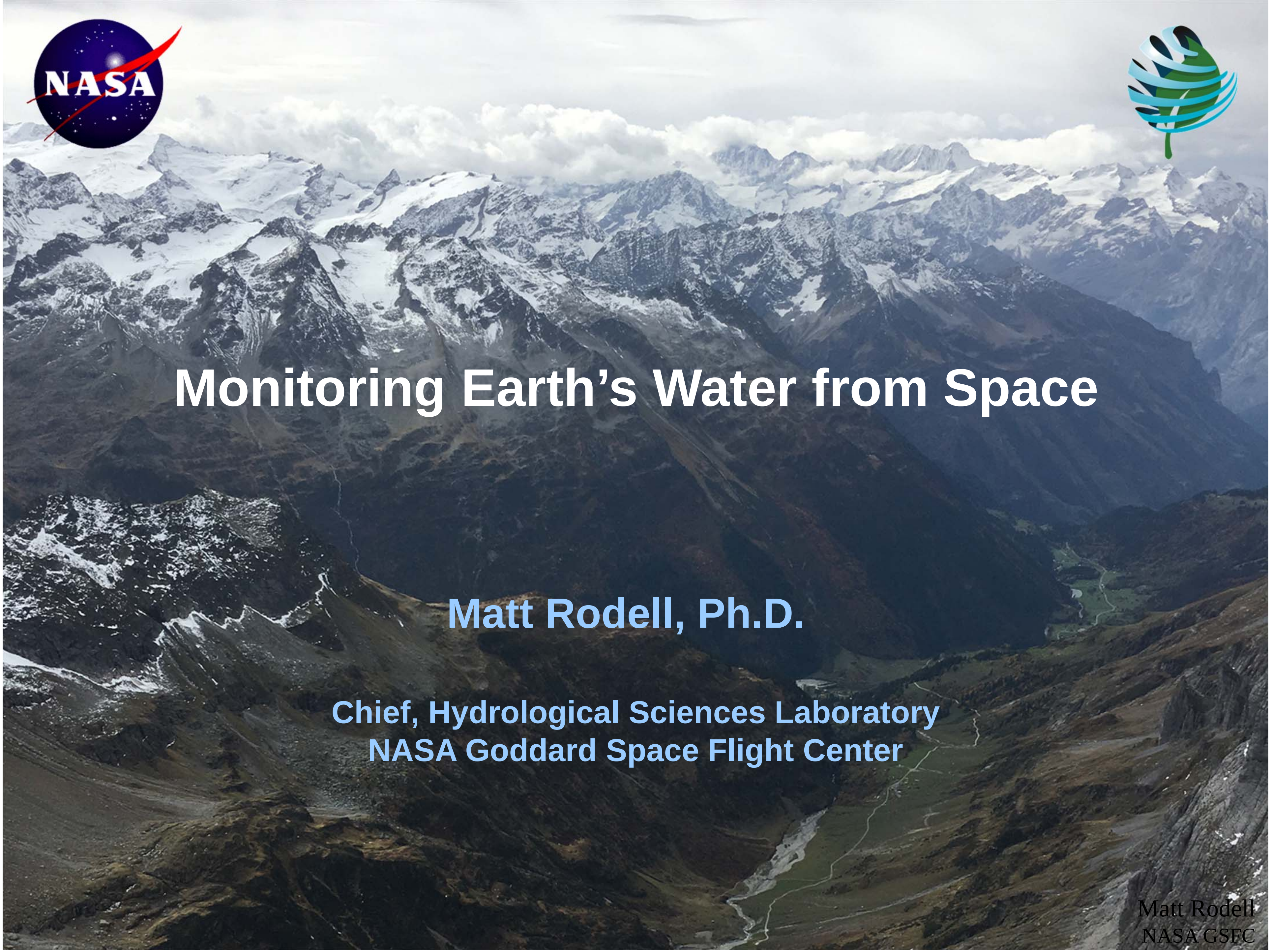


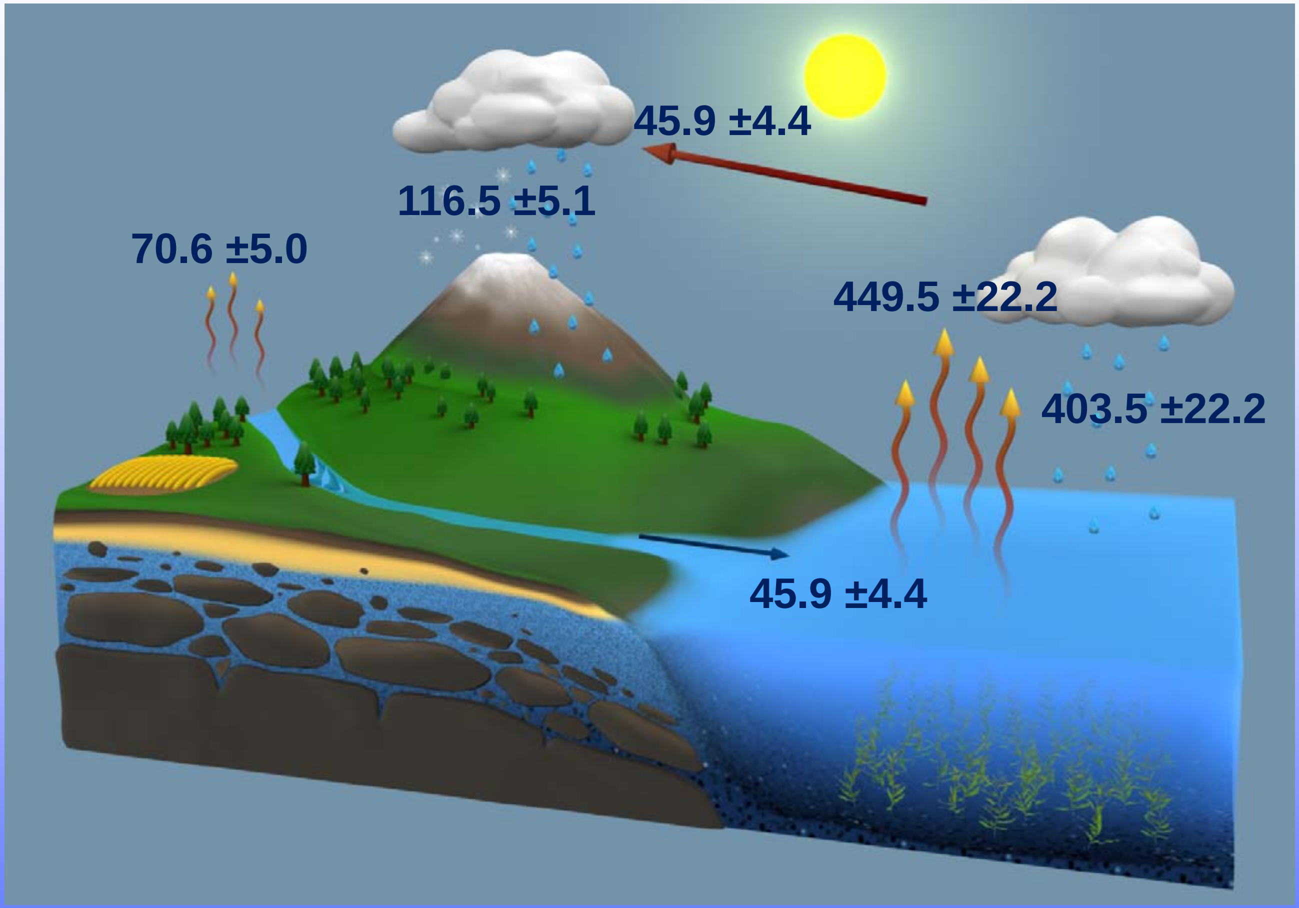
Monitoring Earth’s Water from Space

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

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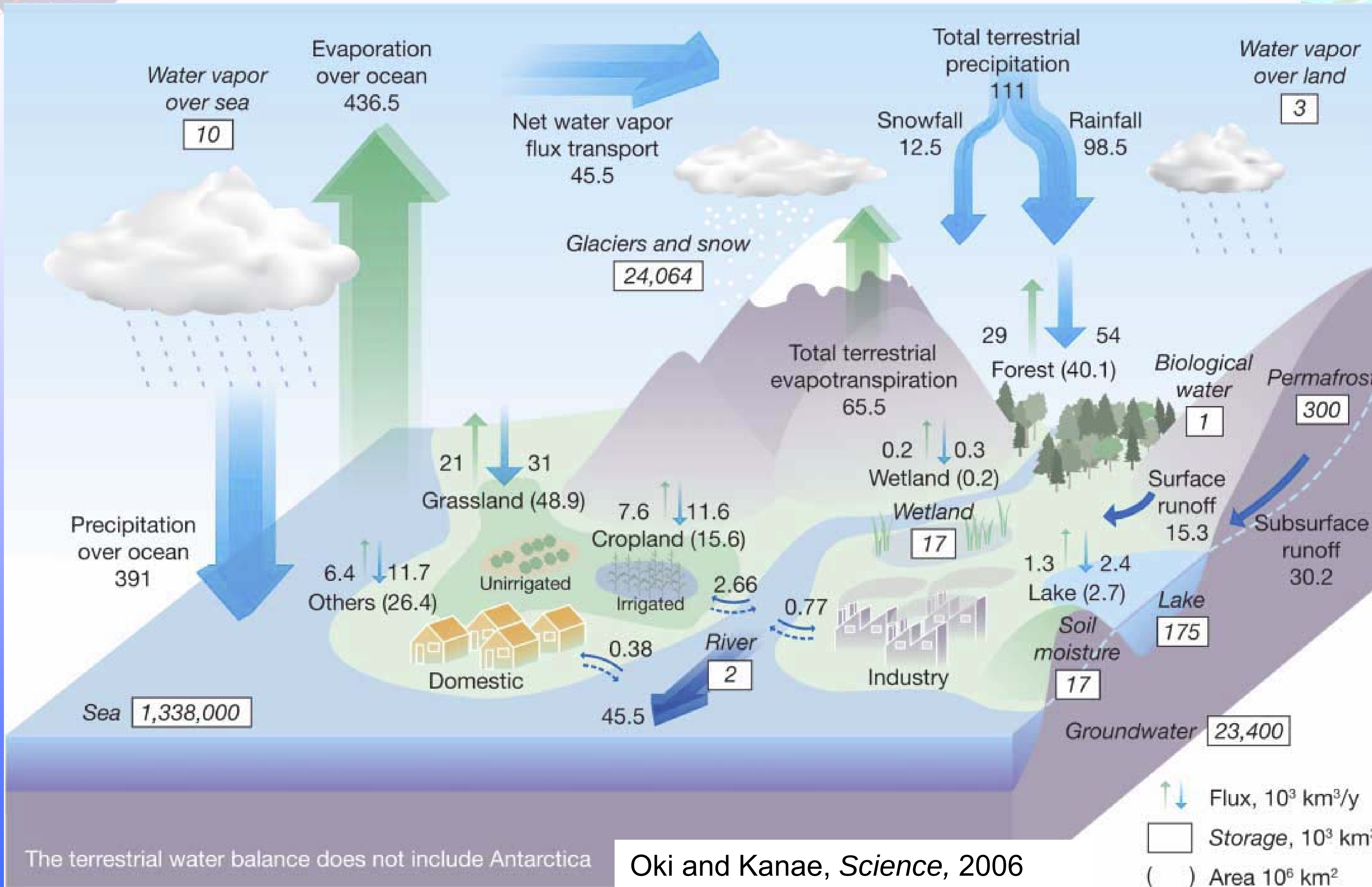
NASA GSFC

