Remote Sensing of Terrestrial Water Storage and Application to Drought Monitoring

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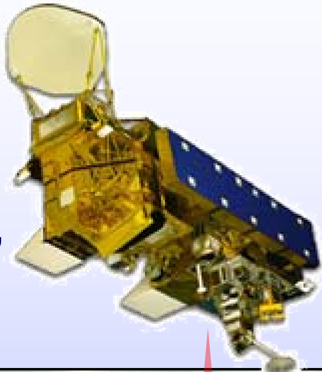
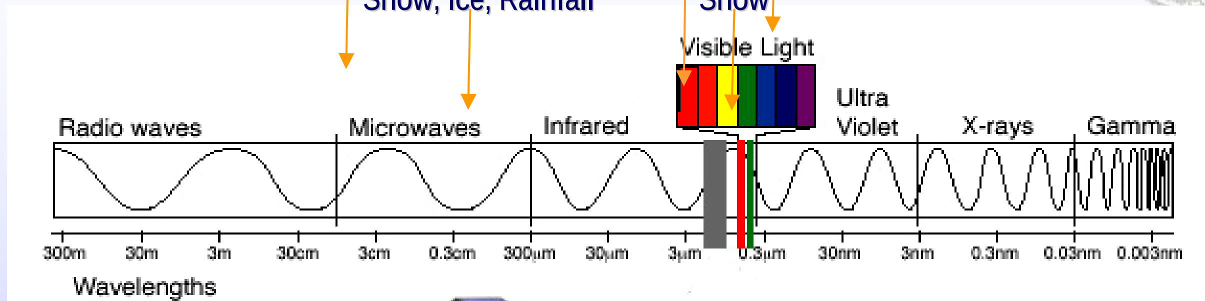
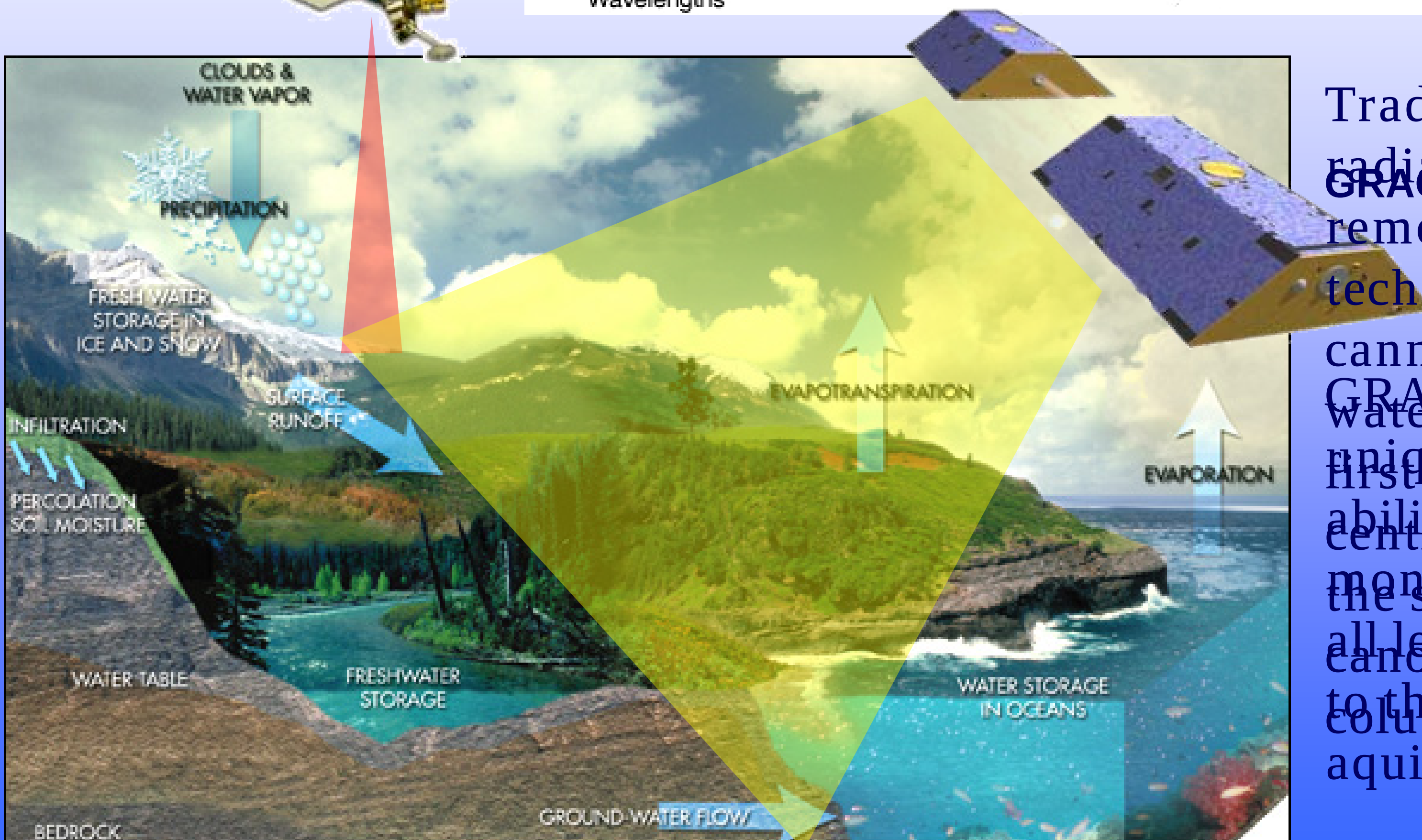
Remote Sensing of the Water Cycle

Aqua: MODIS, AMSR-E, etc.







Traditional radiation-based remote sensing technologies cannot sense water below the first few centimeters of the snow-canopy-soil column

GRACE

GRACE is unique in its ability to monitor water at all levels, down to the deepest aquifer

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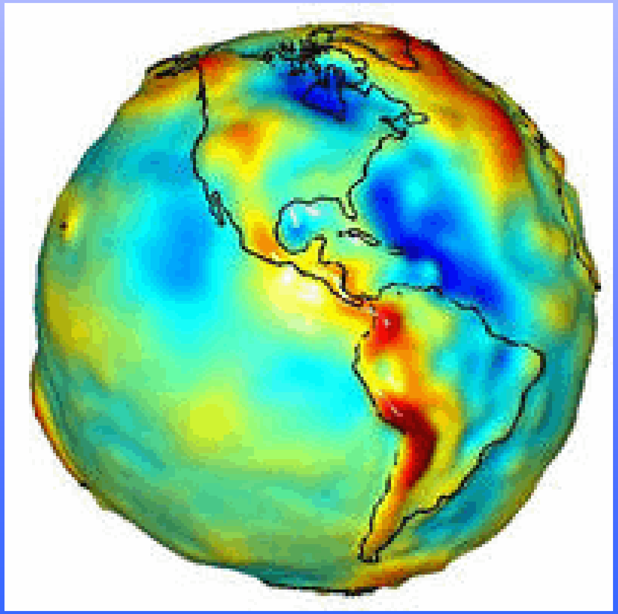
Gravity Recovery and Climate Experiment



Science Goal: High resolution, mean and time variable gravity field mapping for Earth System Science applications

Instruments: Two identical satellites flying in tandem orbit, 215 km apart, ~485 km altitude

Key Measurements: Location and distance between two satellites tracked by GPS and high precision microwave ranging system

