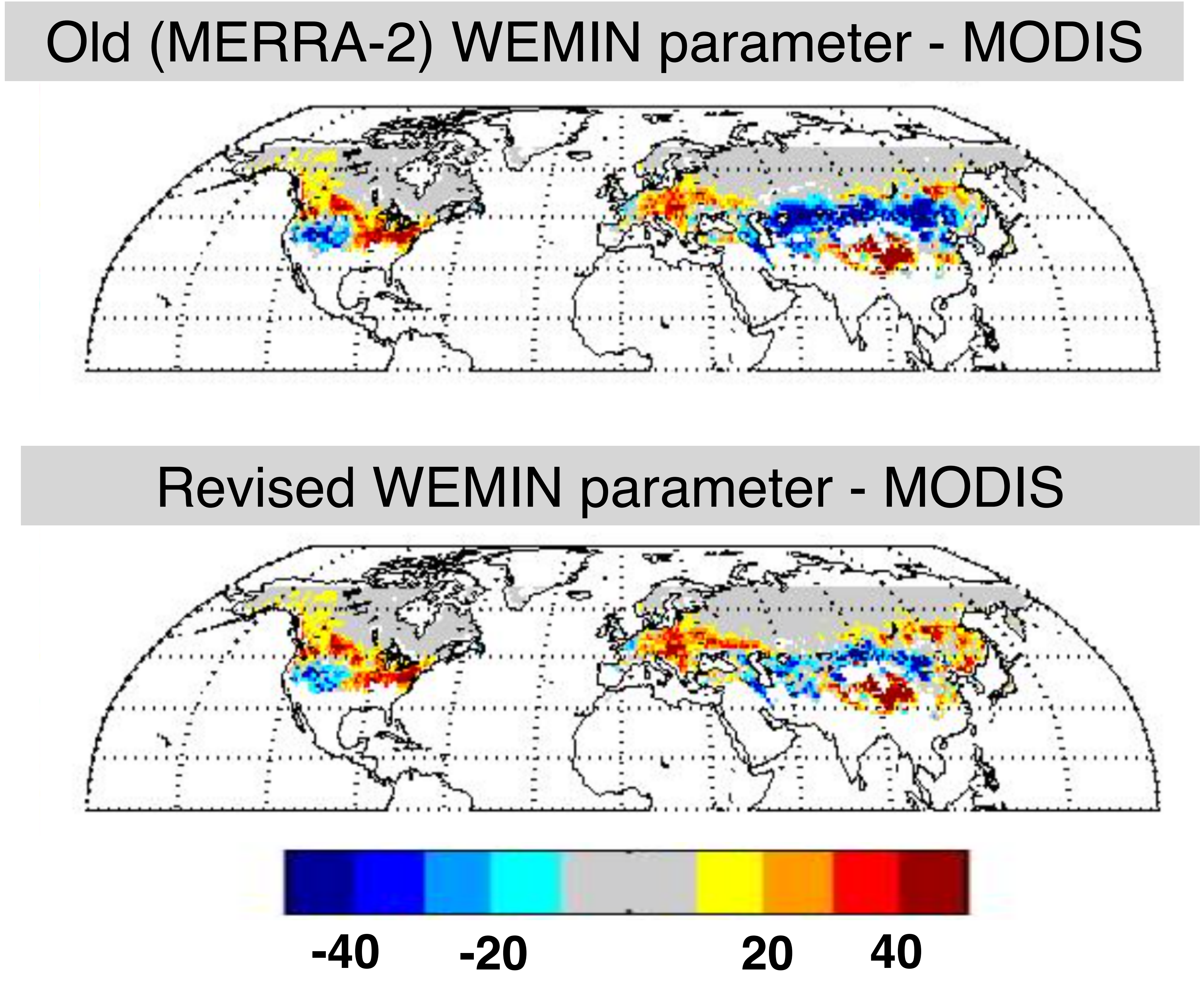

**Preliminary experiments:**
**Jun - Sep, 2014: LA-DAS assimilation of SMOS & ASCAT SM & MERRA-2 obs. (- observed precip. & aerosols).**
**Impact on T2m in regions sensitive to the soil moisture.**

# Comparison to MODIS Snow Cover Fraction

Comparison between MERRA-2 and MODIS snow cover fraction shows large regions of low bias in MERRA-2 (despite overestimated precip. in high lats.)

