NASA Research to Improve Monitoring and Forecasting of Water Resources

John Bolten
Associate Program Manager
NASA Applied Sciences Program
Water Resources

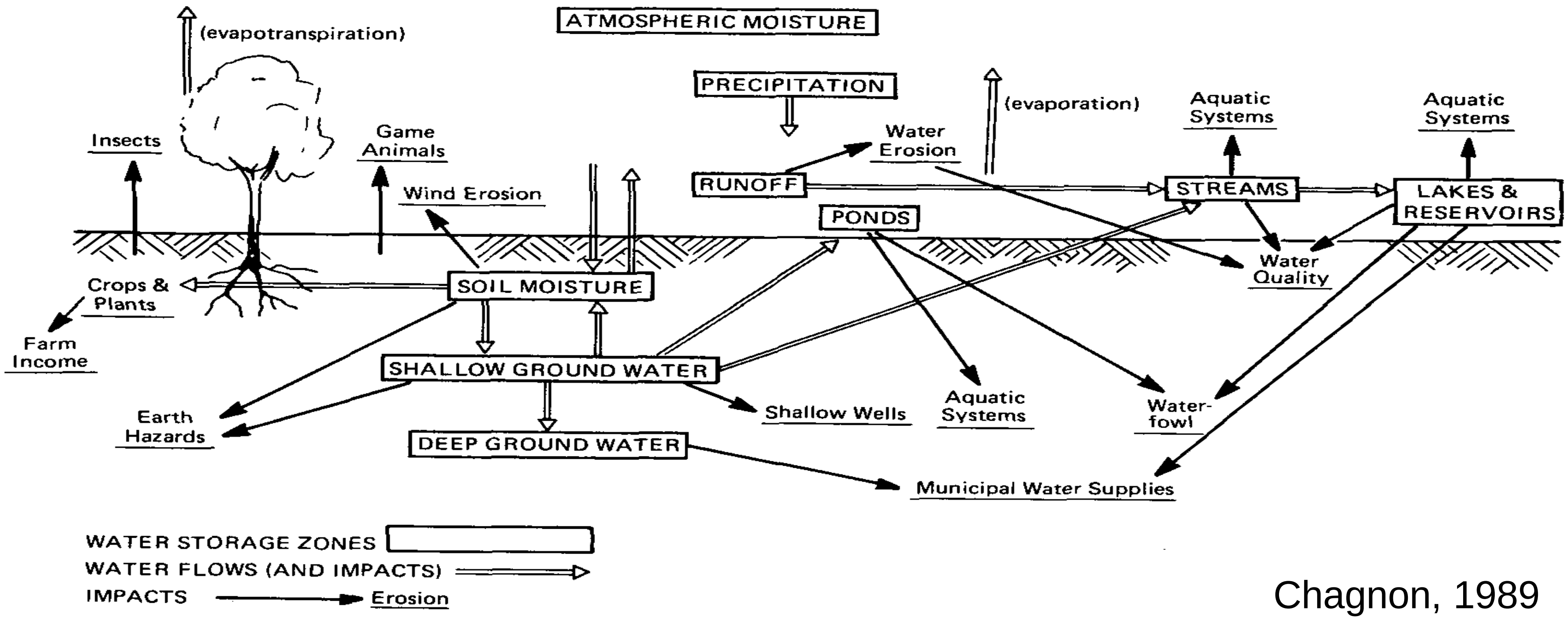
john.bolten@nasa.gov

World Water Week
August 29th, 2017
Stockholm, Sweden

The Great American Eclipse – August 21, 2017

Source: National Geographic

The Water Landscape



Chagnon, 1989

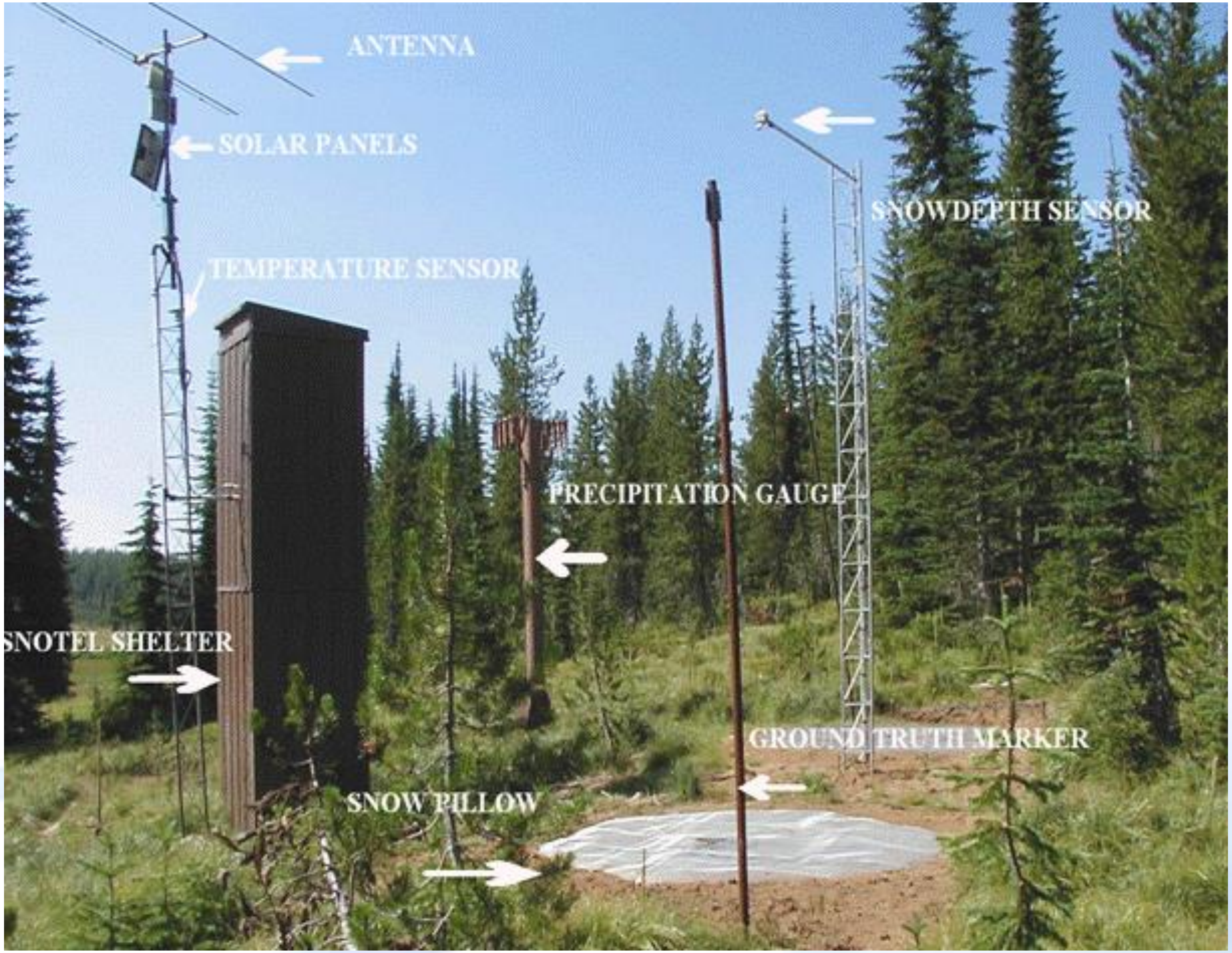
•How can we reduce our uncertainty in the propagation of hydroclimatic extremes?

•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?

Rain and Snowfall



Snow Depth and Snow Water Equivalent

Evapotranspiration

Soil Moisture

Surface Water and River Flow

Groundwater

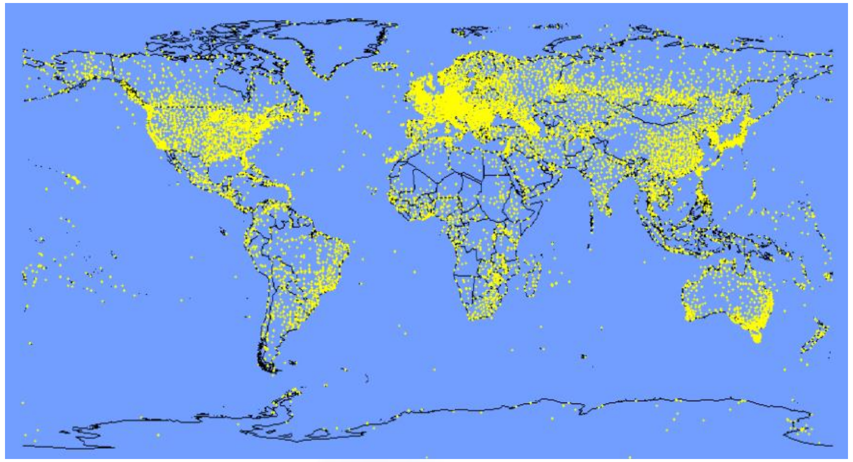
Water Quality

Image: IEEE GlobalSpec

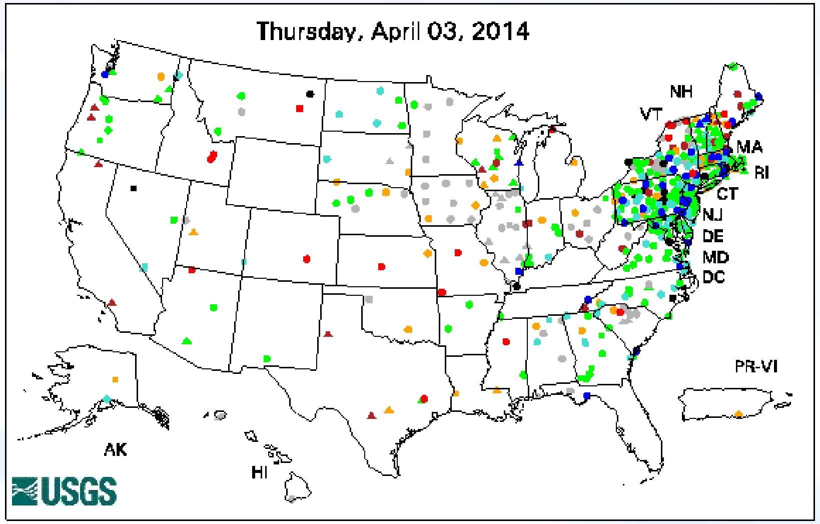
Inadequacy of Surface Observations

Issues:

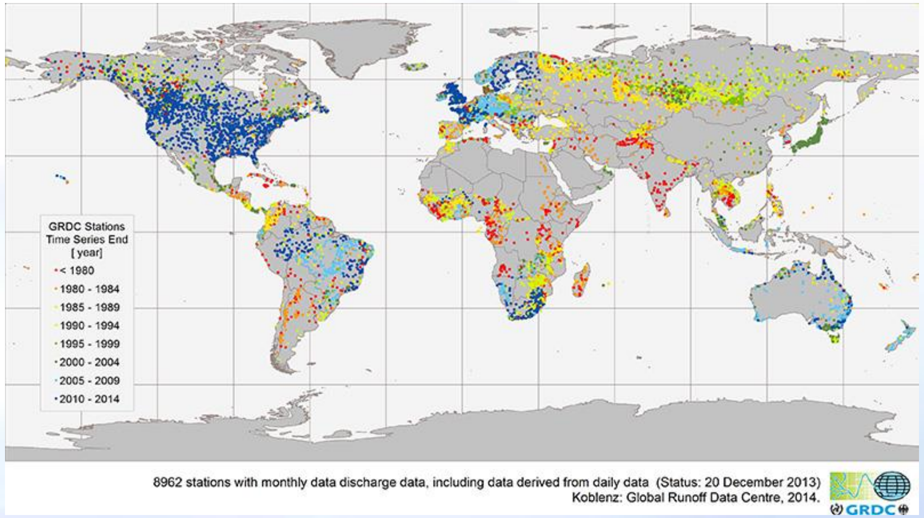
- Spatial coverage of existing stations
- Temporal gaps and delays
- Many governments unwilling to share
- Measurement inconsistencies
- Quality control
- Unrepresentativeness of point obsservations



