# Hydrology from Space: NASA's Satellites Supporting Water Resources Applications

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*Water Forum III: Droughts and Other Extreme Weather Events*
*University of Texas -- 14 October 2013*

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# Overview

- NASA Applied Sciences Applications program
- Water budget balance
- NASA missions supporting hydrology studies
- Summary: Survey

# NASA Earth Science

The NASA Earth Science Division supports basic and applied research on the Earth system and its processes.

Significant efforts are to characterize and understand Earth system processes and to improve predictions of the Earth system.

In the course of Earth science, NASA pursues innovative and practical applications of Earth observations and new scientific knowledge to improve public and private organizations' decision-making activities.

***Science Requirements***

***Technology***

***Missions***

***Research***

***Data Systems***

***Applications***

# NASA Applied Science Program

**NASA's Applied Science Program supports applications activities for early phase missions based on Earth Science Decadal Survey (NRC, 2007)**

**NASA Applied Science Program**

**Mission project office**

**Science Team**

**User community (you!)**

Goal: Develop a mature applications program at the project level, supported by NASA HQ and the mission science teams

# Program Near-Term Goals

- Assess & engage ‘Community of Practice’, ‘Community of Potential’
- Identify commonalities between mission requirements & needs of known applications/ users;
- GRACE applications-focused web site
- Database of user community
- Applications Plan
- User Workshops – joint missions

# Applications Considerations

- Broaden user community and range of applications
- Data accessibility,  latency, and usability
- Data processing / data editing
  - Data format (e.g., typical GRACE application user wants a gridded data product)
  - The most "interesting" or useful applications are often at small spatial scales
  - Need a product that can meet user needs, with reliable uncertainty estimates
  - More L3-type products need to be explored
- Objective information > Decision support tools
- Comprehensive / integrated effort

# Applied Sciences Water Activities

## NASA Water Activities

### Capacity-building: Enable the effective use of water management tools

**How do we build the capacity to impact decisions and society?**

- **SERVIR: regional and in-country government stakeholders**
  *Geographic Areas: US, East Africa, Mesoamerica, Hindu Kush Himalaya*
- **Gulf of Mexico Initiative (GOMI): regional stakeholders**
  *Geographic Areas: US, Mexico*
- **DEVELOP: regional and US/state/local government stakeholders and future workforce**
  *Geographic Areas: US, Colombia, Mexico, Nepal*
- **Applied Remote SEnsing Training (ARSET): regional and US/state/local government stakeholders**
  *Geographic Areas: US, Colombia*

### Applied science research: Build water resource management tools

**How do we use applied science to manage water resources?**

- Water Quality and Resources Monitoring
- Drought Monitoring
- Climate Impacts
- Agriculture: Water Delivery and Irrigation

- Flood Forecasting
- Agriculture: Water Delivery and Irrigation
- Snowpack Monitoring and Management

- Flood Forecasting
- Climate Impacts
- Drought Monitoring

### Basic science research: NASA Energy and Water Cycle Study

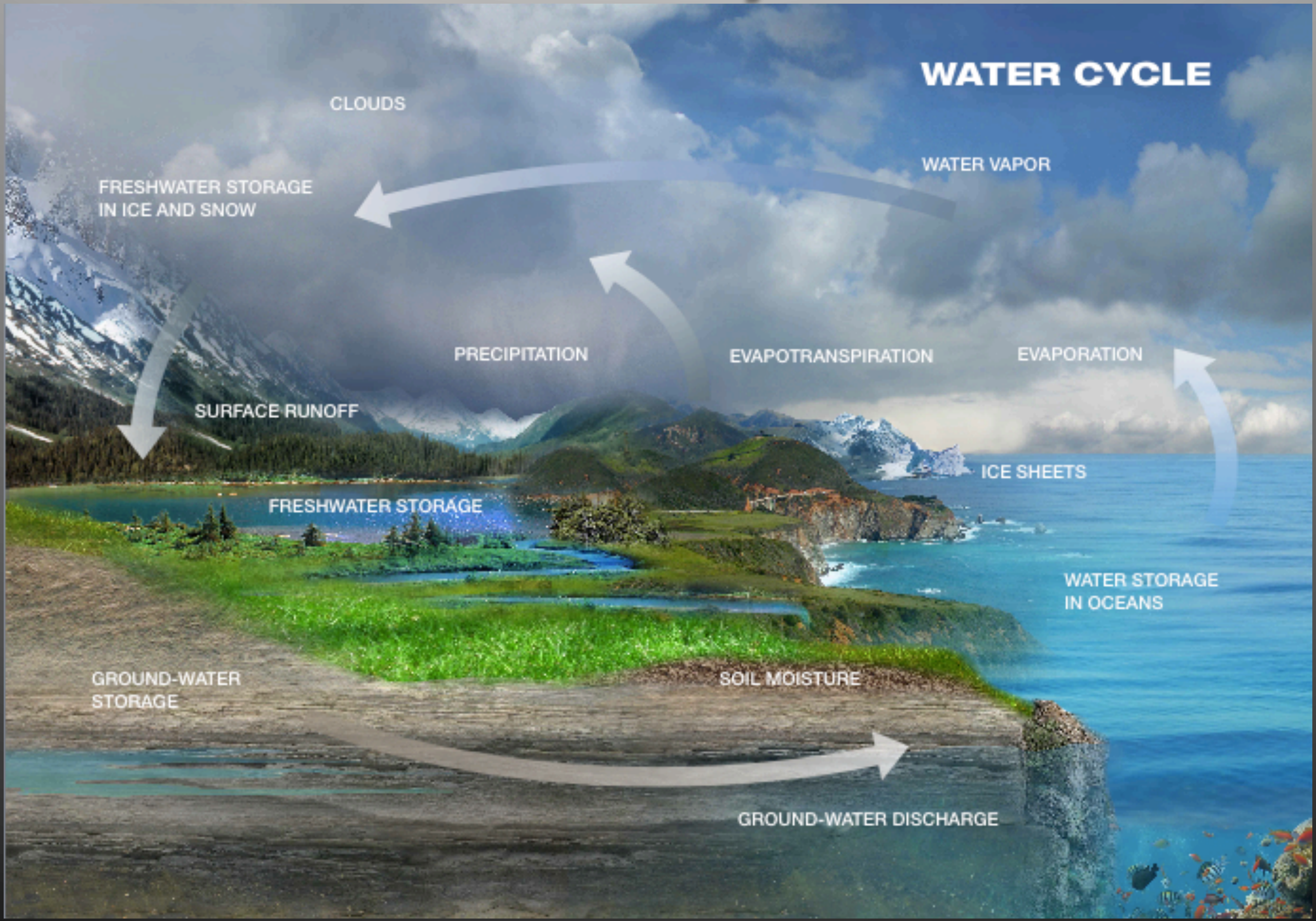
**What processes drive the cycle of water and energy on Earth?**

- Soil Moisture Assessment (AMSR-E/SMOS/SMAP)
- Change in Groundwater Storage (GRACE)
- Water Quality Assessment

- Precipitation Assessment (TRMM/GPM)
- Evaporation Estimation (LDCM)
- Snowpack and Melt Assessment (AMSR-E/MODIS)

