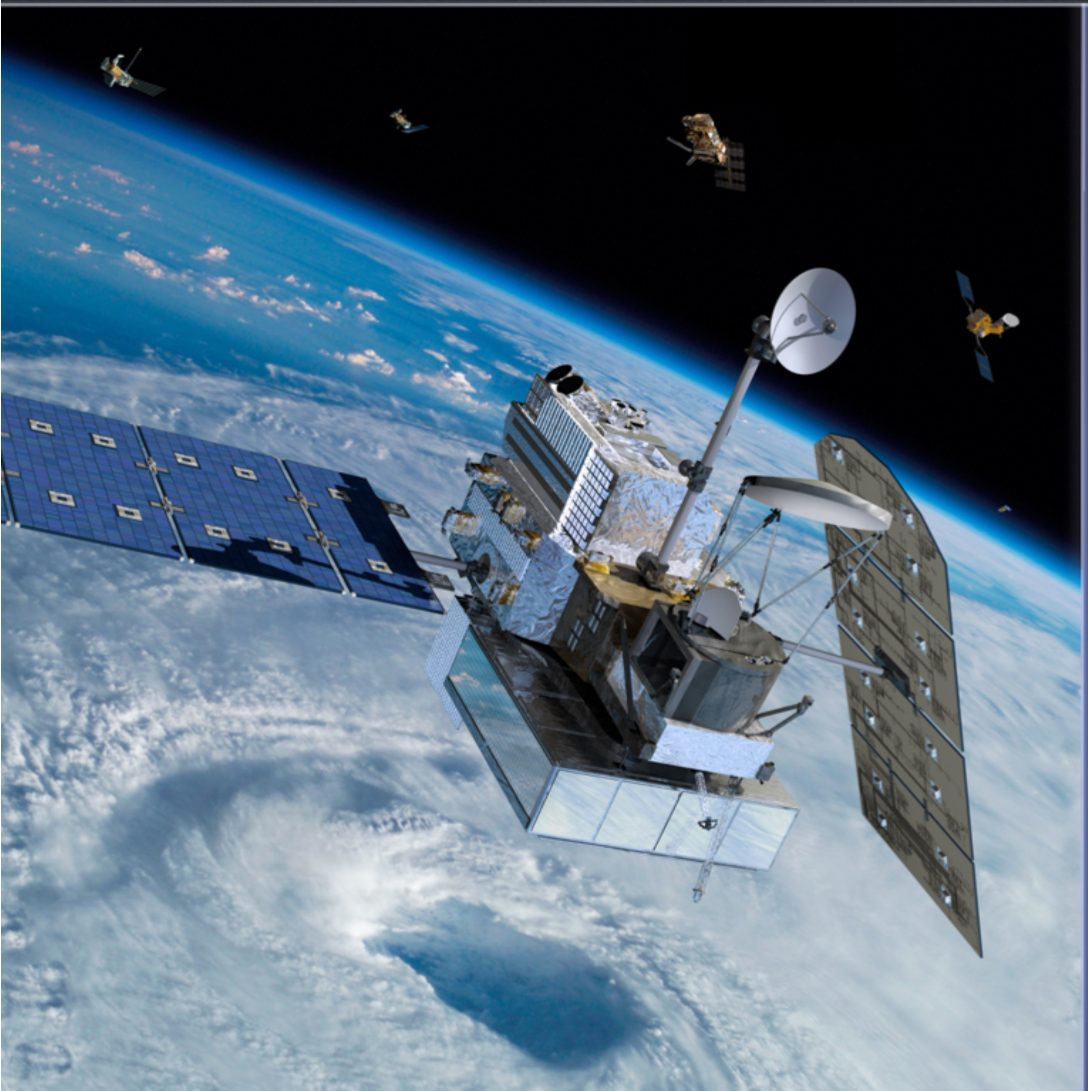
Global Precipitation Measurement (GPM) Mission



Dalia Kirschbaum

Associate Deputy Project Scientist for GPM

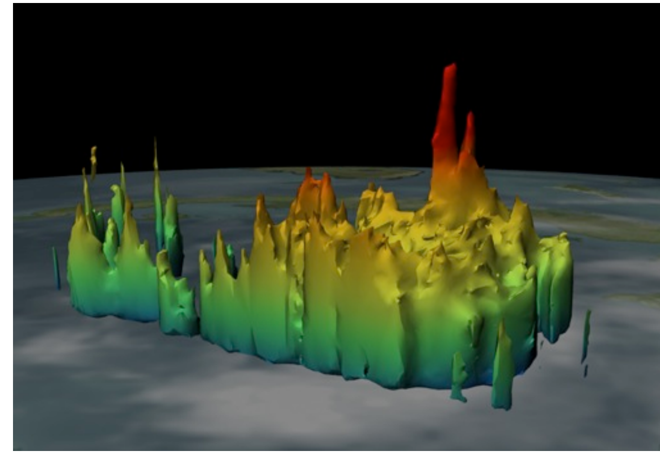
Goddard Space Flight Center

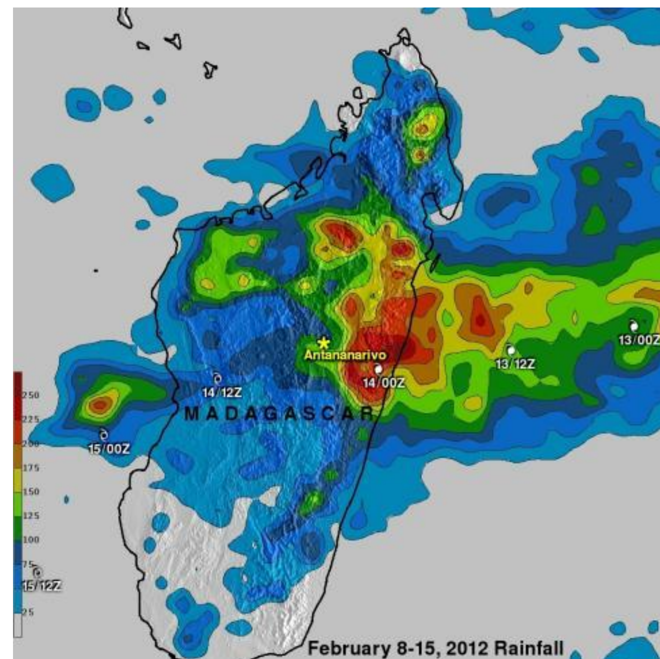
Tropical Rainfall Measuring Mission

- Launched in 1997 to measure tropical rainfall, ended in 2015
- TRMM has a 17-year record of precipitation from latitudes ~35°North to 35°South
- Partnership between NASA and the Japan Aerospace Exploration Agency (JAXA)
- Data at http://trmm.gsfc.nasa.gov

GPM instrument enhancements and improved retrievals estimate light rainfall and snow typically found in higher latitudes

Hot Towers observed in Hurricane Wilma

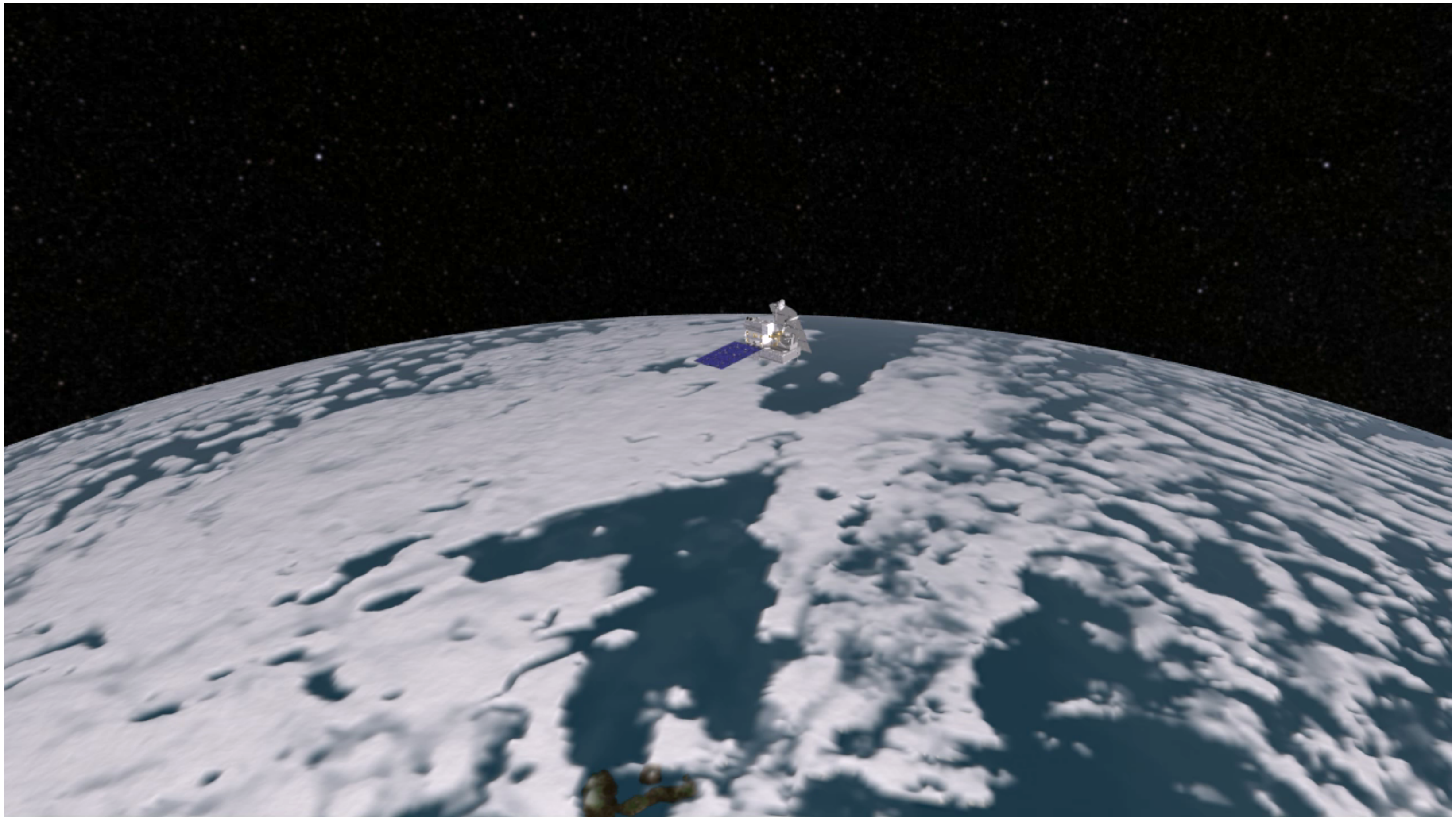




Rainfall Accumulation from Tropical Cyclone Giovanna, triggering deadly floods in Madagascar

GLOBAL PRECIPITATION MEASUREMENT

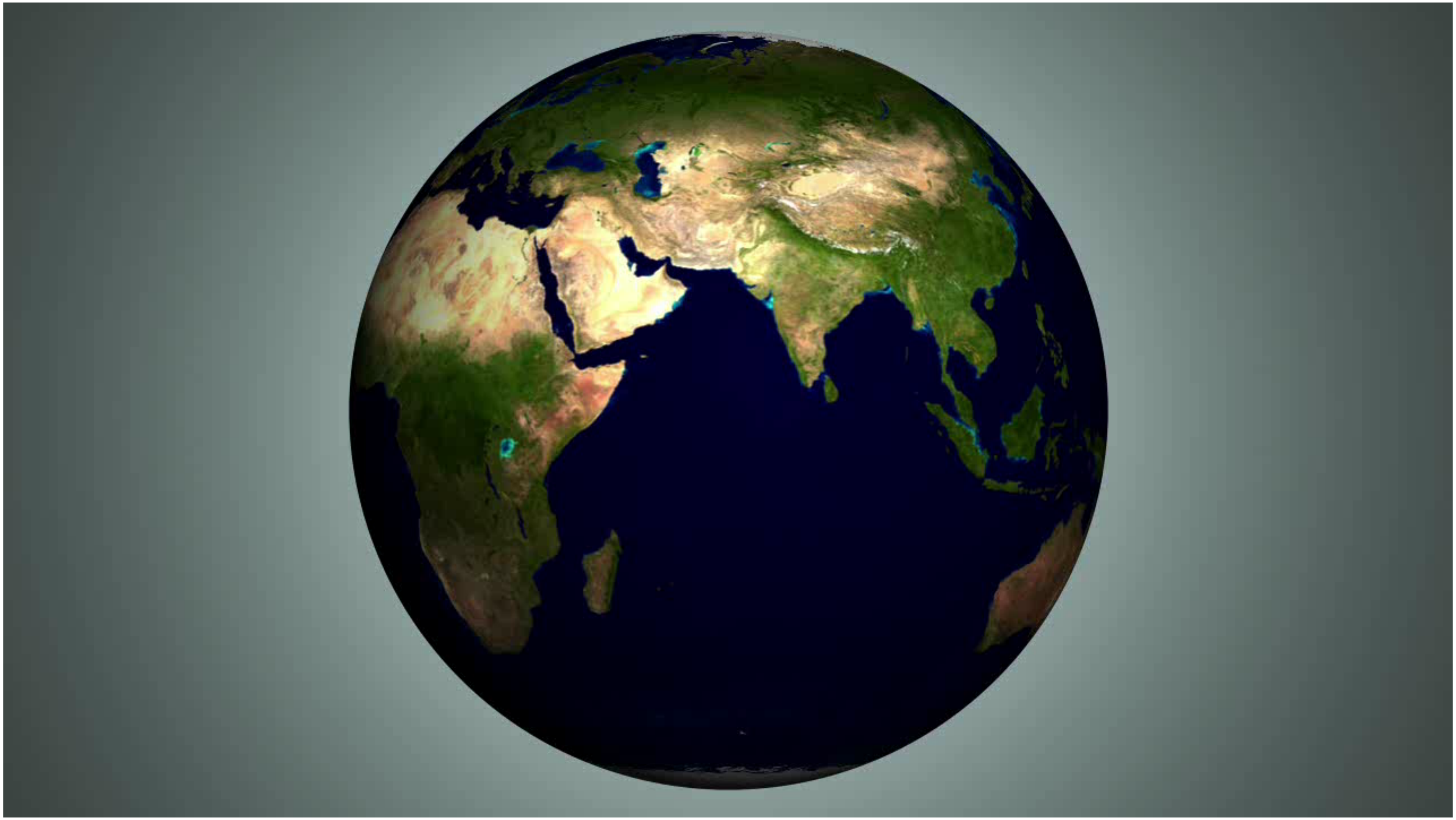
The GPM Core Observatory



Dual-frequency Precipitation Radar (DPR): Ku-Ka bands
Two different radar frequencies look at precipitation in 3-D, similar to a CT scan

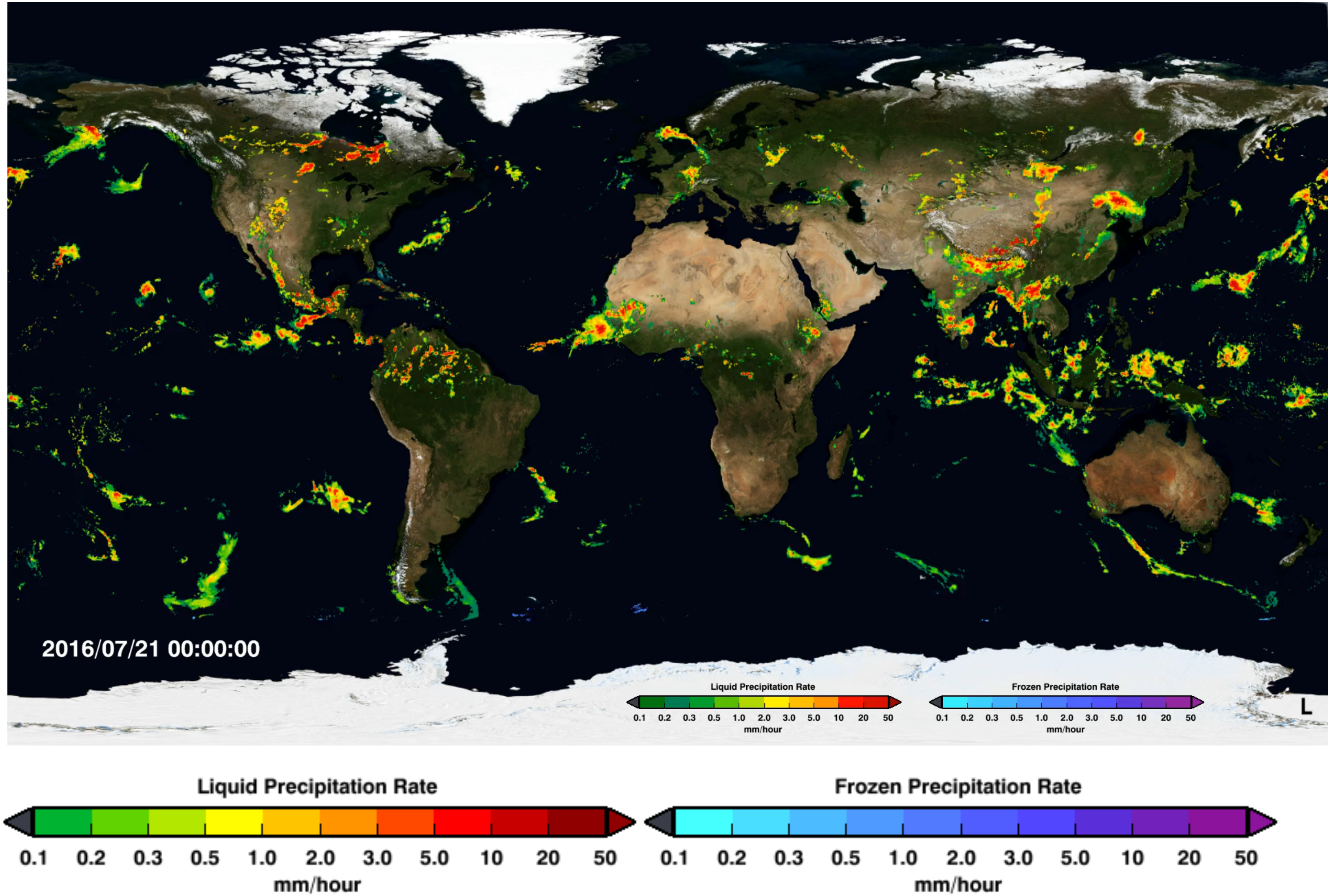
GPM Microwave Imager (GMI): 10-183 GHz
13 channels provide an integrated picture of the energy emitted by precipitation, similar to an X-ray

Global Precipitation Measurement (GPM)



Multi-Satellite Precipitation Data (30 min, 10km by 10km)

IMERG: Integrated Multi-satellitE Retrievals for GPM



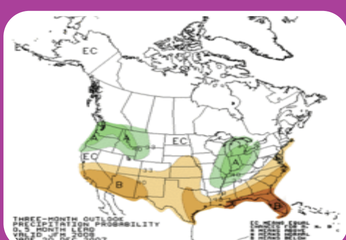
Societal Benefit Areas

Extreme Events and Disasters

- Landslides
- Floods
- Tropical cyclones
- Re-insurance

Water Resources and Agriculture

- Famine Early Warning System
- Drought
- Water Resource management
- Agriculture



Weather, Climate & Land Surface Modeling

- Numerical Weather Prediction
- Land System Modeling
- Global Climate Modeling

Public Health and Ecology

- Disease tracking
- Animal migration
- Food Security

Landslides & Flooding

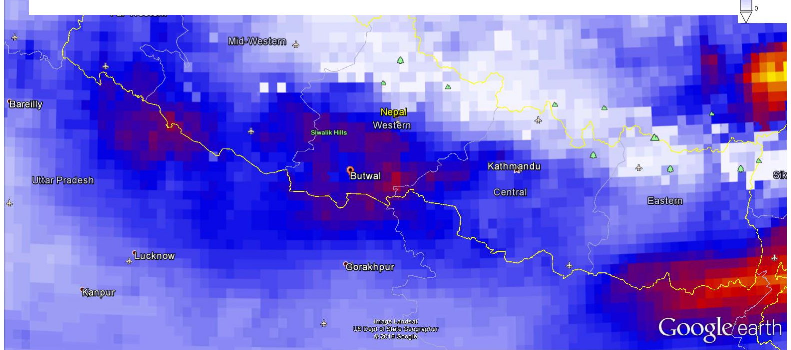
TRMM & GPM provides rain accumulation and distribution data at high resolution to advance predictions of high-impact natural hazard events

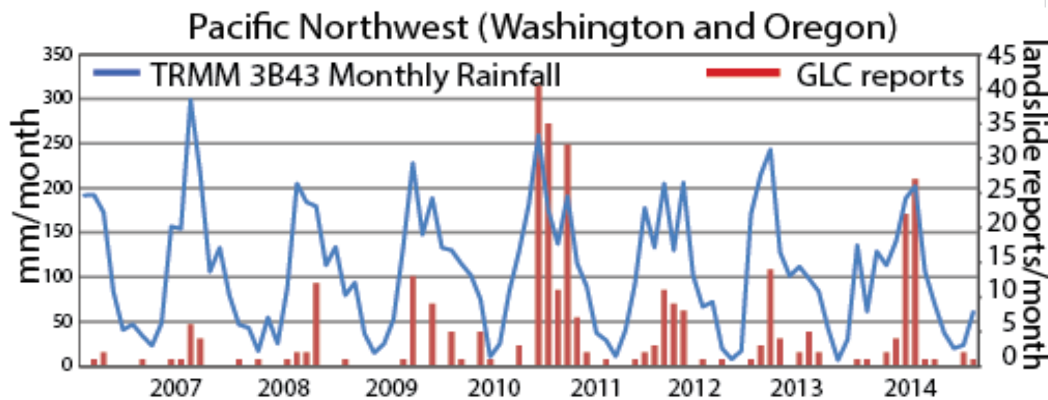
Dozens dead after flash floods and landslides in Nepal

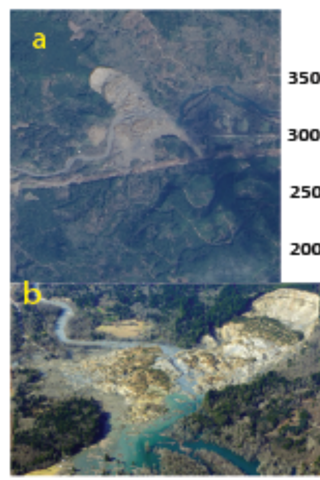
4 hours ago

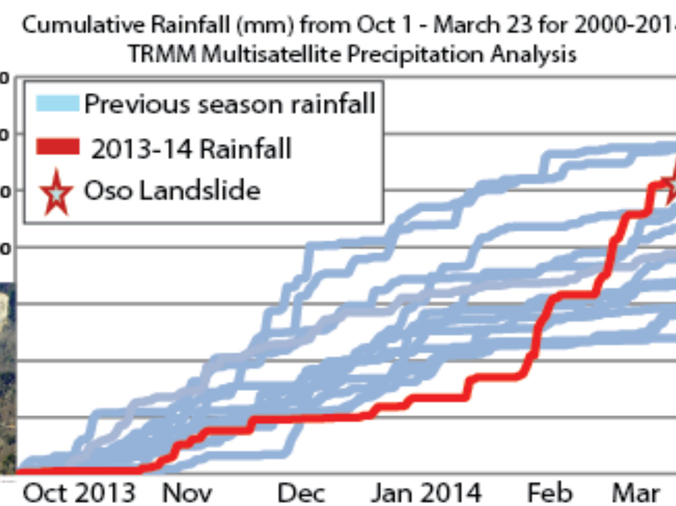
Dozens of people have died in Nepal as flash floods and landslides, caused by monsoon rains, have swept through villages.

Amateur video from Butwal in Nepal's Rupandehi District shows water pushing through flood defences.









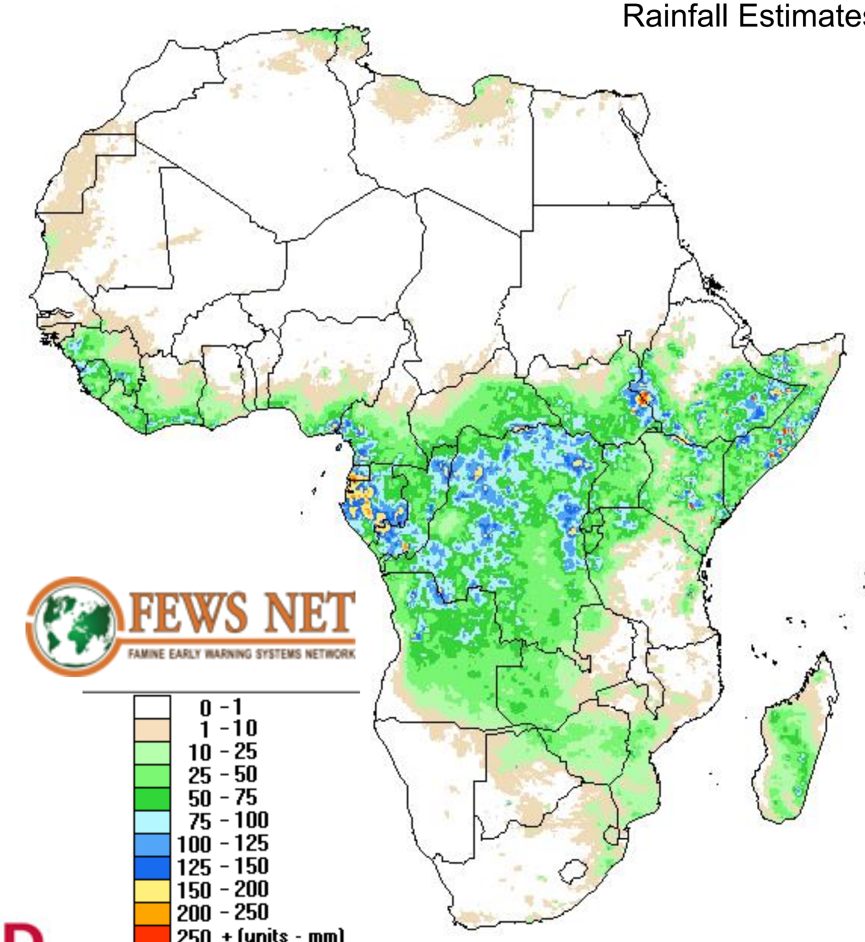
Agriculture and Drought

http://farmlandgrab.org

www.climatecentral.org

Famine Earth Warning System (FEWS) relies on TRMM and other satellites to anticipate poor growing seasons.