Before developing the snow assimilation, the MERRA-2 snow parameters have been refined to reduce the bias

GCM simulation, 15 yr mean Jan. snow cover fraction bias [%]



# Other Land Developments for IESA

- Additional modeling components, including (to date):
  - Interactive vegetation phenology (Catchment-CN)
  - Comprehensive river routing scheme

- Ongoing model improvements, including (to date):
  - Model updates to reduce run-off and LH biases
  - Extensive revision of land parameters and model updates, from SMAP project

- Model development often driven by DA / remotely sensed obs:
  (e.g., SMAP as above, MODIS SCF, GRACE TWS)

# Coupling to the Hybrid 3D-Var

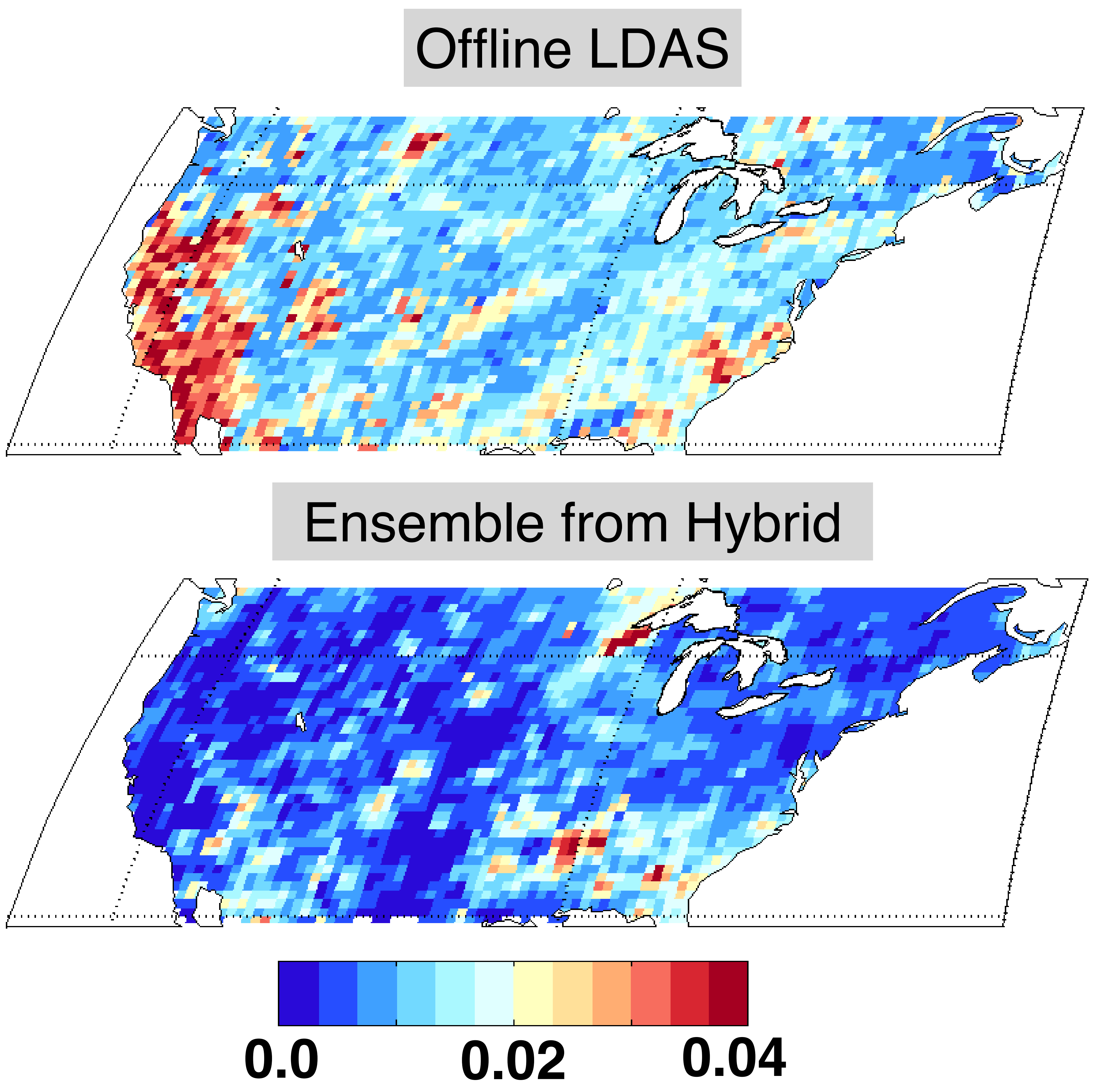
- The LA-DAS is currently the EnKF LDAS coupled to the GEOS-5 3D-Var ADAS
  - Within the LDAS, the land ensemble is created by statistically perturbing atmospheric forcing states and land surface states

