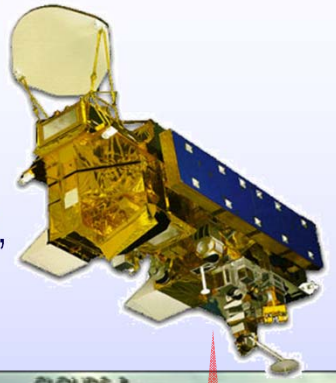
NASA's GRACE-based Drought/Wetness Indicators and Global LDAS

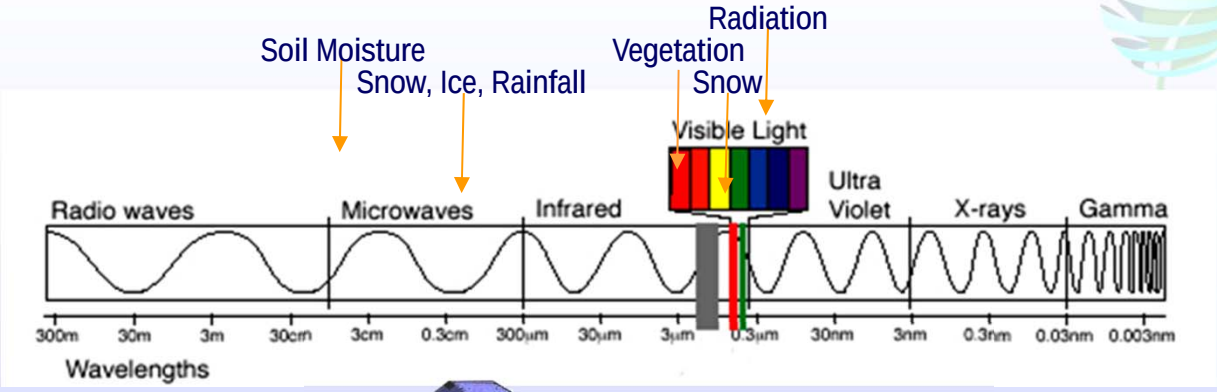
Matt Rodell*, Hiroko Beaudoing, Bailing Li, Sujay Kumar, Ben Zaitchik, and Augusto Getirana

***Hydrological Sciences Laboratory**
NASA Goddard Space Flight Center
Greenbelt, MD

Gravity Recovery and Climate Experiment (GRACE)

Aqua:
MODIS,
AMSR-E,
etc.





GRACE

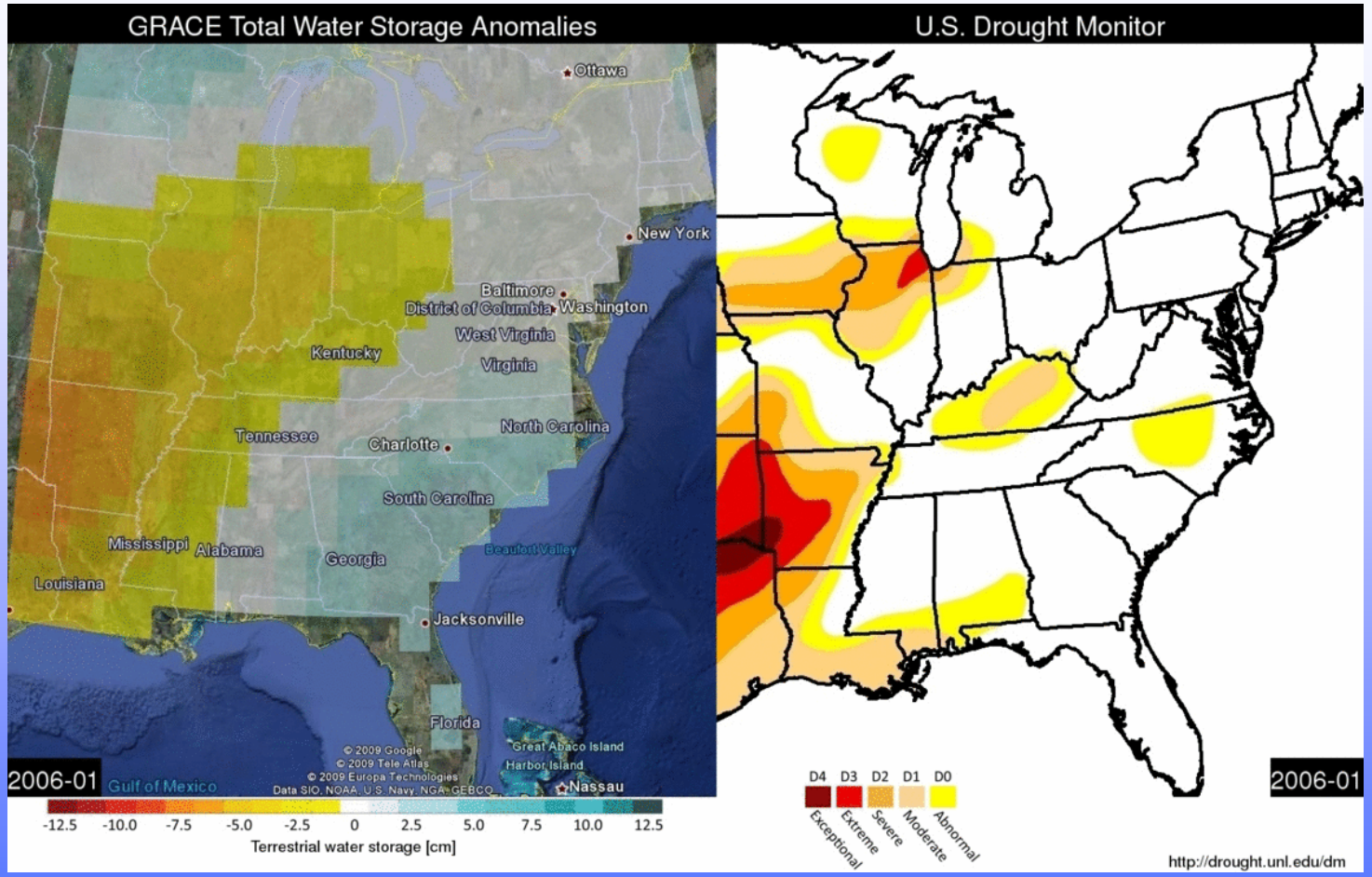
Conventional radiation-based remote sensing technologies cannot sense water below the first few centimeters of the snow-canopy-soil column

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

Matt Rodell
NASA GSFC

GRACE Provides a Unique Perspective on Drought

GRACE observes groundwater and deep soil moisture, key indicators of drought



GRACE captured the evolution of the 2007-08 drought in the southeastern U.S., and is now helping to improve drought monitoring and prediction

Matt Rodell
NASA GSFC

GRACE Hydrology: Challenges

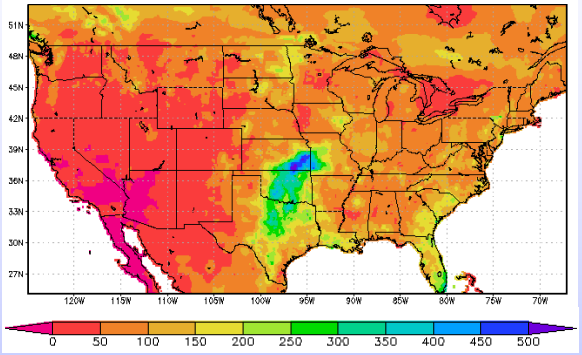
- Spatial resolution: 150,000 km^2 or coarser
- Temporal resolution: 10-day to monthly
- Data latency: possibly 2 weeks; typically 2-4 months
- Lack of vertical information: observations convolve groundwater, soil moisture, surface water, snow

- Why bother? Surface observation networks are inadequate and satellite gravimetry is the only remote sensing technology able to measure water below the first few centimeters of the land surface, including groundwater.

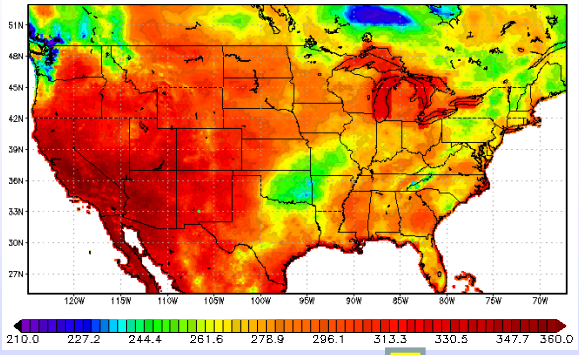
Matt Rodell
NASA GSFC

Integration of GRACE and Other Data via Data Assimilation

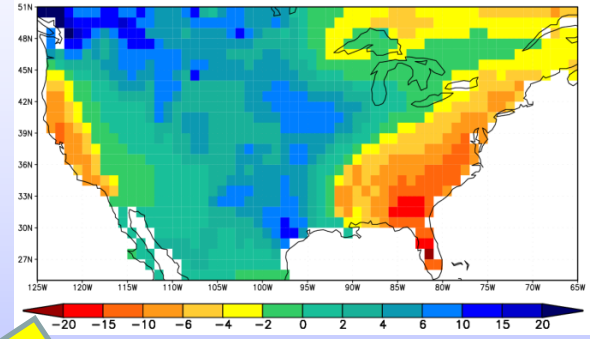
Precipitation (mm/month)



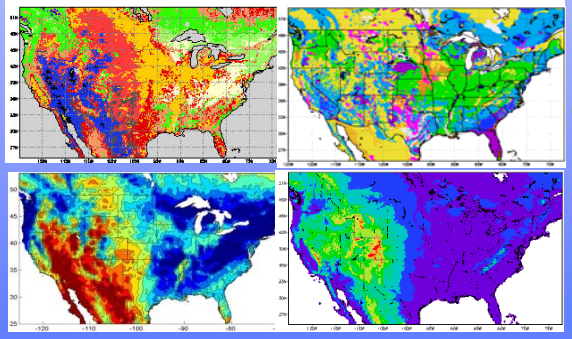
Solar Radiation (W/m2)

