A Multi-Satellite Assimilation and Modeling Platform to Construct a Global and Complete view of the Hydrologic Cycle

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Outline

- **Why Caring About the Hydrologic Cycle and Data Assimilation?**

- **Example of Data Assimilation Applications**

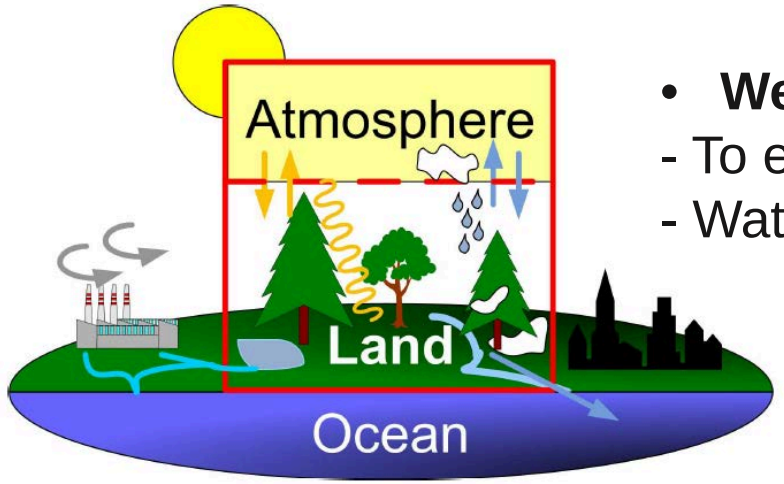
  1. Soil Moisture Profile (i.e., Groundwater and Soil Moisture)

  - Microwave (L-band, 1.4GHz) Observations (SMOS/SMAP)

  - Gravity Observations (GRACE)

- **Summary and Conclusions**

Why Caring About the Hydrologic Cycle?



- **Weather and climate**

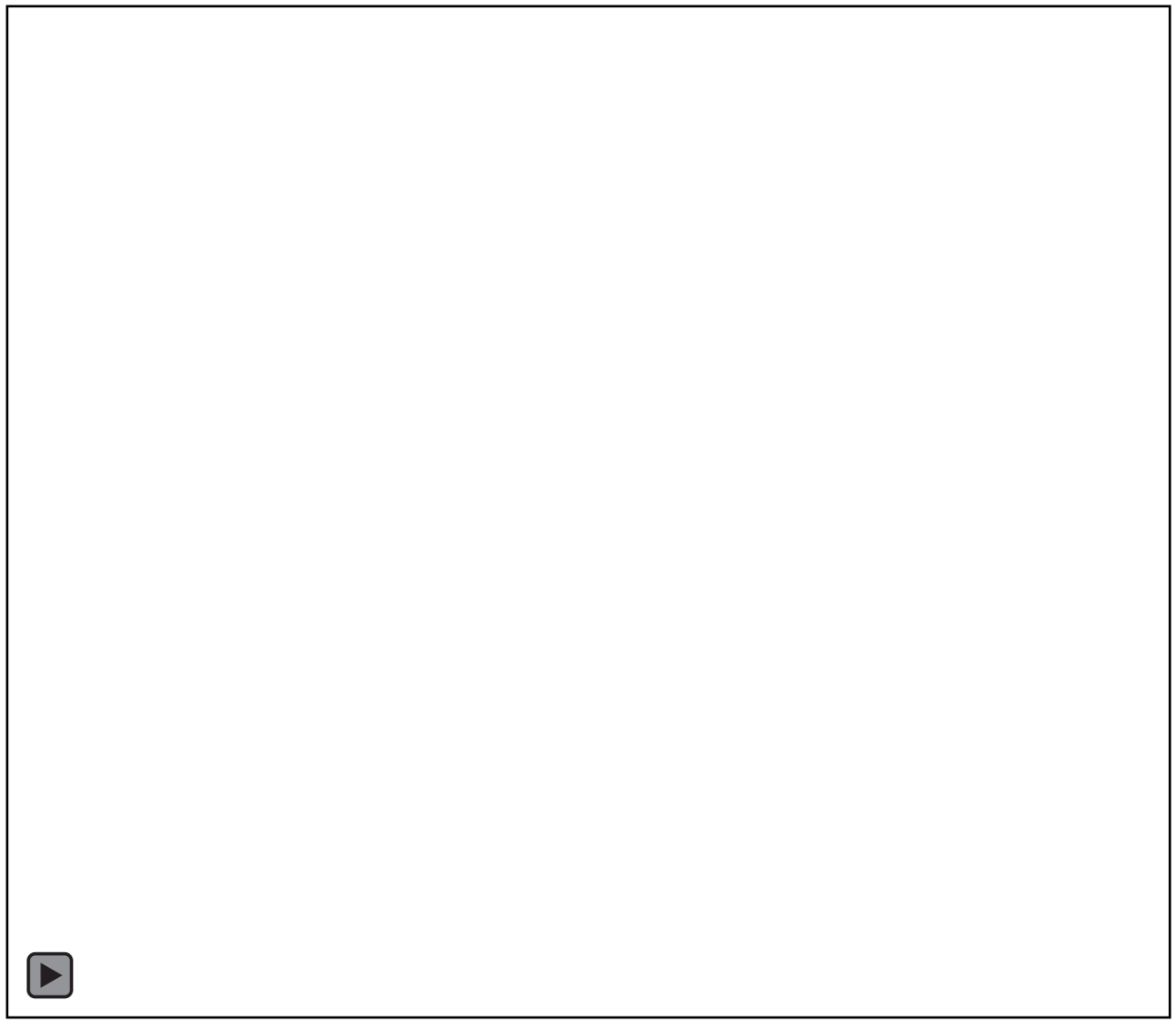
- To enhance weather and climate (and their forecasts)
- Water is the linkage between energy, carbon cycle

- **Economy**
  - To improve agricultural practices
  - To improve flood prediction and drought monitoring

- **Vulnerability due to climate change:** awareness – readiness – adaptation

Observations of the Hydrologic Cycle

Space-based

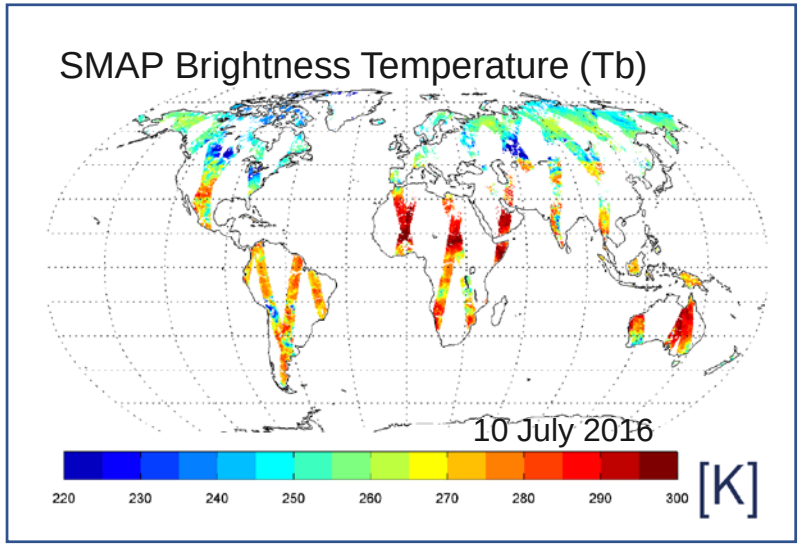


svs.gsfc.nasa.gov

Benefits

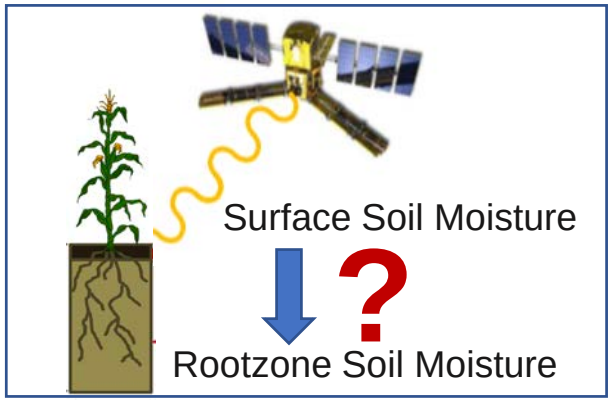
- A window-view from space
- Remotely sensed observations
  Observe inaccessible regions (e.g., complex terrain, conflict regions, etc.)
- Sense different aspects of the environment (**water**, carbon, land use and changes)
- Observe various spatial resolutions
- Direct global snapshots of reality
- Free and open data