- The Hybrid 3D-Var is now operational at GMAO
  - Ensemble used to improve the 3D-Var background error variances
  - 32 member coarse resolution (at 1°) ensemble, no land perturbations applied

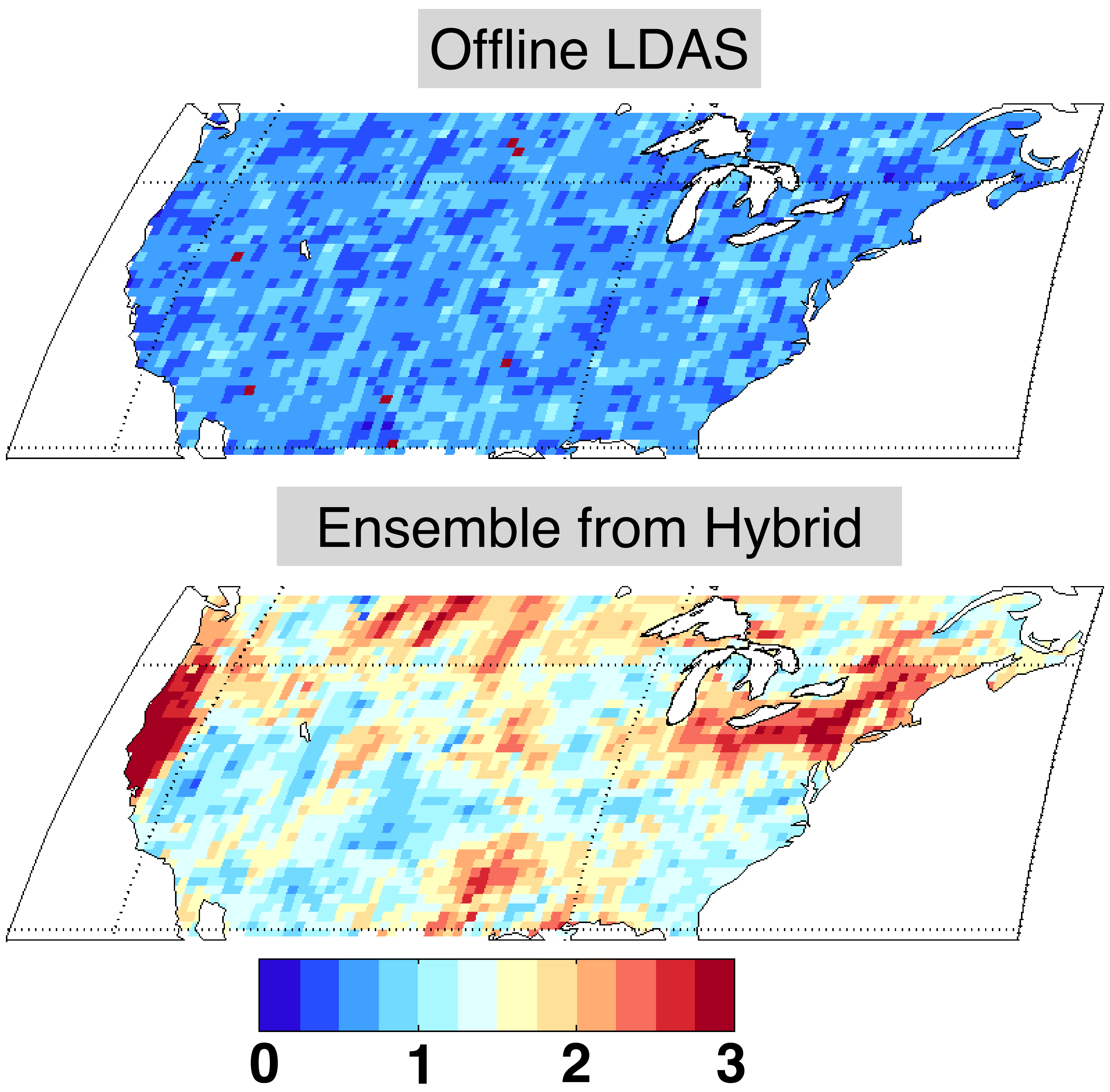
- First step to coupling the land EnKF and Hybrid 3D-Var: Compare ADAS and LDAS ensembles

