Mapping and Monitoring Lakes and Reservoirs with Satellite Observations

Amita Mehta and Sean McCartney

16 February 2021

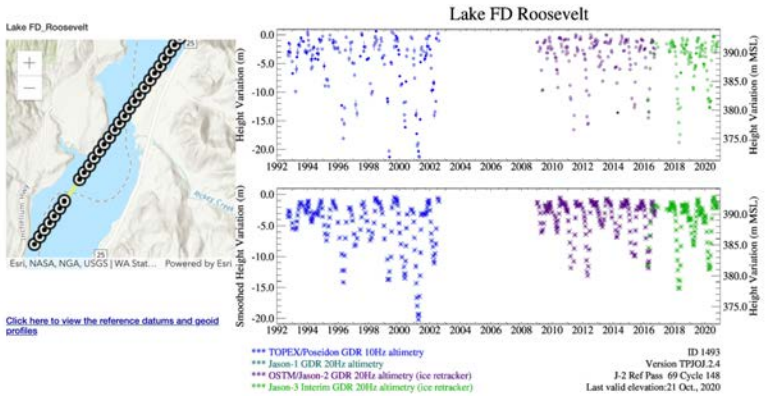
Training Outline

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

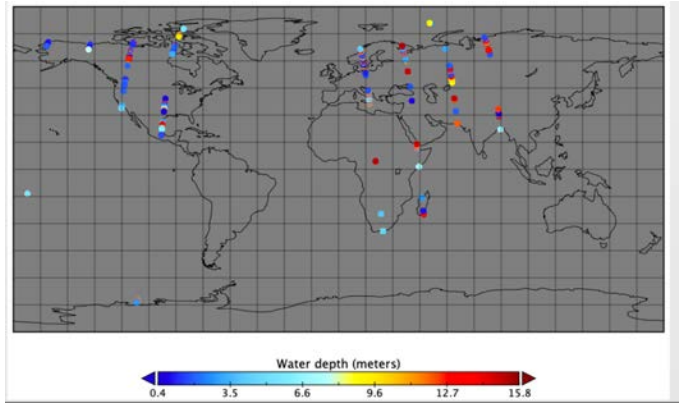
February 16, 2021



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

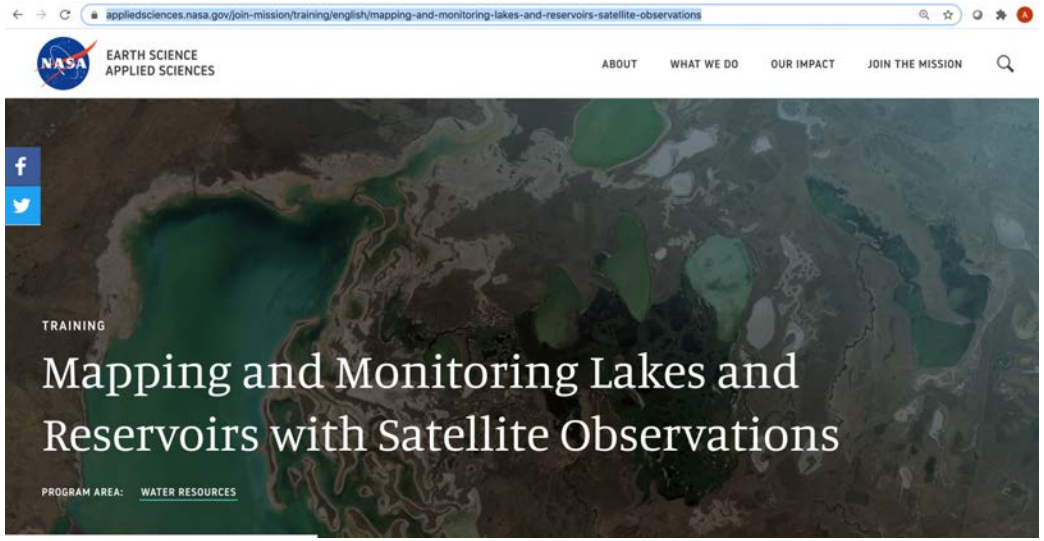
https://nsidc.org/data/atl13

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 23, 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

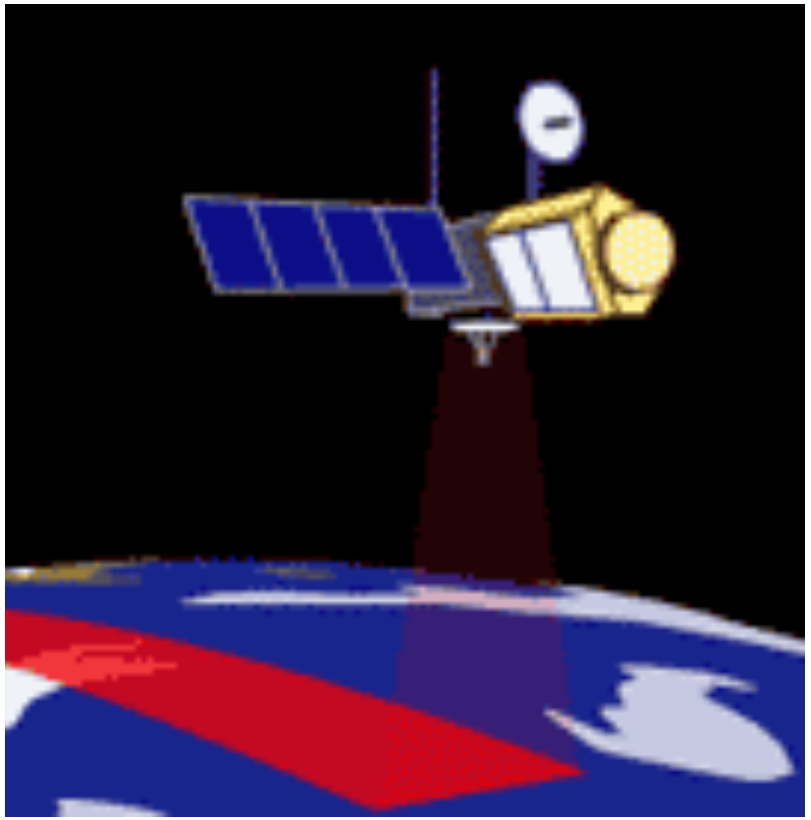
Session-2 Outline

- Satellites with Radar Altimeters for Monitoring Lakes and Reservoirs
- Lake-Level Height Data Derived From the Radar Altimeters
- Examples of Lake Level Height Applications
- Demonstration: Lake Level Height Data Access

Satellites with Radar Altimeters

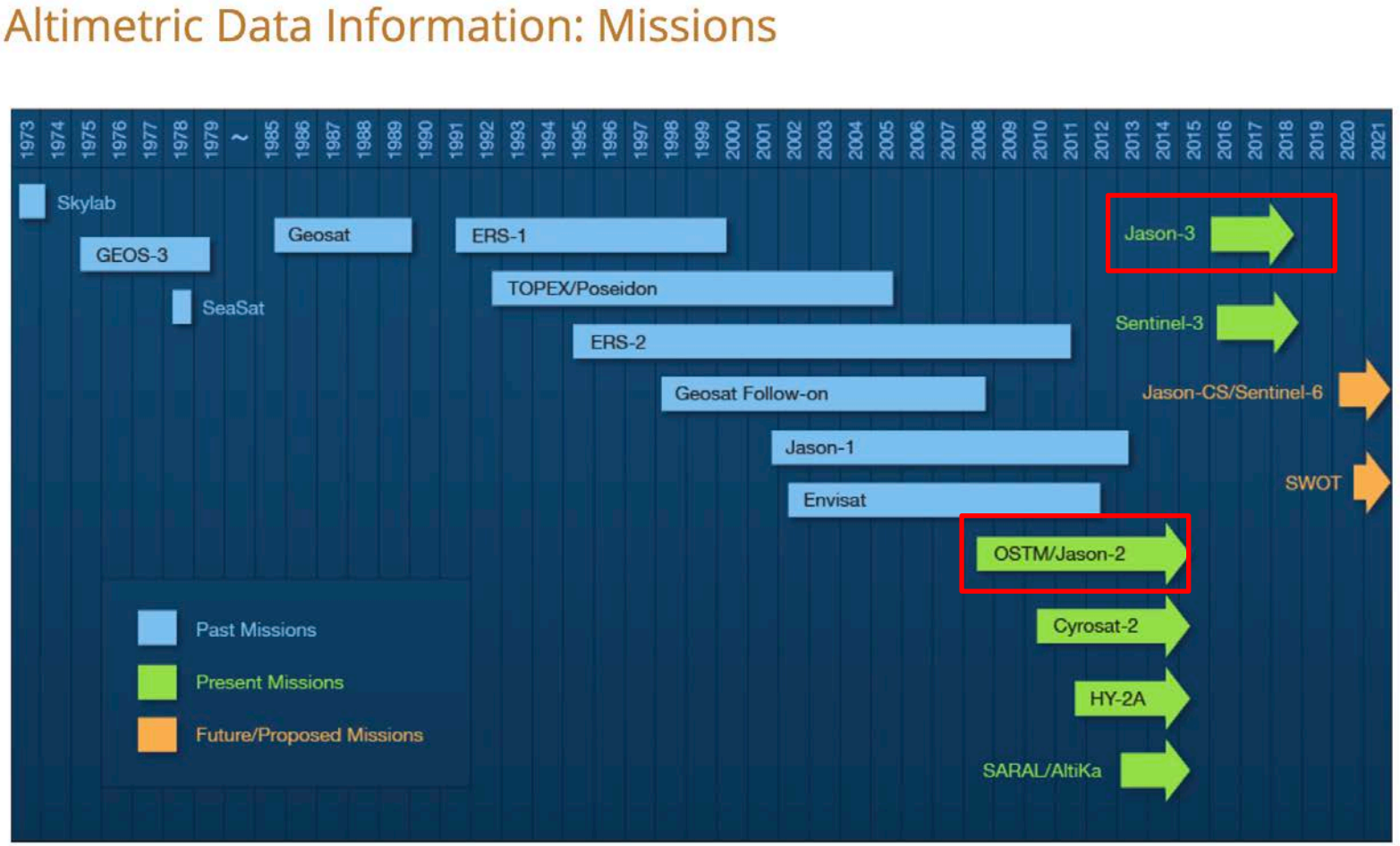
What is an Altimeter?

- Altimetry is a technique for measuring height. A radar used for this altimetry is called an altimeter.
- The time taken by a radar pulse to travel from the satellite antenna to the surface and back (radar echo), combined with precise satellite location data, is measured in altimetry.
- Satellite radar altimeters are used to get sea-surface heights, wind speed, and currents.



