National Aeronautics and
Space Administration

ARSET

Applied Remote Sensing Training

http://arset.gsfc.nasa.gov

@NASAARSET

NASA Satellites, Sensors, and Earth System Models Used for Water Resources Management

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Applied Remote Sensing Training Program (ARSET)

http://arset.gsfc.nasa.gov/

- Empowering the global community through remote sensing training
- Tailored to:
  - policy makers
  - regulatory agencies
  - applied environmental professionals
- Goal: to increase the use of NASA Earth Science models & data for environmental applications:

Disasters

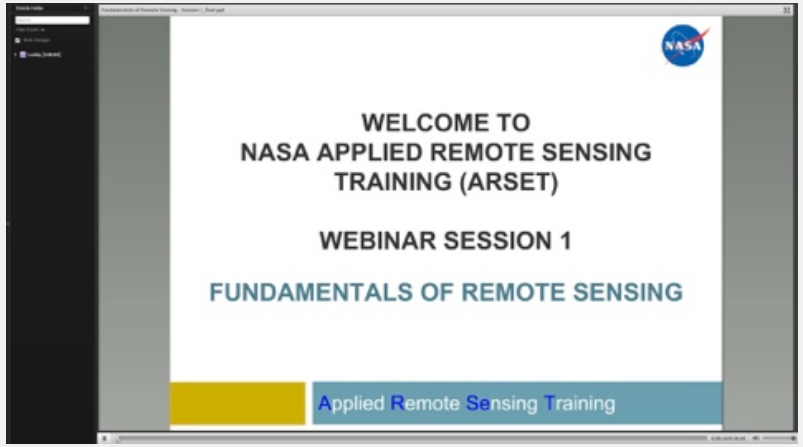
Ecoforecasting

Health & Air Quality

Water Resources

Applied Remote Sensing Training Program (ARSET)

http://arset.gsfc.nasa.gov/



Online Trainings

- 1 hr a week, 4-6 weeks
- Live & recorded
- Include demos on data access

In-person Trainings

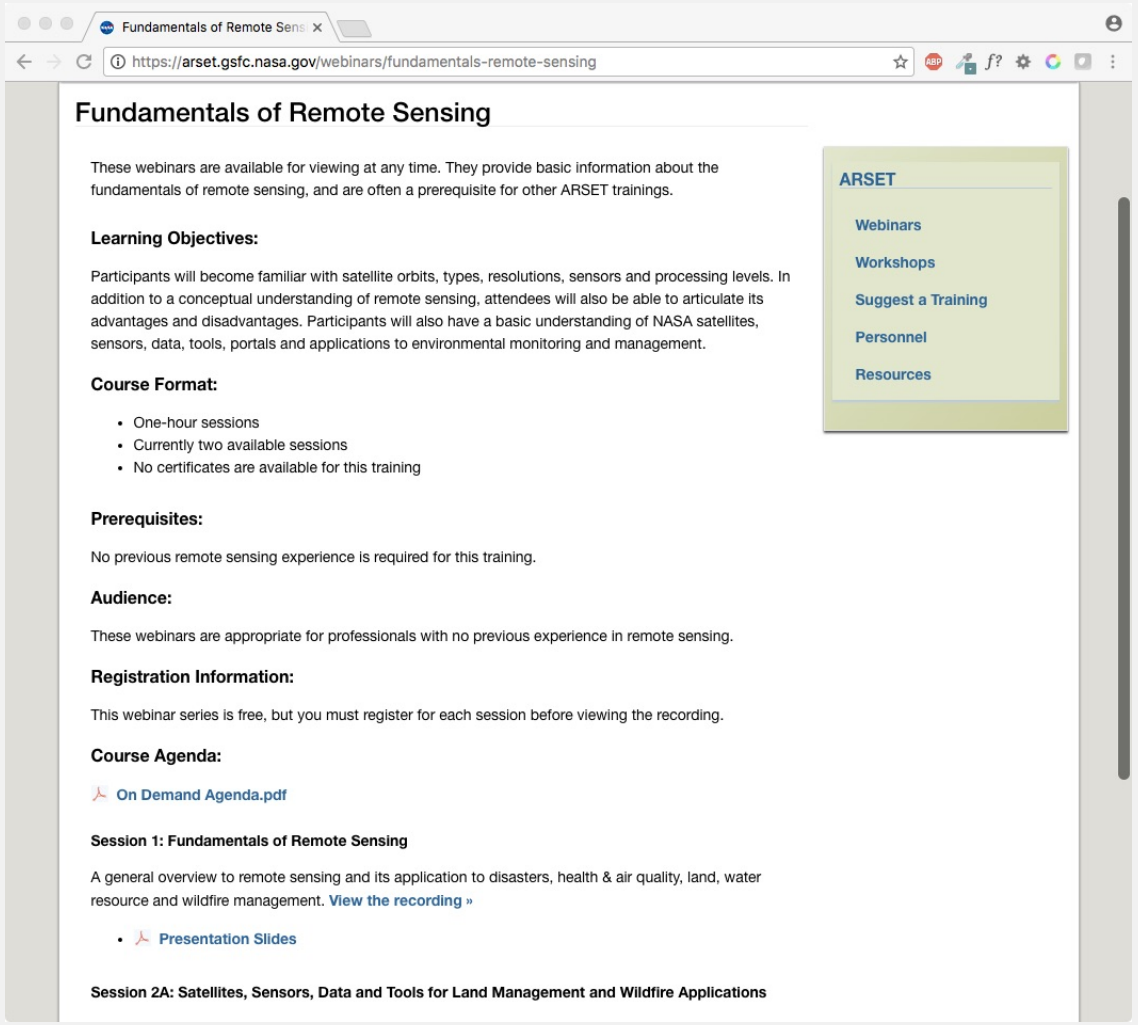
- 2-4 days in a computer lab
- Focus on data access
- Locally relevant case studies

Train the Trainers

- Courses & training manuals
- For groups interested in doing their own remote sensing trainings

Prerequisite

- Session 1: Fundamentals of Remote Sensing
  - http://arset.gsfc.nasa.gov/webinars/fundamentals-remote-sensing



Outline

- Water Resources Management
- Overview of Satellites and Sensors
- Overview of Earth System Models
- Data and Tools

Water Resources Management

Water Resources Management

- For sustainable water management, it is critical to have accurate estimates of water cycle components

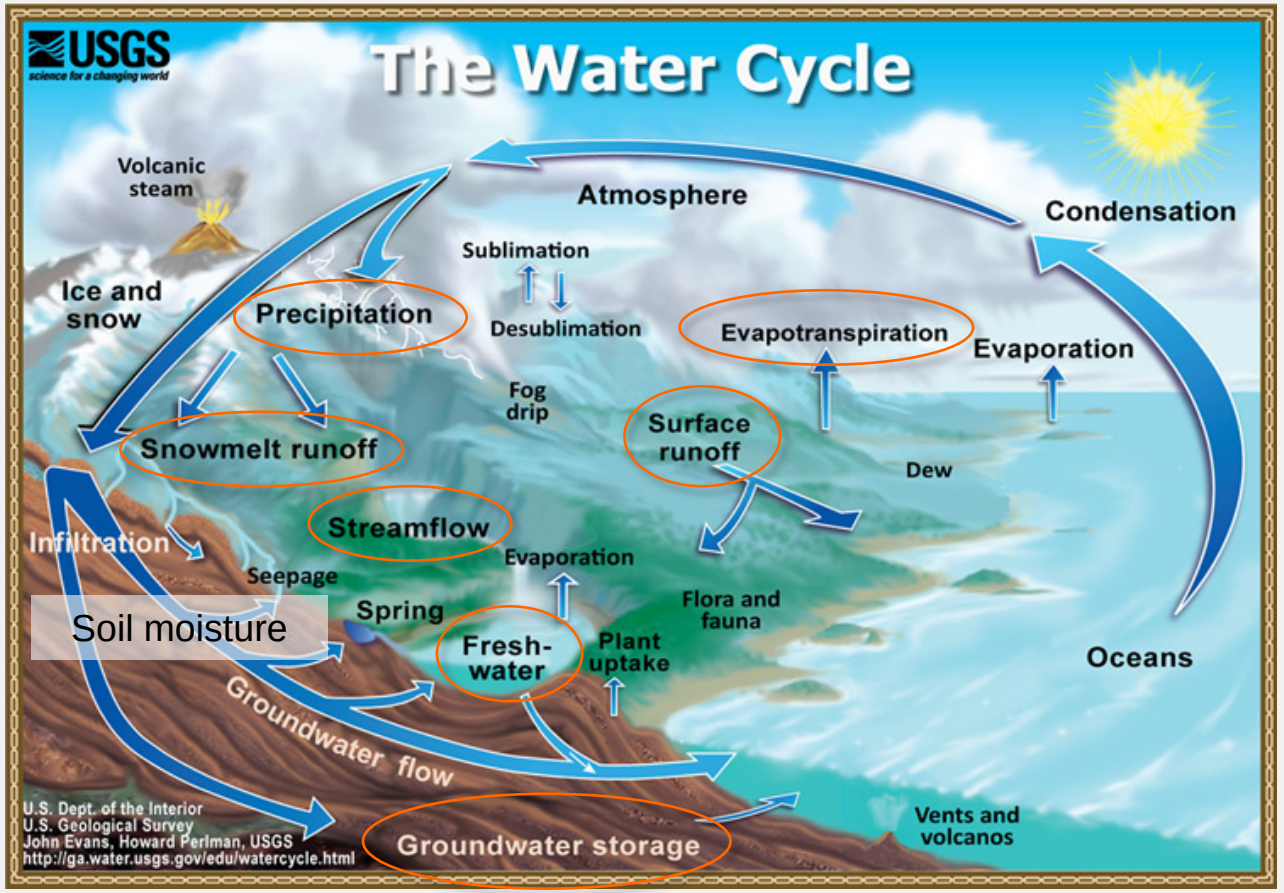


Image Credit: USGS

Water Resources Management

Freshwater Components

Over a watershed, river basin, or region:

- Precipitation (rain, snow) is the main source of fresh water
  - Other regional contributions: runoff and streamflow, lakes, soil moisture, and ground water
- Evaporation and evapotranspiration through loss of water to the atmosphere and runoff outflow contribute to depletion of water
- Surface fresh water availability (W) is largely controlled as follows:

W = (precipitation + runoff in the region) –

(evaporation/evapotranspiration + runoff outflow + infiltration)

Water Resources Data Applications

Freshwater Components Required

Water Allocation	Agricultural & Irrigation Management	Flood & Drought Management	Reservoir & Dam Management
• Water Budget	• Precipitation • Soil Moisture • Evapotranspiration	• Precipitation • Runoff/Streamflow • Soil Moisture • Evapotranspiration • Groundwater	• Reservoir Height • Precipitation • Runoff/Streamflow

Freshwater Information

- Not all water cycle components ca easily be measured directly, such as:
  - Evapotranspiration
  - Runoff
  - Water vapor transport

- NASA satellites and Earth system models measure and calculate all water cycle components

NASA Satellites & Earth System Models

Provide Hourly, Daily, Seasonal, and Multi-Year Time Scales

Useful for water resources management and hydrology model inputs:

- Rain
- Soil Moisture
- Snow and Ice
- Temperature
- Humidity
- Winds
- Surface Radiation

- Ground Water
- Vegetation Index
- Evapotranspiration
- Runoff

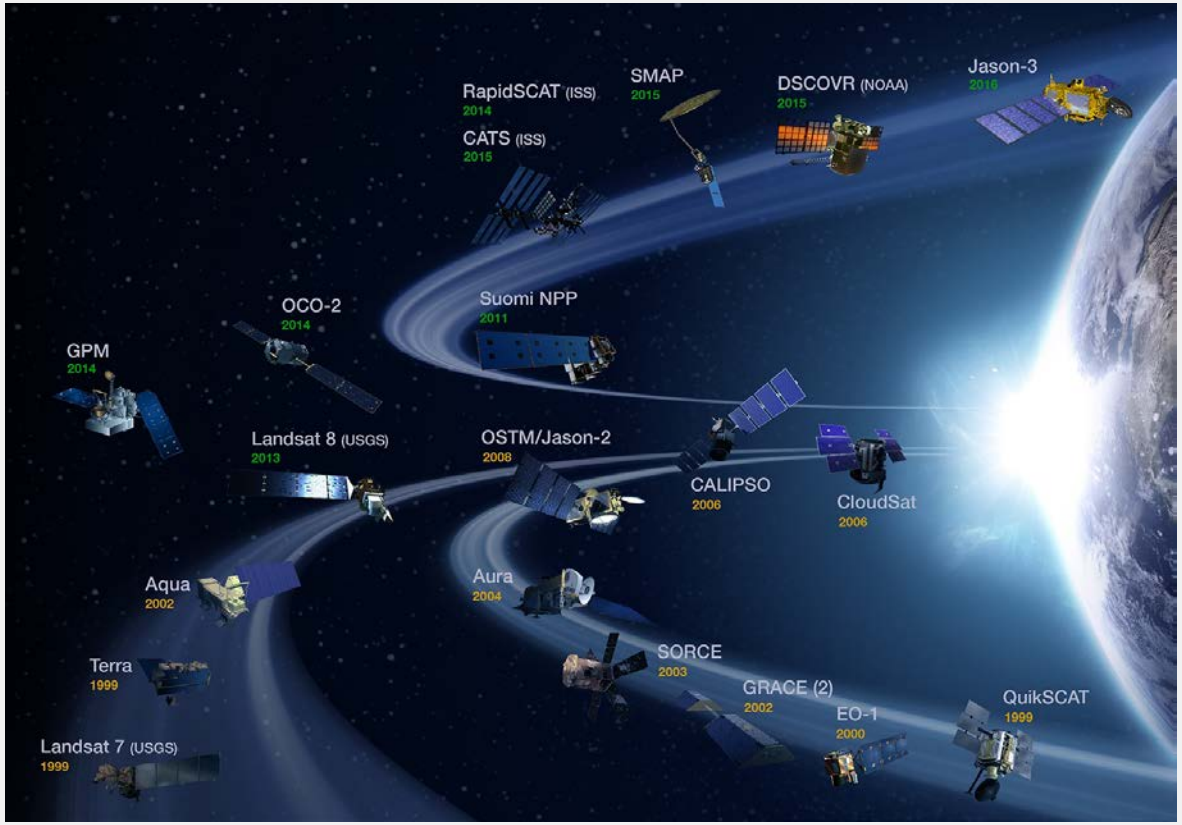
From satellites and models

From satellite observations

From atmosphere-land models that assimilate satellite observations

Overview of Satellites and Sensors

NASA Satellites for Water Resources Monitoring



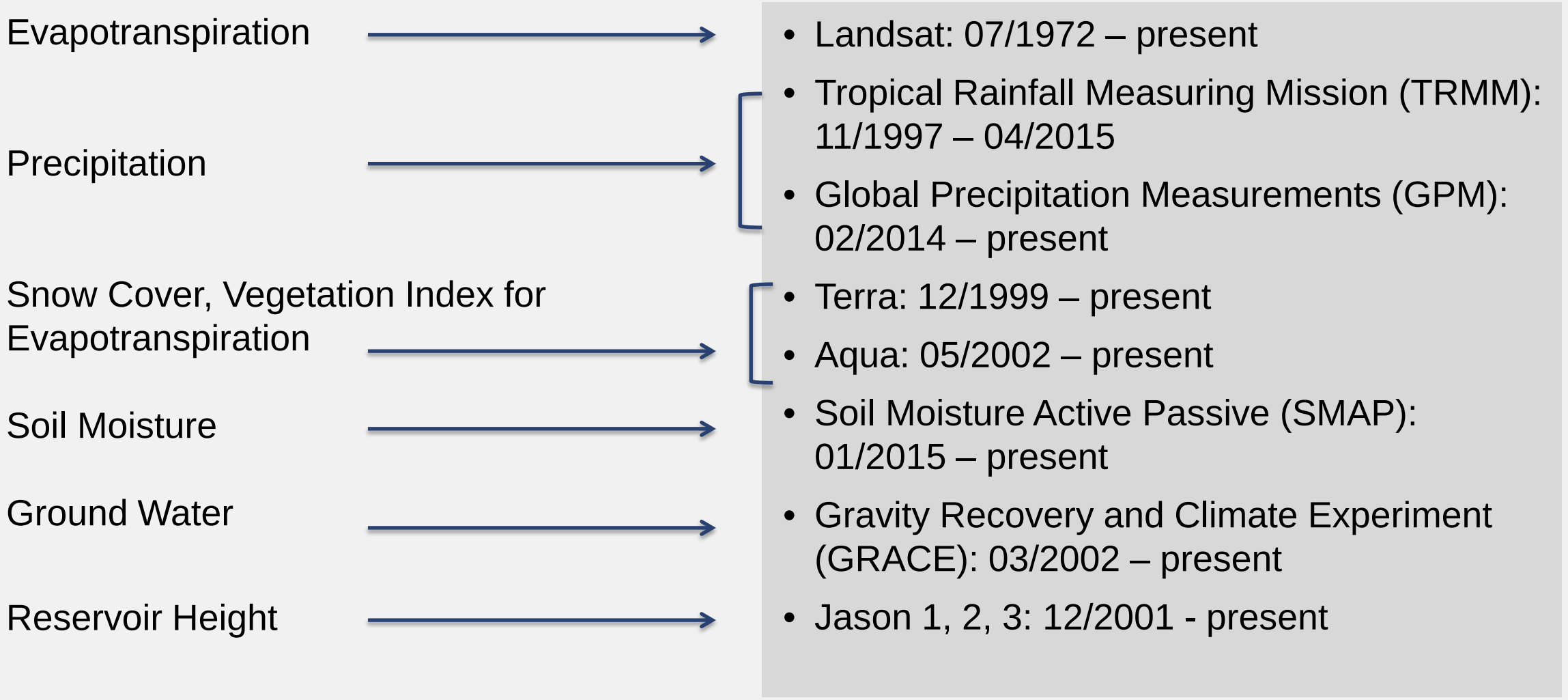
- Landsat: 07/1972 – present
- Tropical Rainfall Measuring Mission (TRMM): 11/1997 – 04/2015
- Global Precipitation Measurements (GPM): 02/2014 – present
- Terra: 12/1999 – present
- Aqua: 05/2002 – present
- Soil Moisture Active Passive (SMAP): 01/2015 – present
- Gravity Recovery and Climate Experiment (GRACE): 03/2002 – present
- Jason 1, 2, 3: 12/2001 - present

NASA Satellites for Water Resources Monitoring

- Each satellite carries one or more sensors or instruments with specific spectral channels to observe geophysical quantities
- This presentation will describe sensors most useful for water resources data

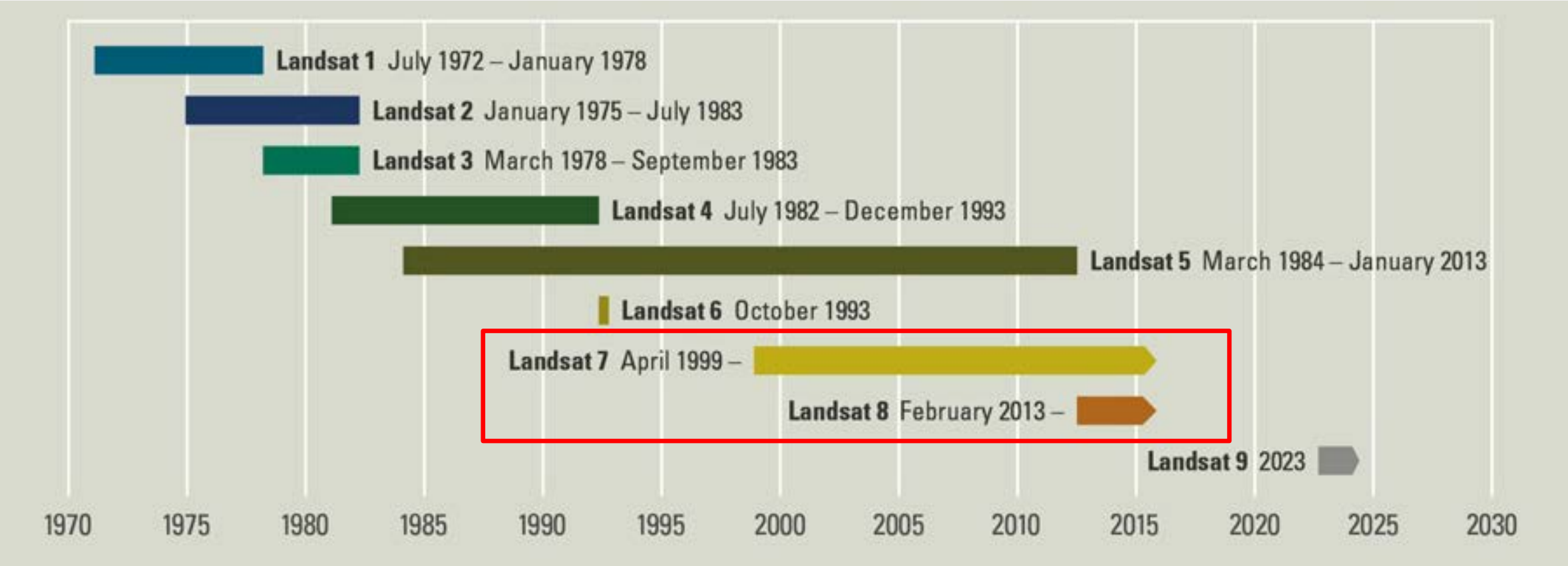
- Landsat: 07/1972 – present
- Tropical Rainfall Measuring Mission (TRMM): 11/1997 – 04/2015
- Global Precipitation Measurements (GPM): 02/2014 – present
- Terra: 12/1999 – present
- Aqua: 05/2002 – present
- Soil Moisture Active Passive (SMAP): 01/2015 – present
- Gravity Recovery and Climate Experiment (GRACE): 03/2002 – present
- Jason 1, 2, 3: 12/2001 - present

