



Remote Sensing of Terrestrial Water Storage and Application to Drought Monitoring

Matt Rodell, Ben Zaitchik, and Rolf Reichle

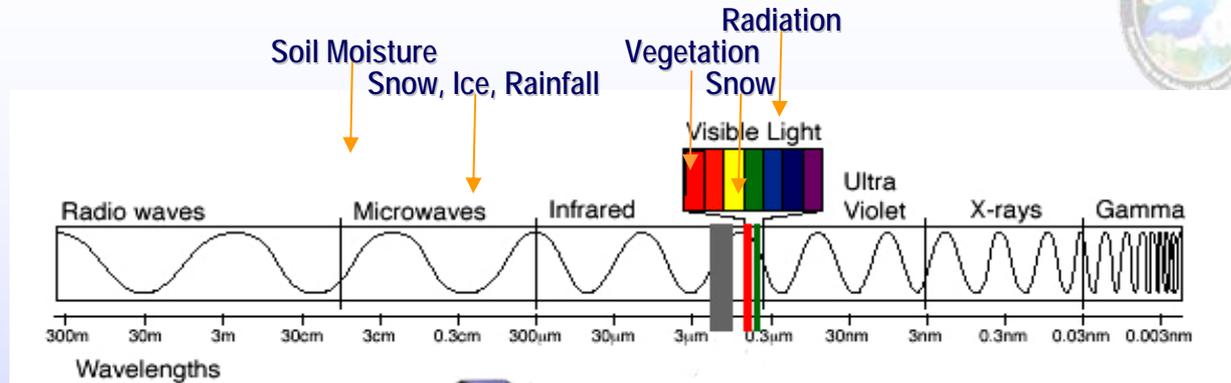
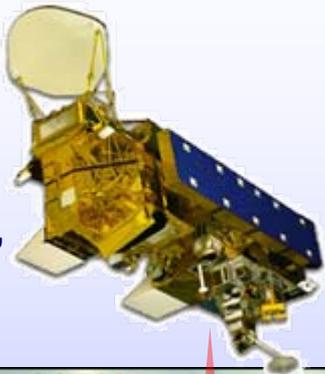
NASA Goddard Space Flight Center



Remote Sensing of the Water Cycle



Aqua:
MODIS,
AMSR-E,
etc.



Traditional radiation-based remote sensing technologies cannot sense water below the surface. GRACE is unique in its ability to monitor water at all levels, down to the deepest aquifer.



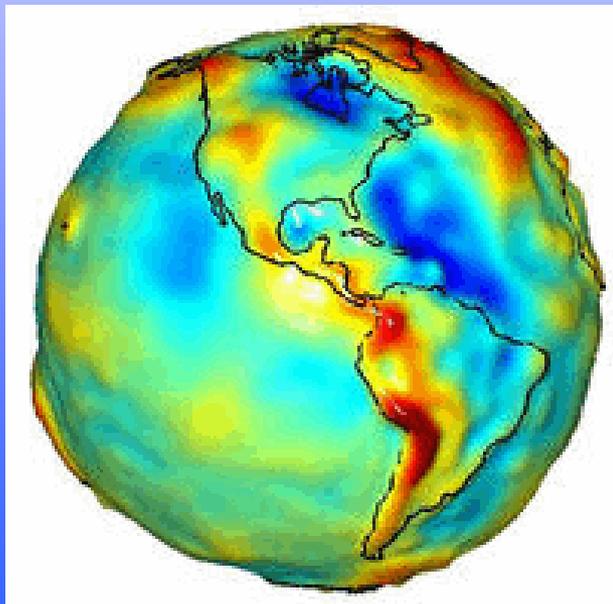
Gravity Recovery and Climate Experiment



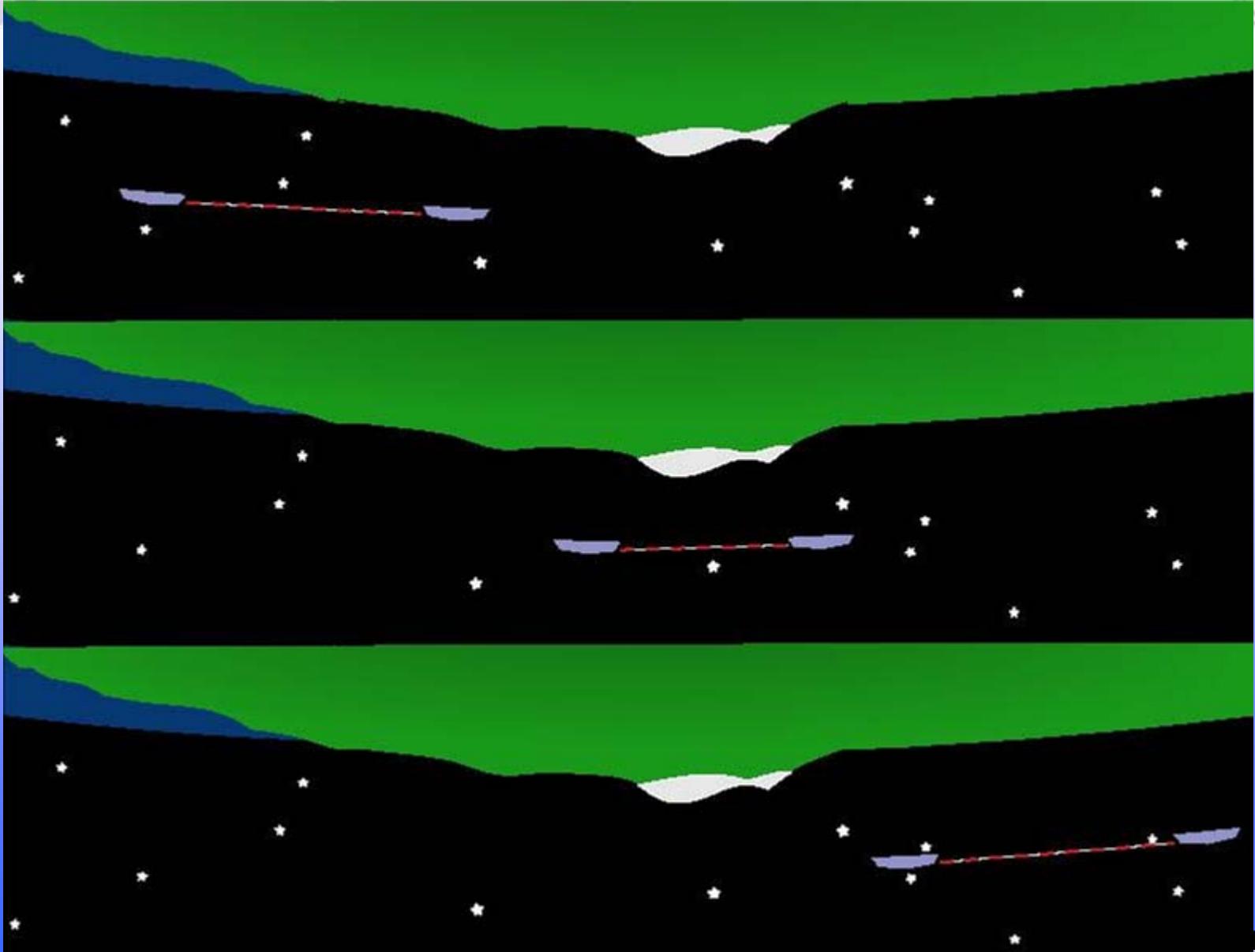
Science Goal: High resolution, mean and time variable gravity field mapping for Earth System Science applications