https://sealevel.jpl.nasa.gov/missions/technology/

Historical and Current Satellites with Altimeters



https://podaac.jpl.nasa.gov/Altimetric_Data_Information/Missions

Jason-2 and Jason-3 Instruments

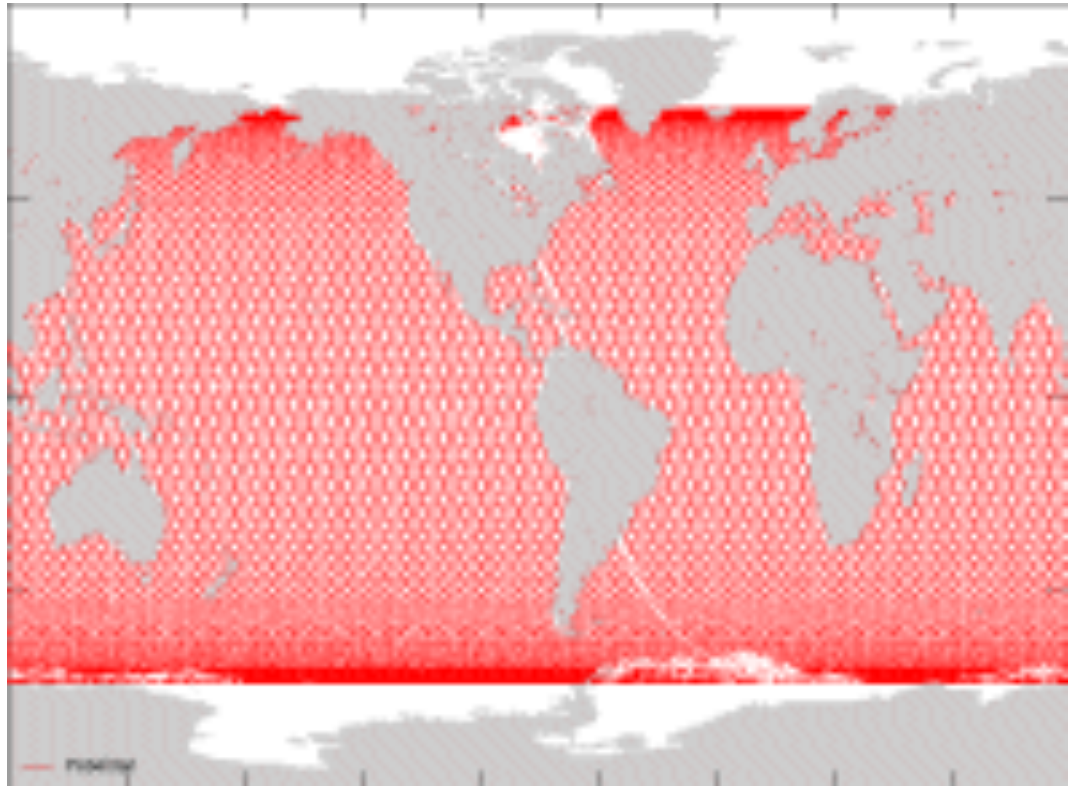
https://www.jpl.nasa.gov/missions/jason-2 & https://eospso.nasa.gov/missions/jason-3

- The Ocean Surface Topography Mission (OSTM)/Jason-2 and Jason-3 extend measurements from Jason-1.
- A collaboration between NASA, NOAA, CNES, and EUMETSAT.
- Launch Dates:

  Jason-2 : June 20, 2008

  Jason-3: January 17, 2016
- Circular, non-sun synchronous orbit
- Global coverage between 66°S to 66°N
- Revisit Time: 9.9 days

Jason-2 orbits every 10 days.

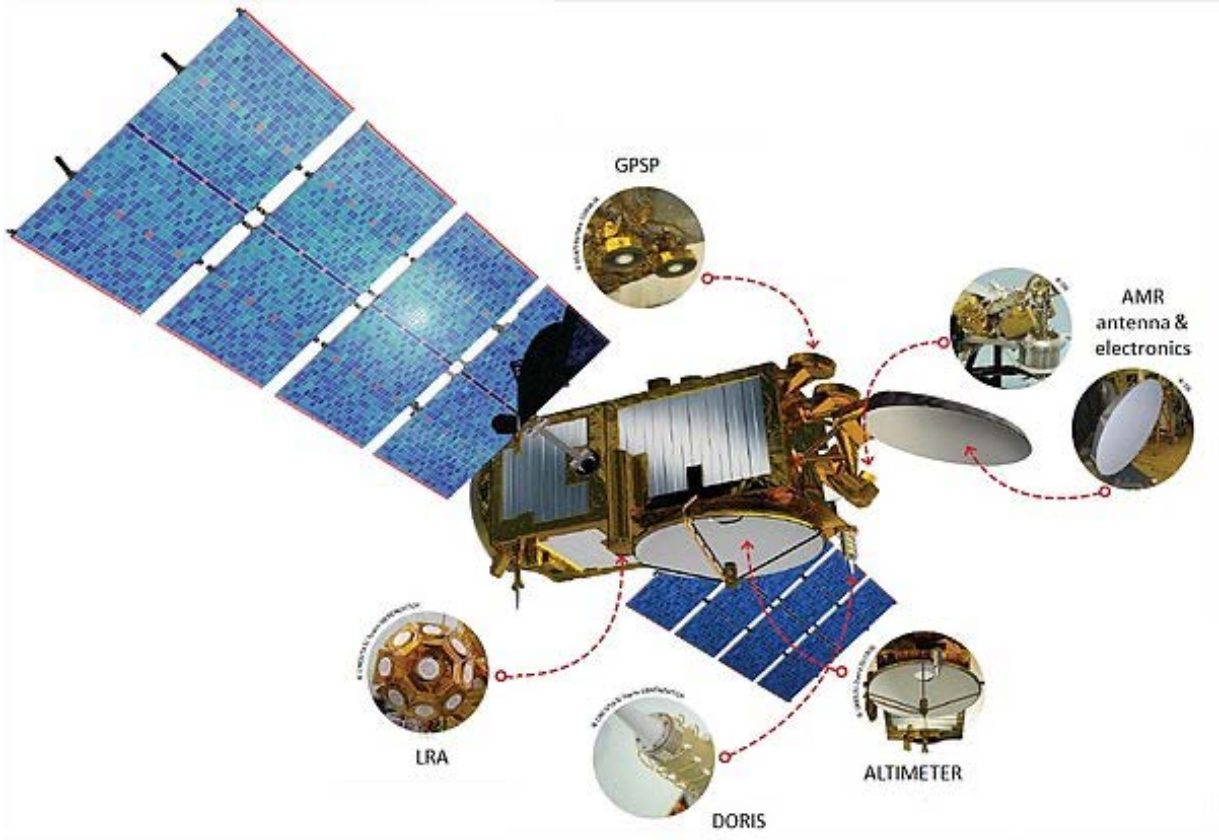


http://www.altimetry.info/missions/current-missions/jason-2/jason-2-orbit

Jason-2 and Jason-3 Instruments

https://www.jpl.nasa.gov/missions/jason-2 & https://eospso.nasa.gov/missions/jason-3

- Poseidon-3 (Jason-2) and Poseidon 3B (Jason-3) radar altimeters
- Advanced Microwave Radiometer
- Doppler Orbitography and Radio-positioning Integrated by Satellite (Doris)
- Laser Retroreflector Array
- Global Positioning System Payload



Also see summary at: https://www.nesdis.noaa.gov/jason-3/mission.html

Poseidon-3 and Poseidon-3B Altimeters

http://www.altimetry.info/missions/current-missions/jason-2/jason-2-instruments/poseidon-3/

- Operates at two frequencies:
  - 13.6 GHz in the K_u band
  - 5.3 GHz in the C band
- Measures range: the distance from the satellite to the Earth's surface from the radar echo.
- Data processing is a major part of altimetry.
- Tutorials about altimetry are available from:

  http://www.altimetry.info/radar altimetry-tutorial/training-material/

- Poseidon-3 requires a ground telecommand to switch from one mode to the other.
- Poseidon-3B allows on-board automatic transitions between modes.

Additional Resources

There are many online radar altimetry tutorials:

https://www.aviso.altimetry.fr/en/multimedia/education/altimetry-courses.html

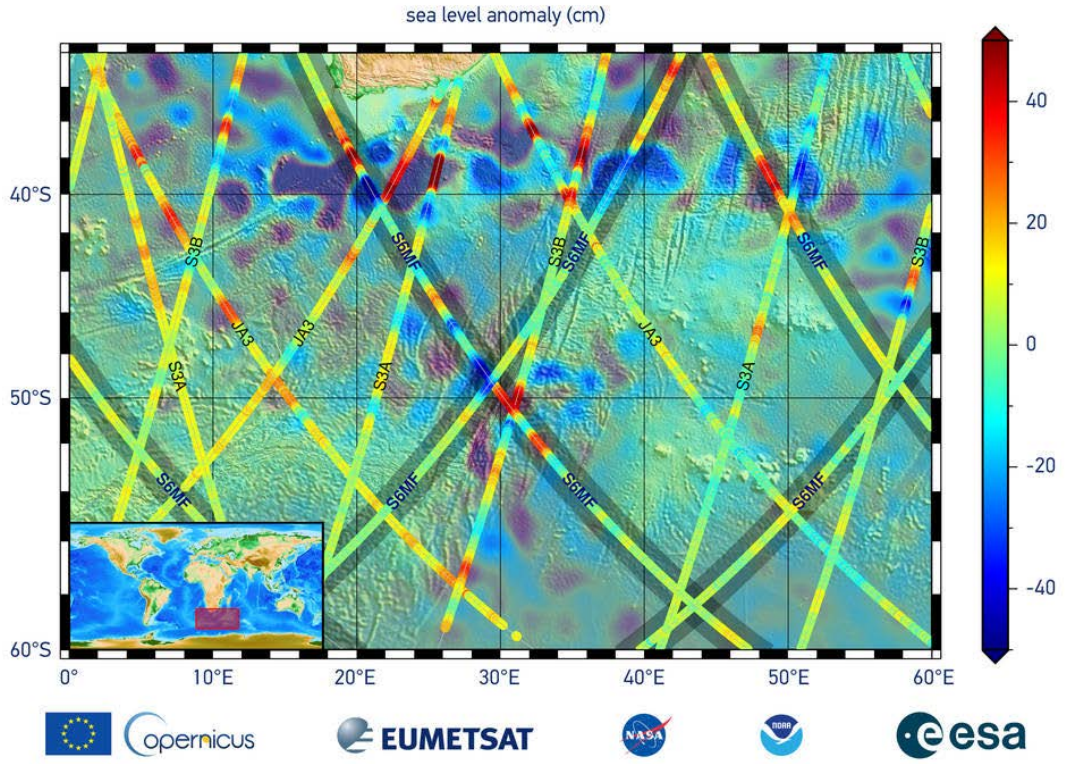
https://podaac.jpl.nasa.gov/Altimetric_Data_Information

http://www.altimetry.info/glossary_/jpl/

Jason Continuity of Service (CS) Mission on Sentinel-6

https://sealevel.jpl.nasa.gov/missions/jason-cs-sentinel-6/summary

- International partnership between NASA, NOAA, ESA, EUMETSAT, and Copernicus.
- Includes two identical satellites designed to continue sea surface height measurements with radar altimeters.
- The first Sentinel-6 (Michael Freilich) Mission launched on November 21, 2020.
- The second satellite will be launched in 2025.

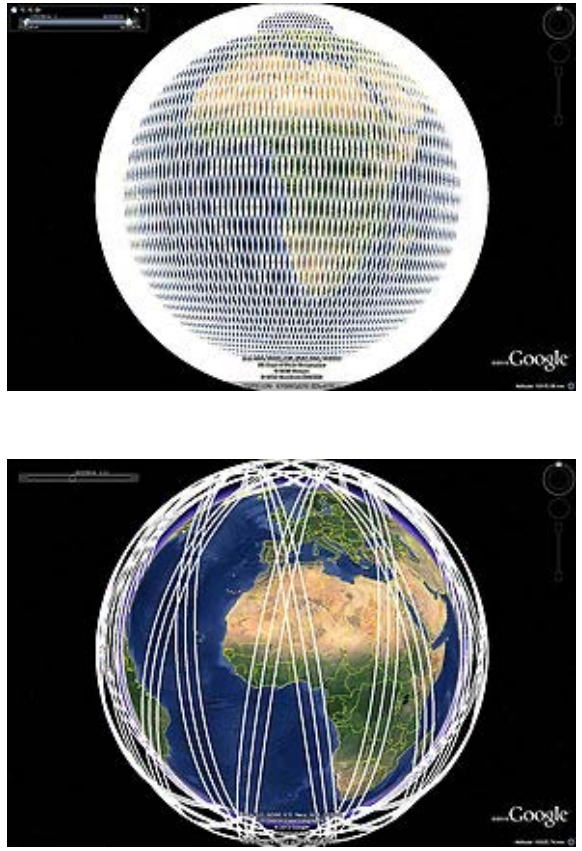


https://www.nasa.gov/press-release/nasa-us-european-partner-satellite-returns-first-sea-level-measurements

Future Mission: Surface Water and Ocean Topography (SWOT) Mission

https://swot.jpl.nasa.gov/mission/overview/

- Jointly developed by NASA, CNES, Canadian, and UK space agencies.
- Targeted to be launched in February 2022.
- Designed to make a survey of Earth's surface water to obtain detailed measurements on how water bodies on Earth change over time.
- Will cover 90% of global lakes, rivers, reservoirs, and oceans at least twice every 21 days.



