Enhancing GRACE/GRACE FO Products for Hydrological Applications

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GRACE Data Assimilation: Motivation

Value of GRACE observations for hydrology is limited by

- product latency
- low spatial resolution
- low temporal resolution
- lack of info on vertical distribution of observed mass changes

Hydrologic models simulate the terrestrial water cycle, but accuracy is limited by

- quality of the input forcing and parameter data
- model developers' understanding of the physics involved
- simplifications necessary to simulate physical processes economically

Data assimilation can harness the advantages of each:

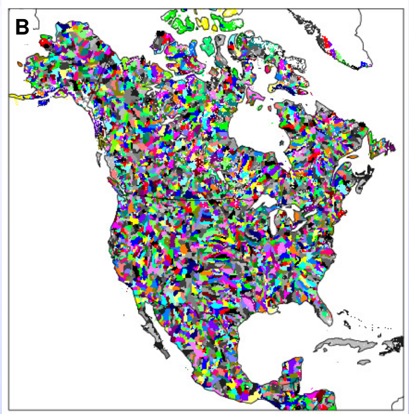
- models provide physically consistent, high resolution output
- models can run up to near-real time
- GRACE and other observations anchor the results in reality
- DA incorporates error information to ensure optimal blending

Challenges to Assimilating GRACE Data

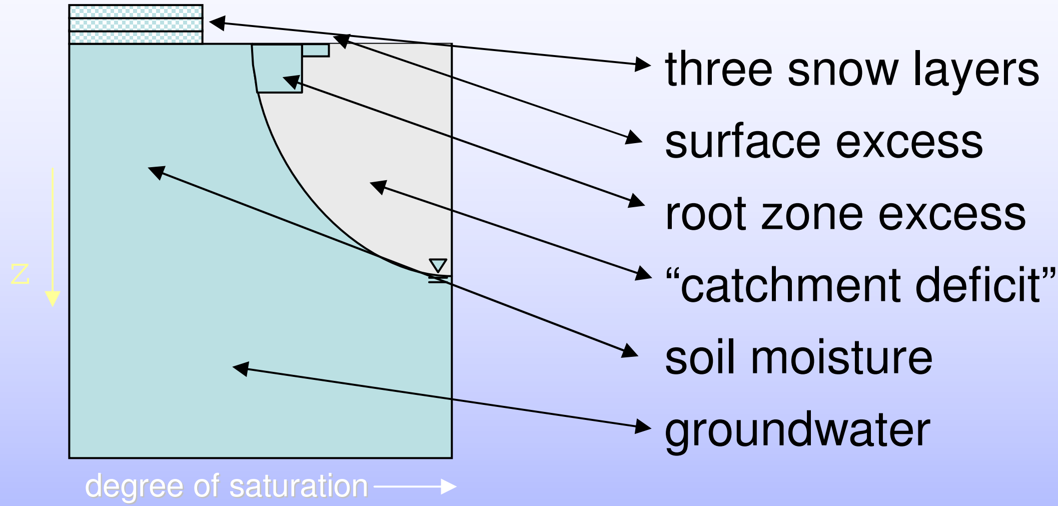
- Spatial resolution of GRACE is coarser than that of models
- We normally assimilate instantaneous observations
- We normally assimilate data describing a single state field (e.g., 2 cm soil moisture)
- We normally assimilate absolute quantities, not anomalies/changes
- Most land surface models do not account for ground water storage
- DA requires rigorous uncertainty estimates with products

GRACE Data Assimilation Configuration

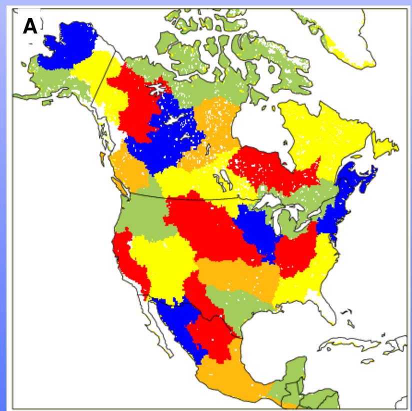
Catchment LSM spatial elements (average size ~2,500 km²)

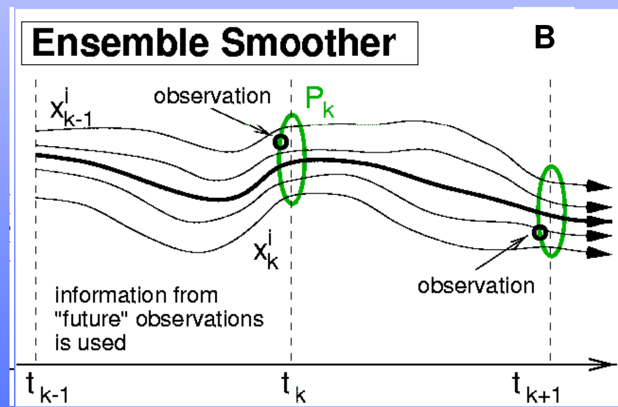


Catchment Land Surface Model (Koster et al., 2000)



GRACE observation scale: river basins (200,000 – 1,000,000 km²)





Data assimilation enables spatial and temporal downscaling and vertical decomposition of GRACE derived terrestrial water storage into groundwater, soil moisture, and snow.

