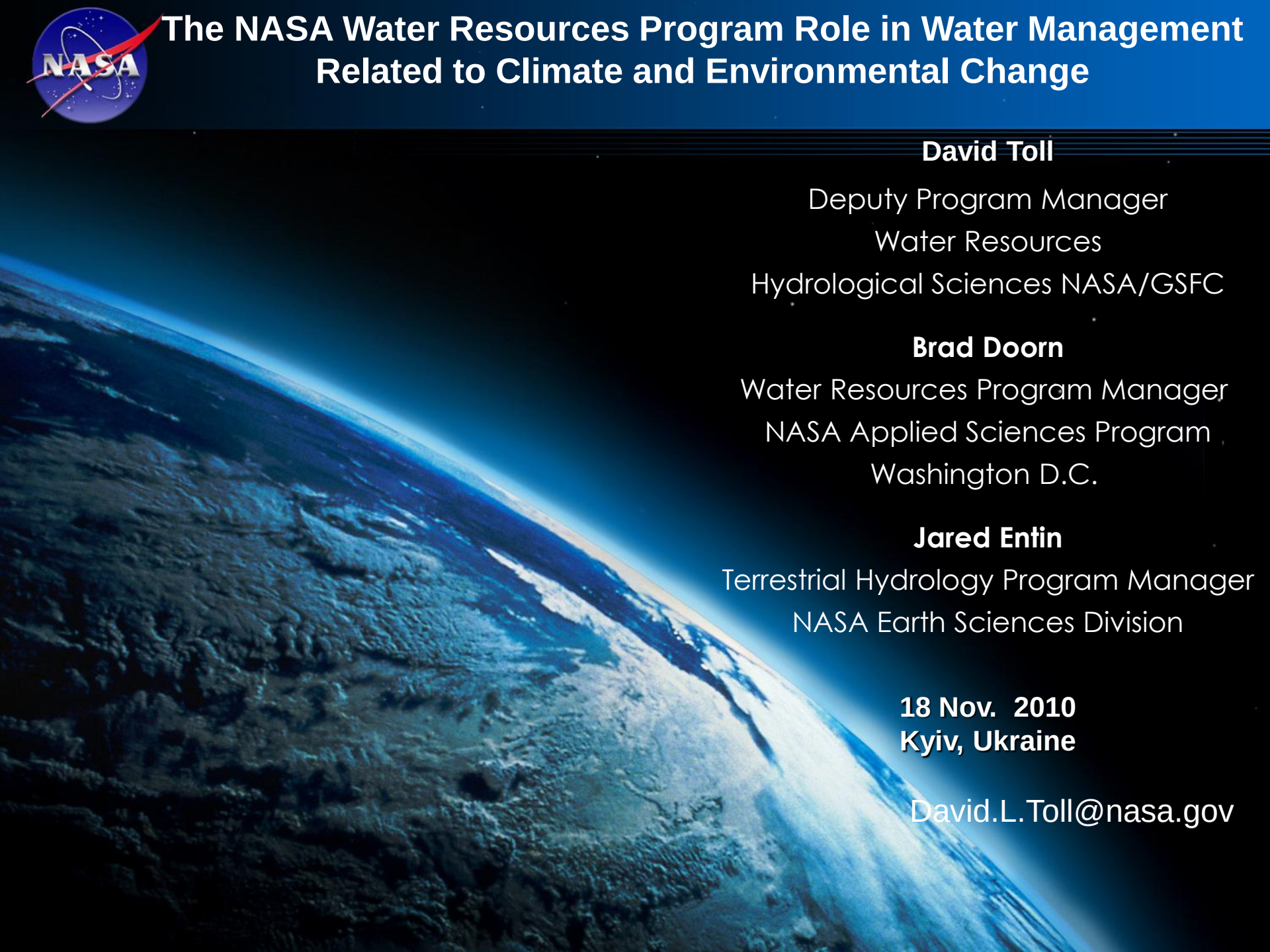
The NASA Water Resources Program Role in Water Management Related to Climate and Environmental Change



David Toll

Deputy Program Manager

Water Resources

Hydrological Sciences NASA/GSFC

Brad Doorn

Water Resources Program Manager

NASA Applied Sciences Program

Washington D.C.

Jared Entin

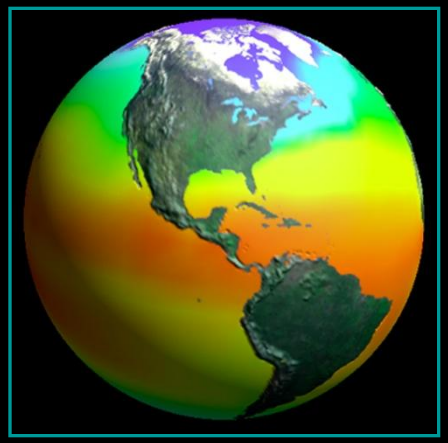
Terrestrial Hydrology Program Manager

NASA Earth Sciences Division

18 Nov. 2010
Kyiv, Ukraine

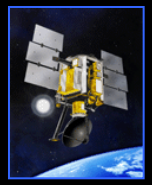
David.L.Toll@nasa.gov

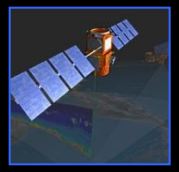
Study Earth from Space to Advance Scientific Understanding and Meet Societal Needs.




Cloudsat


Jason


Quikscat


CALIPSO

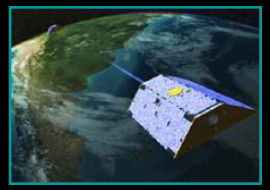

Airborne Science


Aqua

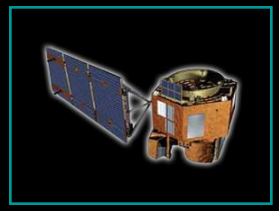

Aura

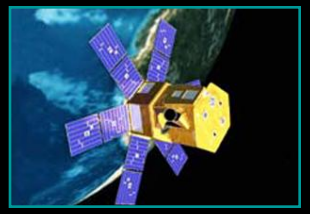

Terra

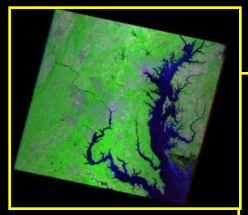

Tropical Rainfall Measureing Mission (TRMM)


Gravity Recovery And Climate Experiment (GRACE)

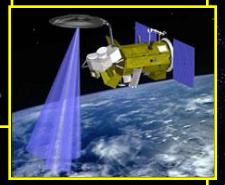

Ice, Clouds,and Land Elevation Satellite (ICESat)

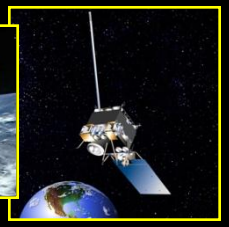

New Millennium Program Earth Observing-1 (NMP EO-1)


Solar Radiation and Climate Experiment (SORCE)


Landsat Data Continuity Mission (LDCM)

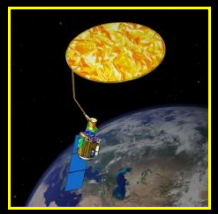

GPM


Aquarius


Geostationary Operational Environmental Satellite (GOES) GOES O/P/R


NOAA Polar Operational Environmental Satellite (POES), N and N'


National Polar-Orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP)


SMAP

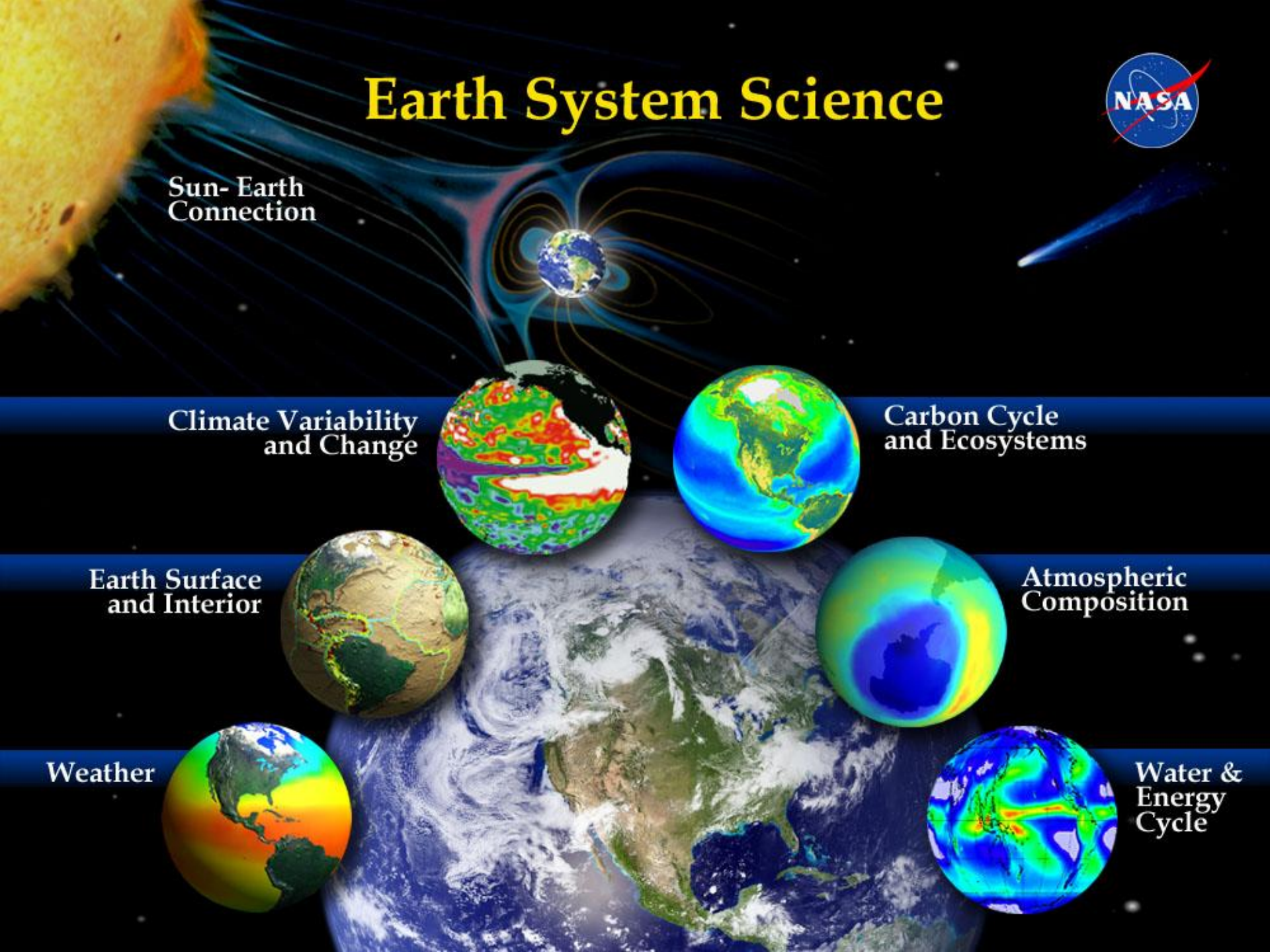

ICESAT-2

NASA develops and operates Earth-observing satellites that monitor changes to our planet's oceans, ice caps, land masses and atmosphere from a unique global perspective. NASA promotes free and open access to data.

GRACE-II (Approved)
SCLP - snowpack
SWOT
HyspIRI

Missions in Operation Missions in Development

Earth System Science



National Aeronautics & Space Administration

Water Resources Program

Summary Space-Based Hydrologic Observations Current Capability

Water Cycle & Related Variable	Sensor	Technology	Horizontal Resolution	Repeat Frequency	Swath Width
Precipitation	TRMM, GOES, DMSP, Meteosat **GPM**	Precip Radar (JAXA) TMI, VIRS	25 km 0.25x0.25deg	daily	247 km 878 km
Soil moisture	SSMI AMSR-E SMAP	Multifrequency Radiometers	12-56 km	5-day	1445 km
Groundwater	GRACE GRACE-II	gravity	100,000 km2	30 days	
Lake/reservoir levels	Topex/Poseidon Jason-1 SWOT	Altimetric radar	350 m	10 day	Single track
Evapotranspiration	MODIS, Landsat, LDCM includes IR	Visible/NIR	250-1000m	1-2 days	
Stream discharge	Topex Poseidon Jason-1, SWOT	Altimetric radar	350m	10-day	Single track
Snow water equivalent	SSMI, AMSR-E, SCLP	Multifrequency Radiometers	12-56 km	5-day	1445 km
Snow cover	MODIS , Landsat, VIIRS	Vis/NIR	250-1000m	1-2 days	2330 km

Future & Planned in Red

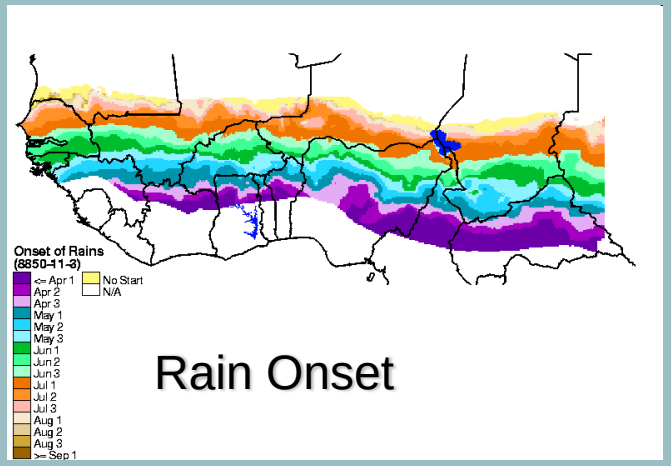
National Aeronautics & Space Administration

Water Resources Program

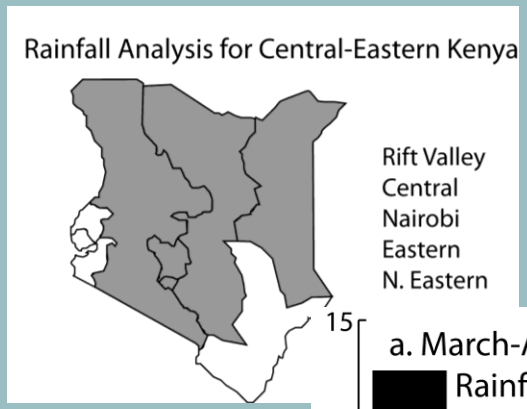
Satellite-based Precipitation

Current (1997-present): Tropical Rainfall Measurement Mission (TRMM)

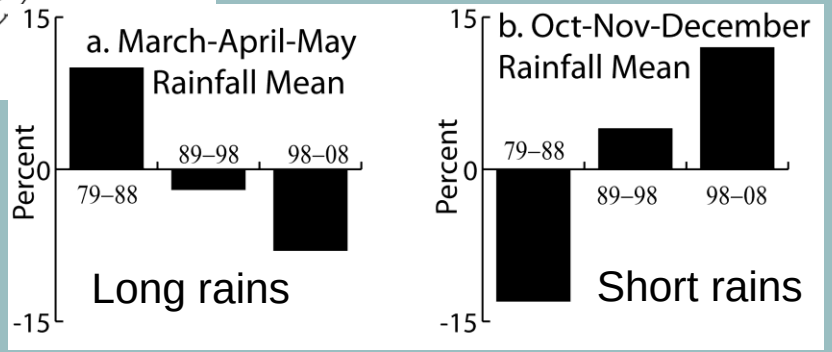
Future (2013): Global Precipitation Measurement (GPM)



Rain Onset



Trends



Funk, C et al. (2008) Proc., Nat. Academy of Sci.