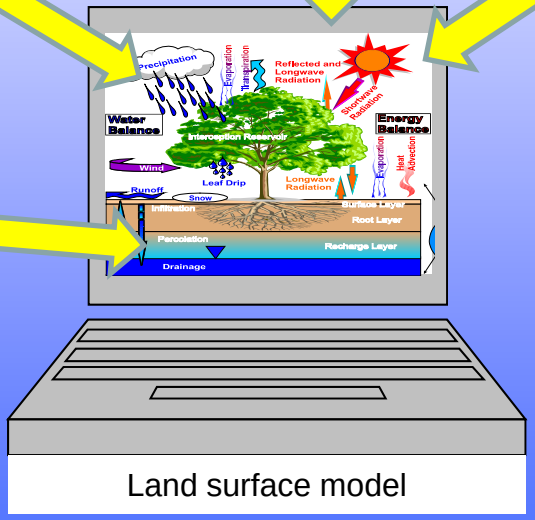


GRACE Water Storage Anomaly (cm)



Other land surface properties and meteorological variables



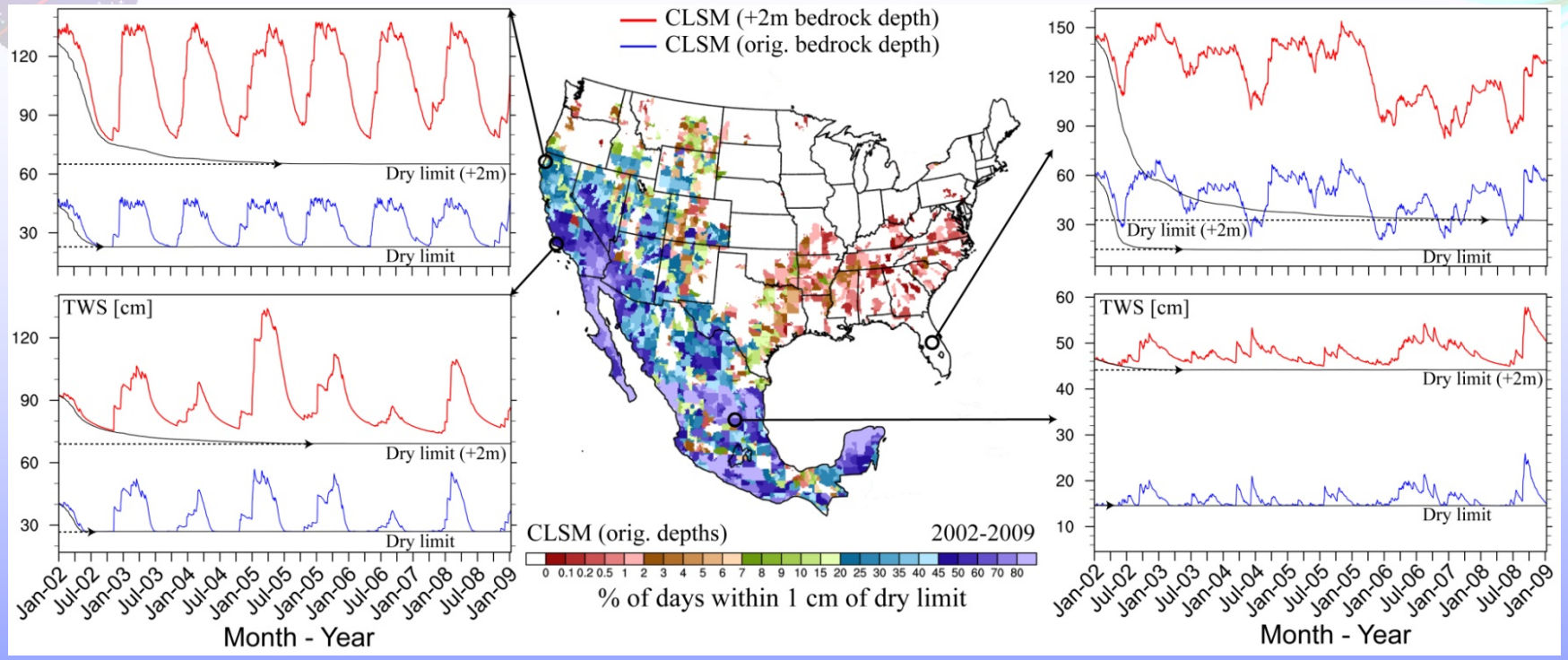


Land surface model

- Data assimilation combines modeled and observed estimates and error info to compute optimal estimates
- Ensemble smoother data assimilation (*Zaitchik et al., J. Hydromet., 2008*)
- Output has improved spatial, temporal, and vertical information

Matt Rodell
NASA GSFC

Preparing for GRACE Data Assimilation



Houborg et al., WRR, 2012

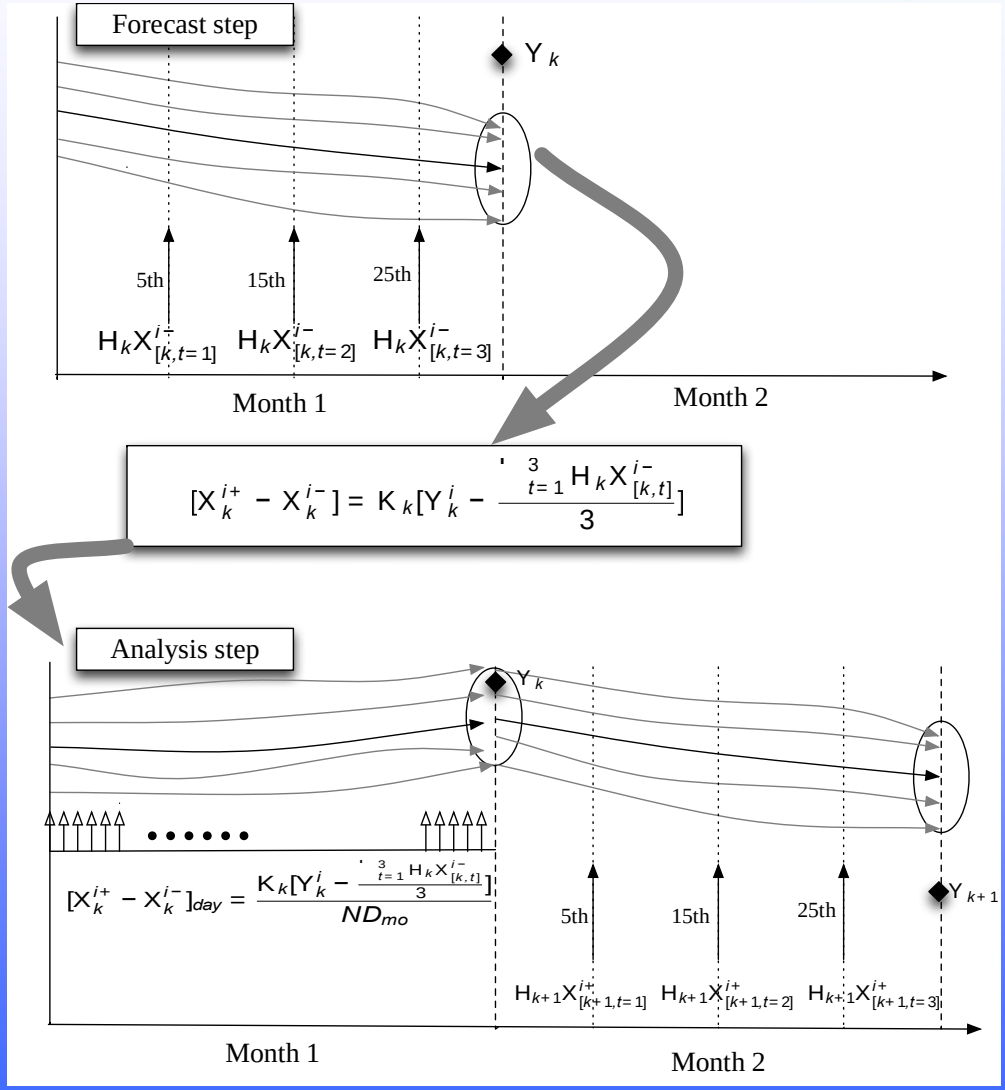
- In some cases Catchment model TWS approached a "dry limit", preventing full impact of GRACE data assimilation
- Dry limit quantified (above) by open loop run with no precipitation
- Particularly important for drought monitoring, but also for climatology
- Problem addressed by increasing the depth to bedrock by 2 m
- Unintended consequences for fluxes (e.g., runoff) determined to be minimal, but in some areas the mode of interannual GW variability increased to 20+ years

