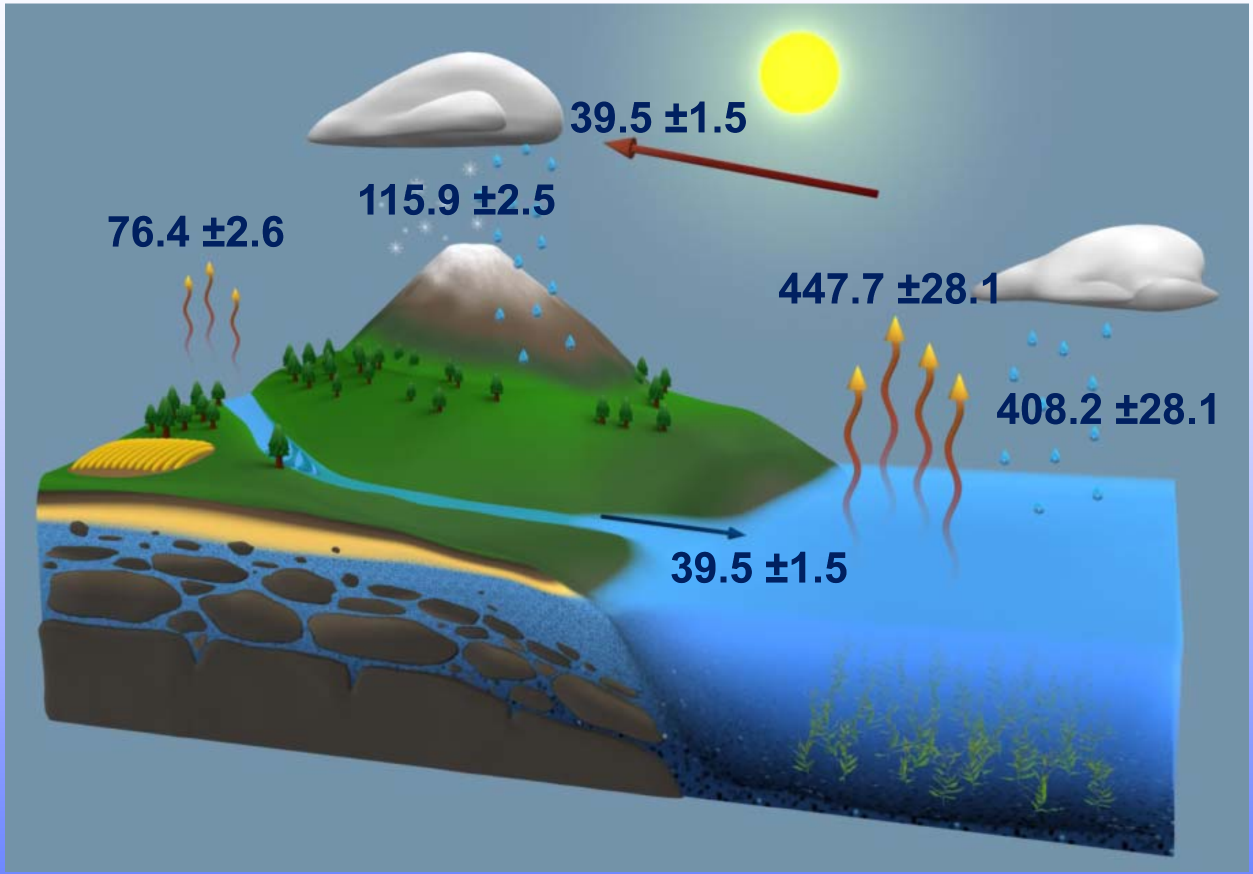
NASA/GSFC Hydrological Sciences Laboratory Overview

Matt Rodell, Ph.D.

Chief, Hydrological Sciences Laboratory
NASA Goddard Space Flight Center

The Global Water Cycle

The continuous movement of water within, on, and above Earth's surface

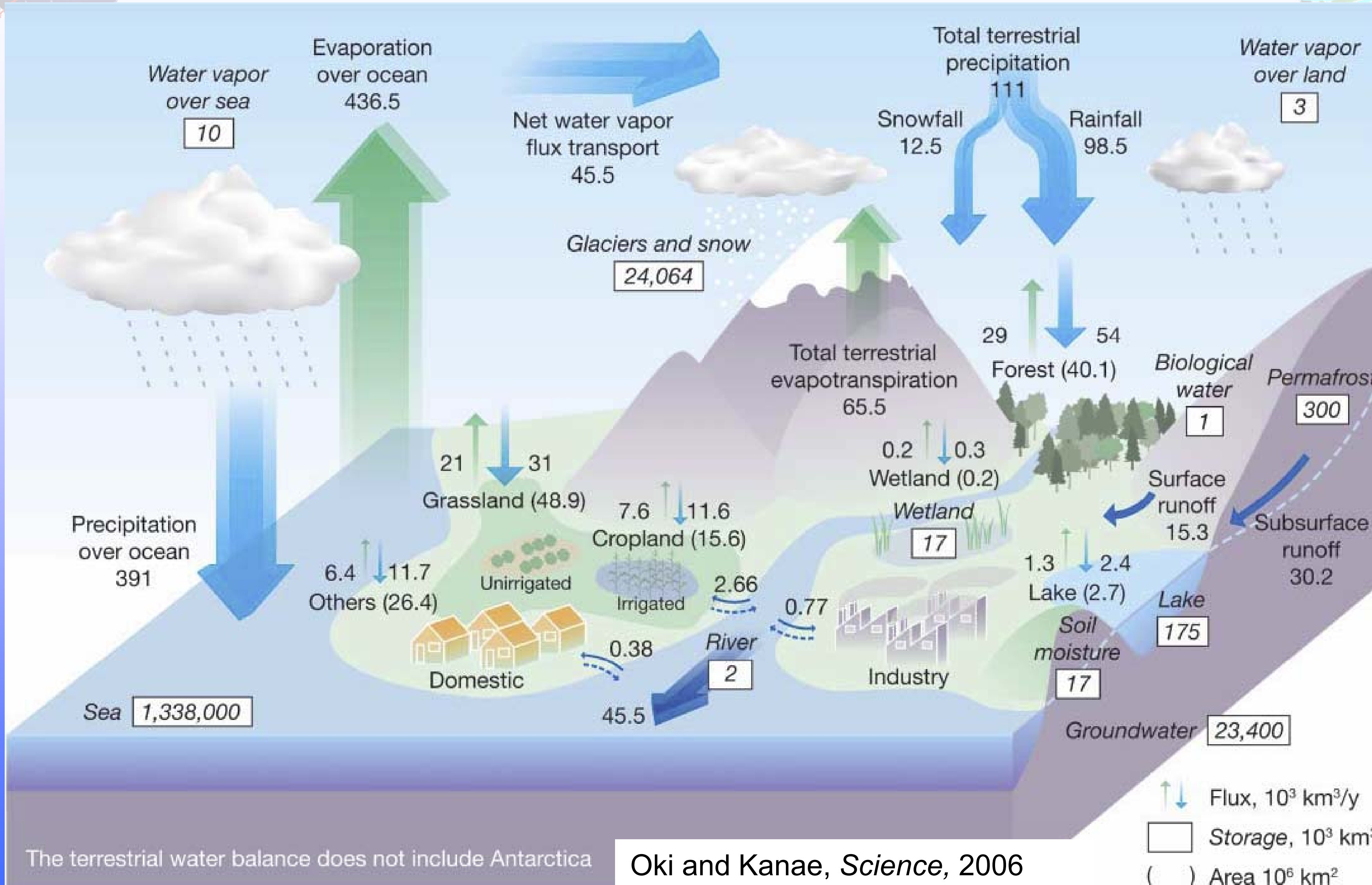


Global mean water fluxes (1,000 km^3/yr) at the start of the 21st century, based on satellite and ground-based observations and data integrating models.

