Mapping the Blue Marble: NASA Research to Improve Monitoring and Forecasting of Water Resources

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AWRA
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Washington, DC
Distribution and Water Use on Earth

Source: Multiple, as reported by the World Bank, 2010
Global Population Density

Source: Population Labs
Projected Global Population Density

Murray et al., Journal of Hydrology, 2012
Blue Water Availability Per Capita

- **Less than 0.5 - Extreme stress**
- **0.5 to >1.0 - High stress**
- **1.0 to >1.7 - Moderate stress**
- **1.7 and over - No stress**
- **No data**

SOURCE: Centre for Environmental Systems Research, University of Kassel
Global Water Cycle

• How can we reduce our uncertainty in the propagation of hydroclimatic extremes?

• For example, will a meteorological drought lead to a hydrological or agricultural drought?  
  • How? When? Where?

• How do phases in P-E relate to soil moisture, surface drainage, base flow, groundwater storage, river discharge, and vegetation productivity?
Objectives

With an integrated system perspective, use examples drawn from current research in the field of hydrology to

• Explain the basic underlying science and interactions.
• Discuss outstanding issues and challenges.
• Illustrate the state of art in earth observing technologies and strategies for environmental monitoring, assessment, and prediction.
• Drought is a normal, recurrent feature of climate, caused by a deficiency of precipitation over an extended period

• Water shortage may be caused by drought, overuse of available water resources, or pollution

• >1 billion people lack access to “improved” water

• 1.8 million people die each year of diarrheal diseases, equivalent to 12 Boeing 747 crashes each day

• The 2011 Texas drought cost $7.6 billion

• The 2012 U.S. drought cost $40 billion
Monitoring
Snow Depth and Snow Water Equivalent
Evapotranspiration
Soil Moisture
Surface Water and River Flow
Groundwater
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.
Remote Sensing and Modeling
Stick man with club in his hands – basic needs, followed food, lived near water
Earth Science Instruments on ISS:
RapidScat, CATS, LIS, SAGE III (on ISS), TSIS-1, OCO-3, ECOSTRESS, GEDI, CLARREO-PF
NASA Earth Science Missions and Instruments

Earth Science Instruments on ISS:
- RapidScat, CATS, LIS, SAGE III (on ISS), TSIS-1, OCO-3, ECOSTRESS, GEDI, CLARREO-PF

Contributing to Water Cycle Studies
Global Precipitation Measurement (GPM)

- Global (50S-50N) precipitation measurement
  - 10 ↔ 85 GHz radiometers
  - 13.6 GHz precipitation radar
  - 27 Nov 1997 to present

- Launched Feb 28, 2014
- Will use inputs from an international constellation of satellites to increase space and time coverage
- Improvements:
  - Longer record length
  - High latitude precipitation
  - including snowfall
  - Better accuracy and coverage

The GPM Core Observatory will provide improved measurements of precipitation from the tropics to higher latitudes

Tropical Rainfall Measurement Mission (TRMM)

- TRMM 14-year mean rainfall
- TRMM 14-year mean rainfall
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
Soil Moisture Active Passive (SMAP)

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
Surface Water Ocean Topography (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)
- Targeted path coincident with river reach

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

Interferometer Concept
- JPL

Source: M. Jasinski/614.3
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 Derived Terrestrial Water Storage Variations**

**GRACE Science Goal:** High resolution, mean and time variable gravity field mapping for Earth System Science applications

**Instruments:** Two identical satellites flying in tandem orbit, ~200 km apart, 500 km initial altitude

**Key Measurement:** Distance between two satellites tracked by K-band microwave ranging system

**Key Result:** Information on water stored at all depths on and within the land surface

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Animation of monthly GRACE terrestrial water storage anomaly fields. A water storage anomaly is defined here as a deviation from the long-term mean total terrestrial water storage at each location.

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GRACE measures changes in total terrestrial water storage, including groundwater, soil moisture, snow, and surface water.
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).

System of physical equations:
- **Surface energy conservation equation**
- **Surface water conservation equation**
- **Soil water flow: Richards equation**
- **Evaporation: Penman-Monteith equation** etc.

\[
P + G_{in} - (Q + ET + G_{out}) = \Delta S
\]

\[
R_n - G = L_e + H
\]
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
Applications
Monitoring Precipitation Memory

Soil Moisture Active Passive Mission

Global Precipitation Measurement Mission, Core Observatory
Leading Indicator of Vegetation Changes

Australia 35 S x 146 E

NDVI & Soil Moisture

Date
Satellite-based soil moisture observations are improving USDA’s ability to globally monitor agricultural drought and predict its short-term impact on vegetation health and agricultural yield.
How Can We Improve Global Crop Forecasts?

