Assimilation of GRACE terrestrial water storage estimates in the North American Land Data Assimilation System

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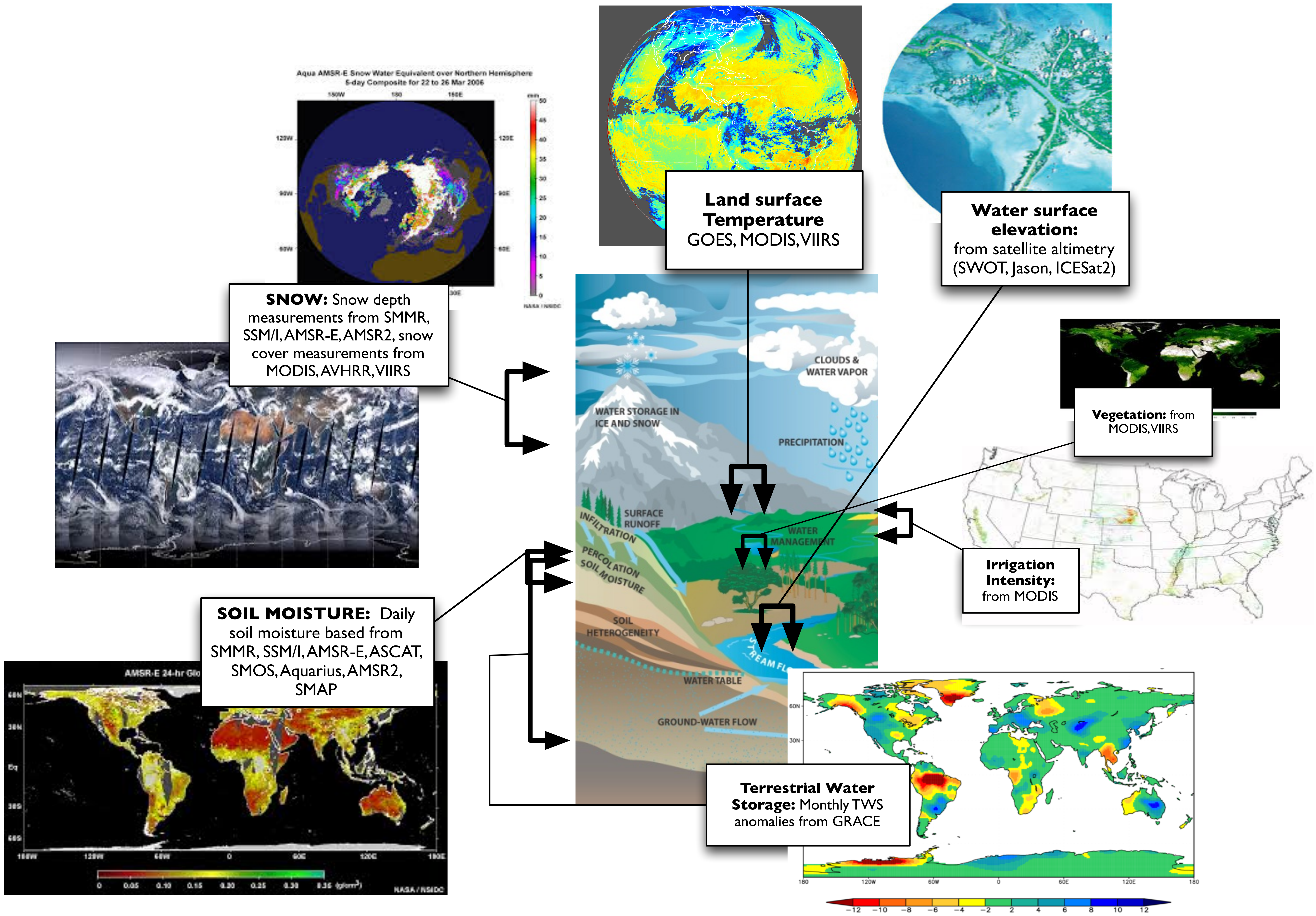
Kumar et al. (2015), "Assimilation of GRACE terrestrial water storage estimates in the North American Land Data Assimilation System, *J. Hydromet., in review*

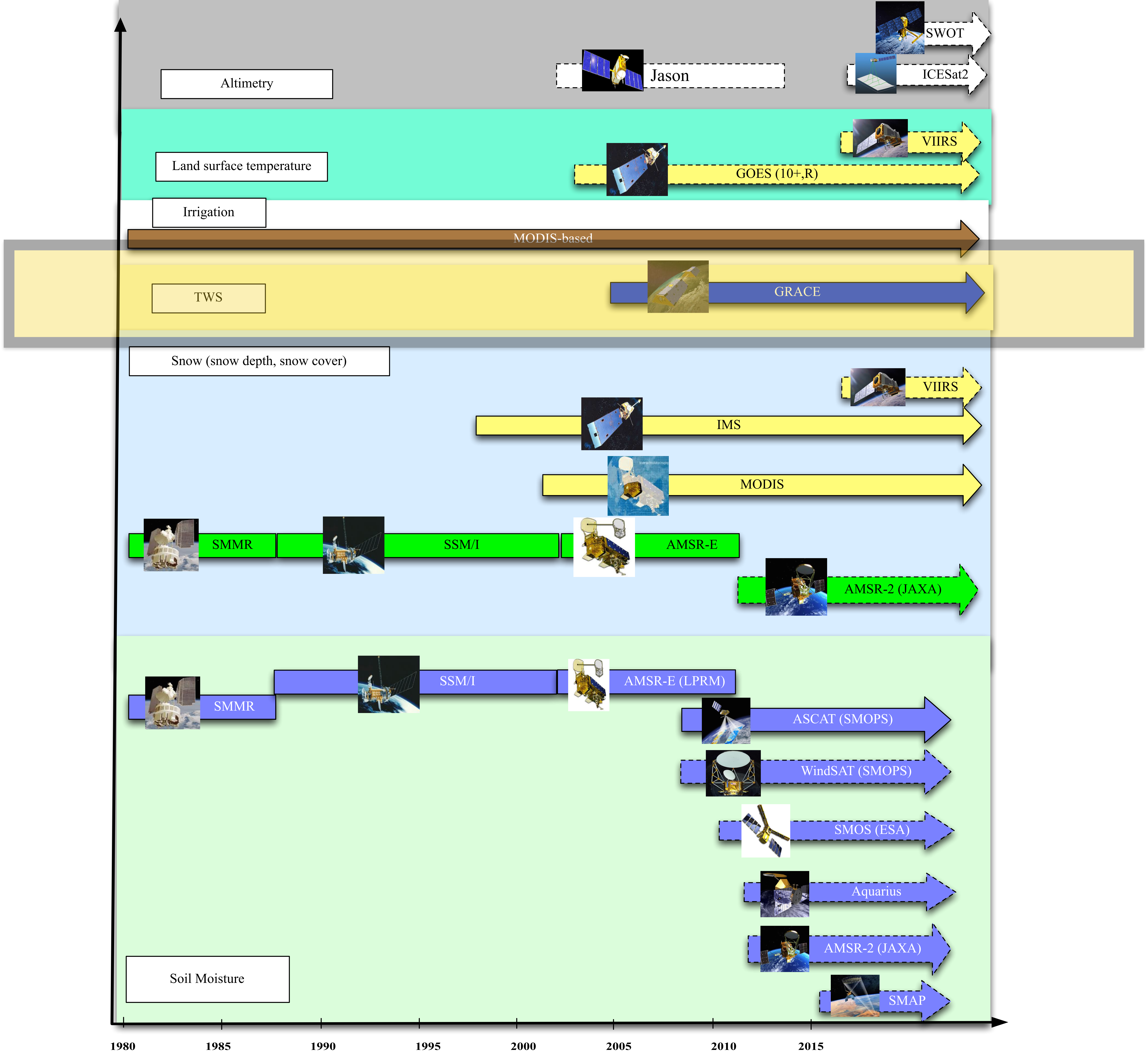
Motivation

- A key focus of the new phase of NLDAS is to include the assimilation of remotely sensed satellite measurements, including soil moisture, snow, terrestrial water storage, land surface temperature, vegetation, altimetry.

- LIS includes the capabilities for the concurrent, multivariate assimilation of these measurements