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

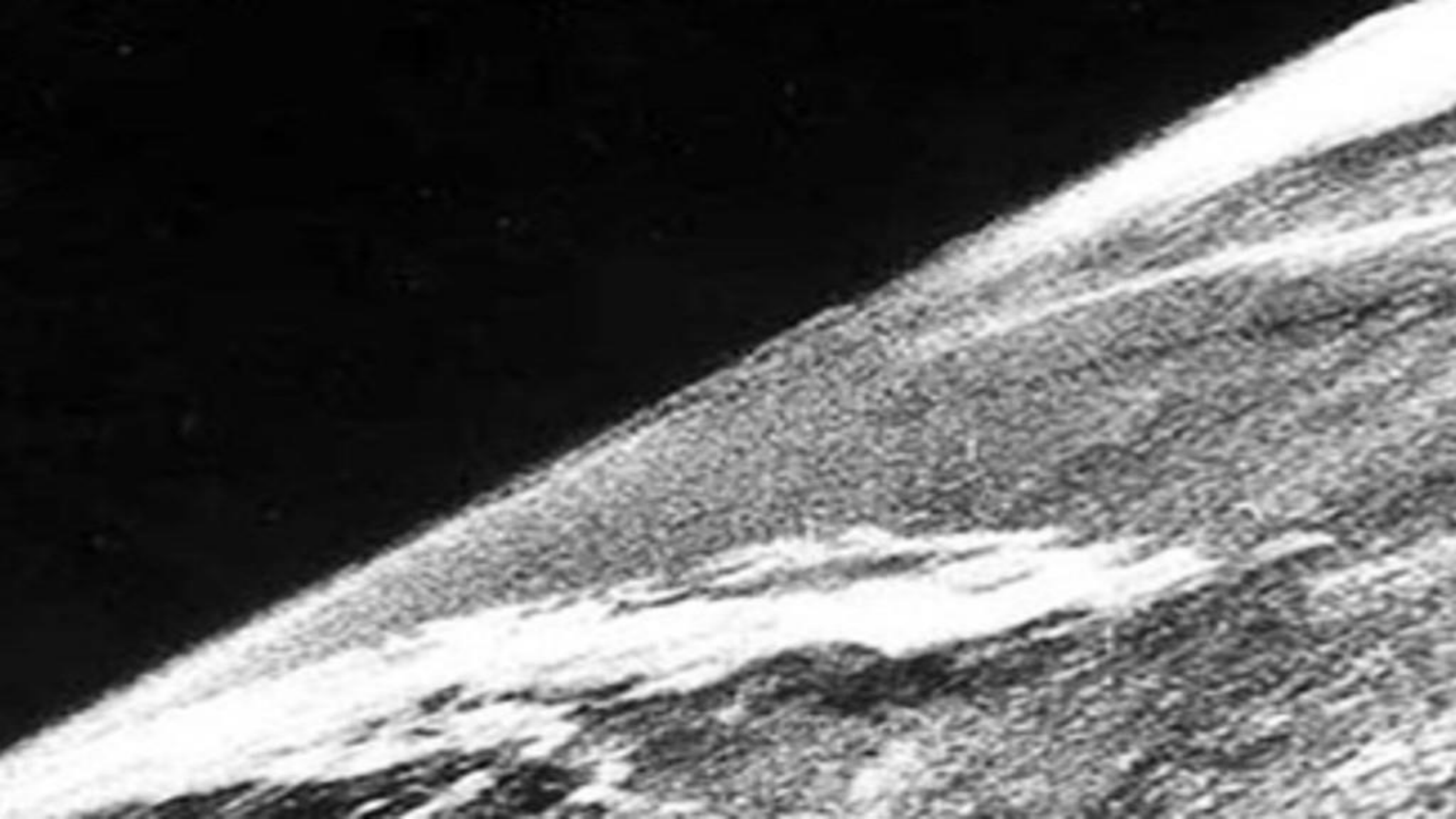


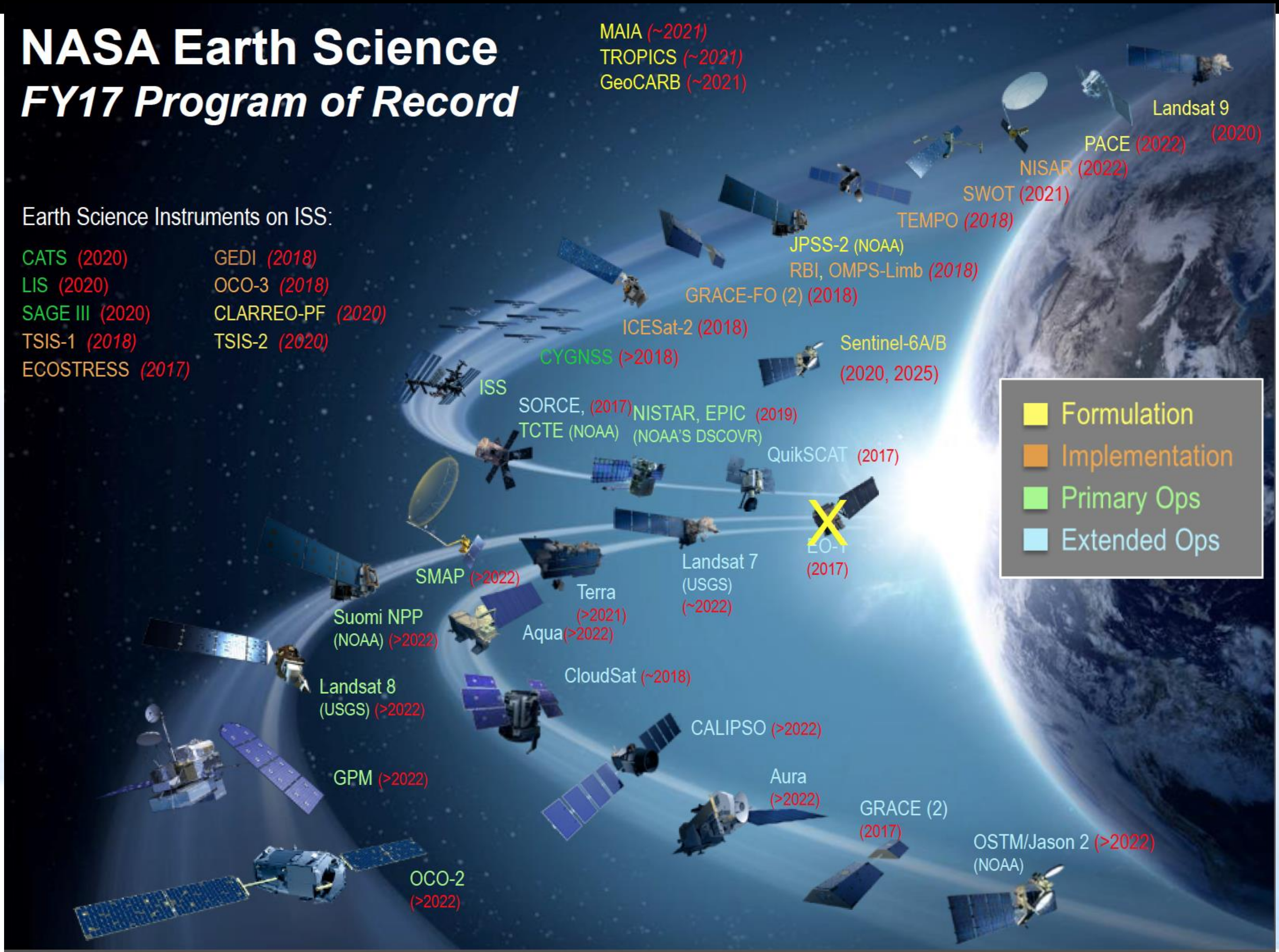
USGS Groundwater Climate Response Network..



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

Remote Sensing and Modeling

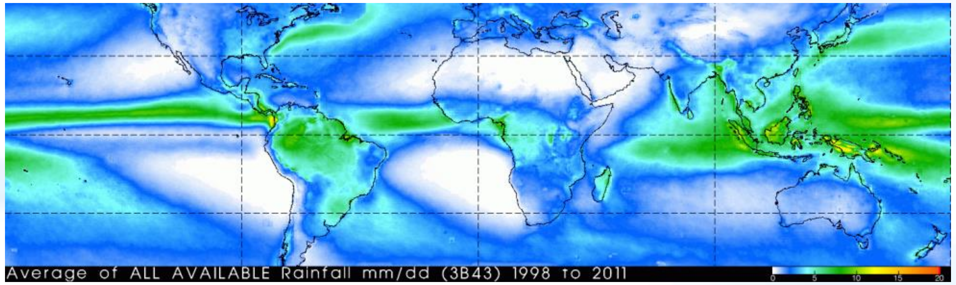



NASA Earth Science
FY17 Program of Record
MAIA (~2021)
TROPICS (~2021)
GeoCARB (~2021)
Earth Science Instruments on ISS:
CATS (2020)
LIS (2020)
SAGE III (2020)
TSIS-1 (2018)
ECOSTRESS (2017)
GEDI (2018)
OCO-3 (2018)
CLARREO-PF (2020)
TSIS-2 (2020)
Landsat 9 (2020)
PACE (2022)
NISAR (2022)
SWOT (2021)
TEMPO (2018)
JPSS-2 (NOAA)
RBI, OMPS-Limb (2018)
GRACE-FO (2) (2018)
ICESat-2 (2018)
CYGNSS (>2018)
Sentinel-6A/B (2020, 2025)
ISS
SORCE, (2017)
TCTE (NOAA)
NISTAR, EPIC (2019)
(NOAA'S DSCOVR)
QuikSCAT (2017)
EO-1 (2017)
Landsat 7 (USGS) (~2022)
SMAP (>2022)
Terra (>2021)
Aqua (>2022)
Suomi NPP (NOAA) (>2022)
CloudSat (~2018)
Landsat 8 (USGS) (>2022)
CALIPSO (>2022)
GPM (>2022)
Aura (>2022)
GRACE (2) (2017)
OSTM/Jason 2 (>2022) (NOAA)
OCO-2 (>2022)
Formulation
Implementation
Primary Ops
Extended Ops

Precipitation

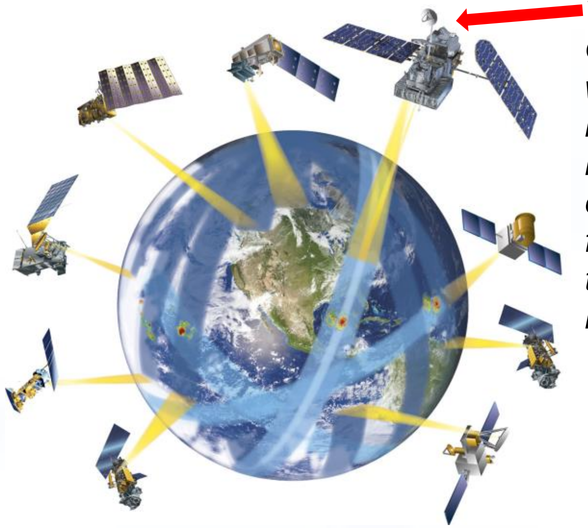
Tropical Rainfall Measurement Mission (TRMM)

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



TRMM 14-year mean rainfall

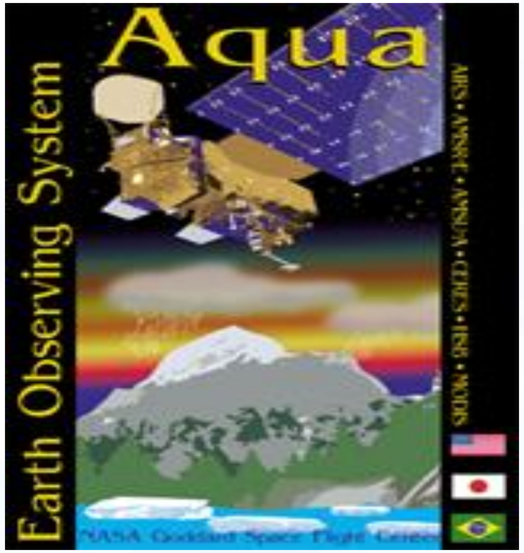
Global Precipitation Measurement (GPM)