Observing of the Hydrologic Cycle from Space

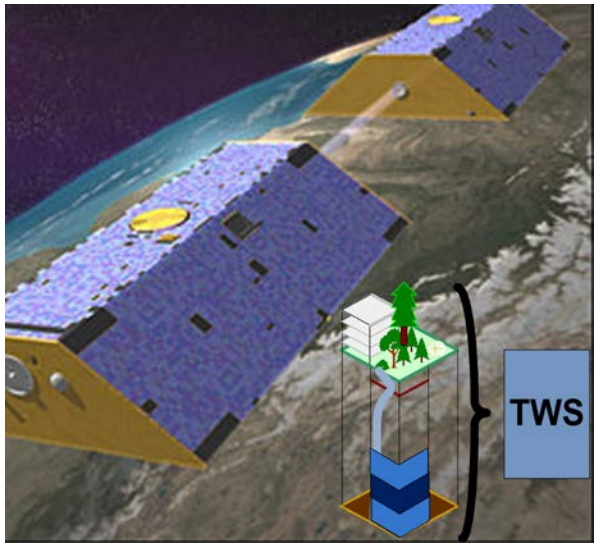


Pitfalls

- **Data gaps (e.g., not space/time continuous)**
- Measurement errors
- **Coarse space/time resolutions**
- Observing only one variable at the time
- Observing the present, not forecasting
- **Not direct observations of the variable(s) of interest (need retrievals, or auxiliary info)**



Gravity Observations (GRACE)
Terrestrial Water Storage (TWS)
Monthly / 3x3 degree



Satellite observations ALONE are not sufficient for a complete understanding of the Hydrologic Cycle

Modeling the Hydrologic Cycle

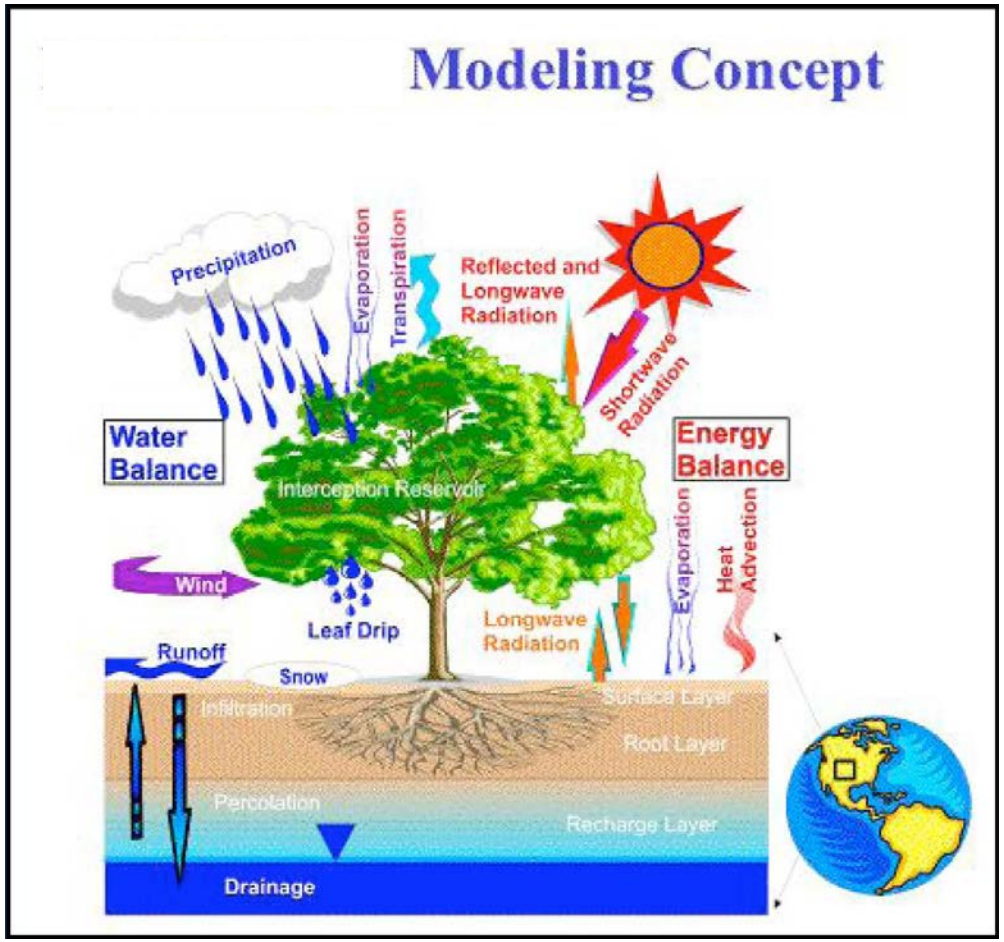
Benefits

- Global, continuous in space and time
- More or less degrees of complexity
- Can make forecasts
- Various spatial and temporal resolutions

Pitfalls

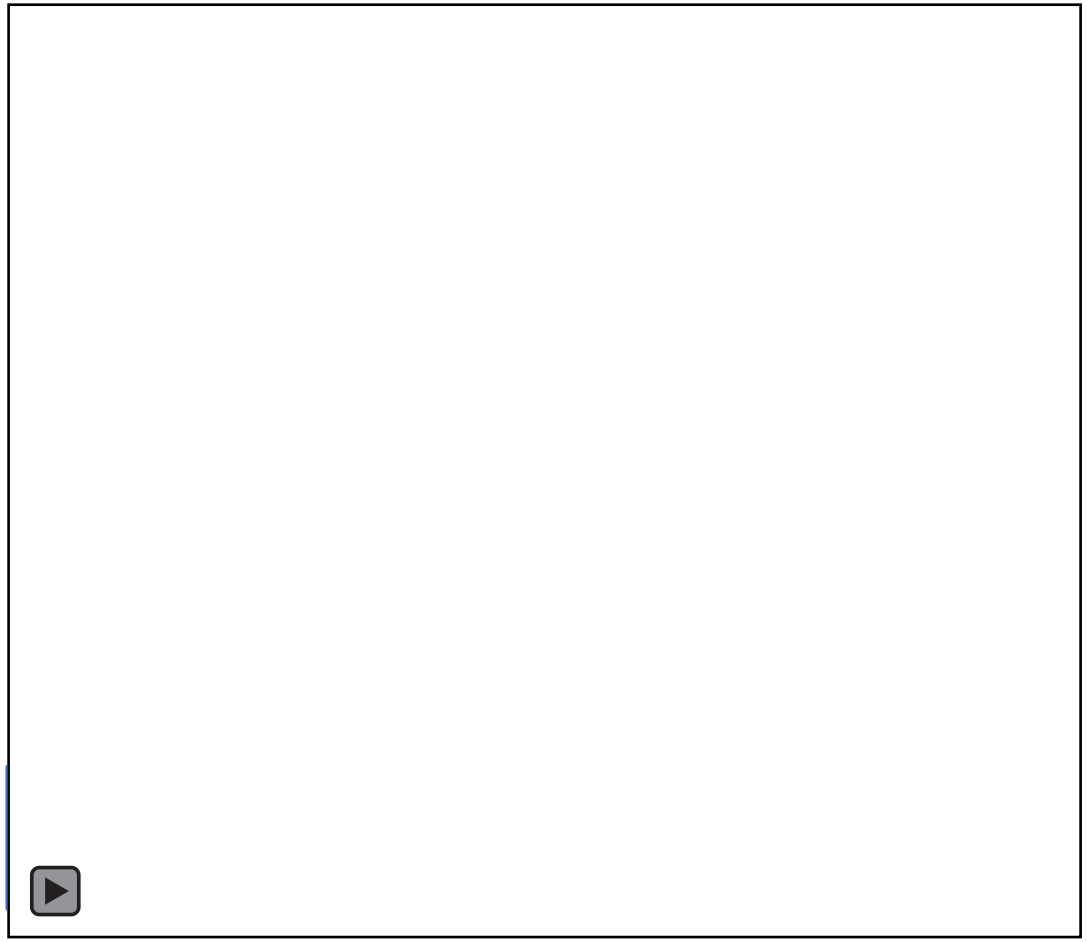
- **Uncertainties in parameters and forcings (i.e., errors)**
- Simplistic approximation of reality