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

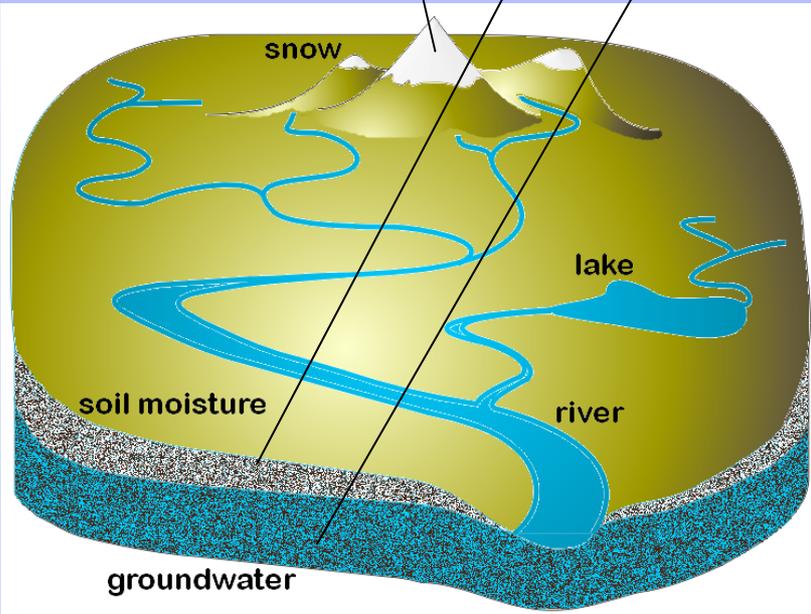
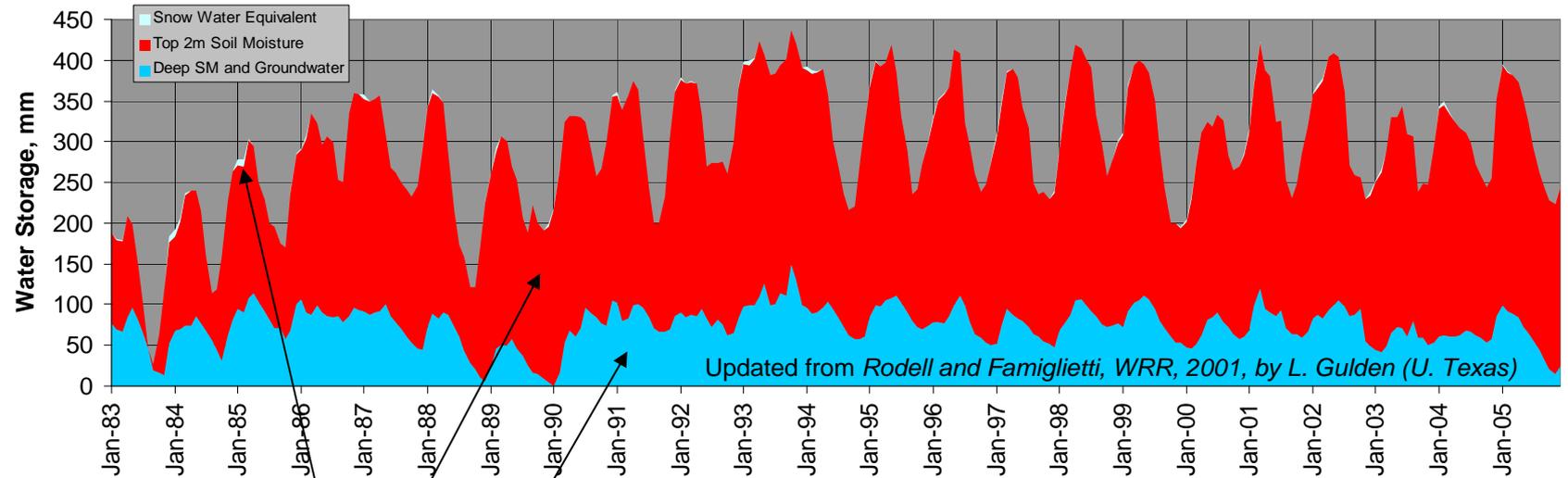


GRACE Intersatellite Ranging

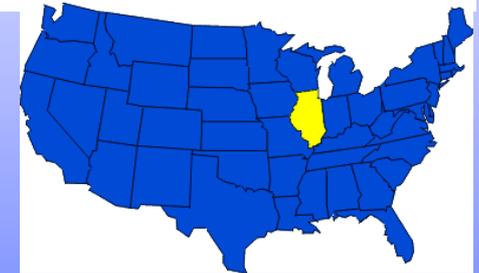




Terrestrial Water Storage Variations



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

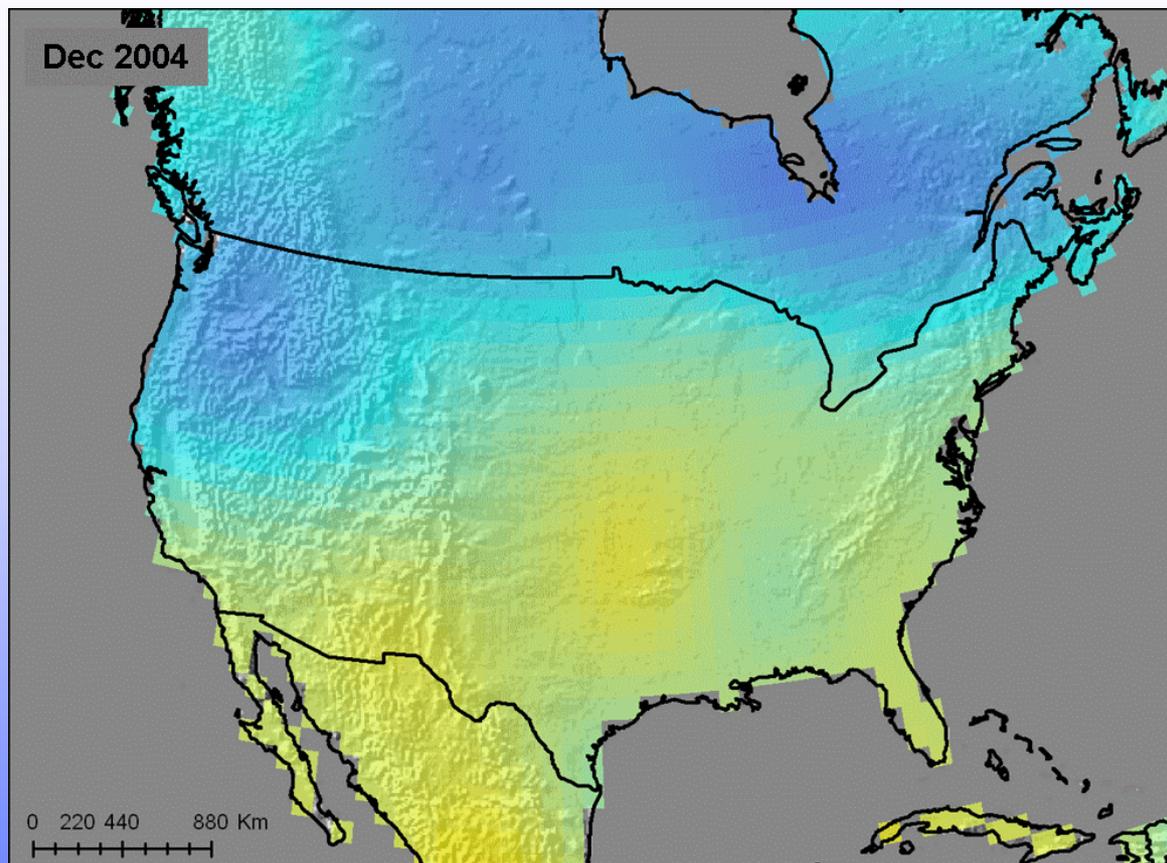


TWS variations are dominated by:

- Soil moisture in temperate regions;
- Snow in polar and alpine regions;
- Surface water in wetlands.