The Global Water Cycle



Oki and Kanae, *Science,* 2006

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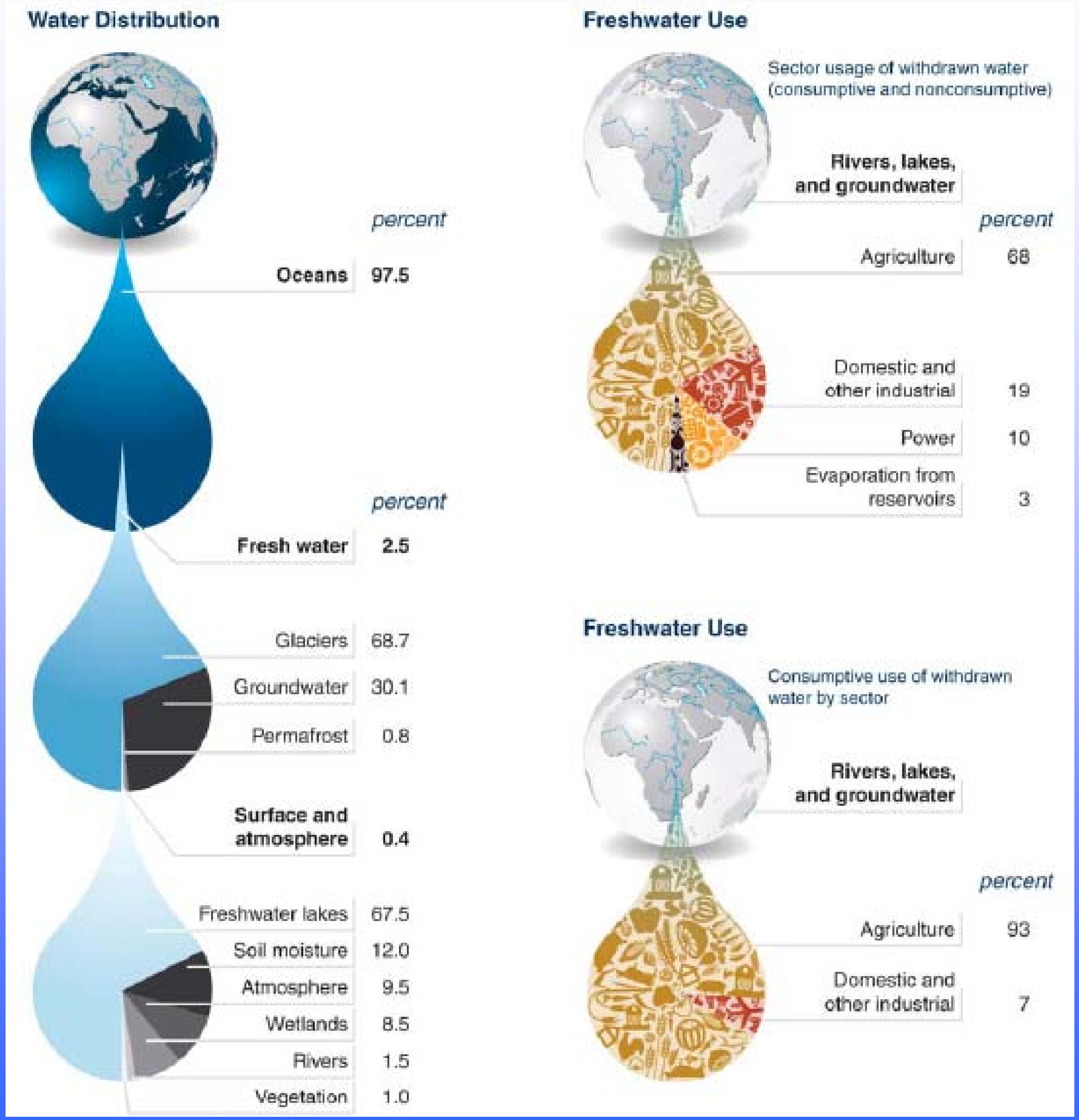
NASA GSFC

Distribution and Usage of Water on Earth



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

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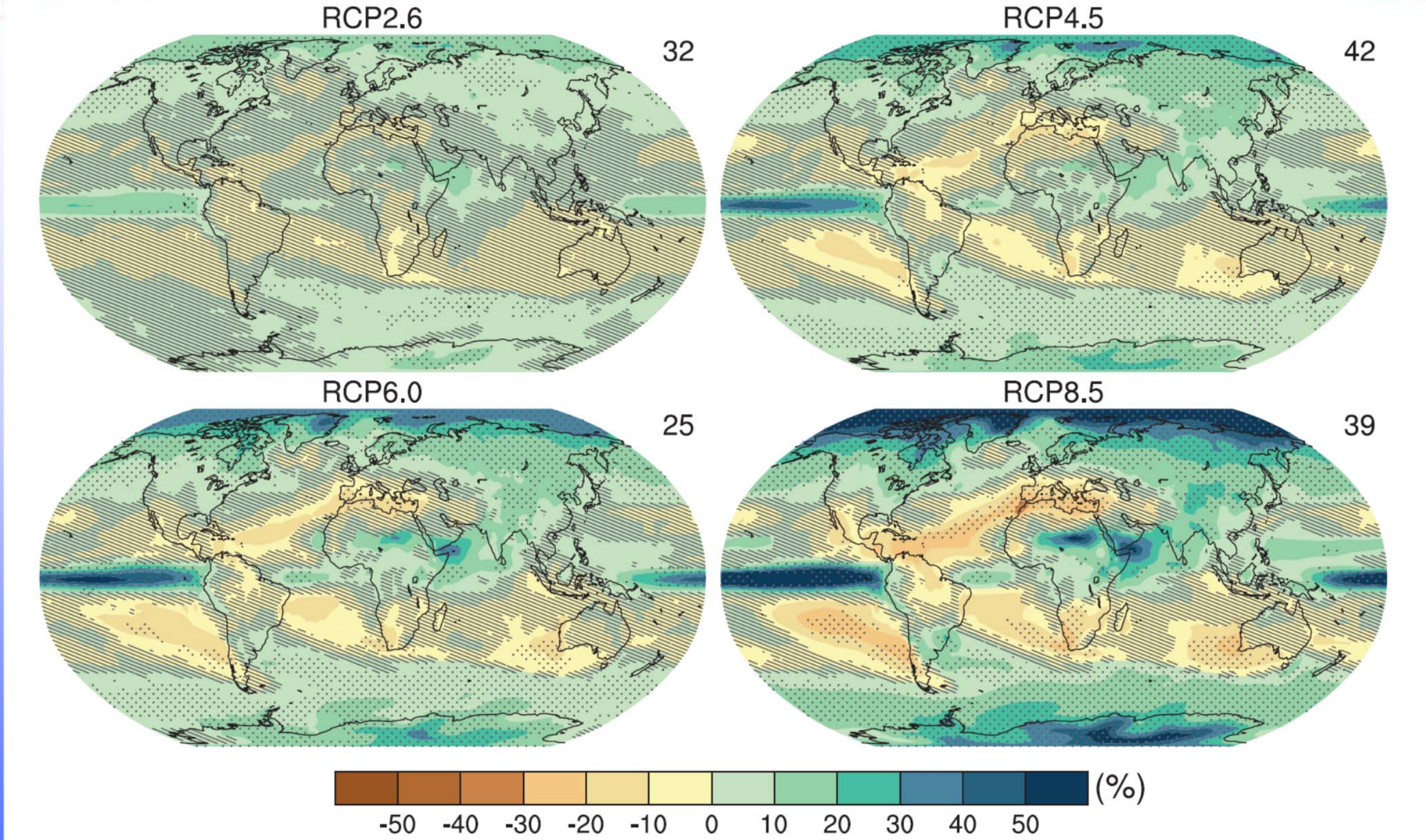
Predicted Climate Change Impacts on Precipitation



IPCC AR5 multi-model mean precipitation changes (%) in 2081-2100 relative to 1986-2005 for scenarios RCP2.6, RCP4.5, RCP6.0 and RCP8.5.
Hatching: multi-model mean <1 standard deviation of internal variability.
Stippling: multi-model mean >2 standard deviations of internal variability and ≥90% of models agree on the sign.

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Monitoring the Water Cycle

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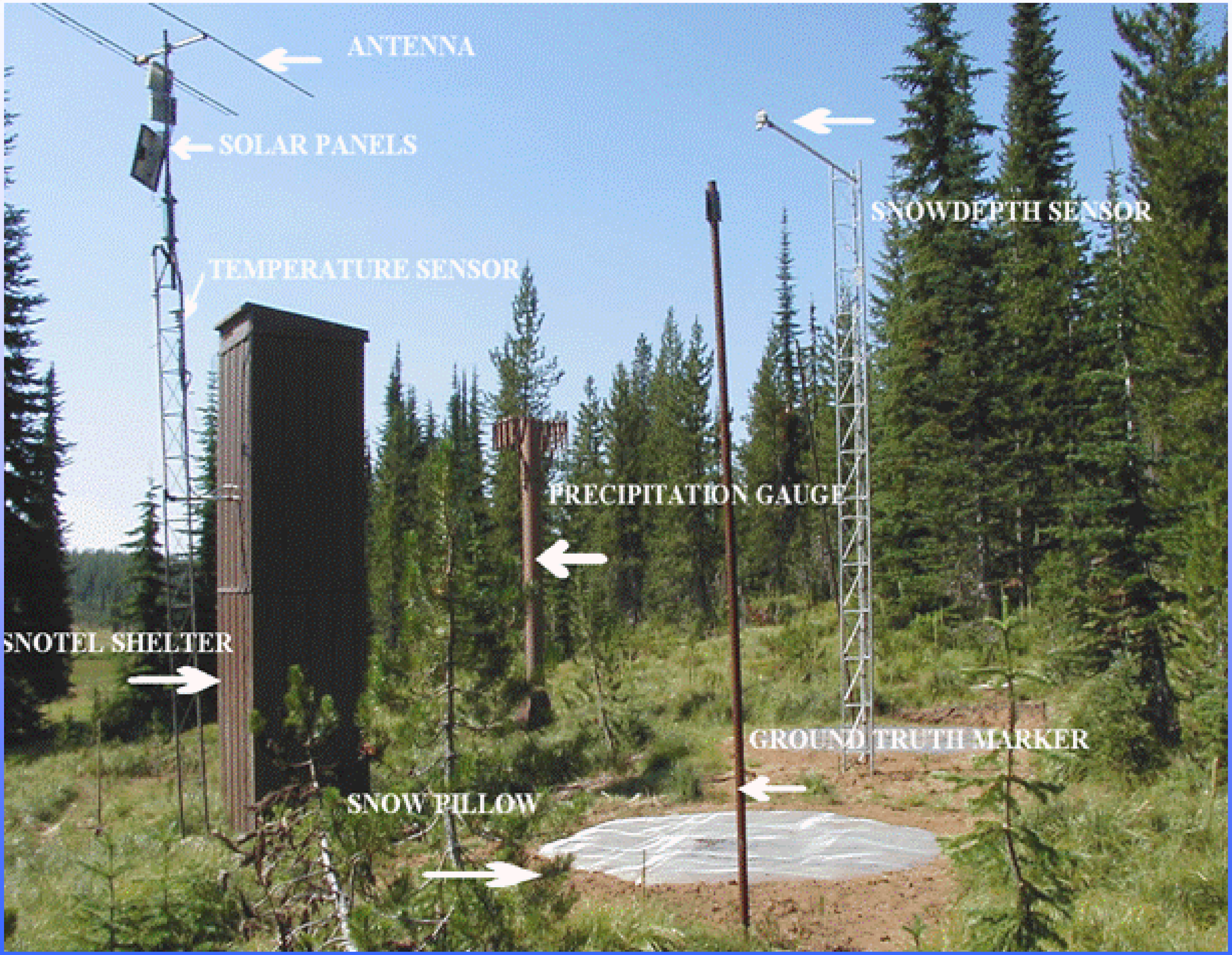
NASA GSFC

