



Practical Applications of GRACE and Future Satellite Gravity Missions

**M. Rodell¹, R. Houborg^{1,2}, B. Li^{1,3}, B.F. Zaitchik⁴,
R. Reichle¹, John Bolten¹, Joe Nigro^{1,5}, Isabella
Velicogna^{6,7}, J.S. Famiglietti⁶**

¹NASA's Goddard Space Flight Center (GSFC), Greenbelt, MD, USA

²Earth System Science Interdisciplinary Center, College Park, MD

³Science Applications International Corporation

⁴Johns Hopkins University, Baltimore, MD

⁶University of California, Irvine, CA

⁷NASA's Jet Propulsion Laboratory (JPL), Pasadena, CA



Obstacles to Using Satellite Gravity for Applications



1) Product latency

- Near-real time information is vital for operational applications

2) Low spatial resolution

- Most practical applications require observations at scales of 0.01 – 2500 km

3) Lack of vertical information

- Groundwater, soil moisture, surface water, or snow

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Potential Applications



Water Resources Assessments

- Drought monitoring
- Ground water depletion
- Seasonal snow load
- Streamflow forecasting (based on upland water storage)
- Transboundary water resources sharing

Weather and Climate Prediction

- Via improved forecast model land surface state initialization
- Implications for Water Resources, Aviation Safety, Agriculture, and Disaster Preparedness

International Security

- Military mobility assessments
- International crises/unrest due to water/drought related disasters



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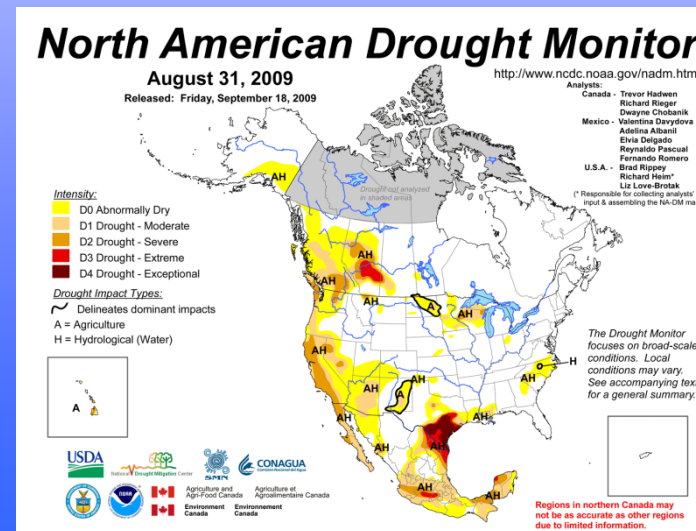
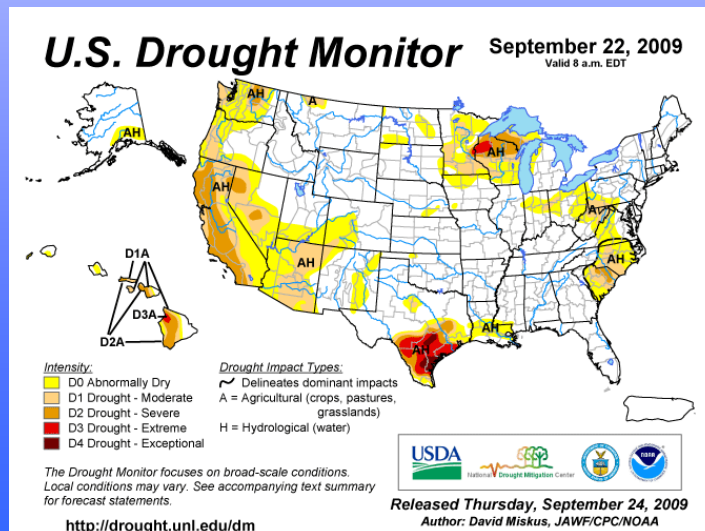
“Integrating Enhanced GRACE Water Storage Data into the U.S. and North American Drought Monitors”



Problem Statement: Current generation of drought monitoring products rely heavily on precipitation indices and subjective reports, and lack objective information on water storage in/on the land surface.

Hypothesis: Drought conditions can be identified more accurately and objectively through the incorporation of GRACE derived water storage variations which have been disaggregated, downscaled, and extrapolated via data assimilation.

