Mapping the Blue Marble:
NASA Research to Improve Monitoring and Forecasting of Water Resources

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MGWA
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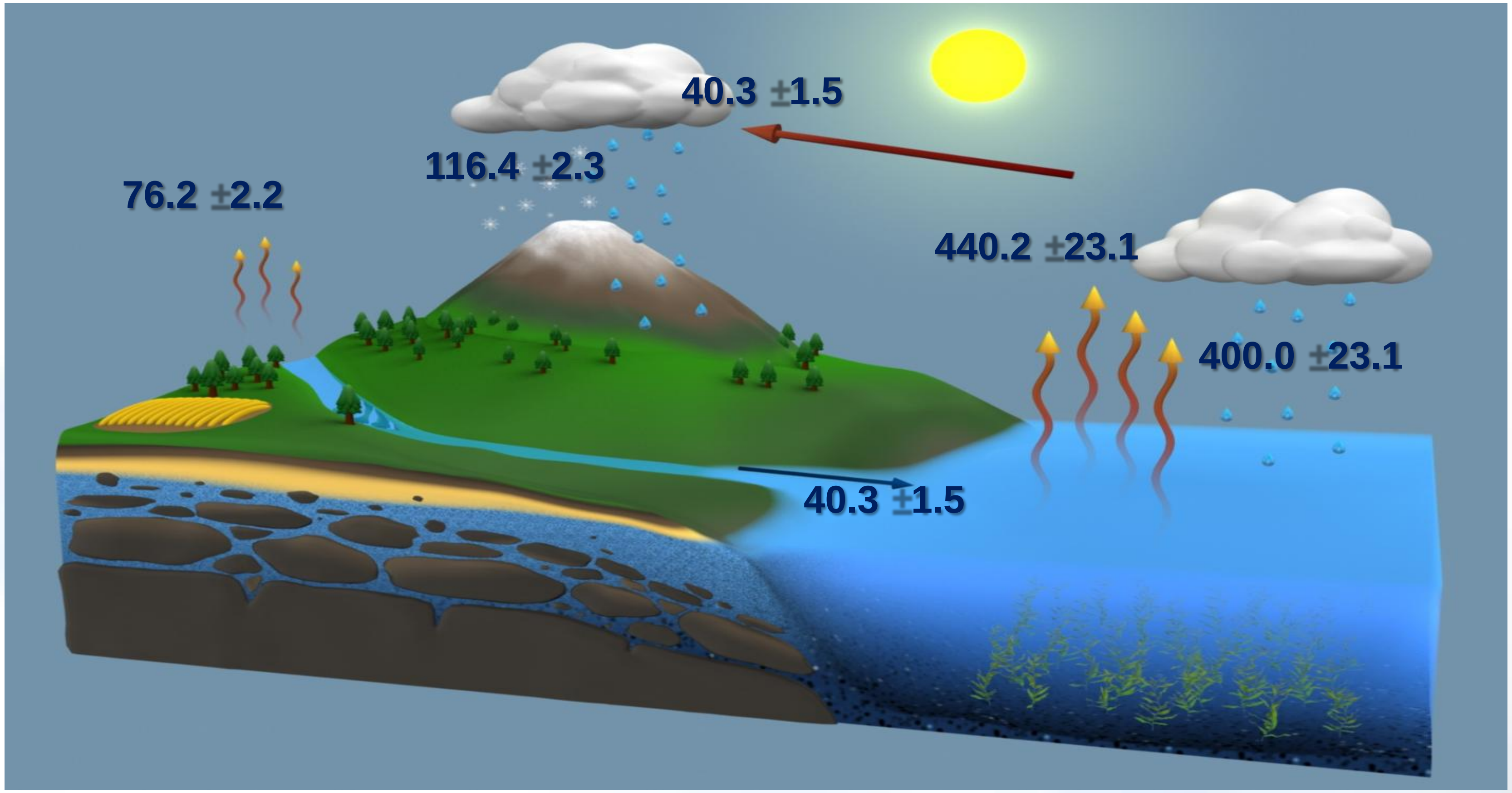
Minneapolis, MN

Global Water Cycle

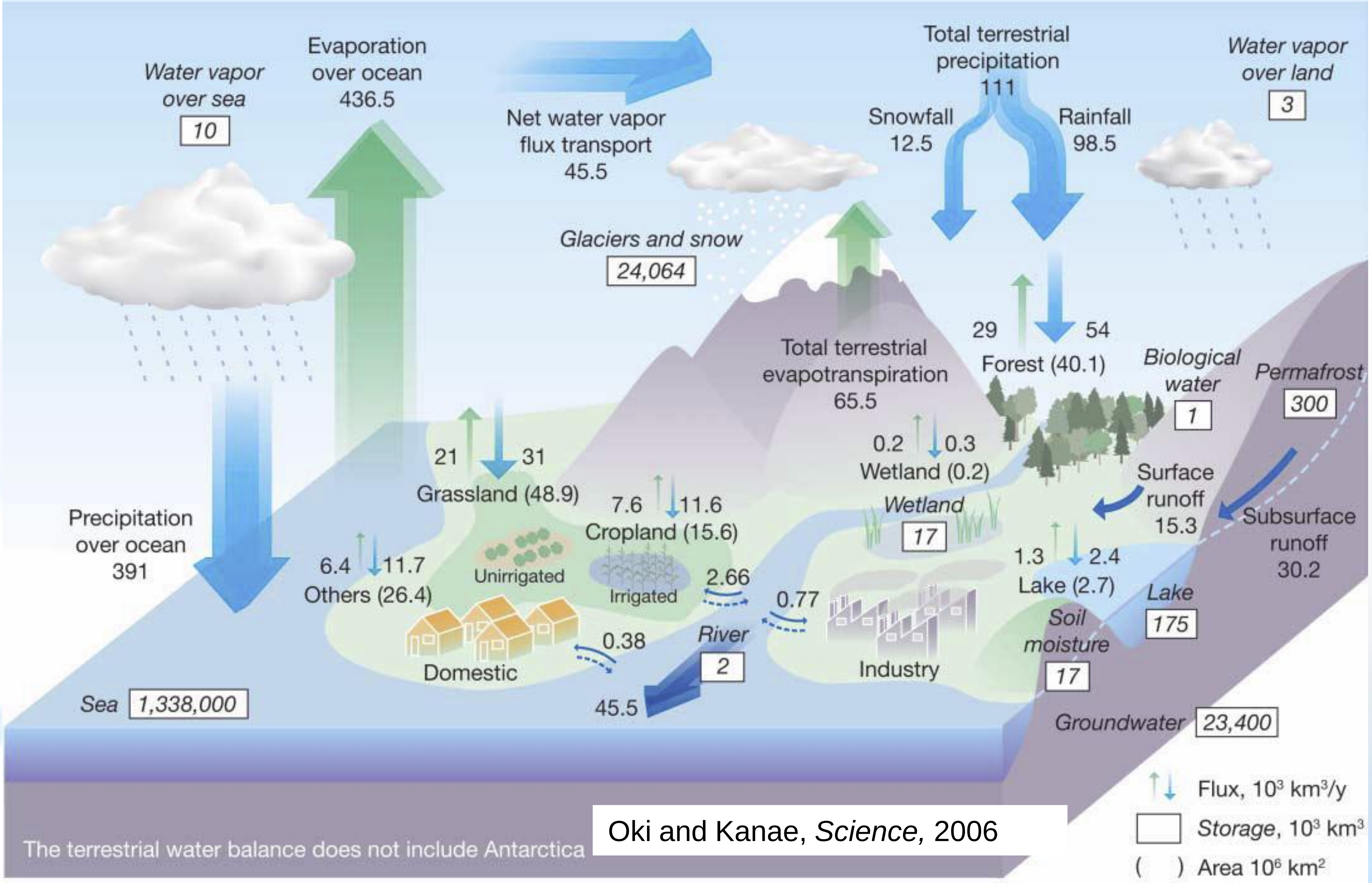
The continuous movement of water within, on, and above Earth's surface



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.

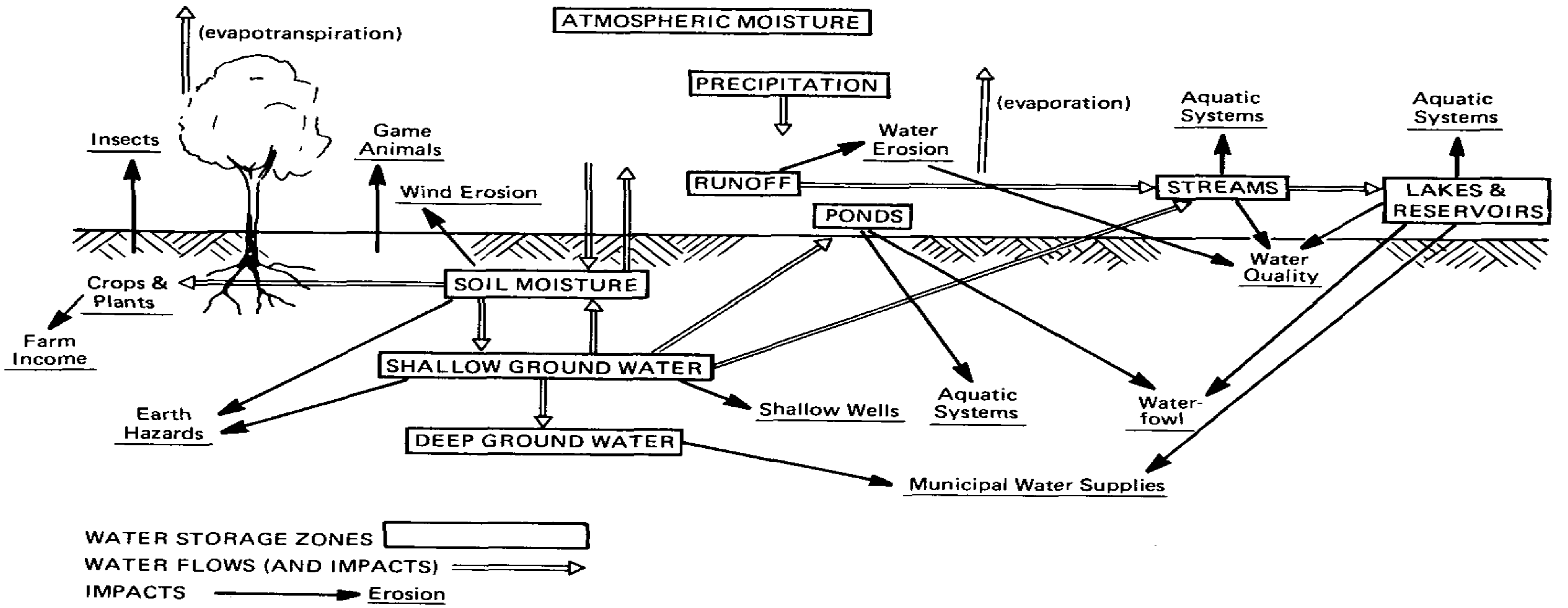
The most noticeable impacts of climate change will be changes in the water cycle

Global Water Cycle



Oki and Kanae, *Science*, 2006

The Water Landscape

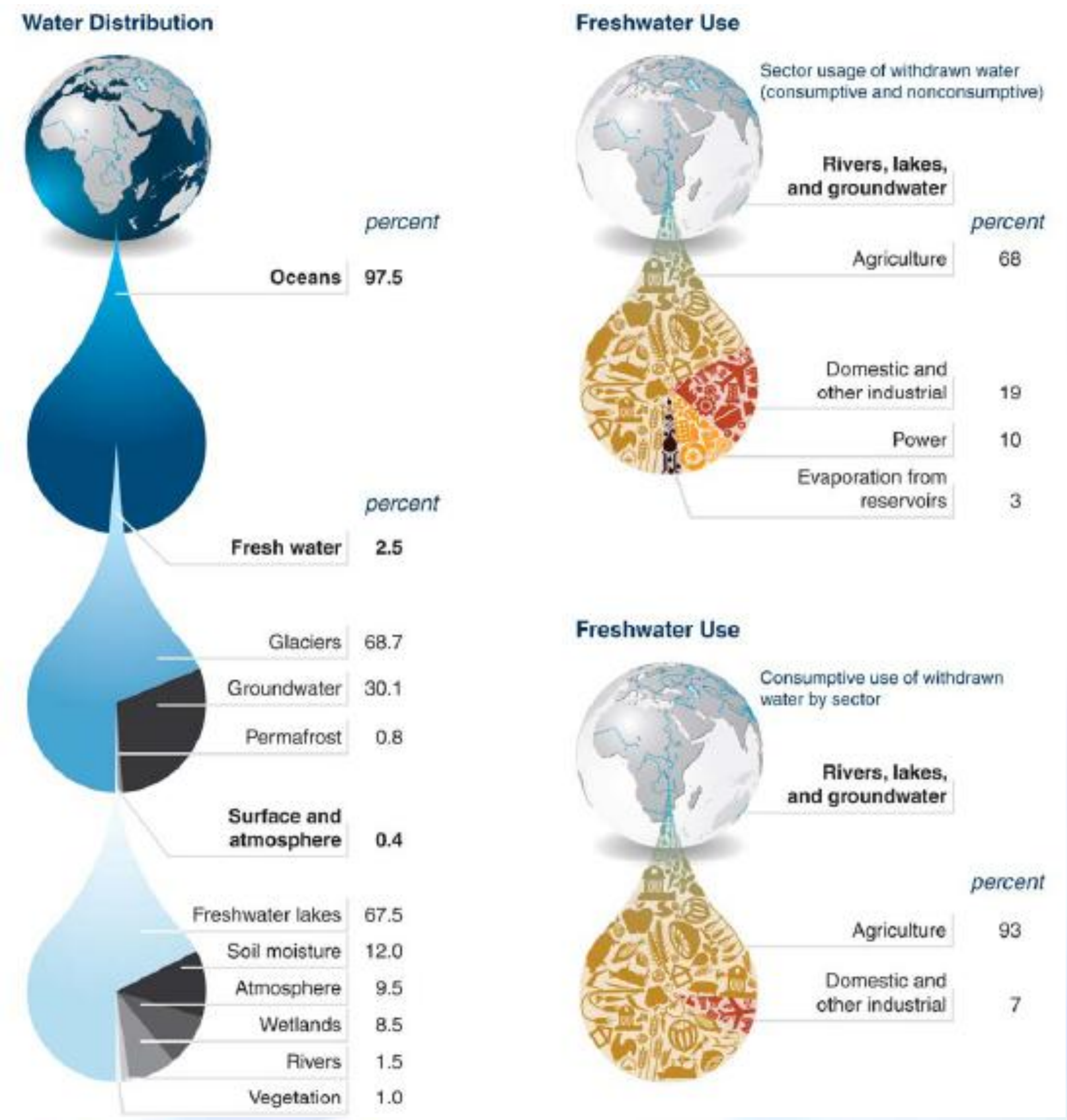


- How can we reduce our uncertainty in the <u>propagation</u> of hydroclimatic extremes?

- For example, will a meteorological drought lead to a hydrological or agricultural drought?
  - How? When? Where?

- How do phases in P-E relate to soil moisture, surface drainage, base flow, groundwater storage, river discharge, and vegetation productivity?

Distribution and Water Use on Earth



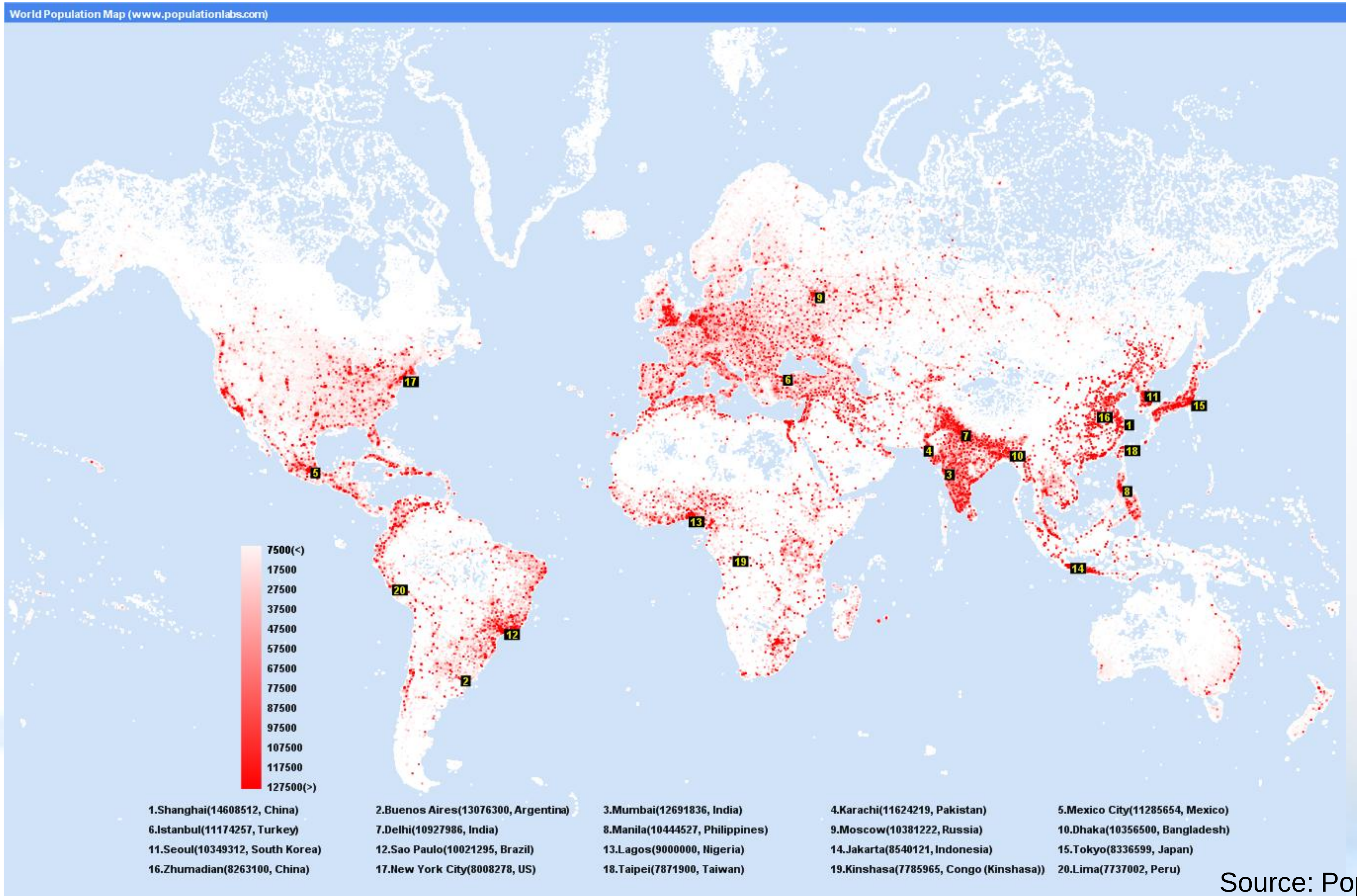
Source: Multiple, as reported by the World Bank, 2010

Objectives

With an integrated system perspective, use examples drawn from current research in the field of hydrology to

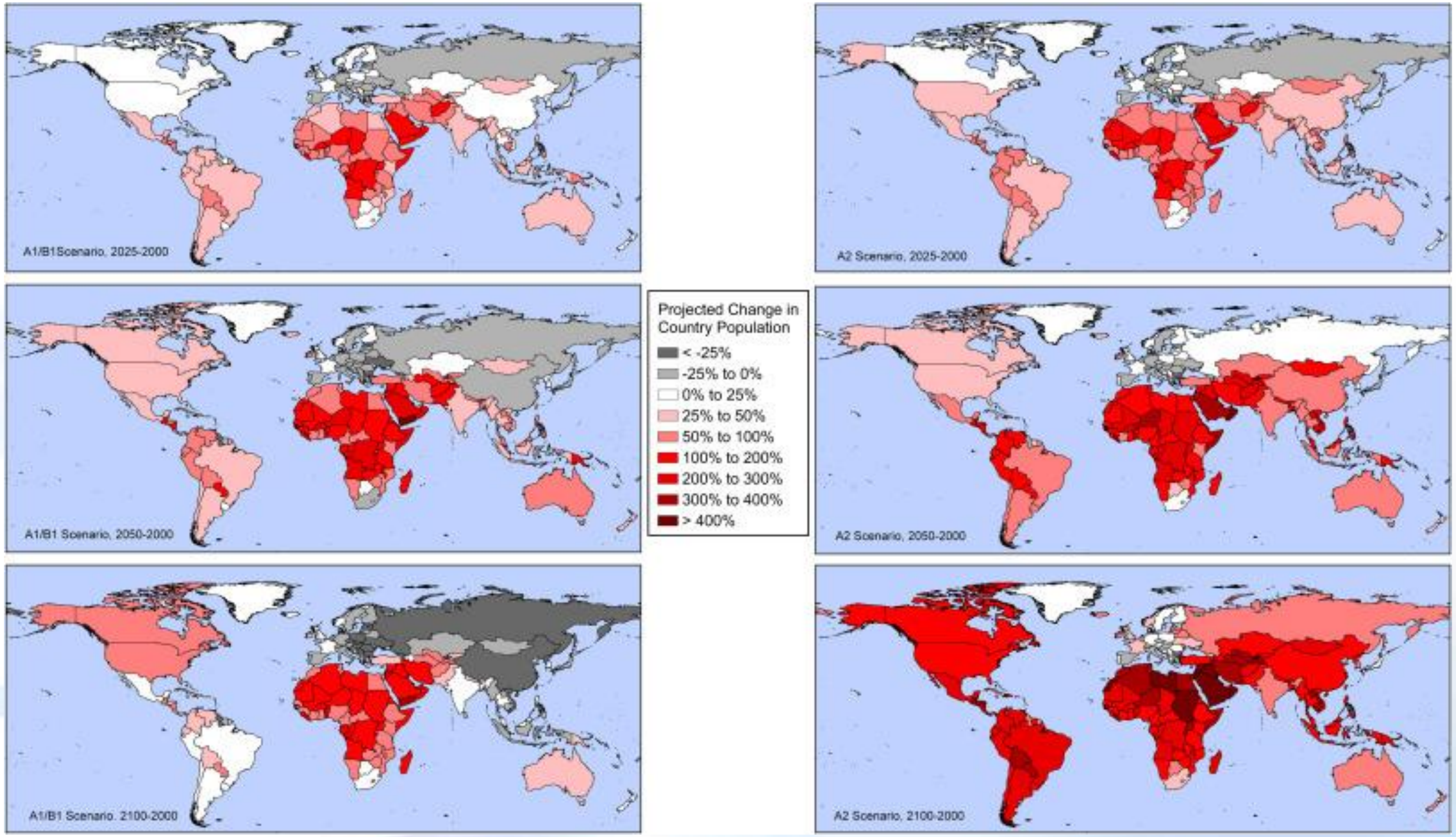
- Explain the basic underlying science and interactions.
- Discuss outstanding issues and challenges.
- Illustrate the state of art in earth observing technologies and strategies for environmental monitoring, assessment, and prediction.

