National Aeronautics and Space Administration

Mapping and Monitoring Lakes and Reservoirs with Satellite Observations

Amita Mehta and Sean McCartney

February 9, 2021

Training Objectives

By the end of this training attendees will learn to:

- Identify the remote sensing data and methodology required to obtain surface water extent, water level, and bathymetry of lakes
- Access water height and bathymetry data for monitoring lake levels
- Illustrate the use of lake level and bathymetry data for lake and reservoir management

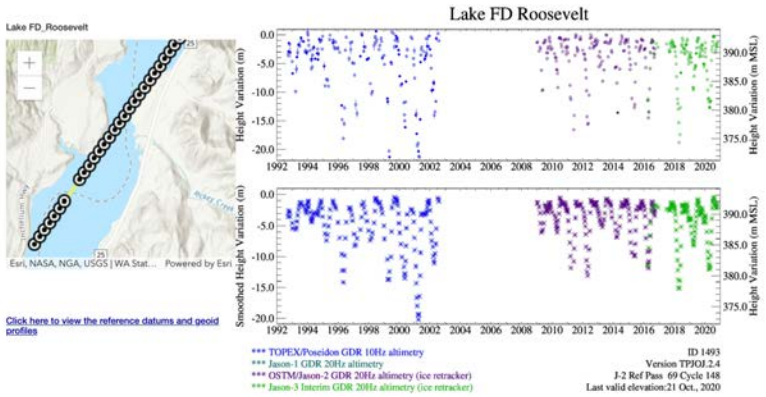
Training Outline

February 9, 2021

Remote Sensing Observations for Monitoring Water Extent, Water Level Height, and Bathymetry in Lakes and Reservoirs

https://global-surface-water.appspot.com/#data

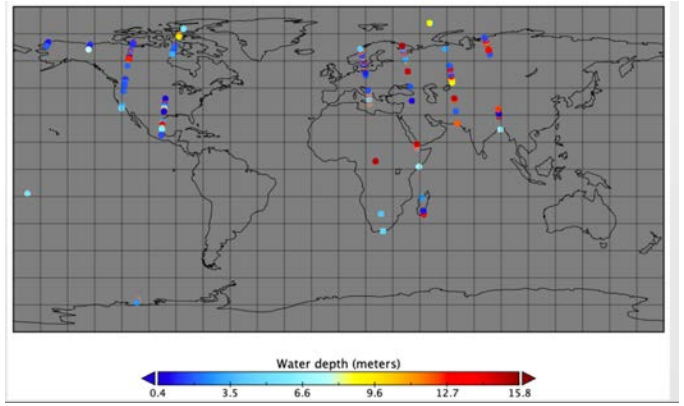
February 16, 2021



Water Level Height Data for Lakes and Reservoirs Using Radar Altimetry

https://ipad.fas.usda.gov/cropexplorer/global_reservoir/gr_regional_chart.aspx?regionid=us&reservoir_name=FD_Roosevelt

February 23, 2021



Water Level Height and Bathymetry Data for Lakes and Reservoirs Using Laser Altimetry

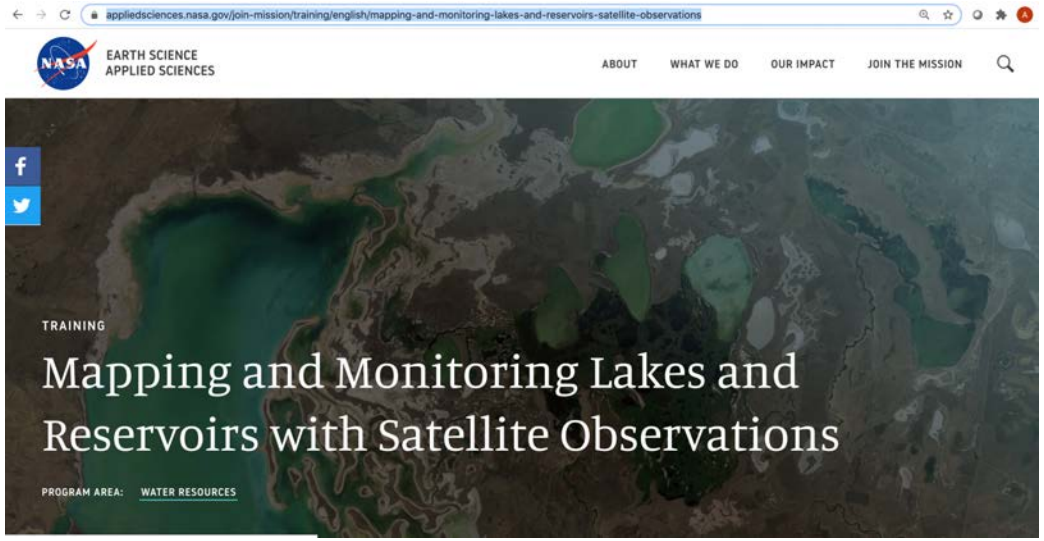
https://nsidc.org/data/atl13

Training Format

- Three, 1.5-hour sessions including presentations and question and answer sessions
- The same content will be presented at two different times each day:
  - Session A: 10:00-11:30 EST (UTC-5)
  - Session B: 16:00-17:30 EST (UTC-5)

- Training materials and recording will be available from:

  https://appliedsciences.nasa.gov/join-mission/training/english/mapping-and-monitoring-lakes-and-reservoirs-satellite-observations

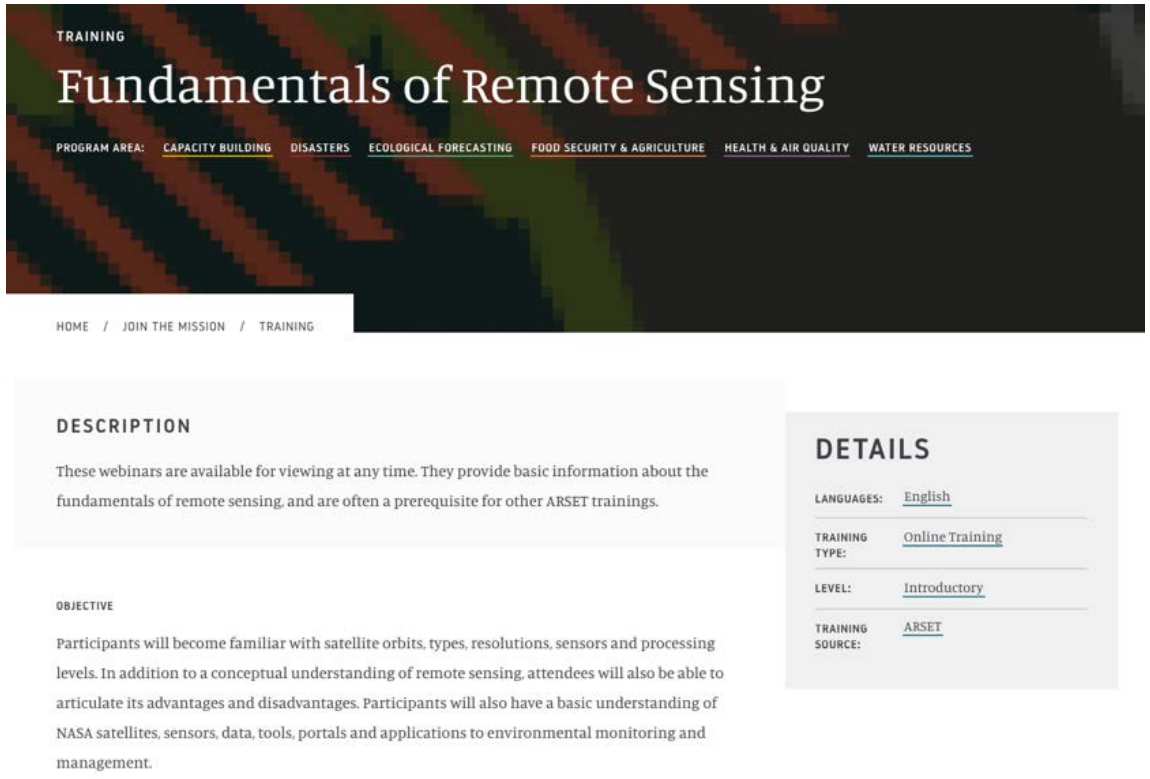


Homework and Certificate

- One homework assignment:
  - Answers must be submitted via Google Form
  - Due date: March 9, 2021
- A certificate of completion will be awarded to those who:
  - Attend all live webinars
  - Complete the homework assignment by the deadline (access from website)
  - You will receive a certificate approximately two months after the completion of the course from: marines.martins@ssaihq.com