Water Storage Anomalies from GRACE



-15.0  15.0
Water Storage Anomaly (cm)

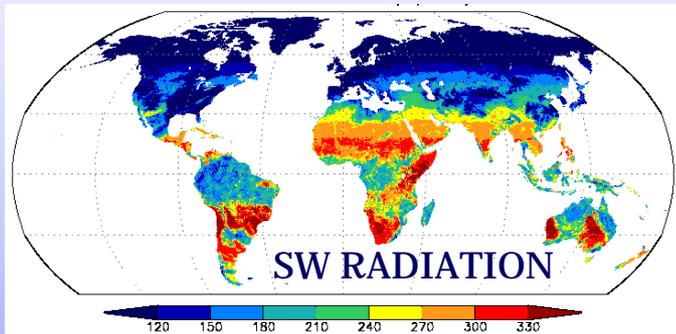
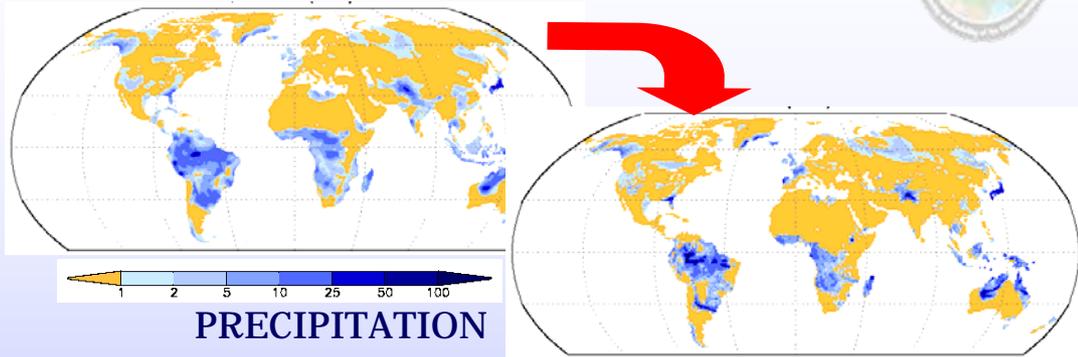
GRACE derived terrestrial water storage data are valuable for climate studies, but they lack the high resolution necessary for many applications



Data Integration Within a Land Data Assimilation System (LDAS)

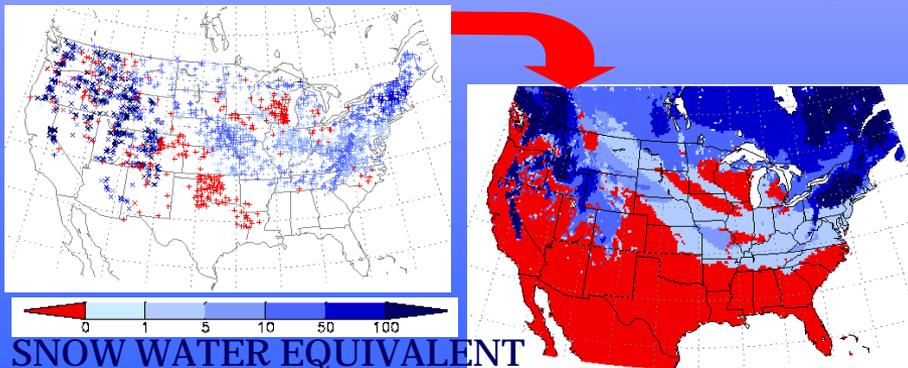
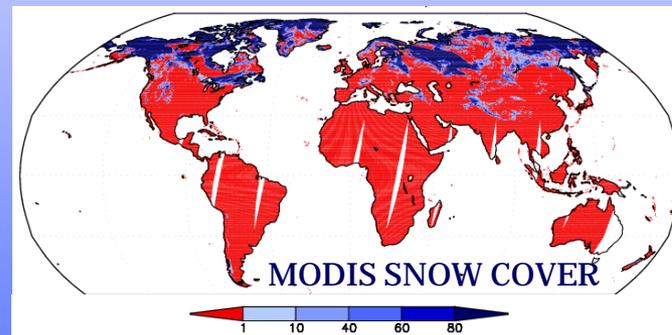


INTERCOMPARISON and OPTIMAL MERGING of global data fields



Satellite derived meteorological data used as land surface model FORCING

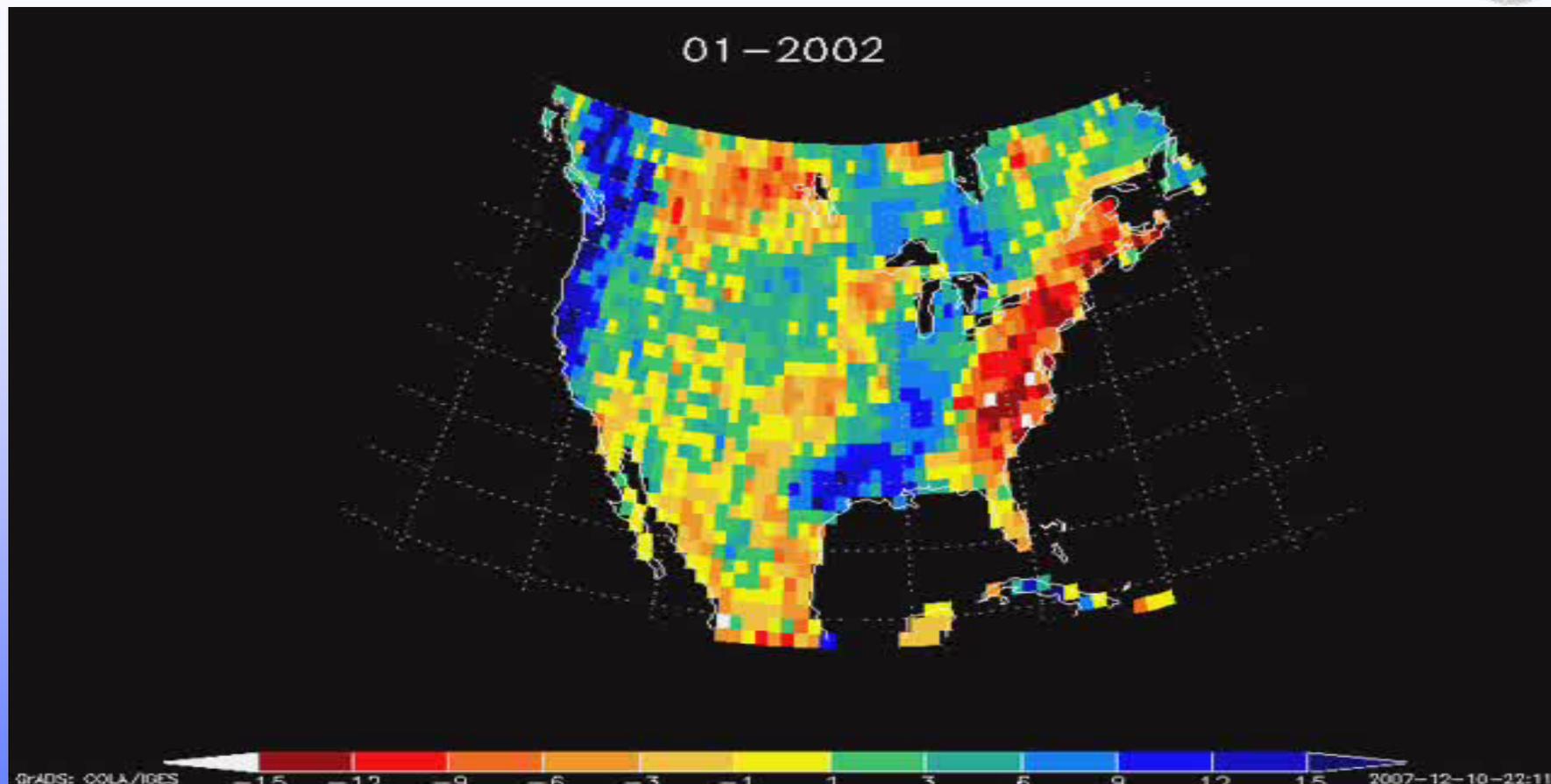
ASSIMILATION of satellite based land surface state fields (snow, soil moisture, surface temp, etc.)