Global Population Density



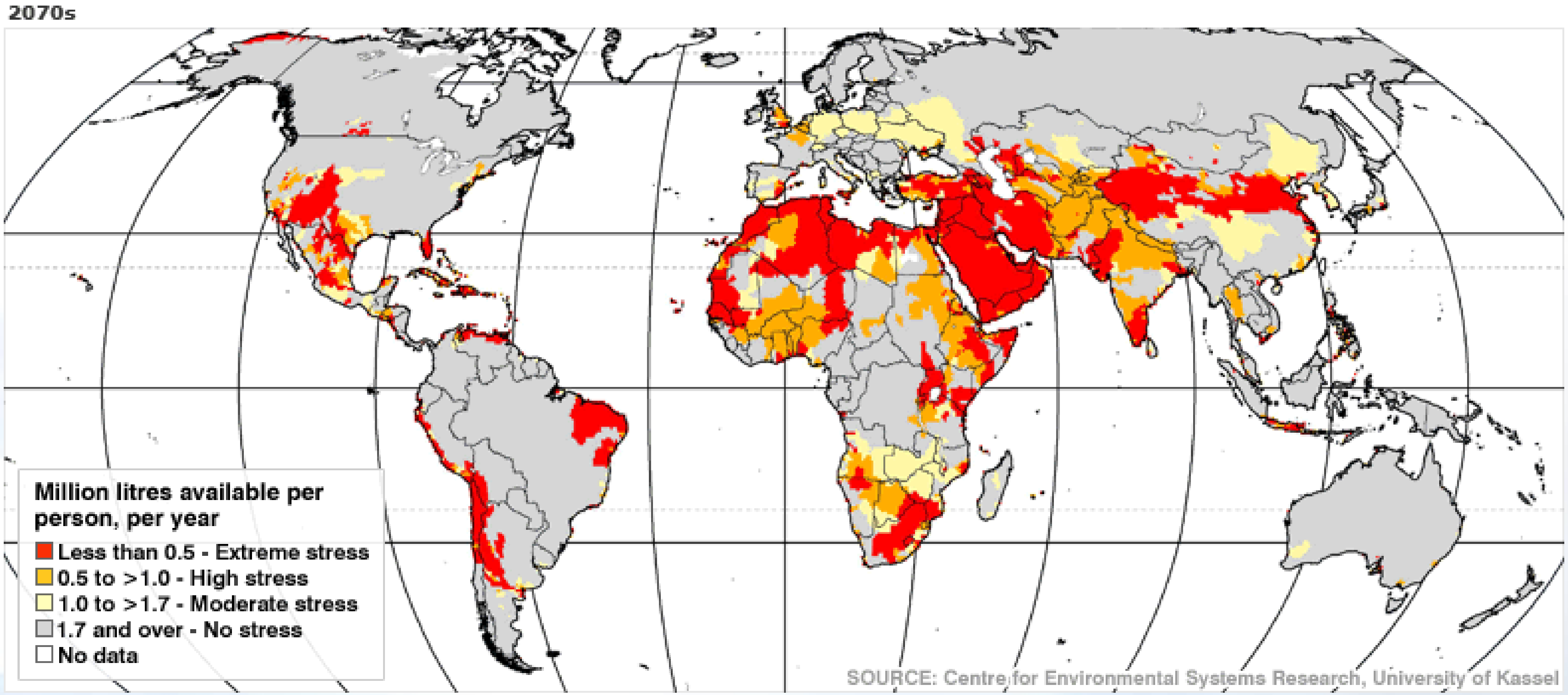
Source: Population Labs

Projected Global Population Density



Murray et al., Journal of Hydrology, 2012

Blue Water Availability Per Capita



Show Me the Water…

• Drought is a normal, recurrent feature of climate, caused by a deficiency of precipitation over an extended period

• Water shortage may be caused by drought, overuse of available water resources, or pollution

• >1 billion people lack access to "improved" water

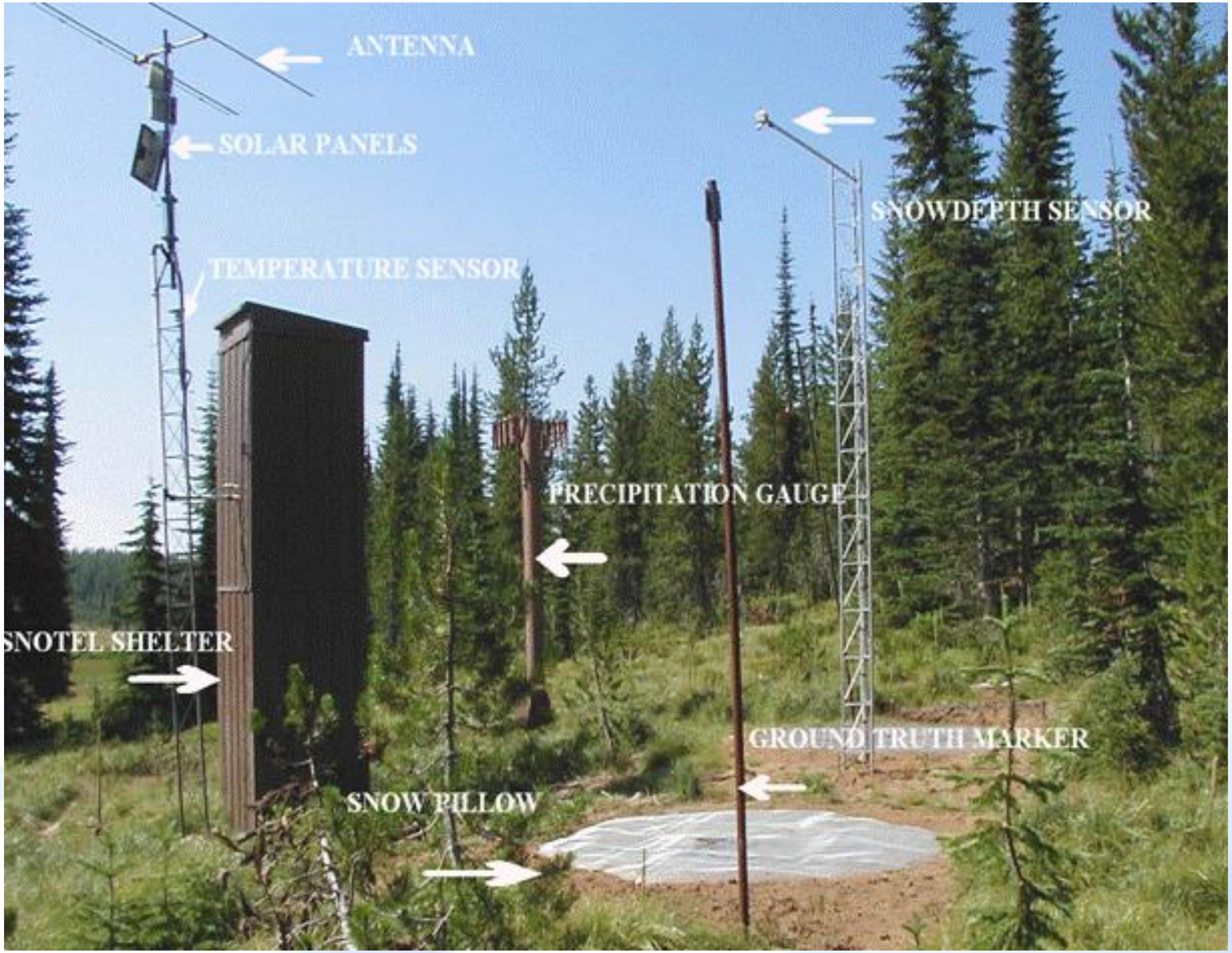
• 1.8 million people die each year of diarrheal diseases, equivalent to 12 Boeing 747 crashes each day

• The 2011 Texas drought cost $7.6 billion

• The 2012 U.S. drought cost $40 billion

Monitoring

Rain and Snowfall



Snow Depth and Snow Water Equivalent

Evapotranspiration

Groundwater

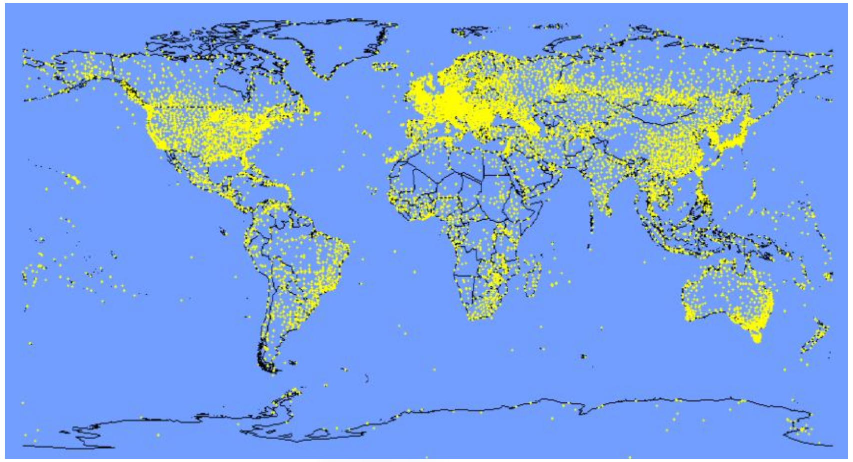
Surface Water and River Flow

Groundwater

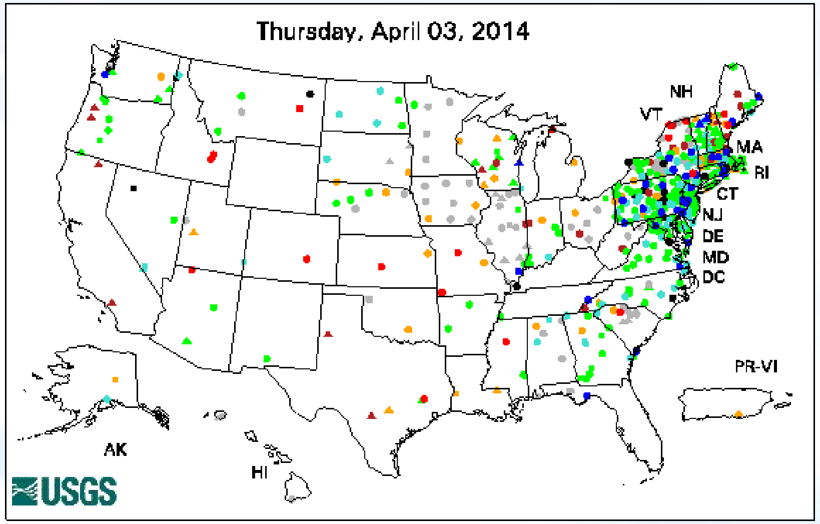
Inadequacy of Surface Observations

Issues:

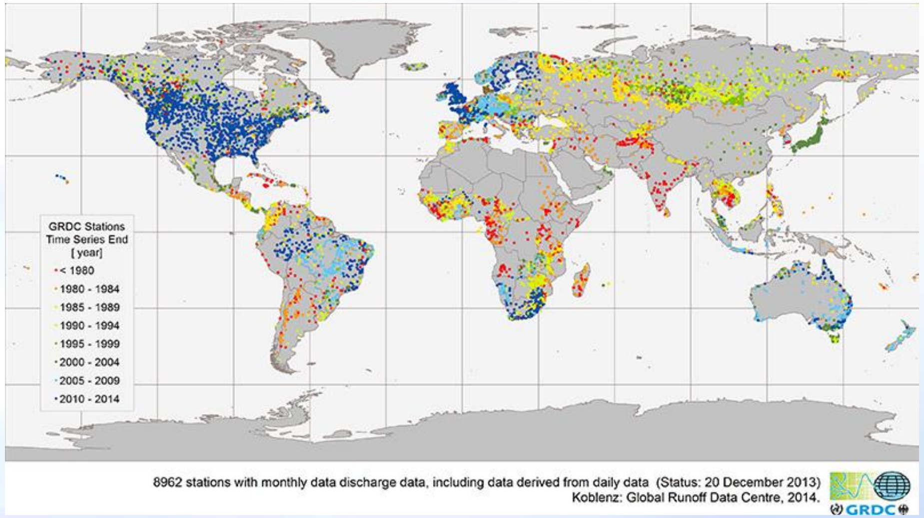
- Spatial coverage of existing stations
- Temporal gaps and delays
- Many governments unwilling to share
- Measurement inconsistencies
- Quality control
- (Un)Representativeness of point obs



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

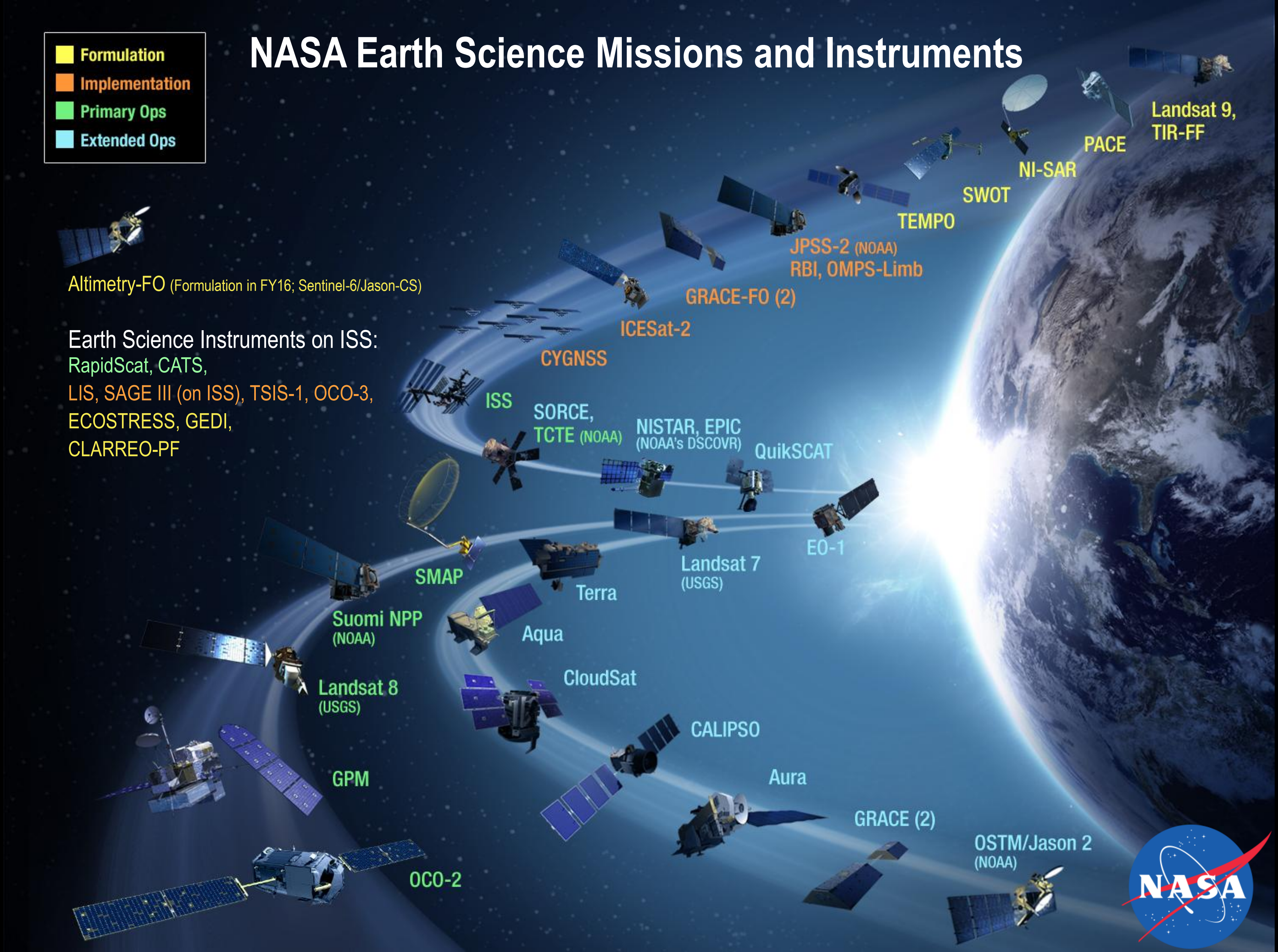


USGS Groundwater Climate Response Network. Very few groundwater records available outside of the U.S.



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

Remote Sensing and Modeling


NASA Earth Science Missions and Instruments
Formulation
Implementation
Primary Ops
Extended Ops
Altimetry-FO (Formulation in FY16; Sentinel-6/Jason-CS)
Earth Science Instruments on ISS:
RapidScat, CATS,
LIS, SAGE III (on ISS), TSIS-1, OCO-3,
ECOSTRESS, GEDI,
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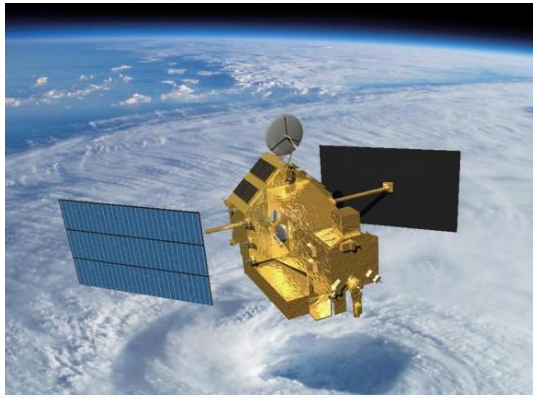
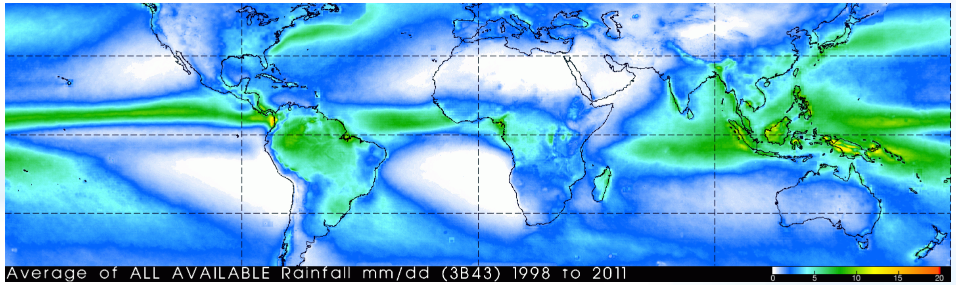
Contributing to
Water Cycle Studies
NASA

Precipitation

Tropical Rainfall Measurement Mission (TRMM)

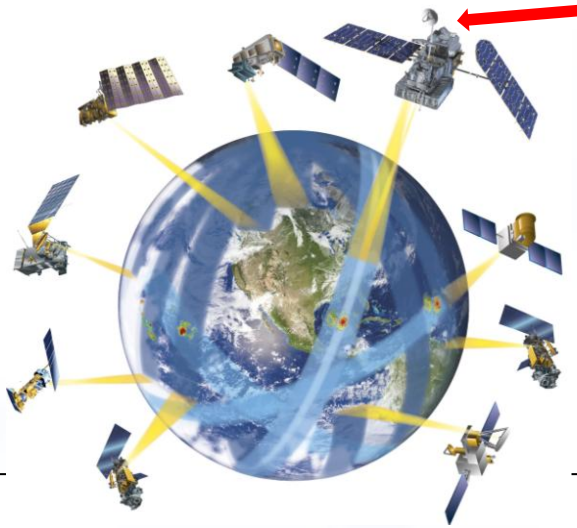


- Global (50S-50N) precipitation measurement
  – 10 ↔ 85 GHz radiometers
  – 13.6 GHz precipitation radar
  – 27 Nov 1997 to present



TRMM 14-year mean rainfall

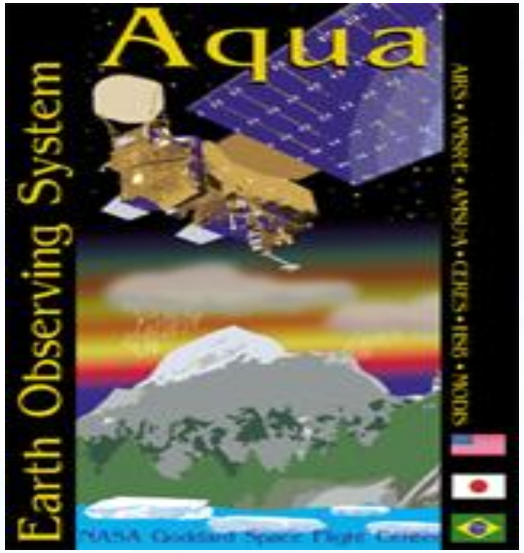
Global Precipitation Measurement (GPM)



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

- Launched Feb 28, 2014
- 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

Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS)



- 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

Soil Moisture Active Passive (SMAP)

31 January 2015

Instruments

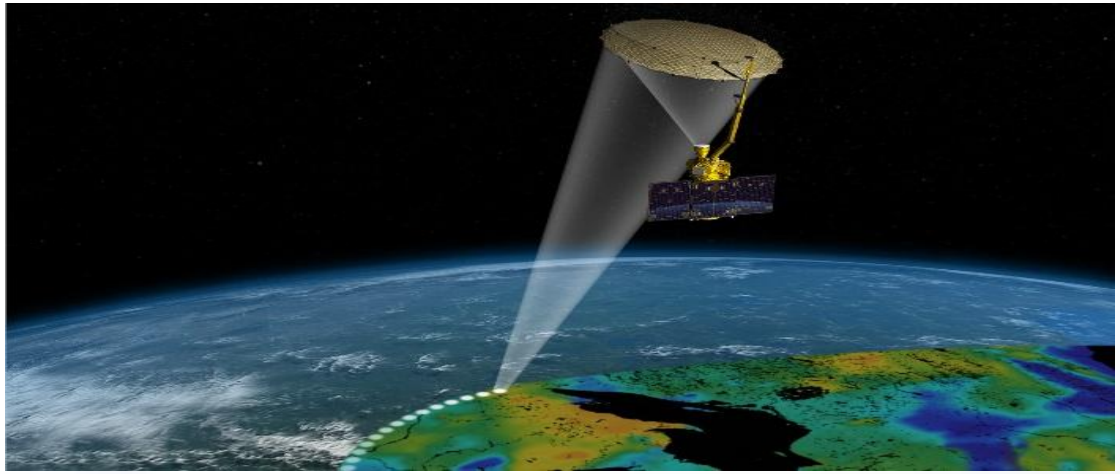
- Radar(1.26 GHz)
  - ✓ High resolution, moderate accuracy
- Radiometer (1.4 GHz)
  - ✓ Moderate resolution, high accuracy

Shared antenna

- Constant incident angle: 40 degrees
- 1000 km wide swath

Orbit

- Sun-synchronous
- 6 am (Descending) / 6 pm (Ascending)
- 685 km altitude
- Global coverage every three days



Product	Description	Gridding (Resolution)	Latency**	
L1A_Radiometer	Radiometer Data in Time-Order	-	12 hrs	Instrument Data
L1A_Radar	Radar Data in Time-Order	-	12 hrs	
L1B_TB	Radiometer T_B in Time-Order	(36×47 km)	12 hrs	
L1B_S0_LoRes	Low-Resolution Radar σ_o in Time-Order	(5×30 km)	12 hrs	
L1C_S0_HiRes	High-Resolution Radar σ_o in Half-Orbits	1 km (1−3 km)[#]	12 hrs	
L1C_TB	Radiometer T_B in Half-Orbits	36 km	12 hrs	
L2_SM_A	Soil Moisture (Radar)	3 km	24 hrs	Science Data (Half-Orbit)
L2_SM_P*	Soil Moisture (Radiometer)	36 km	24 hrs	
L2_SM_AP*	Soil Moisture (Radar + Radiometer)	9 km	24 hrs	
L3_FT_A*	Freeze/Thaw State (Radar)	3 km	50 hrs	Science Data (Daily Composite)
L3_SM_A	Soil Moisture (Radar)	3 km	50 hrs	
L3_SM_P*	Soil Moisture (Radiometer)	36 km	50 hrs	
L3_SM_AP*	Soil Moisture (Radar + Radiometer)	9 km	50 hrs	
L4_SM	Soil Moisture (Surface and Root Zone)	9 km	7 days	Science Value-Added
L4_C	Carbon Net Ecosystem Exchange (NEE)	9 km	14 days	