Value of GRACE: Groundwater and deep soil moisture are important indicators of drought which are rarely included in drought assessments due to a lack of spatially and temporally continuous observations.

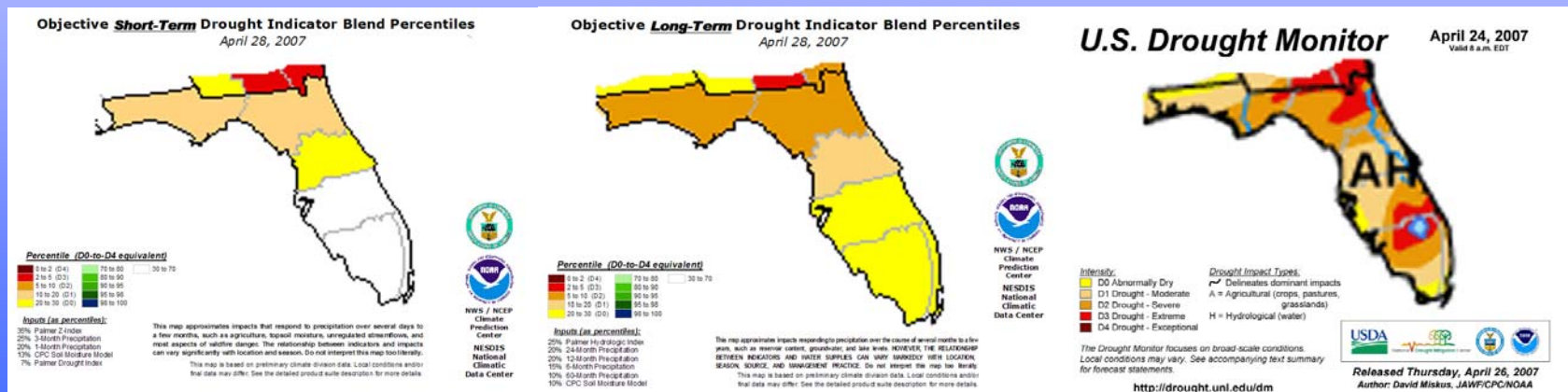




US and North American Drought Monitors



- Two of the premier drought monitoring products (1st Google result for “drought”)
- End users: farmers, water resources decisionmakers, state climatologists, disaster aid providers, agricultural commodities interests
- Starting point is “objective blends”, which rely heavily on precipitation indices
- Final products are drawn by hand based on subjective input
- Would benefit from objective observations of soil moisture and groundwater conditions
- Terrestrial water storage is the ideal observation, if a climatology can be created



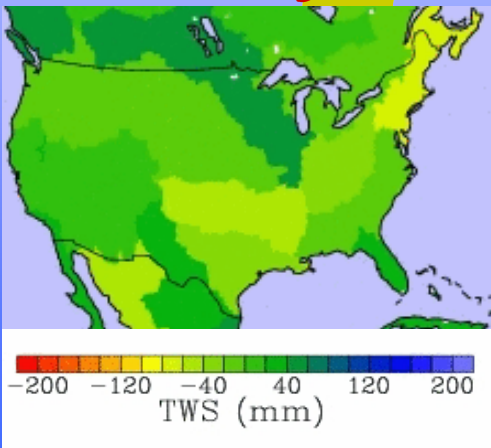


Project Specifications



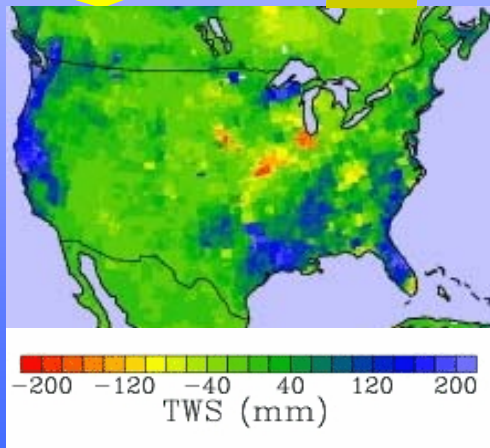
- 60-year retrospective Catchment model simulation for background climatology – reconcile with GRACE DA results and current objective blend formulation
- 20-member ensemble simulations for open loop (OL) and data assimilation (DA) 2002-present
- CSR/GRACE experimental “quick look” fields for timeliness
- Output soil moisture and groundwater fields introduced as rank percentiles to Objective Blends, which are the baseline for Drought Monitor products