→ Mask recently developed to prescribe +2m bedrock depth only as needed

Matt Rodell
NASA GSFC

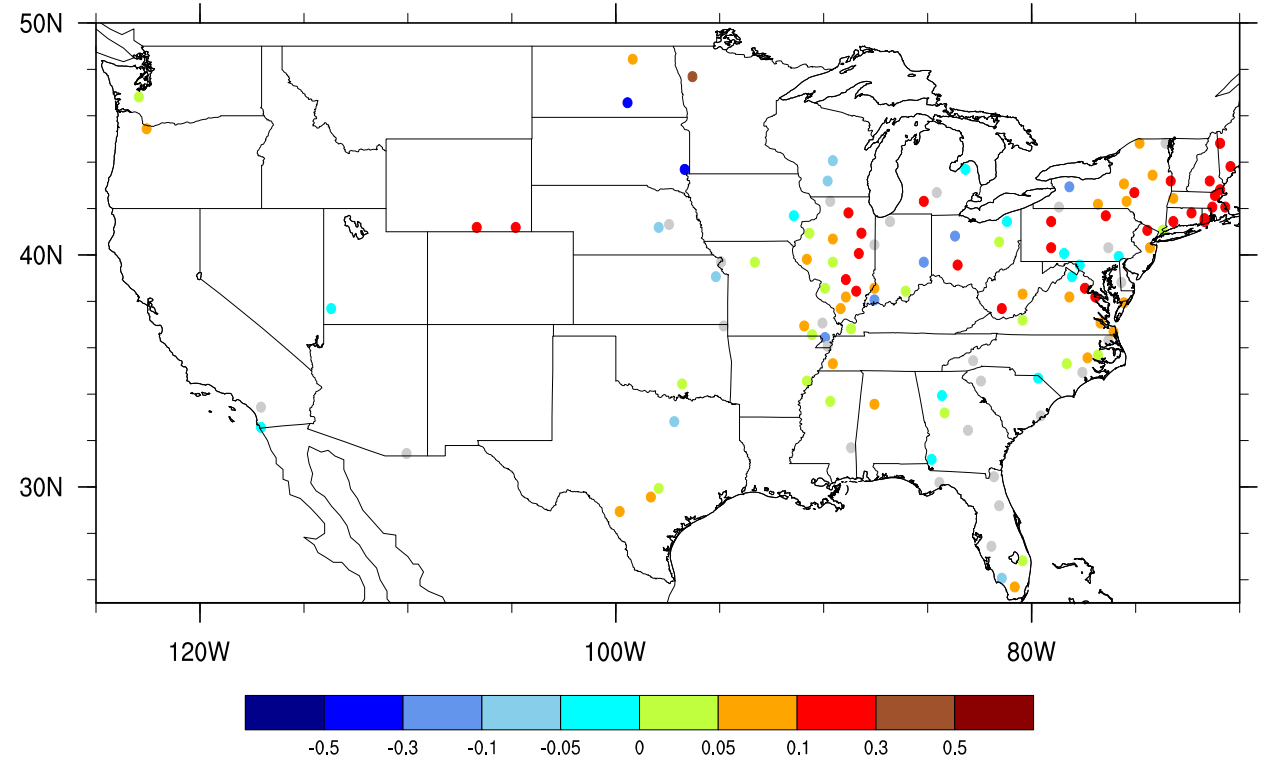
New Gridded GRACE DA within LIS

- Land Information System (LIS) is the software behind GLDAS
- Catchment land surface model w/ depth to bedrock increased by 2 m
- 3-dimensional Ensemble Kalman Smoother
- 20 member ensemble
- Assimilates gridded GRACE TWS anomaly fields as opposed to basin averages
- Horizontal error correlation scale ~300 km
- Prescribed uncertainty in the model and observation must be similar in magnitude, else the assimilated result will be dominated by one or the other



Matt Rodell
NASA GSFC

Evaluation of Gridded GRACE DA: Groundwater



- Evaluation using quality controlled USGS groundwater well records
- Above: Anomaly R differences (DA - OL); warm colors indicate improvements due to DA, cool colors indicate degradations
- Right: Average improvement is significant

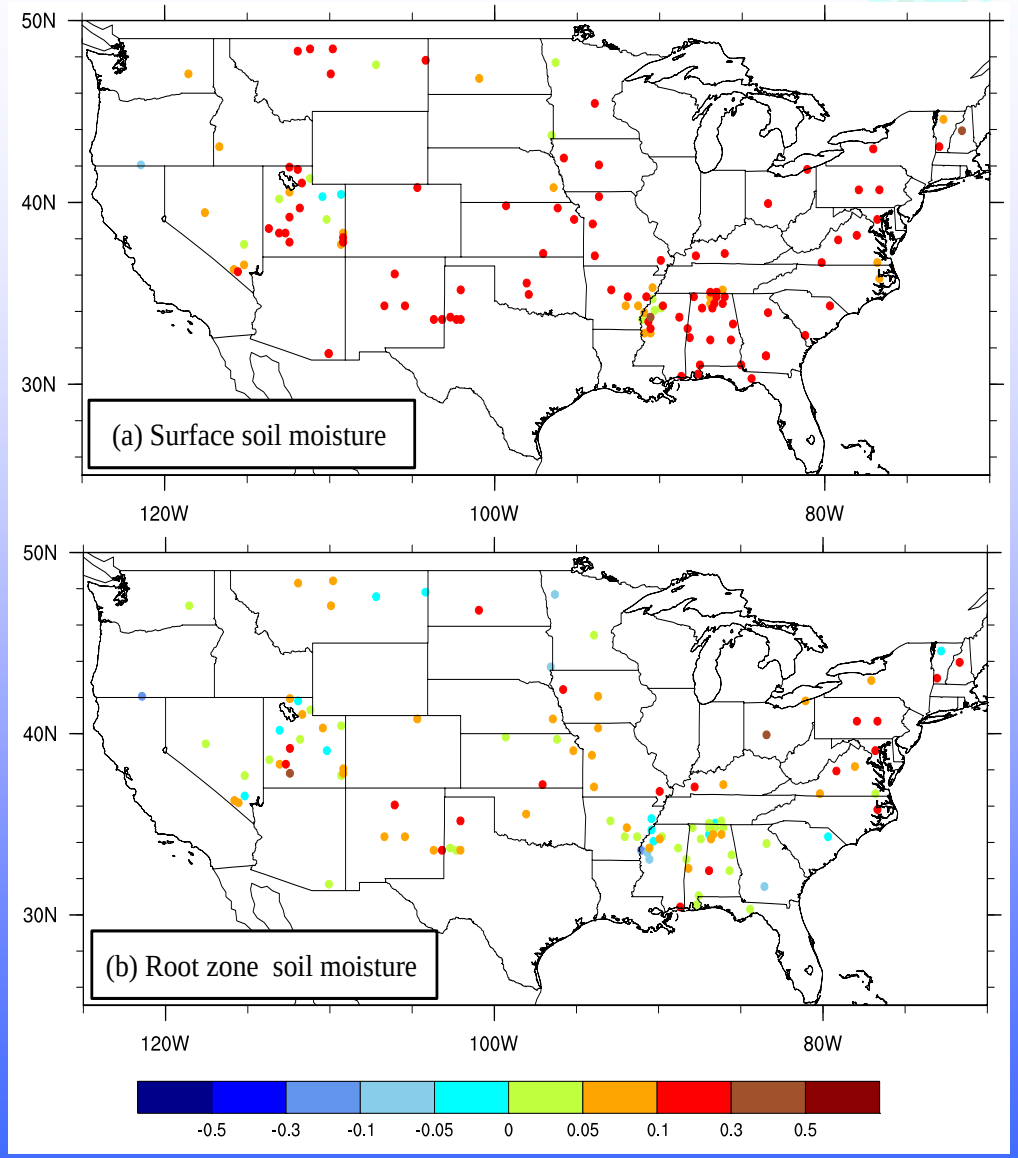
	OL	DA
Anomaly R	0.64+/- 0.02	**0.69 +/- 0.02**

Matt Rodell
NASA GSFC

Evaluation of Gridded GRACE DA: Soil Moisture

- Evaluation using USDA Agricultural Research Service (ARS) and Soil Climate Analysis Network (SCAN) soil moisture measurements
- Right: Anomaly R differences (DA - OL); warm colors indicate improvements due to DA, cool colors indicate degradations
- Below: Average improvement is significant

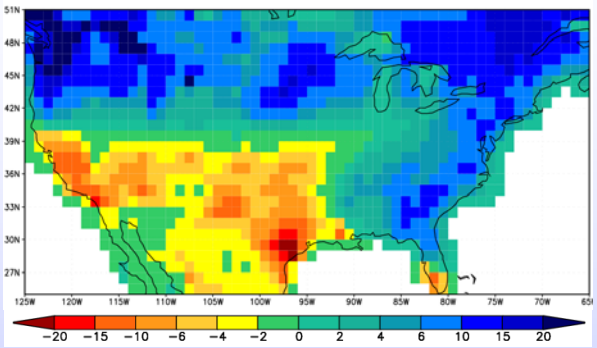
Anomaly R	OL	DA
Surface soil moisture	0.44+/- 0.02	**0.58 +/- 0.02**
Root zone soil moisture	0.48+/- 0.02	**0.54+/- 0.02**



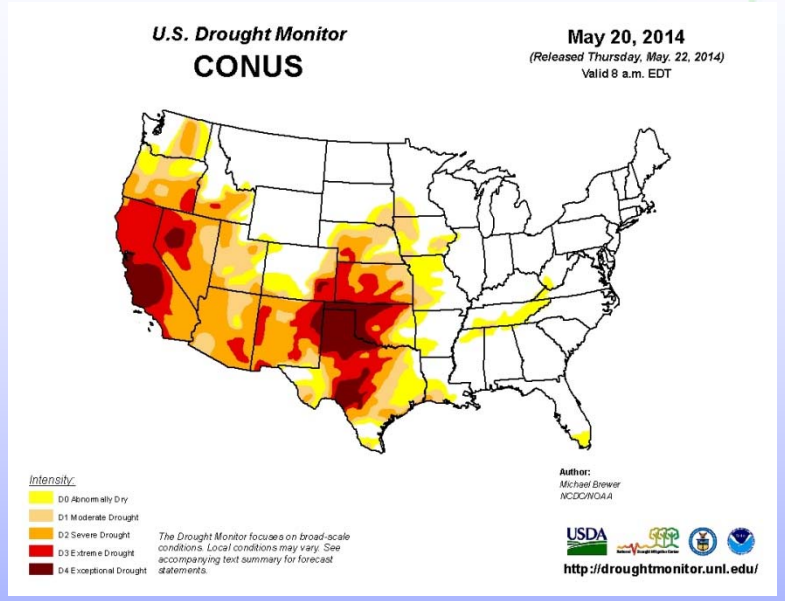
Matt Rodell
NASA GSFC

GRACE Data Assimilation for Drought Monitoring

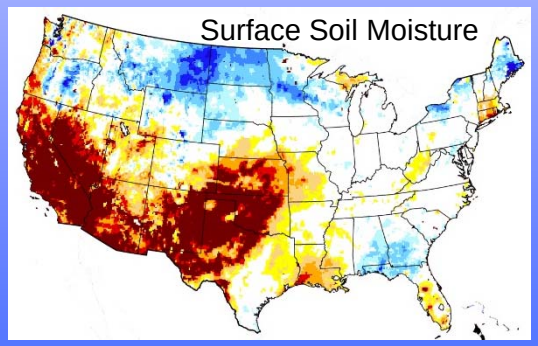
GRACE terrestrial water storage anomalies (cm equivalent height of water) for May 2014 (Tellus CSR RL05 scaled).