Prerequisite

- Fundamentals of Remote Sensing: https://appliedsciences.nasa.gov/join-mission/training/english/fundamentals-remote-sensing



Session 1 Outline

- About ARSET
- About Lakes and Reservoirs
- Satellites and Sensors for Monitoring Lakes and Reservoirs
- Global Surface Water Datasets
- Examples of Monitoring Lakes and Reservoirs
- Demonstration: Global Surface Water Data Access

About ARSET

NASA's Applied Remote Sensing Training Program (ARSET)

https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

- Part of NASA's Applied Sciences Capacity Building Program
- Empowering the global community through online and in-person remote sensing training
- Topics for trainings include:
  - Water Resources
  - Air Quality
  - Disasters
  - Land

NASA's Applied Remote Sensing Training Program (ARSET)

https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

- ARSET's goal is to increase the use of Earth science in decision-making through training for:
  - Professionals in the public and private sector
  - Environmental managers
  - Policy makers

All ARSET materials are freely available to use and adapt for your curriculum. If you use the methods and data presented in ARSET trainings, please acknowledge the NASA Applied Remote Sensing Training (ARSET) program.

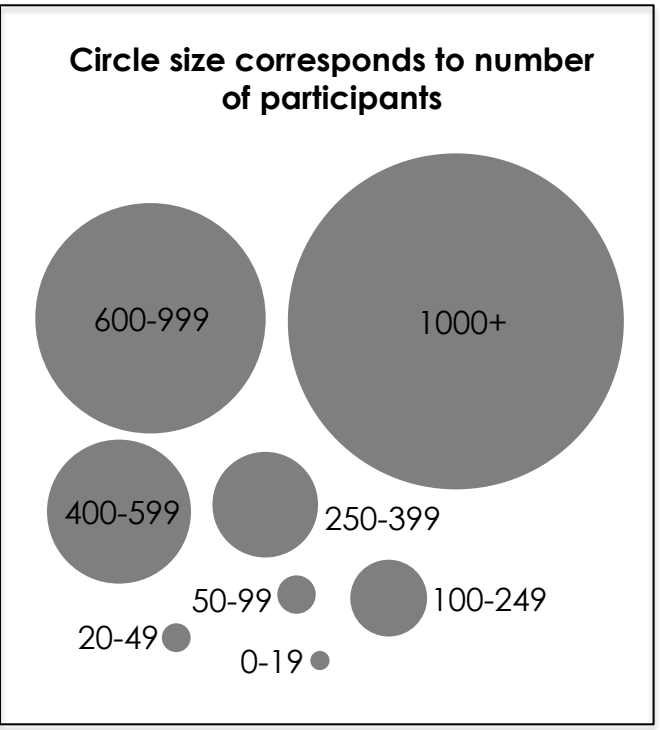
ARSET Trainings

40,000+ participants

170+ countries

140+ trainings

9,000+ organizations



About Lakes and Reservoirs

What is a Lake and a Reservoir?

- **A lake** is where surface water runoff and groundwater seepage accumulate naturally in a location due to surrounding terrain and slope.
- **A reservoir** is an artificial lake that is created by either building a dam on a river, excavating land, or by surrounding land with dikes.

- https://www.usgs.gov/special-topic/water-science-school/science/lakes-and-reservoirs?qt-science_center_objects=0#qt-science_center_objects
- http://www.fao.org/3/U5835E/u5835e03.htm#2.3%20reservoirs%20and%20lakes

Walker Lake, Alaska

https://www.nps.gov/gaar/learn/nature/walker-lake.htm

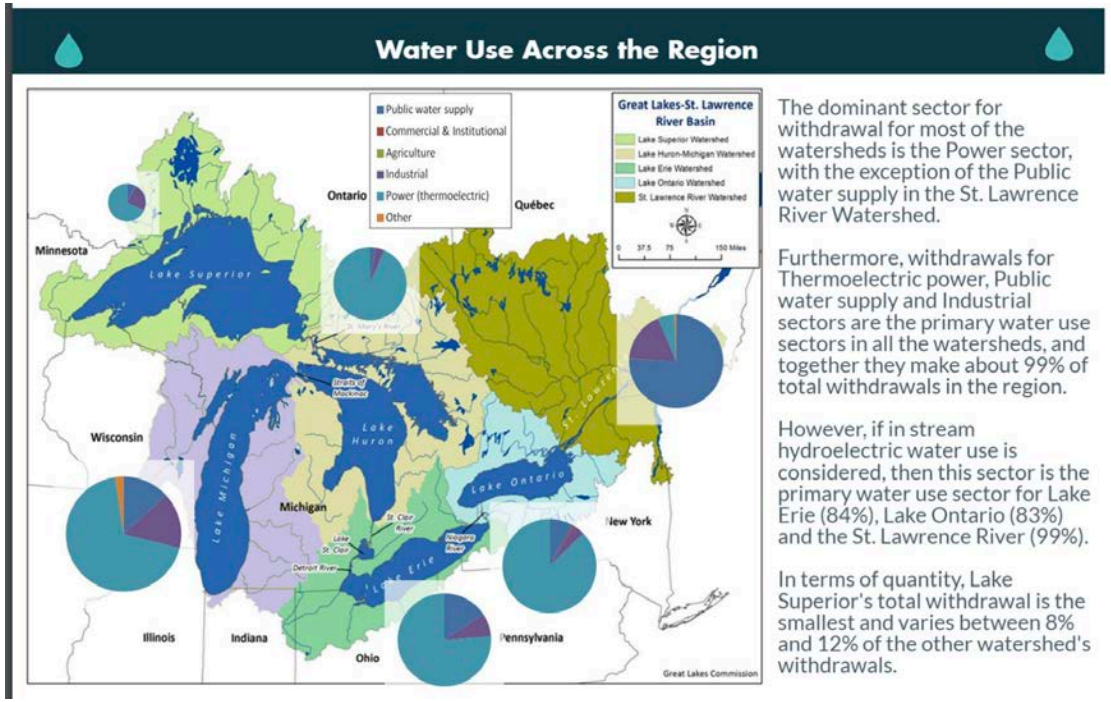
Franklin D. Roosevelt Reservoir, Washington

https://tataandhoward.com/10-largest-reservoirs-united-states/

Importance of Lakes and Reservoirs

- Lakes and reservoirs are components of surface water and play significant role in regional and global hydrological and biogeochemical cycles.
- Provide water for domestic, agricultural, industrial, and hydropower generation usage
- Provide water for cooling oil/gas/nuclear power plants
- Manmade reservoirs are additionally used for water storage and flood control.
- Used for fishing and recreational activities
- Support aquatic ecosystems and wildlife
- Valued for their aesthetic and scenic qualities

The Great Lakes-St. Lawrence River Basin supports water usage of approximately 36 million people with daily water withdrawal varying from 43 to 44 million gallons.