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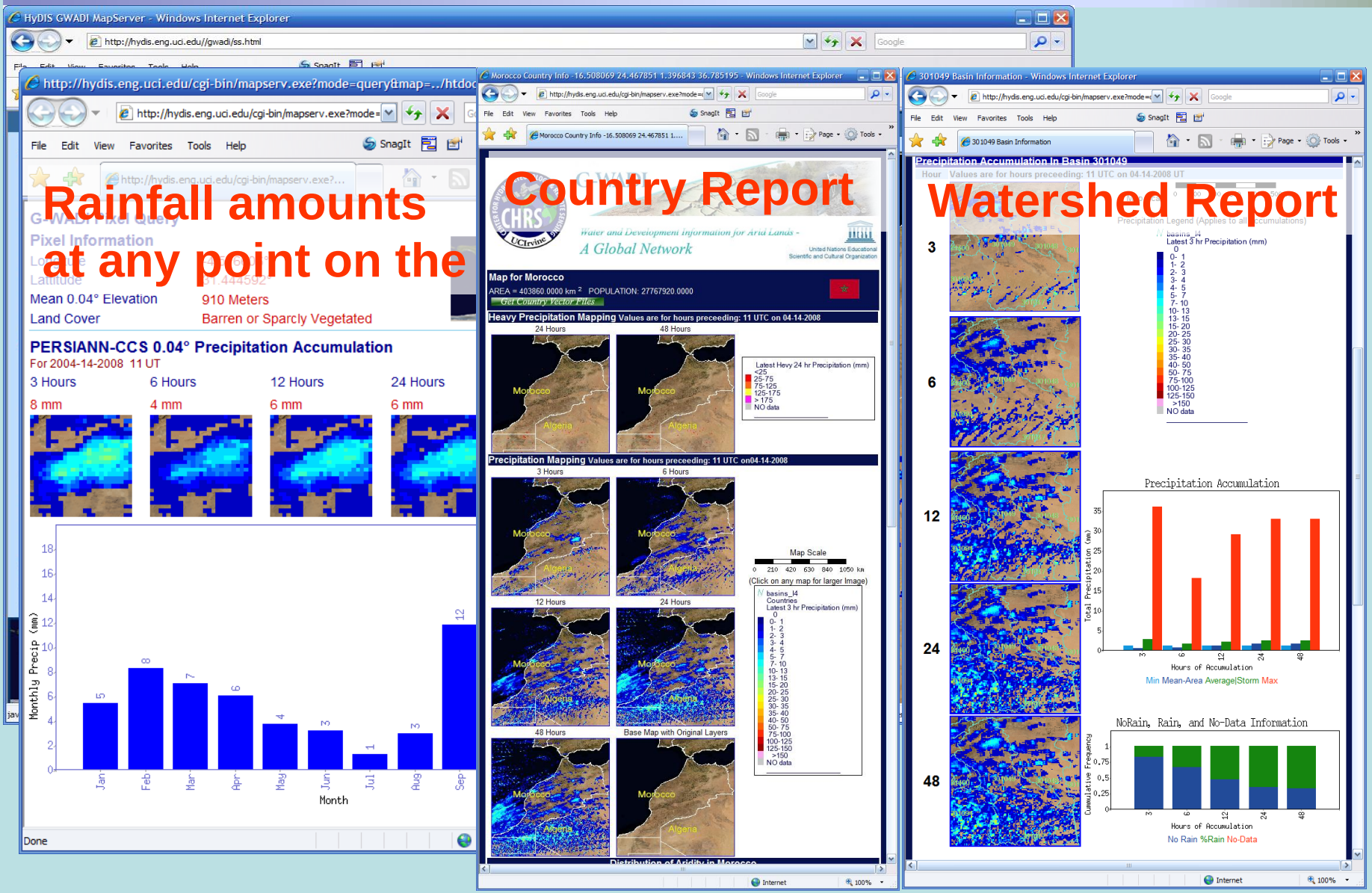
Water Resources Program

Water Cycle Applications – 'G-WADI'



National Aeronautics & Space Administration

Water Resources Program

Soil Moisture Active/Passive (SMAP) Mission

Soil Moisture Mapping

A *dedicated* soil moisture mission selected as a new Earth science mission

NASA fly an active / passive microwave soil moisture with mission in the 2013 timeframe

SMAP consists of an L-Band radar & radiometer in a low Earth, sun-synchronous orbit

Extends soil moisture to deeper depths with improved spatial resolution

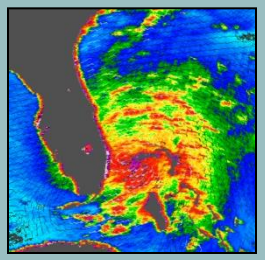
Societal Benefits:

- Water, Energy & Carbon Cycles

- Water and Food

- Water Quality and Human Health

- Water and the Environment



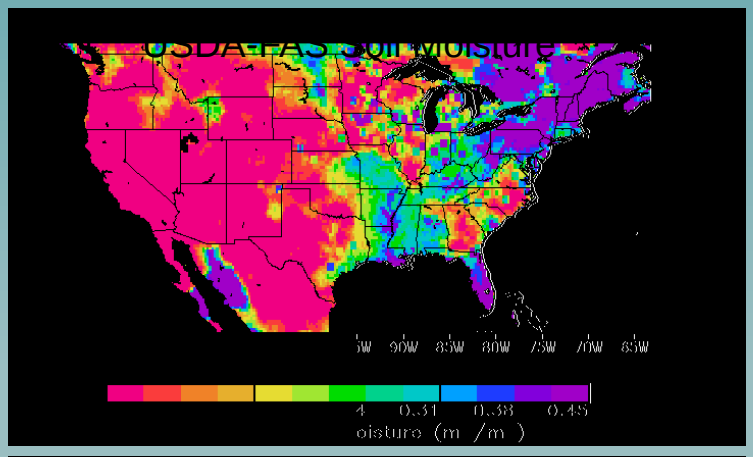
- Weather & Climate Prediction
- Severe Storm Forecasts
- Agriculture Food Production
- Drought Monitoring and Assessment
- Flood Prediction, Assessment and Inundation Mapping

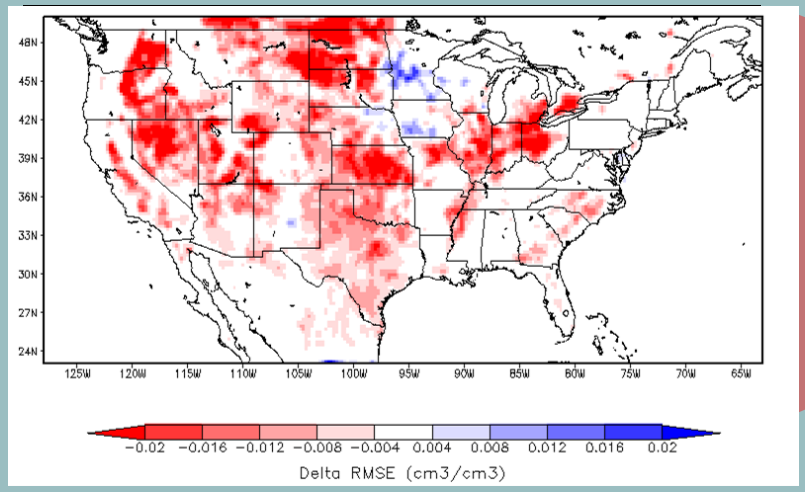
SMAP Applications web site
http://smap.jpl.nasa.gov/benefit/

National Aeronautics & Space Administration

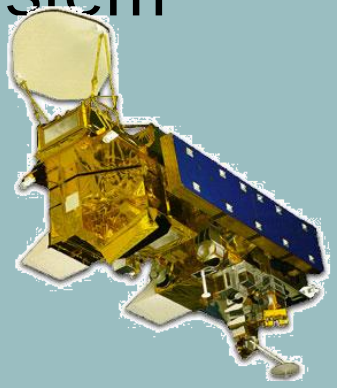
Water Resources Program

Soil Moisture Monitoring & Assimilation





Integrating satellite-based soil moisture from Aqua/AMSR-E into the USDA-FAS Global Crop Production Decision Support System



Bolten & Crow

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

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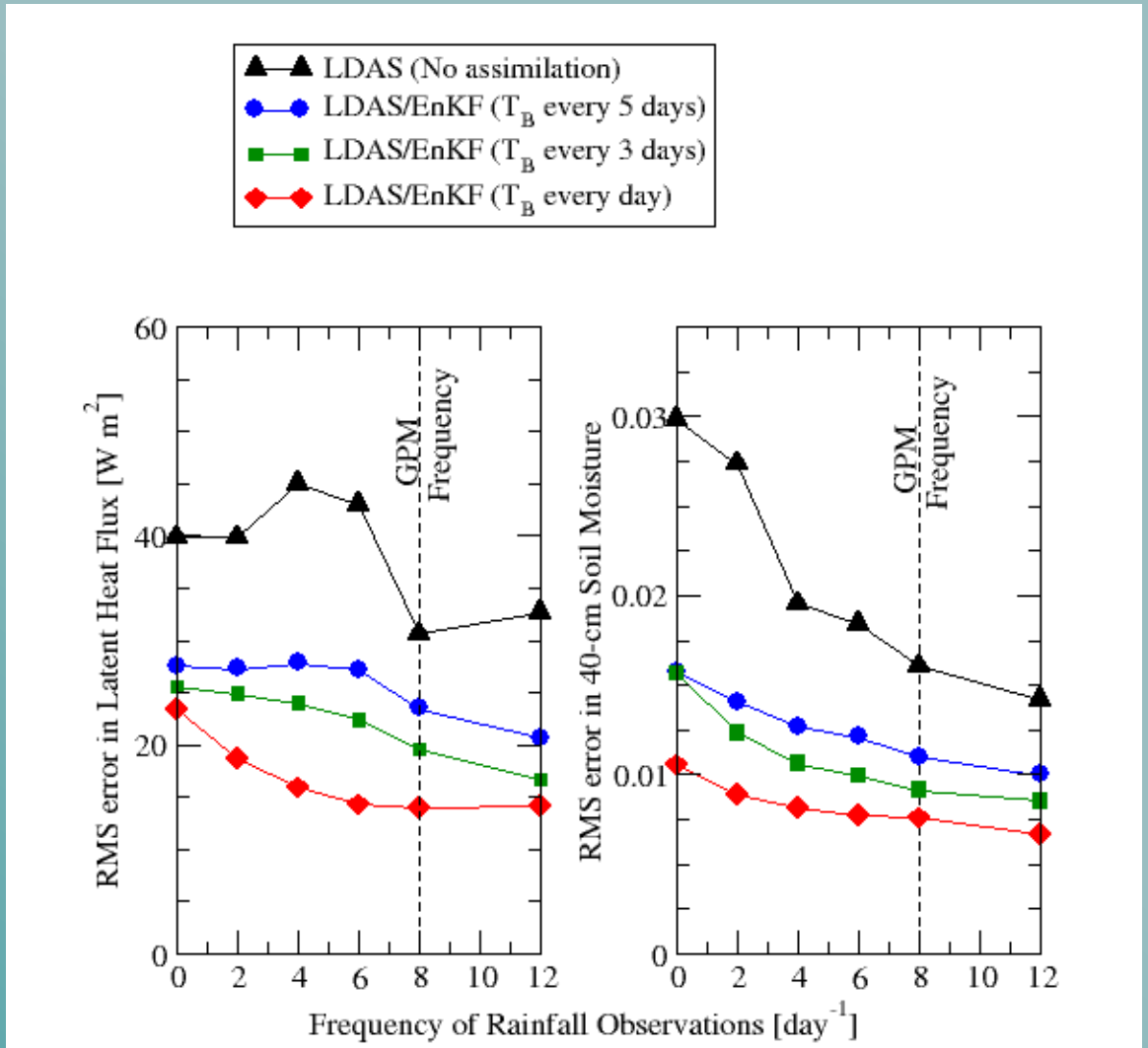
Water Resources Program

Enhanced Land Surface Flux/State Forecasting

SMAP Tb combined with GPM P should reduce flux/state errors as in Crow et al., EOS, 2006

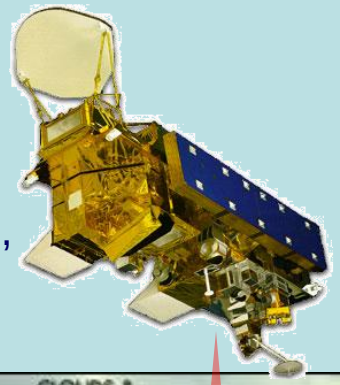


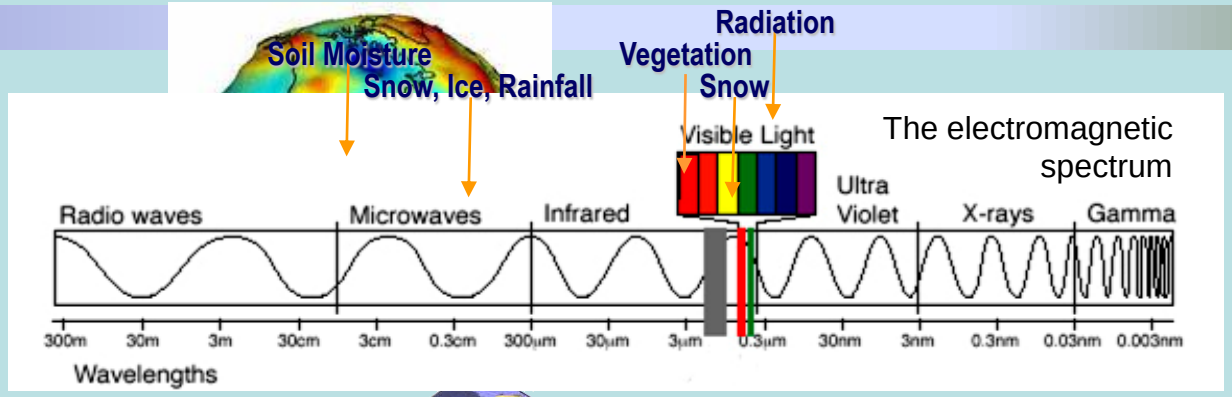
National Aeronautics & Space Administration

Water Resources Program

Remote Sensing of the Water Cycle

Aqua: MODIS, AMSR-E, etc.