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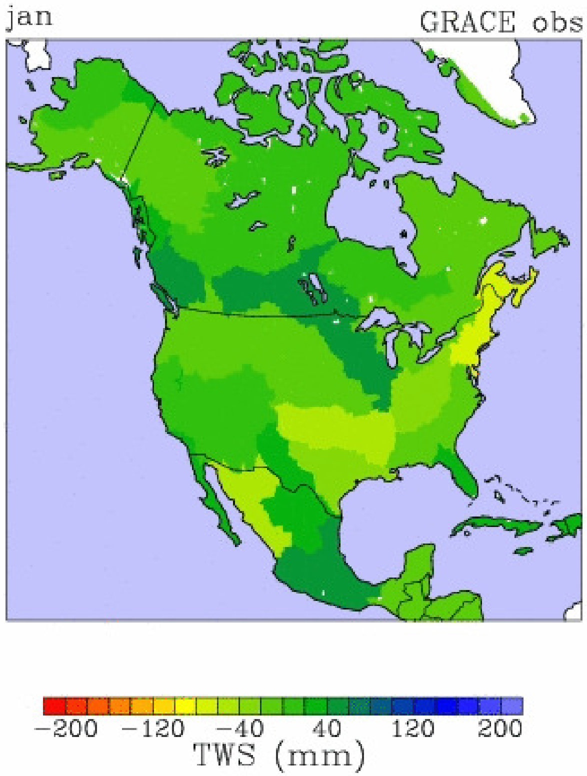
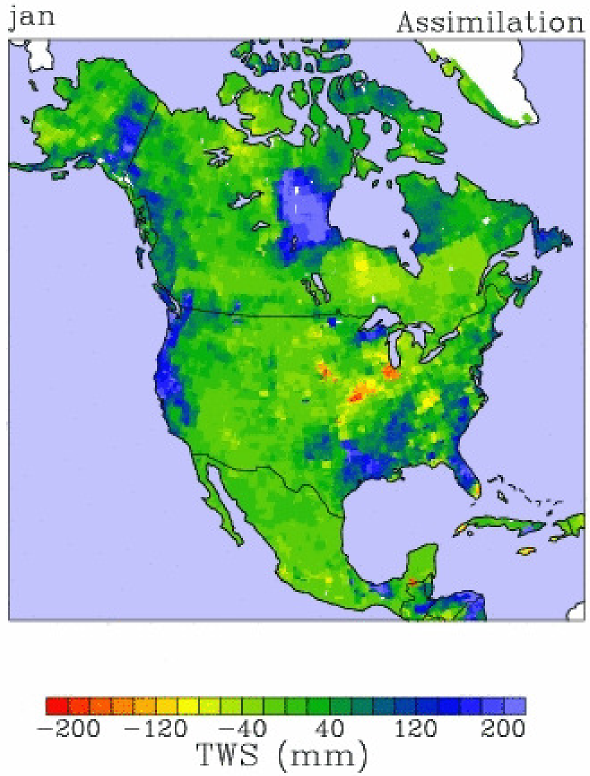
Improvement in Spatial Resolution

GRACE water storage, mm
January-December 2003 loop



Model assimilated water storage, mm
January-December 2003 loop



Monthly anomalies (deviations from the 2003 mean) of terrestrial water storage (sum of groundwater, soil moisture, snow, and surface water) as an equivalent layer of water. Updated from *Zaitchik, Rodell, and Reichle, J. Hydromet., 2008*.