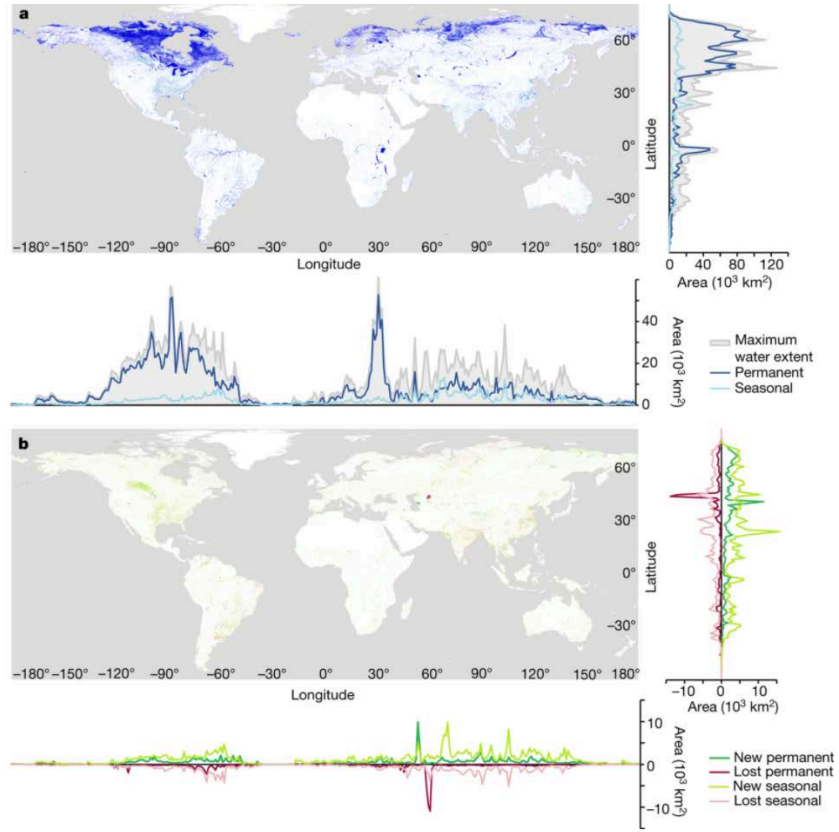


https://www.glc.org/wp-content/uploads/2013/10/WaterUsedB_GeneralFactsheet.pdf

Global Lakes and Reservoirs

- Lakes and reservoirs contain approximately 21% of global freshwater (USGS).
- Based on a recent study (Meyer et al., 2020), globally more than 1.42 + million lakes and reservoirs of at least 10 hectares in size were present between 1995 to 2015.
- A remote sensing-based study (Pekel et al., 2016) showed that globally between 1984 and 2015, permanent surface water has disappeared from an area of almost 90,000 km^2, though new permanent bodies of surface water covering 184,000 km^2 have formed due to new reservoirs!

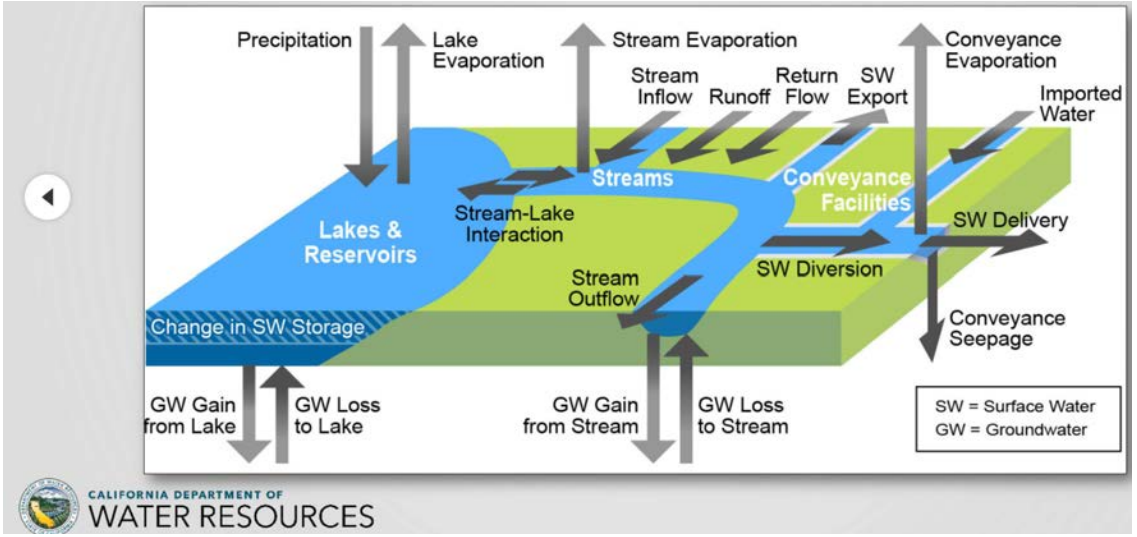
Global Surface Water Distribution and Change



Global maps, with 1° latitude/longitude summaries of surface water area shown on the right and underneath. **a**, Maximum water extent, permanent and seasonal surface water occurrence October 2014 to October 2015. **b**, Gains and loss in permanent and seasonal surface water area between 1984 and 2015. All measurements made from inland and coastal waters are defined only by the GADM reference layer (see Methods).

How are Lakes and Reservoirs Sustained?

- Water inflow sources include rainfall and runoff via streams and rivers, and groundwater seepage into lakes.
- Natural outflow of water from lakes can be via surface streams and/or loss to sub-surface, and ground and loss to the atmosphere through evaporation.
- Withdrawal of water from lakes and reservoirs for human needs also adds to the outflow.
- Inflow and outflow can be somewhat managed in artificial reservoirs created when dams are built on rivers.



https://mavensnotebook.com/2020/05/13/water-resources-management-developing-a-water-budget/

Water volumes in lakes and reservoirs depend on the inflow and outflow of water.

Monitoring Lakes and Reservoirs

- Water volume or storage in lakes/reservoirs is influenced by watershed processes such as precipitation, topography, soil and vegetation cover, runoff, population density, and water consumption rate*.
- Climate variability and change, land use, and water demands can impact both water inflow and outflow and influence the volume of lakes and reservoirs.
- Sediments brought to lakes and reservoirs by streams can alter their physical and chemical characteristics.
- Both the horizontal extent and water depth of lakes are influenced by the above factors.

For sustainable and efficient water resources and ecosystem management, monitoring lake/reservoir area and depth is very important.

*Water quality management is an integral part of lake management. In this webinar we will focus on data sets that help estimate water quantity.

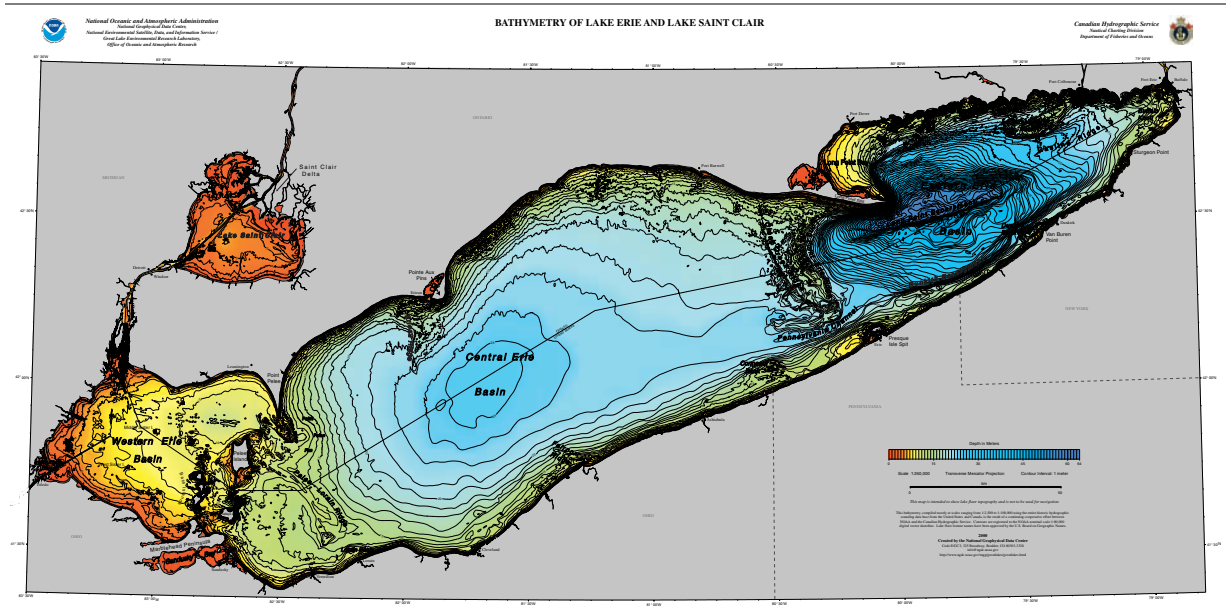
Monitoring Lakes and Reservoirs

- Water volume in a lake can be estimated as:

(Average Lake Area) x (Average Water Depth)

- Shoreline length (or width and length) and bathymetry information help in deciding the average volume of lakes. In addition, water level is required to estimate the volume of water in lakes.
- Lake bathymetry describes bottom topography or depth within the lake.