GRACE
Obs



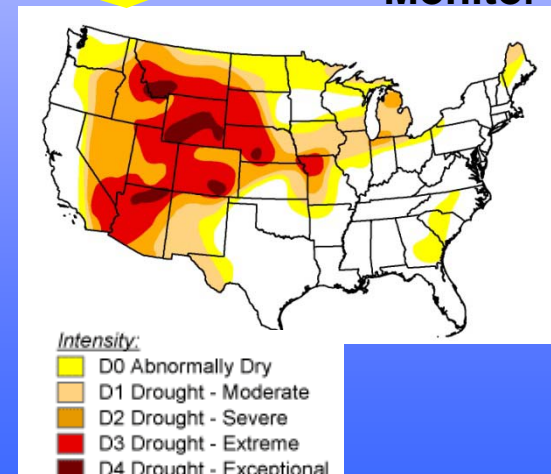
Data Assimilation

LDAS



Objective Blends

Drought
Monitor



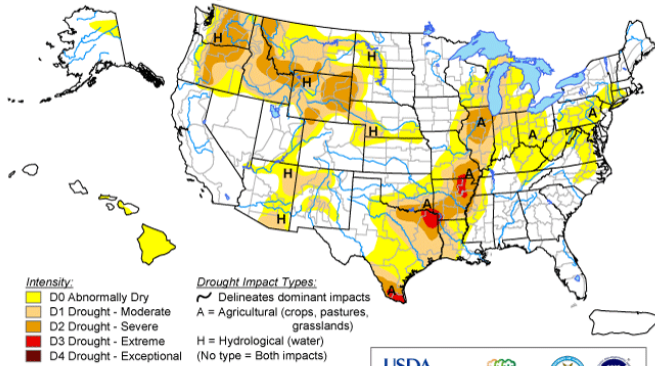


Drought Indicator Products



U.S. Drought Monitor June 28, 2005

Valid 8 a.m. EDT



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

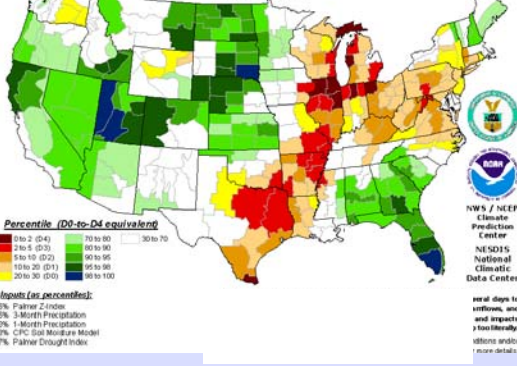
Drought Impact Types:
 ~ Delineates dominant impacts
 A = Agricultural (crops, pastures, grasslands)
 H = Hydrological (water)
 (No type = Both impacts)

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

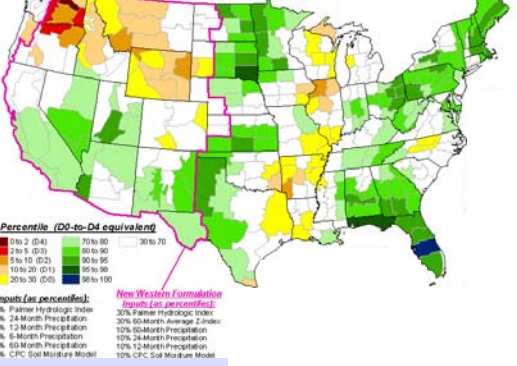
<http://drought.unl.edu/dm>

USDA National Drought Mitigation Center
 Released Thursday, June 30, 2005
 Author: Douglas Le Comte, CPC/NOAA