AFWA Precip

Model - AFWA

Artifact corrected
Better variability

AFWA precip artifact carried over to AFWA surf. SM

Model + Satellite Observations

Image courtesy: C. Reynolds

http://www.pecad.fas.usda.gov/cropexplorer
Can we Isolate the Impact in Food Insecure Regions?

**Figure 1:** Seasonal cycles of the rank correlation between open loop and EnKF soil moisture anomalies with future vegetation anomalies (1 month) averaged within the Extra-tropical Northern (ETNH; to 60° N) and Southern (ETSH; to 60° S) Hemispheres.

**Figure 2:** Global analysis of the net impact of assimilating AMSR-E soil moisture into the USDA water balance model.

**Figure 3:** Comparisons between $R_s(L)^{OL2}$ and $R_s(L)^{EnKF2}$ over a range of $L$ (i.e., 0 to 6 months) for sparsely-instrumented countries with moderate-to-severe food security issues.
Can We Improve End Of Season Yield Forecasts?

VI-yield rank correlation analysis for corn over central and eastern U.S.

Mladenova et al., 2017, JSTARS
Can We Improve End Of Season Yield Forecasts?

Mladenova et al., 2017, JSTARS
• In the United States, an average of 100 people lose their lives in floods annually, with flood damage averaging more than $2 billion.

• The Midwest's "Great Flood of 1993" cost 48 lives and more than $12 billion.

• Flash floods are the number one weather-related killer in the United States—
  • 2,200 deaths in Johnstown, Pennsylvania, May 31, 1889
  • 238 fatalities in Rapid City, South Dakota, June 9, 1972
  • 140 killed in the Big Thompson Canyon nr Denver July 31, 1976
  • 26 dead in Shadyside, Ohio, June 14, 1990

Source: NOAA
Real Time Flood Impact Assessment Tool

http://projectmekongnasa.appspot.com
Applying TRMM Precipitation for Landslide Hazard Assessment

Source: D. Kirschbaum, NASA
Routine Lake Level Monitoring (Jason1/2 & ENVISAT)

Contact: Charon Birkett, U. Maryland

http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir
How much snow?

Using laser radar, known as Lidar, researchers measure the depth of snowpack in California.

1. Laser pulse sent from plane
2. Laser reflects back from the ground.
3. The time it takes the laser to return to the plane is proportional to the elevation. The difference between summer elevation and snow elevation is the snow depth.

How will it melt?

With an advanced light sensor, scientists measure snow's reflectivity—an indicator of how it will melt.

Sources: Thomas Painter, Frank Gelirke, Optech Inc.
Mapping the Sierra Nevada with ASO

Upper Kings River Basin 94,900 AF
Lakes Basin 1,230 AF
Rush Creek Watershed 9,560 AF
Merced River Basin 27,500 AF
Tuolumne River Basin 87,800 AF

Airborne Snow Observatory
Snow Water Equivalent 26th-28th April, 2015

2014 Hetch Hetchy Observed & Forecasted

Inflow (cfs)

Day of Year 2014
Snow water equivalent

April 1
Basin SWE
529 TAF

April 3
2013
Basin SWE
287 TAF

April 3
2015
Basin SWE
57 TAF

April 7
2014
Basin SWE
154 TAF

April 1
2016
Basin SWE
529 TAF

TAF = thousand acre-feet
ASO in the drought (2013-2015) and the near-average (2016)
A 1.3 mile stretch of the California Aqueduct experienced >8” of subsidence, with maximum of 13” at the stretch closest to the center of the subsidence feature.

Tom Farr, JPL, https://science.jpl.nasa.gov/people/Farr/
Subsidence in the San Joaquin Valley

2007–2011

Zhen Liu, Vince Realmuto, Tom Farr, JPL
Determining the Extent of Fallowed Agricultural Land with Satellite Imagery during Drought

**PROJECT TEAM:** NASA Ames Research Center, USGS, USDA National Ag. Statistics Service, California Dept. of Water Resources, NOAA, California State University Monterey Bay

Landsat 5, 7, 8
30m / 0.25 acres
Overpass every 8-16 days

Determining the Extent of Fallowed Agricultural Land with Satellite Imagery during Drought

**PROJECT TEAM:** NASA Ames Research Center, USGS, USDA National Ag. Statistics Service, California Dept. of Water Resources, NOAA, California State University Monterey Bay

For more information, contact forrest.s.melton@nasa.gov, or visit https://c3.nasa.gov/water/projects/1/
Mapping Crop Water Requirements to Assist Growers in Optimizing Water Use

**PROJECT TEAM:** NASA Ames Research Center, California Dept. of Water Resources, Western Growers Association, California State University, Univ. of California Cooperative Extension, Desert Research Institute, USDA Ag. Research Service, USGS, Booth Ranches, Chiquita, Constellation Wines, Del Monte Produce, Dole, Driscoll’s, E & J. Gallo, Farming D, Fresh Express, Pereira Farms, Ryan Palm Farms

NASA SIMS web and mobile data services puts irrigation demand across 8 million acres of farm land directly into the hands of farmers and water managers.