Image courtesy: http://www.jpl.nasa.gov/

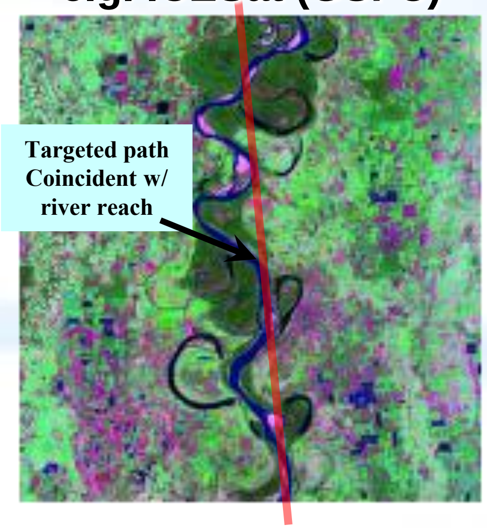
Surface Water Ocean Topography (SWOT)

Stream Discharge and Surface Water Height

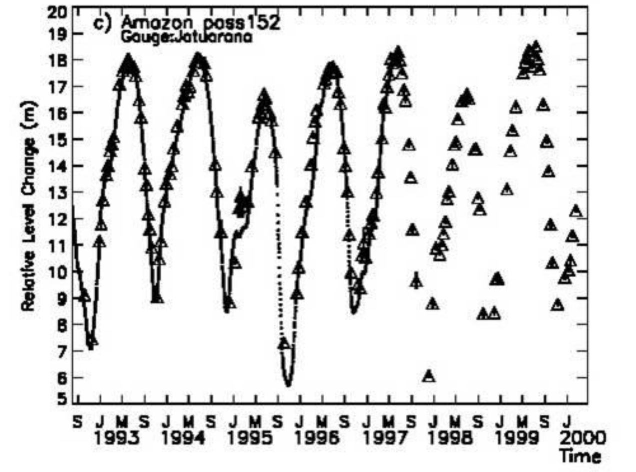
Motivation:
• critical water cycle component
• essential for water resource planning
• stream discharge and water height data are difficult to obtain outside US
• find the missing continental discharge component

Mission Concepts:

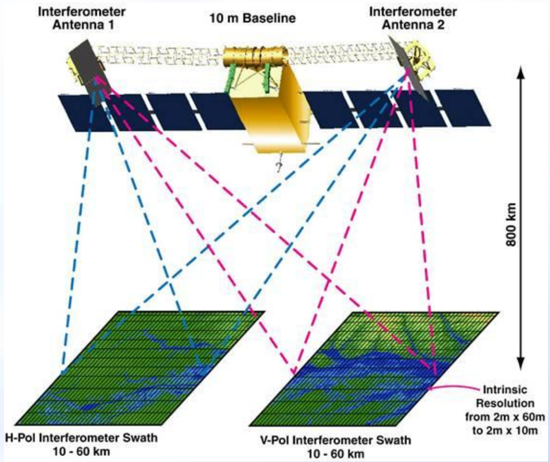
Laser Altimetry Concept
e.g. ICESat (GSFC)



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

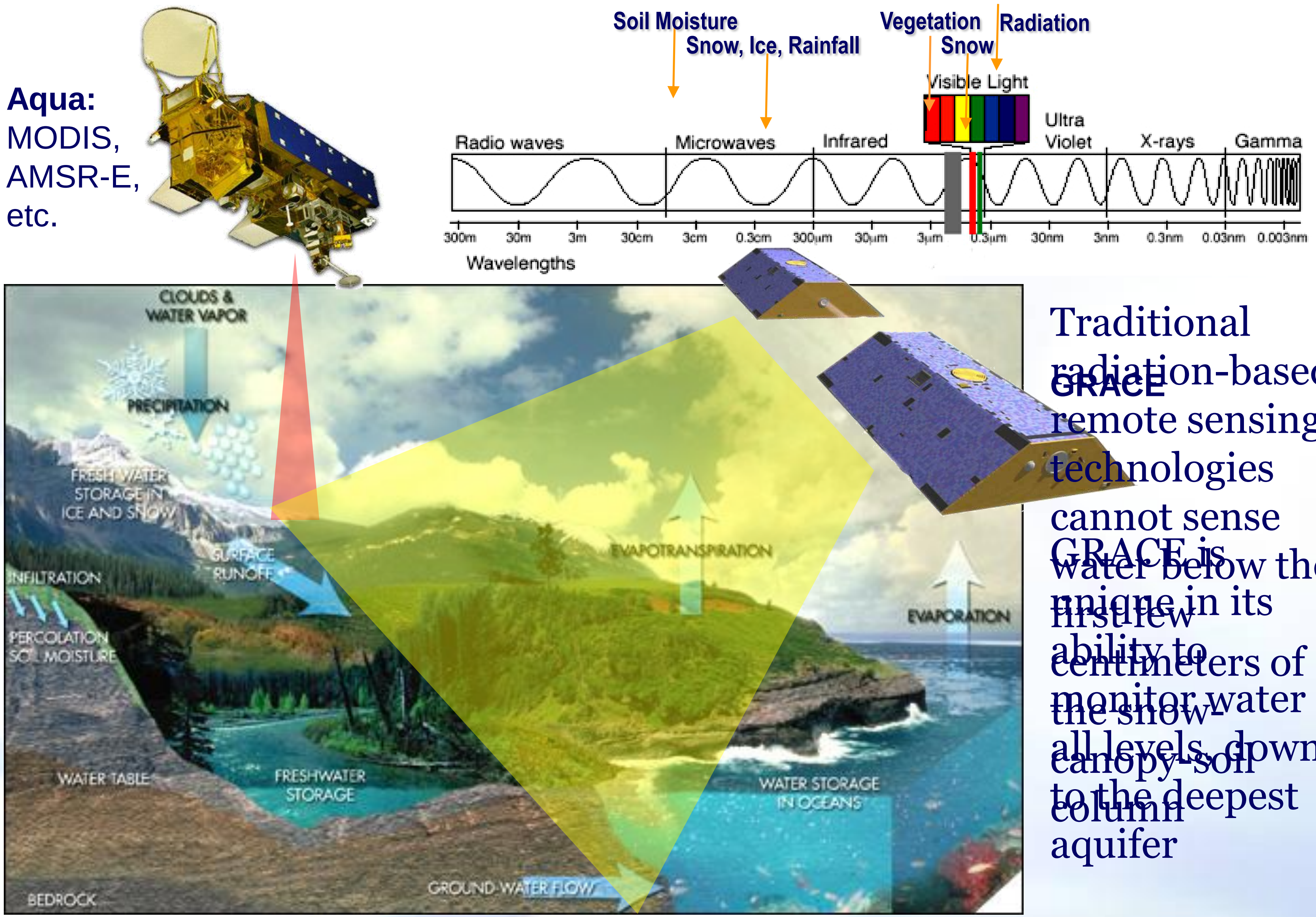


Interferometer Concept
(JPL)



Source: M. Jasinski/614.3

Gravity Recovery and Climate Experiment (GRACE)



Traditional 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

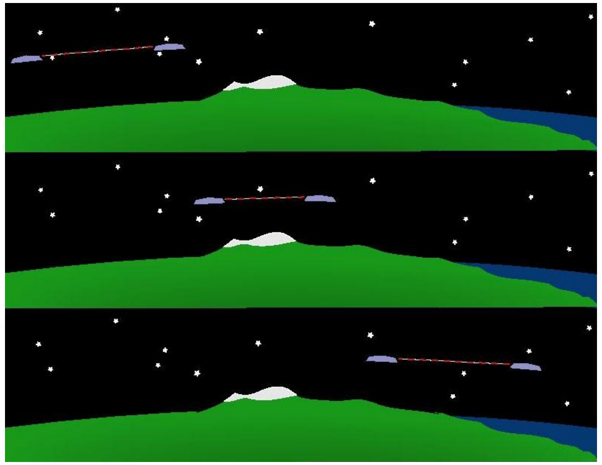
GRACE Derived Terrestrial Water Storage Variations

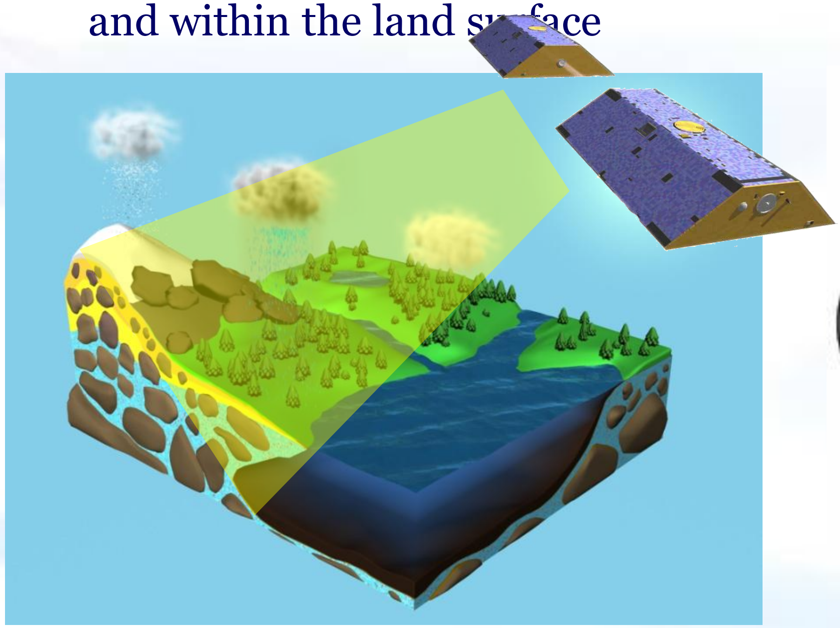
GRACE Science Goal: High resolution, mean and time variable gravity field mapping for Earth System Science applications

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

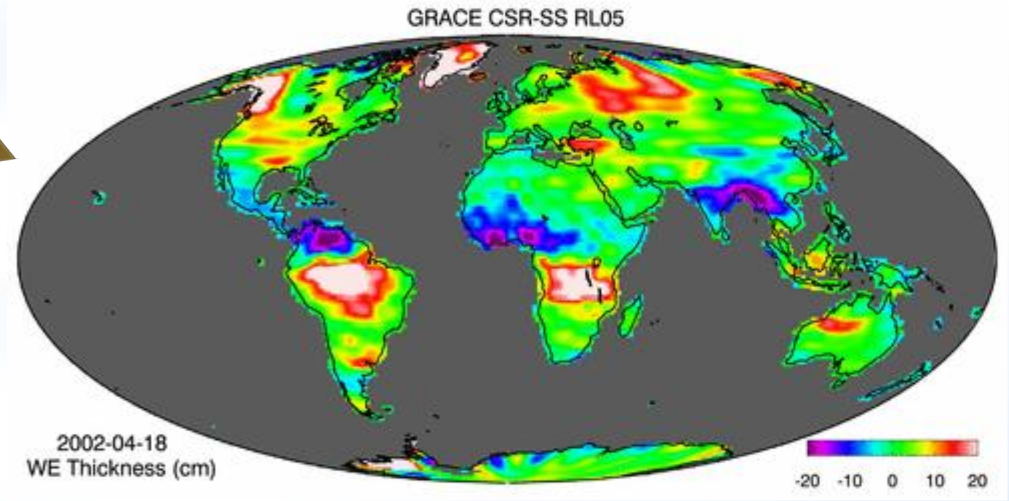
Key Measurement: Distance between two satellites tracked by K-band microwave ranging system

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.

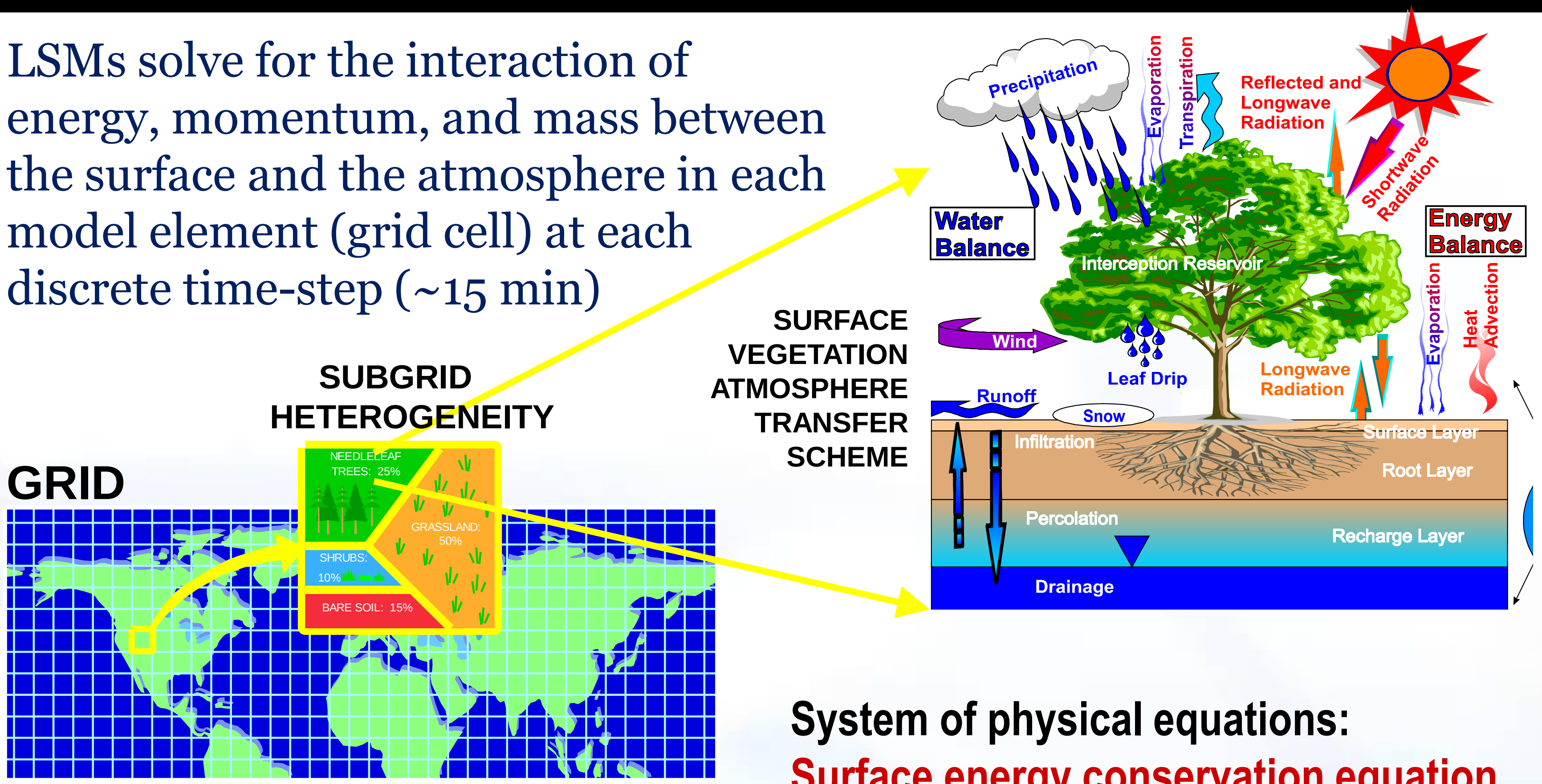


Animation of monthly GRACE terrestrial water storage anomaly fields. A water storage anomaly is defined here as a deviation from the long-term mean total terrestrial water storage at each location.

Matt Rodell
NASA GSFC

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

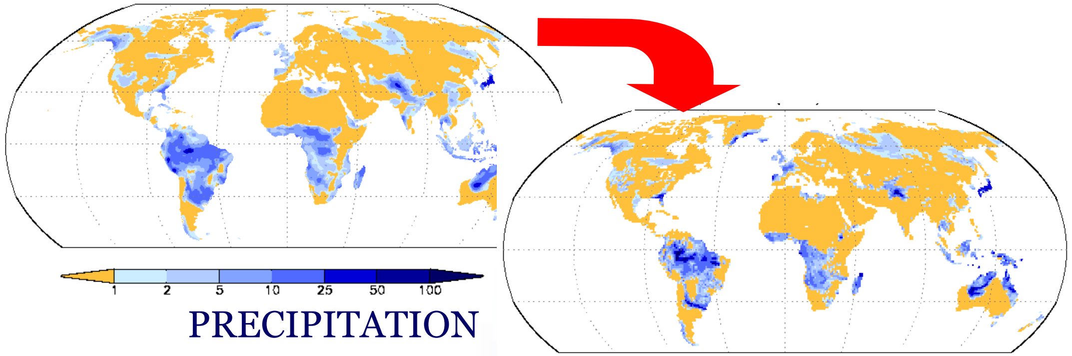
Evaporation: Penman-Monteith equation

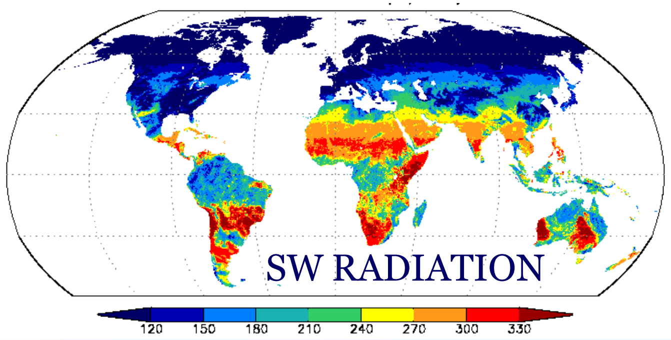
etc.

Matt Rodell
NASA GSFC

Data Integration with a Land Data Assimilation System (LDAS)

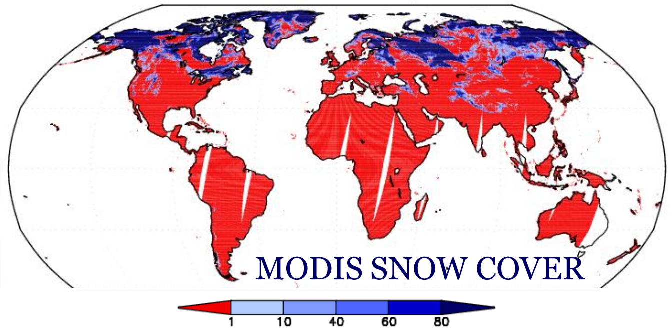
INTERCOMPARISON and OPTIMAL MERGING of global data fields

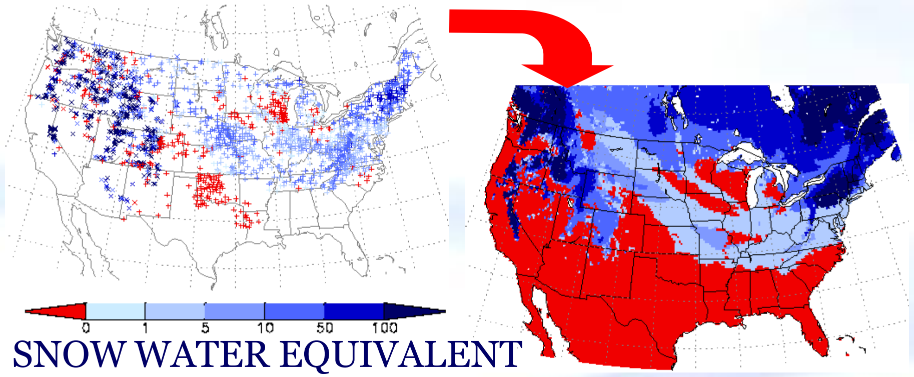




Satellite derived meteorological data used as land surface model FORCING

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





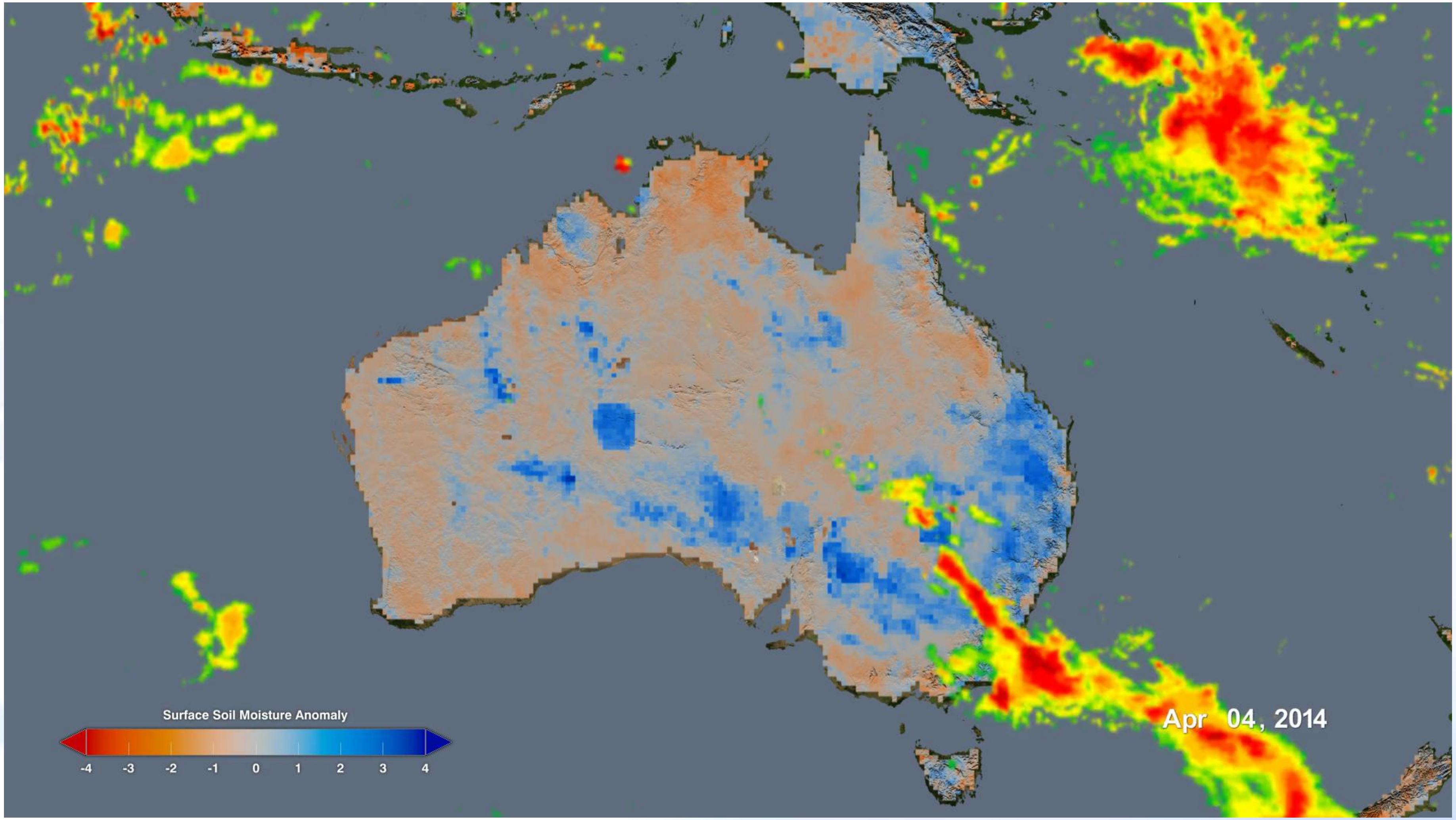
Ground-based observations used to VALIDATE model output