# Hybrid 3D-Var and LDAS Ensemble

**Surface SM ens. stdev [m3/m3]**



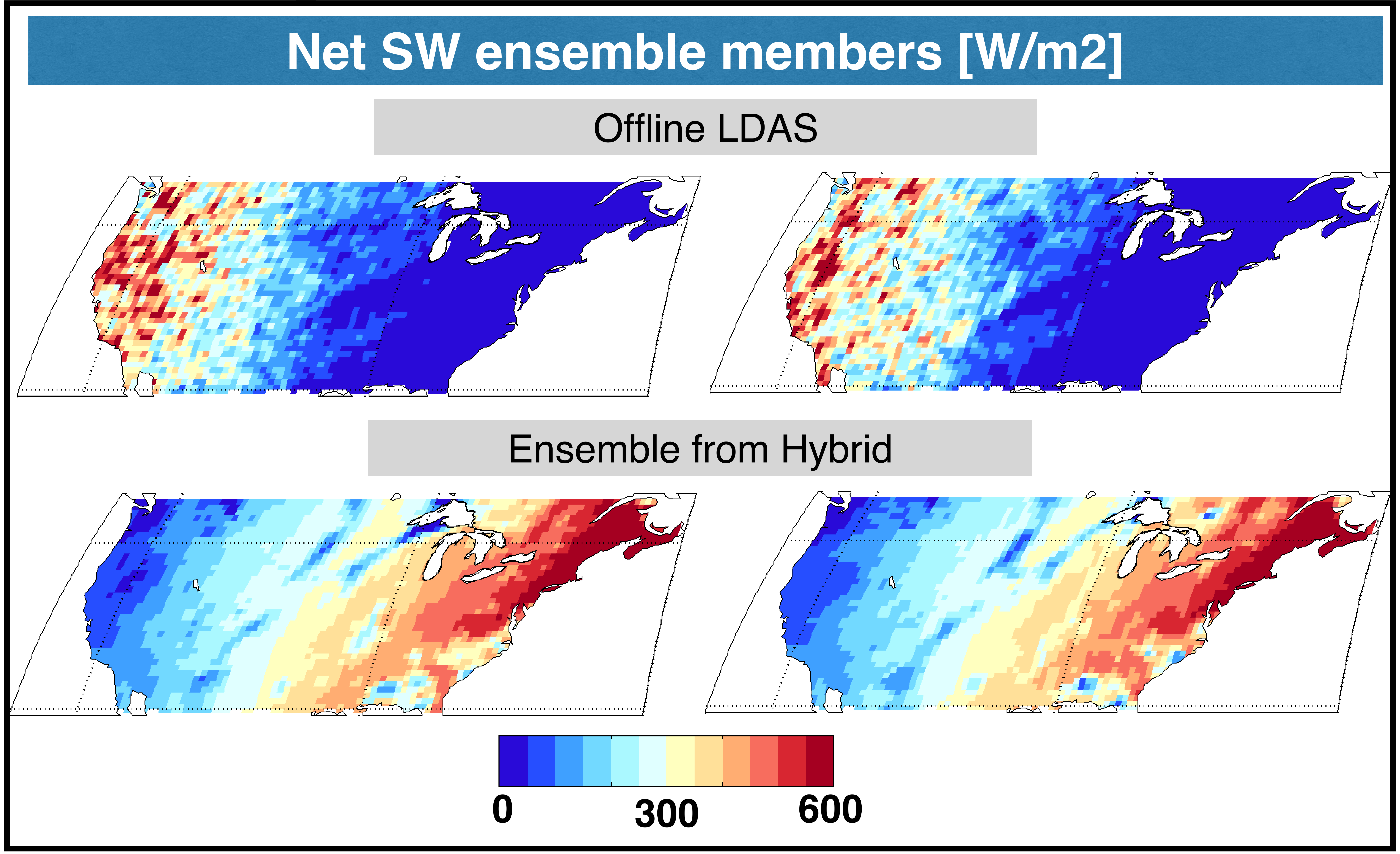

**Surface SM ens. perturbation e-folding scale [°]**

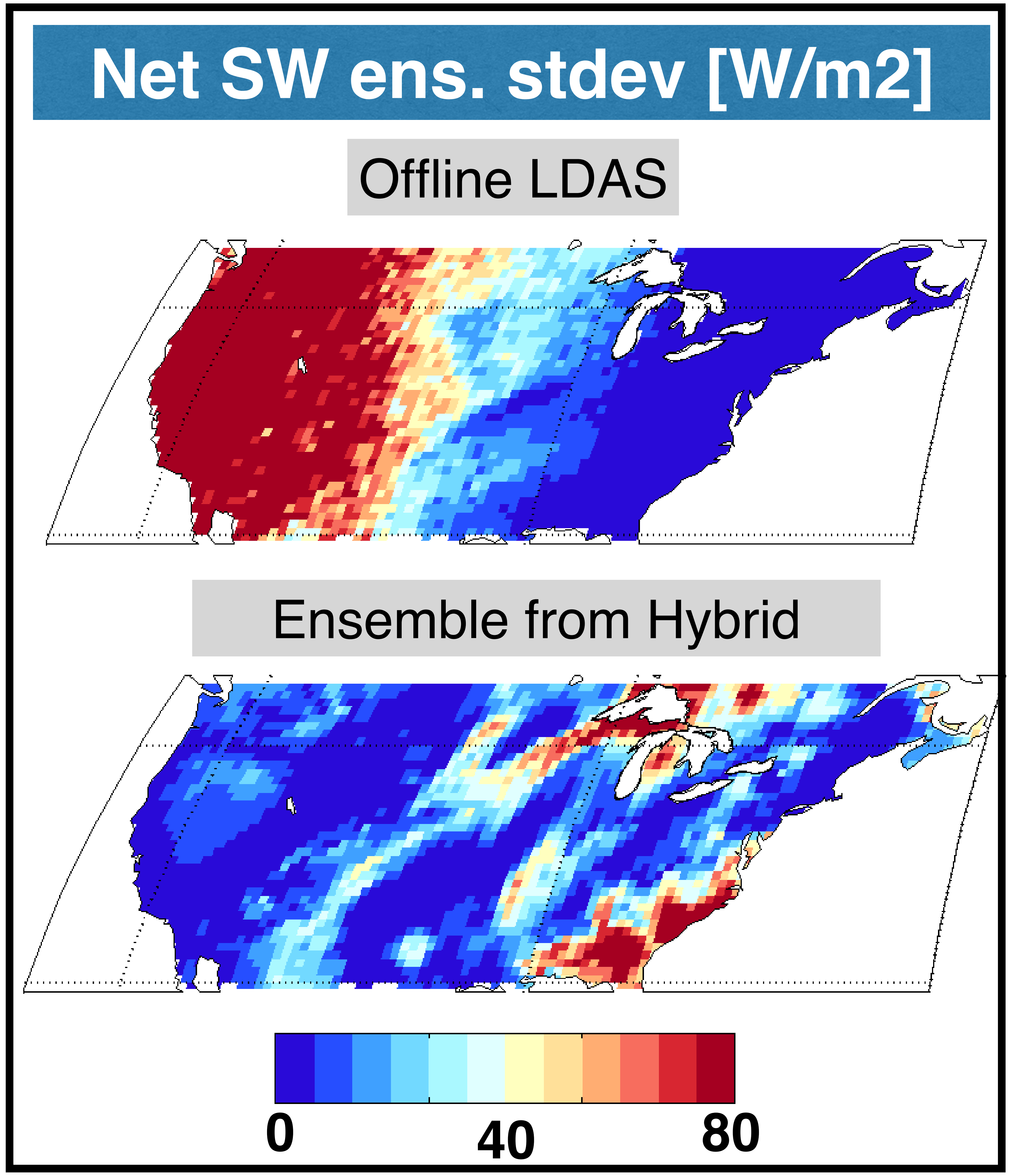



**Hybrid has insufficient ensemble spread (no land perts.).**

**Hybrid has potential to capture 'errors of the day'.**

# Hybrid 3D-Var and LDAS Ensemble




**Hybrid ensemble members more realistic than offline method.**

# IESA Summary

- Future GMAO IESA will include LDAS updating of land surface states (starting with soil moisture and snow), and additional modeling components (starting with vegetation phenology and river routing)
- Intent is to have comprehensive and realistic representation of land surface states and fluxes
  - However (!), improved land states do not necessarily lead to improved atmosphere, success will require strong focus on model development
  - LDAS has been a strong driver of model development at GMAO
- LDAS EnKF and Hybrid 3D-Var not yet coupled, but potential for the LDAS to benefit from the ensemble from the hybrid system