The most noticeable impacts of climate change will be changes in the water cycle

Matt Rodell
NASA GSFC

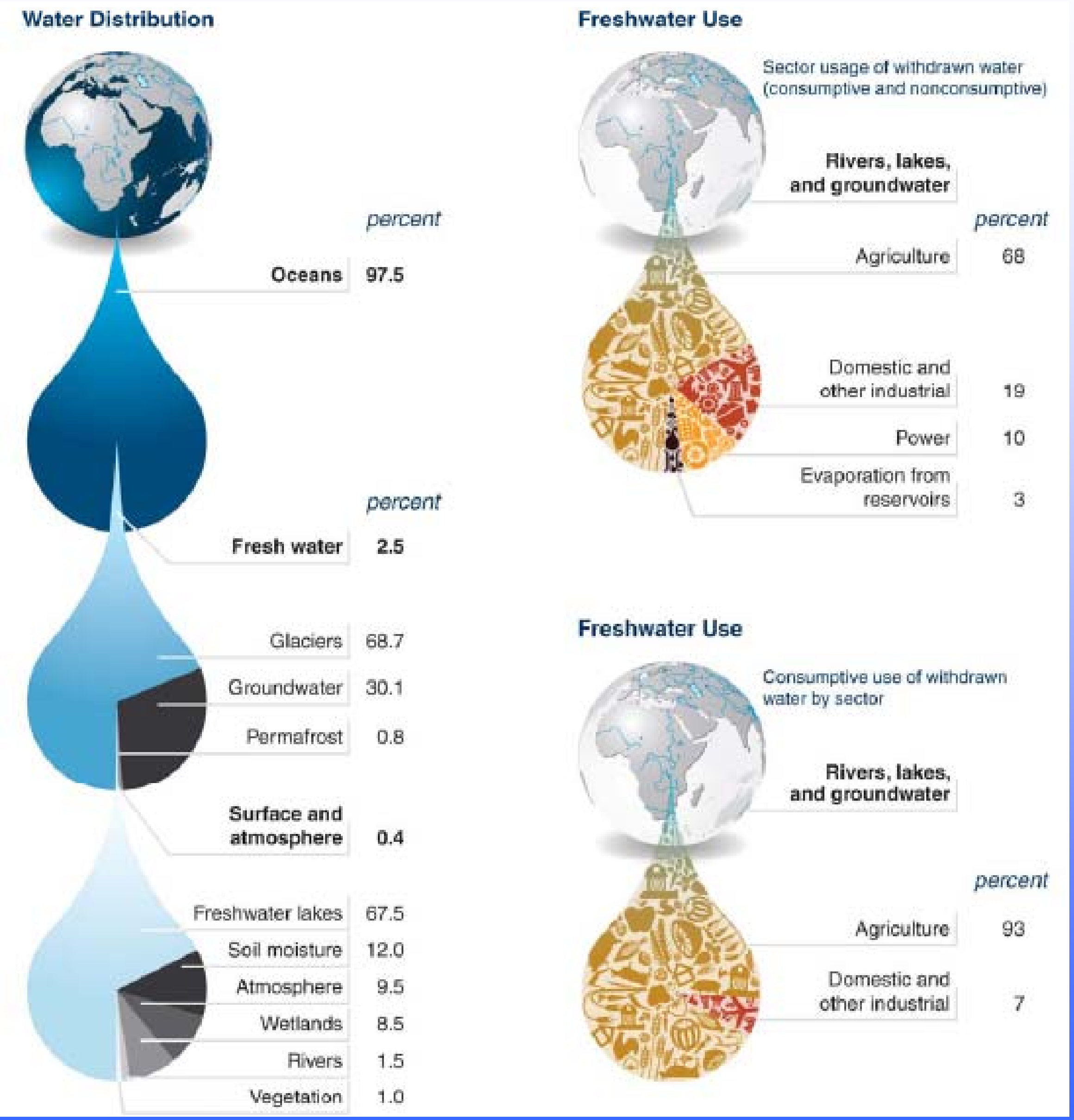
The Global Water Cycle



Oki and Kanae, *Science*, 2006

Matt Rodell
NASA GSFC

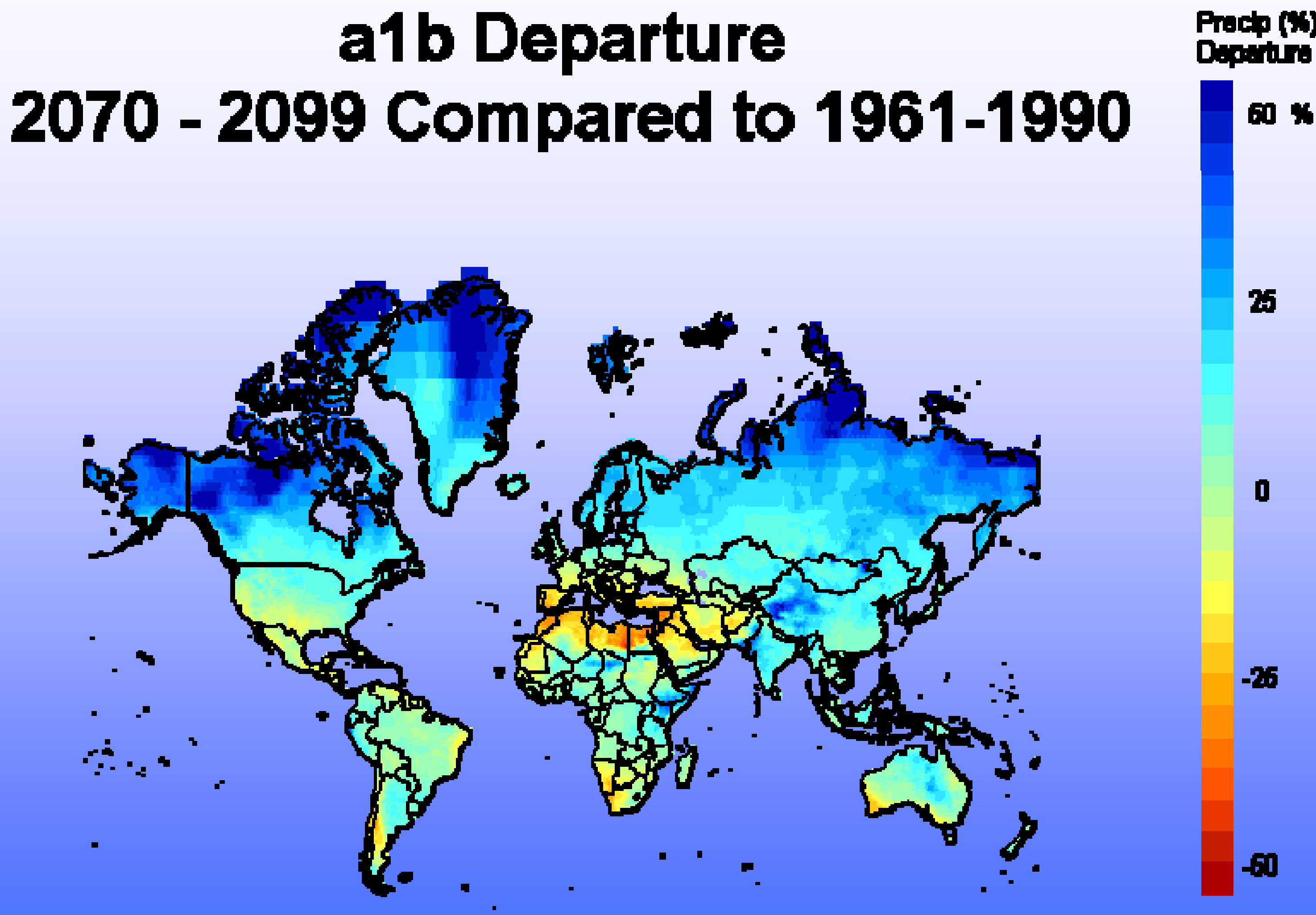
Distribution and Usage of Water on Earth



Source: Multiple, as reported by the World Bank, 2010

Matt Rodell
NASA GSFC

Predicted Climate Change Impacts on Precipitation



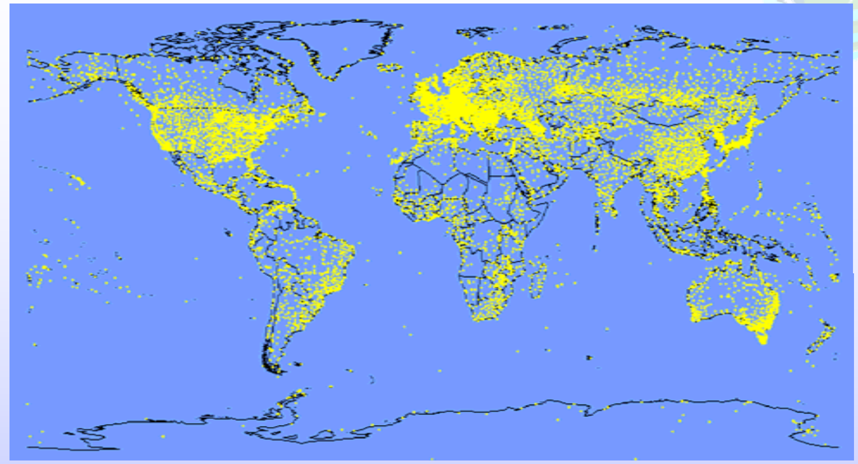
Base climate projection downscaled by Maurer, et al. (2007) Santa Clara University.
Image from http://www.climatewizard.org/#

Matt Rodell
NASA GSFC

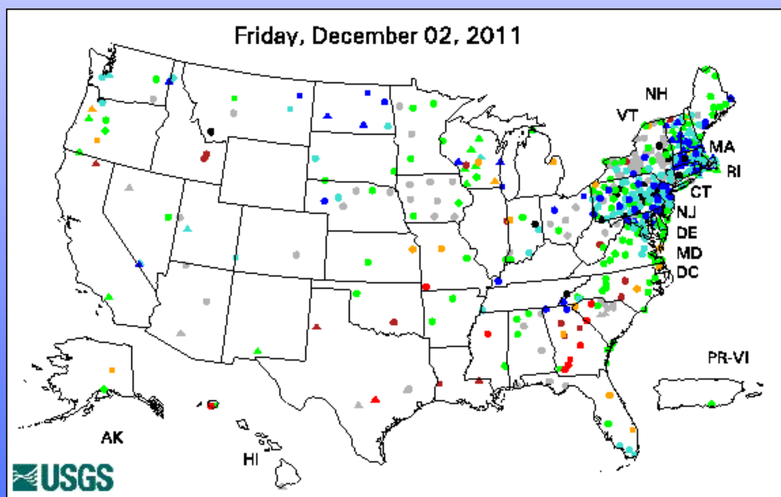
Inadequacy of Surface Observations

Issues:

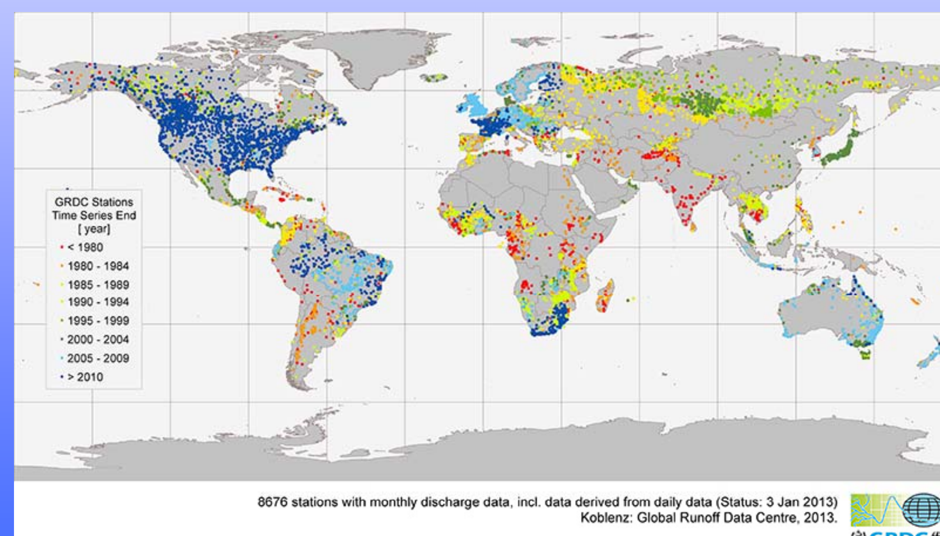
- Spatial coverage of existing stations
- Temporal gaps and delays
- Many governments unwilling to share
- Measurement inconsistencies
- Quality control
- (Un)Representativeness of point obs



Global Telecommunication System meteorological stations. Air temperature, precipitation, solar radiation, wind speed, and humidity only.



