Applications of Remote Sensing for Monitoring The Water Budget Within River Basins

Amita Mehta and Sean McCartney

13 March 2019

Training Objectives

Become familiar with:

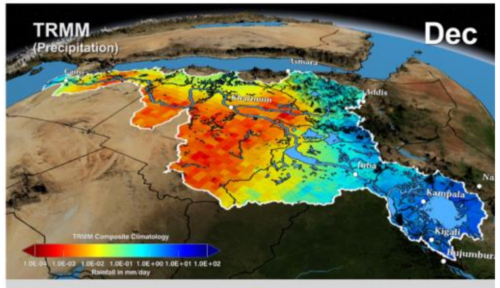
- Remote sensing and Earth system modeling data relevant for river basin management
- Estimation of surface water budgets and their temporal variability in sub-watersheds within river basins using data access tools and QGIS

Training Outline

13 March 2019
Overview of Remote Sensing Data
For River Basin Monitoring

http://wwf.hu/en/the-river-basin-management-plan

20 March 2019
Applications of Remote Sensing for River
Basin Monitoring: Nile Basin

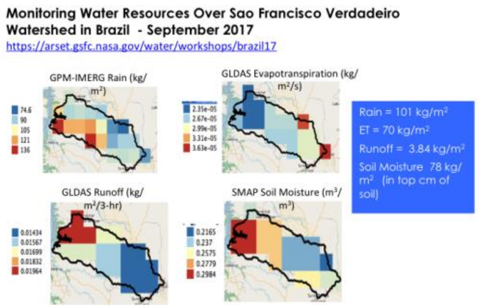


https://svs.gsfc.nasa.gov/4044

27 March 2019
Applications of Remote Sensing for River
Basin Monitoring: Mekong Basin

https://earthobservatory.nasa.gov/images/91761/a-new-reservoir-in-cambodia

3 April 2019
Surface Fresh Water Budget Estimation



https://arset.gsfc.nasa.gov/water/workshops/brazil17

Homework and Certificate

- Homework will be available after Sessions 2 and 4 from:
  https://arset.gsfc.nasa.gov
  - Answers must be submitted via Google Form
  - Due dates: 4 April (Homework 1) & 17 April (Homework 2)
- Certificate of Completion will be awarded to those:
  - Attend all webinars
  - Complete homework assignments
- You will receive certificates approximately two months after the completion of the course from: marines.martins@ssaihq.com

Session-1 Outline

- About ARSET
- River basin monitoring and management: importance and approach
- Overview of remote sensing data sources relevant for river basin monitoring and management
  - River basin delineation
  - Surface water budget components
- Demonstration river basin delineation

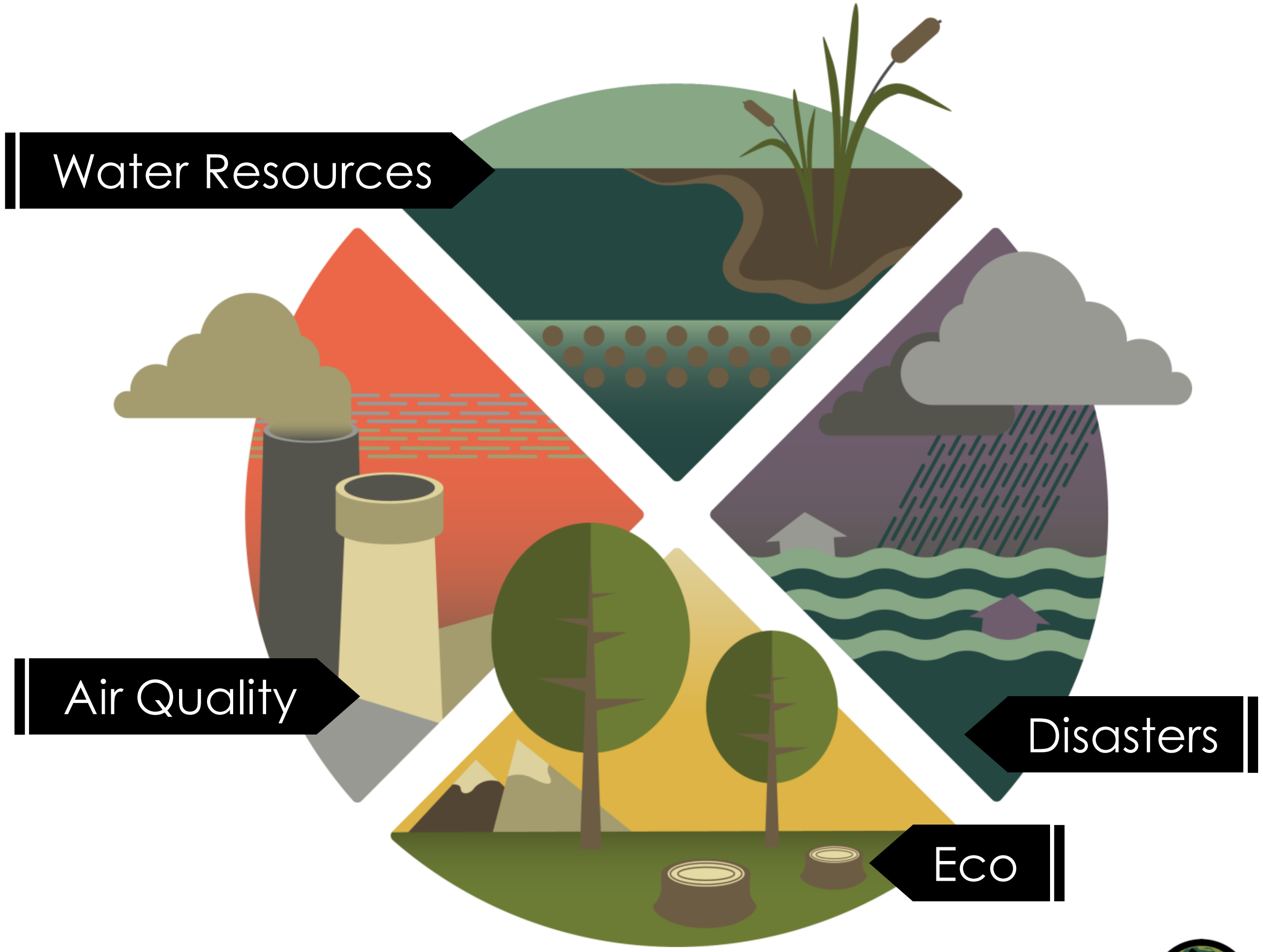
About ARSET

NASA's Applied Remote Sensing Training Program (ARSET)

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

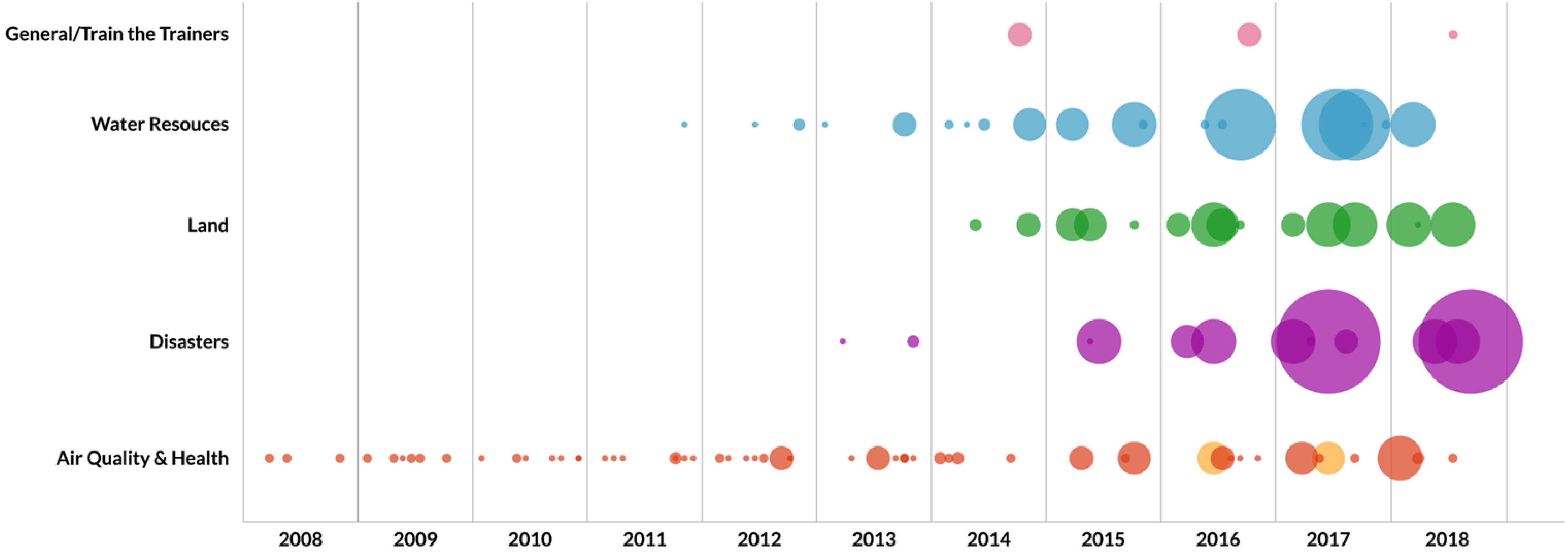
- Part of NASA's Applied Sciences Capacity Building Program
- Empowering the global community through remote sensing training
- Goal to increase the use of Earth science in decision-making through training for:
  - policy makers
  - environmental managers
  - other professionals in the public and private sector

Topics for trainings include:



ARSET Trainings

100 trainings 13,000+ participants 160+ countries 3,700+ organizations



* Size of bubble corresponds to number of attendees

ARSET Team Members

Program Support

- Ana Prados, Program Manager (GSFC)
- Brock Blevins, Training Coordinator (GSFC)
- David Barbato, Spanish Translator (GSFC)
- Annelise Carleton-Hug, Program Evaluator (Consultant)
- Elizabeth Hook, Technical Writer/Editor (GSFC)
- Marines Martins, Project Support (GSFC)
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- Stephanie Uz, Program Support (GSFC)

Acknowledgement:

- We wish to thank Nancy Searby for her continued support

Disasters & Water Resources

- Amita Mehta (GSFC)
- Erika Podest (JPL)
- Sean McCartney (GSFC)

Land & Wildfires

- Cynthia Schmidt (ARC)
- Amber Jean McCullum (ARC)

Health & Air Quality

- Pawan Gupta (MSFC)
- Melanie Cook (GSFC)

ARSET Training Formats

Online

Typically offered via the internet

2-5 weeks long

1-2 hours a week

Available at all skill levels

Live & recorded

Materials available in English & Spanish

Free

In-Person

Hosted with a partner

Typically in a computer lab

2-7 days long

Focus on locally-relevant case studies

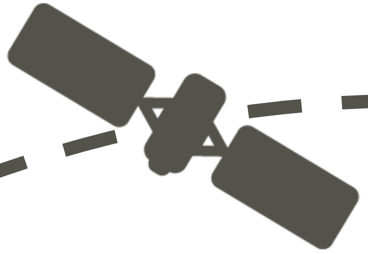
Certain topics can be presented in Spanish

Train the Trainers

Online or in-person

Designed for individuals and organizations looking to develop their own applied remote sensing trainings

ARSET Training Levels



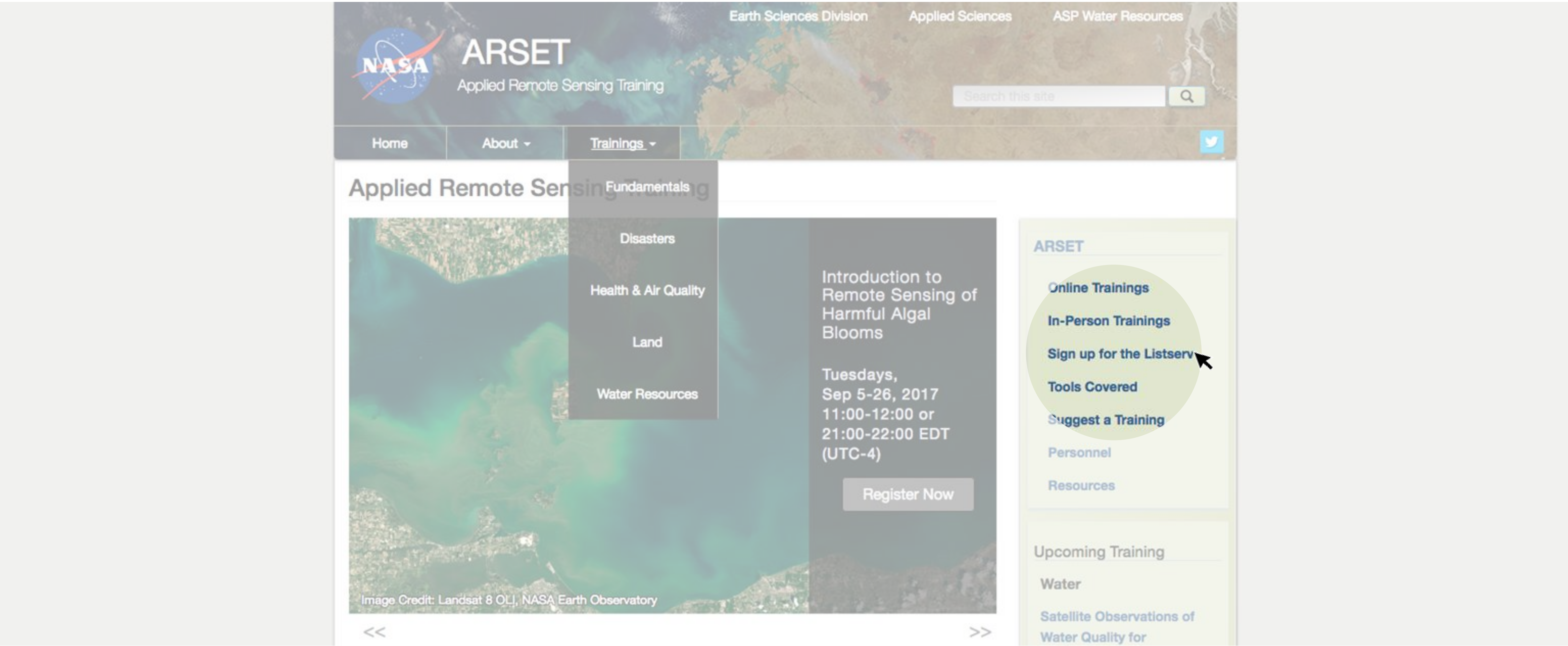
Advanced (Level 2)
Requires level 1 training or equivalent knowledge
In-depth and highly focused topics
Advanced Webinar: SAR Image and Data Processing

Basic (Level 1)
Requires level 0 training or equivalent knowledge
Covers specific applications
Introduction to Synthetic Aperture Radar

Fundamentals (Level 0)
Assumes no prior knowledge of remote sensing
Fundamentals of Remote Sensing

Learn More About ARSET

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



River Basin Monitoring and Management: Importance and Approach

What is a River Basin?