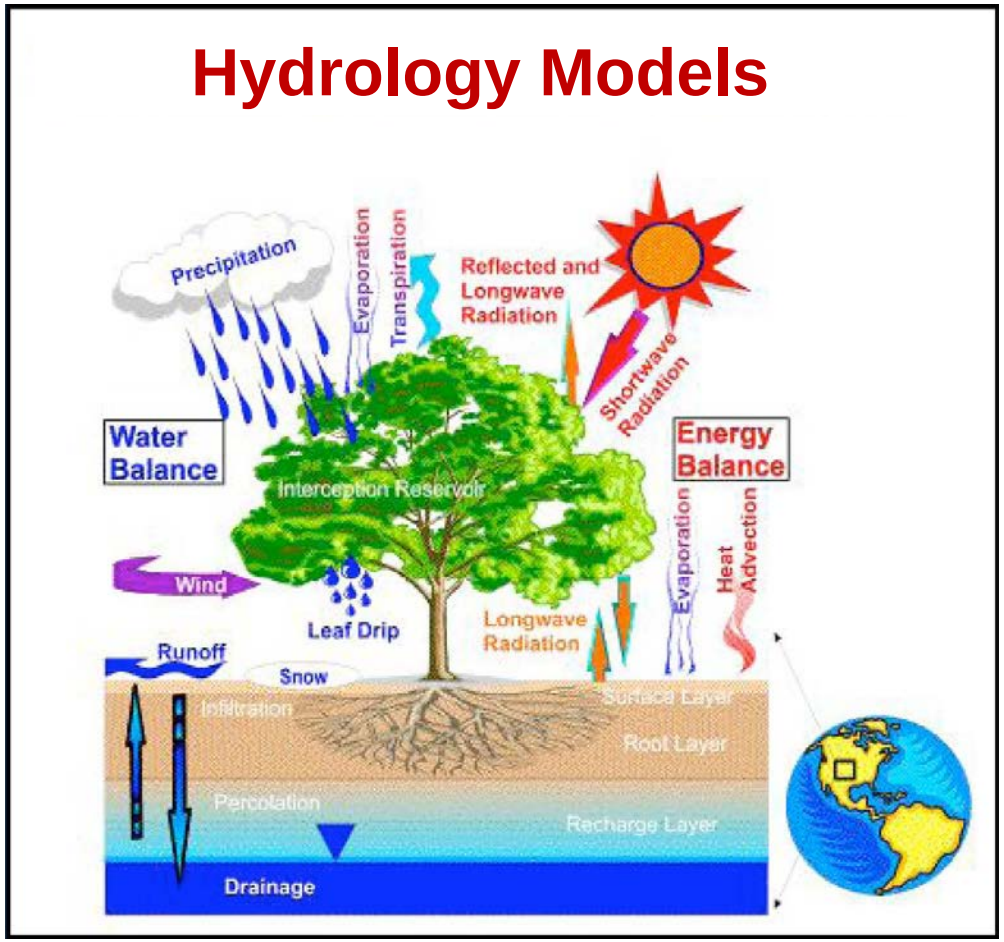
Models ALONE can contain large uncertainties and errors



Common Land Model (CoLM)

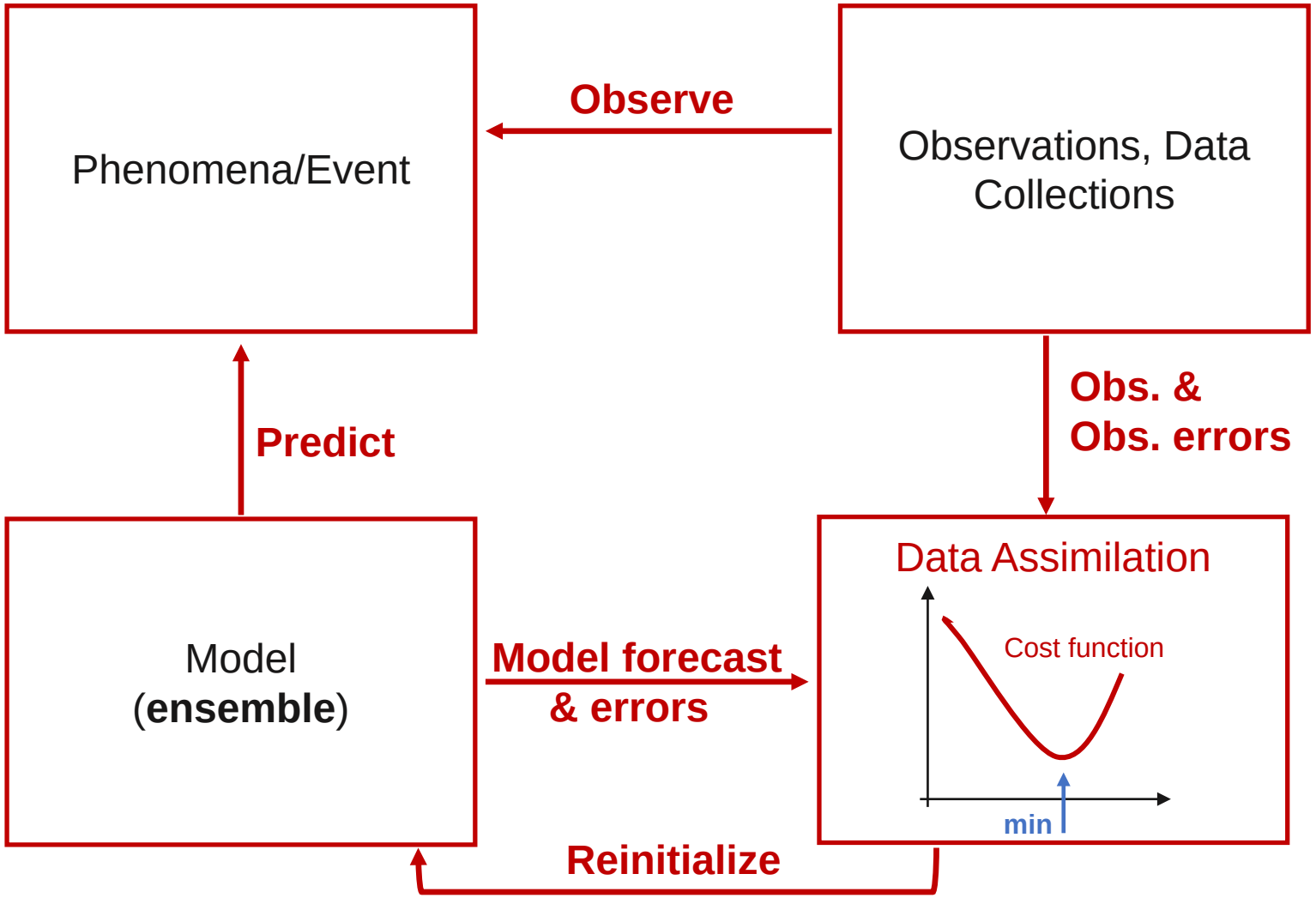
Data Assimilation (DA)





Data Assimilation: a bridge between satellite and models

Data Assimilation (DA)



- Estimates of a specific phenomena can be obtained form **Model** & **Observations**
- Neither are perfect
- Use them in combination to optimize estimates of the specific phenomena

Apply DA to improve regional to global hydrology to overcome pitfalls of satellite observations

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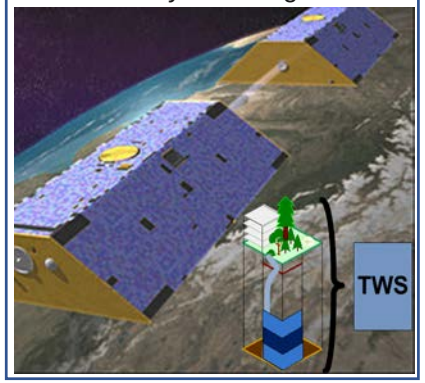
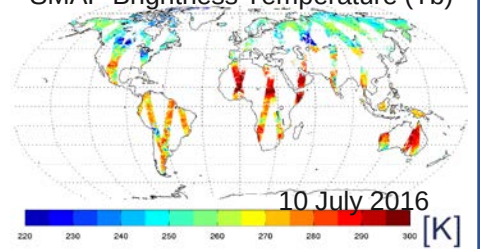
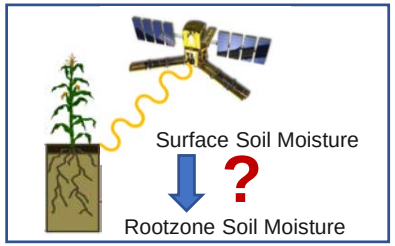
Terrestrial Water Storage (TWS)
Monthly / 3x3 degree