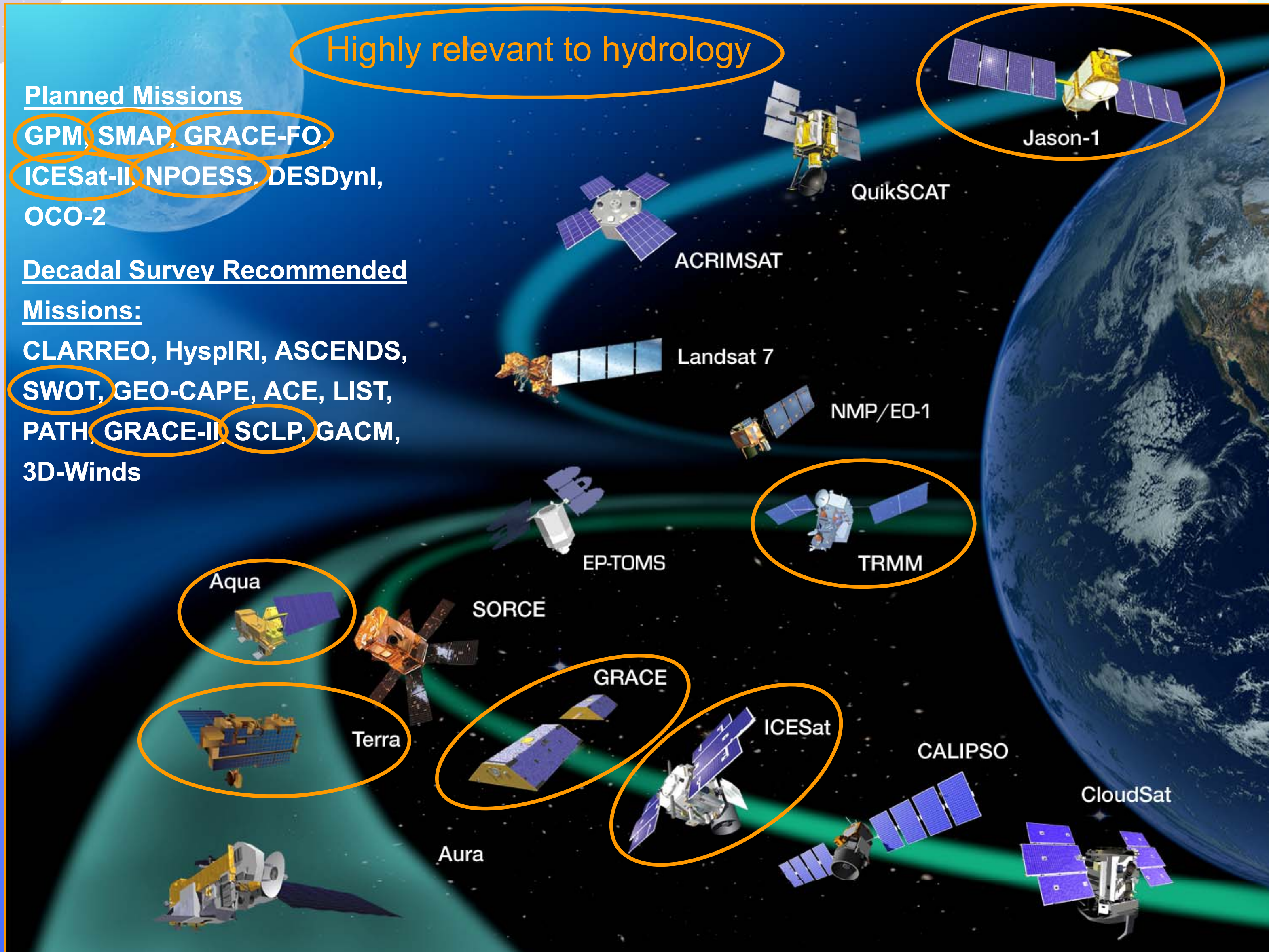
USGS Groundwater Climate Response Network. Very few groundwater records available outside of the U.S.



River flow observations from the Global Runoff Data Centre. Warmer colors indicate greater latency in the data record.

Matt Rodell
NASA GSFC

Present and Future NASA Earth Science Missions

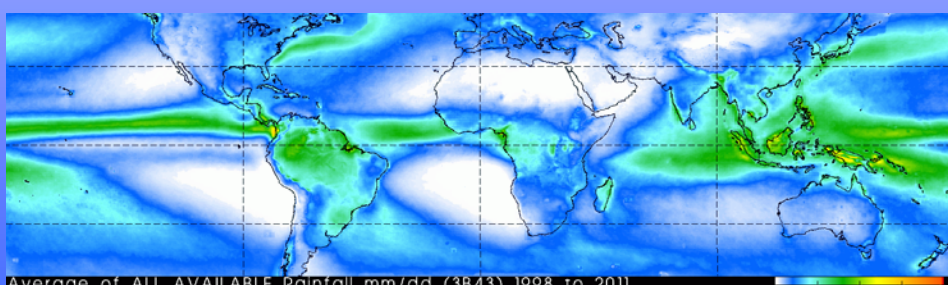


Matt Rodell
NASA GSFC

Precipitation

Tropical Rainfall Measurement Mission (TRMM)

- Global (50S-50N) precipitation measurement
  - 10 ↔ 85 GHz radiometers
  - 13.6 GHz precipitation radar
  - 27 Nov 1997 to present



TRMM 14-year mean rainfall

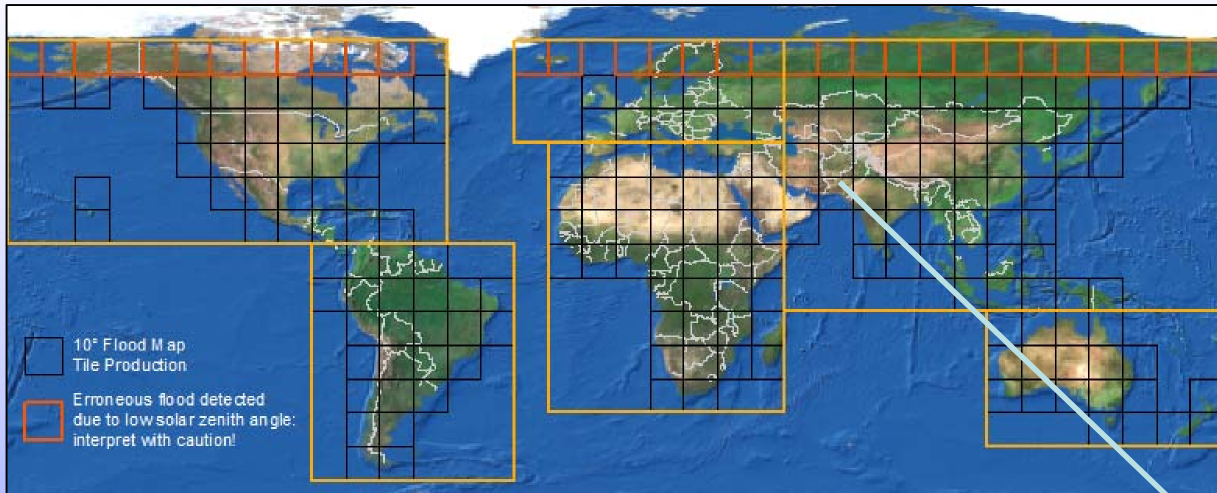
Global Precipitation Measurement (GPM)

The GPM Core Observatory will provide improved measurements of precipitation from the tropics to higher latitudes

- Planned Feb 2014 launch
- Will use inputs from an international constellation of satellites to increase space and time coverage
- Improvements:
  - Longer record length
  - High latitude precipitation
    - including snowfall
  - Better accuracy and coverage

Matt Rodell
NASA GSFC

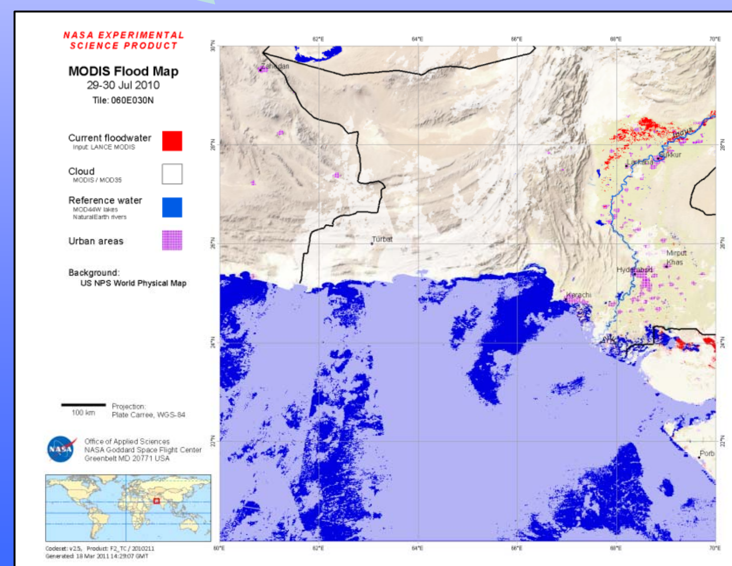
Experimental Global Near Real Time
Surface Water Extent and Flood Extent Maps