Swot orbit in full 21 days (top), and in 3 days (bottom)

https://www.aviso.altimetry.fr/en/missions/future-missions/swot/orbit.html

SWOT Instruments

https://www.aviso.altimetry.fr/en/missions/future-missions/swot/instruments.html

- Wide Swath Altimeter in Ka Band
- Poseidon 3C
- Advance Microwave Radiometer
- DORIS
- GPSP
- LRA

- Poseidon-3C is a radar derived from the Jason-3 Poseidon-3B altimeter operating at the same two frequencies (13.6 and 5.3 GHz).
- Will allow better retrievals of inland water measurements.

SWOT Data Products

https://www.aviso.altimetry.fr/en/missions/future-missions/swot/data-products.html

- River Products:
  - Height
  - Width
  - Discharge

SWOT Data Products

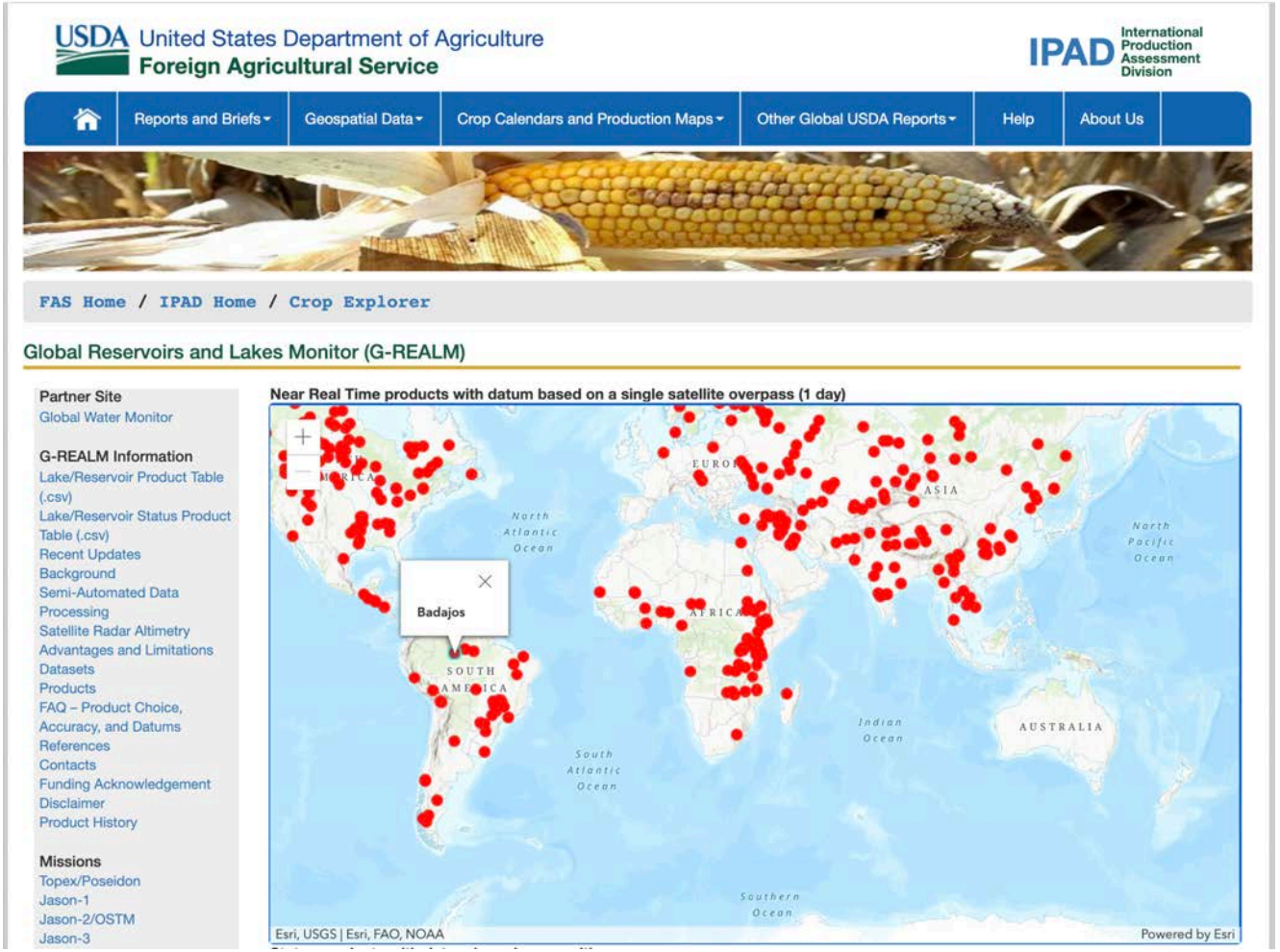
https://www.aviso.altimetry.fr/en/missions/future-missions/swot/data-products.html

- Lake Products:
  - Height
  - Area
  - Changes in Volume

Lake-Level Height Data Derived From Radar Altimeters

Altimeter-based Lake Level Height Data

- Global Reservoirs and Lakes Monitoring (G-REALM)
- https://ipad.fas.usda.gov/cropexplorer/global_reservoir/



Radar Altimetry - Microwave Reflection Echoes

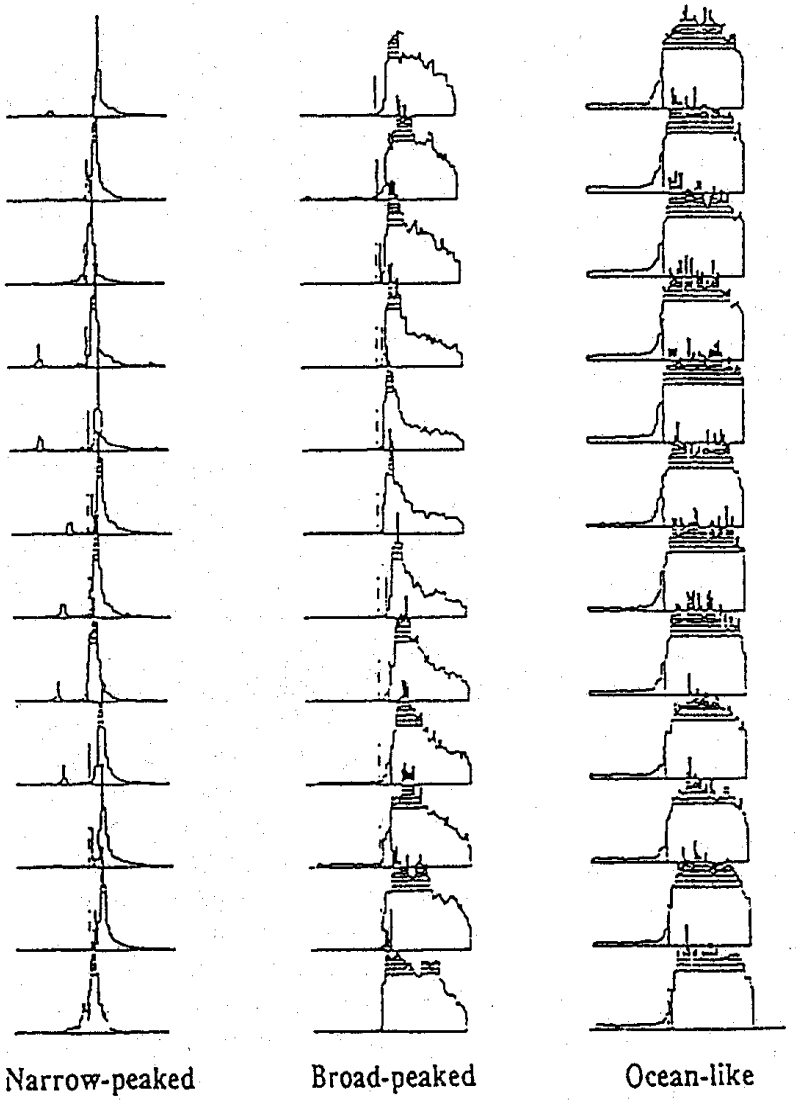
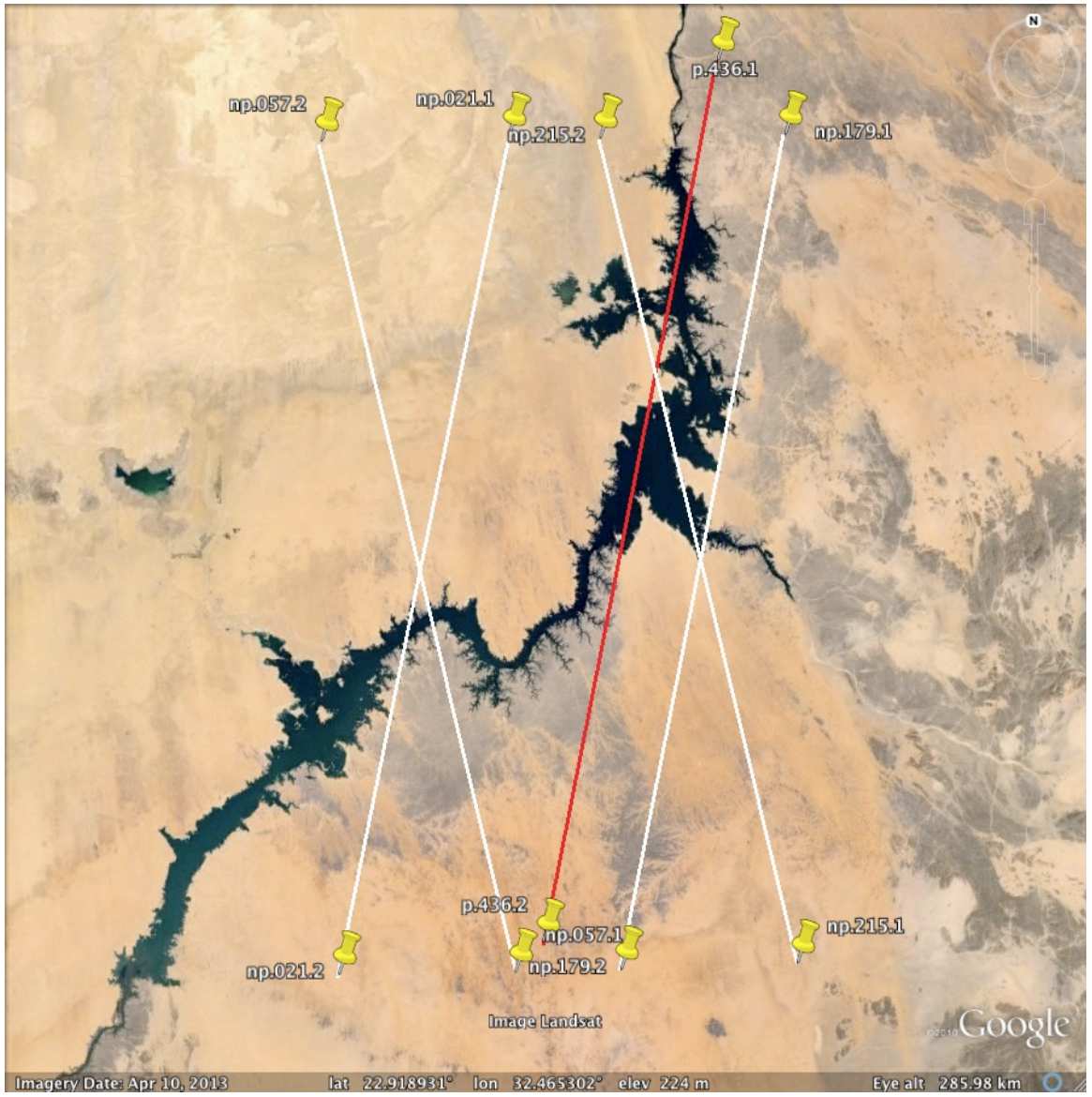


Fig. 1. Three sequences of radar echoes or "waveforms." Each waveform is a representation of power returned as a function of time. Over lakes waveforms are typically ocean-like, but can become broad-peaked or even narrow-peaked under very calm or icy conditions.

- The altimetry instruments do not record an image but collect radar echoes along the ground track.
- Altimetric "Range" is derived from these waveforms.
- With knowledge of the satellite orbit location and certain atmospheric and tidal corrections, the range can be converted to a surface elevation – usually given with respect to a reference ellipsoid datum.