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

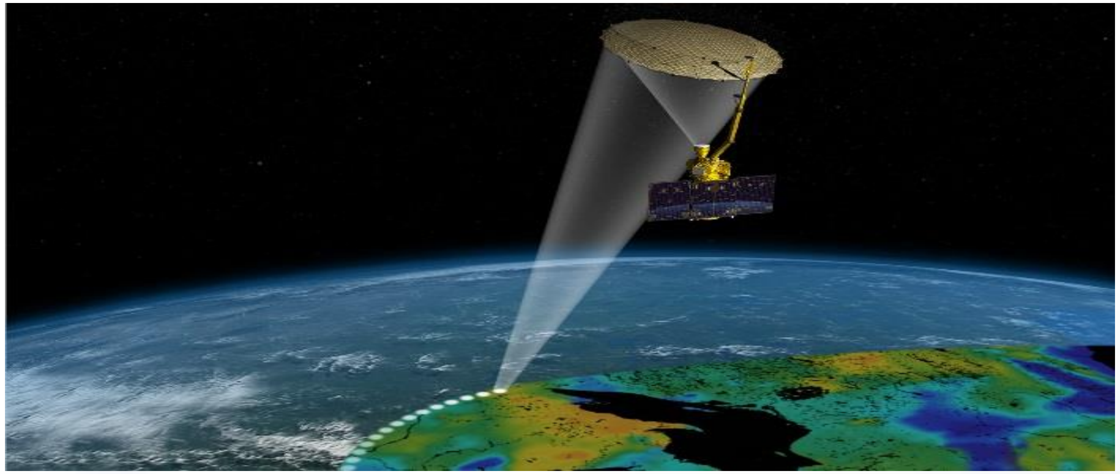
- Radar(1.26 GHz)
  - ✓ High resolution, moderate accuracy
- Radiometer (1.4 GHz)
  - ✓ Moderate resolution, high accuracy

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/

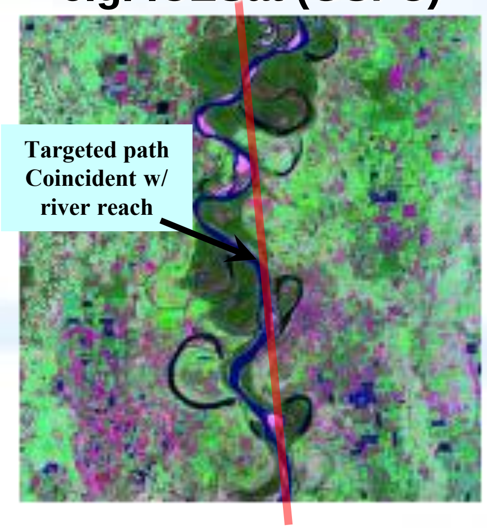
Surface Water Ocean Topography (SWOT)

Stream Discharge and Surface Water Height

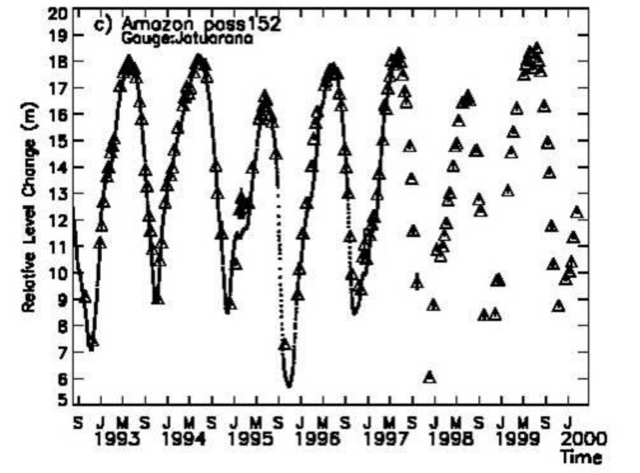
Motivation:
- critical water cycle component
- essential for water resource planning
- stream discharge and water height data are difficult to obtain outside US
- find the missing continental discharge component

Mission Concepts:

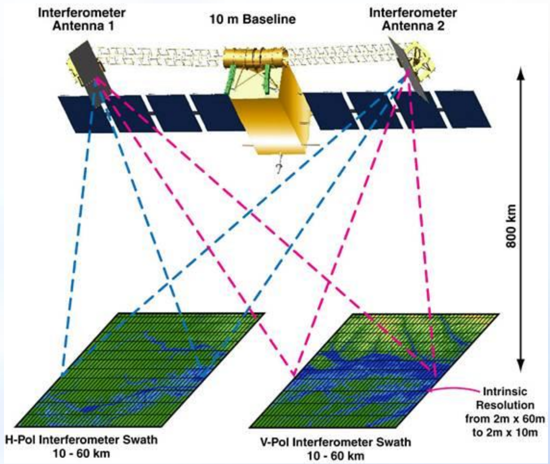
Laser Altimetry Concept
e.g. ICESat (GSFC)



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



Interferometer Concept
(JPL)



Source: M. Jasinski/614.3

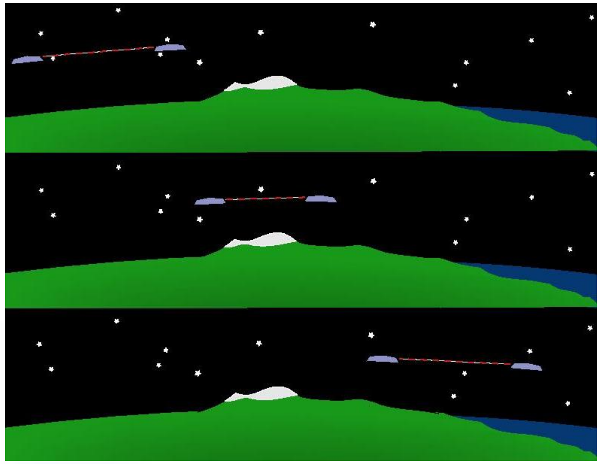
GRACE Derived Terrestrial Water Storage Variations

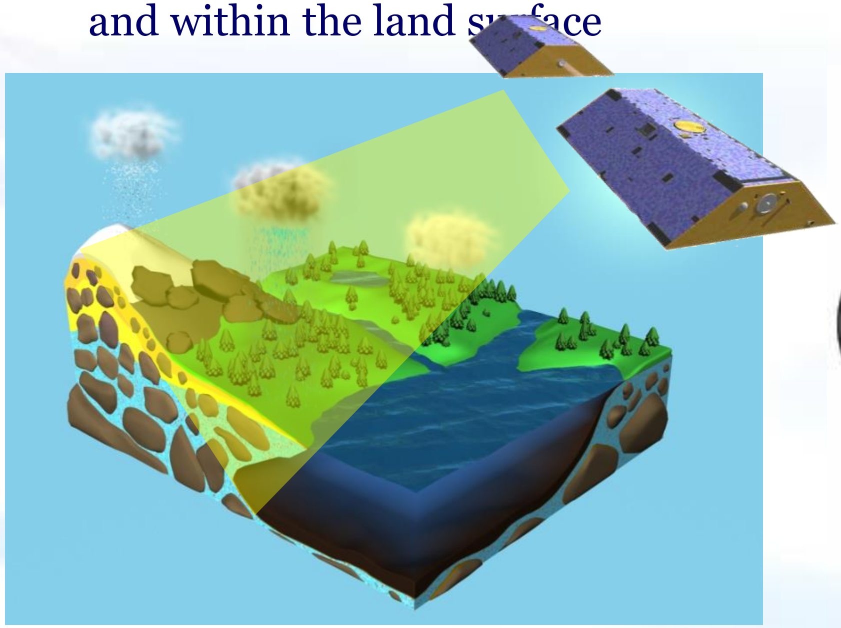
GRACE Science Goal: High resolution, mean and time variable gravity field mapping for Earth System Science applications

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

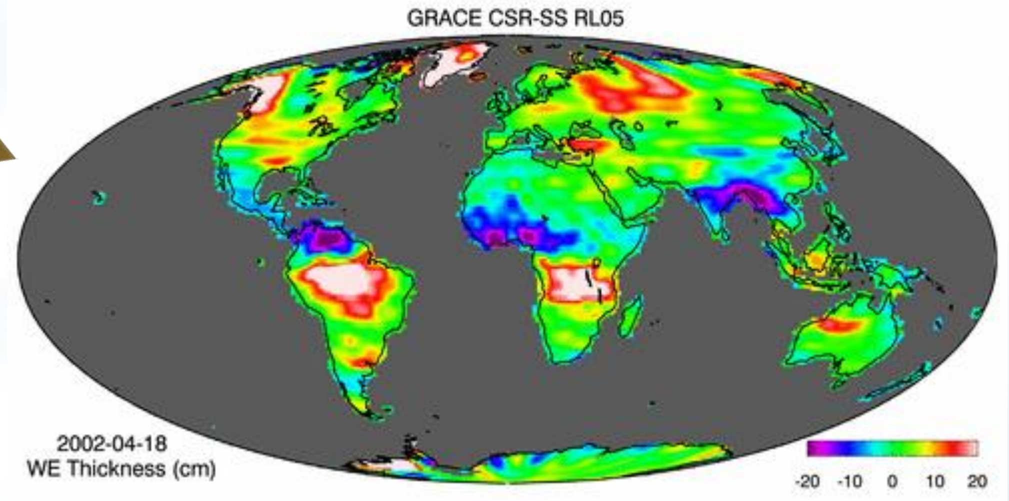
Key Measurement: Distance between two satellites tracked by K-band microwave ranging system

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.