- An area of land that drains water into a river and its tributaries
- A river basin usually has multiple drainage catchments or watersheds separated by ridges and hills called the drainage divide
- Each watershed in a river basin collects rain and/or snow water and drains to a common outlet such as a stream, tributary, lake, or wetland – eventually contributing water to the river
- A river basin consists of surface water and also underlying groundwater

Colorado River Basin

https://www.americanrivers.org/river/upper-basin-colorado-river/

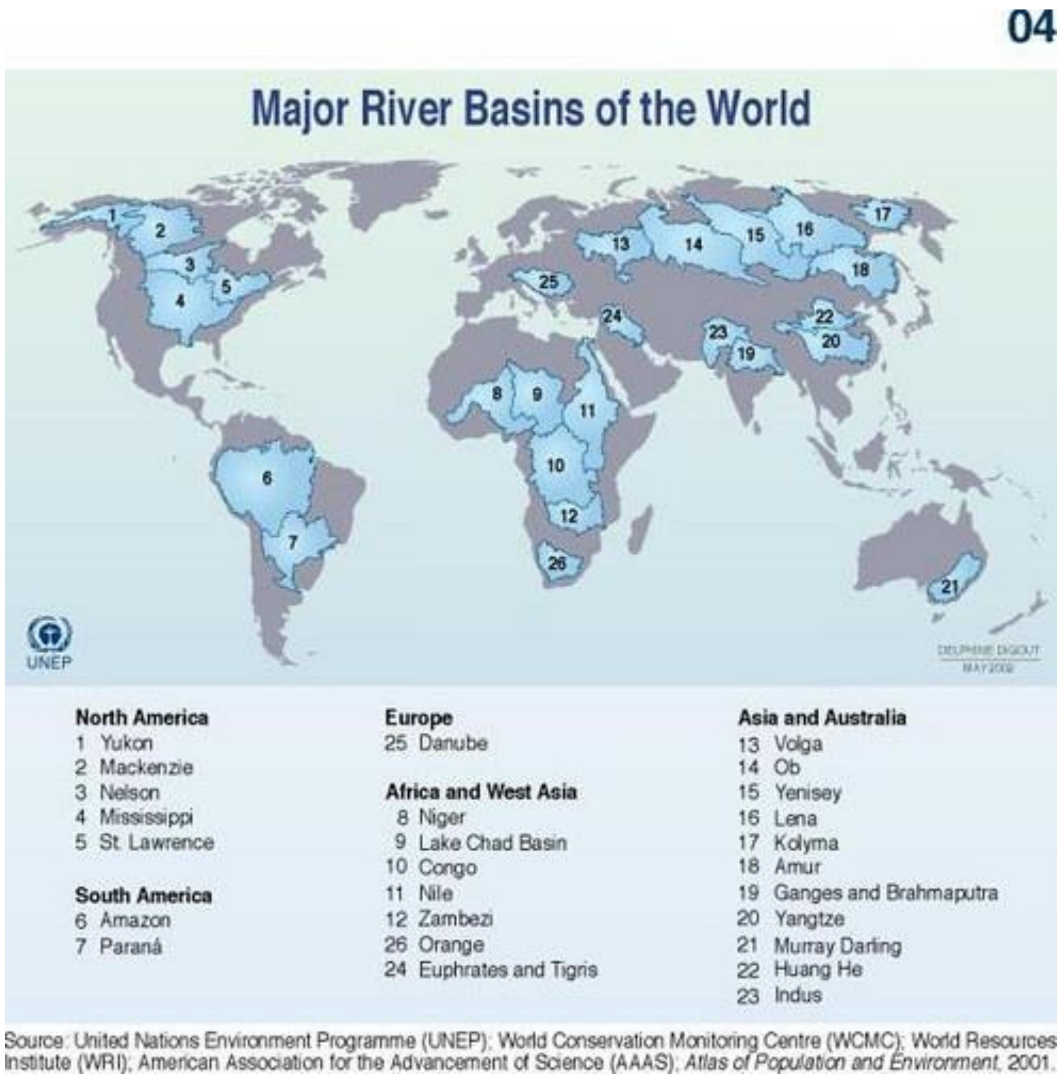
https://water.usgs.gov/edu/watershed.html

Importance of River Basins

- River Basins:
  - connect rivers with surrounding land hydrology, ecology, and socio-economic components within basins
  - are dynamic spatially and temporally, and affect availability of freshwater in the river
- Rivers:
  - are a major source of freshwater for drinking and agricultural activities
  - support a variety of aquatic and terrestrial ecosystems
  - provide means of transportation and hydropower generation

https://wwf.panda.org/our_work/water/rivers/irbm/

Importance of River Basins: The Major Source of Water

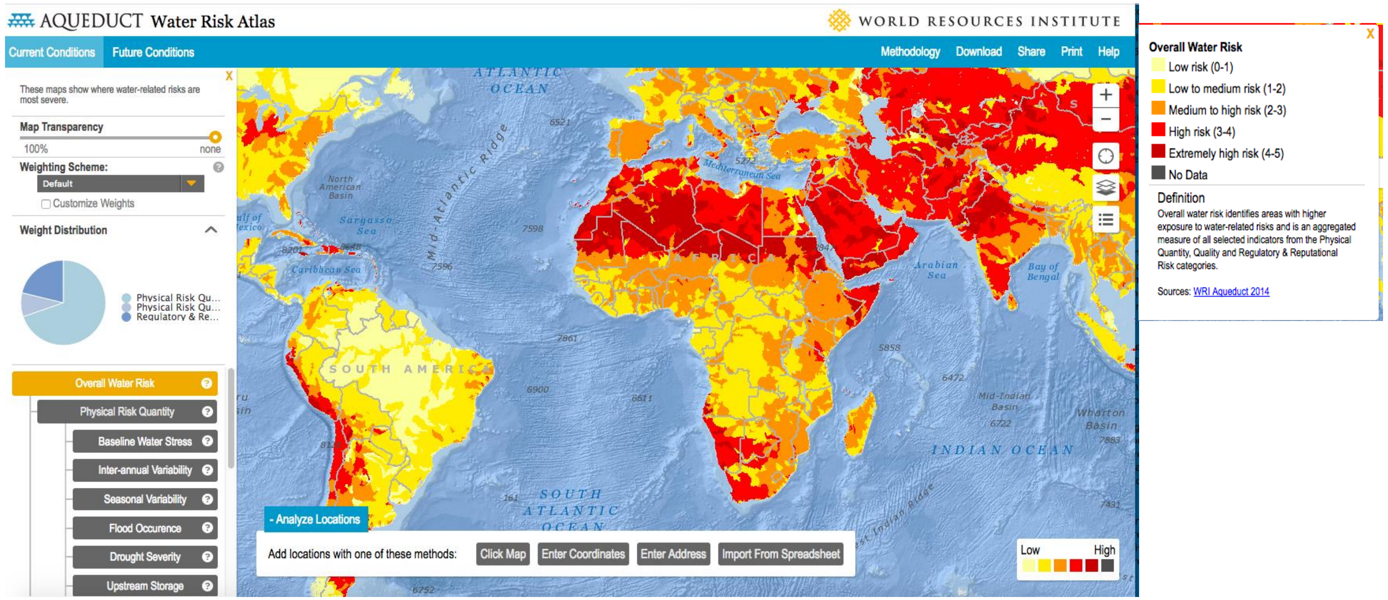


https://www.grida.no/resources/5782

https://www.euratlas.net/geography/world/rivers/index.html

Importance of River Basin Management

- Water stress, flood occurrence, and drought severity are increasing in many parts of the world



http://www.wri.org/applications/maps/aqueduct-atlas/#x=8.00&y=0.40&s=ws!20!28!c&t=waterrisk&w=def&g=0&i=BWS-16!WSV-4!SV-2!HFO-4!DRO-4!STOR-8!GW-8!WRI-4!ECOS-2!MC-4!WCG-8!ECOV-2!&tr=ind-1!prj-1&l=3&b=terrain&m=group

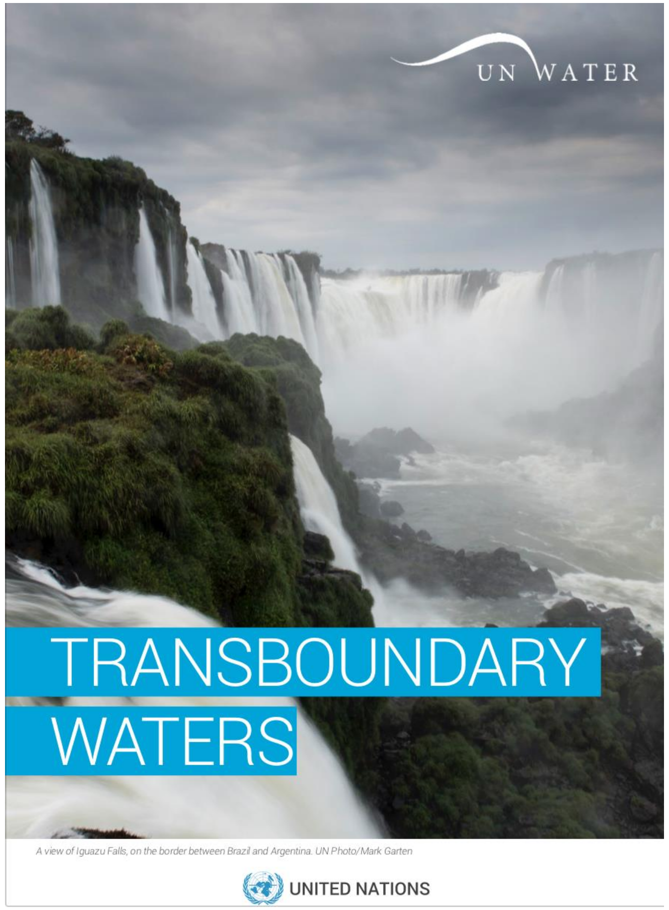
- For water allocation, distribution, and sharing among states/regions within a country or among various countries in the same river basin, river basin management is crucial

http://www.unwater.org/water-facts/transboundary-waters/

Importance of River Basin Management: Transboundary Rivers

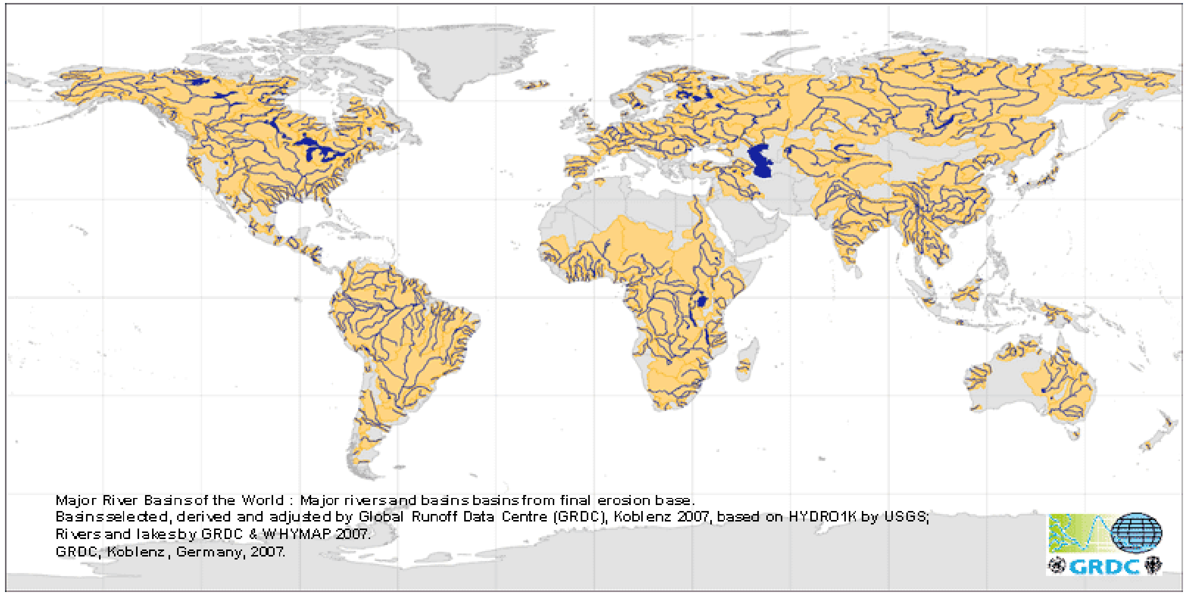
http://www.unwater.org/water-facts/transboundary-waters/

- There are 263 transboundary river basins covering about half the Earth's surface
- 145 states have territory within transboundary lake or river basins, and 30 countries lie entirely within them
- Since 1948, 37 incidents of acute conflict over water have occurred, and approximately 295 international water agreements have been negotiated and signed.



http://www.unwater.org/app/upload/2018/10

Importance of River Basin Management



"River systems are the life blood of our planet, an integral part of the global climate system. As such they feed back to many geophysical processes on local, regional and global scales"

https://www.bafg.de/SharedDocs/Bilder/Bilder_GRDC/major_rivers_and_basins.gif?__blob=poster

- River basin management involves policies and decisions at the river basin scale, which guide actions at sub-basin levels including:
  - Sustainable water supplies for all stakeholders (domestic, industrial, and agricultural)
  - Flood and drought management
  - Improved land and ecosystem management
  - Improved sanitation

https://wwf.panda.org/our_work/water/rivers/irbm/

River Basin Management

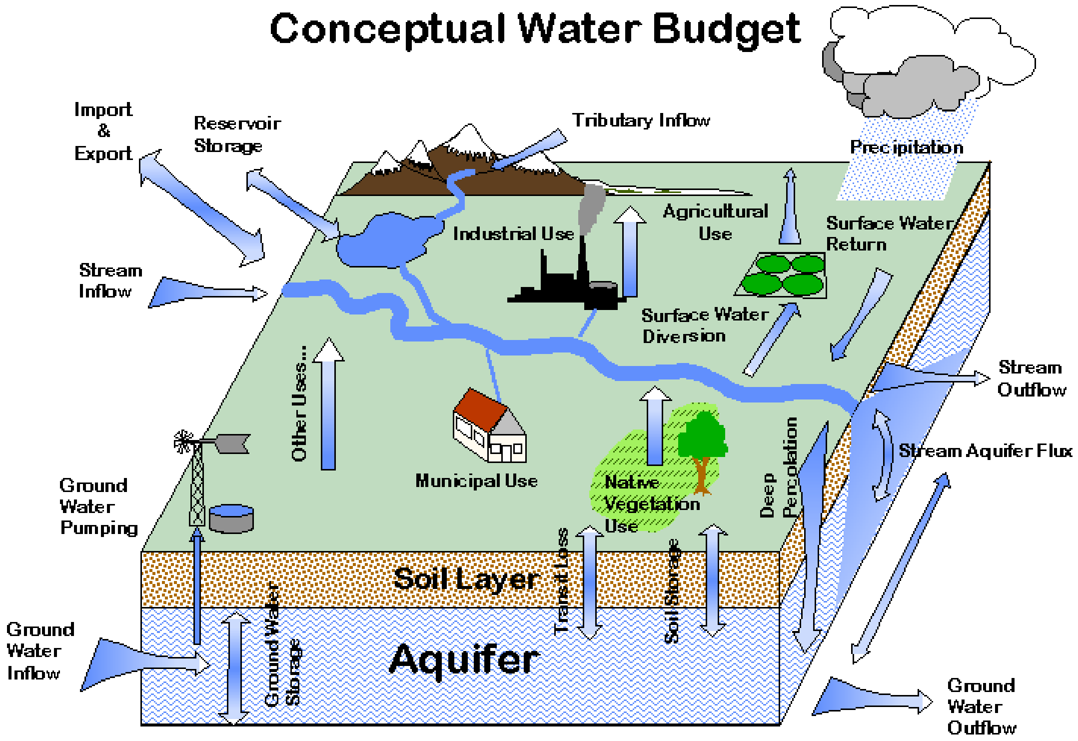
http://www.unece.org/fileadmin/DAM/env/water/publications/WAT_Good_practices/2015_PCCP_Flyer_Good_Practices__LIGHT_.pdf

Some factors for good river basin management practices:

- Multi-level involvement of stakeholders
- **Data and information** - basin level organization is needed in order to implement Integrated Water Resource Management
- Human right to water is key in addressing access to drinking water
- Trust between stakeholders
- Capacity building of stakeholders