Rain and Snowfall



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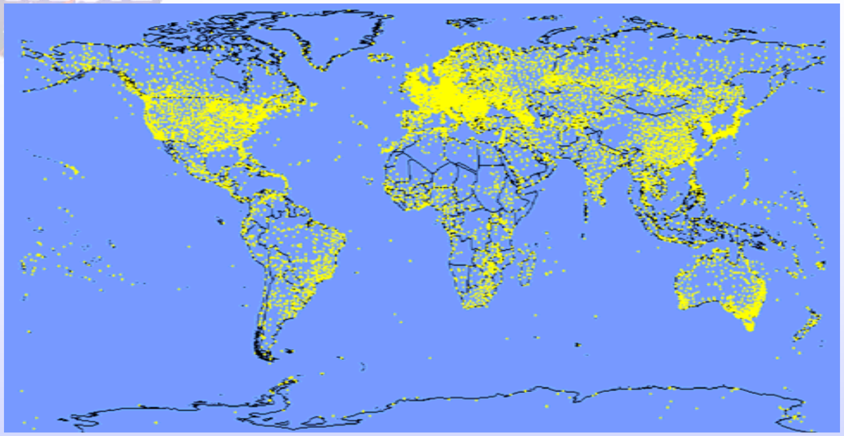
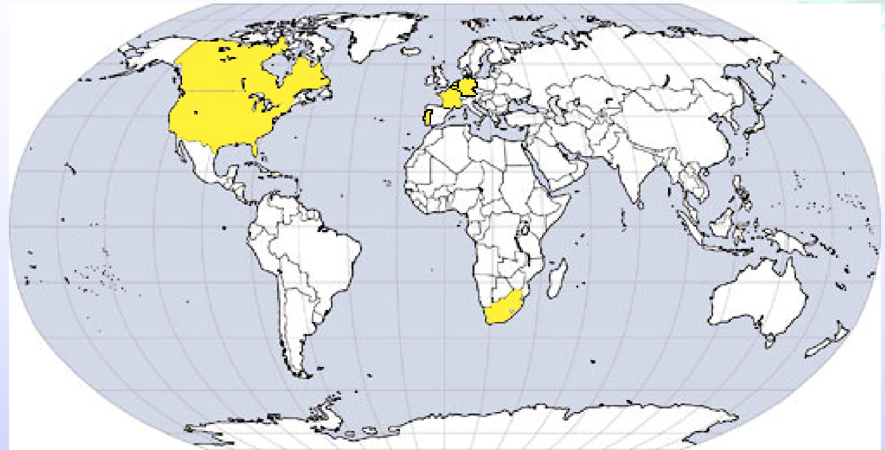
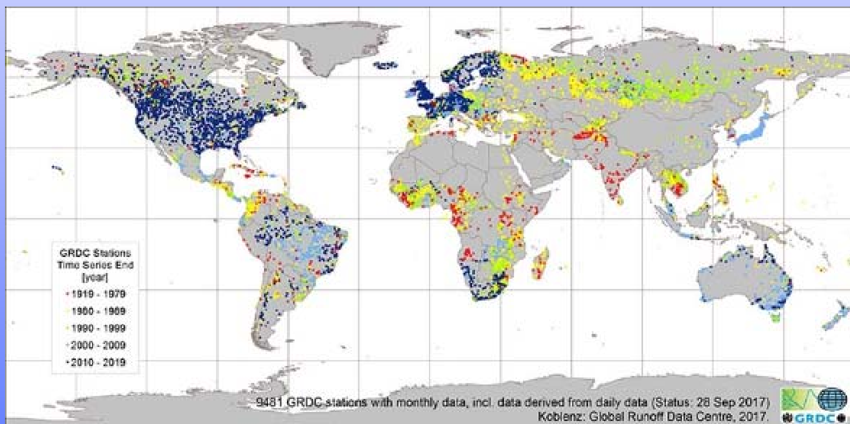
Inadequacy of Surface Observations



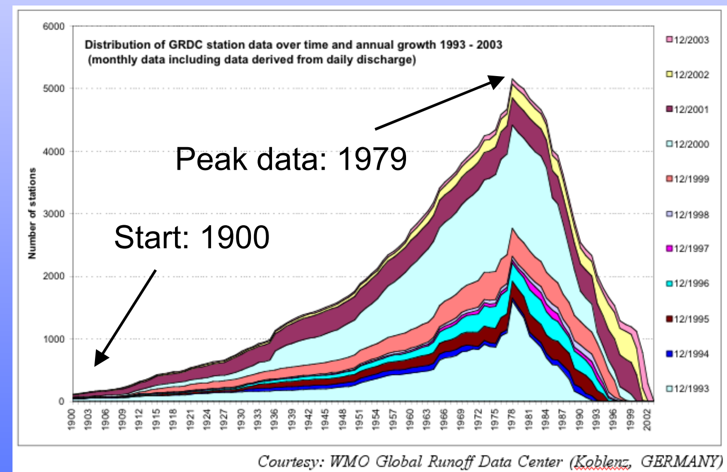
Global Telecommunication System meteorological stations. Air temperature, precipitation, solar radiation, wind speed, and humidity only.



Eight countries make groundwater data publicly available through the Global Groundwater Monitoring Network.



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



WMO Global Runoff Data Centre archive.

Issues include coverage gaps, delays, measurement continuity and consistency, data format and quality control, restrictions on data sharing

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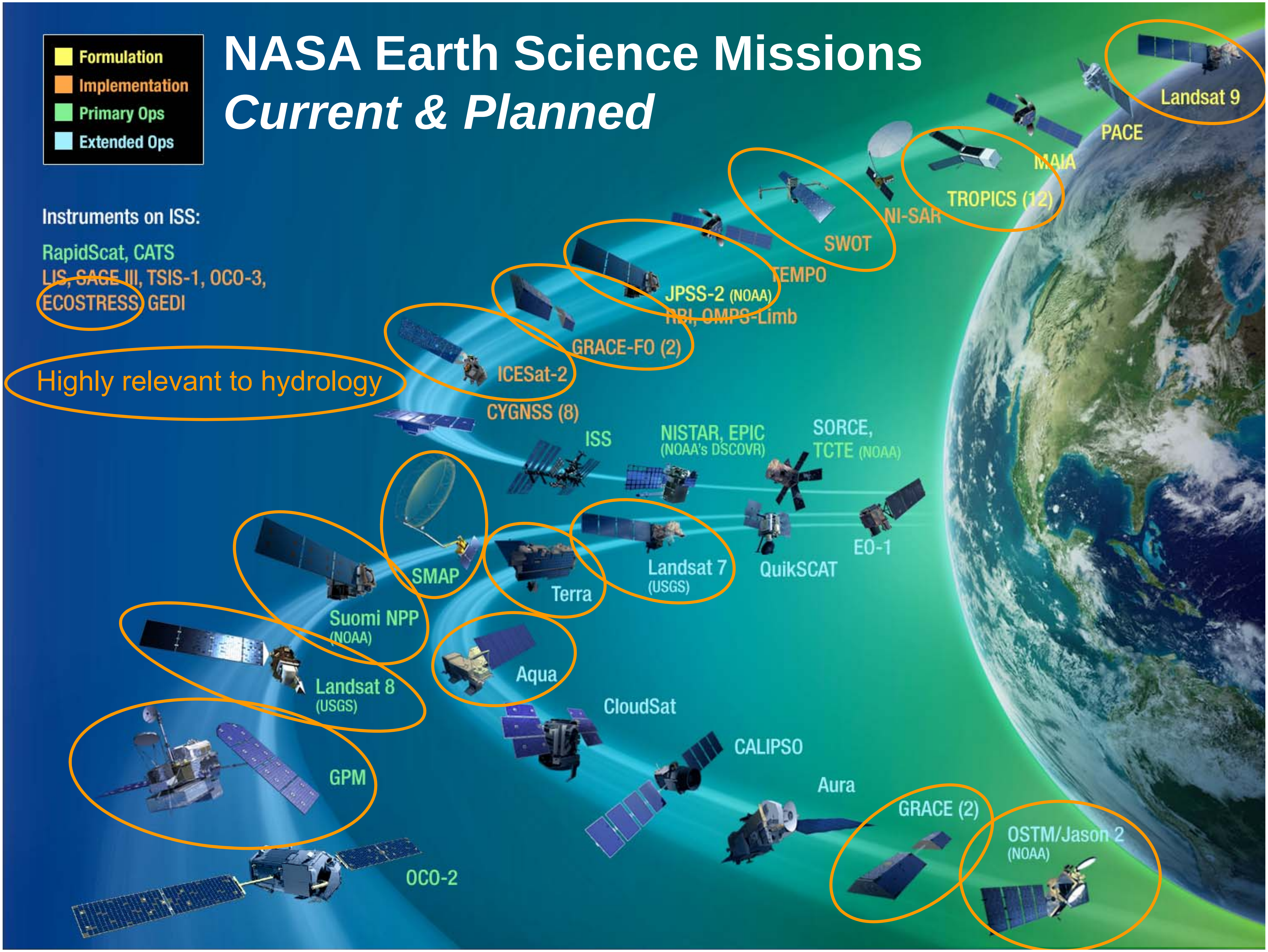
Remote Sensing of the Global Water Cycle

Matt Rodell
NASA GSFC



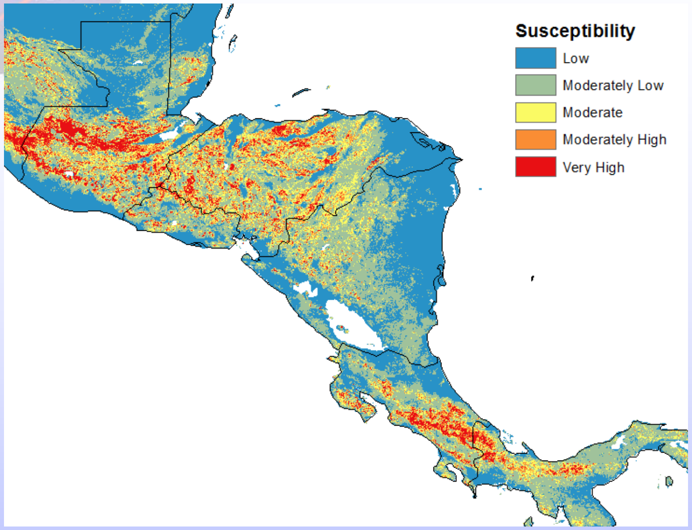
Formulation
Implementation
Primary Ops
Extended Ops
NASA Earth Science Missions
Current & Planned
Instruments on ISS:
RapidScat, CATS
LIS, SAGE III, TSIS-1, OCO-3,
ECOSTRESS, GEDI
Highly relevant to hydrology
Landsat 9
PACE
MAIA
TROPICS (12)
NI-SAR
SWOT
TEMPO
JPSS-2 (NOAA)
RBI, OMPS-Limb
GRACE-FO (2)
ICESat-2
CYGNSS (8)
ISS
NISTAR, EPIC
(NOAA's DSCOVR)
SORCE,
TCTE (NOAA)
SMAP
Terra
Landsat 7
(USGS)
QuikSCAT
EO-1
Suomi NPP
(NOAA)
Landsat 8
(USGS)
Aqua
CloudSat
CALIPSO
GPM
Aura
GRACE (2)
OSTM/Jason 2
(NOAA)
OCO-2

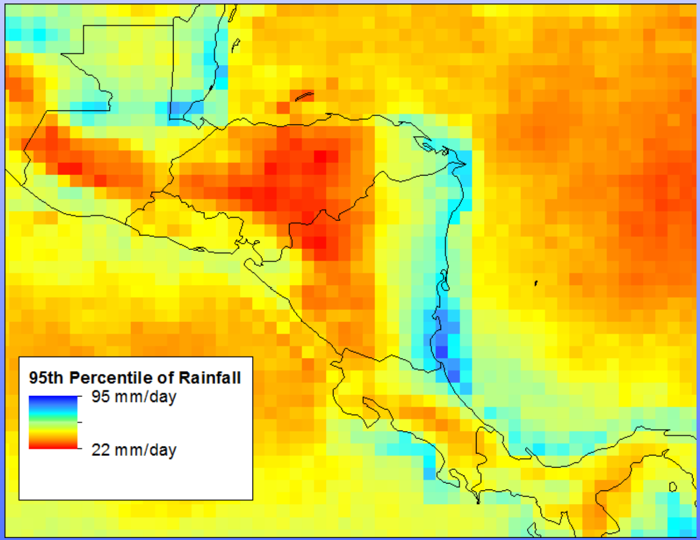
GPM and the IMERG Precipitation Product

Precipitation from GPM core satellite, GPM constellation, and IMERG product
Credit: GSFC Scientific Visualization Studio