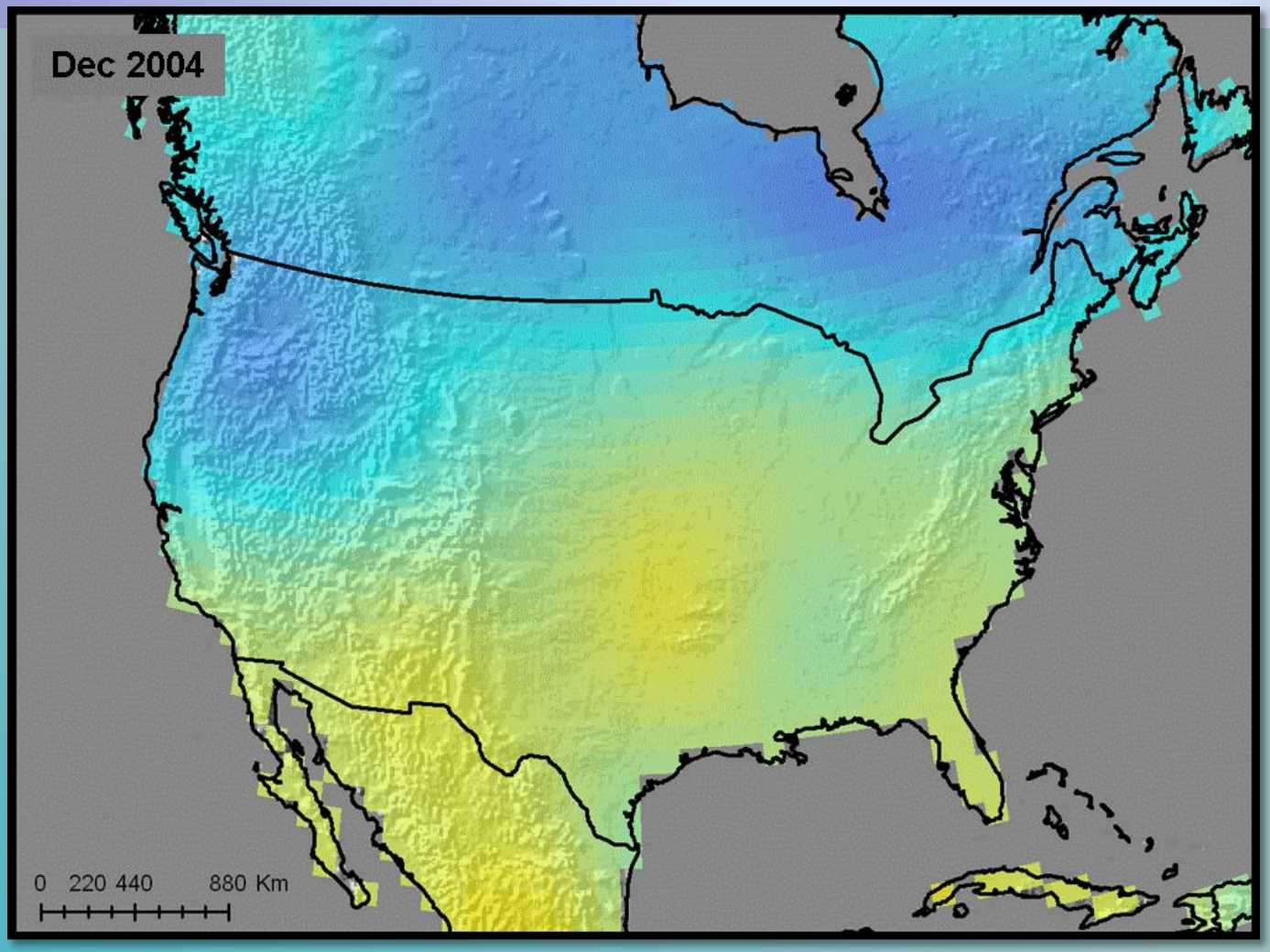
Traditional radiation-based remote sensing technologies measure water in the upper few centimeters of soil or vegetation or snow, including changes in groundwater levels

These precise gravity measurements are used to infer the total wetness of the land surface

National Aeronautics &
Space Administration

Water Resources Program

Terrestrial Water Storage Anomalies from GRACE



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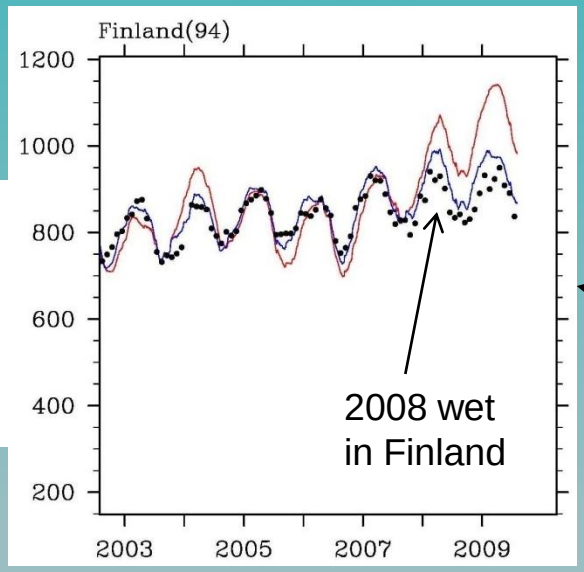
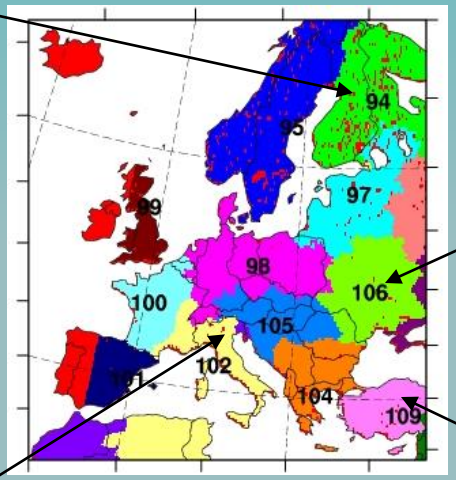
Water Resources Program

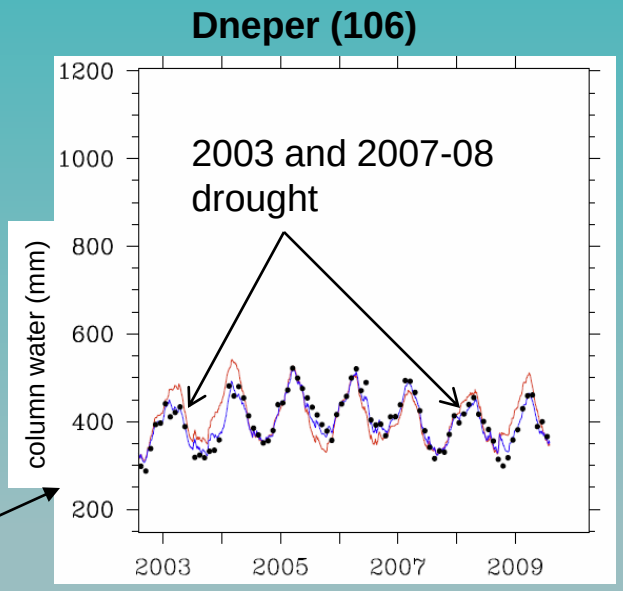
GRACE Terrestrial Water Storage Data Assimilation

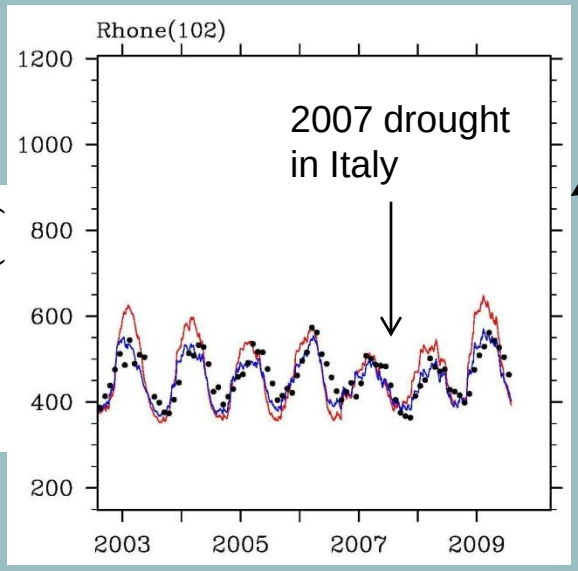
Assimilated results are spatially, temporally, and vertically downscaled



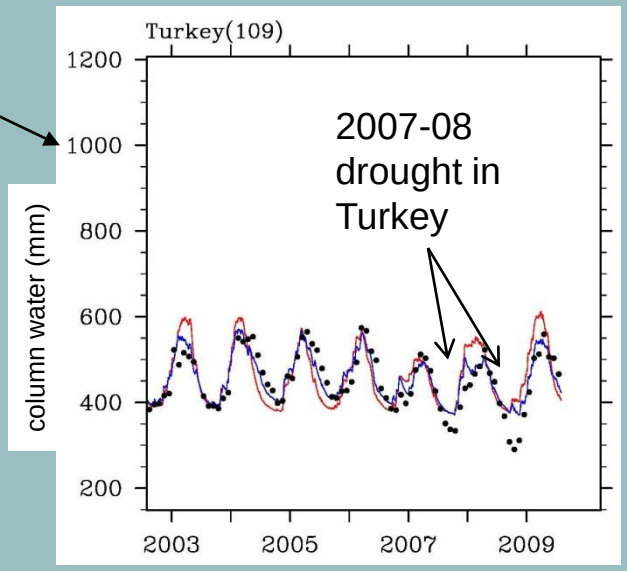
Monthly GRACE data anchor model results in reality







- GRACE Water Storage
- Modeled Water Storage
- Model-GRACE Assimilation



Daily estimates are critical for operational applications

Surface Water Ocean Topography (SWOT)

Stream Discharge and Surface Water Height

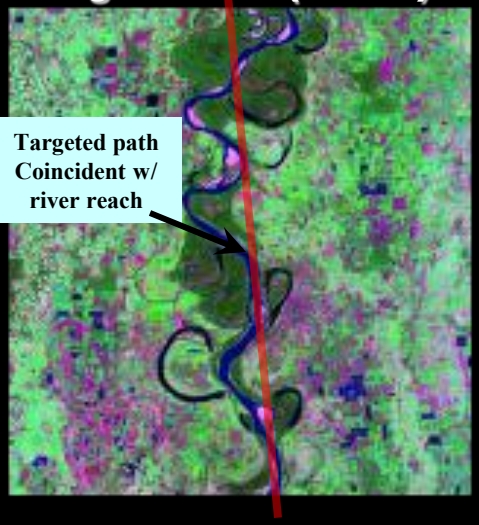
Planned Mission – 2 (Post 2013)

Motivation:

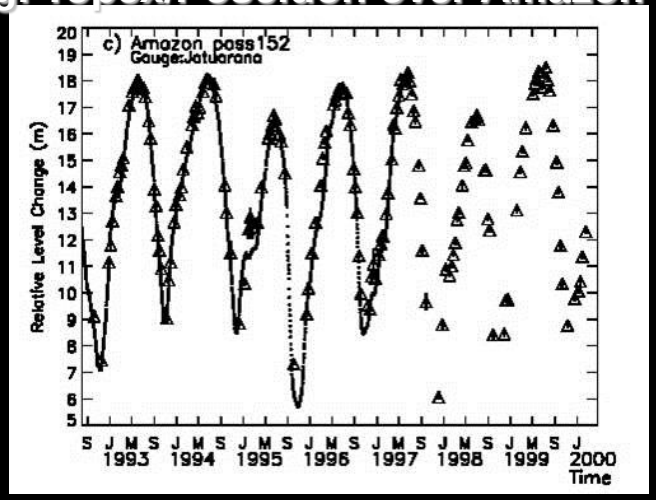
- critical water cycle component
- essential for water resource planning
- stream discharge and water height data are difficult to obtain globally

Mission Concepts:

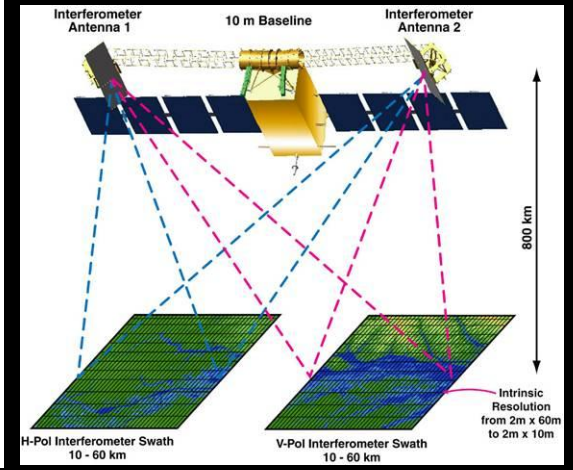
Laser Altimetry Concept
e.g. ICESat (GSFC)



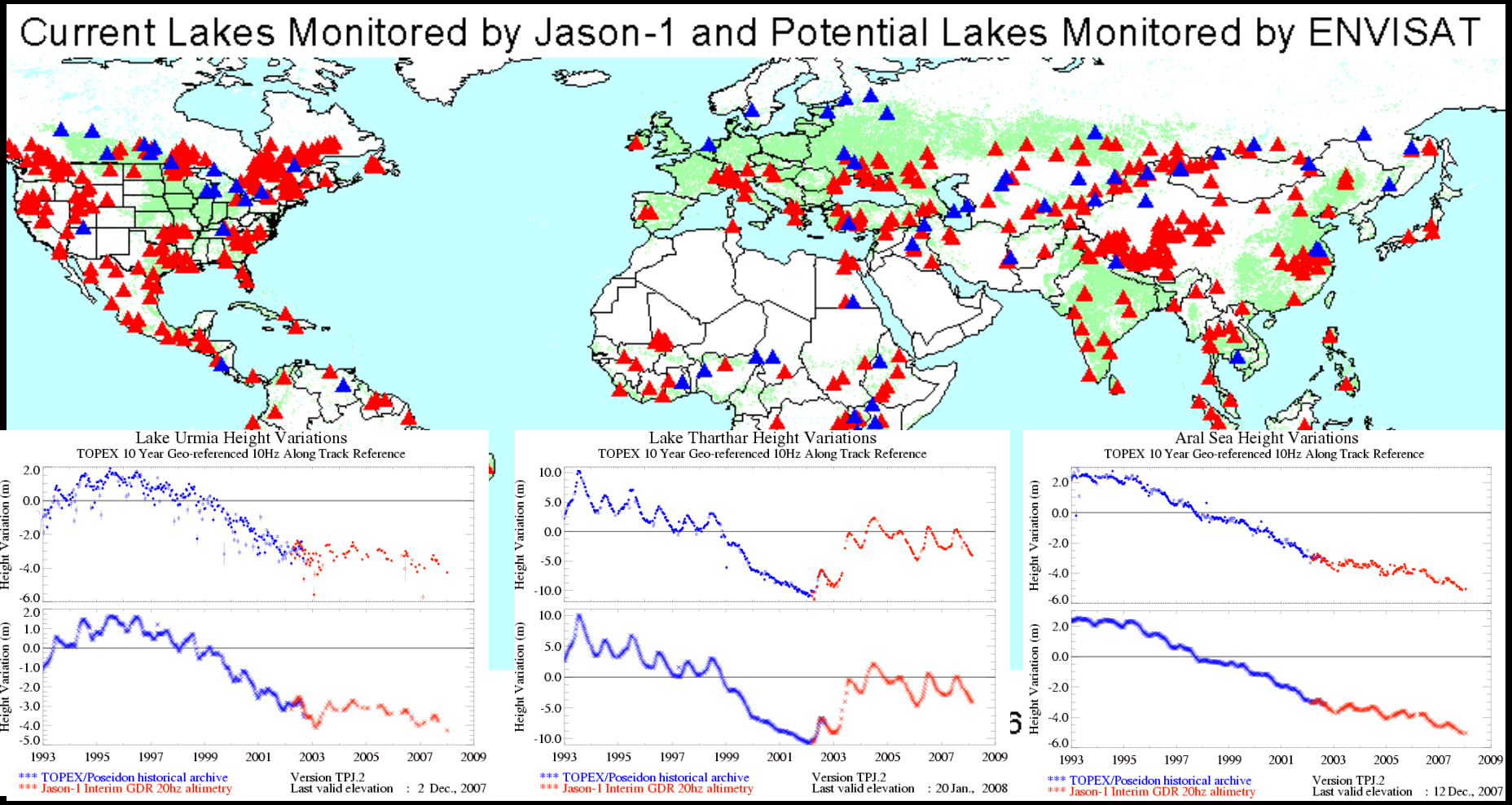
Radar Altimetry Concept
e.g. Topex/Poseidon over Amazon R.



Interferometer Concept
(JPL)



Lake and Reservoir Monitoring



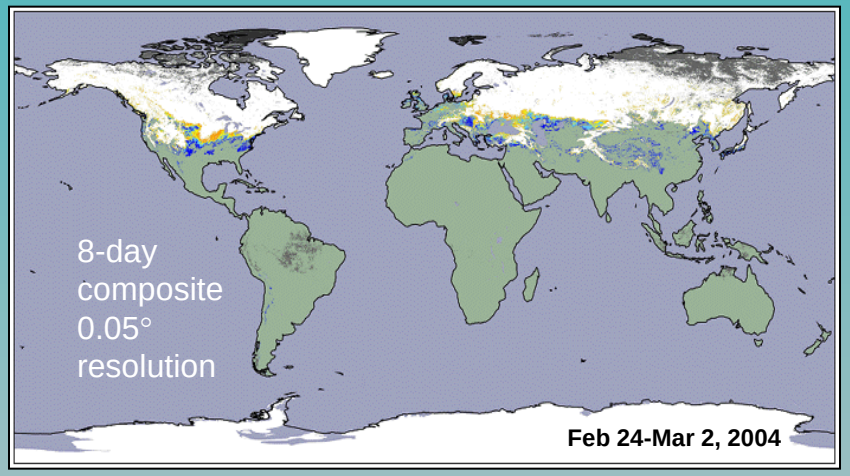
http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir

National Aeronautics & Space Administration

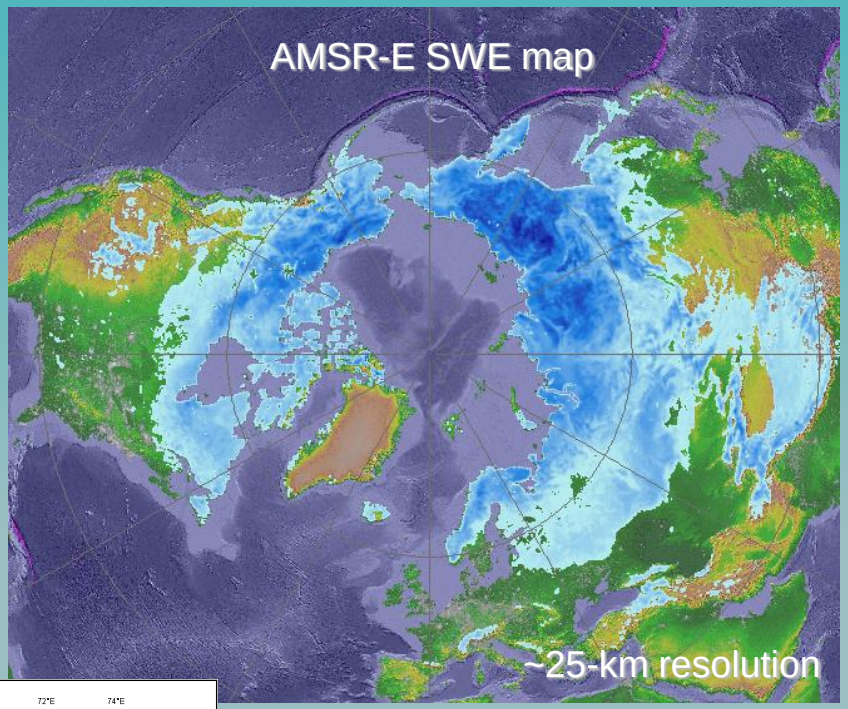
Water Resources Program

MODIS and AMSR-E Snow-Cover and SWE Maps

MODIS 5-km resolution snow map

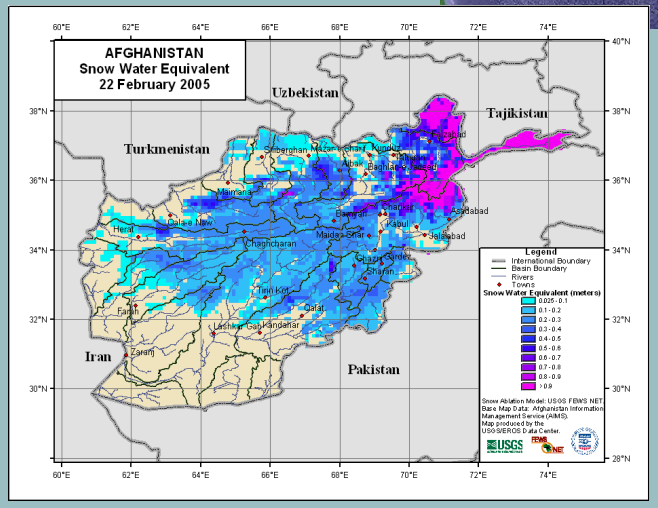


Percent snow cover: 1–19% | 20–39% | 40–59% | 60–79% | 80–100% | no decision



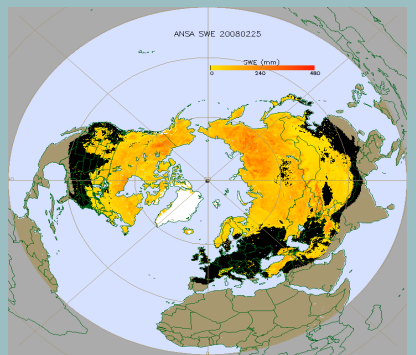
Foster et al., 2010

NASA-NOAA-USGS Using Snow Cover with Land Surface Modeling for Snow Water Equivalent for FEWS-NET



Hall and Riggs, 2007

New MODIS/AMSR-E Blended Product



NASA Applied Sciences Program

A Pathway Between Earth Science & Society

Results of NASA Earth Science Research

Uses by Partners and Stakeholder Communities

NASA Applied Sciences Program

GEOSS Societal Benefit Areas

National Aeronautics &
Space Administration

Water Resources Program

NASA Water Resources

Goal: ***Facilitate application of NASA Earth science products as a routine use in integrated water resources management for the sustainable use of water. Also includes extreme events of drought and floods and the adaptation to the impacts from climate change.***

WATER RESOURCES FUNCTIONAL THEMES:

1) **Streamflow & Floods (Includes Snowpack)**
2) **Drought Monitoring & Prediction**
3) **Irrigation and Water Delivery**
4) **Water Quality**
5) **Climate Change and Water Resources**

International Work: **NASA Applied Sciences Program works primarily through US government agencies to use NASA products for international applications. Directive to support our Nation's societal goals.**

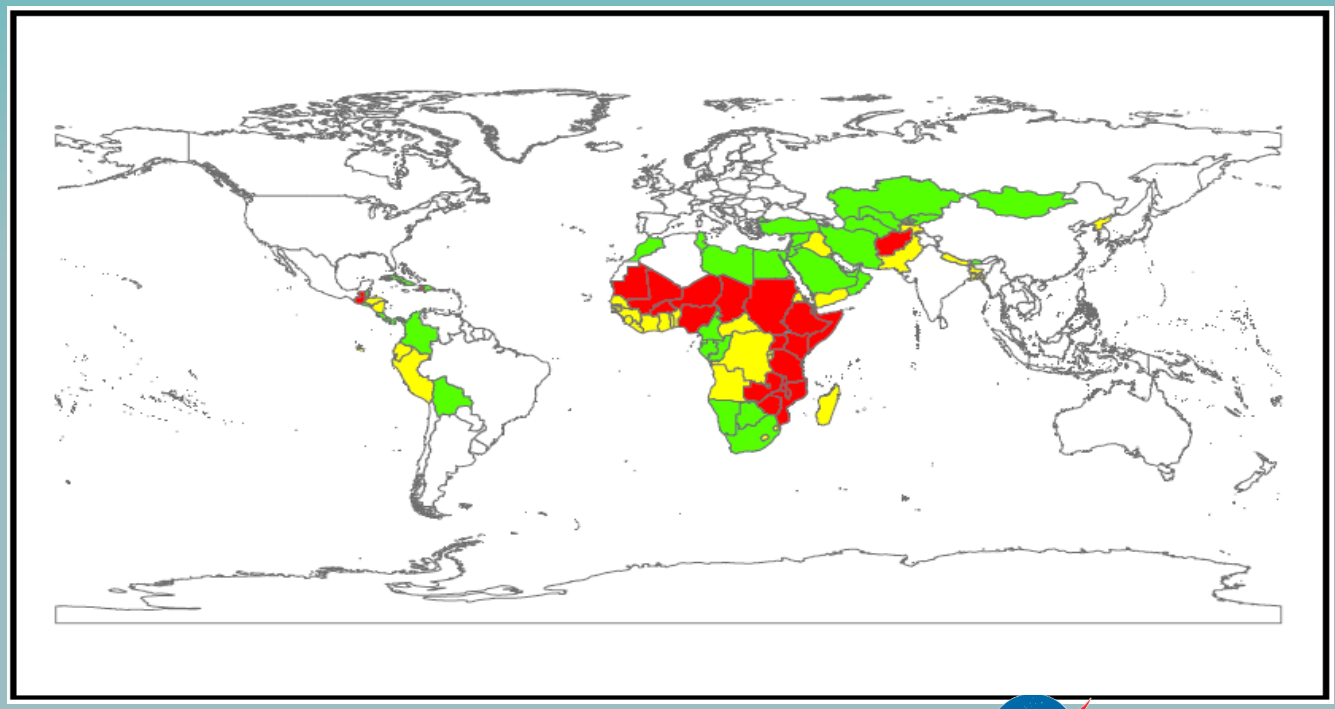
National Aeronautics & Space Administration