Rainfall Estimates



USGS science for a changing world | USAID FROM THE AMERICAN PEOPLE

http://earlywarning.usgs.gov

For more information on the TRMM and GPM Missions:

http://gpm.nasa.gov; http:/gpm.nasa.gov/education

www.nasa.gov/gpm; Movies at: http://svs.gsfc.nasa.gov/

Twitter: NASA_Rain (11K followers) Facebook: NASA.Rain (>20K)

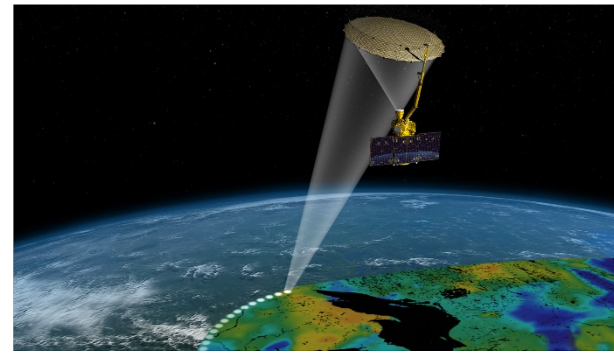
GPM Data Products

Product Level	Description	Coverage
Level 1B GMI, GMI-2 Level 1C GMI, GMI-2 *Latency ~ 1 hour*	Geolocated Brightness Temperature and intercalibrated brightness temperature	Swath, instrument field of view (IFOV)
Level 1B DPR	Geolocated, calibrated radar powers	Swath, IFOV (produced at JAXA)
Level 1C, partner radiometers	Intercalibrated brightness temperatures	Swath, IFOV
Level 2 GMI, GMI2 *Latency ~1 hour*	Radar enhanced (RE) precipitation retrievals	Swath, IFOV
Level 2 partner radiometers	RE precipitation retrievals from 1C	Swath, IFOV
Level 2 DPR *Latency ~3 hours*	Reflectivities, Sigma Zero, Characterization, DSD, Precipitation with vertical structure	Swath, IFOV (Ku, Ka, combined Ku/Ka)
Level 2 combined GMI/DPR *Latency ~3 hours*	Precipitation	Swath, IFOV (initially at DPR Ku swath and then at GMI swath)
Level 3 Latent Heating (GMI, DPR, Combined)	Latent Heating and associated related parameters	0.5 x 0.5 daily and monthly grid
Level 3 Instrument Accumulations	GMI, partner radiometers, combined and DPR	0.1 x 0.1 daily and monthly grid
Level 3 Merged Product	Merger of GMI, partner radiometer, and IR	0.1 x 0.1 hourly grid
Level 4 Products	Model assimilated data	Fine temporal and spatial scale TBD

SMAP

SMAP: Soil Moisture Active Passive

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)
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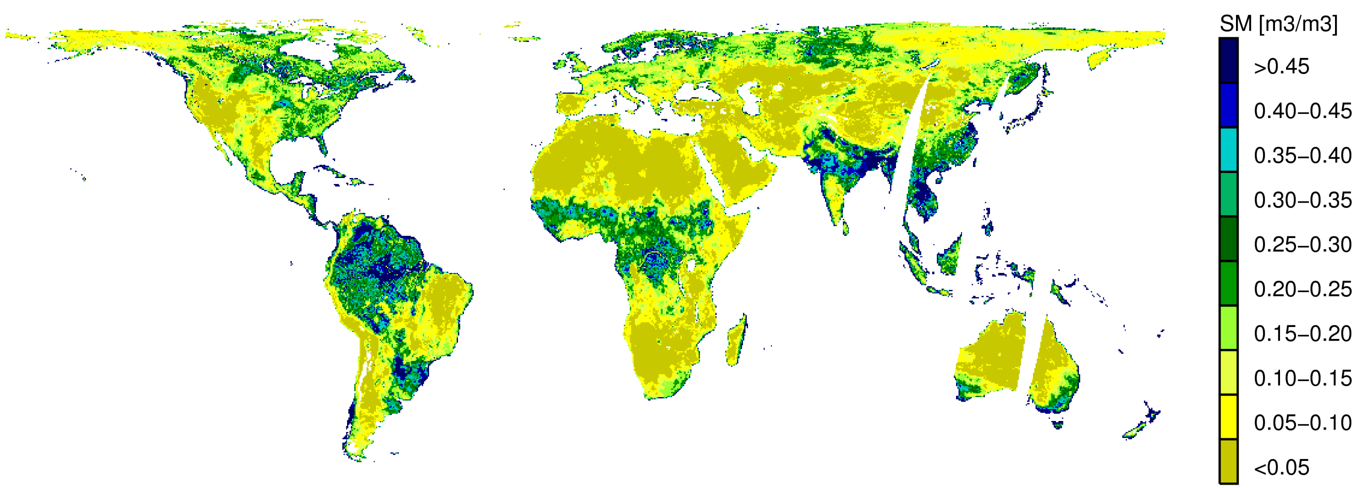
L4_SM	Soil Moisture (Surface and Root Zone)	9 km	7 days	Science Value-Added
L4_C	Carbon Net Ecosystem Exchange (NEE)	9 km	14 days	

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

SMAP

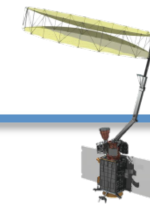
[1] Overview
[2] System
Current
Updated
Data Products
[3] Evaluation
[4] Summary

Level-3 (L3) soil moisture
Passive only product
Spatial Coverage: N: 85.044, S: -85.044, E: 180, W: -180
Spatial Resolution: 36 km x 36 km
Temporal Coverage: 2015-03-31-present
EASE-Grid, Version 2.0



SMAP L3, Passive: 2015/07/28-2015/07/30

Status of SMAP (Soil Moisture Active Passive) Mission



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-- routine science operations began on March 31, 2015

-- the L band radiometer continues to work well; the L band radar transmitter failed on July 7, 2015

-- validated L1 instrument data and beta versions of all L2-L4 products were released to the DAACs by November 1, 2015

-- validated versions of the L2-L4 products are due to be released in May, 2016

-- the SMAP Freeze/Thaw team is currently testing a passive-only algorithm for the SMAP L3_FT product given the demise of the SMAP radar

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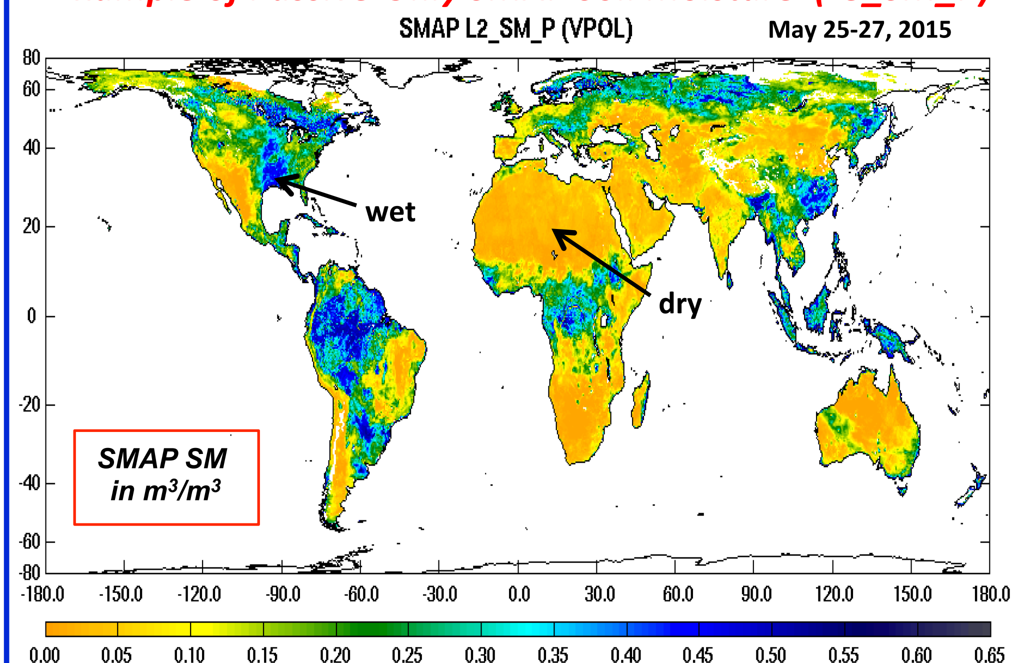
(a) several resolution enhancement approaches for the SMAP radiometer data

(b) possible use of Sentinel-1 C-band radar to replace the SMAP L-band radar in the active/passive disaggregation approach for the L2_SM_AP product

Example of Passive-Only SMAP Soil Moisture (L3_SM_P)



Courtesy of Peggy O'Neill / NASA GSFC Code 617

Status of SMAP (Soil Moisture Active Passive) Mission

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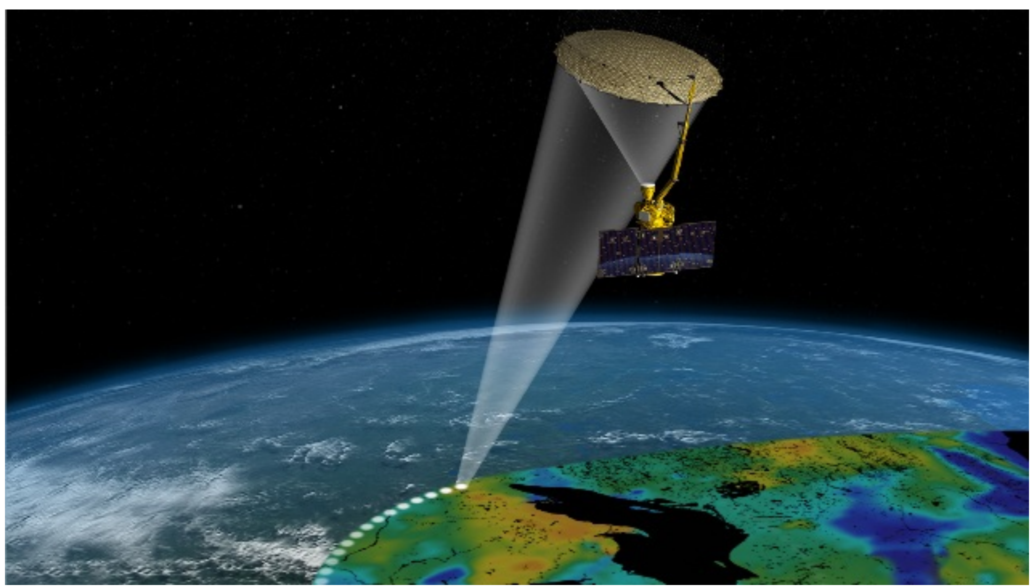
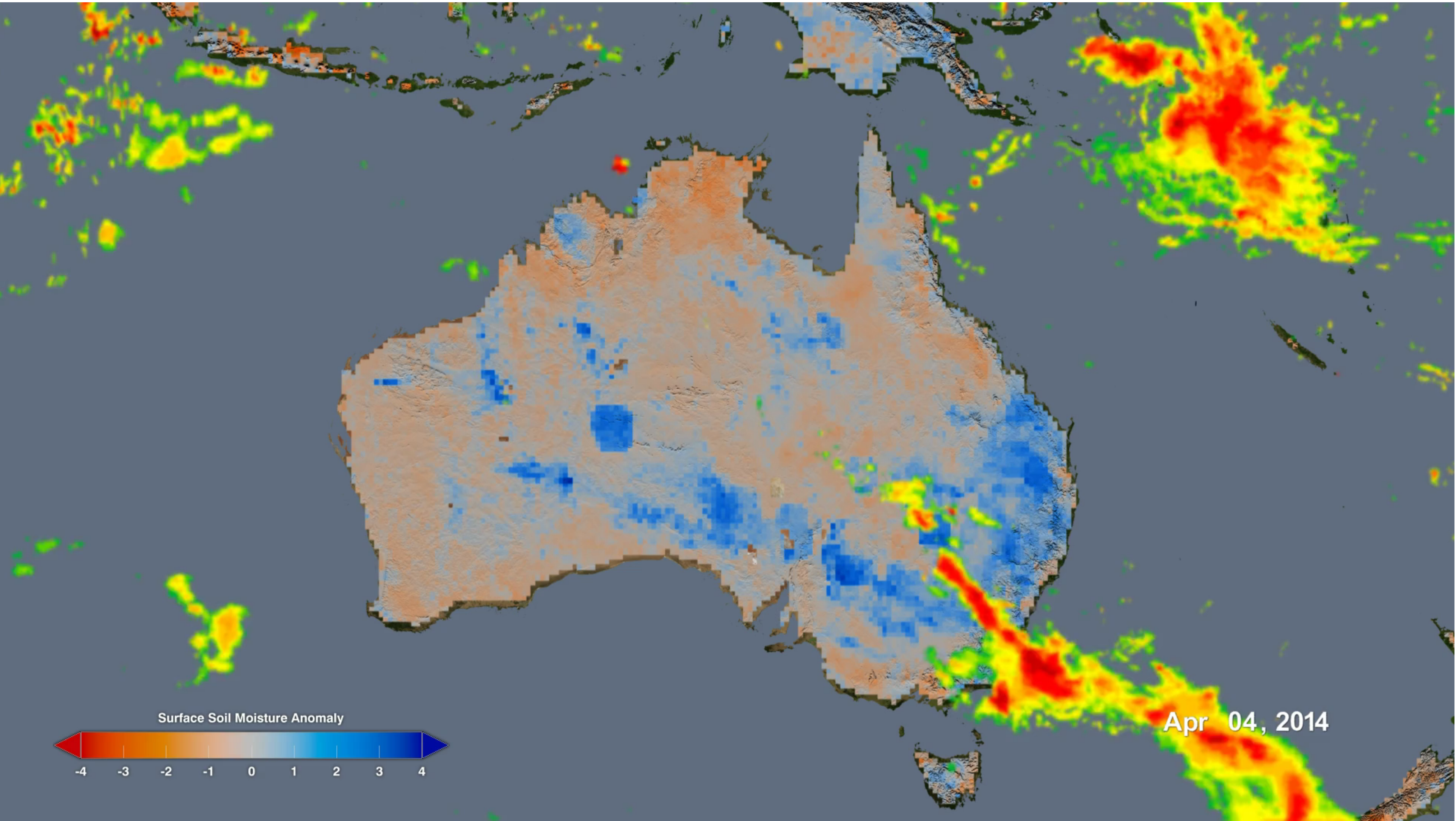
- SMAP science and algorithm teams completed algorithm updates and validated Levels 1-4 data products for public release available at NSIDC and DAACs (May, 2016).



Pairing Precipitation and Soil Moisture to Illustrate 'Precipitation Memory'



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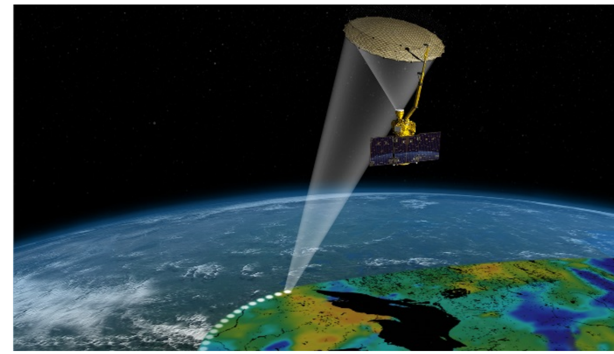

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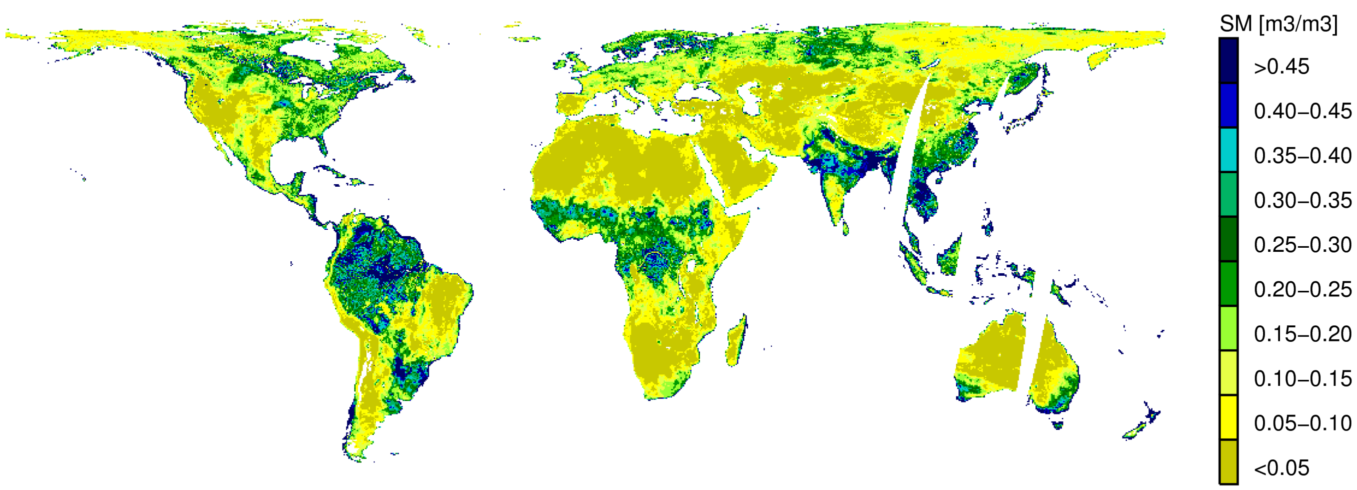

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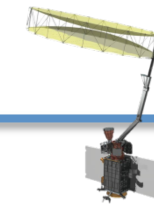

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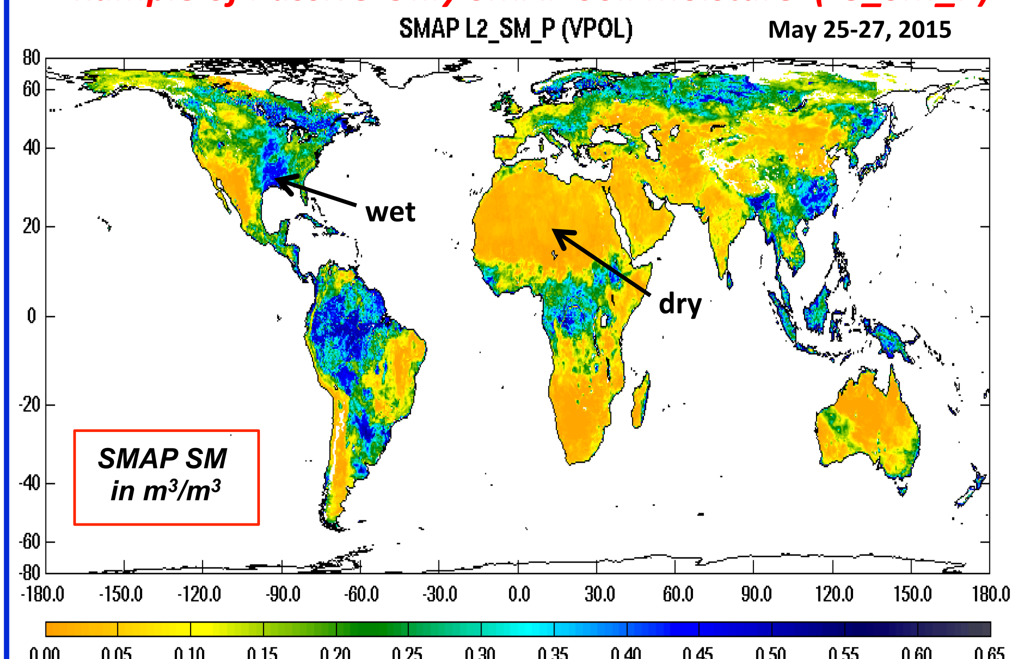
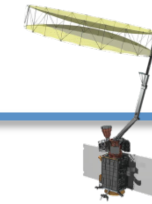


Courtesy of Peggy O'Neill / NASA GSFC Code 617



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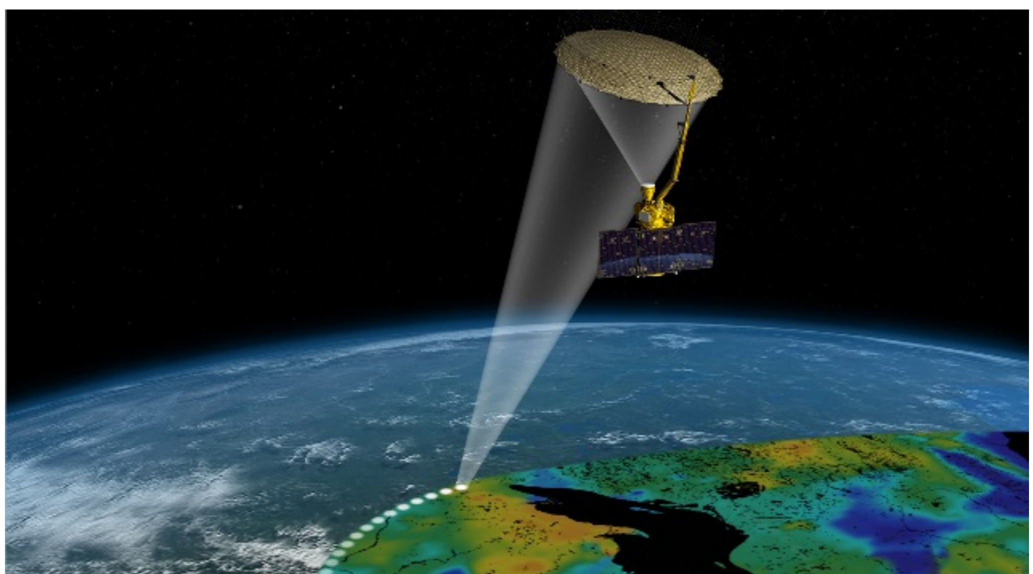

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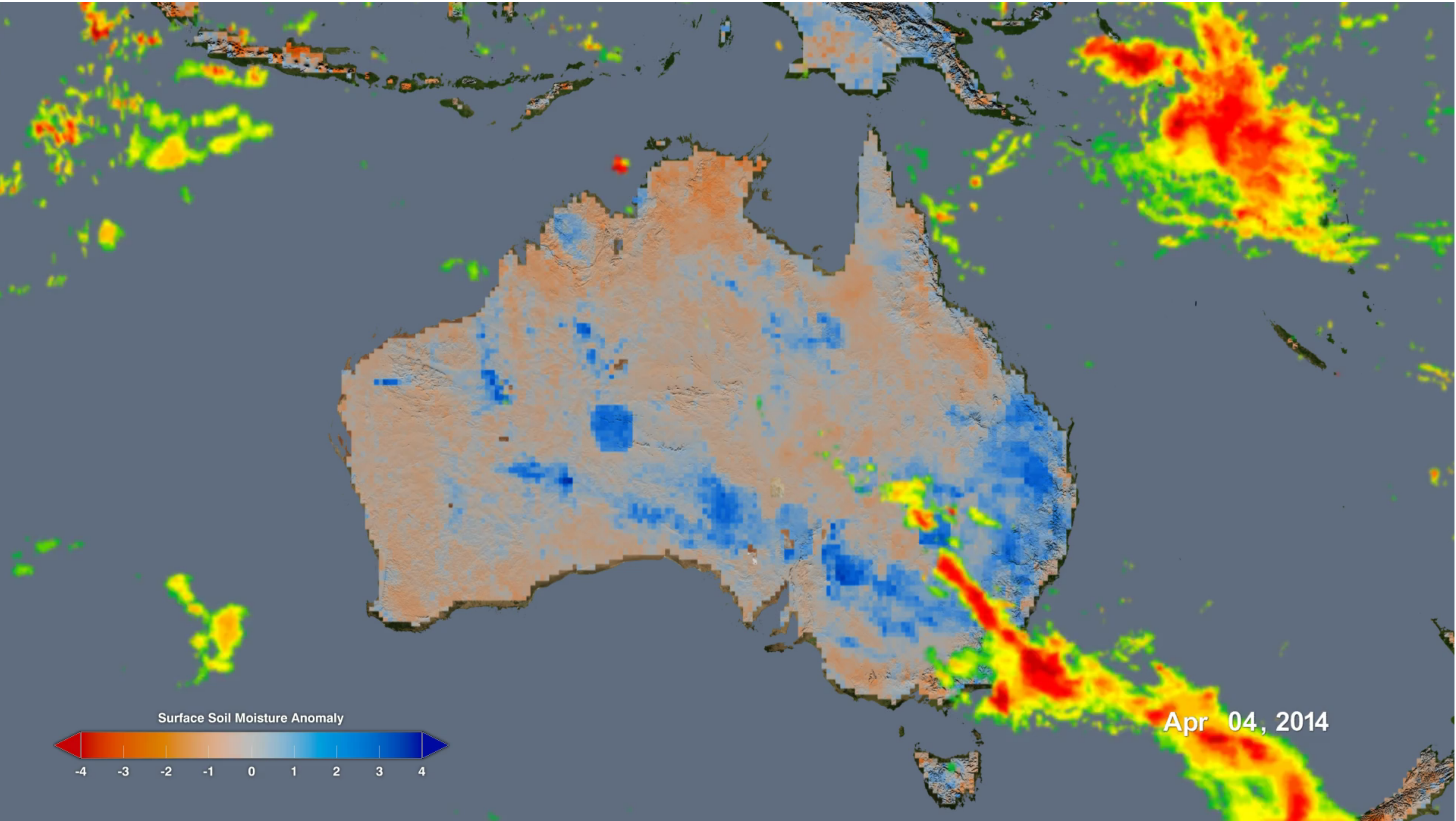
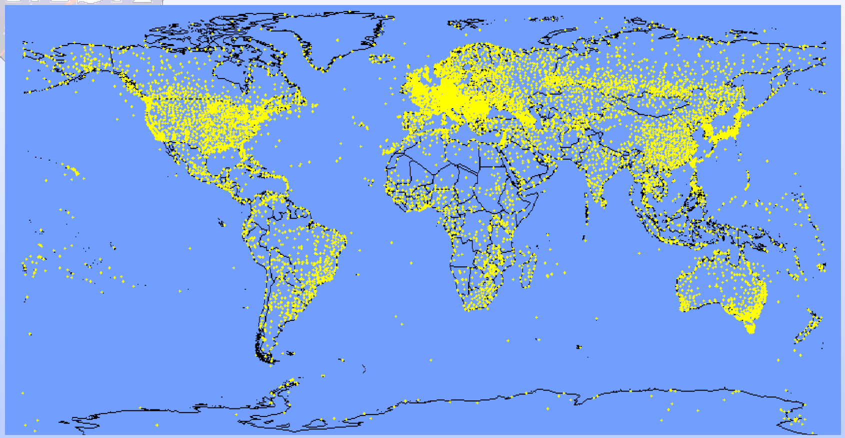


Satellite-Based Remote Sensing of Water Resources

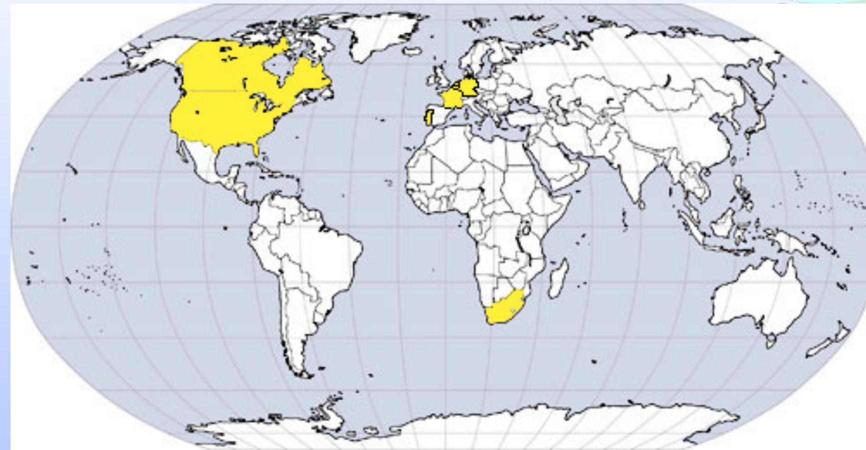
Matt Rodell, Ph.D.

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

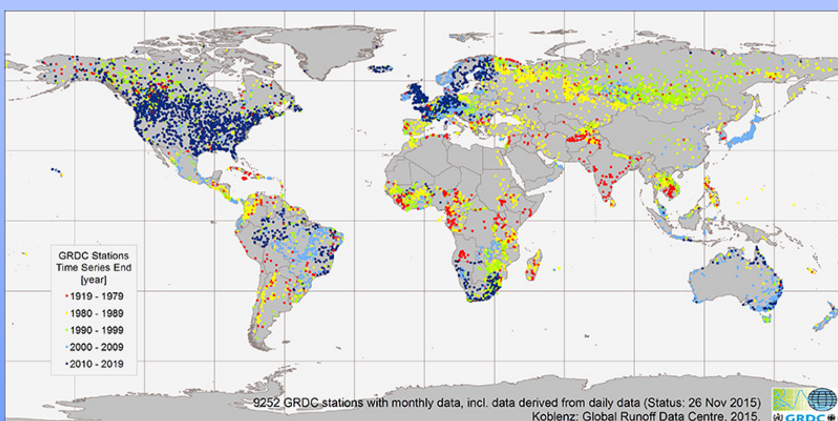
Inadequacy of Surface Observations



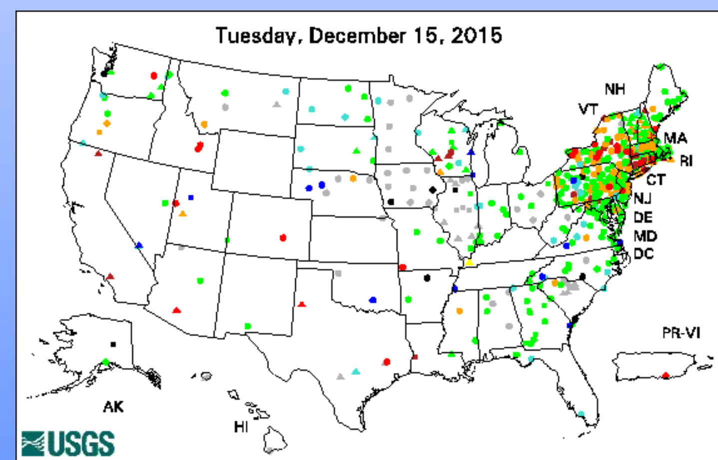
Global Telecommunication System meteorological stations. Air temperature, precipitation, solar radiation, wind speed, and humidity only.



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



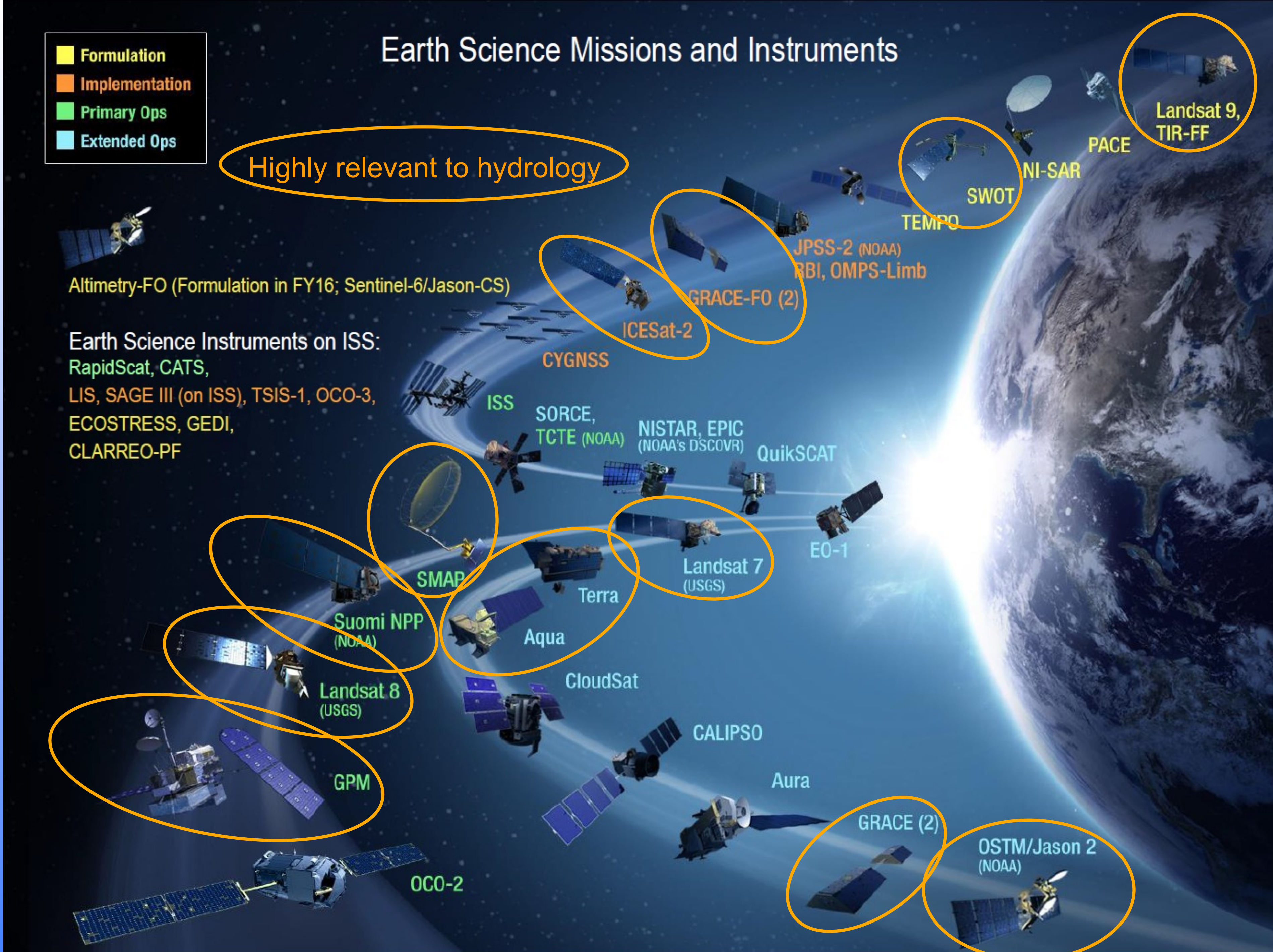
River flow observations from the Global Runoff Data Centre. Lighter circles indicate greater latency in the data record.



USGS Groundwater Climate Response Network.