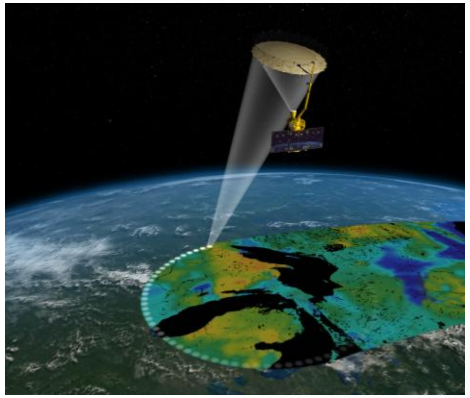
Examples from NASA's GLDAS
http://ldas.gsfc.nasa.gov/

Matt Rodell
NASA GSFC

Applications

Monitoring Precipitation Memory

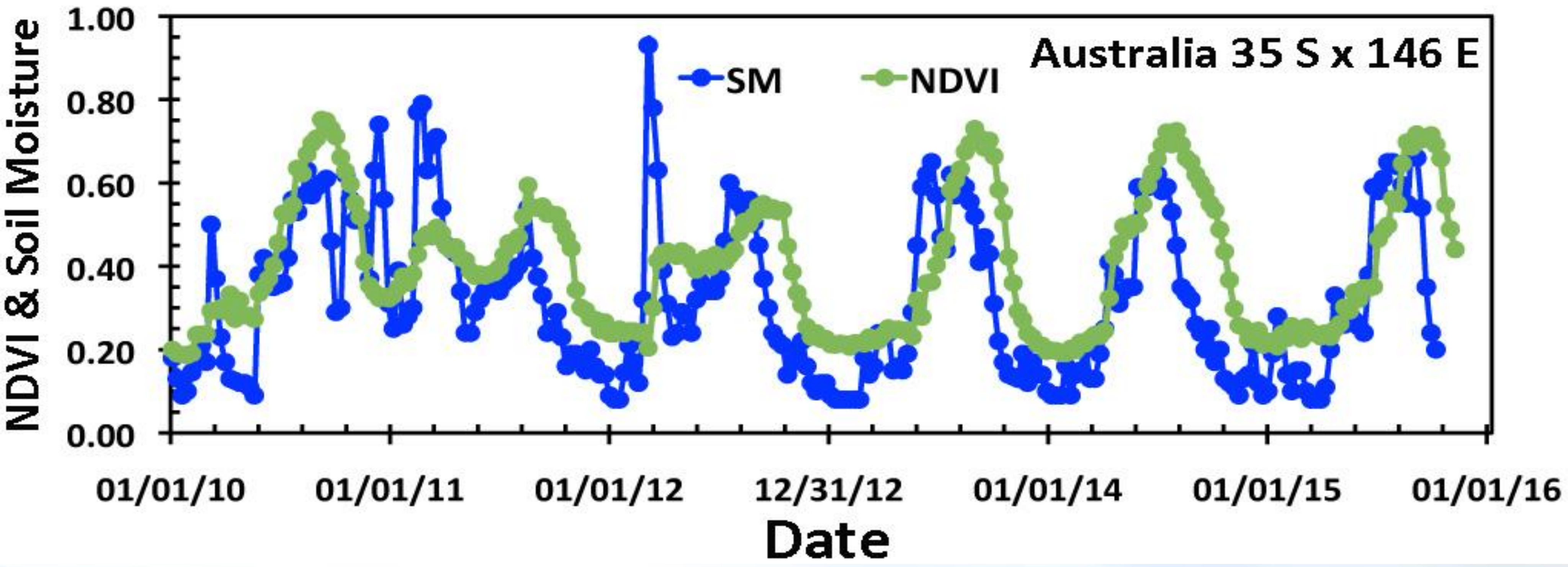




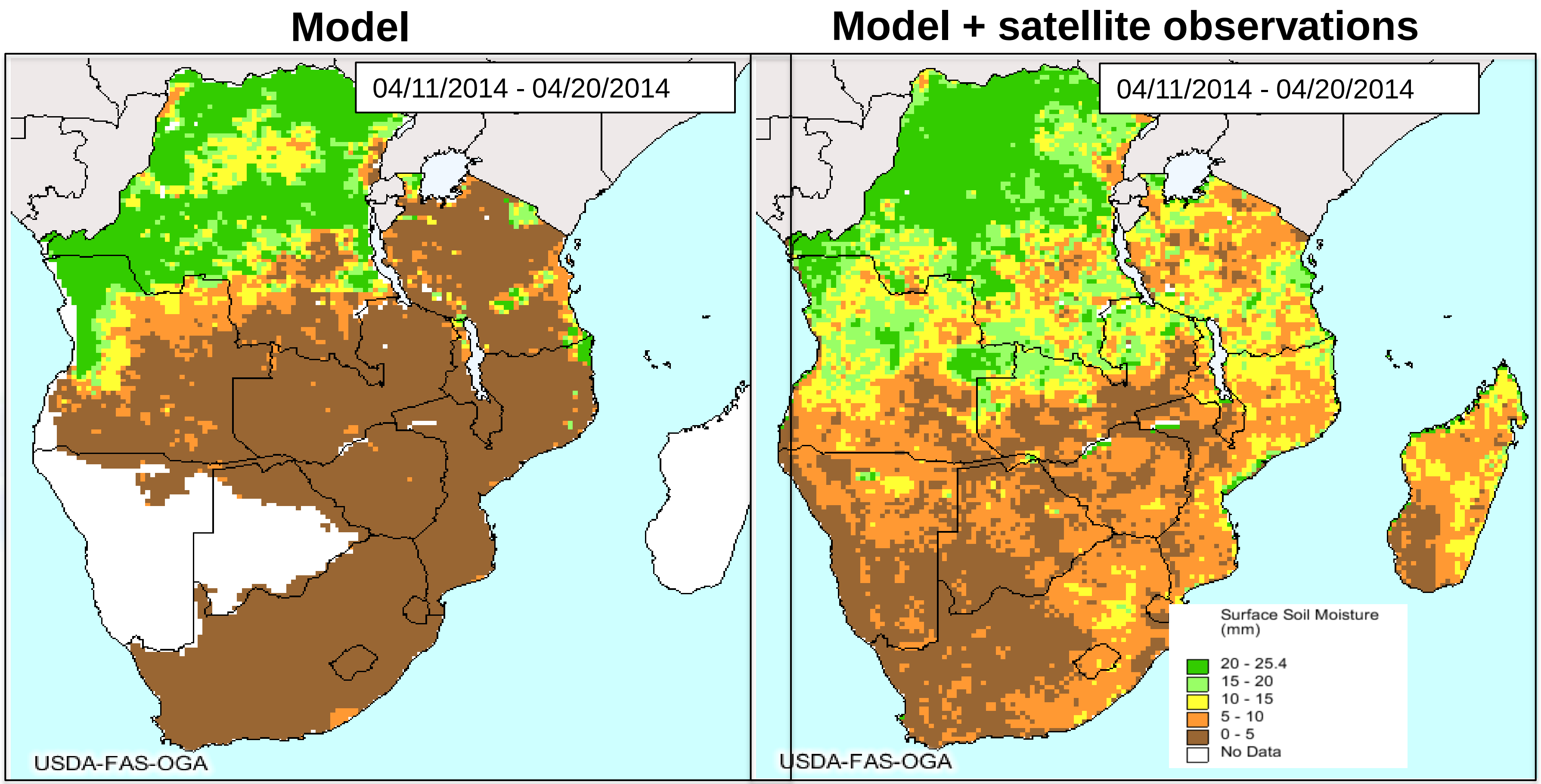
Soil Moisture Active Passive Mission

Global Precipitation Measurement Mission, Core Observatory

Leading Indicator of Vegetation Changes



How Can We Improve Global Crop Forecasts?

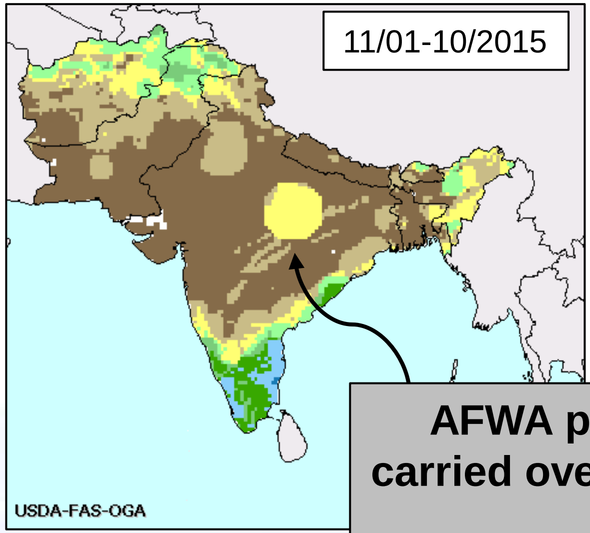


http://www.pecad.fas.usda.gov/cropexplorer/

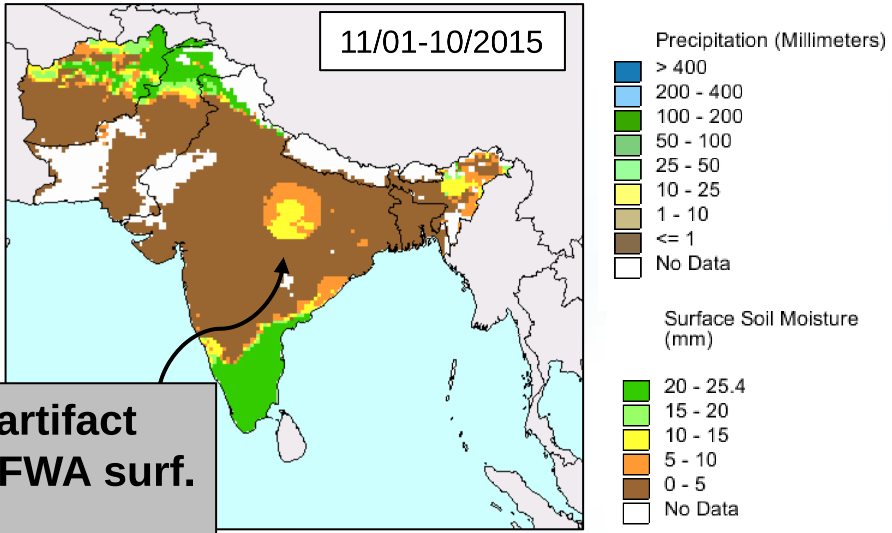
Satellite-based soil moisture observations are improving USDA's ability to globally monitor agricultural drought and predict its short-term impact on vegetation health and agricultural yield.

How Can We Improve Global Crop Forecasts?

AFWA Precip

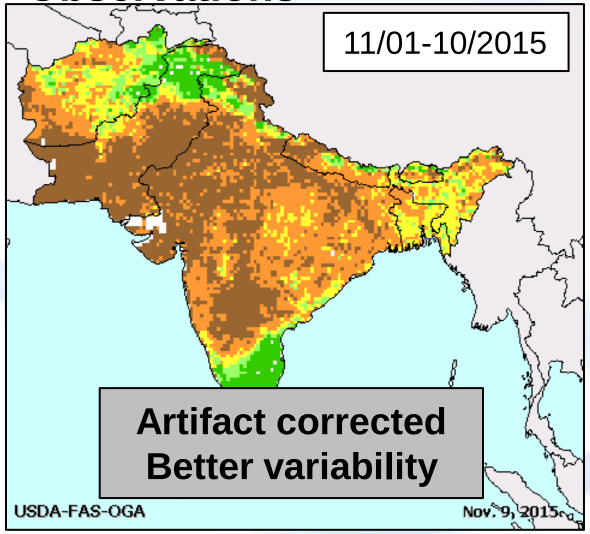


Model - AFWA



AFWA precip artifact carried over to AFWA surf. SM

Model + Satellite Observations



Artifact corrected
Better variability

Image courtesy: C. Reynolds

Can we Isolate the Impact in Food Insecure Regions?

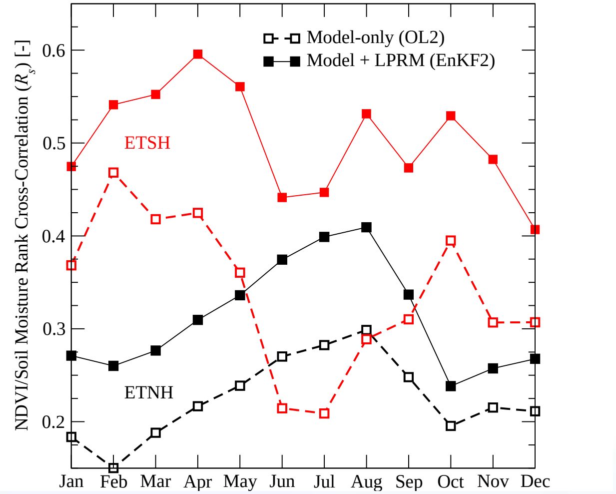


Figure 1: Seasonal cycles of the rank correlation between open loop and EnKF soil moisture anomalies with future vegetation anomalies (1 month) averaged within the Extra-tropical Northern (ETNH; to 60° N) and Southern (ETSH; to 60° S) Hemispheres.

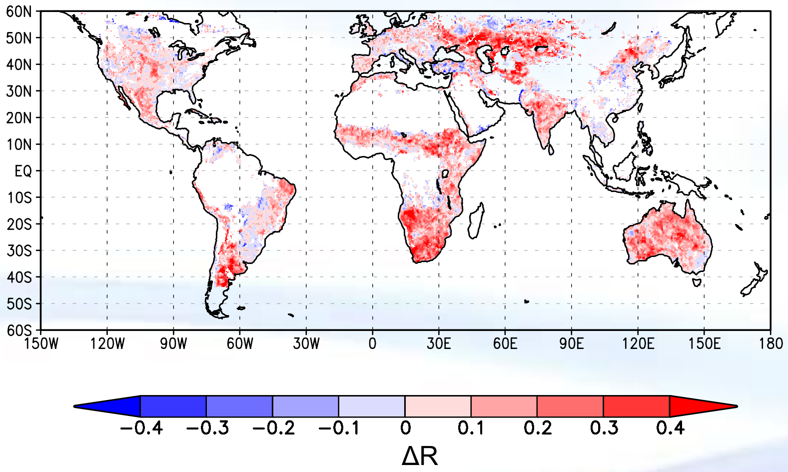


Figure 2: Global analysis of the net impact of assimilating AMSR-E soil moisture into the USDA water balance model.

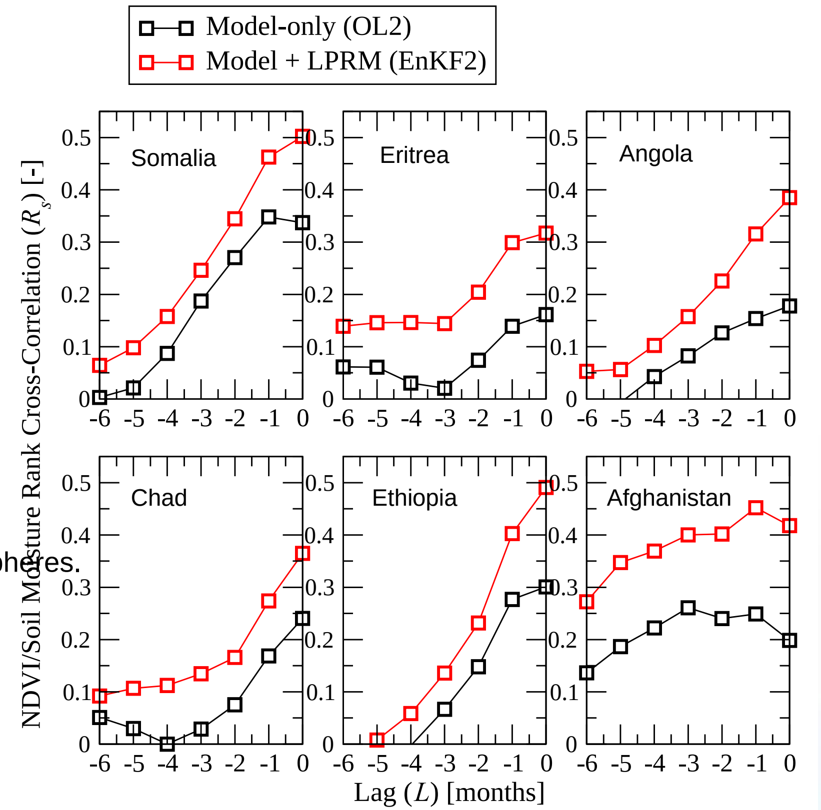
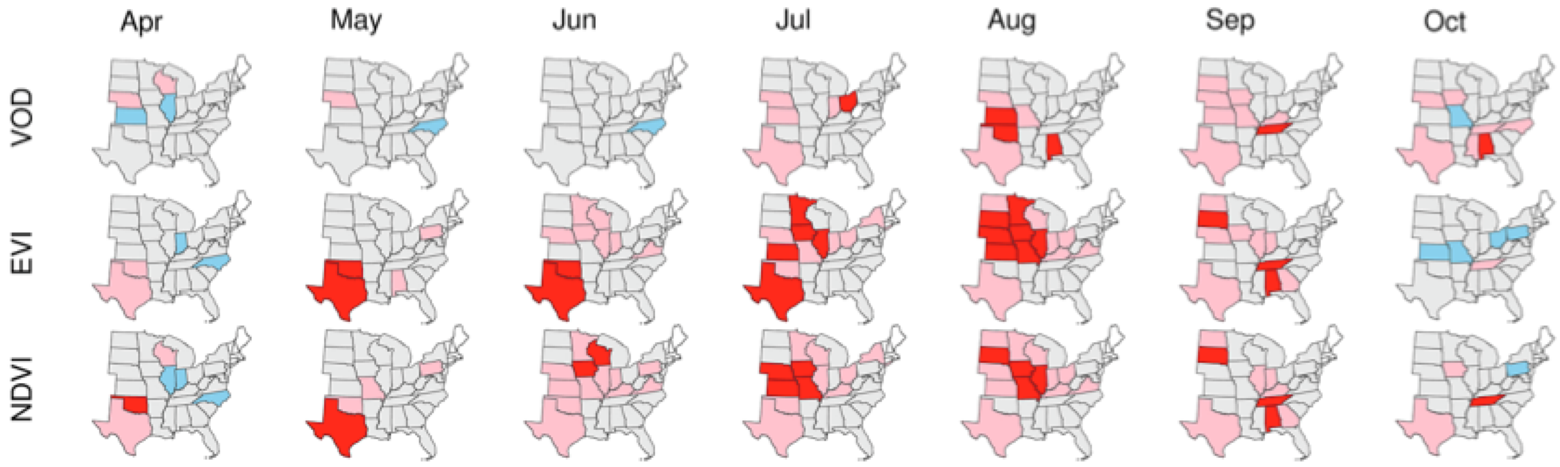


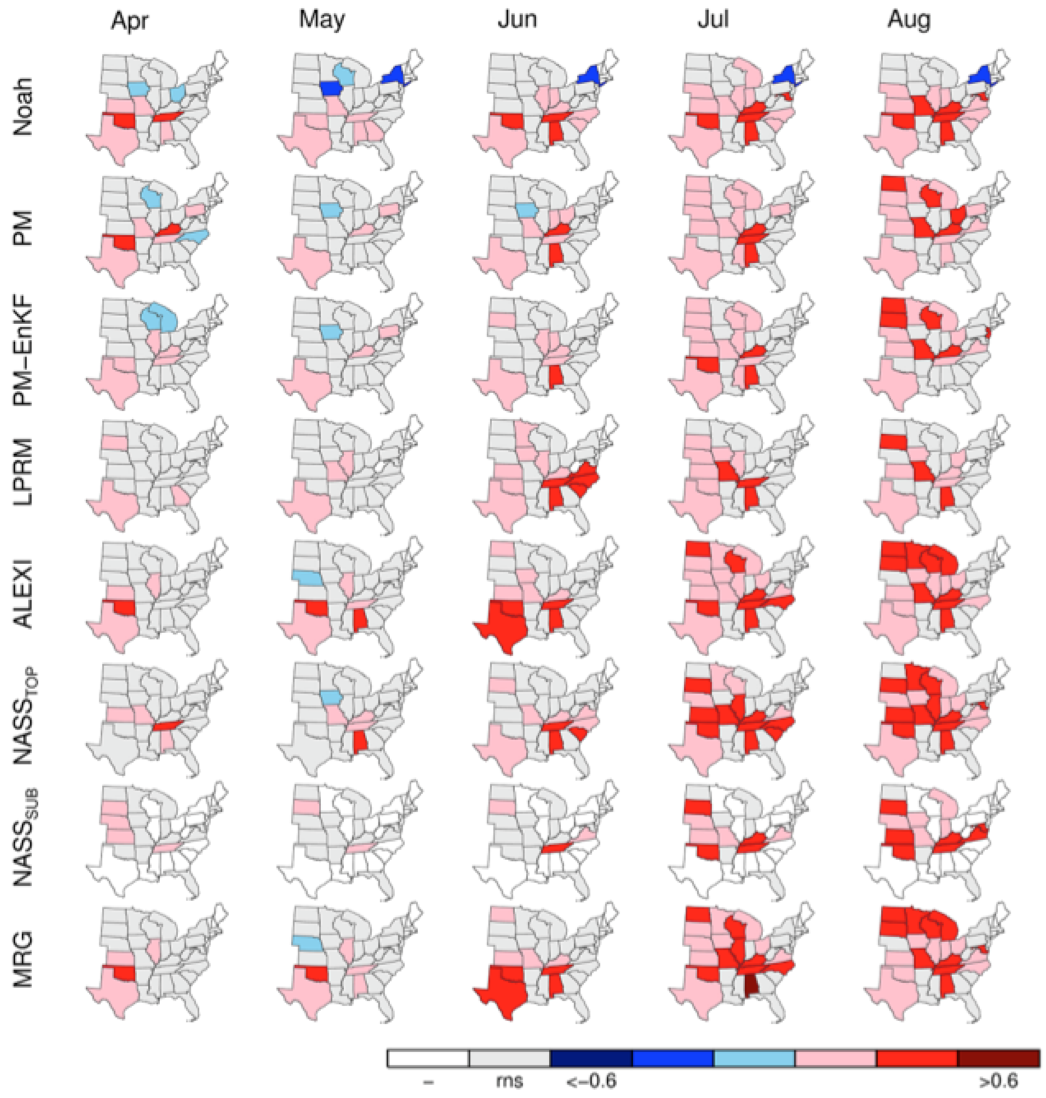
Figure 3: Comparisons between $R_s(L)^{OL2}$ and $R_s(L)^{EnKF2}$ over a range of L (i.e., 0 to 6 months) for sparsely-instrumented countries with moderate-to-severe food security issues.

Can We Improve End Of Season Yield Forecasts?



VI-yield rank correlation analysis for corn over central and eastern U.S.

Can We Improve End Of Season Yield Forecasts?



SM-yield rank correlation analysis for corn over central and eastern U.S.

Floods

• In the United States, an average of 100 people lose their lives in floods annually, with flood damage averaging more than $2 billion.