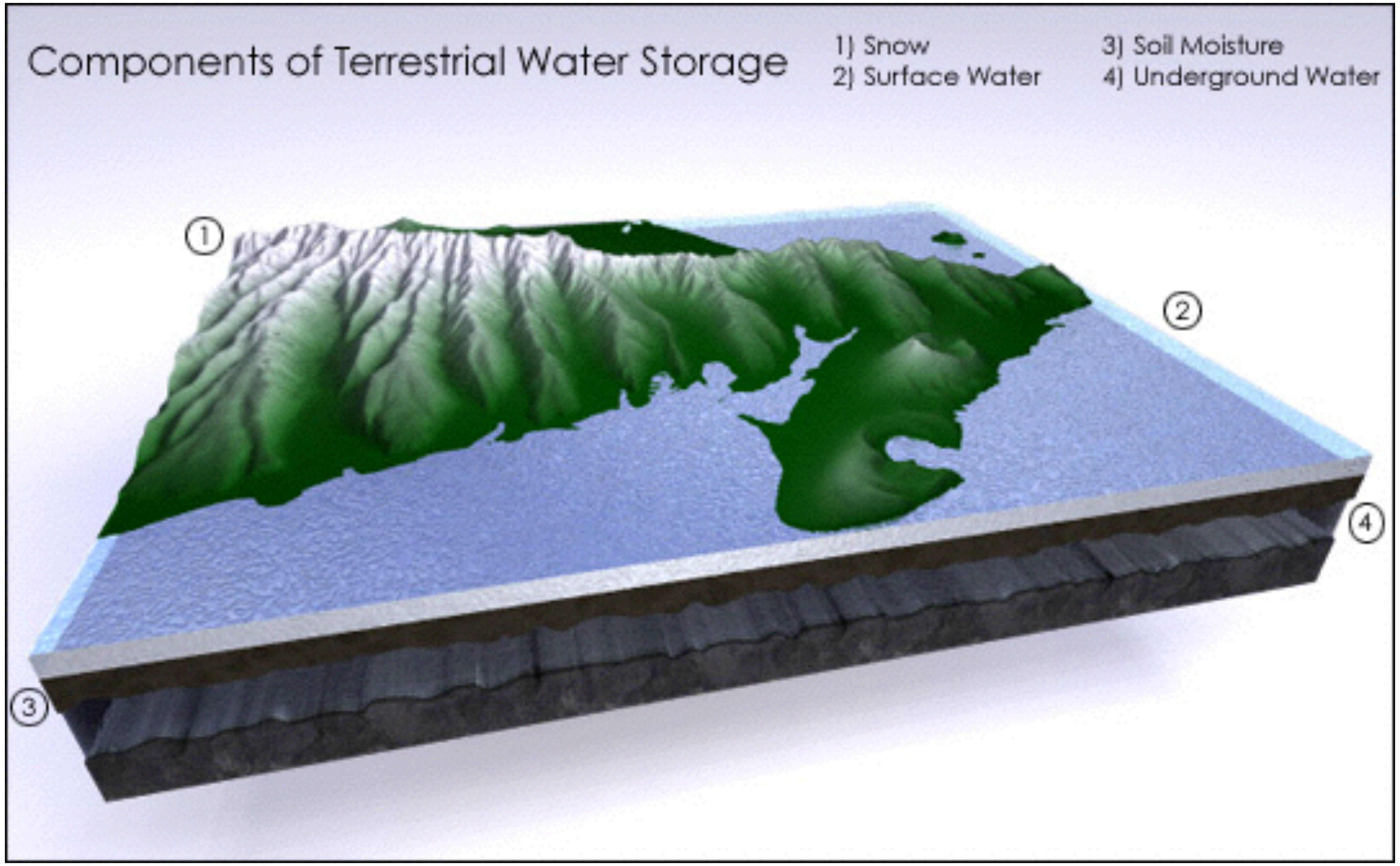


NLDAS relevant remote sensing measurements



Terrestrial Water Storage (TWS)

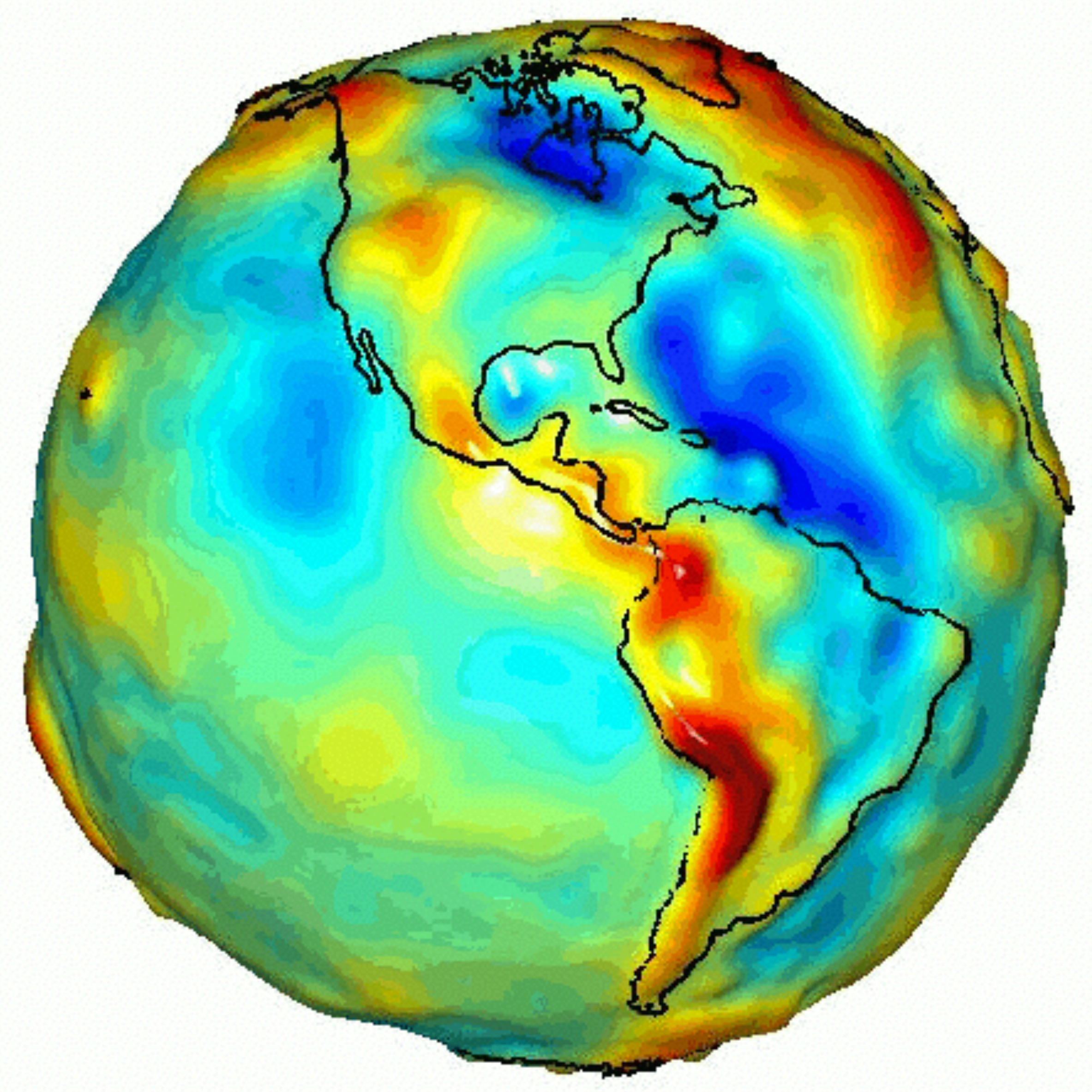
TWS = Snow + Surface water + Soil Moisture + Groundwater



- In CLSM, the simulated TWS is calculated by subtracting the catchment deficit from the maximum available pore space of the catchment and by adding the surface and root zone excess terms
- Ground water storage = TWS - root zone soil moisture - SWE - canopy water storage