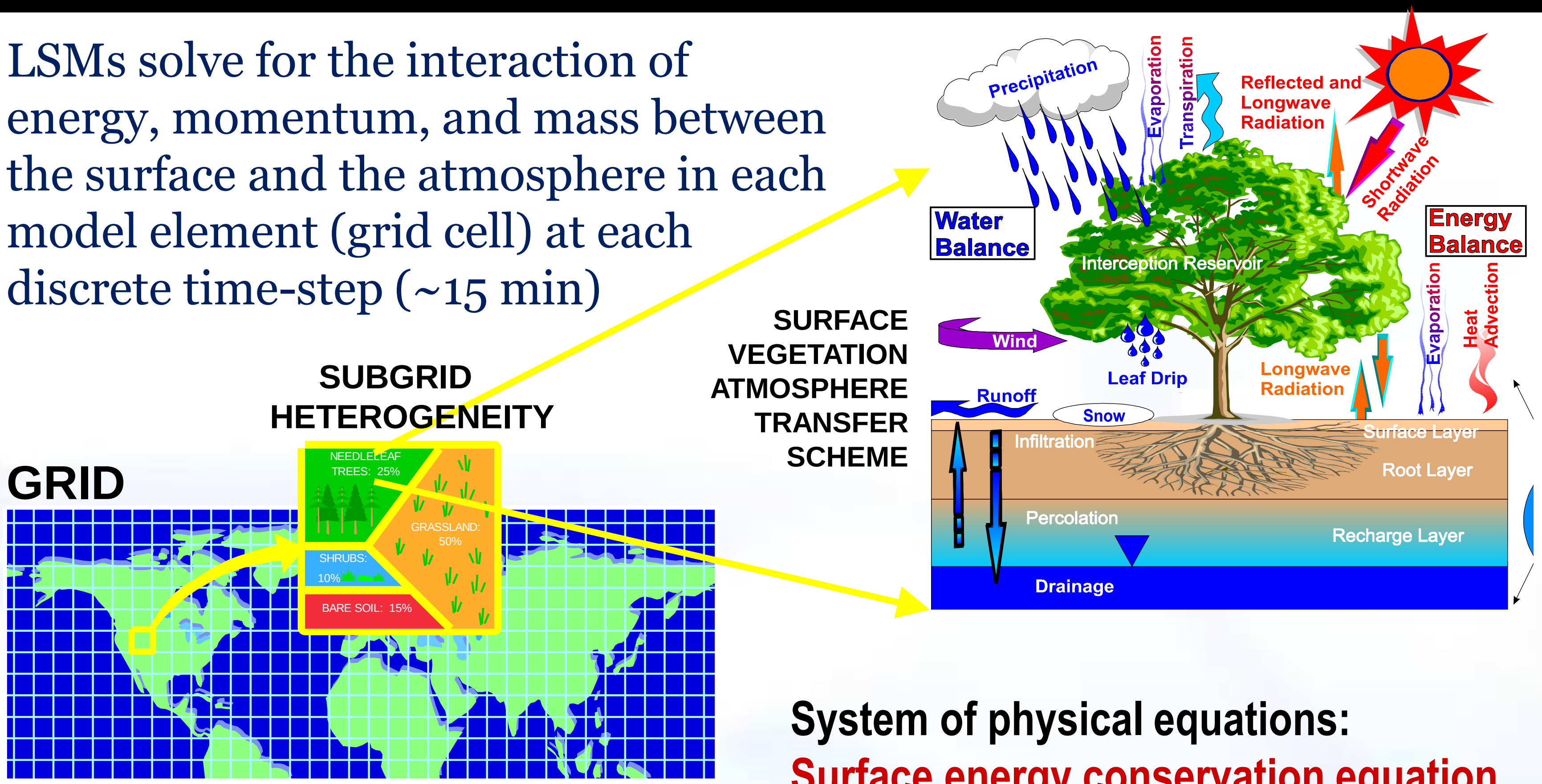


Animation of monthly GRACE terrestrial water storage anomaly fields. A water storage anomaly is defined here as a deviation from the long-term mean total terrestrial water storage at each location.

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

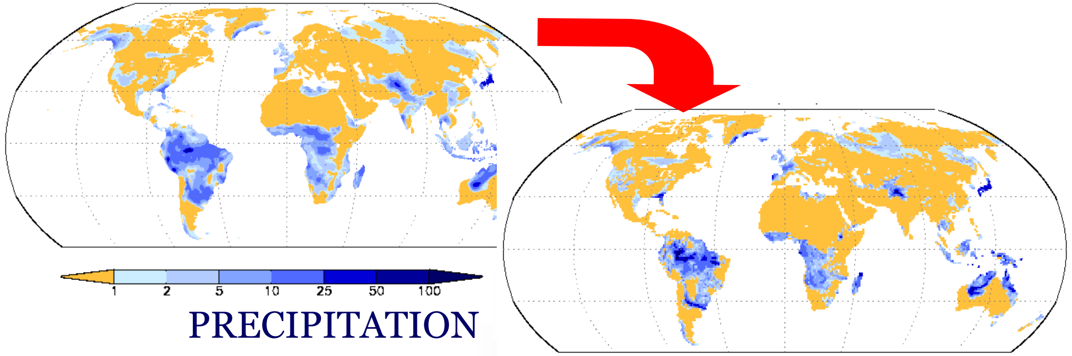
Evaporation: Penman-Monteith equation

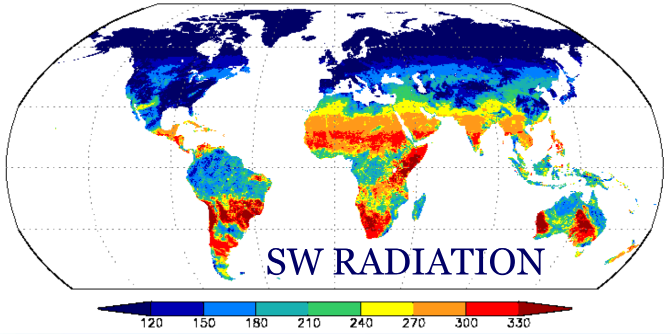
etc.

Matt Rodell
NASA GSFC

Data Integration with a Land Data Assimilation System (LDAS)

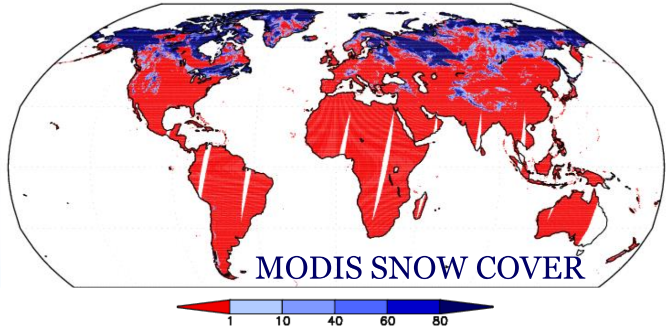
INTERCOMPARISON and OPTIMAL MERGING of global data fields

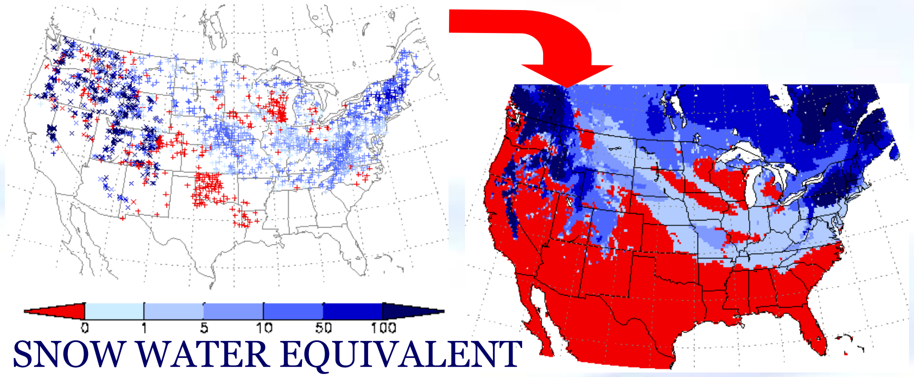




Satellite derived meteorological data used as land surface model FORCING

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





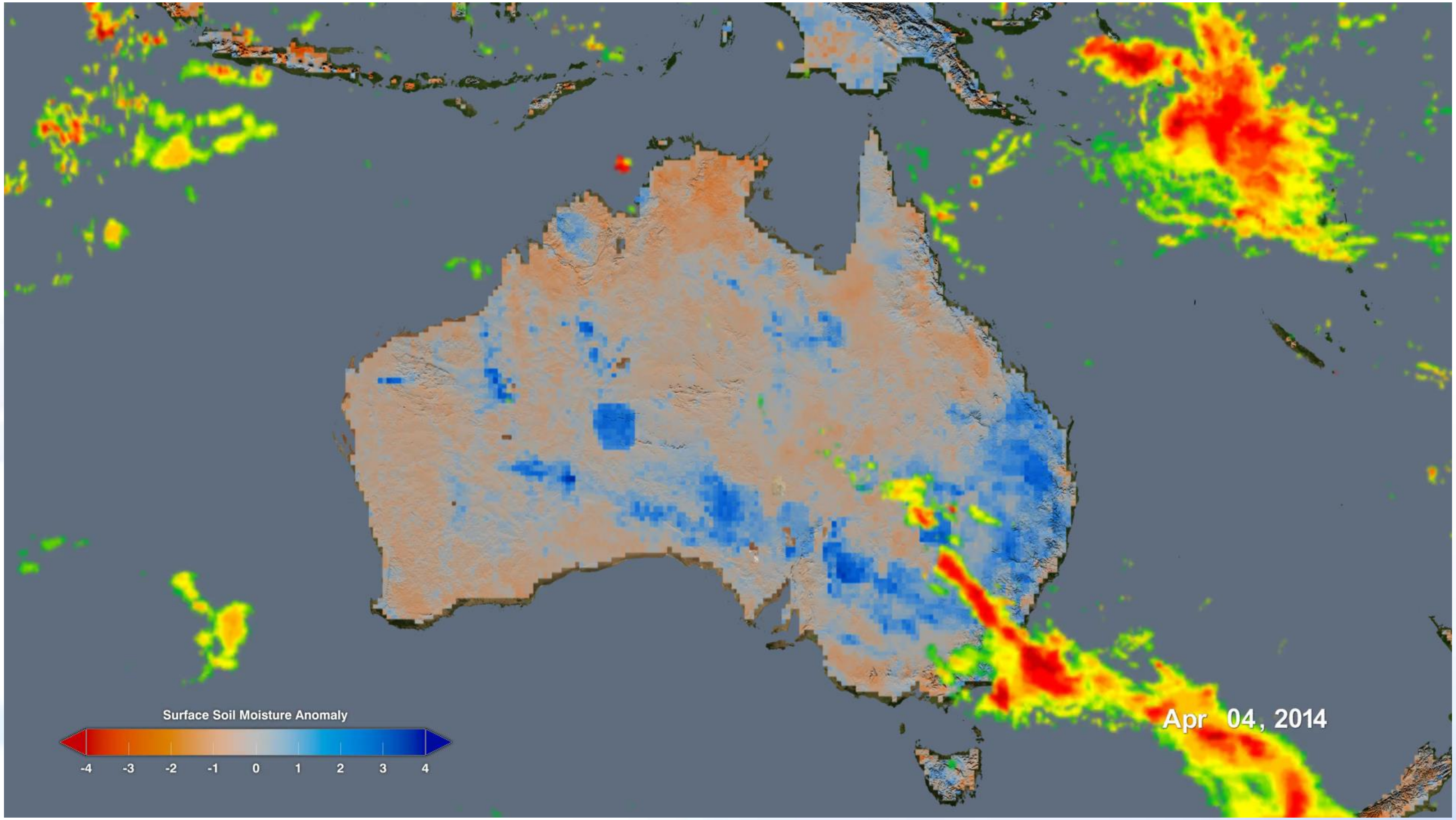
Ground-based observations used to VALIDATE model output