Water Resources Program

The Famine Early Warning Systems Network (FEWS-NET)

- **Using NASA Land Information System (LIS) to Help Extend Coverage beyond Sub-Sahara**
- **Satellite Precipitation**
- **Satellite Snow Cover and Snow Water Equivalent**
- **Satellite Vegetation Greenness**
- **Yield Forecasting**

FEWS NET
FAMINE EARLY WARNING SYSTEMS NETWORK



USGS science for a changing world

NOAA

Linking U.S. Agriculture to the World FAS

National Aeronautics & Space Administration

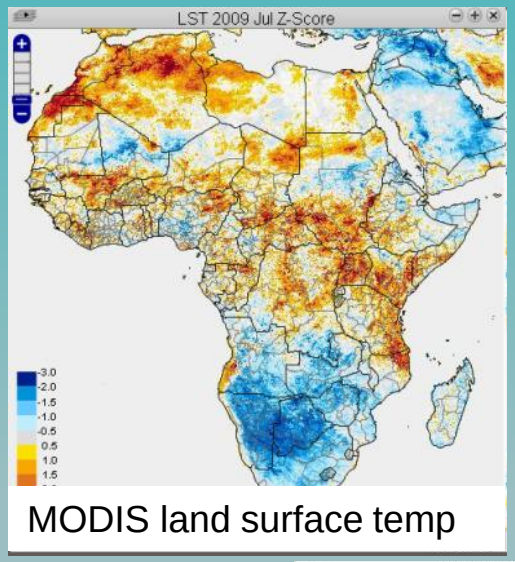
Water Resources Program

NASA Collaborates with the Department of State (DoS) through the U.S. Agency for International Development (USAID)

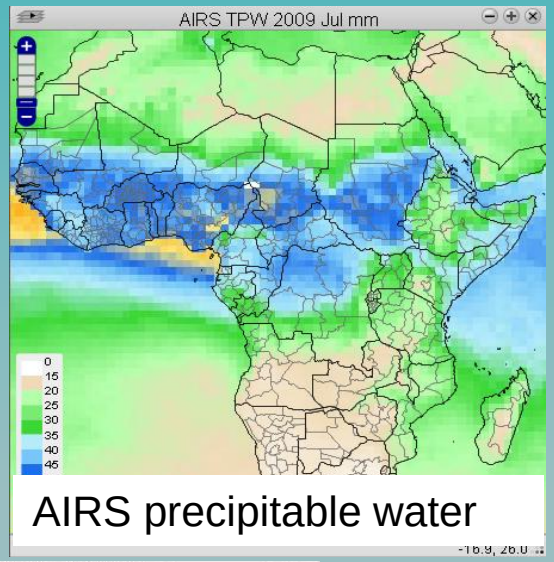
Famine Early Warning System – Network (FEWS –NET)

In agricultural economies, the majority of residents get some or all of their income from agricultural activity. In these regions, food security is highly related to weather-related food production deficits.

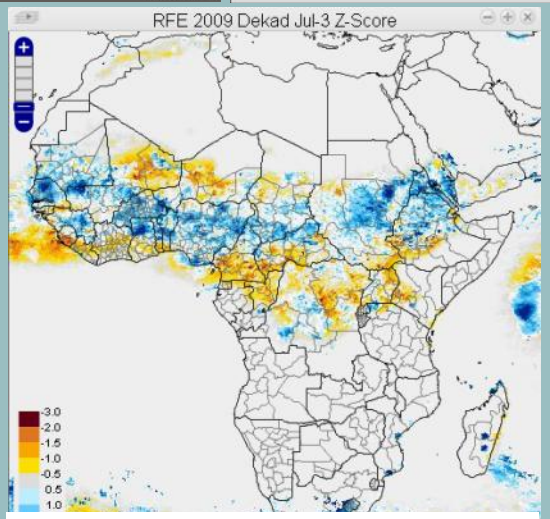
NASA satellite data and models are key input variables for organizations such as the USAID's Famine Early Warning Systems Network (FEWS NET). FEWSNET is a key resource for monitoring food aid needs and supporting food deficit countries.



MODIS land surface temp



AIRS precipitable water



TRMM Rainfall data

National Aeronautics & Space Administration

Water Resources Program

Middle East & North Africa (MENA) NASA Land Data Assimilation System (LDAS) for Regional Water Balance Assessments

Matt Rodell, John Bolten, David Toll, Shahid Habib (NASA/GSFC), Edwin Engman (NASA/GSFC/SAIC)
Joseph Nigro (NASA/GSFC/SSAI), and Mutlu Ozdogan (U. Wisconsin)

- **NASA is partnering with USAID (OMEP) to develop a Land Data Assimilation System for the MENA, which will provide regional water balance assessments to address:**
  - **water availability**
  - **water and agriculture variability**
  - **aquifer monitoring**
  - **evapotranspiration mapping**

Recent Highlights:

- **World Bank has approved a Global Environment Fund (GEF) Regional Grant under the *Mediterranean Sustainable Development Program* to extend the MENA LDAS to multiple regionally- focused NASA Water Information System Platform (WISPs) strategically located through the MENA in conjunction with USAID.**
  - **Linking to USAID Mid East Center of Excellence on Water**

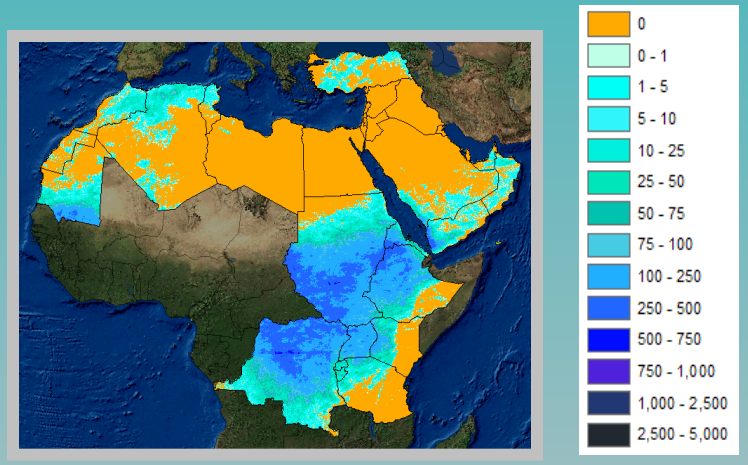


Figure 1. Precipitation (mm/month) for July 2007 at 0.04° resolution, from the UC Irvine PERSIANN-GCCS system. Hourly, near-real time data from PERSIANN will be a primary input to the MENA LDAS.

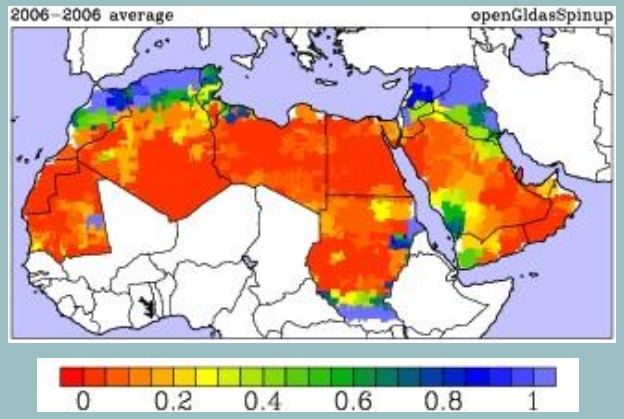


Figure 2. Mean evapotranspiration rate (mm/day) from the MENA LDAS for April, 2006.

SERVIR – *Africa (Flood Potential Early Warning)*

www.servir.net/africa

- **Modeled after SERVIR Central America**
- **To use TRMM precipitation products, hydrological models and GIS tools to build potential flood maps for Lake Victoria Region (Kenya, Tanzania and Uganda) – home to 30 million people and over 175,000 are effected due to devastating floods**

East Africa flood potential map from GHM-Flood for May 23, 2007. Orange triangles designate flood risk areas.

Sensors:
- Terra
- Aqua
- TRMM
- EO-1
- In Situ gauges

Lake Victoria region floods impact Kenya, Uganda and Tanzania (BBC News)

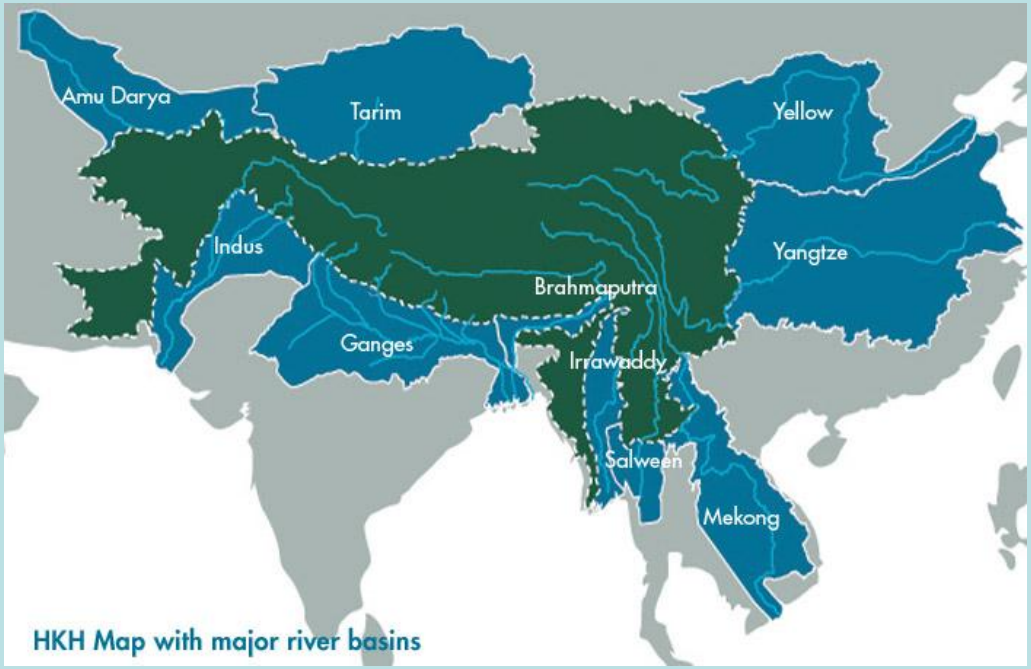
National Aeronautics & Space Administration

Water Resources Program

HIMALA: Climate Impacts in the Himalayas

The Hindu Kush -Himalayan (HKH) region extends 3,500 km over all or part of eight countries from Afghanistan in the west to Myanmar in the east.

The HKH region is the source of the 10 major rivers in Asia.



HKH Map with major river basins

- to enhance the decision making capacity of ICIMOD and its member countries for **management of water resources** (floods, agricultural water) in the short (snow, rainfall) and the long-term (glaciers);
- to introduce the **use of NASA Earth Science products** and models to ICIMOD and its member countries through collaboration with USAID and USGS;
- to explore the **impact of climate change scenarios** on water resources in the Himalayan region using hydrological models.

National Aeronautics & Space Administration

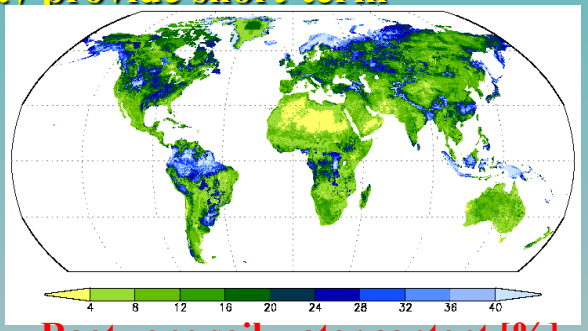
Water Resources Program

Land Data Assimilation System (LDAS)

Provides land surface states (snow depth, soil moisture, temperature, etc.) and fluxes (evaporation, etc.) for water resource applications.

APPROACH: Force land surface models with data from space-based, ancillary and ground observing systems.

Results for water resources applications and weather and climate. Results scalable to local (100m) to global (25 km). When forced with weather data may provide short-term predictions



Root zone soil water content [%]

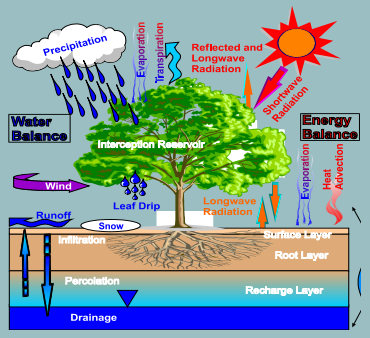
FORCING DATA & PARAMETERS

Precipitation, Temperature, Radiation, etc.
Vegetation Types, Soil Classes, Elevation, etc.

Assimilation Modules

LDAS
North American LDAS
Global LDAS
Land Information System

Land Surface Model



Output

Soil Moisture, Evaporation, Energy Fluxes, River Runoff, Snowpack Characteristics, etc.