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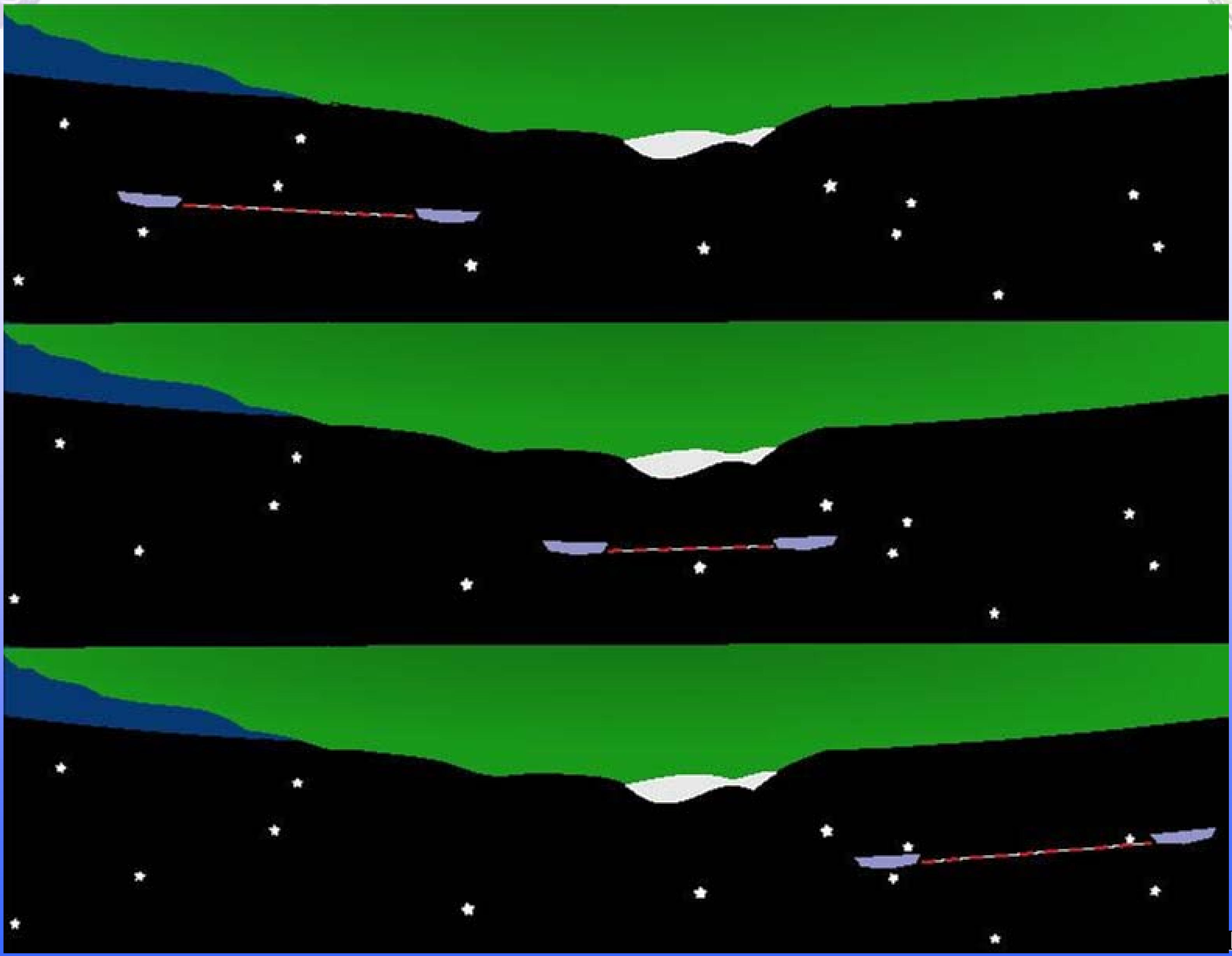
GRACE Intersatellite Ranging



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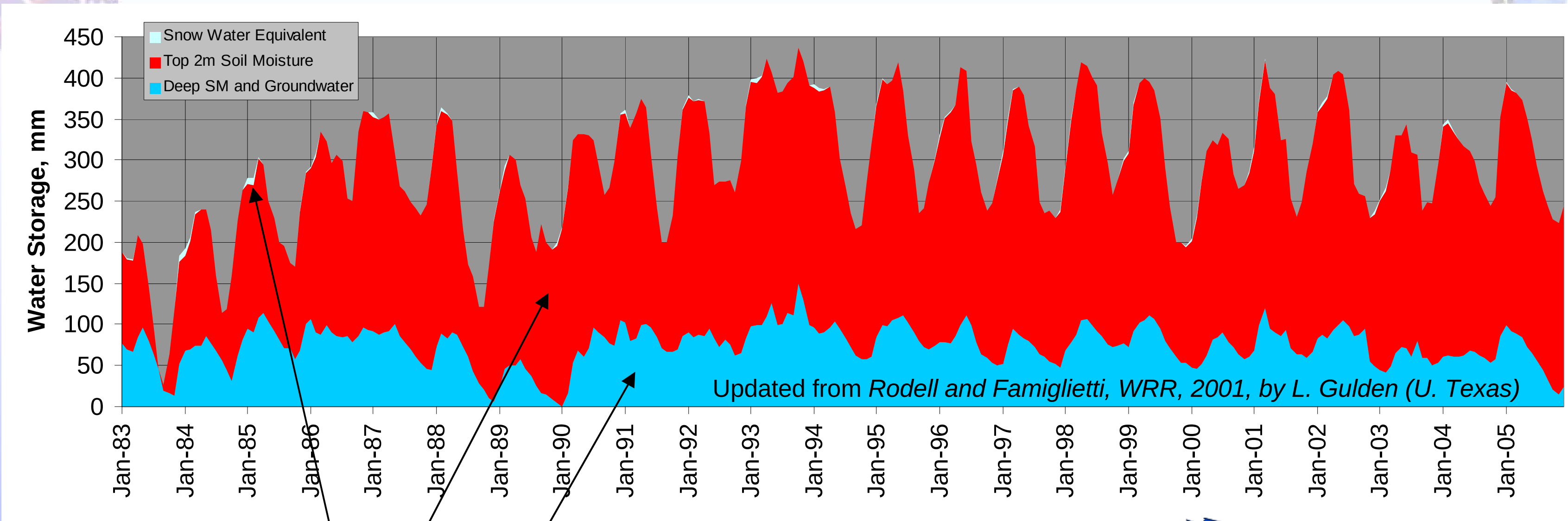
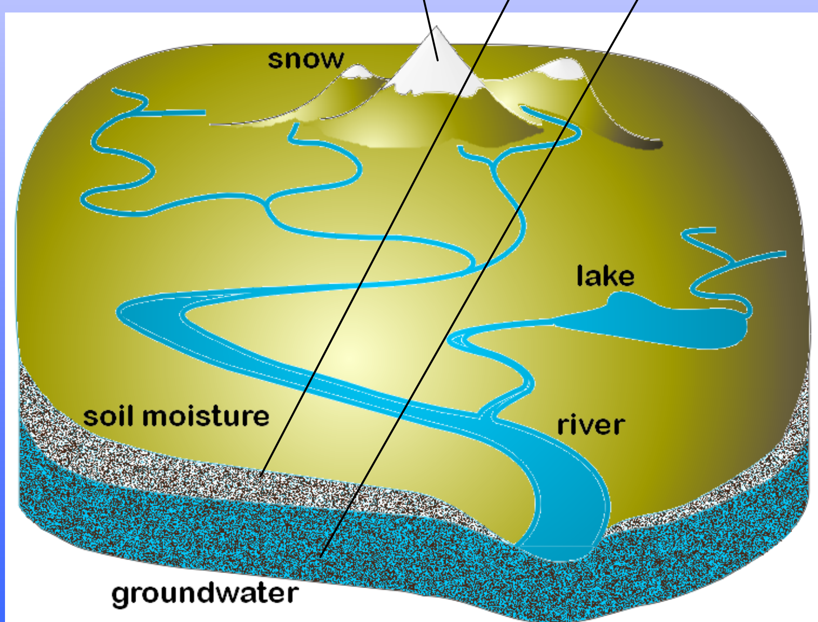
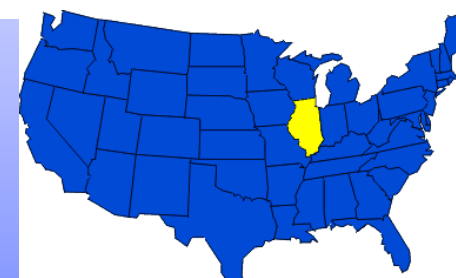
Terrestrial Water Storage Variations





Top: 23 year time series of snow, soil moisture, and groundwater storage in Illinois, USA (right)



TWS variations are dominated by:

Soil moisture in temperate regions;

Snow in polar and alpine regions;

Surface water in wetlands.