# Thanks for listening

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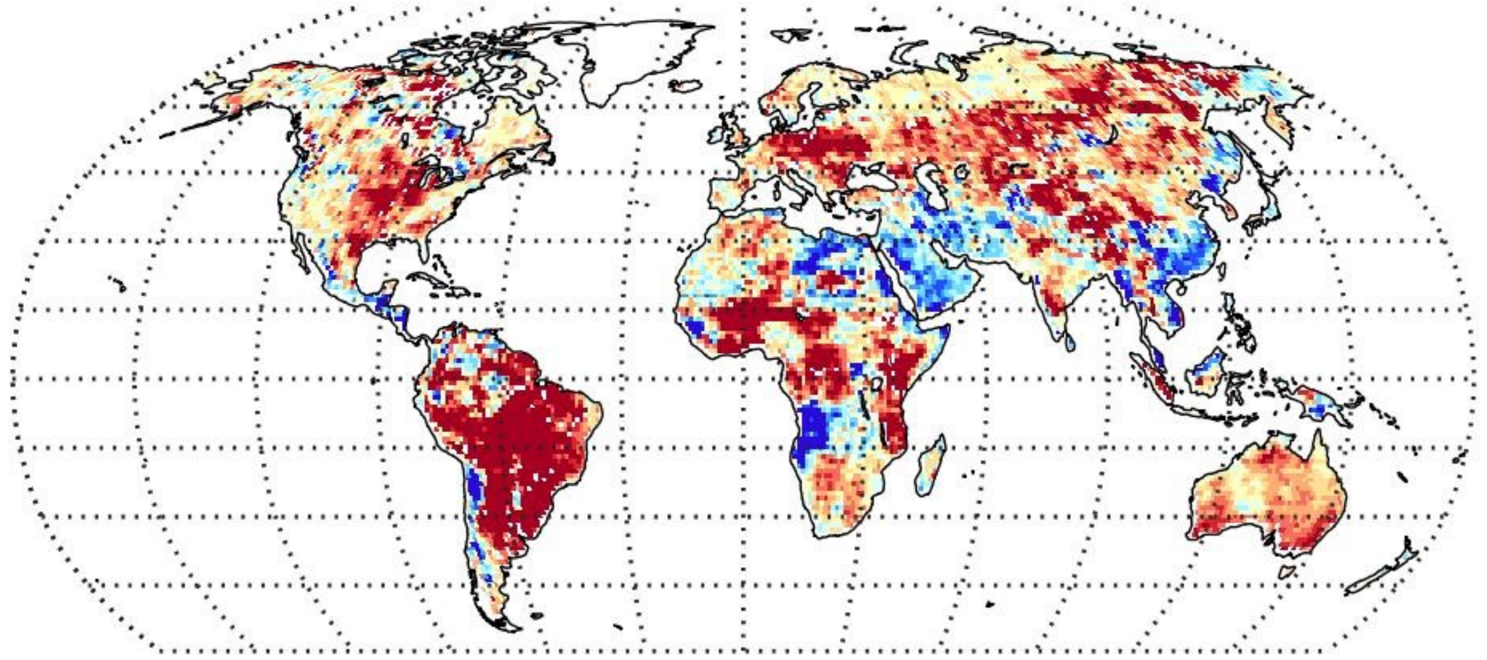
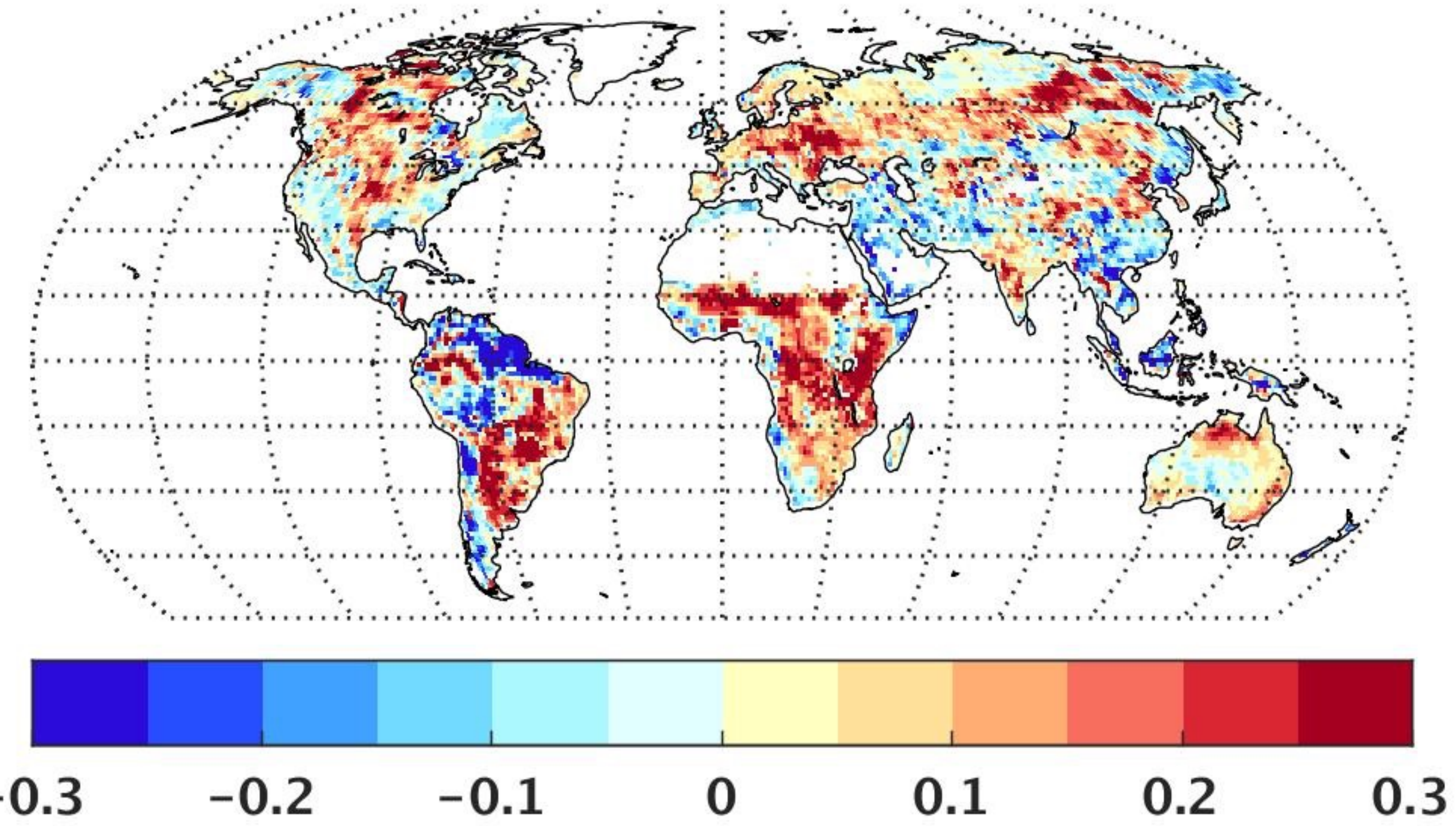
# LH and $T^{2m}$ improvements