Application DSS

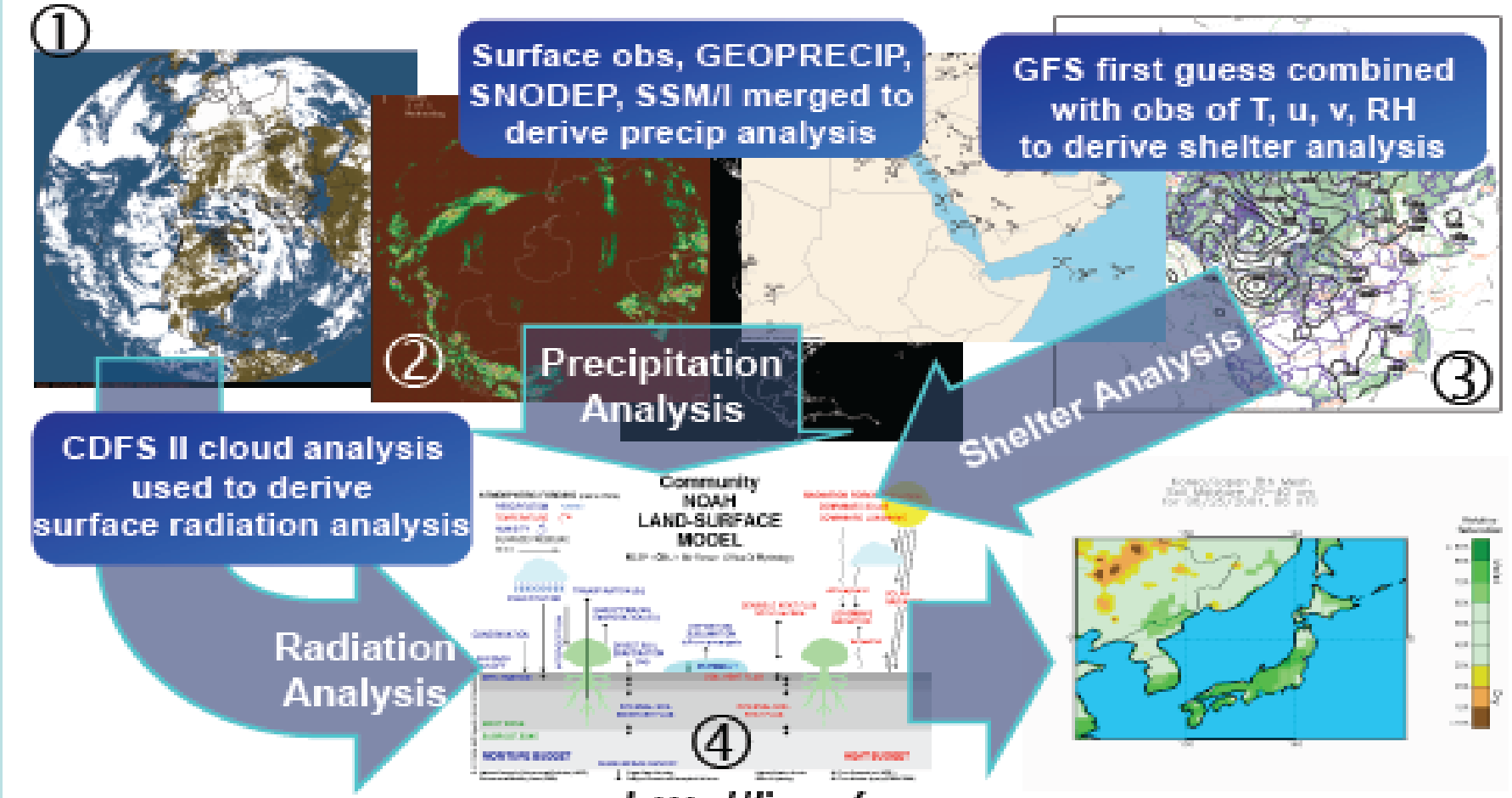
Floods/Drought, Agriculture Management, Water Quality with USDA, Bureau Reclamation, EPA

National Aeronautics & Space Administration

Water Resources Program

NASA LIS in Operations at the Air Force Weather Agency
Also at NOAA NCEP and numerous other locations

NASA Land Information System (LIS) was employed as an operational system for the Air Force Weather Agency (AFWA) in February 2009. This represents a significant milestone for using NASA Earth science research into AFWA operations of near real-time agriculture meteorology, replacing their 'AGRMET' system.



http://lis.gsfc.nasa.gov

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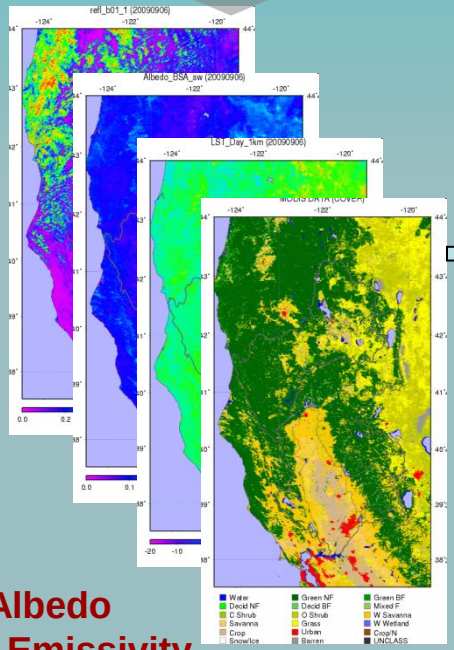
Water Resources Program

Western Water Management (CA DWR, DOI, USDA) Evapotranspiration (ET) Estimation & Modeling

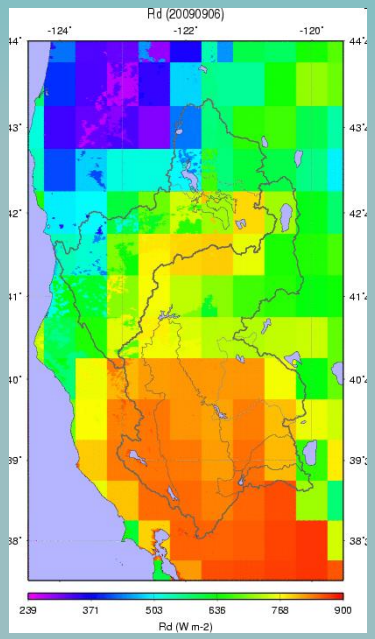
(Lettenmaier, U. Wash.)

MODIS

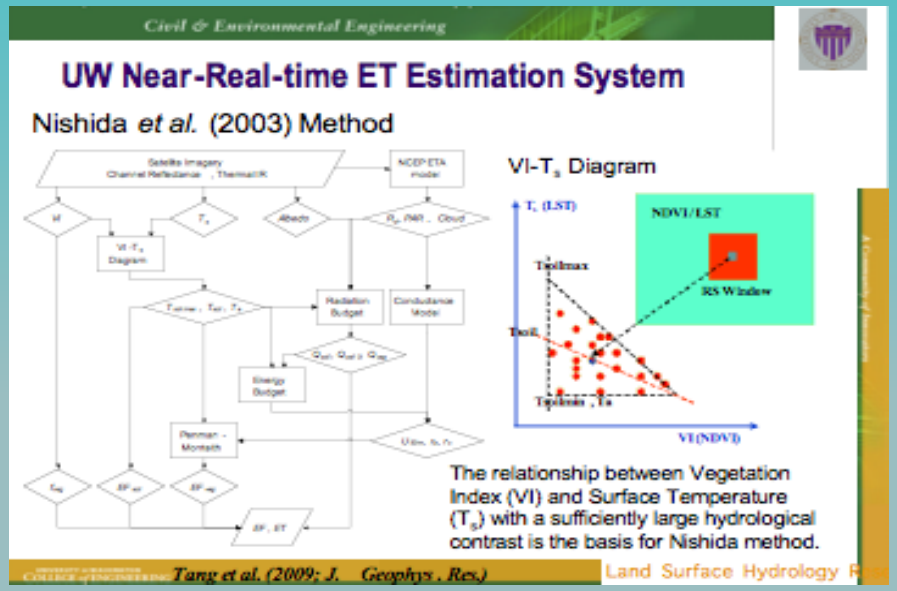
GOES



Albedo
Emissivity
Temperature
Surface reflectance
Vegetation indices
Land cover …



Hourly surface radiation budget (SRB) data



Water management model

Irrigation withdrawal

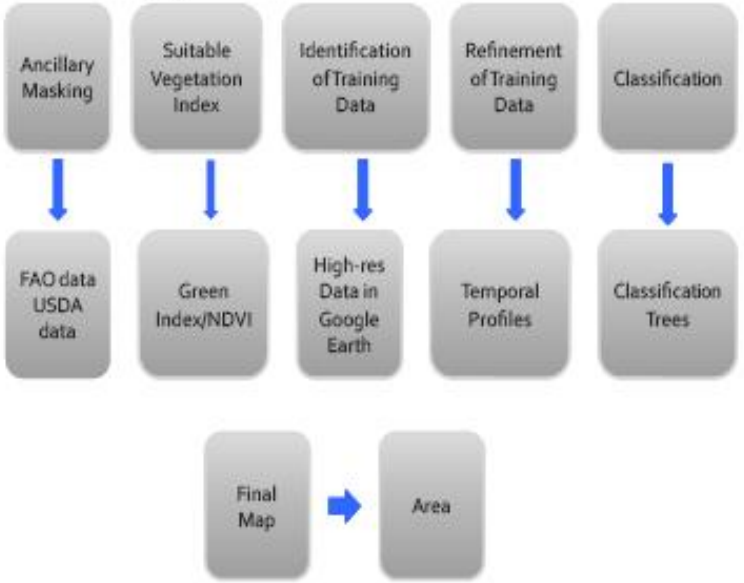
Drought Monitoring

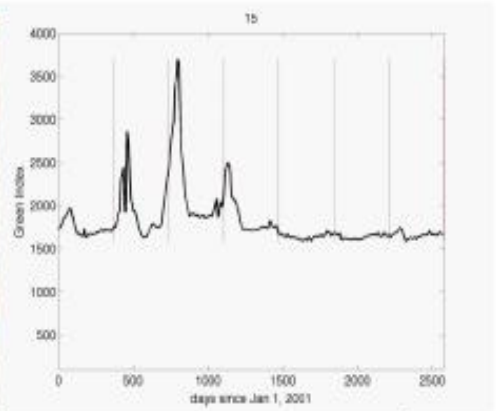
Endangered Species

Mapping Irrigation in Iraq

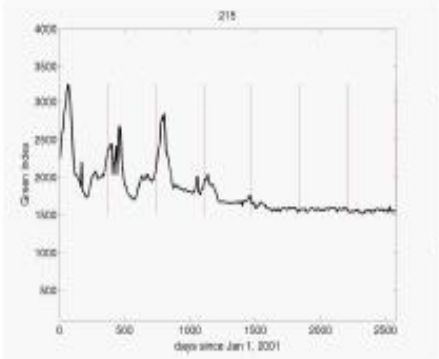
Ozdogan, Reynolds, Wallace, in review.

Methodology:

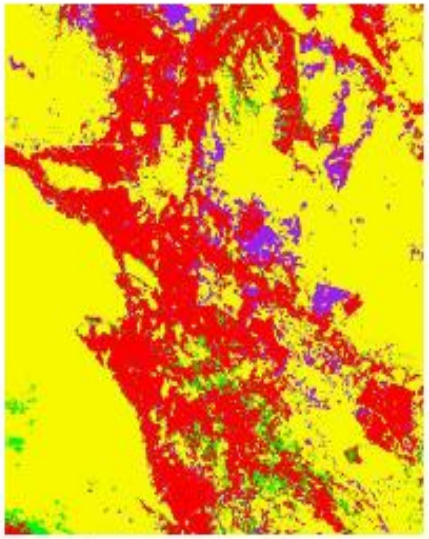




Selection of Training Data using IKONOS imagery in Google Earth and Refinement of Training Data using 250m MODIS NDVI Temporal Profiles.



Identification of areas of Increased or Decreased Irrigation using LANDSAT and MODIS imagery Temporal Profiles



Classification tree SW of Baghdad, showing irrigation change classes where red is continually irrigated 2001-2007 and purple is abandonded irrigation.

National Aeronautics & Space Administration

Water Resources Program

Determining the Feasibility of Mapping and Monitoring the Extent of Cladophora in the Great Lakes with Multi-Scale Remote Sensing

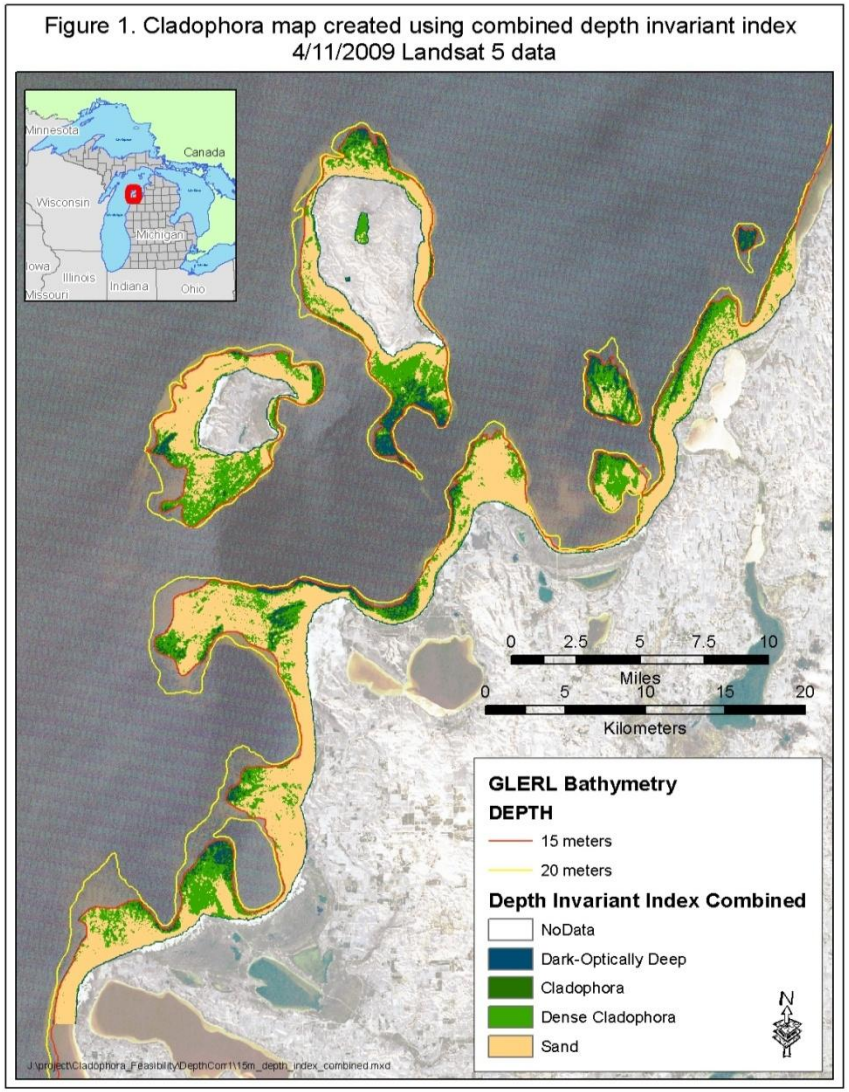
Dr. Robert Shuchman, Michigan Tech Research Institute

A depth invariant algorithm has been generated and successfully tested to map Cladophora in 0-15 meters depth using multi-spectral visible EO satellite data such as Landsat and GeoEye.