Credit: Fritz Policelli, NASA/GSFC

http://oas.gsfc.nasa.gov/floodmap/

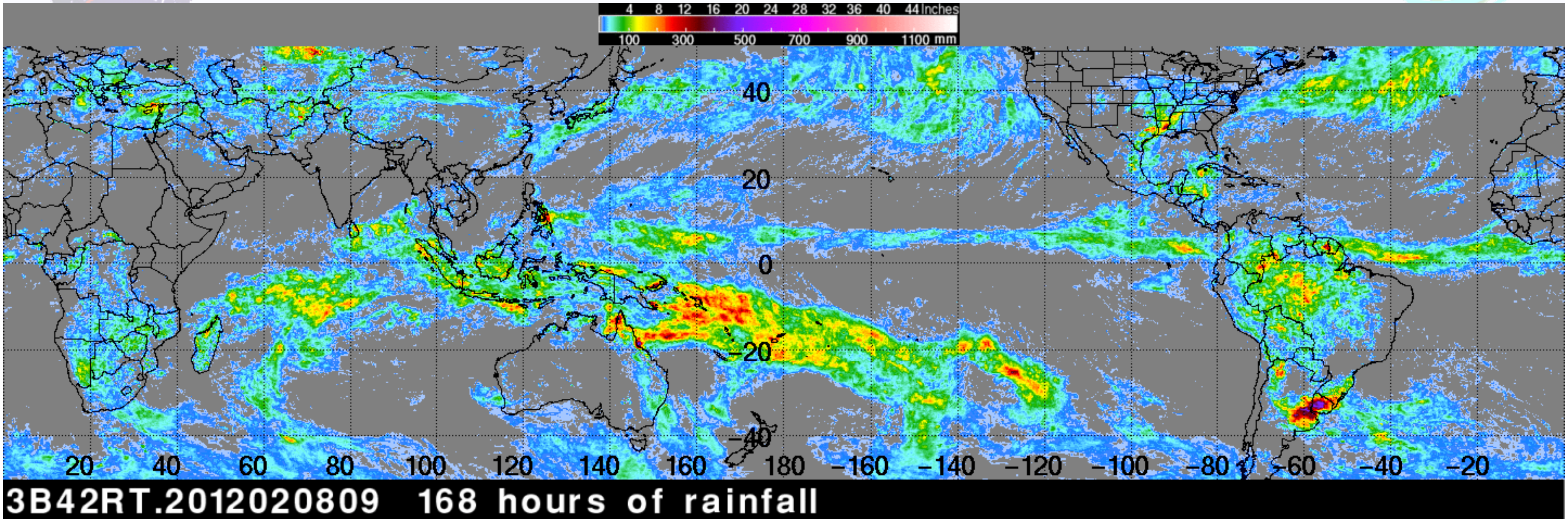
July 2010 Flooding in Pakistan

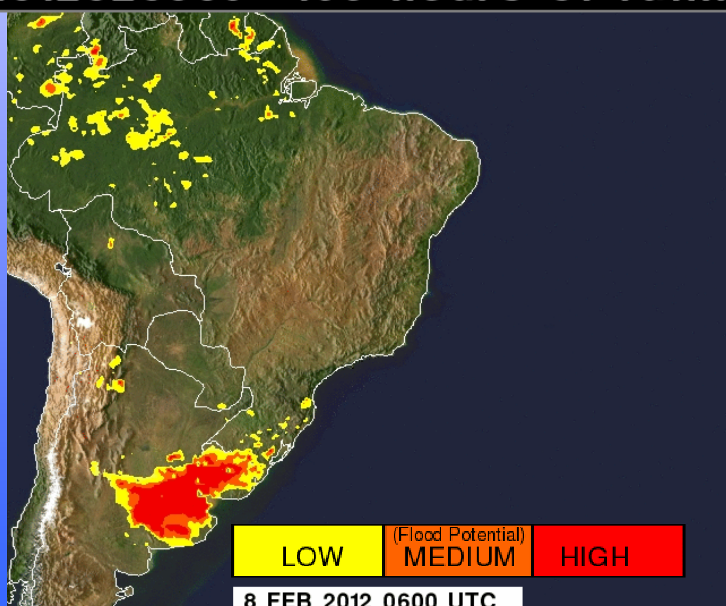


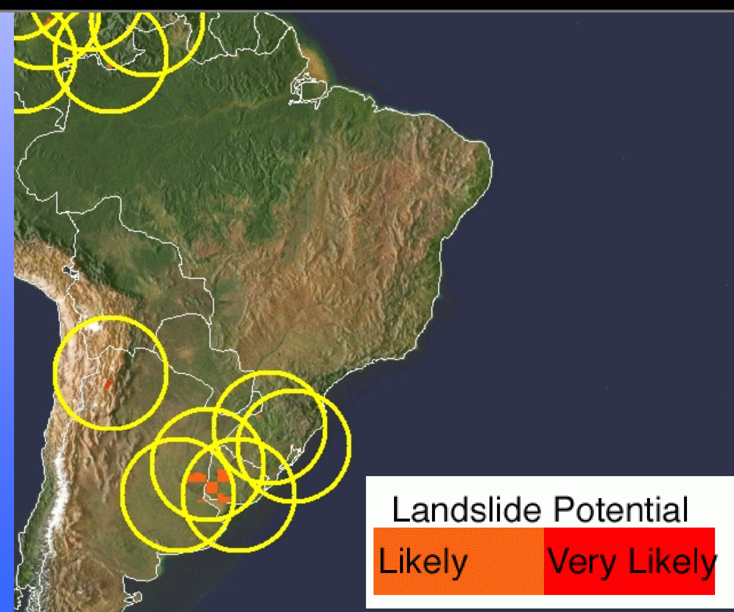
- MODIS Bands 1 and 2 (250m resolution) used for water Identification (algorithm by Bob Brakenridge/ Dartmouth Flood Observatory)
- System development and operation – Dan Slayback (SSAI/ GSFC)
- MODIS product MOD44W used to mask for "normal" water extent
- Two and three day composite products available, updated daily
- Work is on-going to improve masking for cloud and terrain shadow, reprocess historical data, improve "normal" water mask, much more.

Dartmouth Observatory: http://floodobservatory.colorado.edu/LanceModis.html

Applying TRMM Precipitation for Landslide Hazard Assessment

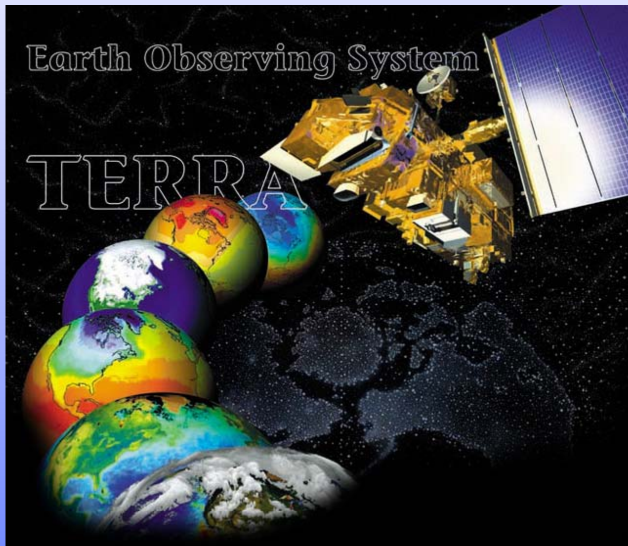






tt Rodell
NASA GSFC

Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS)



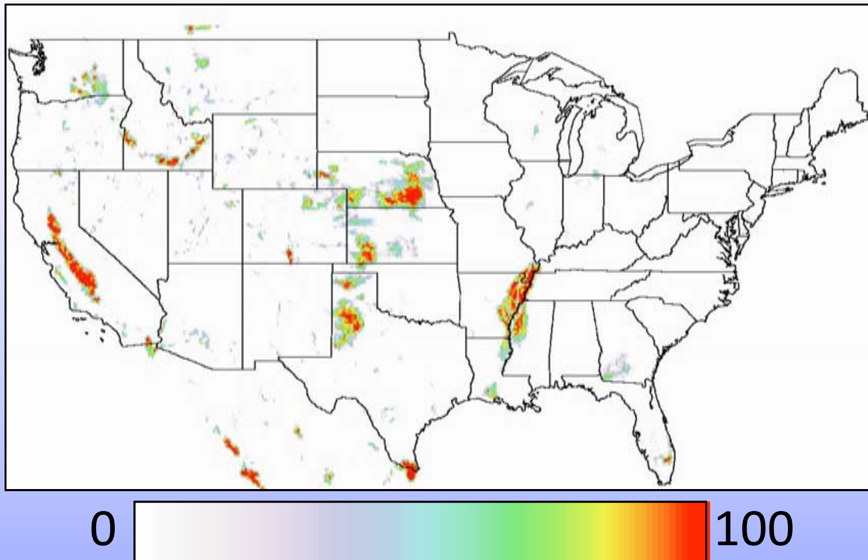
MODIS Data Products:

- surface temperature
- chlorophyll fluorescence
- vegetation/land-surface cover, conditions, and productivity:
  - net primary productivity, leaf area index, and intercepted photosynthetically active radiation
  - land cover type, with change detection and identification;
  - vegetation indices corrected for atmosphere, soil, and directional effects;
- cloud mask, cirrus cloud cover, cloud properties characterized by cloud phase, optical thickness, droplet size, cloud-top pressure, and temperature;
- aerosol properties
- fire occurrence, temperature, and burn scars;
- total precipitable water
- sea ice cover
- snow cover
- derived evapotranspiration

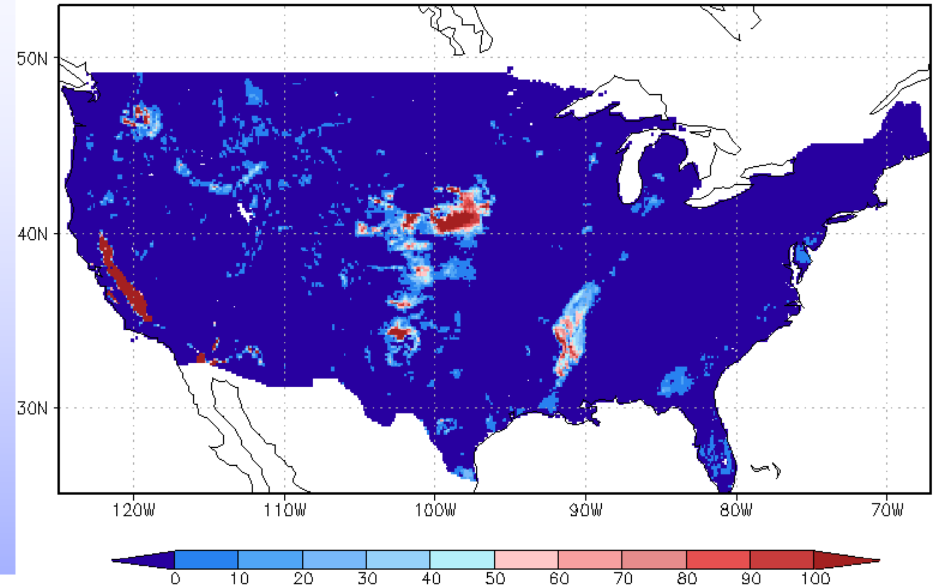
Matt Rodell
NASA GSFC

Simulating Irrigation Based on MODIS Observations

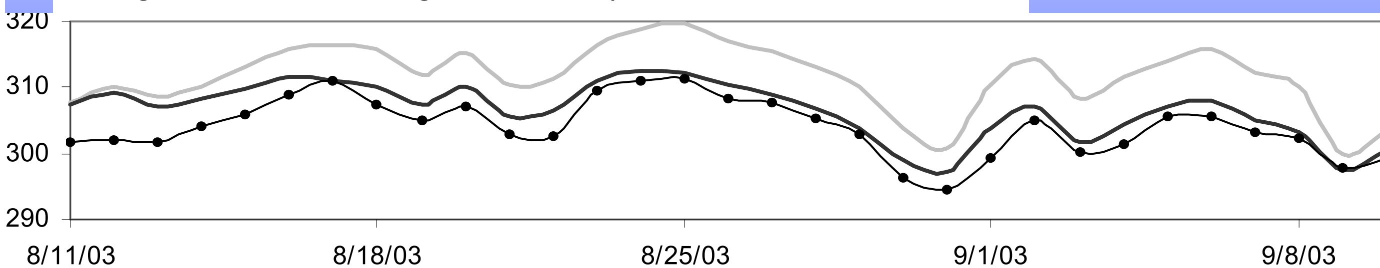
MODIS derived intensity of irrigation, ca. 2002-03



Difference (%) in evapotranspiration between irrigation and control runs, Aug-Sep 2003



Ozdogan, Rodell, Beaudoing, and Toll, J. Hydrometeor., 2010.