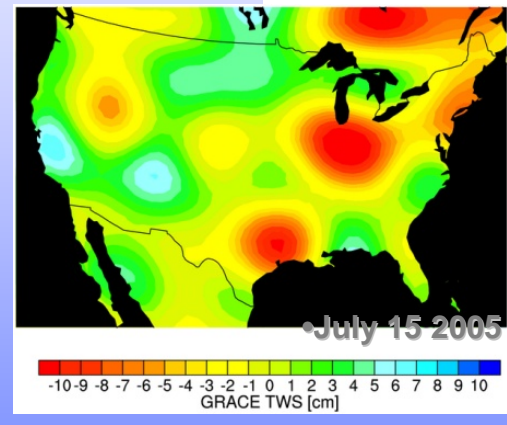
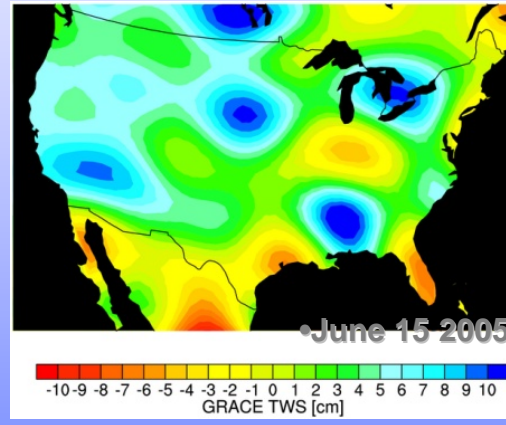
Objective Short-Term Drought Indicator Blend Percentiles June 25, 2005



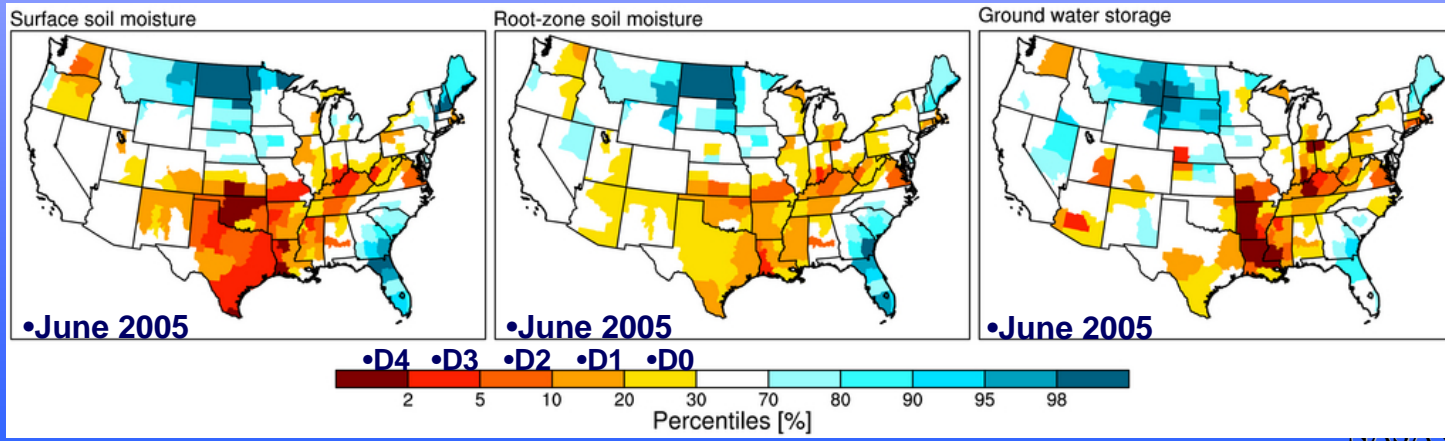
Objective Long-Term Drought Indicator Blend Percentiles June 25, 2005



USDM objective blends



LDAS-based drought indicator percentiles



Model
 NASA/USFC



“Monitoring the Water Cycle in the Arab Region Using NASA Satellite and Data Assimilating Model Technology”



Goal: Map hydrological states (e.g., soil moisture, groundwater) and fluxes (e.g., evaporation, runoff) in the Middle East - North Africa (MENA) region, which will serve as a basis for regional water resources assessments.

Method: Optimize a land data assimilation system (LDAS) for the MENA region, in which GRACE and other satellite observations, surface observations from Arab countries, and publicly-available meteorological analyses will be used to parameterize, force, and constrain a sophisticated land surface model.

Value of GRACE: No other Earth observing satellite system is able to monitor water stored below the first few centimeters of the surface; ground based hydrological observations, if they exist, are rarely shared in MENA.

Benefits:

- Near-real time monitoring of water resources, droughts, & floods across political boundaries
- Historical and regional perspective on local hydrological variability
- A scientific tool for agricultural planning, including irrigation
- Assessment of hydrological impacts of climate change scenarios
- A platform for cooperation and data sharing among nations.