Courtesy: Dr. Charon M. Birkett, NASA-GSFC

Radar Altimetry - Along and Across Track Spatial Resolution



- Along the ground tracks the spatial resolution of the height data is a few hundred meters. The density of ground tracks will depend on the temporal repeatability of the mission.

- For example, there are many more 35-day ground tracks (white) over Lake Nasser than offered by the 10-day altimeter suite (red).

Courtesy: Dr. Charon M. Birkett, NASA-GSFC

Altimeter-Based Lake Level Height Estimation

- Derived from the difference between satellit orbit height and altimeter range (Birkett, 1995) with appropriate corrections for Earth' tides.
- Average height over a pixel is derived.
- Sensitive to satellite orbit accuracy, radar range accuracy, and lake surface conditior (e.g., calm and smooth, rough due to winds icy).
- Altimeters on Jason-2 (and following mission show improved accuracy compared to Jason-1 and TOPEX/Poseidon (Birkett and Beckley, 2010).

Birkett and Beckley, 2010

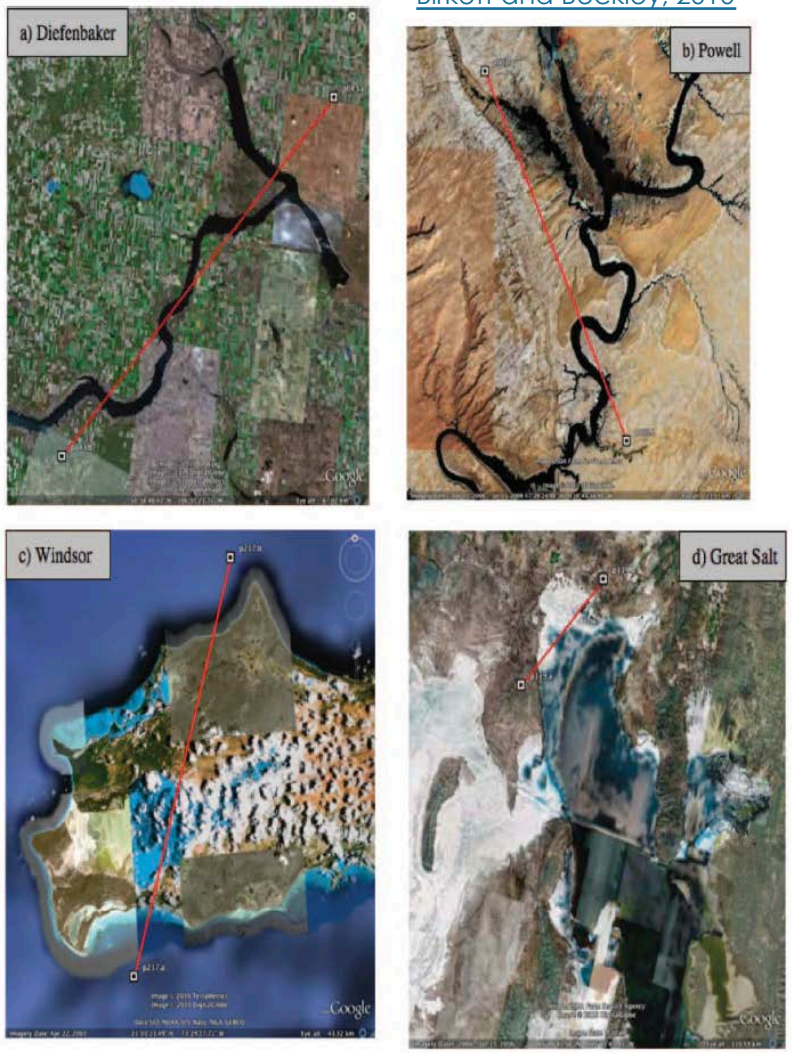
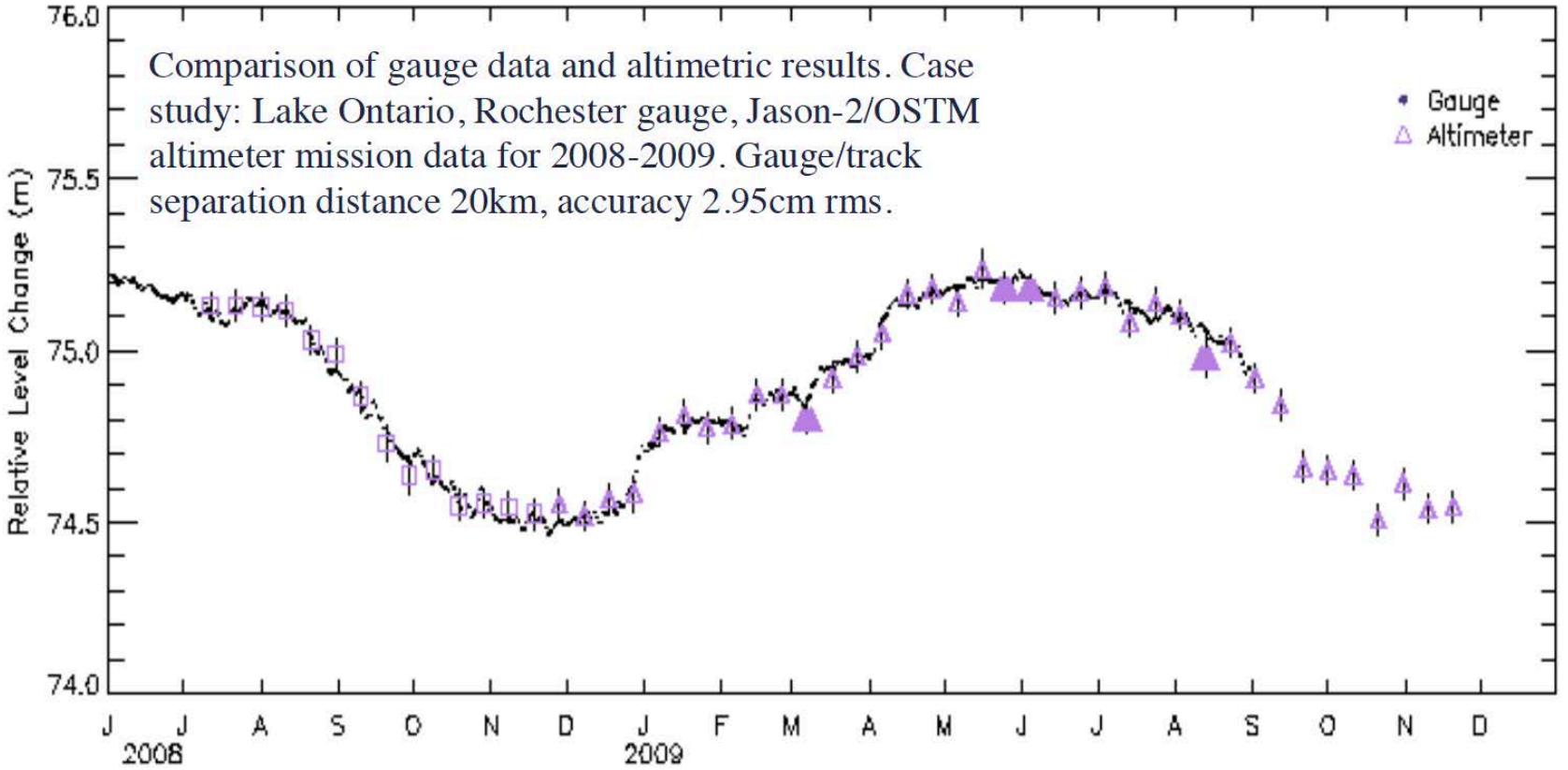


Figure 7. Satellite imagery depicting Jason-2/OSTM ground track locations (in red) across **(a)** Lake Diefenbaker, **(b)** the Powell reservoir region, **(c)** Lake Windsor, and **(d)** Great Salt Lake. Images are courtesy of the 2009 Google Earth software and Maps service.

Validation of Altimeter-Based Height Variations

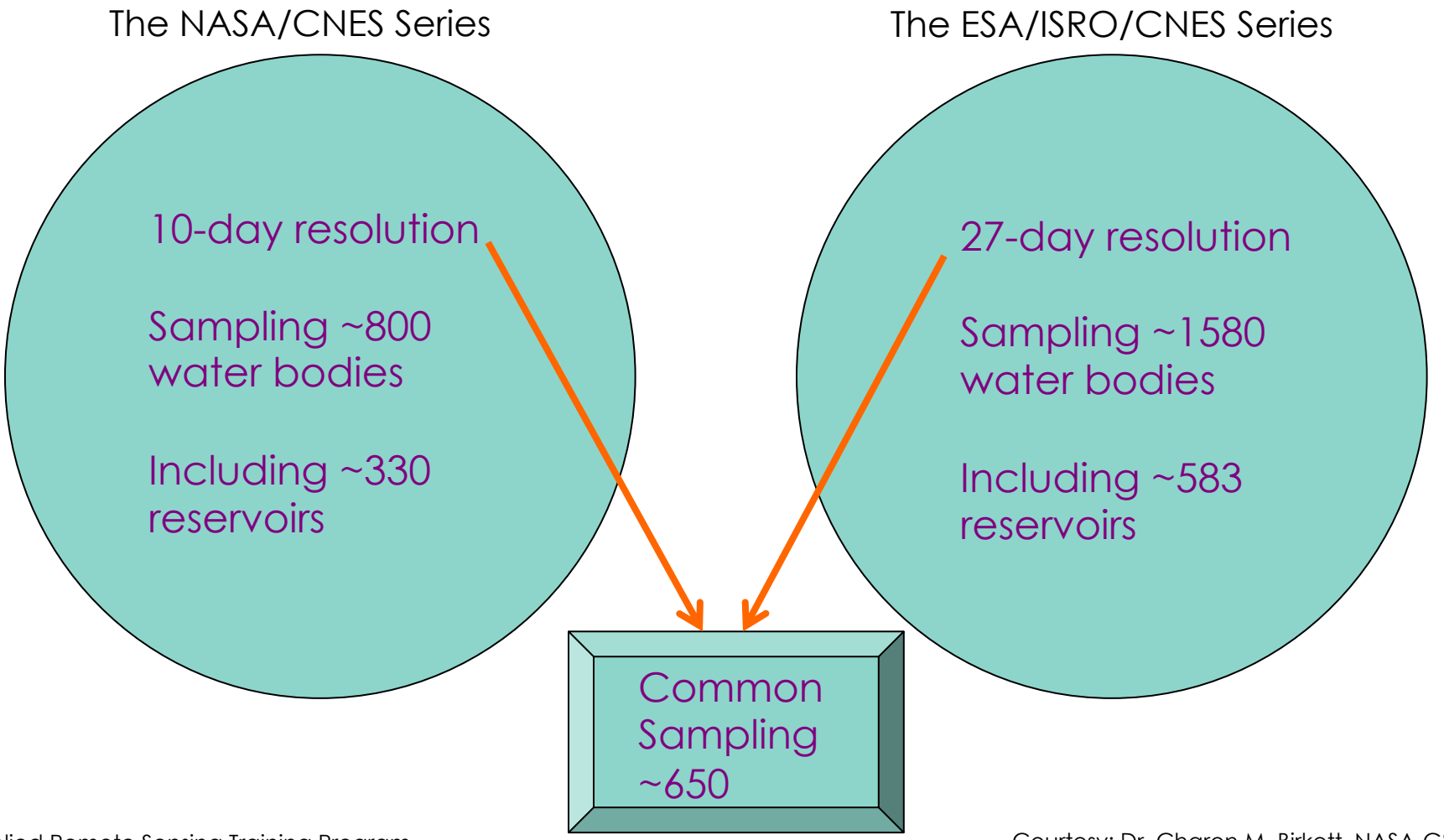
Usually done via comparison with in situ gauge data. Accuracies can be several centimeters to tens of centimeters.



Courtesy: Dr. Charon M. Birkett, NASA-GSFC

How many lakes and reservoirs?

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.