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

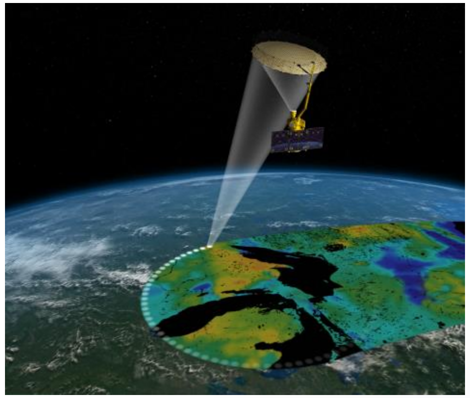
Matt Rodell
NASA GSFC

Applications

Monitoring Precipitation Memory



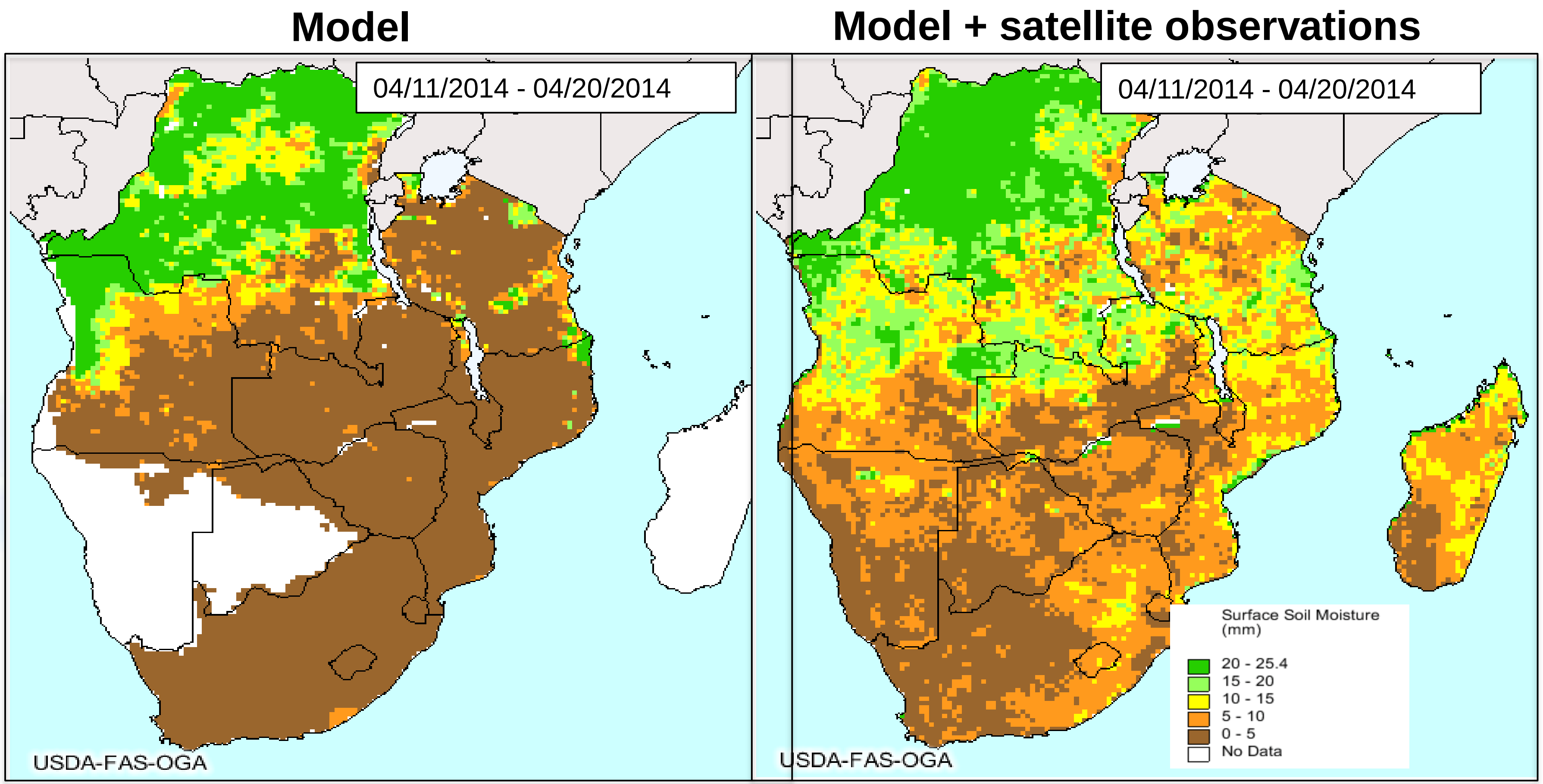
John Bolten, NASA GSFC



Soil Moisture Active Passive Mission

Global Precipitation Measurement Mission, Core Observatory

How Can We Improve Global Crop Forecasts?



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

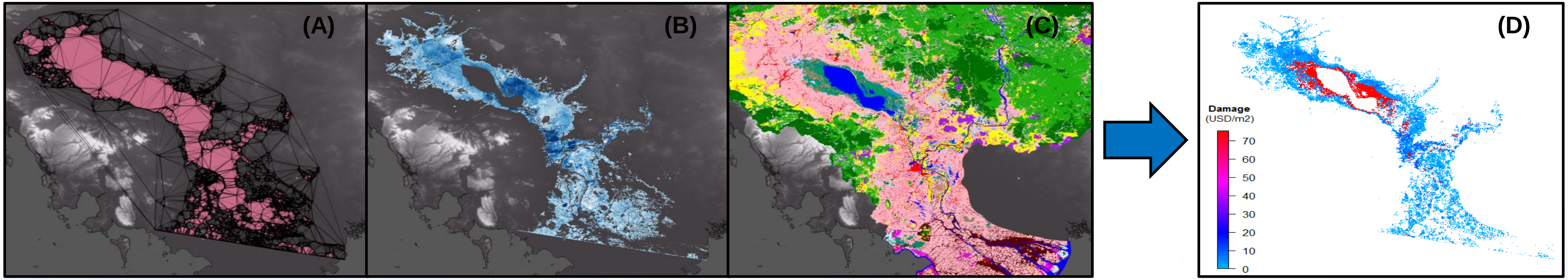
Satellite-based soil moisture observations are improving USDA's ability to globally monitor agricultural drought and predict its short-term impact on vegetation health and agricultural yield.

Real Time Flood Impact Assessment Tool

John Bolten[2], Perry Oddo[1,2], Aakash Ahamed[3]

[1]Hydrological Sciences Lab, NASA GSFC; [2]USRA; [3]Stanford University, Geophysics

Figure 1

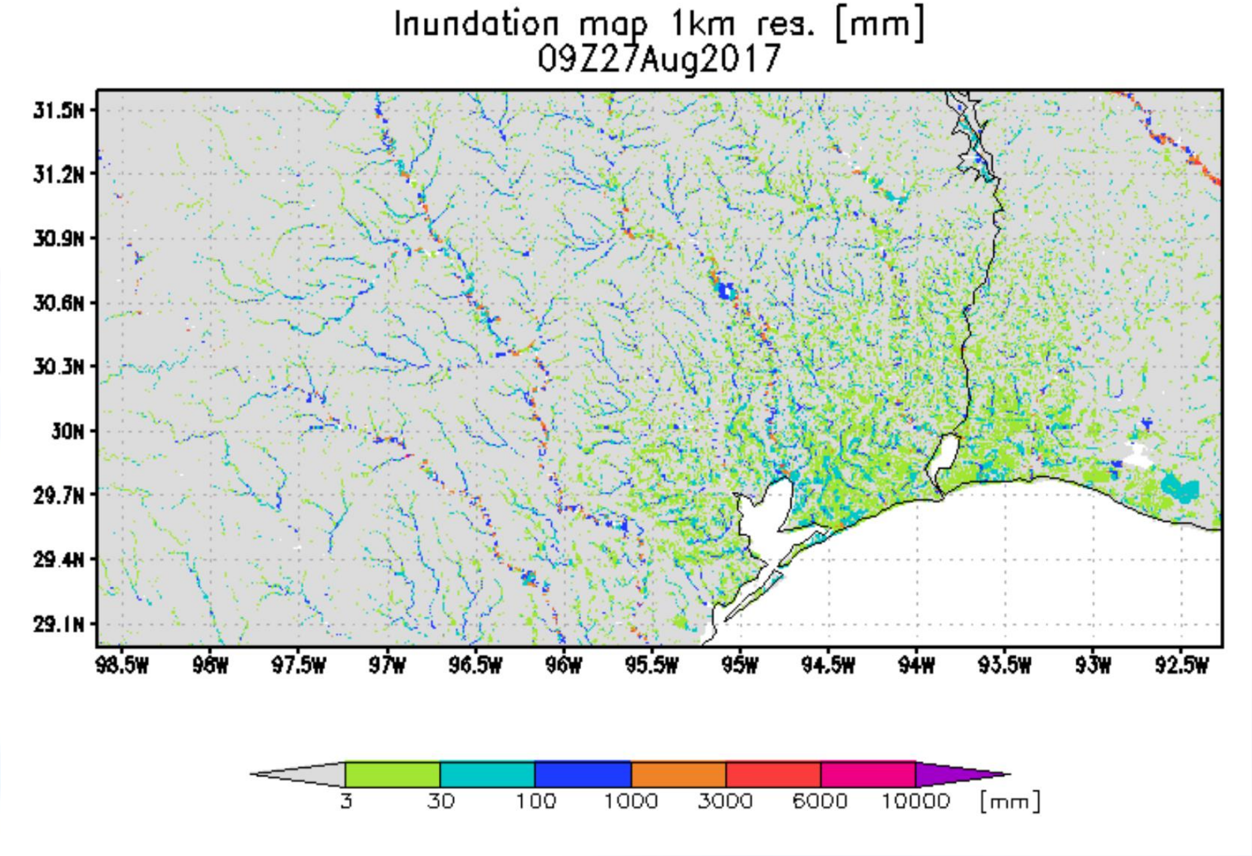


MODIS-derived surface water extents are used to produce flood depth estimates in near real-time. Flood depth estimates are then fed into a standardized flood damage framework to produce damage estimates based on inundated land cover and affected infrastructure.

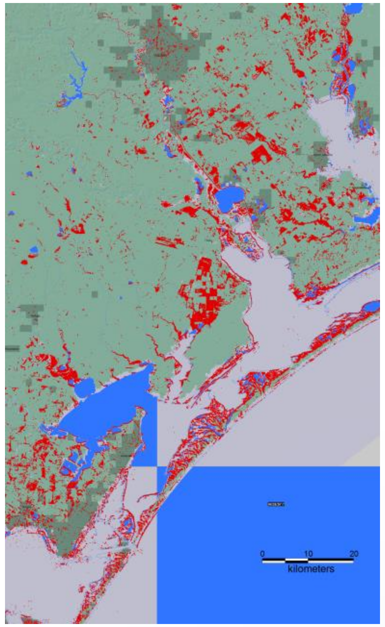
The rapid initial estimates of socioeconomic impacts can provide valuable information to governments, international agencies, and disaster responders in the wake of extreme flood events.

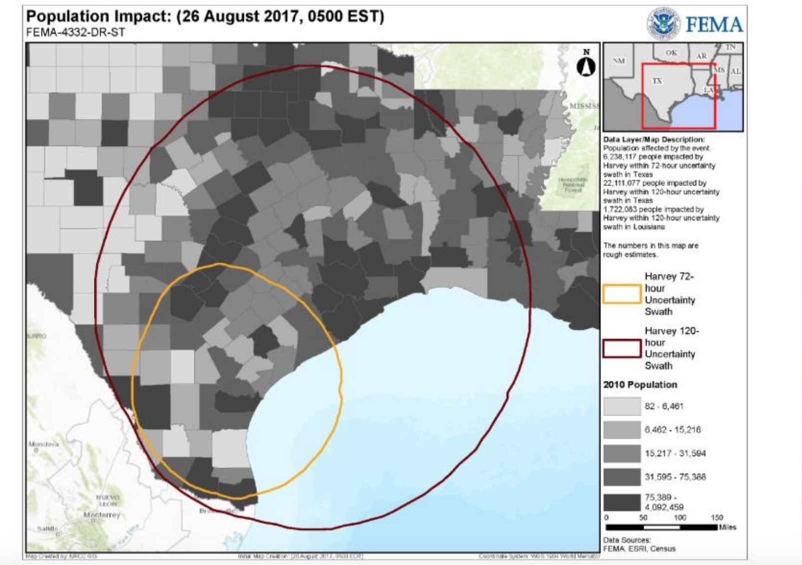
Description	Inundated Pixels	Area (km²)	Damages (USD)
Rice - 1 crop/yr	1505187	12192.01	2,317,168
Mixed Annual Crops	175947	1425.17	1,435,970
Cleared before 2010	4366	35.36	35,661
Orchard	29958	242.66	73,169
Flooded Forest	384433	3113.91	28,265,720
Grassland/Sparse Vegetation	218204	1767.45	497,578
Deciduous Shrubland	142643	1155.41	319,502
Urban	25421	205.91	12,604
Barren - Rock Outcrops	8377	67.85	-
Industrial Plantation	160	1.30	355
Deciduous Broadleaved	883	7.15	56,089
Evergreen/ Broadleaved	269	2.18	17,931
Forest Plantation	0	0.00	-
Bamboo Scrub/Forest	1369	11.09	101,454
Coniferous Forest	0	0.00	-
Mangrove	211	1.71	10,693
Marsh/Swamp	60870	493.05	151,308
Aquaculture	740	5.99	2,496
Aquaculture Rotated with Rice	2168	17.56	3,316