source: earthobservatory.nasa.gov

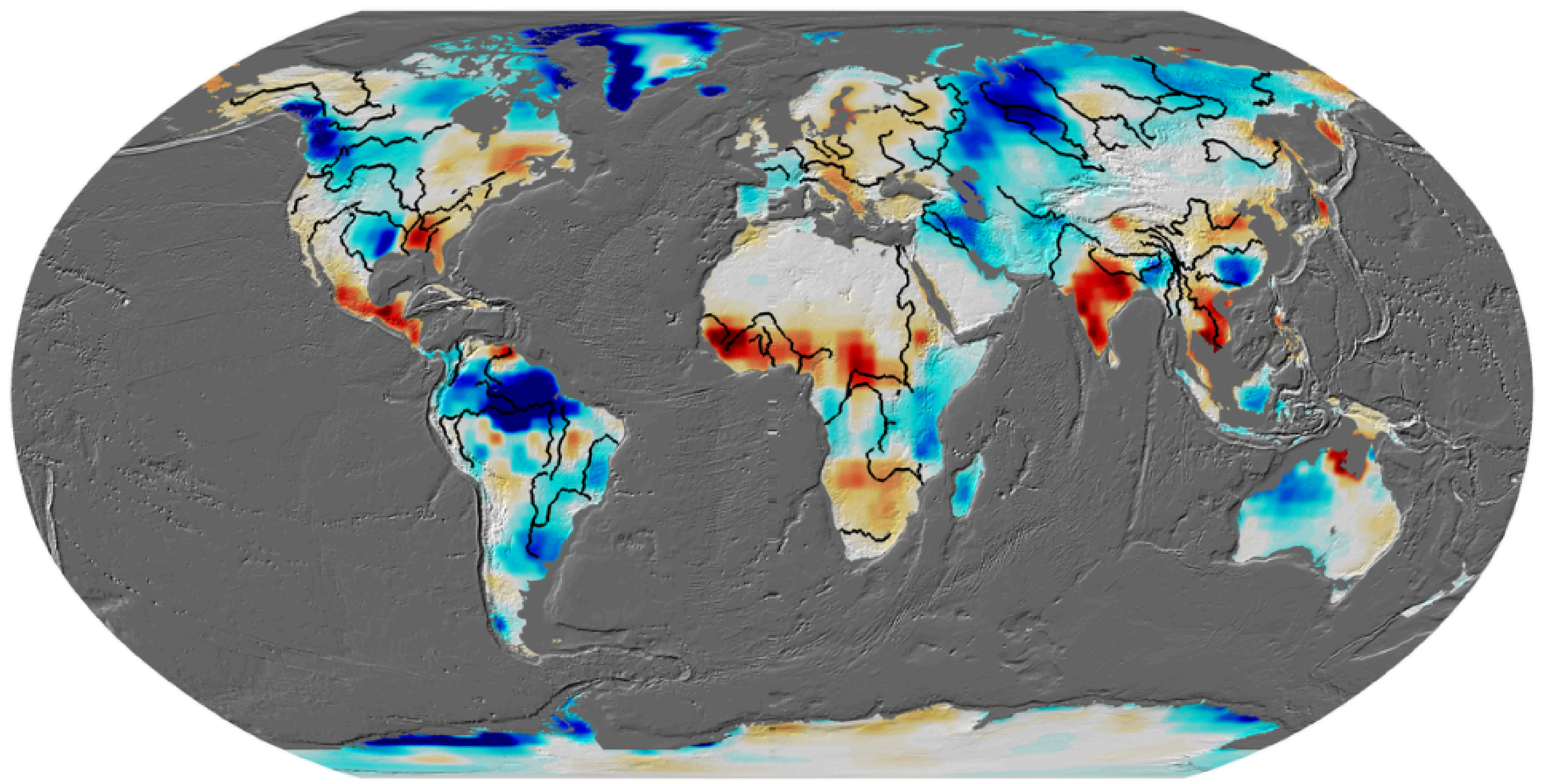
GRACE

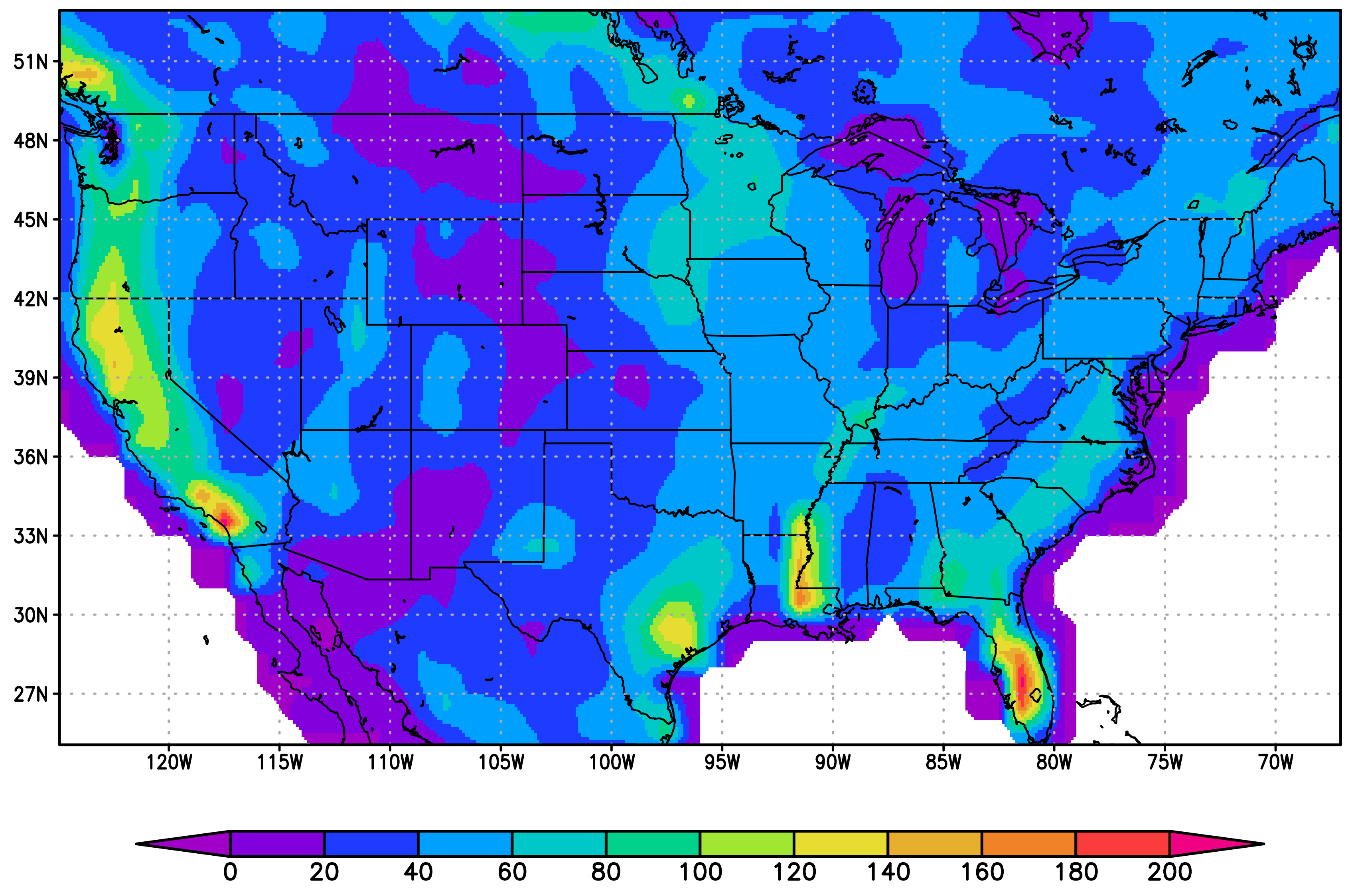


- GRACE - Gravity Recovery and Climate Experiment (launched in 2002) satellite provides measurements of Earth's gravity field anomalies
- Measurements are NOT derived from electromagnetic waves: GRACE uses a microwave ranging system to measure changes in the speed and distance between two identical spacecrafts ("Tom" and "Jerry") flying in a polar orbit about 220 km apart, 500 km above Earth.
- The twin satellites sense minute variations in Earth's gravitational pull. By combining the data of distance between the satellites and GPS measurements of the position of satellites, a detailed map of Gravity anomalies can be constructed
- Estimates of terrestrial water storage changes can be estimated from GRACE measurements after removing the influence of atmospheric and oceanic circulations and impacts of major geophysical events

GRACE data

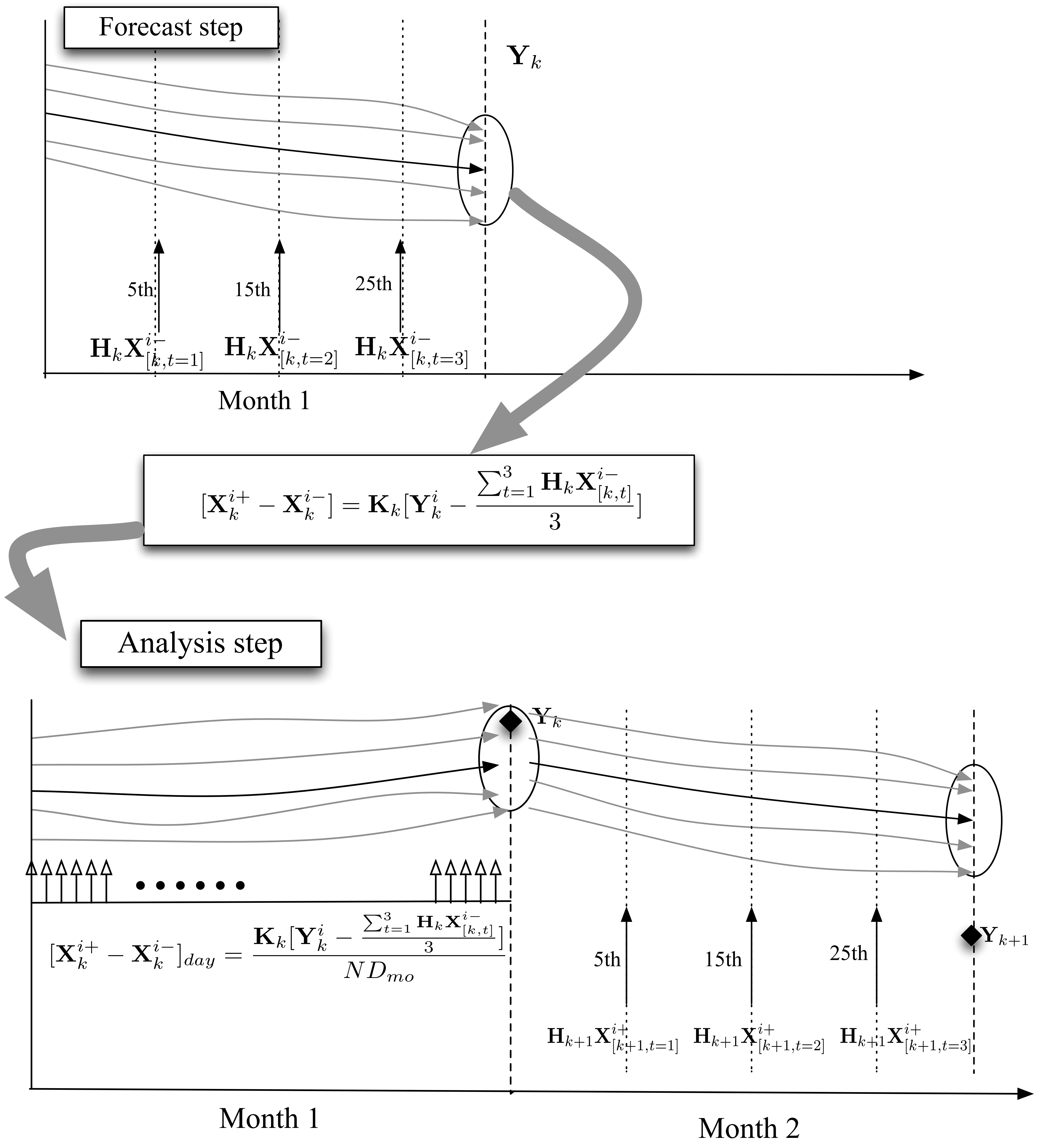
- Standard GRACE products are at 1degree spatial resolution at monthly time scales and provide estimates of TWS anomalies (Tellus RL05 spherical harmonics solution used in this study)
- A number of filtering procedures are applied to reduce measurement errors and to convert data from the spectral domain to geographical coordinates using a Gaussian filter
- Gaussian smoothing means that the TWS estimates and errors are horizontally correlated
- Previous studies employed basin-scale assimilation, which simplifies the handling of spatially correlated errors, but creates artificial boundaries in the assimilation estimates.
- **This study employs gridded GRACE estimates in assimilation, without requiring preprocessing to subjectively defined basins**
- **The study also employs the spatially distributed, temporally static error estimates, instead of uniform error assumptions**