From scales useful for water cycle and climate studies…

To scales needed for water resources and agricultural applications

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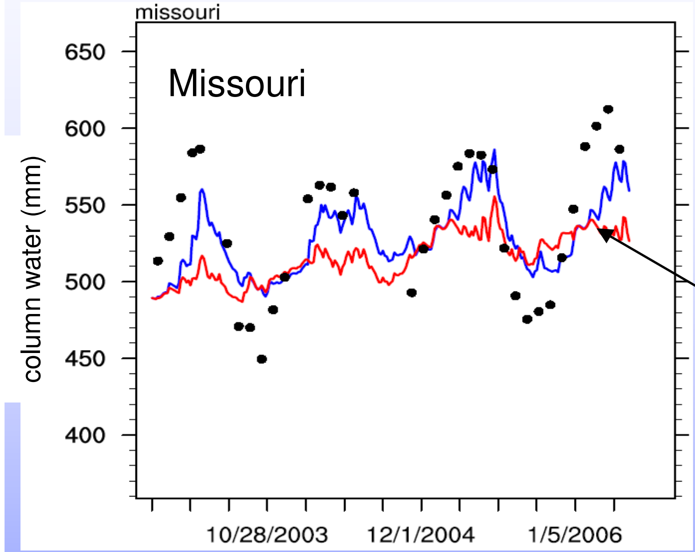
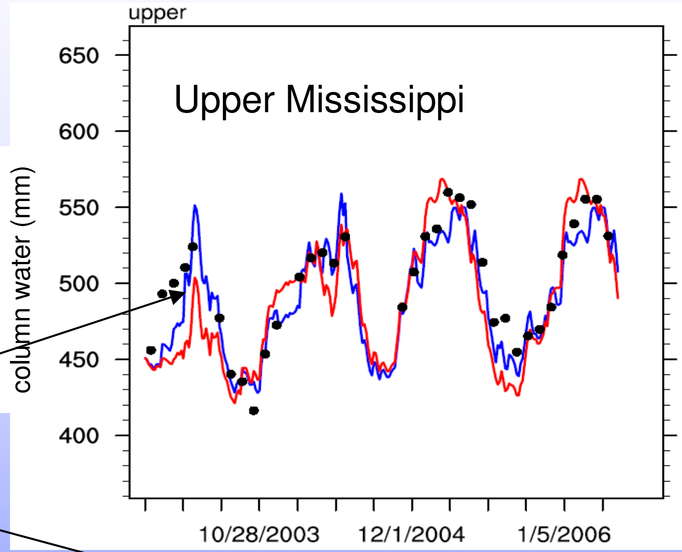
Improvement in Temporal Resolution and Latency

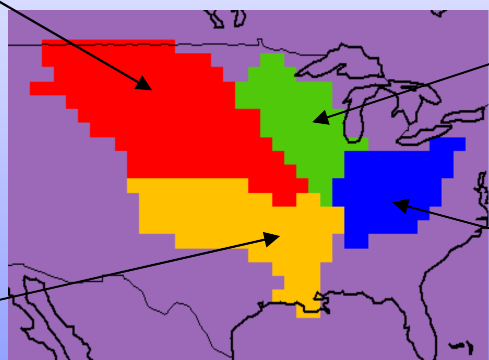
Models produce continuous time series.

Monthly GRACE data anchor model results in reality

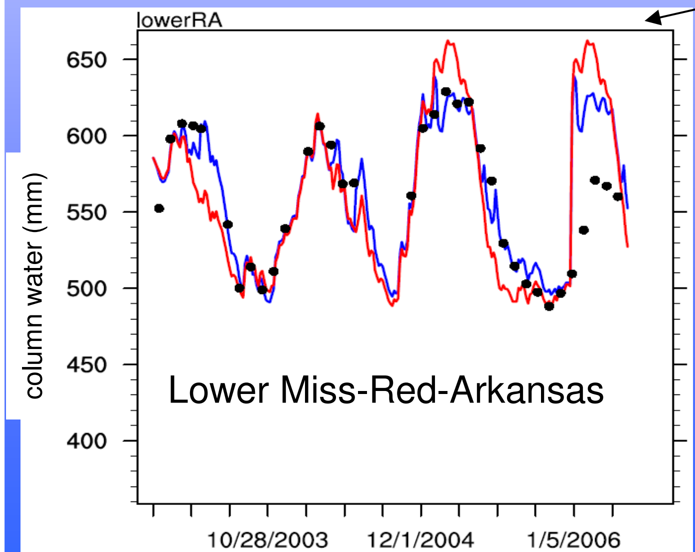




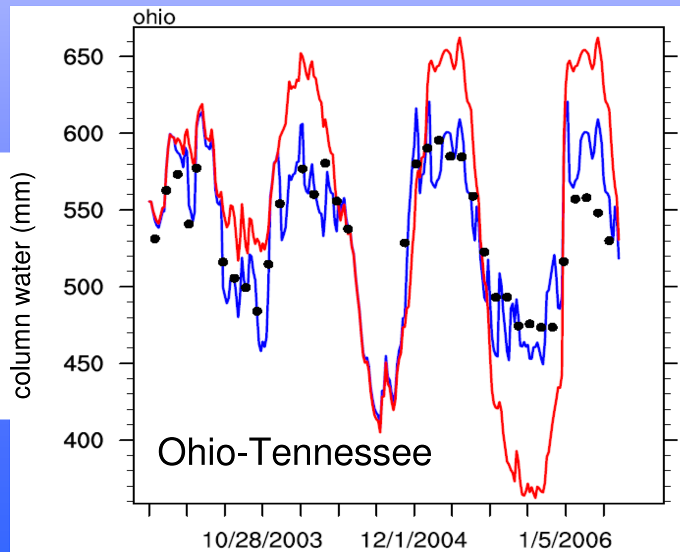
Mississippi River sub-basins



- ● GRACE Water Storage
- Modeled Water Storage (red line)
- Model-GRACE Assimilation (blue line)