NASA Satellites for Water Resources Monitoring



Landsat Satellites and Sensors

http://landsat.gsfc.nasa.gov



Credit: http://landsat.usgs.gov/about_mission_history.php

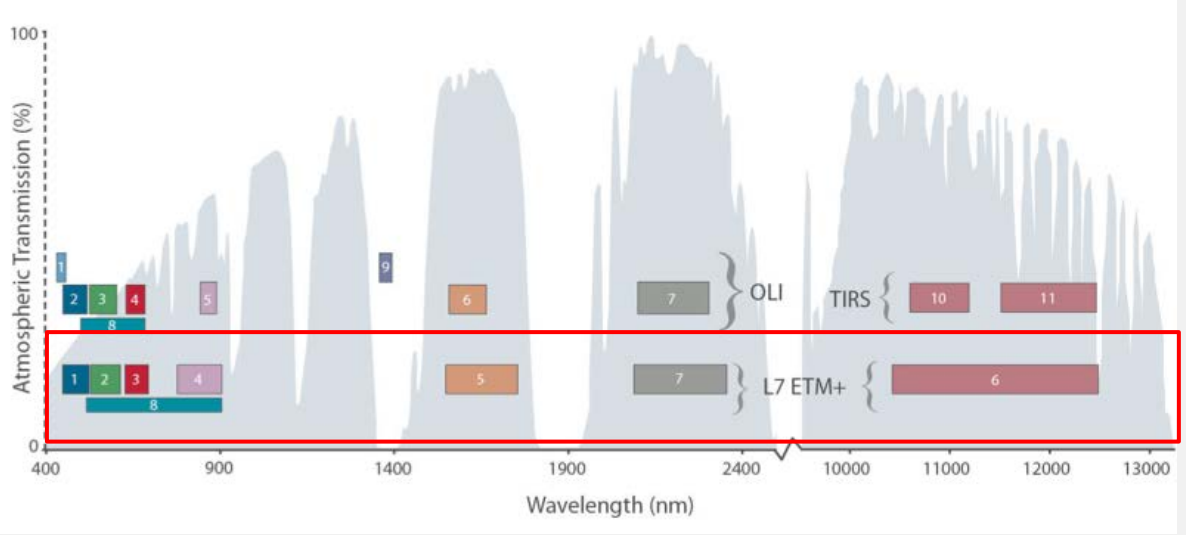
Enhanced Thematic Mapper (ETM+)

http://geo.arc.nasa.gov/sge/landsat/l7.html

- Onboard Landsat-7
- Polar orbiting satellite
- Spatial Coverage and Resolution:
  - Global, Swath: 185km
  - Spatial Resolution: 15m, 30m, 60m
- Temporal Coverage and Resolution:
  - April 15, 1999-present
  - 16-day revisit time

Spectral Bands

- 8 bands (blue-green, green, red, reflected & thermal IR, panchromatic)
  - Bands 1-5, 7: 30 m
  - Band 6: 60 m
  - Band 8:15 m

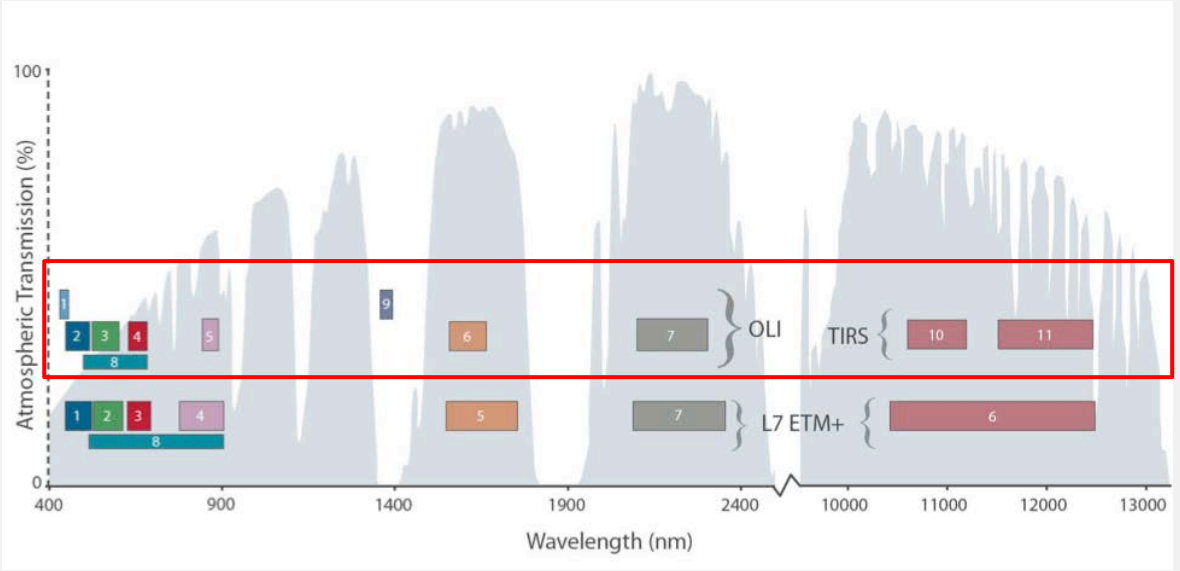


Operational Land Imager (OLI)

- Onboard Landsat-8
- Polar orbiting satellite
- Spatial Coverage and Resolution:
  - Global, Swath: 185km
  - Spatial resolution: 15m, 30m
- Temporal Coverage and Resolution:
  - Feb 11, 2013 – present
  - 16-day revisit time

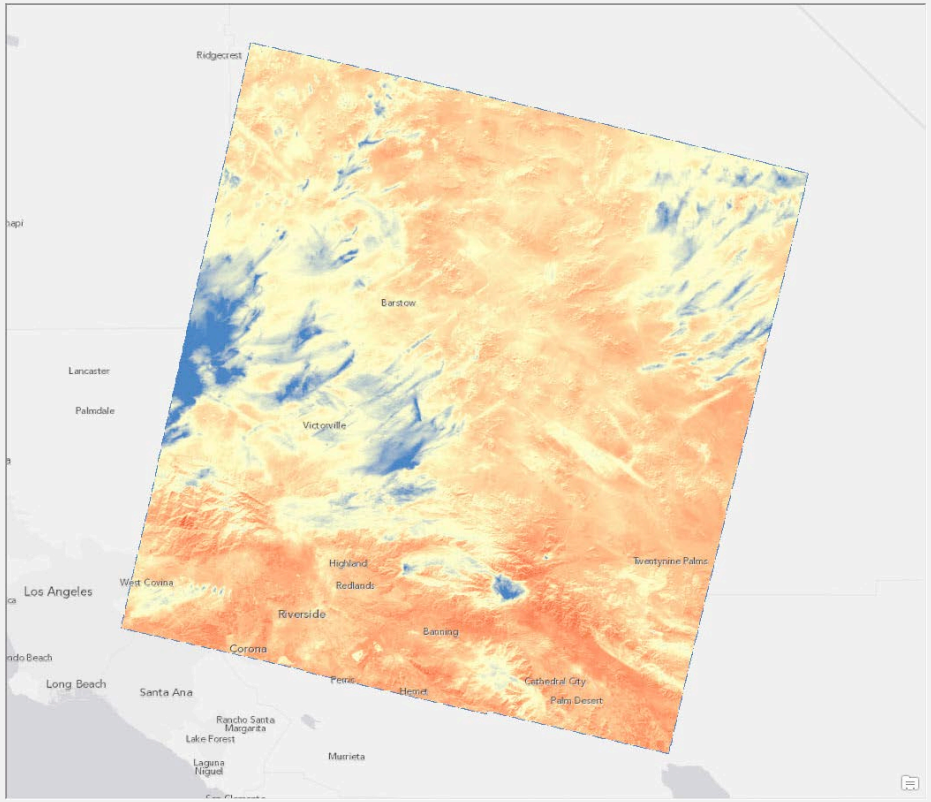
Spectral Bands

- 9 bands (blue-green, green, red, near IR, shortwave and thermal IR)
  - Bands 1-7, 9: 30m
  - Band 8:15m



Landsat Data for Water Resources Applications

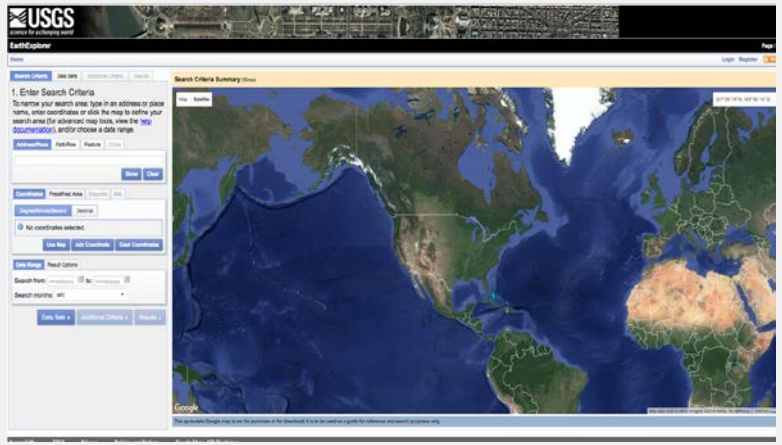
- Freshwater Component
  - Evapotranspiration (ET)
- Landsat Data Used:
  - Thermal Infrared Emission
  - Blue, Green, Red
  - Near Infrared Spectral Reflectance
- Usage:
  - Derive Land Surface Temperature
  - Land Cover to calculate ET



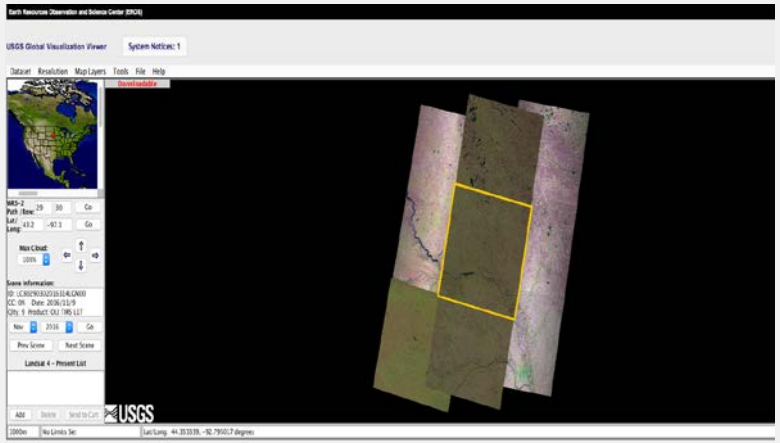
Brightness Temperature from Landsat TIR California where unseasonably warm temperatures were noted on December 16, 2013. Credit: https://blogs.esri.com/esri/arcgis/2014/01/06/deriving-temperature-from-landsat-8-thermal-bands-tirs/

Where to get Landsat Images and Spectral Reflectance Data?

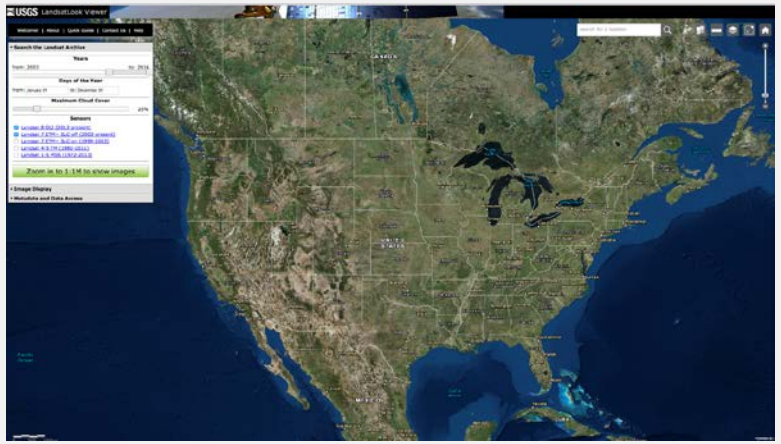
USGS Earth Explorer
http://earthexplorer.usgs.gov/



USGS Global Visualization Viewer
http://glovis.usgs.gov/



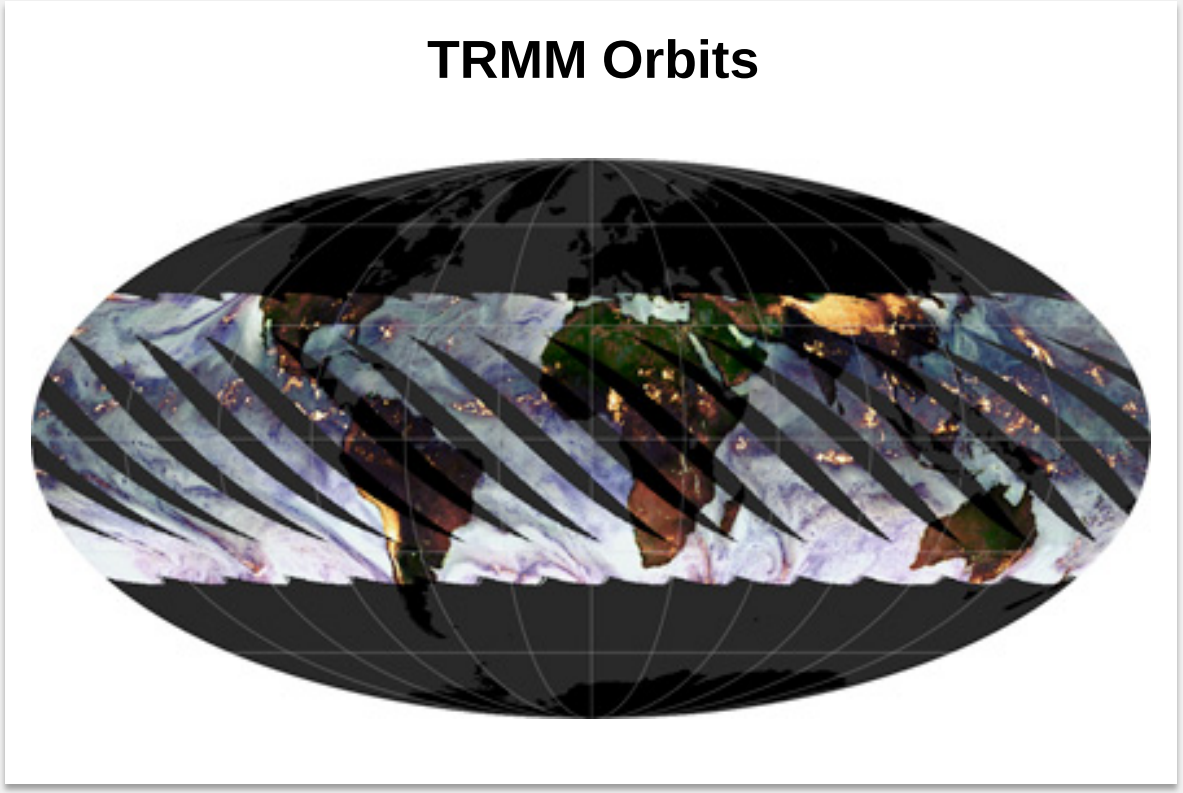
USGS Landsatlook Viewer
http://landsatlook.usgs.gov/viewer.html



TRMM Satellite & Sensors

http://trmm.gsfc.nasa.gov

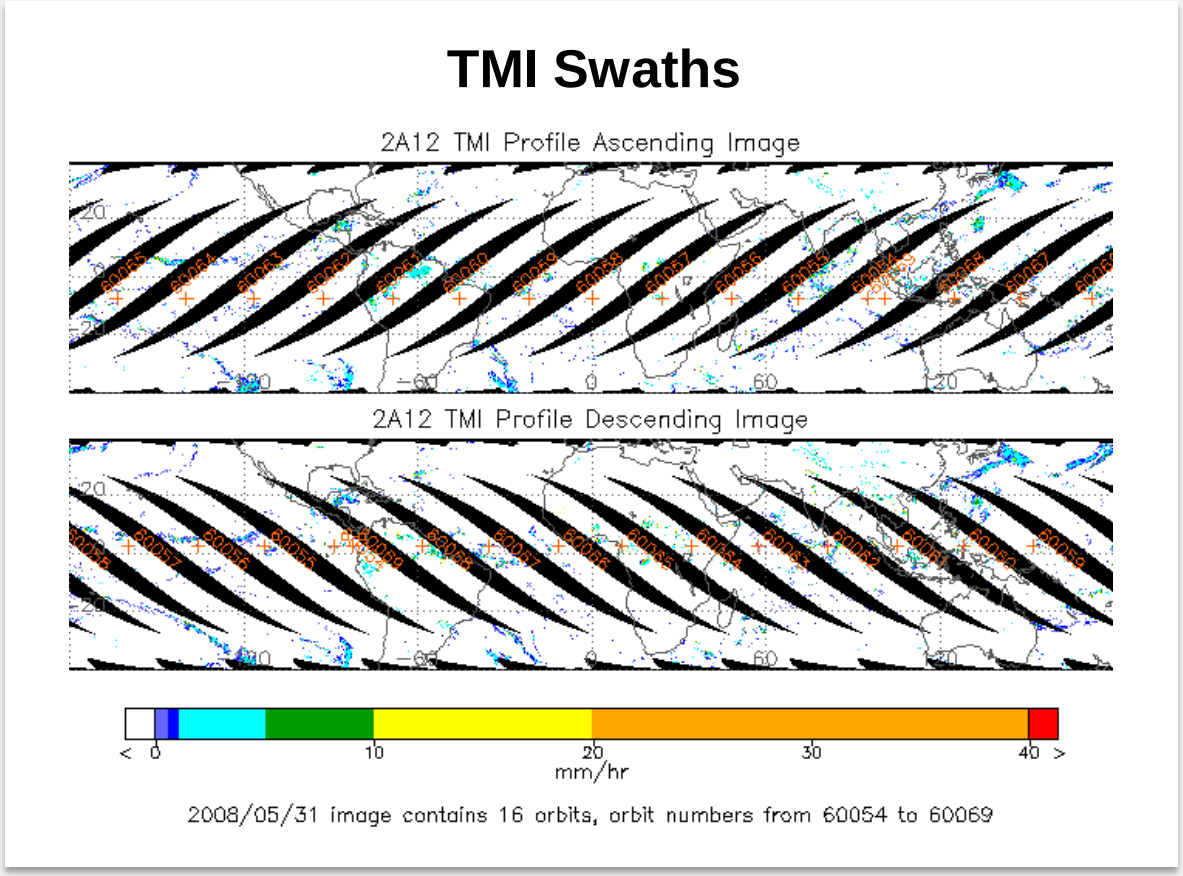
- NASA & JAXA (Japanese Space Agency) Joint Mission
- In a non-polar, low-inclination orbit
- Altitude of approximately 350 km, raised to 403 km after Aug 23, 2001
- Spatial Coverage
  - 16 TRMM orbits a day covering global tropics between 35°S – 35°N latitude
- Revisit Time: 11-12 hrs
  - Time of observation changes daily
- Sensors:
  - TMI, PR, VIRS, LIS, CERES



TRMM Microwave Imager (TMI)

http://pmm.nasa.gov/TRMM/TMI

- Spatial Coverage and Resolution:
  - Coverage: -180°-180°, 35°S-35°N
  - Swath: 760km (878km after 8/2001)
  - Vertical Resolution:
    - 0.5 km from surface – 4 km
    - 1.0 km from 4-6 km
    - 2.0 km from 6-10 km
    - 4.0 km from 10-18 km
- Temporal Coverage and Resolution:
  - Nov 27, 1998 – April 15, 2015
  - 16 orbits per day
- Channel Frequencies
  - 10.7, 19.4, 21.3, 37, 85.5 GHz

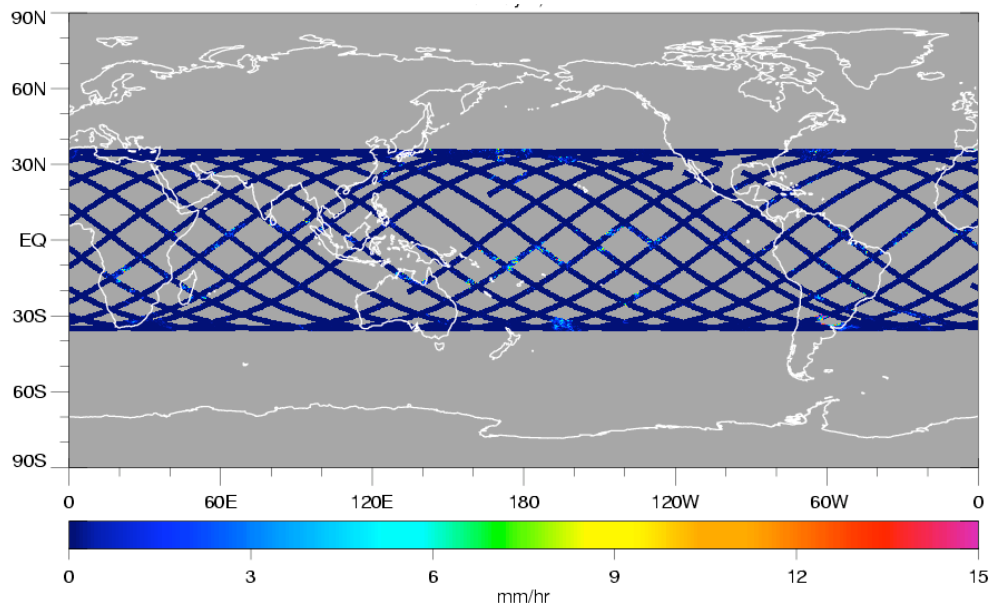


Precipitation Radar (PR)

http://pmm.nasa.gov/TRMM/PR/

- Spatial Coverage and Resolution:
  - Coverage: 35°S – 35°N
  - Swath: 215 km (247 after 8/2001)
  - Spatial Resolution: 4.3km (5 km)
  - Vertical Resolution: 250m (from 0-20 km)
- Temporal Coverage and Resolution:
  - Nov 27, 1998 – Oct 7, 2014
  - ~16 orbits per day
- Frequency:
  - 13.6 GHz

PR Swaths

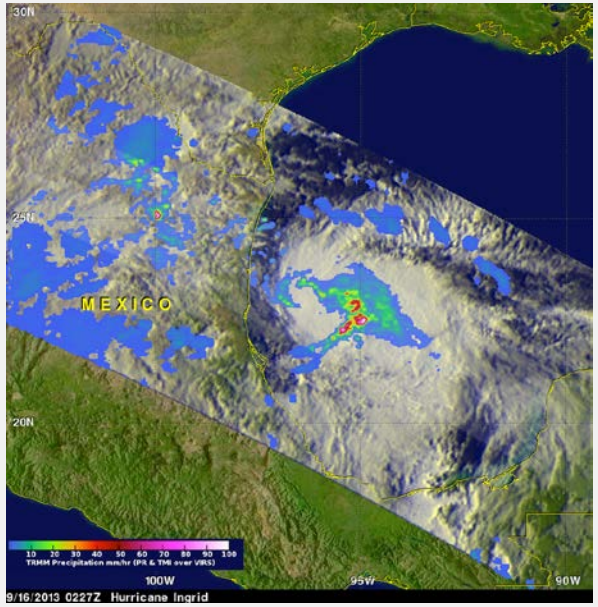


Kummerow, C., et. al, 1998: The tropical rainfall measuring mission (TRMM) sensor package, J. Atmos. Oceanic Technol., 15, 809-817.

