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Joint assimilation of SMOS brightness temperature and GRACE terrestrial water storage observations for improved soil moisture estimation

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Motivation & Hypothesis

- Accurate estimates of soil moisture will enhance weather and climate forecast skill and will improve flood prediction and drought monitoring capability
- Can we improve soil moisture profile estimates by merging both SMOS and GRACE satellite based observations into a land surface model?

Measuring Soil Moisture from Space

Soil Moisture and Ocean Salinity (**SMOS**):
- L-band brightness temperature (Tb) at multiple incidence angles
- Lauched Nov. 2009

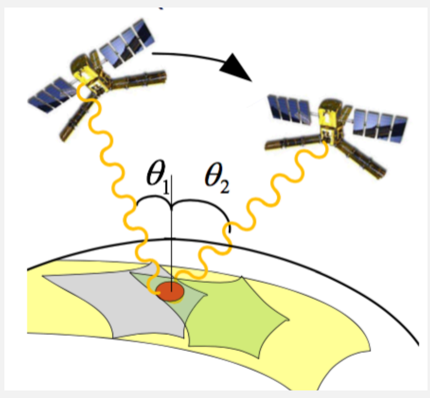


Fig 1. SMOS satellite.

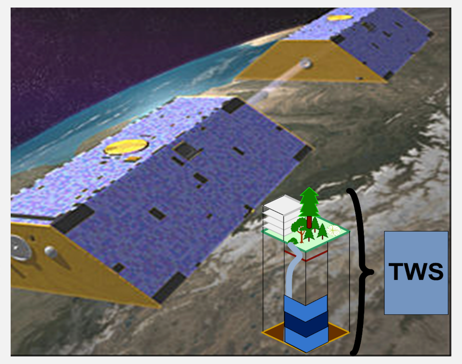
PROS:
- Tb depends on soil moisture
- Frequent obs. (**1 obs./2-3 days**)
- Good spatial resolution (~ **40 km**)

CONS:
- Only sensitive to **surface** soil moisture

Gravity Recovery and Climate Experiment (**GRACE**):
- Gravity observations to provide Terrestrial Water Storage (TWS) anomalies
- Launched Mar 2002

Fig 2. GRACE satellites.

***TWS = groundwater (GW) + soil moisture (SM) + snow (SWE) + canopy storage**



PROS:
- Sensitive to mass changes of the entire soil moisture profile

CONS:
- Coarse temporal resolution (**monthly**)
- Coarse spatial resolutions (**~300 km**)

Modeling Soil Moisture

- Catchment Land Surface Model (LSM), GEOS-5:
- **Surface soil moisture [0-5 cm]**
- **Root zone soil moisture [0-100 cm]**
- **Groundwater, and TWS**

NOTE: catdef is the main prognostic controlling modeled groundwater

- Radiative Transfer Model (RTM) to estimate Tb [De Lannoy et al., 2013]
- Experiment specifics:
- **From Jan. 2010 through Jan 2015;**
- **CONUS domain spatial res. 36 km EASEv2 grid;**
- **MERRA-2 forcings** [Gelaro et al. 2017]

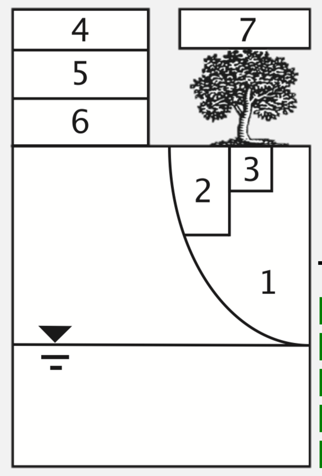


Fig 3. Schematic of Catchment Model [Koster et al., 2000.