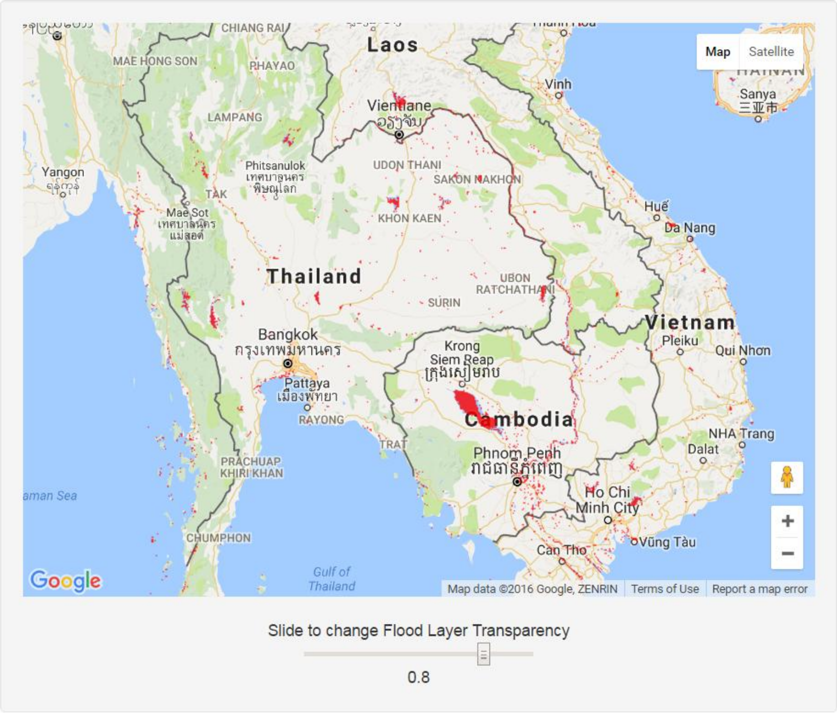
• The Midwest's "Great Flood of 1993" cost 48 lives and more than $12 billion.

• Flash floods are the number one weather-related killer in the United States—

- 2,200 deaths in Johnstown, Pennsylvania, May 31, 1889
- 238 fatalities in Rapid City, South Dakota, June 9, 1972
- 140 killed in the Big Thompson Canyon nr Denver July 31, 1976
- 26 dead in Shadyside, Ohio, June 14, 1990

Source: NOAA

Real Time Flood Impact Assessment Tool



Layers

Optical (source)

- [x] **MODIS 250m Surface Water Extent**

Radar Precipitation (sources)

- [ ] NASA GPM 30 min + Clouds
- [ ] NASA GPM 24 hr
- [ ] NASA GPM 7 day
- [ ] NASA TRMM 3 hr
- [ ] NASA TRMM 72 hr

Precipitation Avg and Anomalies (sources)

- [ ] 30 Day Rainfall Average
- [ ] 30 Day Rainfall Anomaly

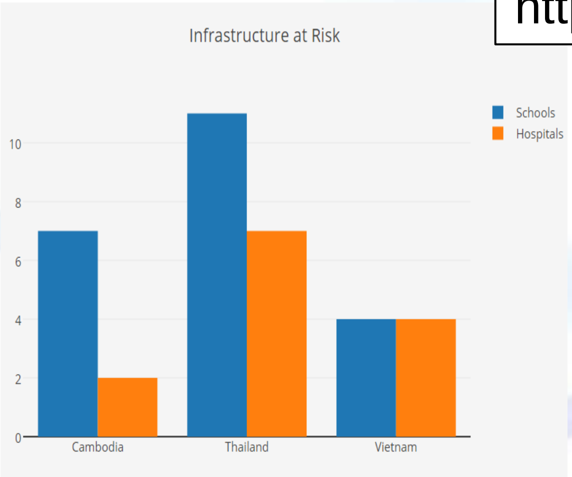
Flood Models (source)

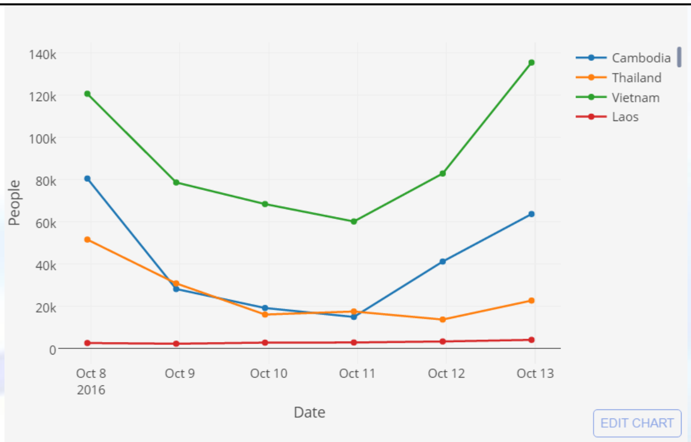
- [ ] NASA TRMM Flood Potential
- [ ] NASA GEOS-5 Flood Potential
- [ ] NASA Extended Flood Potential

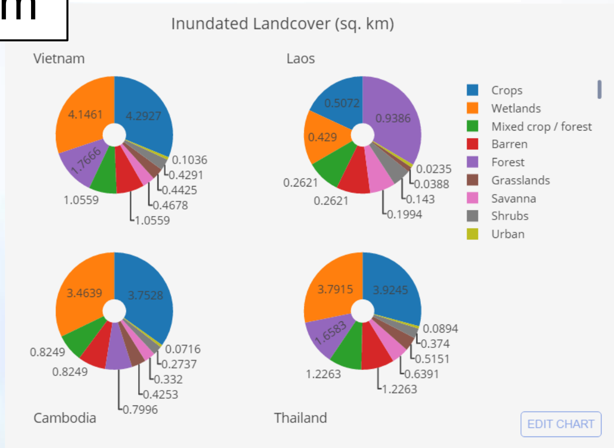
Other Layers (various sources)

- [ ] Mekong River Main Stem
- [ ] River Gages
- [ ] Dams
- [ ] Google Maps Traffic

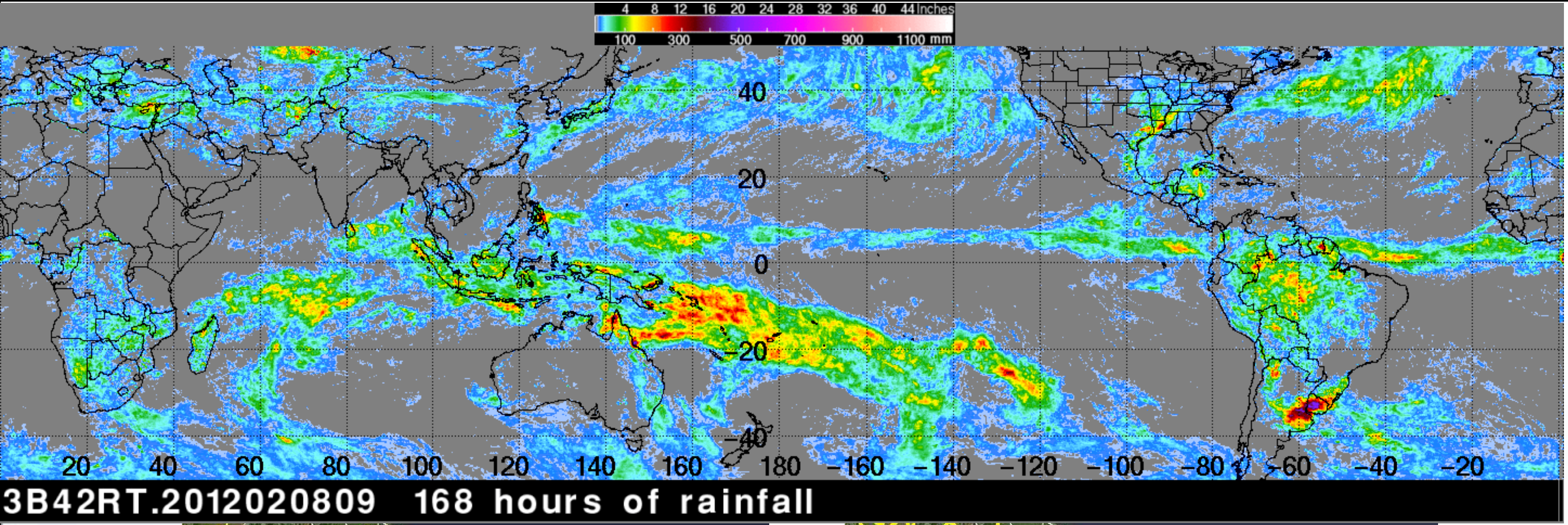
http://projectmekongnasa.appspot.com

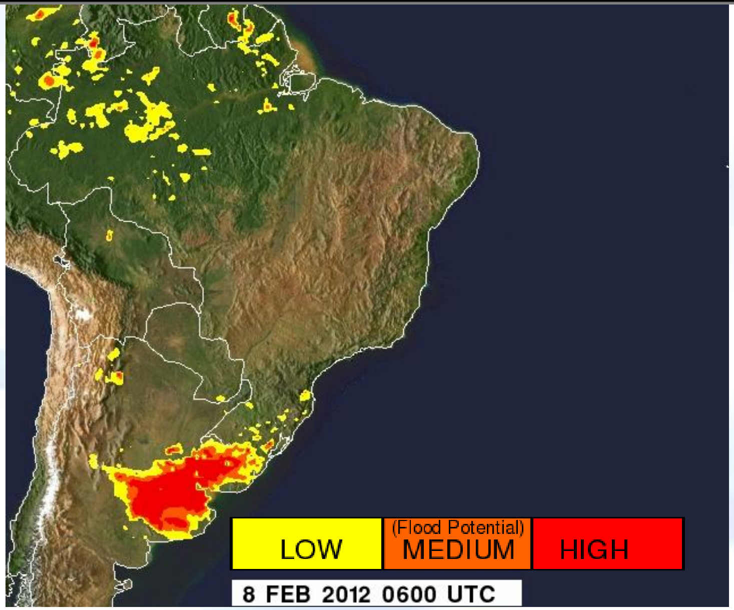


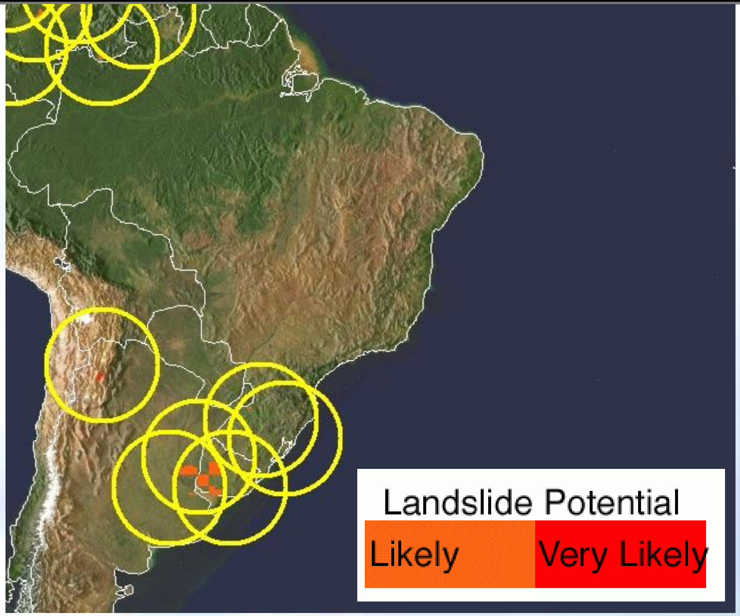




Applying TRMM Precipitation for Landslide Hazard Assessment







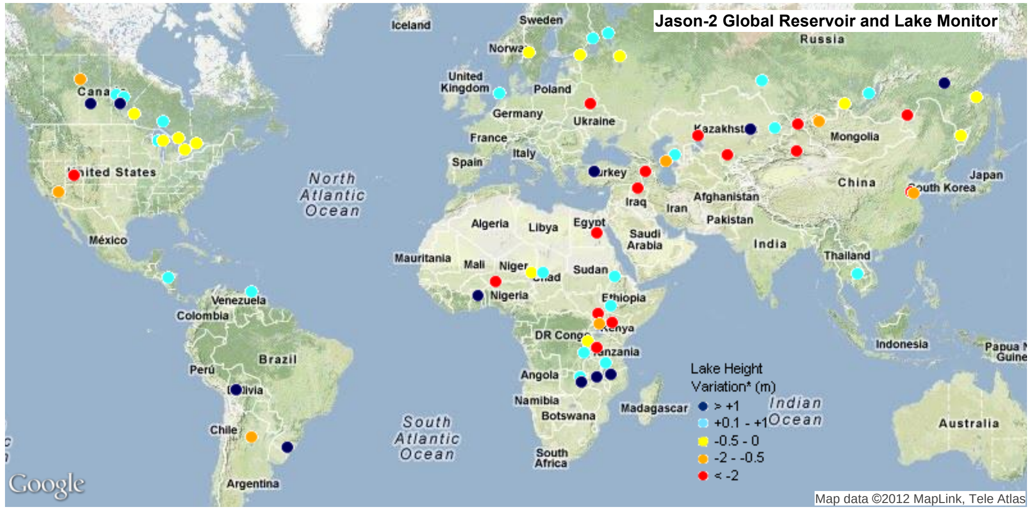
Source: D. Kirschbaum, NASA

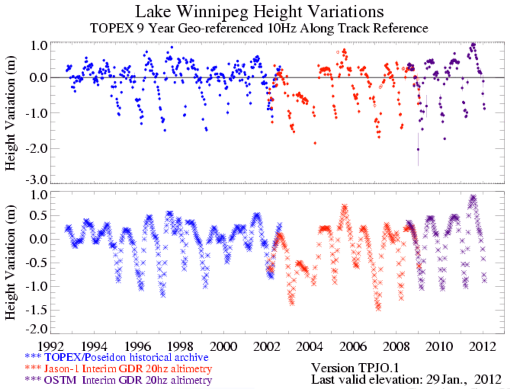
Routine Lake Level Monitoring (Jason1/2 & ENVISAT)

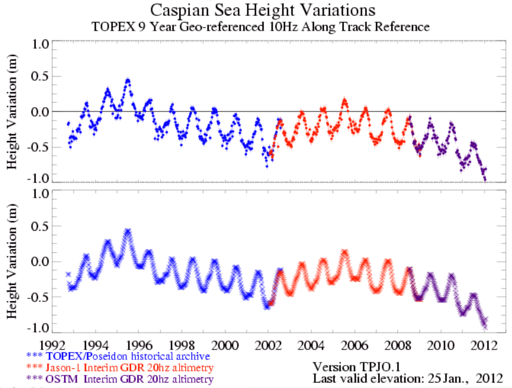
USDA United States Department of Agriculture
Foreign Agricultural Service

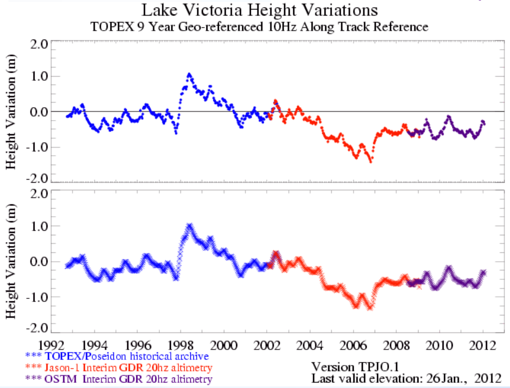
Linking U.S. Agriculture to the World FAS

Toolbox







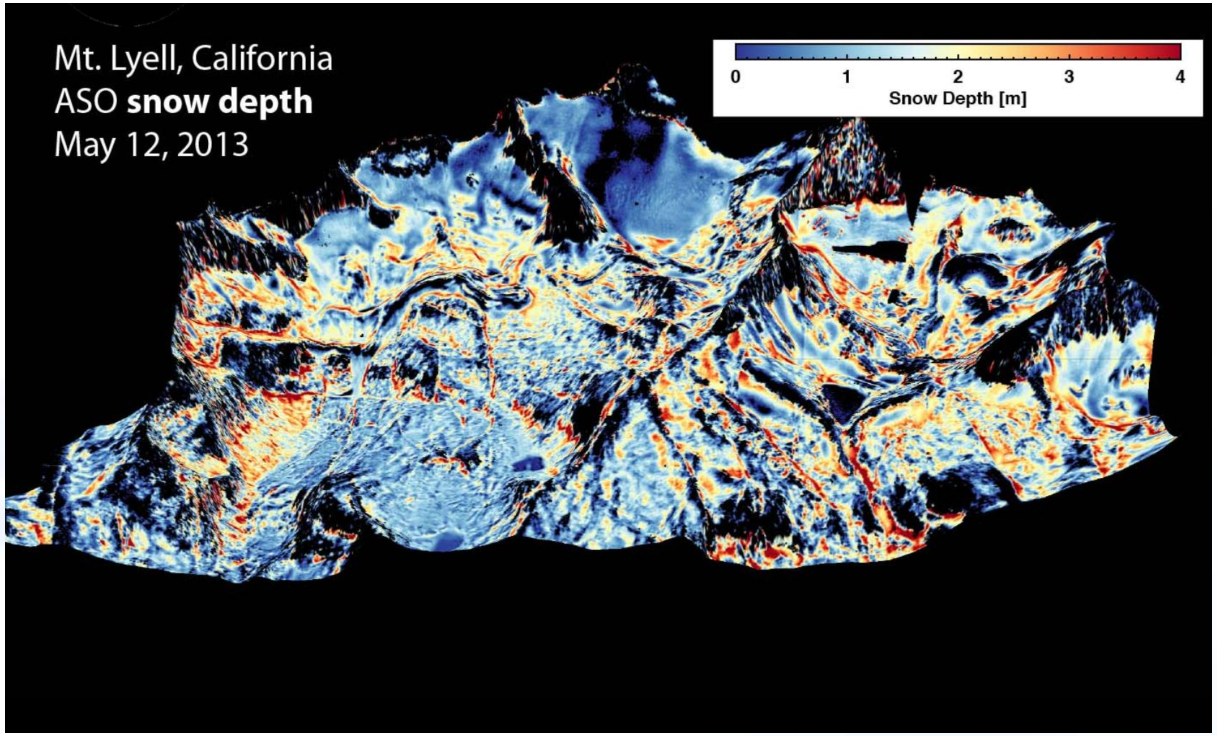


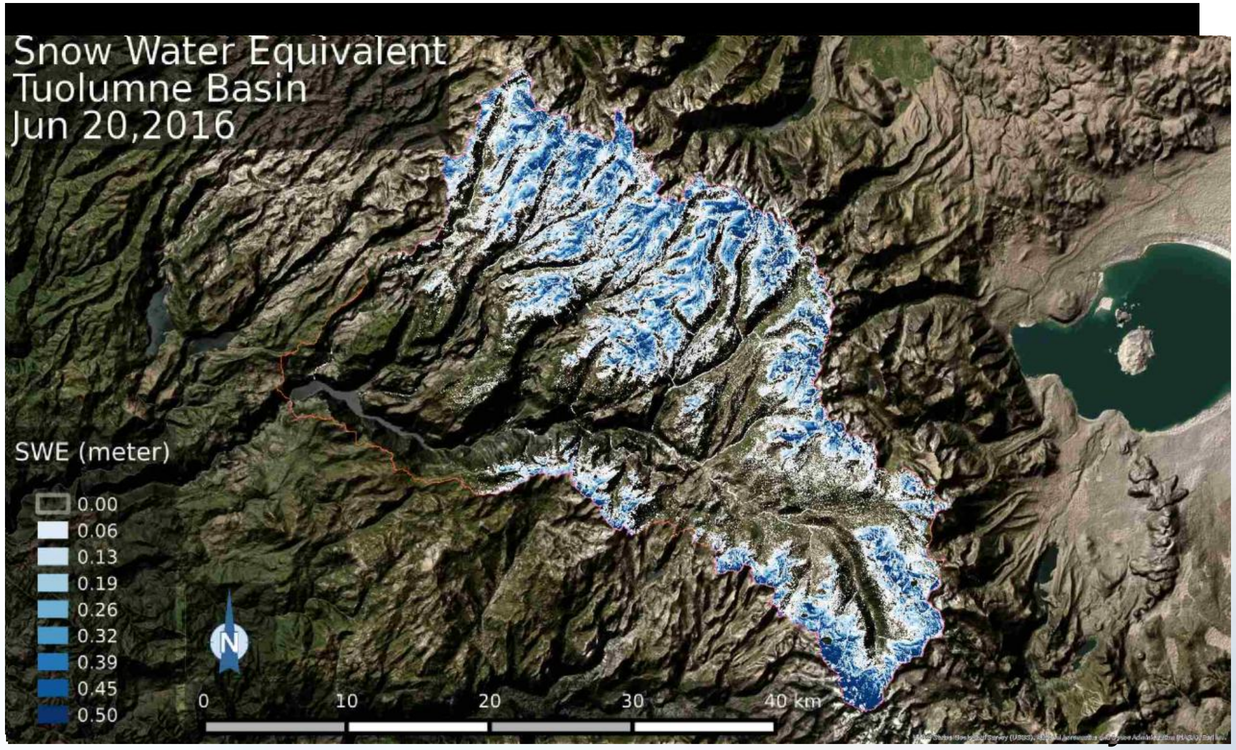
ESSIC Earth System Science Interdisciplinary Center University of Maryland

Contact: Charon Birkett, U. Maryland

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

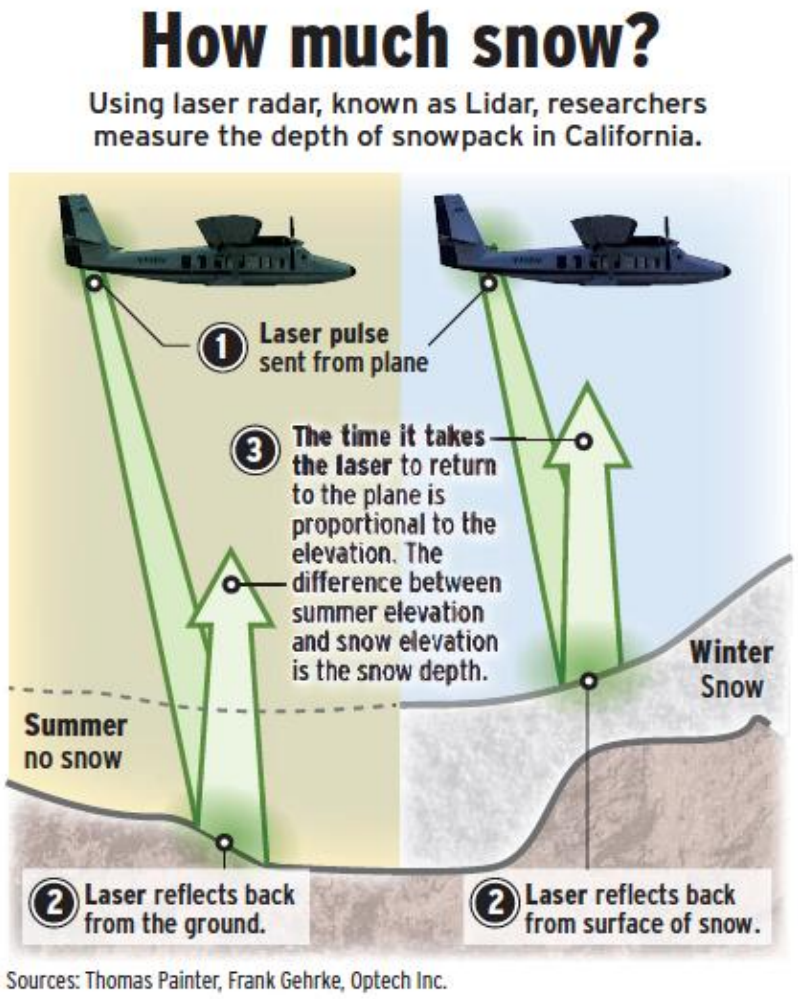
Airborne Snow Observatory: Forecasting Snowmelt Inflow and Timing Airborne Snow Observatory