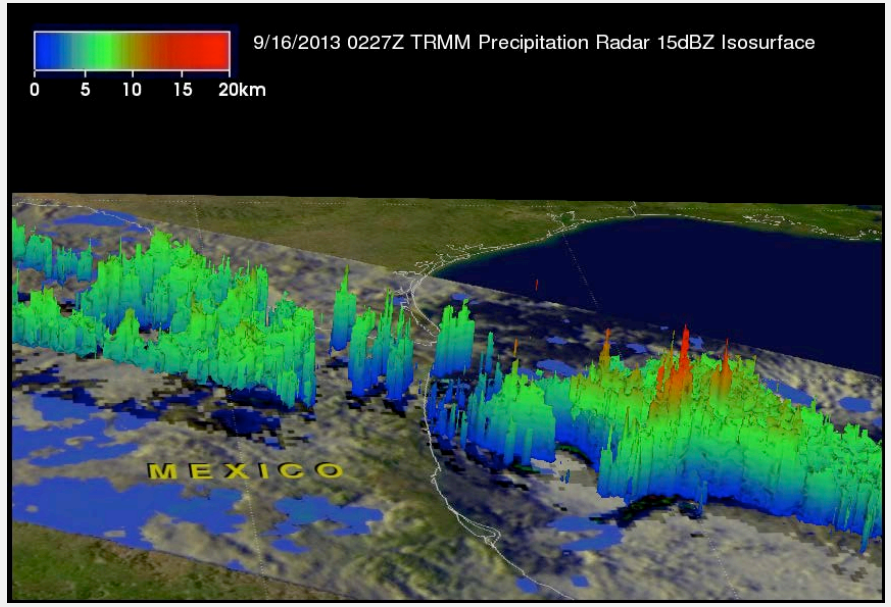
TRMM Data for Water Resources Applications

- Freshwater Component:
  - Rain Rate
- TRMM Data Used: TMI Brightness Temperatures, PR Reflectivity, VIRS Brightness Temperature and Reflectance
- TMI and PR Rainfall on September 16, 2013, at 0227 UTC when TRMM flew over Hurricane Ingrid in Gulf of Mexico
- PR shows 3D structure of the rainfall

TMI Rainfall



PR Rainfall



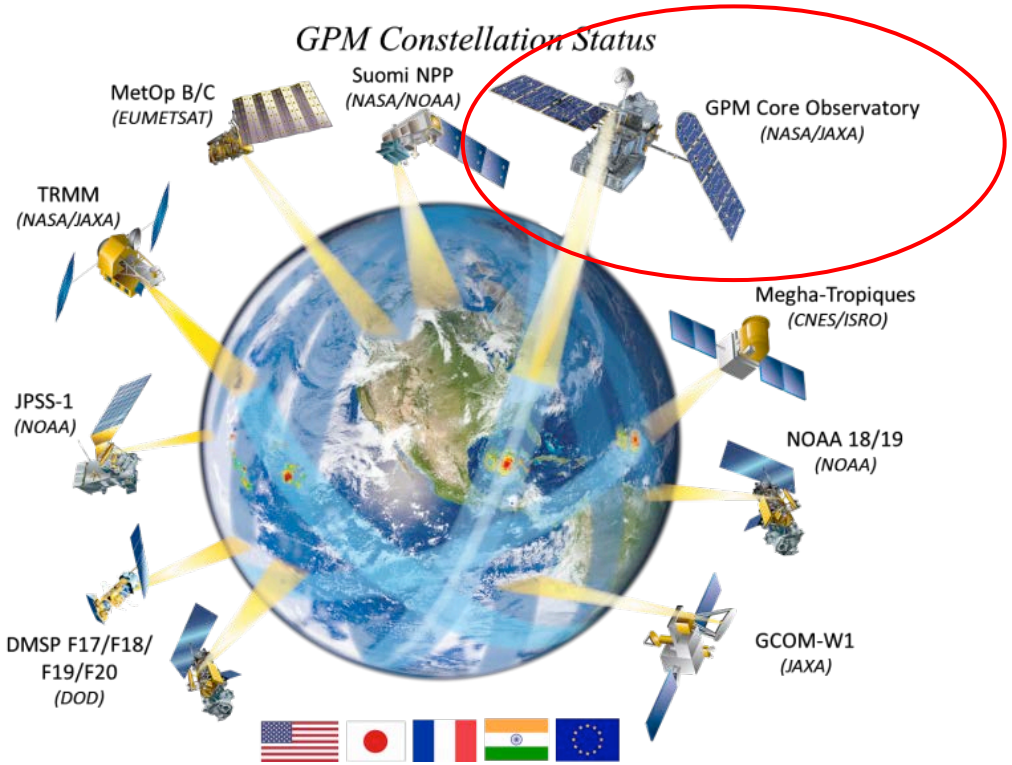
GPM Satellite & Sensors

http://pmm.nasa.gov/GPM

- NASA and JAXA (Japanese Space Agency) Joint Mission
- GPM core satellite is in a non-polar, low inclination orbit
  - Altitude: 407 km
- Spatial Coverage:
  - 16 orbits a day covering global tropics, between 65°S – 65°N
- Along with constellation of satellites, GPM has revisit time of 1-2 hrs over land
- Sensors:
  - GMI, DPR

GPM Core Satellite

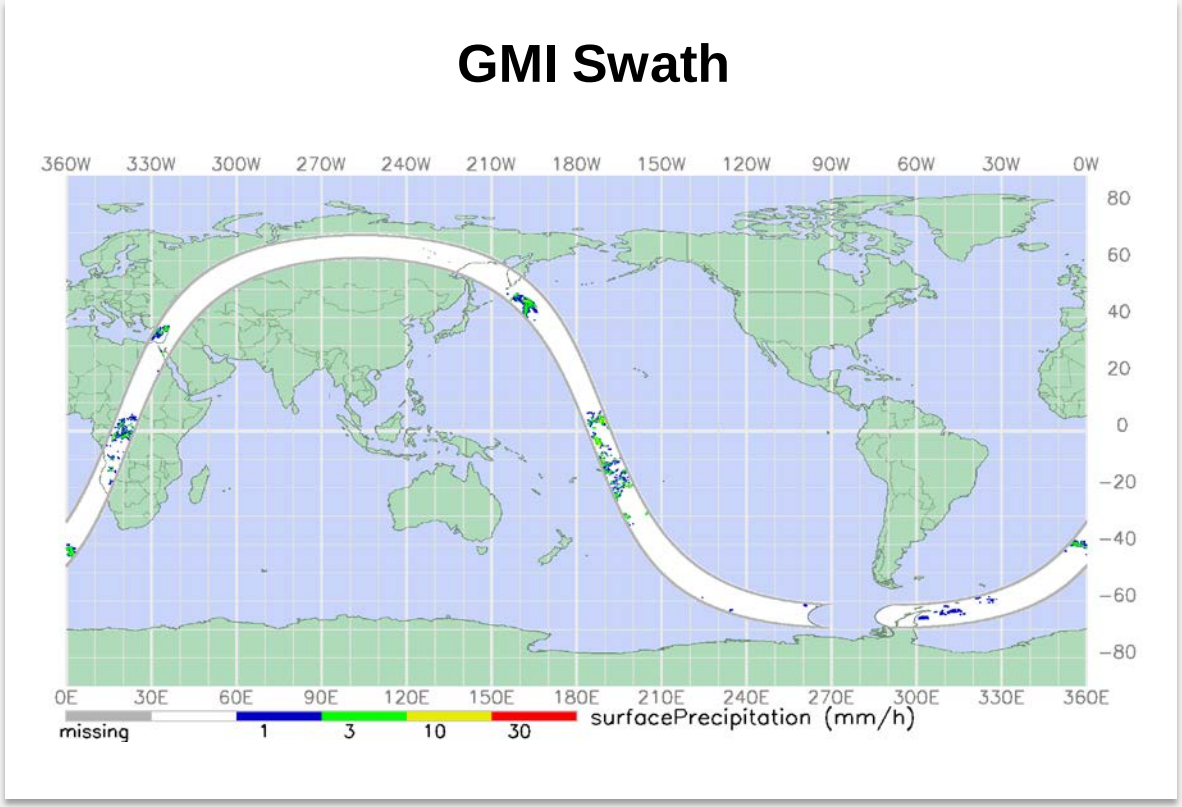
Launched Feb 27, 2014



GPM Microwave Imager (GMI)

http://pmm.nasa.gov/GPM/flight-project/GMI

- Spatial Coverage and Resolution:
  - Coverage: -180°-180°, 65°S-65°N
  - Swath: 885 km
  - Spatial Resolution: 4.4-32 km
  - Vertical Resolution:
    - 0.5 km from surface – 4 km
    - 1.0 km from 4-6 km
    - 2.0 km from 6-10 km
    - 4.0 km from 10-18 km
- Temporal Coverage and Resolution:
  - Feb 2014 – present
  - ~2-4 hr observations
- Channel Frequencies:
  - 10.6, 18.7, 23.8, 36.5, 89, 166, 183 GHz



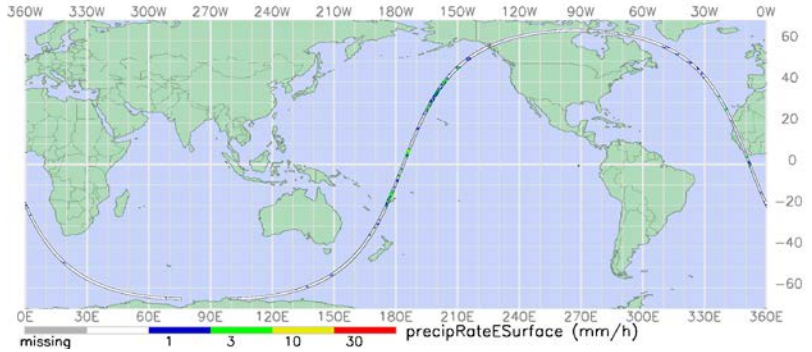
Dual Precipitation Radar (DPR)

http://pmm.nasa.gov/GPM/flight-project/DPR

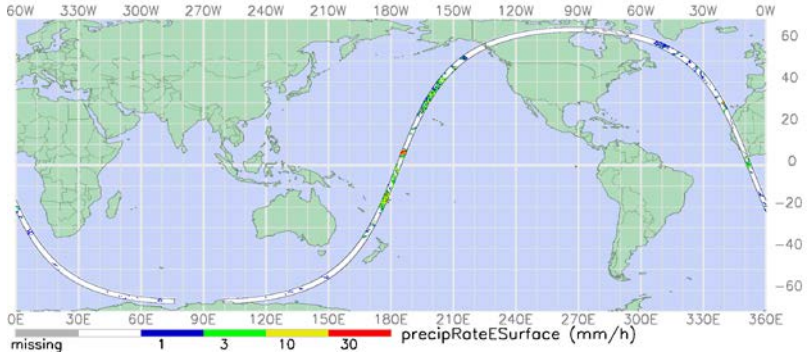
- Spatial Coverage and Resolution:
  - Coverage: -180°-180°, 65°S-65°N
  - Swath: 120 km (Ka) and 245 km (Ku)
  - Spatial Resolution: 5.2 km
  - Vertical Resolution: 250 m (from 0-20 km)
- Temporal Coverage and Resolution:
  - Feb 27, 2014 – present
  - ~2-4 hr observations
- Frequency:
  - 13.6 and 35.5 GHz

DPR Swaths

Ka 35.5 GHZ

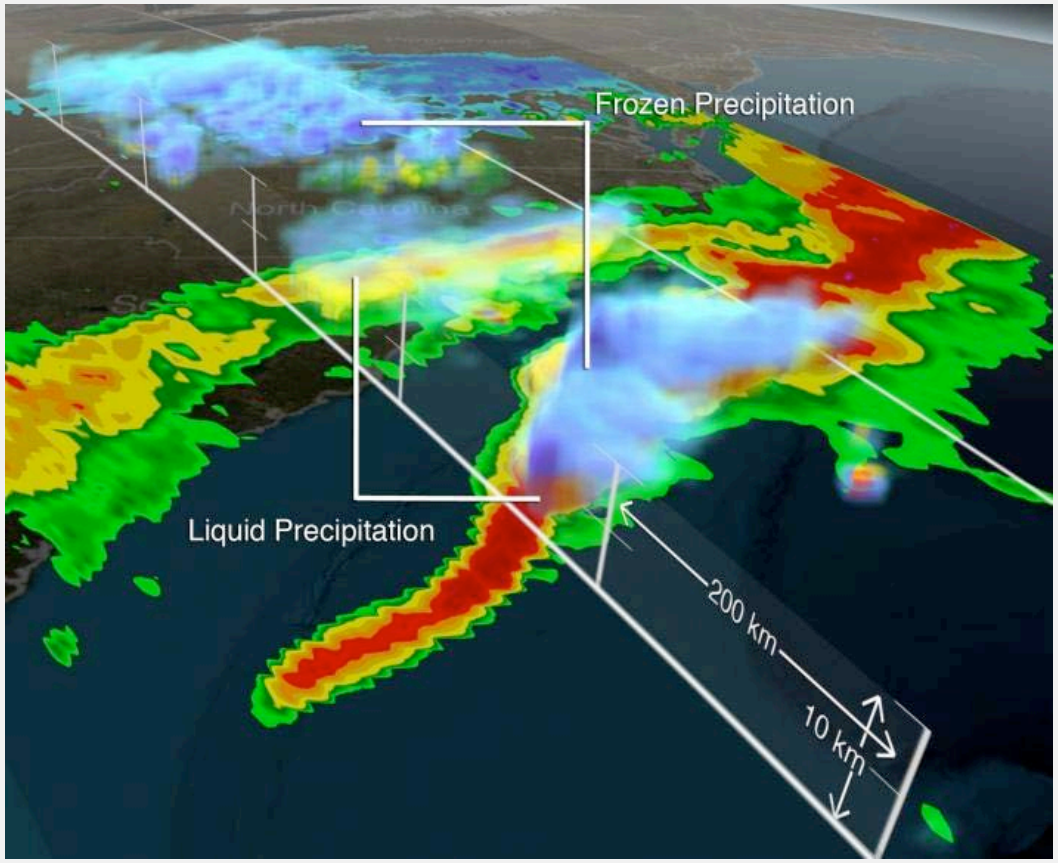


Ku 13.6 GHZ



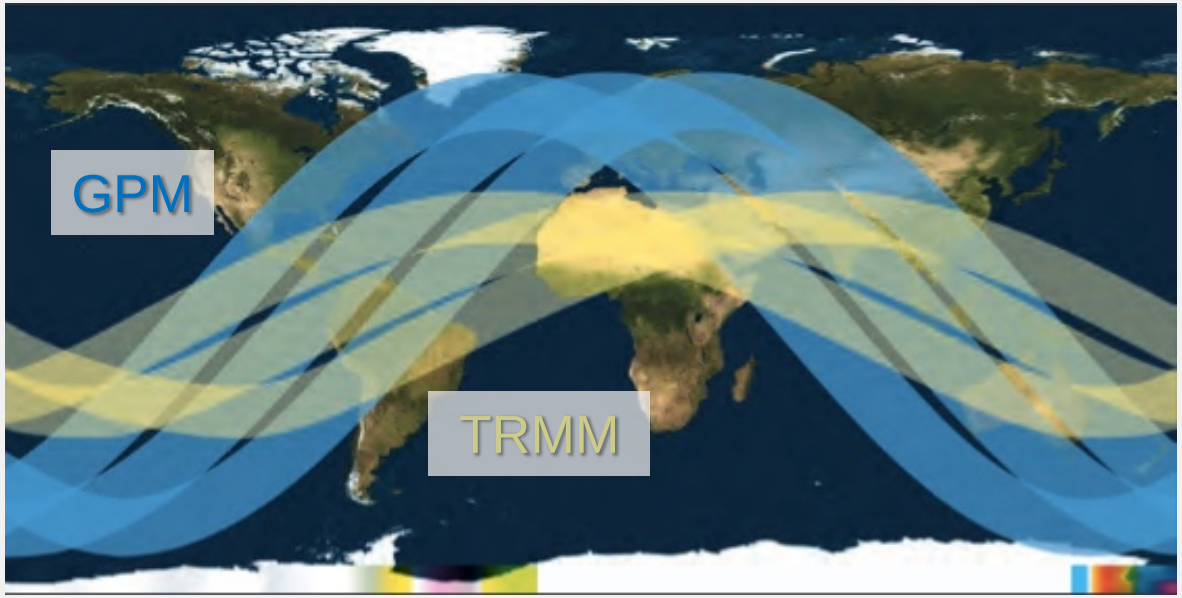
GPM Data for Water Resources Applications

- Freshwater Component:
  - Continues to provide improved rain rates after TRMM
- Provides estimates of snow rates
- GPM data used:
  - GMI brightness temperatures
  - DPR Reflectivities



A storm over the eastern United States showing precipitation, from rain to snow. Observed by GPM Core Satellite on March 17, 2014.
Credit: https://pmm.nasa.gov/image-gallery/gpm-data-march-2014-east-coast-snowstorm

TRMM and GPM Comparison



- TRMM measurements are limited to tropics; GPM measurements span middle and high latitudes

- GMI and DPR provide improved reference standard for inter-calibration of constellation precipitation measurements compared to TMI/PR
- Better accuracy of measurements for GMI & DPR
- GMI has higher spatial resolution than TMI
- Improved light rain and snow detection in GPM (TRMM cannot detect rainfall <0.5mm/hr)
- DPR has better identification of liquid, ice, mixed—phase precipitation particles

Multi-Satellite Algorithms for TRMM and GPM

http://pmm.nasa.gov/science/precipitation-algorithms/

- TRMM and GPM Core satellites are used to calibrate microwave observations from a constellation of national and international satellites
- This multi-satellite algorithms allow improved spatial and temporal coverage of precipitation data
- TRMM Multi-satellite Precipitation Analysis (**TMPA**) is widely used for applications
- TMPA will be extended to match Integrated Multi-satellitE Retrievals for GPM (**IMERG**)

References:

Huffman, G.J., R.F. Adler, D.T. Bolvin, G. Gu, E.J. Nelkin, K.P. Bowman, E.F. Stocker, D.B. Wolff, 2007: The TRMM Multi-satellite Precipitation Analysis: Quasi-Global, Multi-Year, Combined-Sensor PrecipitationEstimates at Fine Scale. J. Hydrometeor., 8, 33-55. MERG_ATBD_V4.5.pdf

TRMM Multi-Satellite Precipitation Analysis (TMPA)

http://precip.gsfc.nasa.gov/trmm_comb.html

- TMPA Combines PR and TMI rain rates
- Inter-calibrates passive rain rates from other satellite sensors (TMI, SSM/II, AMSR, AMSU-B, MHS, IR radiometers)*
- Inter-calibrates with national and international geostationary and NOAA low-Earth orbiting satellites infrared measurements by using VIRS
- Final rain product is calibrated with rain gauge analyses on monthly time scale