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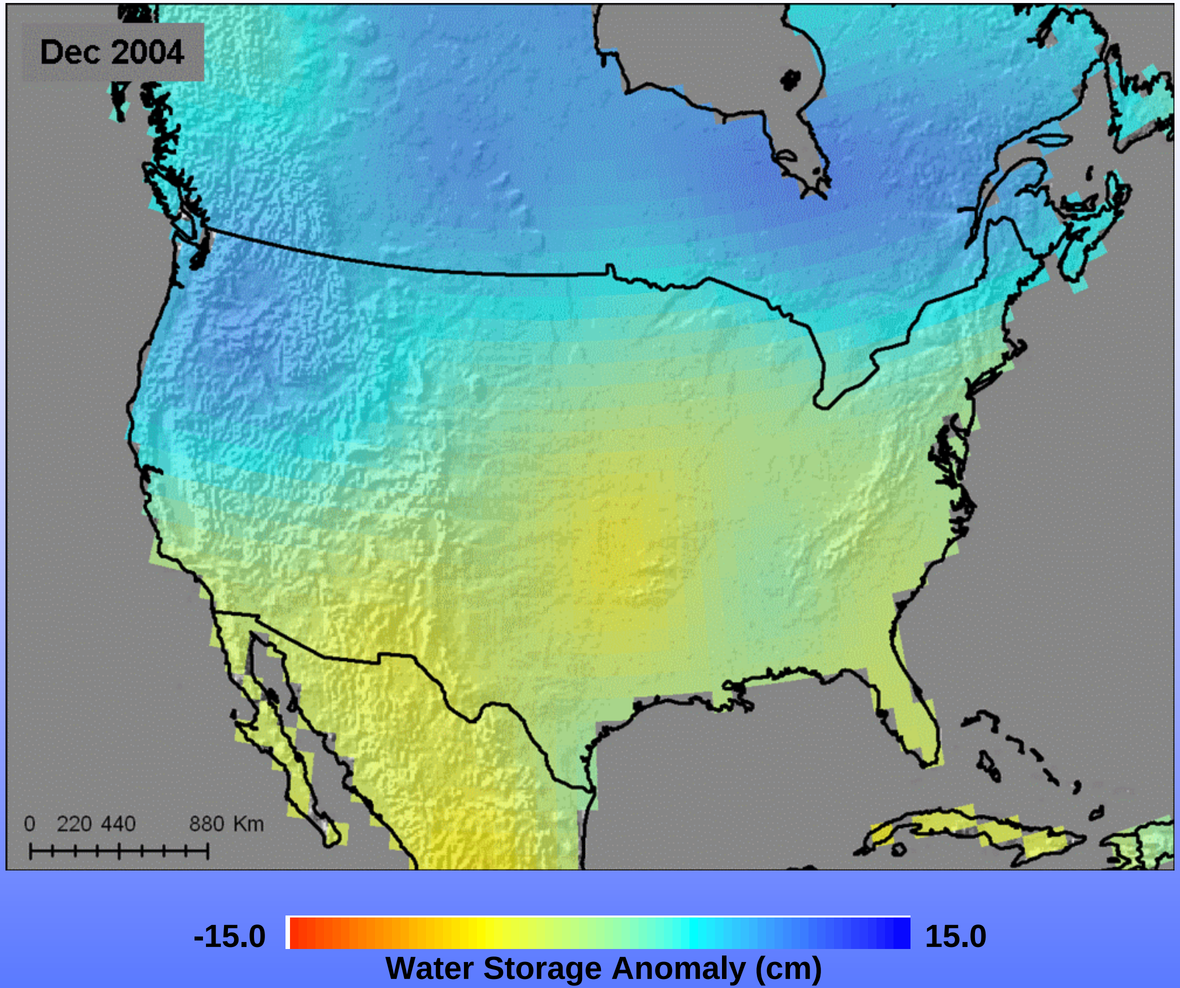
Water Storage Anomalies from GRACE



GRACE derived terrestrial water storage data are valuable for climate studies, but they lack the high resolution necessary for many applications

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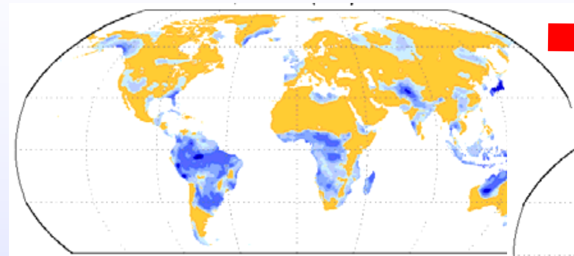
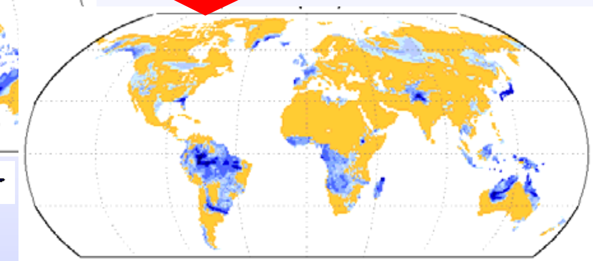
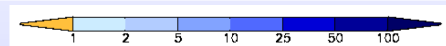
Data Integration Within a Land Data Assimilation System (LDAS)

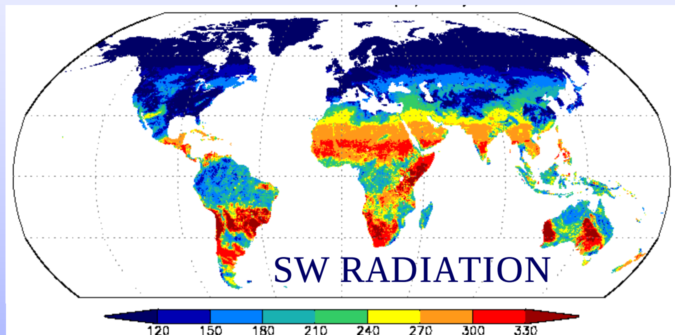
INTERCOMPARISON and OPTIMAL MERGING of global data fields





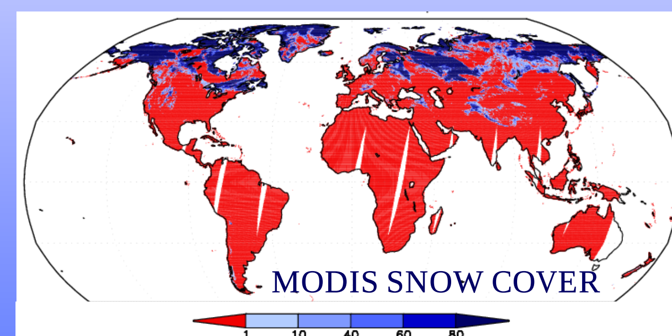


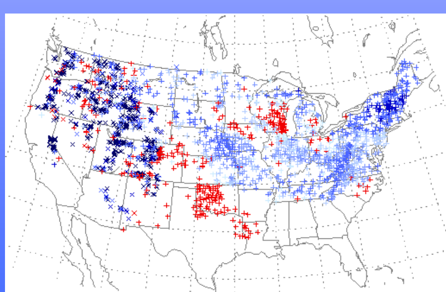
PRECIPITATION

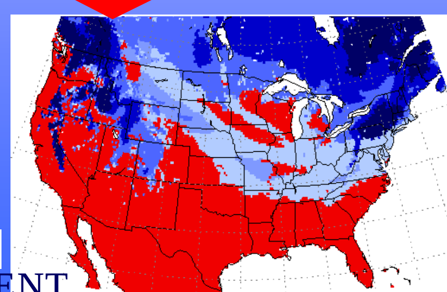


Satellite derived meteorological data used as land surface model FORCING

ASSIMILATION of satellite based land surface state fields (snow, soil moisture, surface temp, etc.)