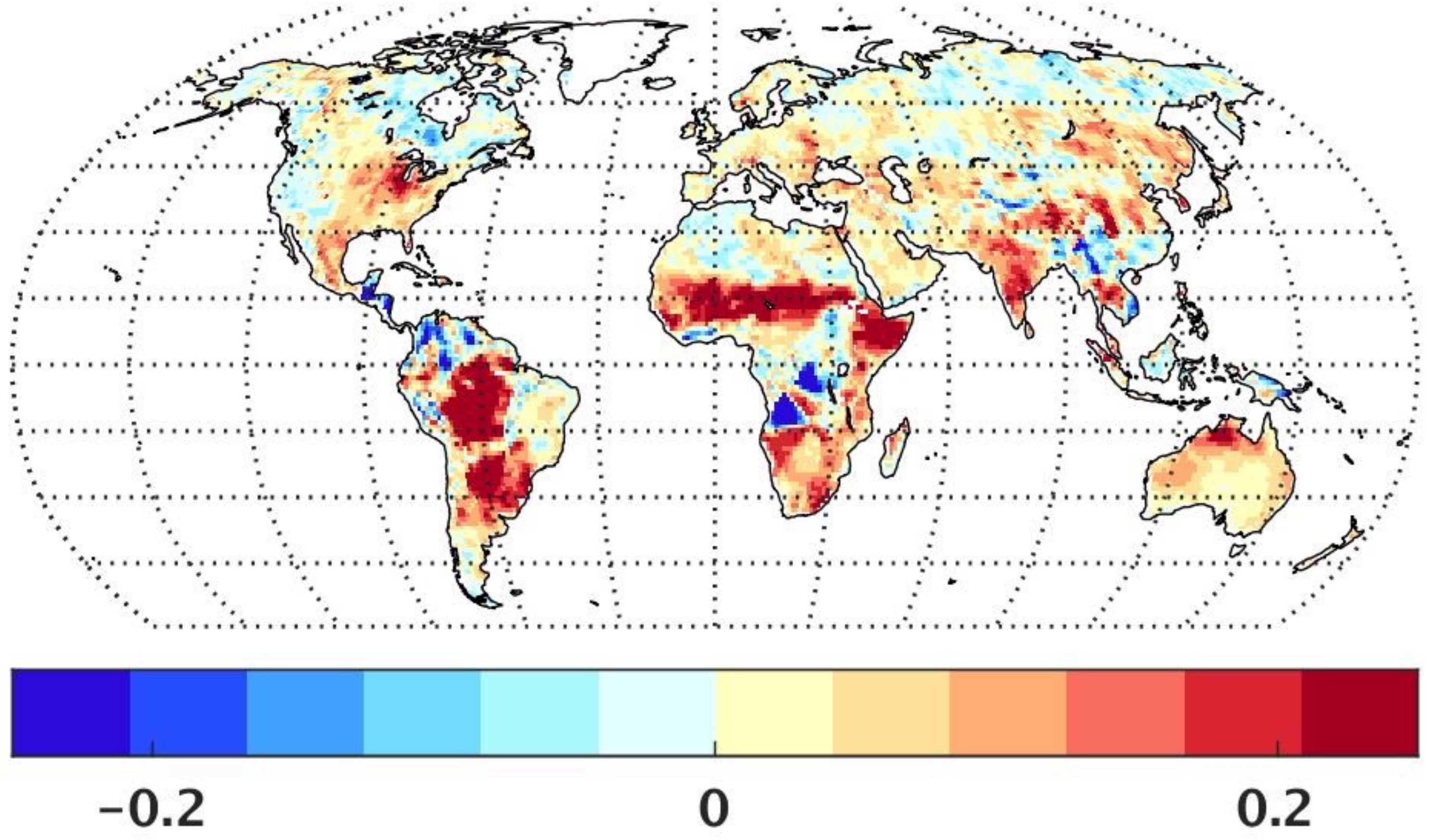
Delta R, v. GLEAM LH [-]
MERRA-2 - MERRA



Delta R, v. Fluxnet-MTE [-]
MERRA-2 - MERRA




Delta R, v. CRU 3.22 $T^{2m}$ [-]
MERRA-2 - MERRA




**Improved $T^{2m}$ anomalies, where $T^{2m}$ is sensitive to precip seen by model land surface.**

**LH anomalies (compared to GLEAM or Fluxnet-MTE) show improvements in same regions.**

# Land Model Parameter Changes

| Parameter or Scheme | Units | MERRA | MERRA- | MERRA-2 |
|---|---|---|---|---|
| Rainfall interception parameters | - | Old | New | |
| Min. SWE in snow-covered area fraction | kg/m2 | 13 | 26 | |
| Max. depth of uppermost snow layer | m | 0.05 | 0.08 | |
| Minimum soil depth | m | 1.0 | | 1.34 |
| Depth-to-bedrock interpolation | - | No | | Yes |
| Soil hydraulic conductivity vertical | 1/m | 2.17 | | 1.0 |
| Surface turbulence scheme | - | Louis | | Helfand |

Reichle et al, 2011, doi:10.1175/JCLI-D-10-05033.1
De Lannoy et al, 2014, doi:10.1002/2014MS000330