Issues include coverage gaps, delays, measurement continuity and consistency, data format and QC, political restrictions

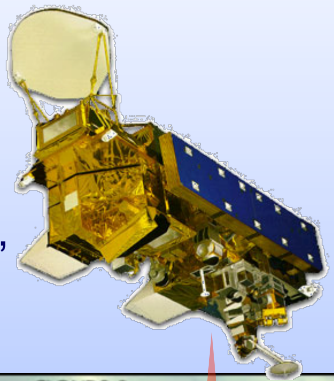
Matt Rodell
NASA GSFC

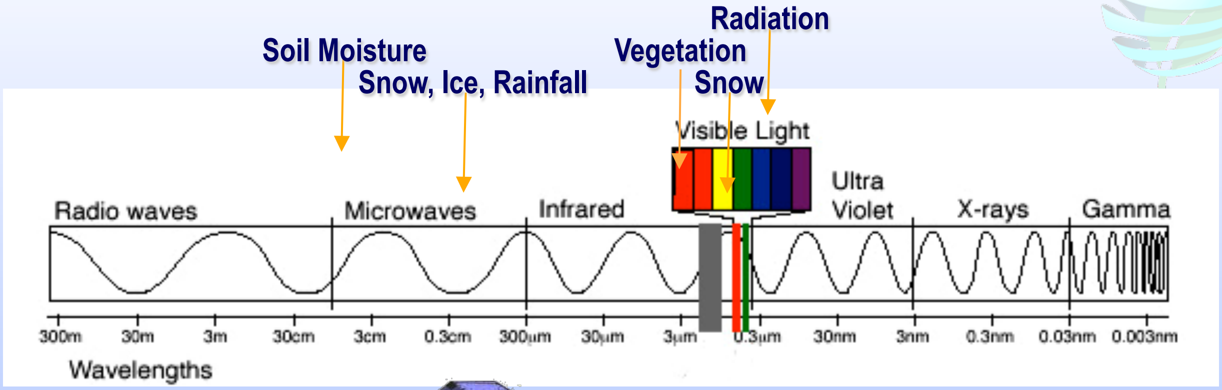


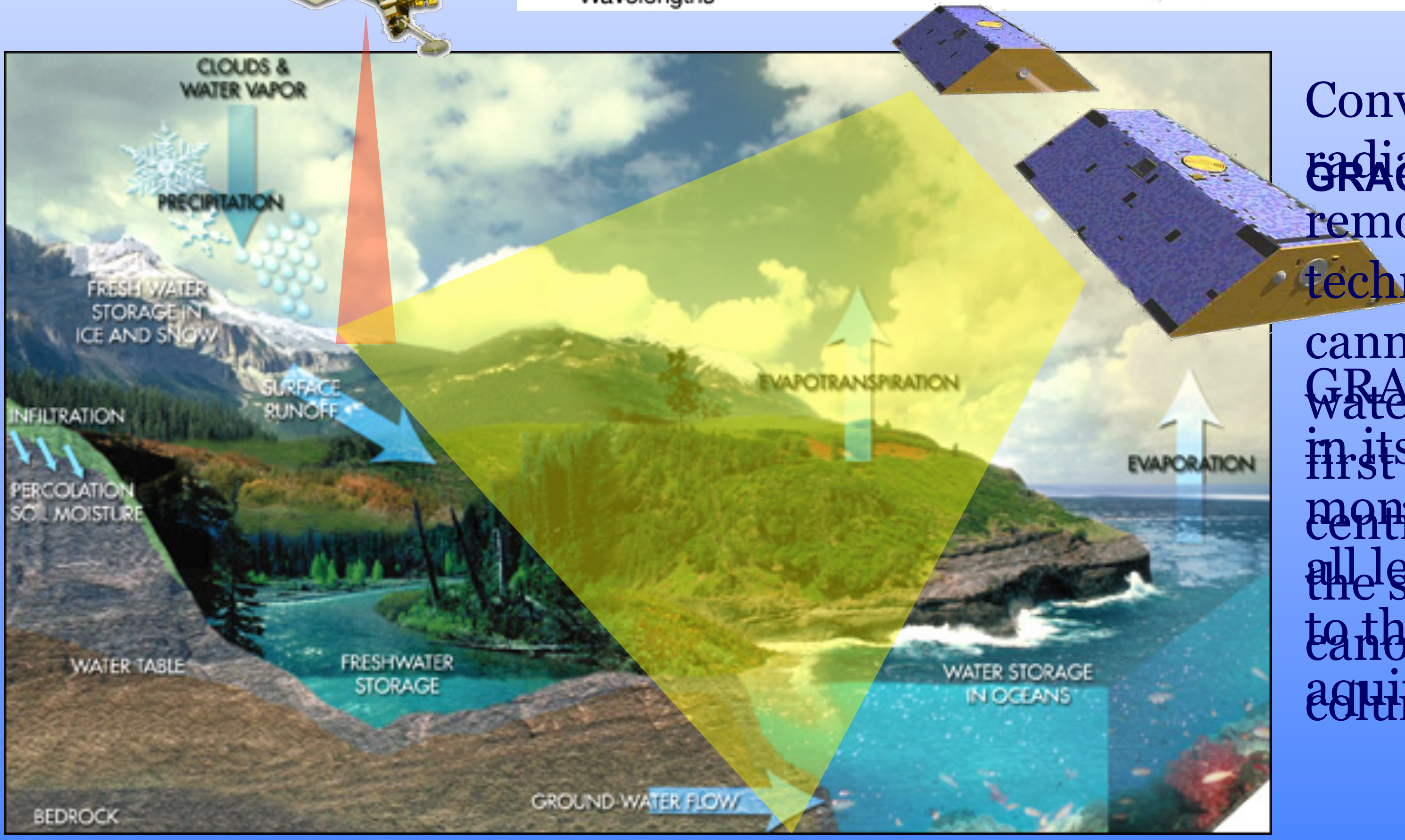
Earth Science Missions and Instruments
Formulation
Implementation
Primary Ops
Extended Ops
Highly relevant to hydrology
Altimetry-FO (Formulation in FY16; Sentinel-6/Jason-CS)
Earth Science Instruments on ISS:
RapidScat, CATS,
LIS, SAGE III (on ISS), TSIS-1, OCO-3,
ECOSTRESS, GEDI,
CLARREO-PF
Landsat 9, TIR-FF
PACE
NI-SAR
SWOT
TEMPO
JPSS-2 (NOAA)
RBI, OMPS-Limb
GRACE-FO (2)
ICESat-2
CYGNSS
ISS
SORCE,
TCTE (NOAA)
NISTAR, EPIC
(NOAA's DSCOVR)
QuikSCAT
EO-1
Landsat 7
(USGS)
SMAP
Terra
Suomi NPP
(NOAA)
Aqua
Landsat 8
(USGS)
CloudSat
CALIPSO
GPM
Aura
GRACE (2)
OSTM/Jason 2
(NOAA)
OCO-2

Gravity Recovery and Climate Experiment (GRACE)

Aqua:
MODIS,
AMSR-E,
etc.







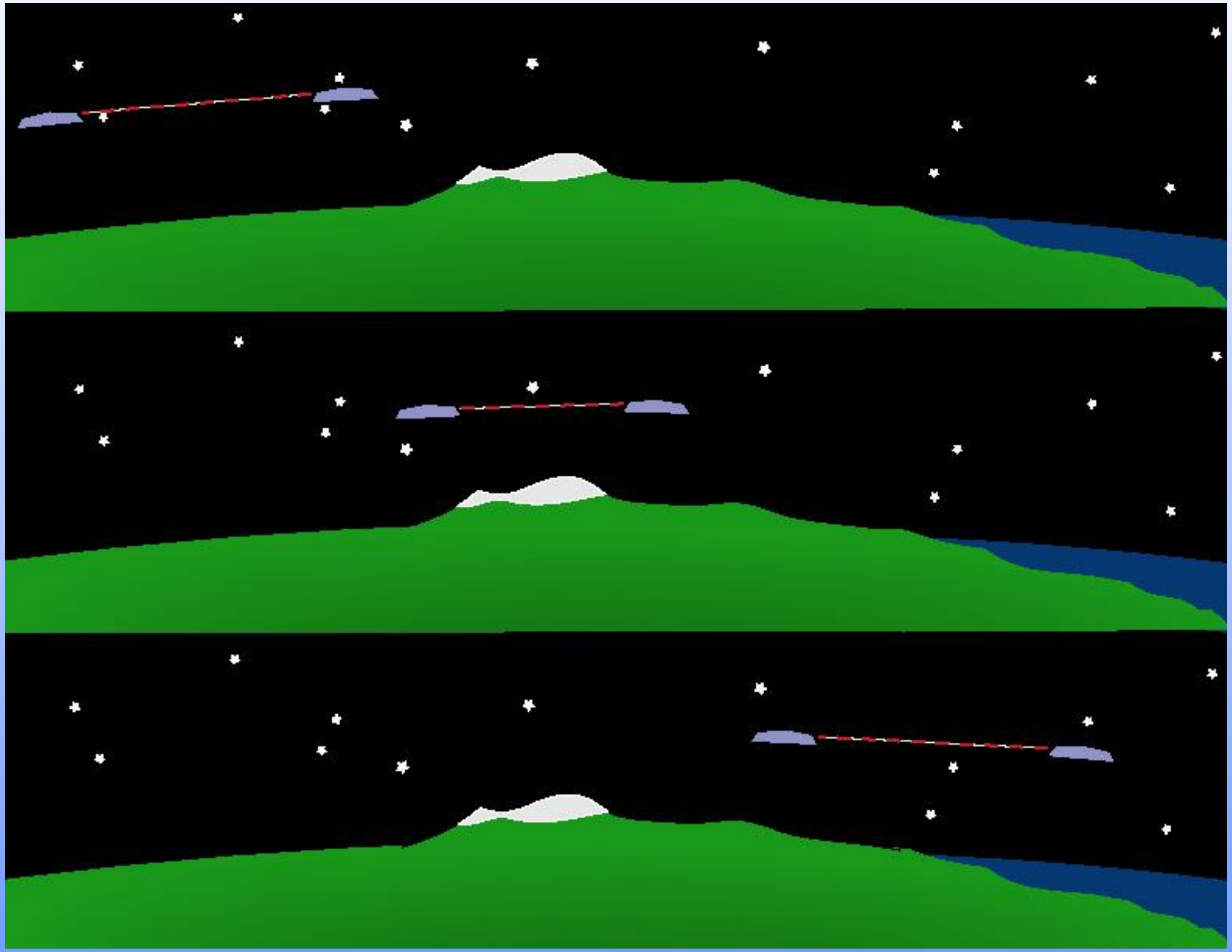
Conventional radiation-based remote sensing technologies cannot sense water below the first few centimeters of the snow-canopy-soil column

GRACE

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

Matt Rodell
NASA GSFC

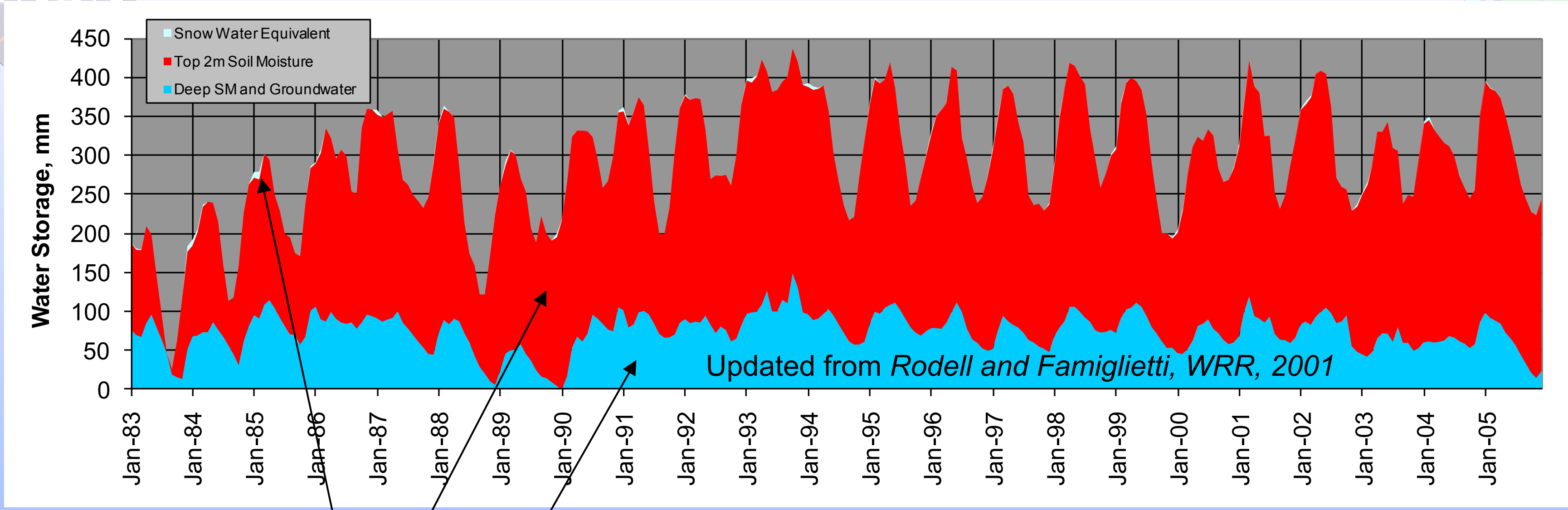
Gravity Recovery and Climate Experiment (GRACE)

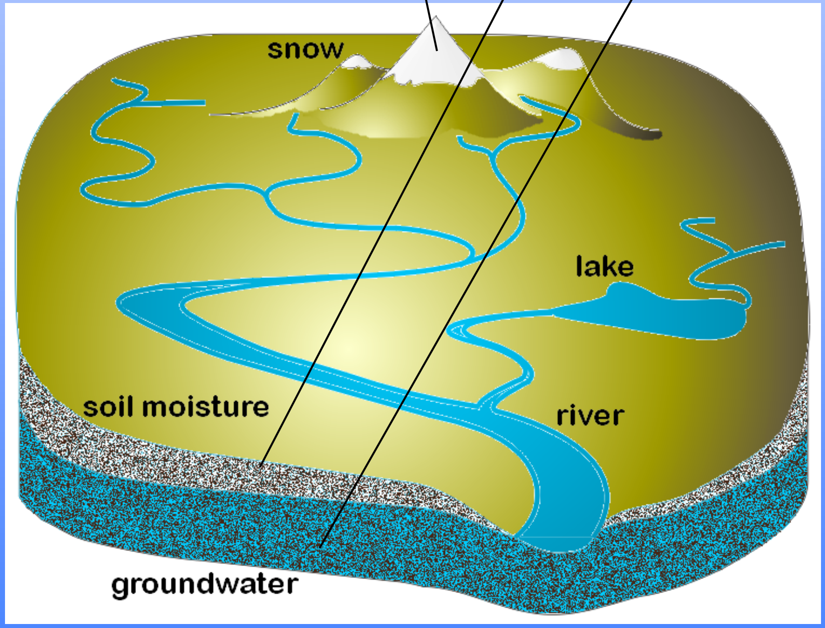


- Two identical satellites flying in tandem, near-polar orbit, ~200 km apart, 500 km initial altitude
- Distance between satellites tracked by K-band microwave ranging system
- Launched 17 March 2002

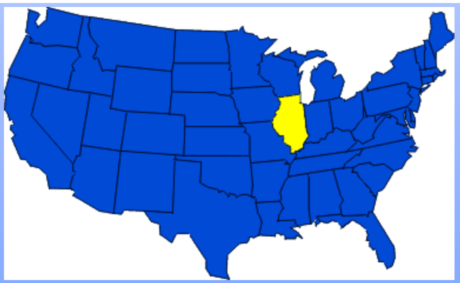
Matt Rodell
NASA GSFC

Terrestrial Water Storage Variations





Top: 23 year time series of snow, soil moisture, and groundwater storage in Illinois, USA (right)



TWS variations are dominated by:

Soil moisture in temperate regions;

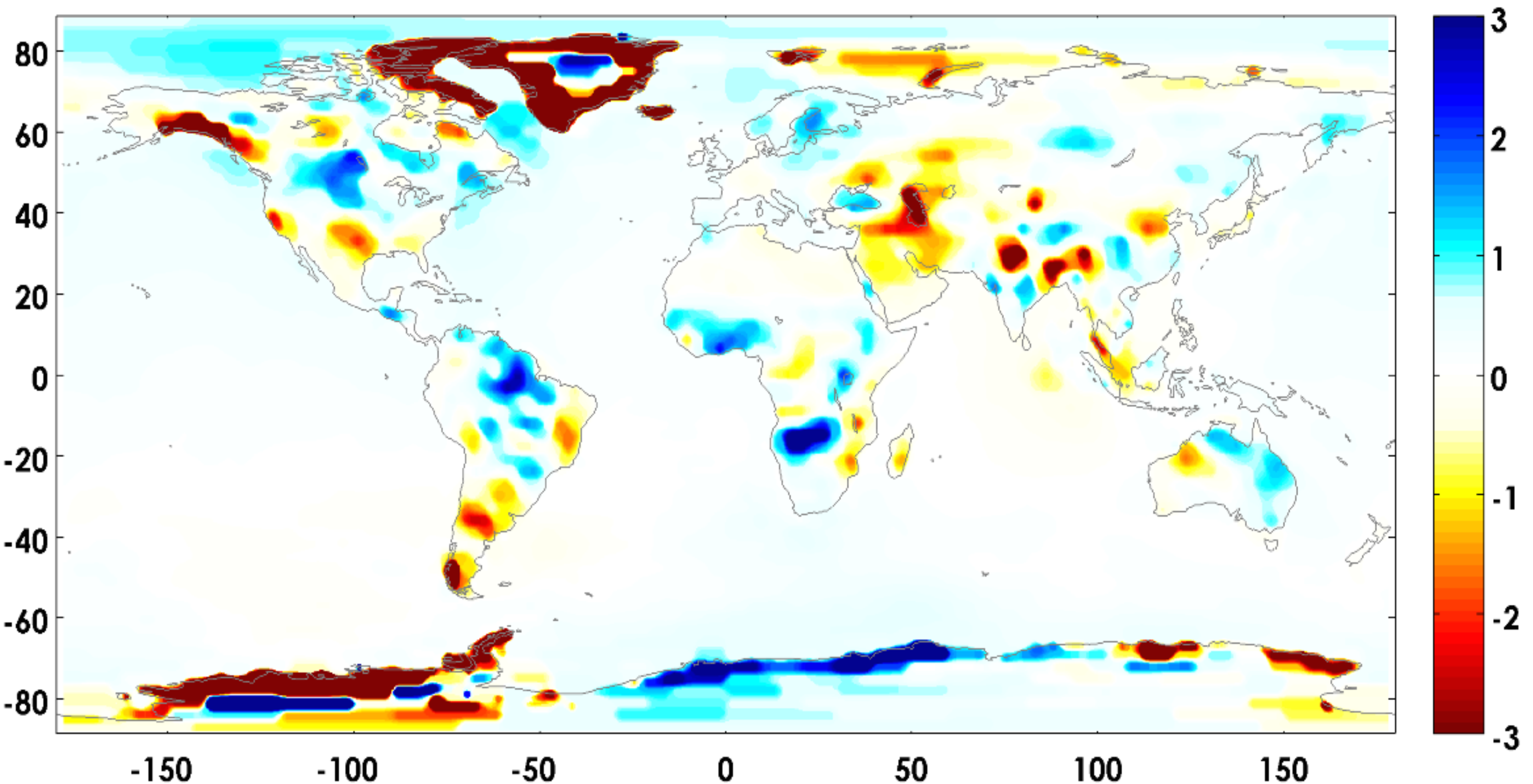
Snow in polar and alpine regions;

Surface water in wetlands.

Matt Rodell
NASA GSFC

Emerging Trends in Terrestrial Water Storage from GRACE

Best fit linear rate of change of TWS (cm/yr), 2002-2015.

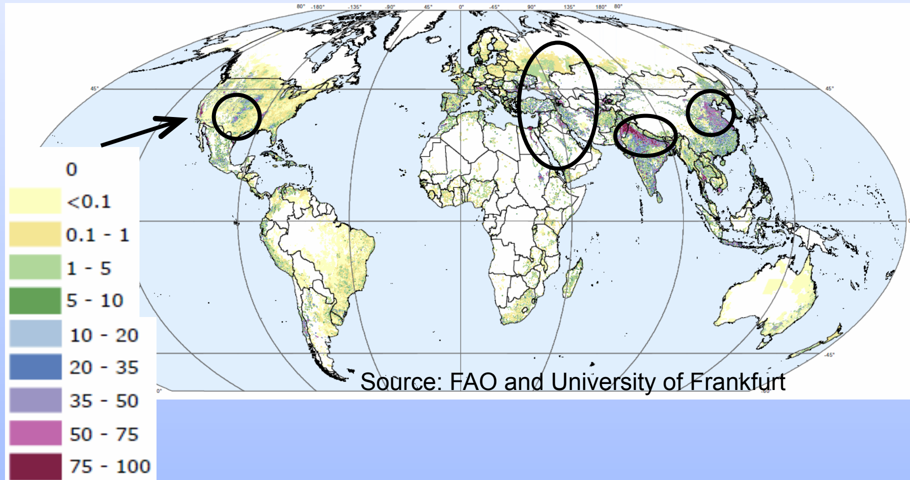


- Data from http://grace.jpl.nasa.gov/data/get-data/jpl_global_mascons/
- Which apparent trends are real and likely to continue?

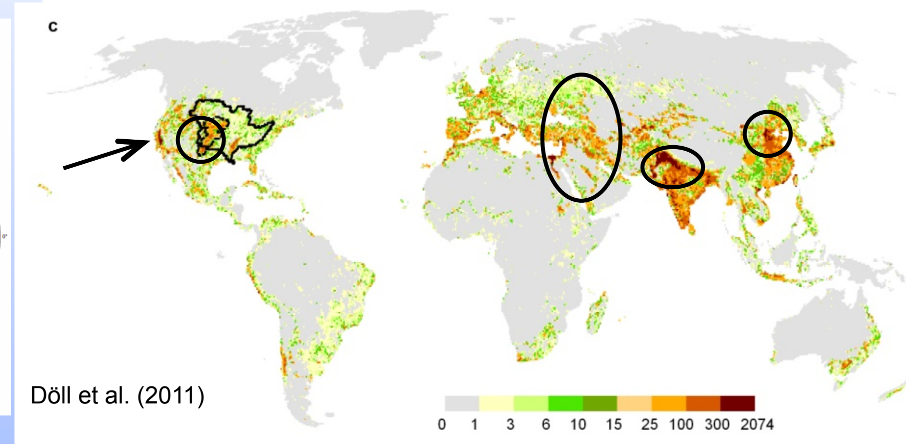
Matt Rodell
NASA GSFC

Exploitation of Water Resources

Percentage of Irrigated Area

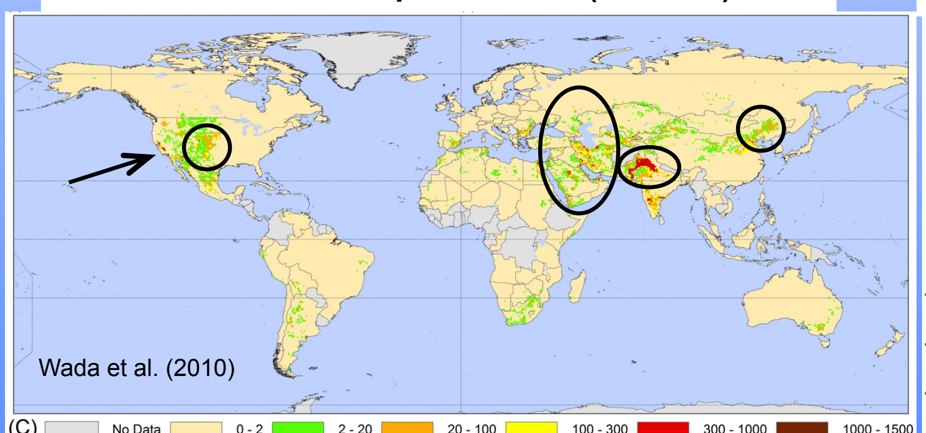


Net Consumptive Use of Ground and Surface Waters, 1998-2002



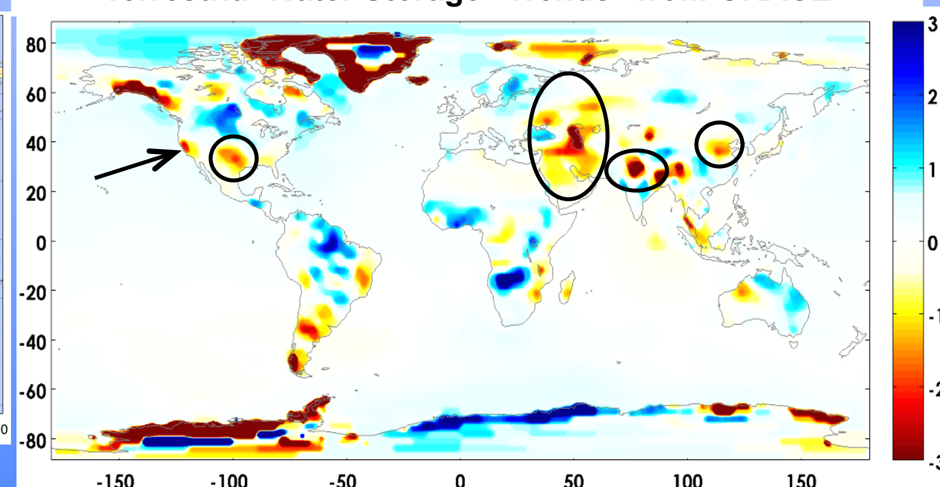
Equivalent height of water (mm/yr)

Groundwater Depletion Rate (ca. 2000)



Equivalent height of water (mm/yr)

Terrestrial Water Storage "Trends" from GRACE

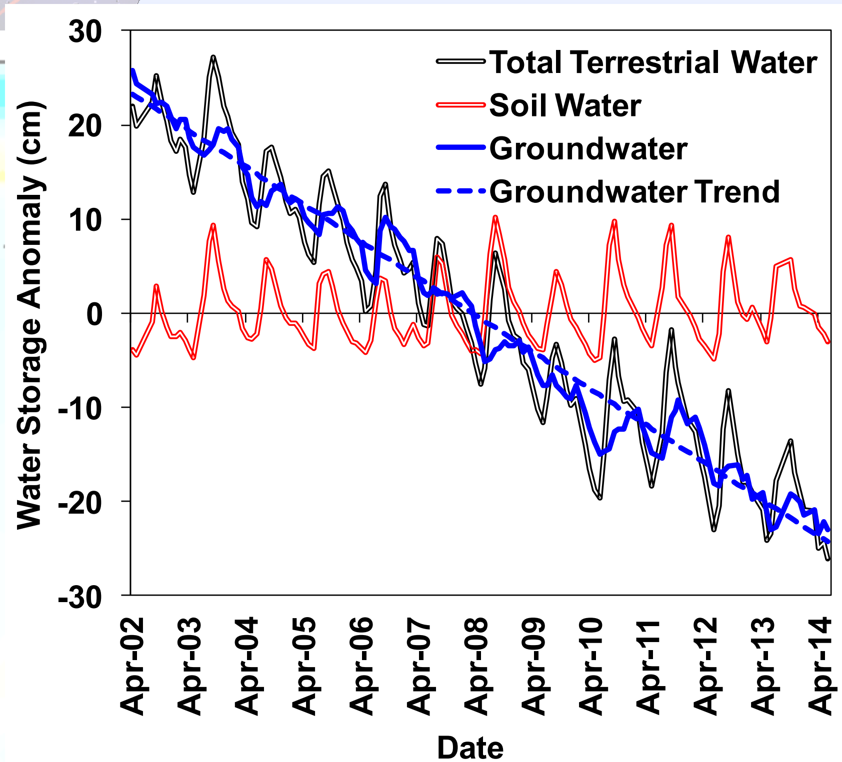


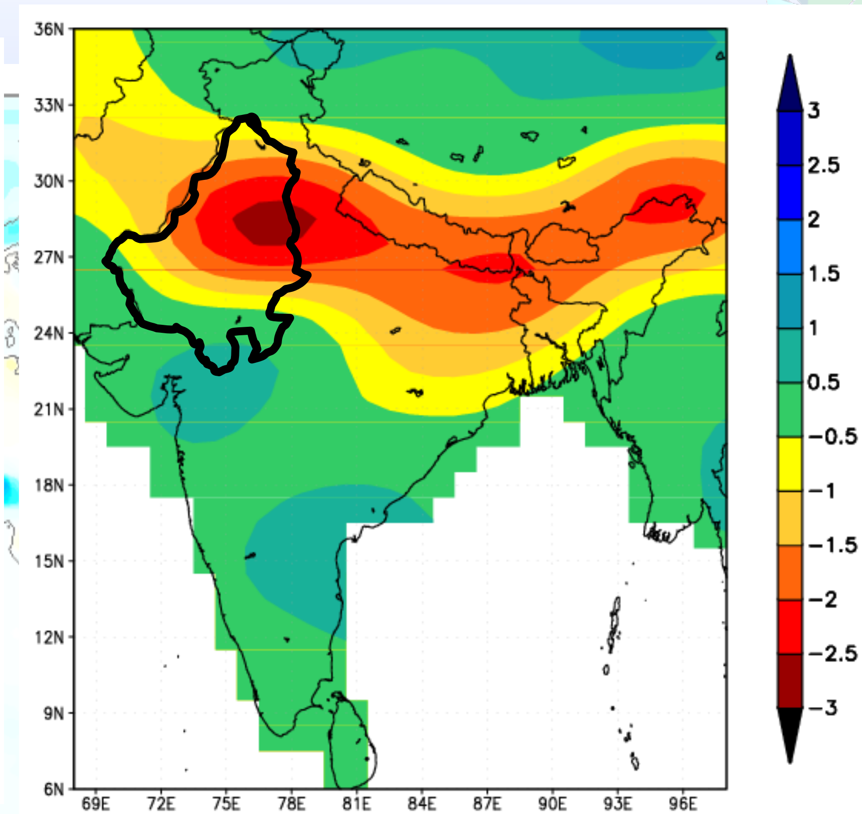
Equivalent height of water (cm/yr)

Matt Rodell
NASA GSFC

Emerging Trends in Global Freshwater Storage

Groundwater Depletion in Northern India





GW = TWS – SM – SWE

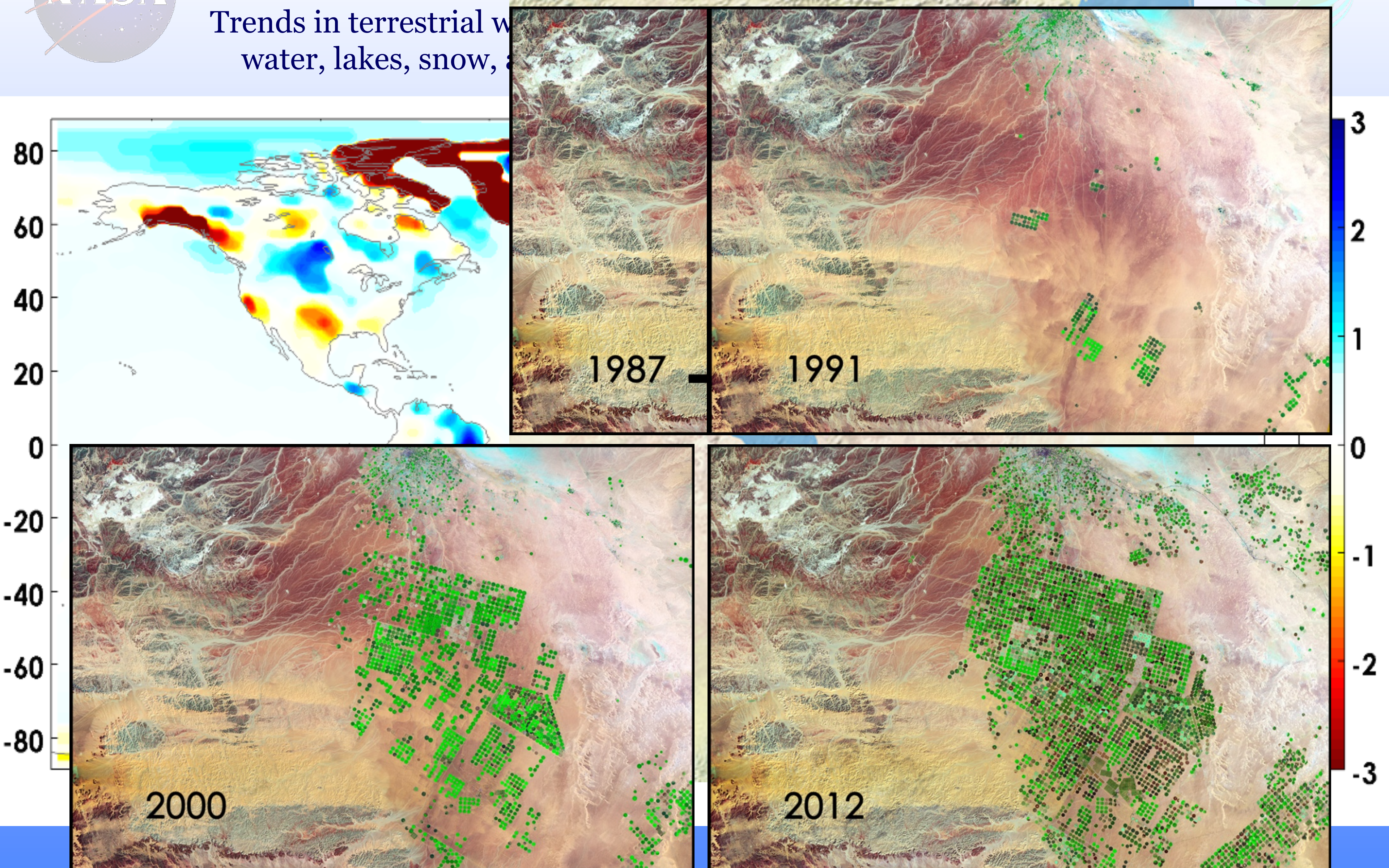
Groundwater continues to be depleted in the Indian states of Rajasthan, Punjab, and Haryana by about 16.0 km³/yr, reduced slightly from our previous (2002-08) estimate of 17.7 ±4.5 km³/yr (Rodell, Velicogna, and Famiglietti, 2009).