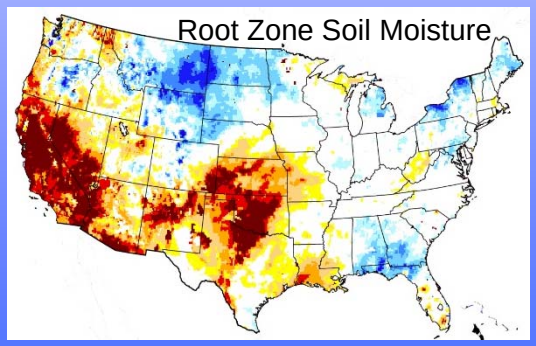


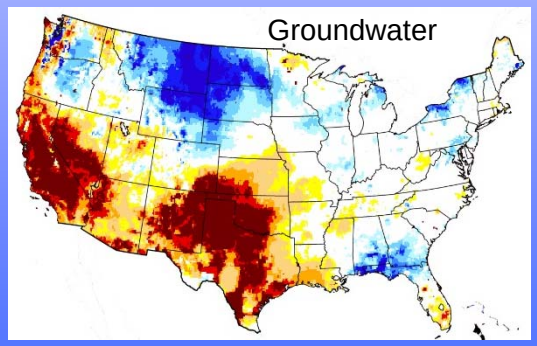
New process integrates data from GRACE and other satellites to produce timely information on wetness conditions at all levels in the soil column, including groundwater. For current maps and more info, see http://www.drought.unl.edu/MonitoringTools.aspx

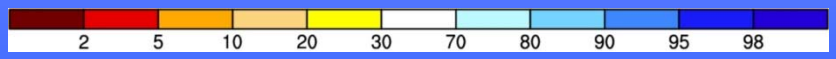


U.S. Drought Monitor product for 20 May 2014.









Drought indicators from GRACE data assimilation (wetness percentiles relative to the period 1948-present) for 19 May 2014.

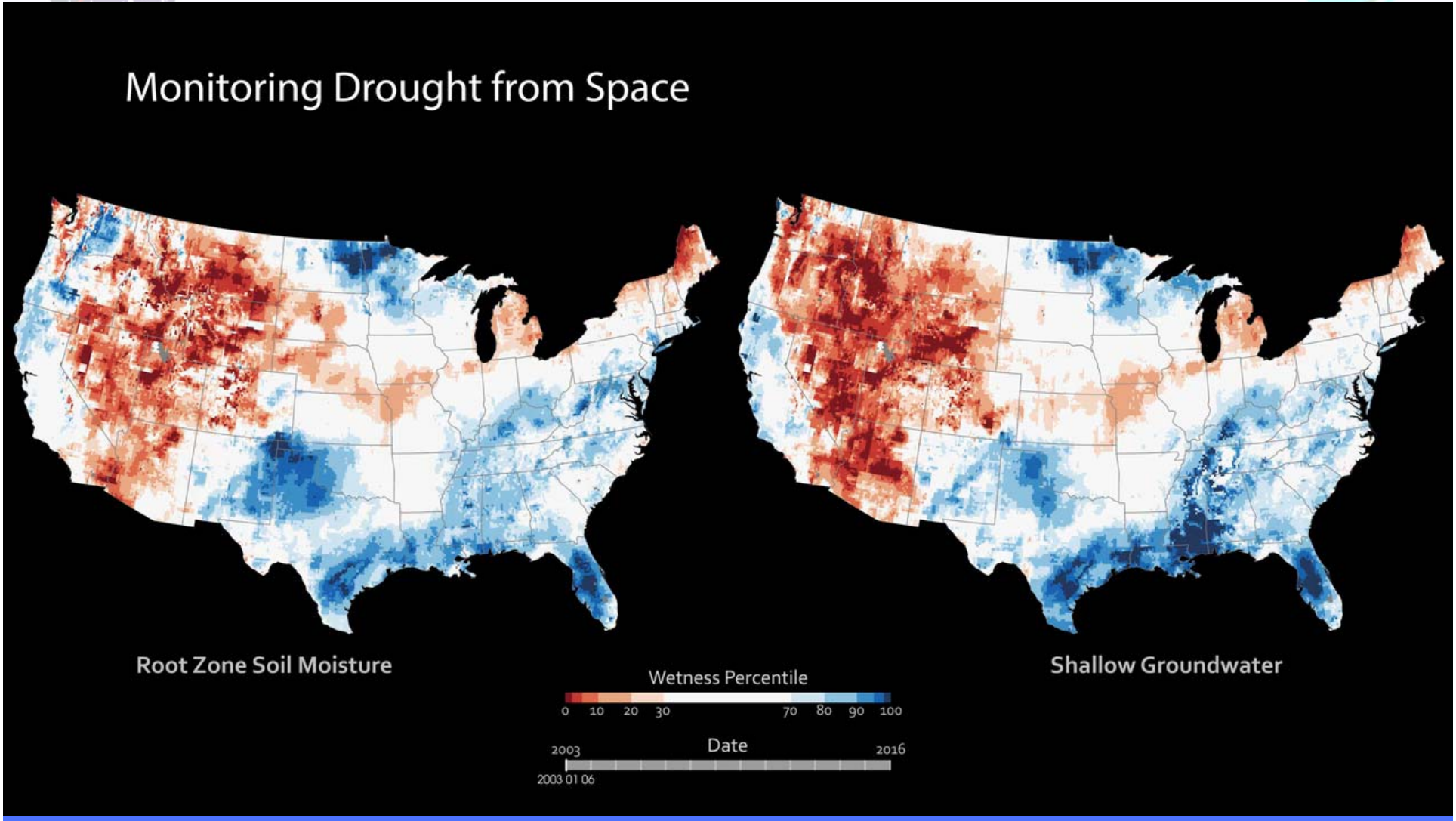
Matt Rodell
NASA GSFC

GRACE DA Based Drought Indicators

- 1948 to 2012 “open loop” (no DA) Catchment LSM simulation provides background climatology
- 2002 to present Catchment LSM simulation with GRACE DA adjusted to be consistent with the climatology using the overlapping period
- NLDAS2 observation-based meteorological forcing (precipitation, solar radiation, etc.) enables extrapolation of GRACE TWS information
- Groundwater and root zone and surface soil moisture outputs are converted to percentiles based on CDF of the long term climatology
- Data and maps are used by the U.S. Drought Monitor authors and posted on a weekly basis at http://drought.unl.edu/MonitoringTools.aspx

Matt Rodell
NASA GSFC

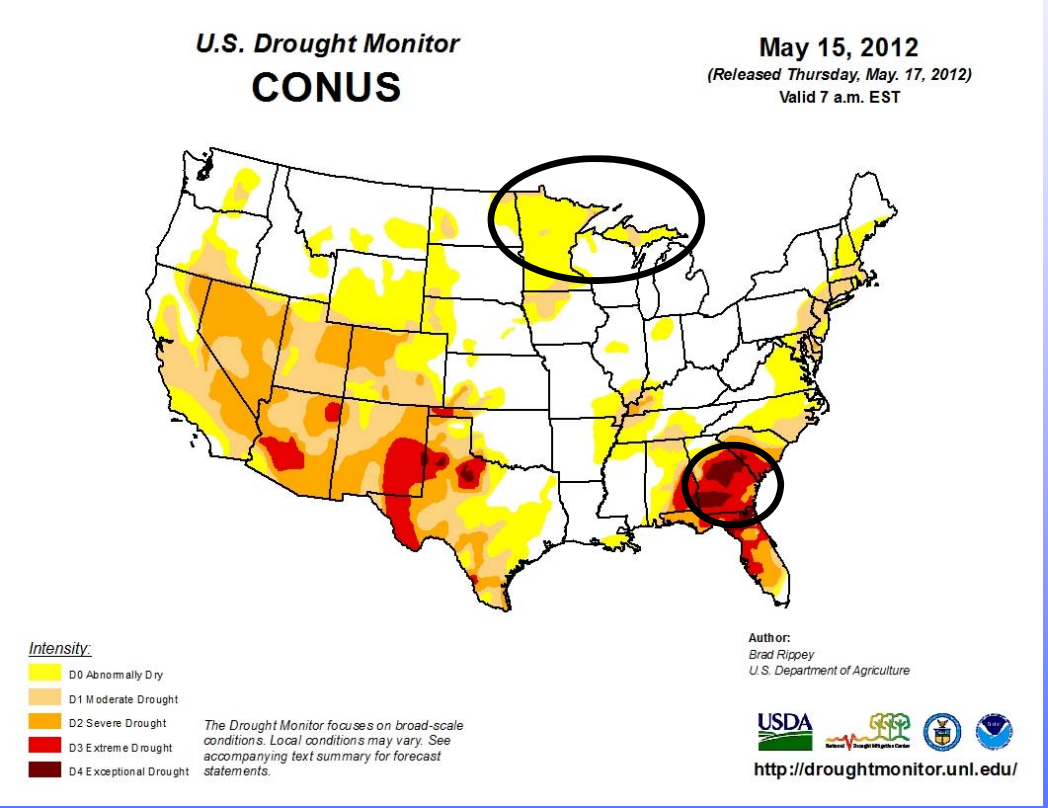
GRACE-DA Drought Indicators



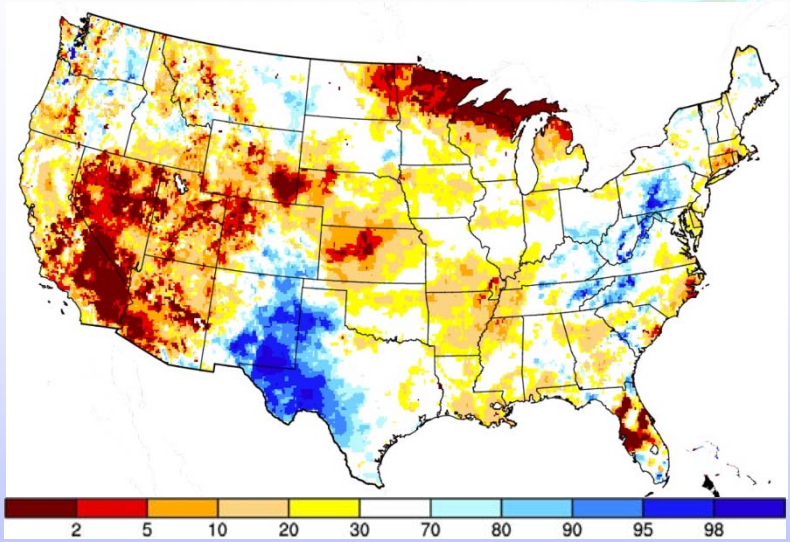
Visualization prepared by Marit Jentoft-Nilsen, NASA/GSFC