TWS components:
[1]: catchment deficit
[2]: root zone excess
[3]: surface soil excess
[4–6]: snow
[7]: canopy storage

Joint Assimilation Methods

- Assimilated Observations:
- GRACE: TWS anomalies
- SMOS: Tb Vertical and Horizontal Polarizations (Tb_V, Tb_H) at 40°

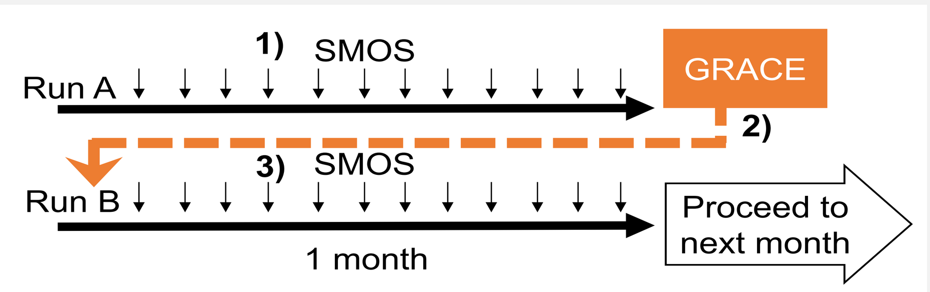
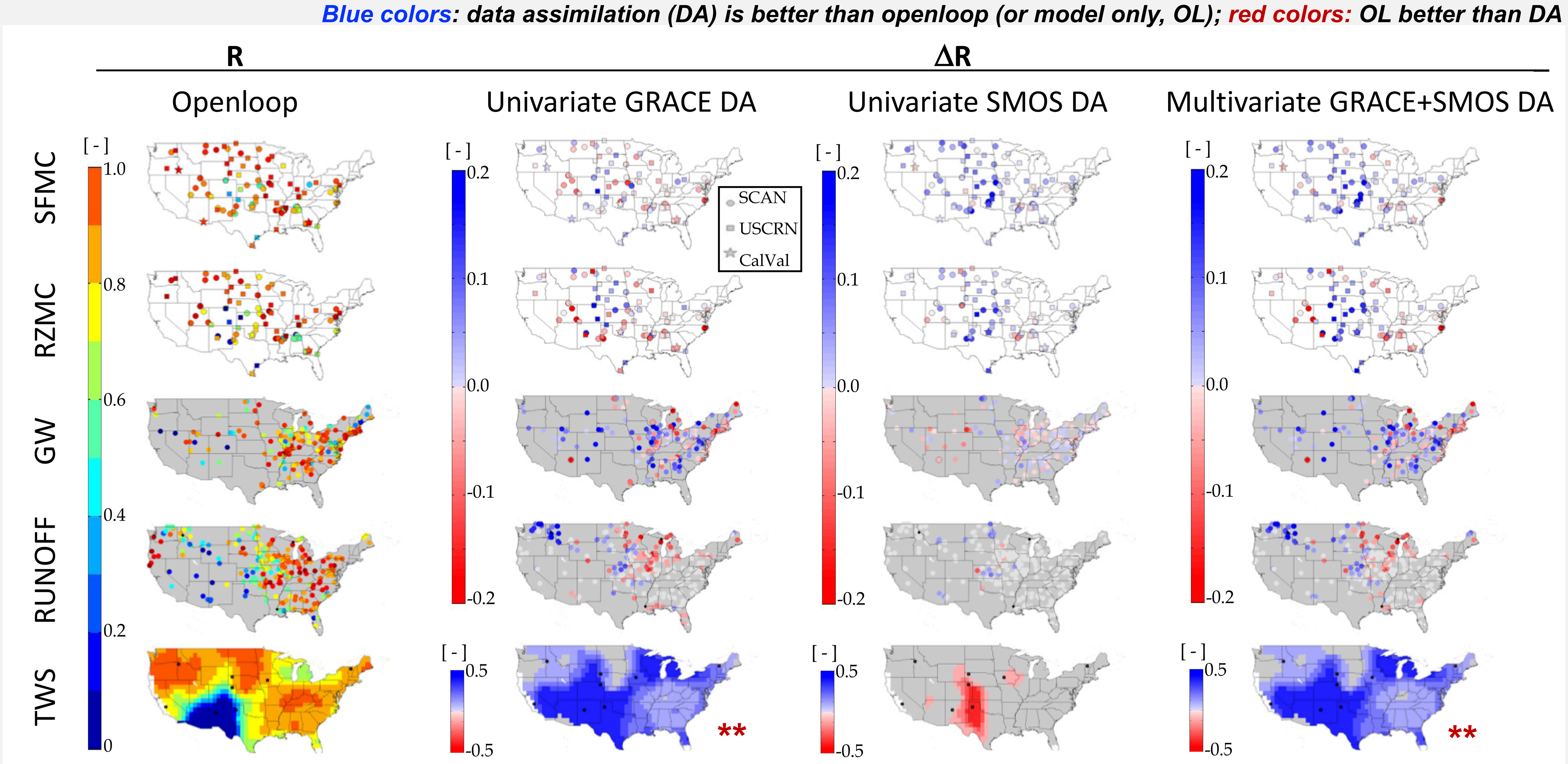