Trends in terrestrial water storage (cm/yr), including groundwater, soil water, lakes, snow, and ice, as observed by GRACE during 2002-15

Matt Rodell
NASA GSFC

Emerging Trends in Global Freshwater Storage
Growth of Irrigation in Saudi Arabia

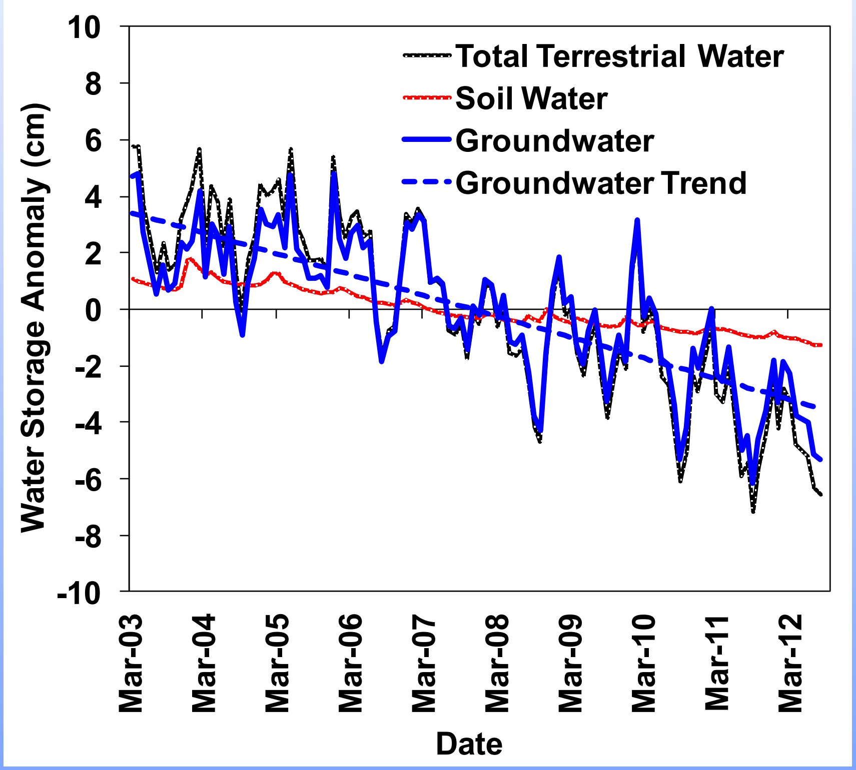
Trends in terrestrial w
water, lakes, snow, a

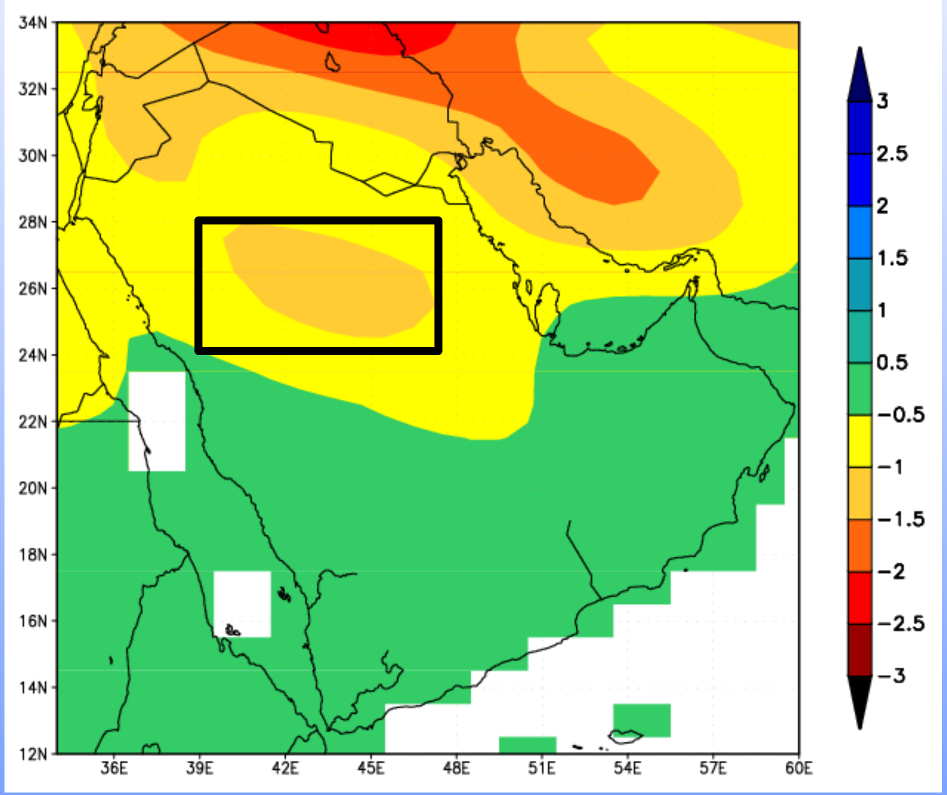


Landsat images prepared by Aries Keck, NASA/GSFC

Matt Rodell
NASA GSFC

Groundwater Depletion in Saudi Arabia





Preliminary estimate of groundwater depletion rate: 2.6 km^3/yr.

This includes the impact of a persistent drought in the region, as indicated by the soil water time series.

Matt Rodell
NASA GSFC

Emerging Trends in Global Freshwater Storage

Rates of change of terrestrial water storage (cm/yr), including groundwater, soil water, lakes, snow, and ice, as observed by GRACE* during 2002-15

**JPL GRACE Mascon hydrology product*

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

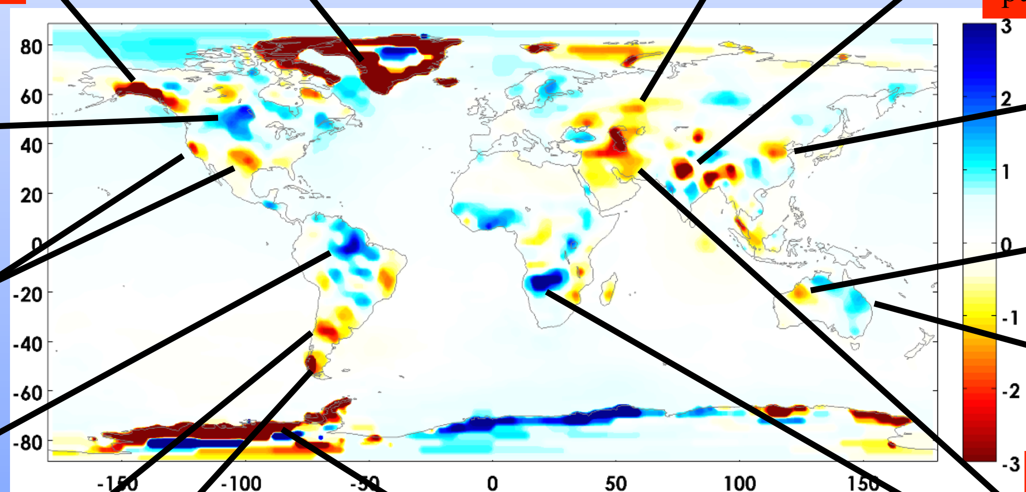
Greenland's ice sheet has been thinning at a rate of 142 km^3/yr

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

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

Overexploitation of freshwater resources in the North China Plain



Recent droughts in California and Texas

Return to normal after wet years in early 2000s

Drought recovery and flooding in east Australia

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

Matt Rodell
NASA GSFC

Summary and Future Prospects

• Due to the incompleteness of ground-based observations, space-based observation of global freshwater resources is critical.

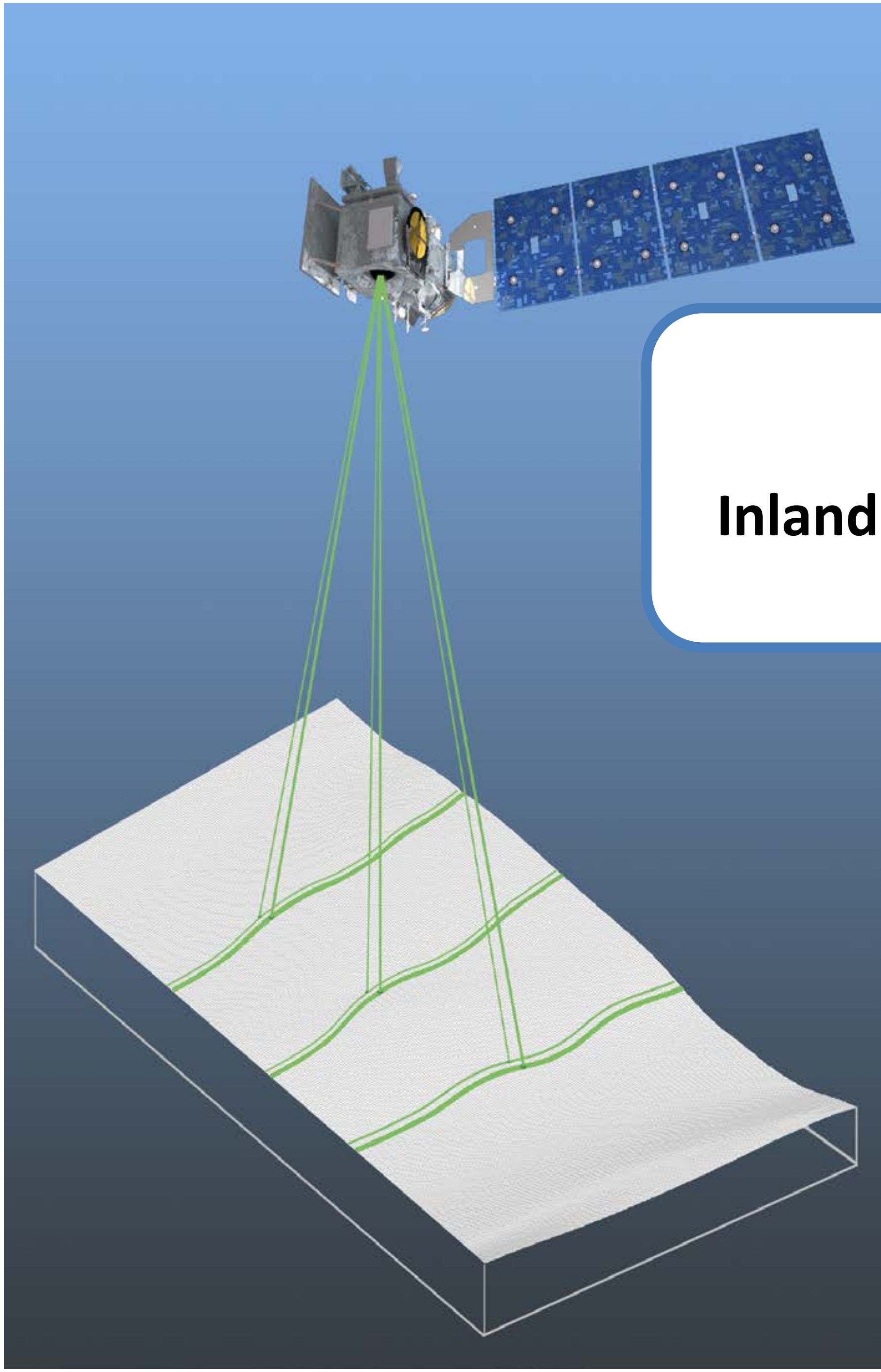
• NASA's GRACE satellite mission is unique in its ability to monitor all forms of water at all depths, including groundwater.

• Emerging trends in terrestrial water storage observed by GRACE can be categorized as natural variations, climate change impacts, or direct consequences of human activities, particularly irrigation.

• The value of GRACE and other satellite data for applications such as drought monitoring can be enhanced by combining them within a land surface model.

• The GRACE Follow-On mission is scheduled to launch by February 2018.

• Commencing in June, the National Research Council's 2017 Decadal Survey in Earth Sciences will set the priorities for NASA's 2020-2030 Earth observing satellite missions.



The ICESat-2 Mission
Inland Water Height Data Product

Michael Jasinski
NASA GSFC
Science Team Lead for
Inland Water Data Product

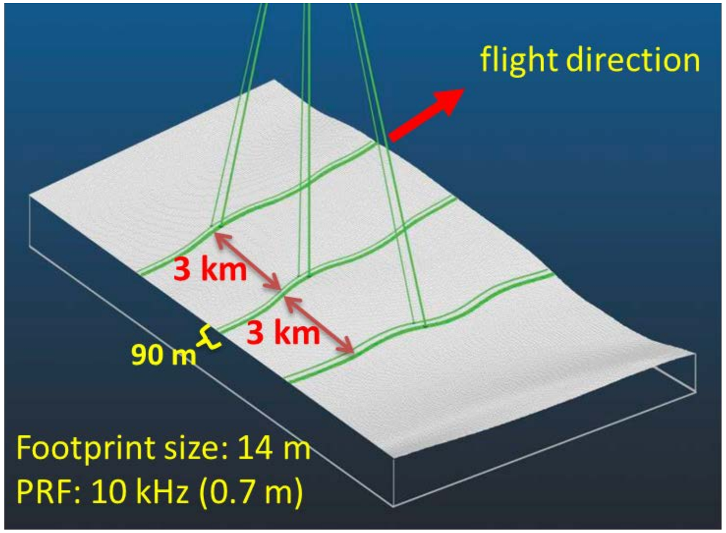
USGS Interagency Mtg
ACWI/SOH
July 28, 2016

ICESat-2/ATLAS Instrument

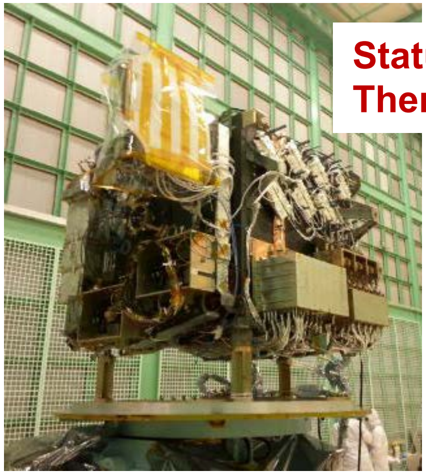
ICE, CLOUD, AND LAND ELEVATION SATELLITE

Instrument

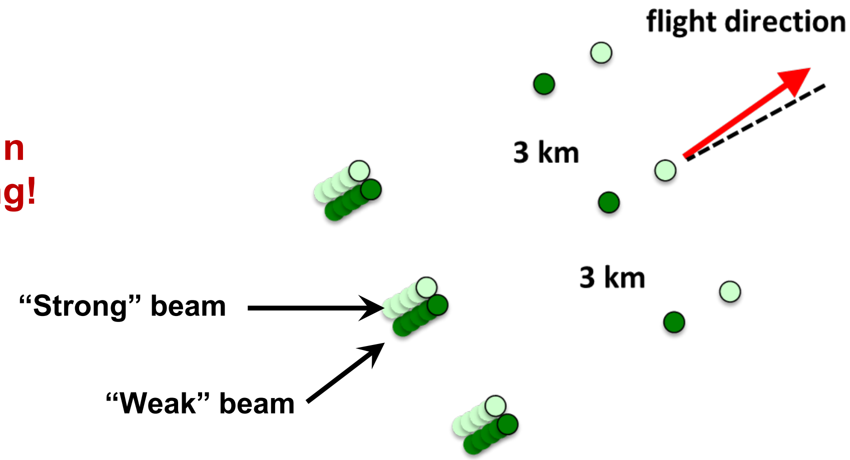
- Advanced Topographic Laser Altimeter System (ATLAS)
- Micro-pulse instr w/single-photon sensitive detection
- 6 beams, arranged in 3 pairs (25/100 μJ)
- 10 kHz pulse repetition rate
- 14m footprint
- spaced 0.7m along-track
- 532nm wavelength



Orbit: 500 km, non-sun-synch, 92° inclination
Repeat: 91 day exact repeat, ~30 day subcycle
Launch Date: ~Nov/Dec 2017
Lifetime: 3 years, with consumables for 7
Partners: GSFC, Orbital Sciences, ULA, KSC



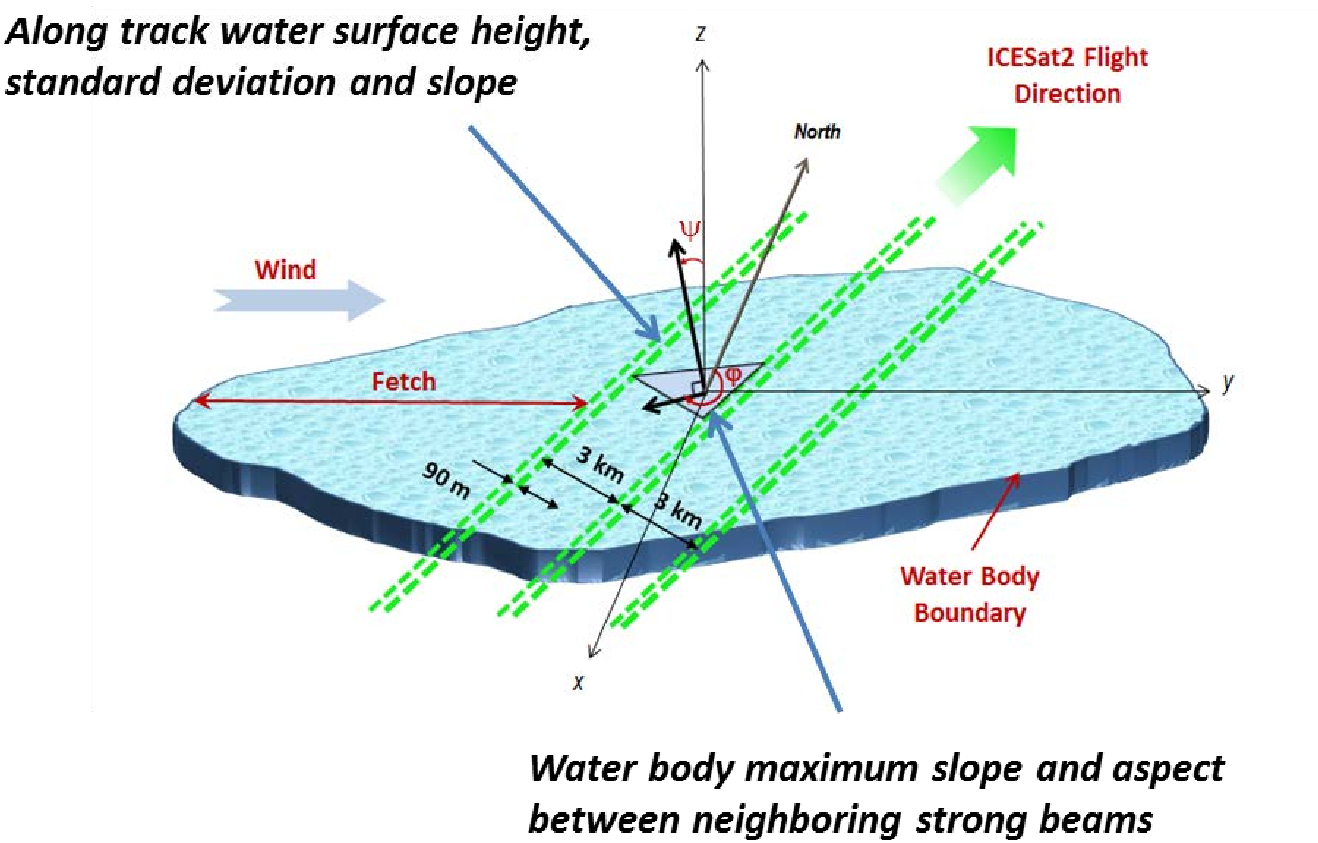
Status: Built and in Thermovac Testing!



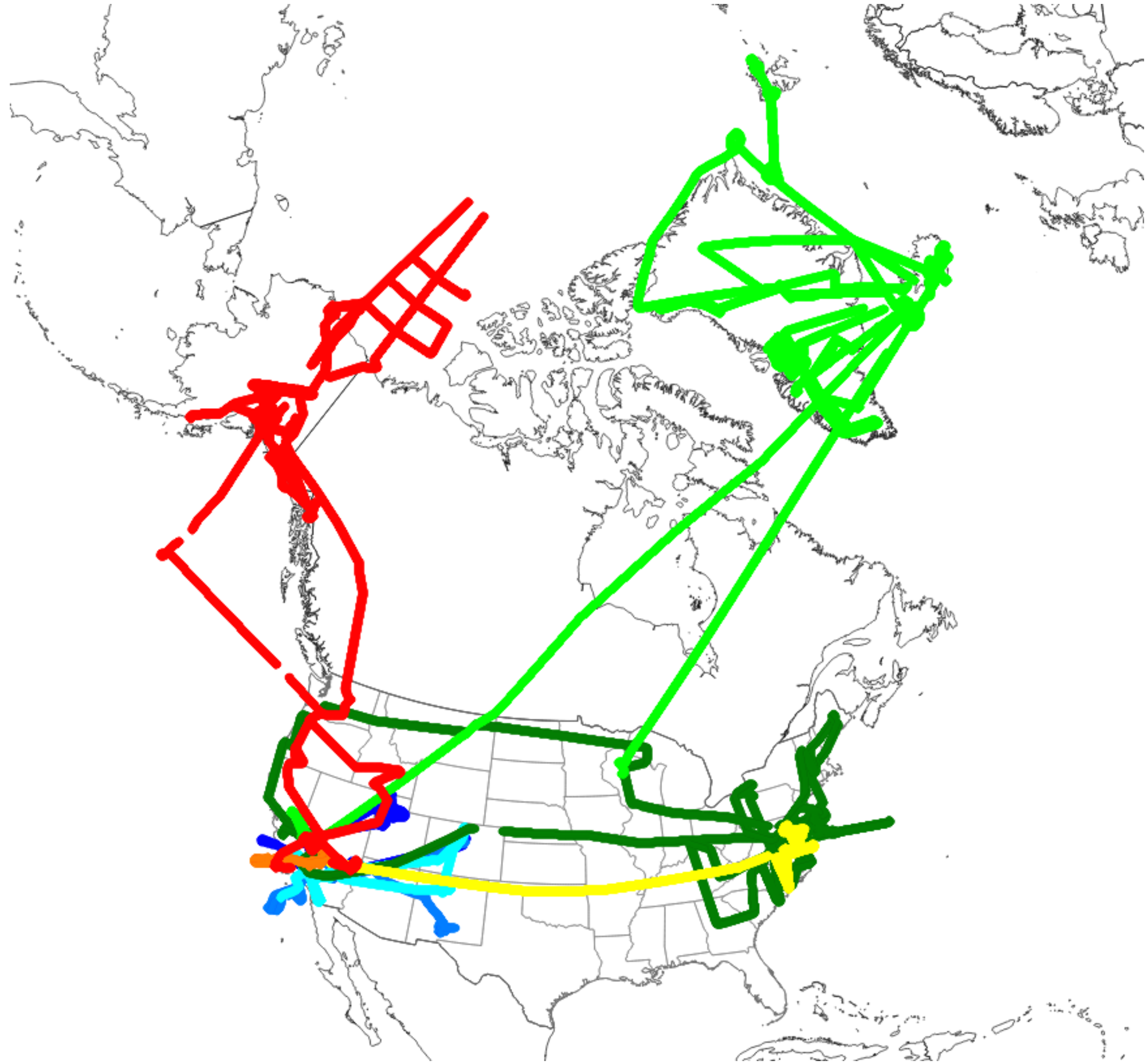
ICESat-2 Data Products

ATBD	Lead	Affiliation	ATLAS Science Data Products	Description
Precision Pointing Determination (PPD)	Bob Schutz / Sungkoo Bae	UTCSR	ancillary data	Precise laser pointing solutions input to all level 2 and higher level products
Precision Orbit Determination (POD)	Scott Luthcke	GSFC	ancillary data	Precise orbit solutions input to all level 2 and higher level products
Level 1A	John DiMarzio	SGT/GSFC	ATL01	Conversion and reformatting of Level 0 data
Level 1B	Rob Jones / Tony Martino	GSFC	ATL02	Apply necessary corrections from housekeeping data, e.g. calibrated ranges
Level 2A	Tom Neumann	GSFC	ATL03	combine elevation corrections, geolocation information, laser spot location (which requires preliminary surface finding) with L1B product
Ice Sheet	Ben Smith	UW	ATL06, 11, 14, 15	Define ice sheet products and parameters
Sea Ice	Ron Kwok	JPL	ATL07, 10, 20, 21	Define sea ice products and parameters
Land/Vegetation	Amy Neuenschwander	U. Texas	ATL08	Define land and vegetation products and parameters
Ocean	James Morison	UW	ATL12, 19	Along track SSH and Significant Wave Height;
Atmosphere	Steve Palm	SSAI/GSFC	ATL04, 09, 16, 17	Atmosphere products and parameters and the calibrated backscatter
Inland Water	Mike Jasinski	GSFC	ATL13	Along track height distribution, ~ 100m segments (variable), cross track max slope and aspect.