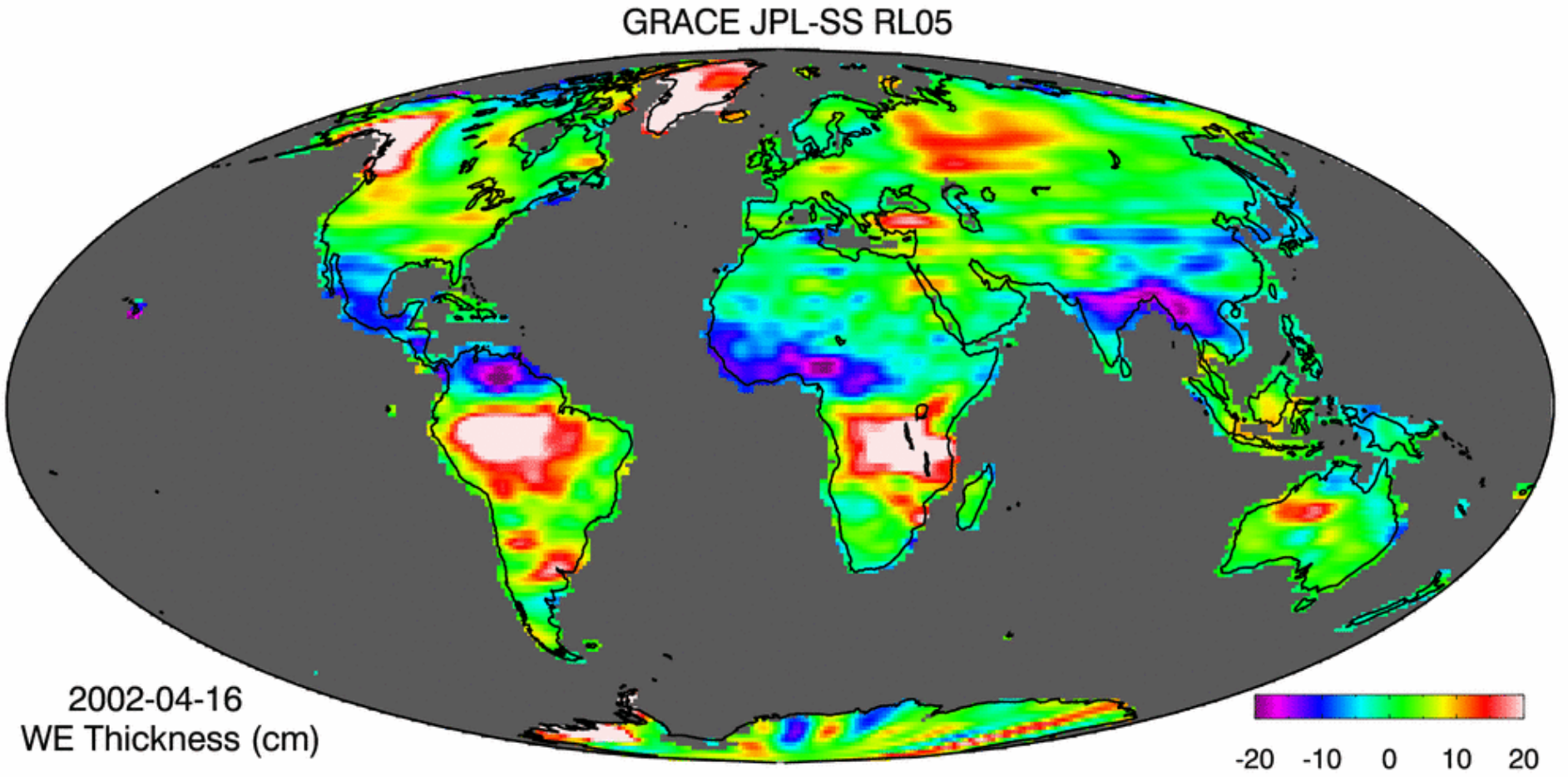
SMAP Brightness Temperature (Tb)





Gravity Observations (GRACE)

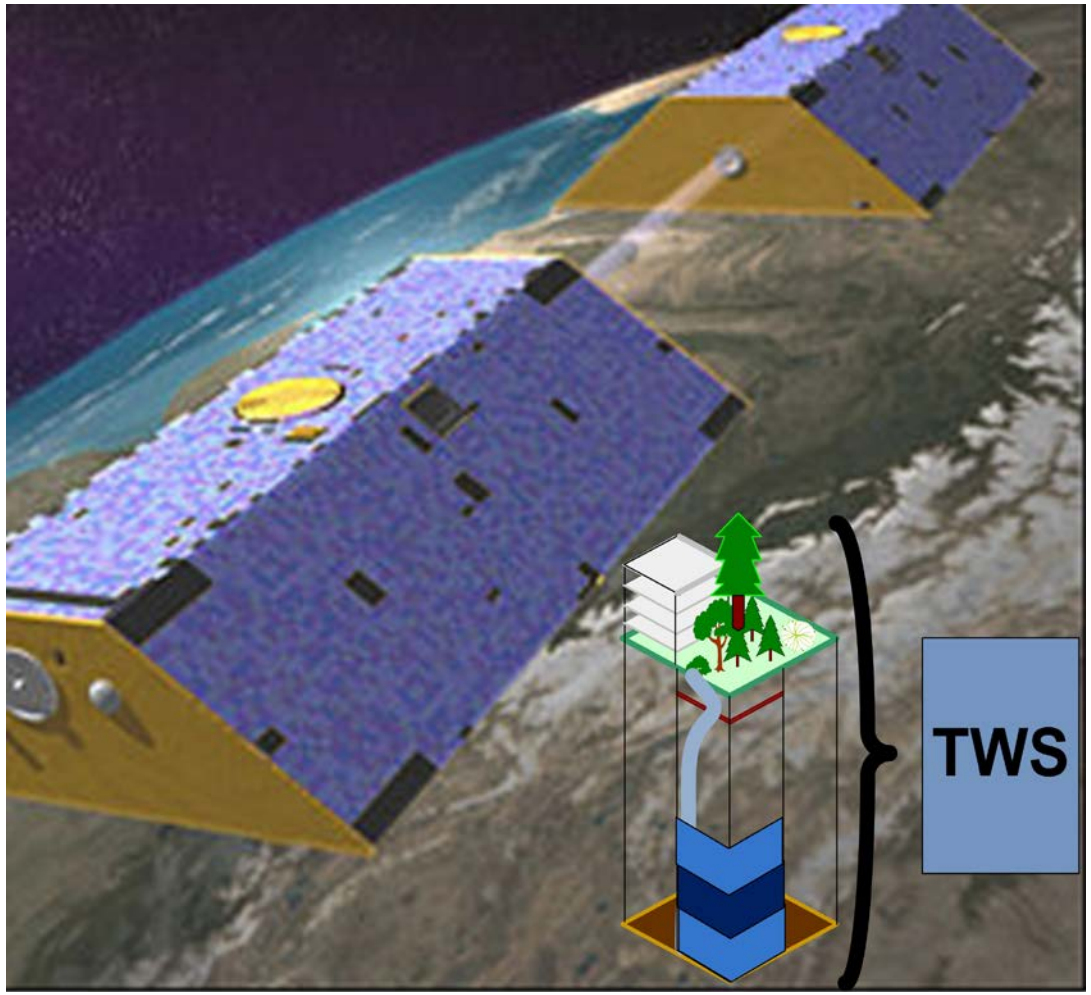
Groundwater from Space: GRACE?



- Gravity varies in **time**
- Water changes the Earth's mass
- Mass changes the gravity field (in **space** and **time**)
- GRACE observations: monthly **TWS** anomalies

Gravity (GRACE) can monitor where the water is now and how it is changing over time

Groundwater from Space: GRACE?