Matt Rodell
NASA GSFC

The Persistence of Deep Drought

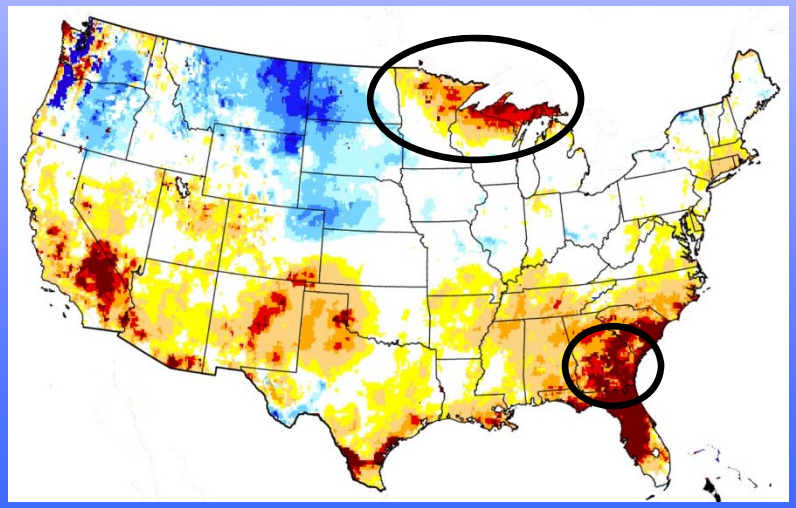


Surface Soil Moisture Drought/Wetness Indicator from GRACE DA, May 14, 2012



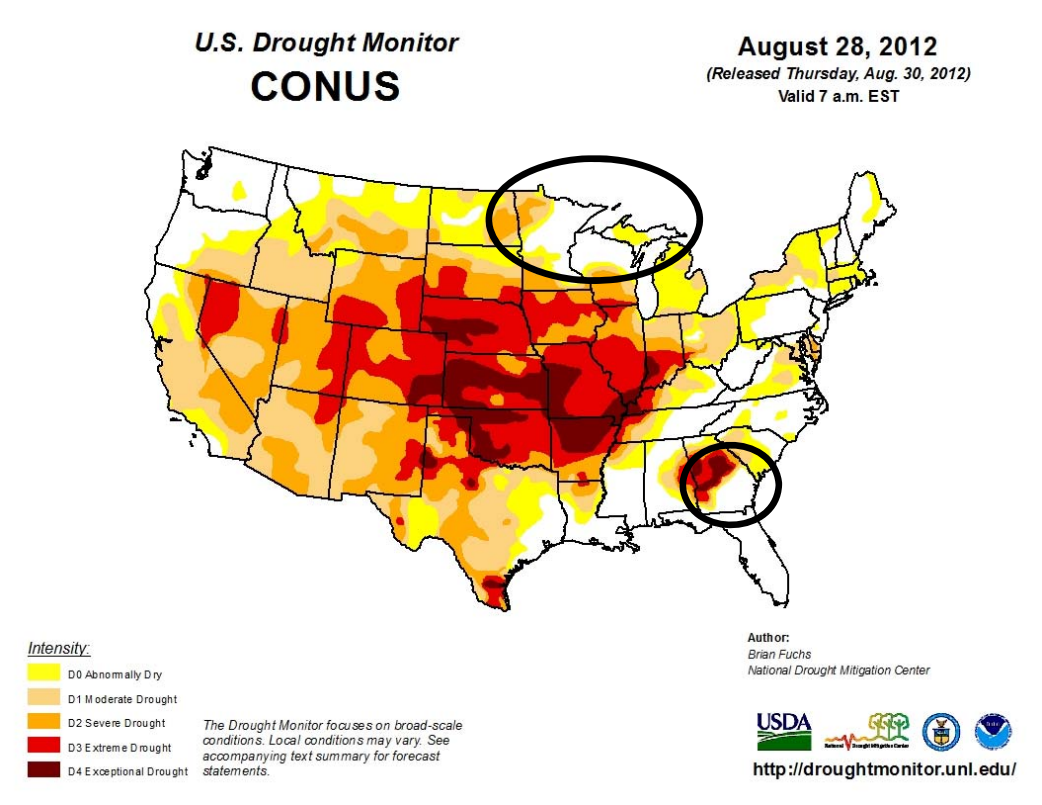
Wetness percentile relative to the period 1948-present

Shallow Groundwater Drought/Wetness Indicator from GRACE DA, May 14, 2012

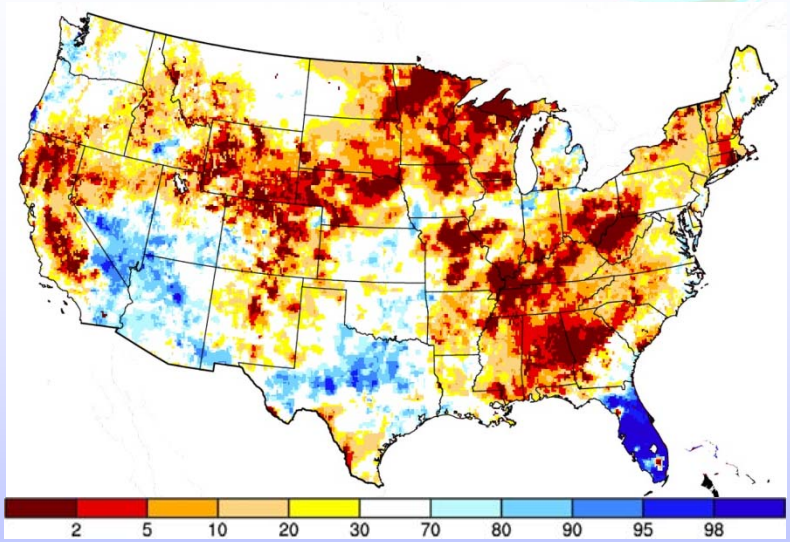


Matt Rodell
NASA GSFC

The Persistence of Deep Drought

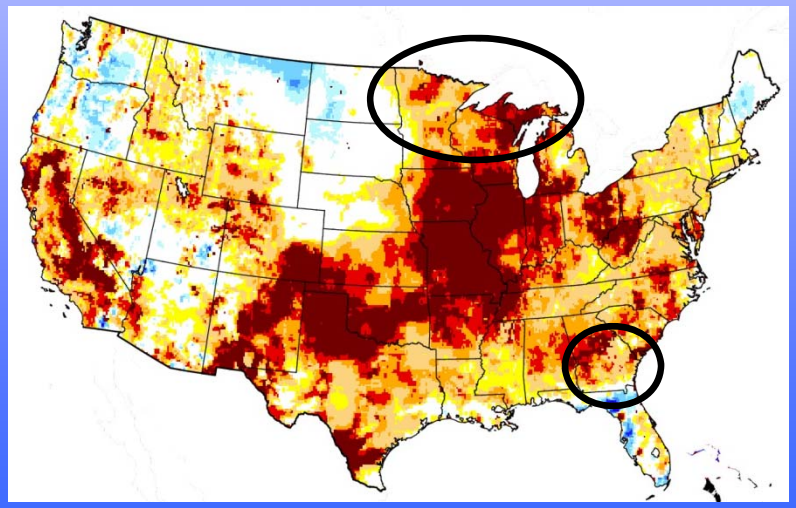


Surface Soil Moisture Drought/Wetness Indicator from GRACE DA, August 27, 2012



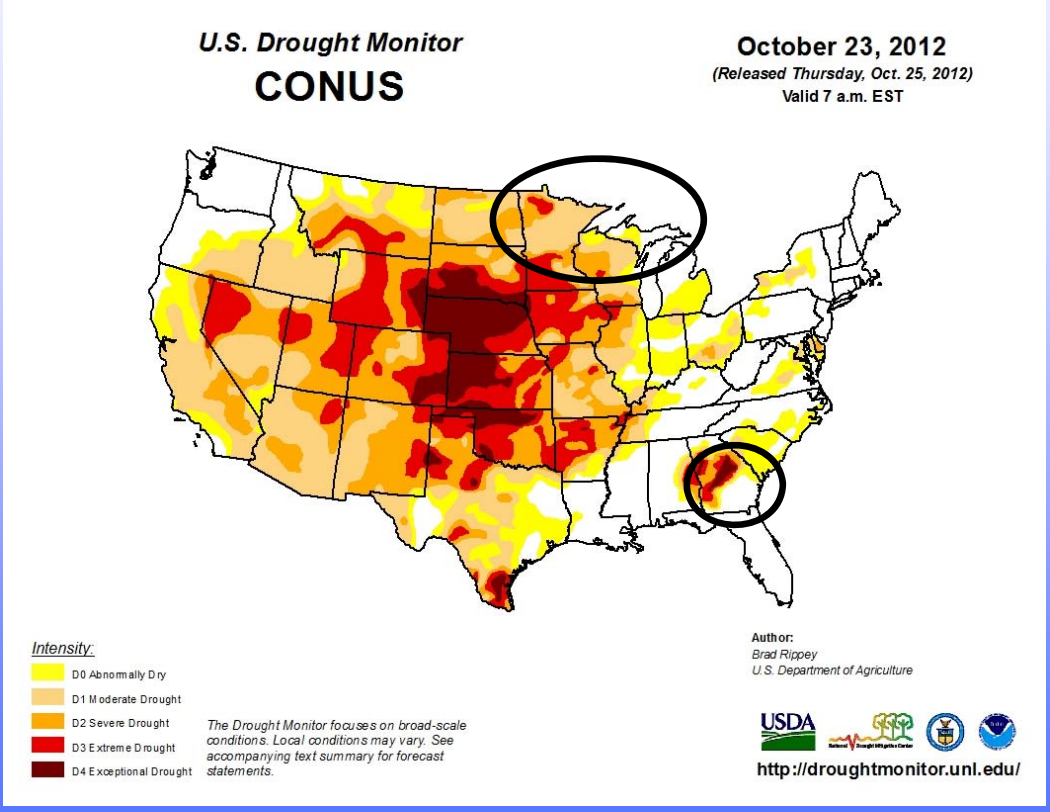
Wetness percentile relative to the period 1948-present