Fig 4. Simplified flowchart of the joint GRACE-TWS and SMOS-Tb data assimilation (DA) system.

1) Run A: One month forecast ensemble integration with SMOS-Tb assimilation (SMOS run A)
2) GRACE-DA: Calculate model TWS observation prediction through spatial aggregation (model-to-observation grid) and temporal aggregation (daily to monthly). Calculate the increments via 3DEnKF analysis. Rewind the model to the beginning of the month and apply the GRACE Increments (Girotto et al., 2016).
3) Run B: Integrate the model from the 1st - to the last day and re-perform SMOS-Tb assimilation (SMOS run B). Repeat for the following month.

Results: Validation

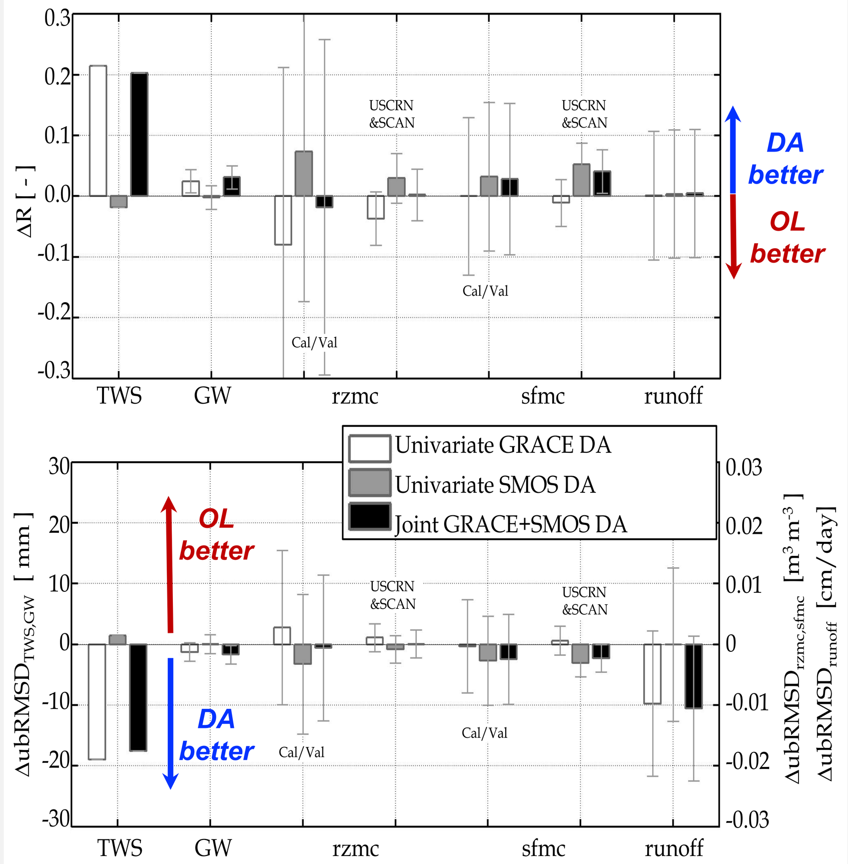
***Blue colors:* data assimilation (DA) is better than openloop (or model only, OL); *red colors:* OL better than DA**



**** TWS skills are computed against the GRACE (assimilated) TWS observations.**

Fig. 5. (column 1) Skills (R), and (columns 2-4) difference in skill (ΔR) between the data assimilation (DA) and openloop (i.e., no assimilation) estimates for surface soil moisture (SFMC), root zone soil moisture (RZMC), groundwater (GW), runoff, and terrestrial water storage (TWS). Skill is measured as the correlation coefficient (R) versus insitu and GRACE (for TWS) measurements.