SNOW WATER EQUIVALENT

Ground-based observations used to VALIDATE model output

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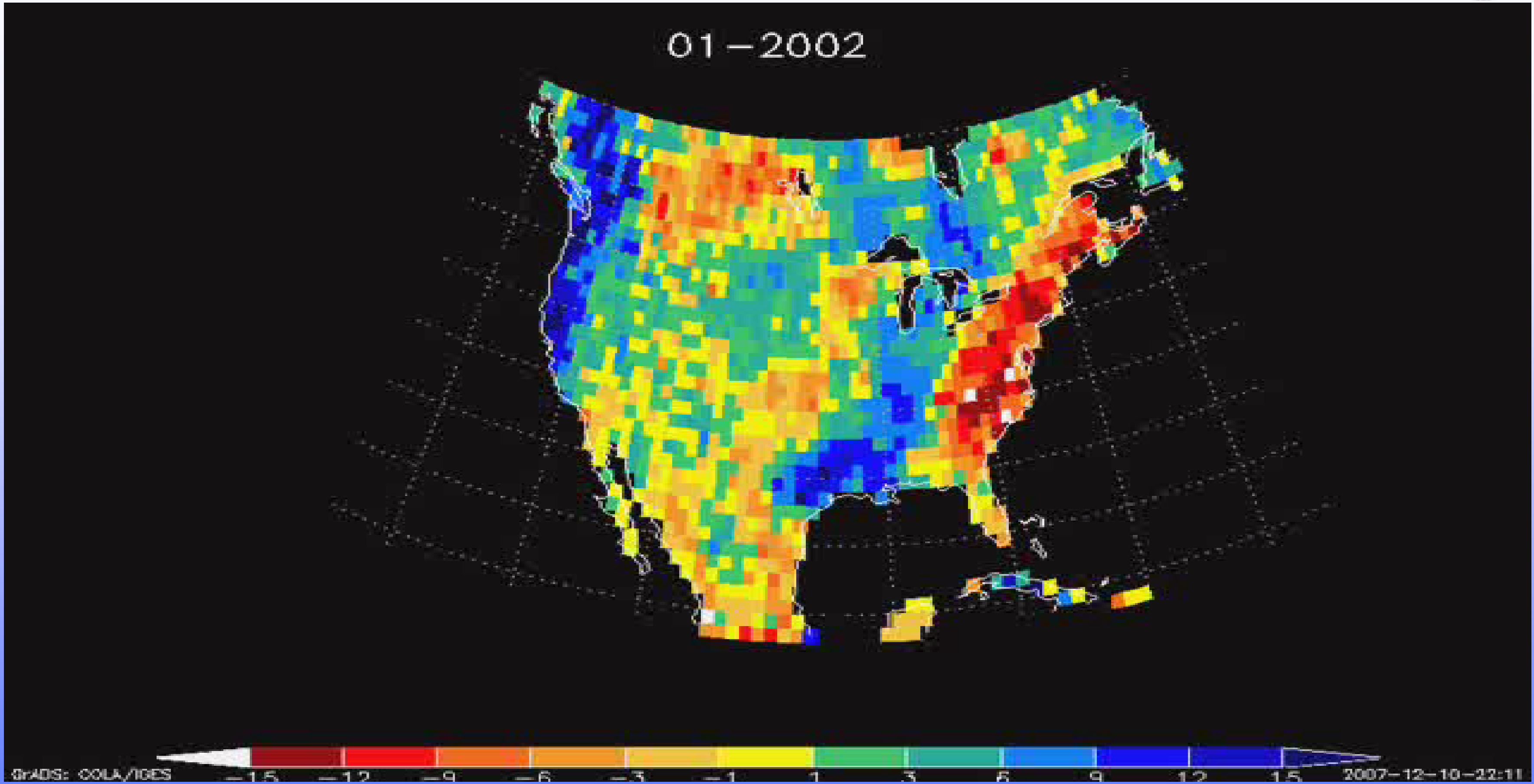
Modeled Water Storage Anomalies (cm)



Land surface models use physical equations to simulate water cycle processes at high resolutions, but accuracy is limited by input data quality and simplifications necessary to run efficiently

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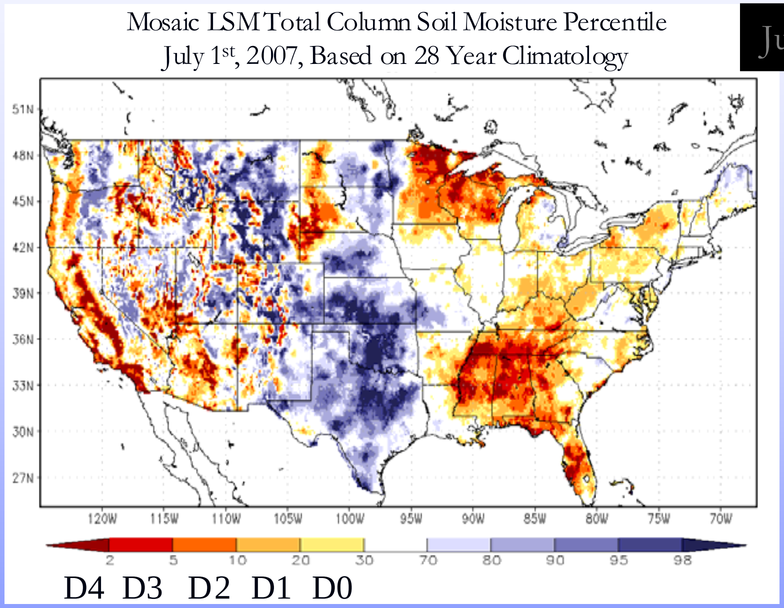
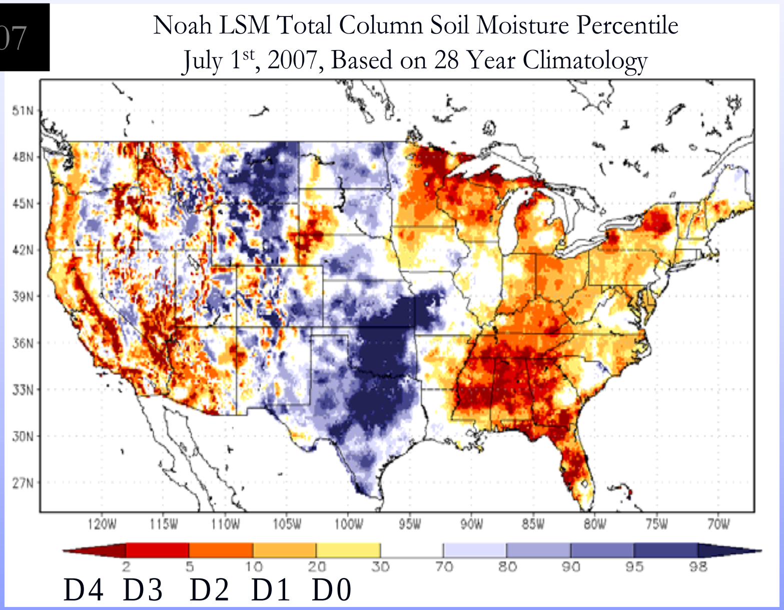
"Application of NLDAS Ensemble LSM Simulations to Continental-Scale Drought Monitoring"