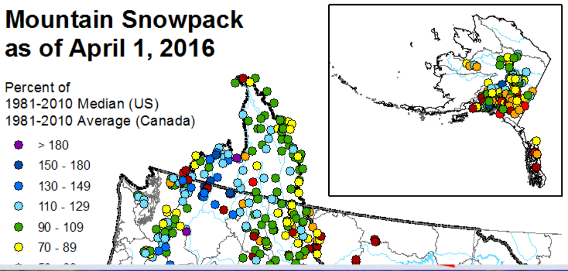


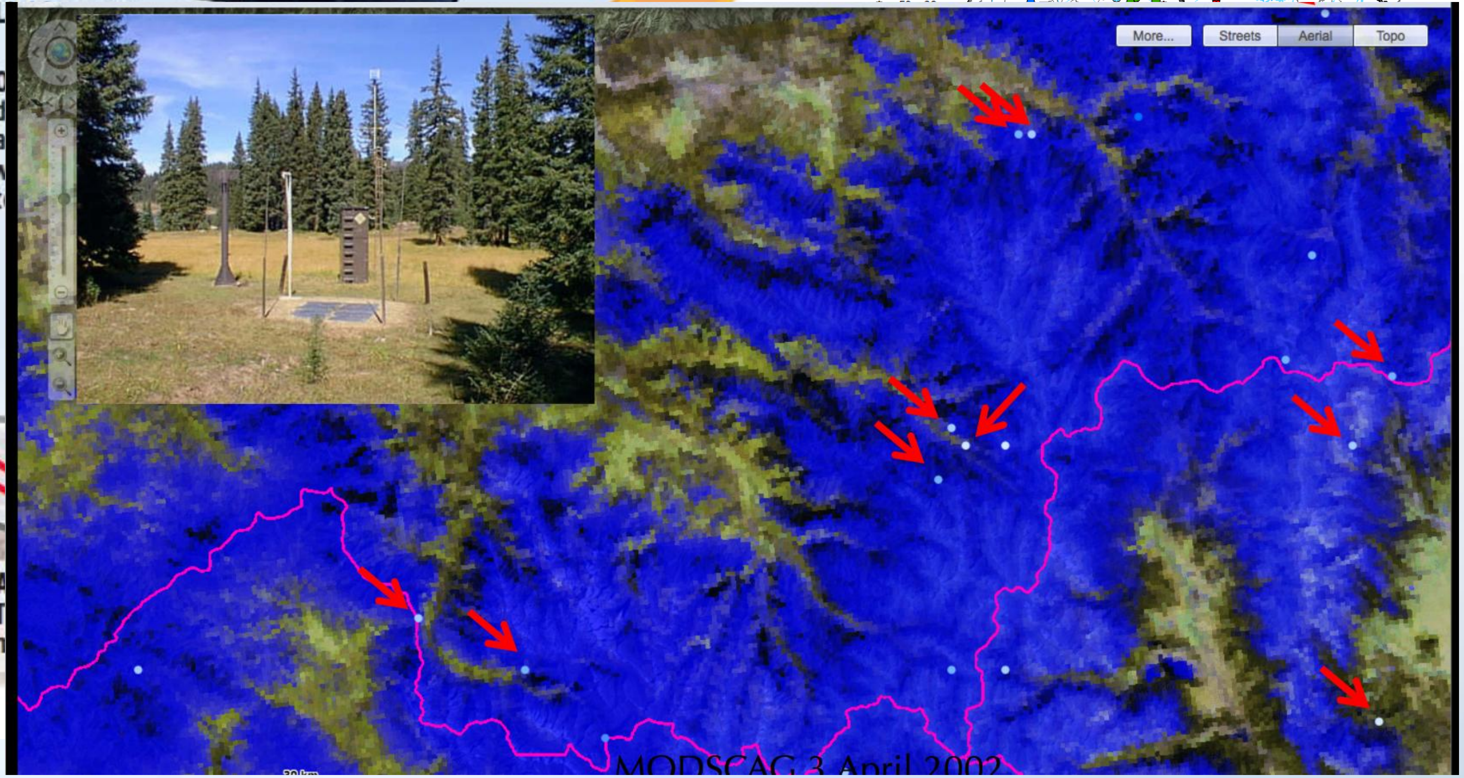


Tom Painter, JPL, http://aso.jpl.nasa.gov/

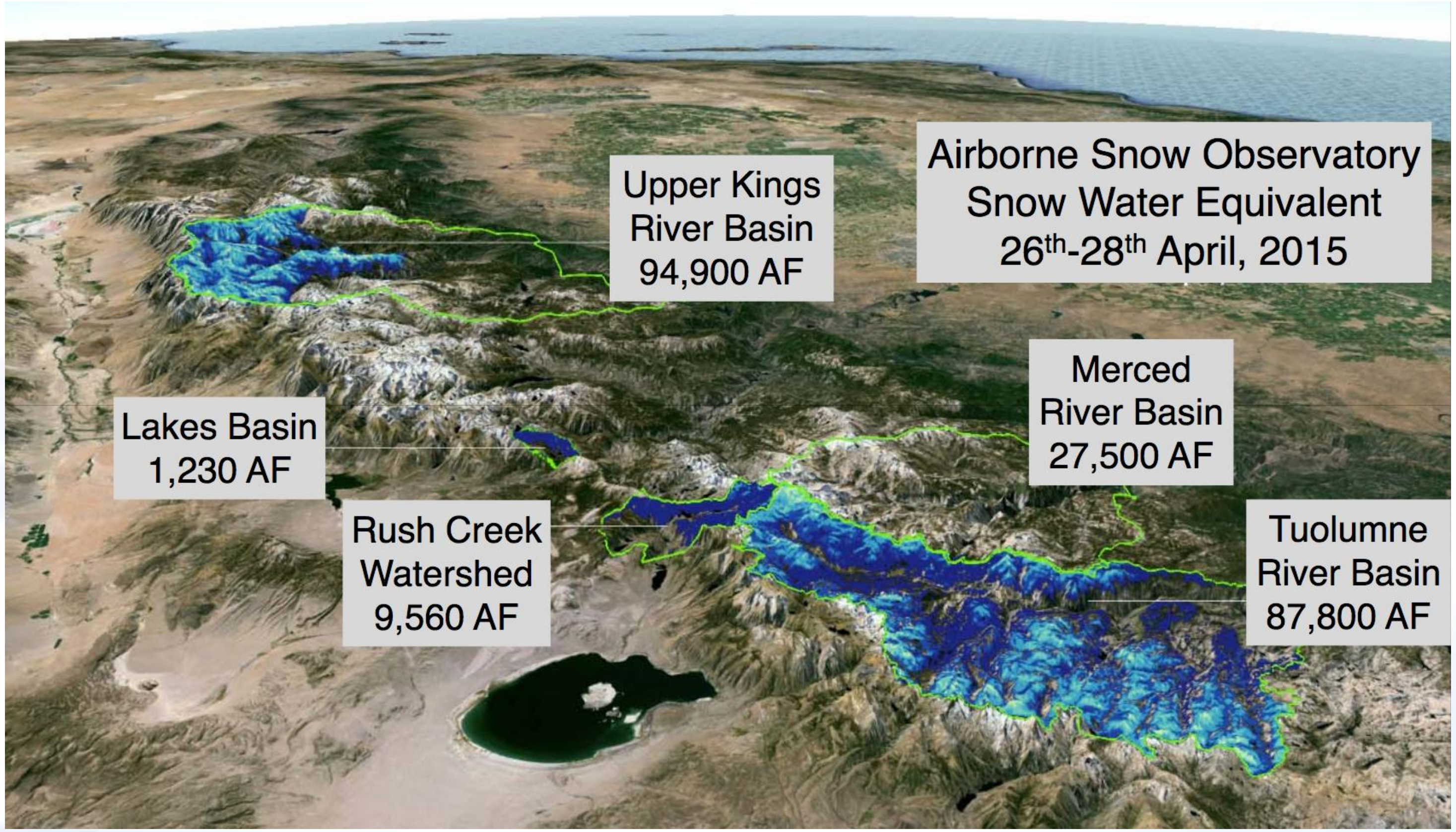
How the Airborne Snow Observatory Works

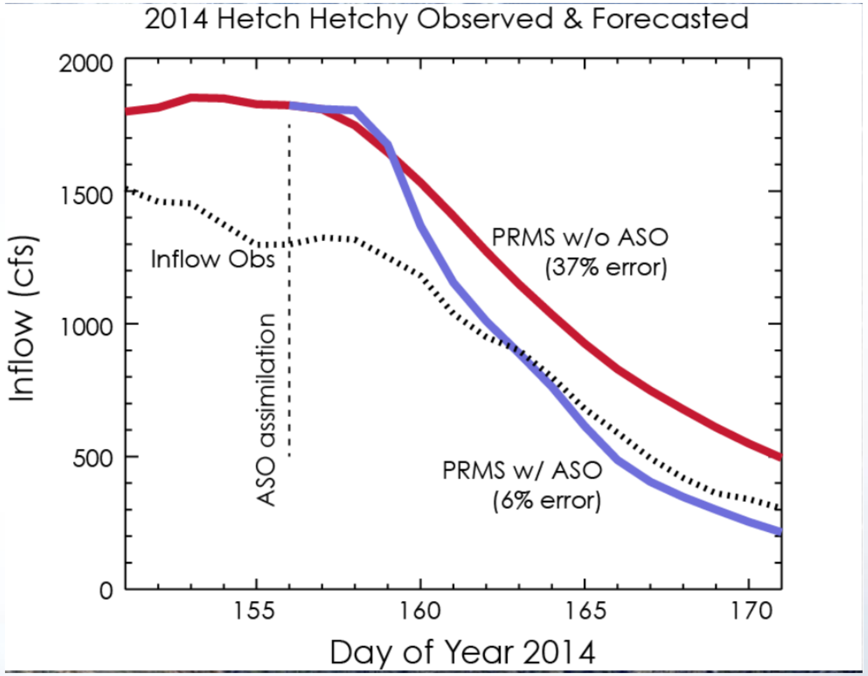




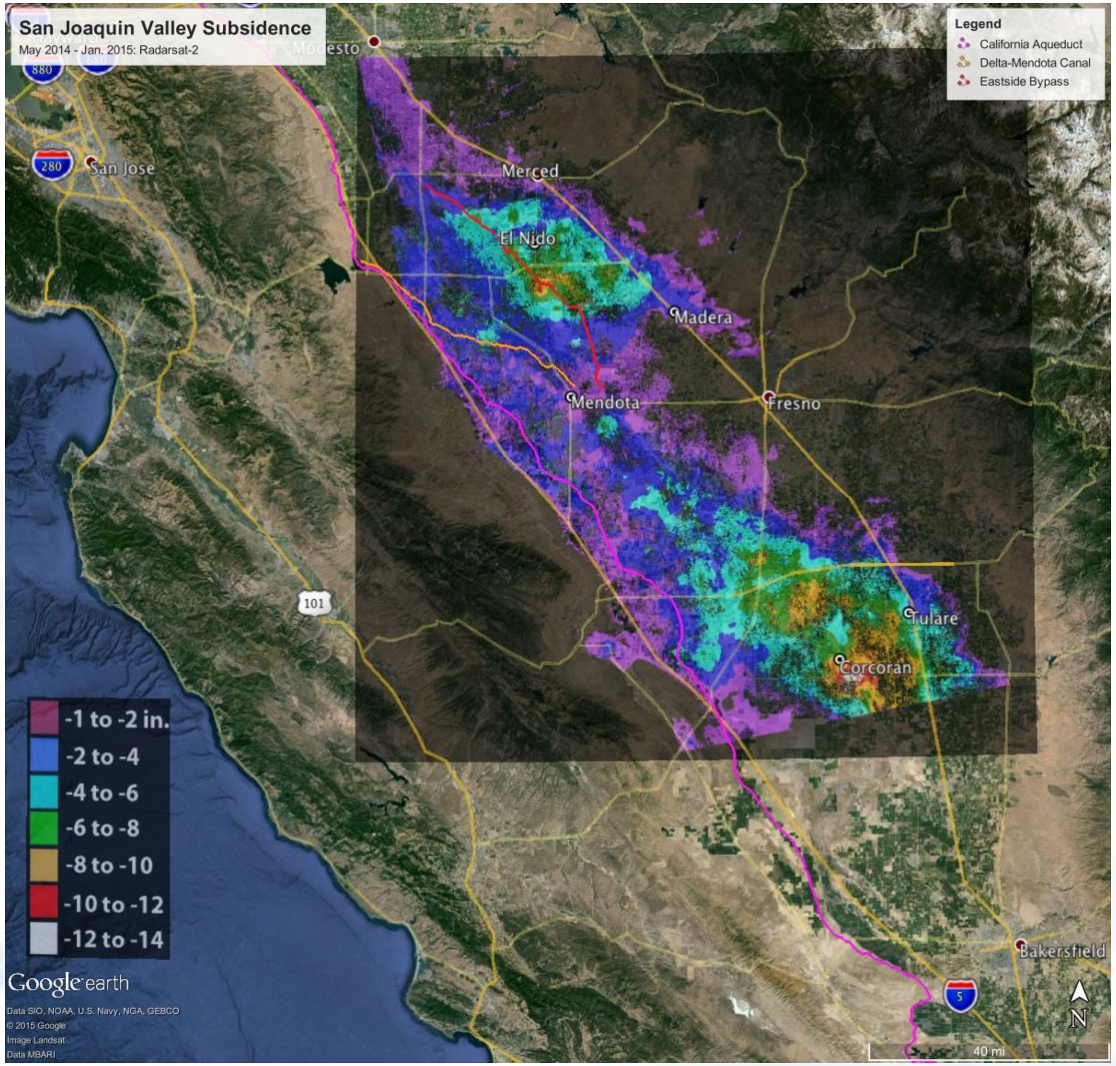


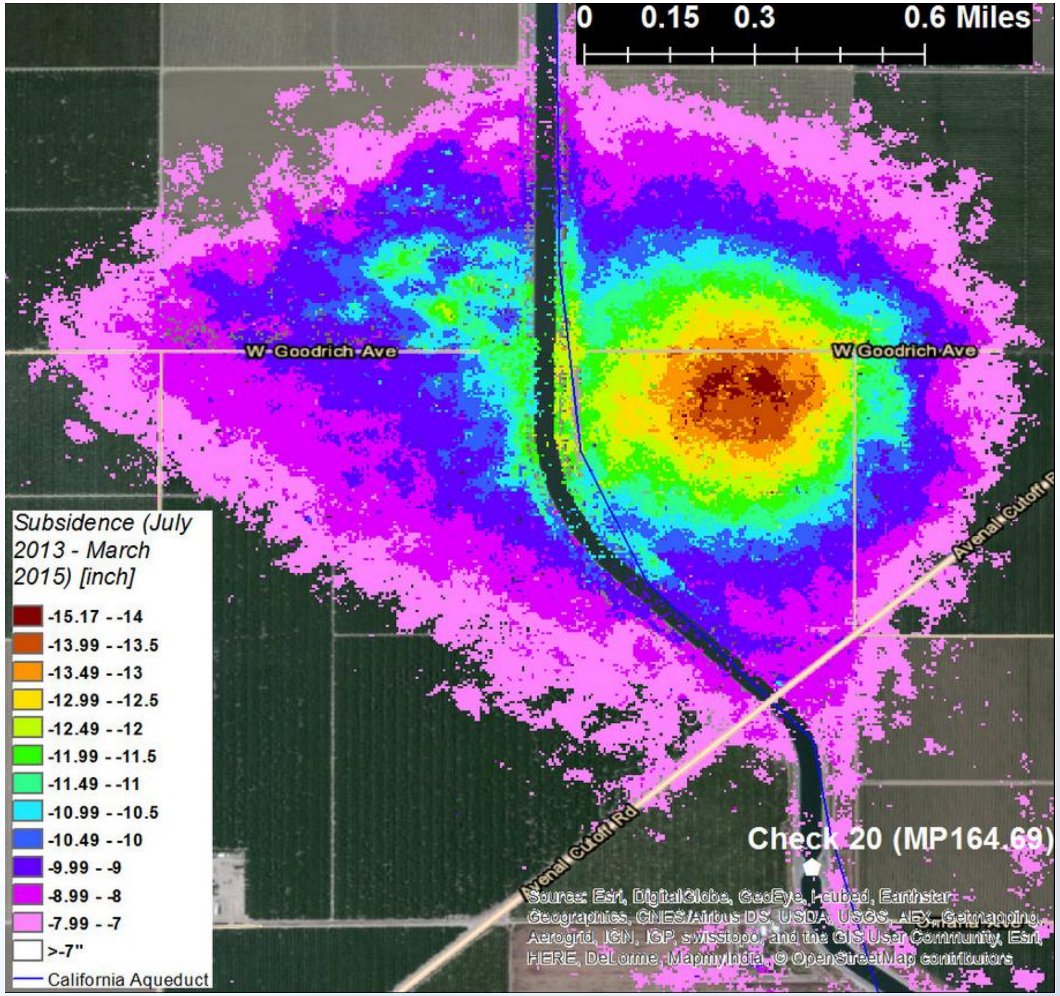
Mapping the Sierra Nevada with ASO





Monitoring Central Valley Land Subsidence



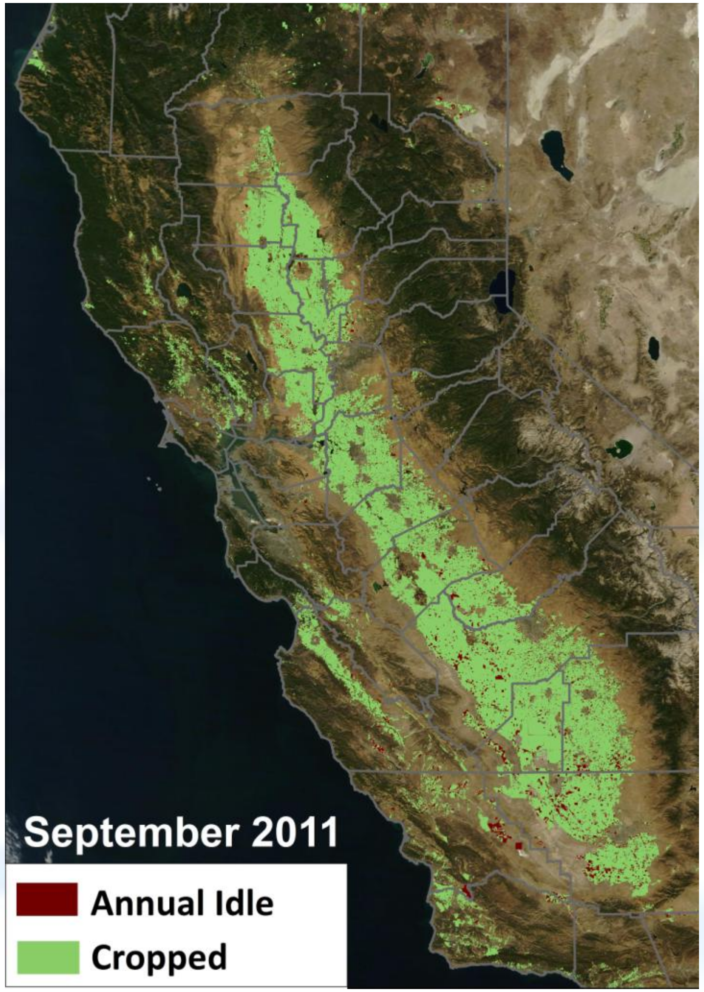


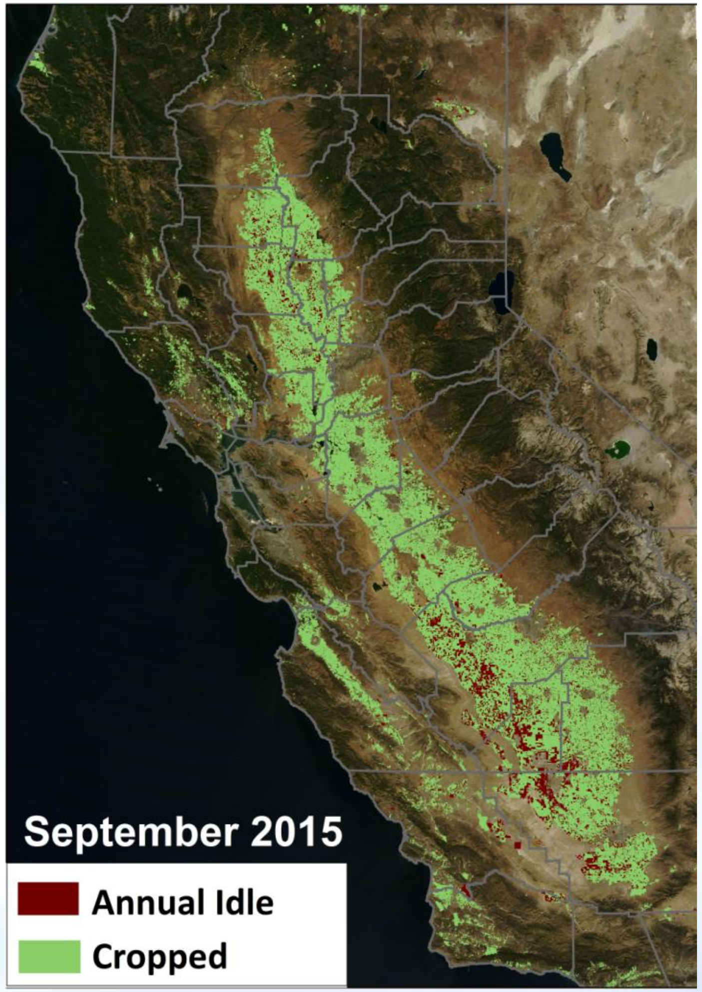
A 1.3 mile stretch of the California Aqueduct experienced >8" of subsidence, with maximum of 13" at the stretch closest to the center of the subsidence feature.