- Improved Seasonal Forecasting (AQUARIUS/MERRA)
- Integrated Water Cycle Assessment (NEWS)

# Water Cycle


WATER CYCLE
CLOUDS
WATER VAPOR
FRESHWATER STORAGE IN ICE AND SNOW
PRECIPITATION
EVAPOTRANSPIRATION
EVAPORATION
SURFACE RUNOFF
ICE SHEETS
FRESHWATER STORAGE
WATER STORAGE IN OCEANS
GROUND-WATER STORAGE
SOIL MOISTURE
GROUND-WATER DISCHARGE

# Water Balance Equation

***Describes the flow of water in and out of a system (drainage basin, soil column, etc.)***

$$\Delta S = P - Q - E$$

Where;

- ***S*** is water storage
- ***P*** is precipitation
- ***Q*** is runoff
- ***E*** is evaporation

# Water Balance Equation

$$\Delta S = P - Q - E$$

*NASA assets that inform these elements;*

***S*** (water storage); GRACE, SMAP, SWOT*, GRACE-FO*

***P*** (precipitation); TRMM, GPM

***Q*** (runoff); SWOT*,

***E*** (evaporation); Meteosat, MODIS, Landsat, HyspIRI*



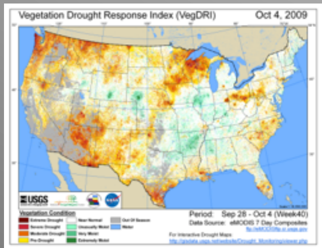
*Proposed Missions – Pre-decisional – for Planning & Discussion Purposes Only

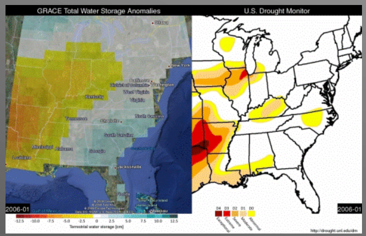
# Solutions During Drought

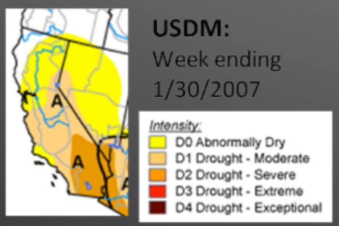
**NASA satellite data products and contributions to drought monitoring can help to determine when the following actions should be taken:**

- **Increasing on-farm reservoir storage for water supply.**
- **Assessing regional surface wetness to infer water availability for pumping for domestic supply.**
- **Assessing aquifer levels supplying communities and farms.**
- **Assessing lake levels for irrigation, recreation and fishing.**
- **Assessing the adequacy of water availability for hydroelectric power generation.**

# Support for U.S. Drought Monitor



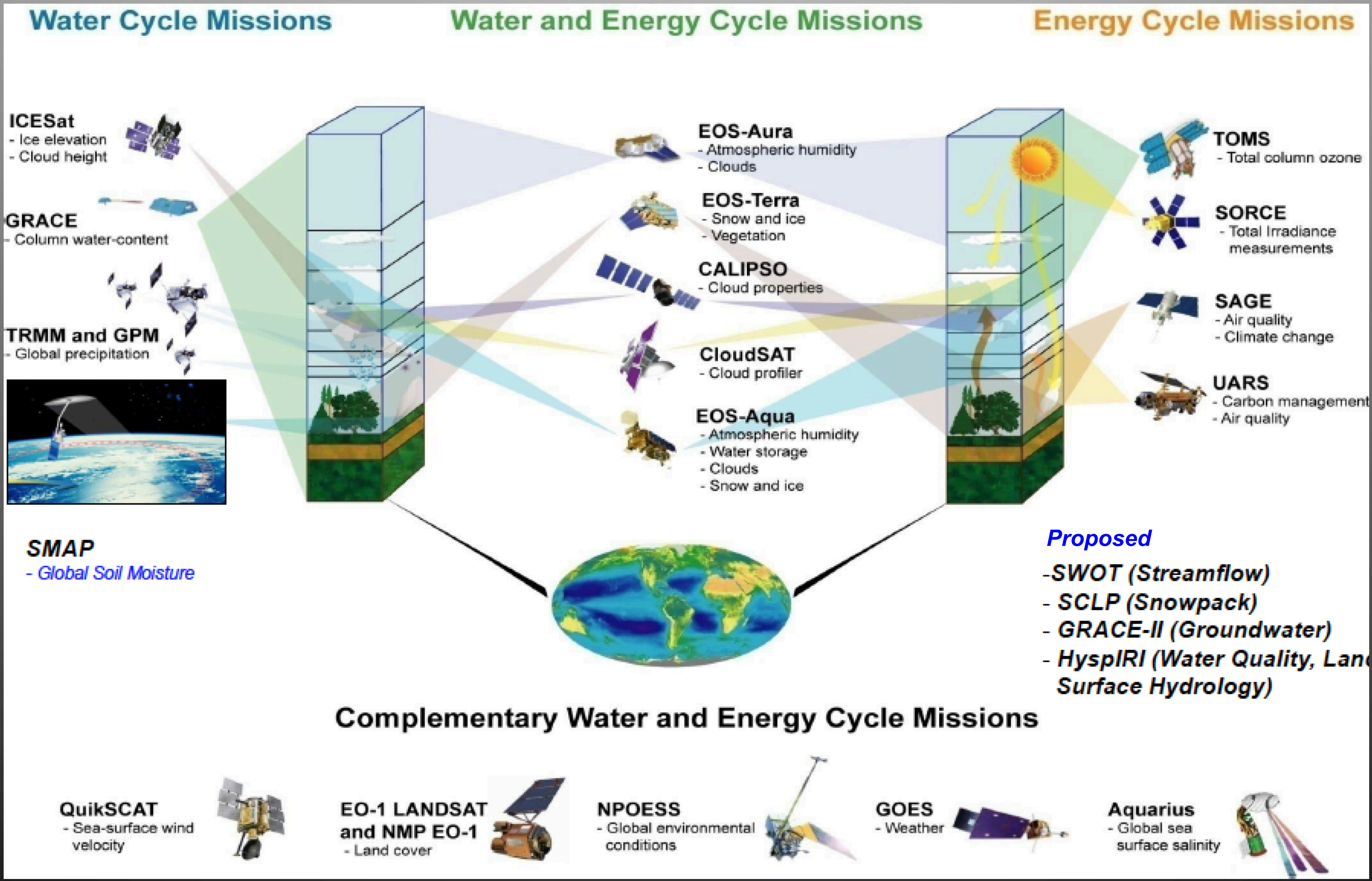




**User community interactions:**
**Drought Forum 2009**

## NASA Funding Several Projects;

- **Expedited MODIS Vegetation Drought Response Index (VegDRI) & Soil Moisture Change:** USGS/EROS and NDMC have integrated MODIS into the national 'VegDRI model' on a rapid, weekly schedule. JPL automated a procedure to provide Soil Moisture Change updated projects.
- **Prototype Terrestrial Water Storage (TWS) Using GRACE Satellite Data:** NASA GSFC and NDMC working to provide GRACE TWS data assimilated in to land surface models for a new key drought indicator including deep soil moisture and ground water.
- **Resolution Benchmark:** NASA results have excellent resolutions to resolve the county-level goal of NIDIS. This is evident in the comparison of SMC, TWS and VegDRI products versus USDM drought maps at the higher resolution.
- **Improvements of USDM are important for users:** NOAA NWS uses 'D2' to trigger drought information statements, IRS for tax deferrals, USDA programmatic usage, and Livestock Forage Disaster Program disbursement ($147,109,381 in 2008, and $77,608,125 in 2009).