-Mosaic-



July 1st, 2007

-Noah-



Soil moisture percentile total column daily snapshot

Courtesy of Brian Cosgrove, NASA/GSFC
Project funded by NOAA CPPA and NASA WMP

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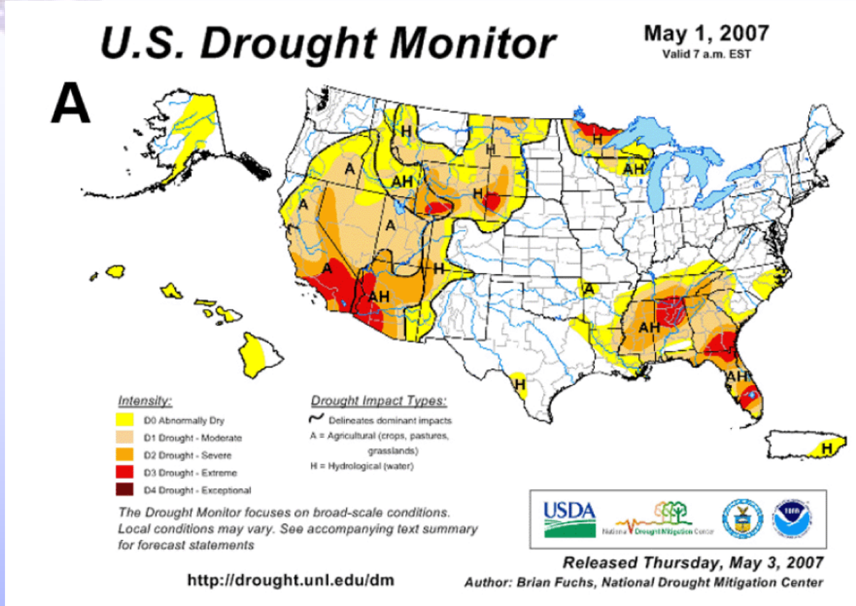
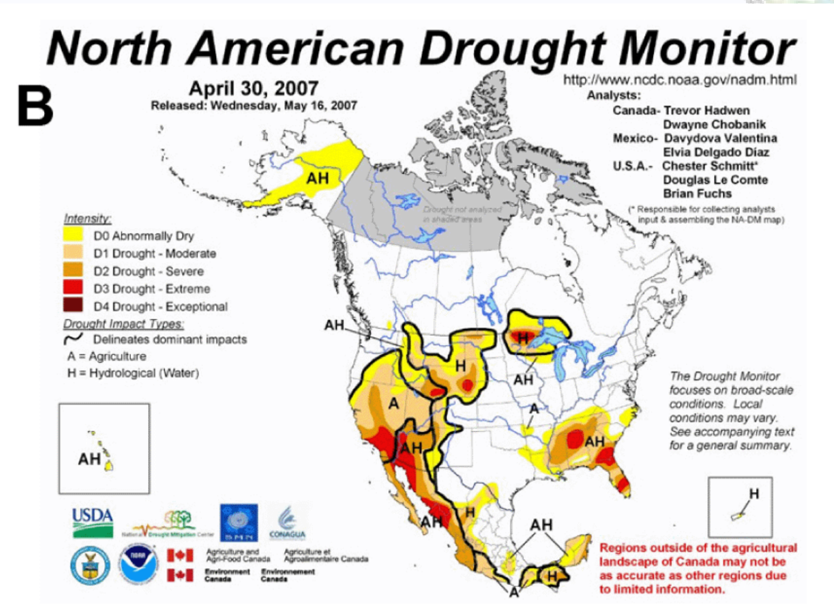
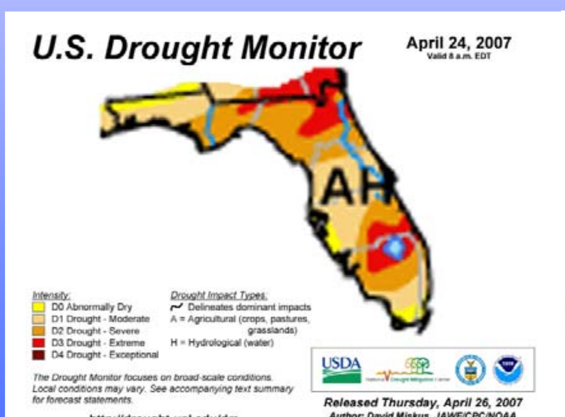
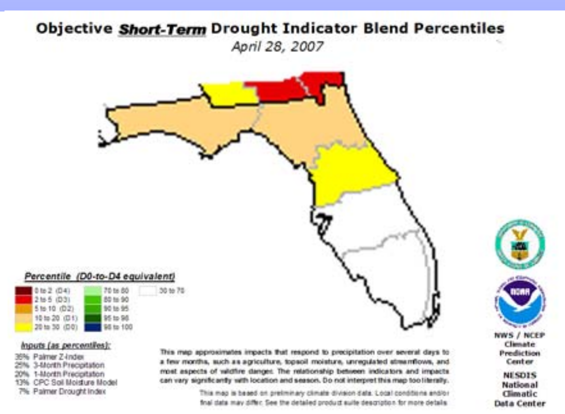
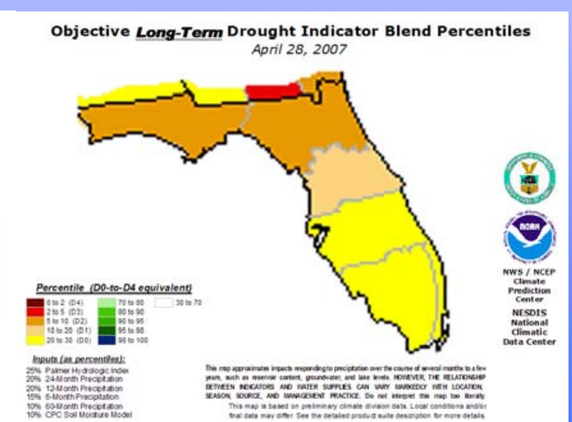
Drought Monitor Products











Most current drought products rely heavily on precipitation indices

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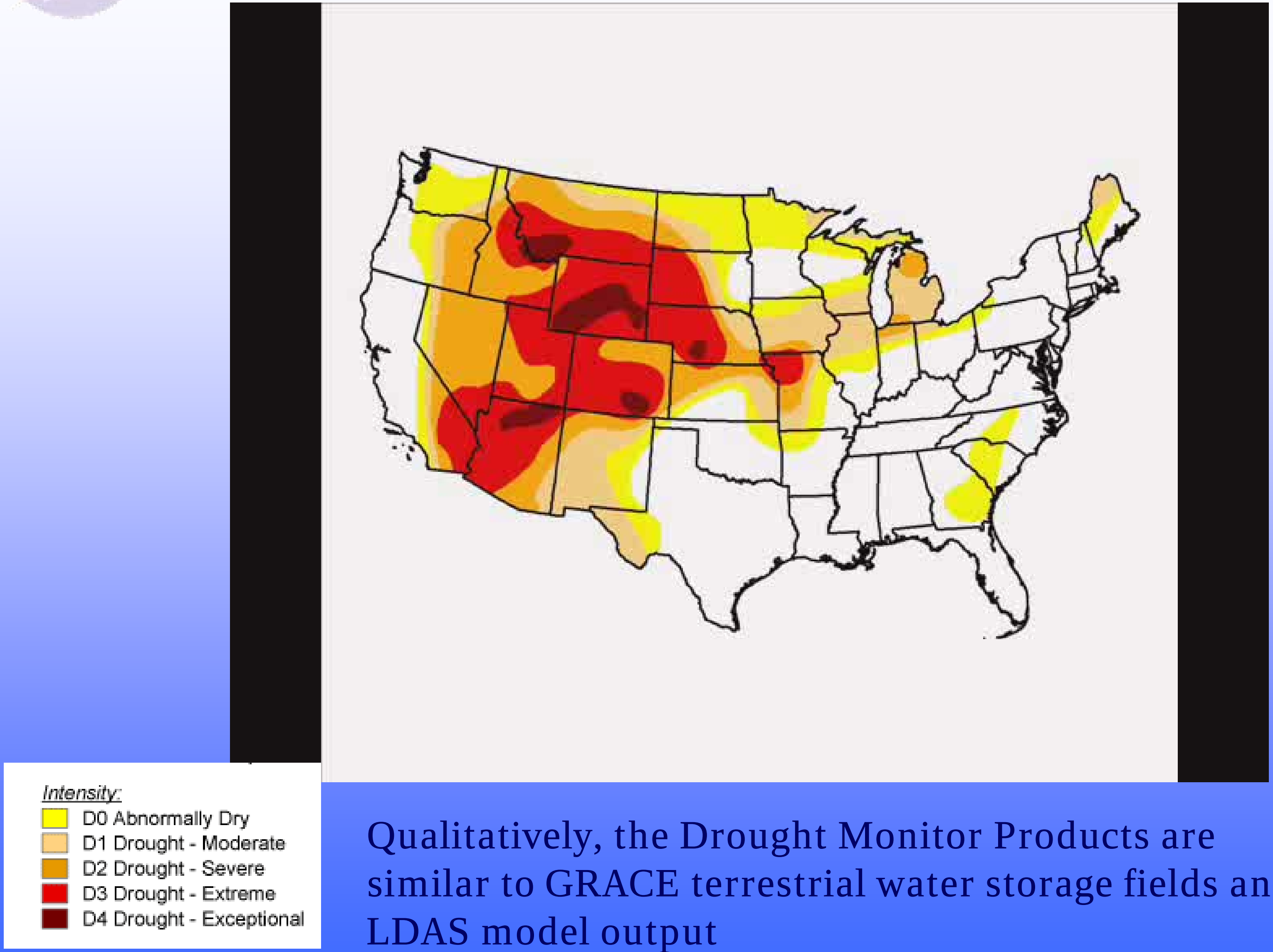
Drought Monitor Products



Qualitatively, the Drought Monitor Products are similar to GRACE terrestrial water storage fields and LDAS model output