River Basin Management

- River Basin Management primarily requires monitoring water availability and demand in the basin
- Water availability depends on basin hydrology and ecology, and is influenced significantly by weather and climate
- Monitoring water availability within a river basin is crucial for efficient and effective basin management*



https://www.water-research.net/index.php/the-hydrological-cycle-water-budgets

* Water quality monitoring also is an important part of river basin management. This webinar focuses on data relevant for monitoring water quantity

River Basin Management

Also requires:

- Accurate identification and delineation of watersheds and stream channels within a basin based on terrain and slope
- Characteristics of the basin – soil and vegetation, lakes and reservoirs, aquifer/groundwater storage
- Information about water demand – residential, agricultural, and industrial – in the basin

This webinar will focus on the application of remote sensing-based data for access to river networks and assessing surface water budget components in river basins

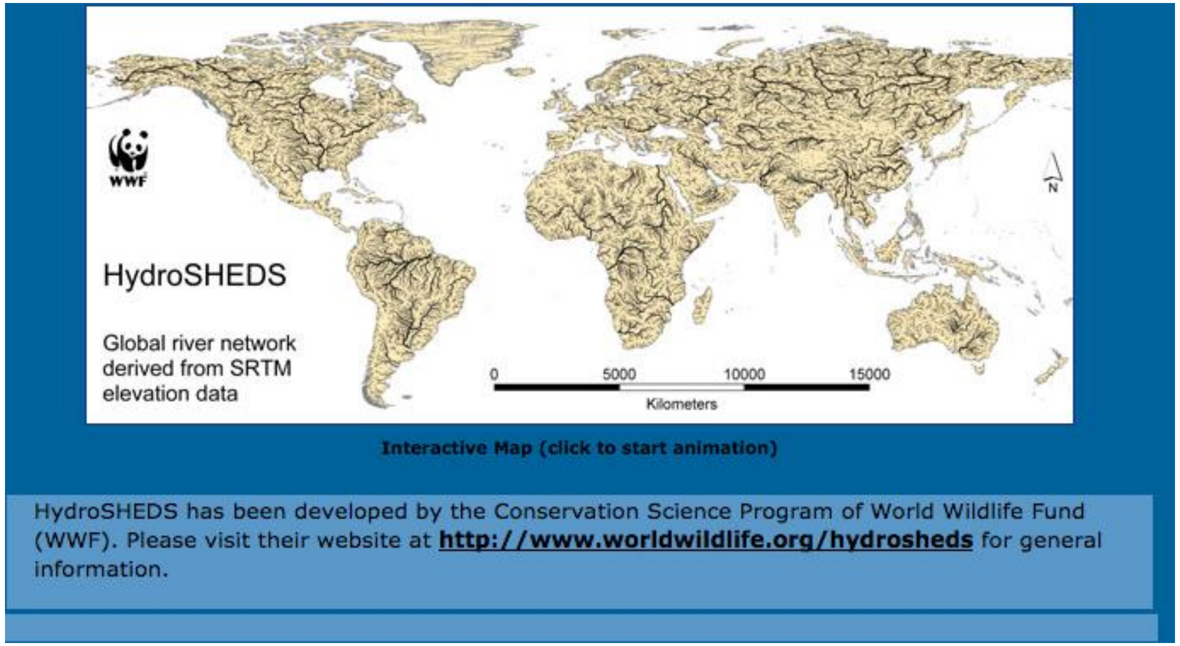
Overview of Remote Sensing Data Sources Relevant for River Basin Monitoring and Management

- River Basin Delineation
- Surface Water Budget Components

River Basin Network Based on Remote Sensing

https://www.hydrosheds.org/ https://hydrosheds.cr.usgs.gov

- **Hydro**logical data and maps based on **SH**uttle **E**levation **D**erivatives at multiple **S**cales (**HydroSHEDS**) provides data sets of stream networks, watershed boundaries, drainage directions, flow accumulations, distances, and river topology information
- HydroSHEDS uses digital elevation data from the Shuttle Radar Topography Mission (SRTM)*, a C-band (5.6 cm) radar, carried on-board the Space Shuttle Endeavour



*See Appendix slides for more information on SRTM

River Basin Network Based on Remote Sensing

https://hydrosheds.cr.usgs.gov/datasets.php

- HydroSHEDS data set development: details, quality check, format, and download information
  - Data void filling
  - Stream identification and hydrologic conditions derived using GIS
  - Removing spurious features
  - Coastal zone “weeding” to reduce the impact of mangroves and vegetation on digital elevation data
  - Stream ”burning” to enforce known river courses onto an elevation surface
  - Modeling valley courses to improve river delineation in low lying areas
  - Quality checking – more uncertainty in flat and vegetated areas

River Basin Data Availability from HydroSHEDS

https://hydrosheds.cr.usgs.gov/dataavail.php

- Data are available for download with the following filename convention: **Extent_DataType_Resolution**

Extent

Identifier	Continent
Af	Africa
As	Asia
Au	Australasia
Eu	Europe
Na	North America
Sa	South America

Resolution

Identifier	in sec/min	in degree	in meters/km
3s	3 arc-second	0.000833333333333	approx. 90 m at the equator
15s	15 arc-second	0.004166666666667	approx. 500 m at the equator
30s	30 arc-second	0.008333333333333	approx. 1 km at the equator
5m	5 minute	0.083333333333333	approx. 10 km at the equator

Data Type

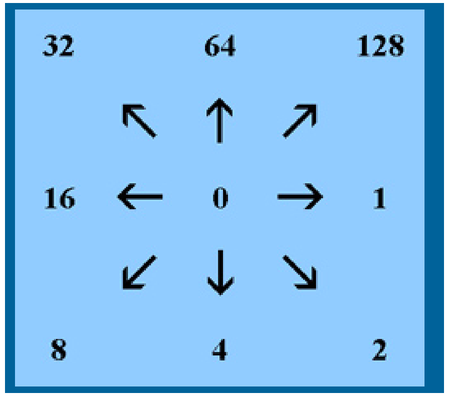
Identifier	Type of data
DEM	Digital elevation model (void-filled)
CON	Hydrologically conditioned elevation
DIR	Drainage directions
ACC	Flow accumulation (number of cells)
RIV	River network (stream lines)
BAS	Drainage basins (watershed boundaries)

River Basin Data Layers and Format from HydroSHEDS

https://hydrosheds.cr.usgs.gov/data.php

- Data are available in ESRI vector and raster* format in WGS84

Layer Name	Format	Data	Resolution
DEM Void-filled Digital Elevation Model	Raster	Elevation in meters	3 arc-sec 15 arc-sec
CON Hydrologically Conditioned Elevation	Raster	Elevation in meters	3 arc-sec
DIR Drainage Direction	Raster	ESRI direction numbers	3 arc-sec 15 arc-sec
ACC Flow Accumulation	Raster	Number of upstream cells draining into each cell	15 arc-sec
RIV River Network	Vector	Unique identifier and maximum flow accumulation number of cells	15 arc-sec
BAS Drainage Basin	Vector	Unique identifier and surface area in km^2	15 arc-sec



*Raster data are also available in binary images in Band Interleaved by Line (BIL) format

Monitoring Water Availability in River Basins

- Monitoring water availability in a basin – water flow in streams within the basin – requires information/observations/modeling of water budget components in the basin
- Water flow in a stream/river depends on the following components in the watershed contributing to the flow:
  - Precipitation
  - Evaporation and Transpiration
  - Infiltration
  - Surface water: soil moisture, reservoirs, and groundwater storage
  - Runoff

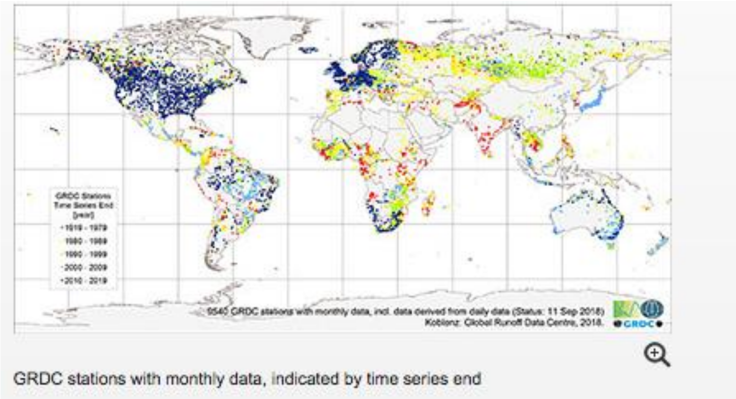
Monitoring Water Availability in River Basins

- Water flow in a stream/river depends on the following components in the watershed contributing to the flow:
  - Precipitation
  - Surface Water: soil moisture, reservoirs, and groundwater storage
  - Evaporation and Transpiration
  - Infiltration: soil characteristics, soil moisture, terrain and slope
  - Runoff

Can be obtained from surface-based and remote sensing observations
Can be calculated based on other observable geophysical parameters
Can be calculated based on a water balance equation

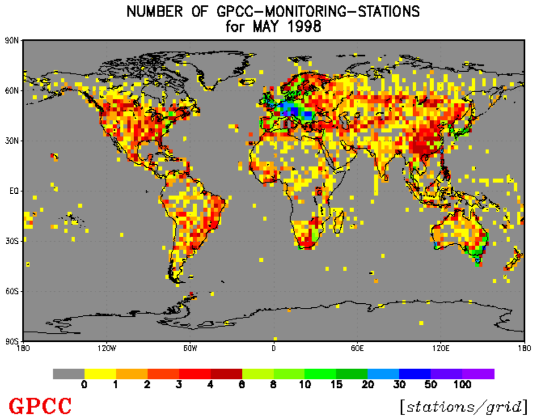
Monitoring Water Budget Components: Surface-Based Observations

River Discharge



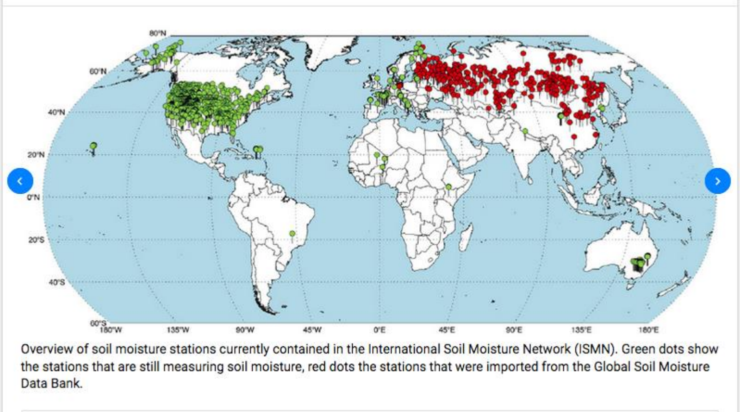
https://www.bafg.de/GRDC/EN/02_srvcs/21_tmsrs/riverdischarge_node.html

Precipitation



Number of rain gauges per grid box. These boxes are 2x2 degrees. (Source: Global Precipitation Climatology Project)

Soil Moisture



https://www.geo.tuwien.ac.at/insitu/data_viewer/

Evapotranspiration

Eddy Covariance System

Lysimeters

Surface measurements are very important, **but** are point measurements, have non-uniform coverage, and data void regions

Monitoring Water Budget Components: Remote Sensing-Based Observations

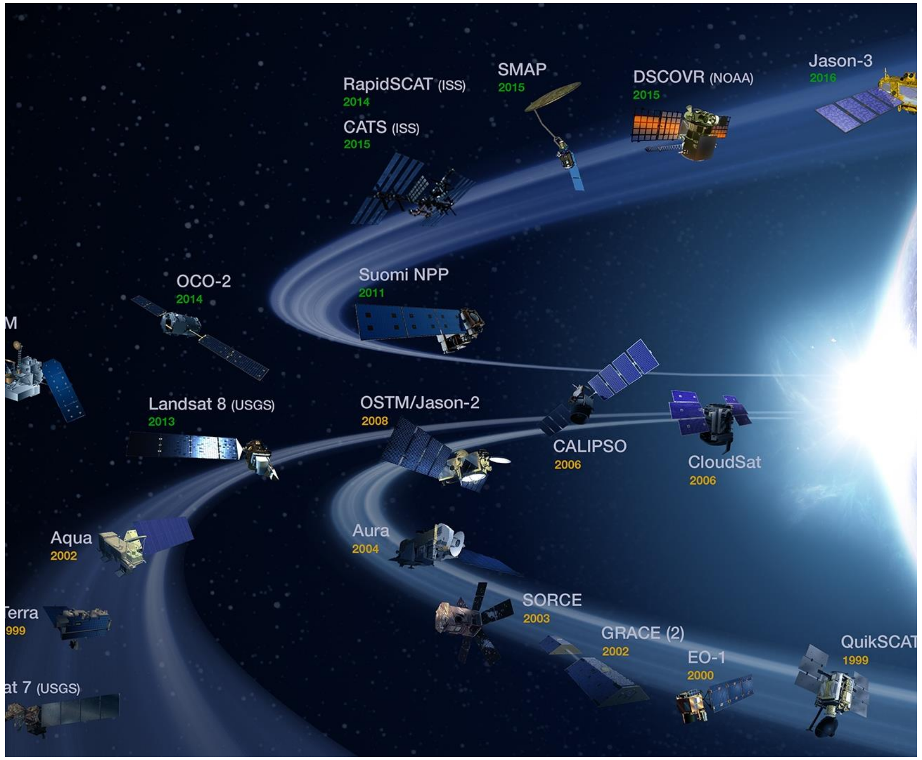
Water Budget Component	Satellites	Earth System Model
Rain	TRMM, GPM	GLDAS
Evapotranspiration	Landsat, Terra, Aqua	
Soil Moisture	SMAP	
Runoff		
*Groundwater	GRACE, GRACE-FO	
*Reservoir Height	Jason 1,2,3	

* We will focus primarily on precipitation, evapotranspiration, soil moisture, and runoff. Groundwater and reservoir height data information is provided in the Appendix

Acronyms are defined in subsequent slides

Current Satellite Missions for Water Budget Components

- Tropical Rainfall Measuring Mission (TRMM): 11/1997 - 04/2015
- Global Precipitation Measurement (GPM): 02/2014 - present
- Landsat 7: 04/1999 - present
- Landsat 8: 02/2013 - 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 - 10/2017
- GRACE Follow-on (GRACE FO): 05/2018 - present
- Jason 2: 06/2008 - present
- Jason 3: 01/2016 - present



Satellites and Sensors for Water Budget Components

Satellites	Sensors	Spectral Measurements	Water Budget Component
TRMM & GPM	Microwave Radiometer and RADAR TMI, PR GMI, DPR	TMI: 10-85 GHz GMI: 10-183 GHz PR and DPR (Ku and Ka)	Precipitation
Terra & Aqua	MODIS	Visible, Near IR, Middle IR	Snow Cover, Evapotranspiration
Landsat 7, 8	TM, ETM+, OLI	Visible, Near IR, Middle IR, Thermal IR	Evapotranspiration
SMAP	Microwave Radiometer	L-Band	Soil Moisture
GRACE & GRACE-FO	Microwave Radar	K-Band	Groundwater
Jason 2, 3	Altimeter	C-Band and Ku-Band	Reservoir Height

TMI : TRMM Microwave Imager
PR Precipitation Radar
GMI: GPM Microwave Imager
DPR: Dual-frequency Precipitation Radar

MODIS: MODerate Resolution Imaging Spectroradiometer
TM: Thematic Mapper
ETM+: Enhanced Thematic Mapper
OLI: Operational Land Imager

For details see **Session 2B** on https://arset.gsfc.nasa.gov/webinars/fundamentals-remote-sensing