Matt Rodell
NASA GSFC

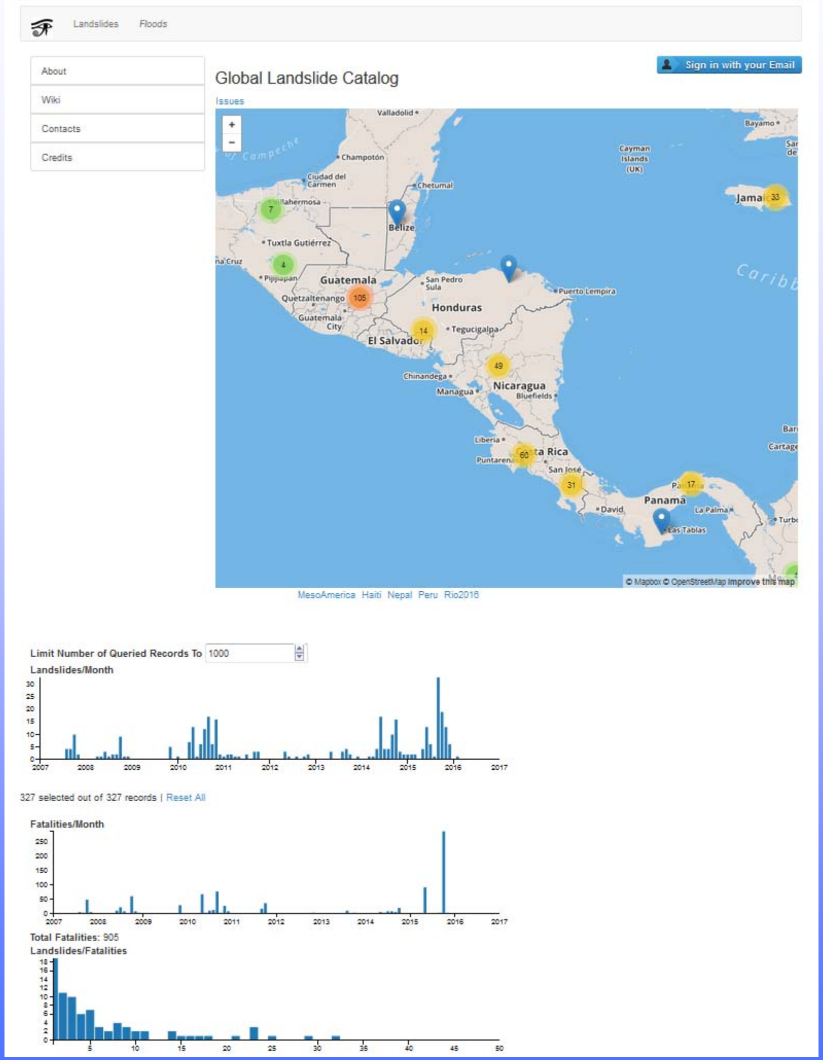
Applying GPM Precipitation for Landslide Hazard Assessment





Credit: Dalia Kirschbaum/GSFC

http://ojo-streamer.herokuapp.com/



Landslides may be predicted based on susceptibility maps (slope, soils, roads, fault zones) and exceedance of daily and antecedent rainfall thresholds

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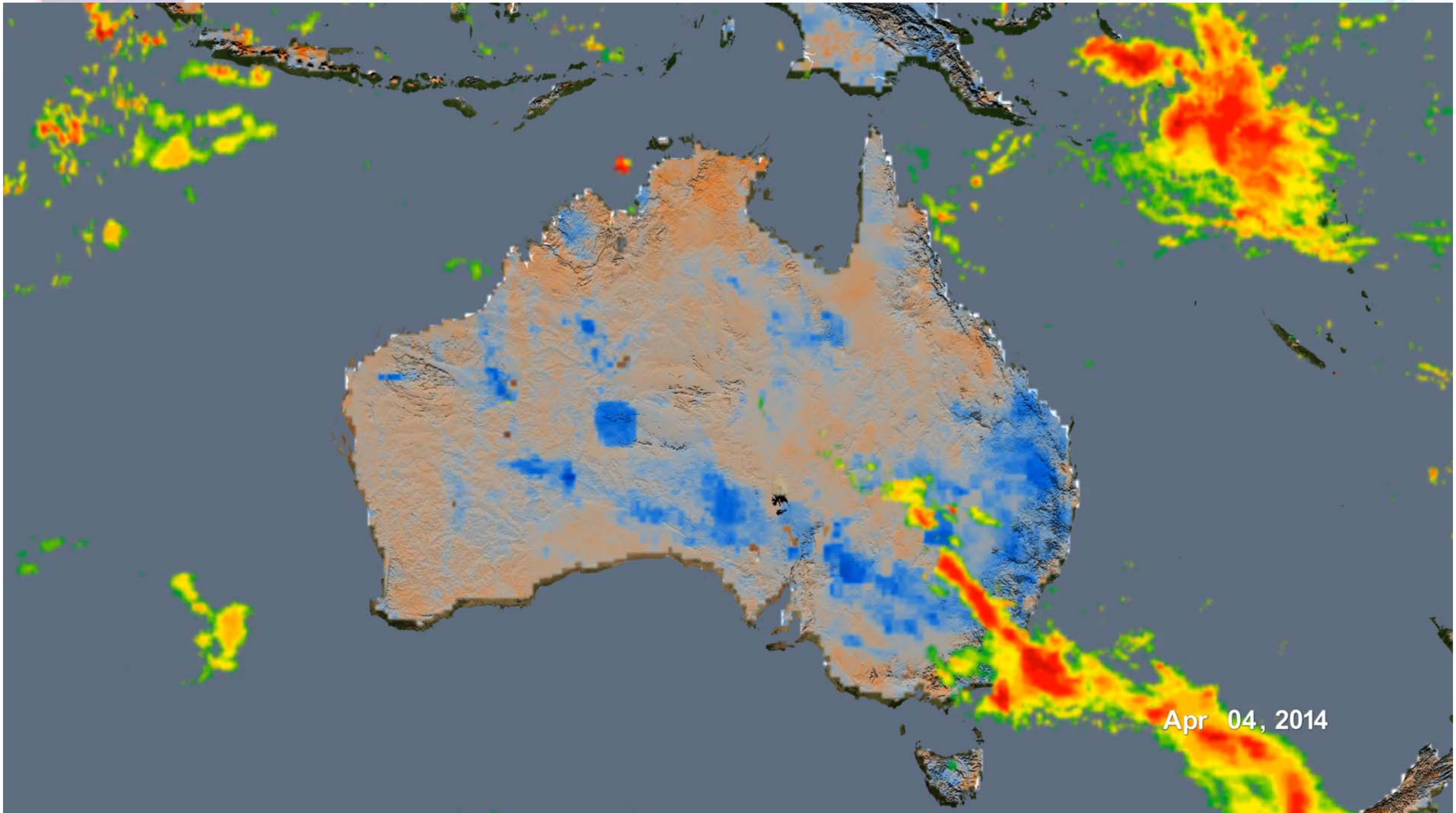
NASA GSFC

Precipitation (GPM) and Soil Moisture (SMOS and SMAP)



Precipitation from GPM and soil moisture based on assimilation of SMOS data
Credit: John Bolten/GSFC and the GSFC Scientific Visualization Studio

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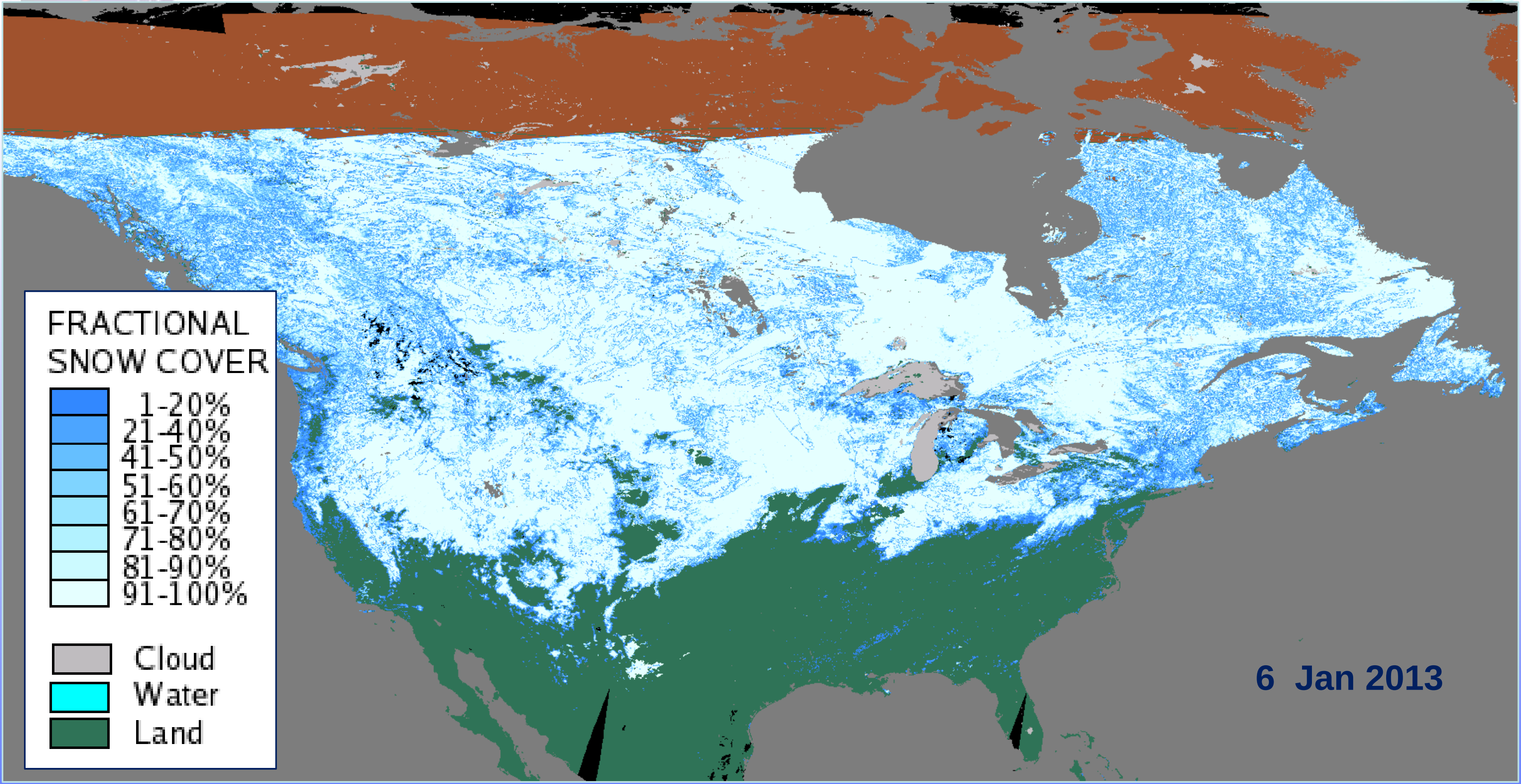
NASA GSFC

MODIS & VIIRS Snow-Cover Map Products



MODIS cloud gap filled (CGF) fractional snow cover map

Hall & Riggs, 2007; Hall et al., 2010

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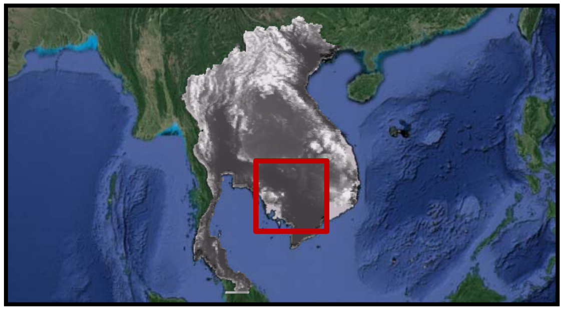
NASA GSFC

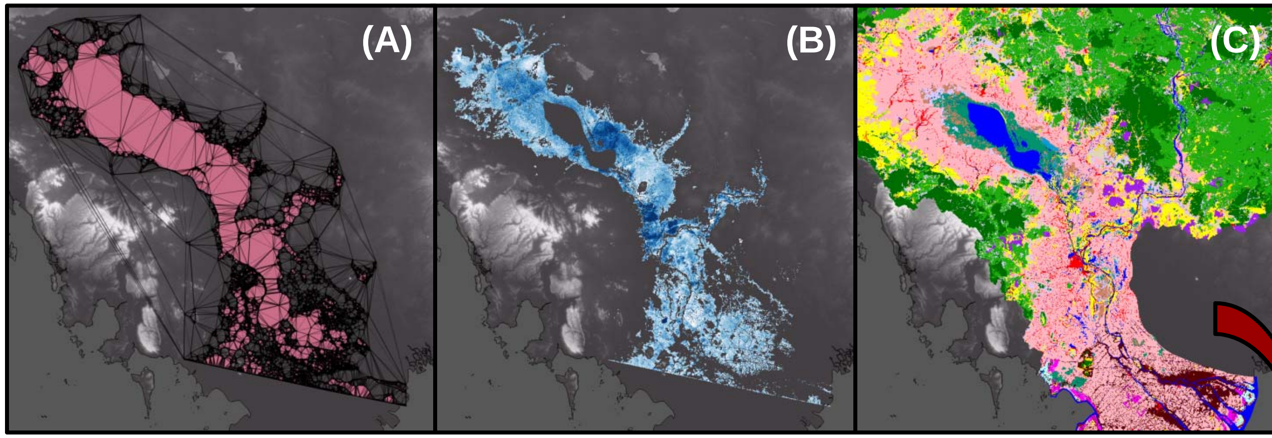
Near Real-Time Flood Detection and Socioeconomic Impact Assessment in the Lower Mekong River Basin