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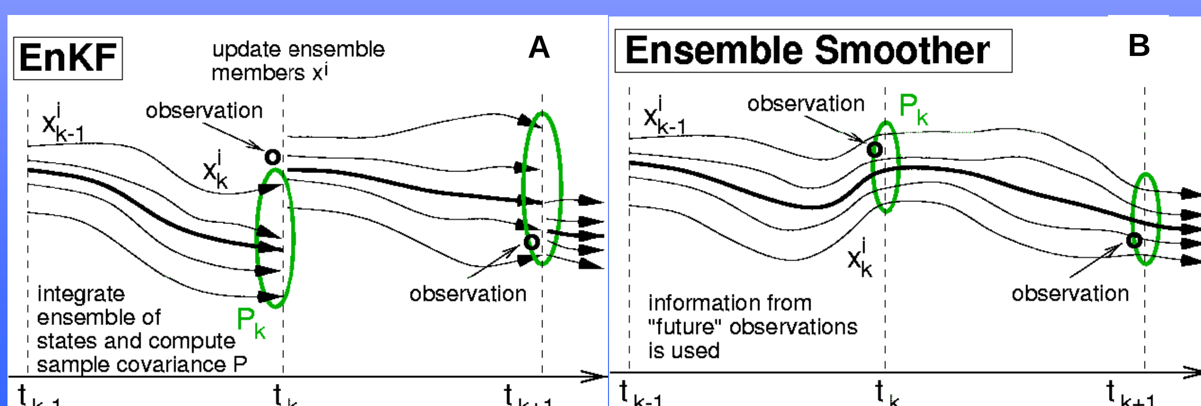
Assimilation of GRACE TWS Data

- LSMs 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
- Value of GRACE observations for hydrology is limited by
  - low spatial and temporal resolutions; product latency
  - lack of info on vertical distribution of observed mass changes
- Data assimilation can harness the advantages of each:
  - LSMs provide physically consistent, high resolution output; run up to near-real time driven by other data
  - GRACE and other observations anchor the results in reality
  - DA incorporates error information to ensure optimal blending



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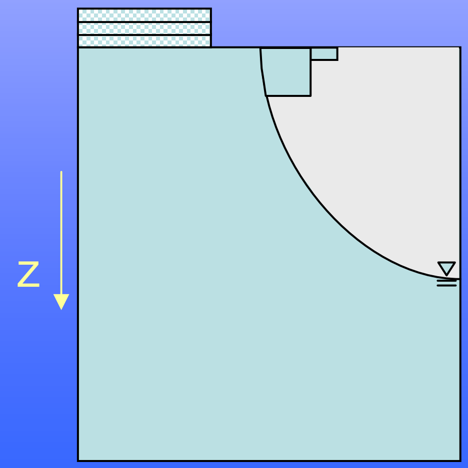
GRACE Data Assimilation Experiment

- Offline simulations of the Catchment LSM using GLDAS forcing data
- 10 year spin-up under 2002 forcing
- 20-member ensemble simulations for open loop (OL) and data assimilation (DA)
- Monthly GRACE anomalies: CSR/GFZ/JPL mean, Jan 2003 - May 2006
- Ensemble Kalman smoother DA

Catchment LSM (Koster et al., 2000):



three snow layers
surface excess
root zone excess
“catchment deficit”

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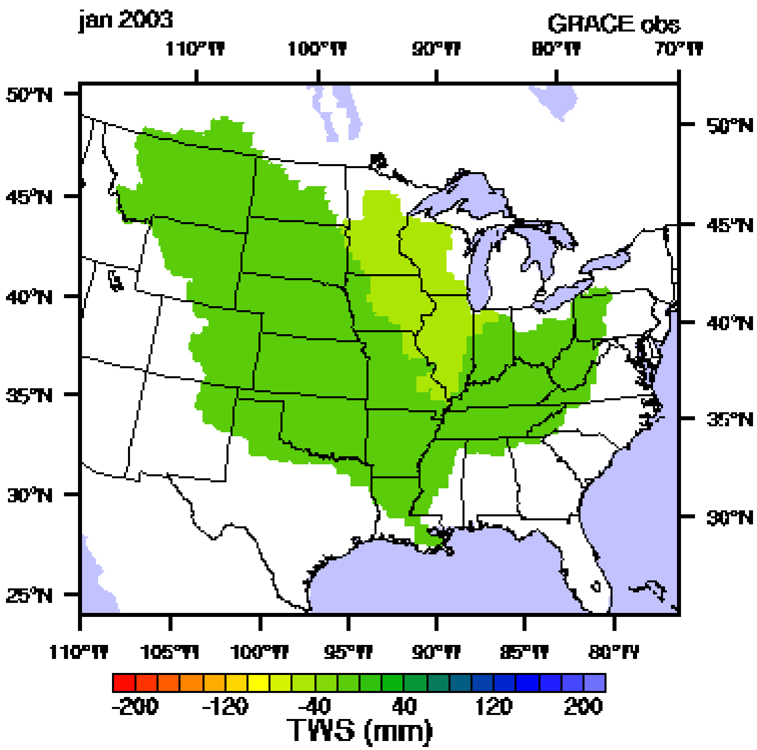
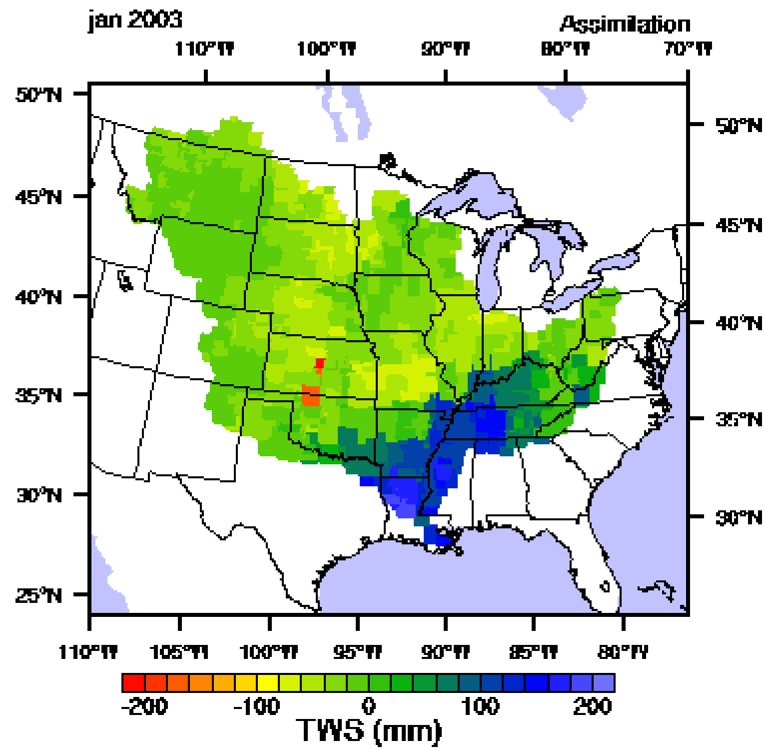
Assimilation of GRACE TWS Data

Results have higher resolution than GRACE alone, better accuracy than model alone.

GRACE TWS anomaly
January 2003 – June 2006



GRACE Assimilating Catchment LSM
TWS anomaly, mm
January 2003 – June 2006



From scales useful for water cycle and climate studies…

To scales needed for water resources and agricultural applications

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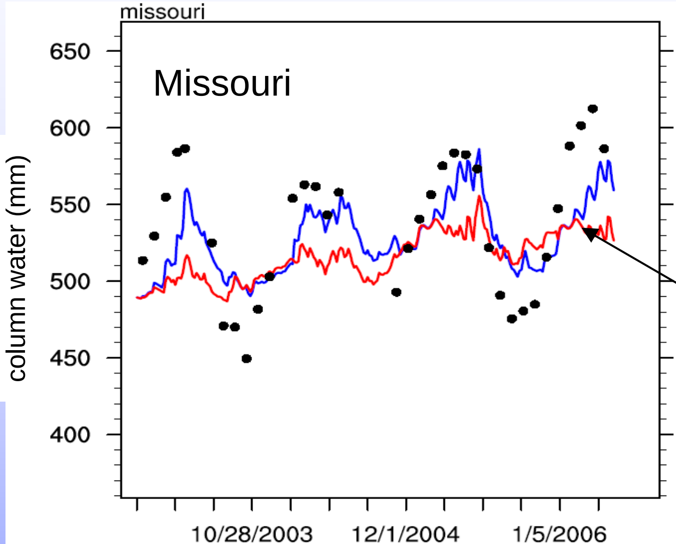
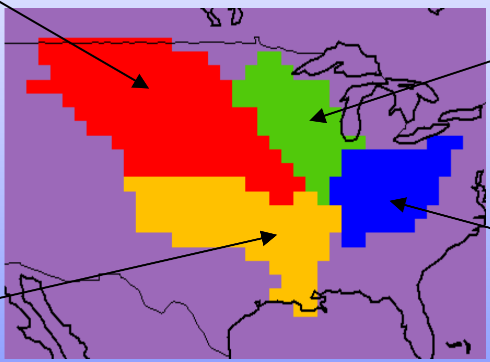
Assimilation of GRACE TWS Data