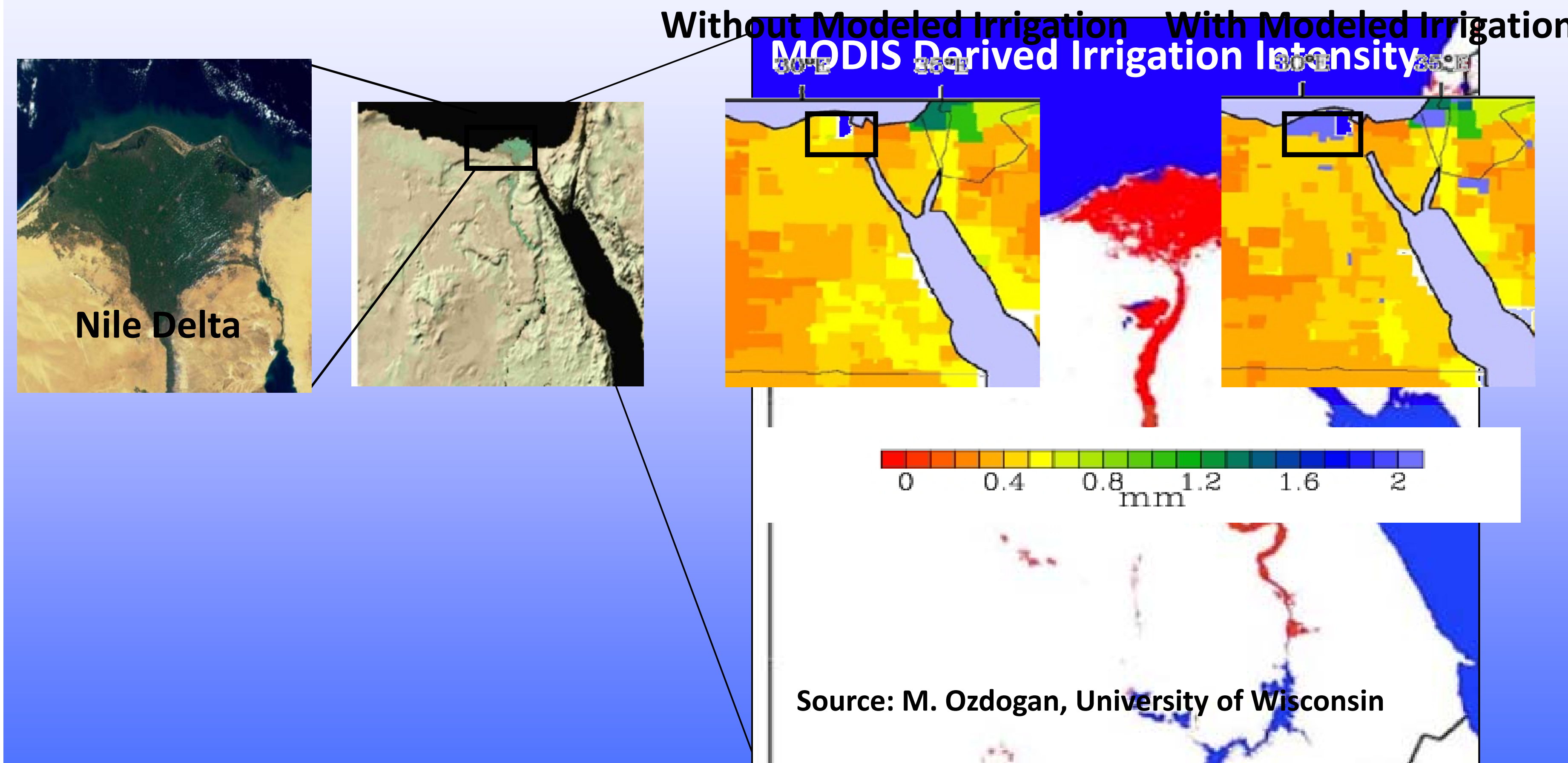


Max surface temperature (K) at an irrigated site, from control run (gray line), irrigation run (black line), and observations (dots)

Innovative algorithm applies irrigation based on MODIS map, crop type, time of year, soil dryness, and common irrigation practices, to improve modeled fluxes

ell
NASA GSFC

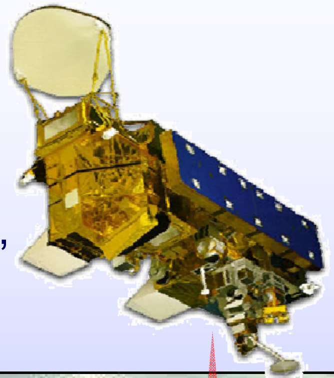
Simulating Irrigation Based on MODIS Observations

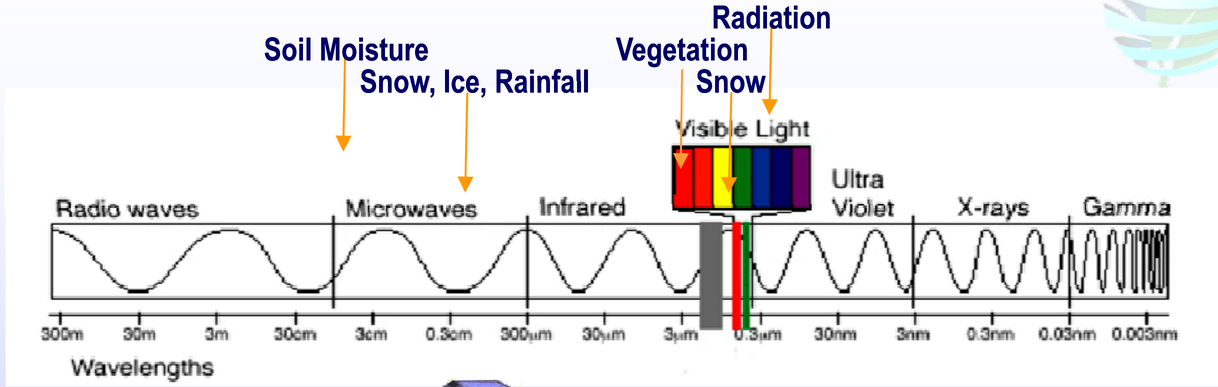


Matt Rodell
NASA GSFC

Gravity Recovery and Climate Experiment (GRACE)

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

Matt Rodell
NASA GSFC

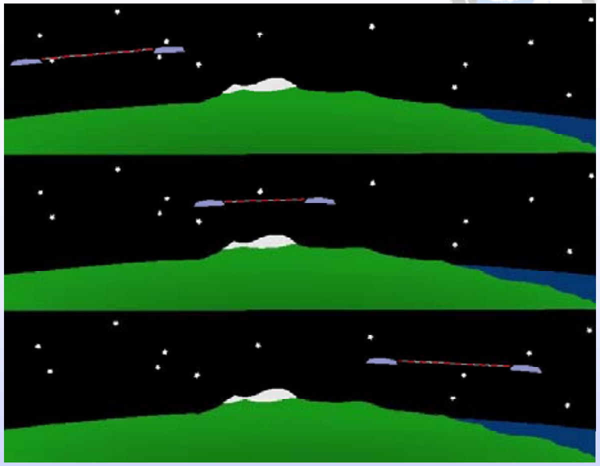
GRACE Derived Terrestrial Water Storage Variations

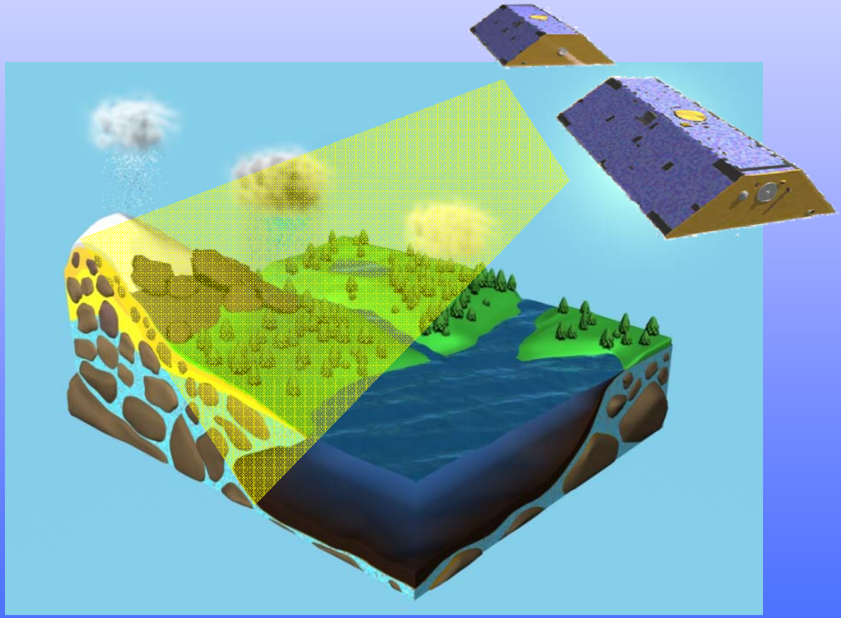
GRACE Science Goal: High resolution, mean and time variable gravity field mapping for Earth System Science applications

Instruments: Two identical satellites flying in tandem orbit, ~200 km apart, 500 km initial altitude

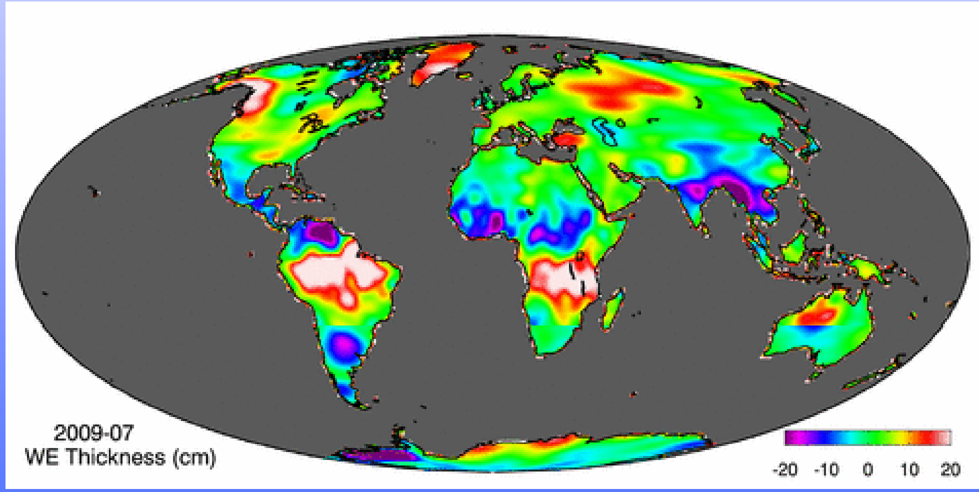
Key Measurement: Distance between two satellites tracked by K-band microwave ranging system

Key Result: Information on water stored at all depths on and within the land surface