- SSM/I and SSMIS: Special Sensor Microwave Imager Special Sensor Microwave Imager/ Sounder – sensor on Defense Meteorology
  Satellite Project (DMSP)

AMSR: Advanced Microwave Scanning Radiometer – sensor on NASA Aqua satellite

AMSU: Advanced Microwave Sounding Unit –sensor on NOAA operational satellite

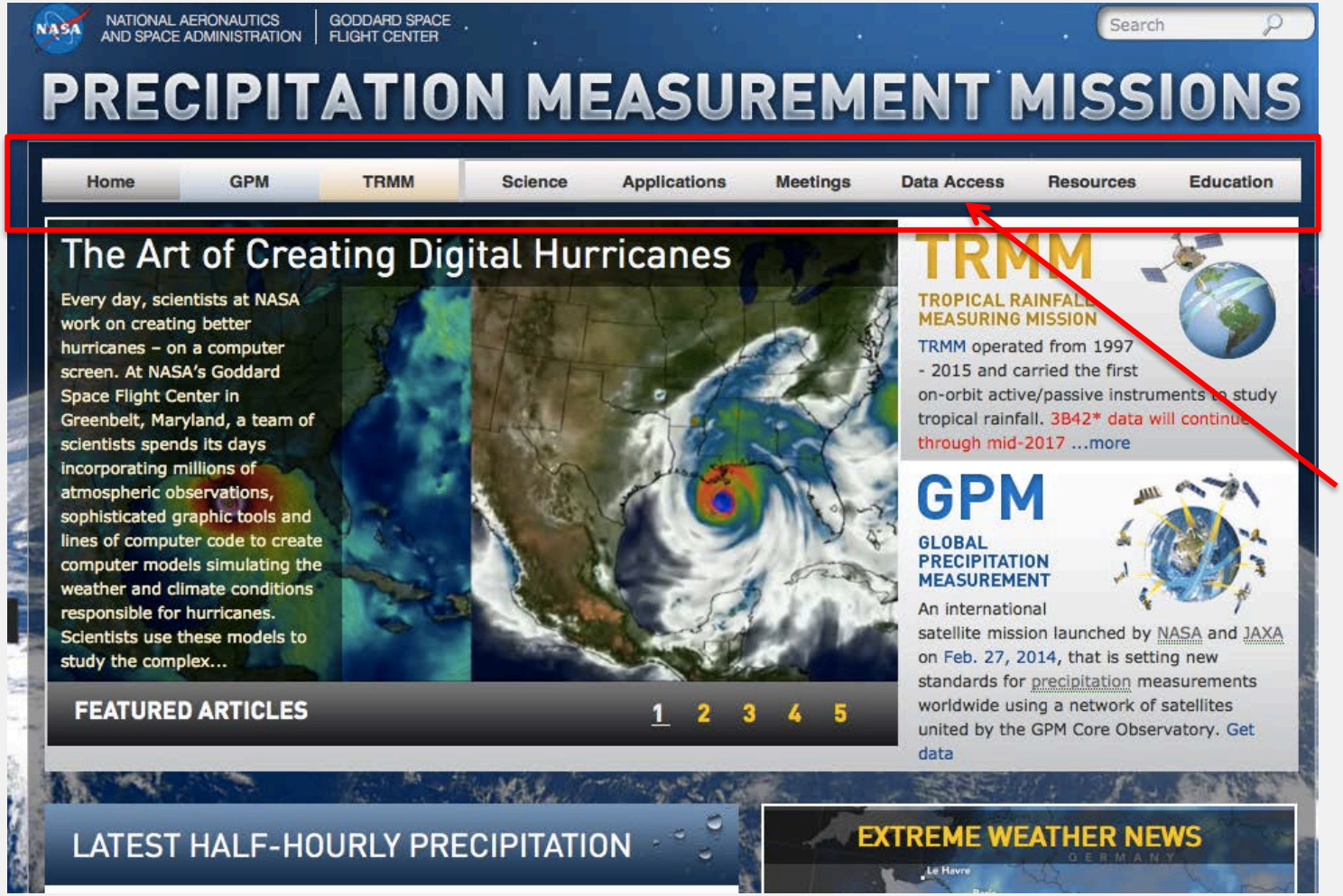
Integrated Multi-satellitE Retrievals for GPM (IMERG)

https://pmm.nasa.gov/sites/default/files/document_files/IMERG_ATBD_V4.5.pdf

- Conceptually similar to TMPA
- GPM constellation satellites include:
  - GCOM-W, DMSP, Megha-Tropiques, MetOp-B, NOAA-N', NPP, NPOESS
- Final rain product is calibrated with rain gauge analyses on monthly time scale

Where to get TRMM & GPM Data?

Precipitation Measurement Missions: http://pmm.nasa.gov/

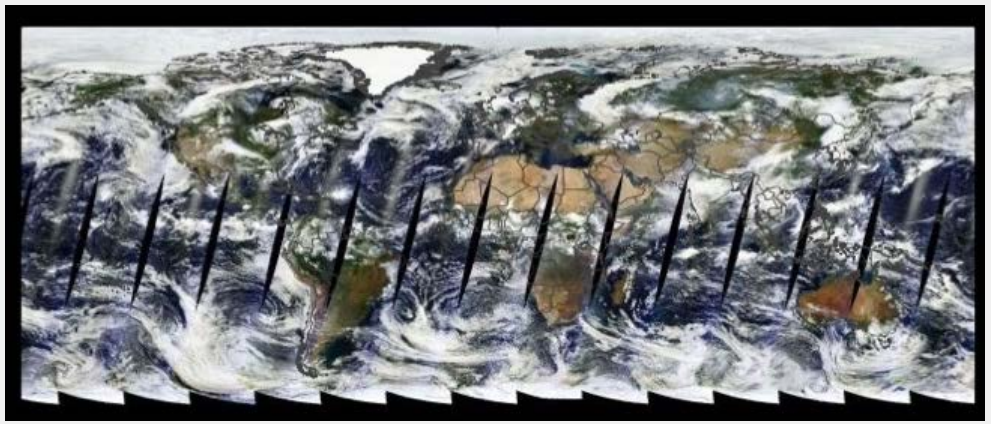


- Home to all the information related to TRMM and GPM
- Links to Level-1 to Level-3 Data Access

Terra and Aqua

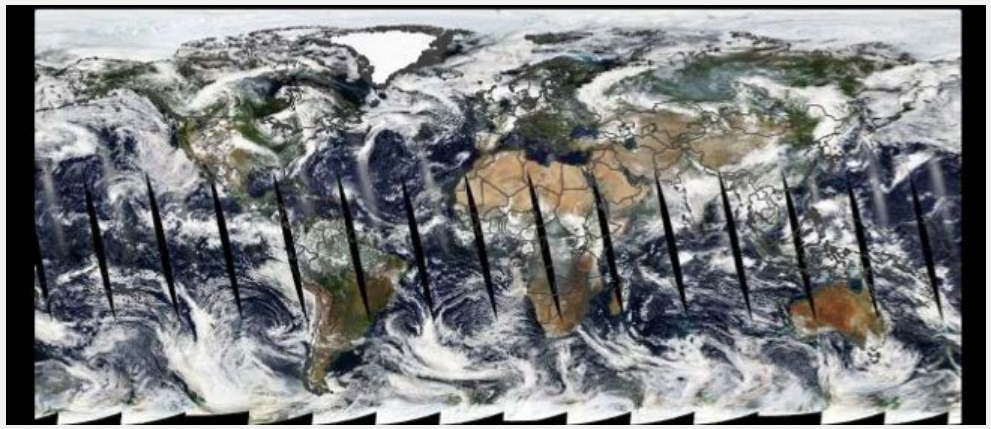
Terra

- Polar orbit, 10:30 a.m. equator crossing time
- Global coverage
- Dec 18, 1999 – present
- 1-2 observations per day
- Sensors:
  - ASTER, CERES, MISR, MODIS, MOPITT



Aqua

- Polar orbit, 1:30 p.m. equator crossing time
- Global coverage
- May 4, 2002 – present
- 1-2 observations per day
- Sensors:
  - AIRS, AMSU, CERES, MODIS, AMSR-E



MODerate Resolution Imaging Spectroradiometer (MODIS)

http://modis.gsfc.nasa.gov

- On board Terra and Aqua
- Designed for land, atmosphere, ocean, and cryosphere observations
- Spatial Coverage and Resolution:
  - Global, Swath: 2,330 km
  - Spatial Resolution Varies: 250 m, 500 m, 1 km
- Temporal Coverage and Resolution:
  - 2000-present, 2 times per day

Spectral Bands

- 36 bands (red, blue, IR, NIR, MIR)
  - Bands 1-2: 250 m
  - Bands 3-7: 500 m
  - Bands 8-16: 1000 m

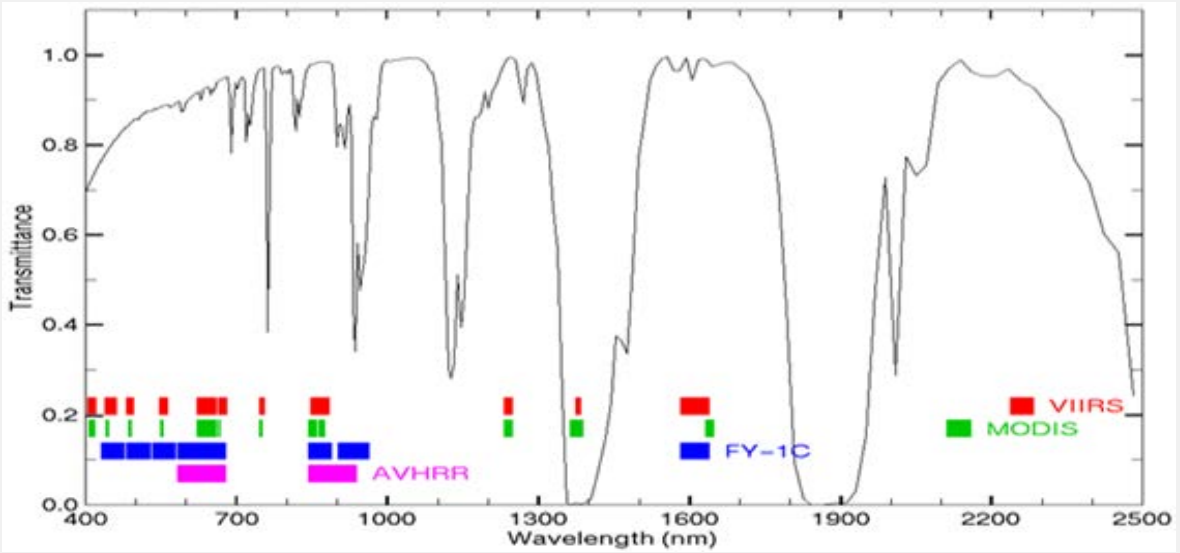
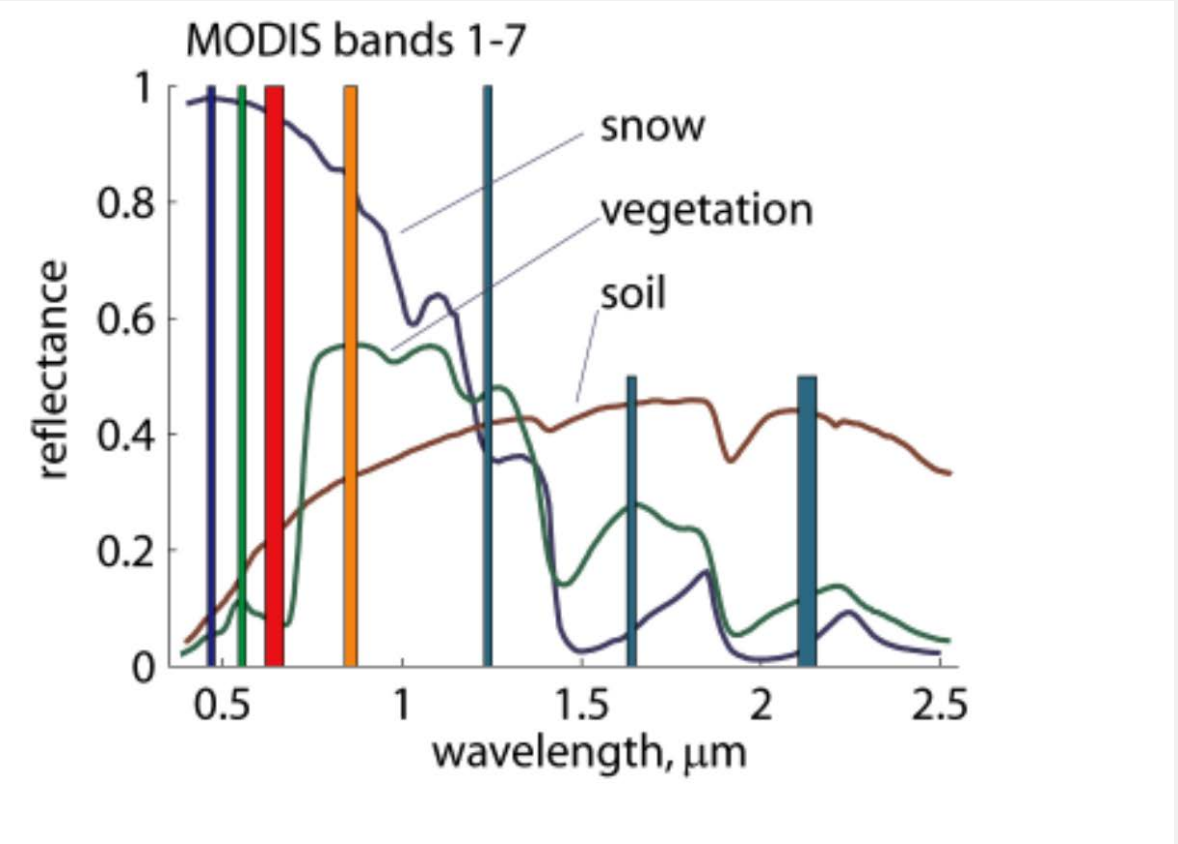


Image Credit: http://cimss.ssec.wisc.edu/

MODIS Data for Water Resources Management

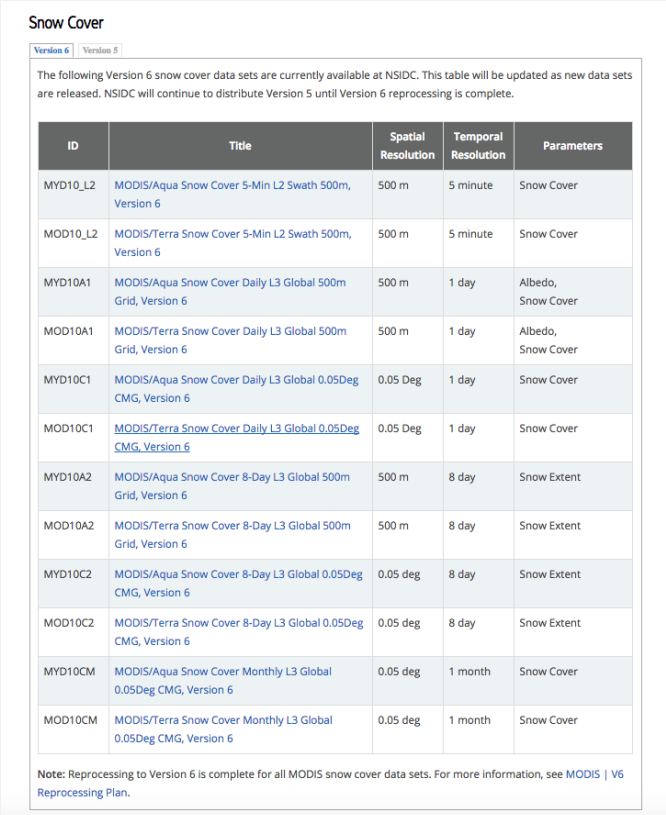
- Freshwater Component:
  - Snow Cover
  - Normalized Difference Vegetation Index (NDVI) - used for ET Estimation
- Two snow cover products based on MODIS Spectral Reflectance
  - Standard MODIS Product
    - Fractional Snow Cover
  - MODIS Snow Covered Area and Grain size (MODSCAG) Product
    - Fractional Snow Cover
    - Grain Size
    - Snow Water Equivalence



Where to get MODIS Standard Snow Cover Products?

National Snow and Ice Data Center

http://nsidc.org/data/modis/data_summaries#snow



Snow Cover

Version 6 | Version 5

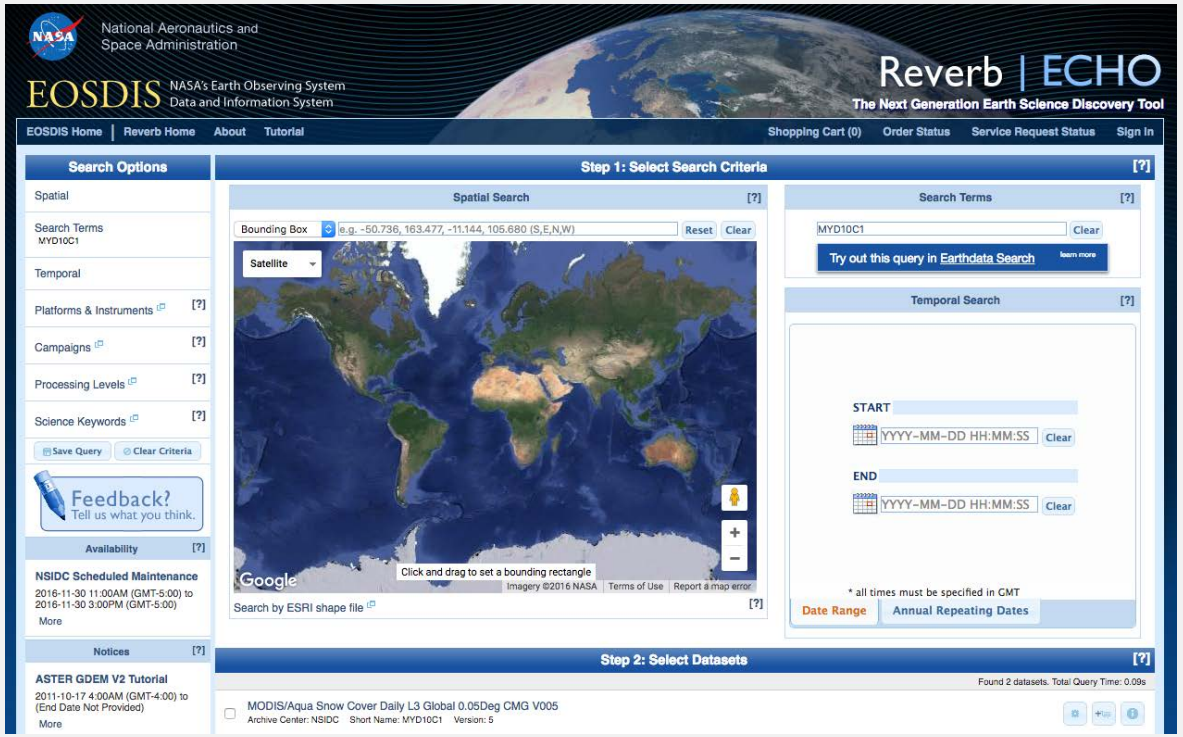
The following Version 6 snow cover data sets are currently available at NSIDC. This table will be updated as new data sets are released. NSIDC will continue to distribute Version 5 until Version 6 reprocessing is complete.

ID	Title	Spatial Resolution	Temporal Resolution	Parameters
MYD10_L2	MODIS/Aqua Snow Cover 5-Min L2 Swath 500m, Version 6	500 m	5 minute	Snow Cover
MOD10_L2	MODIS/Terra Snow Cover 5-Min L2 Swath 500m, Version 6	500 m	5 minute	Snow Cover
MYD10A1	MODIS/Aqua Snow Cover Daily L3 Global 500m Grid, Version 6	500 m	1 day	Albedo, Snow Cover
MOD10A1	MODIS/Terra Snow Cover Daily L3 Global 500m Grid, Version 6	500 m	1 day	Albedo, Snow Cover
MYD10C1	MODIS/Aqua Snow Cover Daily L3 Global 0.05Deg CMG, Version 6	0.05 Deg	1 day	Snow Cover
MOD10C1	MODIS/Terra Snow Cover Daily L3 Global 0.05Deg CMG, Version 6	0.05 Deg	1 day	Snow Cover
MYD10A2	MODIS/Aqua Snow Cover 8-Day L3 Global 500m Grid, Version 6	500 m	8 day	Snow Extent
MOD10A2	MODIS/Terra Snow Cover 8-Day L3 Global 500m Grid, Version 6	500 m	8 day	Snow Extent
MYD10C2	MODIS/Aqua Snow Cover 8-Day L3 Global 0.05Deg CMG, Version 6	0.05 deg	8 day	Snow Extent
MOD10C2	MODIS/Terra Snow Cover 8-Day L3 Global 0.05Deg CMG, Version 6	0.05 deg	8 day	Snow Extent
MYD10CM	MODIS/Aqua Snow Cover Monthly L3 Global 0.05Deg CMG, Version 6	0.05 deg	1 month	Snow Cover
MOD10CM	MODIS/Terra Snow Cover Monthly L3 Global 0.05Deg CMG, Version 6	0.05 deg	1 month	Snow Cover

Note: Reprocessing to Version 6 is complete for all MODIS snow cover data sets. For more information, see MODIS | V6 Reprocessing Plan.