New methodology can be utilized in EPA's Great Lakes Restoration Initiative (GLRI) to create baseline Cladophora extent and biomass maps to support remediation efforts by resource managers of this nuisance algae.

Bottom Type	Dry Weight Density (g/m^2)	Area (m^2)	Dry Weight Biomass (grams)	Approximate Dry Weight Biomass (tonnes)	Approximate Wet Weight Biomass (tonnes)
Dark-Optically Deep	0	41,069,700	0	0	0
Cladophora (Darker green)	31	19,947,600	618,375,600	618	6,184
Dense Cladophora (Lighter green)	53	81,578,700	4,323,671,100	4,324	43,237
Sand	0	167,585,400	0	0	0
				4,942	**49,420**

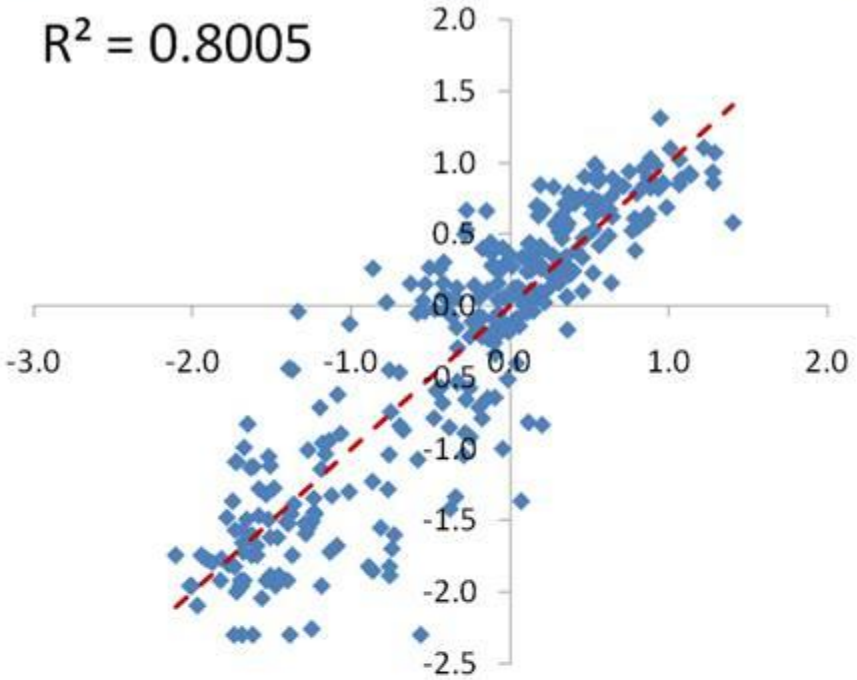
Figure 1. Cladophora map created using combined depth invariant index 4/11/2009 Landsat 5 data

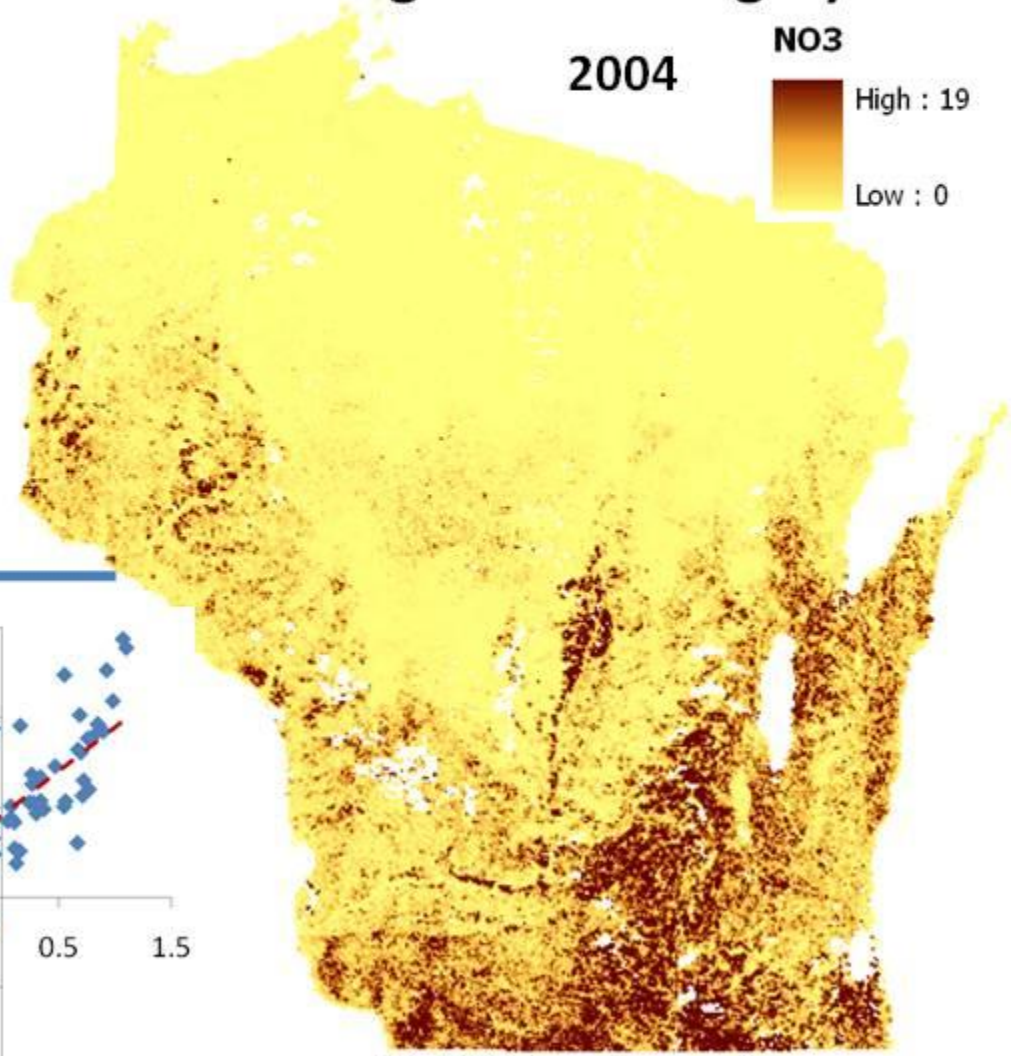


Aditya Singh and Phil Townsend
University of Wisconsin - Madison

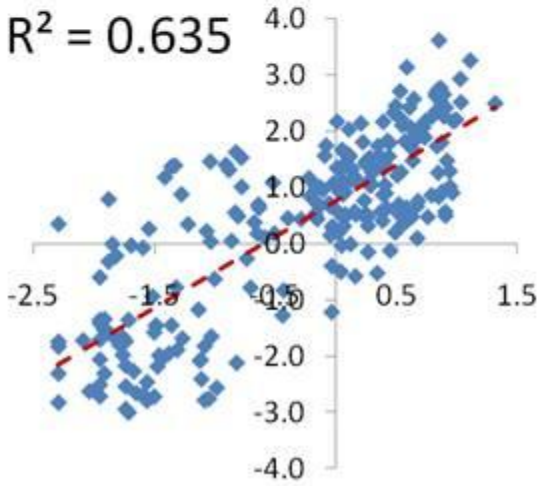
Prediction of Stream Nitrate Using MODIS Imagery

Full model: 2001-2004

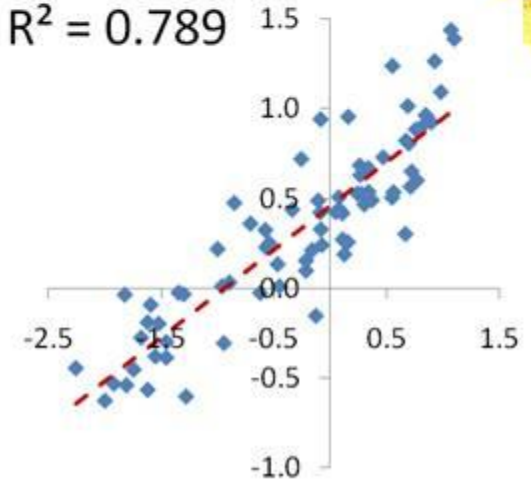




Cross-validation



On Stanley and Maxted (2008)



On Robertson et al. (2006)

Model is for all cover types.

Model for watersheds forest > 50%: $R^2 = 0.672$

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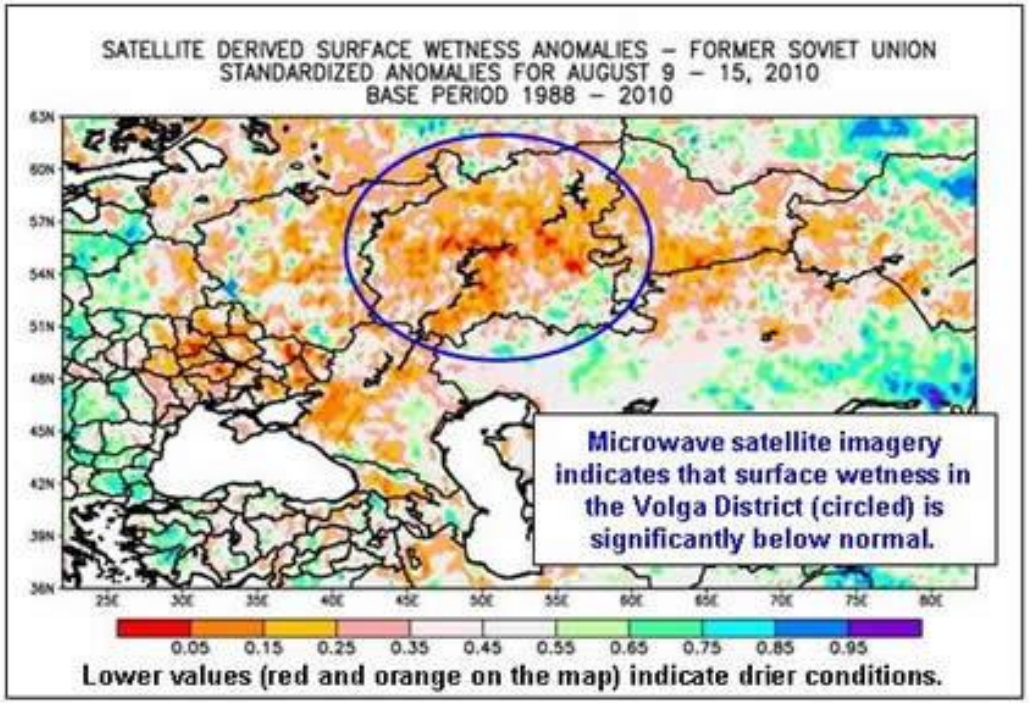
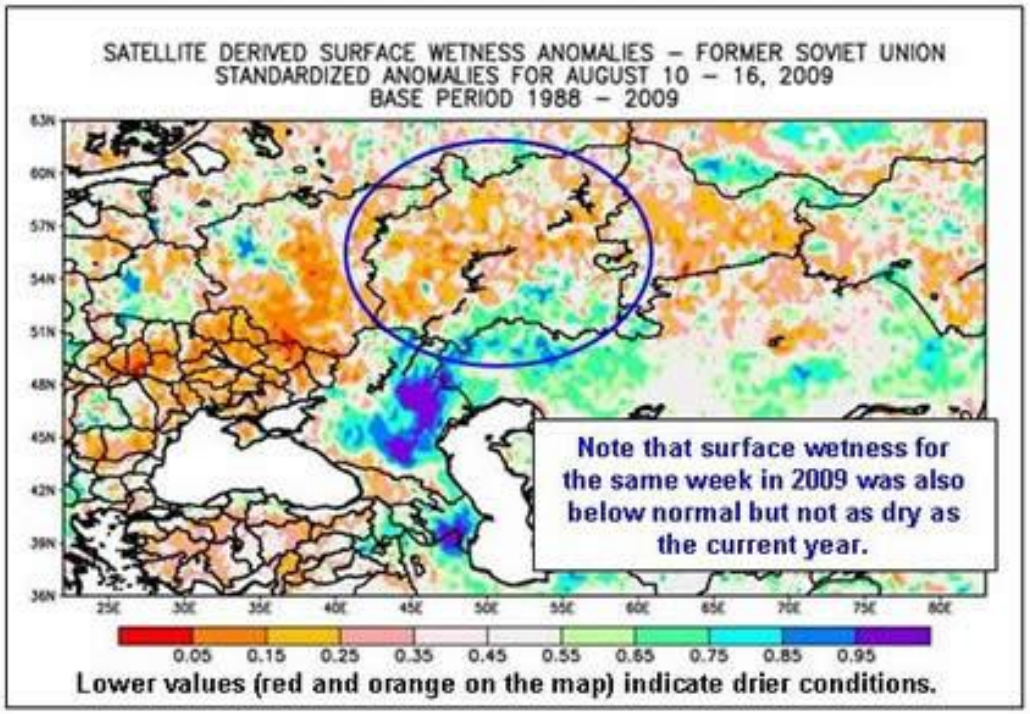
Water Resources Program

Summary

- NASA and Earth Science Satellites Providing Open and Free Data and Products. Numerous Opportunities for Collaboration such as Validation and Optimization of Satellite Data (SMAP, GPM, etc.)
- NASA and Earth Science Satellite Data, Modeling and Visualization Tools Developed for Water Cuyc to Assist Earth Scientists and Resources Managers
- NASA Funds most of their Projects through Peer Reviewed Solicitations. For International Projects NASA Usually Partners with Other Federal Agencies (USAID, ACE), International Organizations (GEO, GEWEX)
- NASA International Work with Expanding SERVIR (8 Sites), Water Information System Platforms in MENA (6), Regional Projects, Global Drought and Flood Modeling.
- NASA Water Resources Sponsoring Global Drought Monitoring and Evapotranspiration Workshops (April 2011)
- Projects such as Transboundary Issues with Dneper River Basin and Black Sea Basin where NASA can use their Regional Strengths and Synoptic Capabilities Using Remote Sensing, Modeling and Data Assimilation.