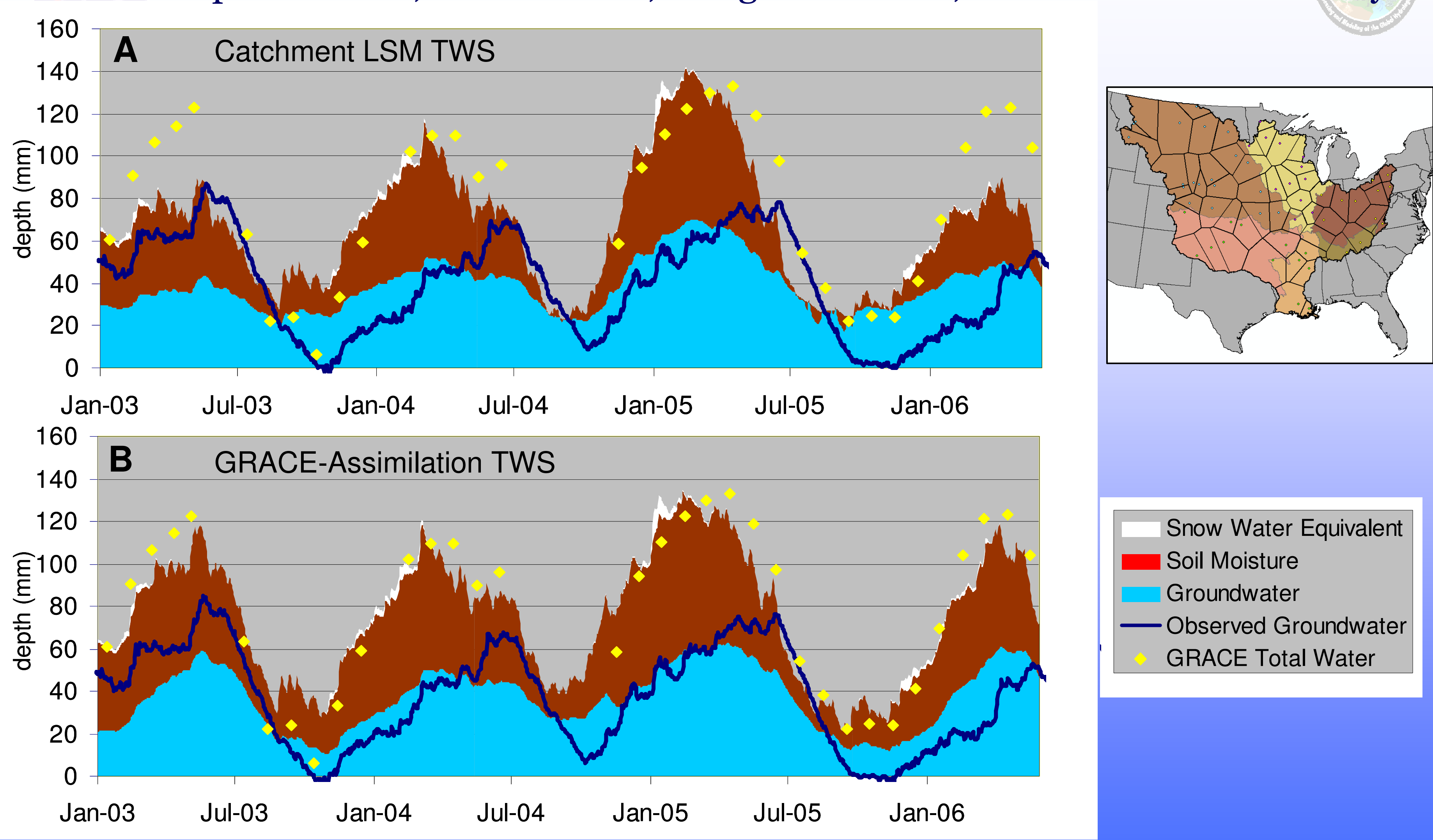


Daily estimates are critical for operational applications



Separation of TWS Components

Models separate snow, soil moisture, and groundwater; GRACE ensures accuracy.



From a global, integrated observation
To application-specific water storage components

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Evaluation of GRACE DA Results

Statistically significant improvement of groundwater estimates

	OL		GRACE DA		
	r	RMSE	r	RMSE	skill
Mississippi	0.59	23.5	**0.69**	18.7	0.20
Ohio-TN	0.78	62.8	**0.82**	41.1	0.35
Upper Miss.	0.29	42.6	0.29	40.1	0.06
Red-Ark. / L.M.	0.69	30.9	*0.72*	26.5	0.14
Missouri	0.41	24.5	**0.66**	19.7	0.20