Ground-based observations used to VALIDATE model output



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



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



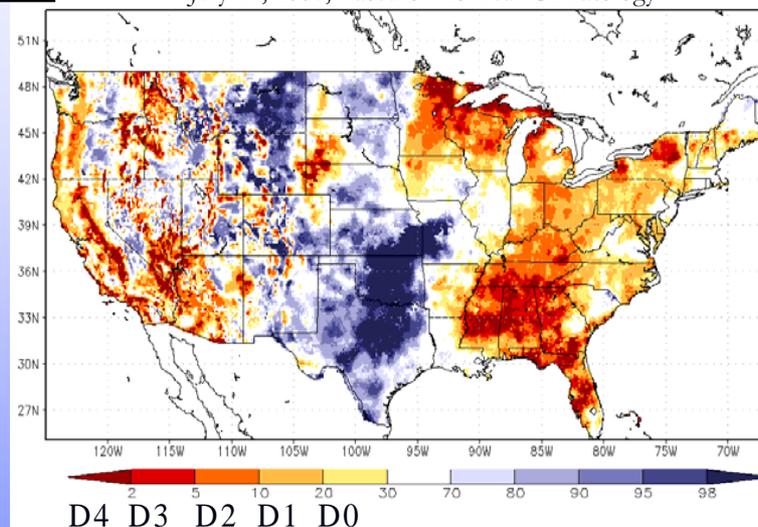
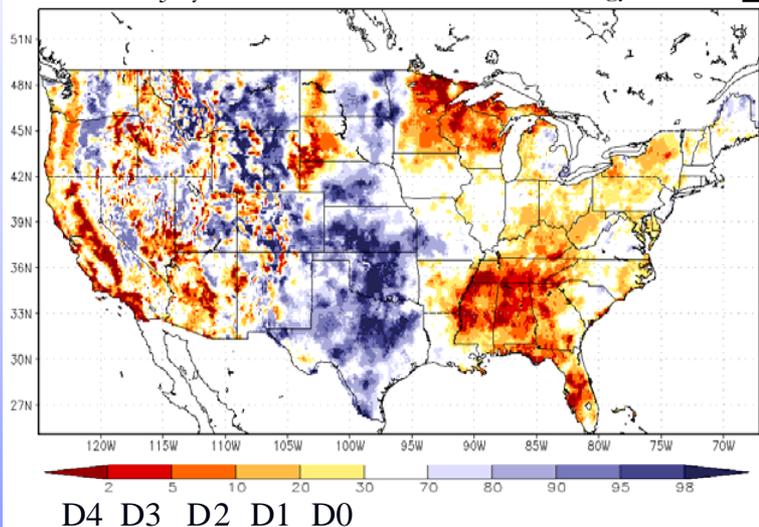
-Mosaic-

-Noah-

Mosaic LSM Total Column Soil Moisture Percentile
July 1st, 2007, Based on 28 Year Climatology

July 1st, 2007

Noah LSM Total Column Soil Moisture Percentile
July 1st, 2007, Based on 28 Year Climatology



Soil moisture percentile total column daily snapshot

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

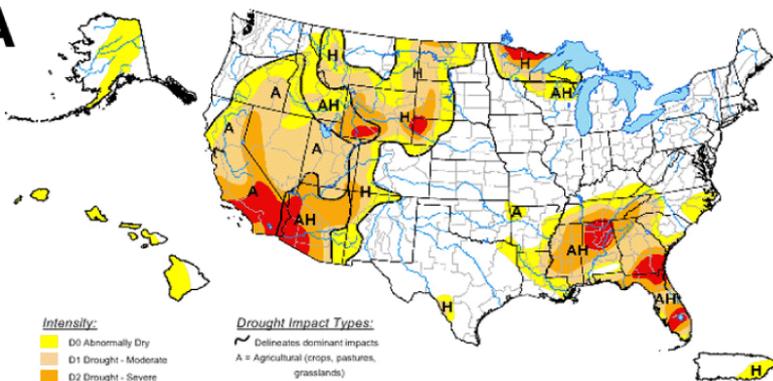


Drought Monitor Products

U.S. Drought Monitor

May 1, 2007
Valid 7 a.m. EST

A



Intensity:

- D0 Abnormally Dry
- D1 Drought - Moderate
- D2 Drought - Severe
- D3 Drought - Extreme
- D4 Drought - Exceptional

Drought Impact Types:

- Delimits dominant impacts
- A = Agricultural (crops, pastures, grasslands)
- H = Hydrological (water)

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements

<http://drought.unl.edu/dm>



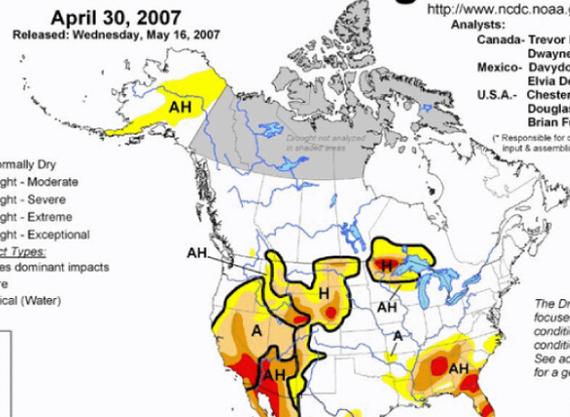
Released Thursday, May 3, 2007

Author: Brian Fuchs, National Drought Mitigation Center

North American Drought Monitor

April 30, 2007
Released: Wednesday, May 16, 2007

B



Intensity:

- D0 Abnormally Dry
- D1 Drought - Moderate
- D2 Drought - Severe
- D3 Drought - Extreme
- D4 Drought - Exceptional

Drought Impact Types:

- Delimits dominant impacts
- A = Agriculture
- H = Hydrological (Water)

<http://www.ncdc.noaa.gov/nadm.html>

Analysts:

- Canada- Trevor Hadwen
- Dwayne Chobanik
- Mexico- Davyova Valentina
- Elvia Delgado Diaz
- Chester Schmitt
- U.S.A.- Douglas Le Comte
- Brian Fuchs

(* Responsible for collecting analysts input & assembling the NA-DM map)

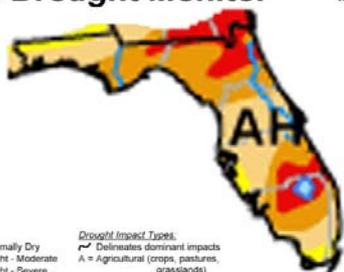
The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text for a general summary.