Inland Water Data Products

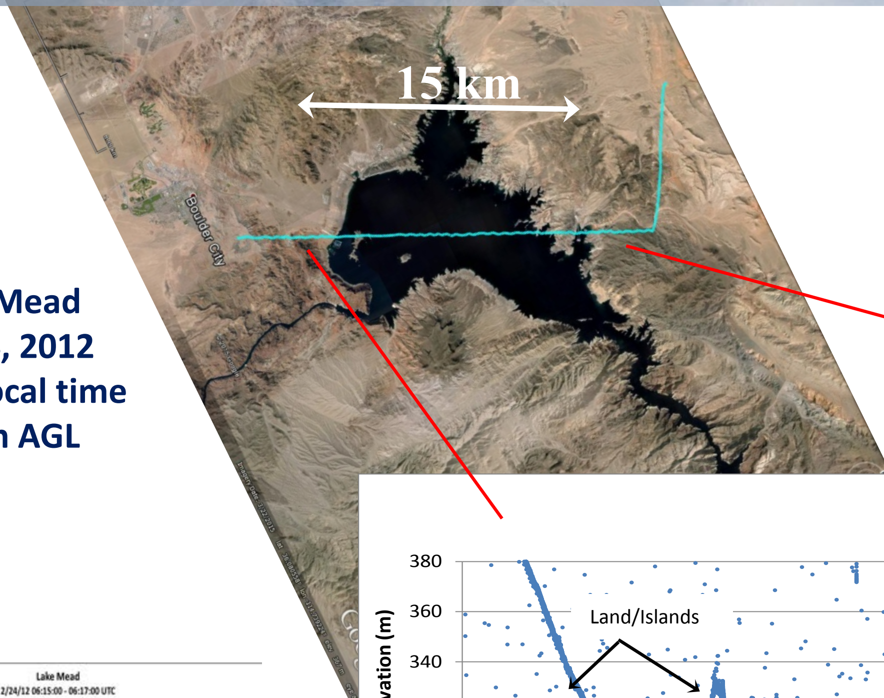


Testing ICESat-2 Inland Water Algorithm w/MABEL Prototype



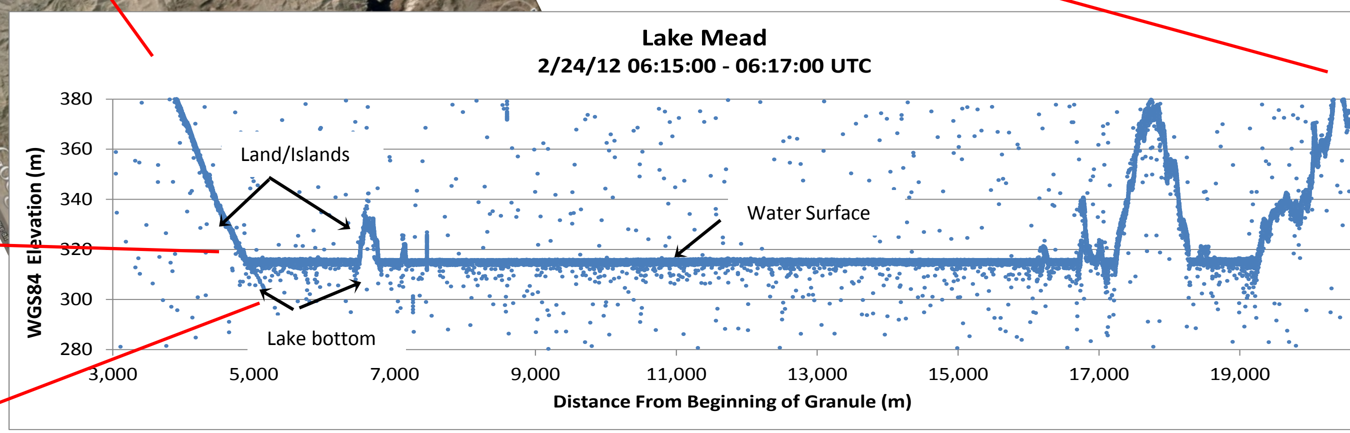
- 2014 Fairbanks, AK
- 2013 Mojave, CA
- 2013 Langley, VA
- 2012 Keflavik, Iceland
- 2012 Wallops, VA
- 2012 Dryden, CA
- 2011 Dryden, CA
- 2010 Dryden, CA

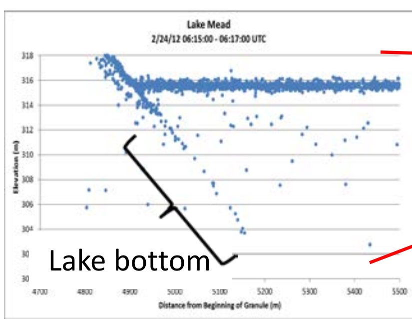
E.g. MABEL flight over Lake Mead



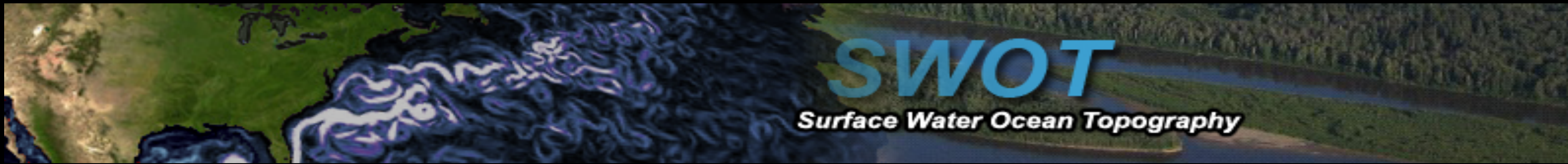
Lake Mead
Feb 24, 2012
11 PM local time
20 km AGL

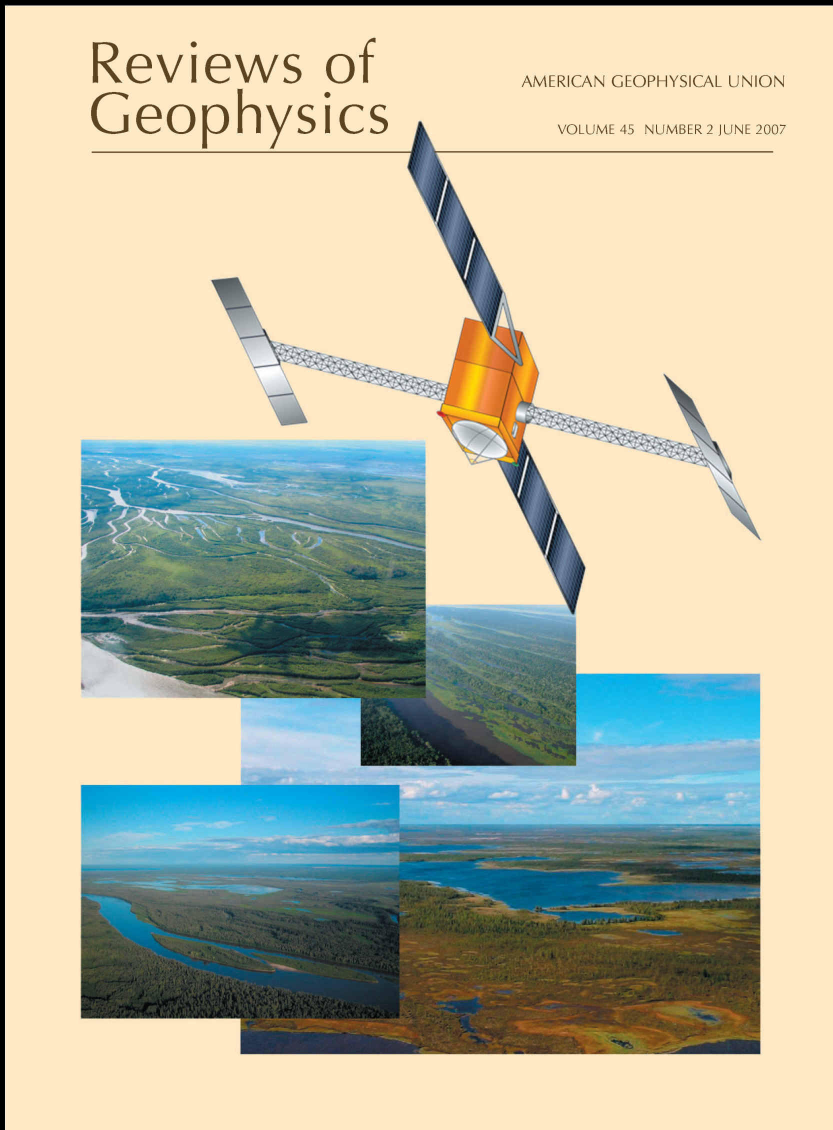
Similar profiles expected from ICESat-2

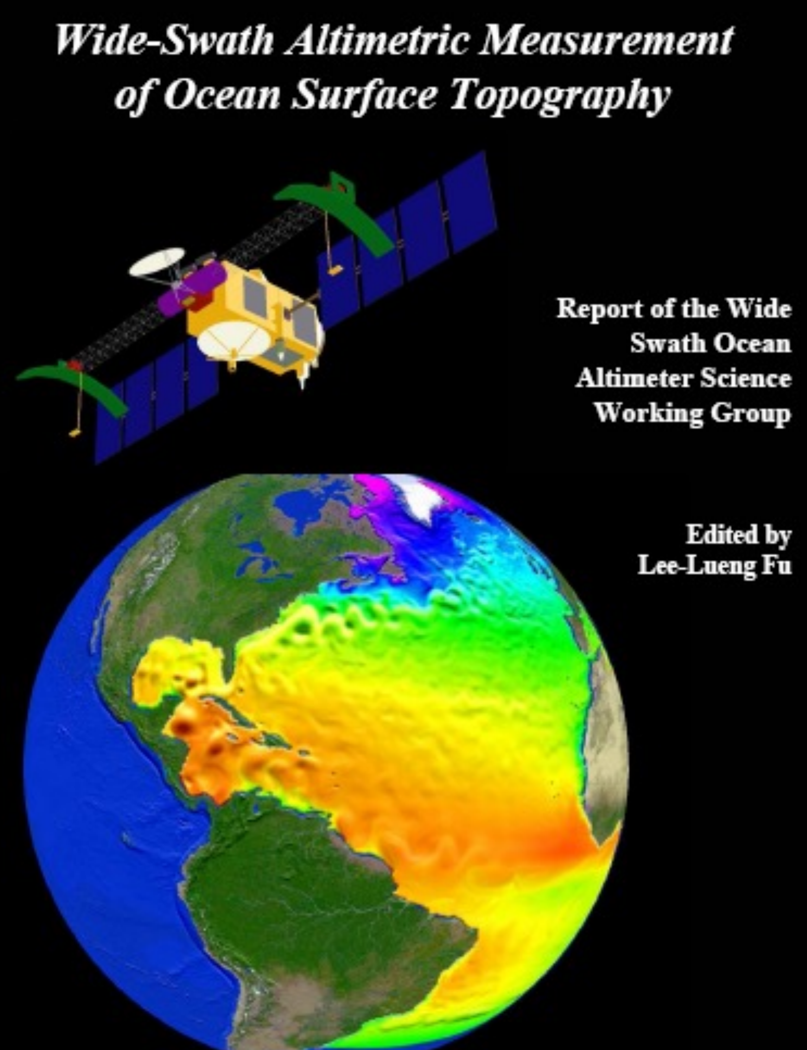




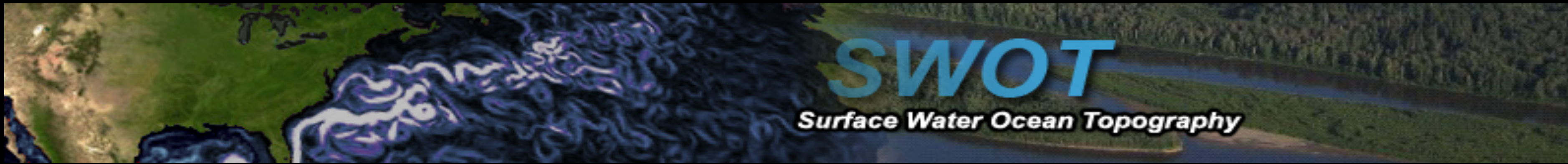
Jasinski, M., Stoll, J., Cook, W., Ondrusek, M., Stengel, E. and K. Brunt. 2016. Inland and Near Shore Water Profiles Derived from the High Altitude, Multiple Altimeter Beam Experimental Lidar (MABEL), *Journal of Coastal Research*, in press.



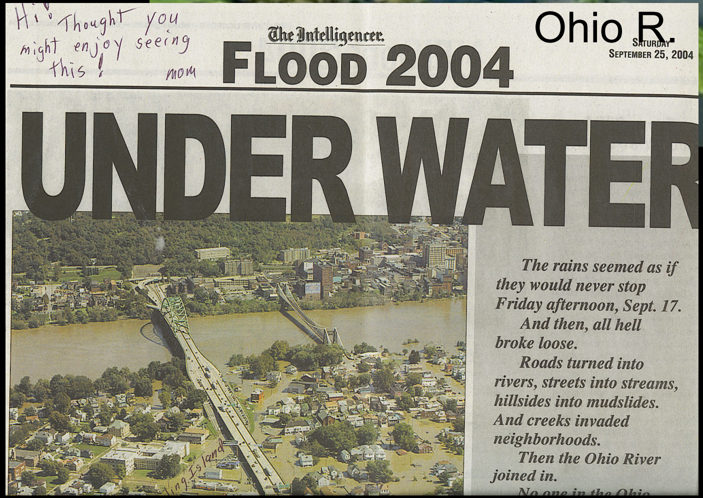




SWOT combines surface water hydrology with physical oceanography.



1. The Problem



The Intelligencer.
SATURDAY September 25, 2004

FLOOD 2004

UNDER WATER

The rains seemed as if they would never stop Friday afternoon, Sept. 17.
And then, all hell broke loose.
Roads turned into rivers, streets into streams, hillsides into mudslides. And creeks invaded neighborhoods.
Then the Ohio River joined in.

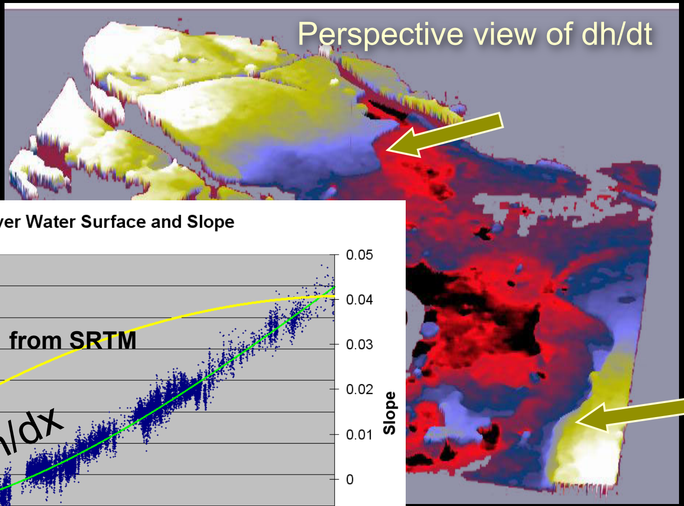
Floods are the number one hazard

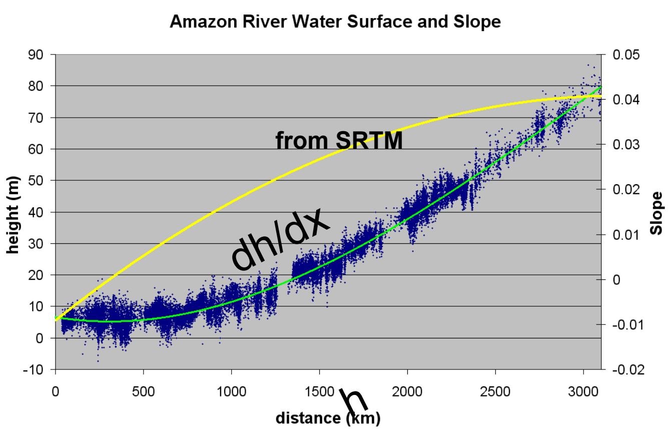
2. The Question

What is the spatial and temporal variability of freshwater stored in the world's terrestrial water bodies?

3. Measurements Required

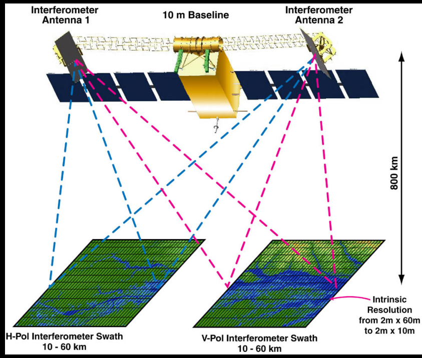
maps of h, which give maps of dh/dt and dh/dx

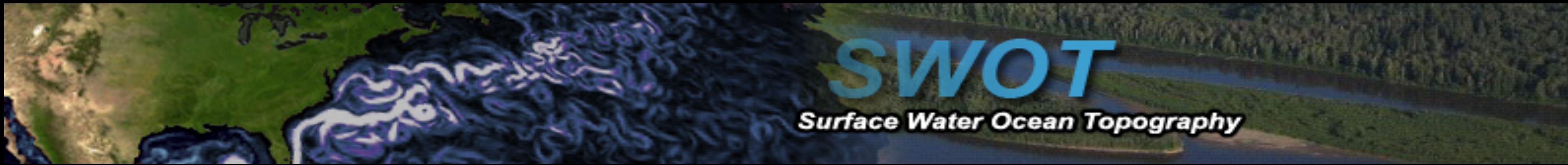




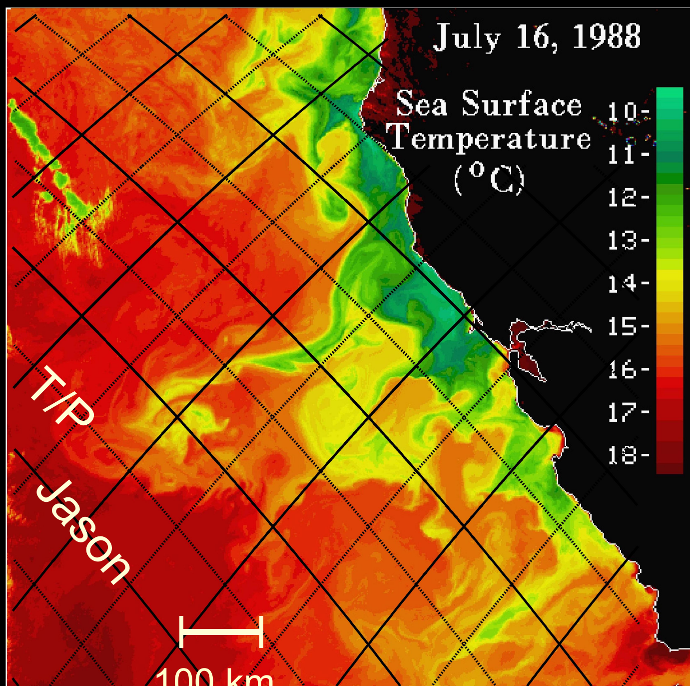
4. The Solution

KaRIN: Ka-band Radar Interferometer. SRTM, WSOA heritage. Maps of h globally and ~weekly (over a 120 km wide swath at 1km resolution)



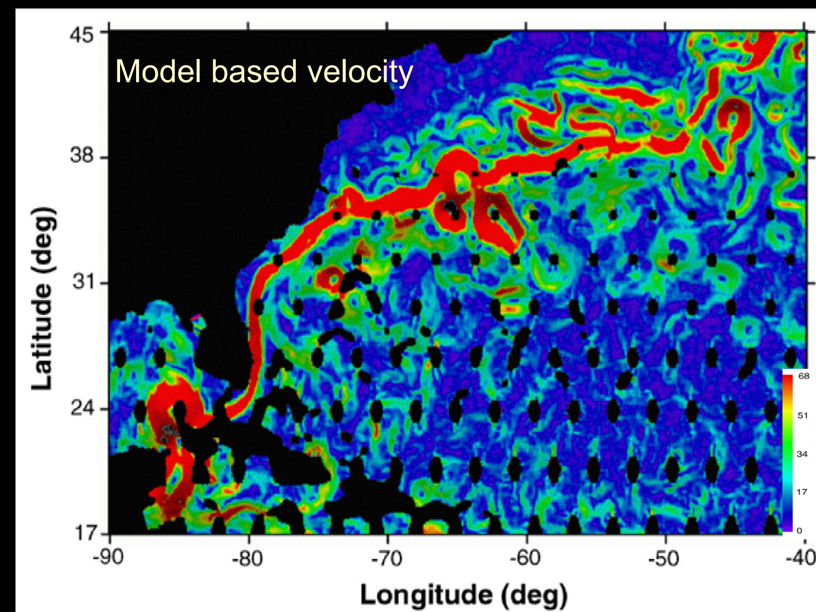


1. The Problem **Altimeters miss considerable ocean area.**

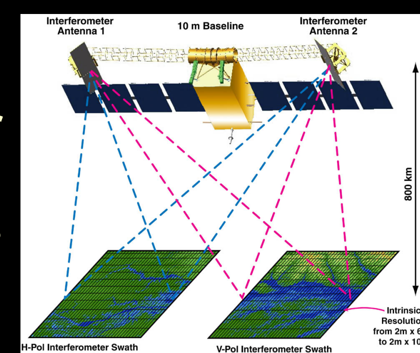


2. The Question What are the energy dissipation, ocean circulation, and climate implications from oceanic eddies which contain 90% of the kinetic energy, but are ~10 km scale in cross-stream direction, e.g. Gulf Stream, Kuroshio.

3. Measurements Required **Maps of h, which give maps of dh/dt and dh/dx allowing derivation of velocity, vorticity, and stress tensor.**



4. The Solution **KaRIN: Ka-band Radar Interferometer. SRTM, WSOA heritage. Maps of h globally and ~weekly.**



Snow Missions

Edward Kim
NASA/GSFC
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301-614-5653

snow.nasa.gov

The Importance of Snow

- Snow is important both as a water resource and as a control on surface energy balance.
- For 1/6 of Earth's population 50-100% of runoff results from snowmelt[1], affecting about a quarter of the global GDP.
- In large parts of the western US, up to 90% of renewable water comes from snow. The current CA drought is mainly due to low snow.
- 9 of the top 20 US floods during 1900-2000 were snow-related.
- Snow is a major source of spring soil moisture for agriculture.

Snow is important, yet simple questions like 'how much snow is there?' and 'when will it melt?' are still difficult to answer; there are large uncertainties using remote sensing or models.

[1]Barnett et al, Nature (17), Nov 2005

snow.nasa.gov

Snow missions

- Must address ***global*** snow
- Therefore must include multiple sensors (community consensus)
  - e.g., Active & passive microwave, lidar, multi-spectral VIS/IR
  - Recent snow mission proposals were single-sensor & algorithms were not robust enough→ proposals not selected
- Need mature sensor technology and algorithms
  - Strengths & limitations of various sensors not well characterized vs. each other
  - Very little work on multi-sensor algorithms used w/great success elsewhere
  - Little existing work on snow retrievals in forest areas (50% snow covered area)
- Satellites are expensive; multi-sensor missions are more expensive
  - Must leverage existing assets (e.g., passive microwave and multispectral)
  - But some satellite assets might go away (passive microwave)
- International partnering is the key to
  - Leveraging technology and algorithm development investments
  - Spreading costs
- Societal benefits and science return already strong

Need multi-sensor field data to perform mission concept trade studies

Snow Measurement Capabilities

- Recent snow remote sensing community consensus: no single sensing technique works well across a wide variety of snow types and conditions.
- What is the optimum combination of sensing techniques to measure
  - regional (global) SWE?
  - global snow melt/energy balance (where, when, how fast)?
- Candidate sensors: radar, lidar, passive microwave, VIS/IR multispectral, BRDF
- Groups in US & Europe are exploring satellite concepts

Need a multi-sensor field campaign to compare techniques, to quantify when each 'breaks' and to understand why.

snow.nasa.gov

SnowEx airborne campaigns

- Year 1 led by NASA GSFC with help from whole snow community
- Will collect a multi-sensor dataset for mission trade studies and algorithm development
- Year 1 focus: snow in forests
- Sites selected for 2016-17
  - Primary: Grand Mesa, CO
  - Secondary: Senator Beck basin, CO
- Airborne sensors
  - Radar: SnowSAR (ESA)
  - Passive mw: AESMIR (GSFC)
  - BRDF: CAR (GSFC)
  - Lidar+ hyperspectral: ASO (JPL)
  - Thermal IR: TBD
  - Photography: TBD

- Year 1 Deployments
  - Sep/Oct 2016 lidar only no-snow background;
  - Feb 2017: with-snow; all sensors
  - Summer 2017: radar only no-snow background
- Ground truth
  - Traditional & new measurements
  - Snow & trees & soil

- SnowEx schedule:
- Year 1 = 2016/17 dedicated campaigns
- Year 2 = 2017/18 no campaign
- Year 3 = 2018/19 dedicated campaigns
- Year 4 = 2019/20 dedicated campaigns
- Year 5 = 2020/21 dedicated campaigns
- Locations for years 3,4,5 TBD

snow.nasa.gov -> snowex

GLOBAL MAPPING OF EVAPOTRANSPIRATION

Thomas R. H. Holmes

Hydrological Sciences Lab, Code 617

ET at the Hydrological Sciences Lab

Importance

- Evapotranspiration (ET) is the link between the energy, water, and carbon cycles
- Accounting for up to 60 % of the return of precipitation to the atmosphere, it plays a key role in climate, meteorology, and agriculture.
- ET is also one of the most unconstrained components of the hydrological cycle.

ET at the Hydrological Sciences Lab

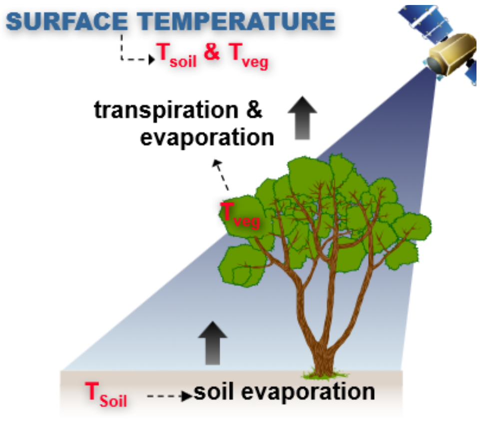
- Use remotely sensed ET as a diagnostic observation for model improvement and/or assimilation;
- Concept development for remote sensing missions to estimate evapotranspiration (ET) at diverse spatial domains (e.g. Decadal Survey)

Challenge

- Evaporative flux does not leave a direct electromagnetic fingerprint that can be exploited by satellite retrievals

Energy balance approach: ALEXI

Applications with Thermal Infrared



Given known radiative energy inputs, how much water loss is required to keep the soil and vegetation at the observed temperatures?

General Method

- Interprets temporal gradients in Surface Temperature as one of the most direct diagnostics of ET
- Atmosphere Land Exchange Inverse (ALEXI: Anderson et al., 1997, 2007)

Thermal Infrared (TIR) implementations (USDA/NOAA)

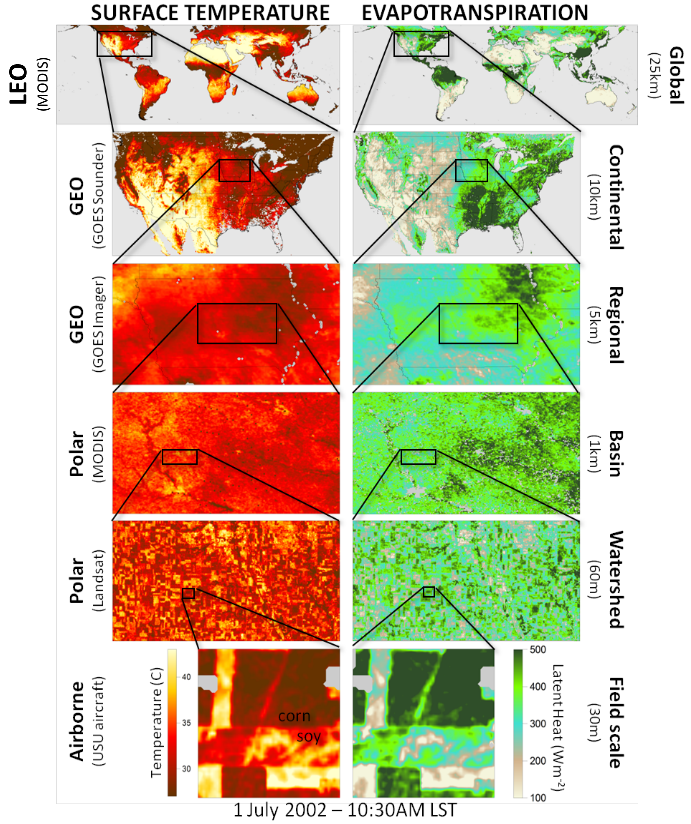
- Using TIR-LST allows to integrate measurements from field to continental scales depending on application:
  - *Field Scale*: crop water use
  - *Regional scale*: early indicator of agricultural drought
  - *Continental to global scales:* Confronting LSM with observations
- MODIS-LST implementation (Chris Hain, NOAA) . Global 5km, 7-day product 2001-Present

Microwave LST implementation (NOAA/NASA/USDA)

- In evaluation. Test run: Global 0.25 degree, 7-day product 2003-2013

Microwave LST

Thermal Infra Red

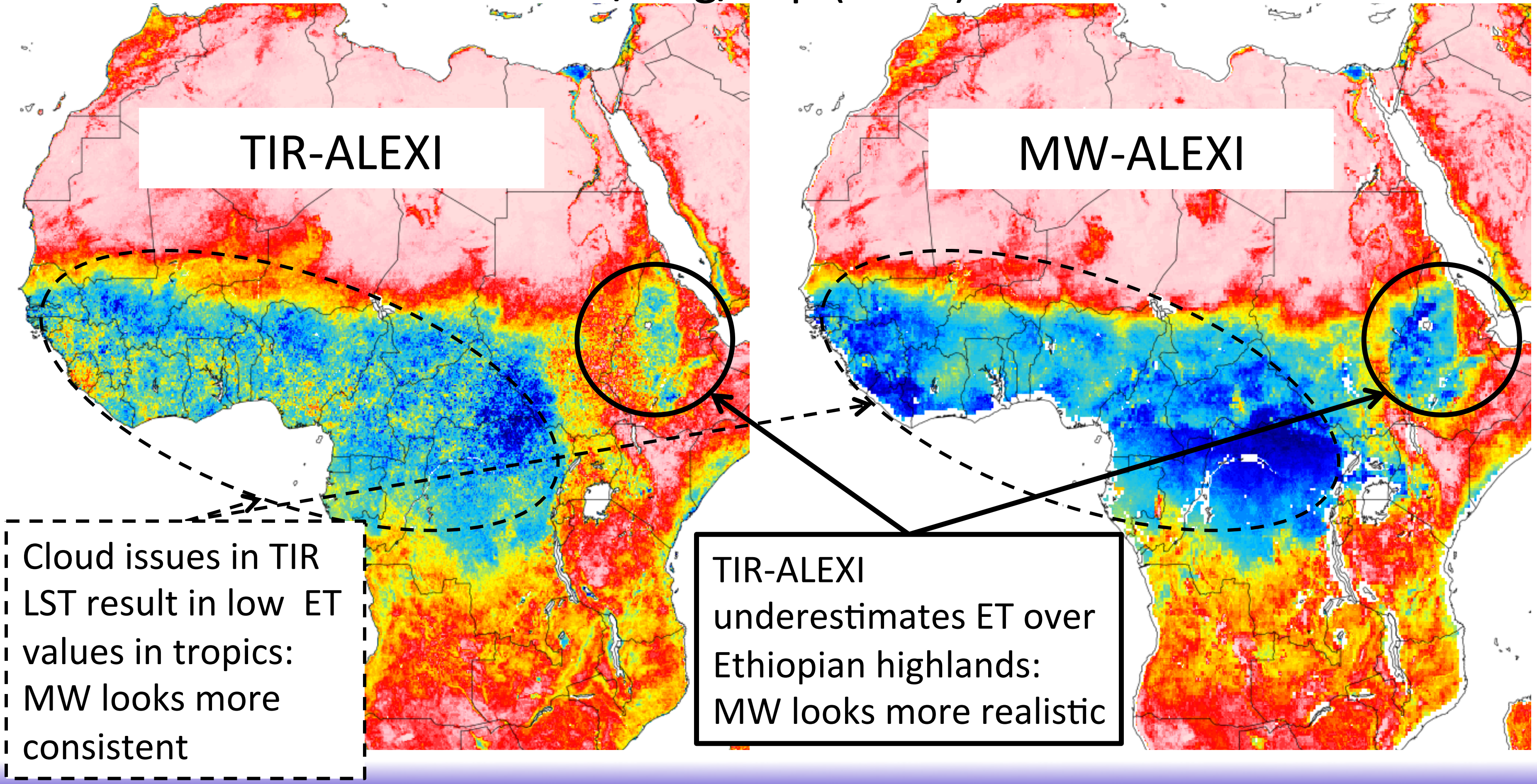


Multi-scale ET maps using land-surface temperature from various satellites

Microwave Implementation of ALEXI

3-month totals

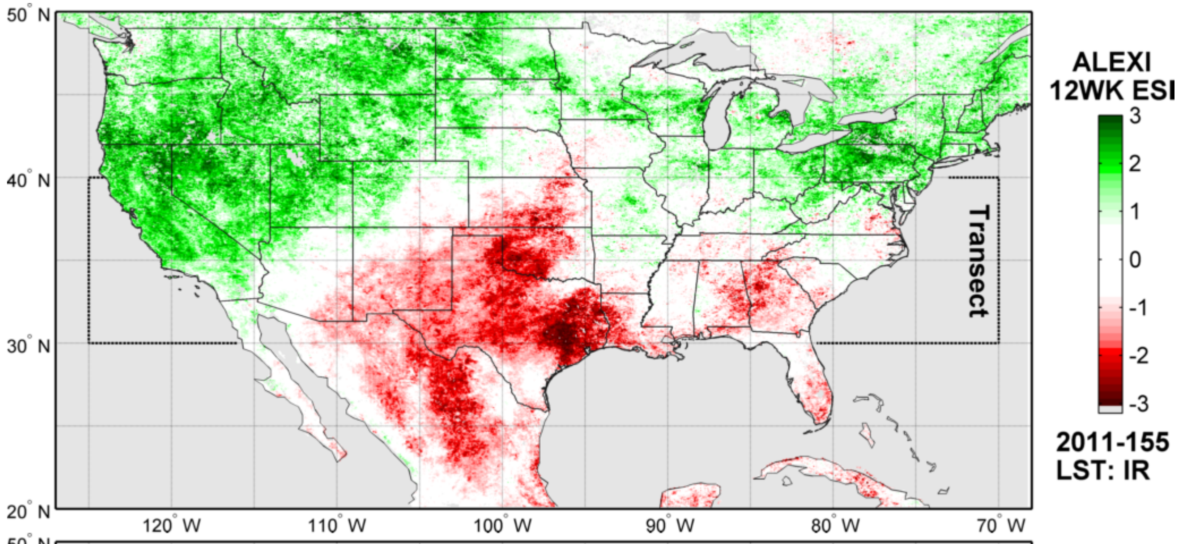
Cumulative - Clear Sky - Evapotranspiration (mm)
Jul/Aug/Sep (2004)