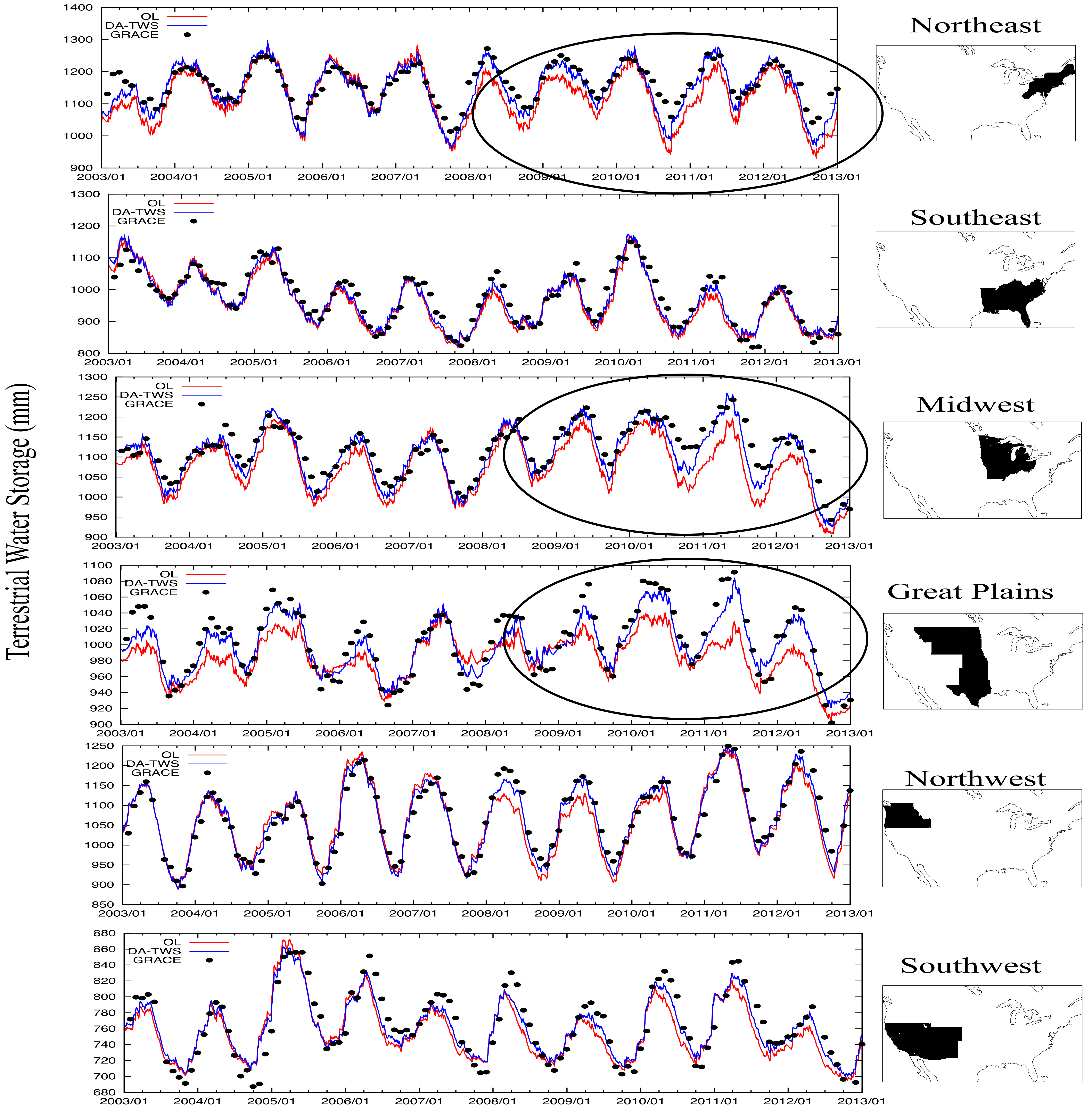
Data Assimilation Method

- GRACE observations are time averaged TWS anomalies and reported at monthly intervals.
- 3-dimensional Ensemble Kalman Smoother (EnKS) temporally disaggregates the observations into a finer, daily scale.
- Products are assimilated with a horizontal error correlation scale of ~ 300 km



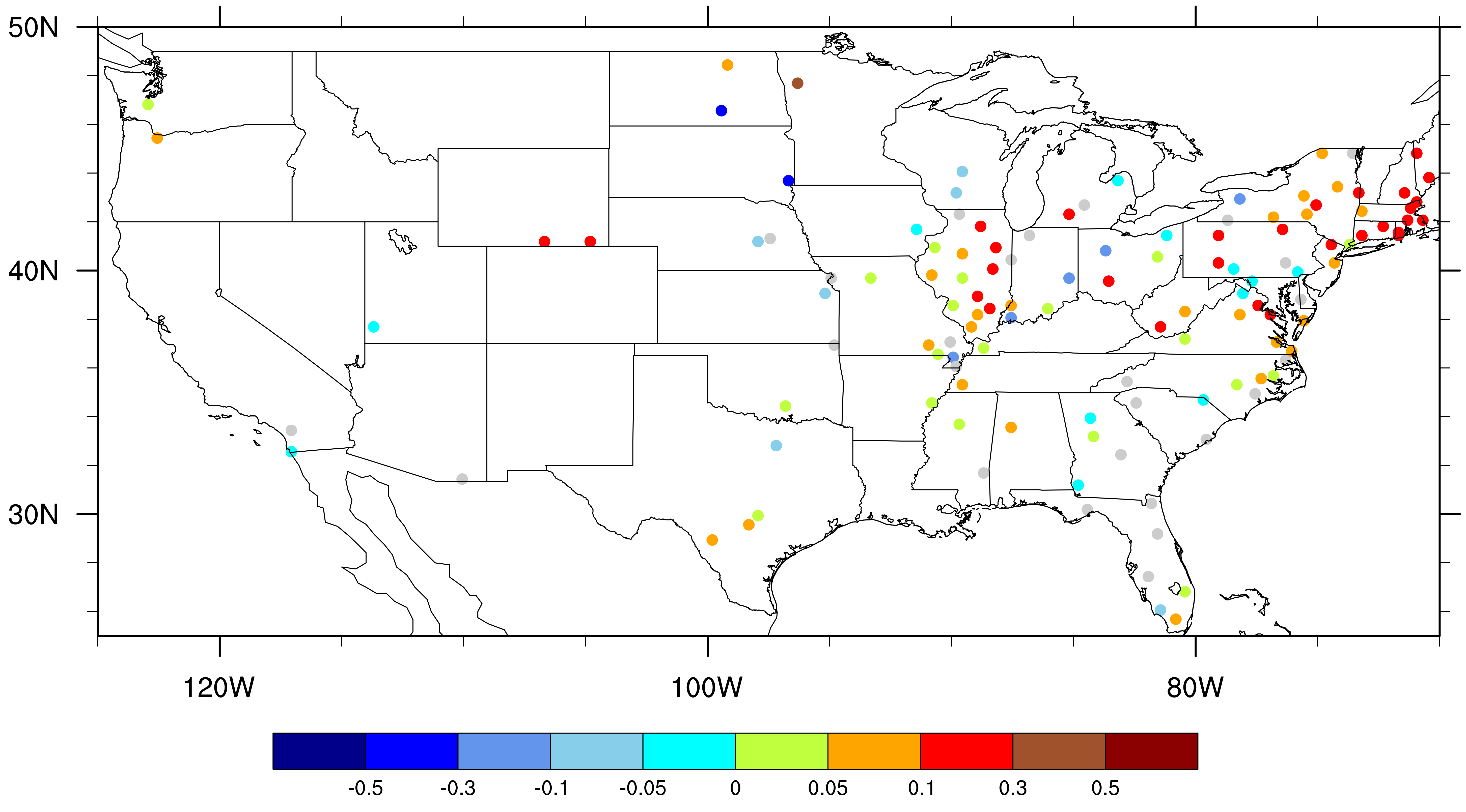
Results:TWS

- GRACE DA leads to changes in the interannual variability of TWS estimates
- Influence of DA is more in the later years and over Northeast, Midwest, Great plains and Southwest
- Unique information in GRACE observations seems to inform the model even with high quality NLDAS precip.



Results: Groundwater

- Compared to quality controlled USGS groundwater well data
- Anomaly R differences (DA - OL); warm colors indicate improvements from DA, cool colors indicate degradations
- Systematic improvements in Upper Mississippi, parts of Northeast; Degradations in the Missouri basin stations.



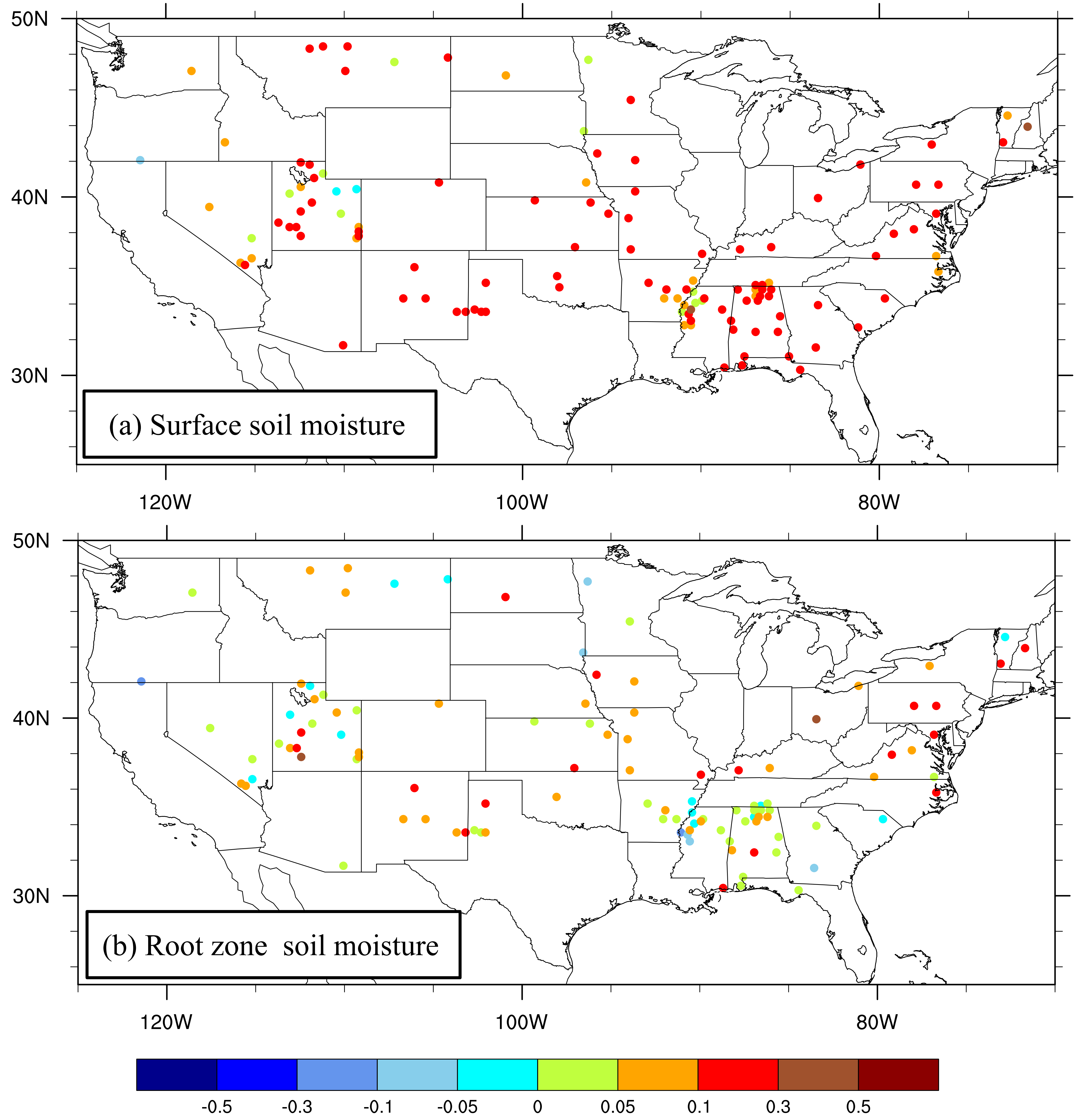
	OL	DA
Anomaly R	0.64+/- 0.02	**0.69 +/- 0.02**