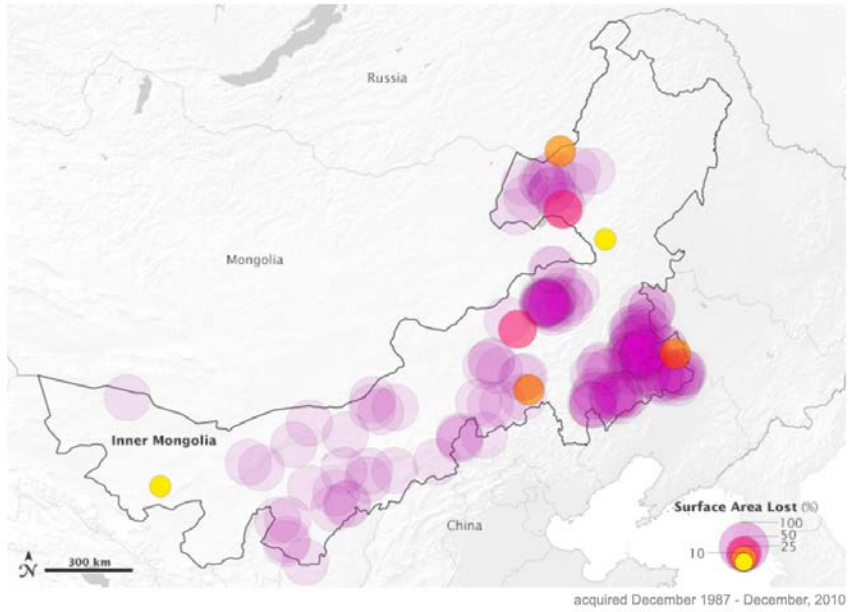
Bathymetry of Lake Erie & Lake Saint Clair



https://www.ngdc.noaa.gov/mgg/image/images/erie_wallsize_300.pdf

Monitoring Lakes and Reservoirs Using Remote Sensing

- Satellite remote sensing provides global, timely, consistent observations.
- Satellites observe lakes and reservoirs and monitor surface area, water level, and bathymetry over time.



acquired December 1987 - December, 2010

Shrinking Lakes on the Mongolian Plateau

acquired August 30, 2001 - August 20, 2006

https://landsat.visibleearth.nasa.gov/view.php?id=85665

Satellites and Sensors for Monitoring Lakes and Reservoirs

Satellites and Sensors for Monitoring Lakes & Reservoirs

Lake Parameter	Satellites	Sensors	Spectral Measurements
Surface Water Extent	Terra & Aqua	MODIS	Optical
Surface Water Extent	Landsat 7, 8, and past data from Landsat 5	ETM+, OLI TM, MSS	Optical
Lake Level Height	Jason 2, 3, and multiple past satellites	Altimeter	C-Band and Ku-Band
Lake Level Height and Bathymetry	ICESat-2	ATLAS	Laser
Lake Polygons	SRTM	Radar	C-Band Synthetic Aperture Radar

ATLAS: Advanced Topographic Lase Altimeter
ETM+: Enhanced Thematic Mapper Plus
ICESat-2: Ice, Clouds, and Land Elevation Satellite mission
MODIS: MODerate resolution Imaging Spectroradiometer
MSS: Multi Spectral Scanner
OLI: Operational Land Imager
SRTM: Shuttle Radar Topography Mission
TM: Thematic Mapper

Satellites and Sensors for Monitoring Lakes & Reservoirs

Surface Water Extent	Satellites	Spatial Resolution	Temporal Coverage and Resolution
Surface Water Extent	*Terra & Aqua	250 m	12/1999 – Present 05/2002 – Present Annual
Surface Water Extent	*Landsat 5, 7, 8	30 m	04/1999 – Present 02/2013 – Present Annual
Lake Level Height	[2]Jason 2, 3	Lakes > 100 km^2	06/2008 – Present 01/2016 – Present 10-day & 35-day
Lake Level Height and Bathymetry	[3]ICESat-2	Lakes > 0.1 km^2	9/2018 – Present 91-day
Lake Polygons	*SRTM	30 m	2/2000

*For details see **Session 2B on:**
https://appliedsciences.nasa.gov/join-mission/training/english/fundamentals-remote-sensing

[2]Details in Session 2

[3]Details in Session 3

Global Surface Water Datasets

Global Lake Polygons: HydroLAKES

- https://www.hydrosheds.org/pages/hydrolakes
- HydroLAKES database provides shoreline polygons of global lakes of 10 hectares and larger.
- More than 1.4 million lakes, both saline and freshwater, are included in the database.
- Based on several near-global and regional datasets combined to obtain global coverage.

Table 1: Datasets used in the creation of HydroLAKES.

Original dataset	Region	Original format and resolution	Reference	Number of lakes
Canadian hydrographic dataset (CanVec)	Canada (entire country)	Vector; 1:50,000	Natural Resources Canada (2013)	863,550
Shuttle Radar Topographic Mission (SRTM) Water Body Data (SWBD)	56° South to 60° North	Raster; 1 arc-second (~30 m at the equator); vectorized and smoothed	Slater et al. (2006)	282,571
MODerate resolution Imaging Spectro-radiometer (MODIS) MOD44W water mask	Russia above 60° North	Raster; 250 m; vectorized and smoothed	Carroll et al. (2009)	167,435
US National Hydrography Dataset (NHD)	Alaska (entire state)	Vector; 1:24:000	U.S. Geological Survey (2013)	58,496
European Catchments and Rivers Network System (ECRINS)	Europe above 60° North and entire Norway	Vector; varying resolutions (~1:250,000)	European Environment Agency (2012)	50,699
Global Lakes and Wetlands Database (GLWD)	World	Vector; 1:1 million	Lehner and Döll (2004)	3,023
Global Reservoir and Dam database (GRanD)	World	Vector; varying resolutions (1:1 million or better)	Lehner et al. (2011)	1,133
Other (own mapping)	World	Vector; varying resolutions (1:1 million or better)	n/a	781
Total				**1,427,688**

HydroLAKES Data Access

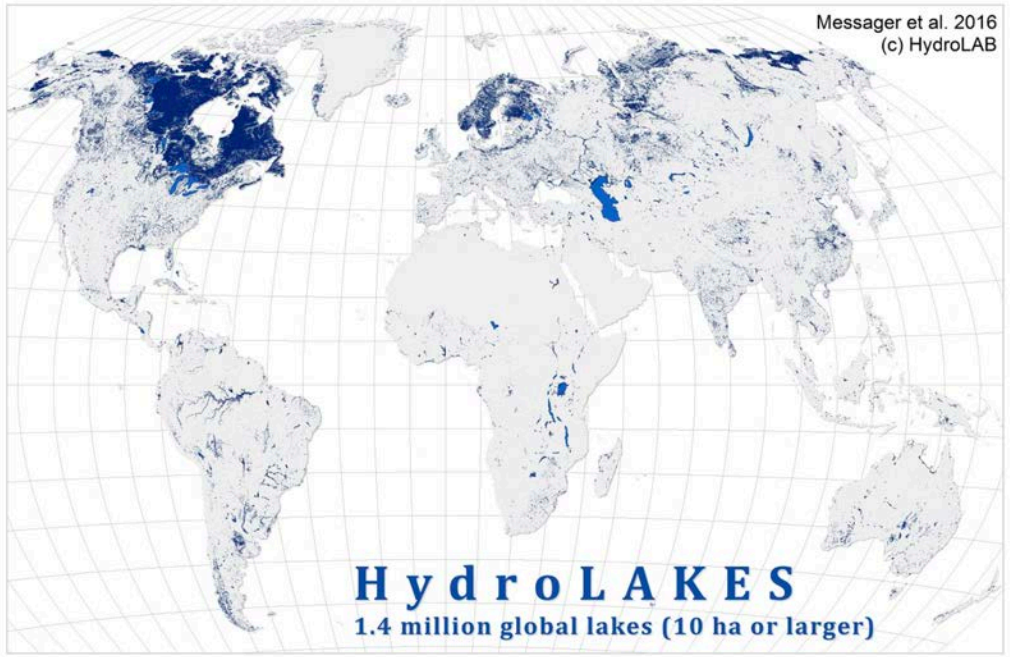
Details of the Database:

HydroLAKES Technical Documentation

Data Download:

The data can be downloaded in 4 different formats:
https://www.hydrosheds.org/pages/hydrolakes

1. Lake polygons (including all attributes) in an ESRI Geodatabase (727 MB zip-file)
2. Lake pour points (including all attributes) in an ESRI Geodatabase (78 MB zip-file)
3. Lake polygons (including all attributes) in a Shapefile (782 MB zip-file)
4. Lake pour points (including all attributes) in a Shapefile (75 MB zip-file)



MODIS Water Mask Data: MOD44W-V06

Based on:

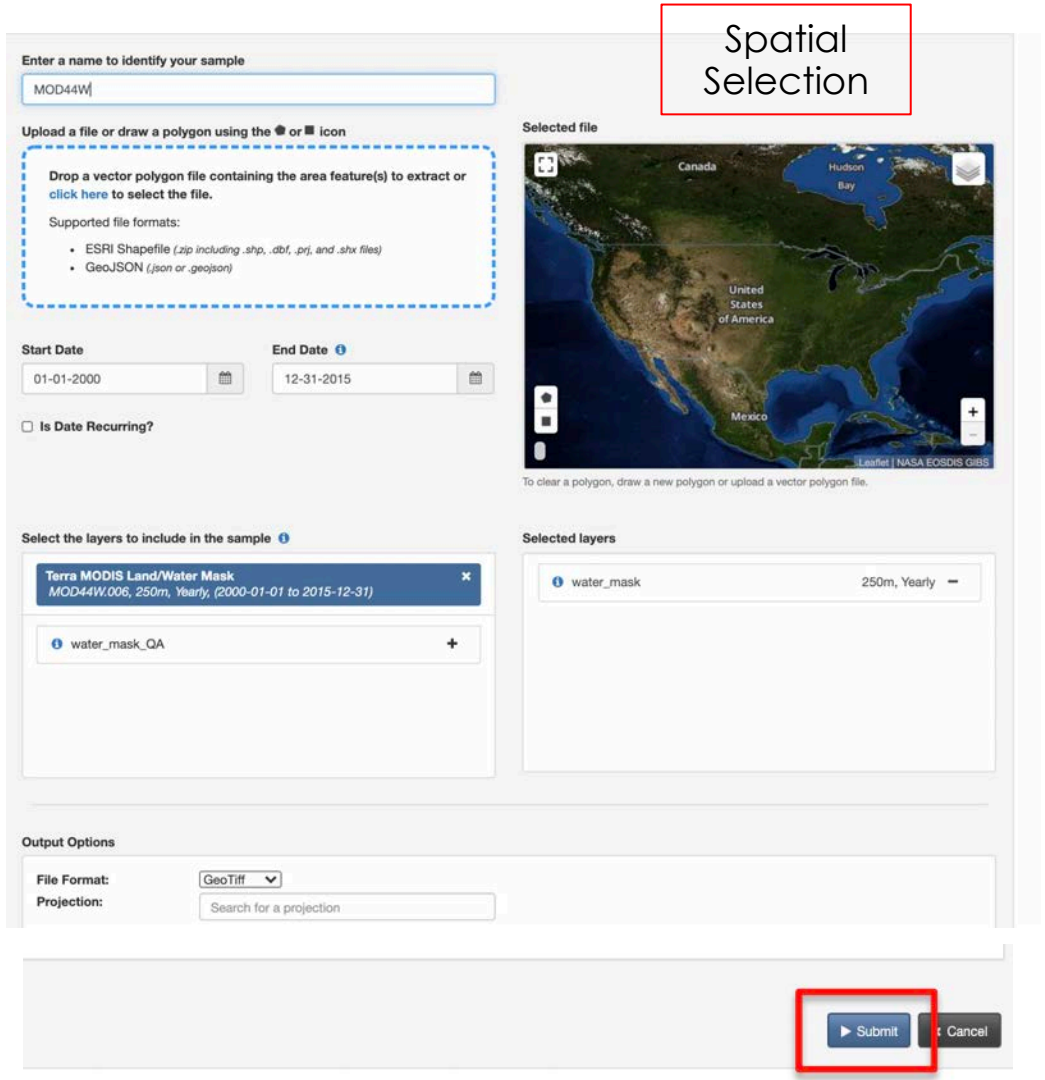
1. SRTM water body dataset and MODIS reflectance data between 54° S to 60° N
2. MODIS alone between 60° N and 90° N
3. Mosaic of Antarctica (MOA) product between 60° S and 90° S (Carroll et al., 2009, 2017)

- MOD44W-V06 is derived using a decision tree classifier using MODIS data every 16 days.
- Global, annual water body mask is derived at 250 m resolution.
- Currently available from 2000 to 2015.
- Improved terrain shadow masking with slope and elevation masking using 30 m SRTM DEM as an input.
- Incorporates new MODIS burned area product MCD64A1 to delineate burn scars.
- https://lpdaac.usgs.gov/documents/109/MOD44W_User_Guide_ATBD_V6.pdf

MOD44W-V06 Data Access using AppEEARS

Application for **E**xchange and **E**xploring **A**nalysis **R**eady **S**amples (AppEEARS):

- https://lpdaacsvc.cr.usgs.gov/appeears/
- Allows spatial and temporal sub-setting.
- Data can be downloaded in GeoTIFF or NetCDF format.
- For more details on using AppEEARs, see this ARSET webinar: https://www.youtube.com/watch?v=KJTyMDyvBik



MOD44W-V06 Data Access using Google Earth Engine (GEE)

https://developers.google.com/earth-engine/datasets/catalog/MODIS_006_MOD44W

MOD44W.006 Terra Land Water Mask Derived from MODIS and SRTM Yearly Global 250m

Dataset Availability

2000-01-01T00:00:00 - 2015-01-01T00:00:00

Dataset Provider

NASA LP DAAC at the USGS EROS Center

Earth Engine Snippet

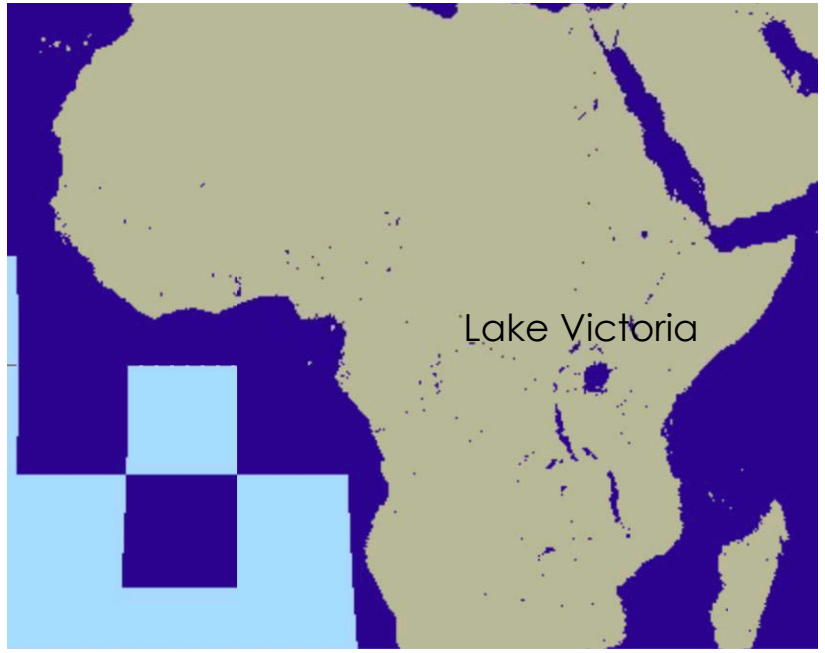
```
ee.ImageCollection("MODIS/006/MOD44W")
```

Tags

water-mask srtm geophysical modis mod44w usgs nasa

Description Bands Terms of Use Citations DOIs

The MOD44W V6 land/water mask 250m product is derived using a decision tree classifier trained with MODIS data and validated with the MOD44W V5 product. A series of masks are applied to address known issues caused by terrain shadow, burn scars, cloudiness, or ice cover in oceans.