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

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

Figure 1

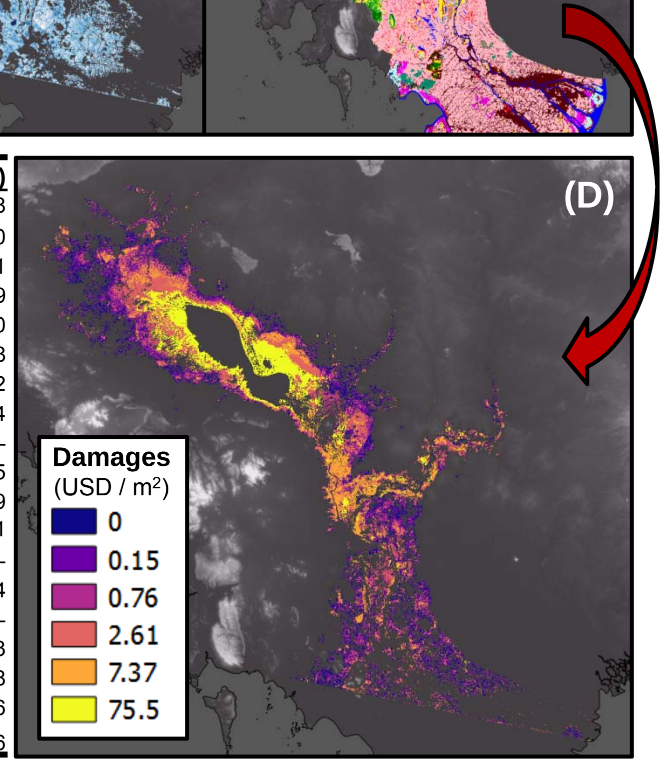




MODIS-derived surface water extents are used to produce flood depth estimates in near real-time. Flood depth estimates are then fed into a standardized flood damage framework to produce damage estimates based on inundated land cover and affected infrastructure.

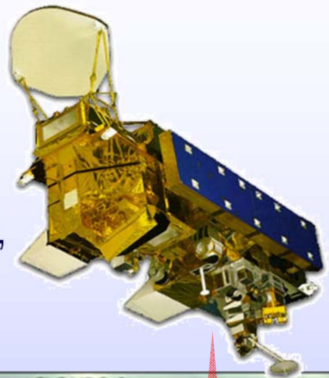
The rapid initial estimates of socioeconomic impacts can provide valuable information to governments, international agencies, and disaster responders in the wake of extreme flood events.

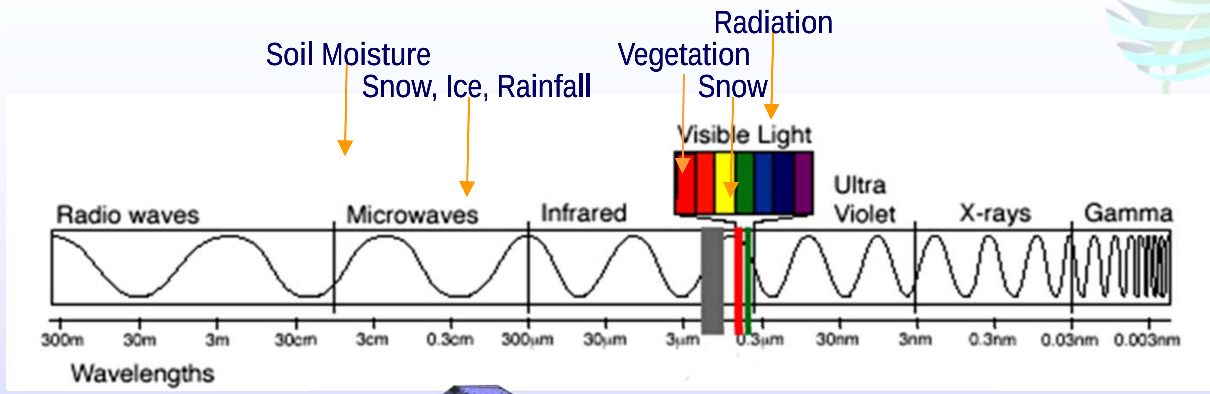
Description	Area (km^2)	Damages (USD)
Rice - 1 crop/yr	12,192.01	2,317,168
Mixed Annual Crops	1,425.17	1,435,970
Cleared before 2010	35.36	35,661
Orchard	242.66	73,169
Flooded Forest	3,113.91	28,265,720
Grassland/Sparse Vegetation	1,767.45	497,578
Deciduous Shrubland	1,155.41	319,502
Urban	205.91	12,604
Barren - Rock Outcrops	67.85	-
Industrial Plantation	1.30	355
Deciduous Broadleaved	7.15	56,089
Evergreen/ Broadleaved	2.18	17,931
Forest Plantation	0.00	-
Bamboo Scrub/Forest	11.09	101,454
Coniferous Forest	0.00	-
Mangrove	1.71	10,693
Marsh/Swamp	493.05	151,308
Aquaculture	5.99	2,496
Aquaculture Rotated with Rice	17.56	3,316

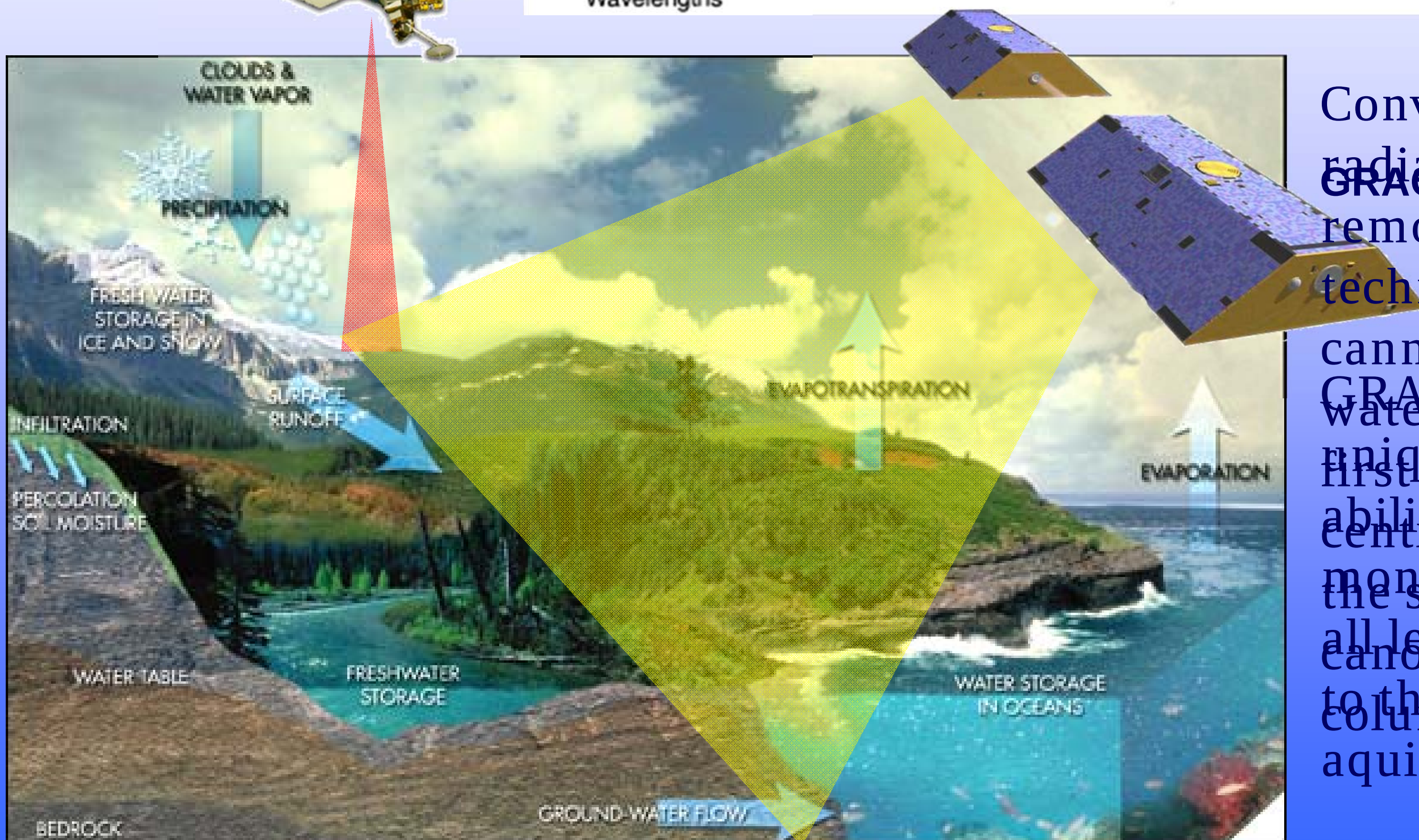


Gravity Recovery and Climate Experiment (GRACE)

Aqua:
MODIS,
AMSR-E,
etc.







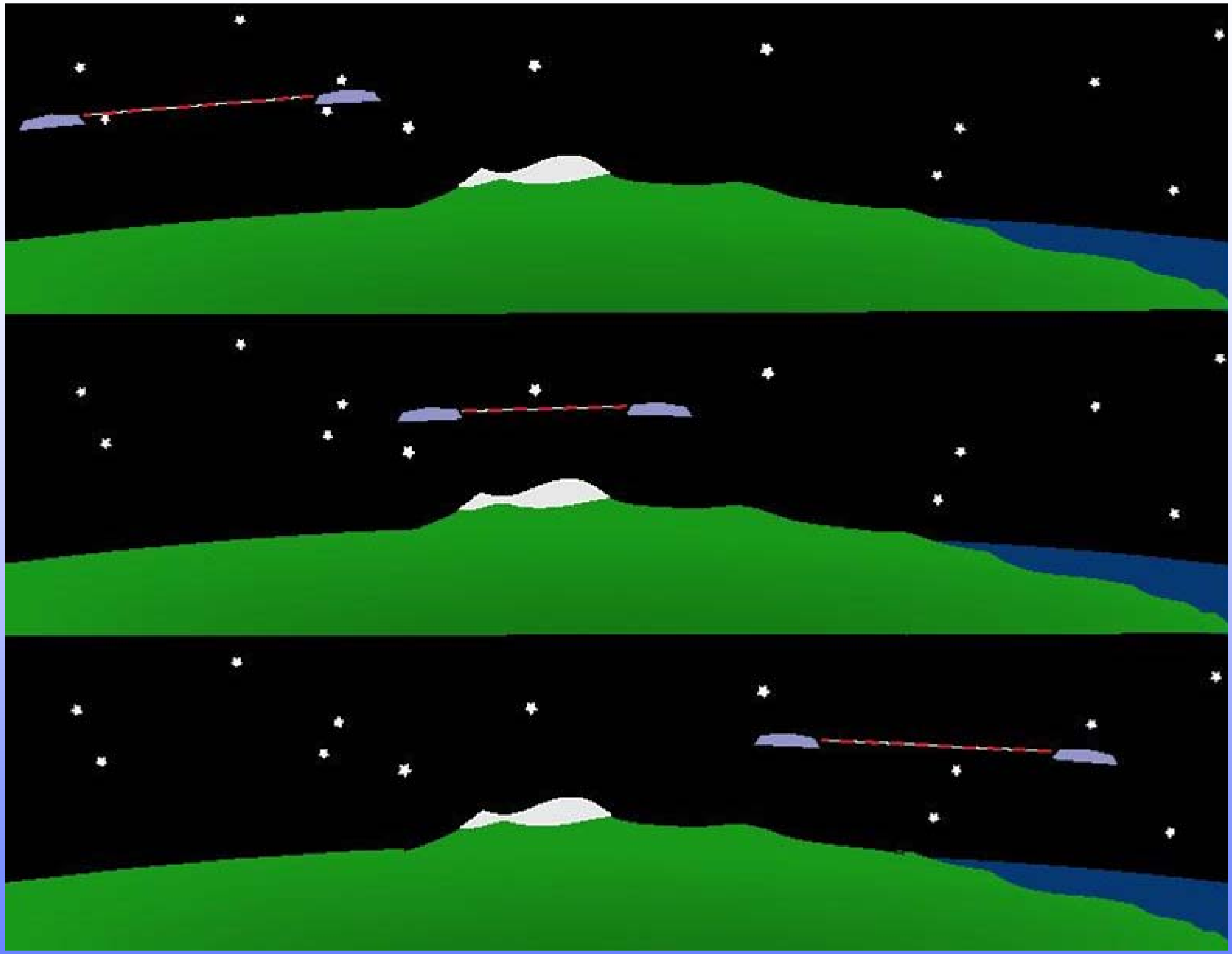
Conventional radiation-based remote sensing technologies cannot sense water below the first few centimeters of the snow-canopy-soil column