Courtesy: Dr. Charon M. Birkett, NASA-GSFC

Continental Water Monitoring – Web-Based Sources

Several web sites, sponsored by various agencies, offer water-level products derived from the satellite radar altimeters:

- https://ipad.fas.usda.gov/cropexplorer/global_reservoir/ 
- http://hydroweb.theia-land.fr/?lang=en&
- https://dahiti.dgfi.tum.de/en/

Radar Altimetry: Advantages

https://ipad.fas.usda.gov/cropexplorer/global_reservoir/#limitations

- The contribution of new height information where traditional gauge (stage) data is absent
- Day/night and all-weather operation
- Generally unhindered by vegetation or canopy cover
- Surface heights are determined with respect to one common reference frame.
- Repeat orbits (to ±1km) enable systematic monitoring of rivers, lakes, wetlands, inland seas, and floodplains.
- Surface water heights are potentially obtainable for any target beneath the satellite overpass.
- The ability to monitor seasonal to inter-annual variations during the lifetime of the missions.
- Validated techniques.

Courtesy: Dr. Charon M. Birkett, NASA-GSFC

Radar Altimetry: Limitations

https://ipad.fas.usda.gov/cropexplorer/global_reservoir/#limitations

- The satellite orbit scenario determines the spatial and temporal coverage.
- Data can only be retrieved along a narrow nadir swath.
- Highly undulating or complex topography may cause data loss.
- Height accuracy (4-20 cm root mean square [RMS] in large open lakes) is dominated by the size and surface roughness of the target.
- Major wind events, heavy precipitation, tidal effects, ice formation, will affect data quality and accuracy.
- Minimum target size (50-100 km^2) is also dependent on many factors and the retrieved heights are an "average" of all topography within the instrument footprint.
- An "average" height instead of a "spot" height at a specific location.

Courtesy: Dr. Charon M. Birkett, NASA-GSFC

Examples of Lake Level Height Applications

Monitor Water Level in Remote and Arid Regions

G-REALM: Sustained Water Level Monitoring of Lake and Reservoirs

Application example

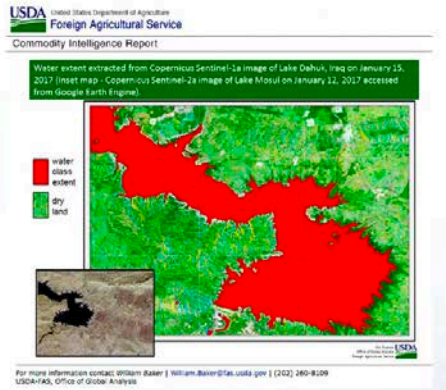
G-REALM provides water level data in **remote arid and semi-arid regions** where water resources vulnerability or poor infrastructure affects regional security. Temporal resolutions 10-35days across the 1992-2018 time span.

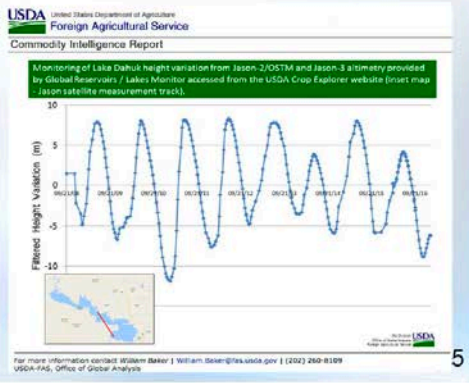
Example: Lake Dahuk (Mosul Dam, Iraq).
The largest dam in Iraq, the waters are a source for hydroelectric power and spring and summer crop irrigation. Recharge depends on snow melt in North-East Turkey.

The most dangerous reservoir in the world due to poor construction and downstream flood potential. The water level has been recently lowered to reduce pressure on the dam.

USDA/FAS regional analysts look to G-REALM products to help assess summer crop statistics.

https://pecad.fas.usda.gov/highlights/2017/02/iraq/index.htm





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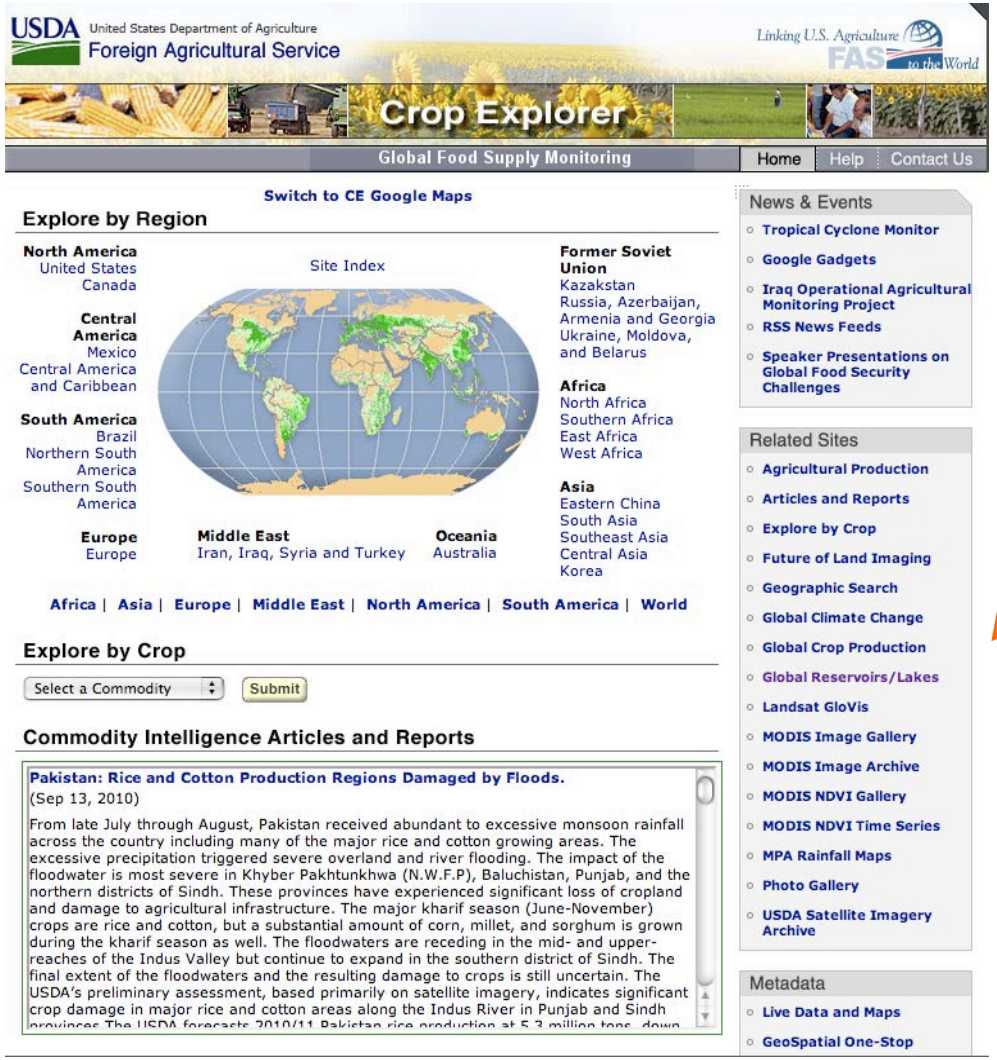
https://appliedsciences.nasa.gov/sites/default/files/2019-09/mission.pdf

Lake/Reservoir Water Level Monitoring Applications to Assist Agriculture-Based Decisions

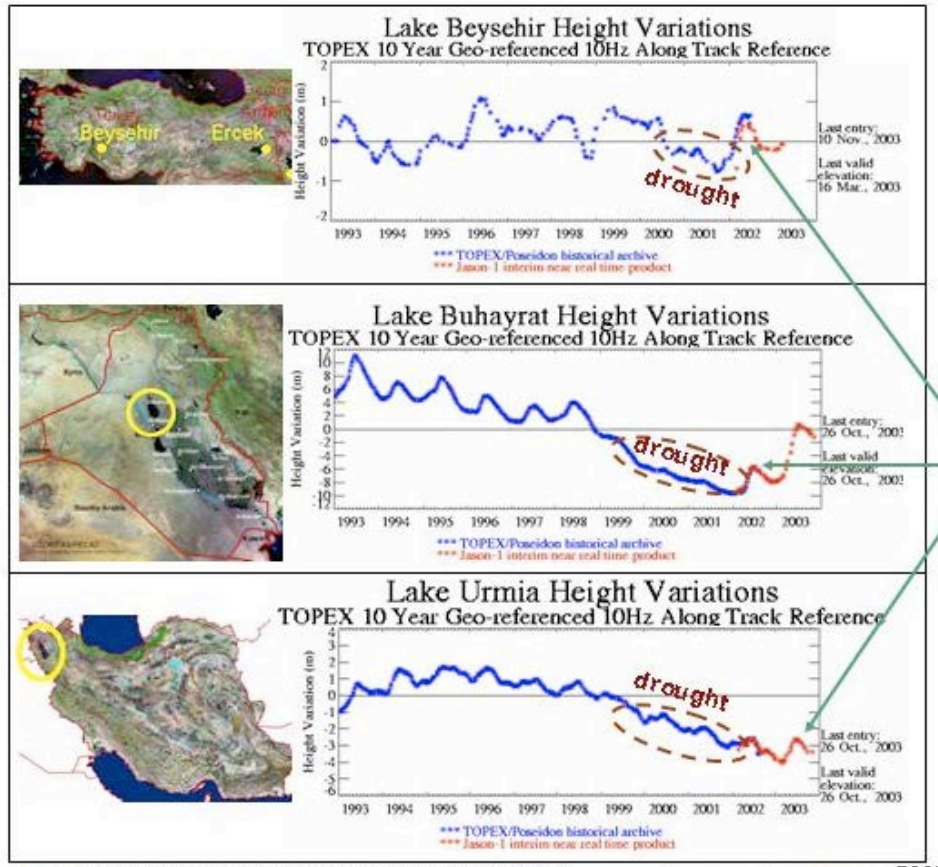


Multiple satellite, ground-based and modeled datasets, including water surface heights for lakes and reservoirs.

Courtesy: Dr. Charon M. Birkett, NASA-GSFC

Applications for Drought and Agriculture

Production Estimates and Crop Assessment Division
Foreign Agricultural Service



Shown are relative lake height variations for Lake Beysehir in Turkey, Lake Buhayrat in Central Iraq and Lake Urmia in northwest Iran. A period of drought occurred from 1999 to 2001. Rainfall in Turkey, northern Iraq and adjacent regions increased in both 2002 and 2003 and has gradually recharged reservoirs.

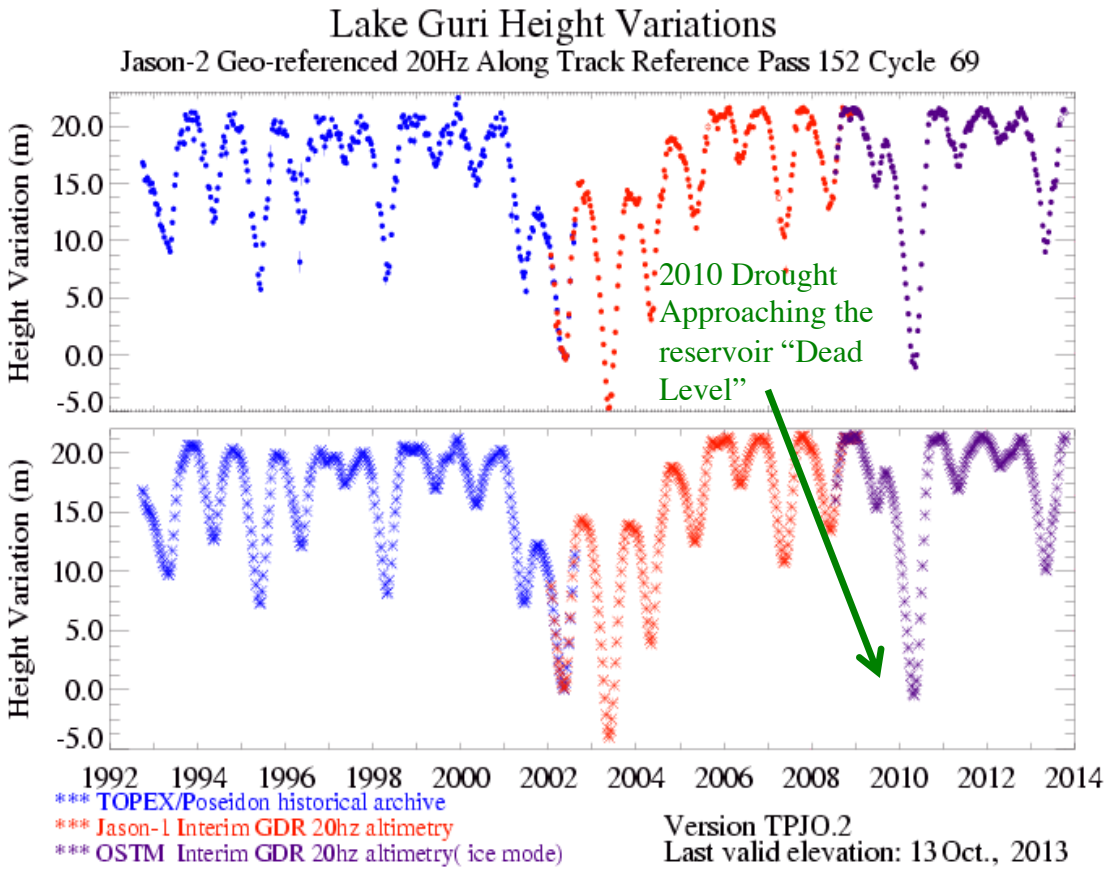
Initial recovery in water levels observed in 2002-2003. Drought began in 1999.