TWS = Terrestrial Water Storage

[sum of groundwater, unsaturated soil moisture profile, snow, vegetation storage]

Advantages:

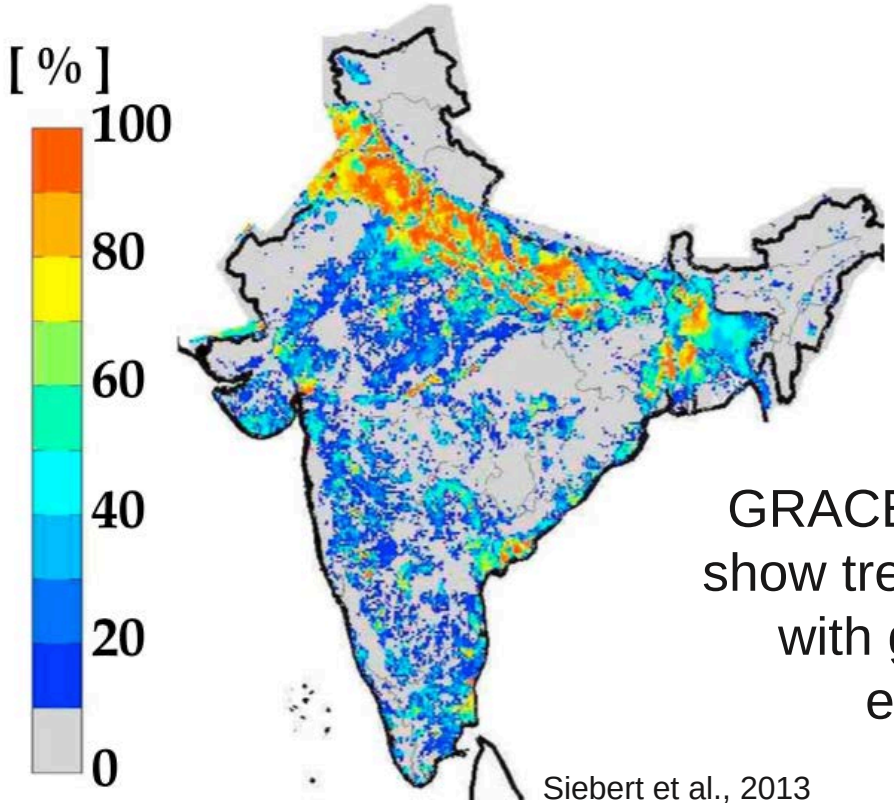
- Unique Mission: can see beyond the surface

Applications:

- Ice Mass Loss [e.g., Antarctica & Greenland]
- Droughts [e.g., Texas, California]
- Groundwater Depletion [e.g., India]
- Sea Level Rise

Groundwater From Space: GRACE and the Indian Aquifer Decline

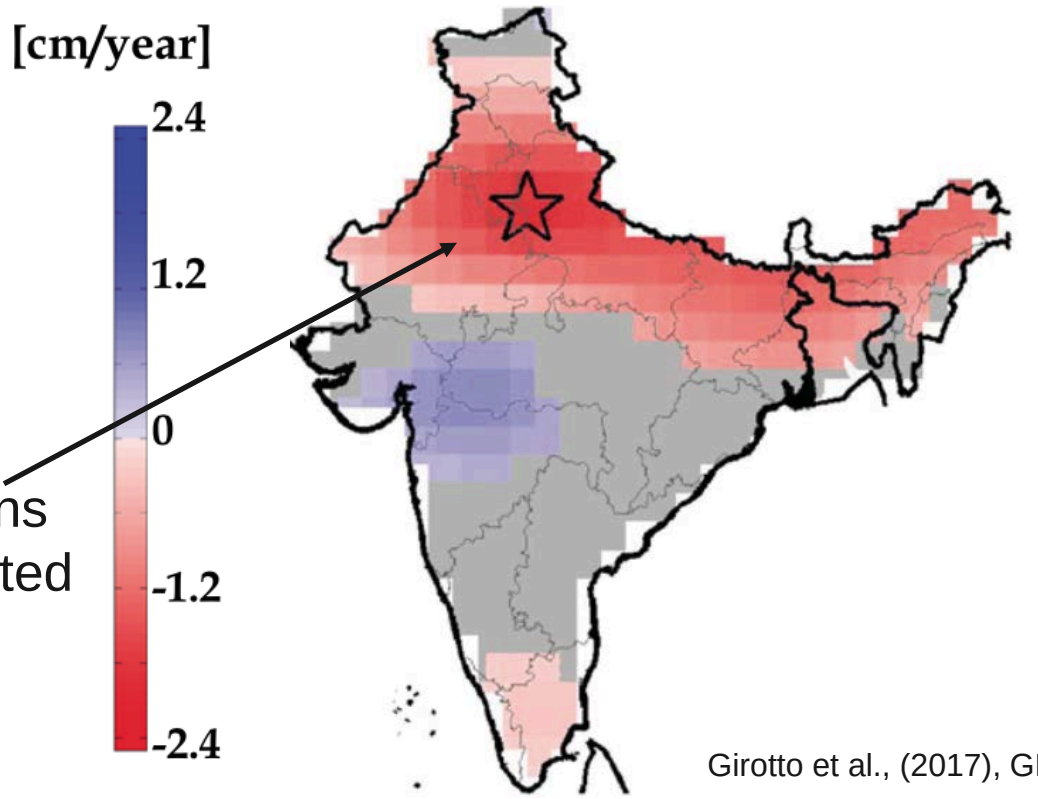
Percentage of area equipped for irrigation



Siebert et al., 2013

GRACE observations show trends associated with groundwater extraction

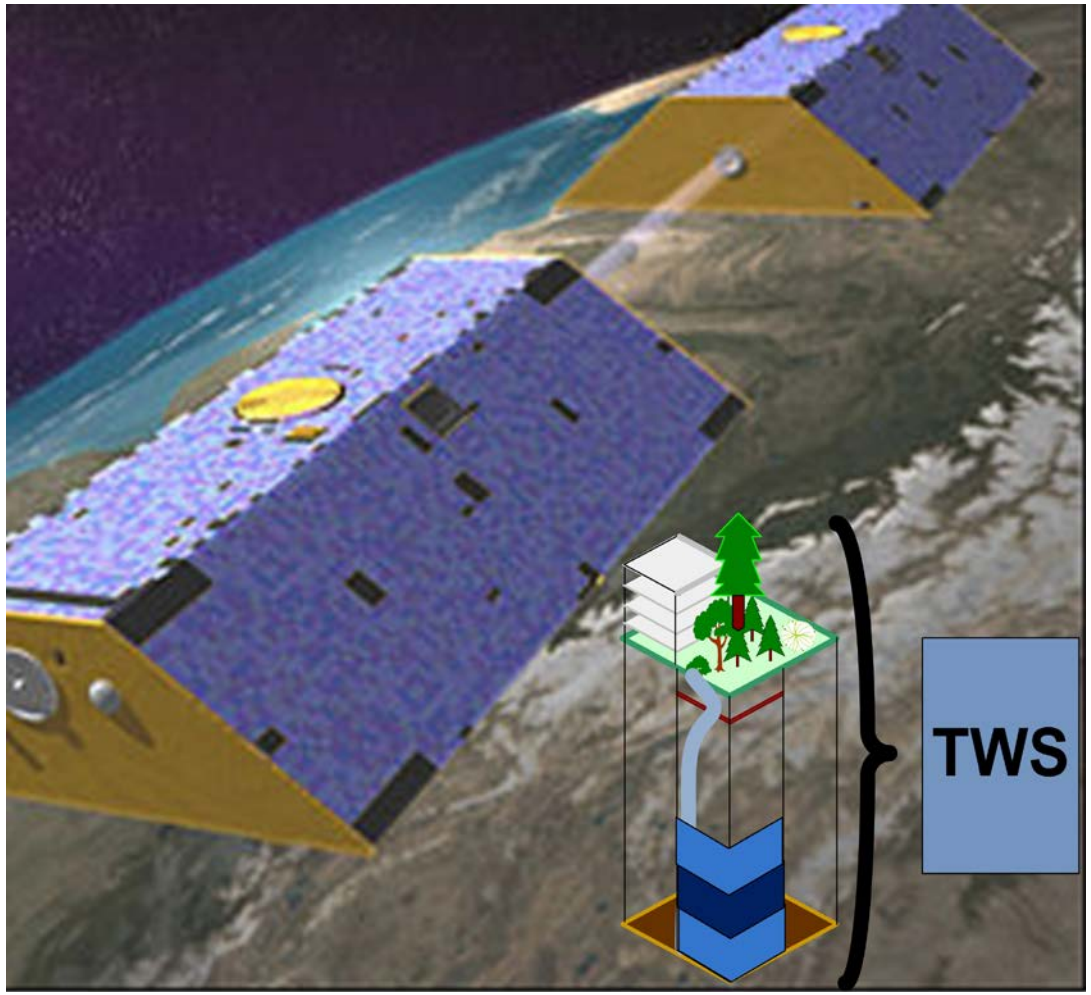
Trends in Terrestrial Water Storage (TWS) [2003-2016]



Girotto et al., (2017), GRL

- **Satellite observations monitor the hydrological cycle in its entirety (i.e., do not know if human or natural)**
- **Most land surface model do not yet account for human driven processes**

Groundwater from Space: GRACE?