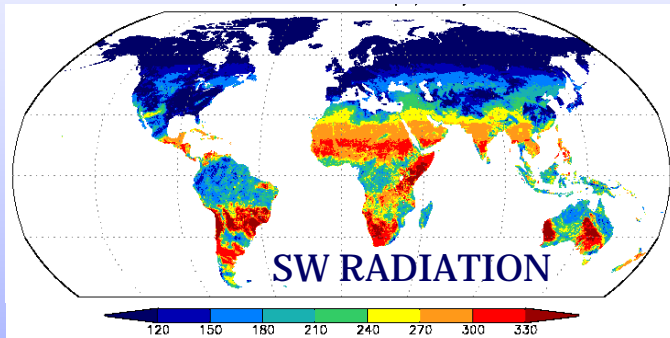
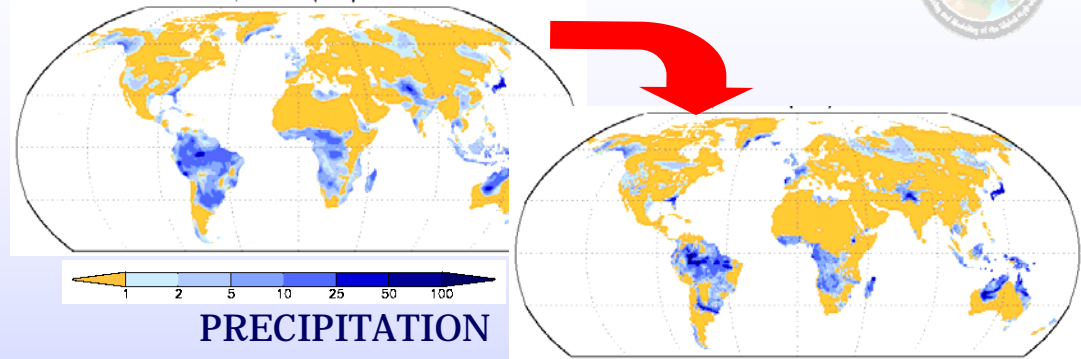




Data Integration Within a Land Data Assimilation System (LDAS)

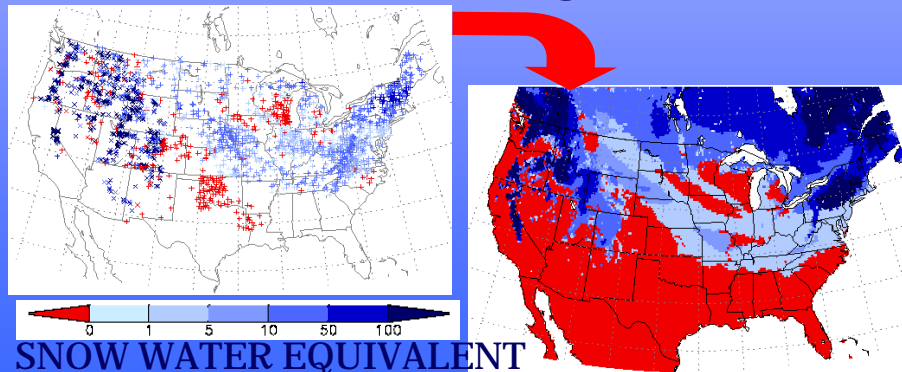
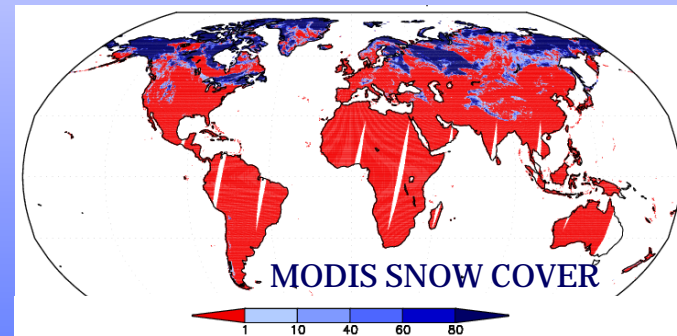