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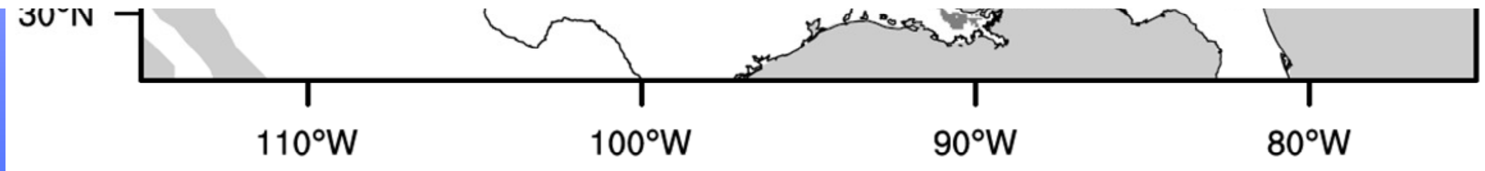
Evaluation of GRACE DA Results

Some improvement of runoff estimates

		r_{TWS}		r_R	
River	**Discharge**	**OL**	**GRACE DA**	**OL**	**GRACE DA**
Kanawha	537	0.41	0.42	0.52	0.52
Wabash	1,001	0.55	**0.62**	0.18	0.18
Illinois	527	0.68	**0.72**	0.30	0.29
Minnesota	160	0.61	**0.69**	0.35	0.36
Arkansas	240	0.19	**0.29**	0.20	0.22
Ouachita	83	0.37	0.35	0.04	0.04
Yellowstone	212	0.24	0.26	0.35	*0.42*
Kansas	107	0.4	**0.49**	0.55	*0.59*



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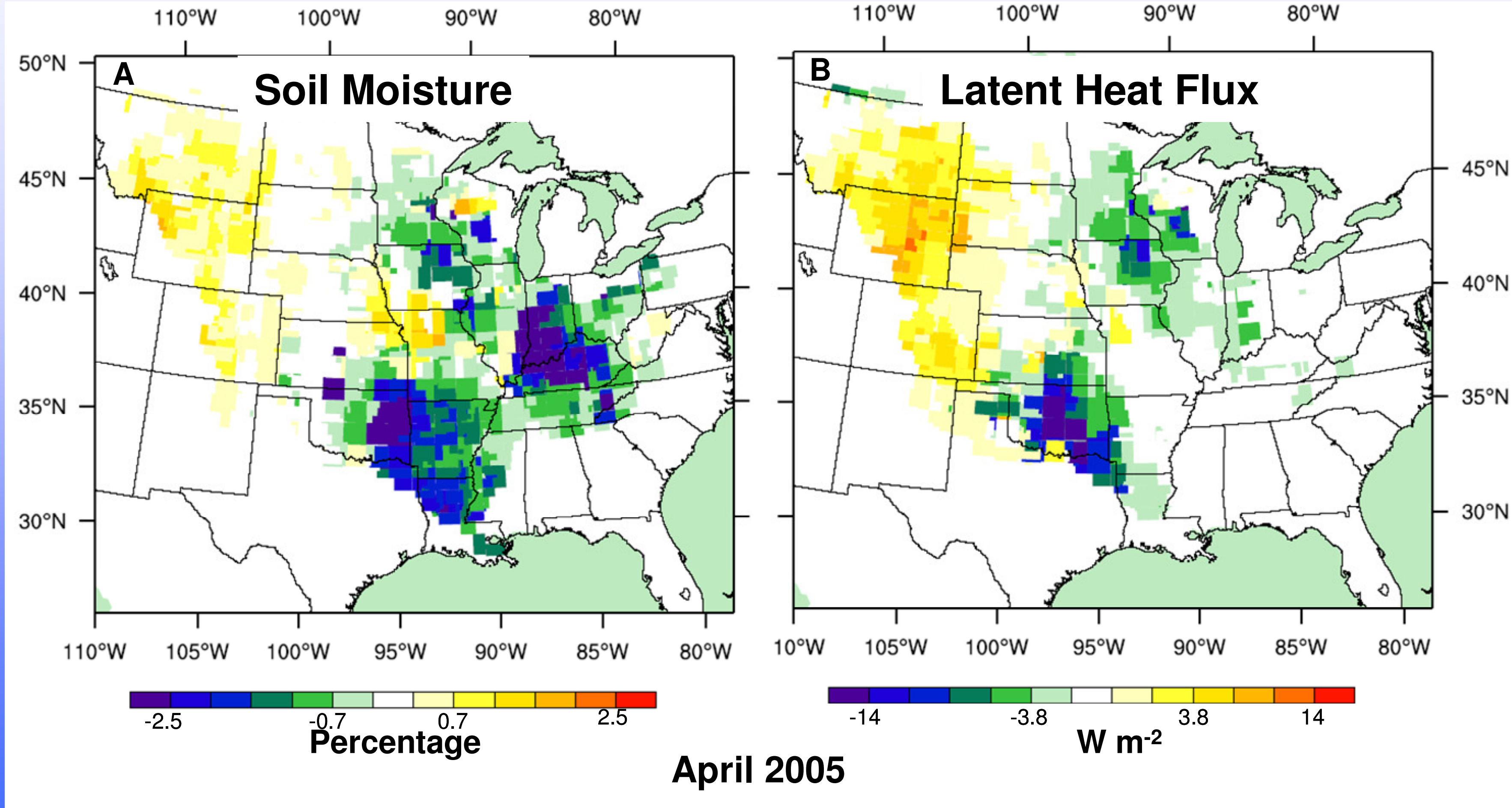
Effects on Other Water Cycle Variables