Disadvantages:

- Column integrated [**no partitioning into storages**]
- **Coarse horizontal resolution** [300-400 km]
- **Coarse temporal resolution** [monthly]
- Strong spatial error correlations

Scales used for global mass balances

DATA ASSIMILATION

Downscaling:
- **Horizontal**
- **Temporal**
- **Vertical**

Scales that are more useful for hydrological applications

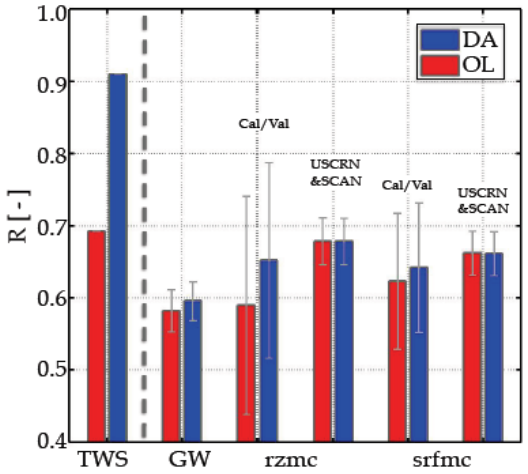
GRACE Data Assimilation: Validation

Soil Moisture:
Point scale observations:
- 157 SCAN (Soil and Climate Analysis Network)
- 95 USCRN (U.S. Climate Reference Network)
Watershed scale:
- 4 Cal/Val USDA sites

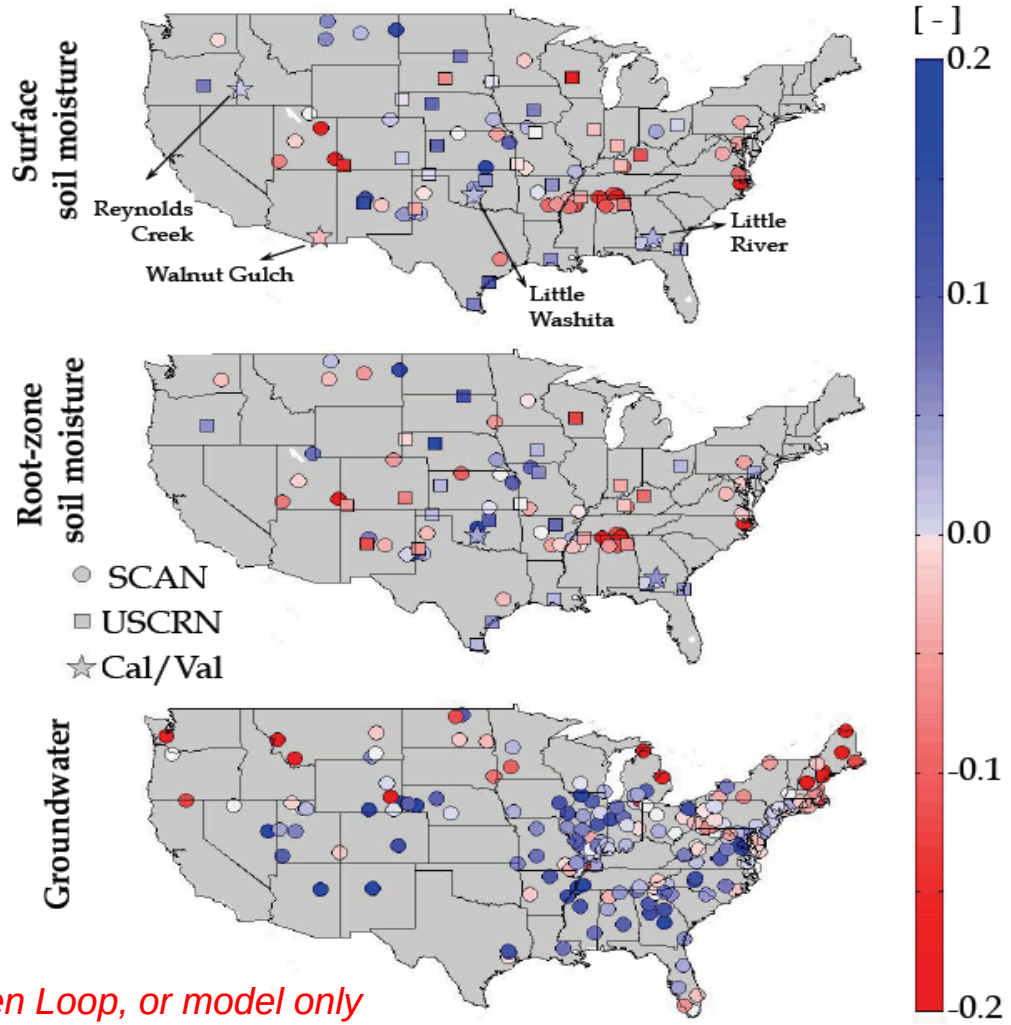
Groundwater:
- 136 USGS (Unconfined aquifer only)

Statistical Methods:
Skill: Anomalies Correlations
Monthly values Jan. 2003 - Dec. 2013

Bulk Statistics



$\Delta R = R_{DA} - R_{OL}$ [BLUE = DA better than OL]



GRACE-DA

- Improves groundwater estimates
- Mixed results for root-zone and surface soil moisture (Short memory? Small increments?)

→ **Add soil moisture (SMOS/SMAP)?**

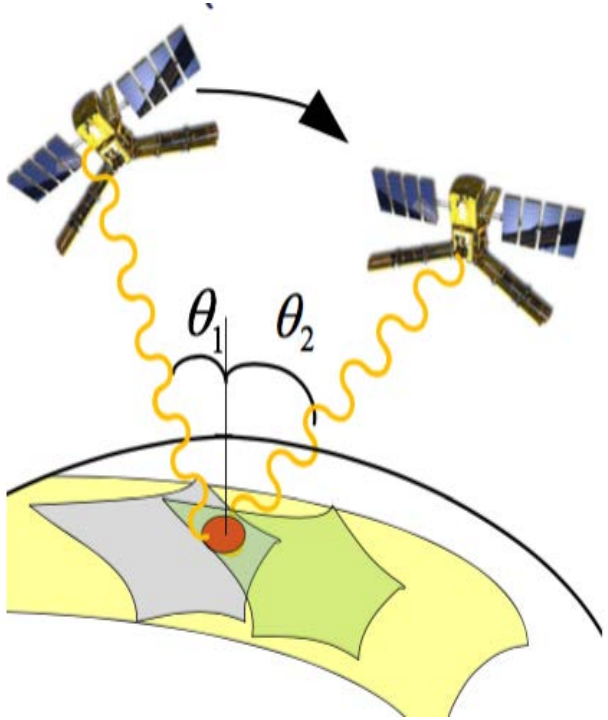
OL = Open Loop, or model only

Girotto et al., (2016), WRR

Microwave (L-band, 1.4GHz) Observations (SMOS/SMAP)

Soil Moisture From Space: SMOS(SMAP)

*Soil Moisture and Ocean Salinity (**SMOS**) Mission*



- L-band at multiple incidence angles
- Lauched: Nov. 2009
- ~40 km resolution

Advantages:

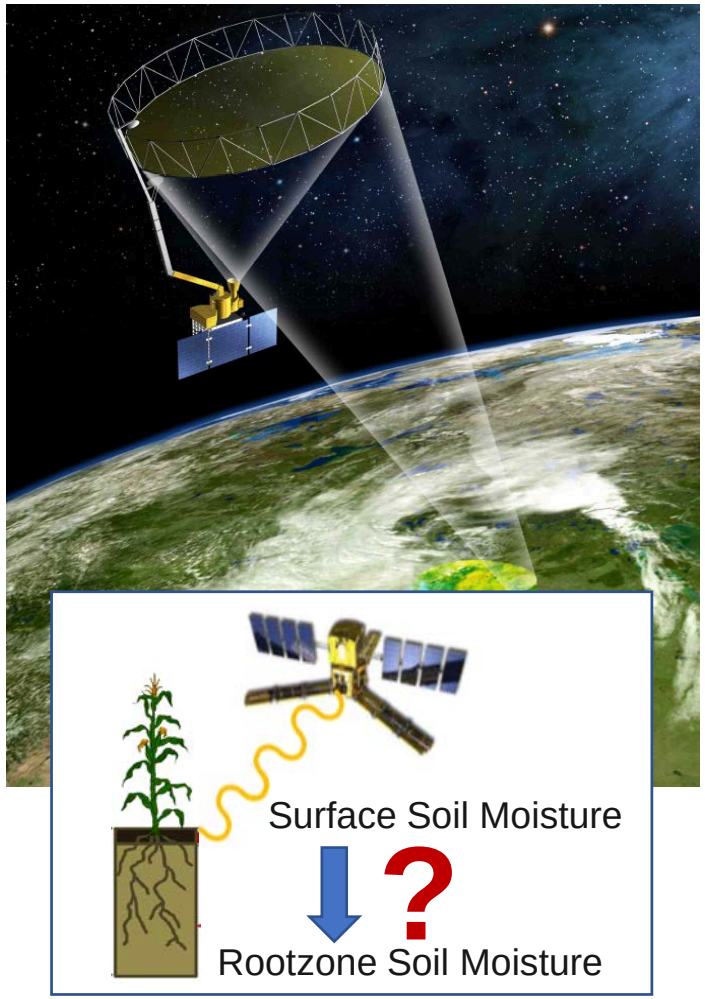
- Tb (L-band,1.4GHz) depends on soil moisture
- Frequent observations (e.g., global coverage **every 2-3 days**)
- "Good" horizontal resolution (**40km**)

Disadvantages:

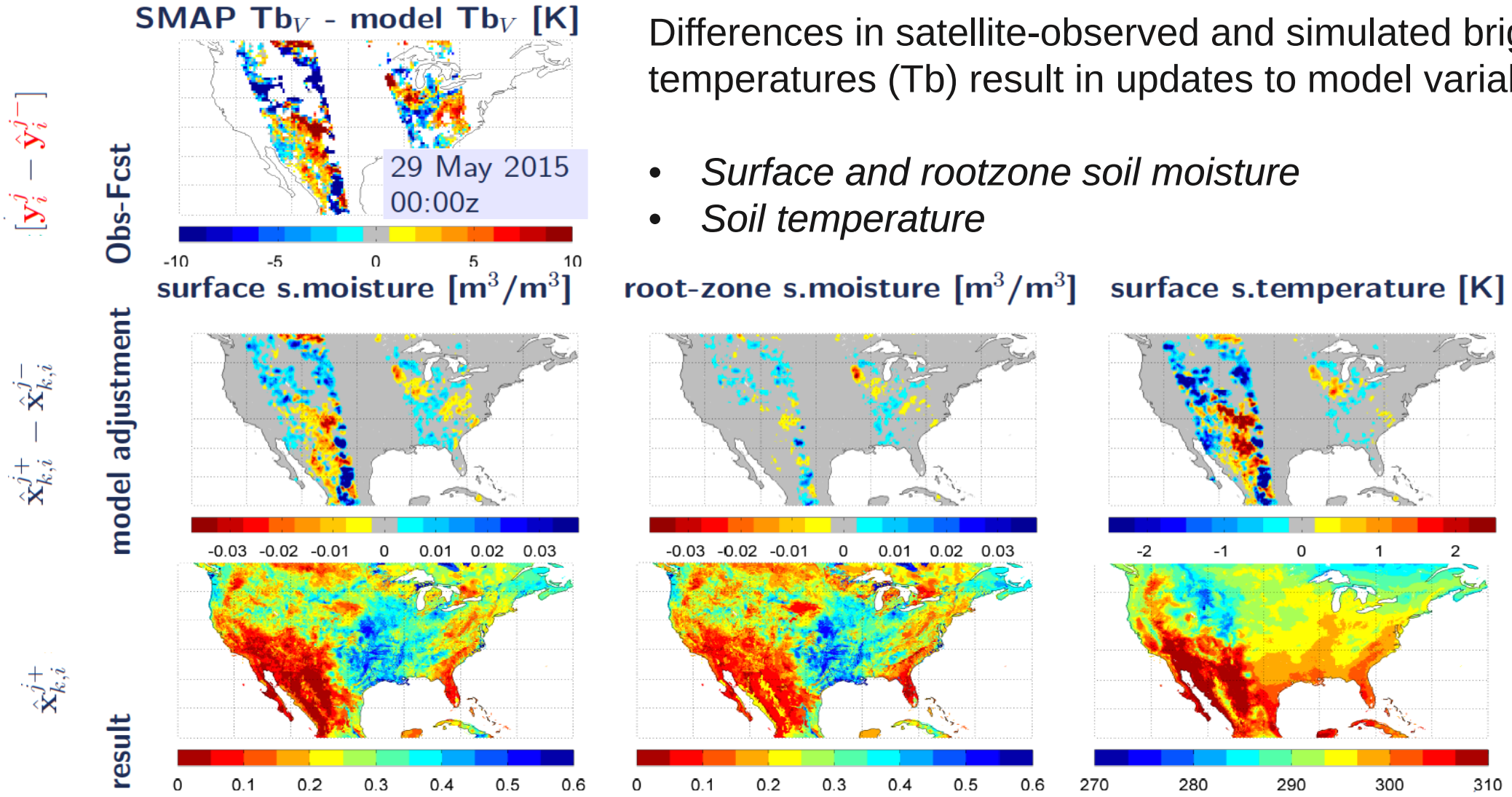
- Data Gaps
- Only sensitive to soil moisture of **surface** layer (i.e., ~<5cm)

What about rootzone and filling the gap?

*Soil Moisture Active Passive (**SMAP**)*



Soil Moisture Data Assimilation (SMOS/SMAP)



Differences in satellite-observed and simulated brightness temperatures (Tb) result in updates to model variables:

- *Surface and rootzone soil moisture*
- *Soil temperature*

De Lannoy and Reichle (2016), JHM

Soil Moisture Data Assimilation: Validation

Soil Moisture:
- 157 SCAN (Soil and Climate Analysis Network)
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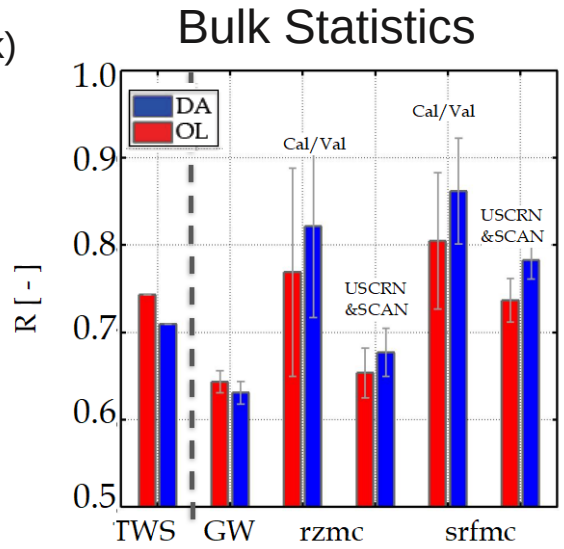
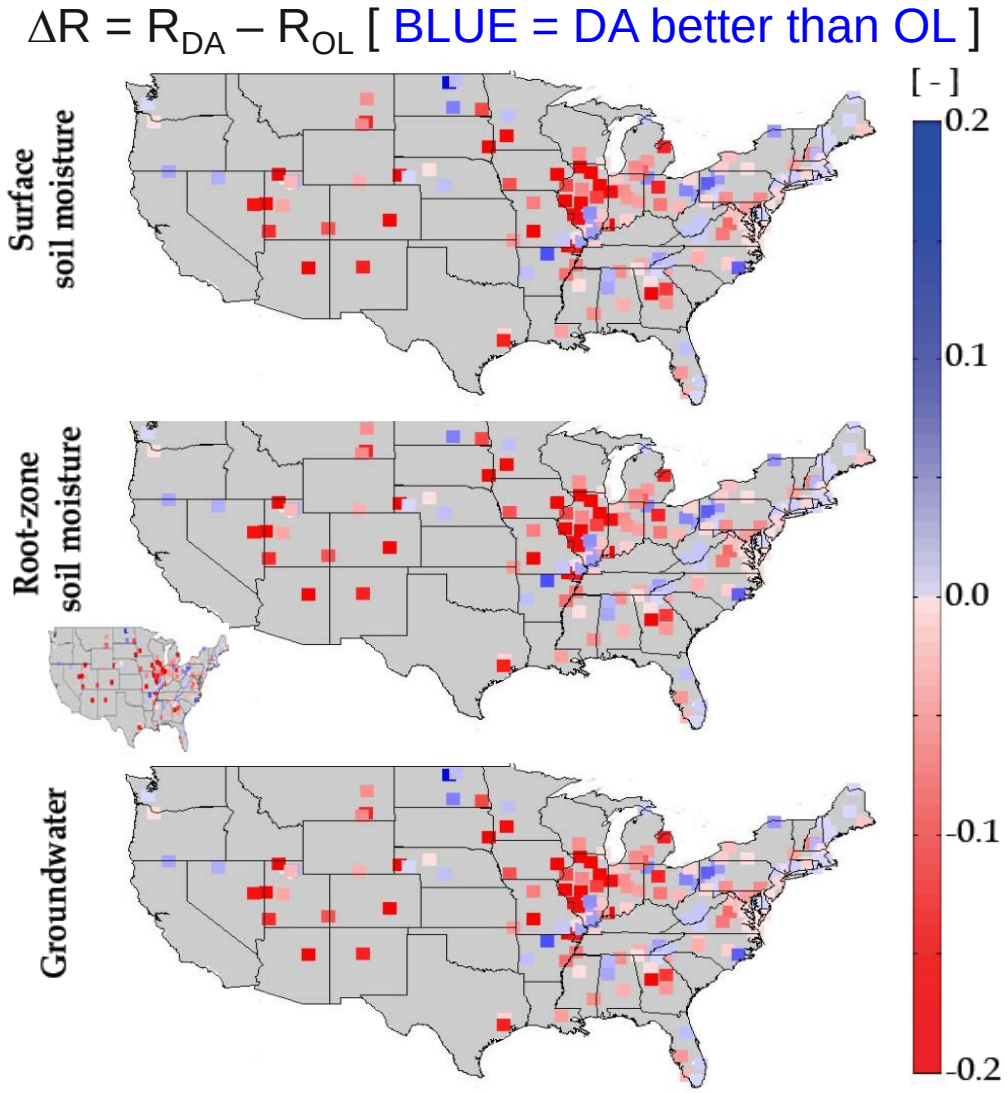