Shallow Groundwater Drought/Wetness Indicator from GRACE DA, August 27, 2012

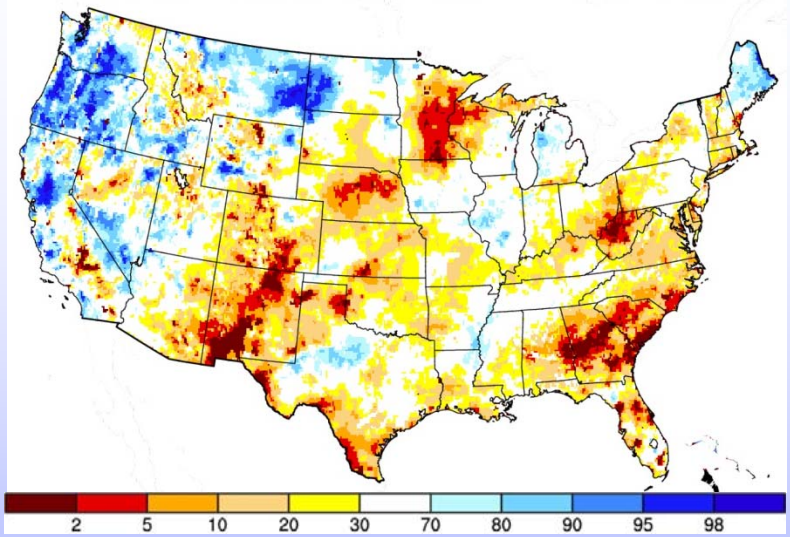


Matt Rodell
NASA GSFC

The Persistence of Deep Drought

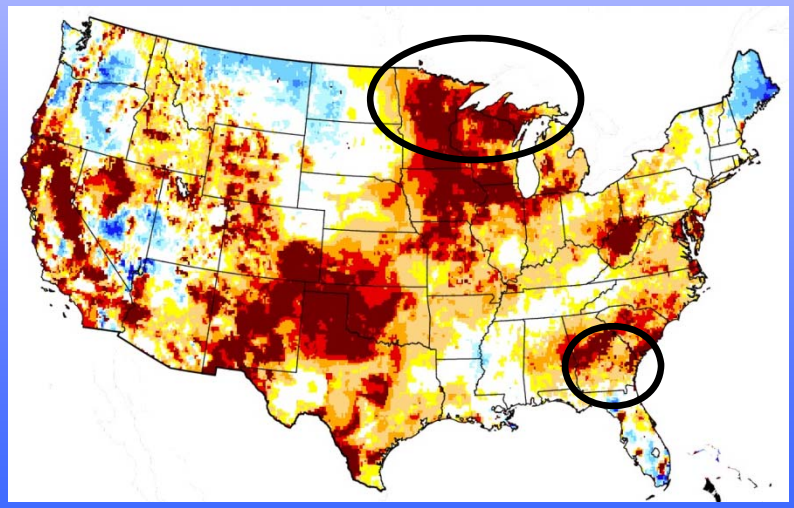


Surface Soil Moisture Drought/Wetness Indicator from GRACE DA, October 23, 2012



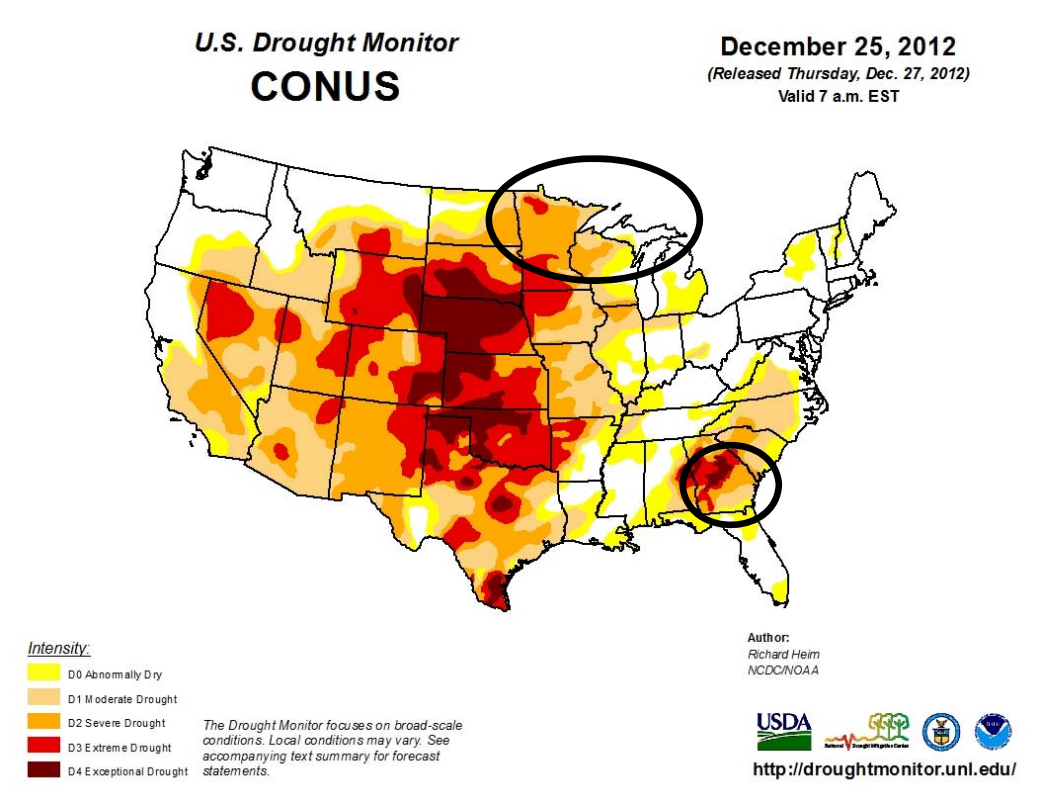
Wetness percentile relative to the period 1948-present