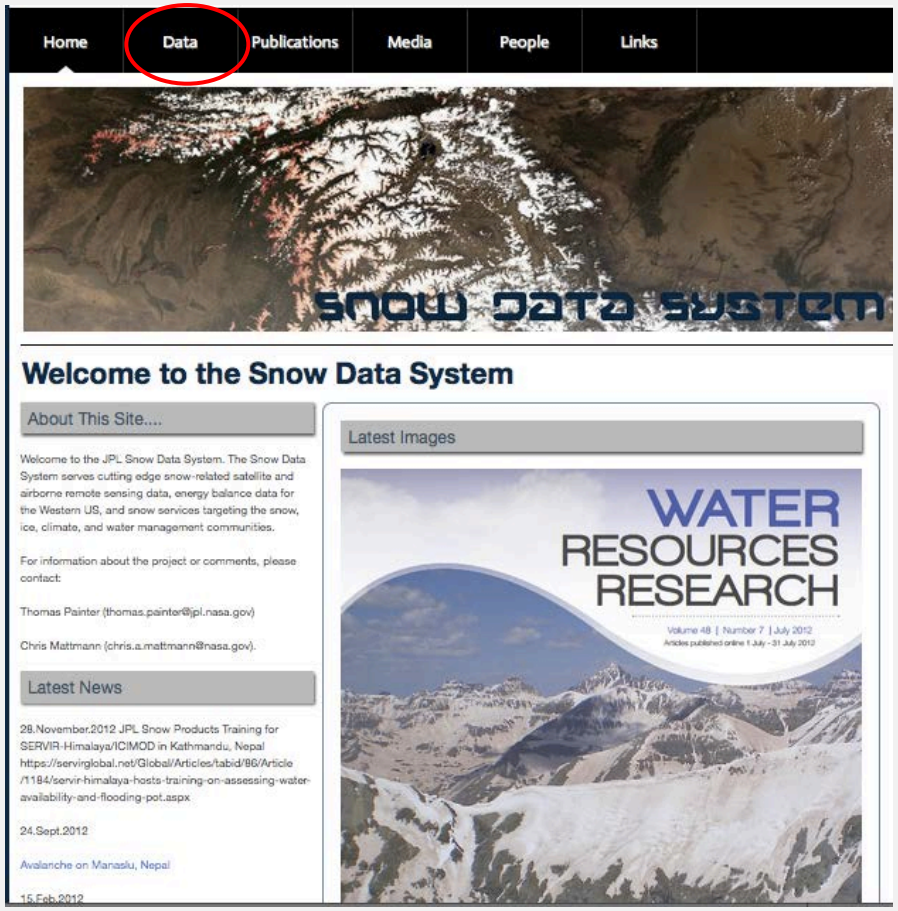
NASA Reverb ECHO

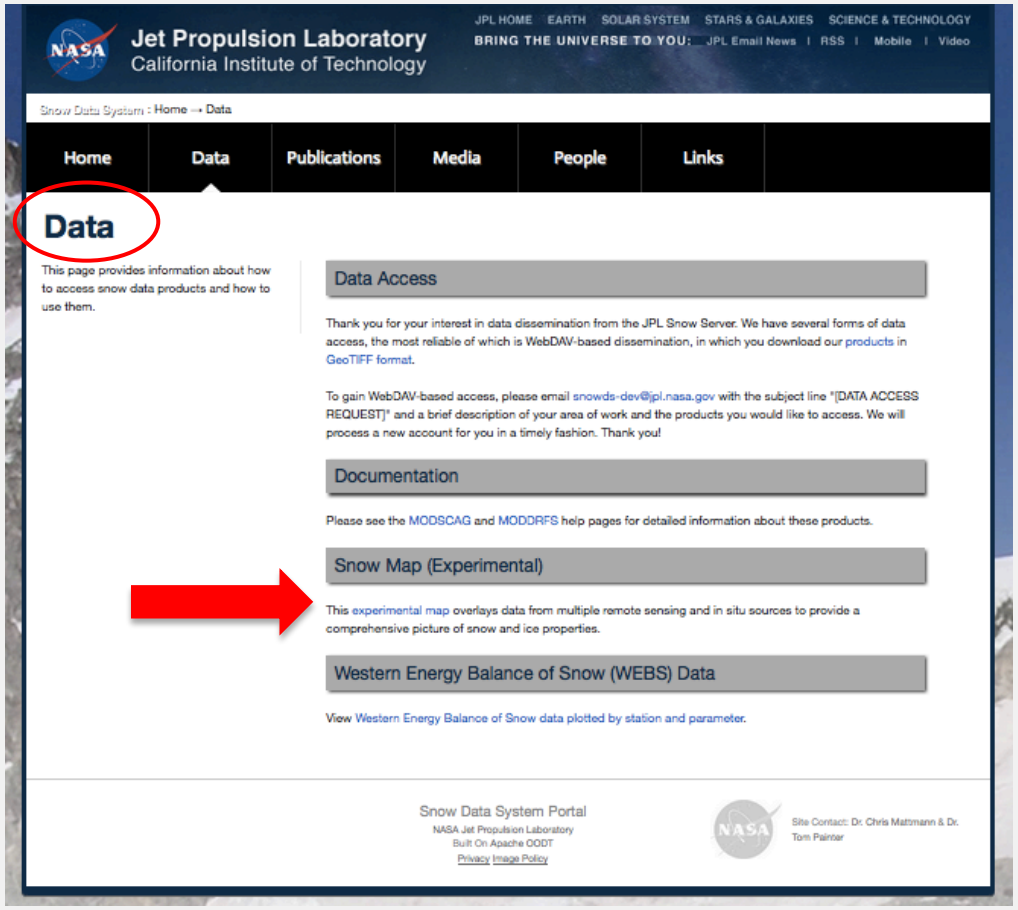
http://reverb.echo.nasa.gov



Where to get MODSCAG Snow Data?

Available from JPL Snow Data Server: http://snow.jpl.nasa.gov/portal/





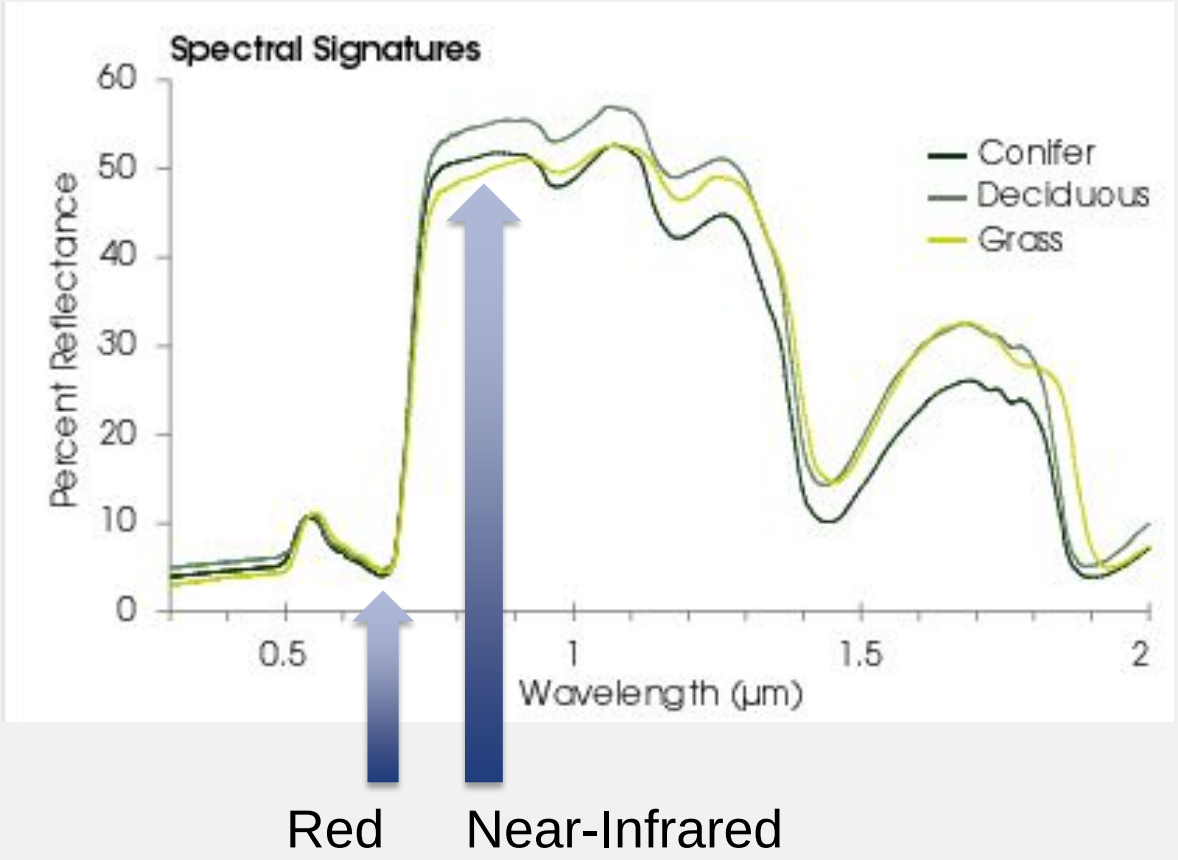
MODIS Normalized Vegetation Index

http://arset.gsfc.nasa.gov/land/webinars/advancedNDVI

- Based on the relationship between red and near-infrared wavelengths
  - chlorophyll strongly absorbs visible (red)
  - plant structure strongly reflects near-infrared

- $NDVI = \frac{\text{Near-Infrared - Red}}{\text{Near-Infrared + Red}}$

- Values range from -1.0 – 1.0
  - Negative values – 0 mean no green leaves
  - Values close to 1 indicate the highest possible density of green leaves



Where to get MODIS NDVI?

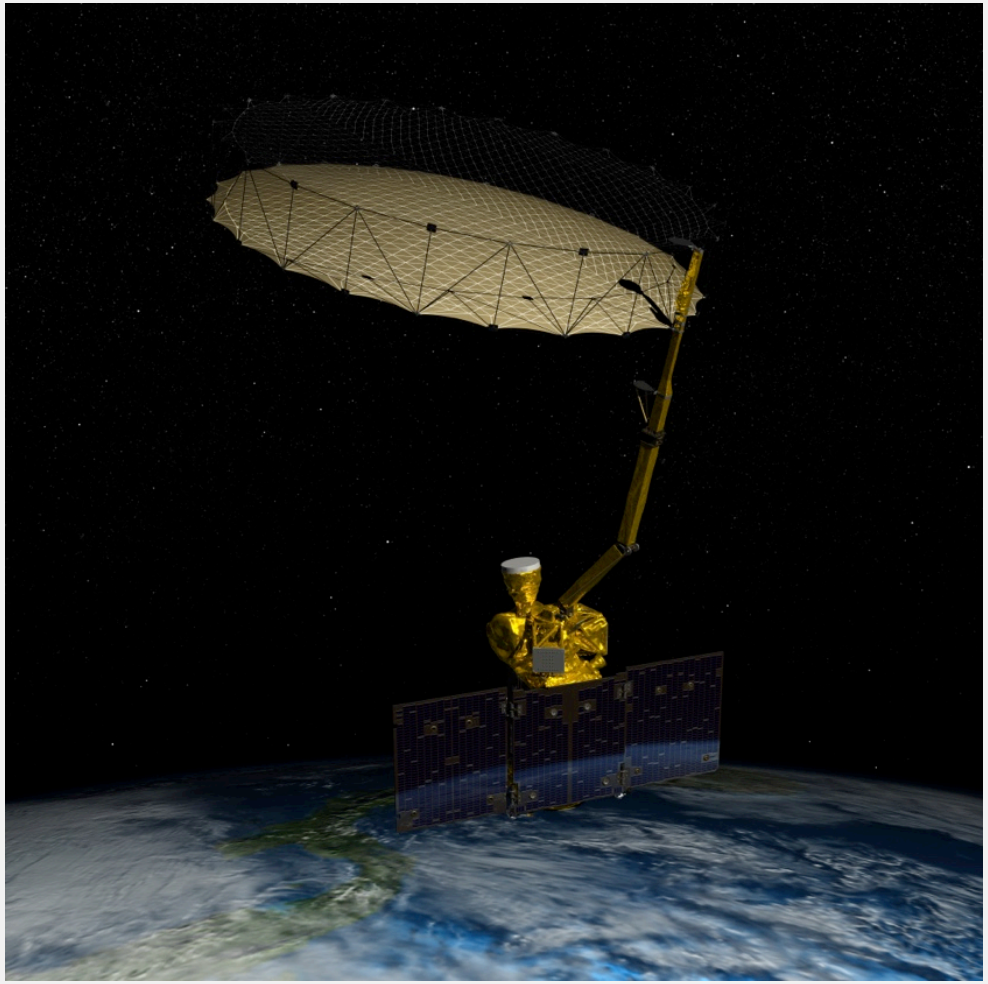
Available from the Land Process Distributed Archive Center (LPDAAC):
https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table

MOD13A1	Terra MODIS	Vegetation Indices	Terra	500	Composites
MOD13A2	Terra MODIS	Vegetation Indices		1000	Composites
MOD13A3	Terra MODIS	Vegetation Indices		1000	Monthly
MOD13C1	Terra MODIS	Vegetation Indices		5600	Composites
MOD13C2	Terra MODIS	Vegetation Indices		5600	Monthly
MOD13Q1	Terra MODIS	Vegetation Indices		250	Composites
MYD13A1	Aqua MODIS	Vegetation Indices	Aqua	500	Composites
MYD13A2	Aqua MODIS	Vegetation Indices		1000	Composites
MYD13A3	Aqua MODIS	Vegetation Indices		1000	Monthly
MYD13C1	Aqua MODIS	Vegetation Indices		5600	Composites
MYD13C2	Aqua MODIS	Vegetation Indices		5600	Monthly
MYD13Q1	Aqua MODIS	Vegetation Indices		250	Composites

Soil Moisture Active Passive (SMAP)

http://smap.jpl.nasa.gov

- Polar Orbit
  - Altitude: 685 km
- Spatial Coverage:
  - Global
- Launched Jan 31, 2015
- Temporal Coverage:
  - April 2015 – present
- Sensors:
  - Microwave Radiometer
  - Microwave Radar (not currently available)

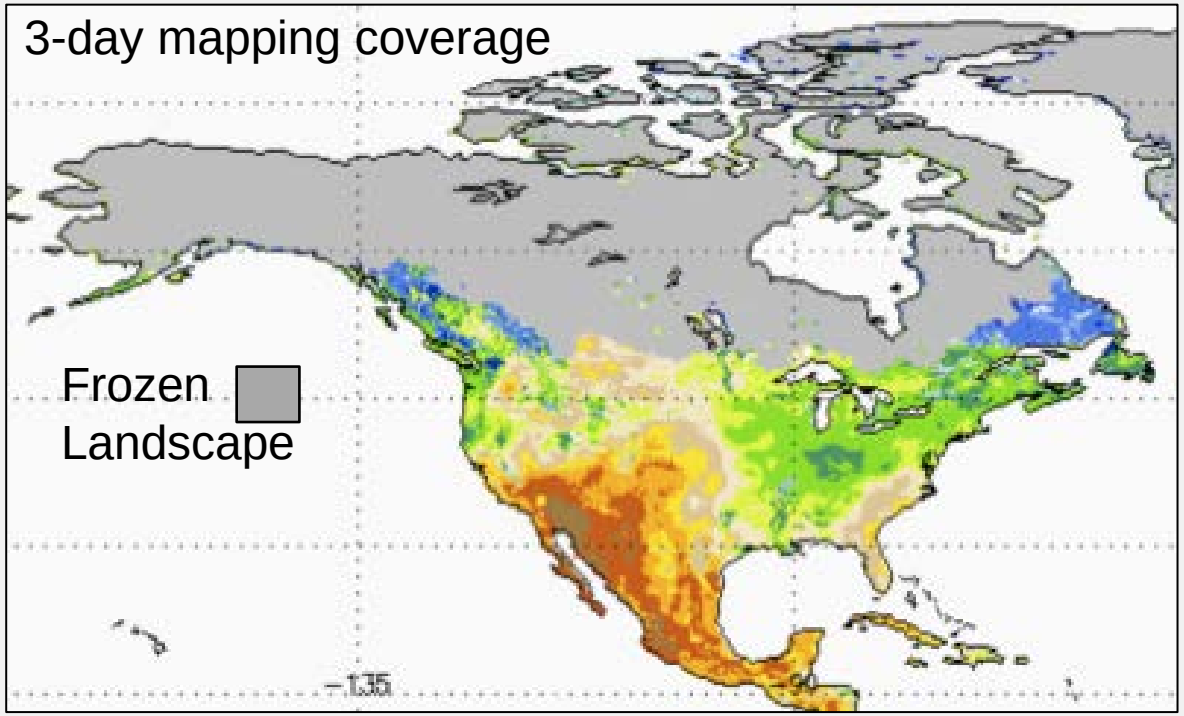


SMAP Microwave Radiometer & Radar

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

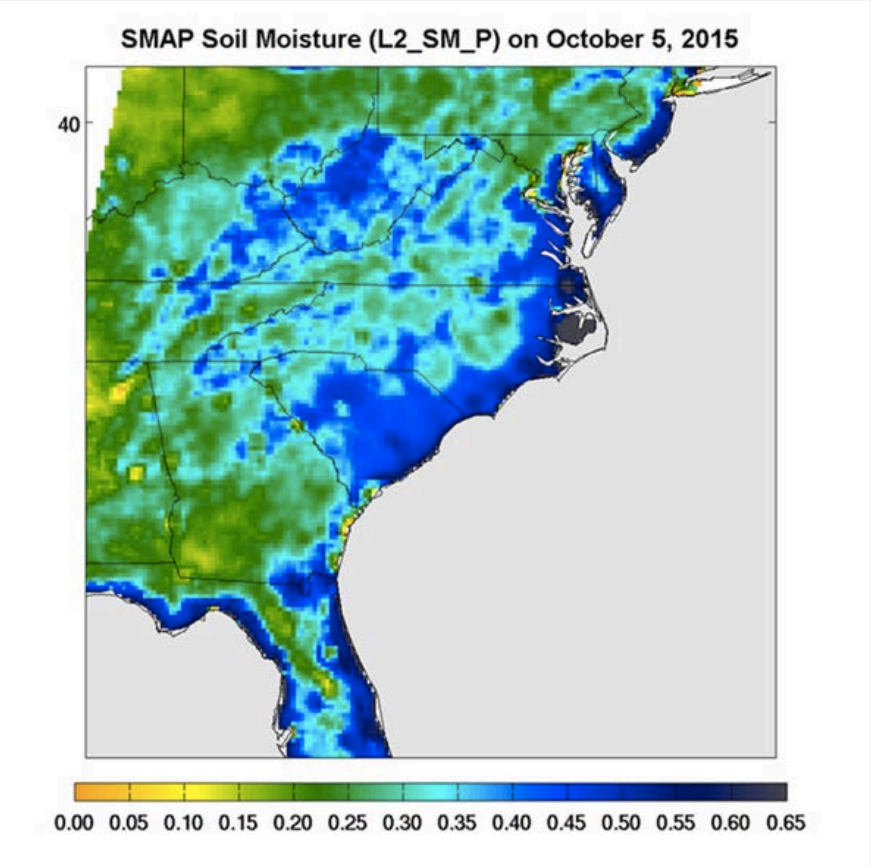
- Radiometer:
  - Swath: 1,000 km
  - Frequency: 1.41 GHz
  - Polarization: H, V, 3rd & 4th Stokes
  - Resolution: 40 km
- Radar: designed to work as Synthetic Aperture Radar (SAR)
  - Frequency: 1.26 GHz
  - Polarization: VV, HH, HV
  - Resolution: 3 km
  - **Stopped operating after Jul 7, 2015**
- Temporal Resolution:
  - Every 3 days