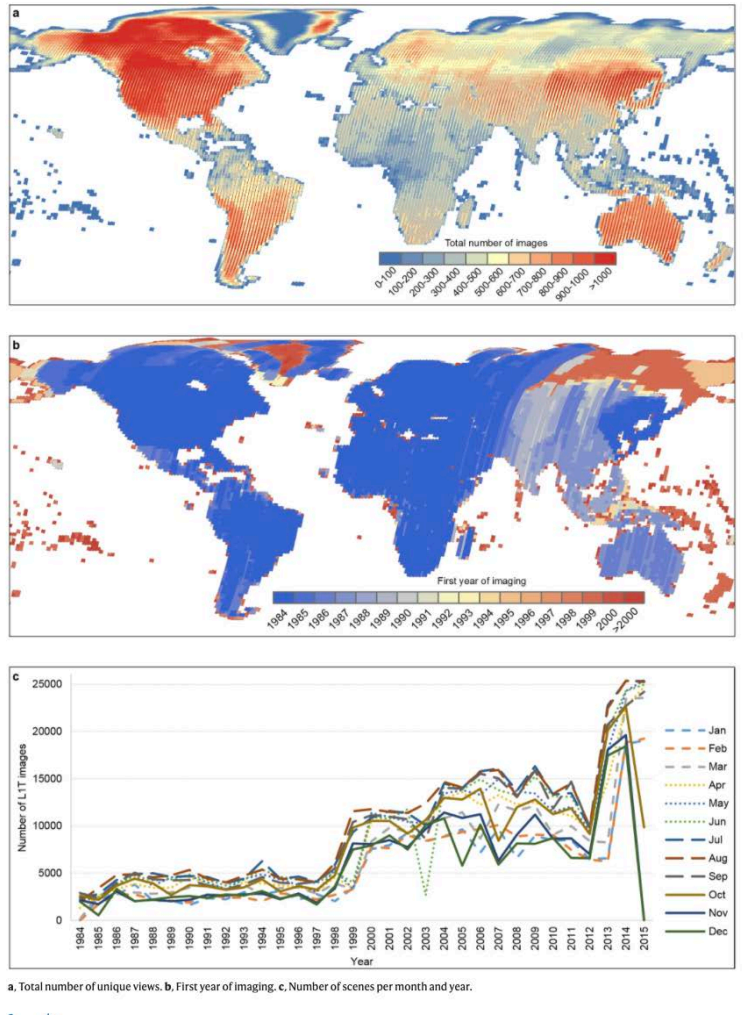


JRC Global Surface Water from Landsat

- http://global-surface-water.appspot.com/#
- Developed by the European Commission's Joint Research Center (JRC)
- Based on entire archive of Landsat 5, 7, and 8 imagery (Pekel et al., 2016)
- Water detection is based on multispectral features using big data techniques such as expert supervision technique, visual analytics, and evidential reasoning (Pekel et al., 2016 and references therein).
- A Google Earth Engine web interface allows the expert system to be run on Landsat 5, 7, and 8 imagery. Access can be provided upon request.

Extended Data Figure 1: Geographic and temporal coverage of the Landsat 5, 7 and 8 L1T archive between 16 March 1984 and 10 October 2015.

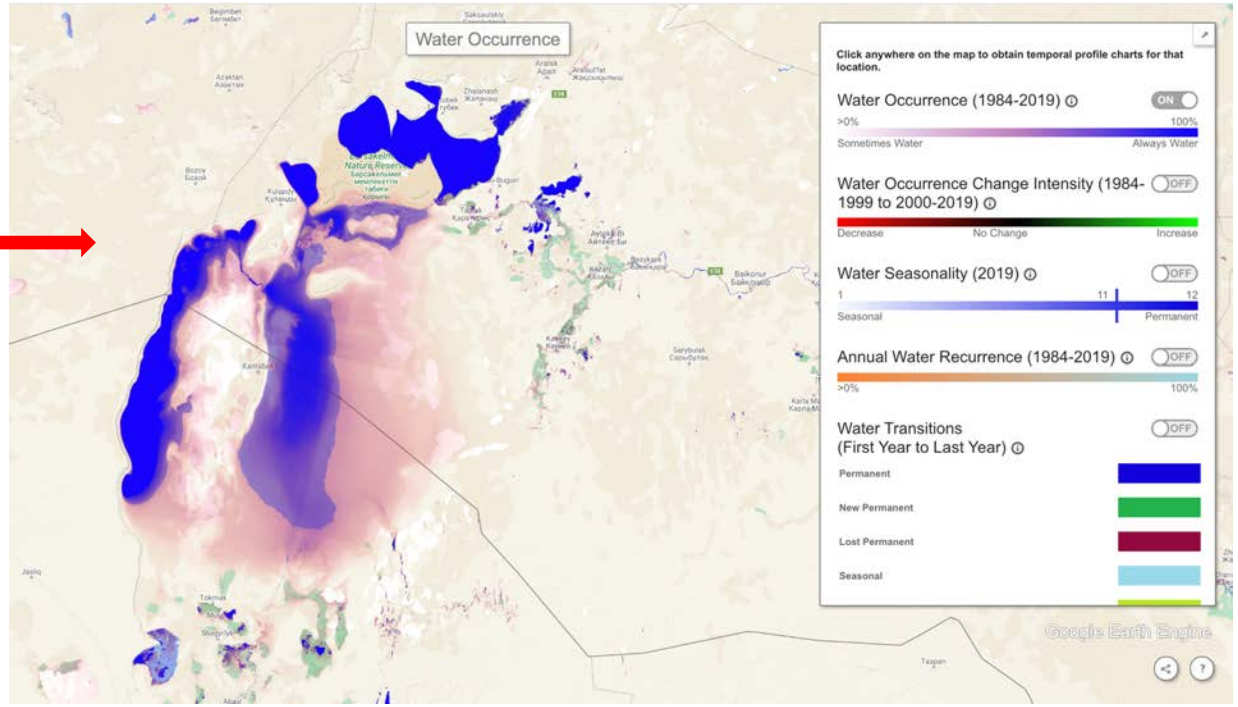
From: High-resolution mapping of global surface water and its long-term changes



a, Total number of unique views. b, First year of imaging. c, Number of scenes per month and year.

JRC Global Surface Water Data Access

- Surface Water data available at 30 m resolution.
- Currently available from 1984 to 2019.
- Data available from Global Surface Water Explorer: http://global-surface-water.appspot.com/#
- Also available from Google Earth Engine (GEE): https://developers.google.com/earth-engine/datasets/catalog/JRC_GSW1_2_GlobalSurfaceWater#bands



Global Surface Water Data Access

Available Data Layers for JRC's Global Surface Water, v1.2 (GEE):

Description | Bands | Terms of Use | Citations

Resolution
30 meters

Bands

Name	Units	Min	Max	Description
occurrence	%	0	100	The frequency with which water was present.
change_abs	%	-100	100	Absolute change in occurrence between two epochs: 1984-1999 vs 2000-2019.
change_norm	%	-100	100	Normalized change in occurrence. (epoch1-epoch2)/(epoch1+epoch2) * 100
seasonality		0	12	Number of months water is present.
recurrence	%	0	100	The frequency with which water returns from year to year.
transition				Categorical classification of change between first and last year.
max_extent				Binary image containing 1 anywhere water has ever been detected.

Examples of Monitoring Lakes and Reservoirs

Monitoring Lake Volume

Application of the JRC surface water area and altimetry-based lake level height in monitoring lake volume changes between 1984 and 2015, (Busker et al. 2019)