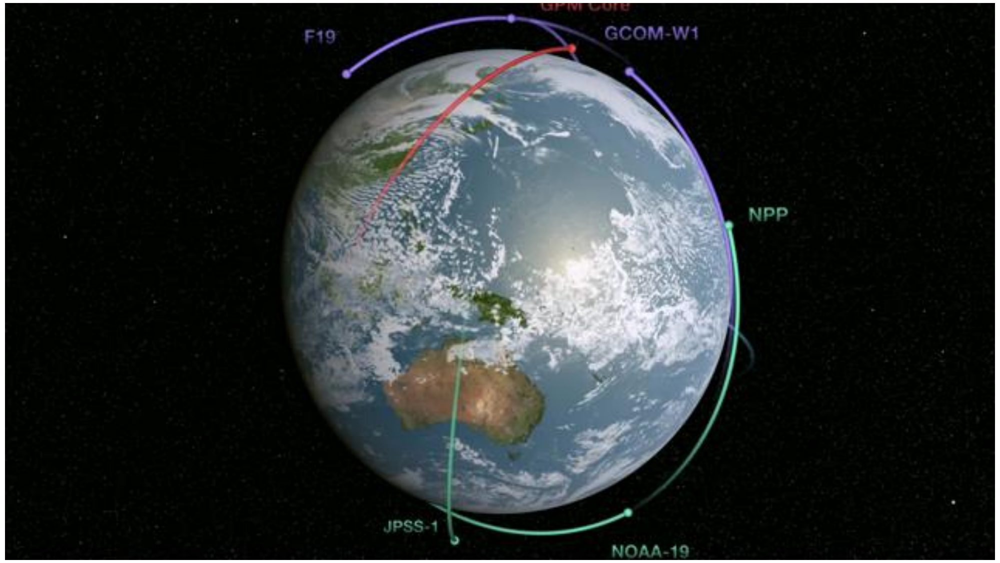
Precipitation From TRMM and GPM: Multi-Satellite Algorithms

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

- TRMM & GPM core satellites are used to calibrate microwave observations from a constellation of national and international satellites
- Allow improved spatial and temporal coverage of precipitation data
- TRMM Multi-satellite Precipitation Analysis (**TMPA**)
- TMPA will be extended to match Integrated Multi-satellitE Retrievals for GPM (**IMERG**)
- Widely used for applications

Precipitation From Integrated Multi-satellitE Retrievals for GPM (IMERG)

- Multiple runs accommodate different user requirements for latency and accuracy
  - "Early" – 5 hours (flash flooding)
  - "Late" – 12 hours (crop irrigation)
  - "Final" – 3 months (research data)
- Spatial resolution: 0.1° x 0.1°, from 60°N - 60°S (will be 90°N - 90°S)
- Temporal resolution: Native time intervals are **half-hourly** and monthly (final only)
  - Value-added products at 3 hours,1, 3, and 7 days are available



TMPA and IMERG

	TMPA	IMERG
Spatial Resolution	0.25° x 0.25°	0.1° x 0.1°
Spatial Coverage	Global, 50°S - 50°N	Global, 60°S - 60°N (will be extended from pole to pole)
Temporal Resolution	3 hours	30 minutes
Temporal Coverage	12/1997 – present*	2/27/2014 – present+

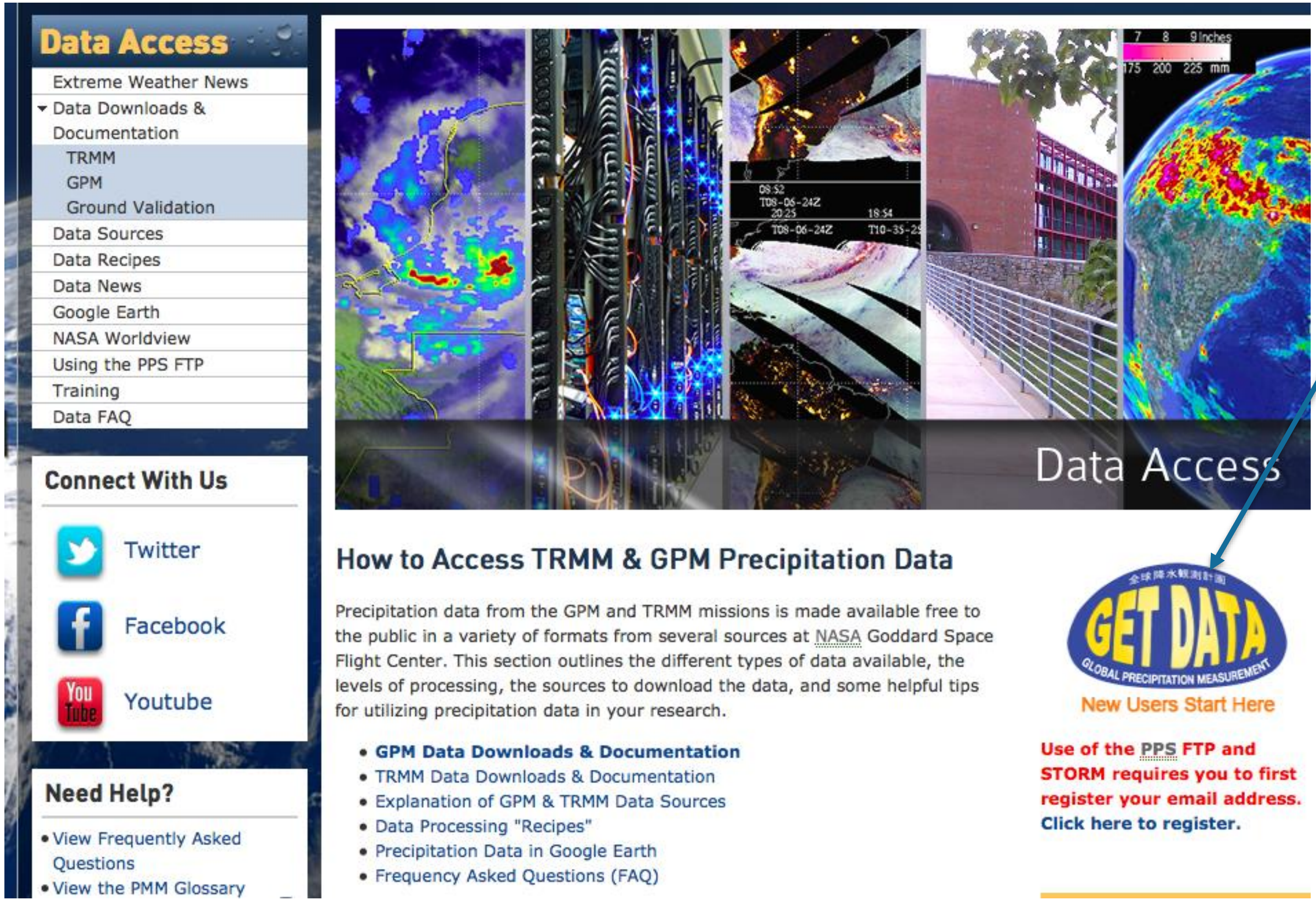
* After April 8, 2015, TRMM climatological calibration is being used to generate TMPA

+ TMPA and IMERG combined data will be available in 2019 at IMERG data resolution

TMPA is widely used for hydrologic and flood modeling and IMERG will replace it in the near future

Precipitation Data Access

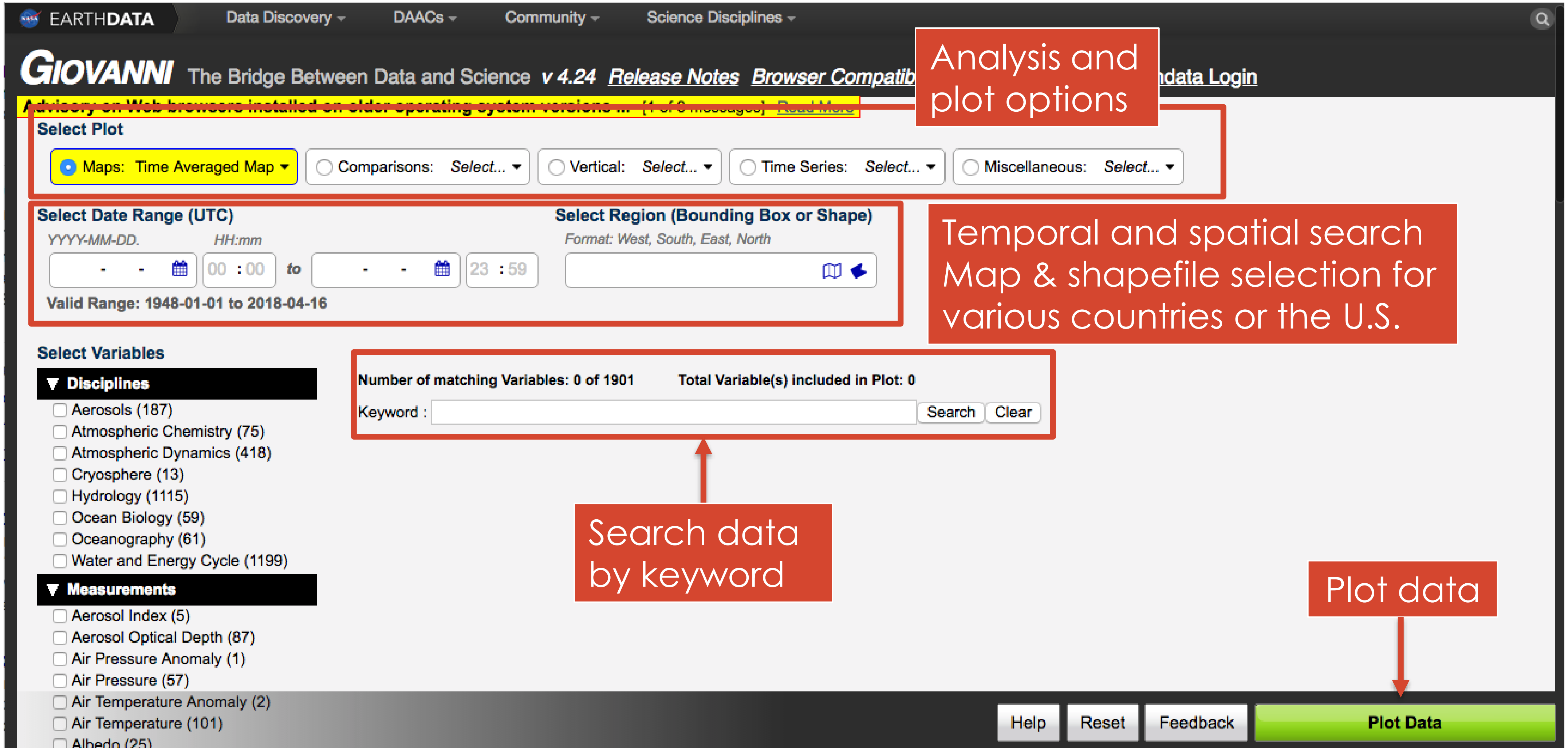
https://pmm.nasa.gov/data-access



- All about GPM data
  - Including updates, news, and FAQ
- Quick data access links and user registration
- For more information about GPM and data access visit: https://pmm.nasa.gov/training

Precipitation Data Access and Analysis Using Giovanni

https://giovanni.gsfc.nasa.gov/giovanni/



Evapotranspiration (ET)

- The sum of evaporation from the land surface, plus transpiration from plants
- ET transfers water from the surface to the atmosphere in vapor form
- Energy is required for ET to take place (for changing liquid water into vapor)

Challenges in Estimation of ET

- ET depends on many variables:
  - solar radiation at the surface
  - land and air temperatures
  - humidity
  - surface winds
  - soil conditions
  - vegetation cover and types
- Highly variable in space and time

There are multiple ET products based on the MODIS vegetation index, thermal infrared bands from MODIS, Landsat-8, and global geostationary satellites

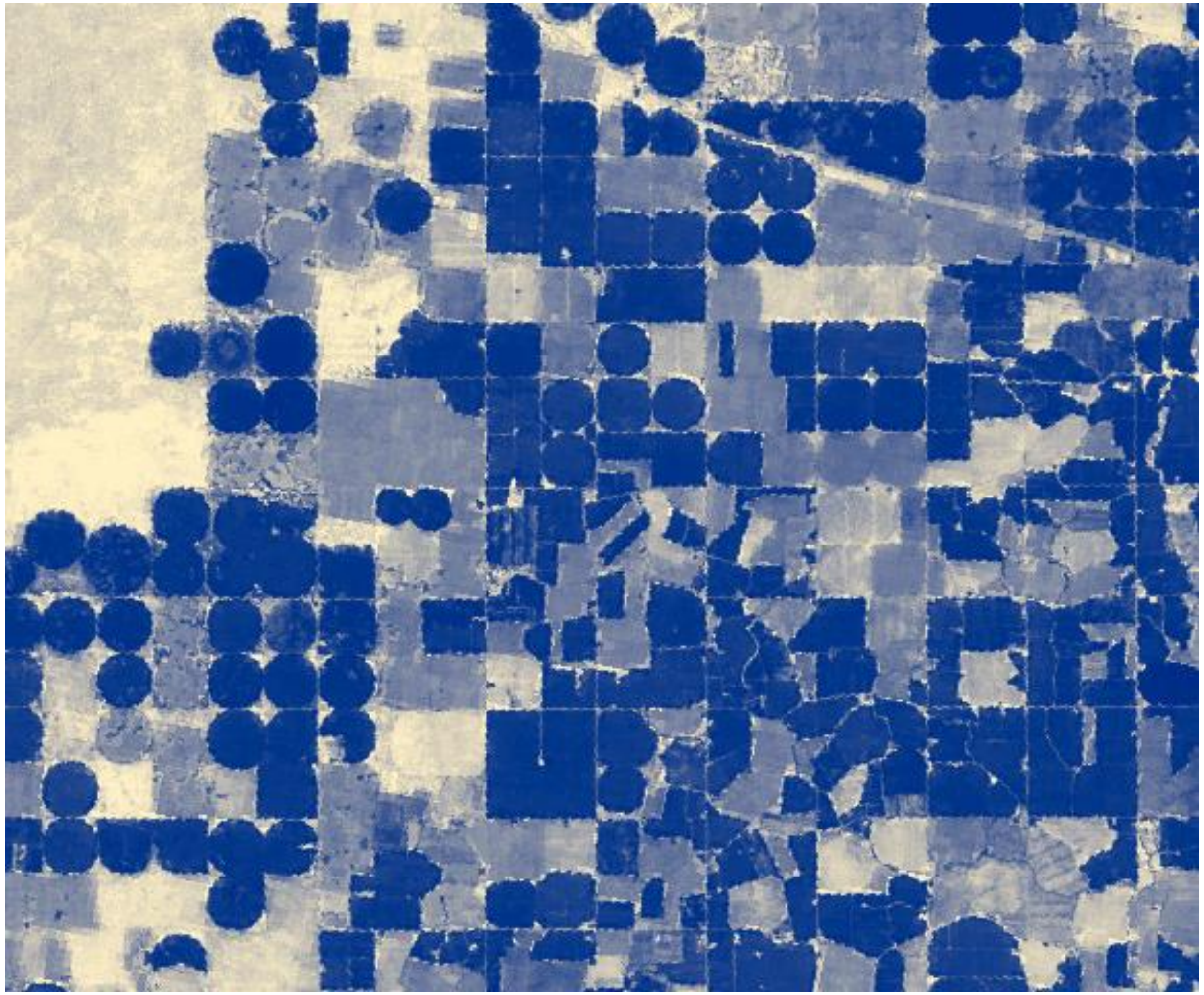


Image Credit: NASA Earth Observatory, Robert Simmon, based on data from the Idaho Department of Water Resources

ET From MODIS

https://lpdaac.usgs.gov/node/1191

MOD16A2: MODIS/Terra Net Evapotranspiration 8-Day L4 Global 500 m SIN Grid V006

Description

The MOD16A2 Version 6 Evapotranspiration/Latent Heat Flux product is an 8-day composite product produced at 500 meter pixel resolution. The algorithm used for the MOD16 data product collection is based on the logic of the Penman-Monteith equation, which includes inputs of daily meteorological reanalysis data along with MODIS remotely sensed data products such as vegetation property dynamics, albedo, and land cover.