GRACE

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

Matt Rodell
NASA GSFC

Gravity Recovery and Climate Experiment (GRACE)



• Two identical satellites flying in tandem, near-polar orbit, ~200 km apart, 500 km initial altitude

• Distance between satellites tracked by K-band microwave ranging system

• Launched 17 March 2002

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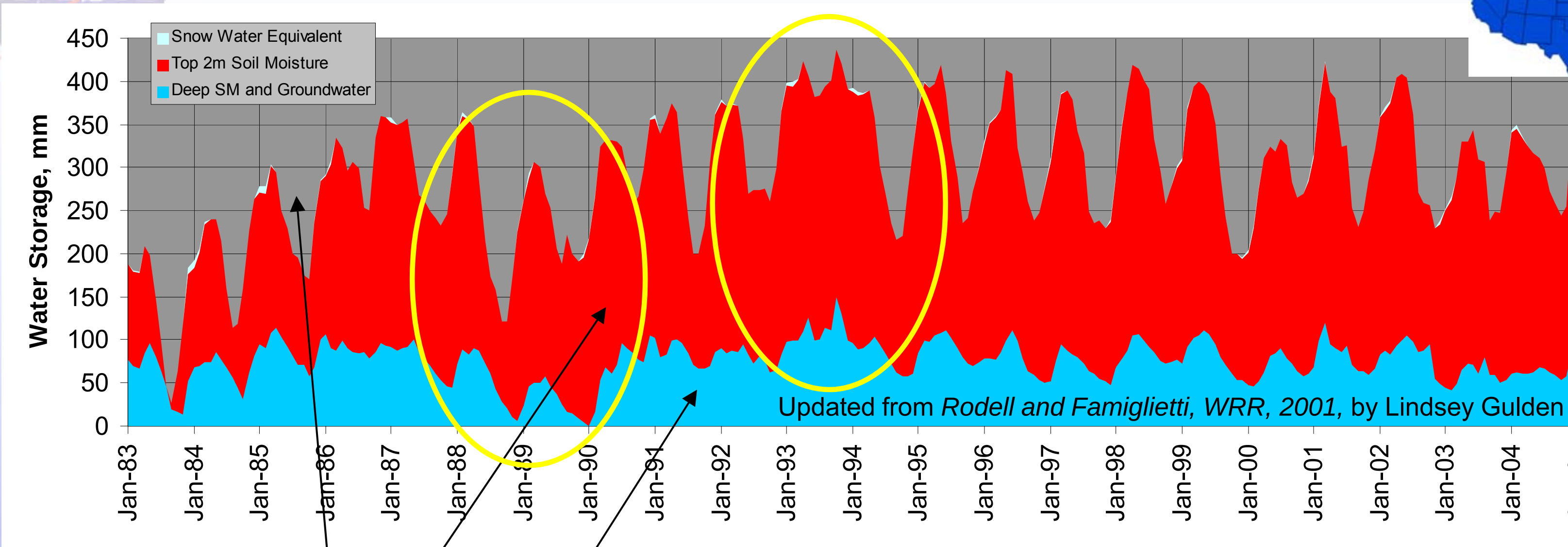
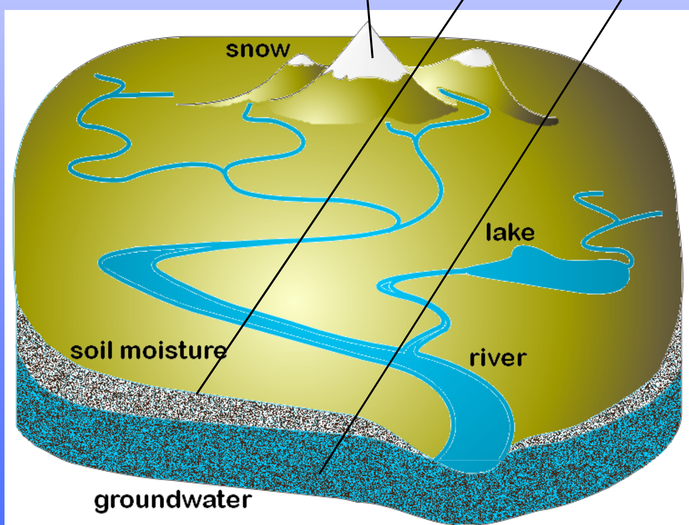
NASA GSFC

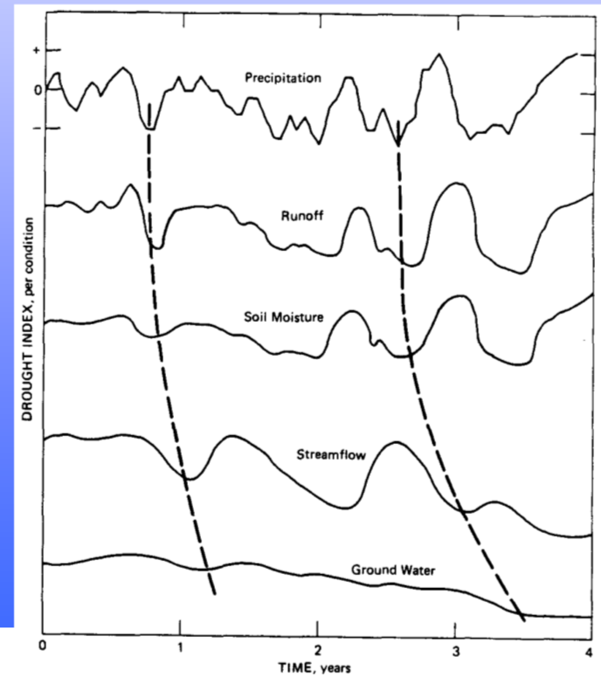
Terrestrial Water Storage Variability





Top: 23-year time series of snow, soil moisture, and groundwater storage in Illinois

Right: Schematic of drought progression in Illinois

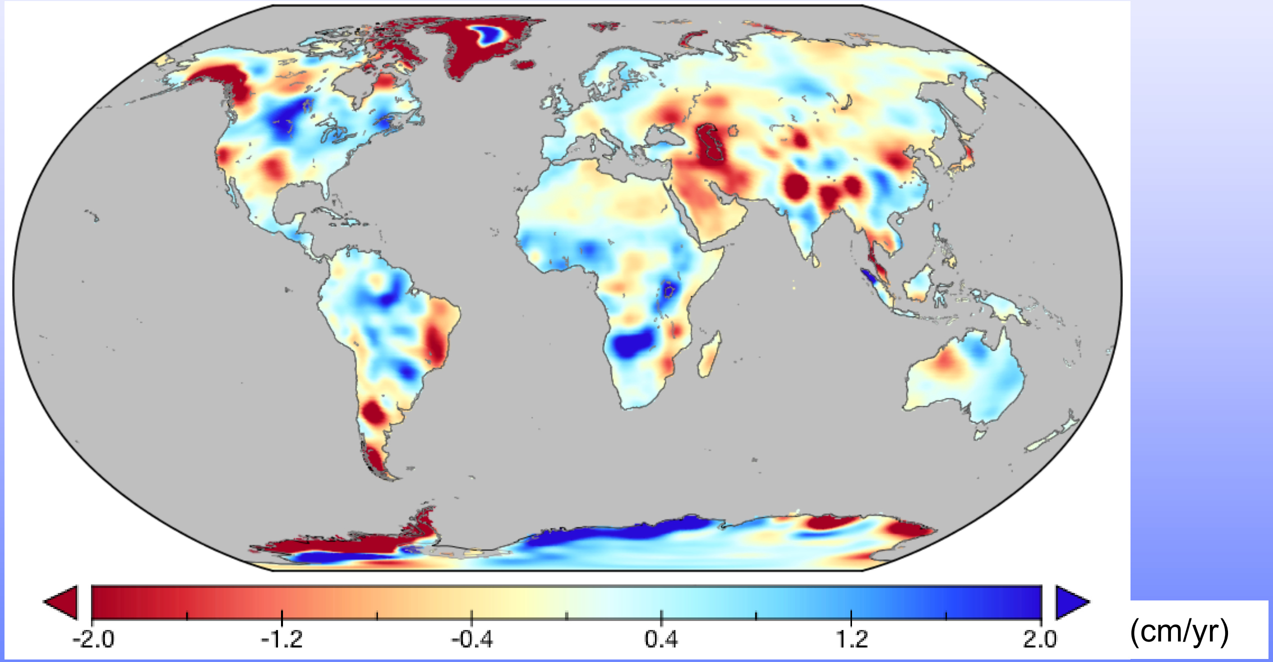


Changnon, 1987

odell
NASA GSFC

“Trends” in Terrestrial Water Storage*, 2002-2016

- Linear rate of change of TWS (cm/yr) after removing the seasonal cycle
- Some trends are real and likely to continue
  - Climate change impacts
  - Human water (mis)management
- Others reflect natural variability and are likely to vanish over time



*based on JPL GRACE Tellus mascon product (Watkins et al., *JGR*, 2015)

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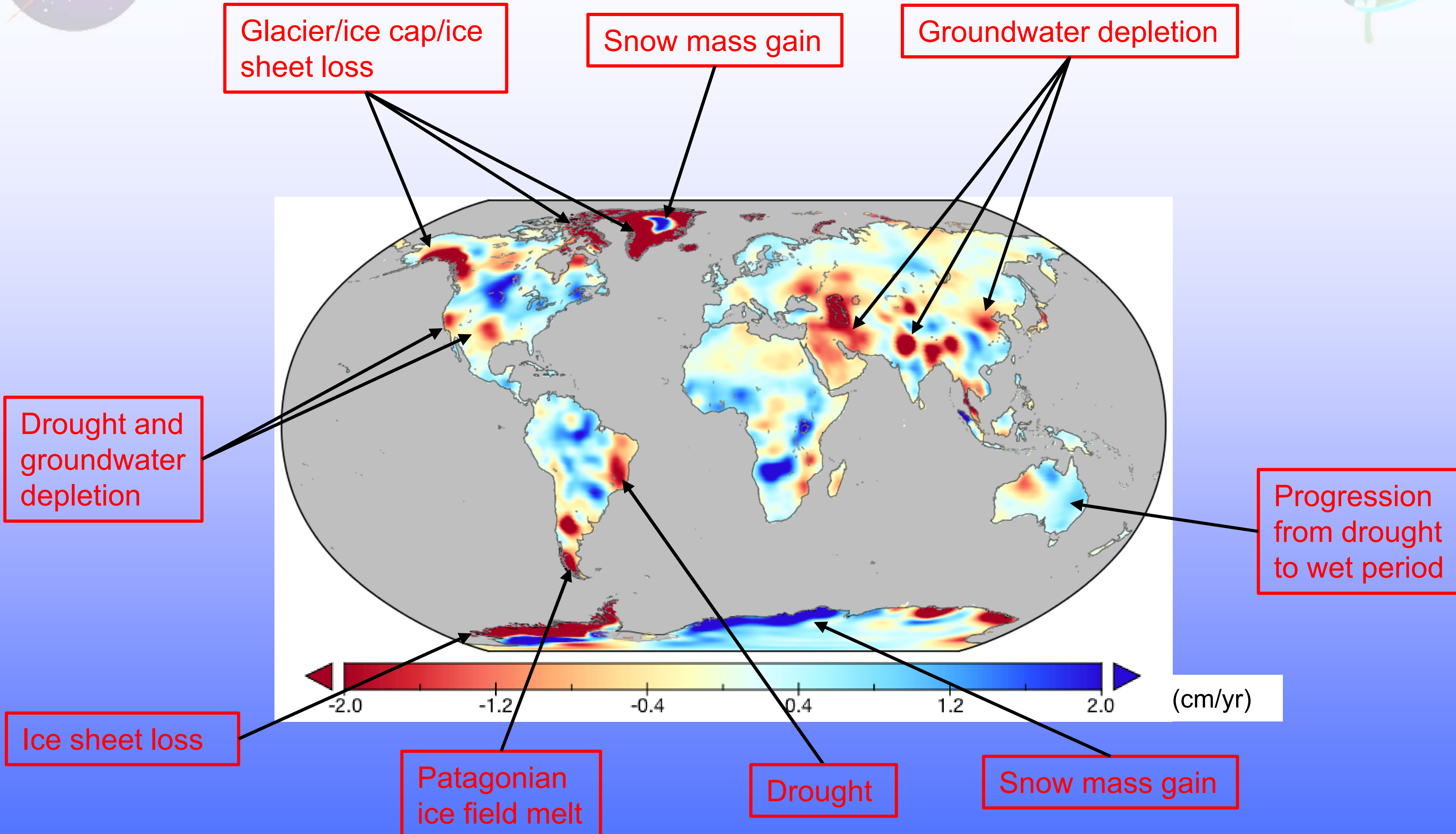
NASA GSFC