Results: Soil Moisture

- Compared to quality controlled SCAN and ARS measurements

- Systematic, significant improvements in surface and root zone soil moisture skills

Anomaly R	OL	DA
Surface soil moisture	0.44+/- 0.02	**0.58 +/- 0.02**
Root zone soil moisture	0.48+/- 0.02	**0.54+/- 0.02**

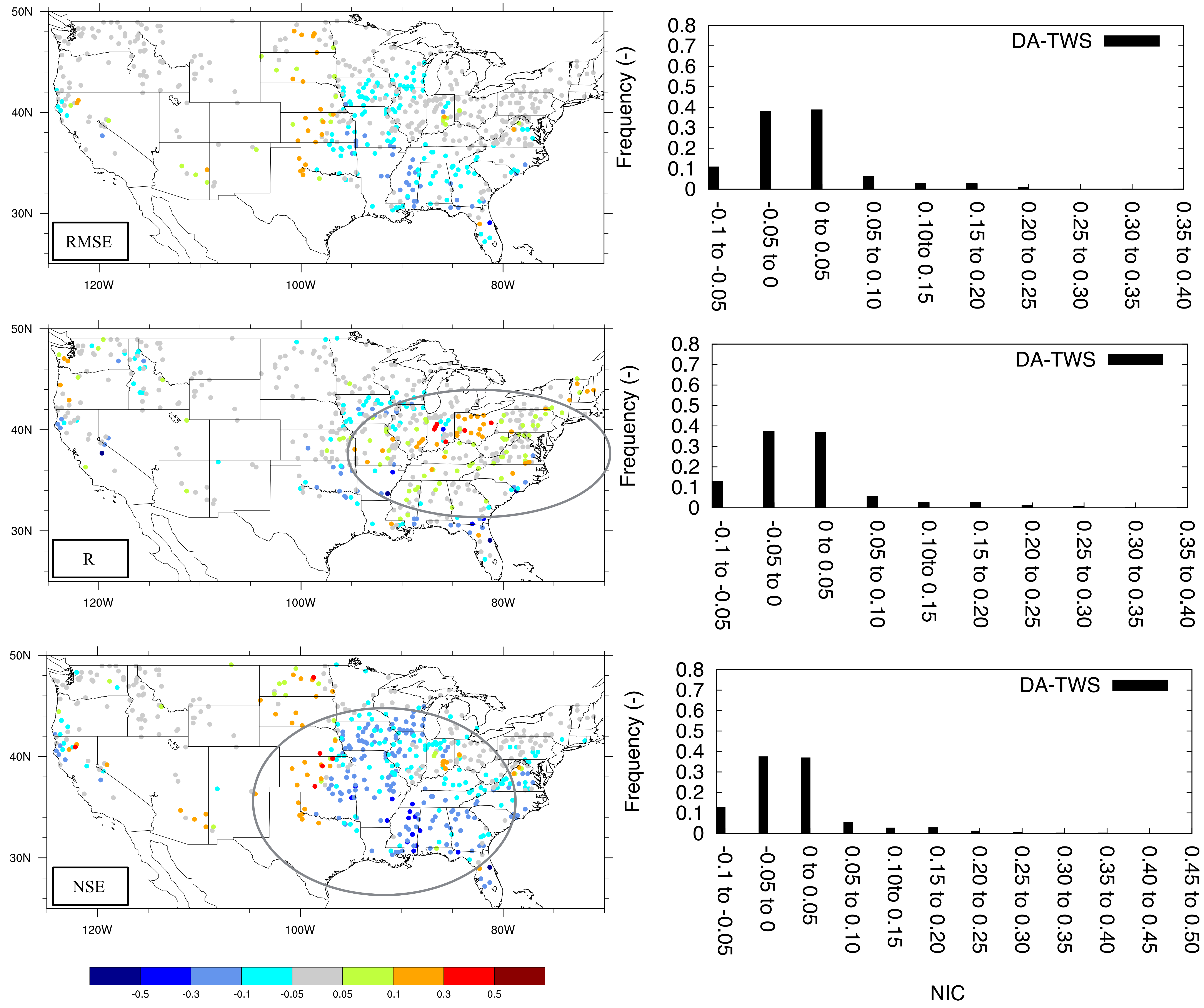


Results: Streamflow

- Compared to USGS daily streamflow data, over unregulated outlets
- Impacts from DA shown as normalized indices (NIC) for RMSE, R and NSE

$$NIC_R = \frac{(R_a - R_o)}{(1 - R_o)}$$

- NIC > 0 implies DA improves; NIC <0 implies DA degrades
- Impact from GRACE DA on streamflow estimates are small

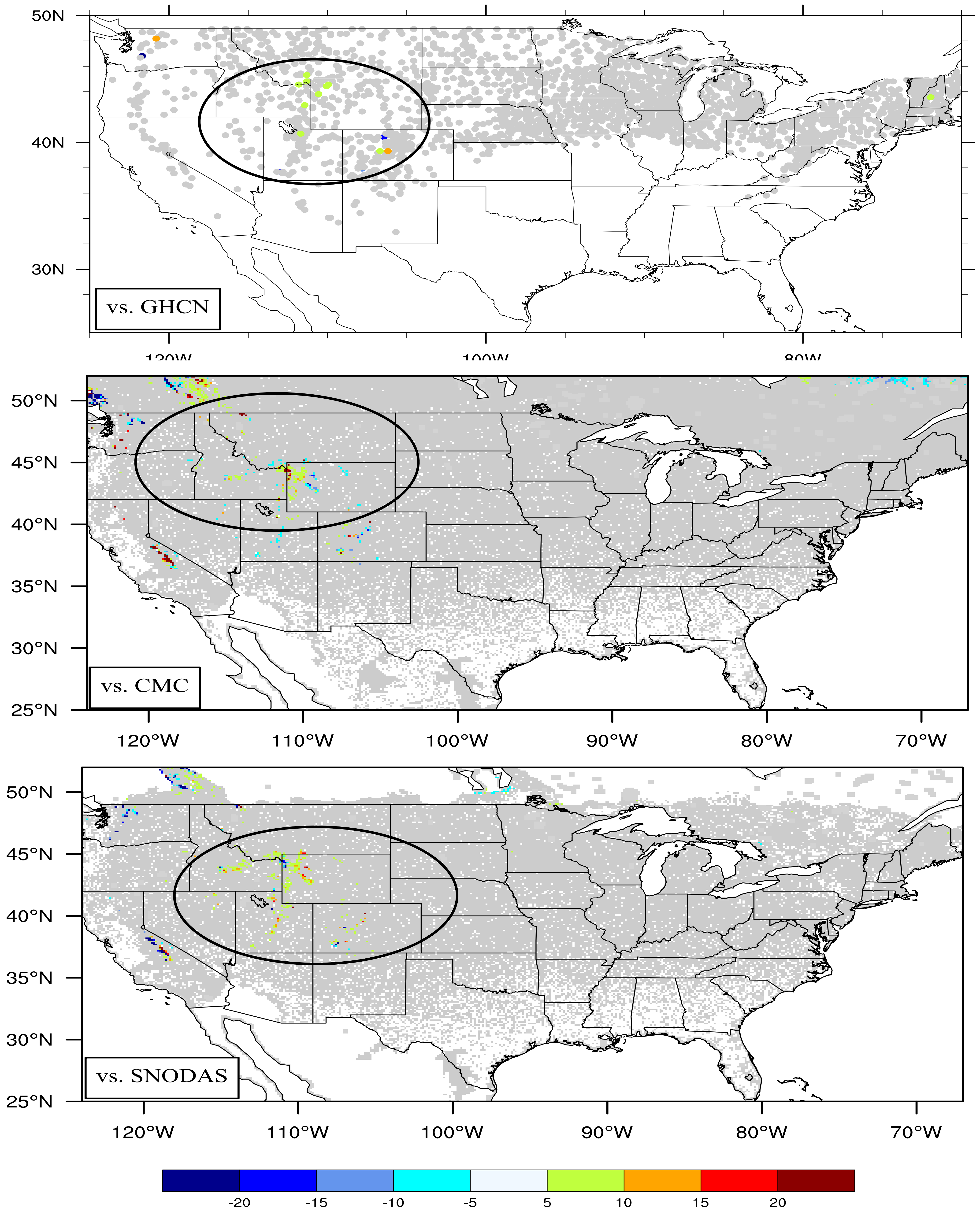


Results: Snowdepth

- Compared to GHCN, CMC and SNODAS (RMSE(OL) - RMSE(DA))