Production Estimates & Crop Assessment Division (PECAD)
Foreign Agricultural Service (FAS)
U.S. Department of Agriculture (USDA)
http://fas.usda.gov/pecad/pecad.html

ESSIC (Earth System Science Interdisciplinary Center), University of Maryland, College Park
NASA Goddard Space Flight Center, Greenbelt, Maryland

Courtesy: Dr. Charon M. Birkett, NASA-GSFC

Applications for Drought and Energy Resources



Venezuela to Ration Water Because of Low El Nino Rainfall

October 22, 2009

Venezuelan President Hugo Chavez urged citizens to cutback on showering time as the country's electric and water supply problems mount.

Venezuela will enact new water conservation methods, including reducing supply by 25 percent until May, because of low El Nino rainfall, President Hugo Chavez announced on TV late last night.

The drier cycle has caused "critically low" levels for the country's hydroelectric stations and drinking water reserves, including the El Guri reservoir, one of the world's largest dams, Chavez said. The El Guri is located on the Caroni River, which provides 70 percent of Venezuela's electricity. Usually the Caroni River, located in the Orinoco Basin, has a high discharge rate, but it has had difficulty replenishing itself lately.

This drought has aggravated the country's already fragile situation. Growing demand for and under-investment in water lead to several major blackouts in Venezuela earlier this year.

Higher water level in Guri Dam fails to solve power crisis

The water level of the reservoir is growing but thermoelectric generation has not expanded

ENERGY

The rainy season is arriving in Venezuela and the water level of the Guri reservoir is starting to increase, but concerns about the serious power crisis facing the country remain.

Following rains, the water level of the Guri Dam has increased by 13 centimeters in two days (File photo)

In fact, the National Electricity Corporation (Corpoelec) informed the authorities of state-run steelmaker Siderúrgica del Orinoco (Sidor) that electricity rationing in the main Venezuelan mill [illegible]mented throughout the year. This steelmaker company will have to maintain its current production level. [illegible]num power consumption of 300 megawatts, which allows for operation of [illegible]y.

Power cut of 2,000 MW required if Guri dam level reaches 240 meters

The largest power reduction must be made in central states and Venezuelan Guayana's Corporation (CVG)

ENERGY

Government authorities believe that the water level of the Guri reservoir will reach the critical level of 240 meters above sea level by June, and at point additional power rationing will be required.

The level of the Guri reservoir is declining over 10 centimeters per day due to the lower flow of the Caroní River (Photo: Gustavo Bandres)

The Executive branch of government has already outlined two scenarios for operating the Guri hydroelectric plant if the reservoir drops to such level. According to a report prepared by the National Electric Corporation (Corpoelec) there are two options: operating the electricity grid with the support of new power plants or without the addition of the new generation units.

The peak oil crisis: countdown at the Guri

by Tom Whipple

☆☆☆☆☆

Please Log in or register to rate this article.

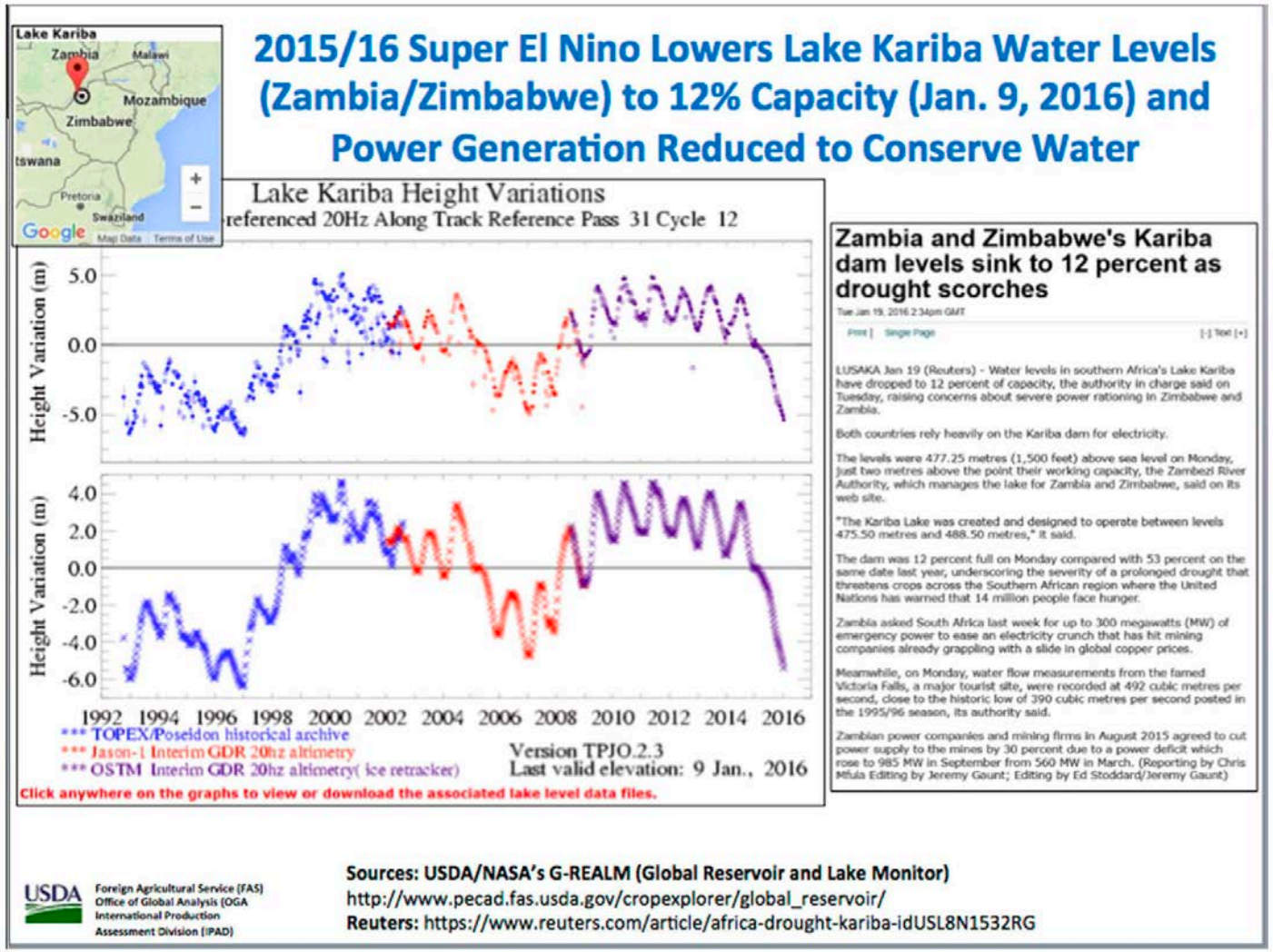
Most Americans have never heard of Venezuela's great Guri dam. Completed in 1978 with 20 generators and 10,200 MW of generating capacity, at one time it had the most generating capacity of any hydro dam in the world.

By way of comparison, the Three Gorges dam in China is to produce 22,500 MW when completed next year and the U.S.'s Grande Coulee which dates back to 1942 can produce 6,800 MW. If you disregard the ecological damage caused by great dams, they can be wonderful things for they produce prodigious amounts of emissions-free energy at very low cost --- provided, of course, it keeps raining in the dam's watershed. Until recently nobody gave this much thought until last summer when El Niño, and perhaps a touch of global warming, started doing funny things to Venezuela's weather.

The rainy season in Venezuela which refills the reservoirs runs from June to October. The summer of 2009 it was a catastrophe. Rainfall was only about one third of normal so that by last fall alarm bells began sounding as it looked as if the water could fall to the level where the dam would have to shut down most of its generating capacity. The Guri dam has a lower and older generating hall with much less capacity than the main hall and there are two smaller dams located downstream from the Guri. The problem is that if they have to stop letting water through to the turbines in the main Guri dam, the water is no longer available to the downstream plants so their output drops markedly too.

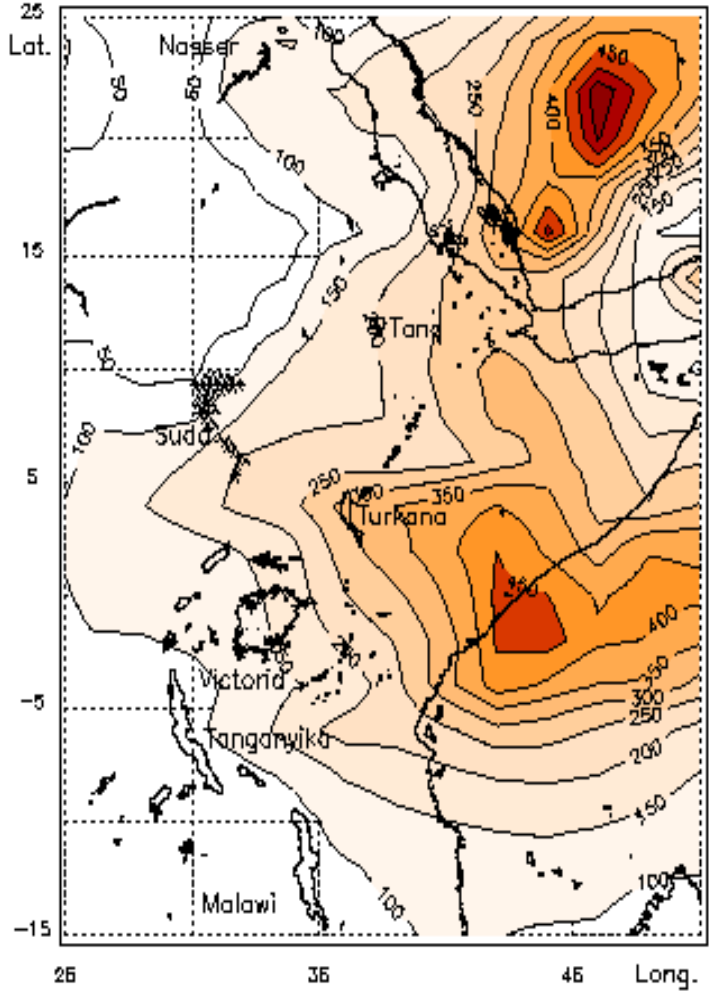
Courtesy: Dr. Charon M. Birkett, NASA-GSFC