# NASA's Water and Energy Cycle Missions



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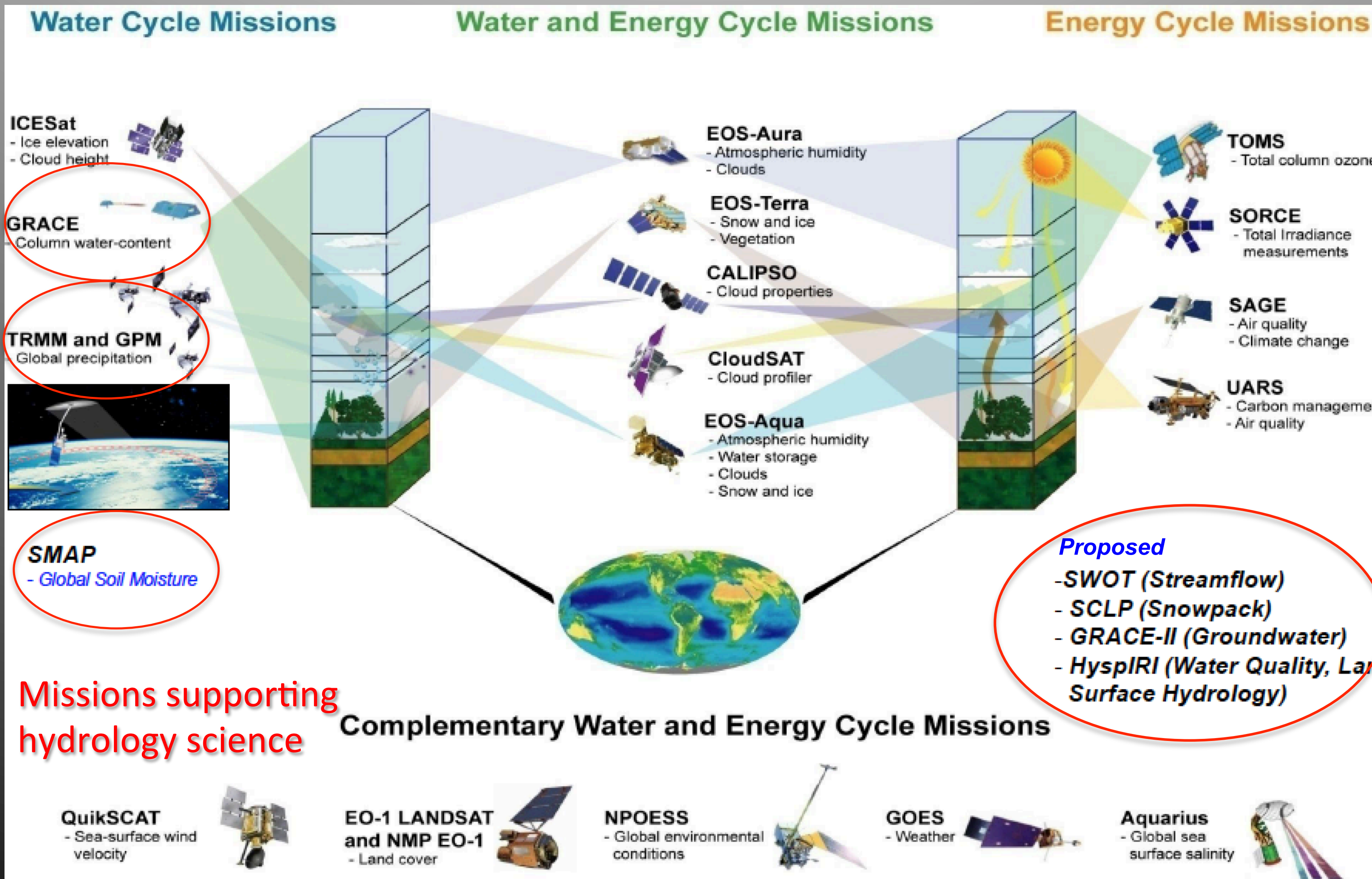
# NASA's Water and Energy Cycle Missions

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# GRACE

## 2002-present

## Gravity Recovery And Climate Experiment - Applications

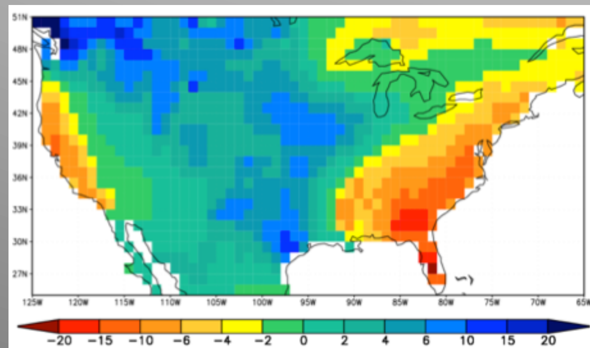
- **Water Resources Assessments**
  - Drought monitoring
  - Ground water depletion
  - Seasonal snow load
  - Streamflow forecasting (based on upland water storage)
  - Transboundary water resources sharing
  - Flood stage and risks (UCI work)
- **Weather and Climate Prediction**
  - Via improved forecast model land surface state initialization
  - Implications for Water Resources, Agriculture, and Disaster Preparedness

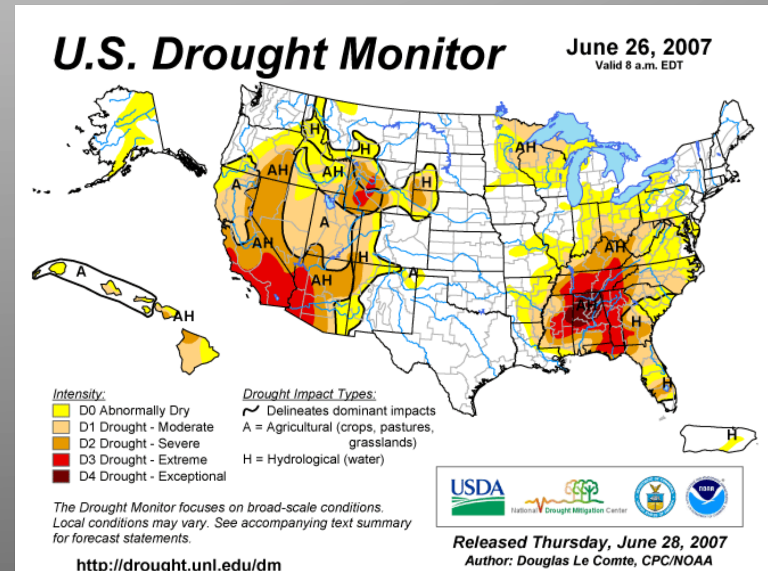
Several agencies are using or considering the use of GRACE data in their decision making processes:

- State of California 2013 Water Plan
- NOAA Drought Mitigation Center
- International Center for Biosaline Agriculture, Dubai, UAE

# GRACE-based Drought Indicators

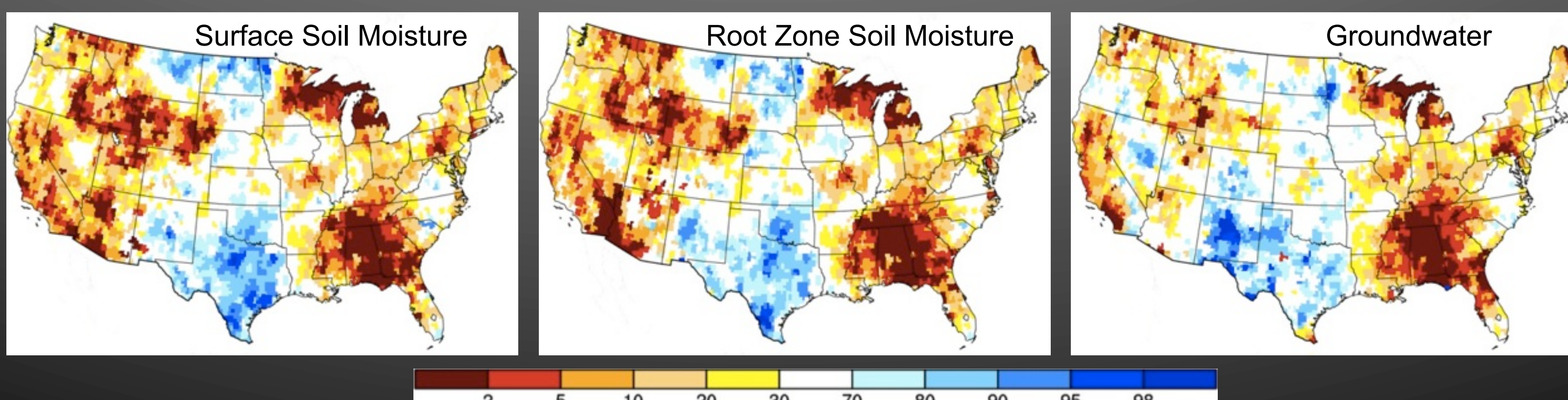
GRACE terrestrial water storage anomalies (cm equivalent height of water) for June 2007.




U.S. Drought Monitor product for 26 July 2011.

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



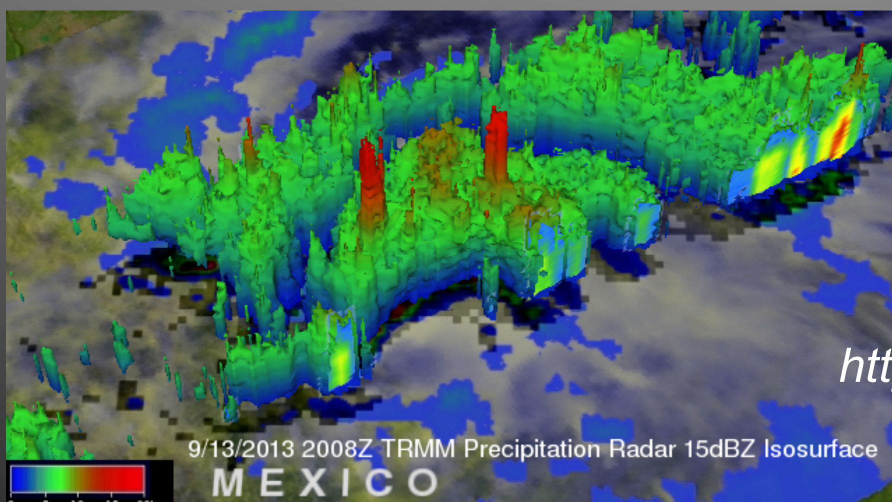

Drought indicators from GRACE data assimilation (wetness percentiles relative to the period 1948-present) for 26 June 2007

# TRMM

## Launched: 1997

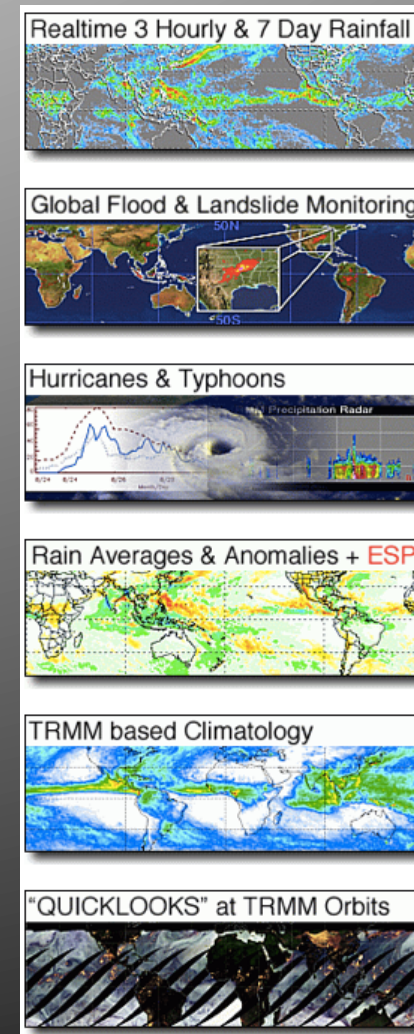
## Tropical Rainfall Measuring Mission

- Launched in 1997 to measure tropical rainfall
- Currently has an nearly 16-year record of precipitation
- Partnership between NASA and the Japan Aerospace Exploration Agency (JAXA)




http://pmm.nasa.gov

Tropical Storm Ingrid on Friday, Sept. 13th
TRMM PR recorded "hot towers" (red) that often signal a tropical cyclone will intensify
Triggered huge landslides and flooding