Hurricane Harvey Response



Source: Bob Adler, University of Maryland





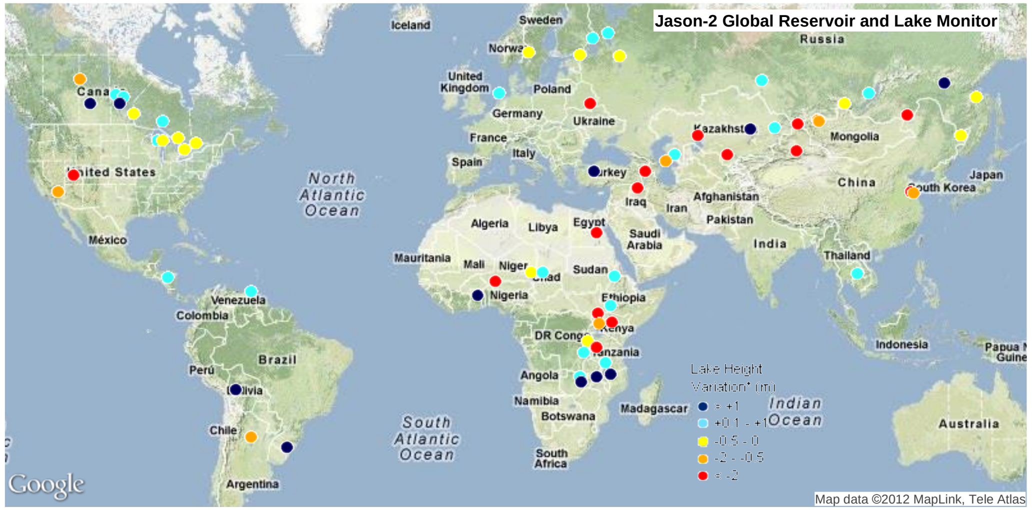
Source: FEMA

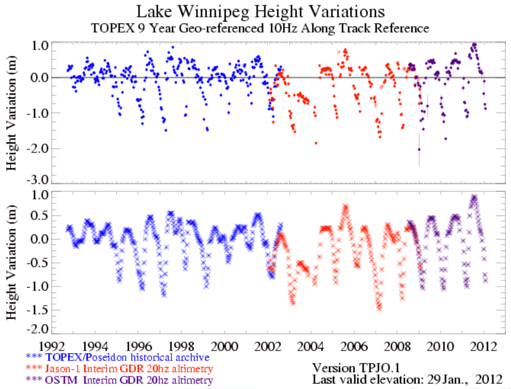
Routine Lake Level Monitoring (Jason1/2 & ENVISAT)

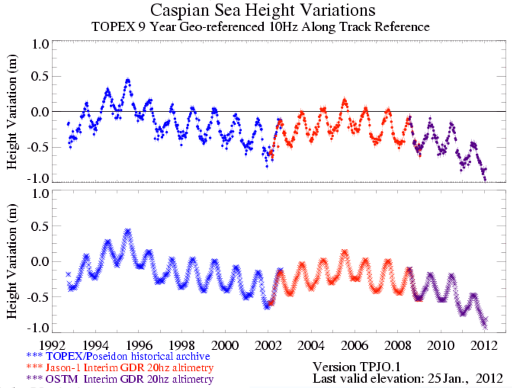
USDA United States Department of Agriculture
Foreign Agricultural Service

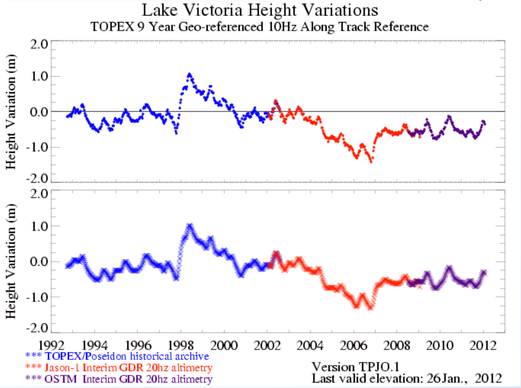
Linking U.S. Agriculture to the World FAS

Toolbox









ESSIC Earth System Science Interdisciplinary Center University of Maryland

Contact: Charon Birkett, U. Maryland

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

ΛSO

2013

Source: Tom Painter, NASA JPL

Subsidence in the San Joaquin Valley

2007–2011

Zhen Liu, Vince Realmuto, Tom Farr, JPL

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

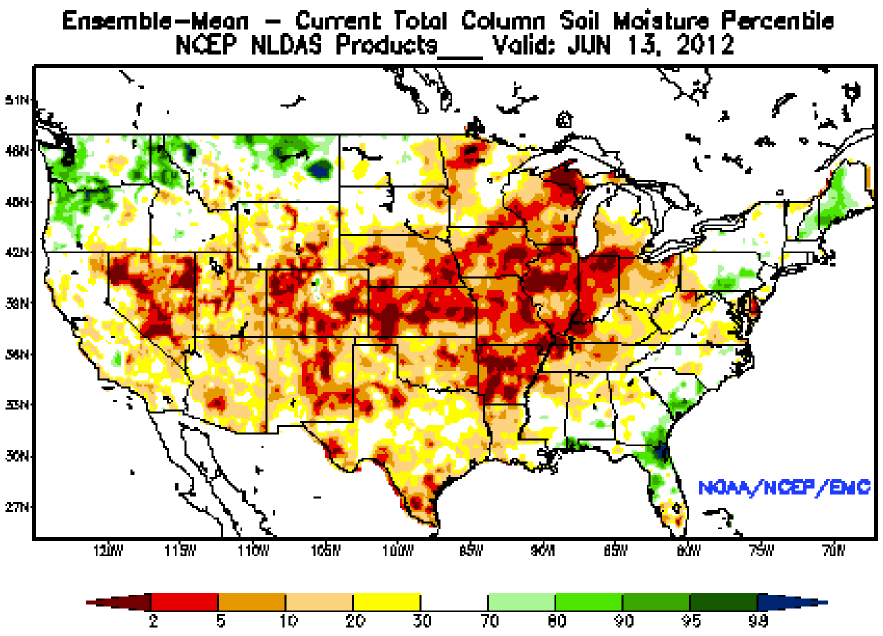
Input: Daily gauge precipitation analyses, NARR near-surface meteorology, NEXRAD radar data, bias-correcting GOES shortwave radiation

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

NLDAS datasets and services are available from the NASA GES DISC:
http://disc.sci.gsfc.nasa.gov/hydrology/

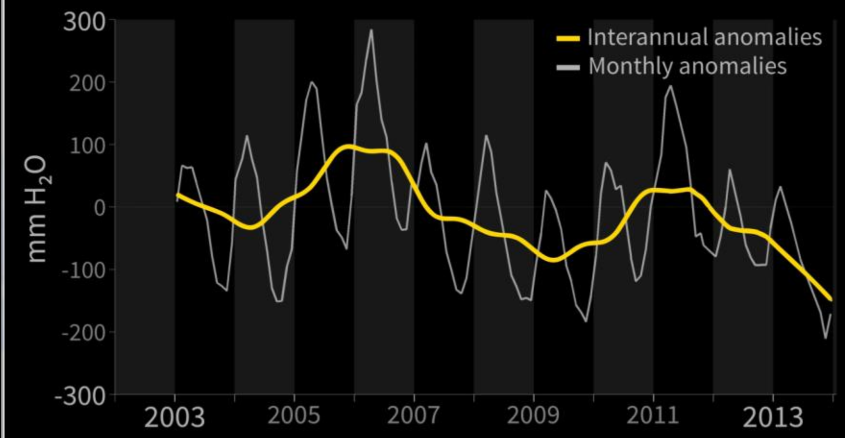
Documentation on NLDAS, including a link to the NLDAS Drought Monitor:
gov/nldas/

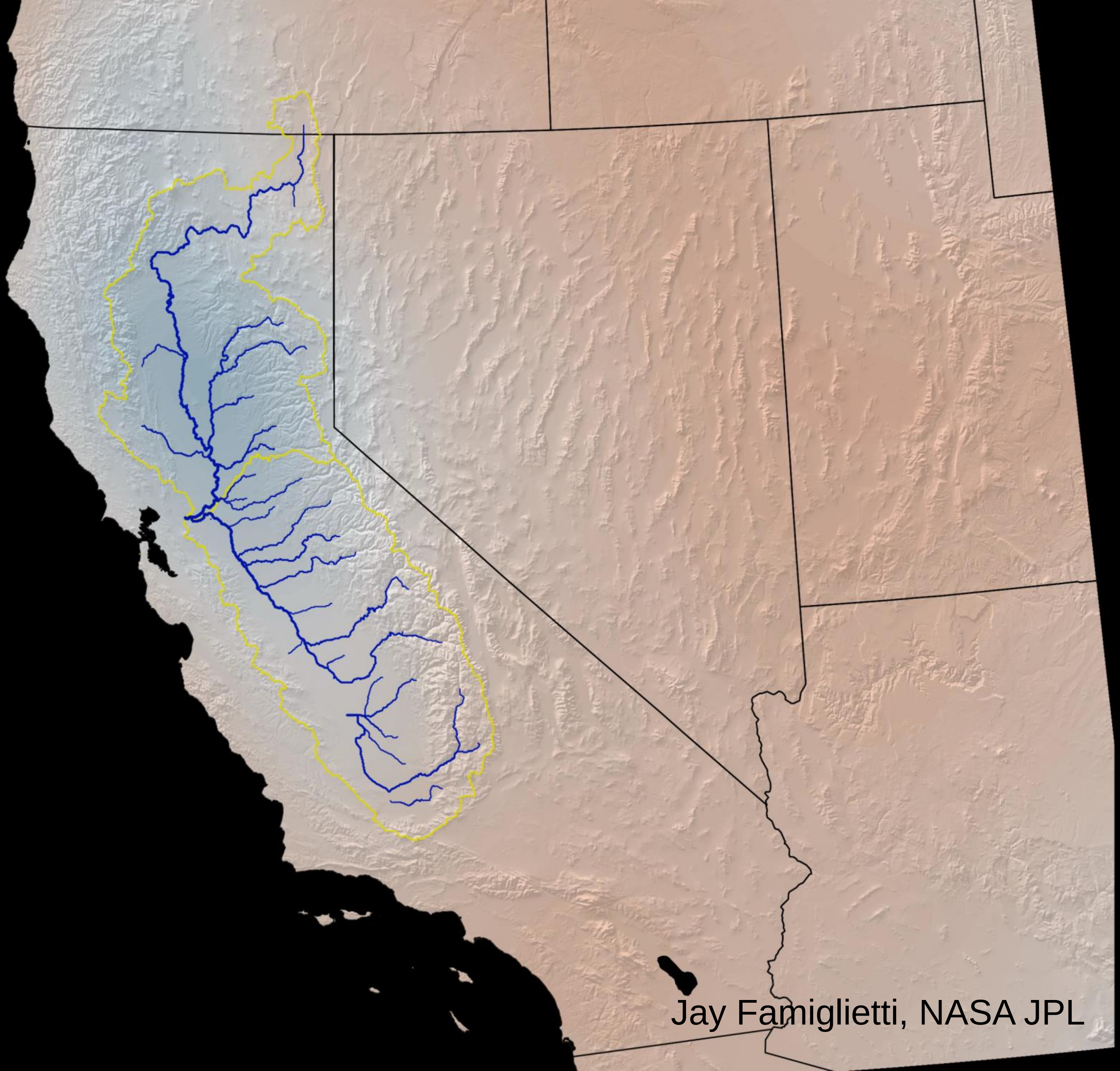
An example of the NLDAS Drought Monitor (below) showing soil moisture percentiles of the 4 land-surface model ensemble-mean (Mosaic, Noah, VIC, & SAC) against the long-term soil moisture climatology of NLDAS. Figure from 13 June 2012.



