Satellite Based Observations of the Terrestrial Water Cycle

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The Global Water Cycle

The continuous movement of water within, on, and above Earth’s surface

Global mean water fluxes (1,000 km³/yr) at the start of the 21st century, based on NASA Energy and Water Cycle Study (NEWS) analysis of satellite and ground-based observations and data integrating model output.

The most noticeable impacts of climate change will be changes in the water cycle
How Do We Monitor the Water Cycle?
Rain and Snowfall
Snow Depth and Snow Water Equivalent

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Evapotranspiration
Soil Moisture
Surface Water and River Flow
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.

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Remote Sensing of the Global Water Cycle
Present and Future NASA Earth Science Missions

Planned Missions
- SMAP, GRACE-FO, ICESat-II
- JPSS, DESDynI, OCO-2

Decadal Survey Recommended Missions:
- CLARREO, HyspIRI, ASCENDS,
- SWOT, GEO-CAPE, ACE, LIST,
- PATH, GRACE-2, SCLP, GACM,
- 3D-Winds

Highly relevant to hydrology

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Present and Future ESA Missions Relevant to Hydrology

Current Missions
  - Cryosat-2
  - EUMETSAT satellites
  - SMOS

Future Missions
  - Sentinel-1
  - EarthCARE
Present and Future JAXA Missions Relevant to Hydrology

Current Missions
- GCOM-W
- ALOS-2
- GPM (with NASA)

Future Missions
- GCOM-C
Precipitation

Tropical Rainfall Measurement Mission (TRMM)

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

Global Precipitation Measurement (GPM)

- 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
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

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Standard MODIS Snow-Cover Map Products

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.


• 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.

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

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

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

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Gravity Recovery and Climate Experiment (GRACE)

Soil Moisture
Snow, Ice, Rainfall
Vegetation
Radiation

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

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Gravity Recovery and Climate Experiment (GRACE)

Aqua: MODIS, AMSR-E, etc.

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

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Soil Moisture Active Passive (SMAP)

**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:**

<table>
<thead>
<tr>
<th>Partners</th>
<th>JPL (project &amp; payload management, science, spacecraft, radar, mission operations, science processing)</th>
<th>GSFC (science, radiometer, science processing)</th>
<th>CSA (science/applications, calibration/validation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk</td>
<td>7120-81 Category 2; 8705.4 Payload Risk Class C</td>
<td></td>
<td></td>
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<tr>
<td>Launch</td>
<td>Jan. 2015 on Delta II system</td>
<td></td>
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<tr>
<td>Orbit</td>
<td>Polar Sun-synchronous; 685 km altitude</td>
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<tr>
<td>Duration</td>
<td>3 years</td>
<td></td>
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<tr>
<td>Payload</td>
<td>L-band 3-channel SAR (JPL)</td>
<td>L-band polarimetric radiometer (GSFC)</td>
<td>Shared 6-m rotating mesh antenna (13 to 14.6 rpm)</td>
</tr>
</tbody>
</table>

http://smap.jpl.nasa.gov/
Routine Lake Level Monitoring (Jason2 & SARAL)

Contacts: Charon Birkett, U. Maryland
and Curt Reynolds, USDA/FAS

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

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ICESat-2 Inland Hydrology

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

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

Contact: Mike Jasinski, NASA/GSFC

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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)
  - Targeted path
  - Coincident w/ river reach

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

- Interferometer Concept (JPL)

Contact: Mike Jasinski, NASA/GSFC
Land Data Assimilation Systems (LDAS)
Data Integration Within a Land Data Assimilation System

**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/

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Global LDAS Data Availability

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

- Access via GDS, FTP, or quick-look visualization in Giovanni (below right)
- GRIB and NetCDF formats
- 3-hourly and monthly; 1.0° and 0.25° global grids
- On-the-fly subsetting (below center)
- Full documentation
- GLDAS supports a growing number of national and international hydrometeorological investigations and water resources applications

GLDAS V1
1.0°, 1979-present: Noah, CLM2, Mosaic, VIC
0.25°, 2000-present: Noah w/ MODIS snow cover assimilation

GLDAS V2
1.0°, 1948-present: Noah
1.0°, 2001-present: CLM3.5, Mosaic, VIC
0.25°, 2000-present: Noah w/ improved MODIS snow cover assimilation

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Discussion

• A constellation of Earth observing satellites launched by various nations provides data that are relevant to the water cycle

• These data have certain advantages over in situ observations, including excellent spatial and temporal coverage, and large scale representativeness and consistency

• Land data assimilation systems (LDAS) based on land surface models are valuable tools for integrating, downscaling, gap-filling, and interpreting satellite and ground based observations

• Satellite Observation Needs/Weaknesses:
  - Water quality
  - River flow (SWOT)
  - Groundwater change at medium-high resolution (GRACE 2)
  - Snowpack
  - Water use