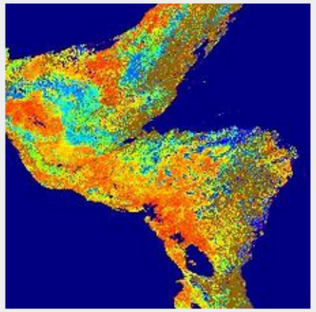
Provided in the MOD16A2 product are layers for composited Evapotranspiration (ET), Latent Heat Flux (LE), Potential ET (PET) and Potential LE (PLE) along with a quality control layer. Two low resolution browse images are also available for each MOD16A2 granule, (1) ET and (2) LE.

The pixel values for the two Evapotranspiration layers (ET and PET) are the sum of all eight days within the composite period and the pixel values for the two Latent Heat layers (LE and PLE) are the average of all eight days within the composite period. Note that the last 8-day period of each year is a 5 or 6-day composite period, depending on the year.

Validation at Stage 1 has been achieved for MODIS Evapotranspiration products.

Improvements/Changes from Previous Versions

- Spatial resolution of Version 6 products increased to nominal 500 meters from nominal 1,000 meters in Version 5.
- Version 5 data products were previously distributed by the Numerical Terradynamic Simulation Group at the University of Montana. The Version 6 products are a continuation of this project.
- Operational Version 6 data products have had additional cloud/aerosol screening applied for the end of the year in which the previous full year of MODIS Leaf Area Index/FPAR (MOD15A2H) and Albedo (MCD43A3) data are available. See Section 3.2.1 of the User Guide for more information.



MOD16A2. Acquired April 15, 2009. Tile H09V07. Central America.

DOI	10.5067/MODIS /MOD16A2.006
Product	Evapotranspiration
Dataset	Terra MODIS
Dataset Version	6
Pixel Size	500
Temporal Granularity	Composites
Spatial Extent	Global
Data Access	NASA Earthdata Search, Data Pool, DAAC2Disk, AppEEARS, EarthExplorer

- Available from MODIS on Terra (MOD16A2) and Aqua (MYD16A2)
- Spatial resolution: 500 m
- Temporal resolution: 8 days
- Temporal coverage: 2010 - present

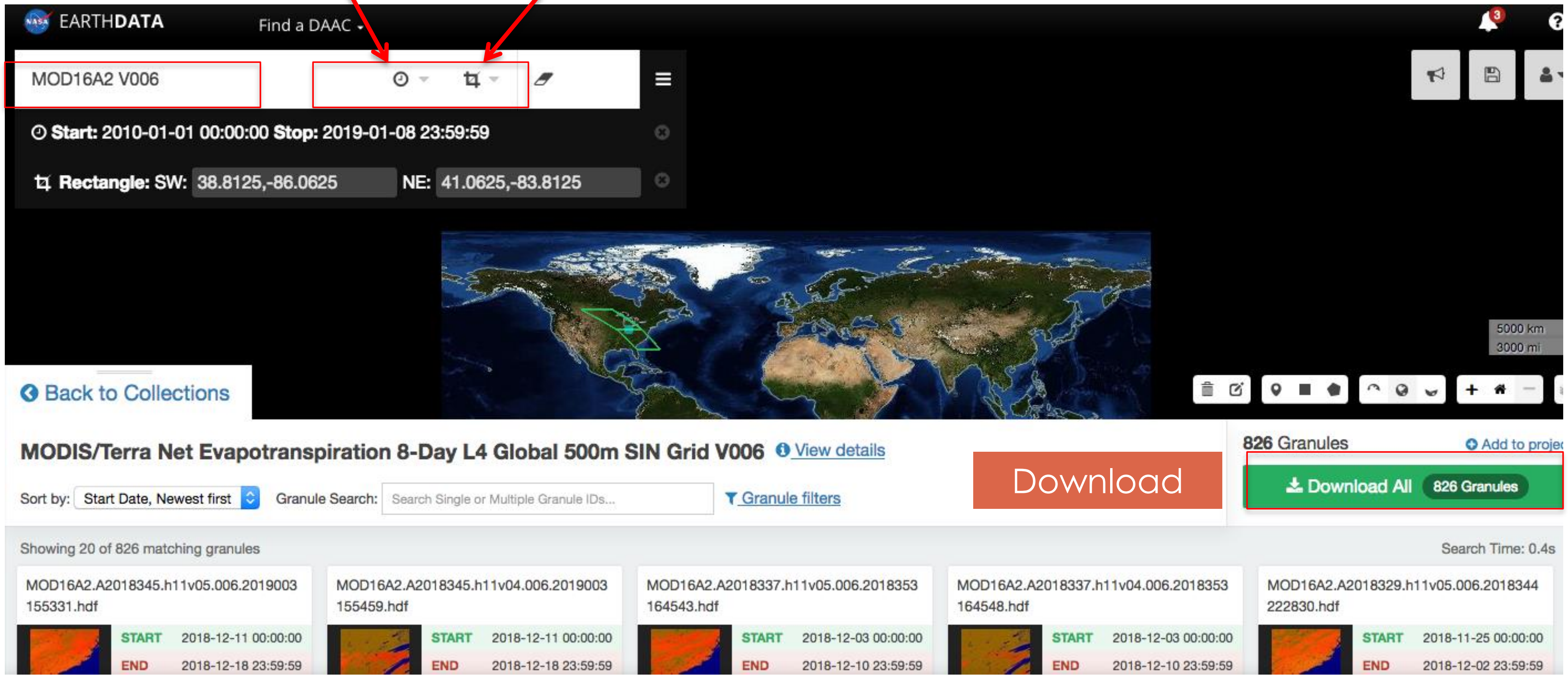
Reference: Running, S., Mu, Q., Zhao, M. (2017). *MOD16A2 MODIS/Terra Net Evapotranspiration 8-Day L4 Global 500m SIN Grid V006* [Data set]. NASA EOSDIS Land Processes DAAC. doi: 10.5067/MODIS/MOD16A2.006

MOD16A2 Data Access Using NASA Earthdata

https://earthdata.nasa.gov

Temporal and spatial search

Product name



Download

ET data granules

NASA Earthdata requires user registration

ET From Landsat

https://arset.gsfc.nasa.gov/sites/default/files/water/ET-SMAP/week4.pdf

Mapping and **E**vapo**T**ranspiration at high-**R**esolution with **I**nternalized **C**alibration (METRIC)

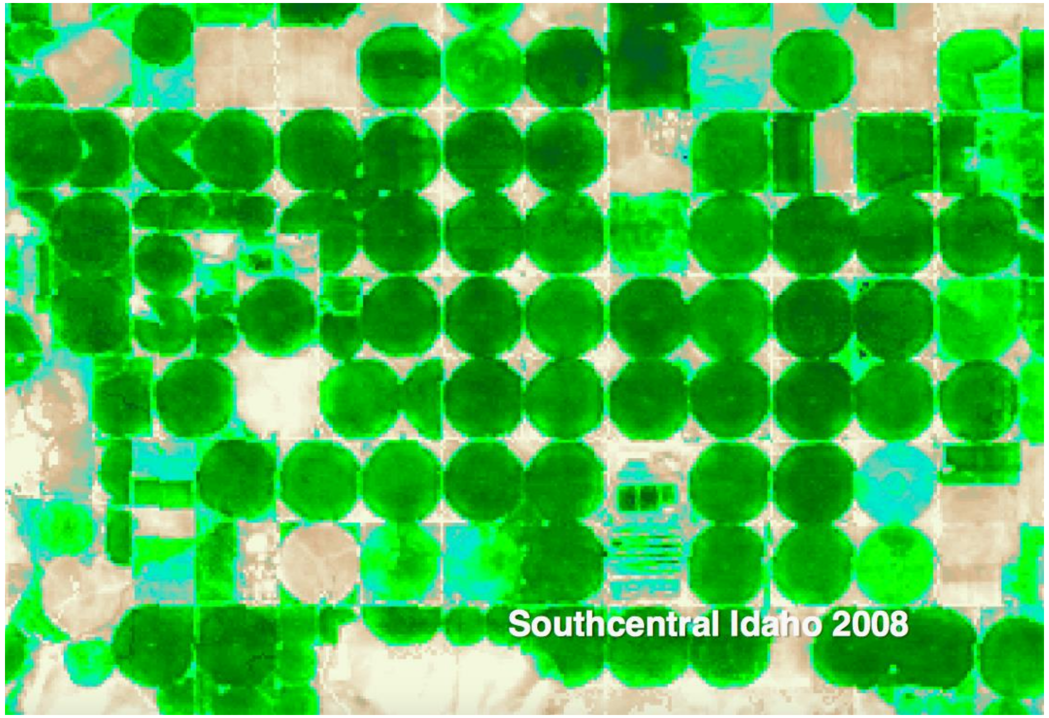


Image Credit: Richard Allen, University of Idaho

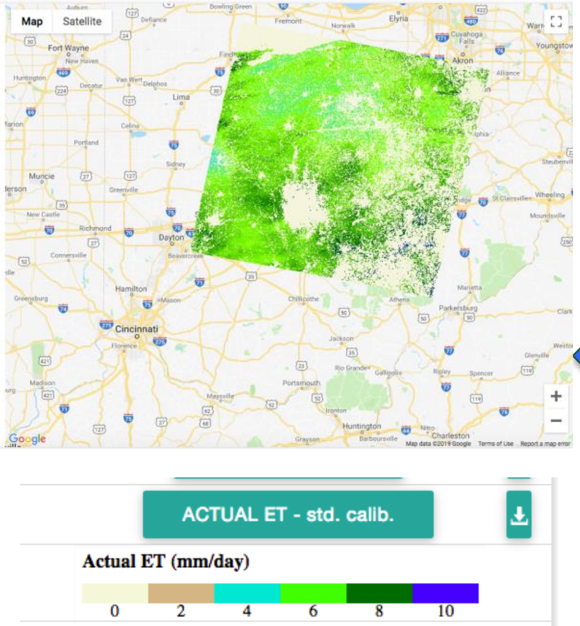
- Spatial resolution: 30 m
- Temporal resolution: 16 days
- Temporal coverage: 2011 - present

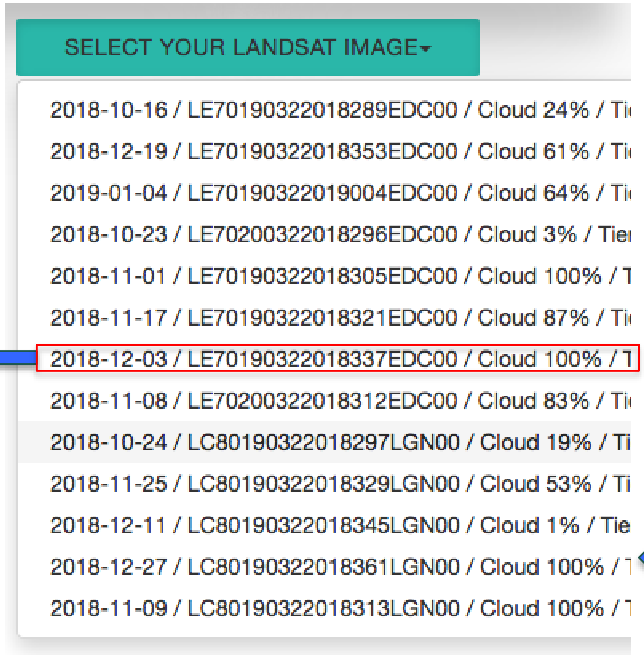
Allen R., T. Masahiro, R. Trezza, 2007: Satellite-Based Energy Balance for Mapping Evapotranspiration with Internalized Calibration (METRIC)—Model , Journal of irrigation and drainage Engineering, 133, 733-943. -- https://doi.org/10.1061/(ASCE)0733-9437(2007)133:4(380)

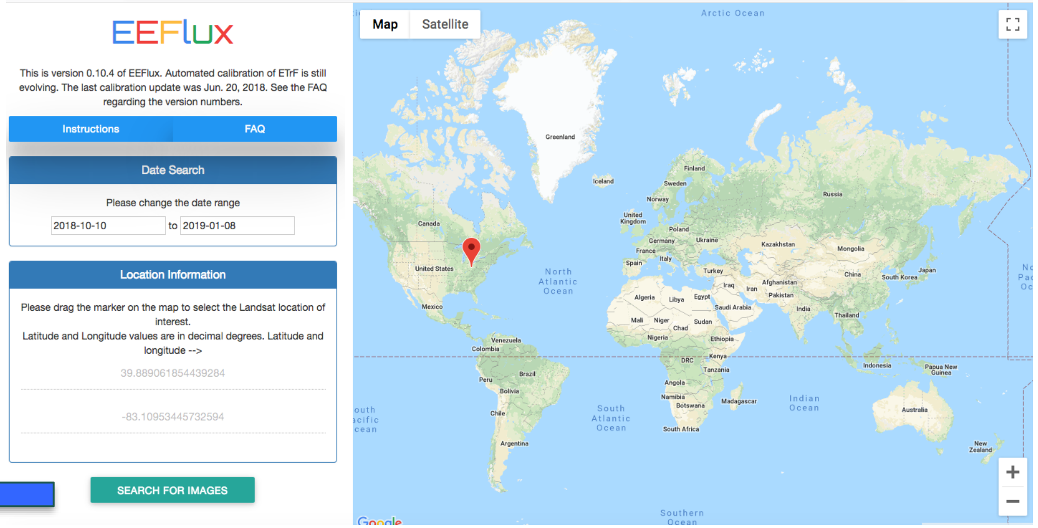
METRIC ET Data Access Using EEFlux

https://eeflux-level1.appspot.com/

Google Earth Engine Evapotranspiration Flux (EEFlux)





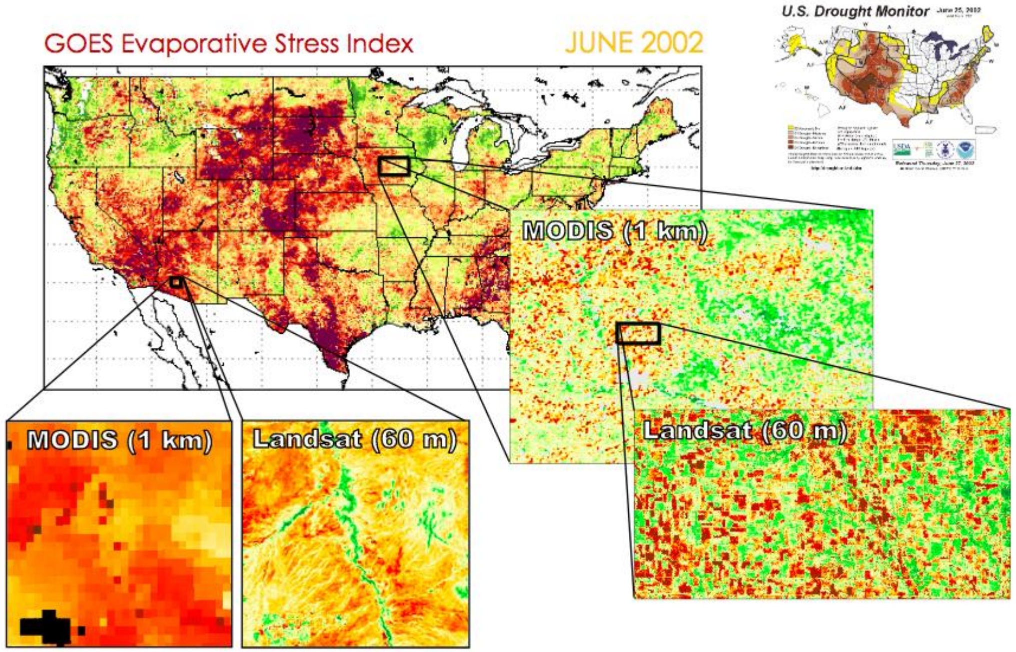


Multi-satellite ET from The Atmosphere-Land EXchange Inverse (ALEXI)

https://www.hydrol-earth-syst-sci.net/15/223/2011/hess-15-223-2011.pdf

- ALEXI ET is derived by using an energy balance model
- Land Surface Temperature is obtained from global geostationary satellites; in addition, MODIS and Landsat are also used in a version of ALEXI
  - For more details:

    https://arset.gsfc.nasa.gov/sites/default/files/water/ET-SMAP/week5-1.pdf



Reference: Anderson et al., 2011, Hydrol. Earth Syst. Sci., 15, 223–239, 2011, doi:10.5194/hess-15-223-2011

ALEXI Data Access

http://catalogue.servirglobal.net/Product?product_id=198

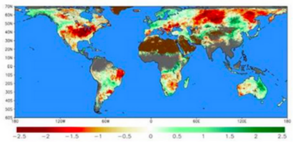
SERVIR GLOBAL | PRODUCT CATALOGUE

DOWNLOAD FACTSHE

EVAPORATIVE STRESS INDEX

This new global geospatial dataset reveals regions of drought where vegetation is stressed due to lack of water, capturing early signals of drought without using observed rainfall data; this is critical in developing regions and other parts of the world lacking sufficient ground-based observations of rainfall.