Shallow Groundwater Drought/Wetness Indicator from GRACE DA, October 23, 2012

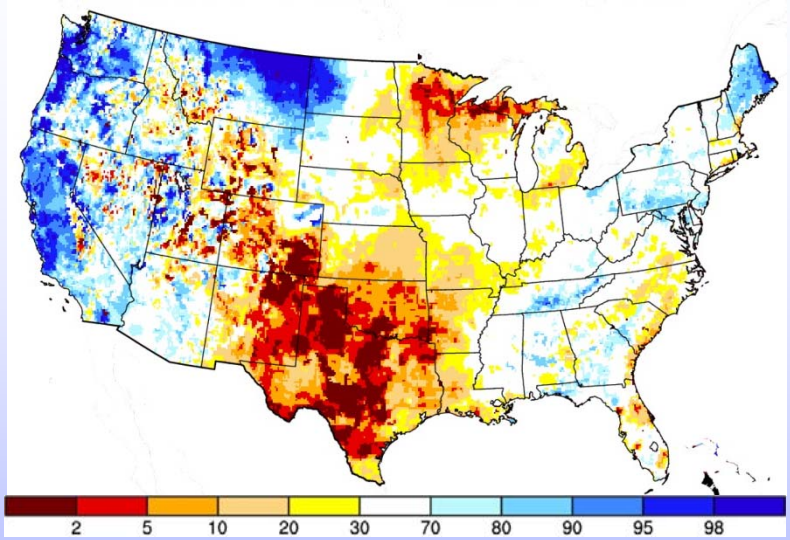


Matt Rodell
NASA GSFC

The Persistence of Deep Drought

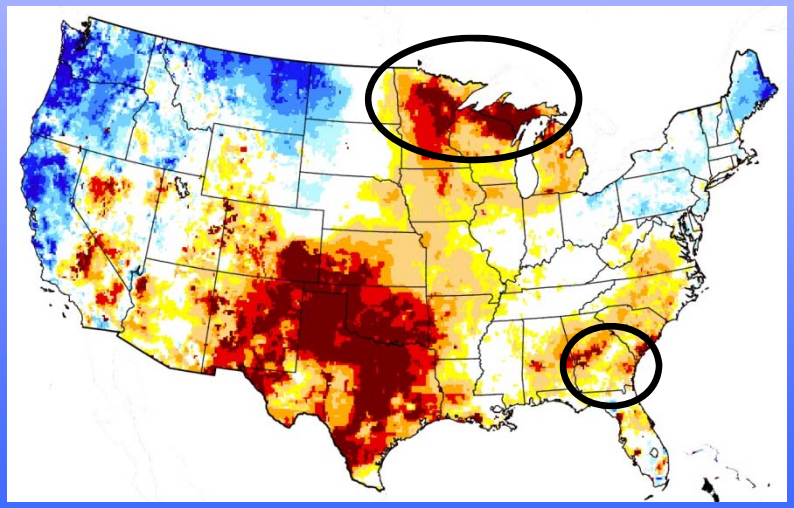


Surface Soil Moisture Drought/Wetness Indicator from GRACE DA, December 24, 2012



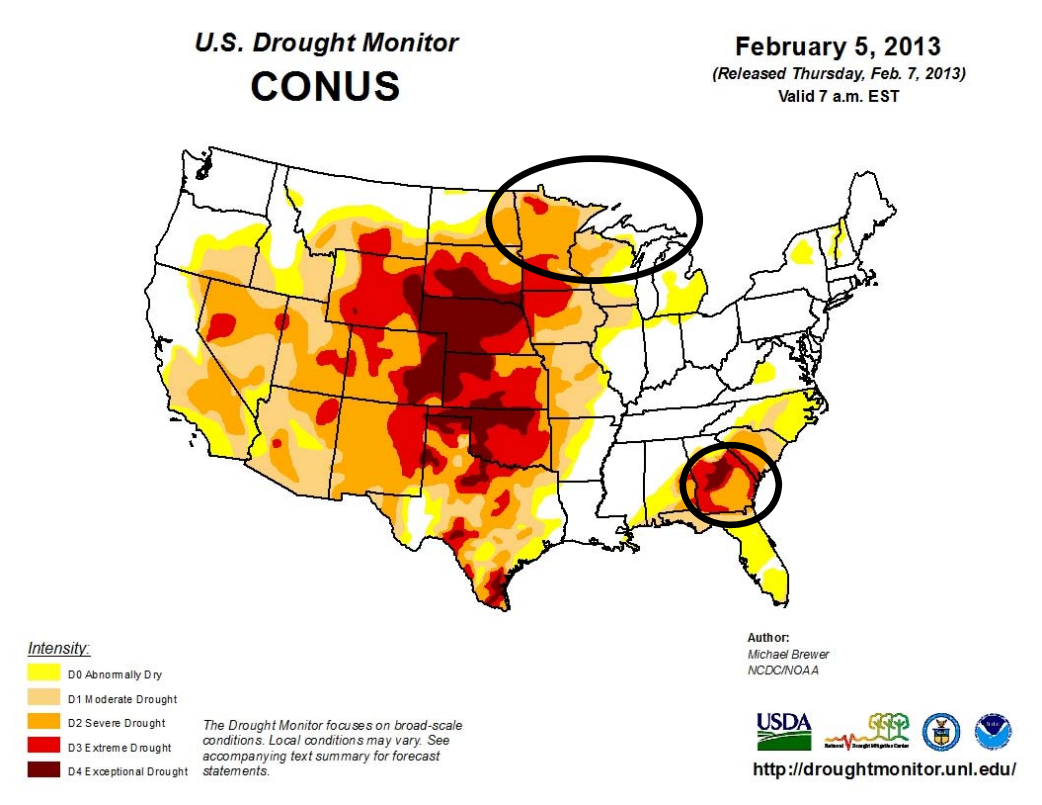
Wetness percentile relative to the period 1948-present

Shallow Groundwater Drought/Wetness Indicator from GRACE DA, December 24, 2012

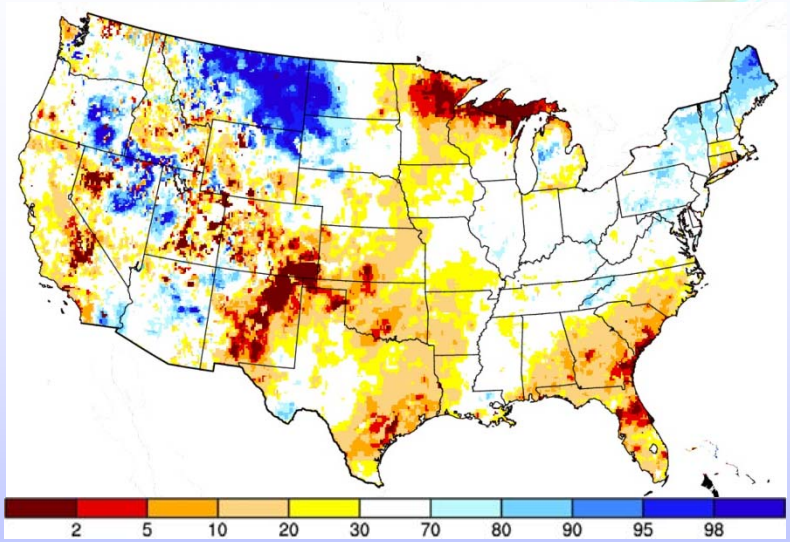


Matt Rodell
NASA GSFC

The Persistence of Deep Drought

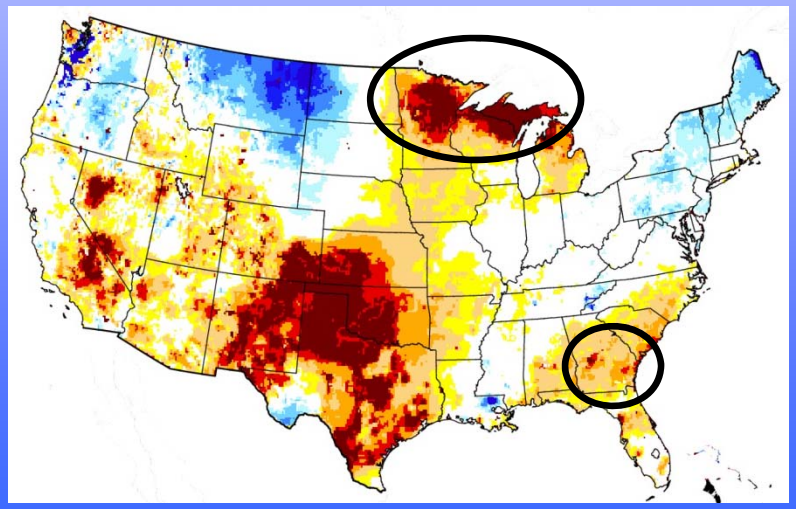


Surface Soil Moisture Drought/Wetness Indicator from GRACE DA, February 4, 2013



Wetness percentile relative to the period 1948-present

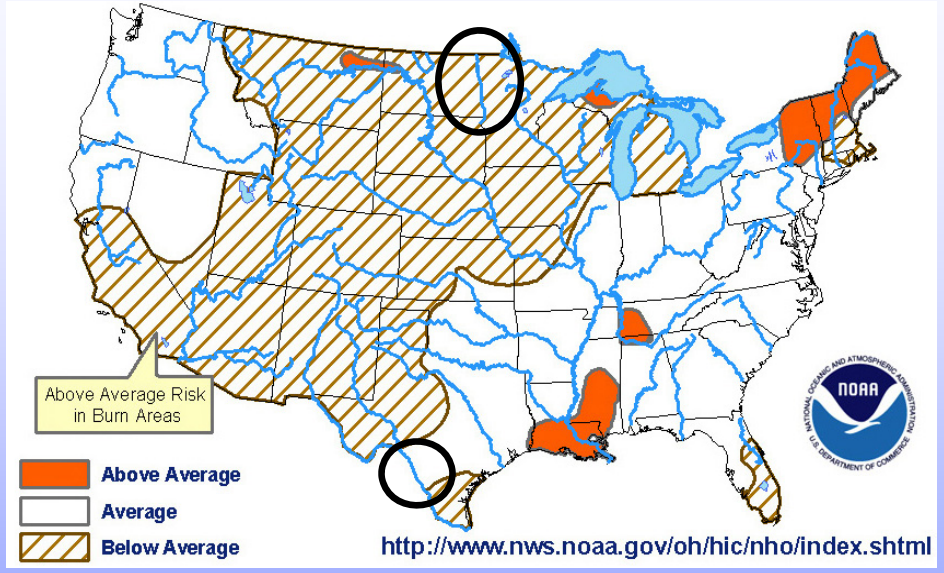
Shallow Groundwater Drought/Wetness Indicator from GRACE DA, February 4, 2013



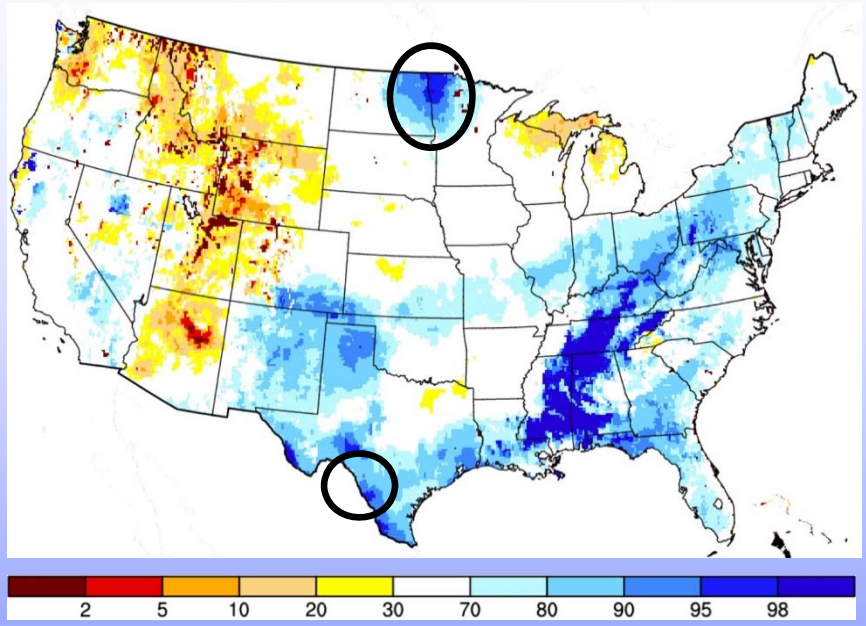
Matt Rodell
NASA GSFC

Antecedent Conditions → Flood Forecast Potential

NOAA's Spring Flood Risk Assessment
Issued March 12, 2004



Shallow Groundwater Drought/Wetness Indicator from GRACE DA, March 8, 2004



Wetness percentile relative to the period 1948-present

From the Dartmouth Flood Observatory

March 28 – April 11, 2004: "Extensive overland flooding in rural areas of the Red River valley." Dead: none. Displaced: 1,000. Damage: $4.5M.

April 4-6, 2004 - "Flooding some of the worst in the history of the U.S.-Mexico border region." Dead: 37. Displaced: 3,500. Damage: ??

Note 1: Wet antecedent conditions are neither a guaranty of nor a prerequisite for flooding.

Note 2: NOAA correctly forecasts spring flooding more often than not.

Matt Rodell
NASA GSFC

Flood and Drought Forecasting

Premise: Terrestrial water storage has significant "memory"→ antecedent conditions that influence drought and flood severity.

Goal: Develop 30-90 day, 0.125° gridded predictions of soil moisture and groundwater conditions and runoff for the continental U.S., and test them as inputs to existing drought, river flow, and flood decision support systems.