Regions outside of the agricultural landscape of Canada may not be as accurate as other regions due to limited information.

U.S. Drought Monitor

April 24, 2007
Valid 6 a.m. EDT



Intensity:

- D0 Abnormally Dry
- D1 Drought - Moderate
- D2 Drought - Severe
- D3 Drought - Extreme
- D4 Drought - Exceptional

Drought Impact Types:

- Delimits dominant impacts
- A = Agricultural (crops, pastures, grasslands)
- H = Hydrological (water)

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

<http://drought.unl.edu/dm>

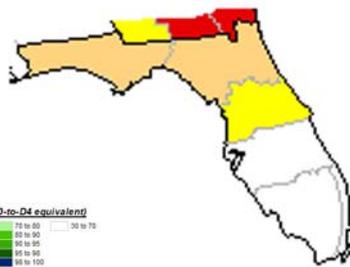


Released Thursday, April 26, 2007

Author: David Miskus, JAW/CPC/NOAA

Objective Short-Term Drought Indicator Blend Percentiles

April 28, 2007



Percentile (D0-to-D4 equivalent)

- 1 to 2 (D4)
- 3 to 5 (D3)
- 6 to 10 (D2)
- 10 to 20 (D1)
- 20 to 30 (D0)
- 30 to 70
- 70 to 80
- 80 to 90
- 90 to 95
- 95 to 98
- 98 to 100

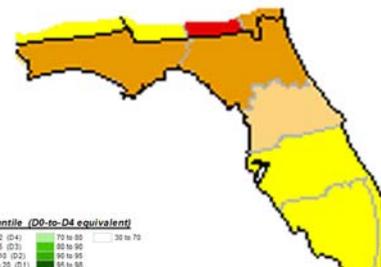
Inputs (as percentiles):

- 30% Palmer Z-Index
- 20% 3-Month Precipitation
- 20% 1-Month Precipitation
- 13% CPC Soil Moisture Model
- 7% Palmer Drought Index

This map approximates impacts that respond to precipitation over several days to a few months, such as agriculture, forest moisture, ungrazed rangelands, and most aspects of wildlife changes. The relationship between indicators and impacts can vary significantly with location and season. Do not interpret this map too literally. This map is based on preliminary climate division data. Local conditions and/or real data may differ. See the detailed product suite description for more details.

Objective Long-Term Drought Indicator Blend Percentiles

April 28, 2007



Percentile (D0-to-D4 equivalent)

- 1 to 2 (D4)
- 3 to 5 (D3)
- 6 to 10 (D2)
- 10 to 20 (D1)
- 20 to 30 (D0)
- 30 to 70
- 70 to 80
- 80 to 90
- 90 to 95
- 95 to 98
- 98 to 100

Inputs (as percentiles):

- 20% Palmer Hydrologic Index
- 20% 24-Month Precipitation
- 20% 12-Month Precipitation
- 10% 6-Month Precipitation
- 10% 60-Day Precipitation
- 10% CPC Soil Moisture Model

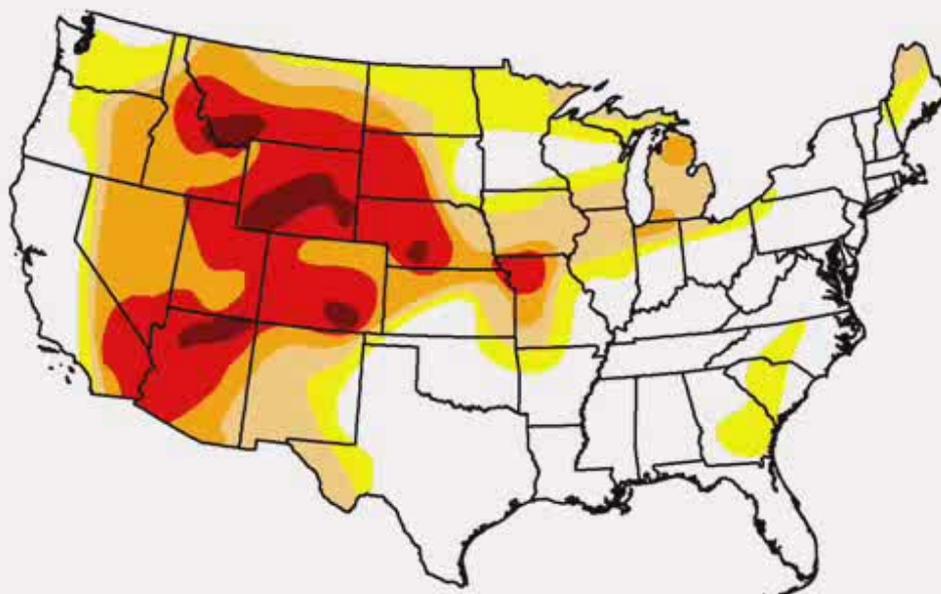
This map approximates impacts responding to precipitation over the course of several months to a few years, such as riverine channel, groundwater, and base water. HOWEVER, THE RELATIONSHIP BETWEEN INDICATORS AND WATER SUPPLIES CAN VARY SIGNIFICANTLY WITH LOCATION, SEASON, SOURCE, AND MANAGEMENT PRACTICE. Do not interpret this map too literally. This map is based on preliminary climate division data. Local conditions and/or real data may differ. See the detailed product suite description for more details.



Most current drought products rely heavily on precipitation indices



Drought Monitor Products



Intensity:

- D0 Abnormally Dry
- D1 Drought - Moderate
- D2 Drought - Severe
- D3 Drought - Extreme
- D4 Drought - Exceptional

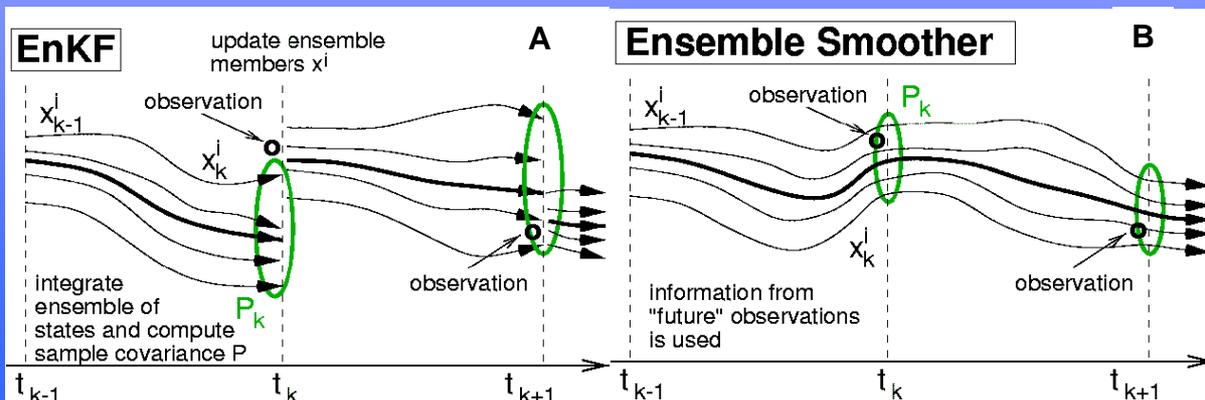
Qualitatively, the Drought Monitor Products are similar to GRACE terrestrial water storage fields and LDAS model output