Applications for Water Resources Management



https://appliedsciences.nasa.gov/sites/default/files/2019-09/mission.pdf

Applications for Flood Monitoring



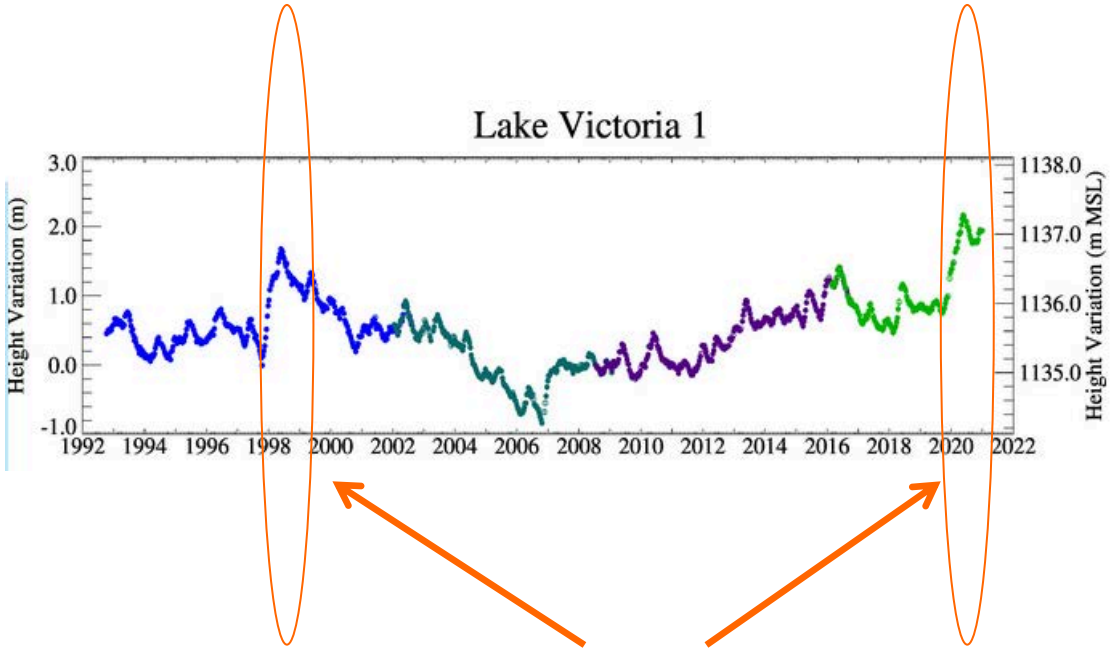
Nile River floods in Sudan leaving 200,000 homeless

KHARTOUM, Sudan (AP) - Floods and heavy rains have destroyed 119,000 houses and left more than 200,000 people homeless in nine Sudanese states, the government said.

The government's Humanitarian Aid Commission said 65 schools and 60 health institutions have also been destroyed and vast tracts of farmland have been inundated.

The government has mobilized troops to fight the worst flooding along the Nile River in a half century and is considering evacuating thousands of people in districts near Khartoum.

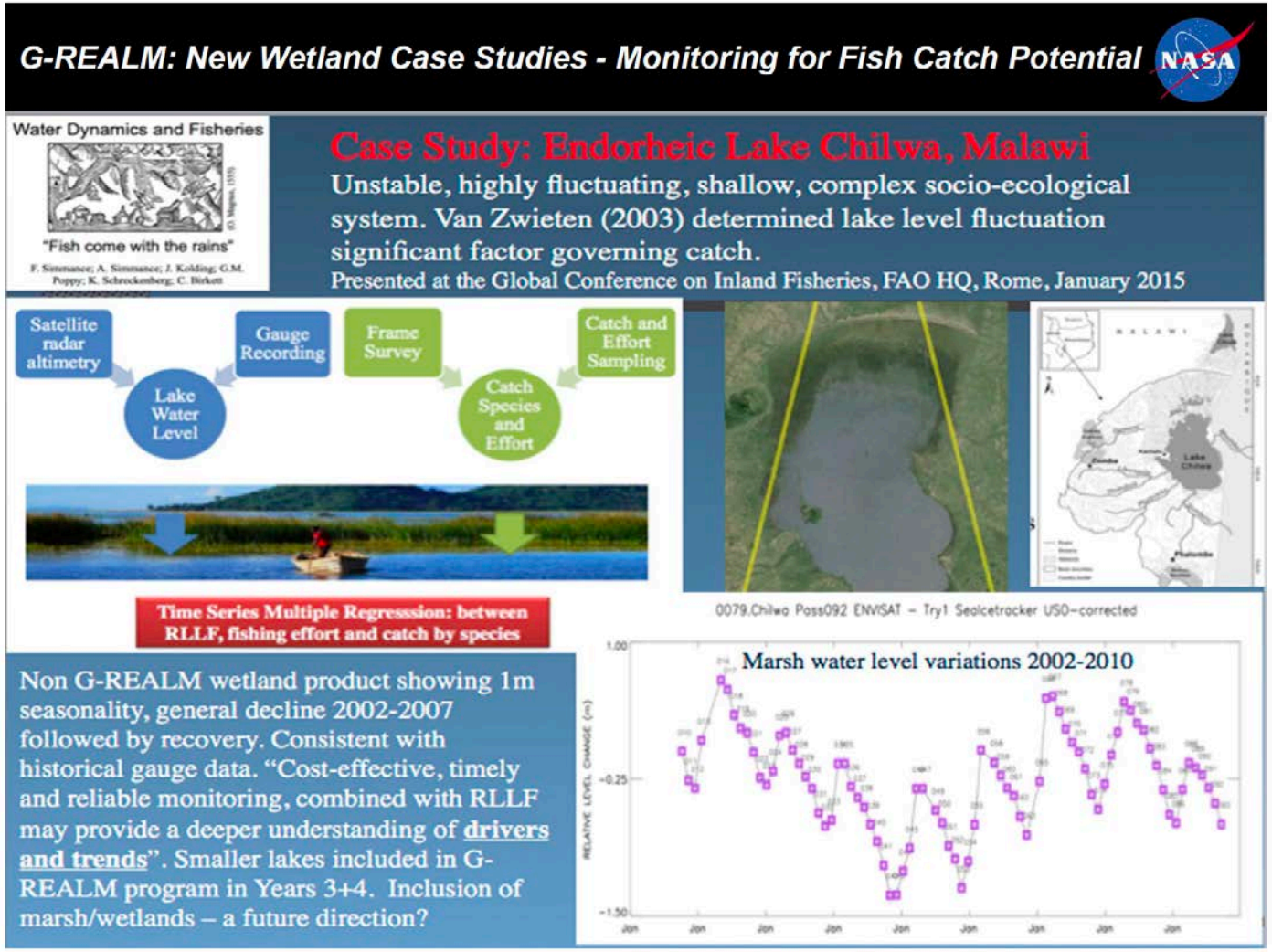
The worst hit regions in Sudan, Africa's larg-



1997/1998 and 2020 Flooding Events

Courtesy: Dr. Charon M. Birkett, NASA-GSFC

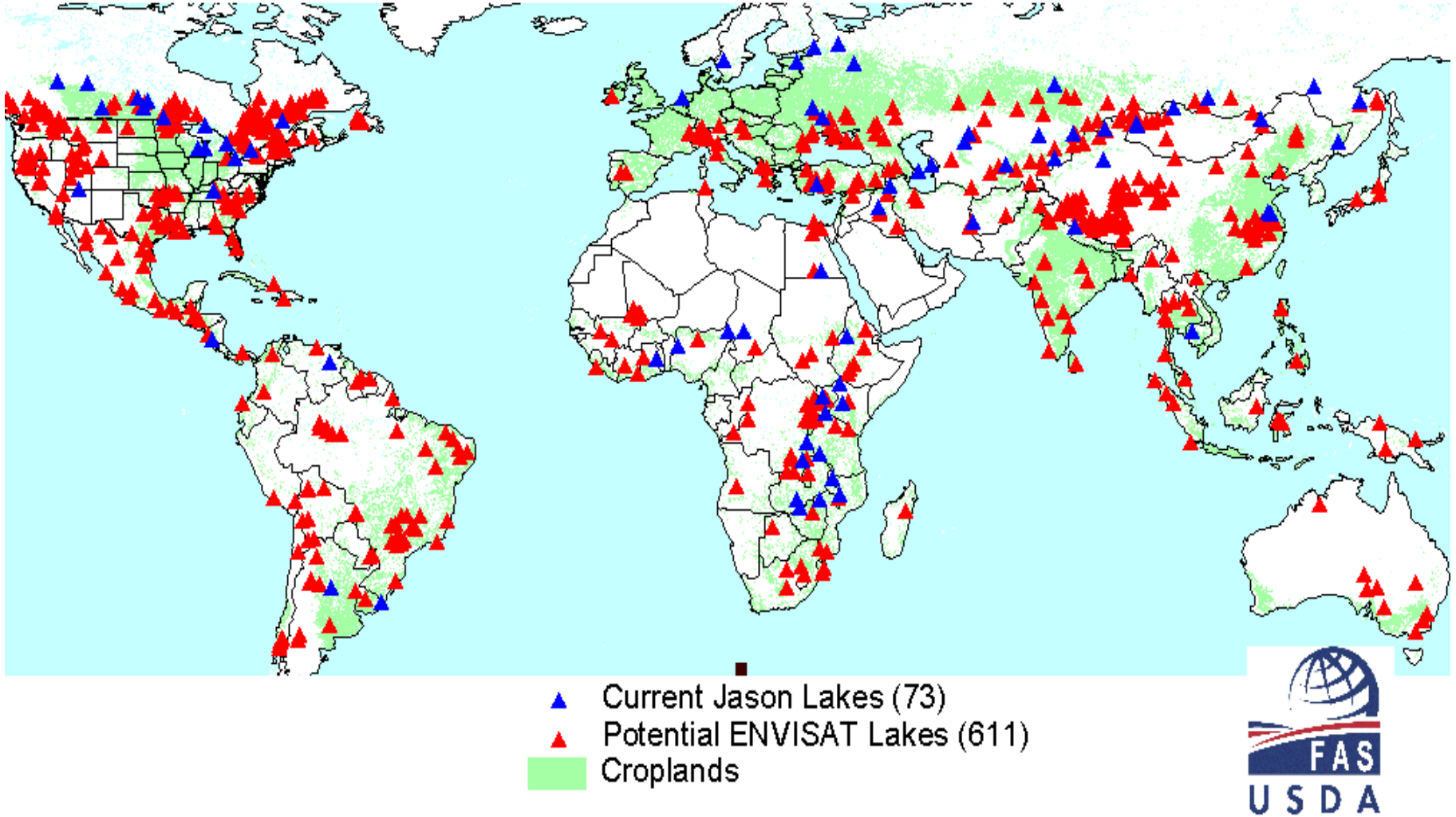
Applications for Fish Catch Potential



https://appliedsciences.nasa.gov/sites/default/files/2019-09/mission.pdf

The Future – The Global Reservoir and Lake Monitor

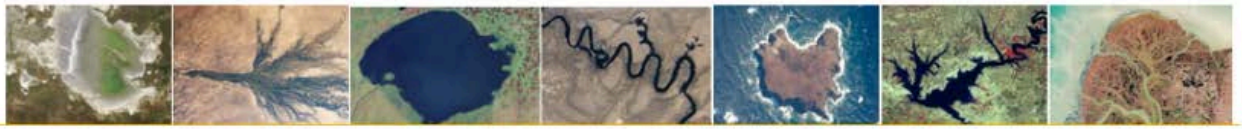
Many hundreds of lakes and reservoirs will be added, with G-REALM continuing to supply both archival and near-real time water level measurements.



Courtesy: Dr. Charon M. Birkett, NASA-GSFC

The Future – The Global Water Monitor

A new website offering additional lake extents and storage, as well as water level products for wetlands and rivers.



Satellite Remote Sensing
Water Storage and Dynamics

Welcome to the Global Water Monitor

https://blueice.gsfc.nasa.gov/GWM

! Website still in progress !

A prototype online source for satellite data products relevant to lakes, reservoirs, river channels, wetlands and global mean sea level.