GRACE data assimilation affects other modeled variables as well



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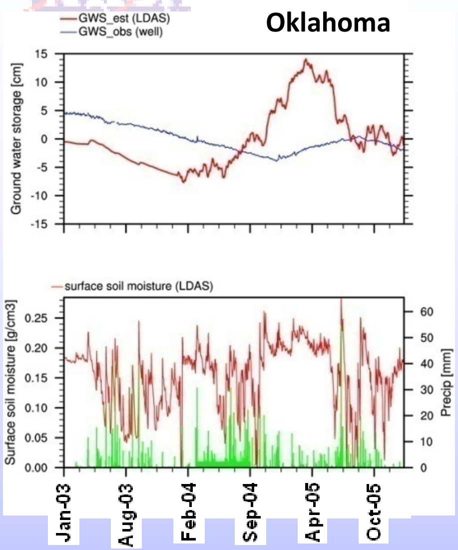
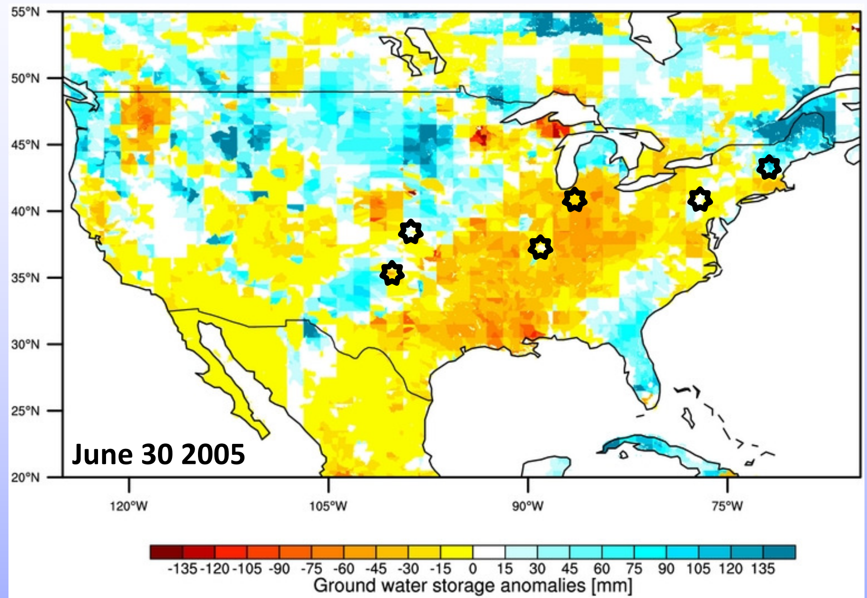
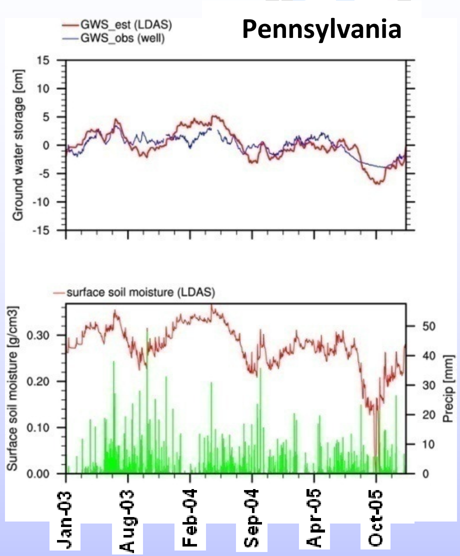
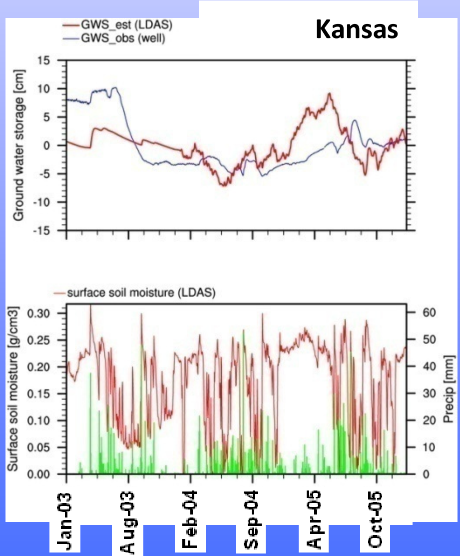
Evaluation of Modeled Groundwater Variations