Well Understood TWS "Trends"



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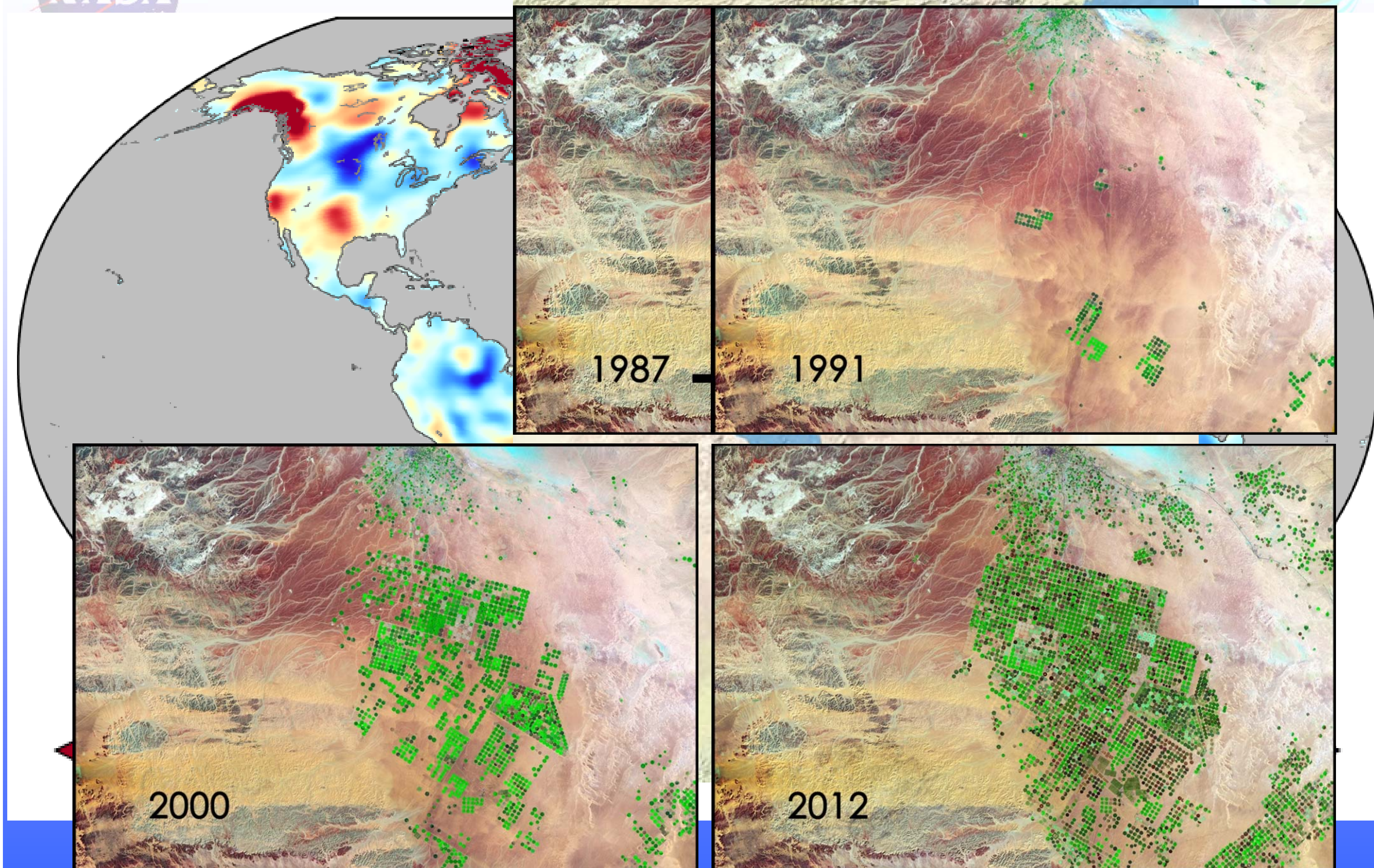
Growth of Irrigation in Saudi Arabia

Emerging Trends in Global Freshwater Storage



Landsat images prepared by Aries Keck, NASA/GSFC

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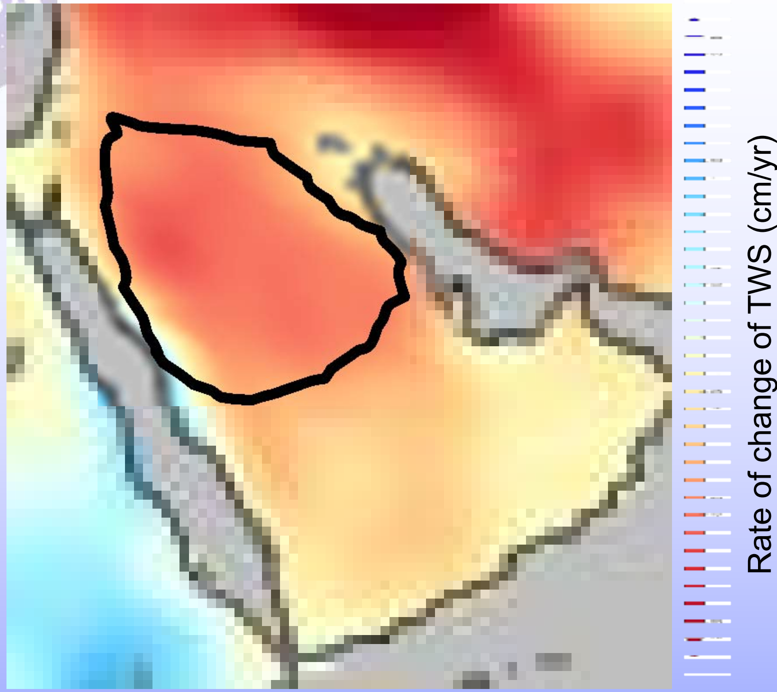
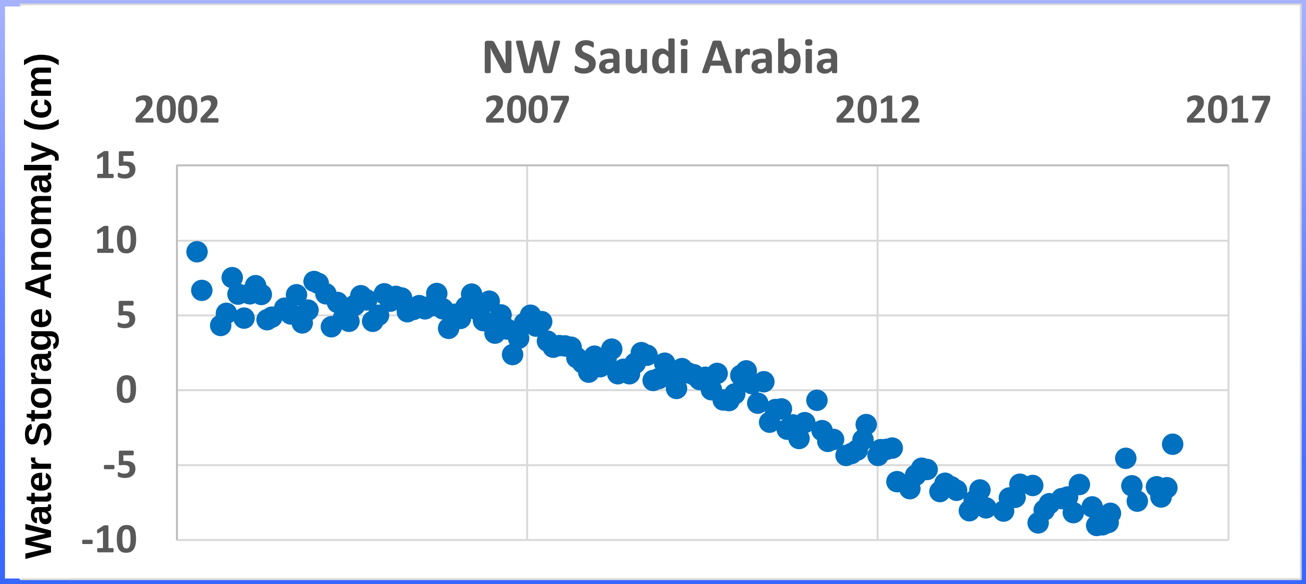
Groundwater Depletion in Saudi Arabia



Terrestrial water storage depletion rate:
-10.5 ±0.2 km^3/yr



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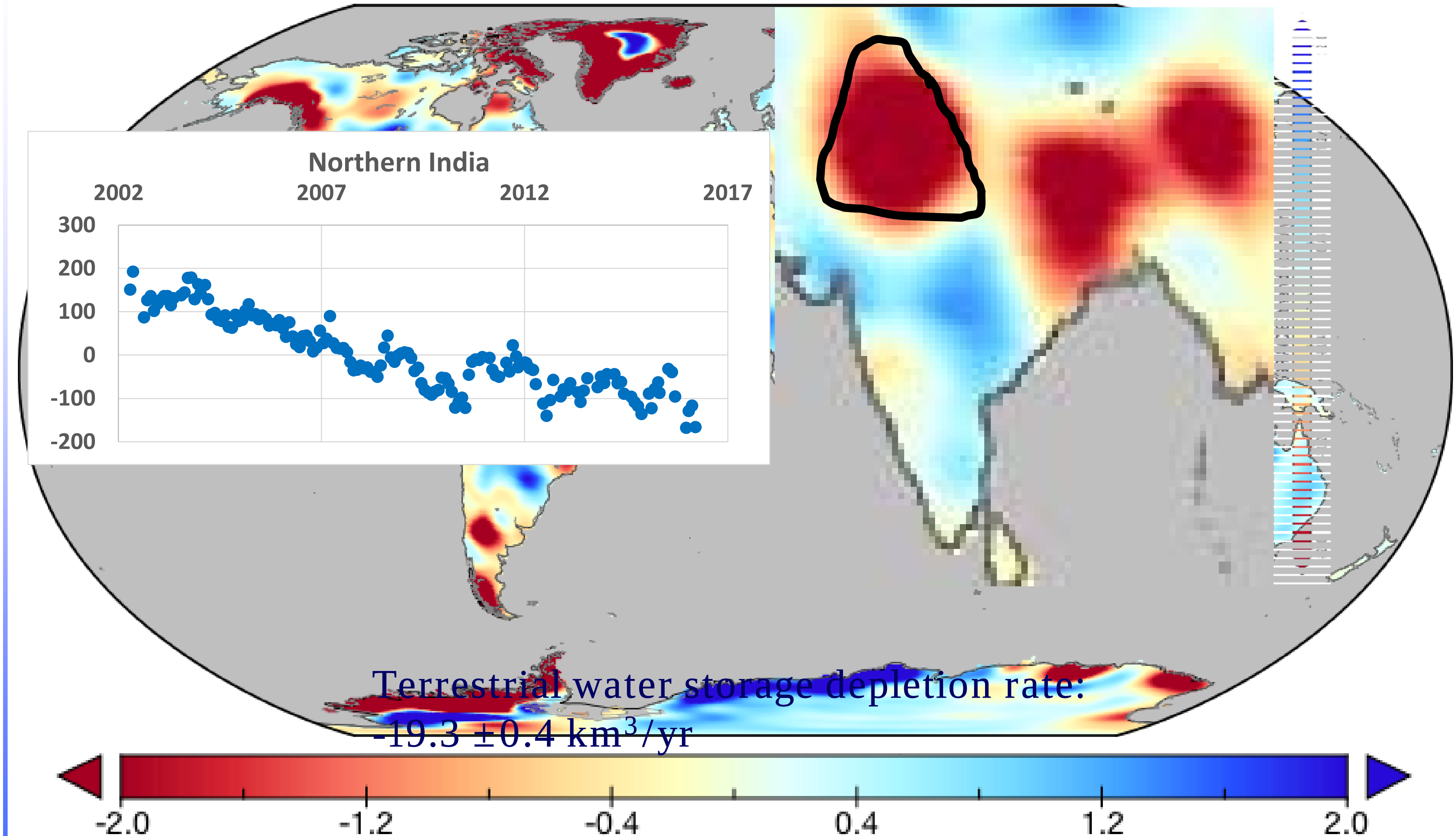
Emerging Trends in Global Freshwater Storage