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



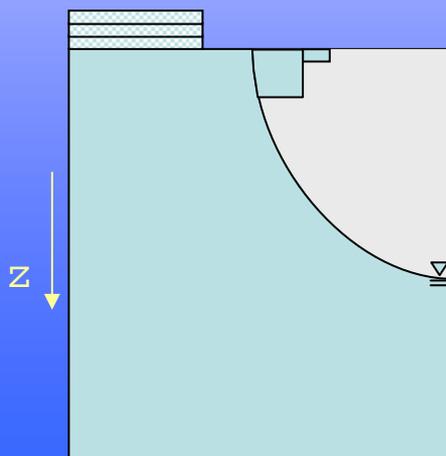


GRACE Data Assimilation Experiment



- 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”

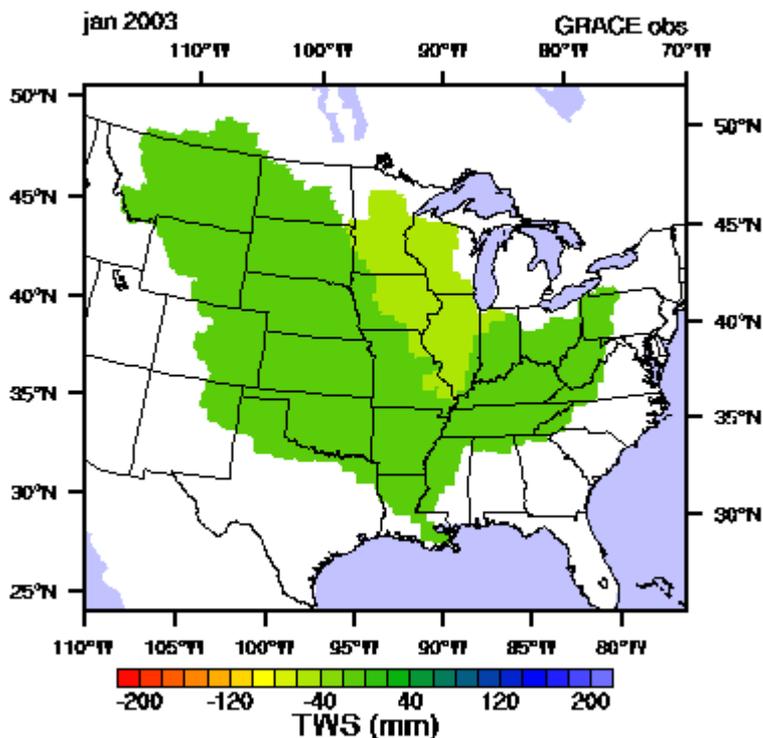


Assimilation of GRACE TWS Data

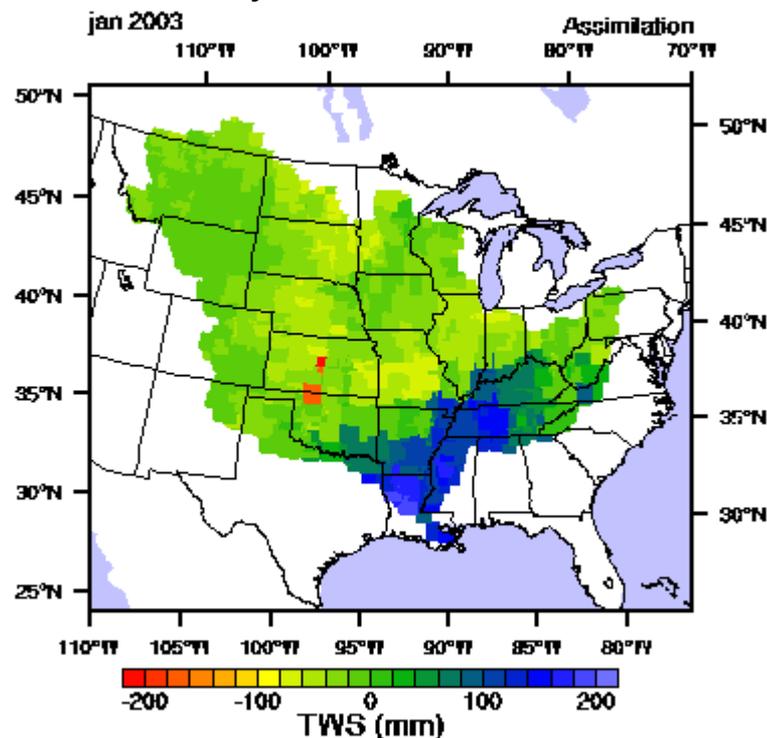


Results have higher resolution than GRACE alone, better accuracy than model alone.