Millions of people in the developing world depend on agriculture for their livelihoods. However, uncertainties in weather patterns and water availability pose a serious challenge to reliable crop production. Officials in charge of water resources need to know where vegetation is stressed due to lack of water so they can more accurately monitor and/or forecast drought, while providing farmers with actionable information related to mitigating the effects of water stress (e.g., irrigation) leading to more informed decisions impacting agriculture and food security.



Application Purpose

The new global dataset, called the Evaporative Stress Index (ESI), available online and produced weekly at 5-kilometer resolution for the entire globe, reveals regions of drought where vegetation is stressed due to lack of water, enabling agriculture ministries to provide farmers with actionable advice about irrigation. The ESI can capture early signals of "flash drought," a condition brought on by extended periods of hot, dry, and windy conditions leading to rapid soil moisture depletion. Reduced rates of water loss can be observed through the use of land surface temperature before it can be observed through decreases in vegetation health or "greenness." The ESI describes soil moisture across the landscape without using observed rainfall data. This is critical in developing regions and other parts of the world lacking sufficient ground-based observations of rainfall. The ESI is based on satellite observations of land surface temperature, which are used to estimate water loss due to

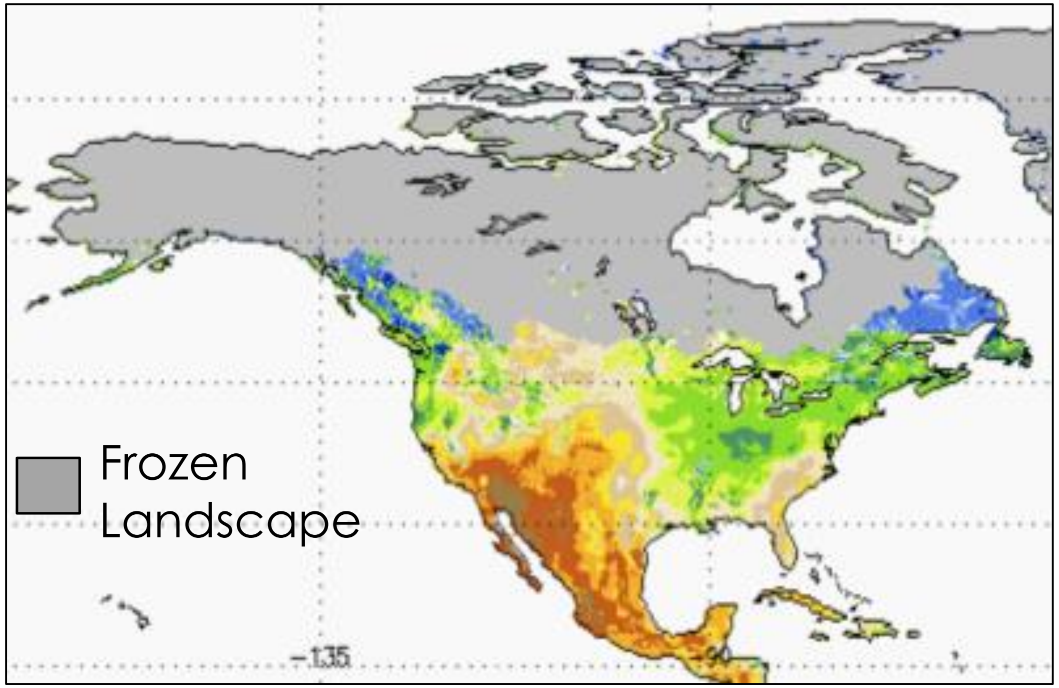
Access Product

- To **analyze** Evaporative Stress Index (ESI) data, go to http://ClimateSERV.servirglobal.net, choose Get Started, draw a polygon or choose a feature on the map, and then select Evaporative Stress Index (ESI) as your Data Source.
- To **download** Evaporative Stress Index (ESI) data as tif files:
  https://gis1.servirglobal.net/data/esi/
- To **visualize** Evaporative Stress Index (ESI) data in a WMS, see ArcGIS REST Service:
  https://gis1.servirglobal.net/arcgis/rest/services/Global/ESI_4WK/MapServer
  https://gis1.servirglobal.net/arcgis/rest/services/Global/ESI_12WK/MapServer

- Spatial resolution: 5 km
- Spatial coverage: Global
- Temporal resolution: 4-week and 12-week composites
- Temporal coverage: 2001- present
- Visualization of data available in ArcGIS and Google Earth

Soil Moisture From SMAP

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

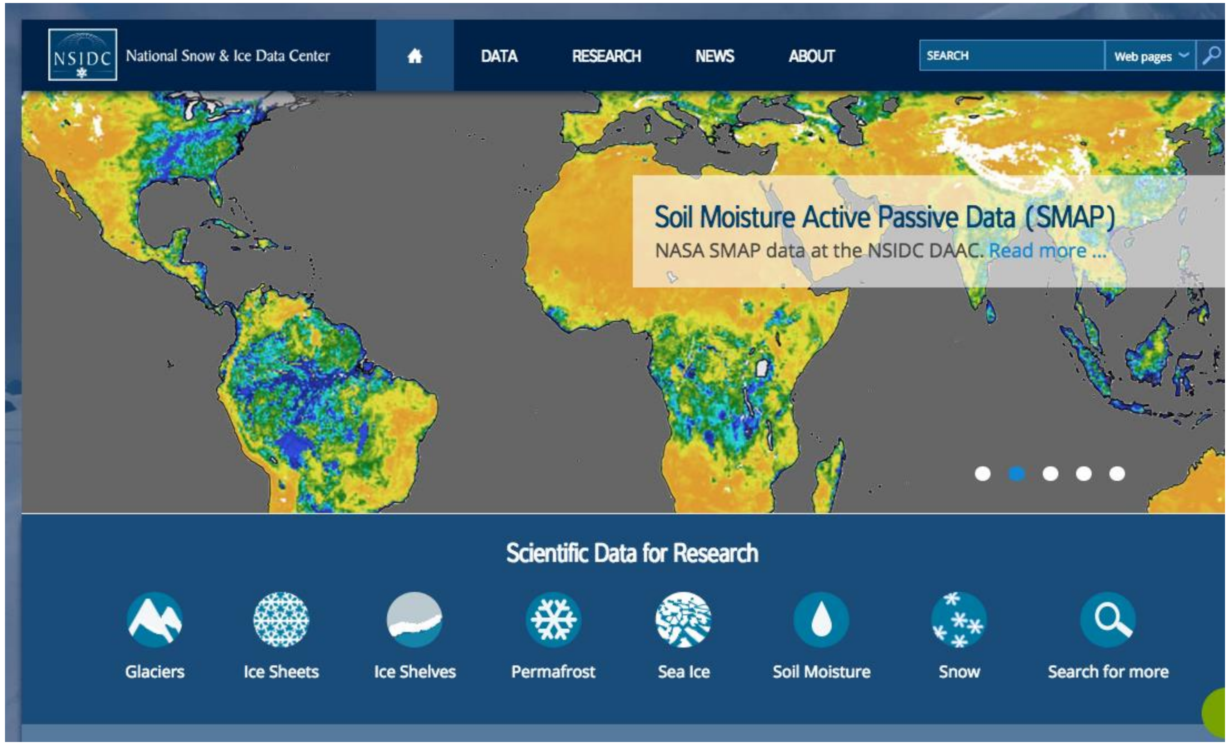


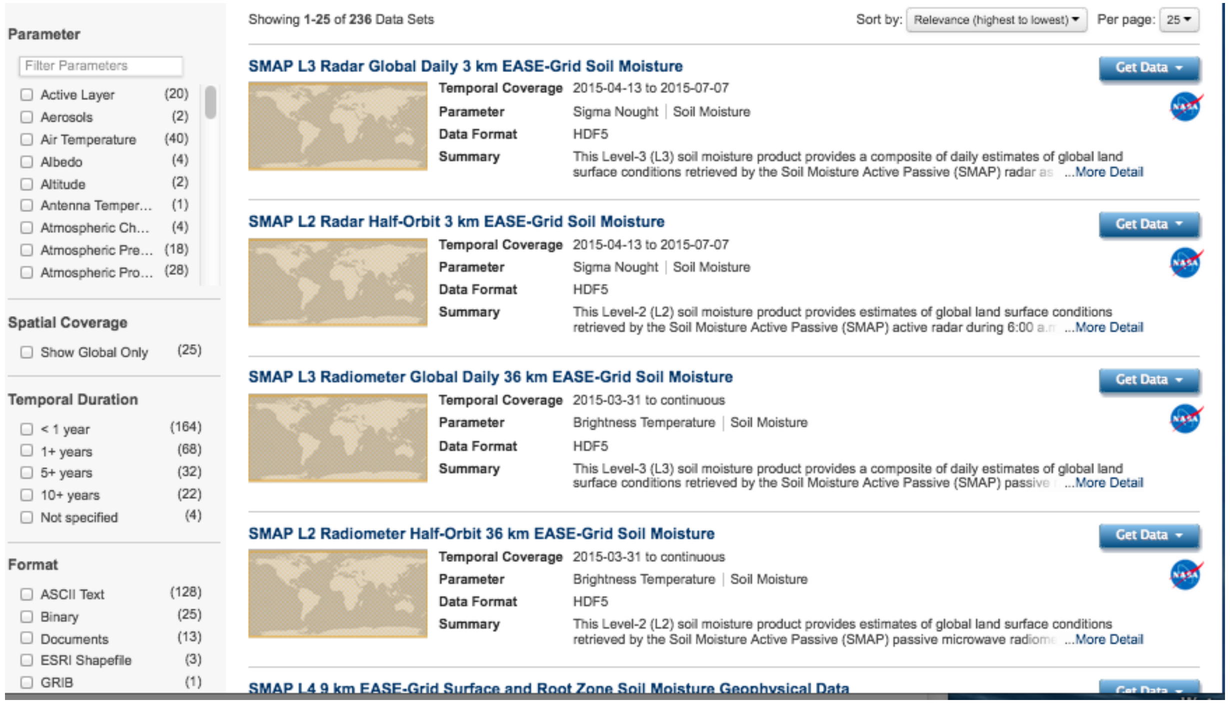
- Measures moisture in the top 5 cm of soil
- Soil moisture derived from L-band radiometer
- Radar, designed to work as Synthetic Aperture Radar (SAR), stopped operating after July 7, 2015
- Currently SAR data from Sentinel-1 (European Space Agency [ESA] satellite) are used together with the passive radiometer on board SMAP
- Spatial resolution: 36 km, 9 km
- Temporal resolution: 3 days
- Temporal coverage: March 2015 - present

SMAP Data Access From NSIDC

http://nsidc.org/data/search/#keywords=soil+moisture/

The National Snow & Ice Data Center:





Level 2 to Level 4 data

SMAP Data Access Using AppEEARS

https://lpdaacsvc.cr.usgs.gov/appeears

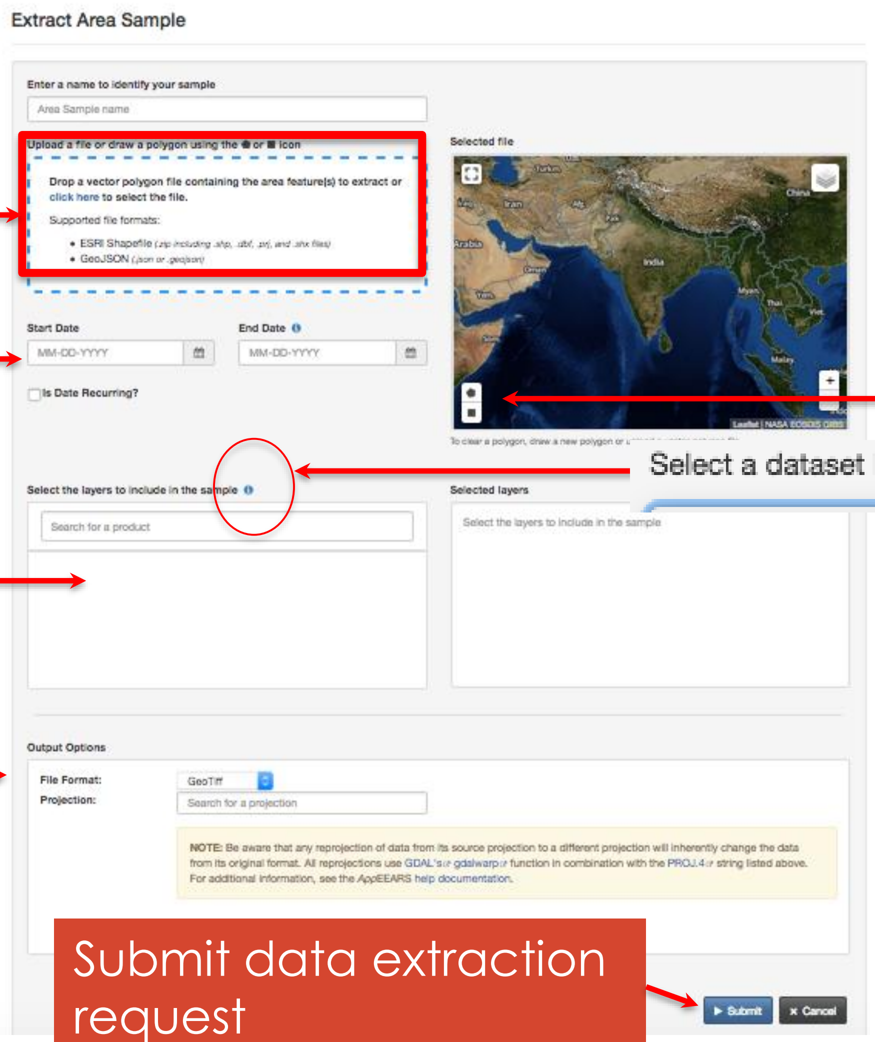
Application for **E**xtracting and **E**xploring **A**nalysis **R**eady **S**amples (***A**pp***EEARS**) /