# Jason Series

## Jason-3 Launch: 2015

## Ocean surface topography measurements - altimetry

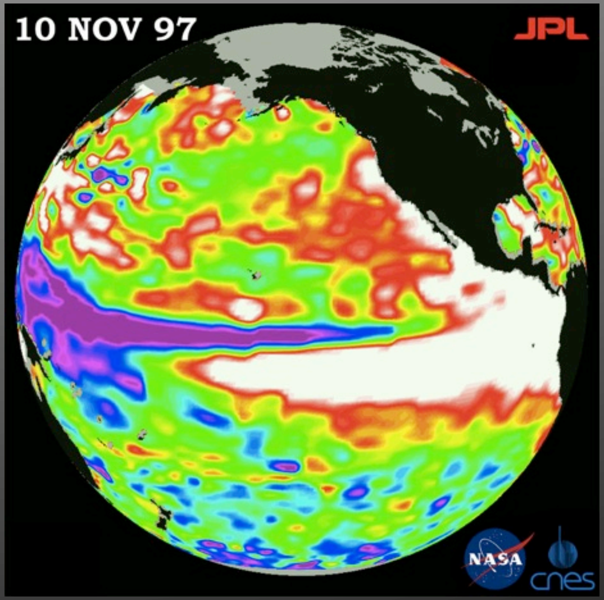
TOPEX/Poseidon, 1992-2006

Jason-1, 2001-2013

OSTM/Jason-2, 2008-present

European; Envisat, ERS, Saral/AltiKa, etc, 1995-2013

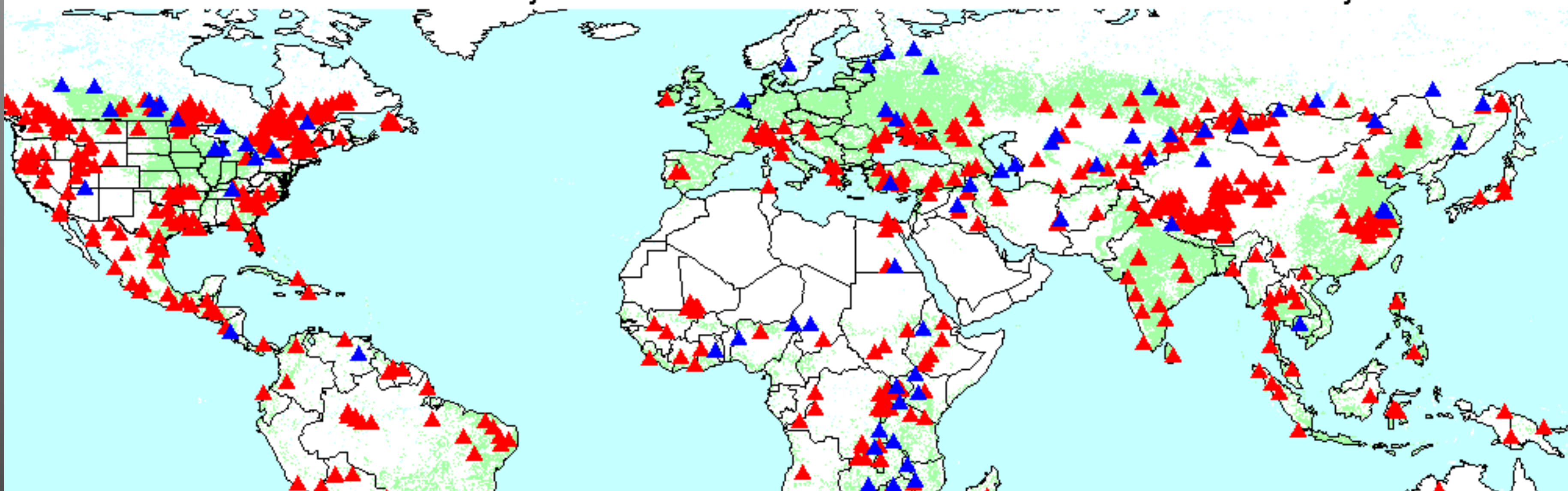
- El Niño/La Niña
- Ocean Currents
- Tides

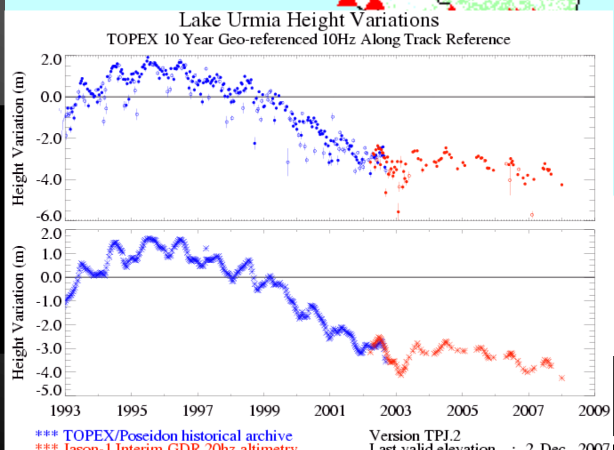


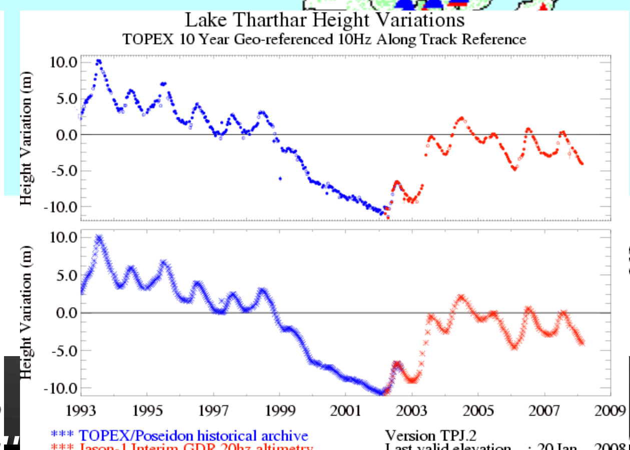
# Jason Series

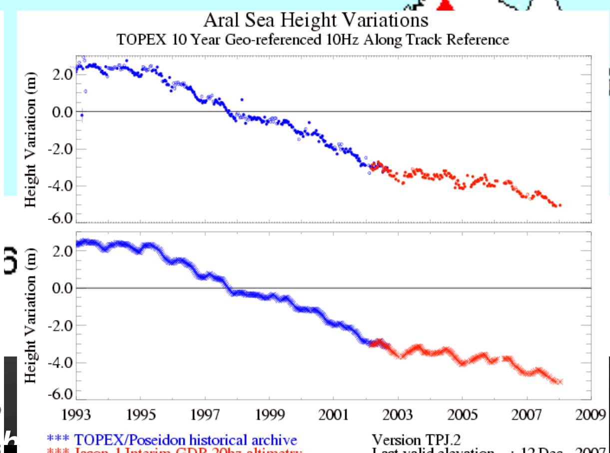
*Hydrology applications;* River & Lake surface height measurements for long-term storage monitoring (> 20 years time series)

Current Lakes Monitored by Jason-1 and Potential Lakes Monitored by ENVISAT






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

Source: C. Birkett

# Jason-Series

## Jason-3 Launch: 2015

*Hydrology applications;*

- Flood forecasting – developing application

Forecasting, calibration of hydrodynamic models, assimilation of river height data

- ➢ Information for improving accuracy of predictions
- ➢ Will be available to stakeholders; water managers, NGO's, water resource & planning agencies, crop modelers, ecological forecasters, climate adaptation community, land management agencies.
- ➢ Immediate application of the toolbox by Flood Management Div of the Institute of Water Modeling-Bangladesh to extend flood forecast lead time to 5+ days