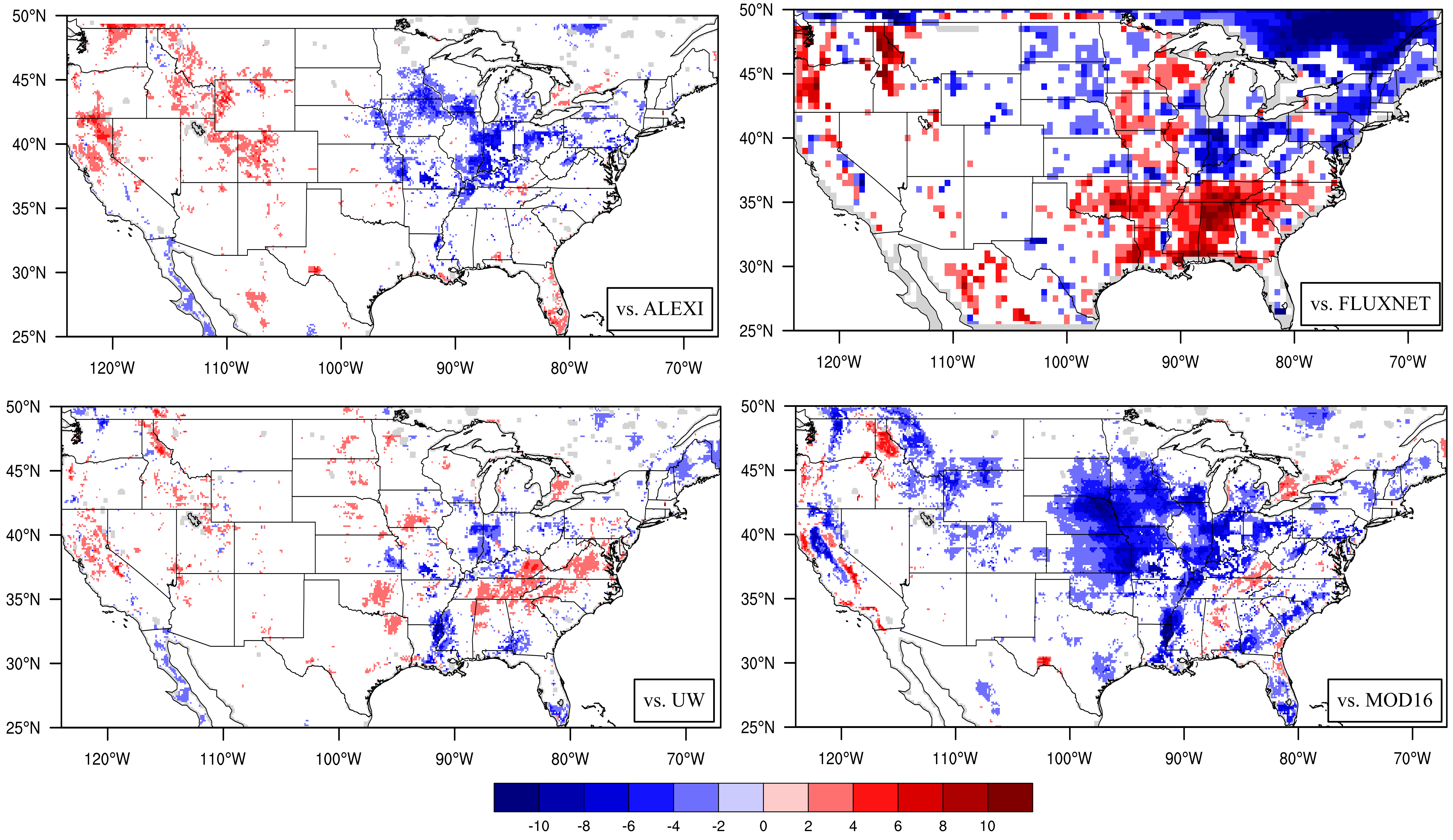
- Impact on snow depth estimates is very small (not statistically significant in most parts of the domain)

- Over the Rocky mountains, Sierra Nevada and Cascades, GRACE-DA provides improvements (consistent in all three comparisons)



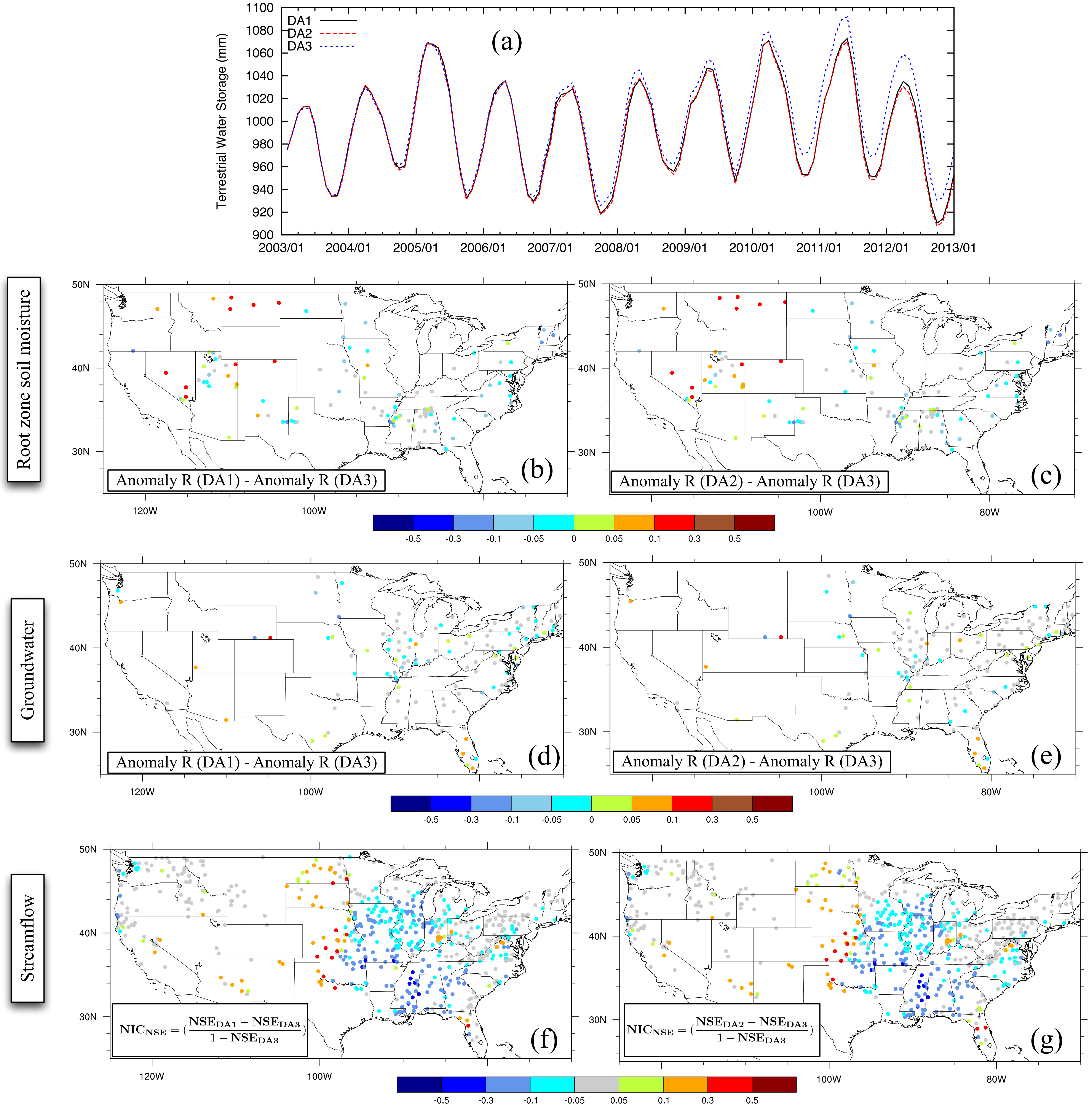
Results: Evapotranspiration

- Compared to ALEXI, FLUXNET, UW, and MOD16 (RMSE(OL) - RMSE(DA))
- Areas of decreased RMSE in the West, Great Plains, Southeast; increased RMSE over upper Mississippi (except in case of MOD16)