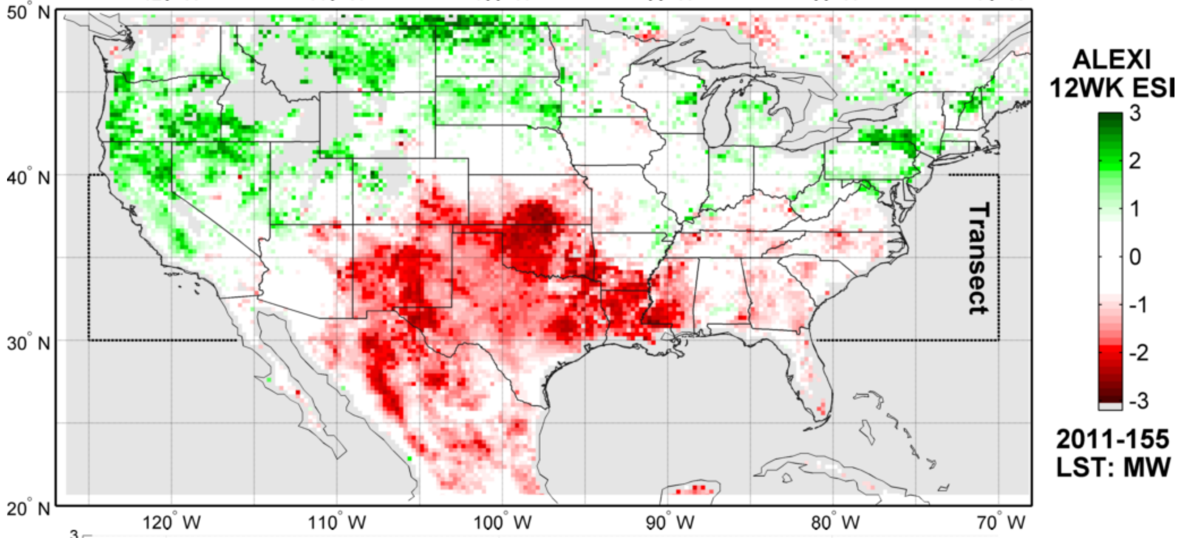


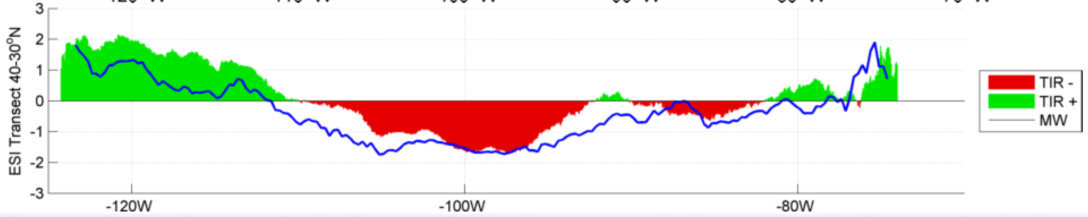
NASA Goddard Space Flight Center
Earth Sciences Division / Hydrological Sciences Lab

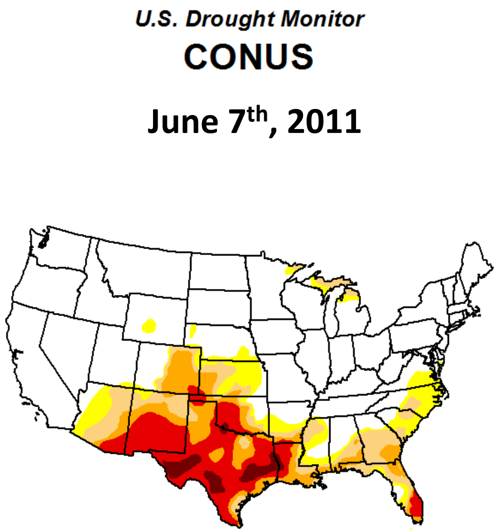
Anomaly analysis with MW-ALEXI

ESI 12week moving window







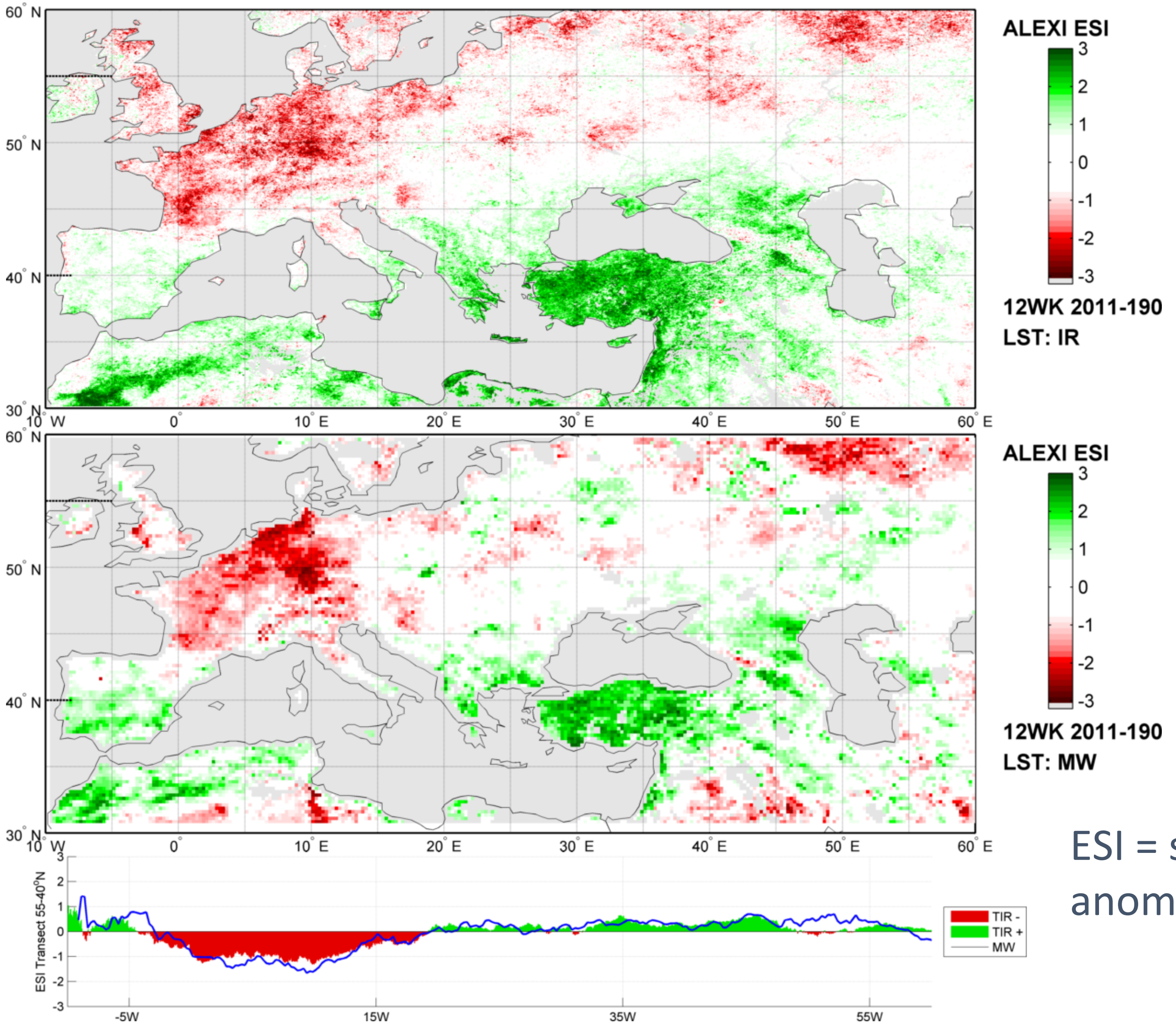


ESI = standardized anomalies in ET/RefET

NASA Goddard Space Flight Center
Earth Sciences Division / Hydrological Sciences Lab

Anomaly analysis with MW-ALEXI

ESI 12week moving window



ESI = standardized anomalies in ET/RefET

Mission Development

- ThermaSat (PI: Alicia Joseph, Code 617)
  - Propose to fly a thermal instrument with (SWIR) Shortwave Infrared band in same orbit with European Space Agency's (ESA's) Sentinel 2 mission. This will afford the near-simultaneous collection of Visible (VIS)/Near Infrared (NIR)/SWIR and TIR data for ET retrievals at a consistent time of day, with 10-day revisit time.

- NRC Decadal Survey:
  - Joseph et al 2016: "Characterizing evapotranspiration, ecosystem productivity and water stress to address global food and water security", *whitepaper in response to ESAS 2017 Request for Information #2*
  - Our vision for combining thermal (high res), with microwave (cloud tolerant), and hyperspectral (ecosystem physiological responses) into a mission to estimate ET and its source components for Agricultural, Weather and Climate applications.

Land Surface Modeling and Data Assimilation

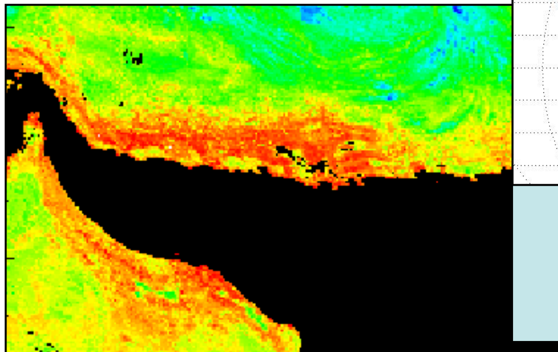
http://lis.gsfc.nasa.gov

Sujay V. Kumar

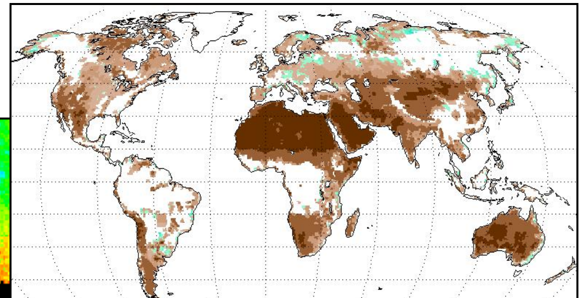
Hydrological Sciences Laboratory

NASA Goddard Space Flight Center

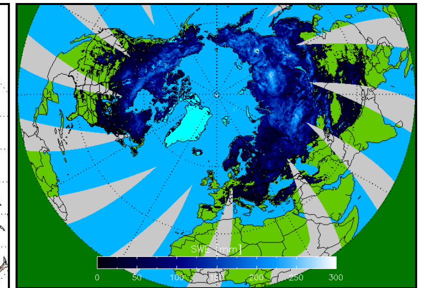
Remote sensing data for land data assimilation



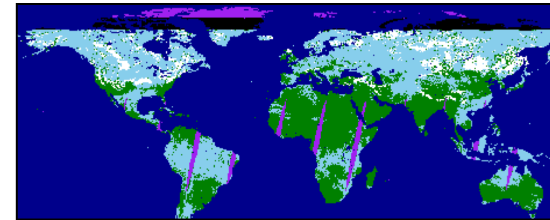
Land surface temperature
(MODIS, AVHRR,GOES,…)



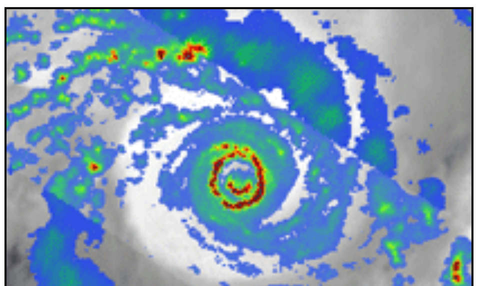
Surface soil moisture
(SMMR, TRMM, AMSR-E,
SMOS, Aquarius, SMAP)



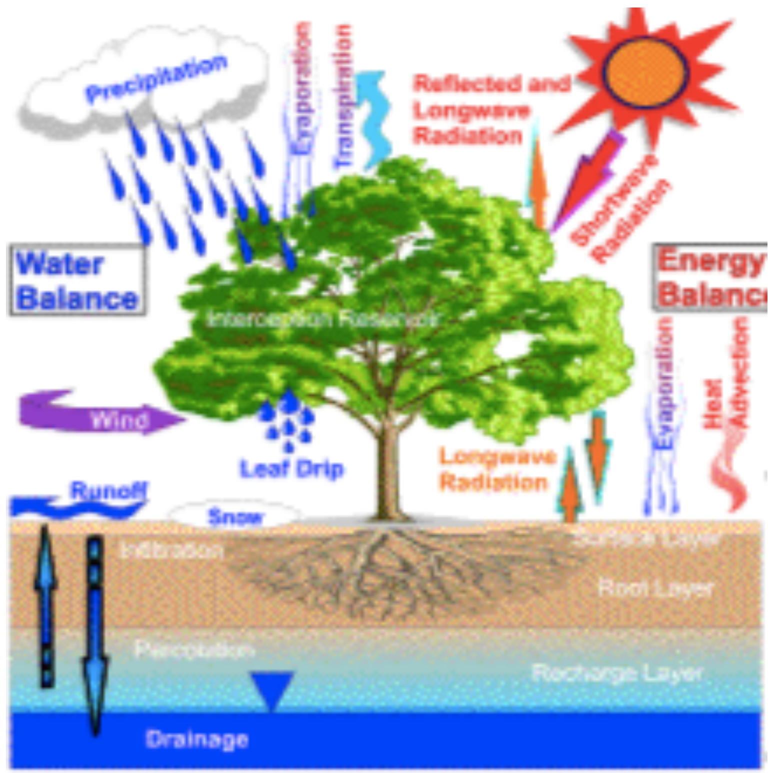
Snow water equivalent
(AMSR-E, SSM/I,
SCLP)



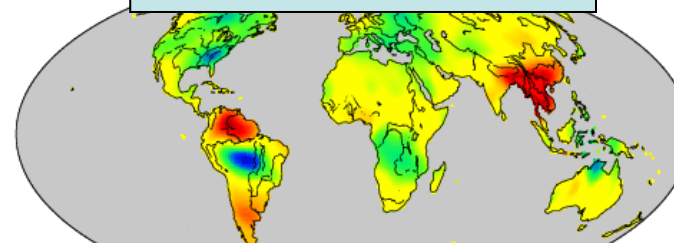
Snow cover fraction
(MODIS, *VIIRS, MIS*)



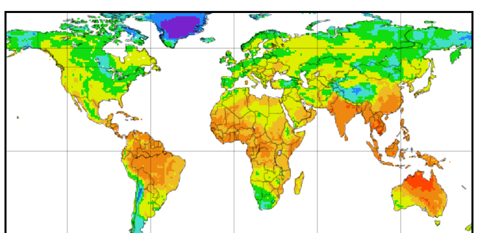
Precipitation
(TRMM, *GPM*)



Water surface elevation
(*SWOT*)



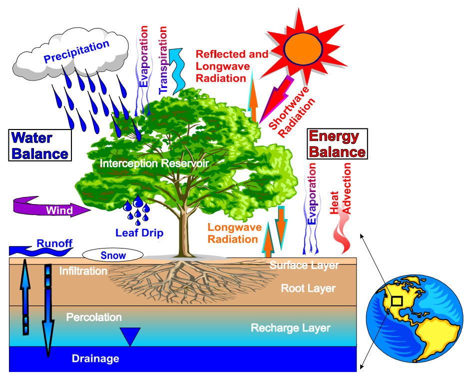
Terrestrial water storage (GRACE)



Radiation
(CERES, *CLARREO*)

Vegetation/Carbon
(AVHRR, MODIS, *DESDynI,*
ICESat-II, HyspIRI, LIST,
ASCENDS)

How do we combine the information from satellite observations and models?



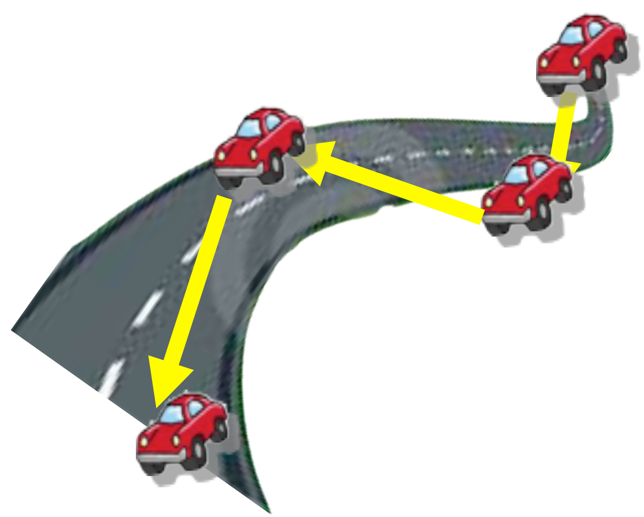
Models

+

Observations

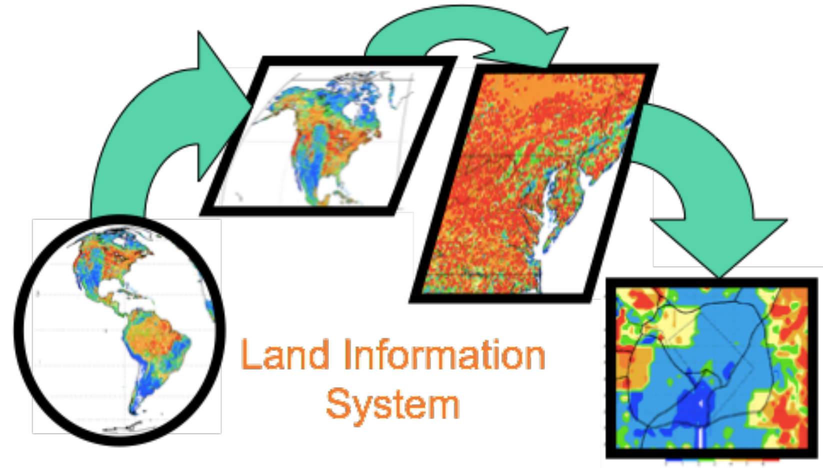
Data assimilation is the method used to incorporate observational data into model forecasts

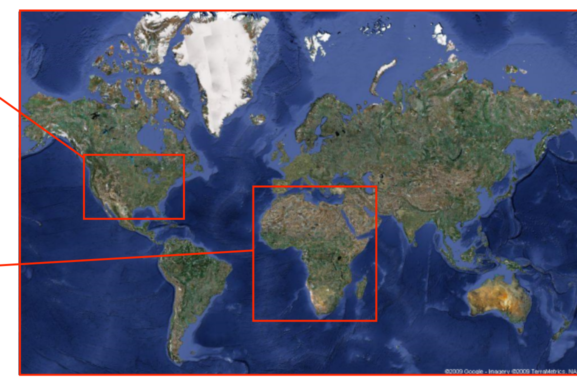
Like a "sleepy-driver" scenario



Land Data Assimilation Systems

- NASA develops remote sensing and modeling techniques to improve our understanding of stocks (soil moisture, snow) and fluxes (evaporation, runoff) of the water cycle through the development of Land Data Assimilation Systems (LDAS)
- Land Information System (LIS; lis.gsfc.nasa.gov)
  - Flexible software that enables LDAS instances
  - Multiple data assimilation options
  - Used for operational/routine land modeling support at 557th Weather Wing USAF, NOAA NCEP, NOAA NOHRSC, USAID, among others.
- Global scale (GLDAS), North America (NLDAS and the National Climate Assessment NCA-LDAS), Africa (FLDAS)

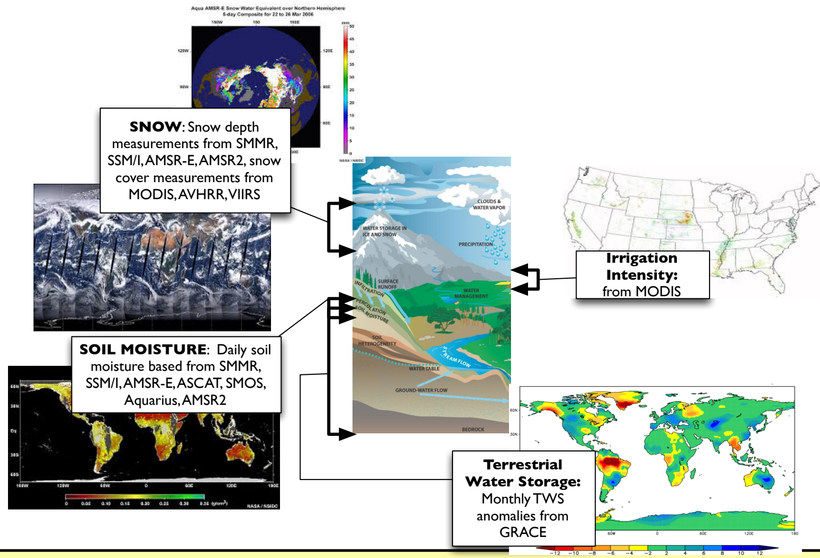


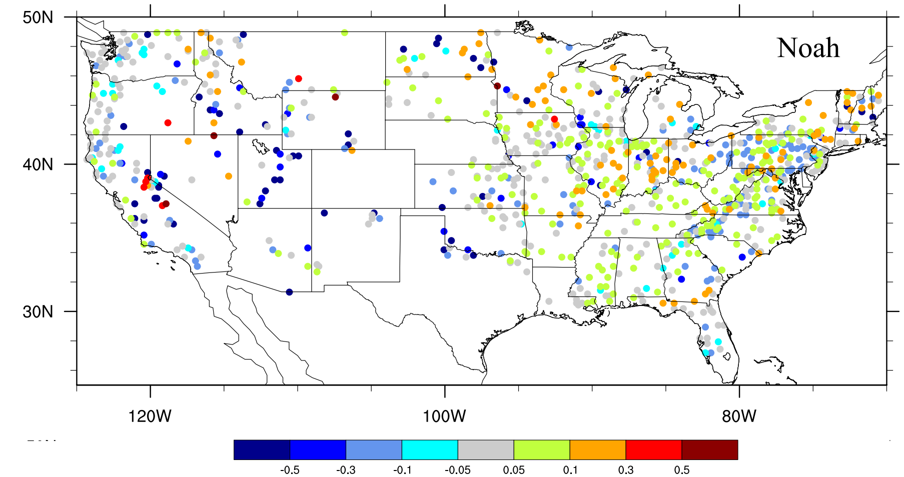


http://lis.gsfc.nasa.gov
http://ldas.gsfc.nasa.gov
http://disc.sci.gsfc.nasa.gov/hydrology

Kumar et al. (2006): Land Information System: An interoperable Framework for High Resolution Land Surface Modeling, Environmental Modeling and Software, Vol 21, pp 1402-1415.

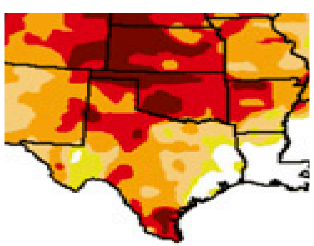
Multivariate assimilation of satellite-derived remote sensing datasets in the National Climate Assessment LDAS



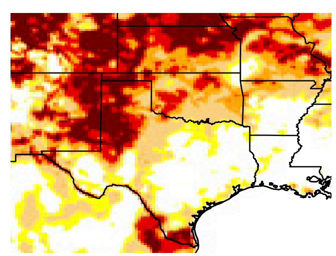


The concurrent, multivariate assimilation of various terrestrial hydrological datasets (soil moisture, snow depth, snow cover, terrestrial water storage, irrigation intensity) has been demonstrated for the NCA LDAS.

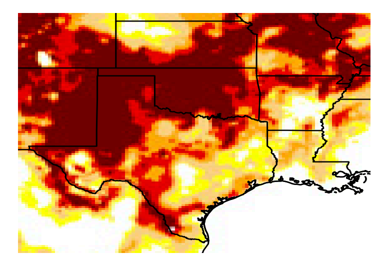
Multivariate assimilation of satellite remote sensing datasets are helpful in improving water budget components, including streamflow



US drought monitor

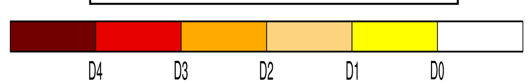


LSM based drought estimate



LSM based drought estimate with data assimilation

Impact of LDA on drought estimates (Sep, 2012).



Kumar et al. (2014): Assimilation of remotely sensed soil moisture and snow depth retrievals for drought estimation, J. Hydromet., 10.1175/JHM-D-13-0132.1

Kumar et al. (2016): Assimilation of gridded GRACE terrestrial water storage estimates in the North American Land Data Assimilation System, J. Hydromet., 10.1175/JHM-D-15-0157.1

Summary

- Land Data Assimilation Systems have been developed for central North America (NLDAS, NCA-LDAS), Africa (FLDAS) and the globe (GLDAS)

- The common goal of these projects is to integrate all relevant data in a physically consistent manner within sophisticated land surface models to produce optimal estimates of hydrological states (e.g. soil moisture, surface temperature) and fluxes (e.g. runoff, evapotranspiration)

- The Land Information System (LIS) is an efficient and configurable software that can be used to specify an instance of LDAS

- LDASs have been used for water availability applications including drought/ flood monitoring, agricultural management, weather and climate initialization.