- Measures the moisture in the top 5 cm of soil



SMAP Data for Water Resources Applications

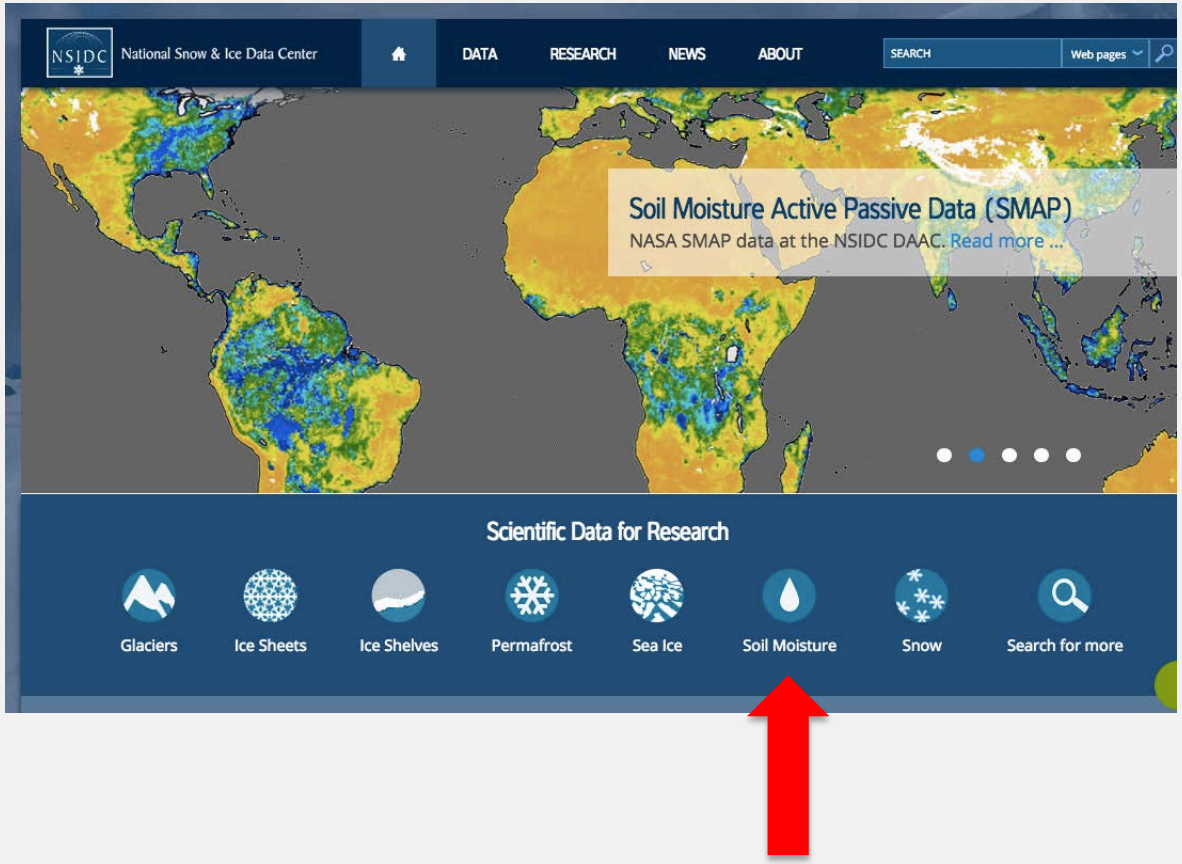
- Freshwater Component:
  - Surface Soil Moisture
  - Freeze/Thaw State
  - Root Zone Soil Moisture
- SMAP Data Used: Radiometer Brightness Temperatures

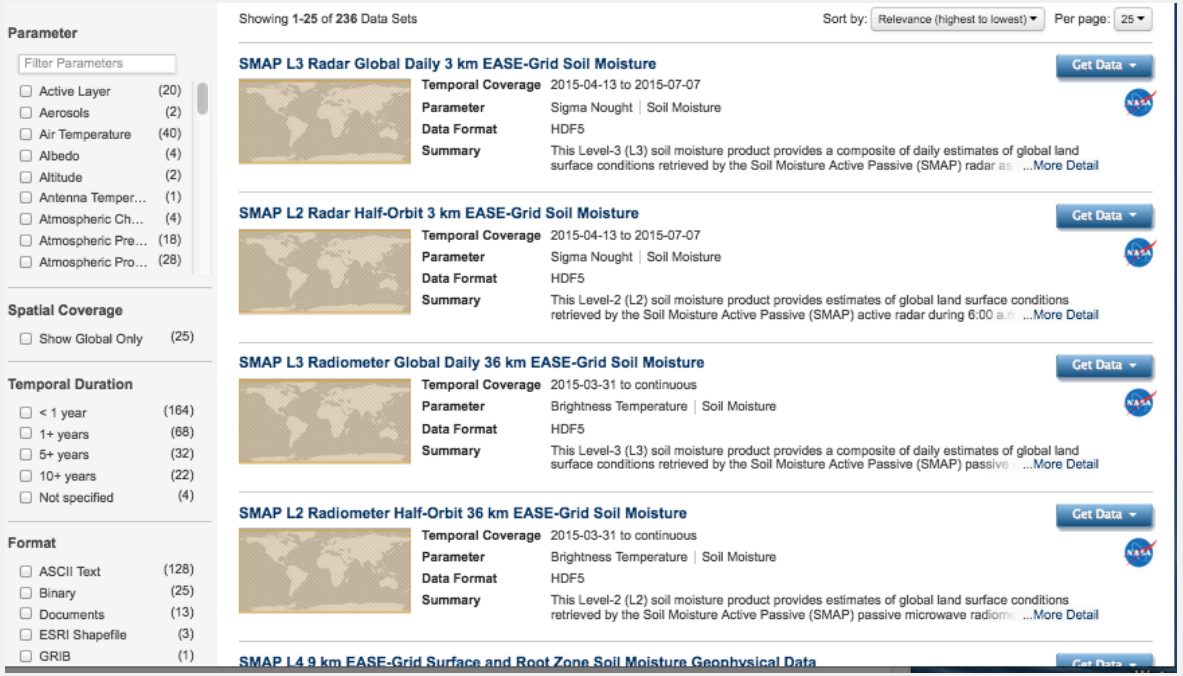


Surface soil moisture from SMAP showing Carolina floods in October 2015. Credit: http://smap.jpl.nasa.gov/news/1253/devastating-carolina-floods-viewed-by-nasas-smap/

Where to get SMAP Data?

Available from the National Snow & Ice Data Center:
http://nsidc.org/data/search/#keywords=soil+moisture/



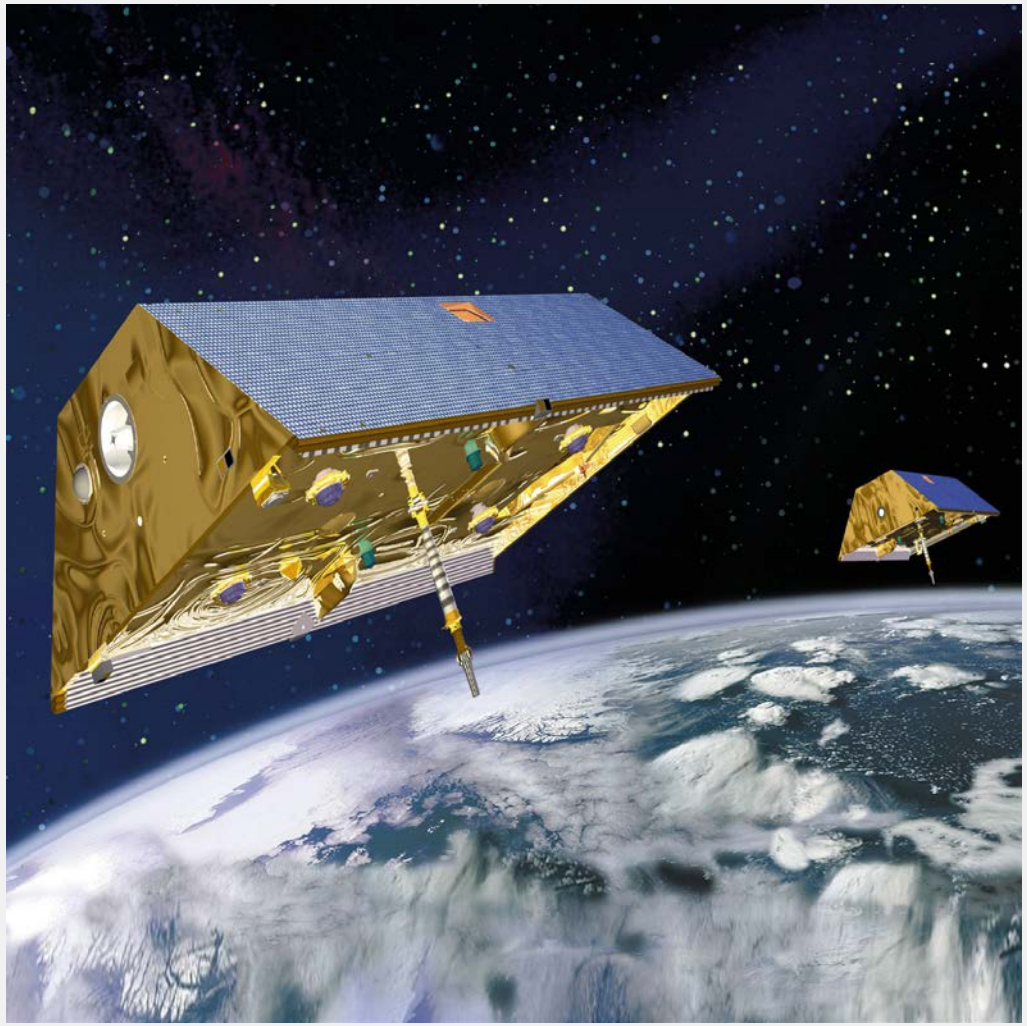


Level-2 to Level-4 data

GRACE Satellite

http://www.jpl.nasa.gov/missions/details.php?id=5882

- Polar, sun-synchronous orbit
- Twin satellite system
- Spatial Coverage and Resolution:
  - Global
  - Resolution: 300-400 km
- Temporal Coverage and Resolution:
  - Mar 17, 2002 – present
  - 250 gravity profiles per day

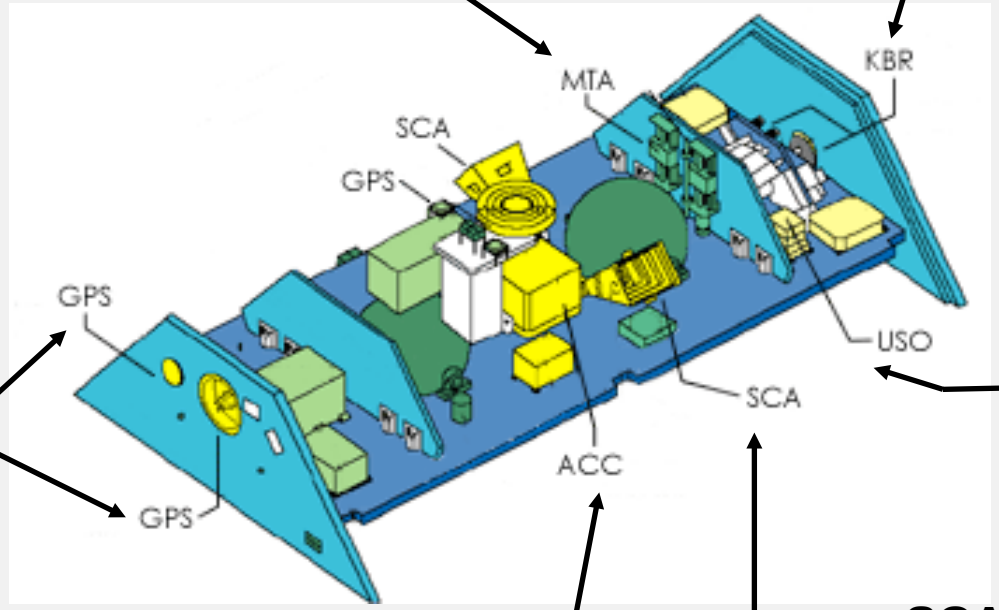


GRACE Sensors

http://earthobservatory.nasa.gov/Features/GRACE/

MTA (Center of Mass Trim Assembly)
Measures the offset between the satellite's center of mass and the "acceleration-proof" mass and adjusts center of mass as needed during the flight

KBR (K-band Ranging System)
Measurements of the distance change between the two satellites needed to measure fluctuations in gravity



USO (Ultra Stable Oscillator)
Provides frequency generation for the K-band ranging system

GPS (Black-Jack GPS Receiver and Instrument Processing Unit)

ACC (SuperSTAR Accelorometers)
Measures the non-gravitational accelerations acting on the satellite

SCA (Star Camera Assembly)
Determines the two satellites' orientation by tracking them relative to the position of the stars

Reference:
http://earthobservatory.nasa.gov/Features/GRACE/page5.php

GRACE Data for Water Resources Applications

Water Component: Ground Water

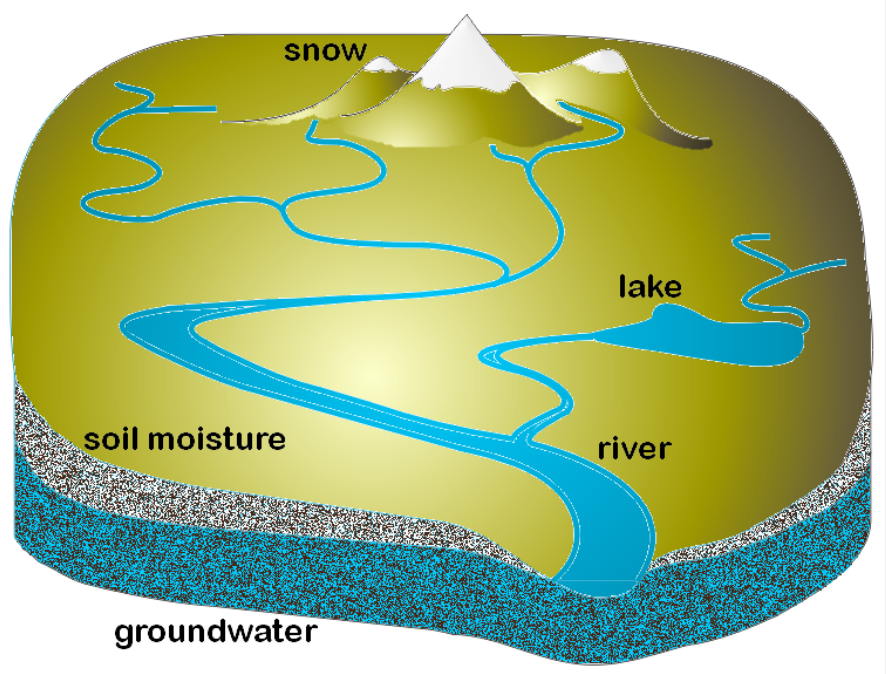
Ground water is derived from GRACE Terrestrial Water Storage

$P - ET - Q = \Delta TWS$

$\Delta TWS = \Delta GW + \Delta SM + \Delta SWE + \Delta SW$

$\Delta GW = \Delta TWS - \Delta SM - \Delta SWE - \Delta SW$

P = precipitation; ET = evapotranspiration; Q = river discharge
ΔTWS = change in terrestrial water storage [from GRACE]
ΔGW = change in groundwater storage [unknown]
ΔSM = change in soil moisture
ΔSWE = change in snow water equivalent
ΔSW = change in surface water storage
[ΔGW, ΔSM, ΔSW from Global Land Data Assimilation System (GLDAS) models]

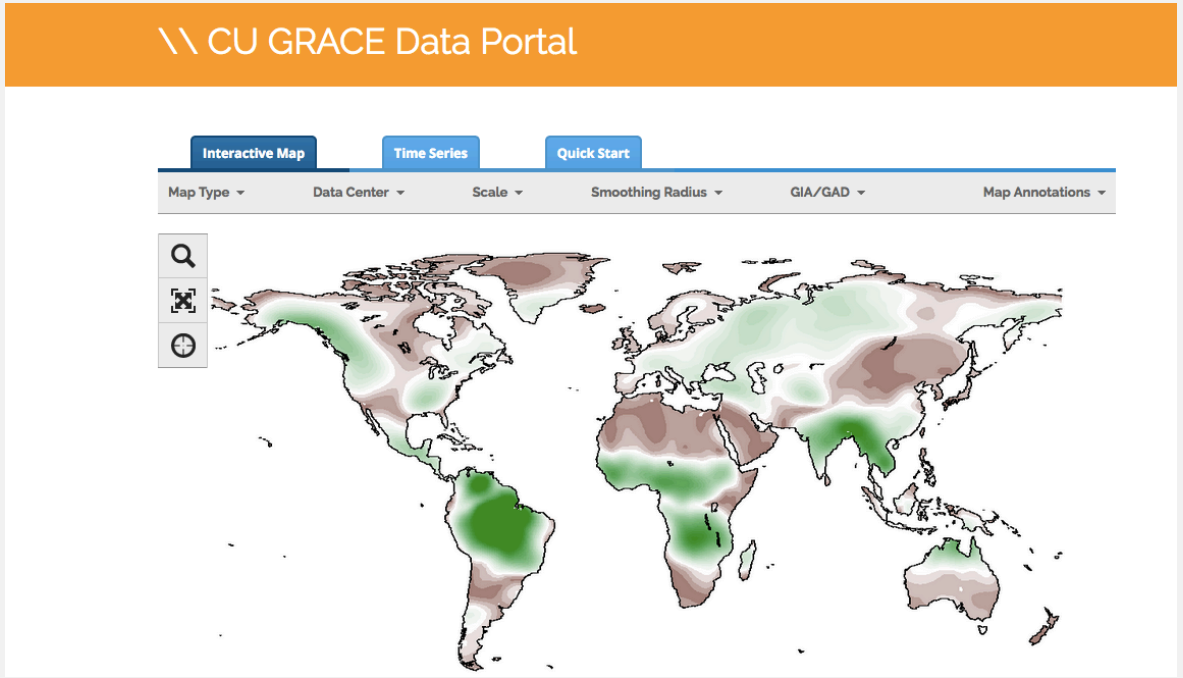


Acknowledgement: John Bolton (NASA-GSFC), Brian Thomas (NASA-JPL)

Where to get GRACE Data?

- Level-0 to Level-2
  - ftp://podaac.jpl.nasa.gov/allData/grace/
  - http://www.csr.utexas.edu/grace/
  - http://isdc.gfz-potsdam.de
- Level 3
  - http://grace.jpl.nasa.gov/data/
  - ICGEM - http://icgem.gfz-potsdam.de/ICGEM/ICGEM.html
  - http://geoid.colorado.edu/grace/

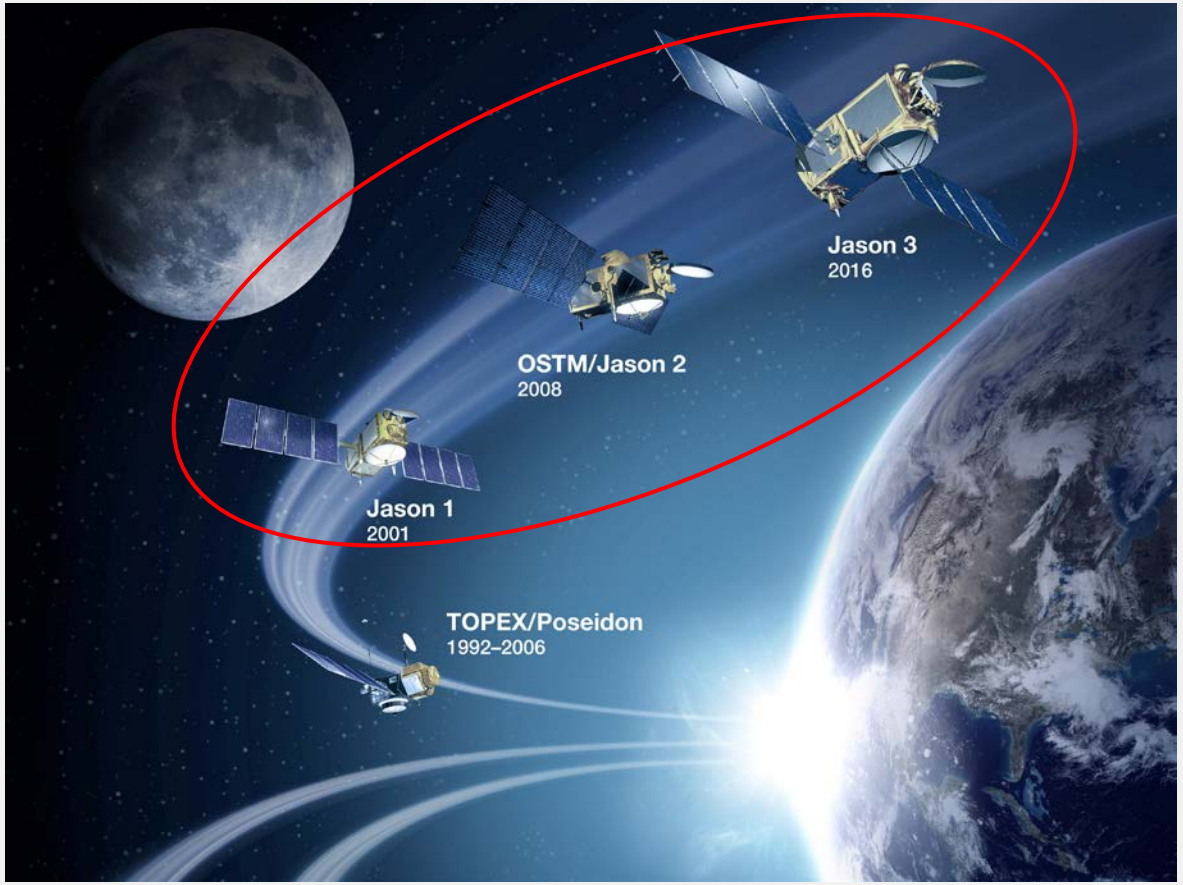
- GRACE Interactive Data Analysis and Download Portal:
  - http://geoid.colorado.edu/grace/