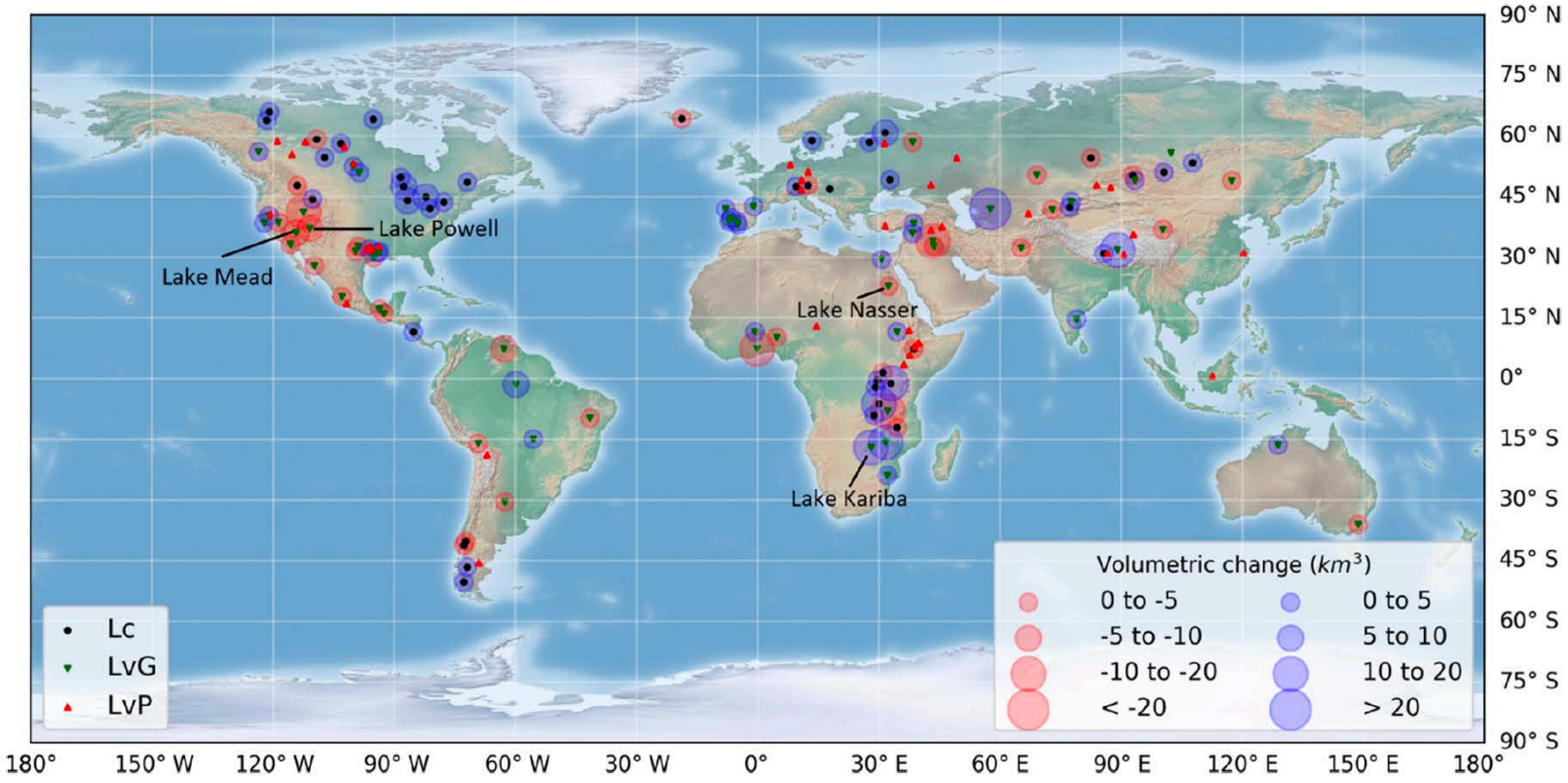
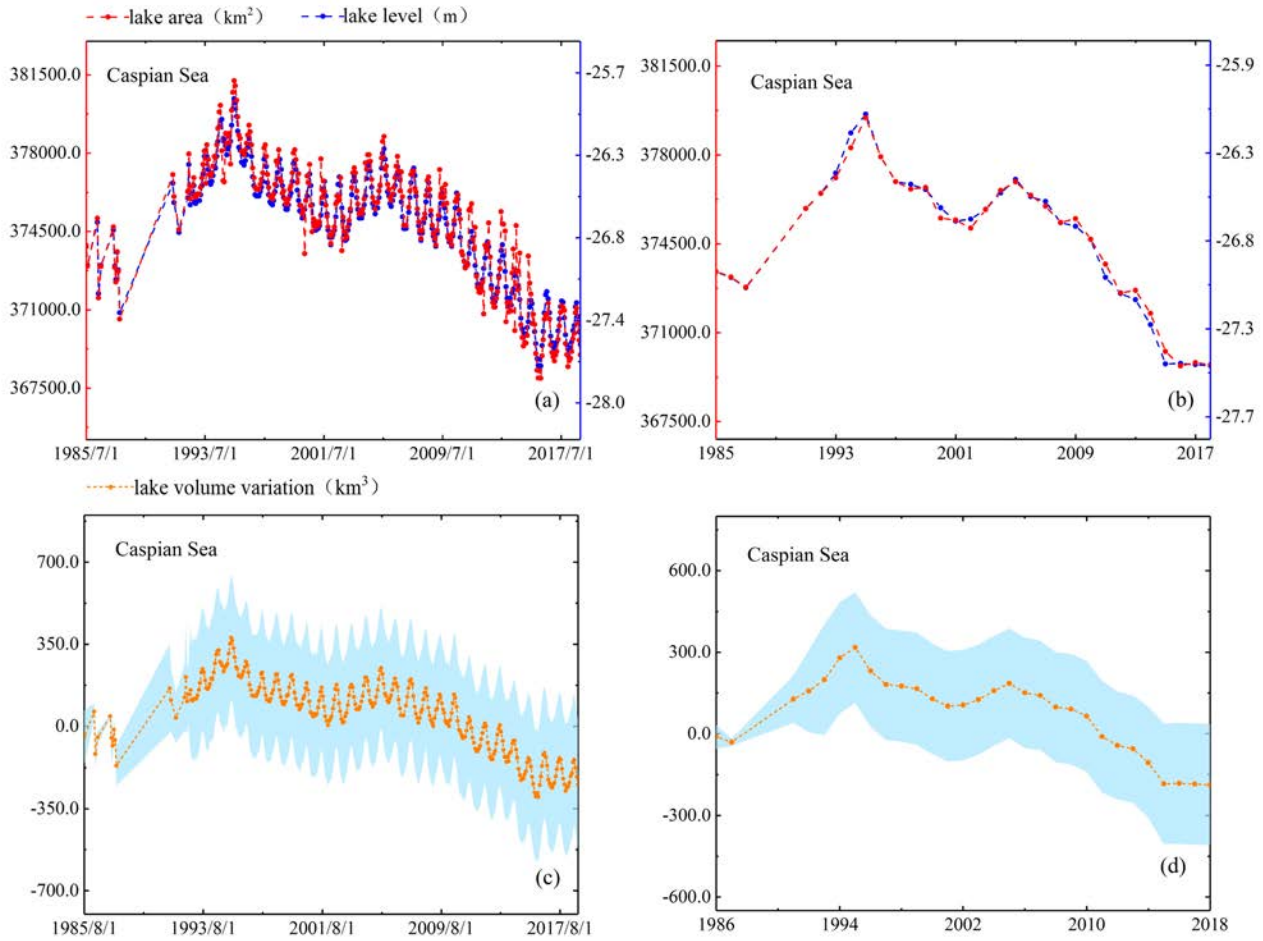


Figure 7. Lake and reservoir types (constant area (Lc), variable area with good (LvG) and poor (LvP) regression performance) with the average volume changes.

Monitoring Lake Area and Volume

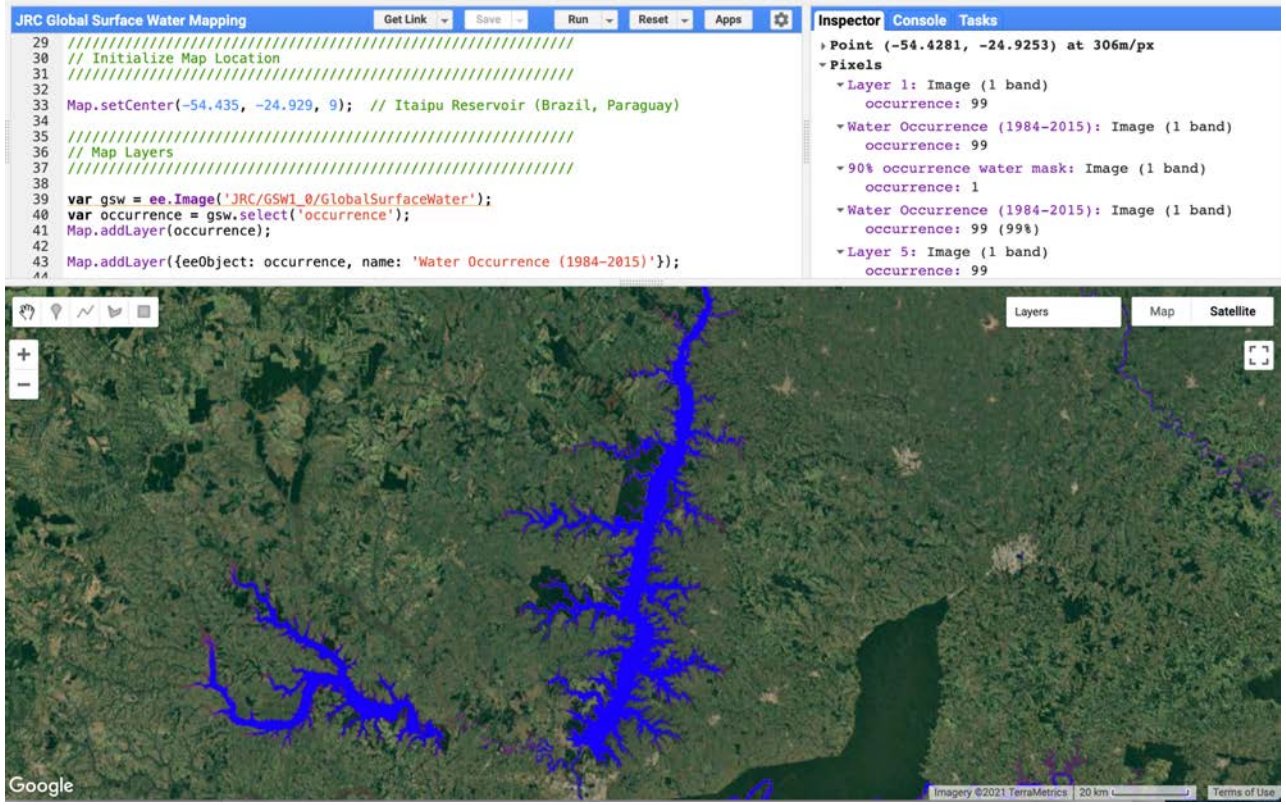
Lake area, level, and volume variations in monthly (**a**, **c**) and annual (**b**, **d**) time scales for the Caspian Sea (Luo et al., 2019)