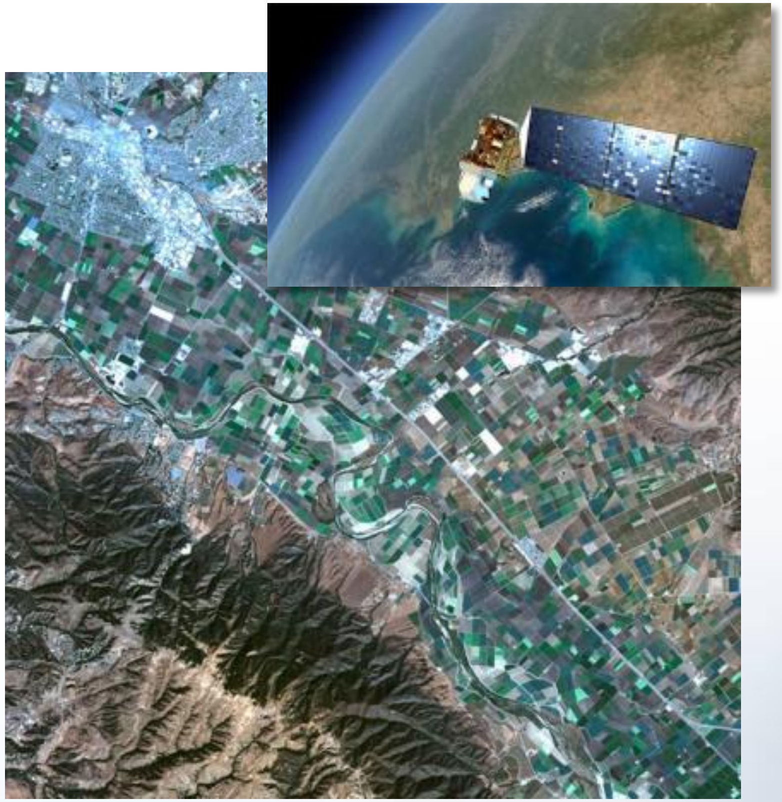
Tom Farr, JPL, https://science.jpl.nasa.gov/people/Farr/

Determining the Extent of Fallowed Agricultural Land with Satellite Imagery during Drought

Project Team: NASA Ames Research Center, USGS, USDA National Ag. Statistics Service, California Dept. of Water Resources, NOAA, California State University Monterey Bay





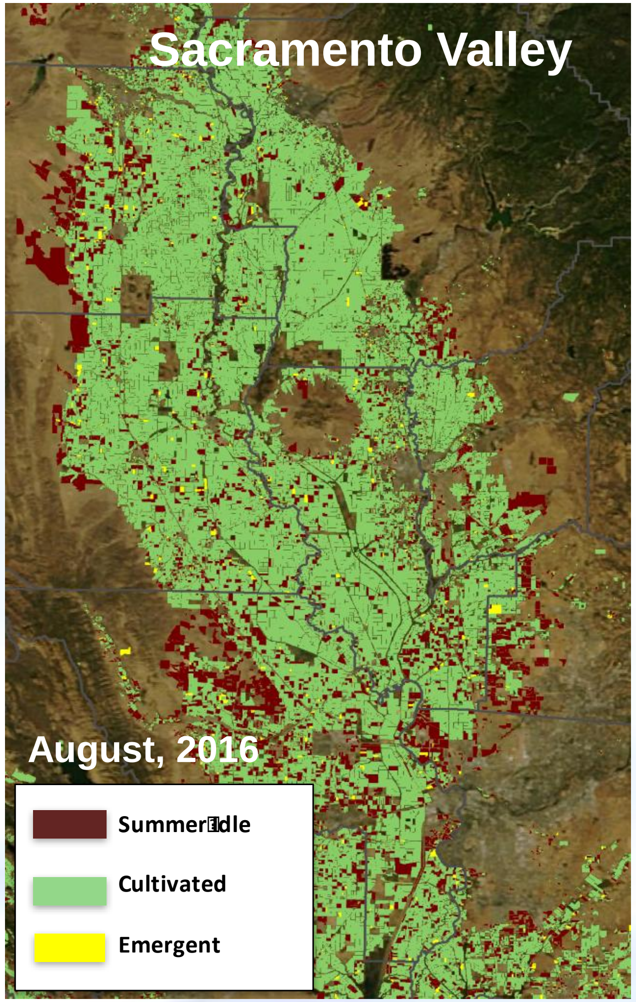


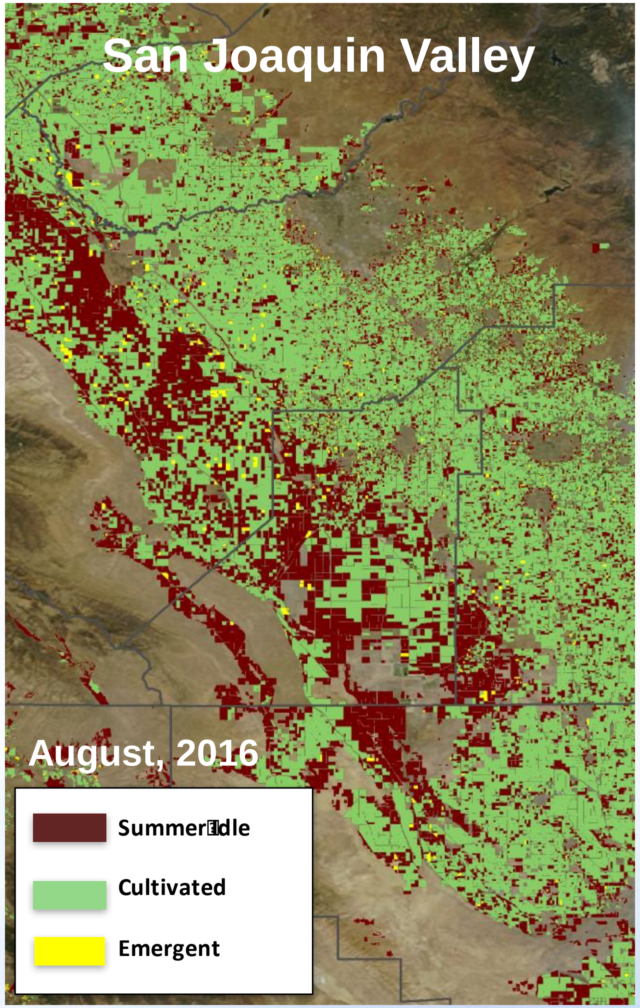
Landsat 5, 7, 8
30m / 0.25 acres
Overpass every 8-16 days

Forrest Melton, NASA ARC-CREST, https://nex.nasa.gov/nex/projects/1372/

Determining the Extent of Fallowed Agricultural Land with Satellite Imagery during Drought

PROJECT TEAM: NASA Ames Research Center, USGS, USDA National Ag. Statistics Service, California Dept. of Water Resources, NOAA, California State University Monterey Bay

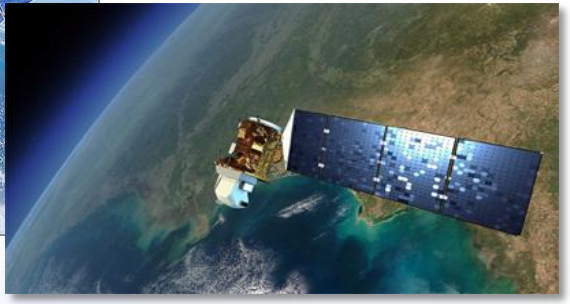




Mapping Crop Water Requirements to Assist Growers in Optimizing Water Use

PROJECT TEAM: NASA Ames Research Center, California Dept. of Water Resources, Western Growers Association, California State University, Univ. of California Cooperative Extension, Desert Research Institute, USDA Ag. Research Service, USGS, Booth Ranches, Chiquita, Constellation Wines, Del Monte Produce, Dole, Driscoll's, E & J. Gallo, Farming D, Fresh Express, Pereira Farms, Ryan Palm Farms

Sentinel-2A



Landsat 8

California's agricultural sector produced $54b In 2014

NASA SIMS web and mobile data services puts irrigation demand across 8 million acres of farm land directly into the hands of farmers and water managers

Students work hand in hand with growers to assess the accuracy of the satellite estimates and quantify benefits

Forrest Melton, NASA ARC, https://c3.nasa.gov/water/projects/1/

NLDAS Data and Drought Monitor

Over 33 years of hourly gridded precipitation, surface meteorology, and land-surface model output, including a real-time drought monitor

NLDAS specifications and variables:

1/8th-degree (~12km) hourly gridded data
from Jan 1979 to near real-time
25-53 North and 125-67 West

Input: Daily gauge precipitation analyses, NARR near-surface meteorology, NEXRAD radar data, bias-correcting GOES shortwave radiation

Output: Surface fluxes, snow cover/depths, soil moistures/temperatures, runoff, many others

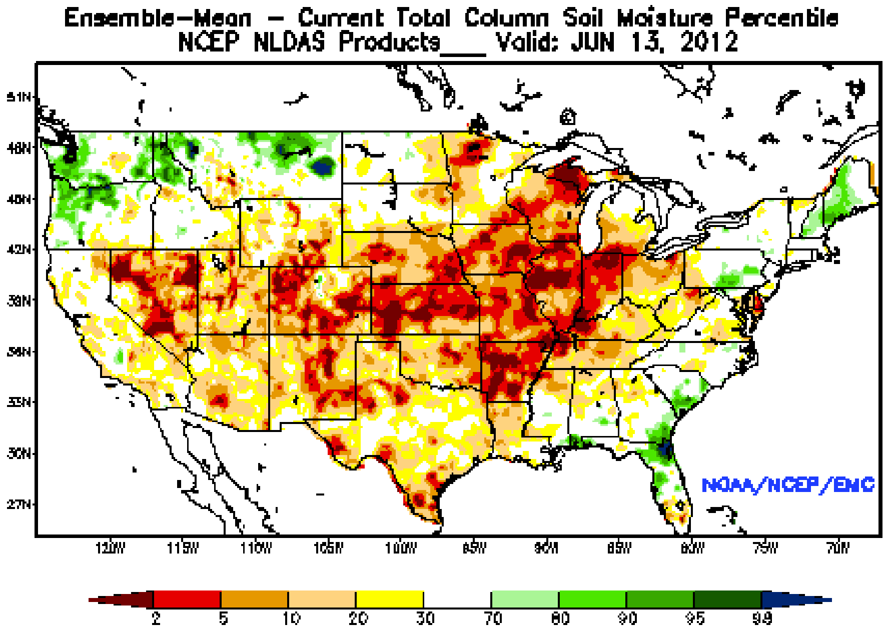
NLDAS datasets and services are available from the NASA GES DISC:

gsfc.nasa.gov/hydrology/

Documentation on NLDAS, including a link to the NLDAS Drought Monitor:

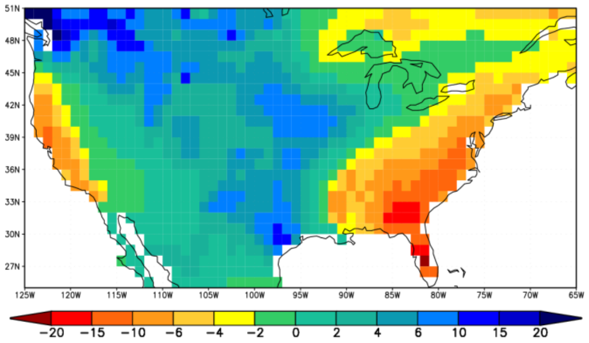
gov/nldas/

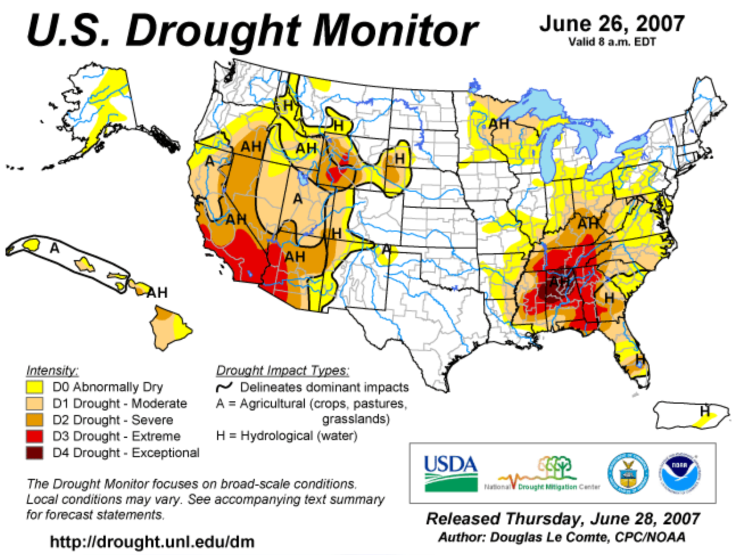
An example of the NLDAS Drought Monitor (below) showing soil moisture percentiles of the 4 land-surface model ensemble-mean (Mosaic, Noah, VIC, & SAC) against the long-term soil moisture climatology of NLDAS. Figure from 13 June 2012.



GRACE Data Assimilation for US Drought Monitor

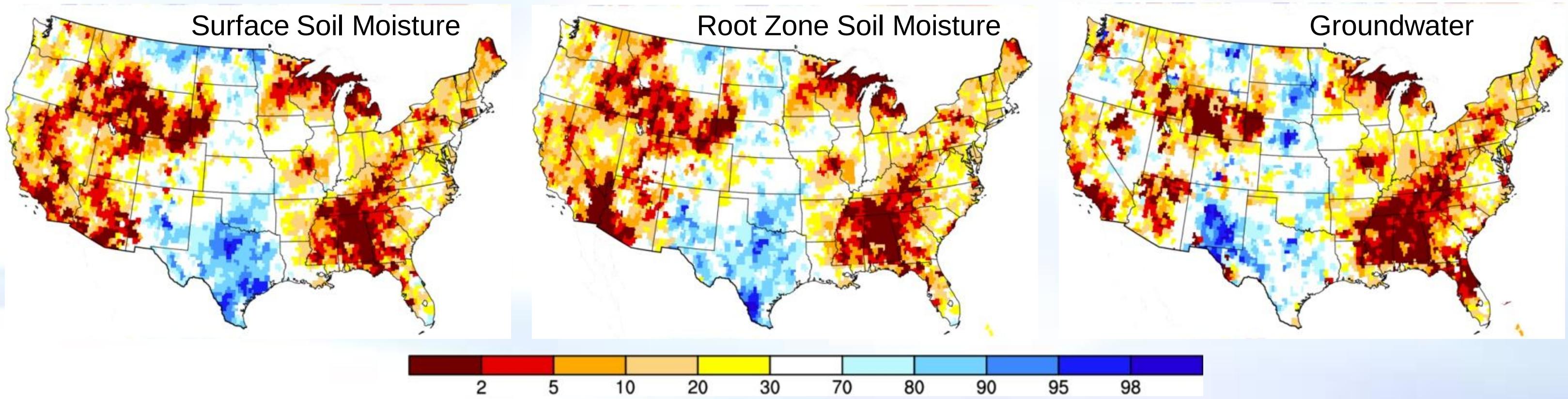
GRACE terrestrial water storage anomalies (cm equivalent height of water) for June 2007 (Tellus CSR RL05 scaled).





U.S. Drought Monitor product for 26 June 2007.

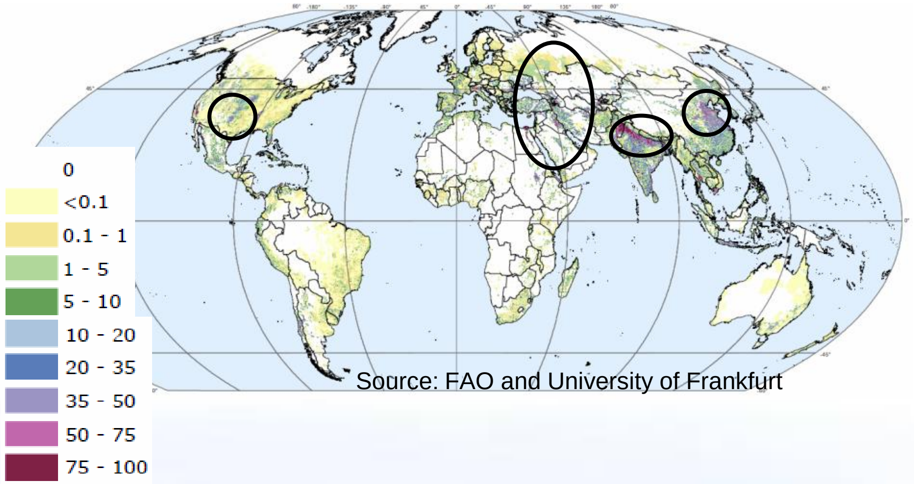
New process integrates data from GRACE and other satellites to produce timely information on wetness conditions at all levels in the soil column, including groundwater. For current maps and more info, see http://www.drought.unl.edu/MonitoringTools.aspx



Drought indicators from GRACE data assimilation (wetness percentiles relative to the period 1948-present) for 25 June 2007.

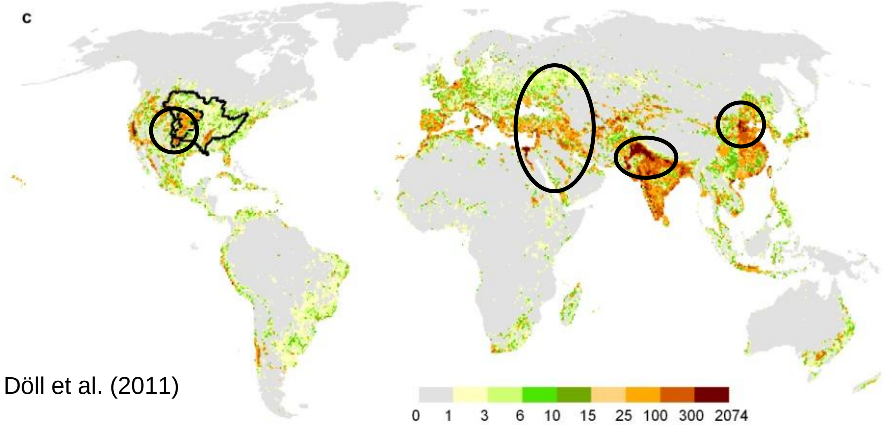
How Can We Characterize the Exploitation of Global Water Resources?

Percentage of Irrigated Area



Source: FAO and University of Frankfurt

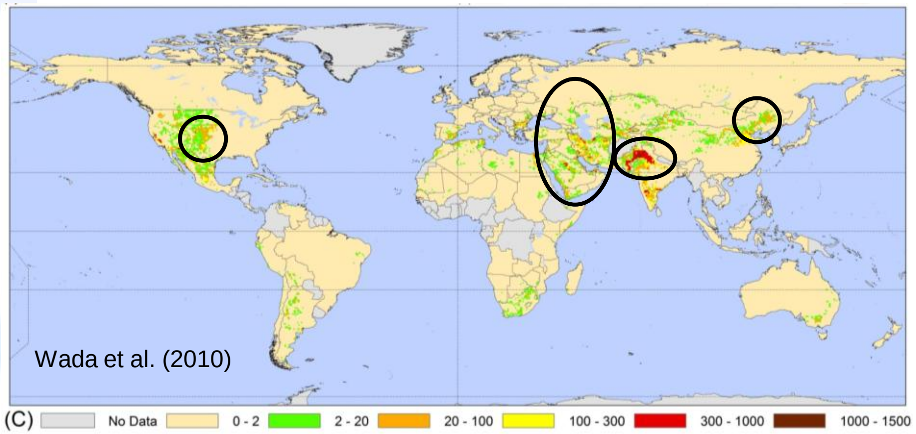
Net Consumptive Use of Ground and Surface Waters, 1998-2002



Döll et al. (2011)

Equivalent height of water (mm/yr)

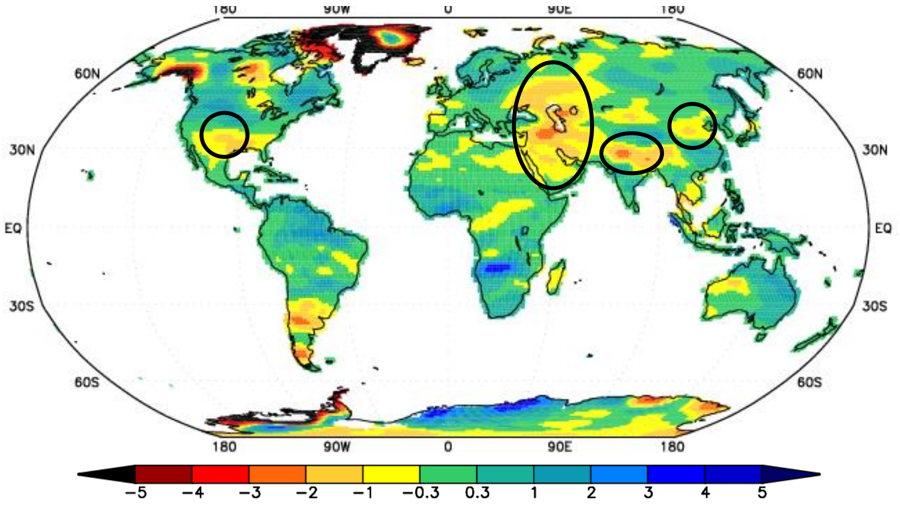
Groundwater Depletion Rate (ca. 2000)



Wada et al. (2010)

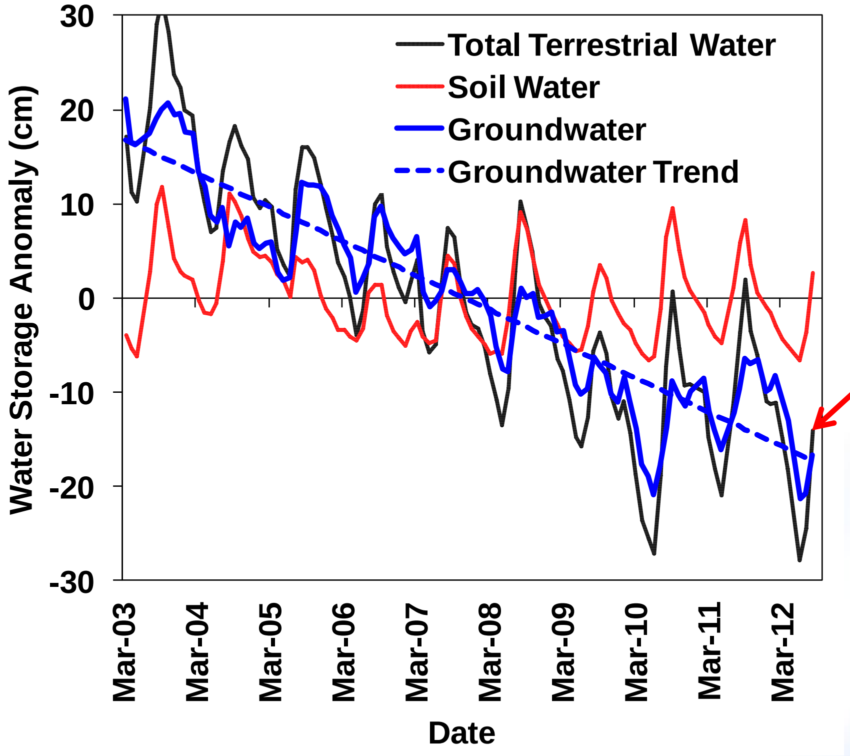
Equivalent height of water (mm/yr)

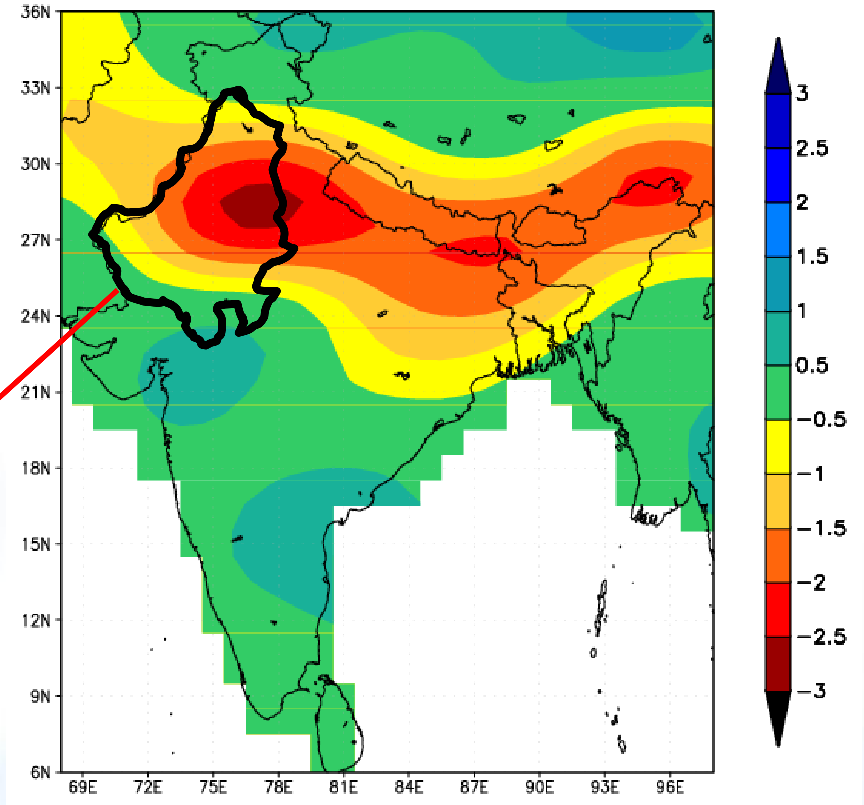
Terrestrial Water Storage "Trends" from GRACE



Equivalent height of water (cm/yr)

Groundwater Depletion in Northern India



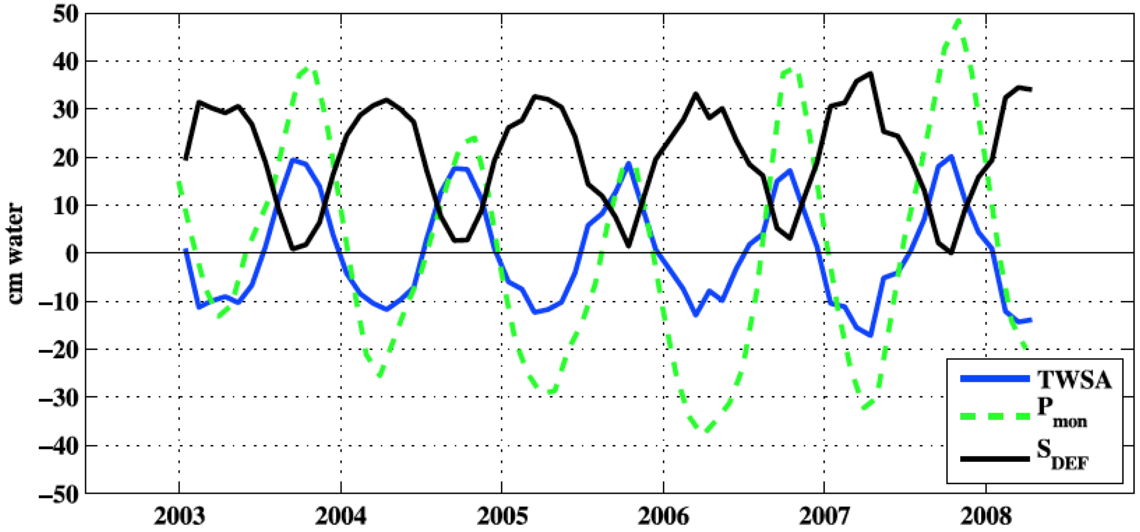


Rate of change of terrestrial water storage (cm/yr) from 2003-2012 based on NASA/GRACE satellite observations.