Jason 1, 2, and 3

http://sealevel.jpl.nasa.gov/missions/

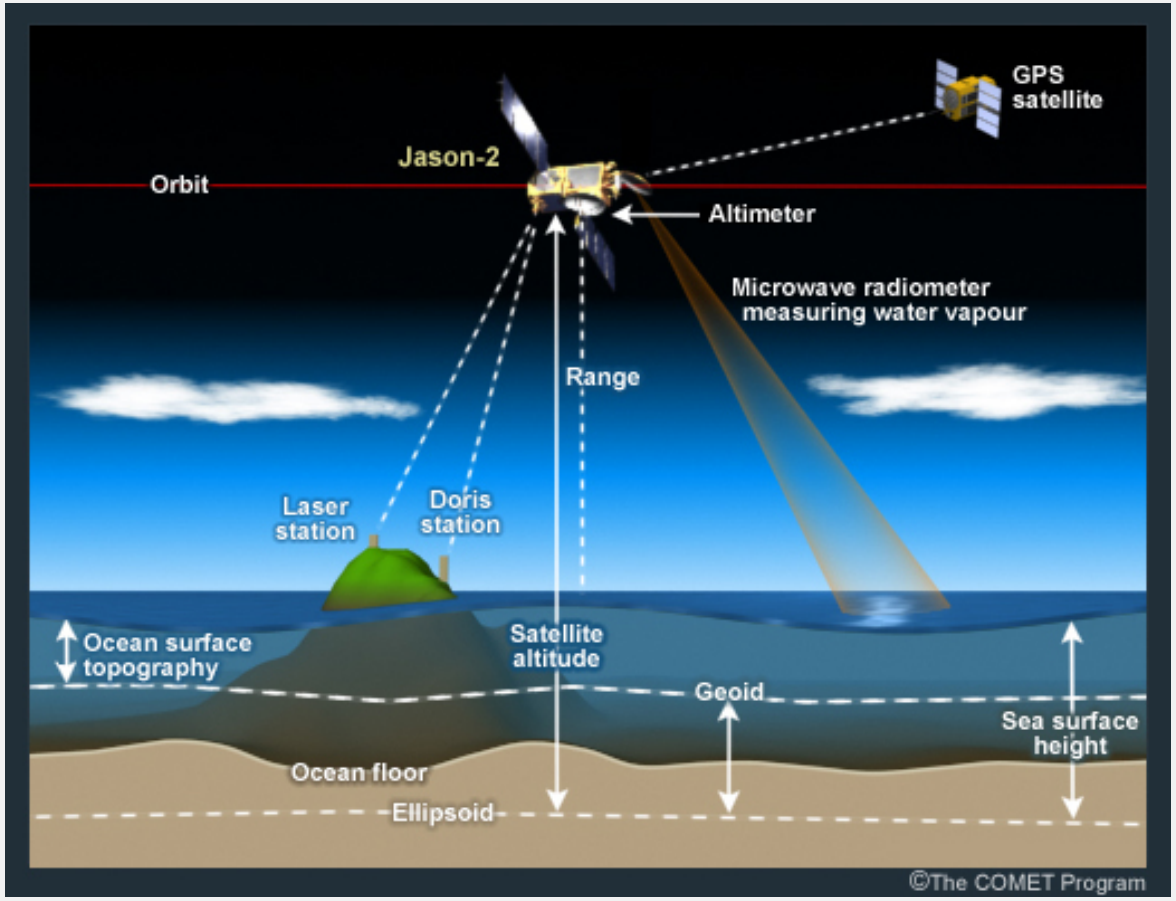
- Non-polar orbit
- Spatial Coverage:
  - Covers 95% of world's oceans
  - 66°S-66°N
- Temporal Coverage:
  - Revisit Time: 10 hrs
  - Jason-1 December 2001 to July 2013
  - Jason-2 6/2008-present
  - Jason-3 1/2016-present
- Sensors:
  - Poseidon Altimeter
  - Advanced Microwave Radiometer (AMR) and DORIS



NASA, NOAA, CNES, and EUMETSAT Joint Missions

Poseidon Altimeter

- Estimates the height of the ocean surface with respect to a reference sea level
- A Radar with transmission frequencies of 5.3 GHz (C-band), 13.575 GHz (Ku-band)
- Spatial resolution: 11.2 km x5.1 km
- Also used for determining selected in-land reservoir height (research to application product)



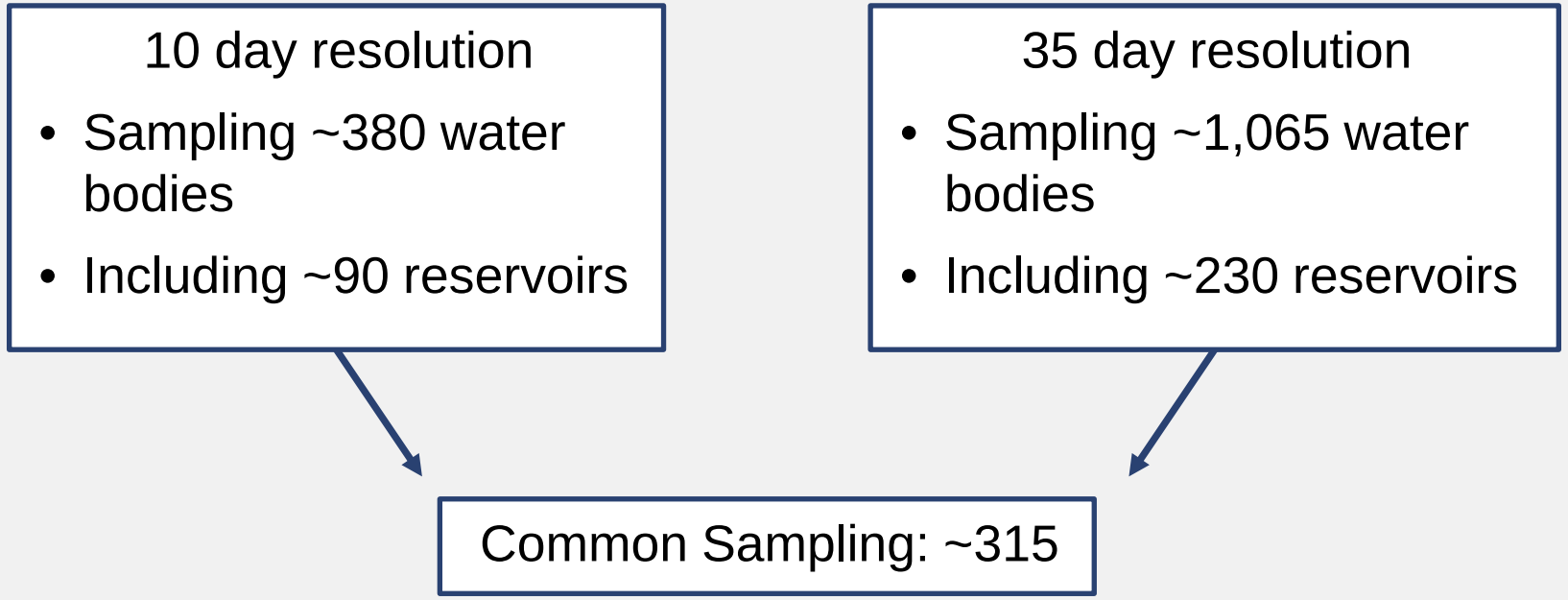
Reference: https://www.eumetsat.int/jason/print.htm

Image Credit: https://www.eumetsat.int/jason/print.htm

Jason 2 & 3 Data for Water Resources Applications

Inland Lake Heights

- Current satellite radar altimeters only view a certain proportion of the world's largest water bodies, with a trade-off between temporal and spatial resolution



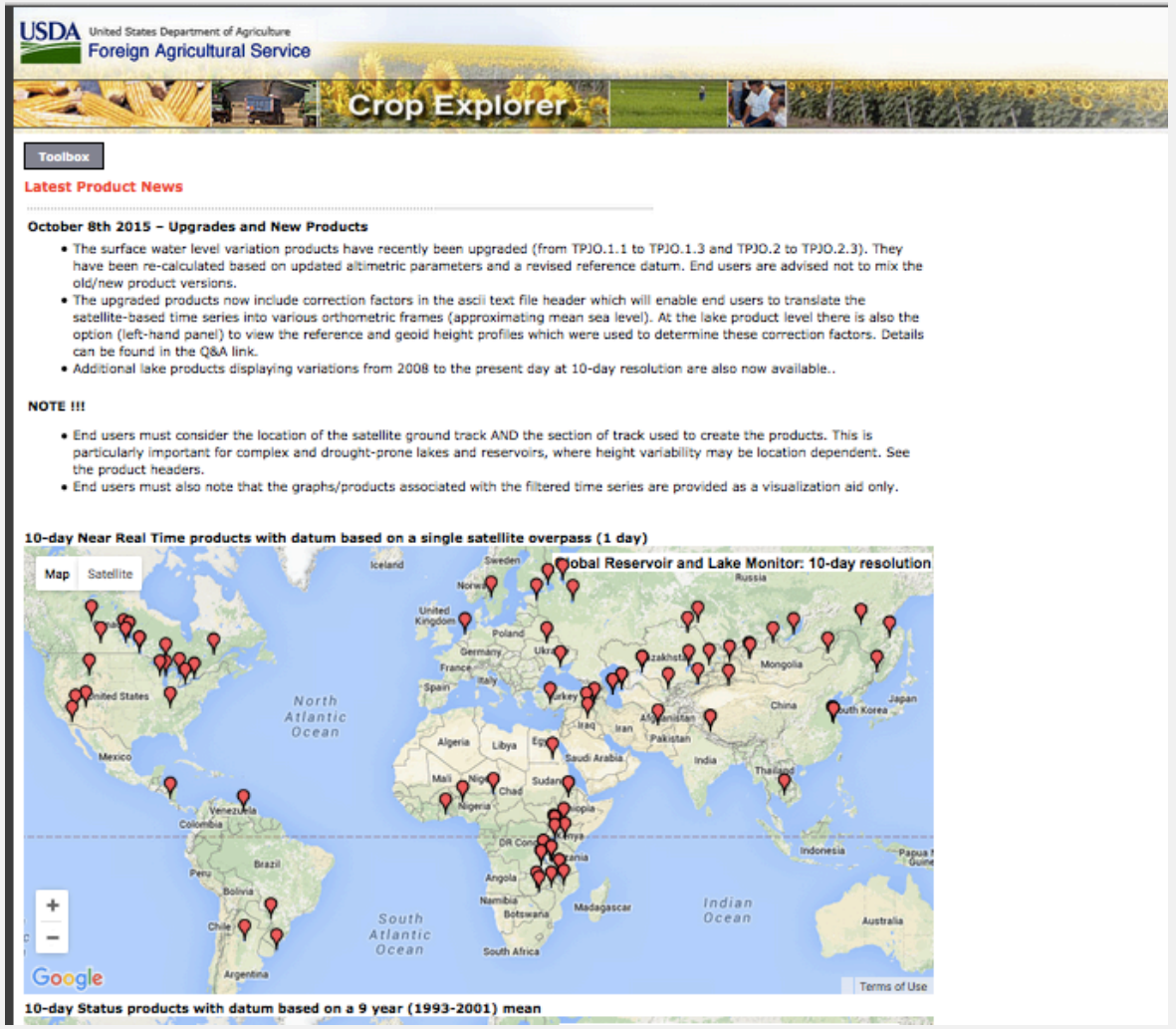
Acknowledgement: Charon M. Birkett, Earth System Science Interdisciplinary Center, University of Maryland, College Park

Where to get Jason Data and Lake Level Heights?

USDA Crop Explorer

U.S. Department of Agriculture
Foreign Agricultural Services

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



Overview of Earth System Models

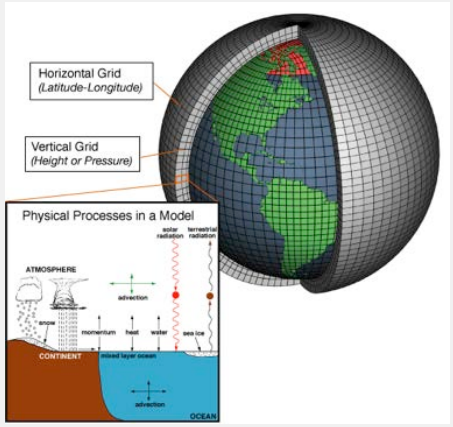
Earth System Models Provide Value-Added Information

Remote Sensing + Surface Observations + Numerical Models

Satellite Data

Surface Measurements and In-Situ Data

Numerical Models



NASA Models Useful for Water Resources Management

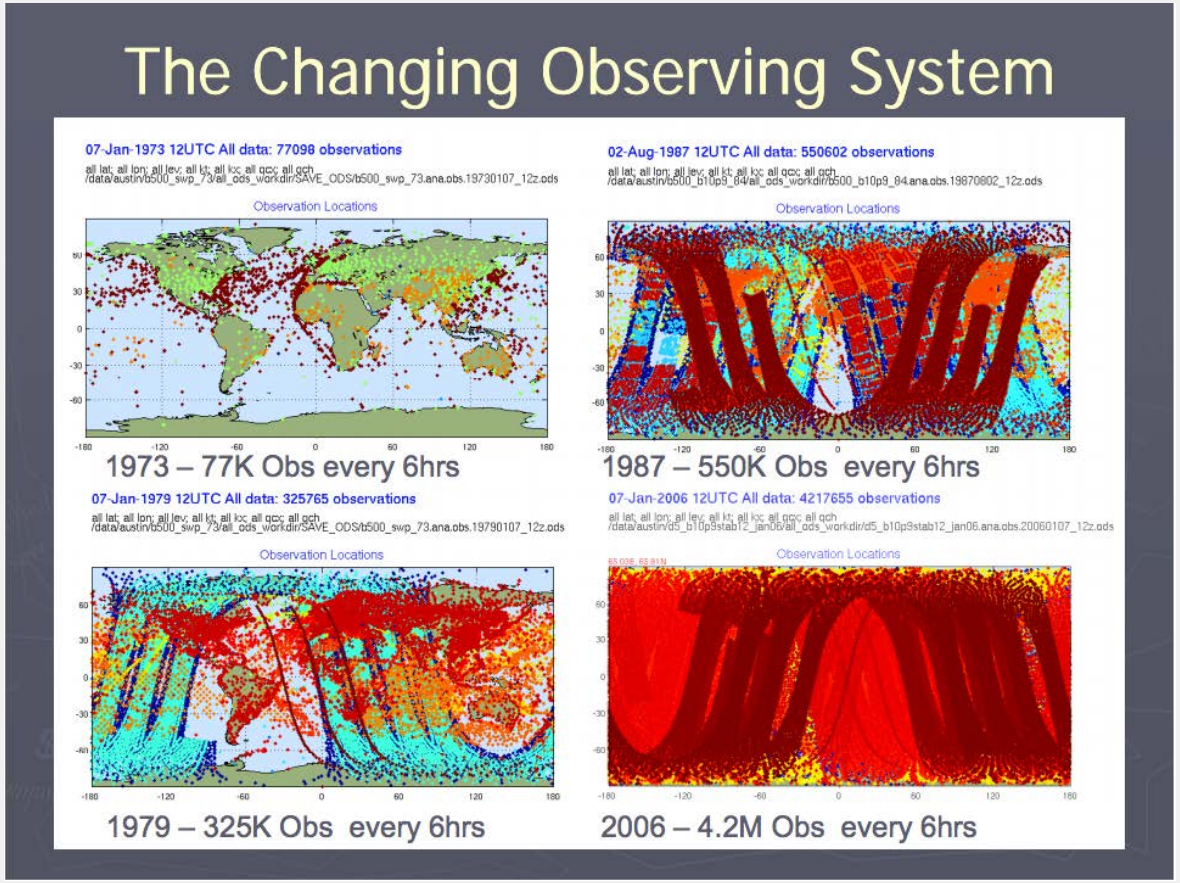
Atmosphere-Ocean-Land Models

- GEOS-5:
  - The Goddard Earth Observing System Version 5
- MERRA:
  - Modern Era Retrospective-Analysis for Research and Application
- GLDAS and NLDAS:
  - Global Land Data Assimilation System
  - North American Land Data Assimilation System

MERRA

https://gmao.gsfc.nasa.gov/reanalysis/MERRA/

- Blends the vast quantities of observational data with output data of the Goddard Earth Observing System (GEOS) model (1979 – present)
- Provides state-of-the-art global analyses on weather to climate time scales
- Focuses on improvement in hydrological cycle
- MERRA-Land Model: offline land surface model forced with MERRA precipitation merged with gauge-based data from the NOAA Climate Prediction Center



Coverage of satellite data assimilated in MERRA

Reference: Bosilovich, M., 2009. https://gmao.gsfc.nasa.gov/pubs/docs/MERRA_Purdue_Sep09.pdf

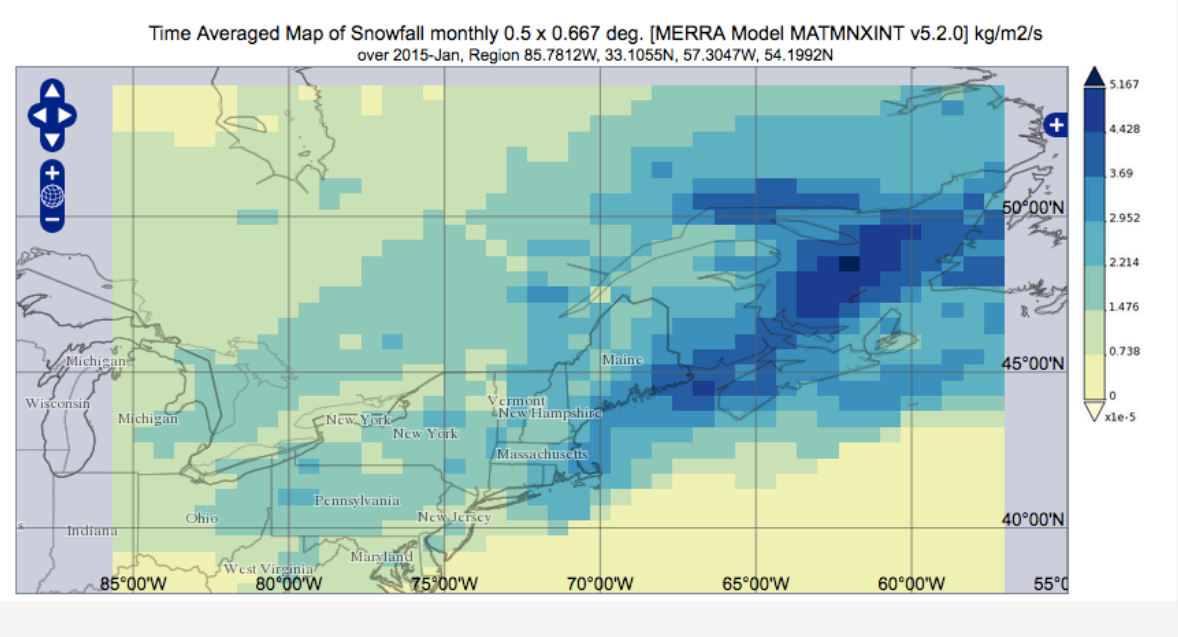
MERRA Data for Water Resources Applications

https://gmao.gsfc.nasa.gov/reanalysis/MERRA/

- Output:
  - Rain
  - Snow
  - Weather and Climate Parameters
    - temperature, humidity, winds, clouds, surface radiation
- MERRA Online Atlas:
  - updated regularly with monthly comparisons versus existing reanalyses and some global observed data sets

    https://gmao.gsfc.nasa.gov/ref/merra/atlas/

Snowfall Over the Northeastern U.S. During January 2015



Reference: Bosilovich, M., 2009. https://gmao.gsfc.nasa.gov/pubs/docs/MERRA_Purdue_Sep09.pdf

Global & North American Land Data Assimilation Systems

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

- Integrates ground and satellite observations within numerical models to produce consistent, high resolution fields of land surface states and fluxes
- Uses data from MODIS, TRMM, GOES
- GLDAS and a version of NLDAS use the Land Information System (LIS) with different sources of inputs:
  - Meteorological Analysis
  - Surface Solar Radiation
  - Precipitation
  - Soil Texture
  - Vegetation Classification and Leaf Area Index
  - Topography

Global Land Data Assimilation Systems

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

Four land surface model versions: Noah, CLM2, Mosaic, and VIC

Inputs

- Rainfall: TRMM and multi-satellite based data
- Meteorological Data: global reanalysis and observations-based data from Princeton University
- Vegetation Mask, Land/Water Mask, Leaf Area Index: MODIS (GLDAS-2)
- Clouds and Snow (for surface radiation): NOAA and DMSP Satellites

Integrated Outputs Include:

- Soil Moisture
- Evapotranspiration
- Surface/Sub-Surface Runoff
- Snow Water Equivalent

Reference: Rodell, M., P. R. Houser, U. Jambor, J. Gottschalck, K. Mitchell, C.-J. Meng, K. Arsenault, B. Cosgrove, J. Radakovich, M. Bosilovich, J. K. Entin, J. P. Walker, D. Lohmann, and D. Toll, 2004. The Global Land Data Assimilation System. Bulletin of the American Meteorological Society, 85(3):381–394.

