Overview of NASA's Earth Observation Systems for Hydrology

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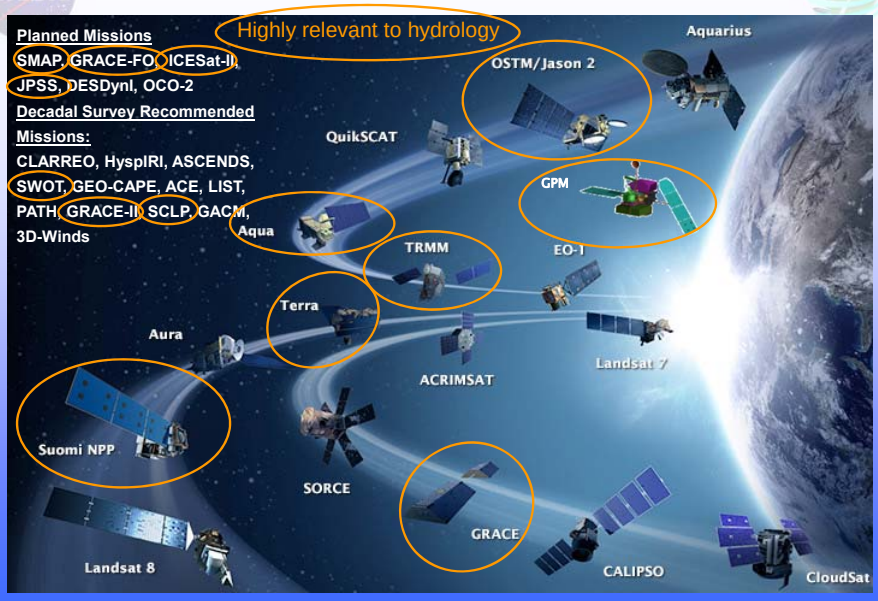
22 January 2015

ACWI – SoH Meeting

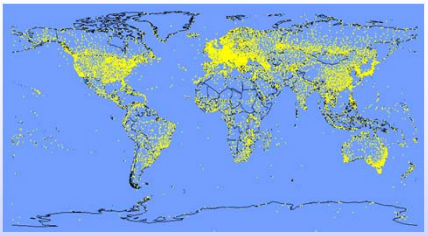
Present and Future NASA Earth Science Missions



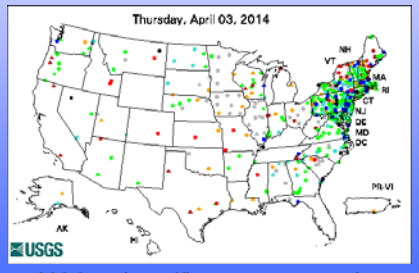
Inadequacy of Surface Observations

Issues:

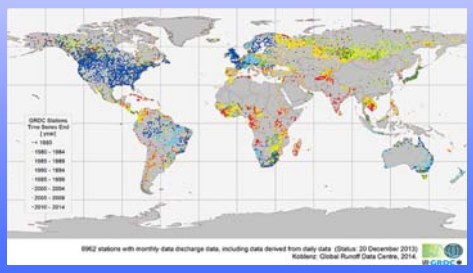
- Spatial coverage of existing stations
- Temporal gaps and delays
- Many governments unwilling to share
- Measurement inconsistencies
- Quality control
- (Un)Representativeness of point obs



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



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



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

NASA's Hydrologic Observations

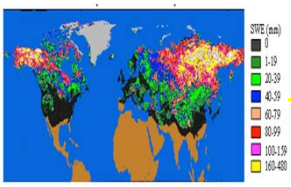


Figure 1: Snow water equivalent (SWE) based on Terra/MODIS and Aqua/AMSR-E. Future observations will be provided by JPSS/VIIRS and DWSS/MIS.

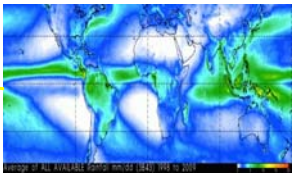


Figure 2: Annual average precipitation from 1998 to 2009 based on TRMM satellite observations. Future observations will be provided by GPM.

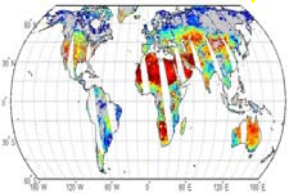


Figure 3: Daily soil moisture based on Aqua/AMSR-E. Future observations will be provided by SMAP.