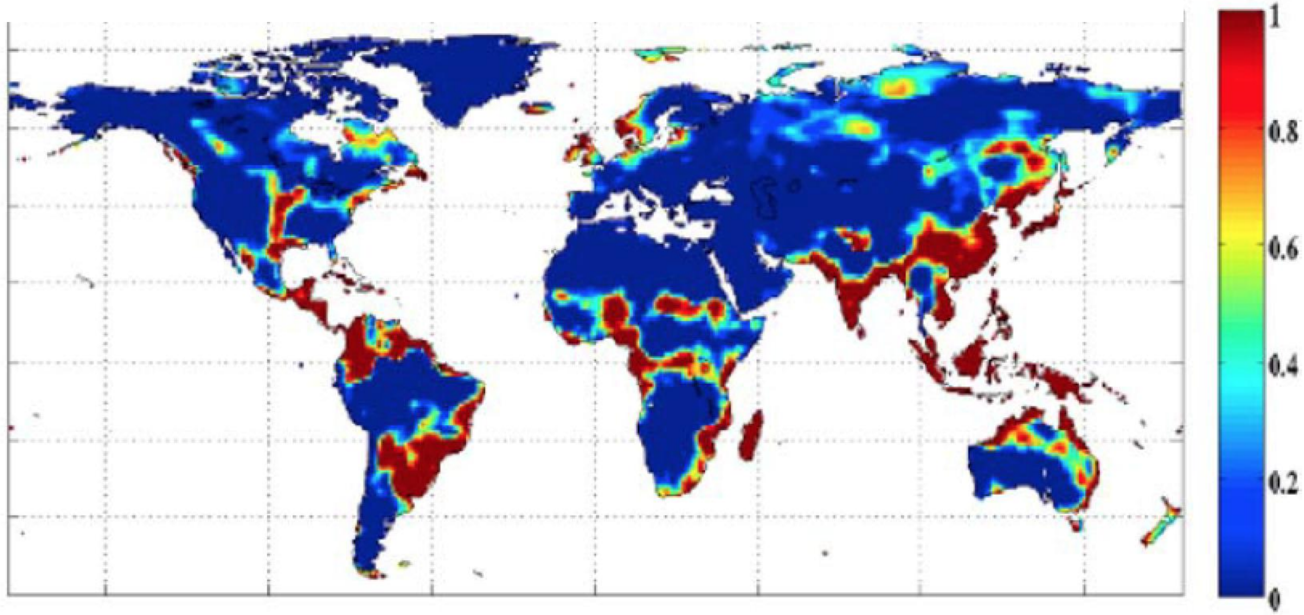
GW = TWS – SM – SWE

Groundwater continues to be depleted in the Indian states of Rajasthan, Punjab, and Haryana by about 16.0 km^3/yr, reduced slightly from our previous (2002-08) estimate of 17.7 ±4.5 km^3/yr (Rodell et al., *Nature*, 2009).

GRACE-Based Flood Potential



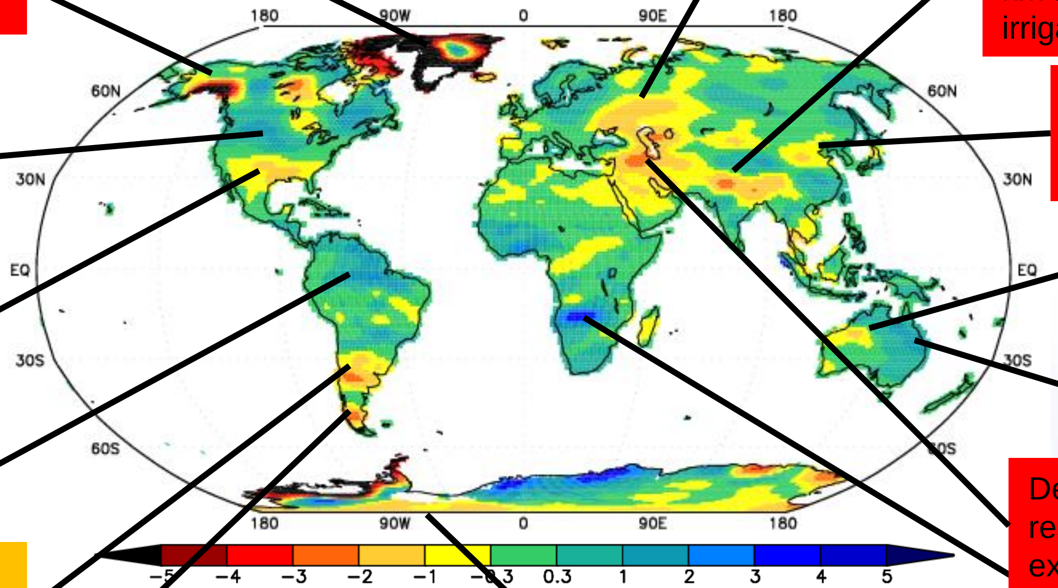
TWSA – Terrestrial Water Storage Anomaly
Pmon – Integrated Precipitation Anomaly
Sdef – Storage Deficit



REAGER AND FAMIGLIETTI, GRL 2009

Emerging Trends In Global Freshwater Storage

Trends in terrestrial water storage (cm/yr), including groundwater, soil water, lakes, snow, and ice, as observed by GRACE during 2003-13



Greenland's ice sheet has been thinning at a rate of 142 km^3/yr

Russian droughts in 2010 and 2012

Groundwater is being depleted across northern India at rate of about 54 km^3/yr due to pumping for irrigation

Alaska's glaciers have been melting at 84 km^3/yr

Drought gave way to flooding in the Missouri River basin in 2011

Overexploitation of freshwater resources in the North China Plain

Recent droughts in the southeastern U.S. and Texas

Return to normal after wet years in early 2000s

Drought recovery and flooding

Recovery from 2004-05 drought in the Amazon

Depletion of water resources in Middle East exacerbated by drought

2010 Chile earthquake and drought in southern Argentina

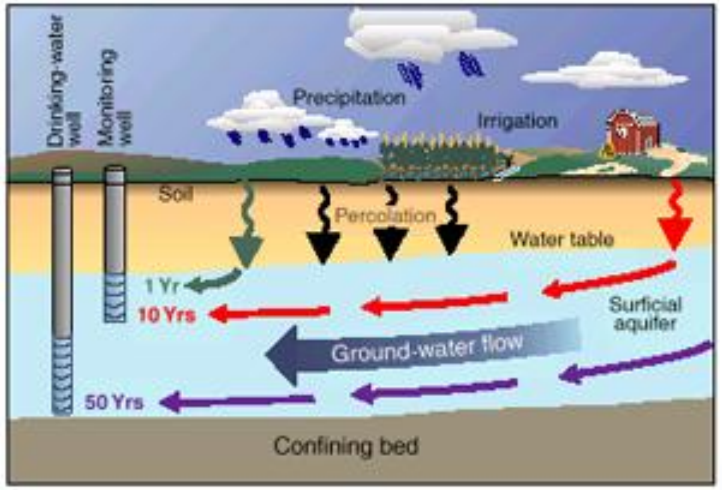
Patagonian glacier melt

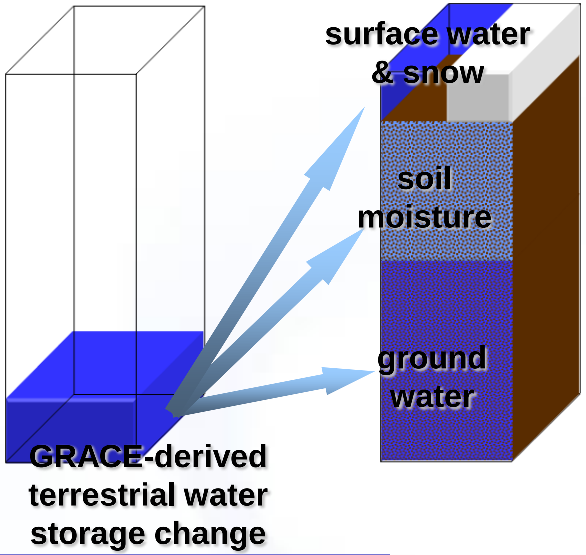
The western Antarctic ice sheet has been thinning at a rate of 65 km^3/yr

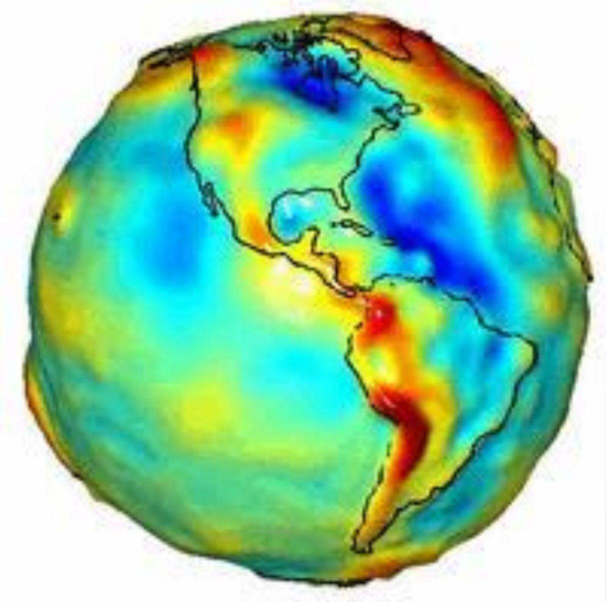
Return to normal in the Okavango Delta after drought ended in 2007

GRACE observes changes in water storage caused by natural variability, climate change, and human activities such as groundwater pumping

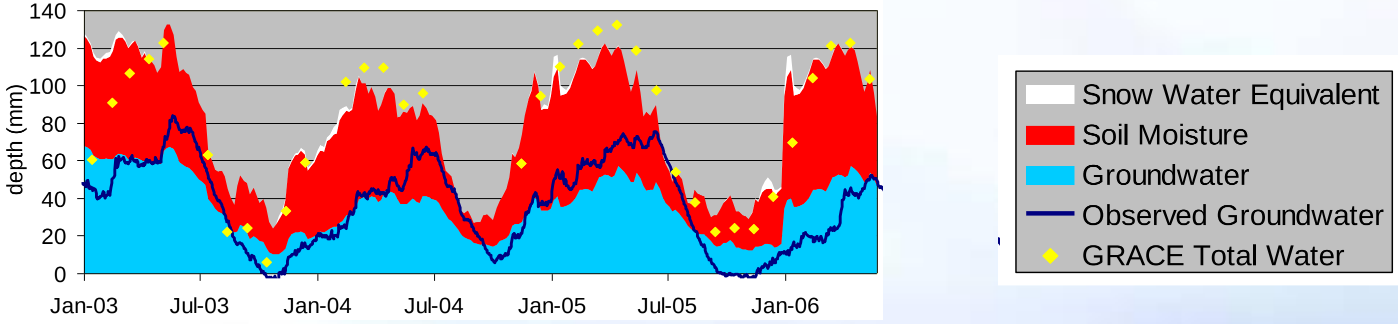
Applying GRACE to Constrain Regional Groundwater







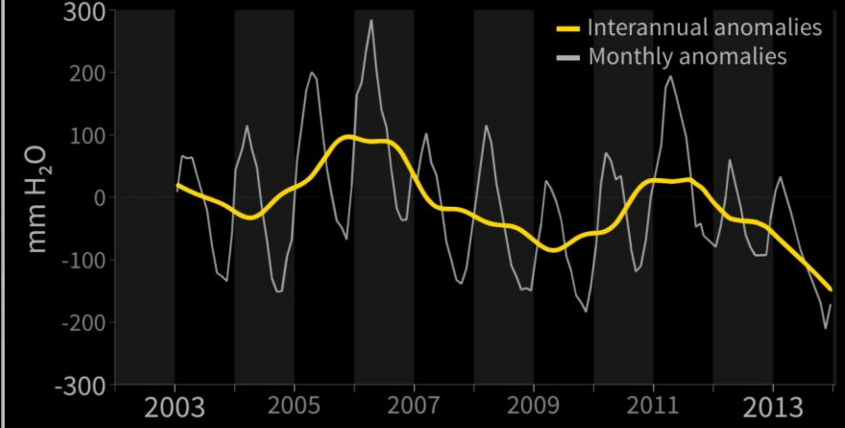
The Gravity Recovery and Climate Experiment (GRACE) satellite can monitor changes in terrestrial water storage and help 'close the water budget'

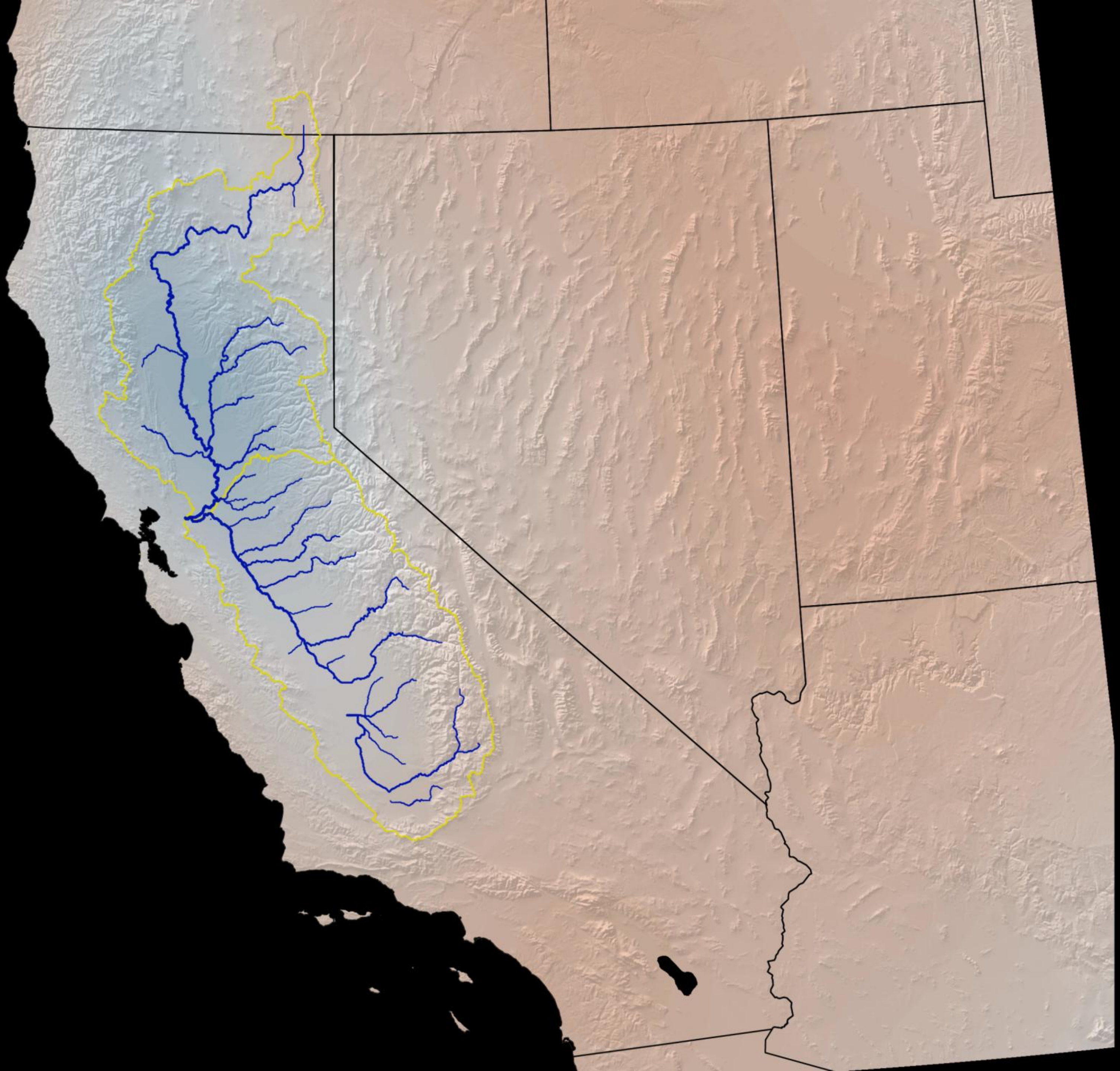


Zaitchik, Rodell, and Reichle, J. Hydromet., 2008

GRACE observations of Terrestrial Water Storage changes in California

2002 05 09





NASA Applied Sciences Program

NASA Applied Sciences Program Water Resources Current Projects

PI	Title	PI Org.	Associate PM	Solicitation
AGHAKOUCHAK	Advancing Drought Onset Detection and Seasonal Prediction Using a Composite of NASA Model and Satellite Data	UCI	Melton	ROSES 2013 – WR Anomaly Outlook
BOLTEN	Enhancing the USDA Global Crop Production Decision Support System with NASA Soil Moisture Active Passive (SMAP) Satellite Observations	NASA/GSFC	Lee	ROSES 2013 – WR Anomaly Outlook
DAY	Advancing Water Supply Forecasts in the Colorado River Basin for Improved Decision Making	Riverside Tech. Inc.	Melton	ROSES 2013 – WR Anomaly Outlook
GEBREMICHAEL	Optimizing Reservoir Operations for Hydropower Production in Africa through the use of Remote Sensing Data and Seasonal Climate Forecasts	UCLA	Lee	ROSES 2013 – WR Anomaly Outlook
HOSSAIN	Towards Operational Water Resources Management in South Asia Exploiting Satellite Geodetic and Remote Sensing Technologies	UW	Lee	ROSES 2013 – WR Anomaly Outlook
JACOBS	Satellite Enhanced Snowmelt Flood Predictions in the Red River of the North Basin	UNH	Bolten	ROSES 2013 – WR Anomaly Outlook
PETERS-LIDARD	Predicting Middle Eastern and African Seasonal Water Deficits using NASA Data and Models	NASA/GSFC	Bolten/Lee	ROSES 2013 – WR Anomaly Outlook
RODELL	Integrating GRACE and GRACE Follow On Data into Flood and Drought Forecasts for the Continental U.S.	NASA/GSFC	Bolten	ROSES 2013 – WR Anomaly Outlook
STANFORD	Decision Support System (DSS) to Enhance Source Water Quality Modeling and Monitoring using Remote Sensing Data	Hazen – Sawyer, P.C.	Lee	ROSES 2013 – WR Anomaly Outlook
BIRKETT	The Global Reservoir and Lake Monitor (GRLM): Expansion and Enhancement of Water Height Products.	UMD	Bolten	ROSES 2013 – Drought
DOZIER	Assessing Water Resources in Remote, Sparsely Gauged, Snow-Dominated Mountain Basins	UCSB	Melton	ROSES 2013 – Drought
HAIN	Development of a Mult-Scale Remote Sensing Based Framework for Mapping Drought over North America	NOAA	Melton	ROSES 2013 – Drought
BECKER-RESHEF	Global monitoring of agricultural drought: A contribution to GEO GLAM	UMD	Bolten	ROSES 2013 – Drought
MELTON	Mitigation of Drought Impacts on Agriculture through Satellite Irrigation Monitoring and Management Support	NASA/ARC	Bolten	ROSES 2013 – Drought
PAINTER	Integration of precision NASA snow products with the operations of the Colorado Basin River Forecast Center to improve decision making under drought conditions	NASA/JPL	Melton	ROSES 2013 – Drought
ROSENZWEIG	Adaptation Planning for Climate Change Impacts using Advanced Decision Support and Remote Sensing: Irrigated Agriculture in California's Central Valley	NASA/GSFC	Melton	ROSES 2013 – Drought
VERDIN	Fallowed Area Mapping for Drought Impact Reporting and Decision Making	USGS	Melton	ROSES 2013 – Drought
WARDLOW	The Quick Drought Response Index (QuickDRI): An Integrated Approach for Rapid Response Agricultural Drought Monitoring	UNL	Melton	ROSES 2013 – Drought

NASA Applied Sciences Program Water Resources Contact

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NASA Applied Sciences Program Water Resources

Earth Science Serving Society

The goal of the ASP Water Resources application area is to apply NASA satellite data to improve the decision support systems of organizations and user groups that manage water resources. The ASP Water Resources application area partners with Federal agencies, academia, private firms, and international organizations.

LEARN MORE

https://c3.nasa.gov/water/

SERVIR

SERVIR is a joint development initiative of NASA and USAID, working in partnership with leading regional organizations around the globe, to help developing countries use information provided by Earth observing satellites and geospatial technologies for managing climate risks and land use.

Mapping of harmful microalgae in El Salvador

Frost mapping in Kenya

Flood Forecasting In Bangladesh

Questions?

John Bolten
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john.bolten@nasa.gov

Bradley Doorn, Forrest Melton, Christine Lee
NASA Applied Sciences Program
Matt Rodell
NASA GSFC