Demonstration: Global Surface Water Data Access

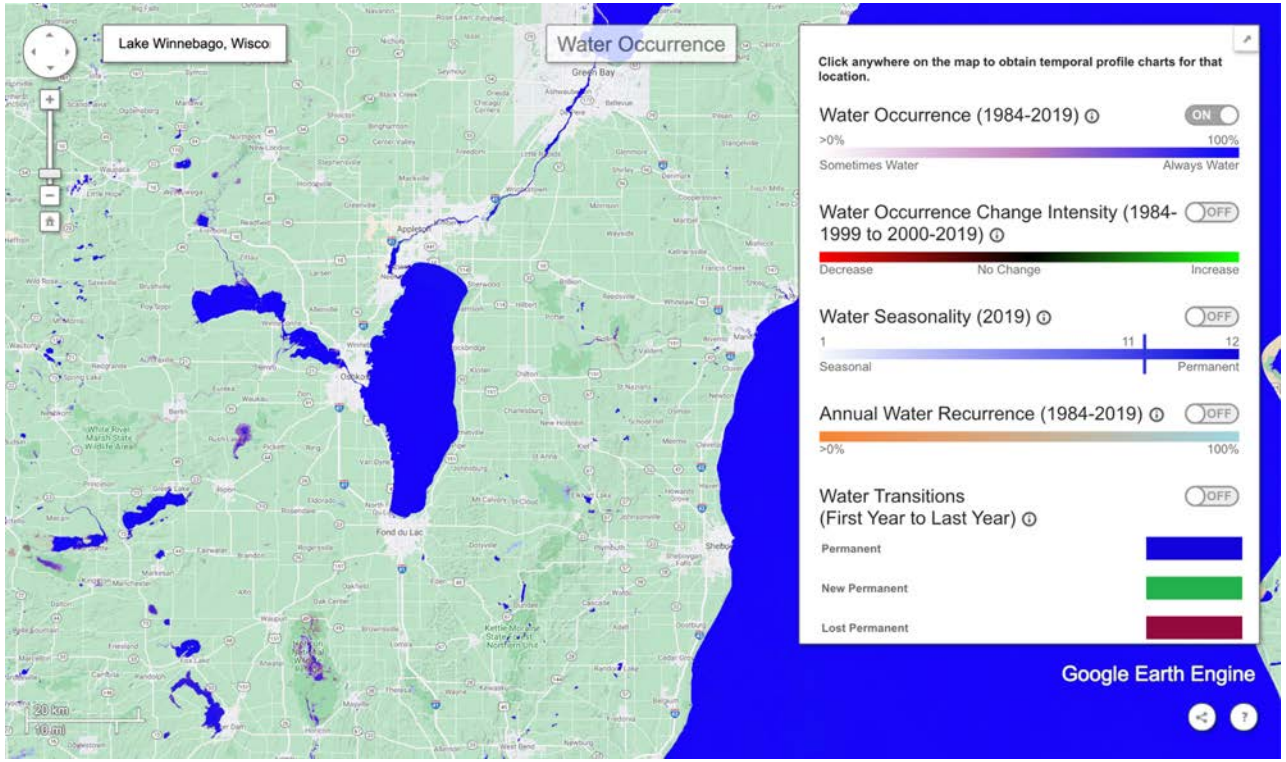
Demonstration – Google Earth Engine

- Demo 1:
  - JRC Global Surface Water Data
  - Google Earth Engine
  - Itaipu Reservoir (Brazil, Paraguay)
  - Code from the demo can be found in the following repository: https://code.earthengine.google.com/32b3a777d191ad871764fc80cf2c6190



Demonstration – Global Surface Water Explorer

- Demo 2:
  - JRC Global Surface Water Data
  - Global Surface Water Explorer
  - Lake Winnebago (Wisconsin, USA)
  - http://global-surface-water.appspot.com/map



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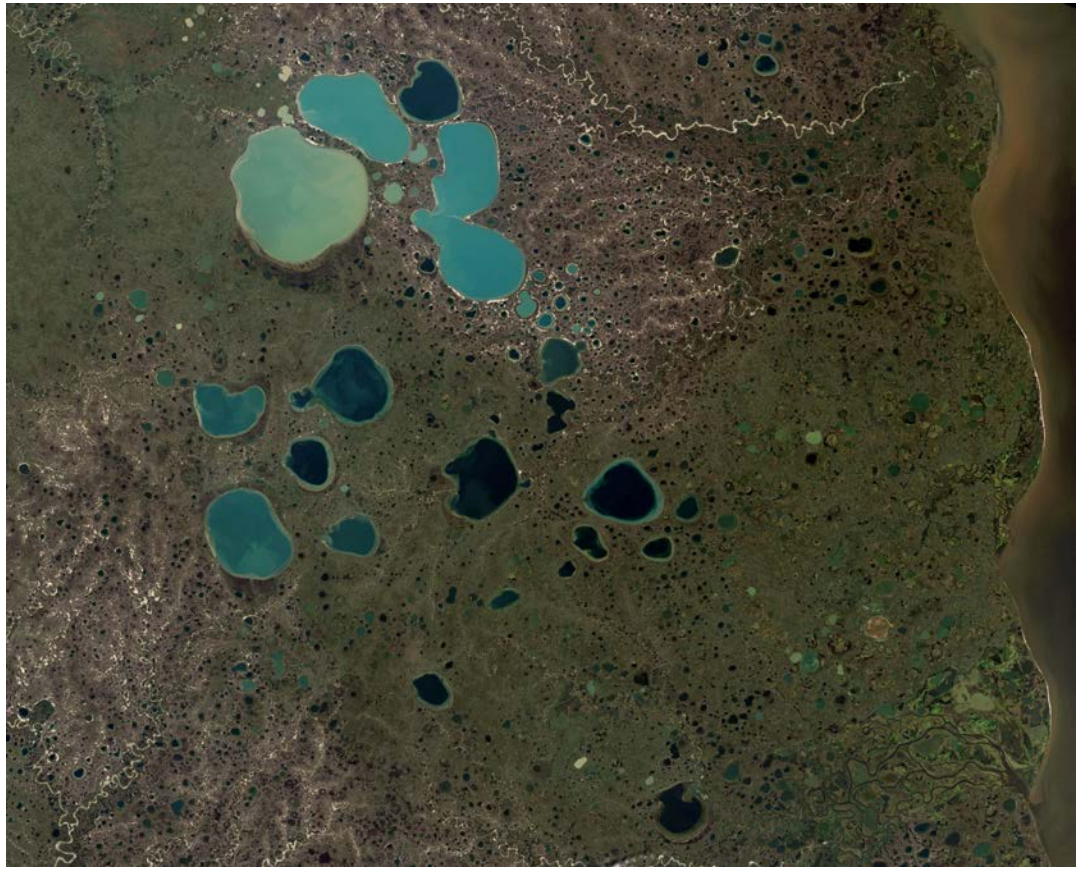
Questions

- Please enter your questions in the Q&A box. We will answer them in the order they were received.
- We will post the Q&A to the training website following the conclusion of the webinar.



https://earthobservatory.nasa.gov/images/6034/pothole-lakes-in-siberia

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- Training Webpage:
  - https://appliedsciences.nasa.gov/join-mission/training/english/mapping-and-monitoring-lakes-and-reservoirs-satellite-observations
- ARSET Website:
  - https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset


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Thank You!