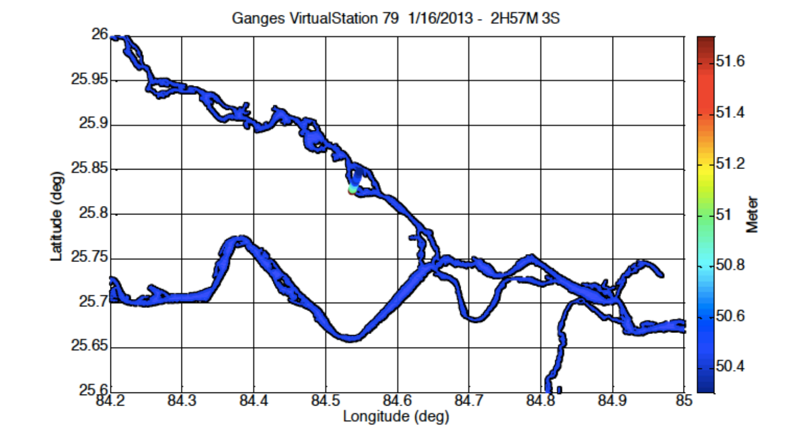
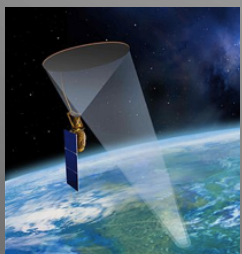



**Figure 1a.** Example of the image output of the JASON-2 toolbox. This is a working version. Additional functionalities will be added when the toolbox is developed with a GUI.

# Upcoming & Proposed Earth Missions
## supporting hydrology science

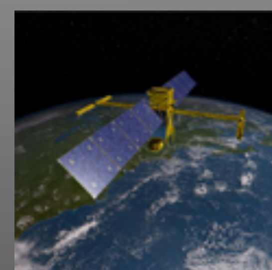
SMAP 2014



GPM 2014

GRACE-FO* 2017

SWOT* 2020



NISAR* 2021

HyspIRI* 2022

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# SMAP

## Soil Moisture Active Passive Mission

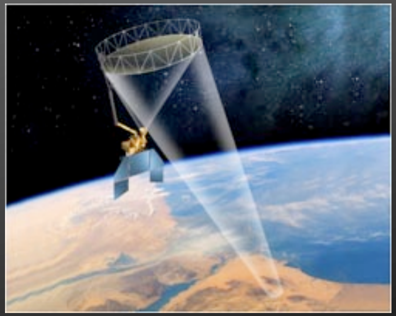
## Launch: 2014

### Weather & Climate Forecasting:

- Soil moisture variations affect the evolution of weather and climate over continental regions.
- Accurate soil moisture information enhances the skill of numerical weather prediction and seasonal climate models.
- Improved seasonal climate predictions will benefit water management, agriculture, and fire, flood and drought hazards monitoring.

### Drought:

- Soil moisture strongly affects plant growth and hence agricultural productivity, especially during conditions of water shortage and drought.
- With no global in situ network for soil moisture monitoring, global estimates of soil moisture and plant water stress must be derived from models.
- These model predictions (and hence drought monitoring) can be greatly enhanced with SMAP observations.



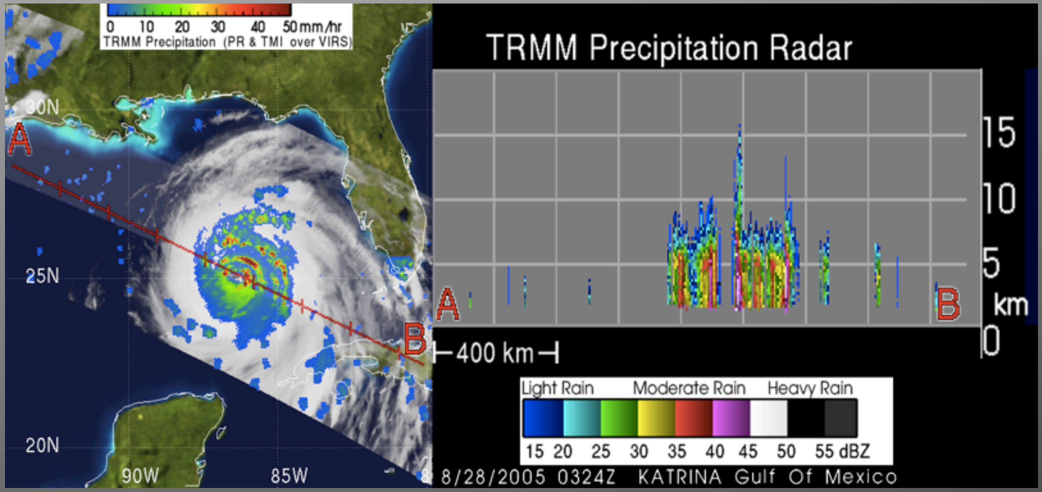
*Artist's Concept*

# GPM

## Launch: 2014

### Global Precipitation Measurement

- GPM builds upon TRMM's concept and will look at precipitation with greater accuracy around the world
- GPM will use inputs from an international constellation of satellites to provide improved space and time coverage of precipitation




*TRMM radar (PR) cross-sections of hurricanes available in real-time for operational analysis*

*http://gpm.nasa.gov*

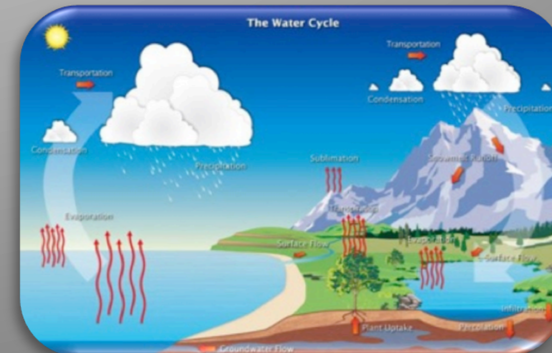
# GPM

## Applications

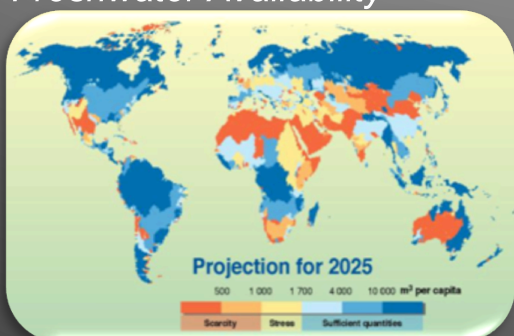
*Flooding*


*Landslides*


*Land surface and climate modeling*

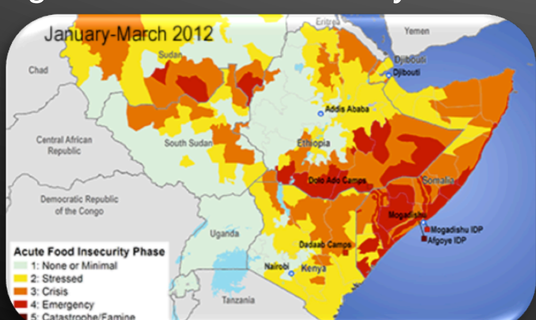



*Freshwater Availability*

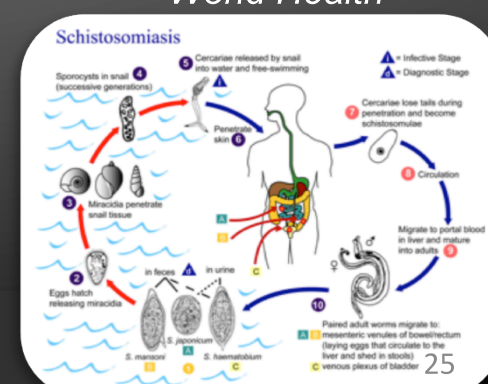



The rain and snow data gathered from the TRMM and GPM missions already provide and will extend our capabilities to study a wide range of applications for scientific research and societal benefit.