Students work hand in hand with growers to assess the accuracy of the satellite estimates and quantify benefits.

California's agricultural sector produced $54b in 2014.
Over 33 years of hourly gridded precipitation, surface meteorology, and land-surface model output, including a real-time drought monitor

NLDAS specifications and variables:

1/8th-degree (~12km) hourly gridded data from Jan 1979 to near real-time
25-53 North and 125-67 West

Input: Daily gauge precipitation analyses, NARR near-surface meteorology, NEXRAD radar data, bias-correcting GOES shortwave radiation

Output: Surface fluxes, snow cover/depths, soil moistures/temperatures, runoff, many others

NLDAS datasets and services are available from the NASA GES DISC:

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

Documentation on NLDAS, including a link to the NLDAS Drought Monitor:

http://ldas.gsfc.nasa.gov/nldas/

An example of the NLDAS Drought Monitor (below) showing soil moisture percentiles of the 4 land-surface model ensemble-mean (Mosaic, Noah, VIC, & SAC) against the long-term soil moisture climatology of NLDAS. Figure from 13 June 2012.
Applying GRACE to Constrain Regional Groundwater

The Gravity Recovery and Climate Experiment (GRACE) satellite can monitor changes in terrestrial water storage and help ‘close the water budget’.

Zaitchik, Rodell, and Reichle, J. Hydromet., 2008
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 km$^3$/yr, reduced slightly from our previous (2002-08) estimate of 17.7 ±4.5 km$^3$/yr (Rodell et al., Nature, 2009).
GRACE observations of Terrestrial Water Storage changes in California

2002 05 09

Water Equivalent Height Anomaly (mm)
GRACE-Based Flood Potential

TWSA – Terrestrial Water Storage Anomaly
Pmon – Integrated Precipitation Anomaly
Sdef – Storage Deficit
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

Greenland’s ice sheet has been thinning at a rate of 142 km³/yr

Alaska’s glaciers have been melting at 84 km³/yr

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

Recent droughts in the southeastern U.S. and Texas

Recovery from 2004-05 drought in the Amazon

2010 Chile earthquake and drought in southern Argentina

Patagonian glacier melt

The western Antarctic ice sheet has been thinning at a rate of 65 km³/yr

Groundwater is being depleted across northern India at a rate of about 54 km³/yr due to pumping for irrigation

Russian droughts in 2010 and 2012

Overexploitation of freshwater resources in the North China Plain

Return to normal after wet years in early 2000s

Drought recovery and flooding

Depletion of water resources in Middle East exacerbated by drought

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
Water Quality Analysis Tool (WQAT)

- Provides simplified access to remote sensing imagery of indicators of nutrient pollution (chlorophyll a = algal blooms) and for establishing chlorophyll criteria.

- EPA’s satellite remote sensing methodology for the Florida nutrient criteria rulemaking could be reproduced with WQAT.

- GIS and Excel knowledge level (low barrier to entry).

- WQAT improves access and use of complex models as well as enhances and supports nutrient management decisions.

**Target Opportunity**

- **Webinar to describe WQAT on Sept 24**
- **Beta testing beginning end of Sept** – State participation welcome!
- Contact: lehrter.john@epa.gov
NASA Satellite Data Volumes

...Volume

![Graph showing trends in archive and distribution volume](image)

<table>
<thead>
<tr>
<th>EOSDIS FY2015 Metrics</th>
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<tr>
<td>Unique Data Products</td>
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<td>Distinct Users of EOSDIS Data and Services</td>
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<td>Average Daily Archive Growth</td>
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<td>Total Archive Volume (as of Sept. 30, 2015)</td>
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<tr>
<td>End User Distribution Products</td>
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<tr>
<td>End User Average Daily Distribution Volume</td>
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High Performance Computing and The Rise of the Cloud

NEX
Google Earth Engine
Microsoft Azure
Amazon Web Services
The NASA Earth Exchange (NEX) is a virtual collaborative that brings scientists together in a knowledge-based social network and provides the necessary tools, computing power, and access to big data to accelerate research, innovation and provide transparency.
NASA Applied Sciences Program Water Resources

Earth Science Serving Society

The goal of the ASP Water Resources application area is to apply NASA satellite data to improve the decision support systems of organizations and user groups that manage water resources. The ASP Water Resources application area partners with Federal agencies, academia, private firms, and international organizations.

LEARN MORE

https://c3.nasa.gov/water/
SERVIR is a joint development initiative of NASA and USAID, working in partnership with leading regional organizations around the globe, to help developing countries use information provided by Earth observing satellites and geospatial technologies for managing climate risks and land use.
Thank you!

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