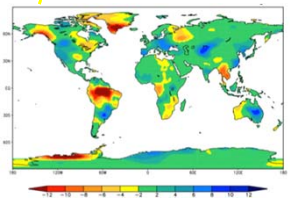
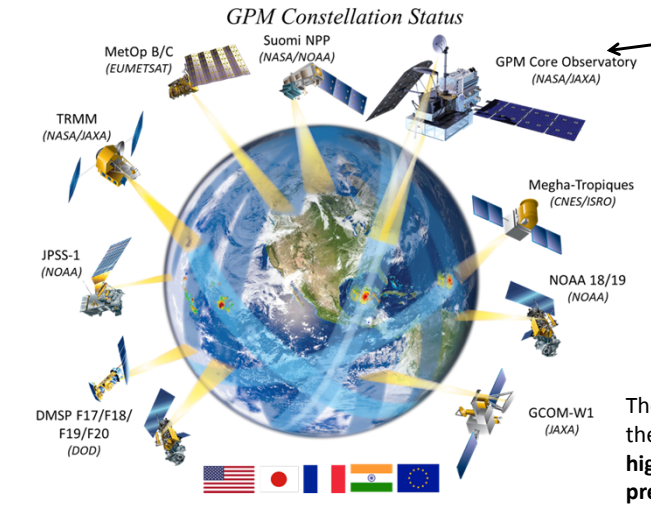


Figure 4: Changes in annual-average terrestrial water storage (the sum of groundwater, soil water, surface water, snow, and ice, as an equivalent height of water in cm) between 2009 and 2010, based on GRACE satellite observations. Future observations will be provided by GRACE-II.

Figure 5: Current lakes and reservoirs monitored by OSTM/Jason-2. Shown are current height variations relative to 10-year average levels. Future observations will be provided by SWOT.

Precipitation

Global Precipitation Measurement (GPM)



GPM Core Observatory
(NASA/JAXA, Launched February 2014)

Instruments:

- DPR (Ku & Ka band)
- GMI (10-183 GHz)
- 65º Inclination, 407 km
- 5 km best footprint
- Sensitivity of 0.2 – 110 mm/hr rain rates and falling snow

Active Joint Projects (19 International PI's)

The GPM constellation forms the foundation for providing **high quality 3-hour merged precipitation estimates around the world**. Calibration using the Core Observatory ensures consistency across the different platforms

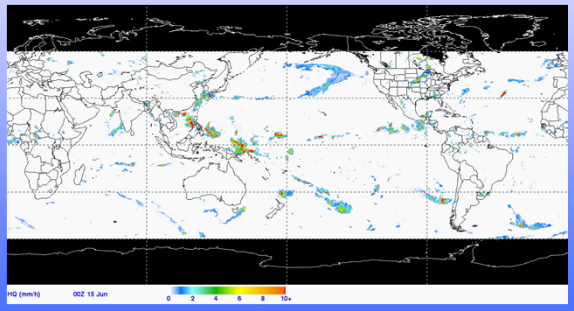
Precipitation: Merged Datasets

Global Precipitation Climatology Project (GPCP)
- International community activity in GEWEX, 1979-present
- Fully global merger of microwave, IR, sounding, and gauge data
- Recognized international standard for climate study, with >1500 citations
- Present Version 2 funded as NOAA CDR, Version 3 funded in NASA MEaSUREs

TRMM Multi-satellite Precipitation Analysis (TMPA)
- Pioneered constellation concept
- Pioneered multiple "runs": near- and post-real time
- Has driven wide public use of global satellite precipitation, ~1000 citations

Integrated Multi-satellitE Retrievals for GPM (IMERG)
- Unified U.S. algorithm team led by GSFC
- 0.1°x0.1°, 30-min., 60°N-S
- Runs at 4 hours, 8 hours, and 2 months
- Will cover 1998-present
- First release in Dec. 2014; replace TMPA in Feb. 2016

Contact: George Huffman/612



Goddard has a sustained record of pioneering merged satellite datasets

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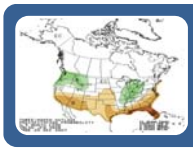
GPM Societal Benefit Areas

Extreme Events and Disasters
- Landslides
- Floods
- Tropical cyclones
- Re-insurance

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

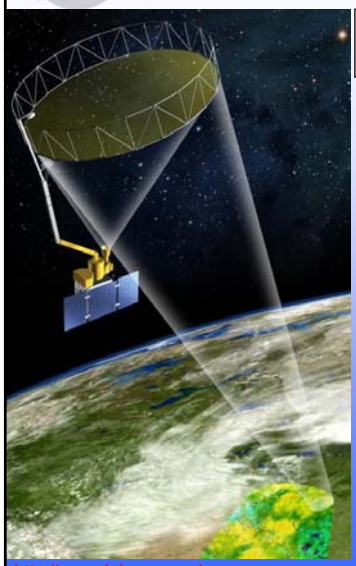


Weather, Climate & Land Surface Modeling
- Numerical Weather Prediction
- Land System Modeling
- Climate Modeling

Public Health and Ecology
- Disease tracking
- Animal migration
- Food Security

Soil Moisture

Soil Moisture Active Passive (SMAP)