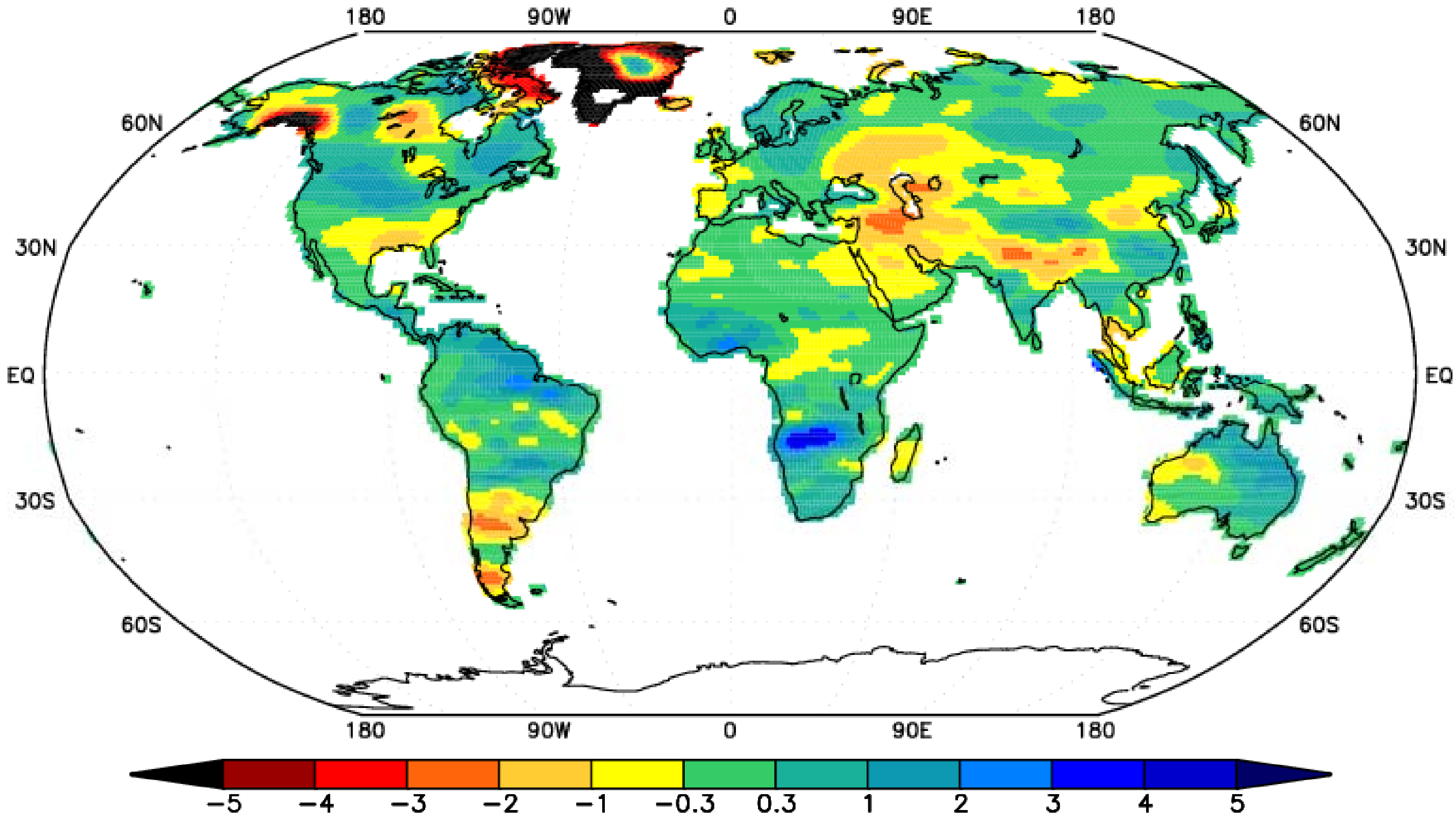
GRACE measures changes in total terrestrial water storage, including groundwater, soil moisture, snow, and surface water.



Animation of monthly GRACE terrestrial water storage anomaly fields. A water storage anomaly is defined here as a deviation from the long-term mean total terrestrial water storage at each location.

Matt Rodell
NASA GSFC

Emerging Trends in Terrestrial Water Storage from GRACE

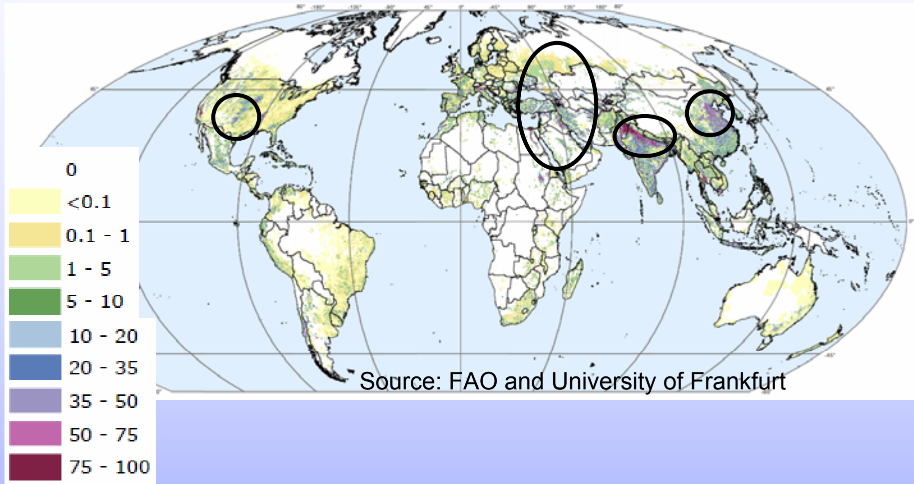


- "Trends" in GRACE derived terrestrial water storage, 2003-2012.
- Best fit linear rate of change of TWS after removing the seasonal cycle.
- Based on land hydrology product from GRACE Tellus (CSR RL04).
- Which apparent trends are real and likely to continue?

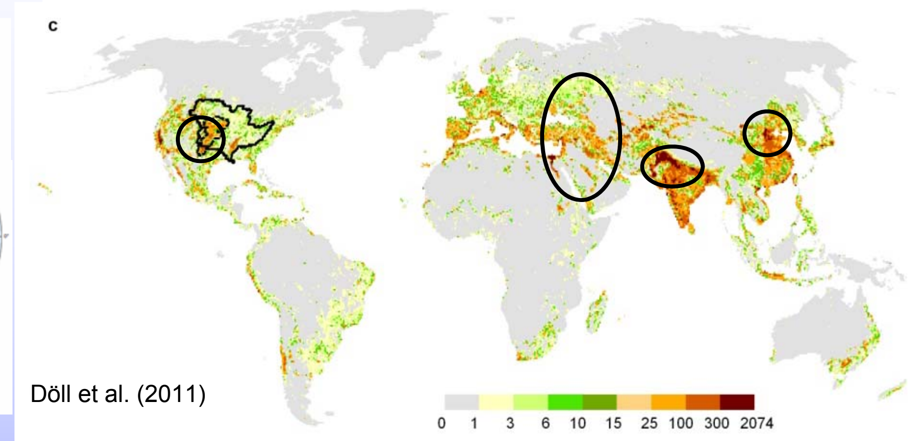
Matt Rodell
NASA GSFC

Exploitation of Water Resources

Percentage of Irrigated Area

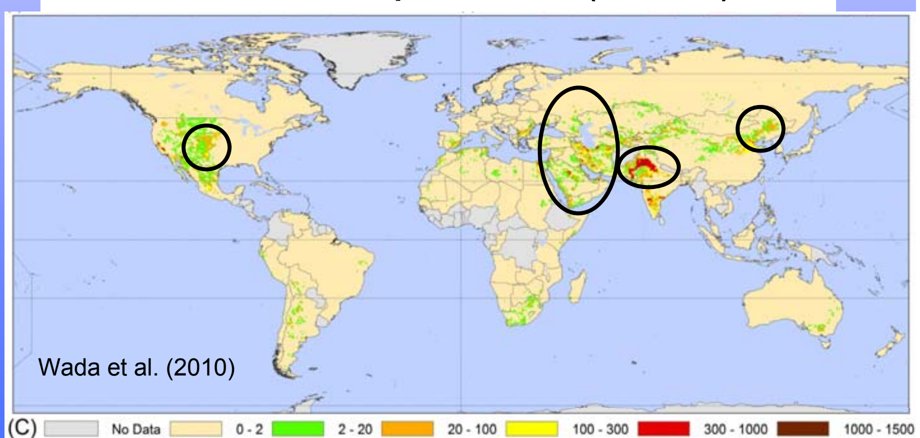


Net Consumptive Use of Ground and Surface Waters, 1998-2002



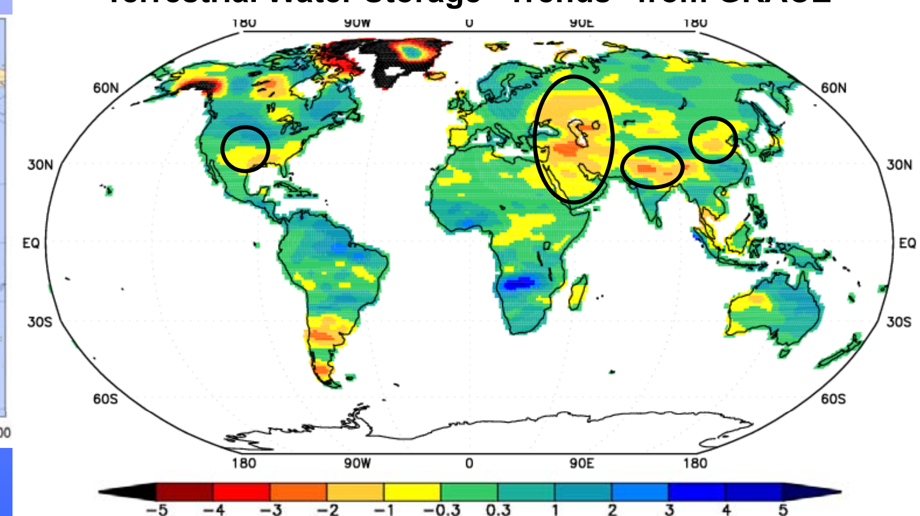
Equivalent height of water (mm/yr)

Groundwater Depletion Rate (ca. 2000)



Equivalent height of water (mm/yr)

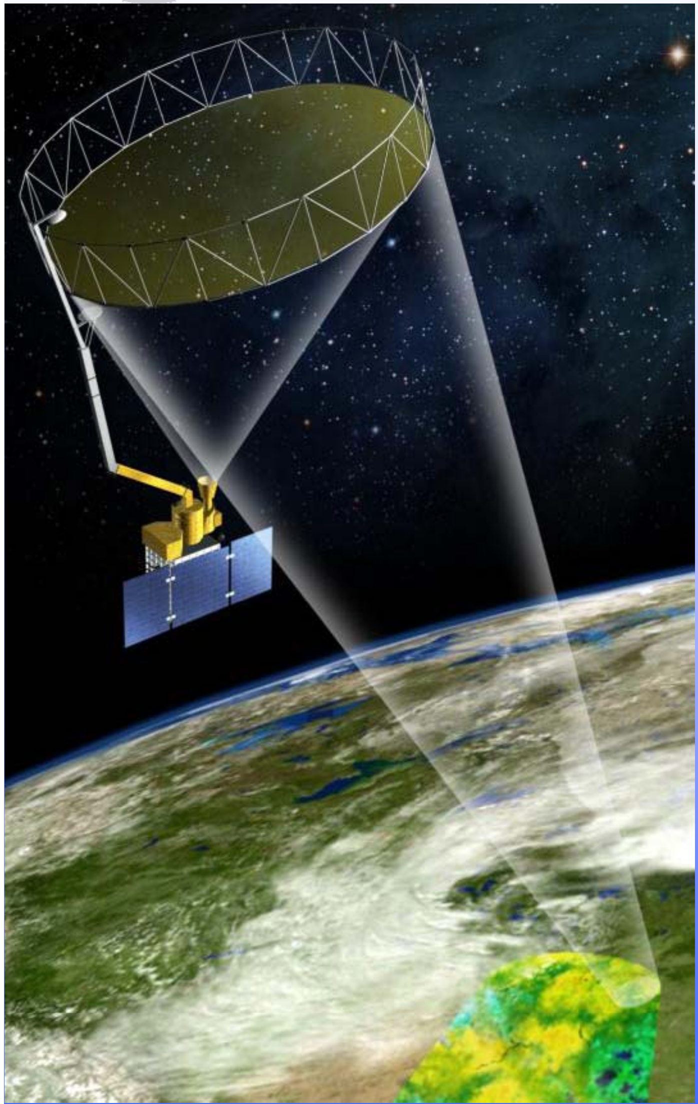
Terrestrial Water Storage "Trends" from GRACE



Equivalent height of water (cm/yr)

Matt Rodell
NASA GSFC

Soil Moisture Active Passive (SMAP)