GRACE observations of Terrestrial Water Storage changes in California

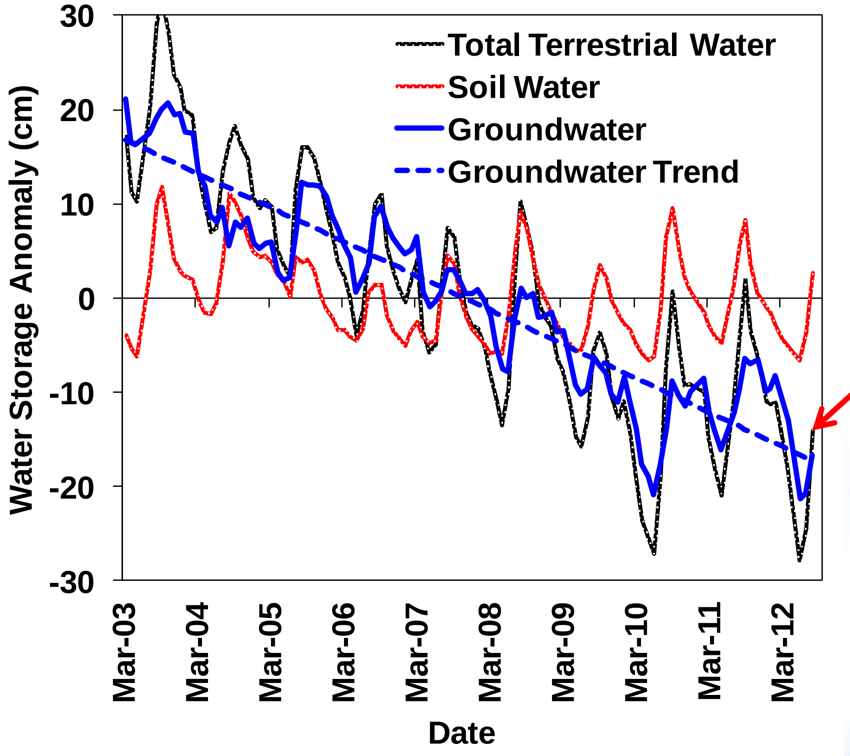
2002 05 09

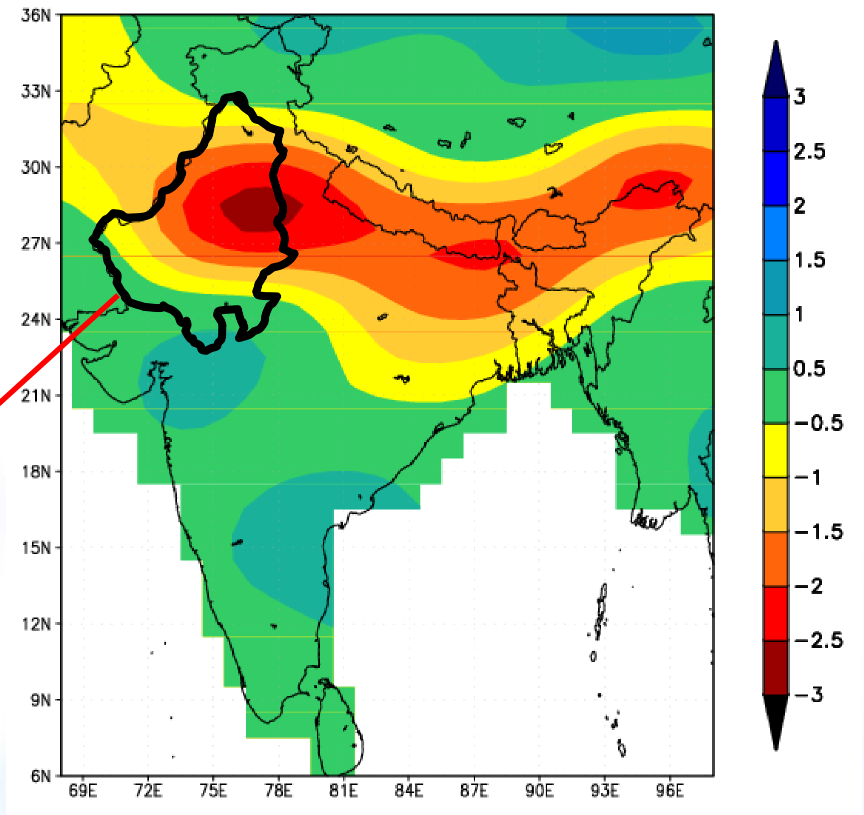




Jay Famiglietti, NASA JPL

Groundwater Depletion in Northern India



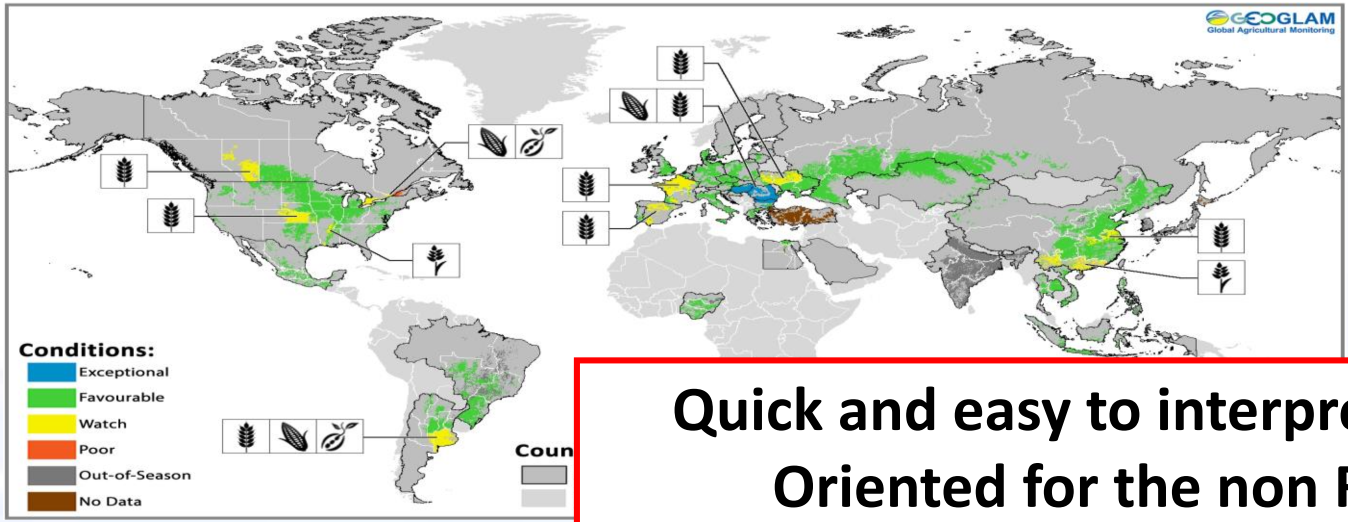


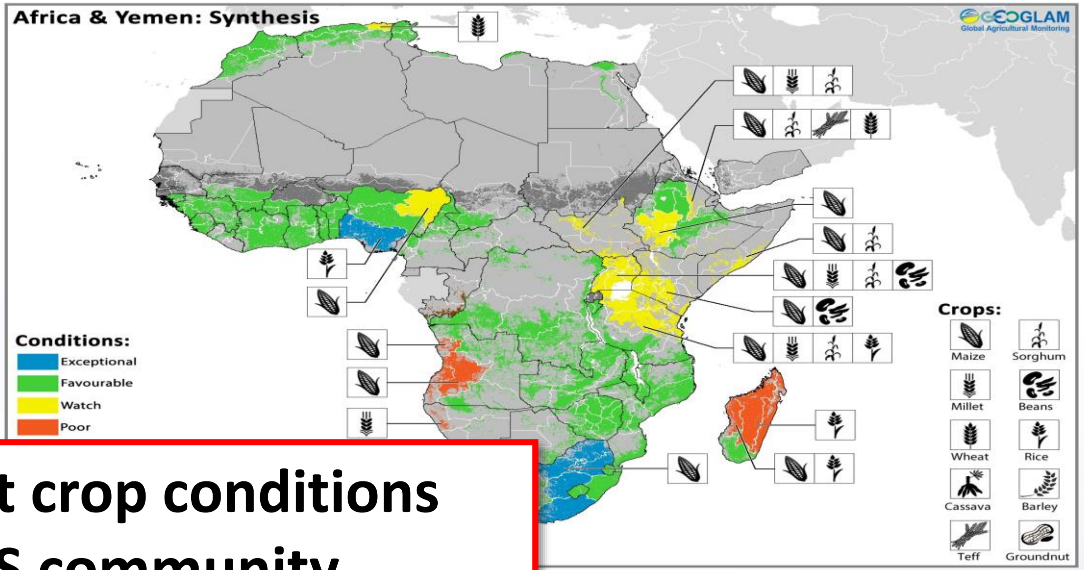
Rate of change of terrestrial water storage (cm/yr) from 2003-2012 based on NASA/GRACE satellite observations.

GW = TWS – SM – SWE

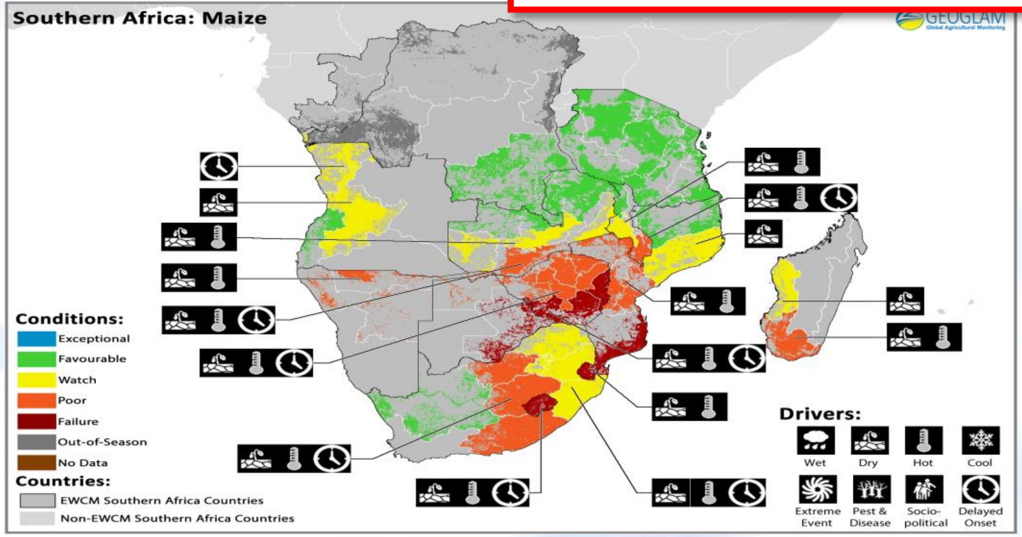
Groundwater continues to be depleted in the Indian states of Rajasthan, Punjab, and Haryana by about 16.0 km^3/yr, reduced slightly from our previous (2002-08) estimate of 17.7 ±4.5 km^3/yr (Rodell et al., *Nature*, 2009).