Key Datasets

- GRACE and GRACE FO TWS anomalies (U. Texas "regularized" fields)
- Princeton and NLDAS-2 meteorological forcing
- NASA GEOS-5 seasonal forecasts

Model

- NASA's Land Information System (LIS) software infrastructure
- Catchment Land Surface Model
- Gridded, ensemble smoother GRACE data assimilation

Matt Rodell
NASA GSFC

NASA's Land Data Assimilation Systems

North American LDAS

- NOAA, NASA, (and 6 other US institutions) 1998-present
- 1/8 degree resolution, central North America

Global LDAS

- An instance of LIS with a massive archive of input and output data
- NASA (and NOAA) 2000-present
- 1/4 and 1.0 degree resolutions, all land 60S-90N

Land Information System (LIS)

- NASA 2002-present
- Software configurable for any domain and resolution
- Multiple data assimilation options
- Can be run uncoupled or coupled to an atmospheric model
- Adopted by all other NASA LDAS projects & NOAA & AFWA

Others: MERRA-Land; European LDAS; Middle East North Africa (MENA) LDAS; South American LDAS; LDAS-University of Tokyo; etc.

Matt Rodell
NASA GSFC

GLDAS operations—1) Incoming data*

Dataset	Function	Download size / daily	Raw+processed Size / year	Coverage	Archive size	Source
GDAS	Forcing	976 MB (*30)	31-420 GB	2000/01 ~	2.4 TB	NCEP
ECMWF	Forcing	139 MB	48 GB	2001/09 ~	1.7 TB	ECMWF
NLDAS2	Forcing	45.6 MB	16 GB	1979 ~	560 GB	NCEP/NASA
AFWA radiation	Forcing	1060 MB	582 GB	2001/03 ~	2.5 TB	AFWA/AGRMET-LIS
MODIS SNOW	Assimilation	3.8 MB	7.3 GB	2000/02 ~	102 GB	NASA
CMAP pentad	Forcing		0.63 GB	2001/01 ~	54 GB	CPC
Princeton	Forcing		5 GB	1948-2010	315 GB	Sheffield et al 2006
AFWA 3-hourly	Analysis	184 MB	13-61 GB	2001/10 ~	257 GB	AFWA/AGRMET-LIS
CMORPH 8km	Forcing	28 MB	9.6 GB	2002/12	107 GB	CPC

Table of active GLDAS incoming datasets

Green background is downloaded/processed daily, Yellow--once a month, Gray—occasionally (also GRACE).

Downloading is fully automated in all datasets.

Preprocessing is automated for GDAS and ECMWF while manual processing is required for AFWA radiation, MODIS SNOW, and CMAP disaggregation (for now).

Current disk usage: Forcing ~ 12 TB; Parameter ~ 1.3 TB; Satellite observation data sets to come for assimilation

*As of 1 April 2014

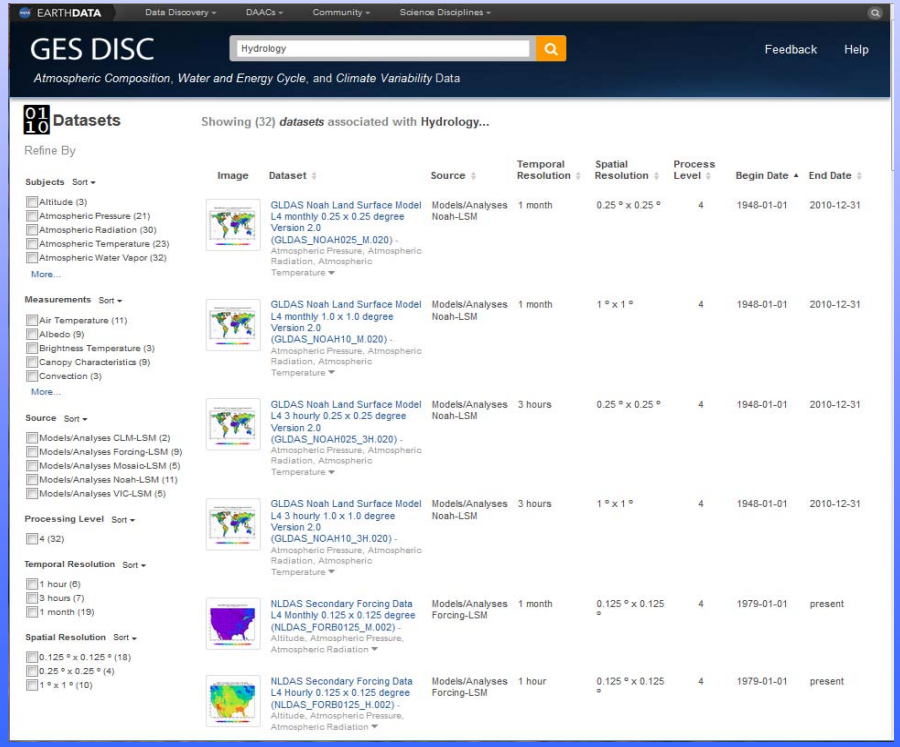
GLDAS Data Availability

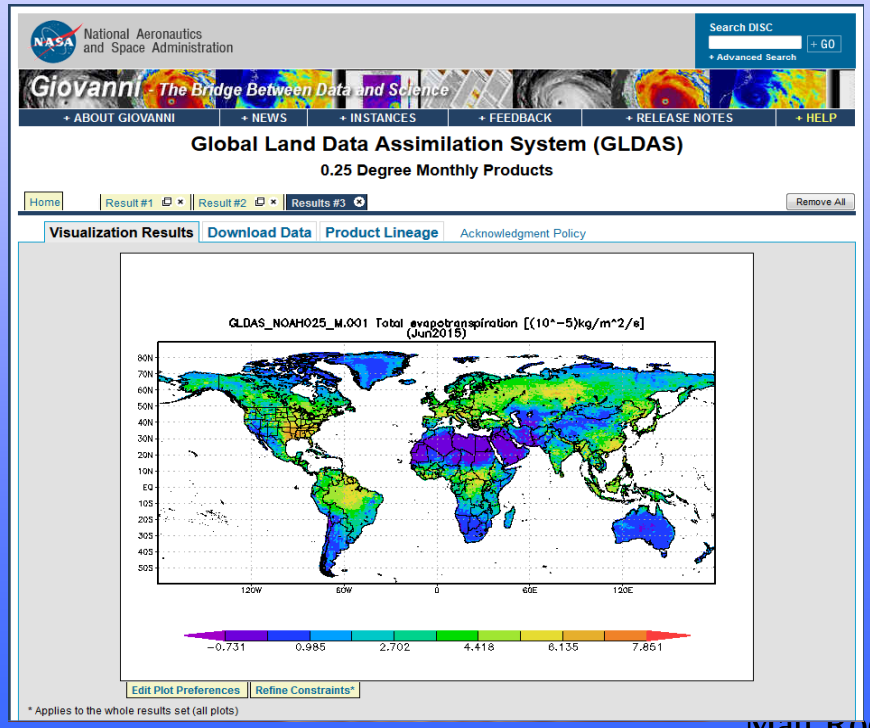
http://disc.gsfc.nasa.gov/hydrology

- Access via GDS, FTP, or quick-look visualization in Giovanni (below right)
- GRIB and NetCDF formats
- 3-hourly and monthly; 1.0° and 0.25° global grids
- On-the-fly subsetting (below center)
- Full documentation
- GLDAS supports a growing number of national and international hydrometeorological investigations and water resources applications

GLDAS V1
1.0°, 1979-present: Noah, CLM2, Mosaic, VIC
0.25°, 2000-present: Noah w/ MODIS snow cover assimilation
Forcing: Berg et al. (2003) for 1979-1999, GDAS + CMAP + AGRMET for 2000-present

GLDAS V2
1.0°, 1948-present: Noah
1.0°, 2001-present: CLM3.5, Mosaic, VIC
0.25°, 2000-present: Noah w/ improved MODIS snow cover assimilation
Forcing: Princeton for 1948-2000, GDAS + TMPA + AGRMET for 2001-present





Matt Rodell
NASA GSFC

GLDAS Data Usage

Download Statistics from the GES DISC

Month	Unique Users	Files	Volume (TB)
2013-04	346	1,341,642	2.01
2013-05	359	1,907,570	2.17
2013-06	398	874,131	1.31
2013-07	370	1,055,181	2.35
2013-08	331	810,217	2.25
2013-09	418	1,037,359	2.99
2013-10	321	3,538,842	3.24
2013-11	544	7,112,971	5.28
2013-12	477	4,363,910	7.10
2014-01	452	3,911,171	4.08
2014-02	523	3,032,037	4.33
2014-03	753	5,342,619	10.48

Matt Rodell
NASA GSFC

GLDAS Future Plans

- GLDAS2.1 will replace GLDAS1.0 multi-model products for 2001 onwards:
  - 1) Add other/updated LSMs:
    - a) LIS7/Noah 3.3 [available from HDISC for 1948-2010 @ 1° & 0.25°]
    - b) LIS7/Catchment Fortuna 2.5 [completed for 1948-2012 @ 1°; in prep for HDISC]
    - c) LIS7/VIC 4.12 [modifying Shugong's global parameter dataset of VIC4.11 with MODIS44W land mask and 60S-90N extent]
    - d) CLM4.5 [originally planned for stand alone, now awaiting integration in LIS]
  - 2) Reprocess CMAP with new disaggregation code and post-processed pentad CMAP [CMAP real-time pentad product has drift; old disaggregation process caused inconsistencies] [complete]
  - 3) Improve QC/QA for AGRMET Shortwave radiation, bias-correct to SRB data [complete]
  - 4) Runoff routing using Augusto Getirana's code in LIS7
- Runoff routing for GLDAS2.0 1948-2012 output (Princeton V2 forced Noah 3.3, 1.0° and 0.25°)
- GLDAS2.2 will assimilate MODIS snow cover and AMSR-E soil moisture at 0.25° for 2002 onwards
- Global implementation of irrigation simulation schemes
- Extending U.S. drought/wetness indicators to global scale [ongoing under a NASA project]
- Seasonal forecast drought/wetness indicators for the U.S. [ongoing under a new NASA project]

Matt Rodell
NASA GSFC