NRC Earth Science Decadal Survey (2007) recommended SMAP as a tier-one mission

Primary Science Objectives:

- **Global, high-resolution mapping of soil moisture and its freeze/thaw state to**
  - **Link terrestrial water, energy, and carbon cycle processes**
  - **Estimate global water and energy fluxes at the land surface**
  - **Quantify net carbon flux in boreal landscapes**
  - **Extend weather and climate forecast skill**
  - **Develop improved flood and drought prediction capability**

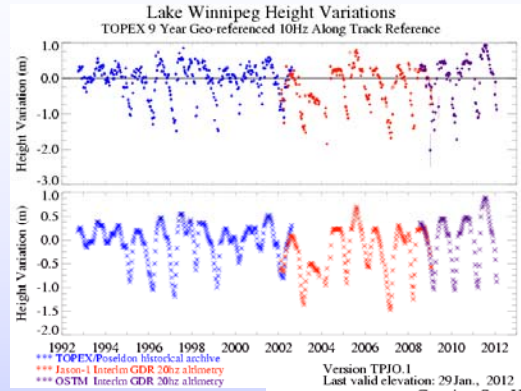
Mission Implementation (confirmed for Phase C in May 2012):

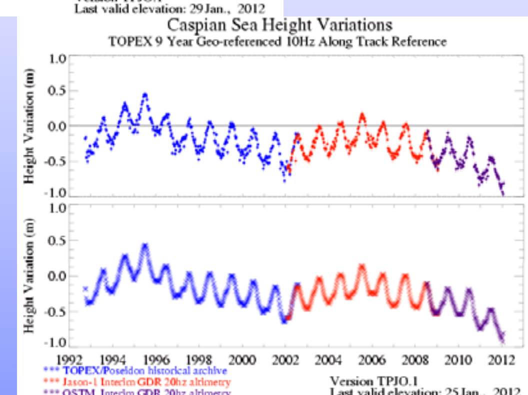
Partners	• JPL (project & payload management, science, spacecraft, radar, mission operations, science processing) • GSFC (science, radiometer, science processing)
Risk	• 7120-81 Category 2; 8705.4 Payload Risk Class C
Launch	• Oct. 2014 on Delta II system
Orbit	• Polar Sun-synchronous; 685 km altitude
Duration	• 3 years
Payload	• L-band 3-channel SAR (JPL) • L-band polarimetric radiometer (GSFC) • Shared 6-m rotating mesh antenna (13 to 14.6 rpm)

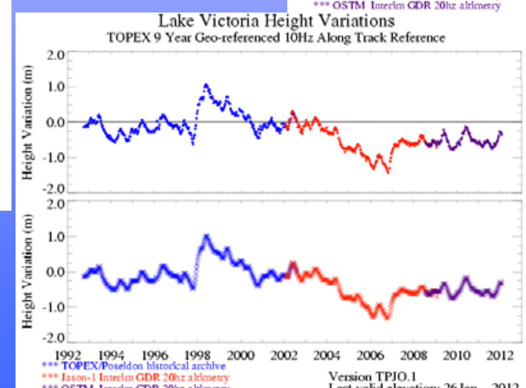
http://smap.jpl.nasa.gov/

Matt Rodell
NASA GSFC

Routine Lake Level Monitoring (Jason1/2 & ENVISAT)







Contact: Charon Birkett, U. Maryland

http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir

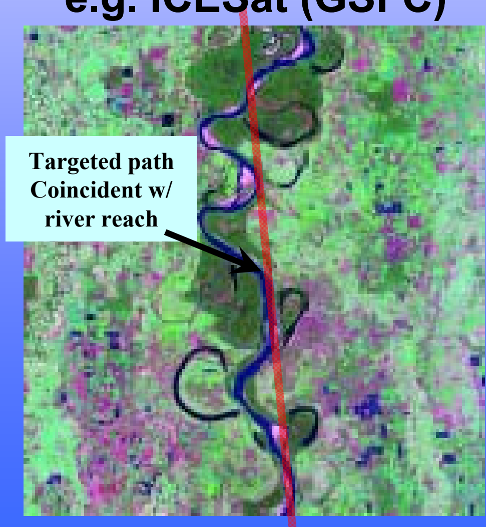
Matt Rodell
NASA GSFC

Surface Water Mission Concept (SWOT)
Stream Discharge and Surface Water Height

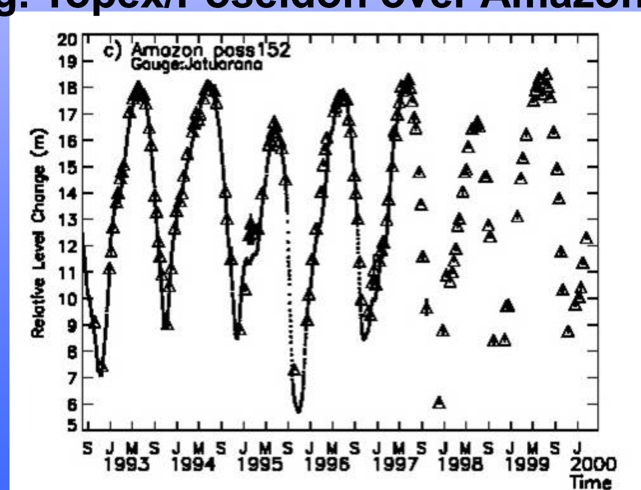
Motivation:
- critical water cycle component
- essential for water resource planning
- stream discharge and water height data are difficult to obtain outside US
- find the missing continental discharge component

Mission Concepts:

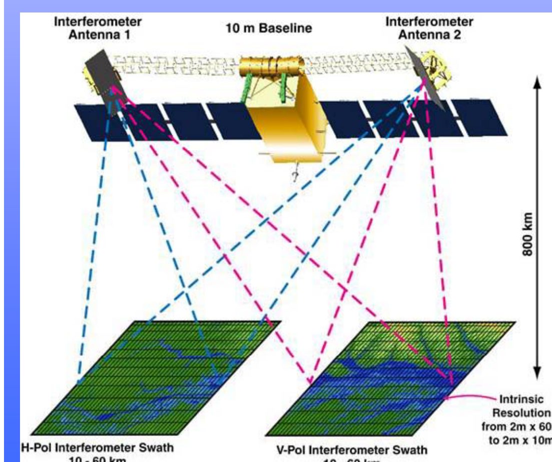
Laser Altimetry Concept
e.g. ICESat (GSFC)



Radar Altimetry Concept
e.g. Topex/Poseidon over Amazon R.



Interferometer Concept
(JPL)

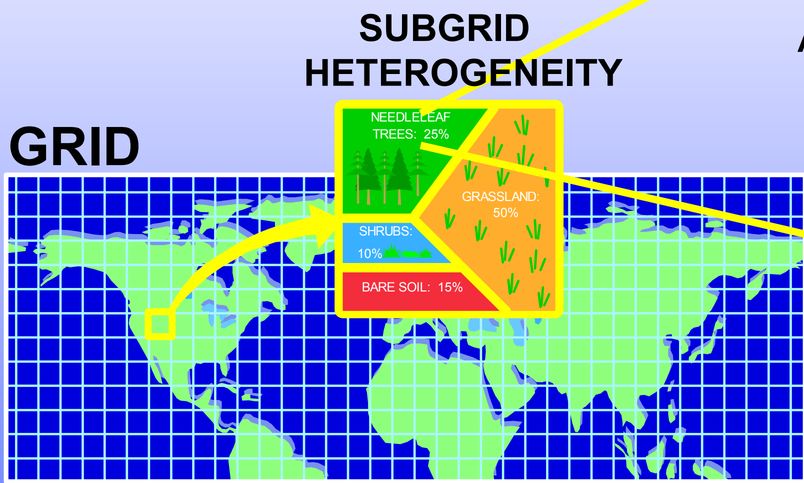


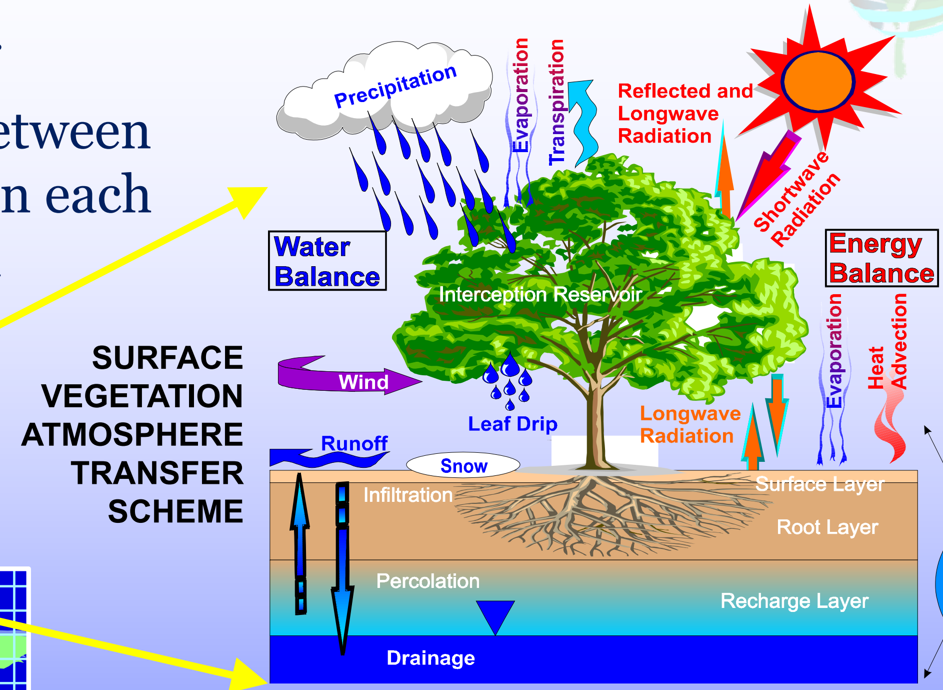
Source: M. Jasinski/614.3

Matt Rodell
NASA GSFC

Land Surface Model Structure

LSMs solve for the interaction of energy, momentum, and mass between the surface and the atmosphere in each model element (grid cell) at each discrete time-step (~15 min)





Input - Output = Storage Change

$P + G_{in} - (Q + ET + G_{out}) = \Delta S$

$R_n - G = L_e + H$

System of physical equations:

Surface energy conservation equation

Surface water conservation equation

Soil water flow: Richards equation

Evaporation: Penman-Monteith equation

etc.