Extract data by custom shapefile

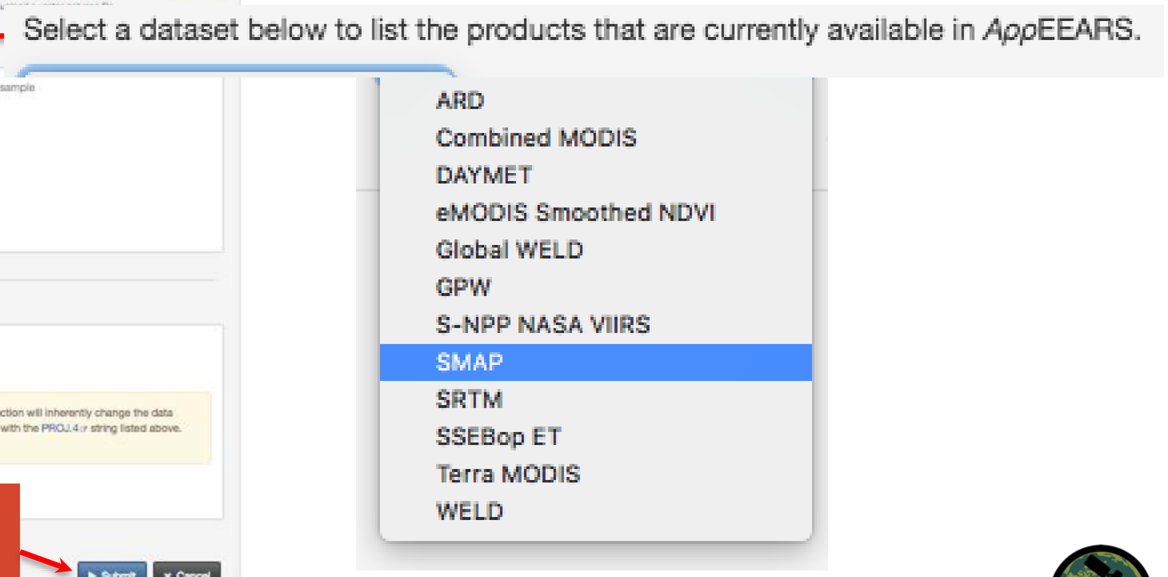
Temporal selection

Data & layer selection

Data format



Extract data within a box or polygon shapefile



Submit data extraction request

Global Land Data Assimilation System (GLDAS) for Water Budget Data

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

A water and energy balance model with assimilation of remote sensing data

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 (LAI): MODIS (GLDAS-2)
- Clouds and Snow (for surface radiation): NOAA and DMSP satellites

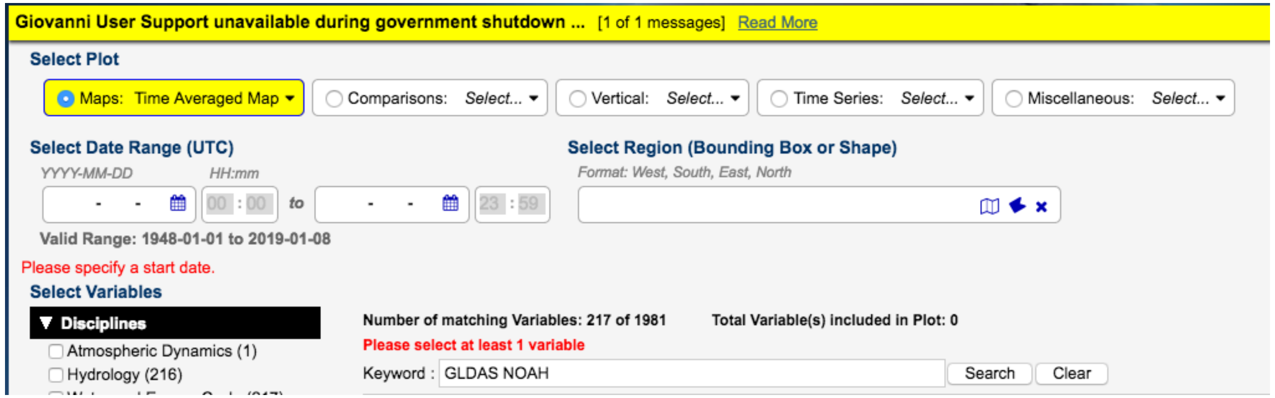
Integrated outputs include:

- 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.

Water Budget Data Access From GLDAS Using Giovanni

https://giovanni.gsfc.nasa.gov/giovanni/

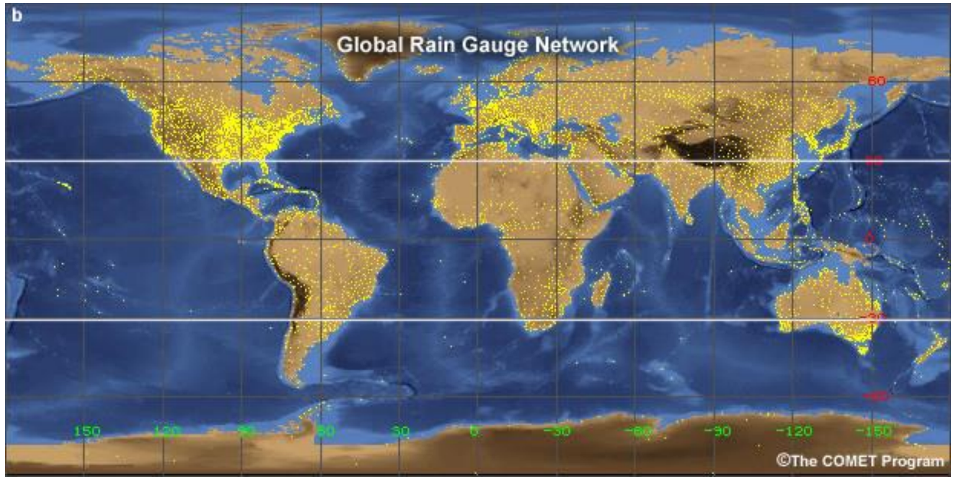


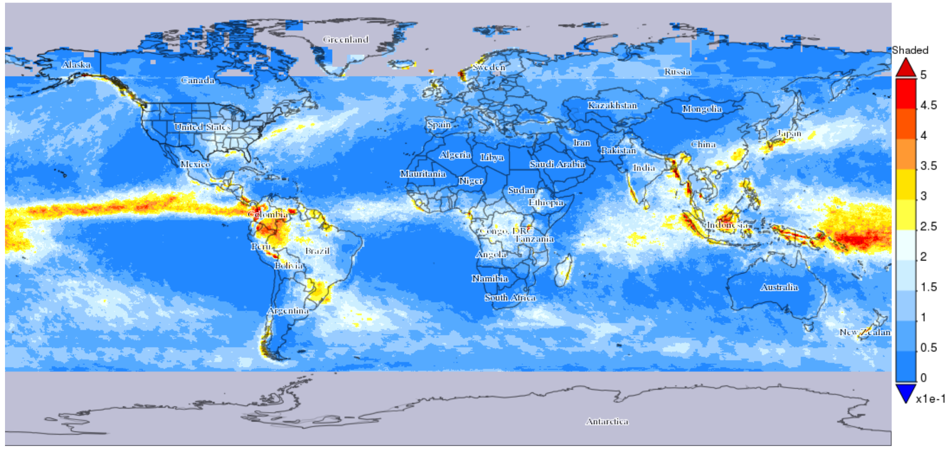
Snow melt (GLDAS_NOAH025_3H v2.1)	kg m-2	GLDAS Model	3-hourly	0.25 °	2000-01-01	2018-11-30
Soil temperature (0 - 10 cm underground) (GLDAS_NOAH025_3H v2.1)	K	GLDAS Model	3-hourly	0.25 °	2000-01-01	2018-11-30
Soil moisture content (40 - 100 cm underground) (GLDAS_NOAH025_3H v2.1)	kg m-2	GLDAS Model	3-hourly	0.25 °	2000-01-01	2018-11-30
Downward shortwave radiation flux (GLDAS_NOAH025_3H v2.1)	W m-2	GLDAS Model	3-hourly	0.25 °	2000-01-01	2018-11-30
Sensible heat net flux (GLDAS_NOAH025_3H v2.1)	W m-2	GLDAS Model	3-hourly	0.25 °	2000-01-01	2018-11-30
Albedo (GLDAS_NOAH025_3H v2.1)	%	GLDAS Model	3-hourly	0.25 °	2000-01-01	2018-11-30
Soil moisture content (100 - 200 cm underground) (GLDAS_NOAH025_3H v2.1)	kg m-2	GLDAS Model	3-hourly	0.25 °	2000-01-01	2018-11-30
Baseflow-groundwater runoff (GLDAS_NOAH025_3H v2.1)	kg m-2	GLDAS Model	3-hourly	0.25 °	2000-01-01	2018-11-30
Soil temperature (10 - 40 cm underground) (GLDAS_NOAH025_3H v2.1)	K	GLDAS Model	3-hourly	0.25 °	2000-01-01	2018-11-30
Evapotranspiration (GLDAS_NOAH025_3H v2.1)	kg m-2 s-1	GLDAS Model	3-hourly	0.25 °	2000-01-01	2018-11-30
Storm surface runoff (GLDAS_NOAH025_3H v2.1)	kg m-2	GLDAS Model	3-hourly	0.25 °	2000-01-01	2018-11-30
Soil moisture content (0 - 10 cm underground) (GLDAS_NOAH025_M v2.0)	kg m-2	GLDAS Model	Monthly	0.25 °	1948-01-01	2010-12-31
Snow depth water equivalent (GLDAS_NOAH025_M v2.0)	kg m-2	GLDAS Model	Monthly	0.25 °	1948-01-01	2010-12-31
Transpiration (GLDAS_NOAH025_M v2.0)	W m-2	GLDAS Model	Monthly	0.25 °	1948-01-01	2010-12-31
Snow depth (GLDAS_NOAH025_M v2.0)	m	GLDAS Model	Monthly	0.25 °	1948-01-01	2010-12-31

- Spatial resolution: 0.25° x 0.25°
- Temporal resolution: 3 hourly, monthly
- Temporal coverage: 2000 - present

Advantages of Remote Sensing & Modeling Data

- Remote sensing-based data provide near-global to 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 budget components
- 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 to subset, download, analyze, and visualize data**
- **Data are available in near-real time for the last 10+ years**





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

Bottom: Annual Precipitation (2015) from NASA GPM

Challenges in Using Remote Sensing & Modeling 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, and available from different portals—training is required to learn how to access them
- While the data are generally validated with selected surface measurements, regional and local assessment is recommended
- Often additional processing is needed for specific applications

Demonstration of Data Access

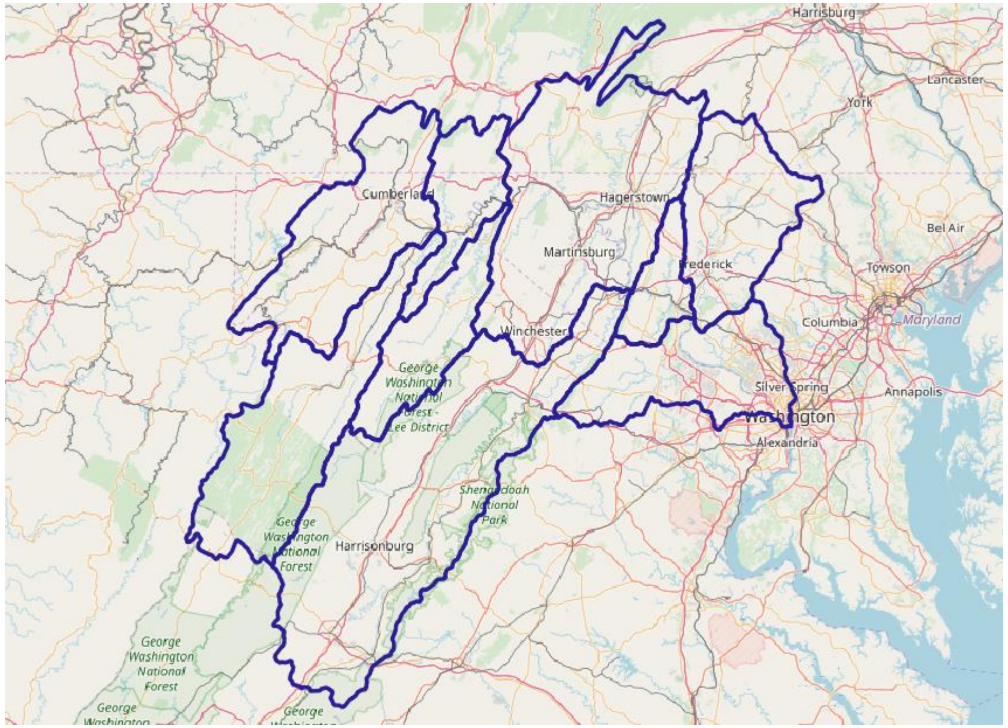
- HydroSHEDS

River Basin Network from HydroSHEDS

https://www.hydrosheds.org/ https://hydrosheds.cr.usgs.gov

Parana River Basin

Potomac River Basin



Thank You

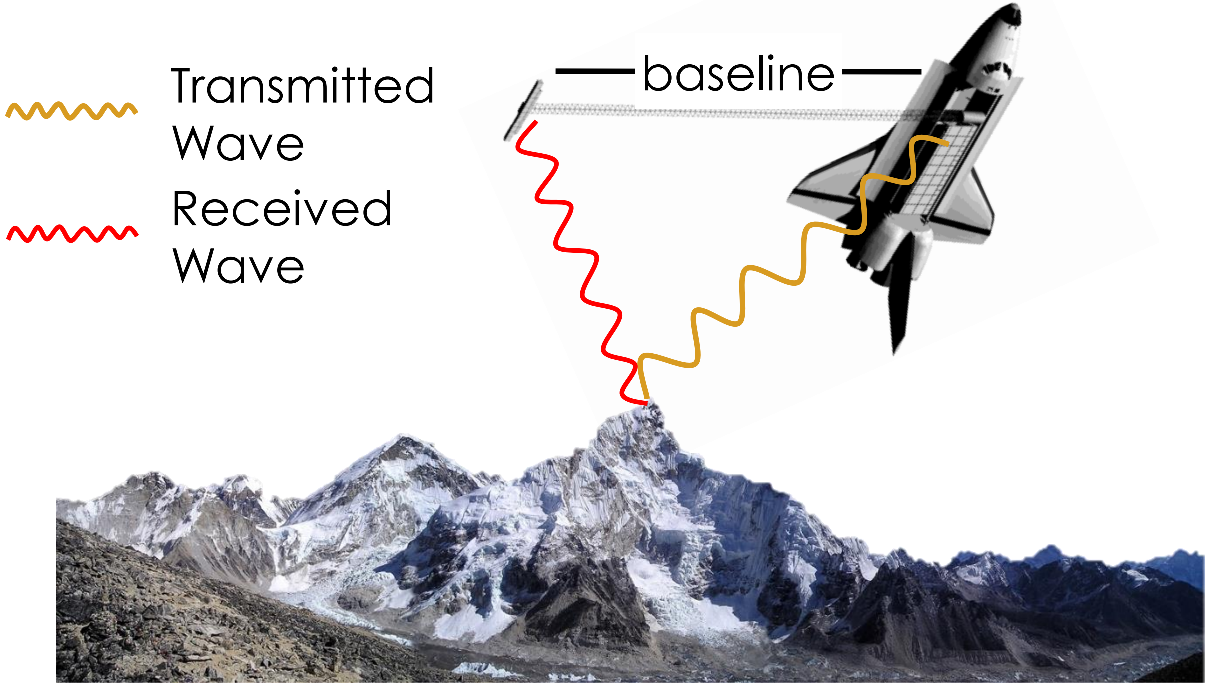
Appendix

Terrain Data from Shuttle Radar Topography Mission (SRTM)

https://www2.jpl.nasa.gov/srtm/mission.htm

- C-band (5.6 cm) SAR mission
- NASA Space Shuttle Endeavour
- Completed in February 2000
- 176 orbits around Earth in 11 days
- Generated digital elevation maps of all land between 60°N-56°S latitude
- ~80% of Earth's total land mass
- SRTM used interferometry to generate topographic (elevation) maps
- For detailed information see: https://arset.gsfc.nasa.gov/sites/default/files/water/Brazil_2017/Day3/S6P2.pdf