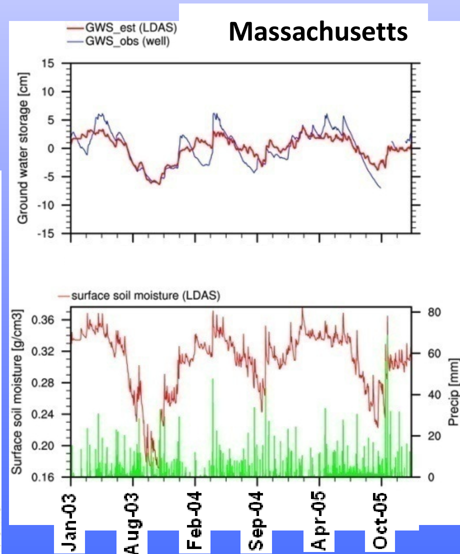


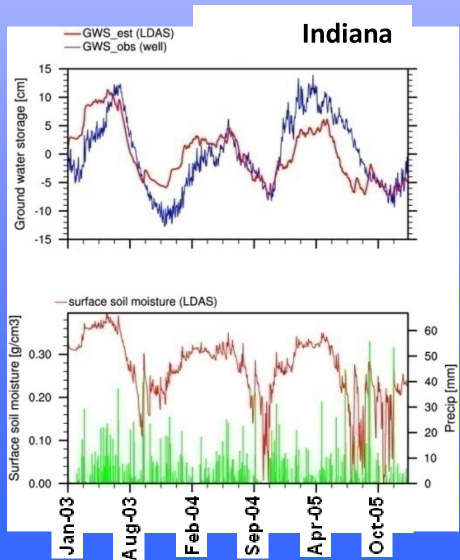
LDAS groundwater storage

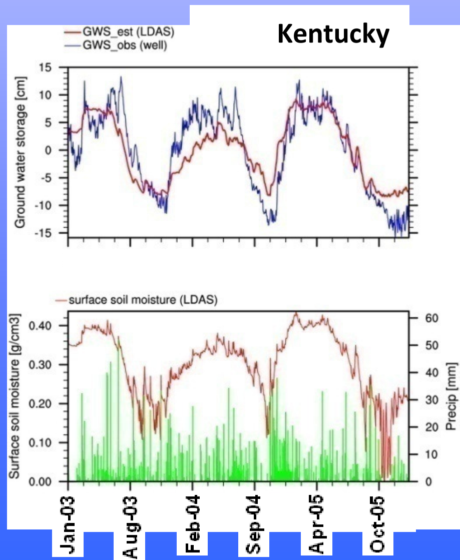












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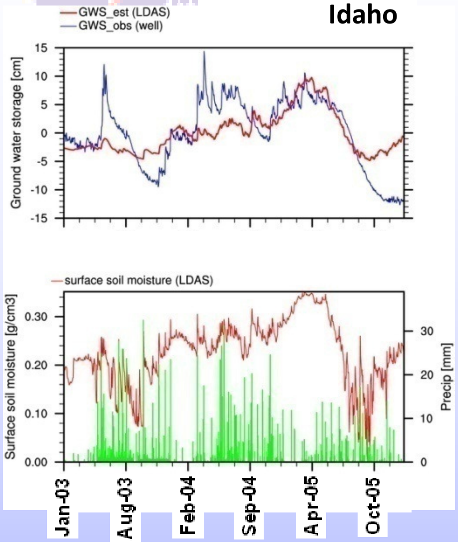
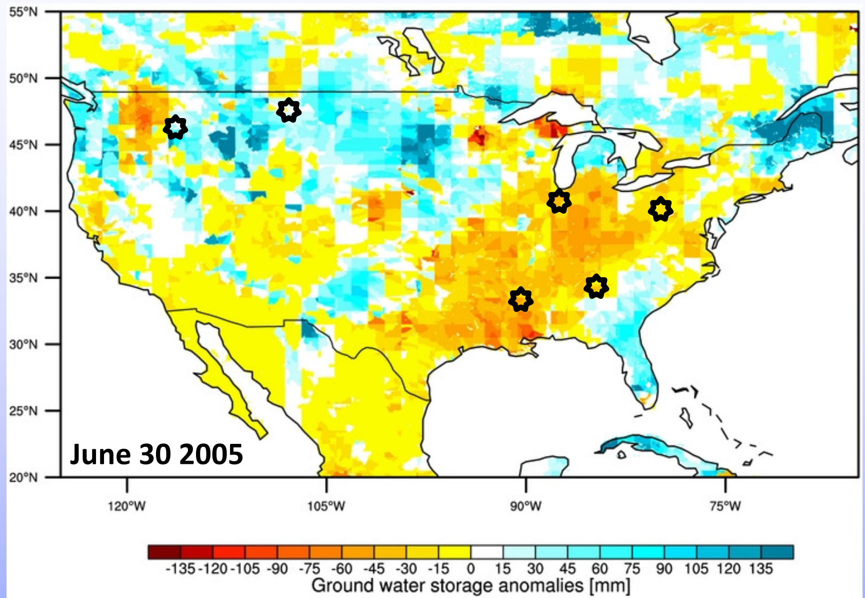
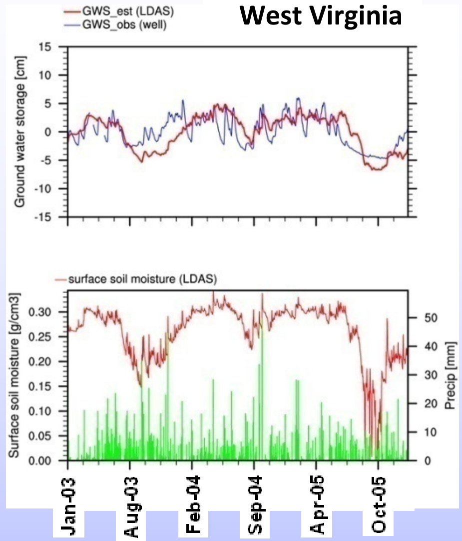
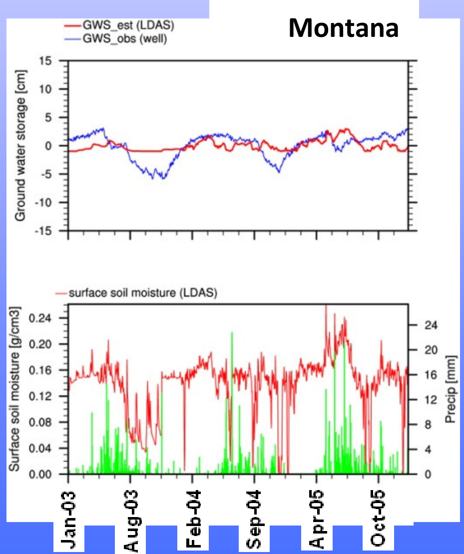
Evaluation of Modeled Groundwater Variations