Matt Rodell
NASA GSFC

LSM Input and Output Fields

Input Parameters:

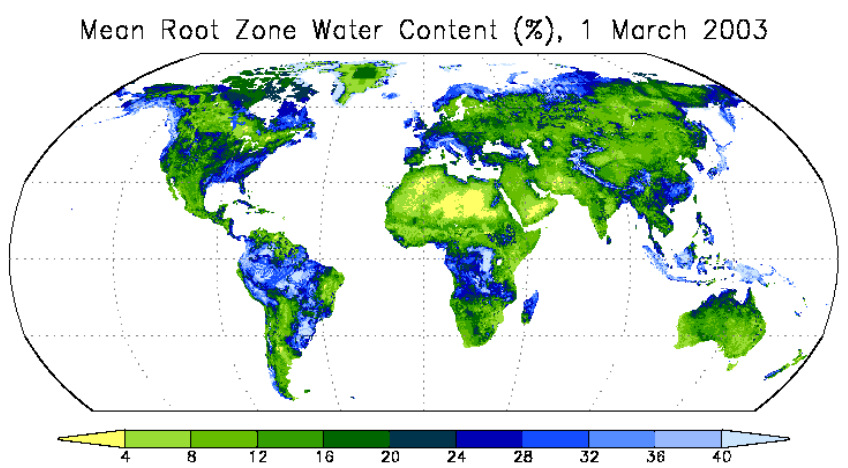
vegetation class
vegetation greenness/LAI
soil type
elevation

Required Forcing Fields:

total precipitation
convective precipitation
downward shortwave radiation
downward longwave radiation
near surface air temperature
near surface specific humidity
near surface wind speed *(U & V)*
surface pressure

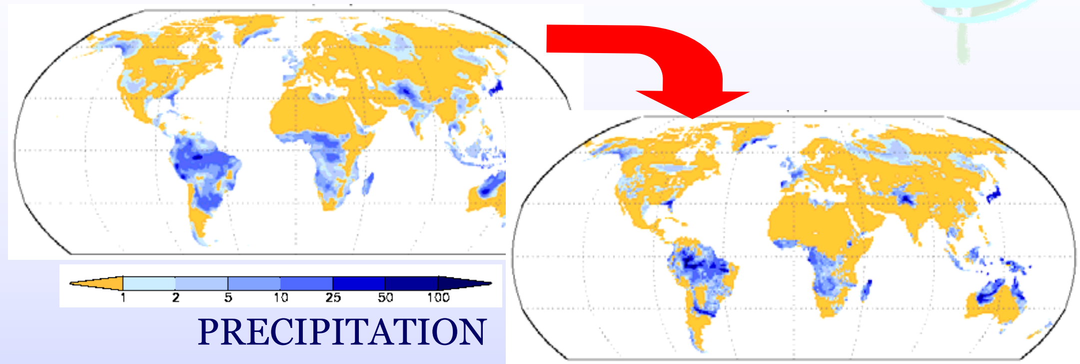
Summary of Output Fields:

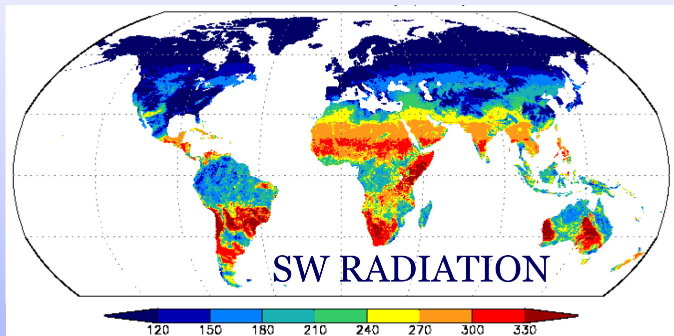
soil moisture in each layer
snow water equivalent
soil temperature in each layer
surface and subsurface runoff
evaporation
transpiration
latent, sensible, and ground heat fluxes
snowmelt
snowfall and rainfall
net shortwave and longwave radiation



Data Integration Within a Land Data Assimilation System (LDAS)

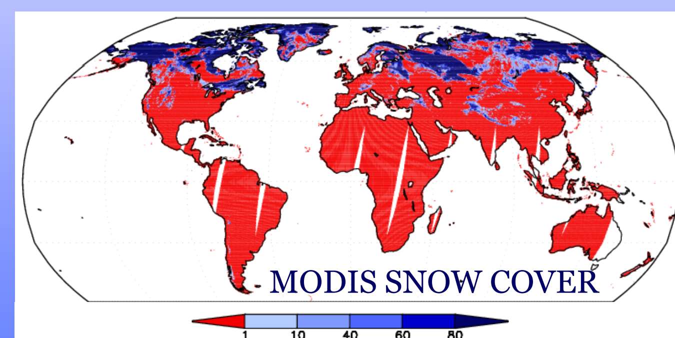
INTERCOMPARISON and OPTIMAL MERGING of global data fields

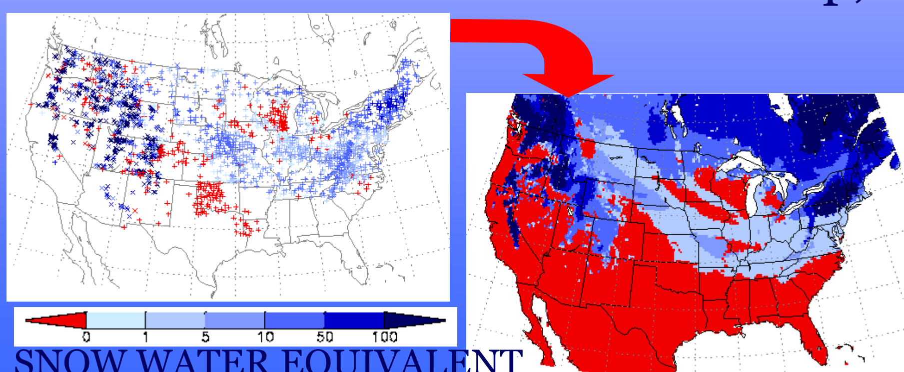




Satellite derived meteorological data used as land surface model FORCING

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





Ground-based observations used to VALIDATE model output

Examples from NASA's GLDAS
http://ldas.gsfc.nasa.gov/

Matt Rodell
NASA GSFC

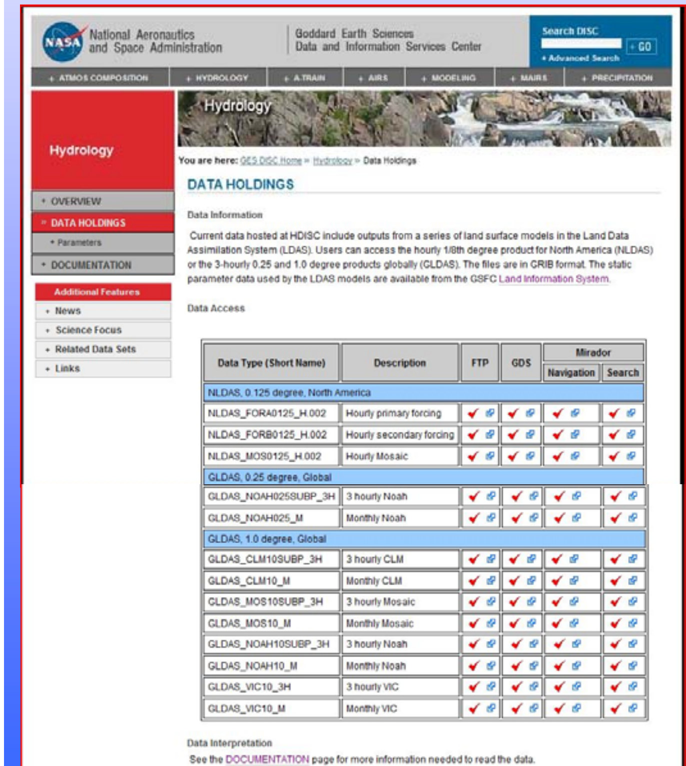
GLDAS Data Availability

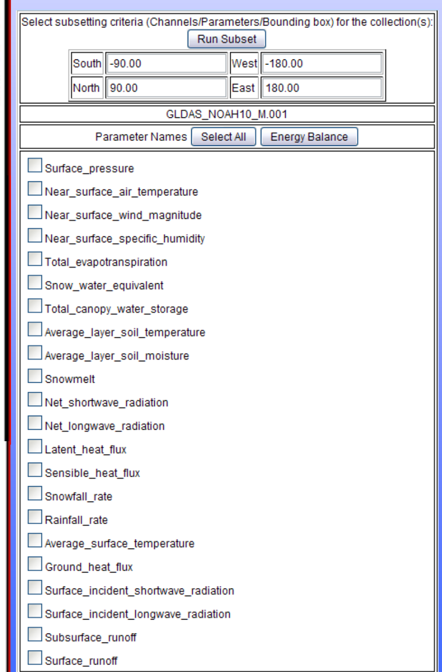
http://disc.gsfc.nasa.gov/hydrology

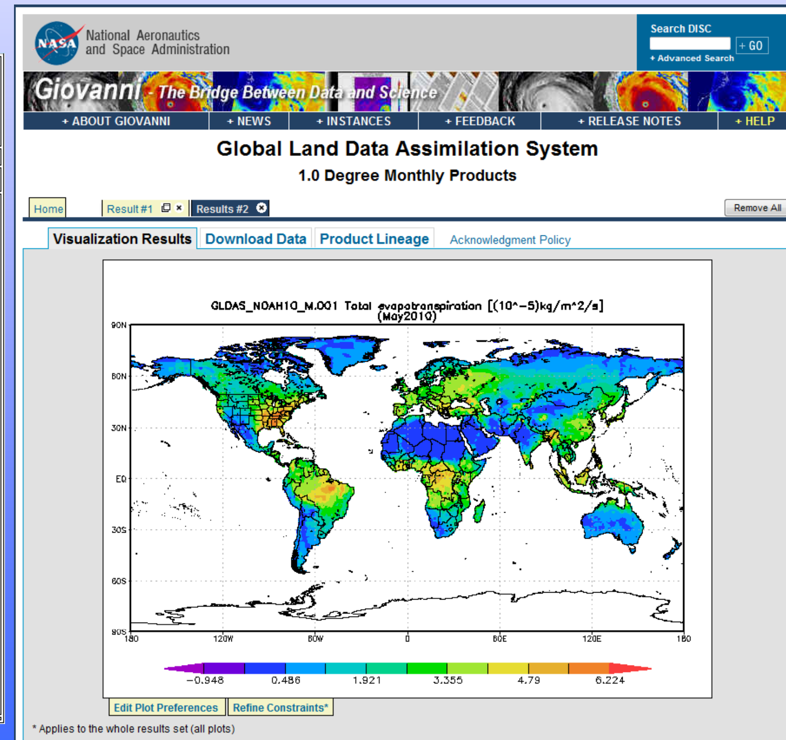
- Access via GDS, FTP, or quick-look visualization in Giovanni (below right)
- GRIB and NetCDF formats
- 3-hourly and monthly; 1.0° and 0.25° global grids
- On-the-fly subsetting (below center)
- Full documentation
- GLDAS supports a growing number of national and international hydrometeorological investigations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

Summary

• The water cycle effects everyone, everyday, and is important to monitor as it is modified by climate change and direct human impacts

• Impacts on the water cycle will be the most noticeable consequence of climate change

•Due to the incompleteness of ground-based observations, space-based observation of the water cycle is critical

• NASA's satellite observations provide a wealth of data for science and applications which must be synthesized in a physically meaningful way → Land Data Assimilation Systems

• Scientists at GSFC have spearheaded many innovative applications of remotely sensed hydrology data that have international value

Matt Rodell
NASA GSFC