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

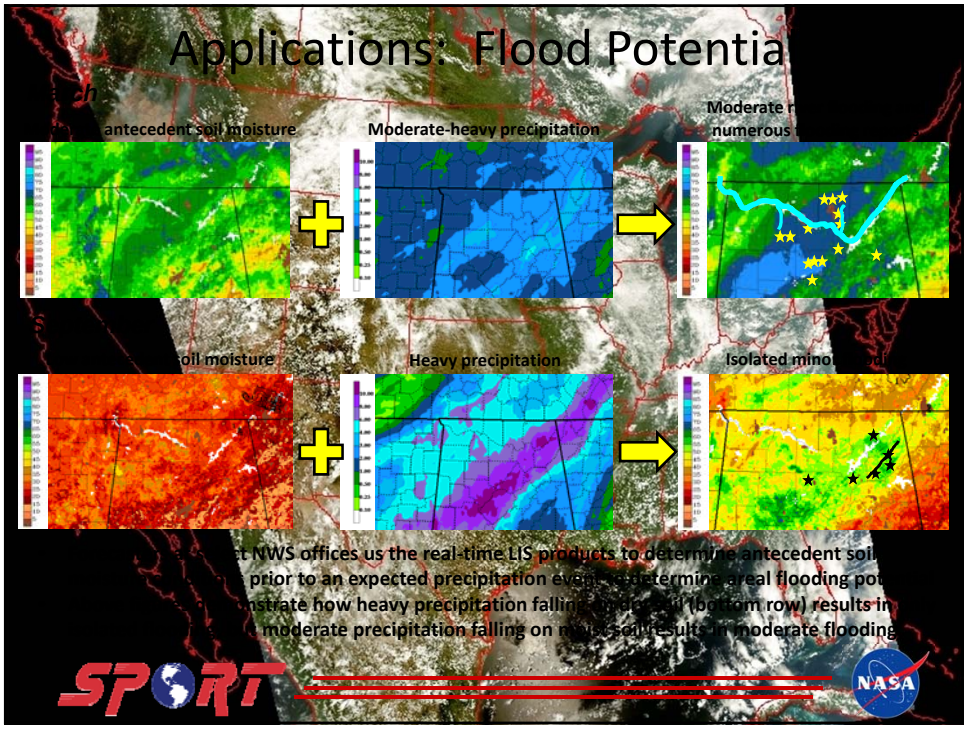
NRC Earth Science Decadal Survey (2007) recommended SMAP as a tier-one mission

Primary Science Objectives:

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

Mission Implementation (Launch January 29, 2014):

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



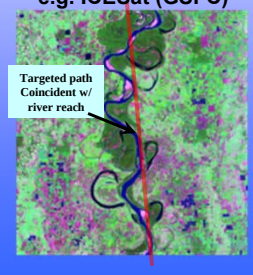
Surface Water & Snow

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

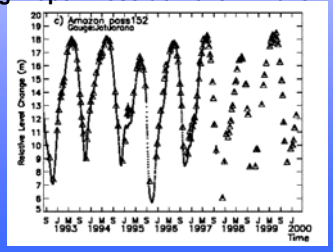
Motivation:
- critical water cycle component
- essential for water resource planning
- stream discharge and water height data are difficult to obtain outside US
- find the missing continental discharge component

Mission Concepts:

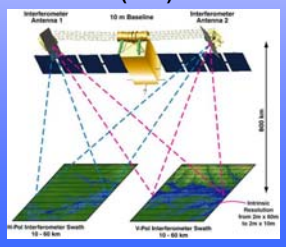
Laser Altimetry Concept e.g. ICESat (GSFC)



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

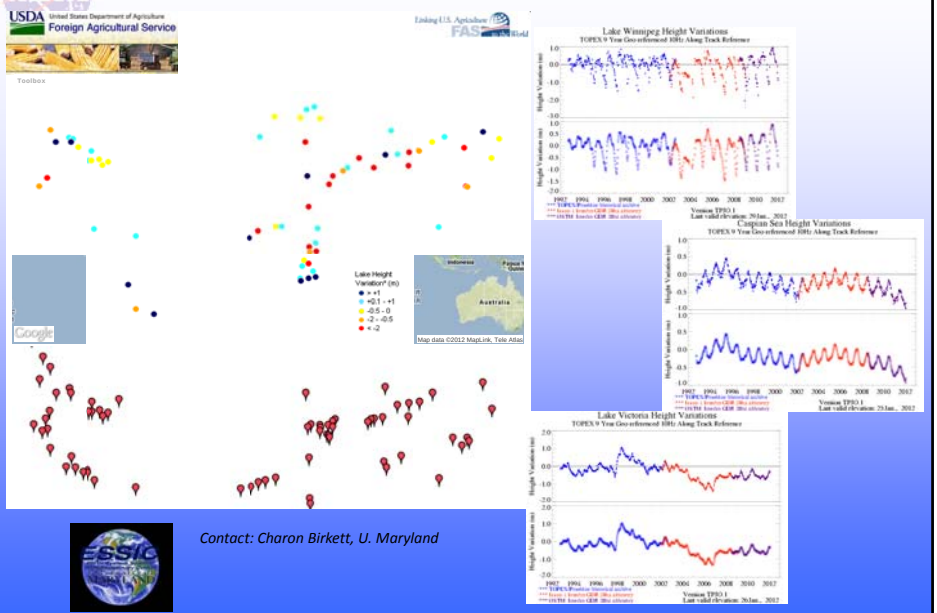


Interferometer Concept (JPL)