*Agriculture/Famine Early Warning*




*World Health*



# GRACE-FO*

## Projected Launch: 2017

**Hydrology:**

- Groundwater is a useful indicator of climate variability and human impacts on the environment.
- Combining GRACE data with hydrologic modeling enables scientists and water managers to observe the dynamic changes in groundwater over large regions or where well data is sparse.
- GRACE-FO* would continue to provide global measurements of the hydrological cycle.
- These measurements provide information on;
  - seasonal and inter-annual river basin water storage changes,
  - human influences on regional water storage changes,
  - large-scale evapotranspiration,
  - land-ocean mass exchange
  - continental aquifer changes.

| | GRACE | GRAIL | GRACE-FO | Next-Gen GRACE |
|---|---|---|---|---|
| Launch Date | 2002 | 2011 | 2017 | TBD |
| Target | Earth | Moon | Earth | Earth |
| Ranging Instrument | Microwave | Microwave | Microwave plus demonstration of laser interferometer | Laser coupled with drag-free technology enabling lower orbit and higher resolution |

*Artist's Concept*



*Proposed Missions – Pre-decisional – for Planning & Discussion Purposes Only

# SWOT*

## Surface Water and Ocean Topography
## Projected Launch: 2020

### Floods:

- Flooding hydraulics are currently well modeled but poorly measured.
- SWOT* would provide water level records for flooding events that underlay a given satellite overpass.
- SWOT* scientists would also be able to look at synergistic combinations of SWOT* and other satellite datasets, modeling, and in situ observations to improve capabilities.

Hydrology

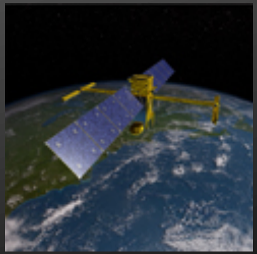
### Drought:

- Drought monitoring from model predictions can be greatly enhanced through assimilation of space-based water surface observations.
- Combining AirSWOT, SWOT* with other satellite data and modeling (i.e., GRACE) may improve observations and predictive capabilities.

Oceanography

### Reservoirs:

- Reservoir storage and water levels are poorly known.
- Changes in reservoir storage can be unknown to downstream neighboring communities and countries.
- SWOT* is being designed to accurately measure monthly to seasonal changes in reservoir storage. The information would be made available to water managers and other interested parties.



*Artist's Concept*



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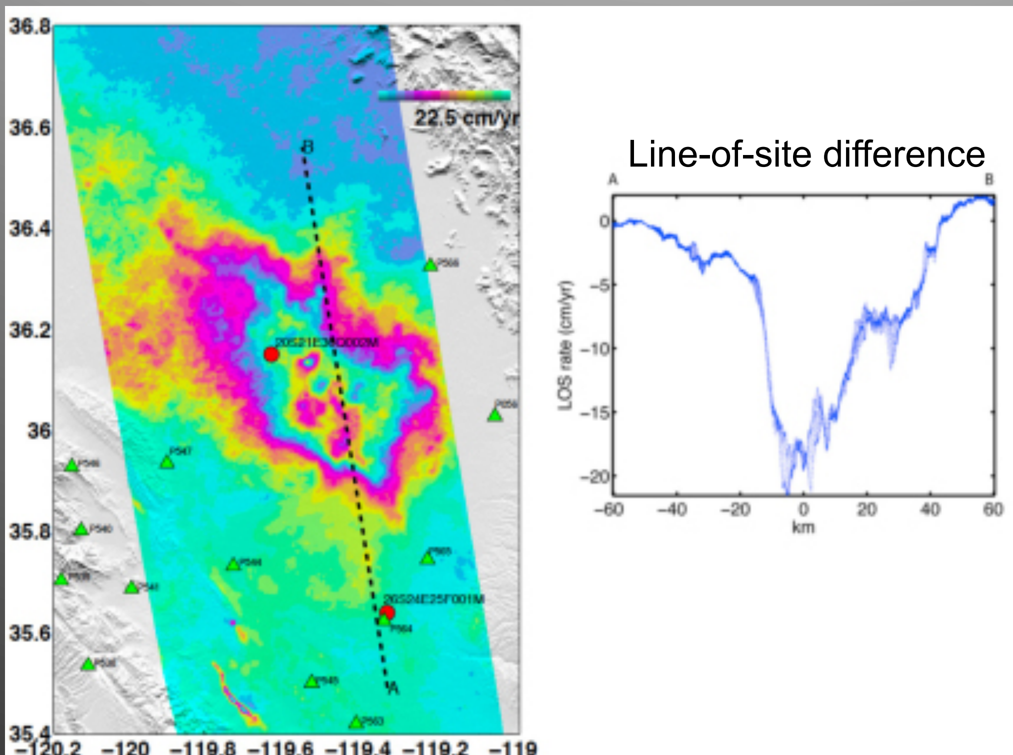
# InSAR – NI-SAR*

## Projected Launch: 2020

**Interferometric Synthetic Aperture Radar**

Space Radar Interferometry Measures Ground Water-related Subsidence/Inflation




Differential radar images determine ¼ meter land subsidence due to agricultural land use. L-band ALOS PALSAR satellite interferometry in the southern Central Valley between June 2007 and December 2010

- NASA-Indian L-band SAR Mission (NI-SAR)*
- Current data comes from other international space agencies



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# HyspIRI*

## Projected Launch: 2022

Hyperspectral Infrared Imager

- Would allow study of the world's ecosystems and provide critical information on natural disasters such as volcanoes, wildfires and drought.
- Would be able to identify the type of vegetation that is present and whether the vegetation is healthy.
- Would provide a benchmark on the state of the worlds ecosystems against which future changes could be assessed.