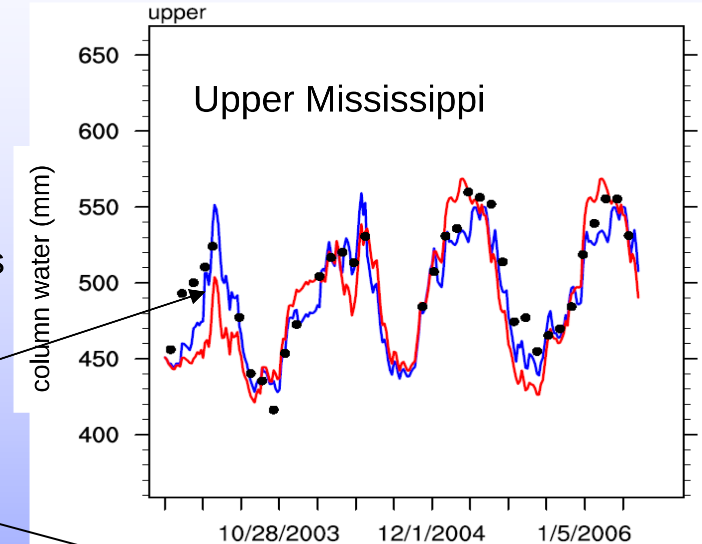
LDAS models produce continuous time series; near-real time capable.

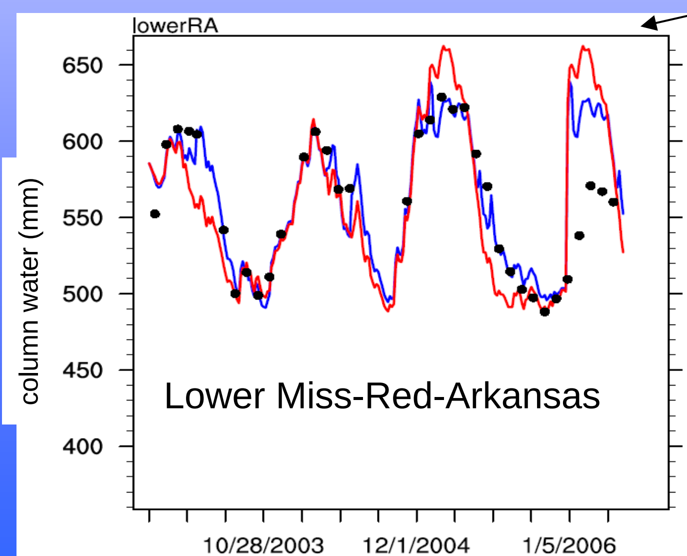


Monthly GRACE data anchor model results in reality

Mississippi River sub-basins





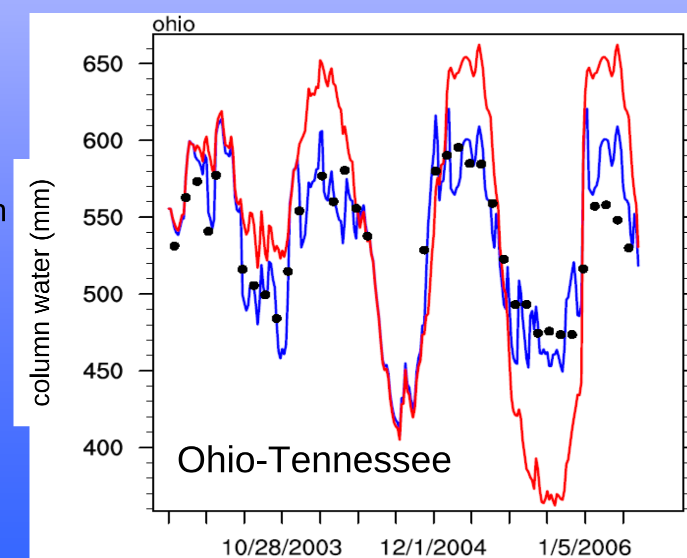


● GRACE Water Storage

Modeled Water Storage

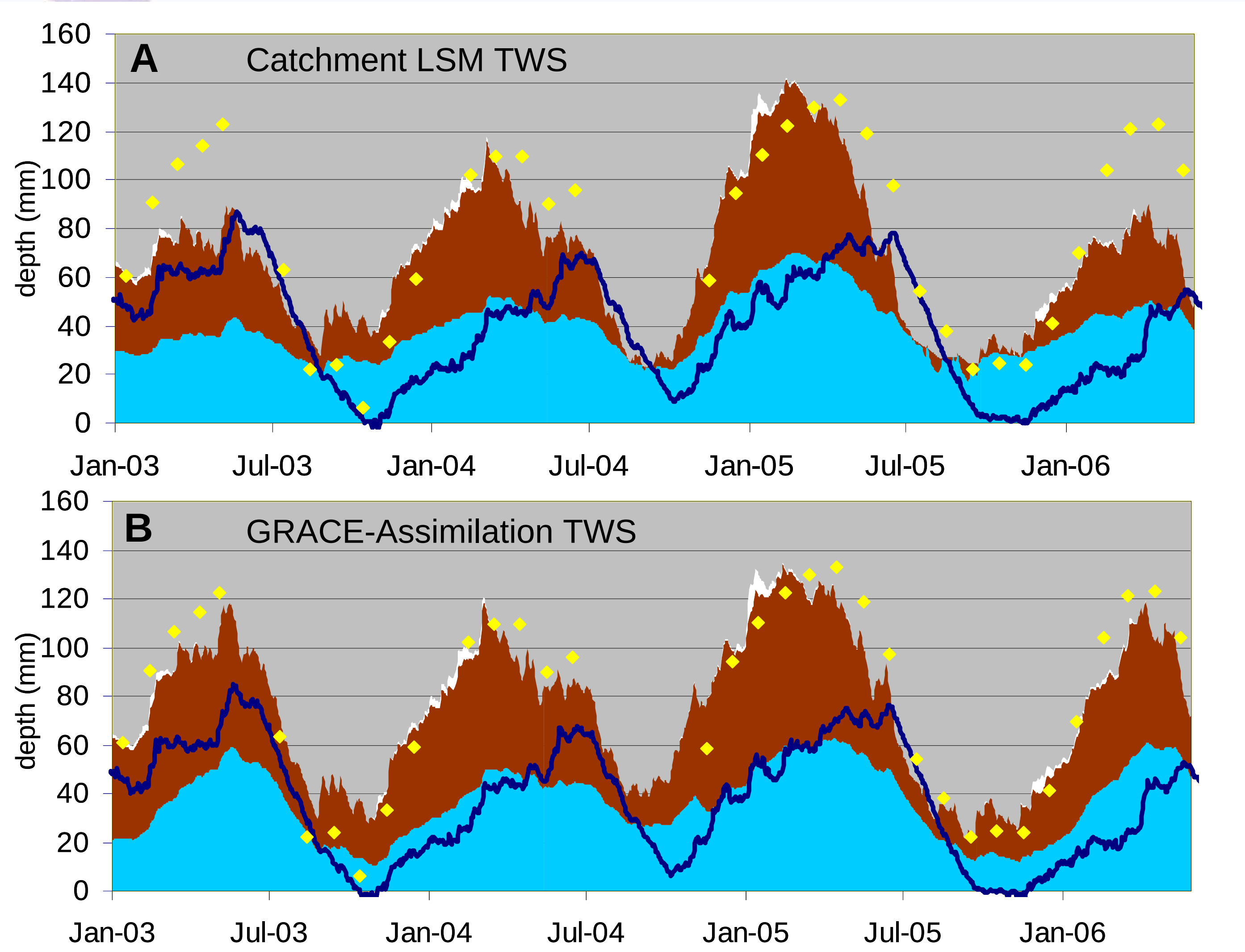
Model-GRACE Assimilation

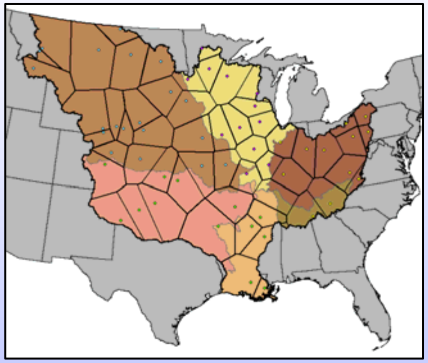
Daily estimates are critical for operational applications