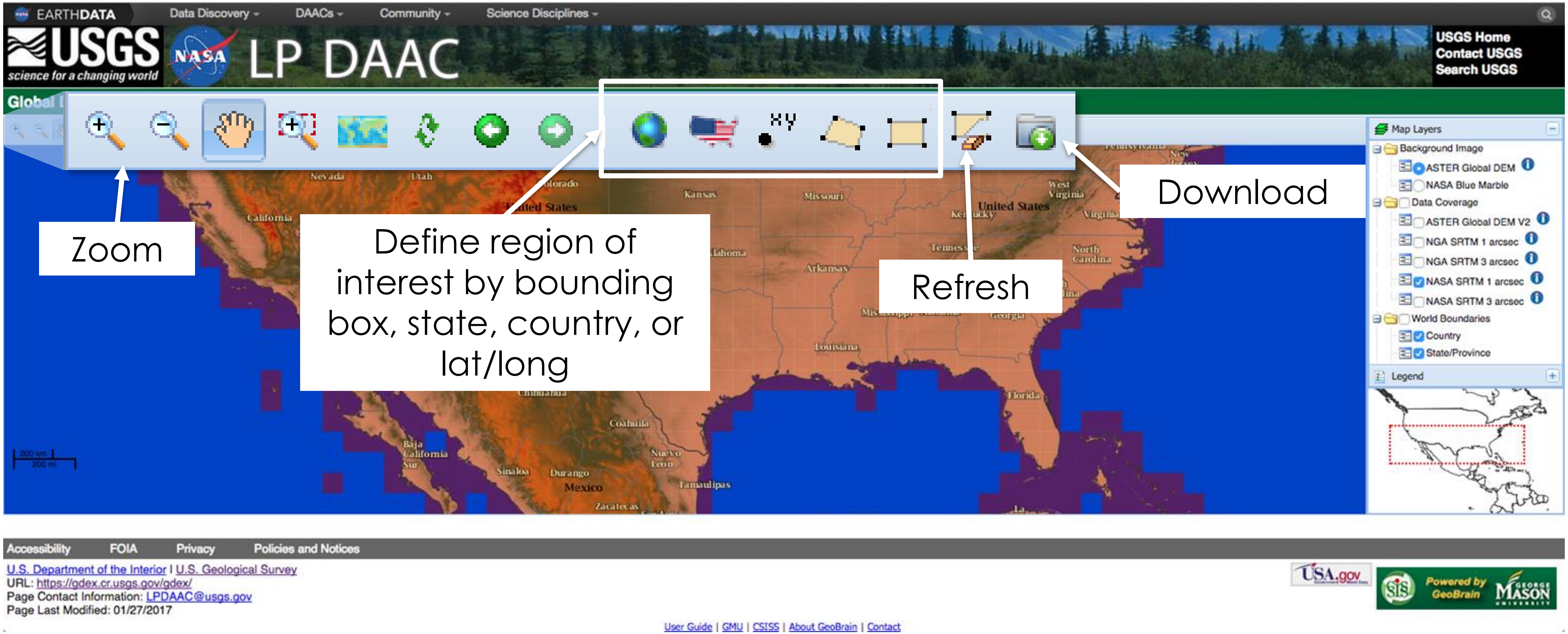
Radar signals being transmitted and received on the SRTM mission (not to scale)



Spatial resolution: 30 m

SRTM Elevation Data Access from Global Data Explorer (GDEx)

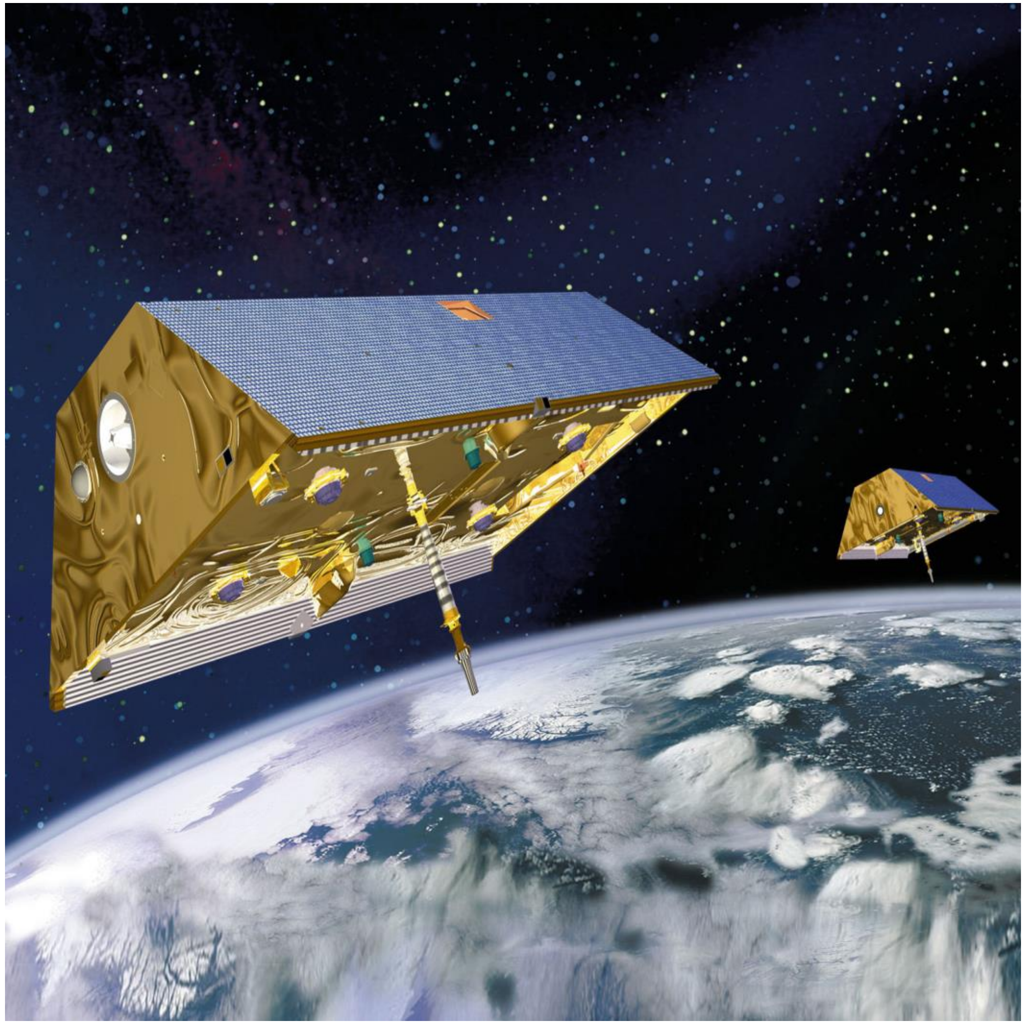
http://gdex.cr.usgs.gov/



GRACE and GRACE-FO

- Polar, sun-synchronous orbit
- Twin satellite system
- Spatial coverage and resolution:
  - Global
  - Resolution: 1° x 1°
- Temporal Coverage and Resolution:
  - March 17, 2002 - present
  - 250 gravity profiles per day

Note: GRACE-FO currently is still in In-Orbit-Checkout (IOC) phase. Data will be available mid-2019

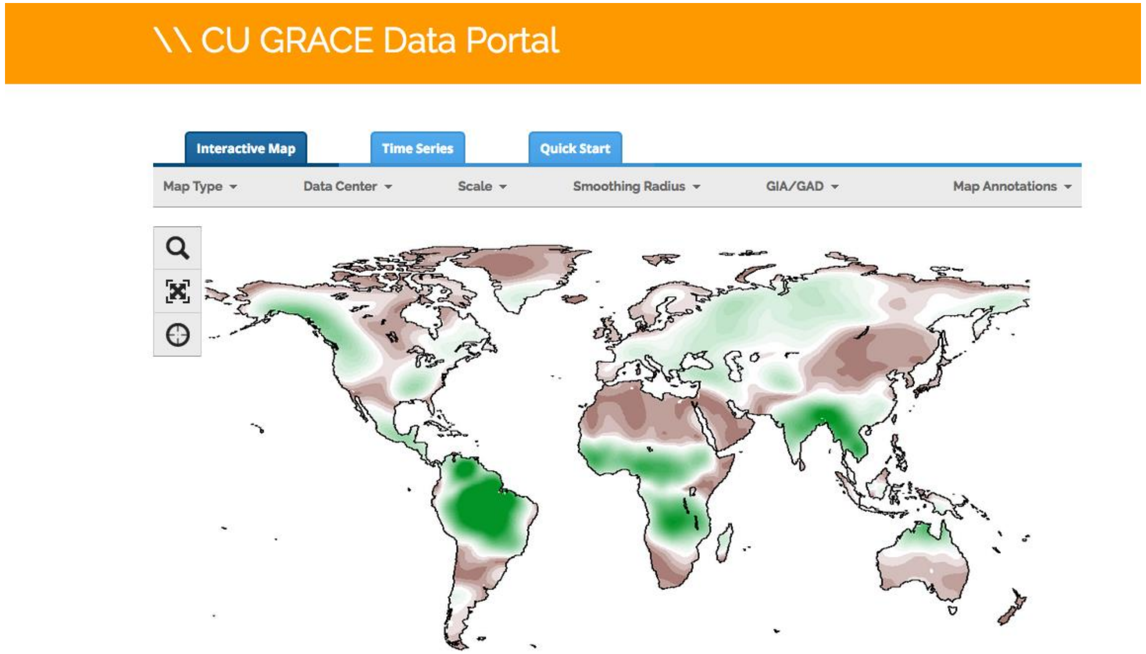


http://www.jpl.nasa.gov/missions/details.php?id=5882

GRACE and GRACE-FO Data Access

- Level-0 to Level-2
  - ftp://podaac.jpl.nasa.gov/allData/grace/
  - http://www.csr.utexas.edu/grace/
  - https://isdc.gfz-potsdam.de/grace-isdc/
  - https://isdc.gfz-potsdam.de/grace-fo-isdc/

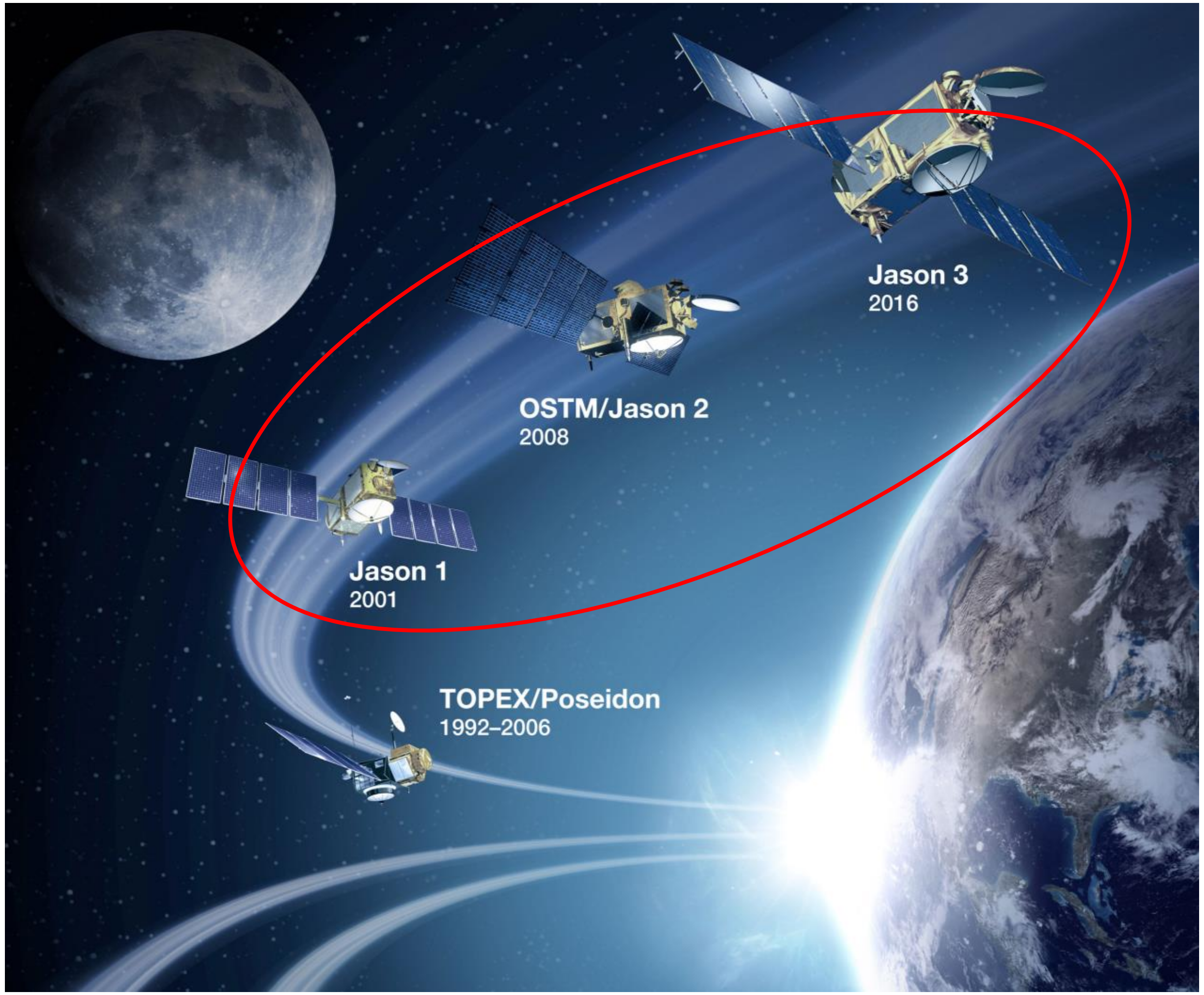
- Level 3
  - http://grace.jpl.nasa.gov/data/
  - http://geoid.colorado.edu/grace/
  - https://podaac.jpl.nasa.gov/GRACE-FO



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

Jason 1, 2, and 3

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



NASA, NOAA, CNES, and EUMETSAT Joint Missions

- Non-polar orbit
- Spatial Coverage:
  - Covers 95% of the world's oceans
  - 66°N-66°S latitude
- Temporal Coverage:
  - Revisit time: 10 hours
  - Jason-1: 12/2001 - 7/2013
  - Jason-2: 06/2008 - present
  - Jason-3: 01/2016 - present
- Sensors:
  - Poseidon altimeter
  - Advanced Microwave Radiometer (AMR) and DORIS

Jason 2 & 3 Data for Reservoir 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

10 day resolution

- Sampling ~380 water bodies
- Including ~90 reservoirs

35 day resolution

- Sampling ~1,065 water bodies
- Including ~230 reservoirs

Common Sampling: ~315

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

Jason Reservoir Height Data Access

USDA Crop Explorer

U.S. Department of Agriculture
Foreign Agricultural Services

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