Source: M. Jasinski/614.3

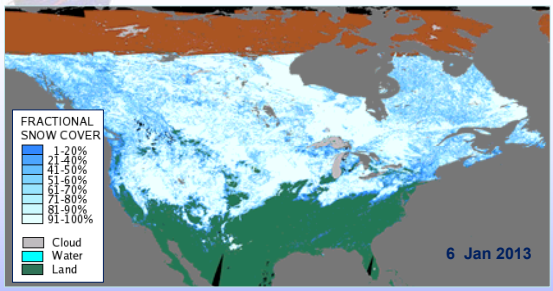
Routine Lake Level Monitoring (Jason1/2 & ENVISAT)



Contact: Charon Birkett, U. Maryland

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

Standard MODIS Snow-Cover Map Products



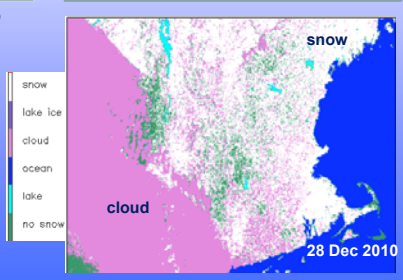
MODIS cloud gap filled (CGF) fractional snow cover map

MODIS snow-cover maps have been used for:

- Stream-discharge modeling to support drought and flooding decisions;
- Updating land-surface models, including calculating snow-water equivalent in the models;
- Validating model results;
- Monitoring snow-cover changes over time at regional and hemispheric scales;
- Developing climate-quality data records of snow cover.

Ordering Statistics: **7,417,521** MODIS snow product granules ordered in first 6 mos. of 2014 (NSIDC).

- Products are available daily at up to 500 m resolution (2000 – present);
- Dataset and algorithms were developed in the Hydrological Sciences and the Cryospheric Sciences Laboratories.



MODIS binary snow map shows the result of a major snowstorm in the northeastern U.S.

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

Contacts: Dorothy Hall/615, George Riggs/SSAI/615

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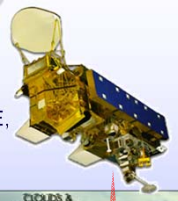
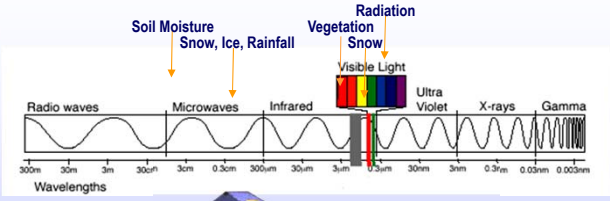
Terrestrial Water Storage and Ground Water

Gravity Recovery and Climate Experiment (GRACE)

Aqua: MODIS, AMSR-E, etc.



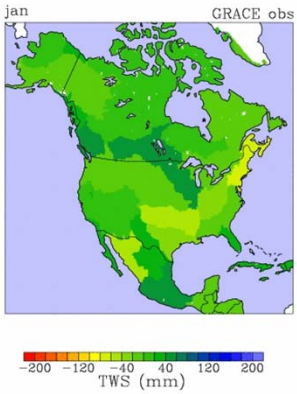


Traditional radiation-based remote sensing technologies cannot sense water below the first few centimeters of the snow-canopy-soil column

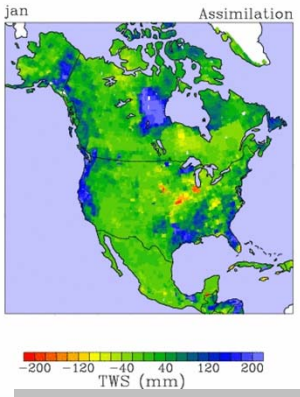
GRACE is unique in its ability to monitor water at all levels, down to the deepest aquifer