Global NRT MODIS and Landsat Flood Mapping/ NRT Flood Extent and Impact Assessment in S.E. Asia

Fritz Policelli, NASA GSFC

John Bolten, NASA GSFC

Aakash Ahamed, USRA/ GSFC

Colin Doyle, UT Austin

Jessica Fayne, U. South Carolina

Dan Slayback, SSAI/ GSFC

Bob Brakenridge, U. Colorado

Joe Nigro, , SSAI/NASA GSFC

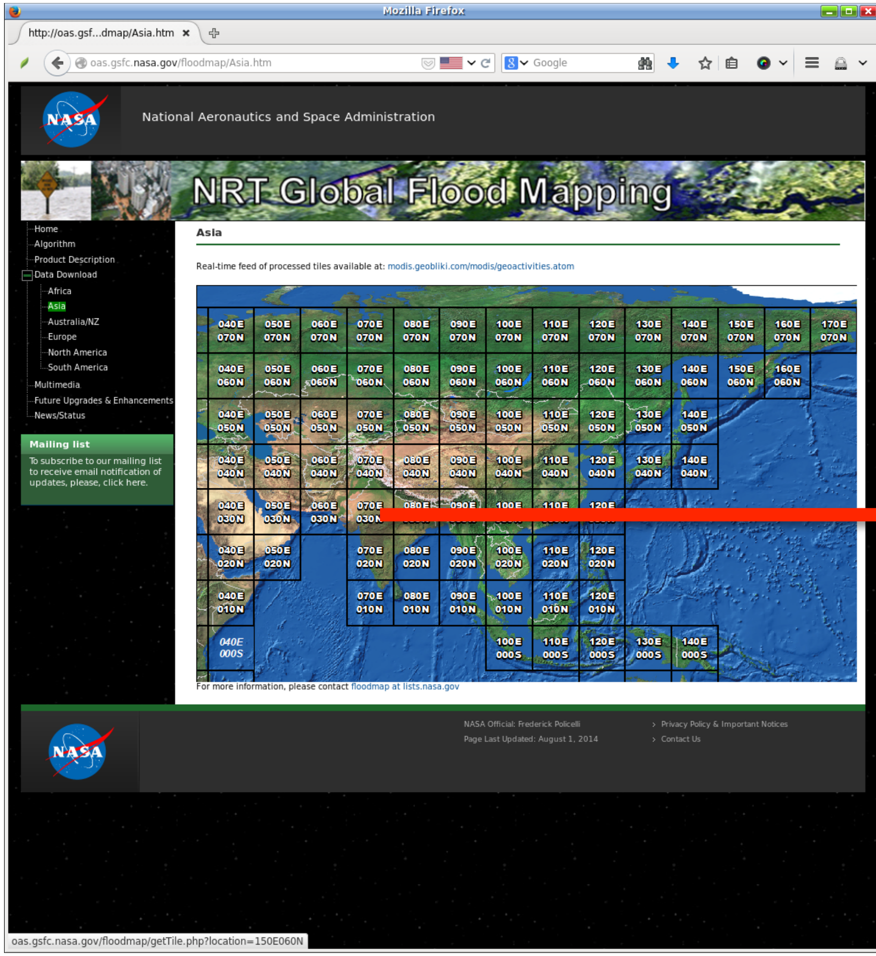
July 28, 2016

Goddard Space Flight Center
Office of Applied Sciences

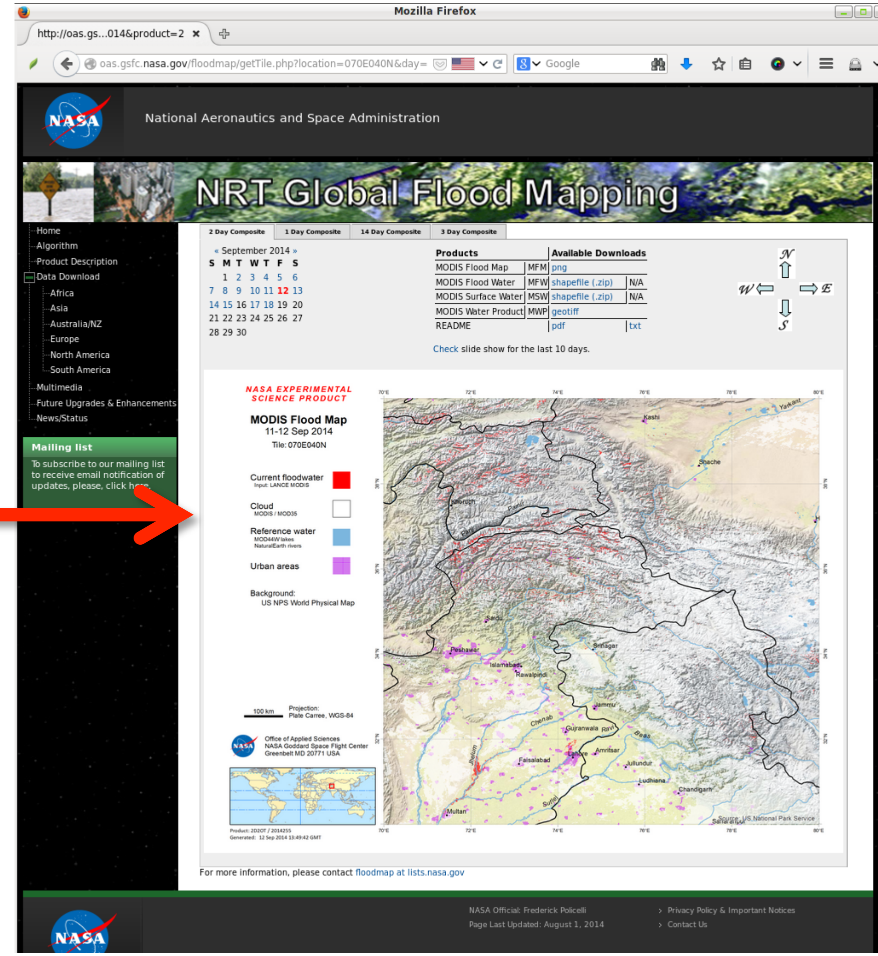
Dartmouth Flood Observatory

Original MODIS product distribution system:

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



Continental tile index

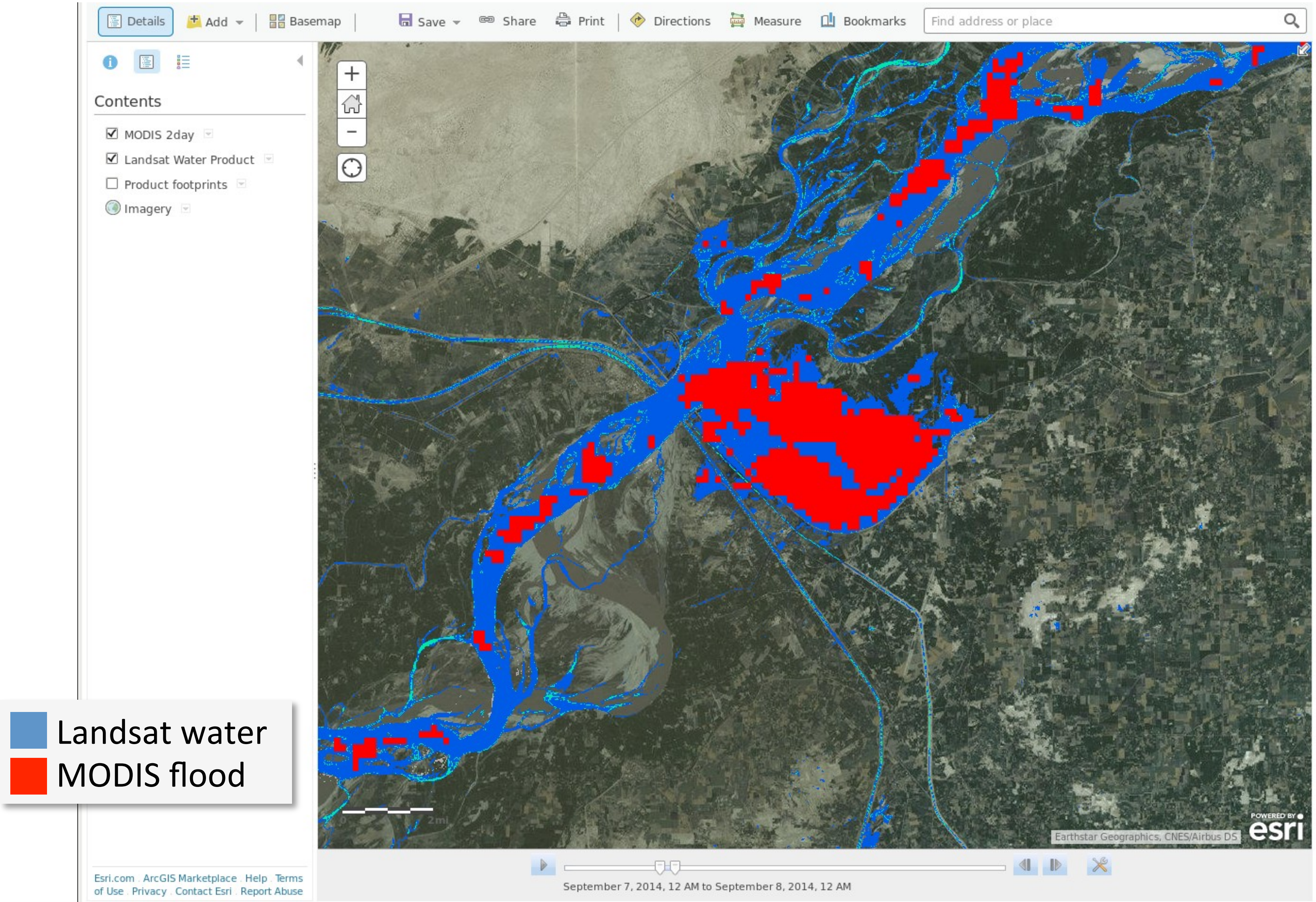


Specific tile

- Date selector
- Available product/format downloads

Image Services Approach: Example display / query online w/ ArcGIS Server

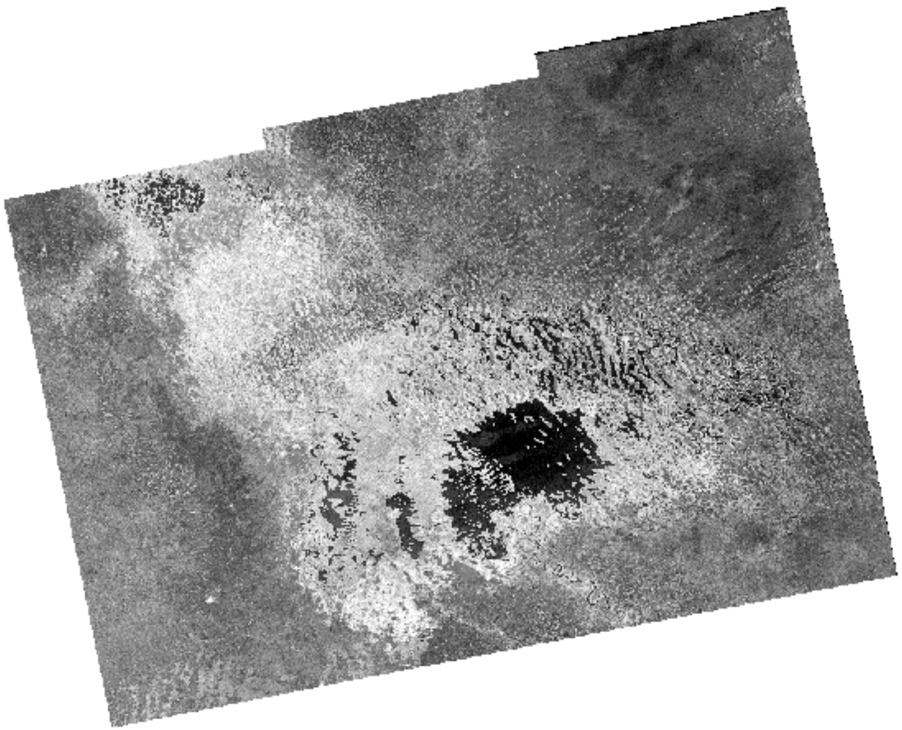
Zoom to detail, change of basemap layer, viewing date, etc.



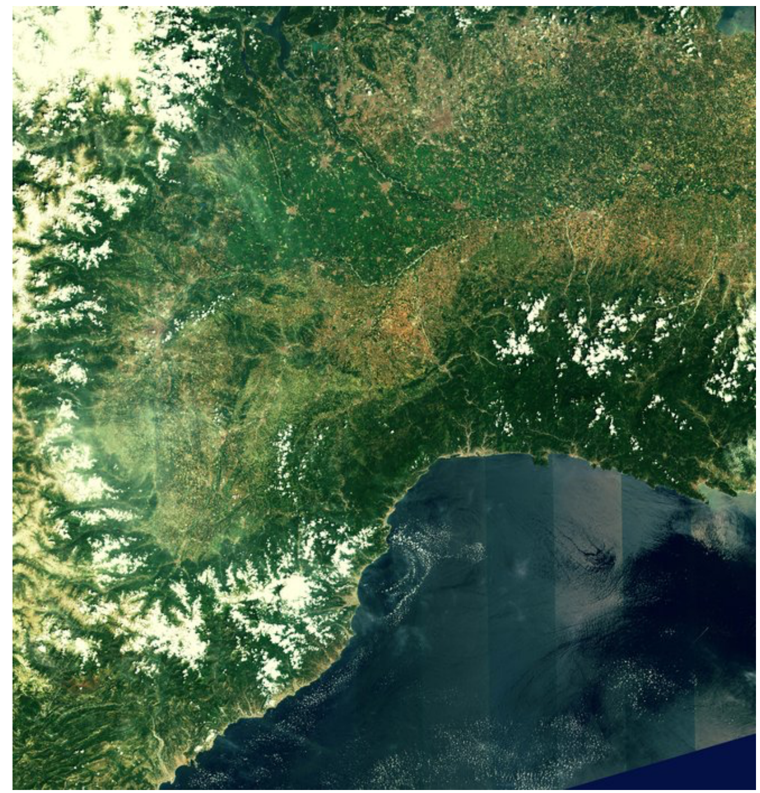
Automated MODIS Flood Map Production System

- Fully automated (since Nov 2011)
- 223 10x10° tiles x 3 products (2-day, 3-day, 14-day) = 669 daily product suite generated
- 1-day composite production mode
- Product suites include: geotiffs, shapefiles, KML (Google Earth), and graphic maps (png)
- Products typically available within 6 hours of Aqua overpass (~ 8:00 PM local time)
- Delivery via web download, and (from June 2014) via live ArcGIS Image Services

Working on Sentinel-1, -2 Flood Mapping Capability



Sentinel-1 Lake Chad

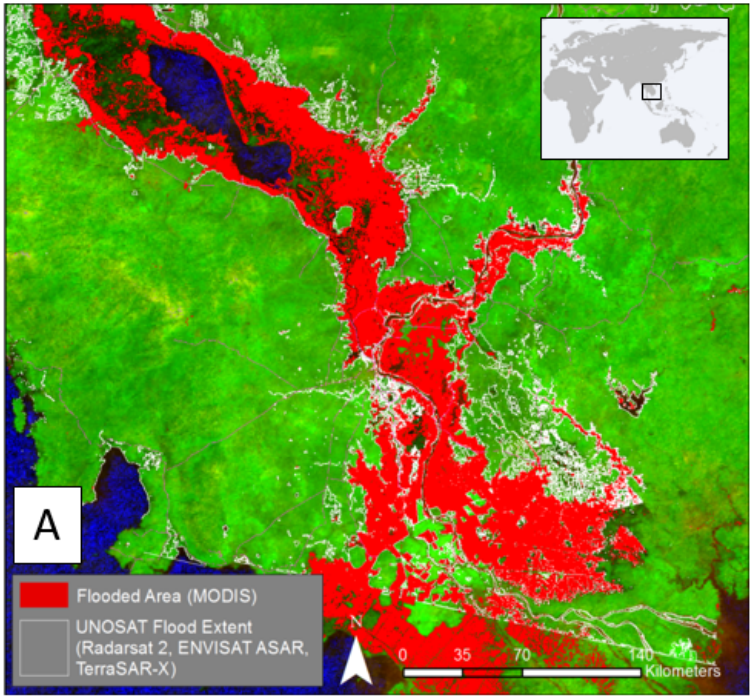


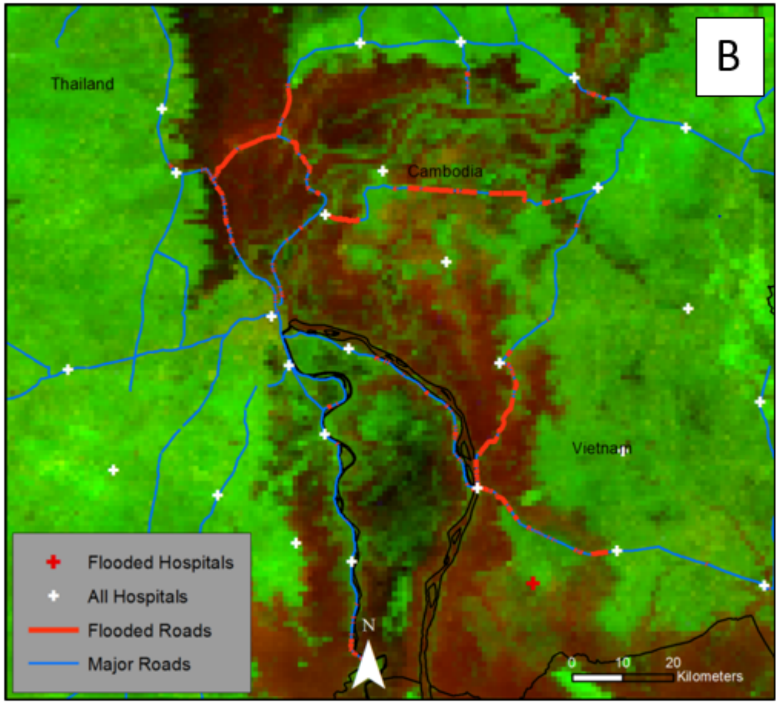
Sentinel-2 Southern Europe

NRT Flood Extent and Impact Assessment in SE Asia

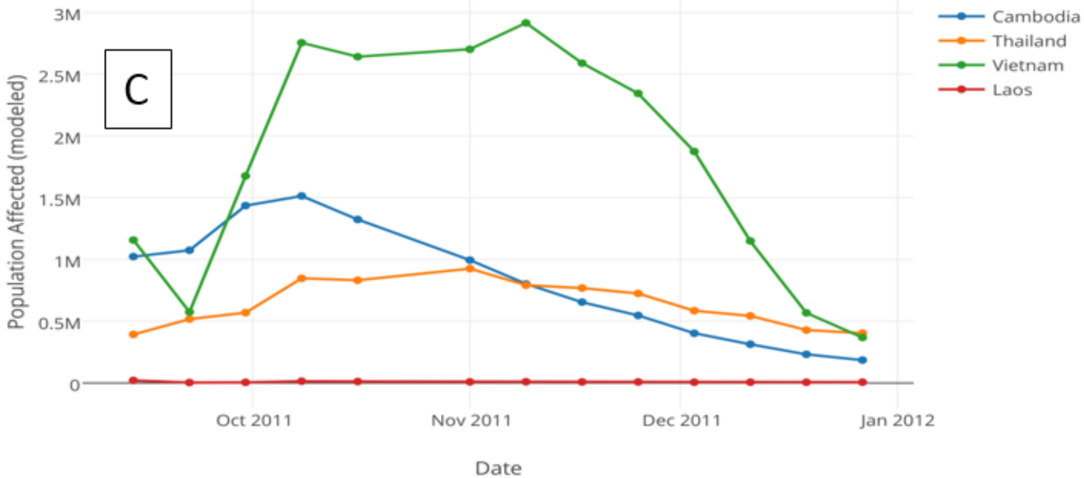
J. Bolten (GSFC), A. Ahamed (USRA/GSFC), J. Fayne (USC/GSFC), C. Doyle (UTA)

Capability	Data / Method / Notes
Regional flood extent (Daily, 4-day, 8-day)	250m LANCE – MODIS + NDVI change detection algorithms (http://nrt1.modaps.eosdis.nasa.gov)
Socioeconomic Impact Estimates	SEDAC – Population, Infrastructure, Agriculture (http://sedac.ciesin.columbia.edu/)
Web Interface (in dev.)	http://mekongflood.appspot.com
Historic analysis tool	Analyze historic events for product validation





(A) Flood extent (10/16/2011) from MODIS (red) and UNOSAT tasked SAR (white).
(B) Map of flooded and unflooded roads and hospitals during 2011 flooding.
(C) Time series of population affected by flooding.

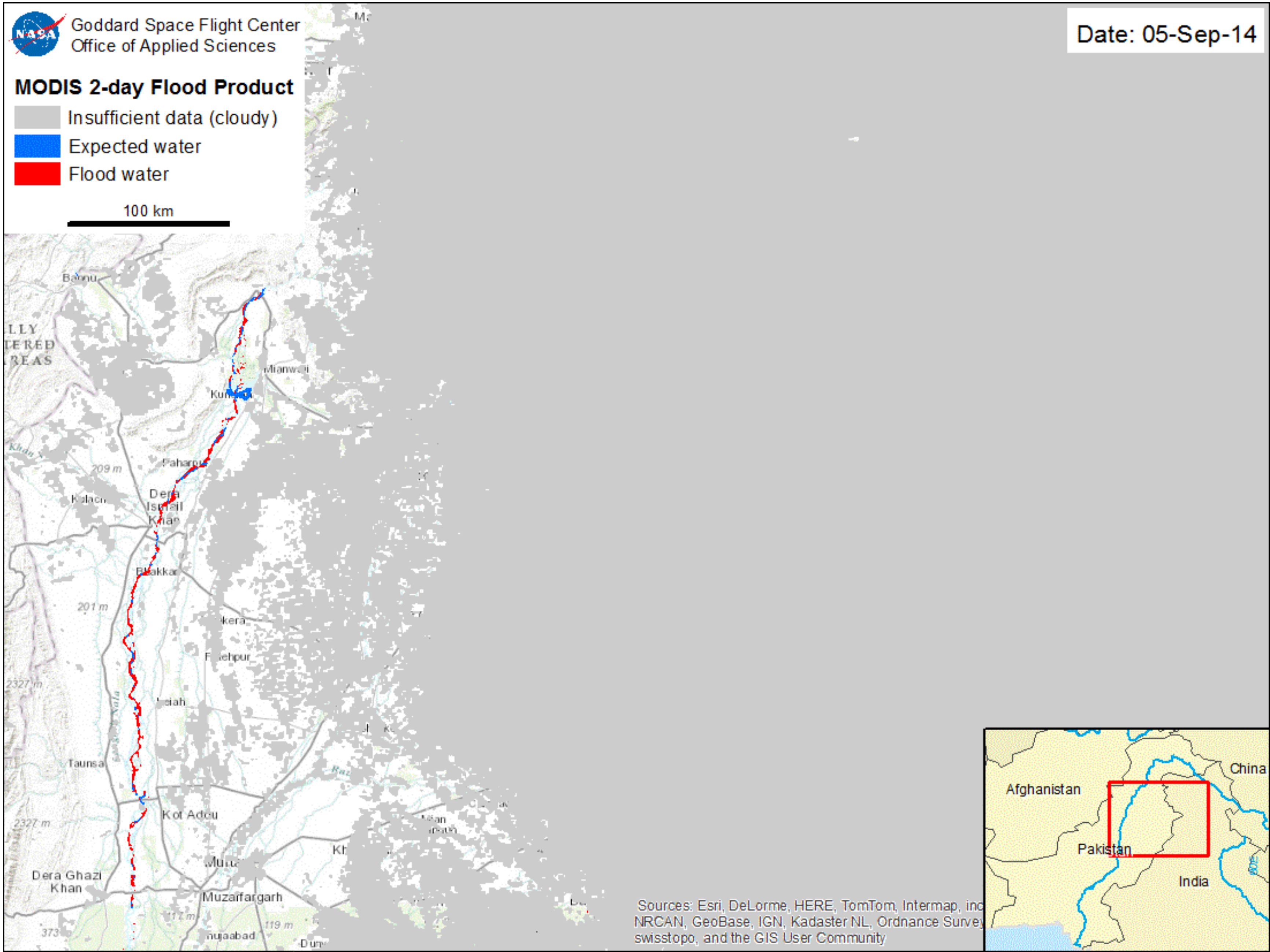


Submitted Publications:

1) Ahamed, A., Bolten, J.D., Doyle, C.S., (In Review). Near Real-Time Flood Impact Assessment Systems for Southeast Asia. Submitted to *International Journal of Applied Earth Observation and Geoinformation.*
2) Fayne, J.V., Bolten, J.D., Doyle, C.S., Fuhrmann, S., Rice, M.T., Houser, P.R., Lakshmi, V., (In Review). Flood Inundation Mapping Using Daily MODIS Observations. Submitted to *International Journal of Remote Sensing.*
3) Ahamed, A., Bolten, J.D., Doyle, C.S., (In Review). Near Real Time Flood Detection and Impact Assessment. Mekong River Basin Case Study. In *Remote Sensing of Hydrological Extremes.*
4) Fayne, J. V., Bolten, J.D., Lakshmi, V., Ahamed, A., (In Review). Optical and Physical methods for Mapping Flooding with Satellite imagery. In *Remote Sensing of Hydrological Extremes.*

Comments/ Questions ?

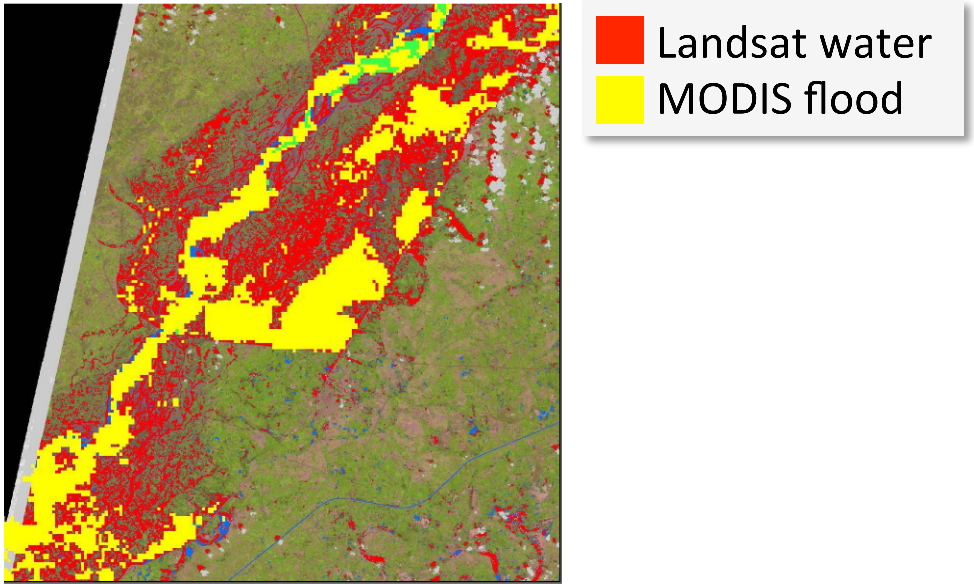
Pakistan Flooding – Sept 2014



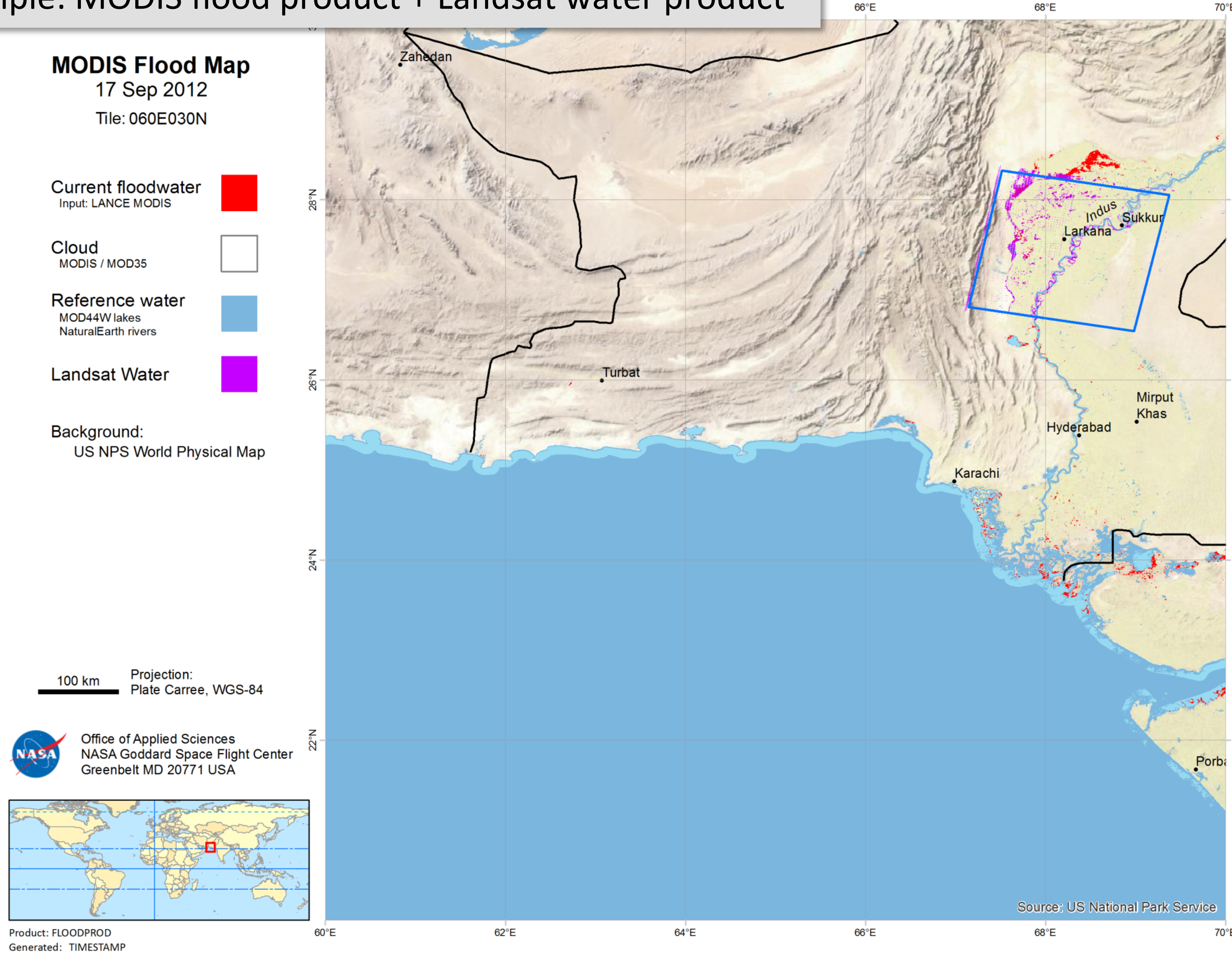
Landsat Water Product

Features:

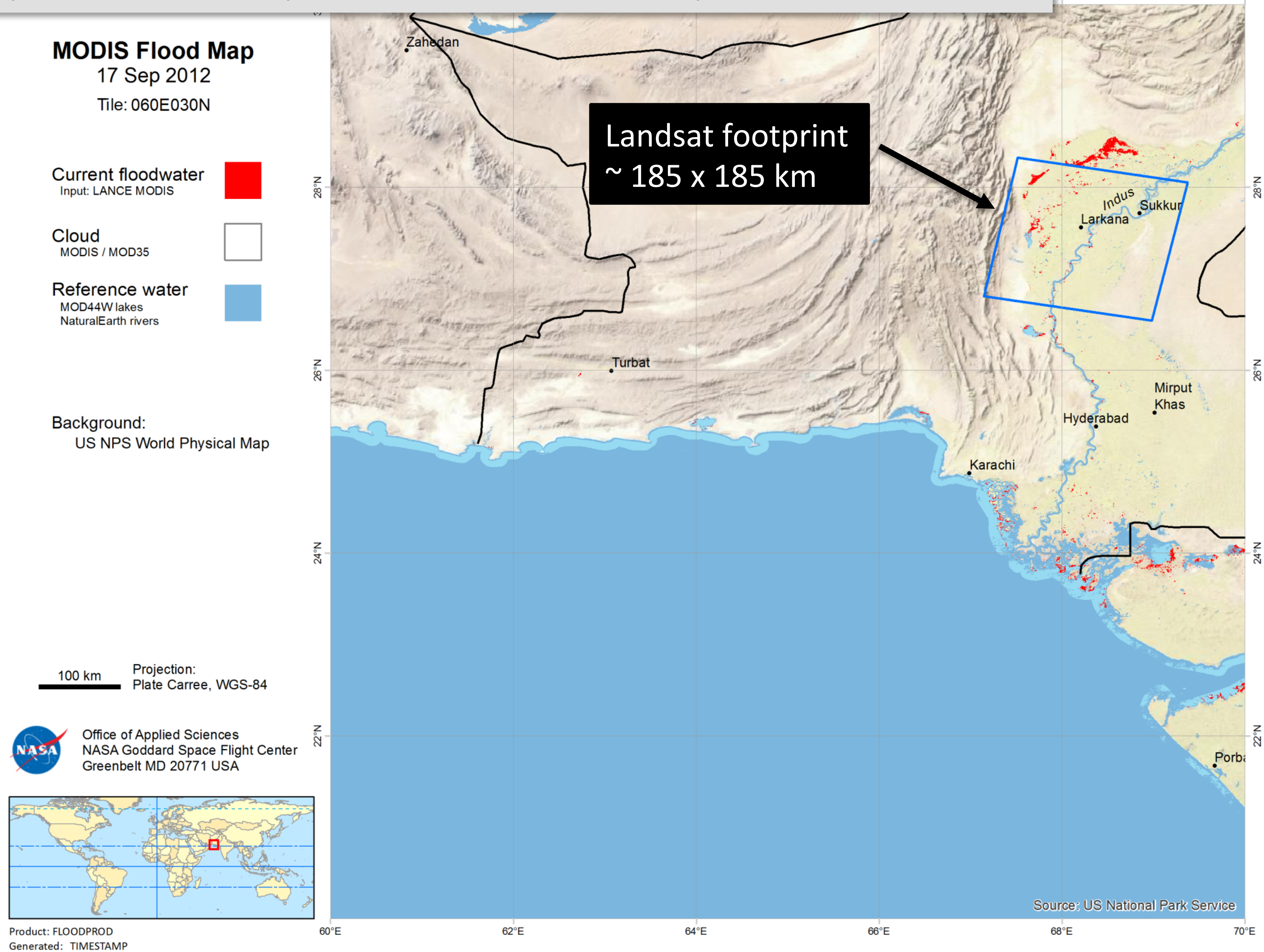
- 30 m resolution can provide useful detail when available (MODIS is at 250 m)
- Additional spectral bands improve water detection (we use a multi-index algorithm)
- Automated processing of Landsat 7 and 8 imagery when available from USGS (typically several hours after 10:30AM local time acquisition for Landsat 8)
- Processing triggered only for targeted scenes of interest
  - Scenes targeted based on flood alerts (Stuart Frye's geoBPMS system)