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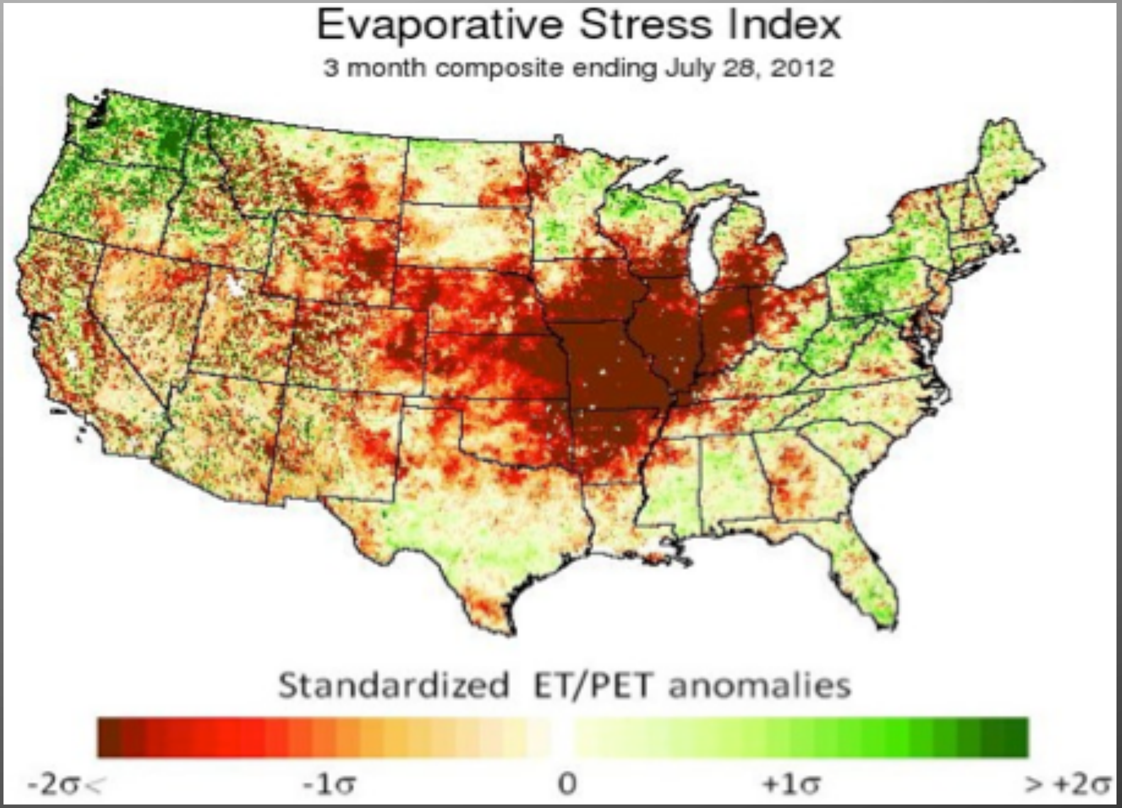
# HyspIRI*

## Projected Launch: 2022

in 2011, the US experienced the worst drought in the Midwest since the Dust bowl of the 1930s. The next year, the region was hit with an even more severe drought, impacting almost all agricultural land in the US (~80%), devastating crops, weakening food security, and reducing the total national GDP




The Evaporative Stress Index (based on thermal data) enables early detection

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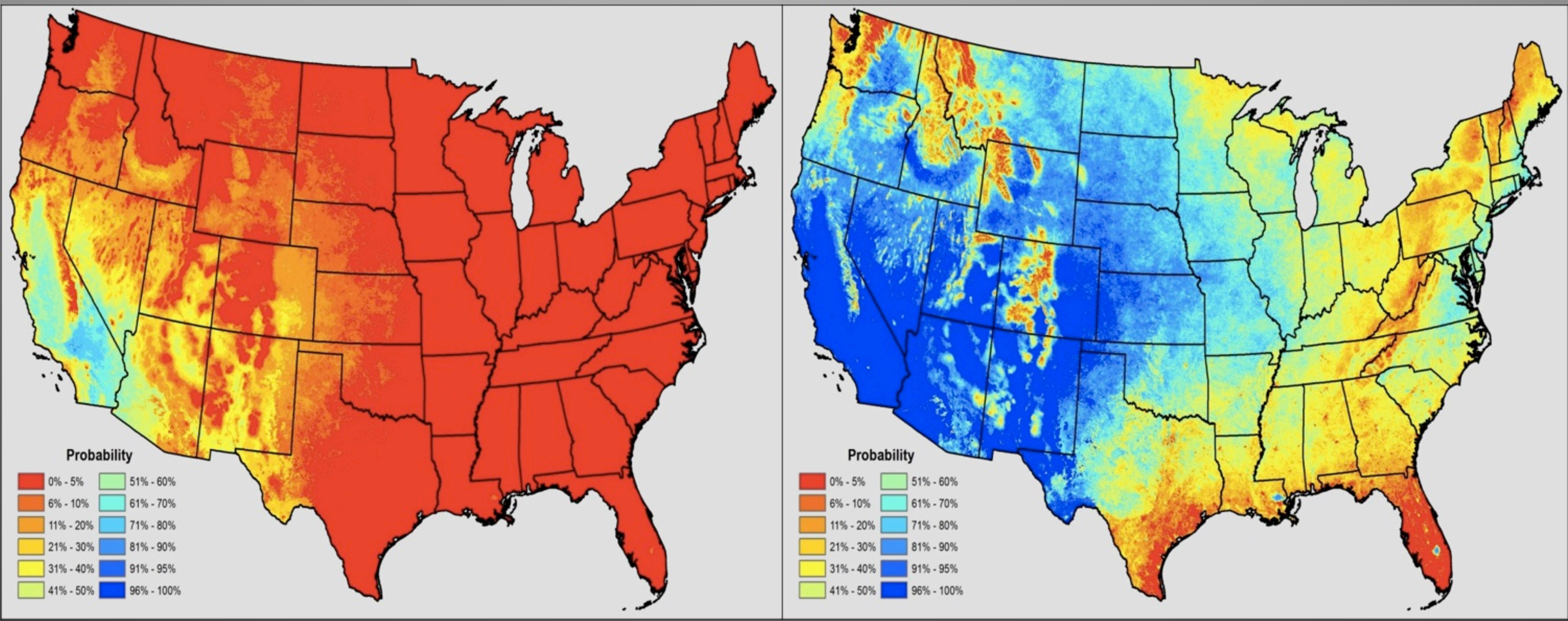
# Ecosystem Stress and Water Use

4 days = high probability of providing water consumption over US




Probabilities of producing valid estimates of water consumption over annual growing periods of the lower 48-states using thermally-based energy balance when satellite revisit time is 16 days (LEFT) and 4 days (RIGHT). Blue indicates high probability of acquiring valid estimates. [Morton C, Huntington J and Allen R, 2012]

# Next Steps and Questions

What are the operational requirements for drought and drought-related applications?

- What are current barriers to satellite data use?
  - How can we develop a common language between missions/agencies/NGOs?
  - Interpretation of the data products/measurements into actionable info
  - Need to develop data format standards AND make it available to the public
  - How can we ensure involvement from private industry, state agencies, and universities;
    CUASHI, DEVELOP, SERVIR, NASA education and outreach programs?

*Goal: Identify partners to transition research to operations for both measurements and applications (operational capacity)*

# Questionnaire on use of NASA data for drought-related applications

**NASA Applied Sciences Questionnaire**
**Water Forum III: Droughts and Other Extreme Events**

What are the operational requirements for drought and drought-related applications?

Do you currently use NASA data in your research/operations? If so, please name the data and comment on its availability, utility, and performance.

What do you consider to be the biggest challenge to incorporating satellite data for improved operational capacity?

How can we enhance and support involvement from private industry, state agencies, and universities in NASA Applications effort?

Name and email (Optional): ___________________________________________

**PLEASE RETURN FORM TO: mss@jpl.nasa.gov or john.bolten@nasa.gov**

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*University of Texas, 14 October 2013*

# Thank you