GRACE Data Assimilation

GRACE water storage, mm
January-December 2003 loop



Model assimilated water storage, mm
January-December 2003 loop



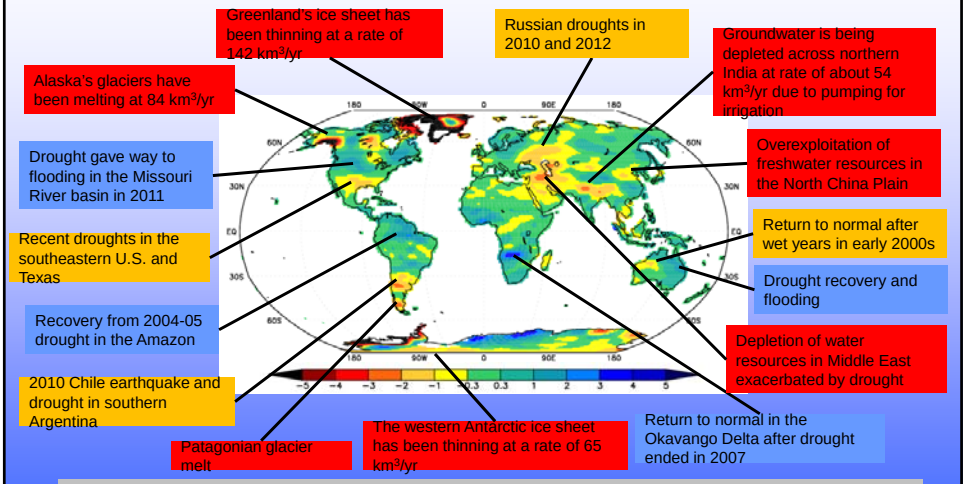
Monthly anomalies (deviations from the 2003 mean) of terrestrial water storage (sum of groundwater, soil moisture, snow, and surface water) as an equivalent layer of water. Updated from *Zaitchik, Rodell, and Reichle, J. Hydromet., 2008.*

From scales useful for water cycle and climate studies…

To scales needed for water resources and agricultural applications

Emerging Trends in Global Freshwater Storage

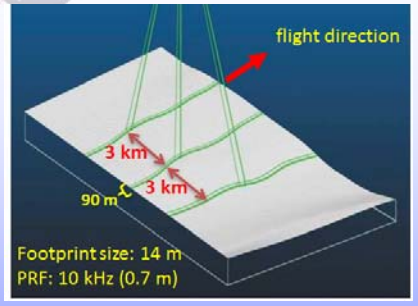
Trends in terrestrial water storage (cm/yr), including groundwater, soil water, lakes, snow, and ice, as observed by GRACE during 2003-13



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

Additional Hydrologic Satellites

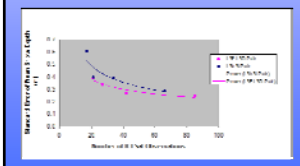
ICESat-2 Inland Hydrology



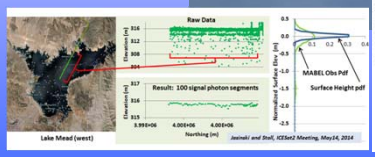
Contact: Mike Jasinski/617

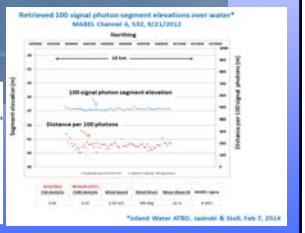
ICESat-2 Inland Water Body Targets (E.g. Lehner and Doll, 2004)

ICESat-2 algorithm development from MABEL



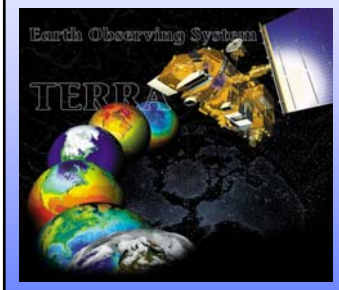
Feasibility of snow depth from ICESat observations over Uinta Mtns, Utah.





Typical Inland Water Height ATL13 Producy tested using MABEL 2012 observations over Lake Mead (left) and Chesapeake Bay (right).

Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS)



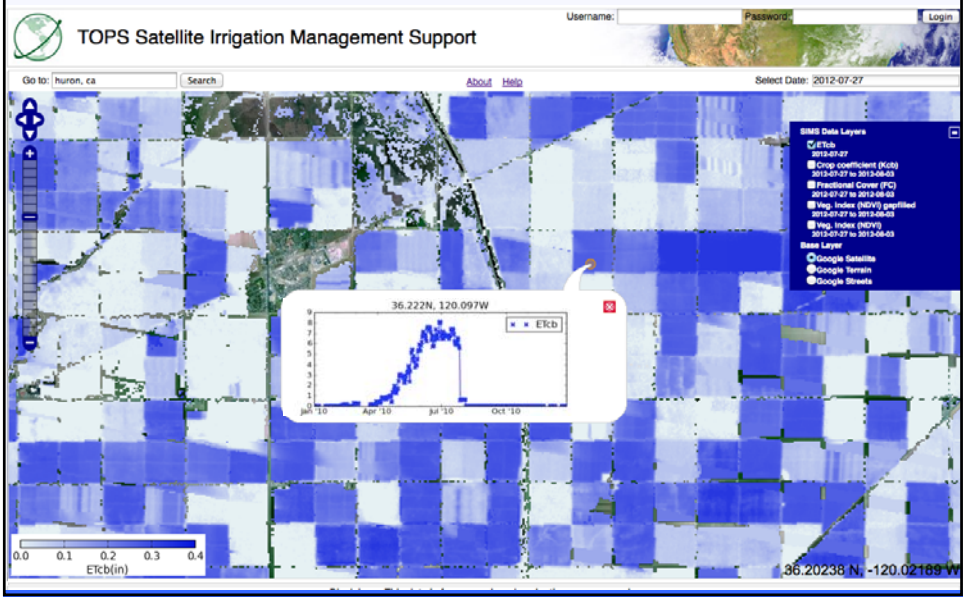
MODIS Data Products:

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

Evapotranspiration

F. Melton/NASA Ames

Satellite Irrigation Management Support (SIMS) Framework



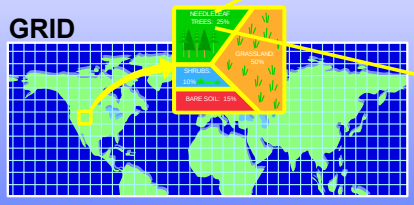
Land Surface Modeling, Data Integration & Data Assimilation

Land Surface Model Structure

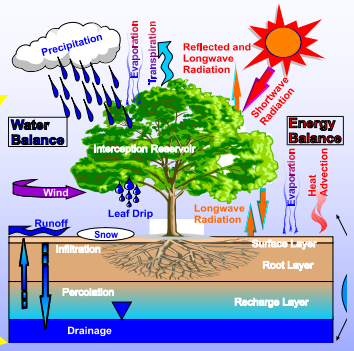
LSMs solve for the interaction of energy, momentum, and mass between the surface and the atmosphere in each model element (grid cell) at each discrete time-step (~15 min)

SUBGRID HETEROGENEITY

GRID



SURFACE VEGETATION ATMOSPHERE TRANSFER SCHEME



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

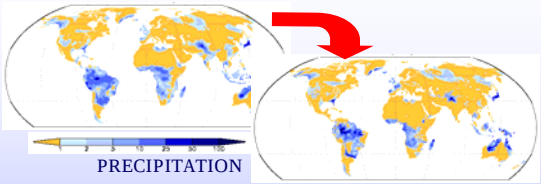
Soil water flow: Richards equation

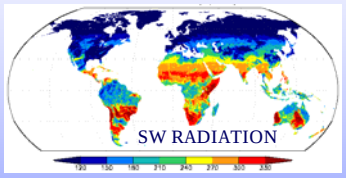
Evaporation: Penman-Monteith equation

etc.

Data Integration Within a Land Data Assimilation System (LDAS)

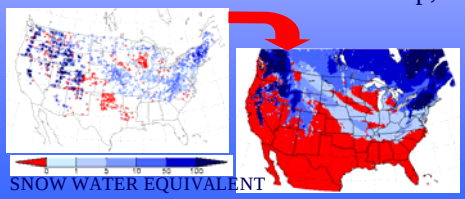
INTERCOMPARISON and OPTIMAL MERGING of global data fields





Satellite derived meteorological data used as land surface model FORCING

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



Ground-based observations used to VALIDATE model output

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

Matt Rodell
NASA GSFC

NASA SPoRT

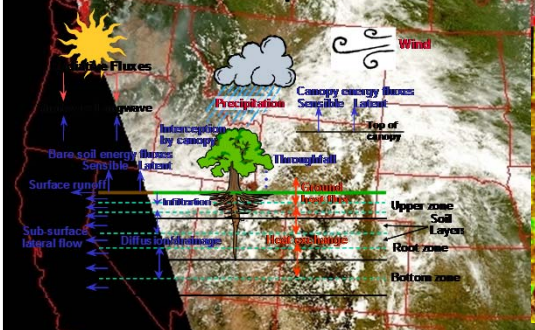
Short-term Prediction Research Transition (SPoRT) Center

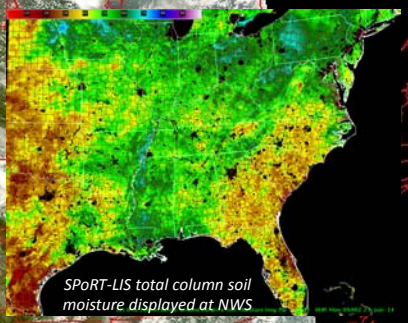
Mission: Transition unique NASA and NOAA observations and research capabilities to the operational weather community to improve short-term weather forecasts on a regional and local scale.

- ollaboration with numerous WFOs and National Centers across
- ivities began in 2002, first products to NWS in 2003
- by NOAA since 2009 through "proving ground" activities
- adigm for transition of research and
- l data to "operations"

- apability of NASA and NOAA
- oducts to weather applications
- efit
- ruments with climate missions
- bly data to solve shor
- blems