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



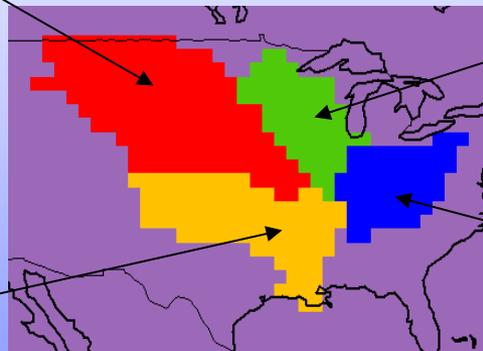
Assimilation of GRACE TWS Data



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

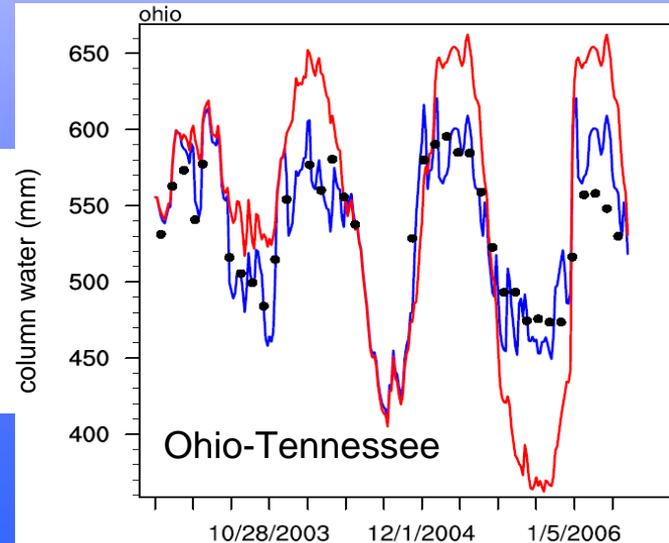
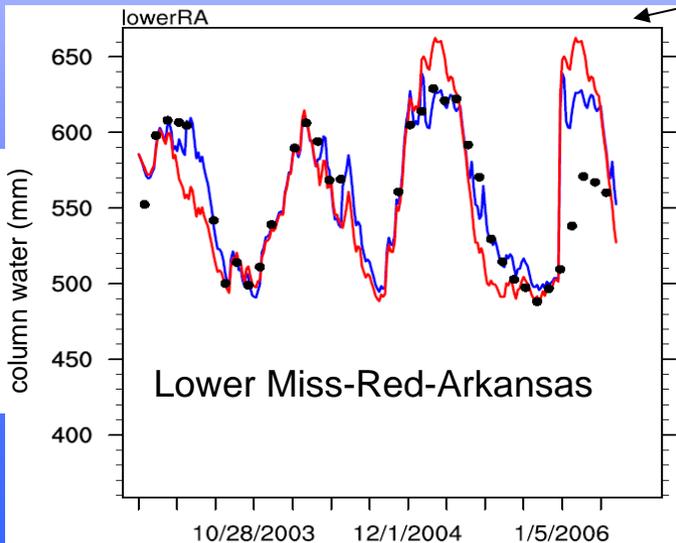
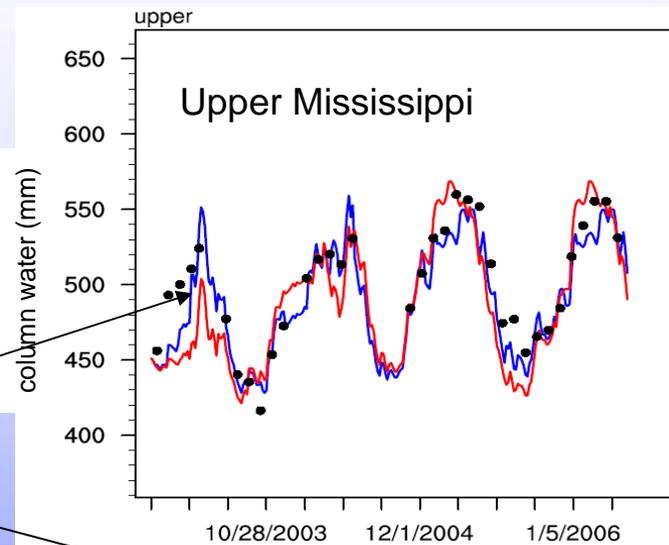
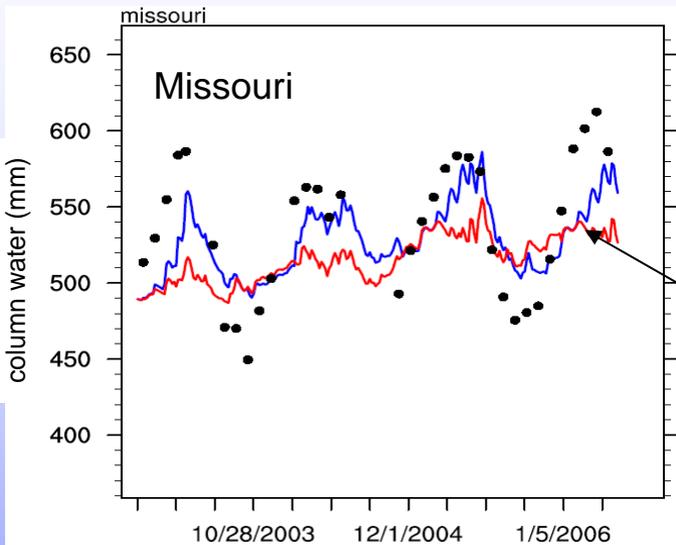
Monthly GRACE data anchor model results in reality

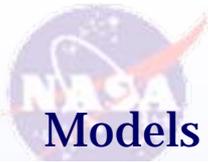
Mississippi River sub-basins



- GRACE Water Storage
- Modeled Water Storage
- Model-GRACE Assimilation

Daily estimates are critical for operational applications

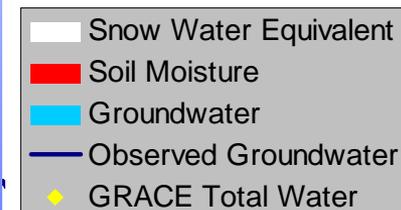
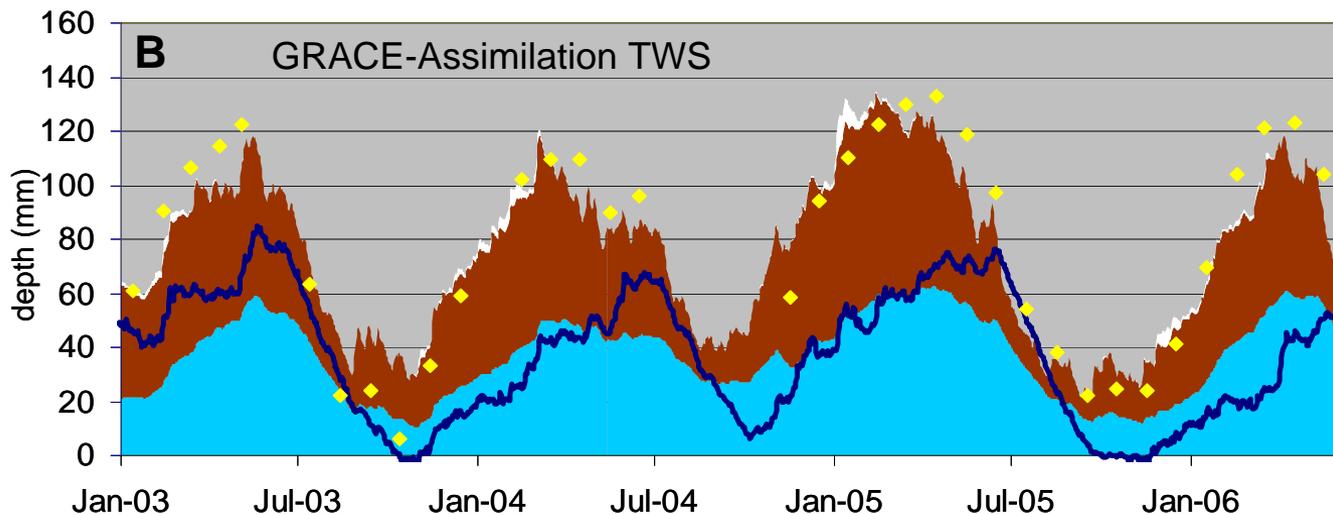
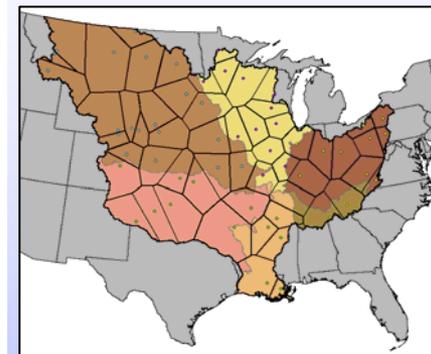
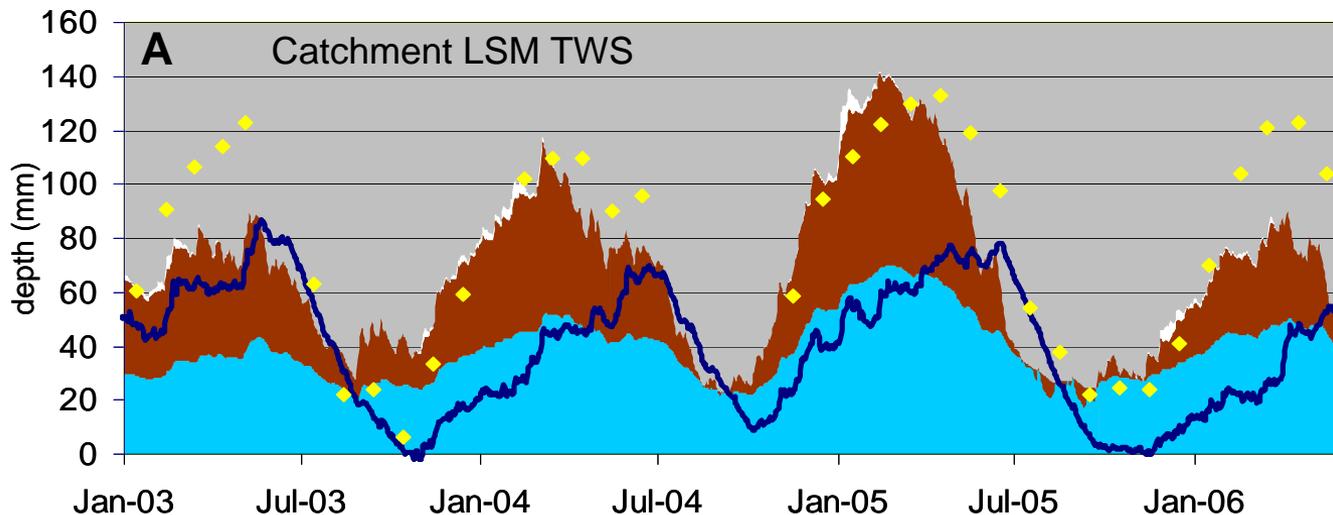