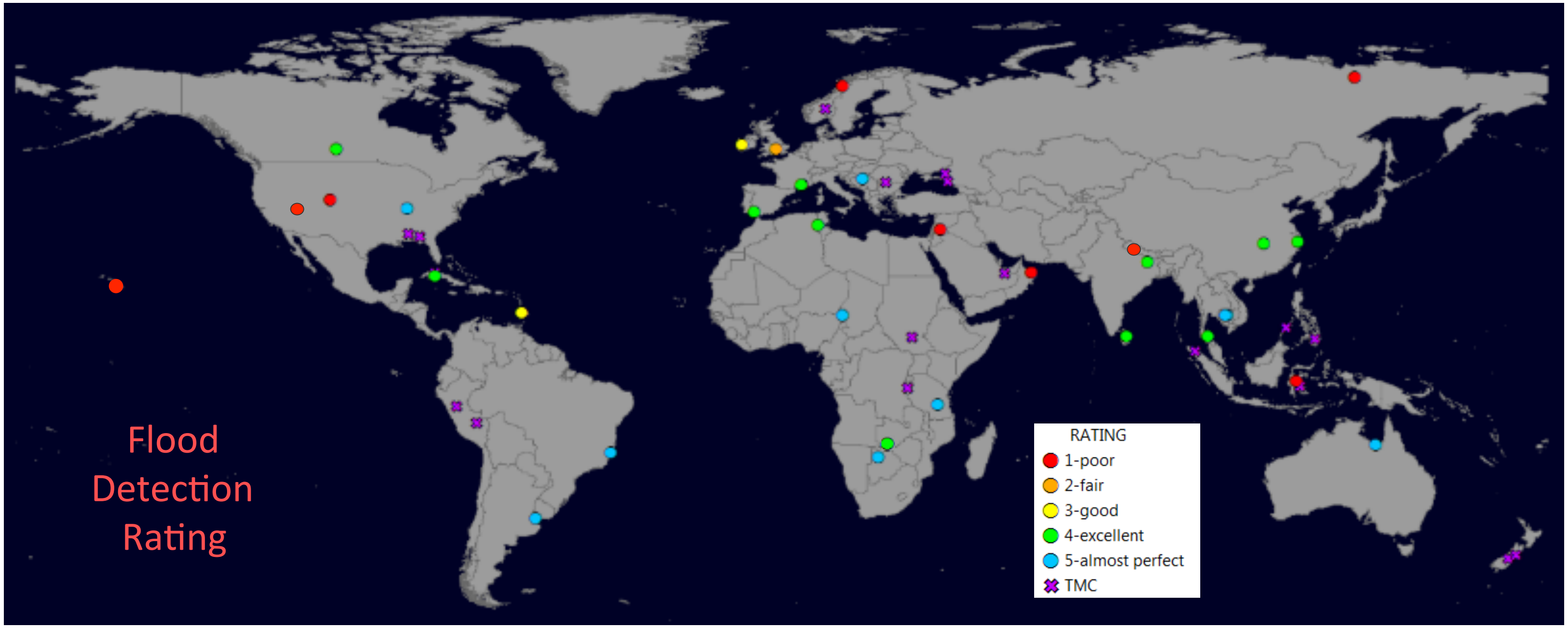


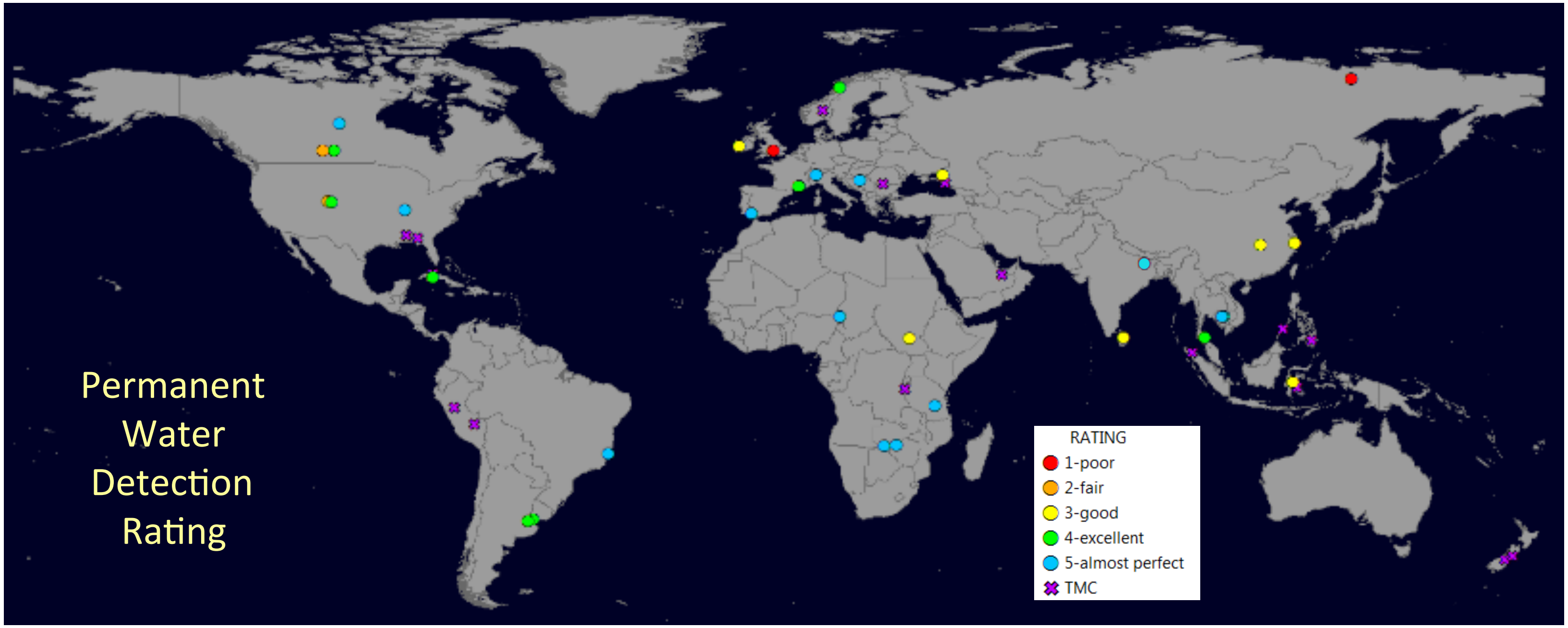
Example: MODIS flood product + Landsat water product



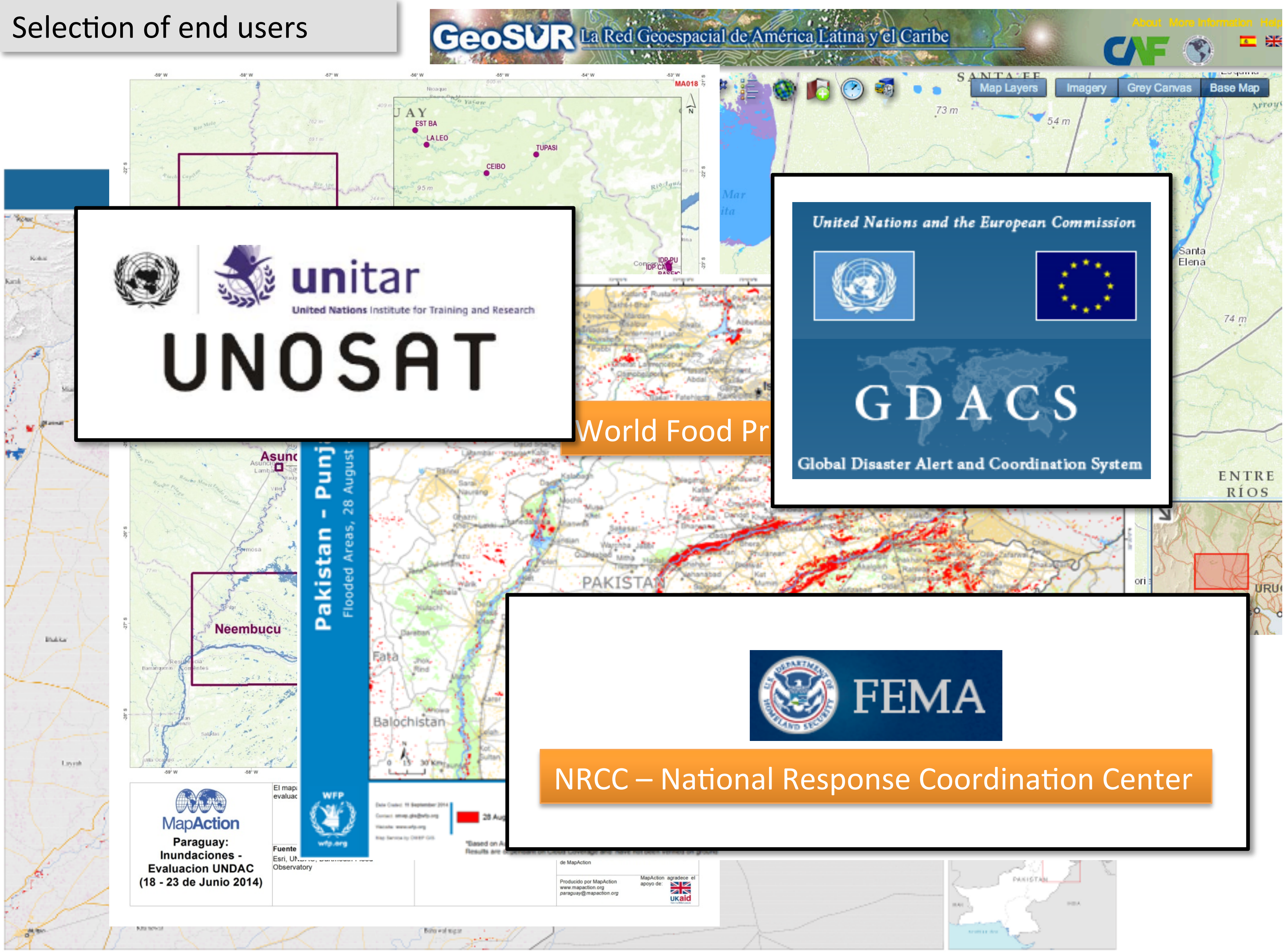
Example: MODIS flood product for one tile, 17-Sep-12 (Pakistan event)




Flood Detection Rating
RATING
1-poor
2-fair
3-good
4-excellent
5-almost perfect
TMC

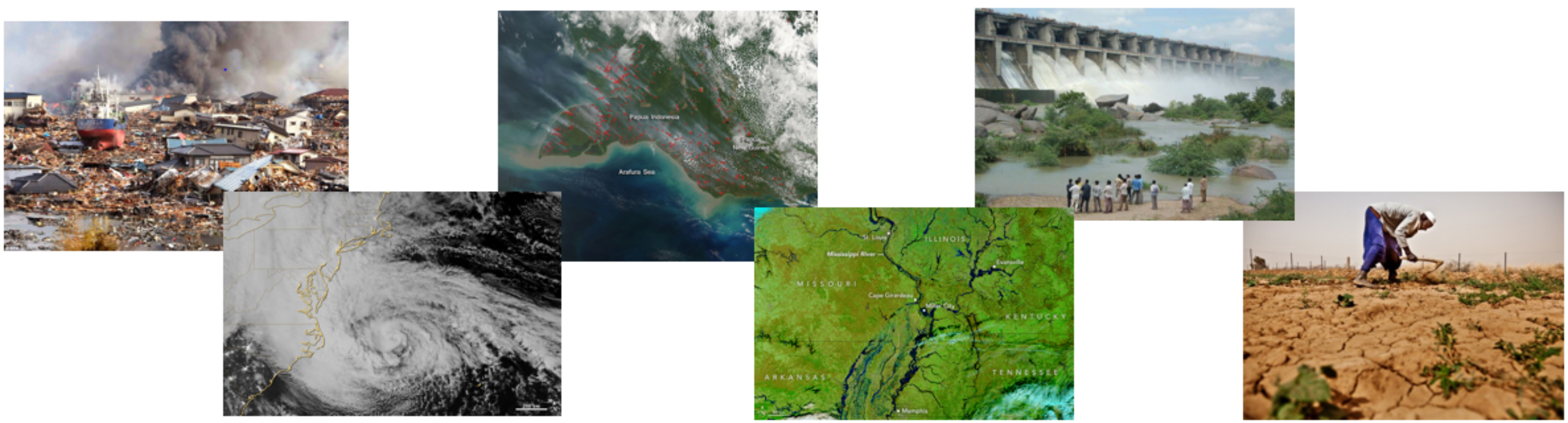

Permanent Water Detection Rating
RATING
1-poor
2-fair
3-good
4-excellent
5-almost perfect
TMC

Selection of end users

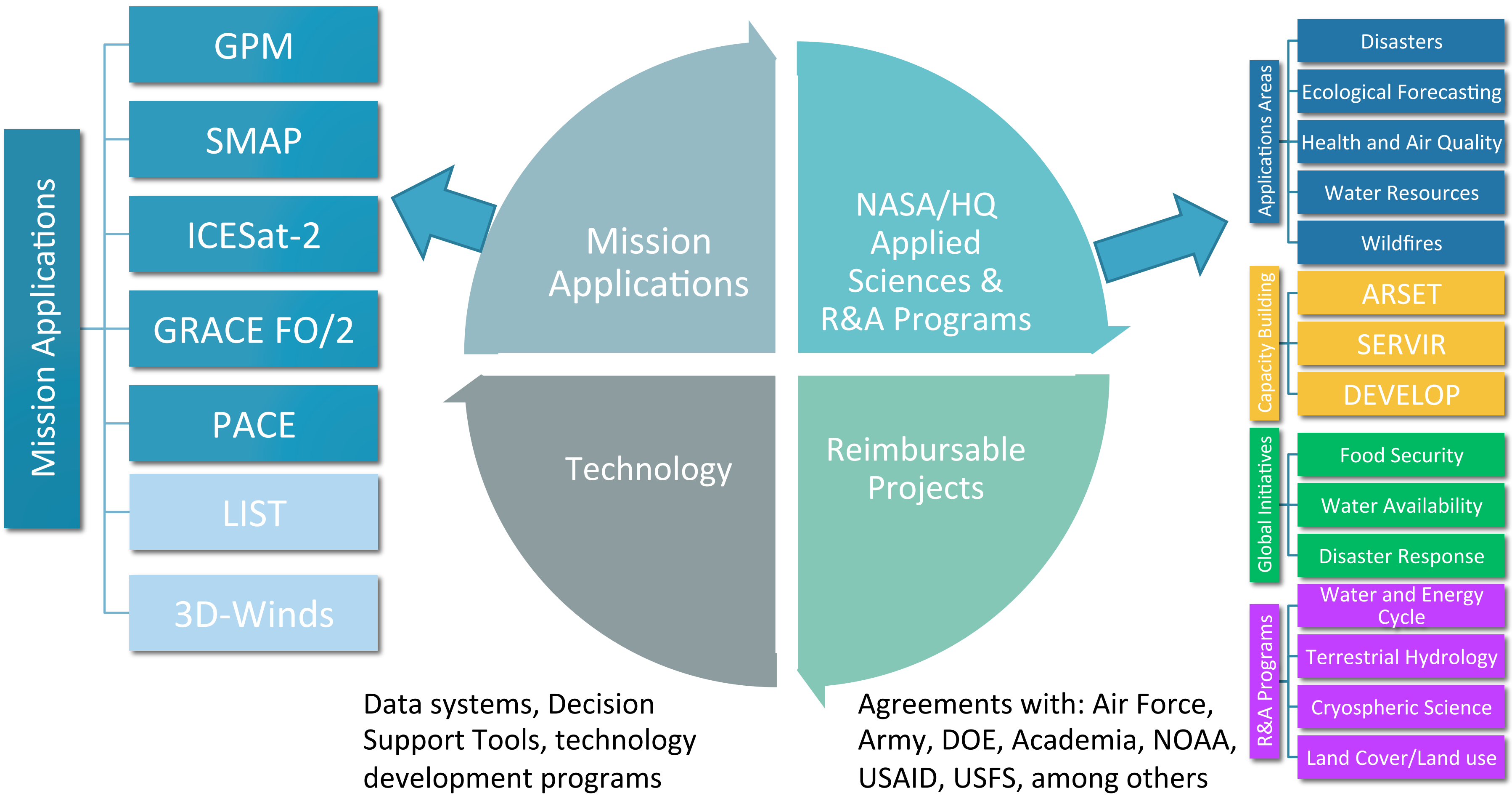


NASA GSFC Applied Sciences

JULY, 2016

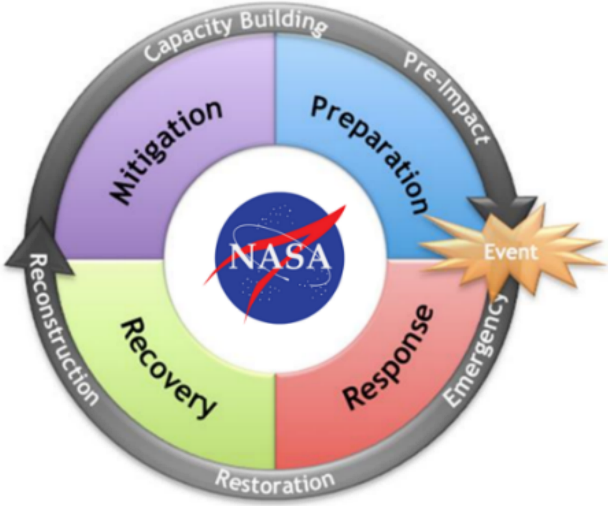


Applied Sciences Portfolio at GSFC

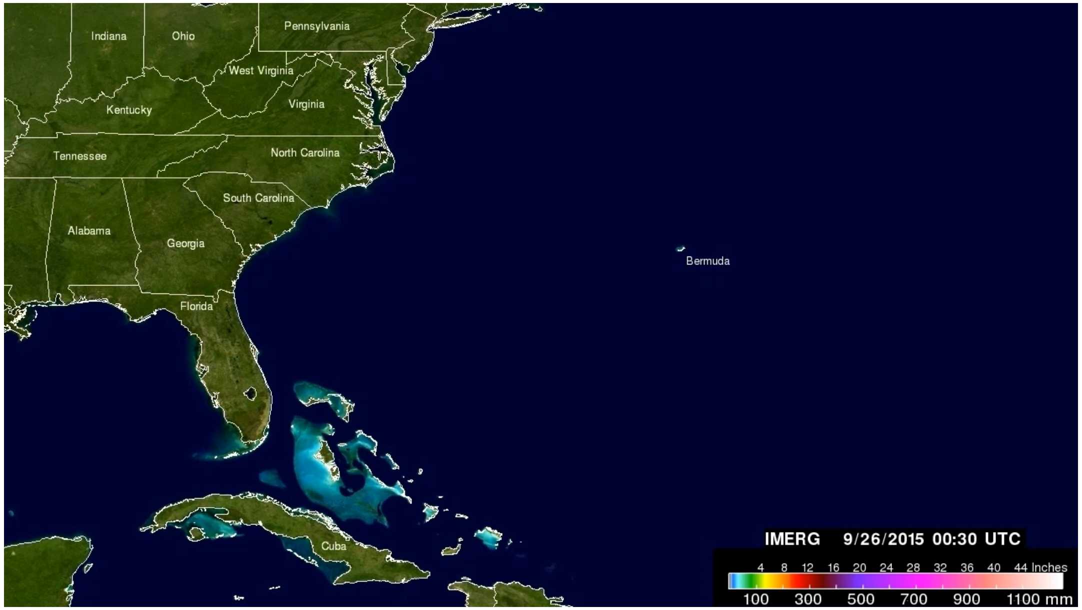


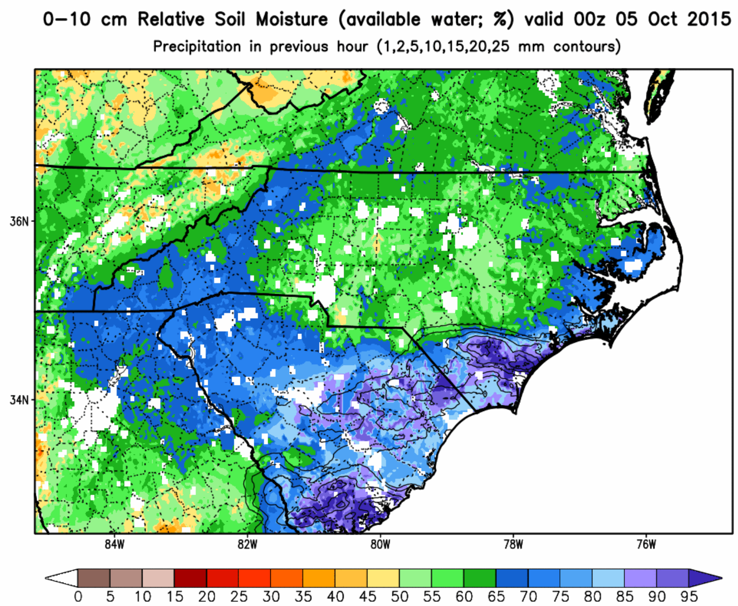
Disaster Response

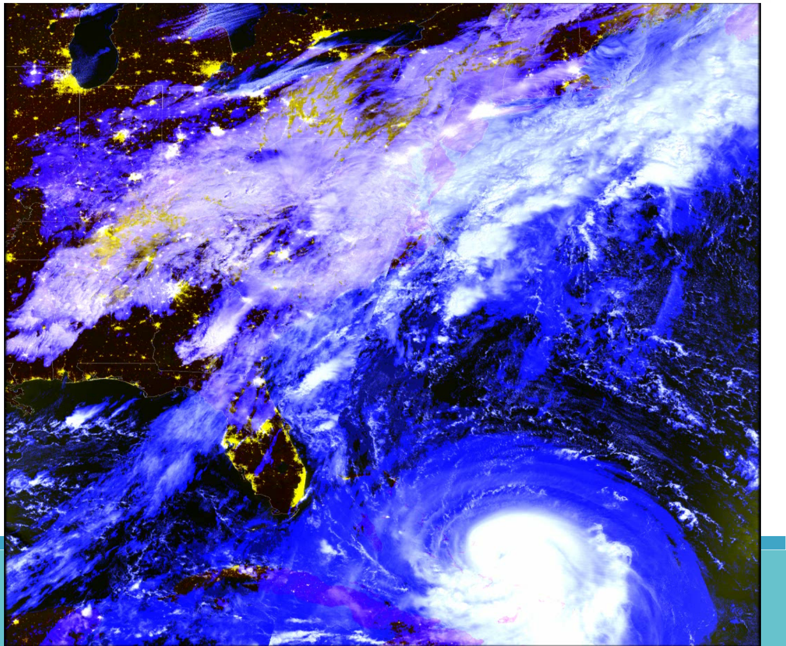
- Disaster application science answering questions and supporting decisions transforming EO data and research results into environmental intelligence
- Coordination and collaboration informing brokers, managers, and responders with critical products and services
- Creation and leverage of partnerships strengthening and enabling effective response throughout the disaster lifecycle



NASA Observes Historic Rainfall Amounts for Nor'easter and Joaquin







Examples of Daily NASA Products Provided to FEMA via the U.S Hazard Data Distribution System for Disaster Response.

Top L. NASA's Integrated Multi-satellitE Retrievals for GPM (IMERG) showed historic rainfall in the Carolinas.

Top R. NASA's Land Information System running operationally at MSFC using NOAA Stage IV precipitation and other forcing inputs produced analyses and short term forecasts of soil moisture and other parameters (SpORT)

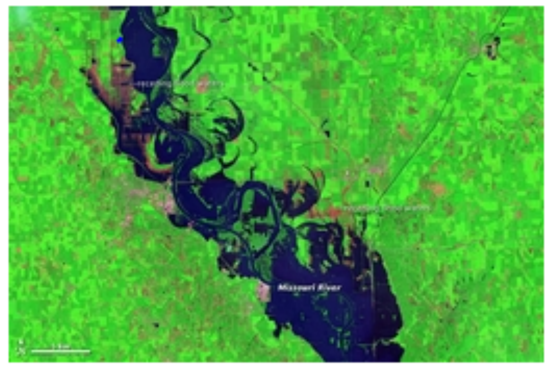
Bottom R. VIIRS nighttime environmental products provided for detection of technological failures (power outages and infrastructure damage).

Water Resources

Focus Areas

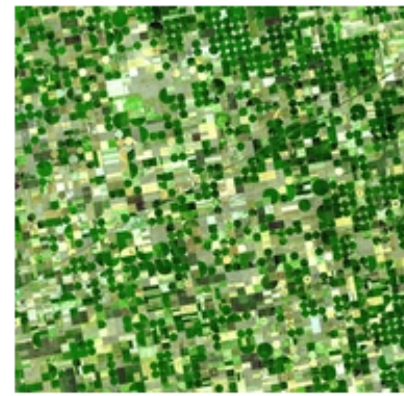
Drought

The Water Resources Application Area provides support for efforts to integrate remote sensing and other NASA technologies into decision support systems for drought monitoring, impact assessment and mitigation. Additional funding ...



Streamflow and flood forecasting

The Water Resources Application Area provides support for efforts to integrate remote sensing and other NASA technologies into decision support systems for monitoring and forecasting of streamflow and flood risk. ...



Evapotranspiration and irrigation

The Water Resources Application Area provides support for efforts to integrate remote sensing and other NASA technologies into decision support systems for monitoring and forecasting of evapotranspiration and irrigation demand. ...

Earth Sciences Division   Applied Science

ARSET

Applied Remote Sensing Training

Home | About | Trainings

http://arset.gsfc.nasa.gov/

NASA Remote Sensing Observations for Flood Management

Dates: Monday, June 8, 2015 to Monday, June 29, 2015

Registration Closes: Friday, March 18, 2016

This training introduces remote sensing resources available for monitoring extreme precipitation and flooding, as well as flood mapping tools for flood management and planning.

Course Format:

- Four, one-hour sessions
- Introductory Webinar - no remote sensing experience necessary

Technology

EOSDIS: Earth Observing System Data and Information System

- *EOSDIS* is designed as a distributed system, with major facilities at *Distributed Active Archive Centers* (DAACs) located throughout the United States.

LANCE: Land, Atmosphere Near Real-time Capability for EOS

- Provide near real-time (NRT) data products within 3 hours of observation to meet the timely needs of applications users.

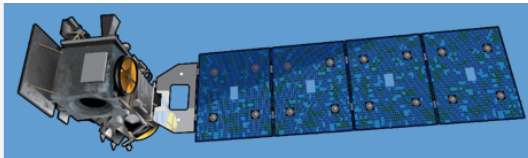
AIST: Advanced Information Systems Technology (AIST)

- The objectives of the AIST program are to identify, develop and (where appropriate) demonstrate advanced information system technologies

Mission Applications

Flood Response using ICESat-2*

- ICESat-2 will provide **along track water body height, slope and roughness**
- **Flood event monitoring, flood mapping & forecasts**
  ICESat-2 with any latency could be used for historic analysis, re-analysis and calibration/validation studies at regional to global scales
- **Near real-time monitoring of seasonal and flash floods**
  ICESat-2 is expected to improve subsurface water storage change measurements due to its accuracy and dense along/cross-track resolution; Combined with other observations, ICESat-2 will be used to build a global surface water monitoring system especially valuable for river basins that lack in situ data.



ICESat-2

ICE, CLOUD, AND LAND ELEVATION SATELLITE-2

http://icesat-2.gsfc.nasa.gov/

Quick View

Payload

Science Instrument:

ATLAS – Advanced Topographic Laser Altimeter System developed at GSFC

- Measures time of flight of laser pulses
- Measures pointing direction
- single-photon sensitive detection
- 6 beams, arranged in 3 pairs
- 10 kHz pulse-rep. rate
- 14m footprint
- spaced 0.7m along-track
- 532nm wavelength
- 524 kg, 686 W

Mission Architecture

- Orbit: 500 km, non-sun-synch, 92° inclination
- Repeat: 91 day exact repeat, ~30 day subcycle
- Downlink: 8 contacts per day (Svalbard (Norway), Poker Flatt (Alaska))
- Science Data: 588 Gbits/day
- Launch Vehicle: Delta-II, 1765 kg capability

Implementation

- Launch Date: October 2017
- Lifetime: 3 years, with consumables for 7
- Partners: GSFC, Orbital Sciences, ULA, KSC
- Mission Category: 2
- Mission Class: C, with selected redundancy

- **Based on ICESat-2 Proposed Early Adopter Research. For more information, visit: http://icesat-2.gsfc.nasa.gov/applications**

Goals for Applied Science Activities

1. Identify core capabilities across GSFC and other NASA Centers related to the applied sciences portfolio
2. Promote and expand the reach of NASA data, products, models, technology and within end user communities
3. Foster and expand partnerships with other NASA centers, government agencies, NGOs, commercial and private sectors
4. Establish two-way feedback channels to communicate potential opportunities to the NASA and end user communities