Groundwater Depletion in Northern India



Trends in terrestrial water storage (cm/yr), including groundwater, soil water, lakes, snow, and ice, as observed by GRACE during 2002-16

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Integration of GRACE and Other Data

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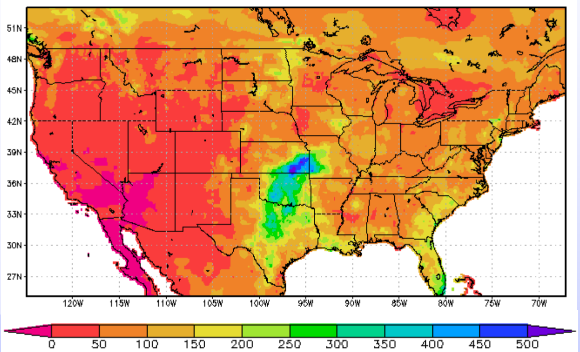
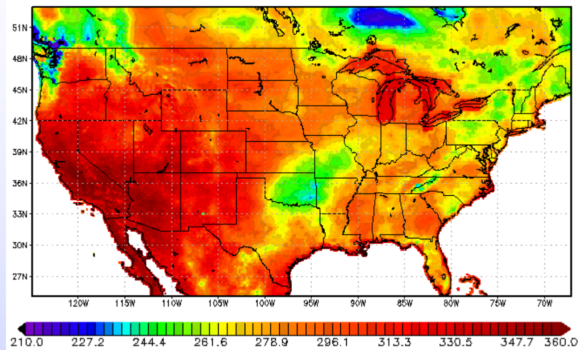
Integration of GRACE and Other Data via Data Assimilation

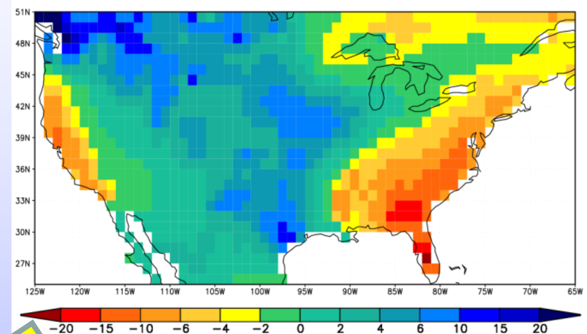
Precipitation (mm/month)



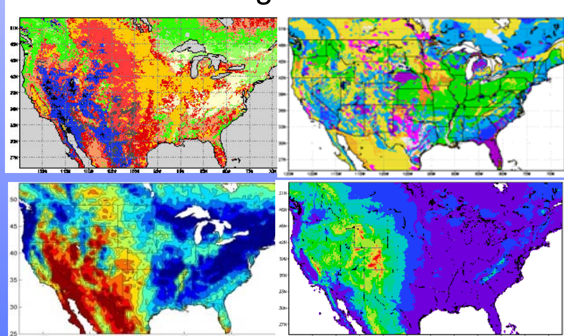
Solar Radiation (W/m2)

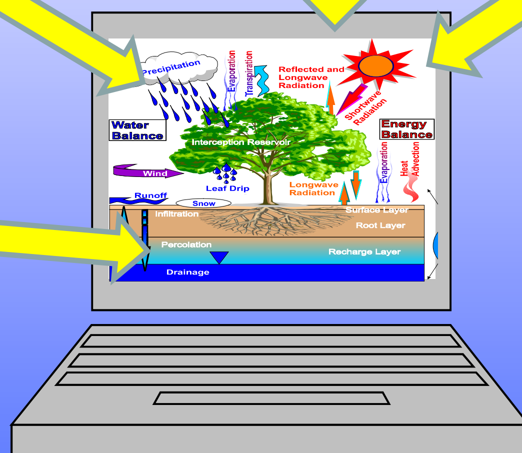


GRACE Water Storage Anomaly (cm)



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

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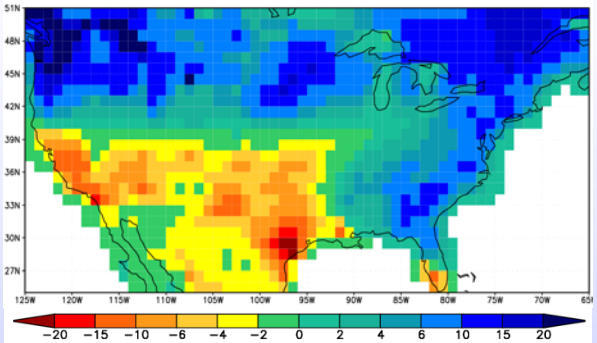
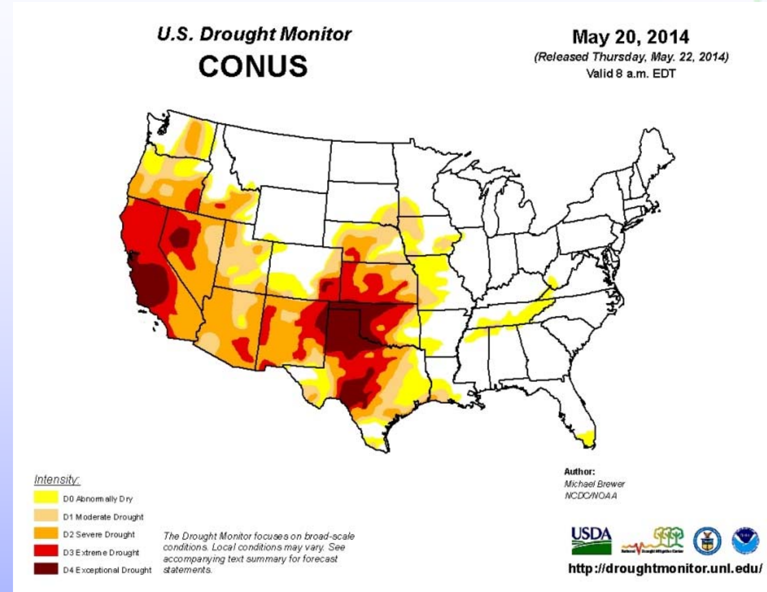
NASA GSFC

GRACE Data Assimilation for Drought Monitoring

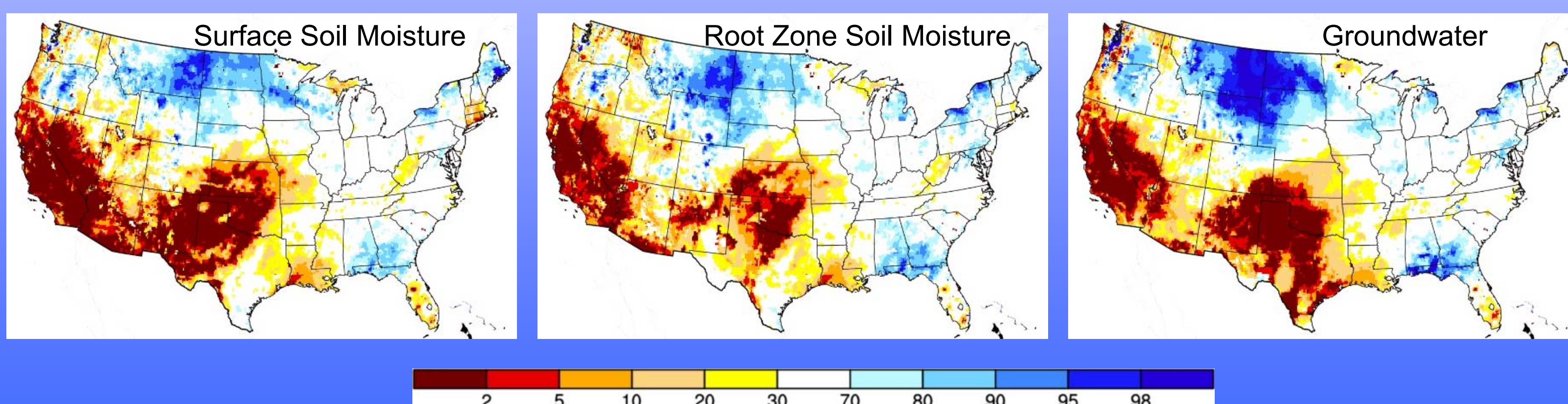
GRACE terrestrial water storage anomalies (cm equivalent height of water) for May 2014 (Tellus CSR RL05 scaled).





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

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 19 May 2014.

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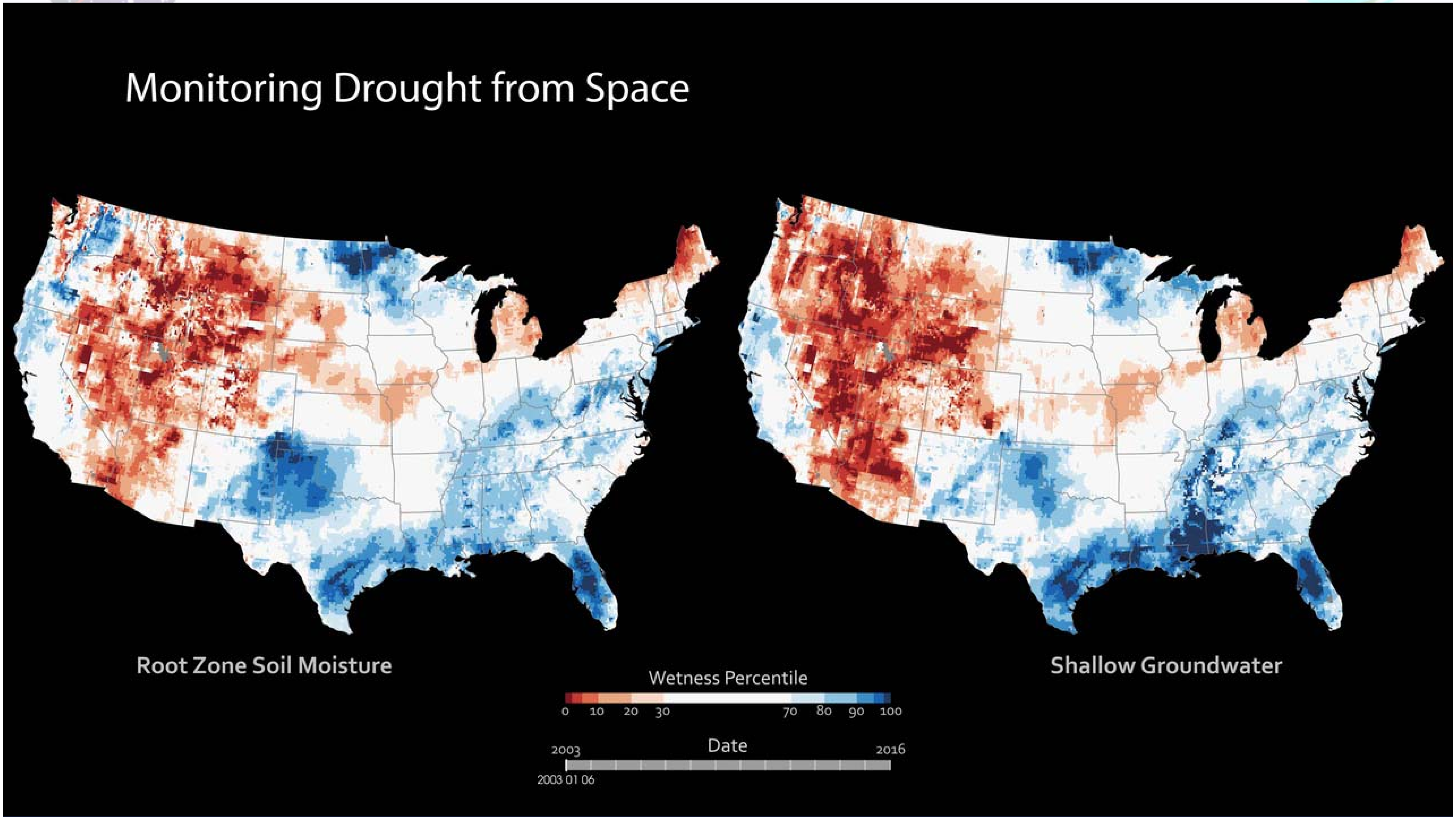
NASA GSFC

GRACE-DA Drought Indicators



Visualization prepared by Marit Jentoft-Nilsen, NASA/GSFC

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