Influence of scaling factor and measurement errors

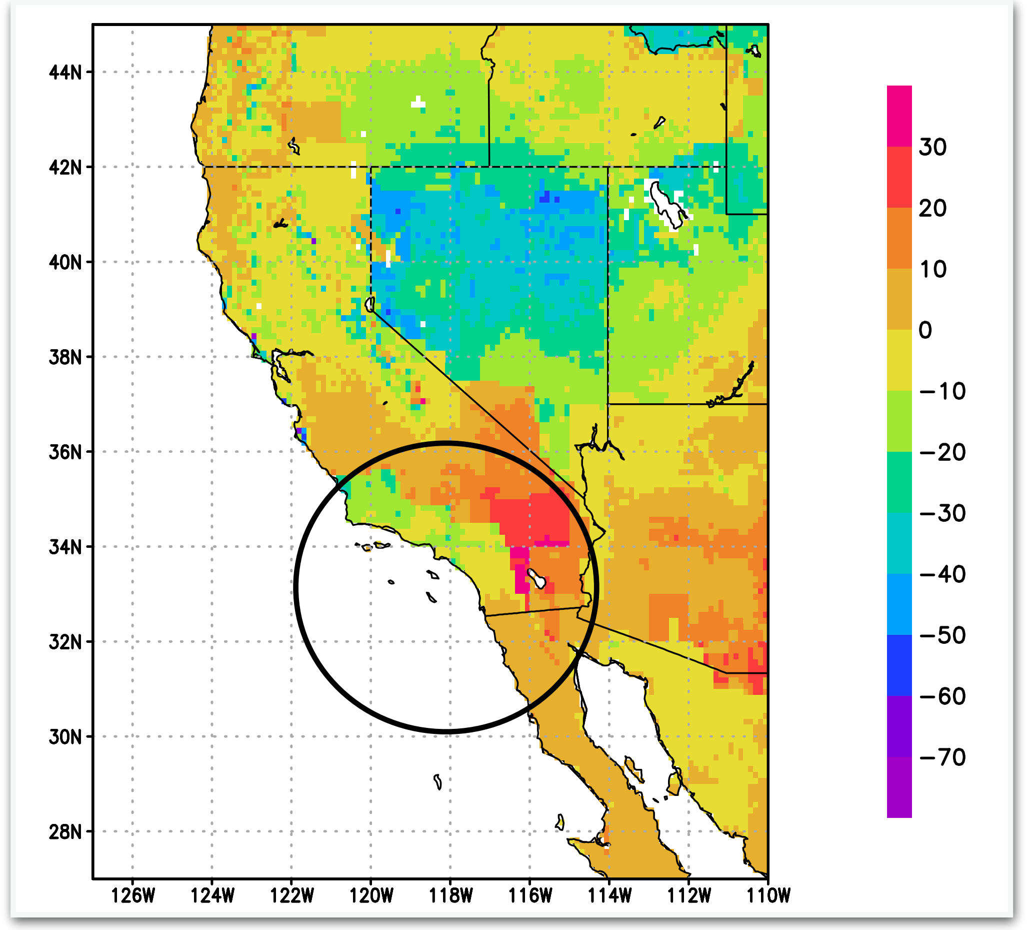
- Filtering procedures are applied to reduce the level of noise to generate the gridded GRACE data, which also lead to loss of signal
- To reduce the differences between the signal amplitudes of the original and filtered data a multiplicative scale factor was developed
    - DA1 - distributed measurement error + scaling factors
    - DA2 - uniform error + scaling factors
    - DA3 - uniform error + no scaling
- Scaling factor seems to have a large influence than the distributed measurement error

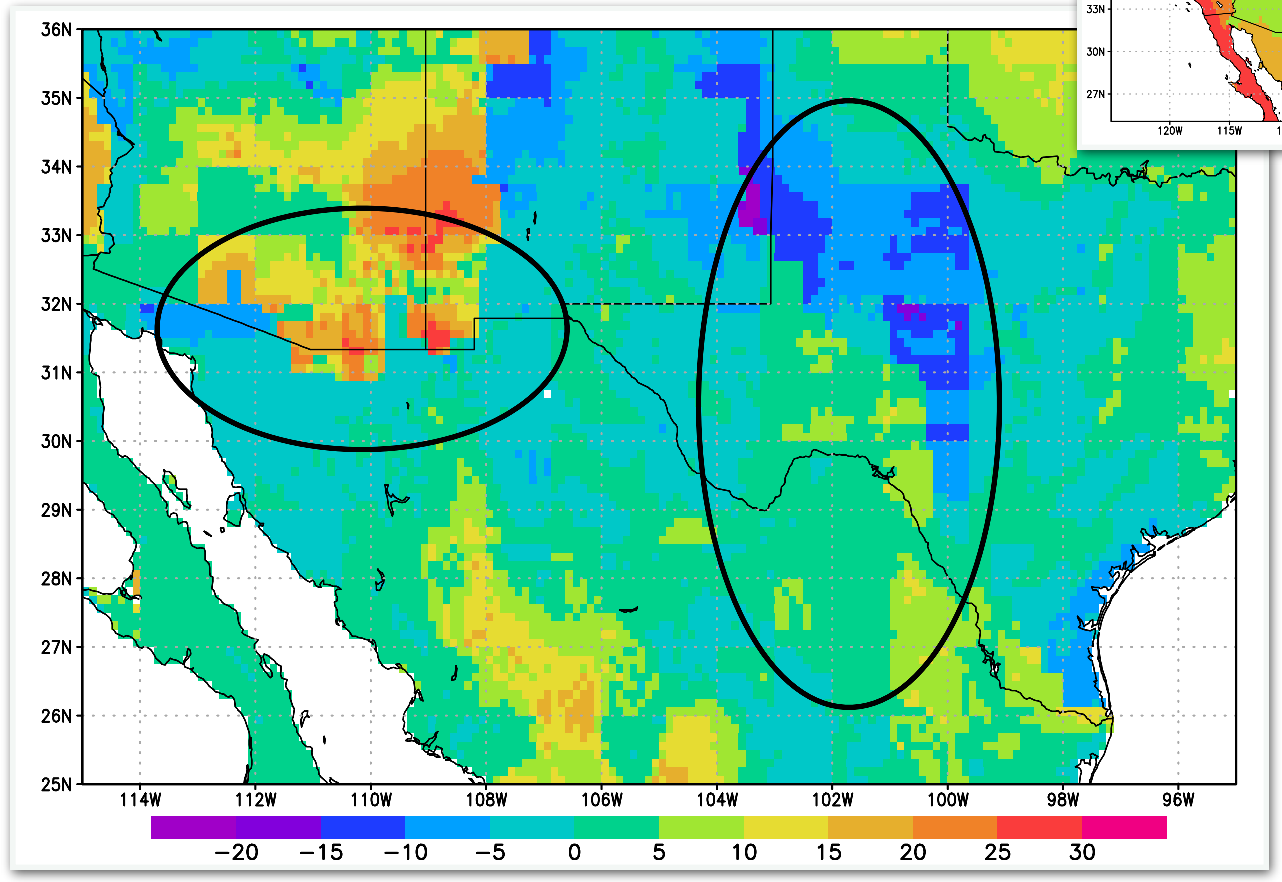


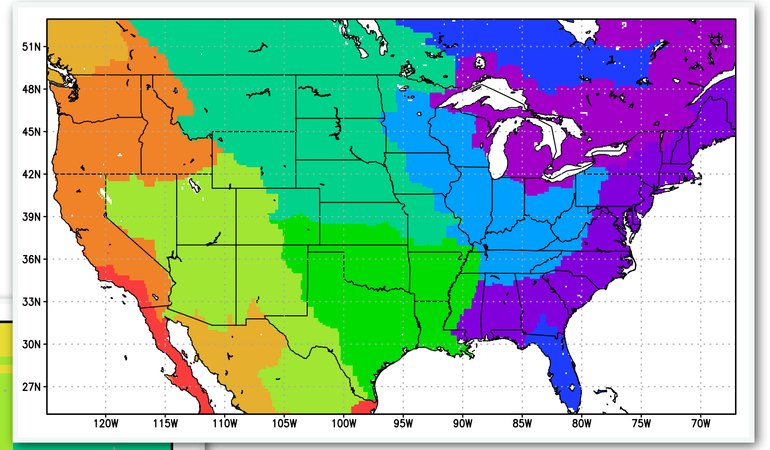
Comparison of DA with gridded and basin averaged data

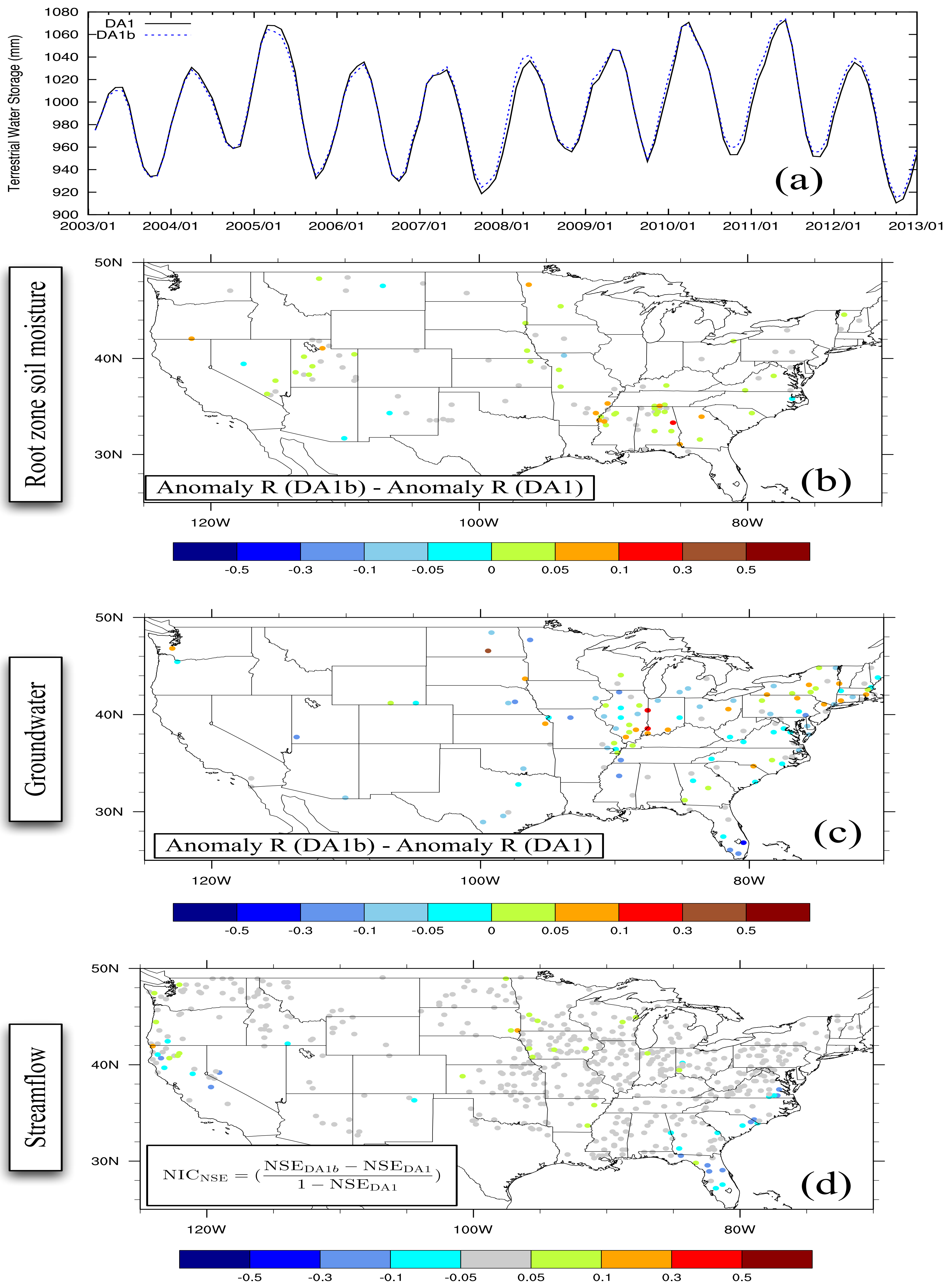
- DA1 - default configuration with gridded GRACE data, distributed measurement errors, use of scaling factors
- DA1b - basin scale DA with distributed measurement errors and scaling factors
- DA1b includes artifacts of basin boundaries
- Basin averaged DA has marginally higher skills for root zone soil moisture; Groundwater skill comparison shows mixed results; Small differences in the streamflow fields