Fig. 6. Bulk statistics: skill differences between assimilation and openloop experiments (i.e., skill of DA minus skill of the OL) when compared to independent in situ measurements of groundwater (GW), root-zone soil moisture (rzmc), surface soil moisture (sfmc), and runoff. TWS skills are computed against the GRACE (assimilated) TWS observations.



Results: Impact on Soil Moisture Profile

Blue colors*: data assimilation (DA) reduces OL uncertainty; *red colors: DA increases OL uncertainty

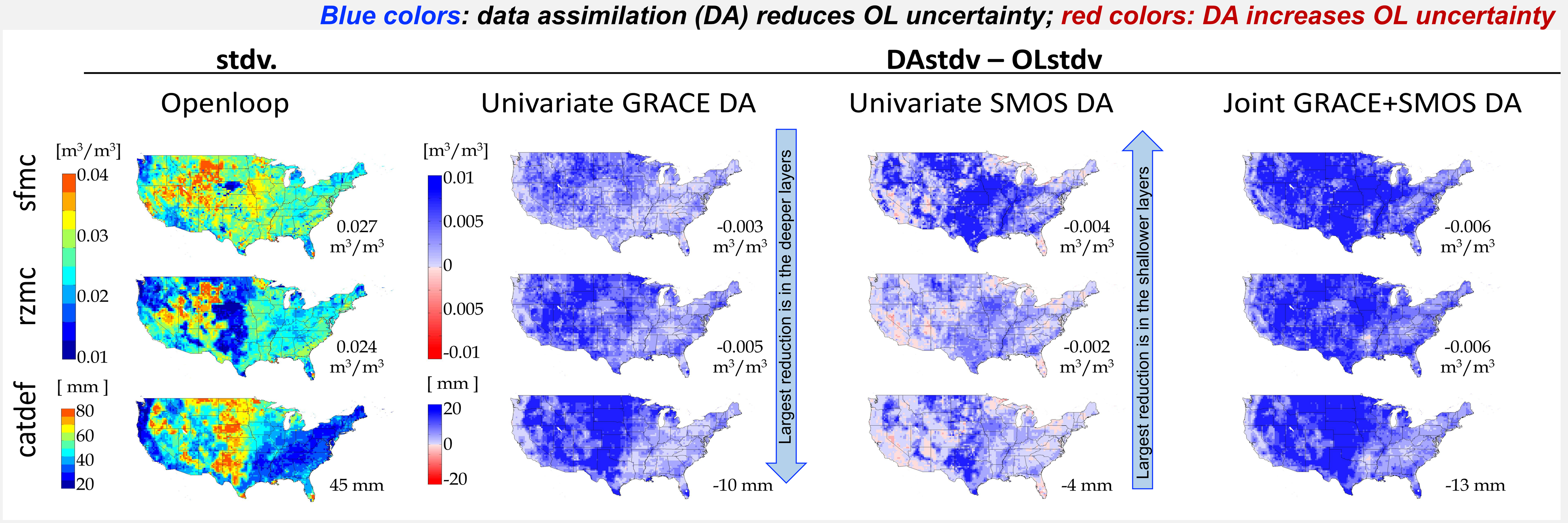


Fig. 7. (column 1) typical monthly ensemble standard deviation (i.e., ensemble spread) of the openloop (i.e., no assimilation), and (columns 2-4) reduction in ensemble standard deviation (DAstdv–OLstdv) between the data assimilation (DA) and openloop for surface soil moisture (sfmc), root zone soil moisture (rzmc), and catchment deficit (catdef).

Conclusions

- GRACE-DA improves groundwater while SMOS-DA improves surface and rootzone soil moisture.
- The joint GRACE-TWS & SMOS-Tb assimilation maintains good skills in TWS, groundwater, surface and rootzone soil moisture.
- GRACE and SMOS DA are complementary as:
- GRACE-DA is responsible for most of the ensemble spread reduction in deeper moisture layer (i.e., catdef).
- SMOS-DA is responsible for most of the ensemble spread reduction in shallower moisture layers (i.e., sfmc).

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