Operational SPoRT LIS

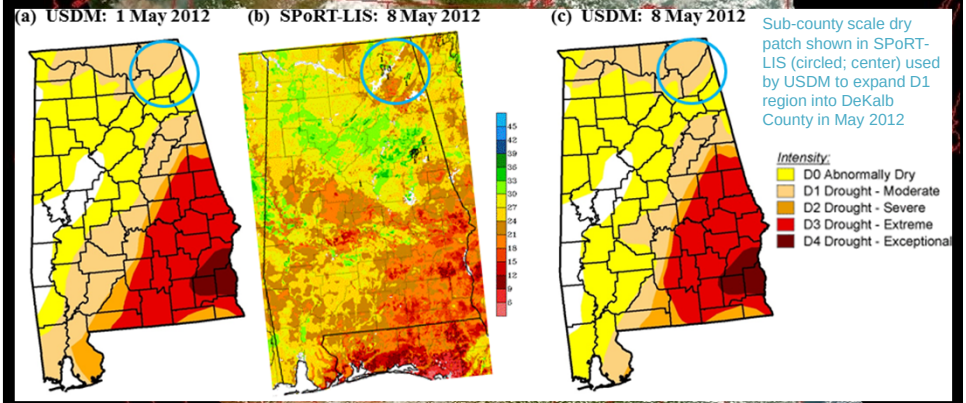




SPoRT-LIS total column soil moisture displayed at NWS

- **ation System (LIS) is used to perform long-term integration of Noah Land**
- **ted in real-time (4 times per day) at high spatial resolution (3 km)**
- ng: NLDAS-2, Multi-Sensor, Multi-Radar (MRMS), and GFS forecast
- e/health: Green Vegetation Fraction (GVF) from MODIS (will use VIIRS)
- use of latent observations while retaining their impact on later cycles
- **isture (SMOS/SMAP) should give even more accurate LIS soil moisture f**
- erational system in first half of 2015; S[illegible] data shortly after launch
- **s, used for situational awareness and local modeling**

Applications: Drought Monitor



Sub-county scale dry patch shown in SPoRT-LIS (circled; center) used by USDM to expand D1 region into DeKalb County in May 2012

SPoRT LIS has been used by NWS forecasters in Huntsville to refi
he county scale as part of their participation in the US Drought

output from LIS could also be ap ed situational awareness a
arnings and potential for fires

Water Quality

Development of Numeric Water Quality Criteria from the Satellite Record

Blake Schaeffer[1], James Hagy[1], Robyn Conmy[1], John Lehrter[1], and Richard Stumpf[2]

[1]US EPA, Gulf Breeze, FL; [2]NOAA, Silver Spring, MD

Highlight: EPA adopts water quality criteria derived using satellite data products

- The remote sensing methodology and results presented in this paper were adopted by EPA in the recent rule for numeric criteria in Florida waters http://water.epa.gov/lawsregs/rulesregs/florida_coastal.cfm

- Water quality criteria were developed for all of Florida's coastal waters using the satellite date records

- The methods for developing criteria from the 13-year satellite time-series were vetted by the EPA Science Advisory Board and could be used by other coastal states and states with large inland waters where remote sensing can be used reliably.

Schaeffer BA, Hagy JD, Conmy RN, Lehrter JC, Stumpf RP. 2012. An approach to develop numeric water quality criteria for coastal waters using the SeaWiFS satellite record. *Environmental Science and Technology* 46:916-922.

Schaeffer, Hagy, & Stumpf. An approach to developing numeric water quality criteria for coastal waters: transitioning from SeaWiFS to MODIS and MERIS. *Water Research*. (*In Review*).

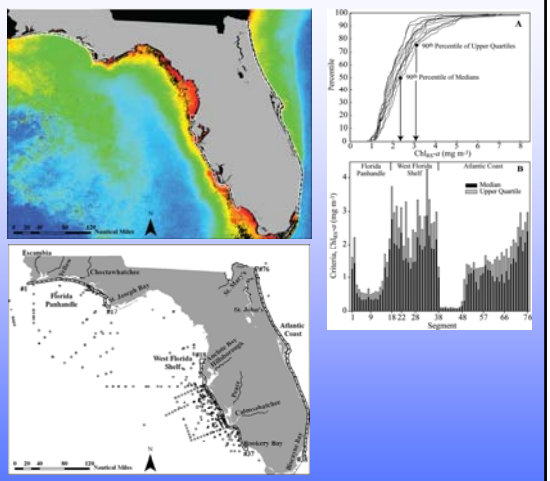


Figure 1: Numeric water quality criteria for the coastal water bodies of Florida were proposed by EPA in November 2013 based on this work.

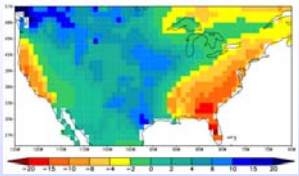
ESD Applied Sciences – (Water Quality)

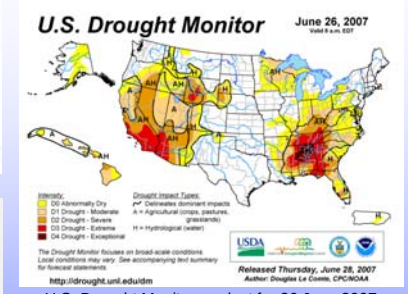
Applications

& Training

GRACE Data Assimilation for Drought Monitoring

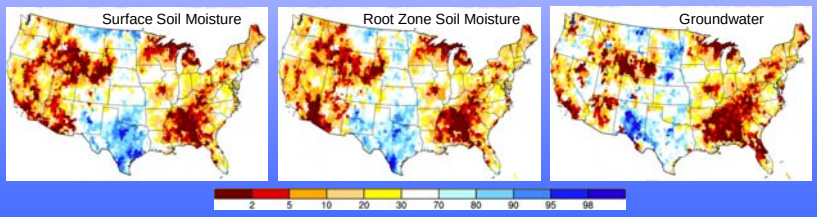
GRACE terrestrial water storage anomalies (cm equivalent height of water) for June 2007 (Tellus CSR RL05 scaled).