North American Land Data Assimilation System-2 (NLDAS-2)

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

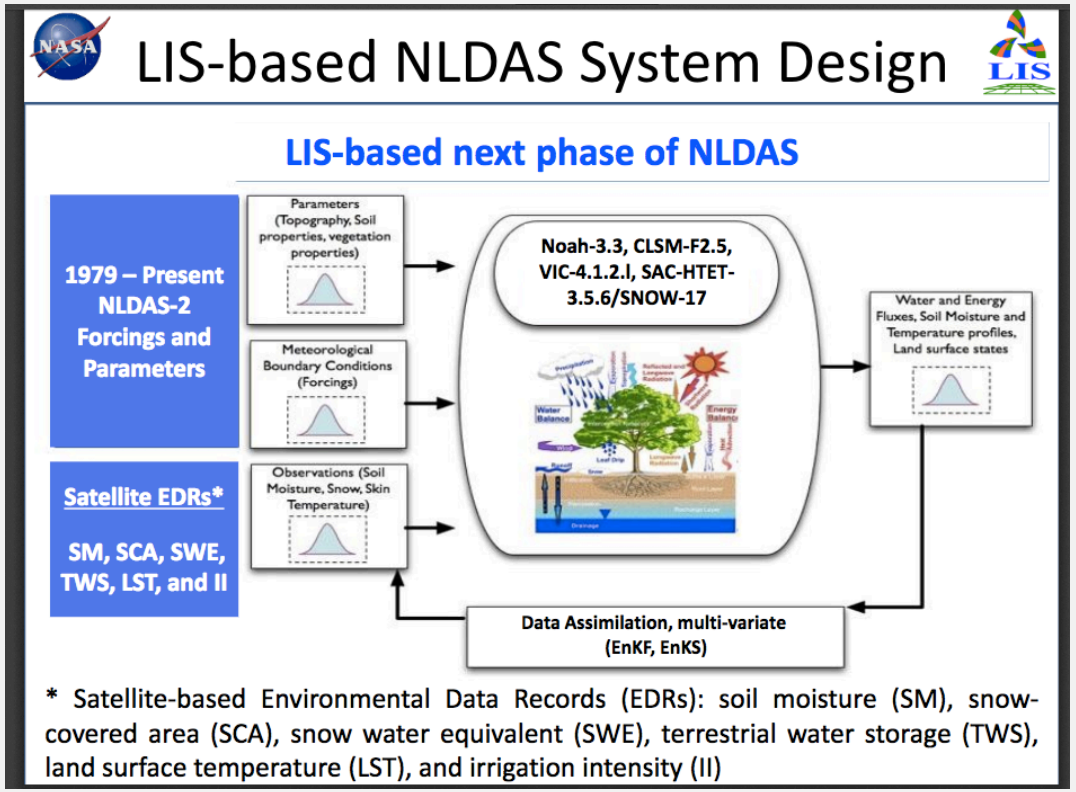
Four land surface model versions: Noah, CLM2, Mosaic, and VIC

Inputs

- Precipitation: NOAA-CPC rain gauges
- Meteorological Data, Surface Radiation Data: North American Regional Analysis

Integrated Outputs Include:

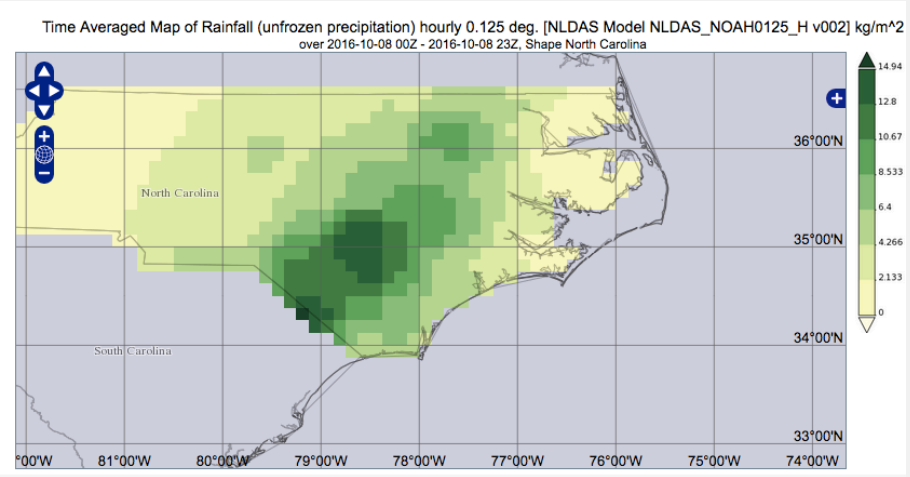
- Soil Moisture
- Evapotranspiration
- Surface/Sub-Surface Runoff
- Snow Water Equivalent



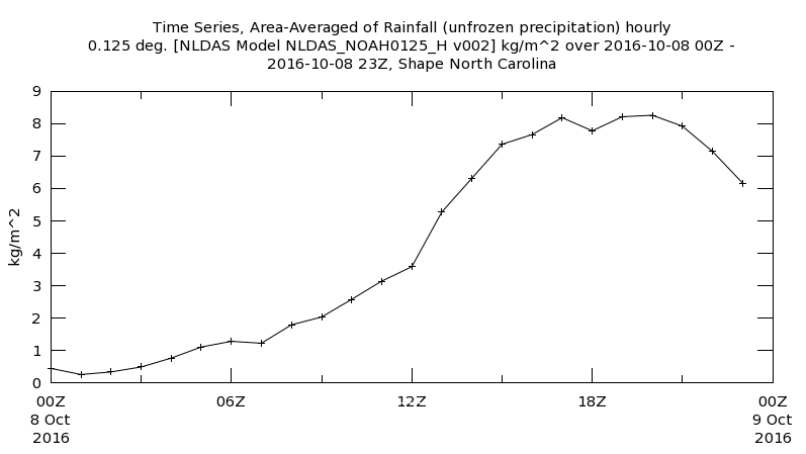
Courtesy: David Mocko (NASA-GSFC), http://ldas.gsfc.nasa.gov/nldas/presentations/NLDAS-LIS-status-future_2015-03-11.pdf

GLDAS and NLDAS for Water Resources Applications

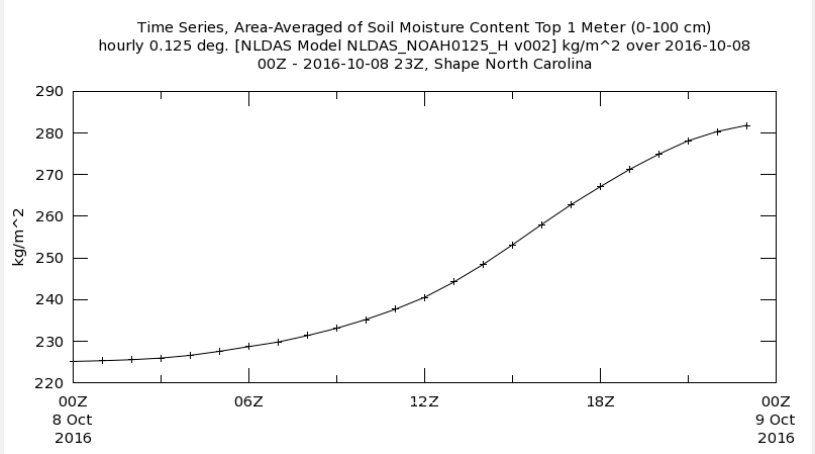
- Freshwater Components: all available
- Right: rainfall over North Carolina on October 8, 2016, associated with Hurricane Matthew
- Below: Hourly time evolution of water components averaged over North Carolina on October 8, 2016



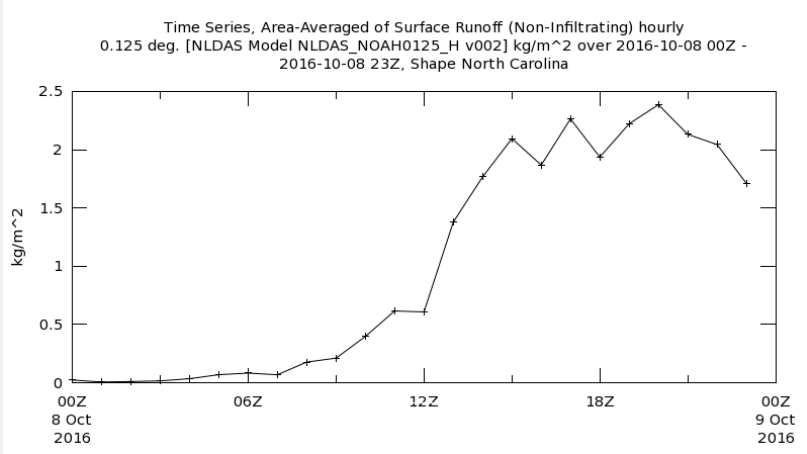
Rainfall



Soil Moisture



Runoff



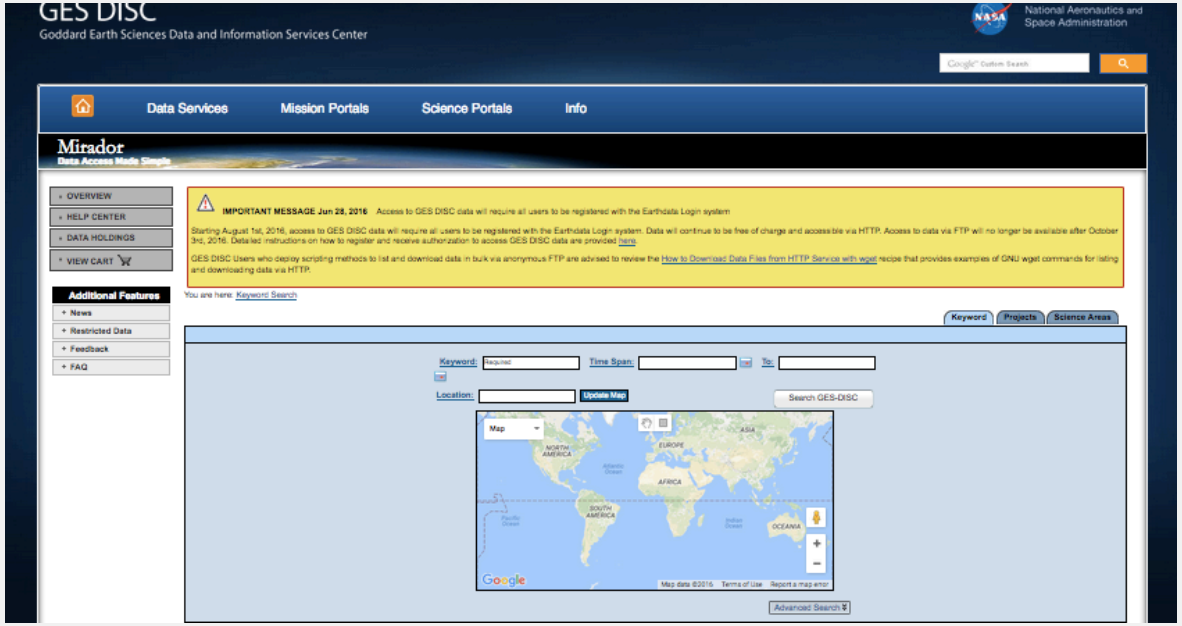
Where to get MERRA and LDAS Data?

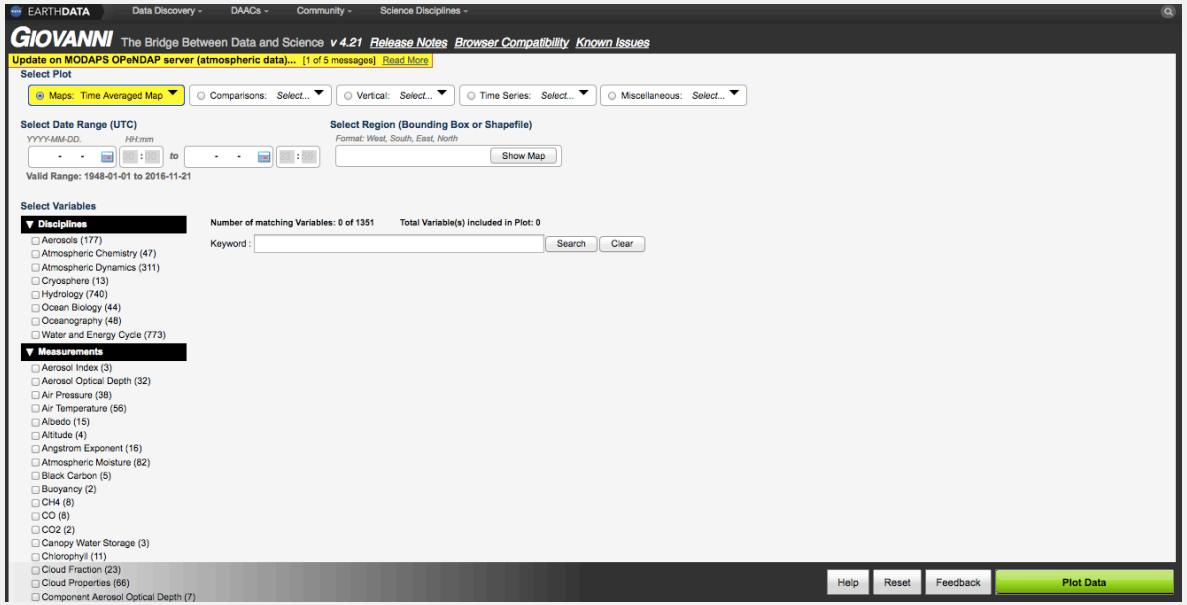
Mirador

http://mirador.gsfc.nasa.gov/

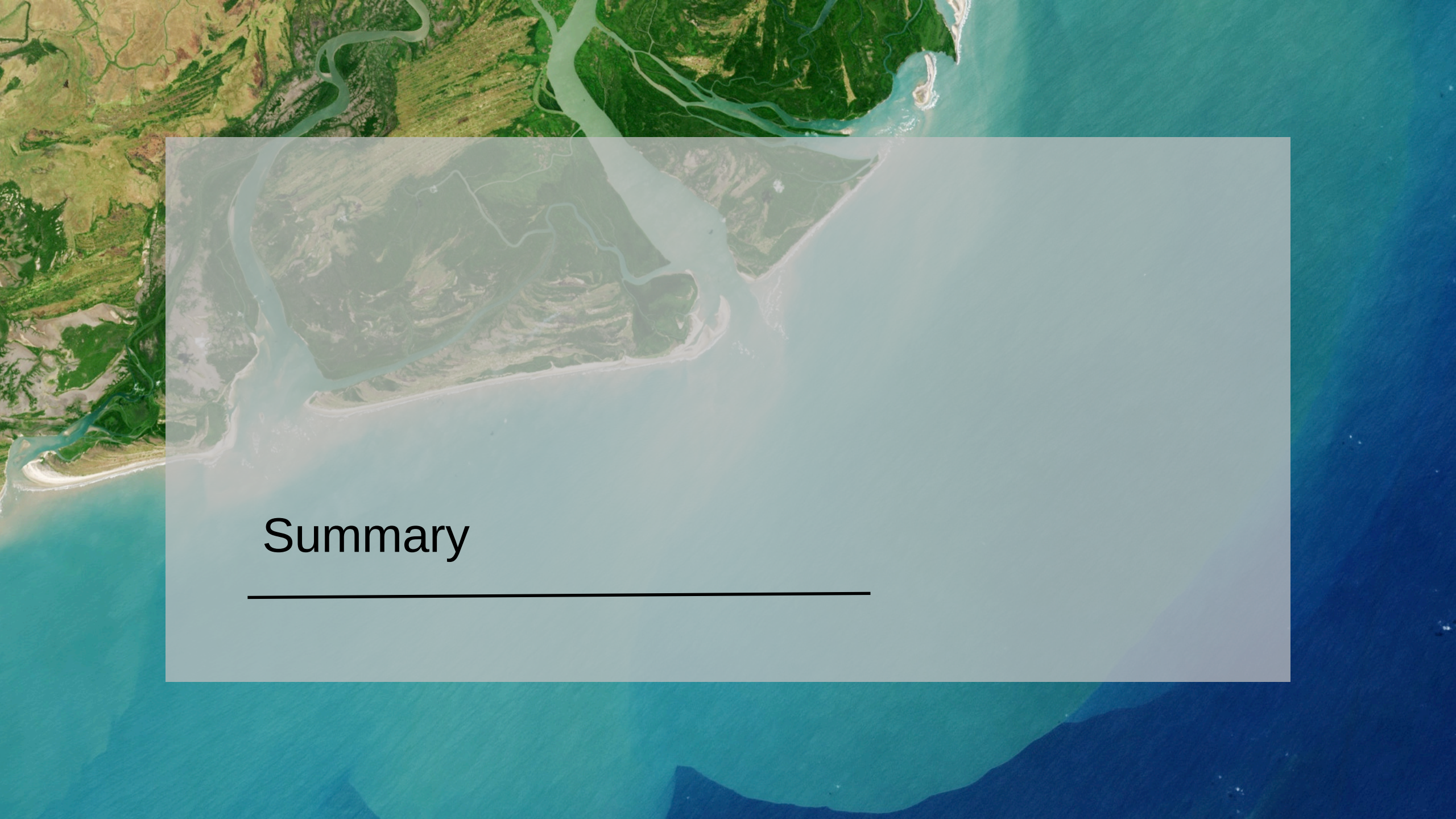
Giovanni

http://giovanni.gsfc.nasa.gov/giovanni/





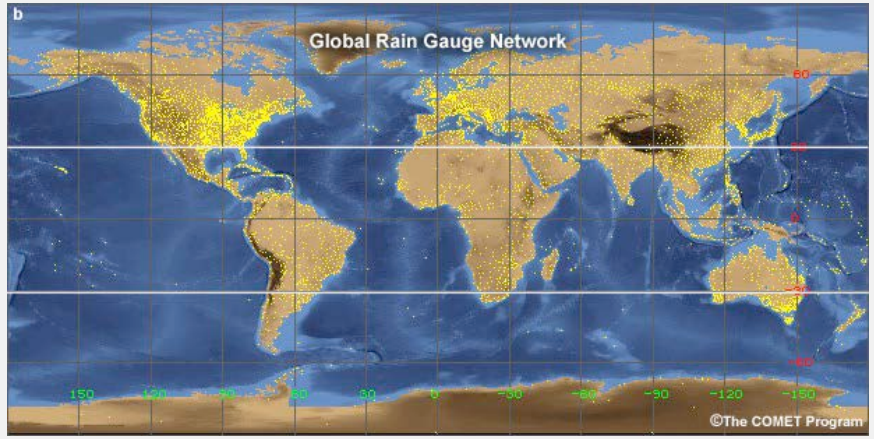
Spatial and Temporal Sub-Setting and Download

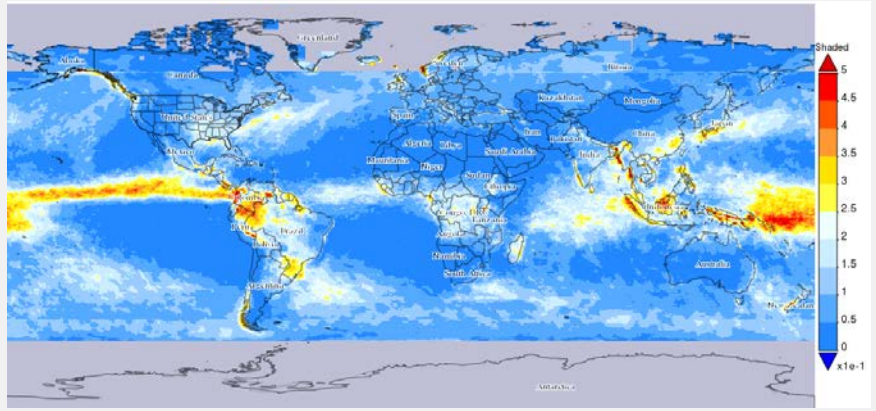


Summary

Advantages of NASA Water Resources Data

- Remote sensing-based data provide near-global - global coverage compared to surface-based, spatially non-uniform point measurements
- Provide data where surface-based measurements are unavailable
- Earth systems models integrate surface-based and remote sensing observations and provide uniformly gridded, frequent information of water resources data parameters
- Earth system models provide parameters that aren't directly observed by satellites (e.g. runoff, ET)
- Data are **free** and there are web-based tools for data





Top: Global rain gauge locations. Credit: Introduction to Tropical Meteorology, The COMET Program

Bottom: Annual Precipitation (2015) from NASA GPM

Limitations of NASA Water Resources Data

- All freshwater components are measured by different satellites and sensors with varying spatial and temporal resolutions, coverage, and quality
- Satellite and model data files are large and in different data formats: training is required to learn how to access them
- Often additional processing may be needed for specific applications
- While the data are generally validated with selected surface measurements, regional and local assessment is recommended

Water Resources Data From NASA Satellites and Models

Freshwater Component	Satellite/Sensor	Model	Data Access
Rain Amount	GPM /(GMI, DPR) & TRMM /(TMI, PR) – IMERG and TMPA Multi-satellite data	GLDAS & NLDAS forcing data from NOAA Climate Prediction Center MERRA	https://pmm.nasa.gov/ http://mirador.gsfc.nasa.gov/ http://giovanni.gsfc.nasa.gov/giovanni/
Snow Cover	Terra & Aqua/MODS	-	http://nsidc.org/data/modis/data_summaries#snow http://reverb.echo.nasa.gov/reverb/ http://snow.jpl.nasa.gov/portal/

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Soil Moisture	SMAP/(Microwave Radiometer)	GLDAS & NLDAS	http://nsidc.org/data/search/#keywords=soil+moisture/ http://mirador.gsfc.nasa.gov/ http://giovanni.gsfc.nasa.gov/giovanni/
Land Cover And NDVI (For ET Estimation)	Landsat/OLI Terra & Aqua/MODS	-	http://earthexplorer.usgs.gov http://glovis.usgs.gov/ http://landsatlook.usgs.gov/viewer.html https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table

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Runoff	-	GLDAS & NLDAS	http://mirador.gsfc.nasa.gov/ http://giovanni.gsfc.nasa.gov/giovanni/
Ground Water	GRACE/K-band Ranging System	GLDAS & NLDAS	http://grace.jpl.nasa.gov/data/ http://geoid.colorado.edu/grace/ http://mirador.gsfc.nasa.gov/ http://giovanni.gsfc.nasa.gov/giovanni/
Reservoir Height	Jason/Altimeter	-	http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir

ARSET ListServ

https://lists.nasa.gov/mailman/listinfo/arset

Thank You!