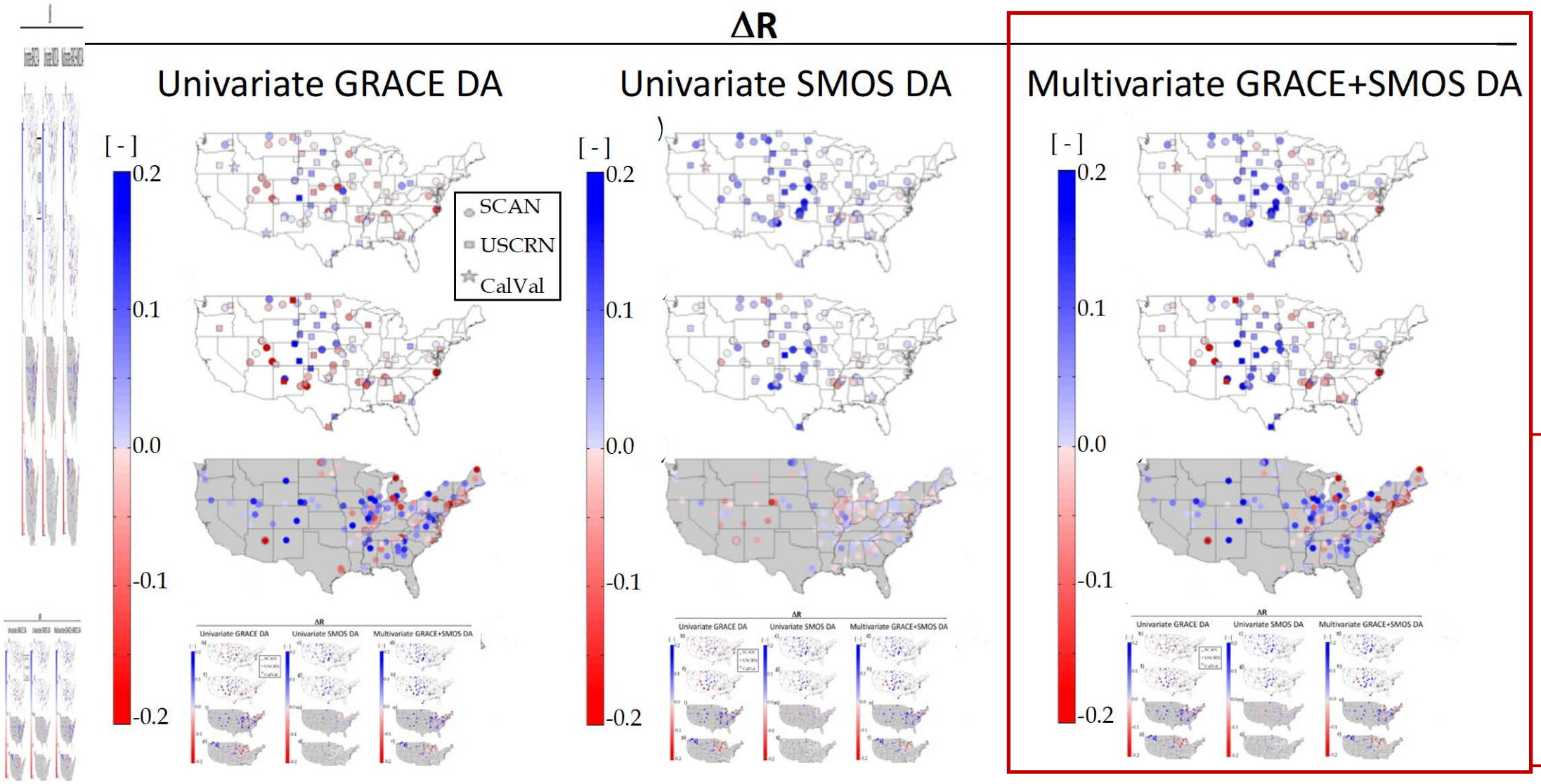
SMOS-DA

- Beneficial for surface and root zone soil moisture
- But has degraded groundwater

What if we incorporate both GRACE+SMOS together?

Girotto et al., (in review)

GRACE+SMOS Data Assimilation: Validation



Best estimates when both SMOS & GRACE obs. are assimilated!

Girotto et al., (in review)

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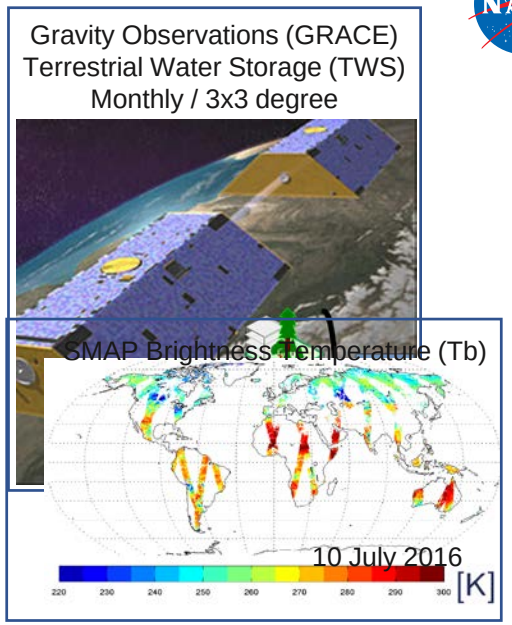
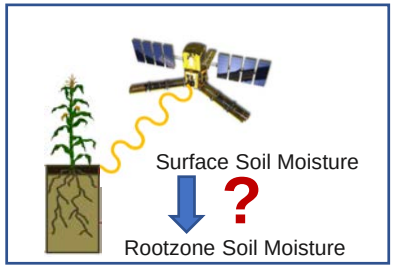
- **Conclusions & Future Directions**

Summary

- **Understanding the Hydrological Cycle is critical for weather and climate forecasts, economic developments, etc.**
- **GRACE-DA for improved groundwater**
- **SMOS(SMAP)-DA as gap filling method, for improved soil moisture**
- **Combination SMOS+GRACE leads to better hydrology than using them individually**
- **Data Assimilation can be used to estimate variables that are not directly observed (E.g.,** SMOS(SMAP) surface → rootzone soil moisture)





Data Assimilation Enhances the Usefulness of the Remotely Sensed Observations

A Multi-Sensor Data Assimilation Platform

The number of earth satellite observations is increasing but the majority of these observations are not yet fully exploited in a comprehensive manner for ***Environmental Science Applications*** *(e.g., hydrology, environmental, urban planning, etc.)*

Thanks for your attention!

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