INTERCOMPARISON and OPTIMAL MERGING of global data fields



Satellite derived meteorological data used as land surface model FORCING

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



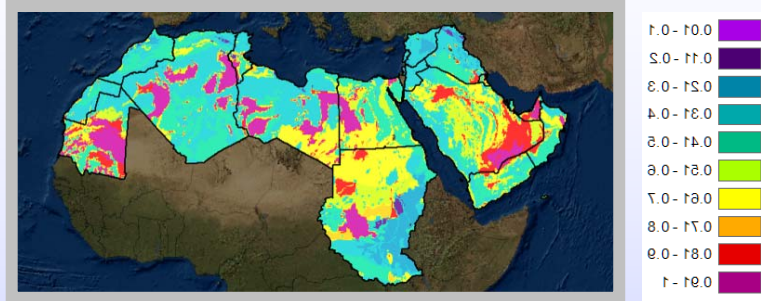
Ground-based observations used to VALIDATE model output



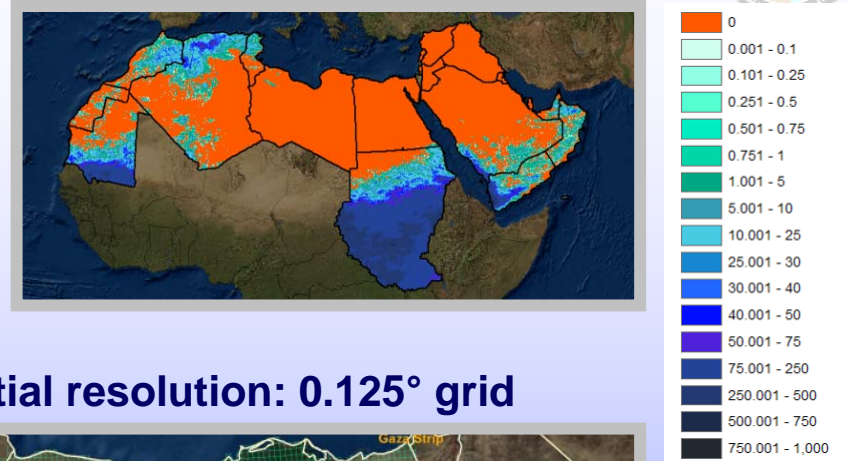
“Arab LDAS” Inputs and Configuration



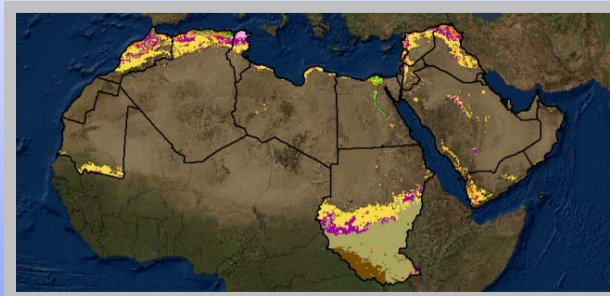
Fraction of Sand



PERSIANN 0.04° Precipitation (mm), July 2007



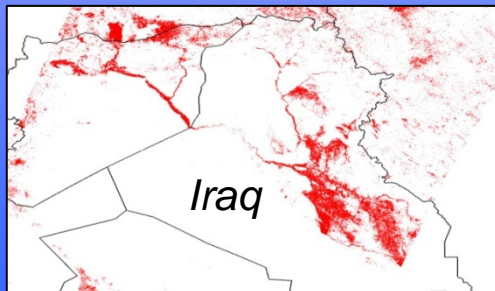
Dominant Land Cover Type



Spatial resolution: 0.125° grid



MODIS-based Irrigated Area



- Other:
- GRACE Data Assimilation
 - Runoff routing
 - Regional datasets

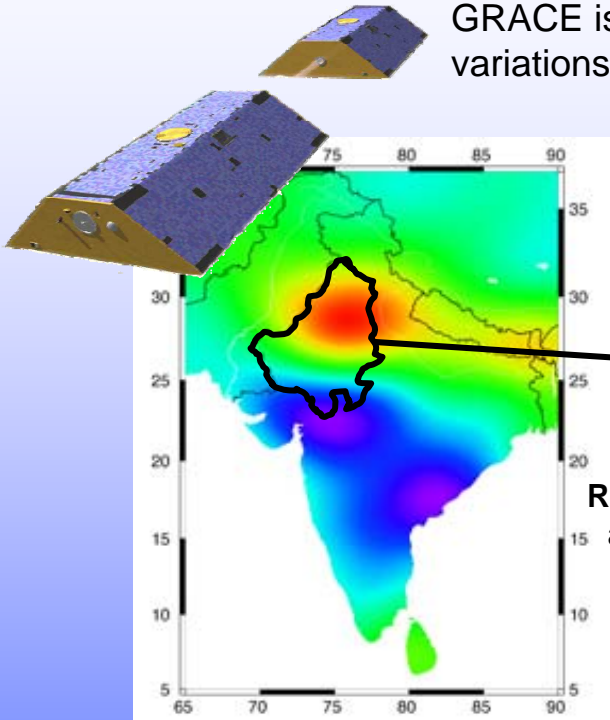


Groundwater Monitoring Example: NW India



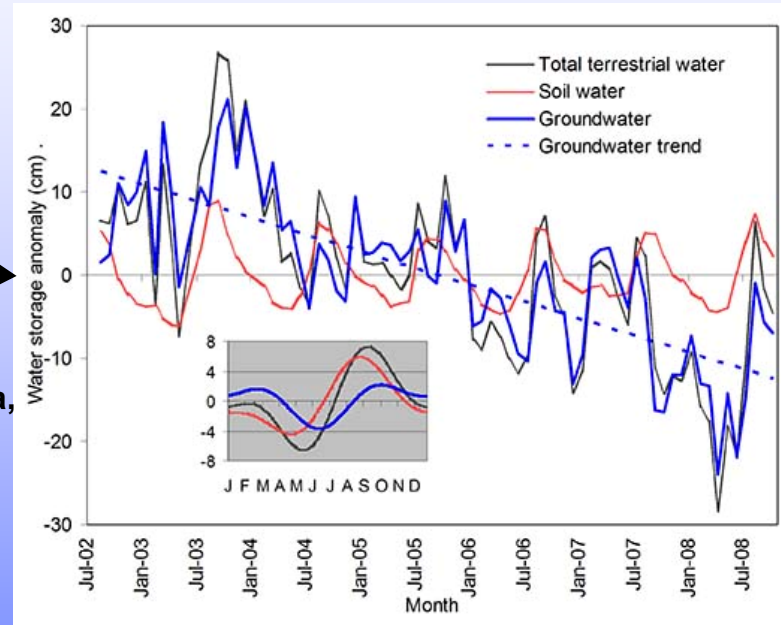
The water table is declining at an average rate of 33 cm/yr

GRACE is unique among Earth observing missions in its ability to monitor variations in all water stored on land, down to the deepest aquifers.



Rodell, Velicogna, and Famiglietti, *Nature*, 2009

Trends in groundwater storage during 2002-08, with increases in blue and decreases in red. The study region is outlined.



Time series of total water from GRACE, simulated soil water, and estimated groundwater, as equivalent layers of water (cm) averaged over the region. The mean rate of groundwater depletion is 4 cm/yr. Inset: Seasonal cycle.

During the study period, 2002-08, 109 km³ of groundwater was lost from the states of Rajasthan, Punjab, and Haryana; triple the capacity of Lake Mead



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Potential Solutions



1) Product latency

- Near-real time information is vital for operational applications

Solutions: More rapid processing of raw data; Data assimilation

2) Low spatial resolution

- Most practical applications require observations at scales of 0.01 – 2500 km

Solutions: Lower altitude, drag-free, laser ranging (sans aliasing) mission; DA

3) Lack of vertical information

- Groundwater, soil moisture, surface water, or snow

Solutions: Combine with other observations (e.g., SMOS, SMAP); DA

4) Low temporal resolution

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Solutions: Mascons; Constellation of satellites; DA



Conclusions



- GRACE is already proving to be valuable for practical applications including drought monitoring, regional water resources assessments, and estimating rates of groundwater depletion
- Obstacles to using satellite gravimetry for practical applications include data latency, coarse spatial and temporal resolutions, and lack of vertical structure
- Some of these obstacles may be overcome with a high performance follow-on to GRACE; others will require more efficient and innovative processing of level-1 data or data integration/assimilation
- An emerging obstacle is the lack of commitment to a follow-on mission, such that water managers may be afraid to rely on GRACE
- It is always important to remember the value of satellite gravimetry for hydrology: it is the **only** remote sensing technique capable of measuring water stored below the first few centimeters of the surface