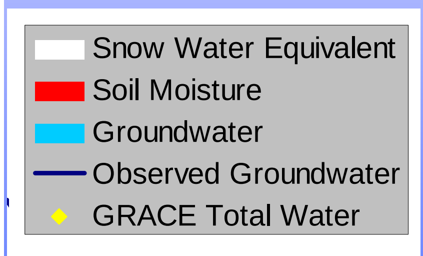


Assimilation of GRACE TWS Data

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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Assimilation of GRACE TWS Data

GRACE data assimilation improves groundwater storage 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

OL = open loop (no data assimilation)

r = coefficient of correlation

RMSE = root mean square error (mm H_2O)

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“Integrating Enhanced GRACE Water Storage Data into the U.S. and North American Drought Monitors”

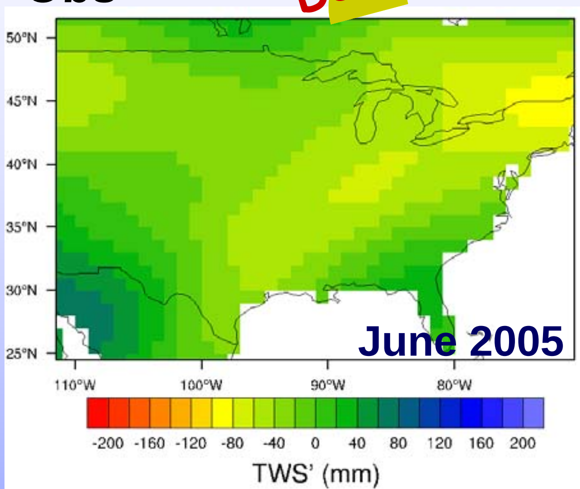
GRACE Obs

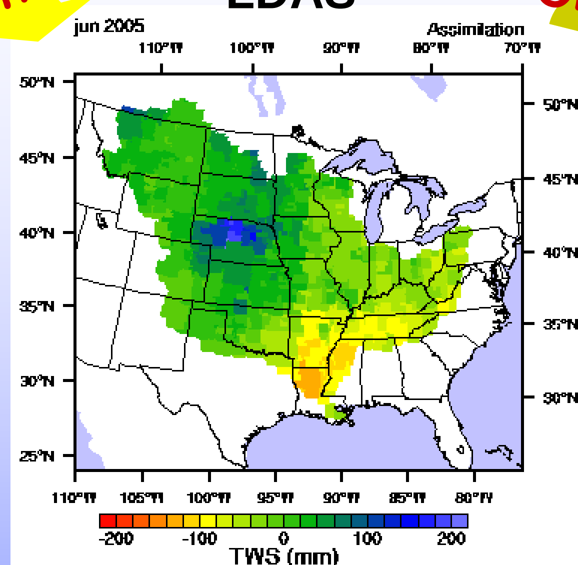
Data Assimilation

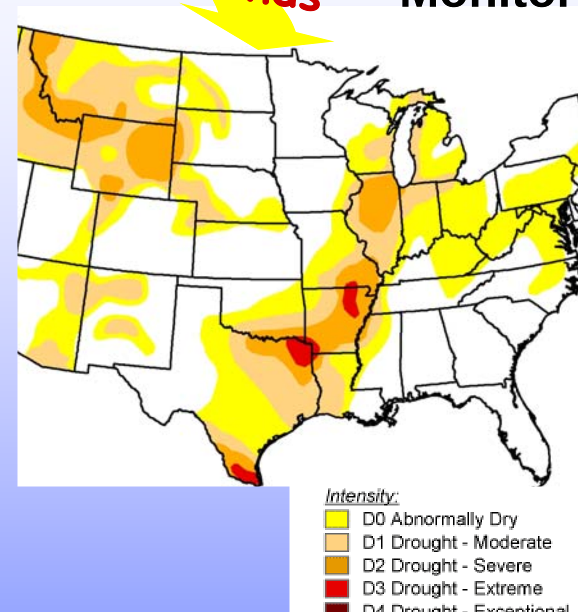
LDAS

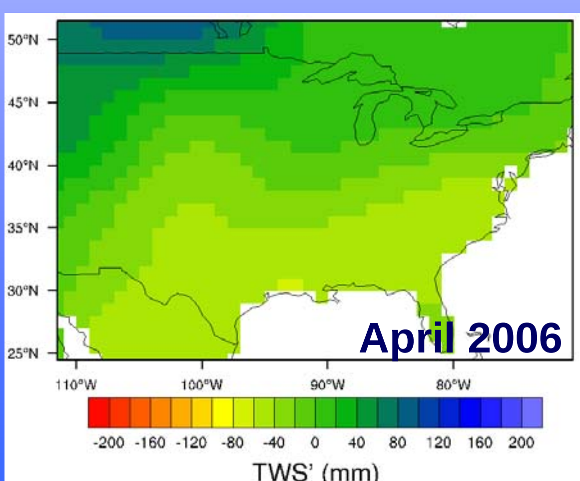
Objective Blends

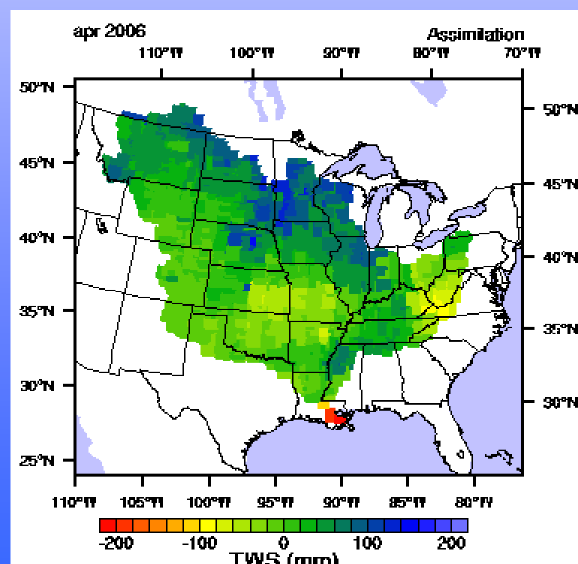
Drought Monitor

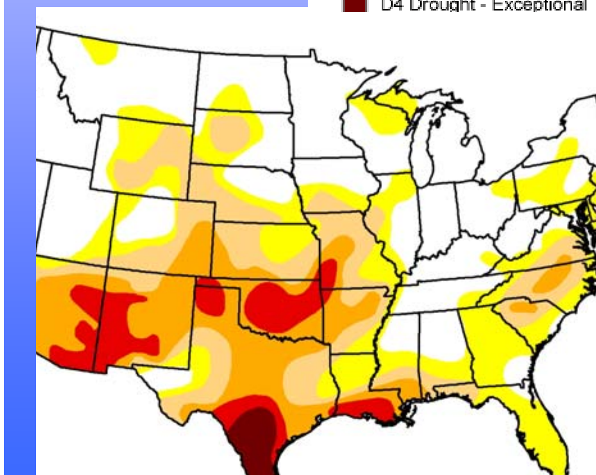












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Summary

• GRACE is well suited for drought monitoring

- Global coverage
- Integrated observation of relative state of total water storage

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

- Auxiliary observations
- LDAS models

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

- Spatial and temporal downscaling
- Data gap filling
- Quality control

References and Online Data Portals

North American Land Data Assimilation System (NLDAS)
- Mitchell et al., JGR, 2004
- http://ldas.gsfc.nasa.gov/

Global Land Data Assimilation System (GLDAS)
- Rodell et al., BAMS, 2004
- http://disc.gsfc.nasa.gov/hydrology/

Gravity Recovery and Climate Experiment (GRACE)
- Tapley et al., Science, 2004
- http://gracetellus.jpl.nasa.gov/month_mass.html
- http://grace.sgt-inc.com/

GRACE Data Assimilation
- Zaitchik, Rodell, and Reichle, J. Hydromet., 2008 (in press)