Assimilation of GRACE TWS Data



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



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



Assimilation of GRACE TWS Data



GRACE data assimilation improves groundwater storage estimates

	OL		GRACE DA		
	<u>r</u>	<u>RMSE</u>	<u>r</u>	<u>RMSE</u>	<u>skill</u>
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 H₂O)

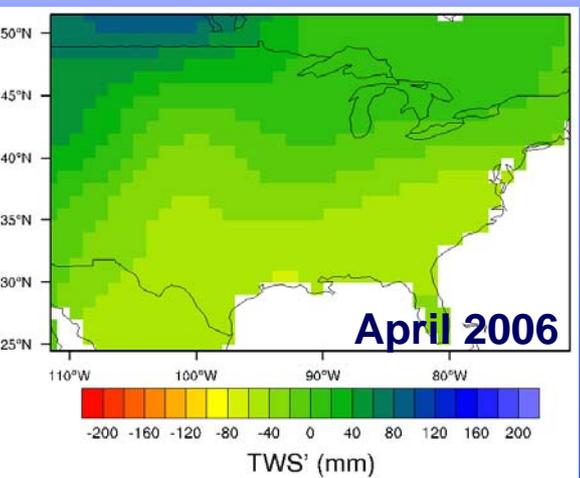
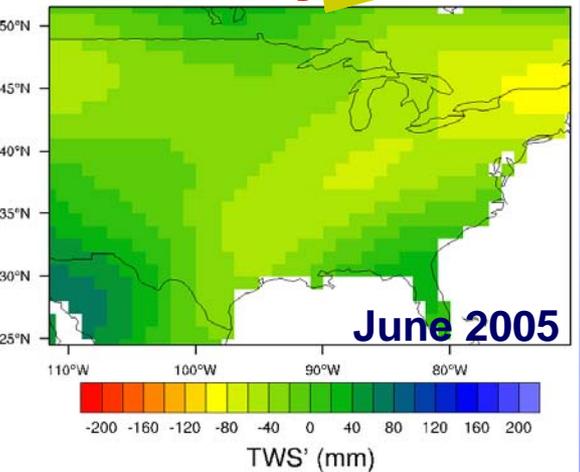


“Integrating Enhanced GRACE Water Storage Data into the U.S. and North American Drought Monitors”

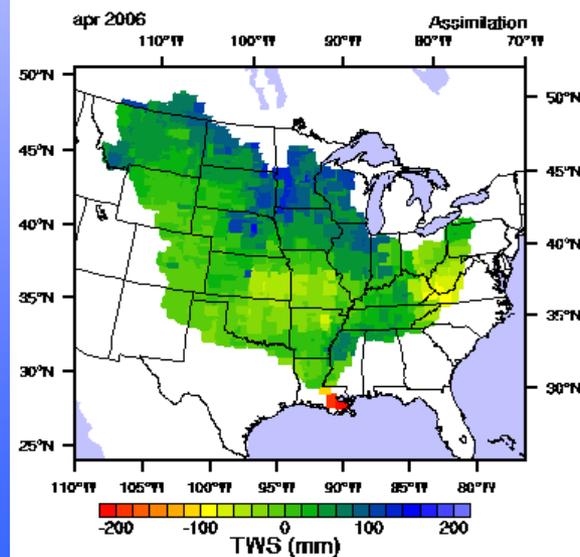
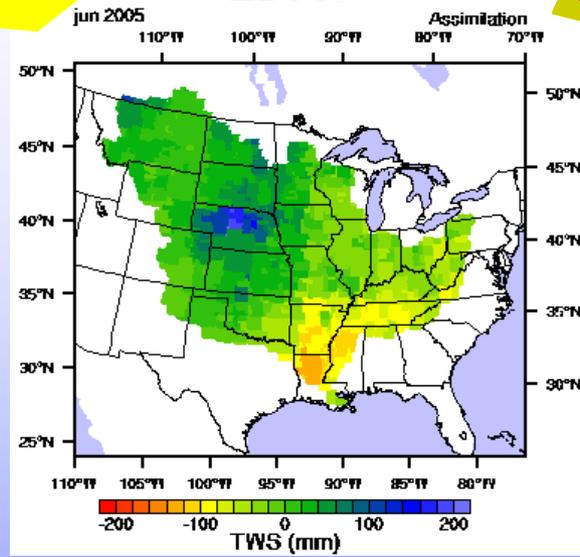


**GRACE
Obs**

Data Assimilation

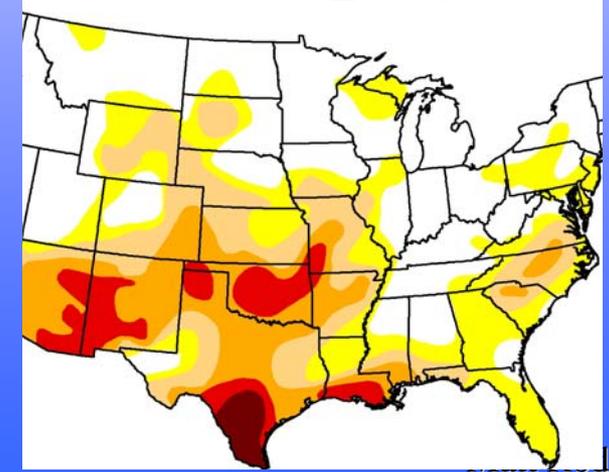
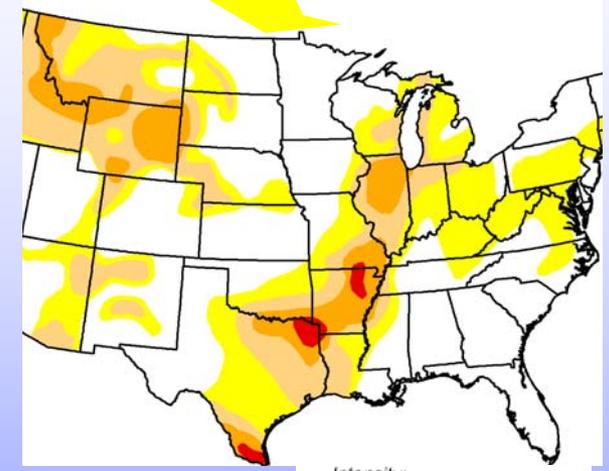


LDAS



Objective Blends

**Drought
Monitor**





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)