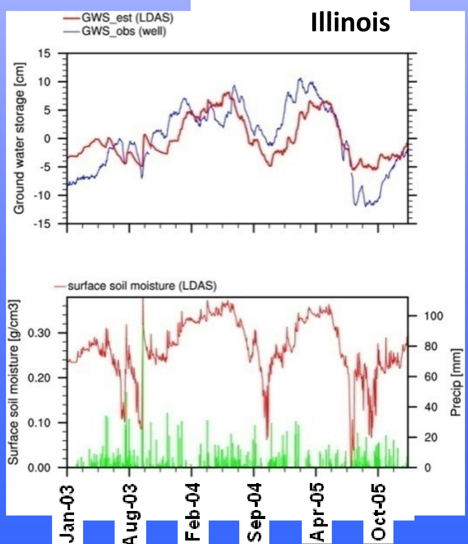


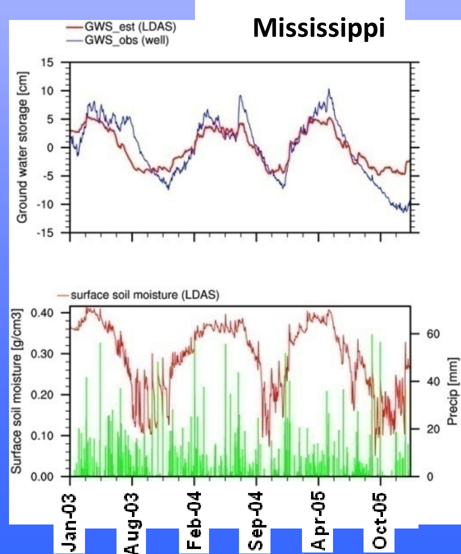
LDAS groundwater storage

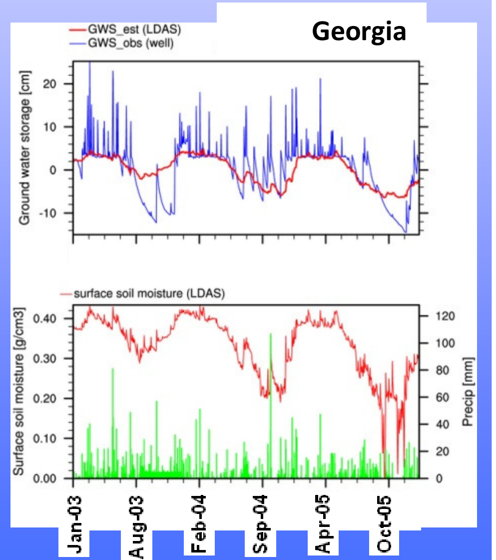












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Discussion

• GRACE is unique in its ability to monitor water in all forms and at all depths

• The value of GRACE derived TWS data can be enhanced by merging them with information from other sources

• Data assimilation synthesizes the advantages of observations and numerical models:

- More accurate than model alone

- Higher spatial and temporal resolutions than observations alone

- Latency is eliminated

- TWS is separated into components

• Data assimilation makes GRACE suitable for many applications

• Care must be taken to:

-properly reconcile short GRACE time series with longer term model climatology

- ensure that the model's dynamic range is sufficient