Jul 2006 | TWS(DA1b) - TWS(DA1) | Jun 2008



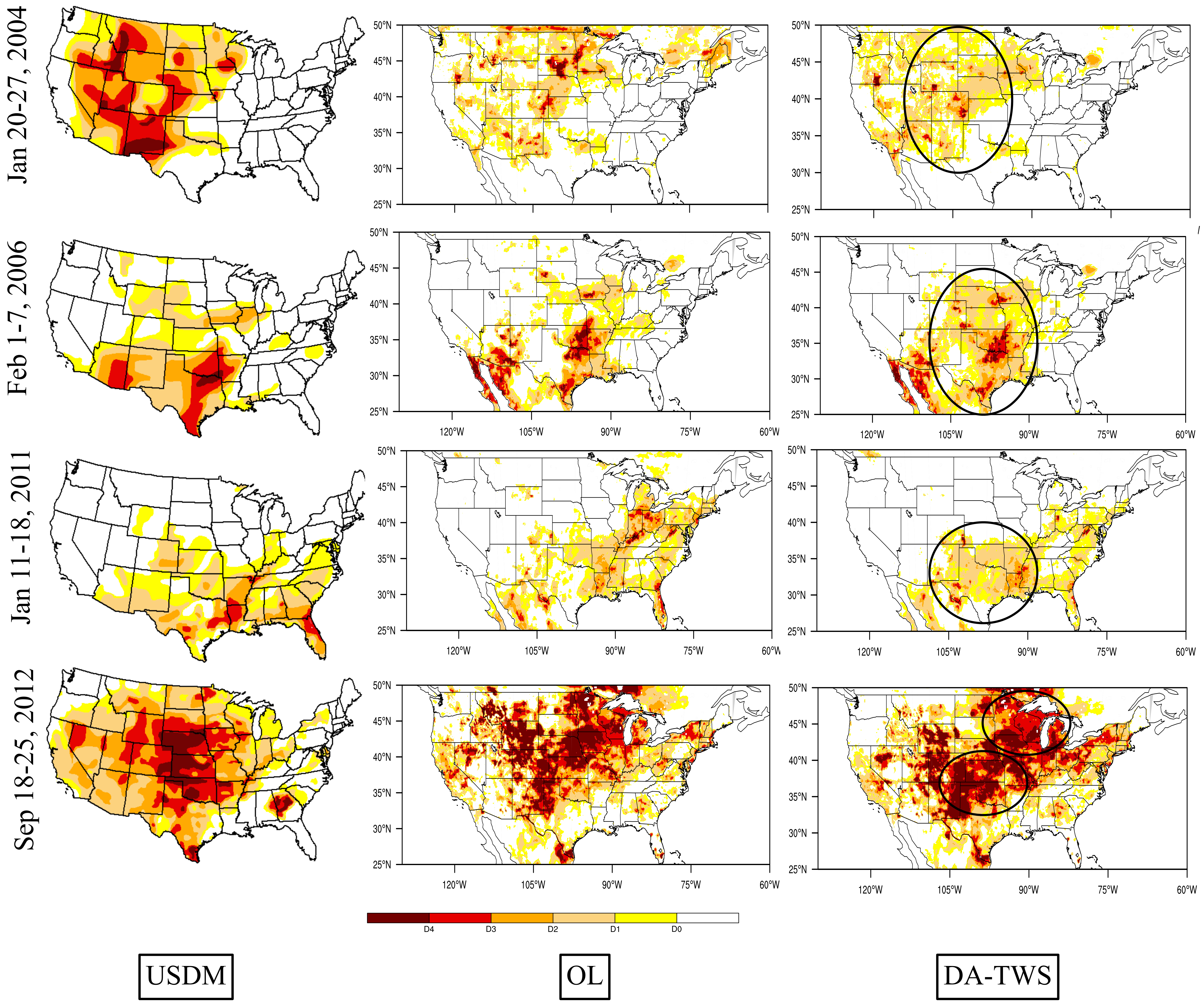






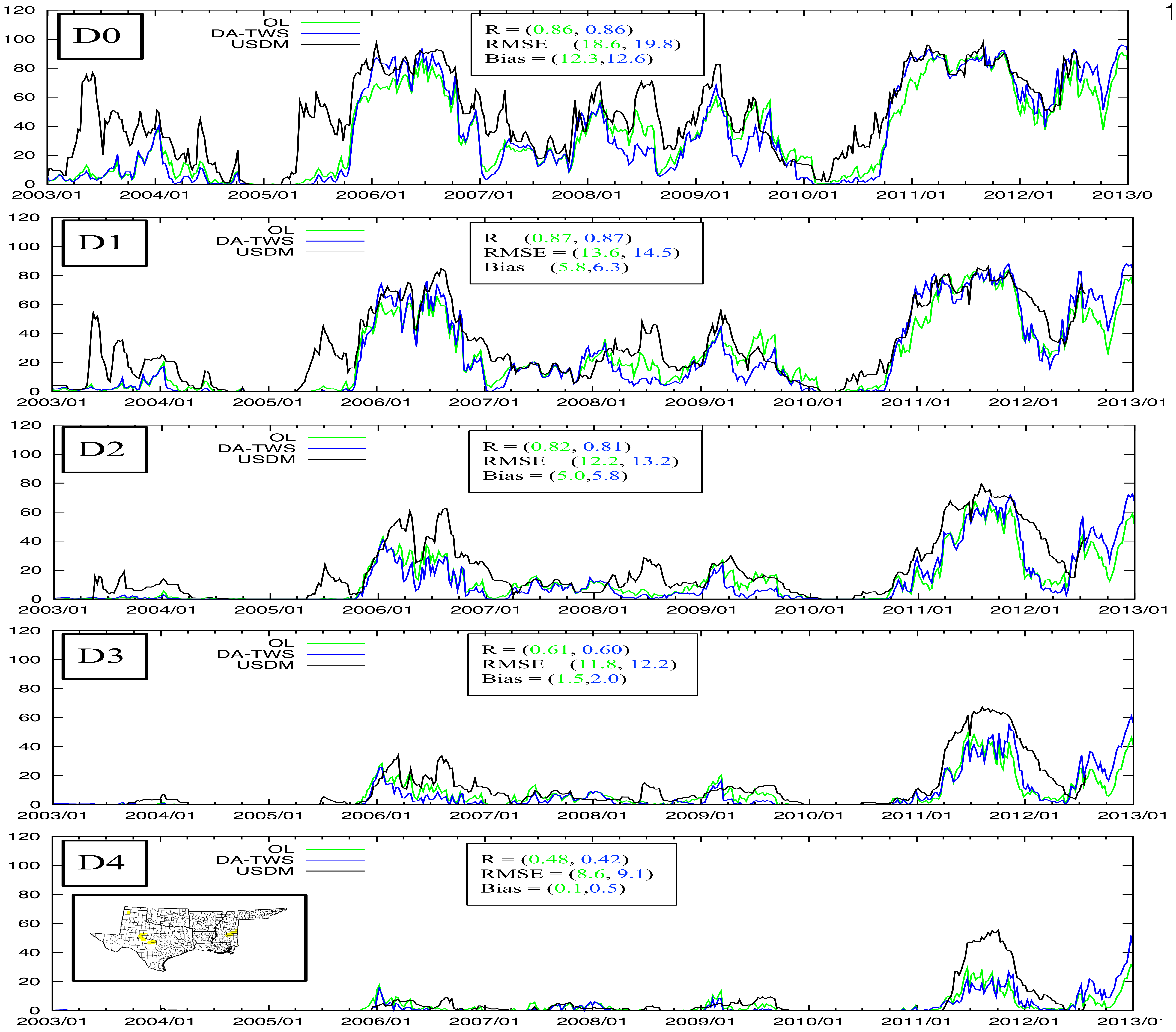
Impact on drought estimates

- 2004 ; OL underestimates drought severity
- 2006; The underestimation of the D0-D2 categories are improved by DA
- 2011; Onset of the Texas drought is improved in DA
- 2012; OL overestimates drought severity over Minnesota, Iowa, Wyoming and underestimates over Kansas, Oklahoma



Comparison of drought area estimates

- OL skills are high; Impact of DA is mixed
- Stronger agreement with USDM in the DA integration for 2006-2007, 2011, 2012, reduced agreement in late 2008, 2009.
- Drought area representation is marginally improved by GRACE DA in late 2012 drought.



Summary

- GRACE DA assimilation provides significant improvements in soil moisture and groundwater estimates; marginal impacts on streamflow, snow and ET
- The skills from gridded and basin averaged DA were comparable
- The use of scaling factors was more impactful compared to the use of distributed measurement errors
- The impact of GRACE-DA on drought estimates were mixed; GRACE-DA improved the representation of moderate droughts in general.