The ongoing drought in the Volga and Central Districts of European Russia has delayed the launch of the fall sowing campaign for 2011/12 winter grains. According to the Ministry of Agriculture, fewer than 21,000 hectares of winter crops had been planted by August 18 compared to 571,000 hectares by the same date last year.

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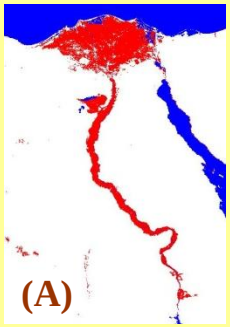
Water Resources Program

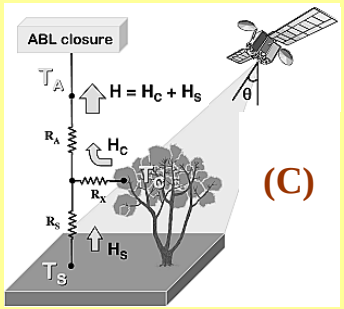
Project Nile: Improved Hydrometeorological Information for Water Management

Ben Zaitchik (JHU), Shahid Habib (NASA/GSFC), Mutlu Ozdogan (U. Wisc.), Martha Anderson (USDA/ARS)

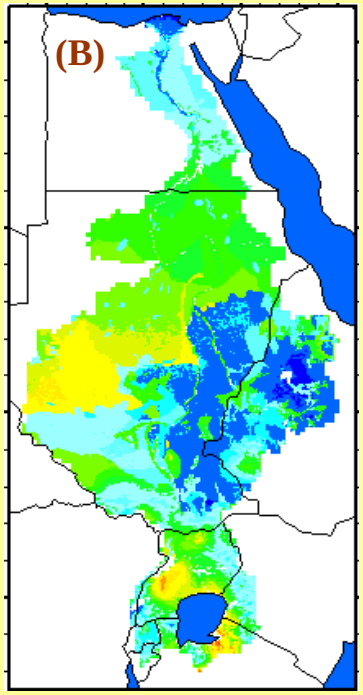
Project Nile utilizes NASA observation and modeling tools to inform decision support systems currently being developed for the Nile Basin.

Recent Highlight:
In April 2010, Project Nile team members will meet with Nile partners and stakeholders in Nairobi and Addis Ababa.



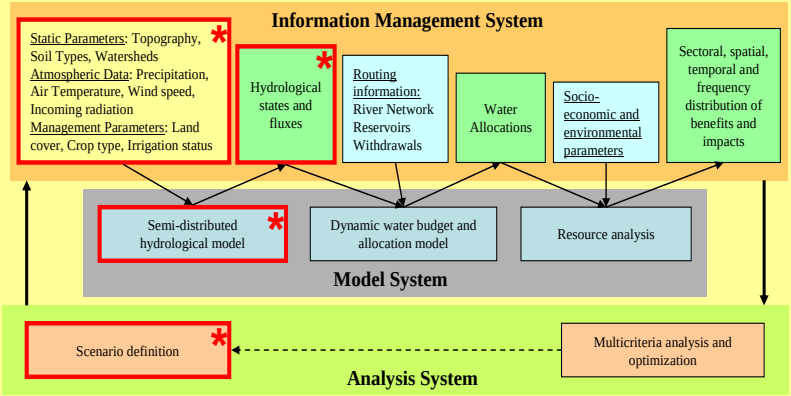


Nile-LDAS



Project operation:
Satellite-derived information on land cover and soil properties, including MODIS-derived irrigation maps (A), feed into a high-resolution LDAS (B). Both are assessed against independent satellite-derived ET estimates (C). LDAS estimates of hydrologic storages and fluxes are incorporated into regional decision support systems (D), & are validated against inventoried in situ data records.

(D)



National Aeronautics & Space Administration

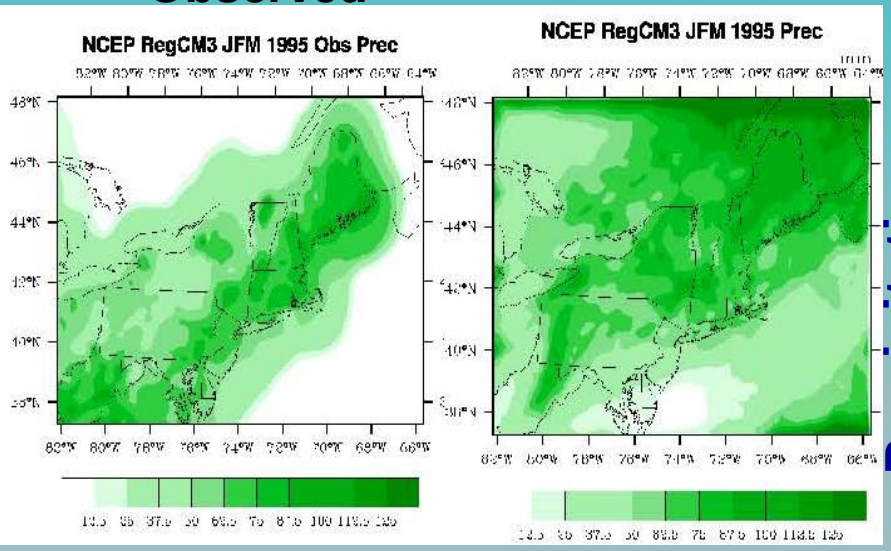
Water Resources Program

Climate & Hydrologic Downscaling

Regional Downscaling

Observed

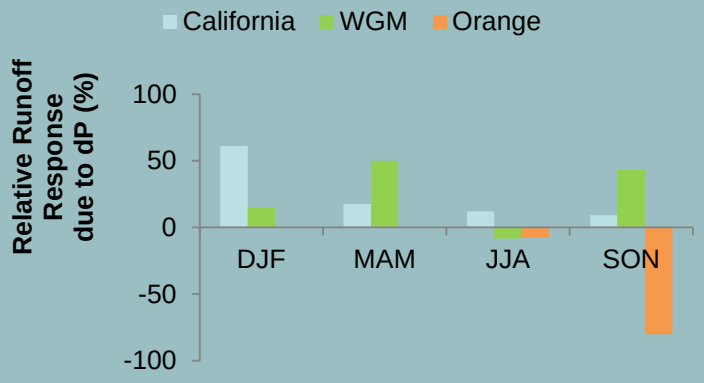
Modeled



Precipitation

CCSR, GISS, UCONN

Hydrologic Downscaling



Climate Downscaling

Regional Climate Modeling (Left)

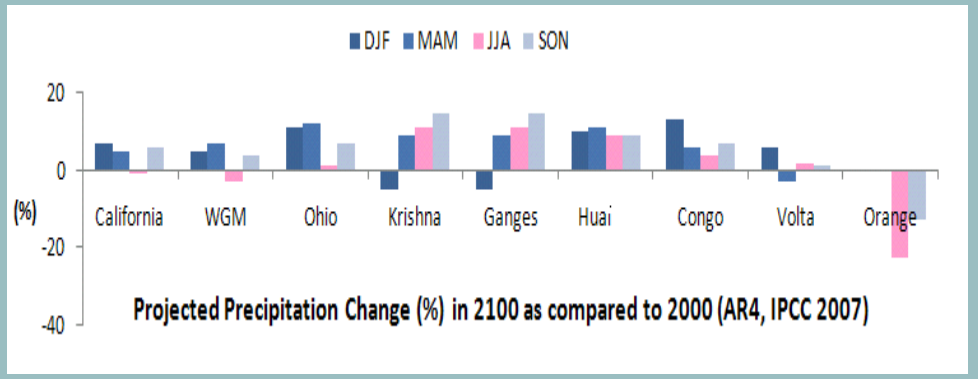
- Examples from NASA Goddard Institute for Space Studies
- Especially useful for assessing extreme events of flooding & droughts

Statistical Down Scaling Modeling

- Regional Ensemble Multi-Model
- Percent likelihoods for Precipitation & Temperature

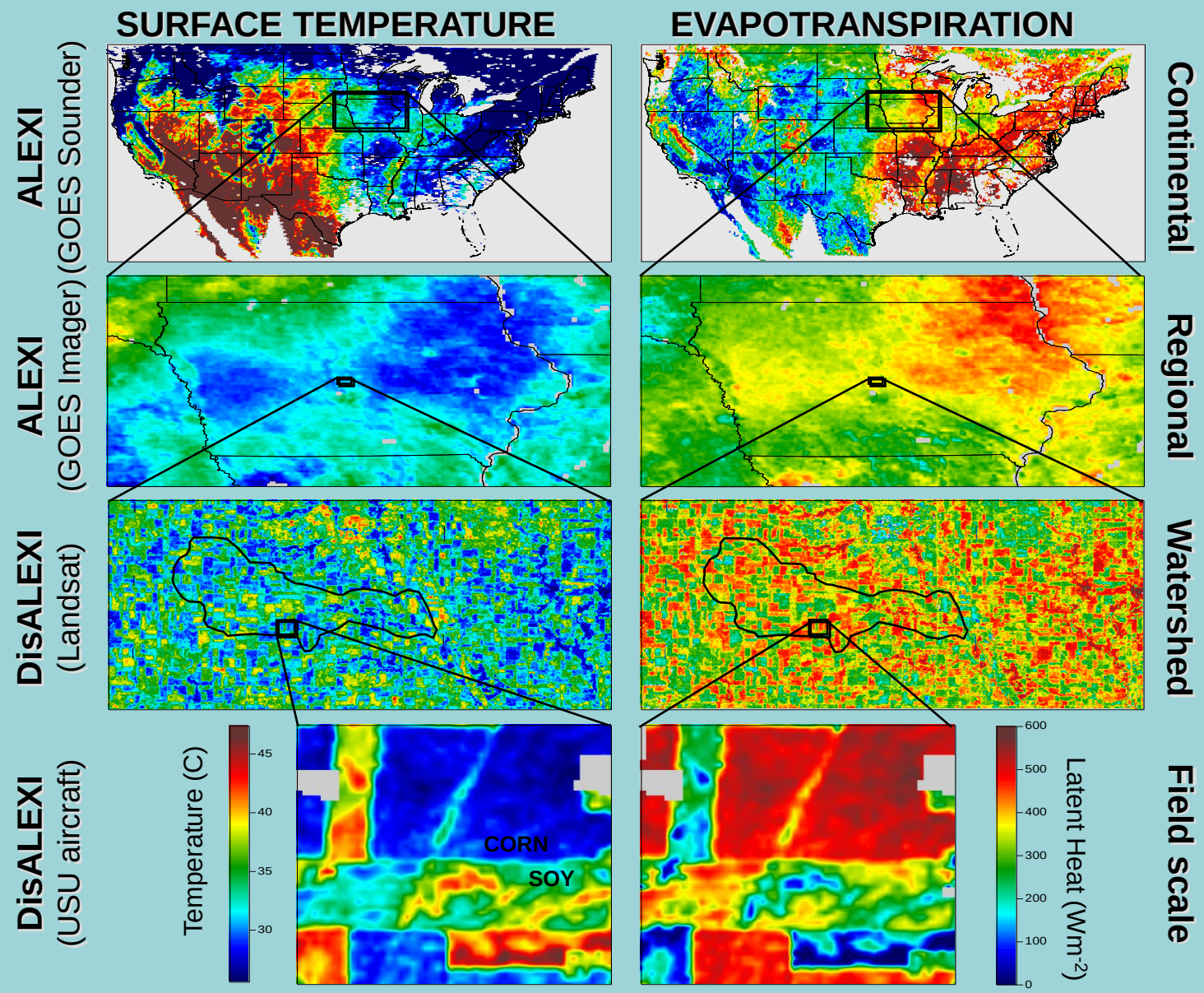
Hydrologic Downscaling

Land Data Assimilation Systems Hydrologic Modeling (Streamflow, ET, Snowpack, etc.) U. Illinois



Seasonal Streamflow by Season Using IPCC Climate Projections

Mapping Evaporation, Moisture Stress, Drought (Eta/Etp) from Space Using Satellite Thermal IR (Anderson and others - USDA)



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Water Resources Program

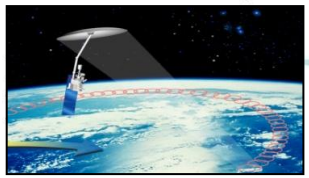
NASA's Water and Energy Satellites

Water Cycle Missions

ICESat
- Ice elevation
- Cloud height

GRACE
- Column water-content

TRMM and GPM
- Global precipitation



SMAP
- Global Soil Moisture

Water and Energy Cycle Missions

EOS-Aura
- Atmospheric humidity
- Clouds

EOS-Terra
- Snow and ice
- Vegetation

CALIPSO
- Cloud properties

CloudSAT
- Cloud profiler

EOS-Aqua
- Atmospheric humidity
- Water storage
- Clouds
- Snow and ice

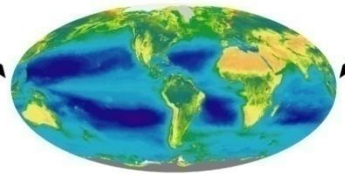
Energy Cycle Missions

TOMS
- Total column ozone

SORCE
- Total Irradiance measurements

SAGE
- Air quality
- Climate change

UARS
- Carbon management
- Air quality



Planned Missions
- **Global Precipitation Measurement**
- **SCLP (Snowpack)**
- **Surface Water Ocean Topography**
- **GRACE-II (Groundwater)**
- **HyspIRI (Water Quality, Land Surface Hydrology)**

NASA's Data are Free, Open Access & Numerous Products

Complementary Water and Energy Cycle Missions

QuikSCAT
- Sea-surface wind velocity

EO-1 LANDSAT and NMP EO-1
- Land cover

NPOESS
- Global environmental conditions

GOES
- Weather

Aquarius
- Global sea surface salinity