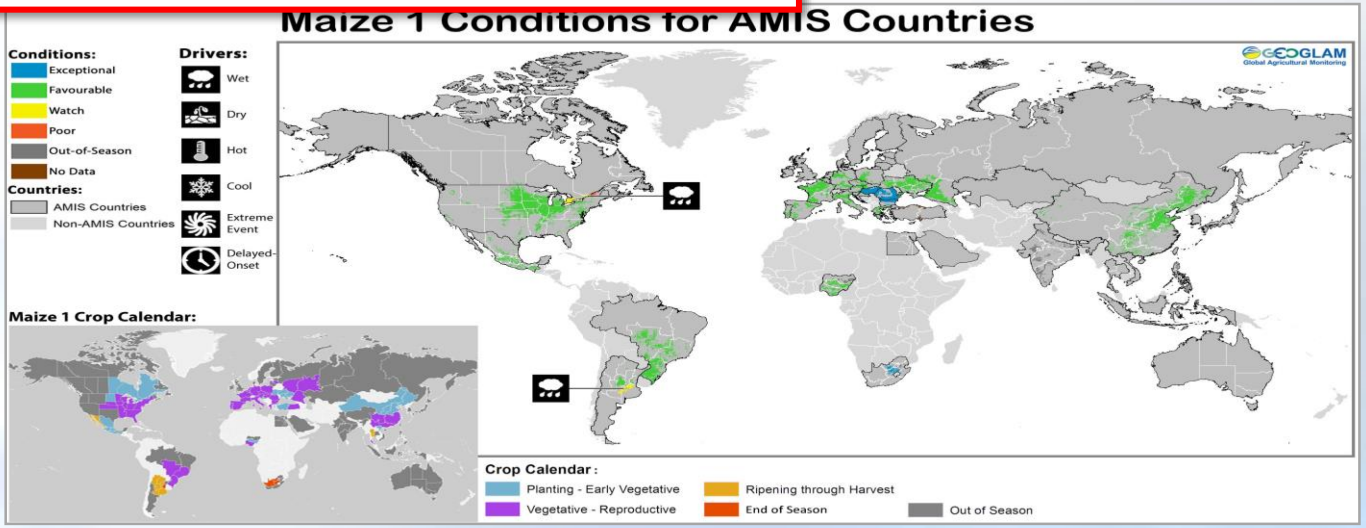
GEOGLAM - Global Agriculture and Drought Monitoring





Quick and easy to interpret crop conditions
Oriented for the non RS community





Source: Inbal Becker-Reshef, UMD

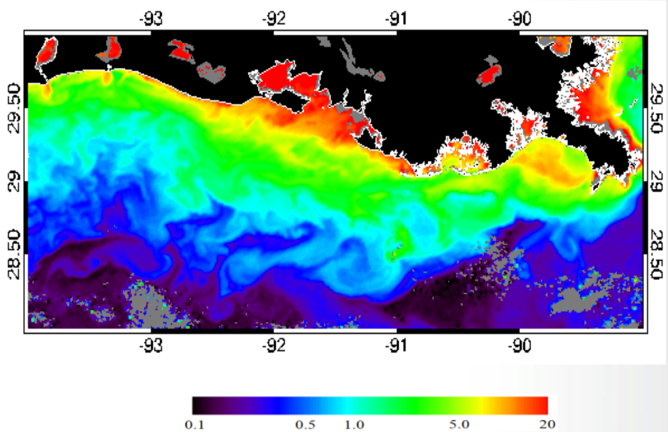
Technologies and Tools

Water Quality Analysis Tool (WQAT)

- Provides simplified access to remote sensing imagery of indicators of nutrient pollution (chlorophyll a = algal blooms) and for establishing chlorophyll criteria
- EPA's satellite remote sensing methodology for the Florida nutrient criteria rulemaking could be reproduced with WQAT
- GIS and Excel knowledge level (low barrier to entry)
- WQAT improves access and use of complex models as well as enhances and supports nutrient management decisions

➢ **Target Opportunity**

- **Webinar to describe WQAT on Sept 24**
- **Beta testing beginning end of Sept** – State participation welcome!
- Contact: lehrter.john@epa.gov



Chlorophyll-a (µg/l)

The Western Water Application Office (WWAO)

- Provide western water decision-makers a more accessible entry point to NASA and its capabilities
- Emphasize decision-maker "pull" in identifying and developing applications
- Pursue a variety of approaches to application identification, maturation and transition
- Apply a more formal "project" approach to application implementation

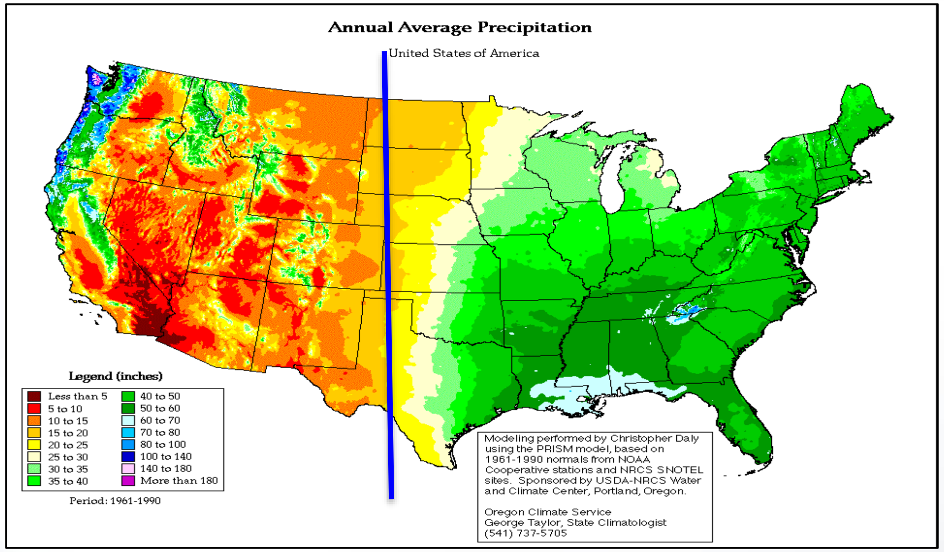


Figure 1 - ***A 30-year climatology of annual U. S. Precipitation. The red line denotes the 100th meridian. (Source: C. Daly, Oregon State University)***

The Western United States is defined by the Department of Interior (DoI) as those states that are on or west of the 100th meridian and encompasses the states represented by the Western Governor's Association (WGA). It is roughly the divide between the "wet" east and the "dry" west

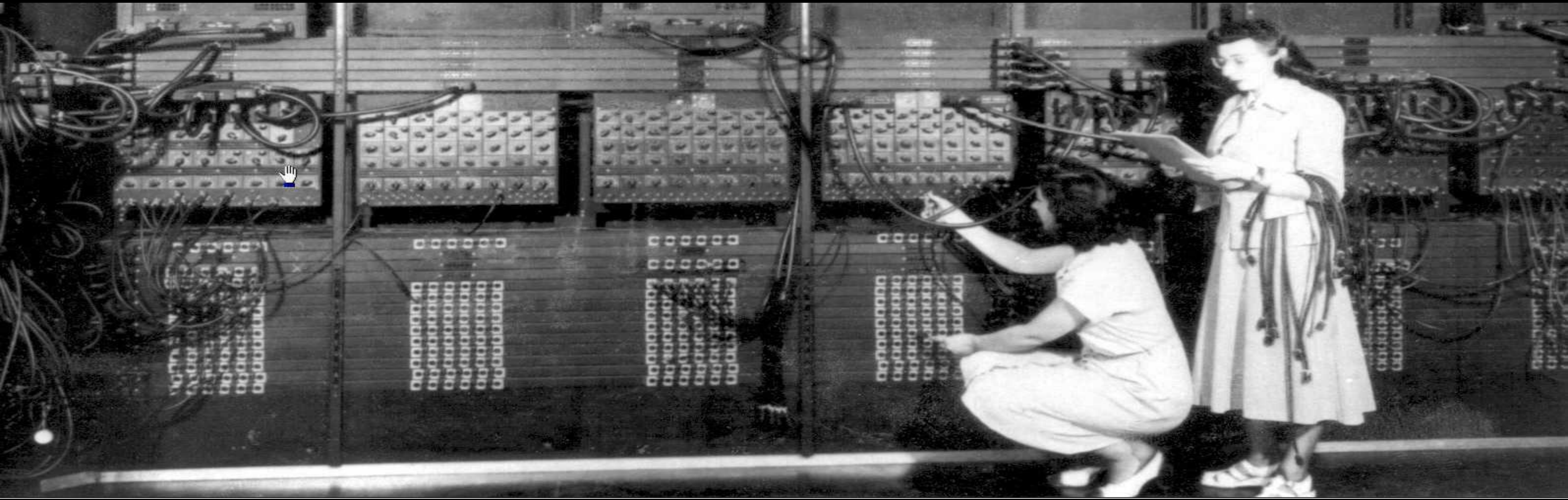
SERVIR

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.

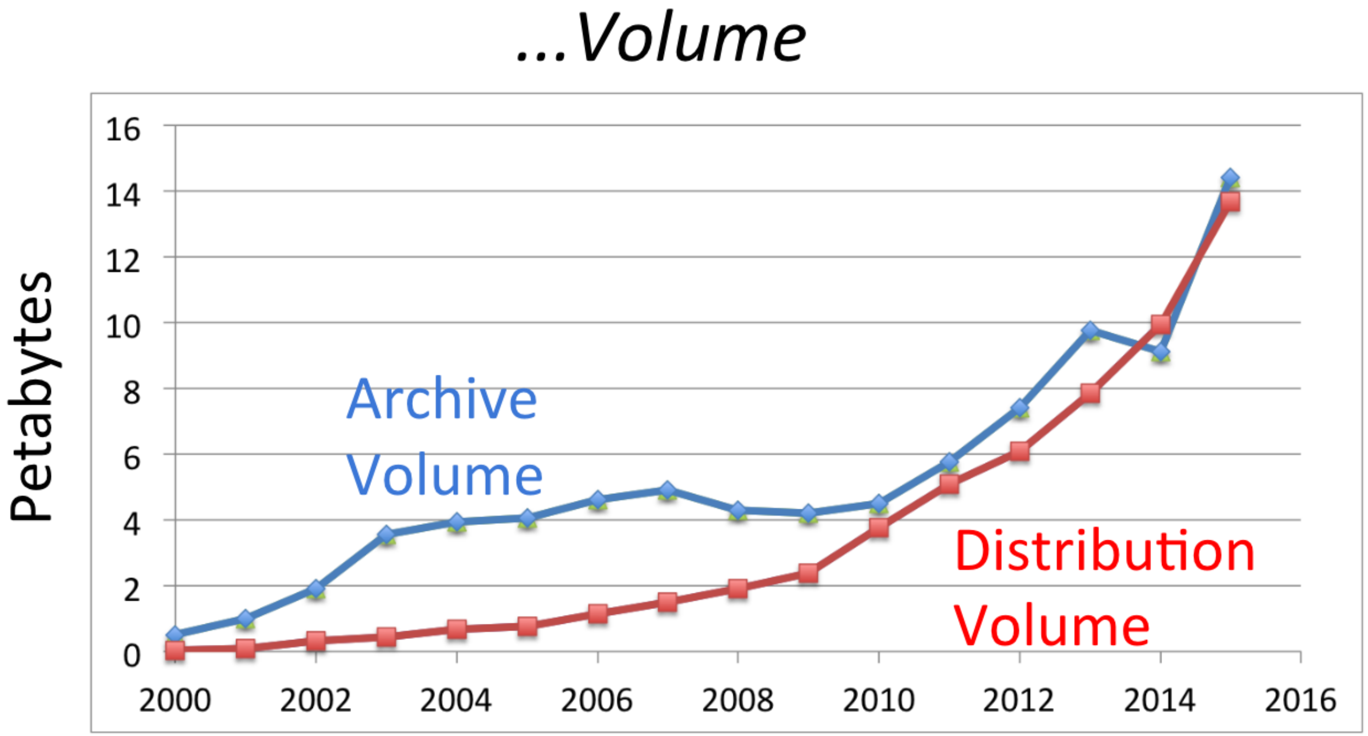
Mapping of harmful microalgae in El Salvador

Frost mapping in Kenya

Flood Forecasting In Bangladesh



NASA Satellite Data Volumes



EOSDIS FY2015 Metrics	
Unique Data Products	9,462
Distinct Users of EOSDIS Data and Services	2.6 M
Average Daily Archive Growth	16 TB/day
Total Archive Volume (as of Sept. 30, 2015)	14.6 PB
End User Distribution Products	1.42 B
End User Average Daily Distribution Volume	32.1 TB/day

High Performance Computing and The Rise of the Cloud

NEX

Google Earth Engine

Microsoft Azure

amazon web services

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/

Thank you!

John Bolten
Associate Program Manager
NASA Applied Sciences Program
Water Resources

john.bolten@nasa.gov

Bradley Doorn, Forrest Melton, Christine Lee
NASA Applied Sciences Program

World Water Week
August 28, 2017
Stockholm, Sweden