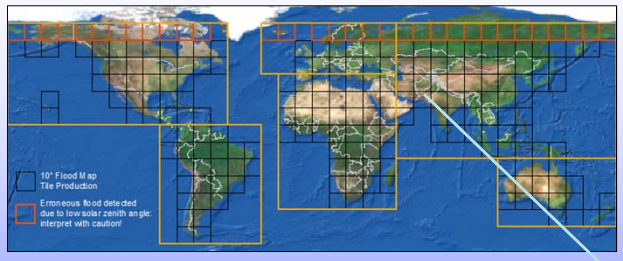
U.S. Drought Monitor product for 26 June 2007.

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



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

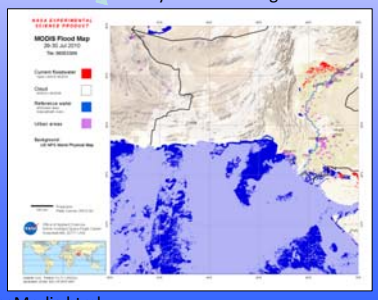
Experimental Global Near Real Time Surface Water Extent and Flood Extent Maps



Credit: Fritz Policelli, NASA/GSFC

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

July 2010 Flooding in Pakistan



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

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

Applied Remote Sensing Training (ARSET)

http://arset.gsfc.nasa.gov

GOAL: To Increase utilization of NASA observational and model data for decision-support through training activities for environmental professionals.

Application Areas: water resources, disasters, air quality, and land management.

Online courses: Live and recorded, 4-6 weeks in length.

In person training courses: In a computer lab, 2- 4 days.

Train the Trainers: Courses and training manuals for organizations interested in conducting their own remote sensing training, beginning in 2015

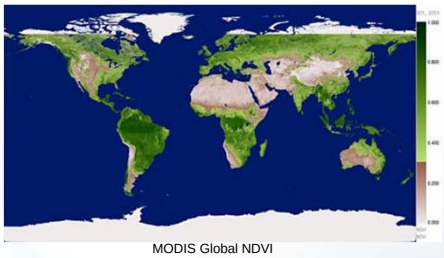
Accomplishments (2008 – 2014)

- 46 trainings completed
- 2300+ participants worldwide
- 700+ Organizations

Webinar: Introduction to NASA Earth Science Data Products, Portals, and Tools: September 16-October 14, 2014

Instructors: Brock Blevins, and Amita Mehta

- **Relevance:** Introductory webinar intended for a new audiences to NASA Earth Science with a focus on application of EO data for water resources, air quality, agriculture, disaster management and ecoforcasting.
- **111 participants, 96 organizations, 34 countries, 19 states.**
- **15 International and National Conservation organizations:** WWF, IUCN, WCS, UNOSAT, UNEP-WCMC, UNITAR, Conservation International
- **5 US Federal and State agencies:**
  - EPA, BLM, USGS, USDA, Delaware DNR
- **End-of -Training Survey Results**:
  - Over 70 % had moderate to limited knowledge of remote sensing
  - 100% responded that the training met expectations and materials were appropriate
  - Over 58% would like to participate in advanced webinars and 37% in person trainings in the future



MODIS Global NDVI

Participants from 34 countries

Summary & Conclusions

- Due to the incompleteness of ground-based observations, space-based observation of the water cycle is critical.
- Satellite and Earth observations with modeling can now be used to help quantify the entire water cycle.
- 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'
- Impacts on the water cycle will be the most noticeable consequence of climate change.
- There are several new hydrologic satellites with many innovative applications of remotely sensed hydrology data that have national and international value.

Data, Visualization & Educational Materials

http://www.csr.utexas.edu/grace/education/ - GRACE educational materials

http://gracetellus.jpl.nasa.gov/data/gracemonthlymassgridsland/ - GRACE data, images, and animations (scroll down to "The LAND gridded data and browse images are available here")

http://smap.jpl.nasa.gov/ - Soil Moisture Active Passive Mission

http://trmm.gsfc.nasa.gov/ - Tropical Rainfall Measurement Mission

http://pmm.nasa.gov/GPM/ - Global Precipitation Measurement Mission

http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir - Satellite based monitoring of lake and reservoir levels

http://disc.sci.gsfc.nasa.gov/giovanni/overview/index.html - Giovanni Earth science data visualization tool

http://drought.unl.edu – National Drought Mitigation Center

https://c3.nasa.gov/water/ - NASA Water Resources Applications Projects

http://grace.jpl.nasa.gov/news/ - Features on groundwater depletion detected by GRACE

http://water.gsfc.nasa.gov - NASA water and remote sensing training