(Main Contact: Charon.M.Birkett@nasa.gov)

Important Note

Water Monitor - Lakes and Reservoirs	2018 Water Resources Lake Storage and Status Indicators
Water Monitor - Rivers and Wetlands	2018 Water Resources Alaska Streamflow Usangu Project
Water Monitor - Global Mean Sea Level	Ongoing NASA Ocean Surface Topography

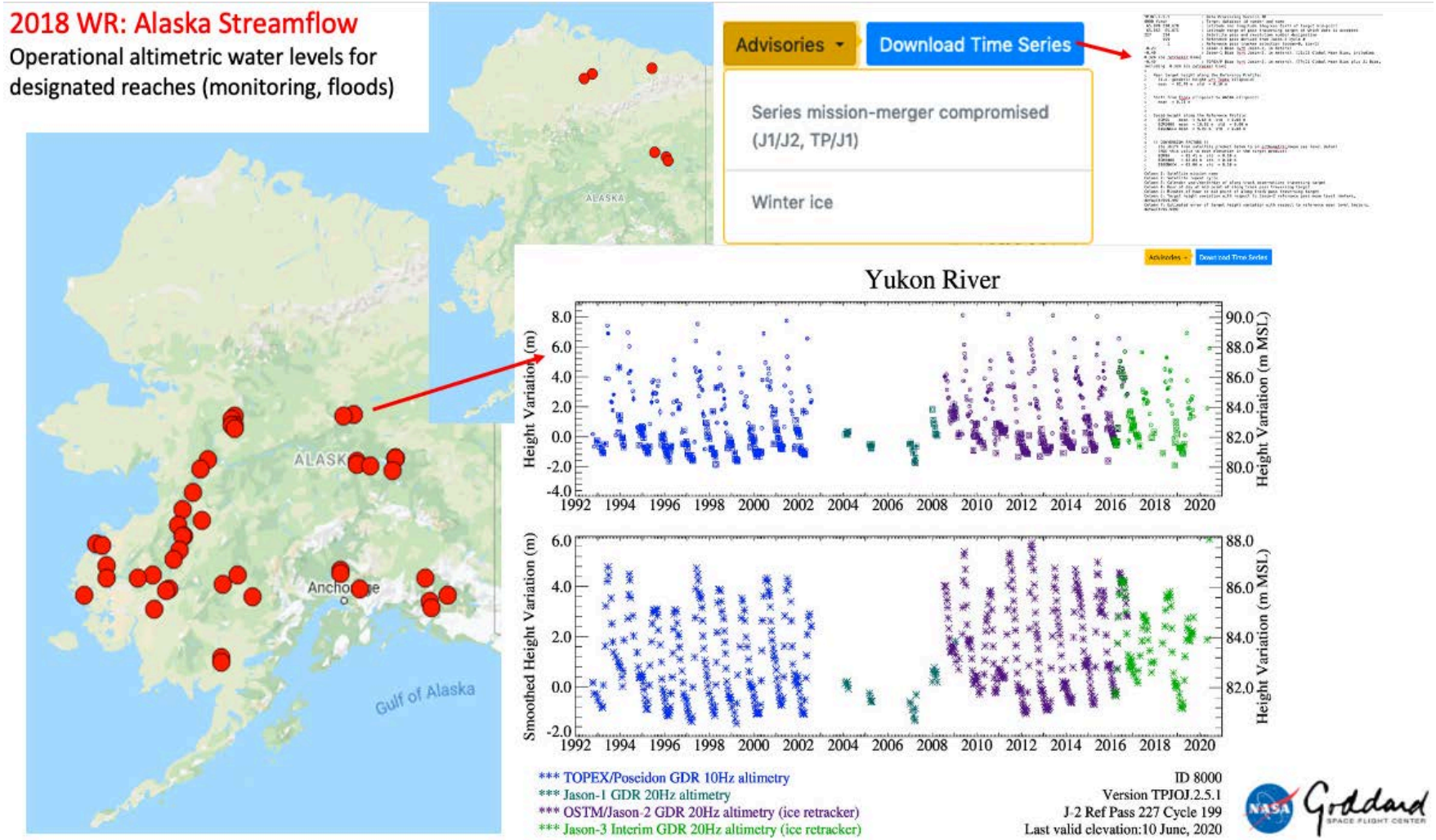
NASA USDA USGS science for a changing world KBR

NASA Goddard Space Flight Center

Courtesy: Dr. Charon M. Birkett, NASA-GSFC

The Future – The Global Water Monitor for River Reach Water Level Variations

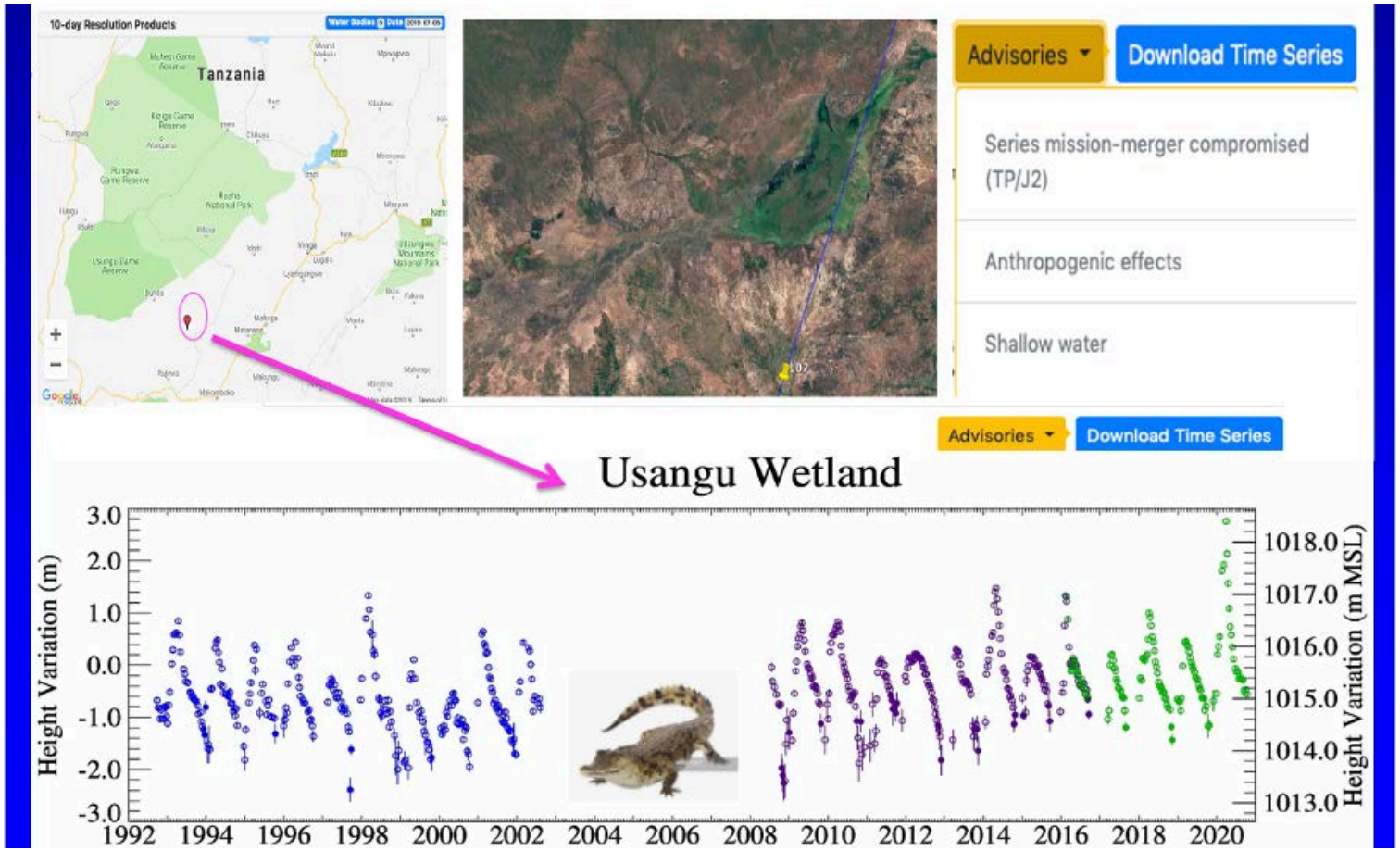
Alaska River Monitoring for Potential Flood Warnings



Courtesy: Dr. Charon M. Birkett, NASA-GSFC

The Future – The Global Water Monitor for Wetland Water Level Variations

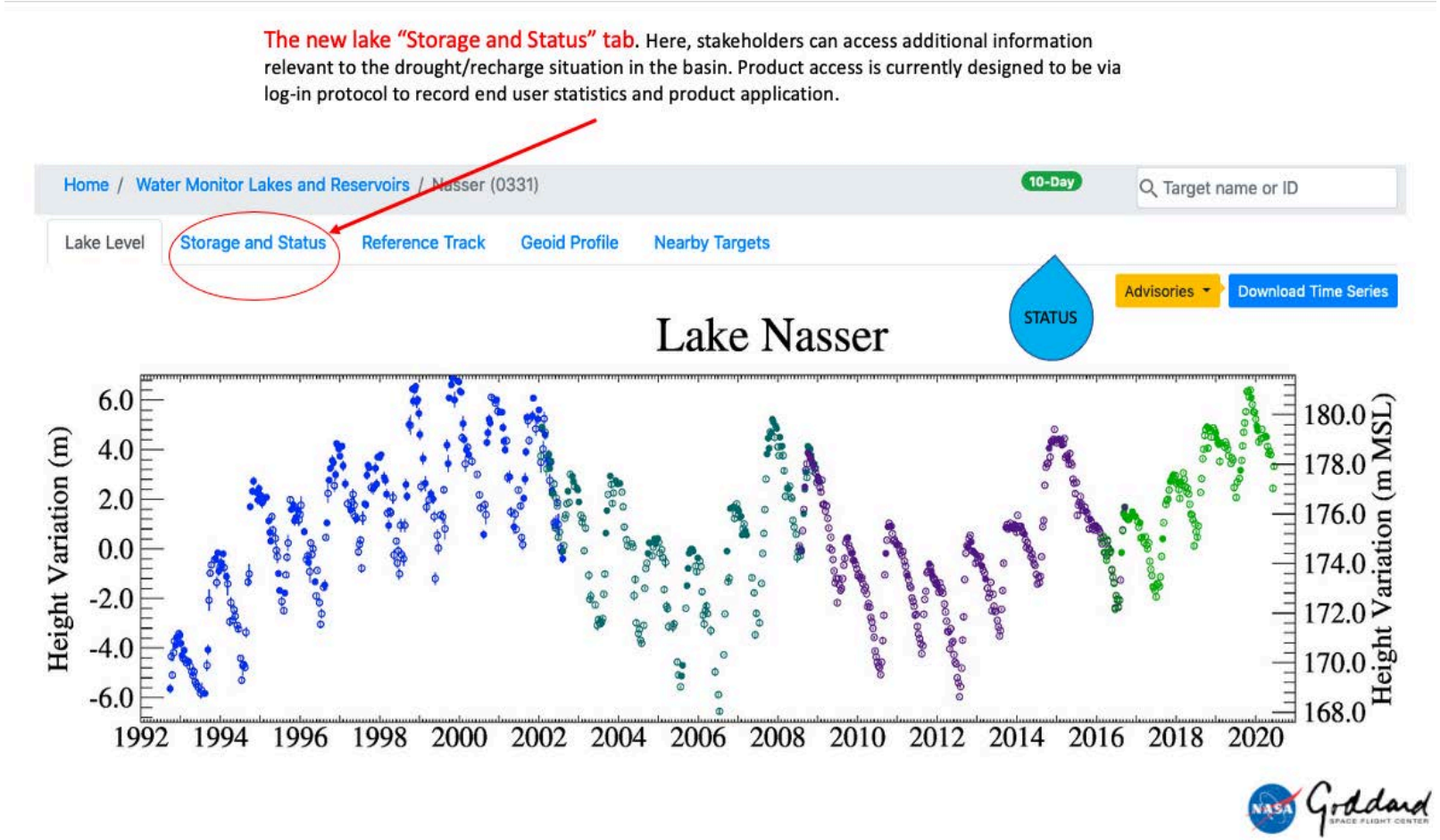
Applications can be water or energy resources, agriculture, and conservation.



Courtesy: Dr. Charon M. Birkett, NASA-GSFC

The Future – The Global Water Monitor For Lake Levels, Extents, Storage, and Status Indicators

Combining water levels, extents and bathymetry, and supplying warning indicators to highlight drought and flood conditions.



Courtesy: Dr. Charon M. Birkett, NASA-GSFC

Demonstration: Access Lake Level Height Data Global Reservoirs and Lakes Monitoring (G-REALM)

https://ipad.fas.usda.gov/cropexplorer/global_reservoir /

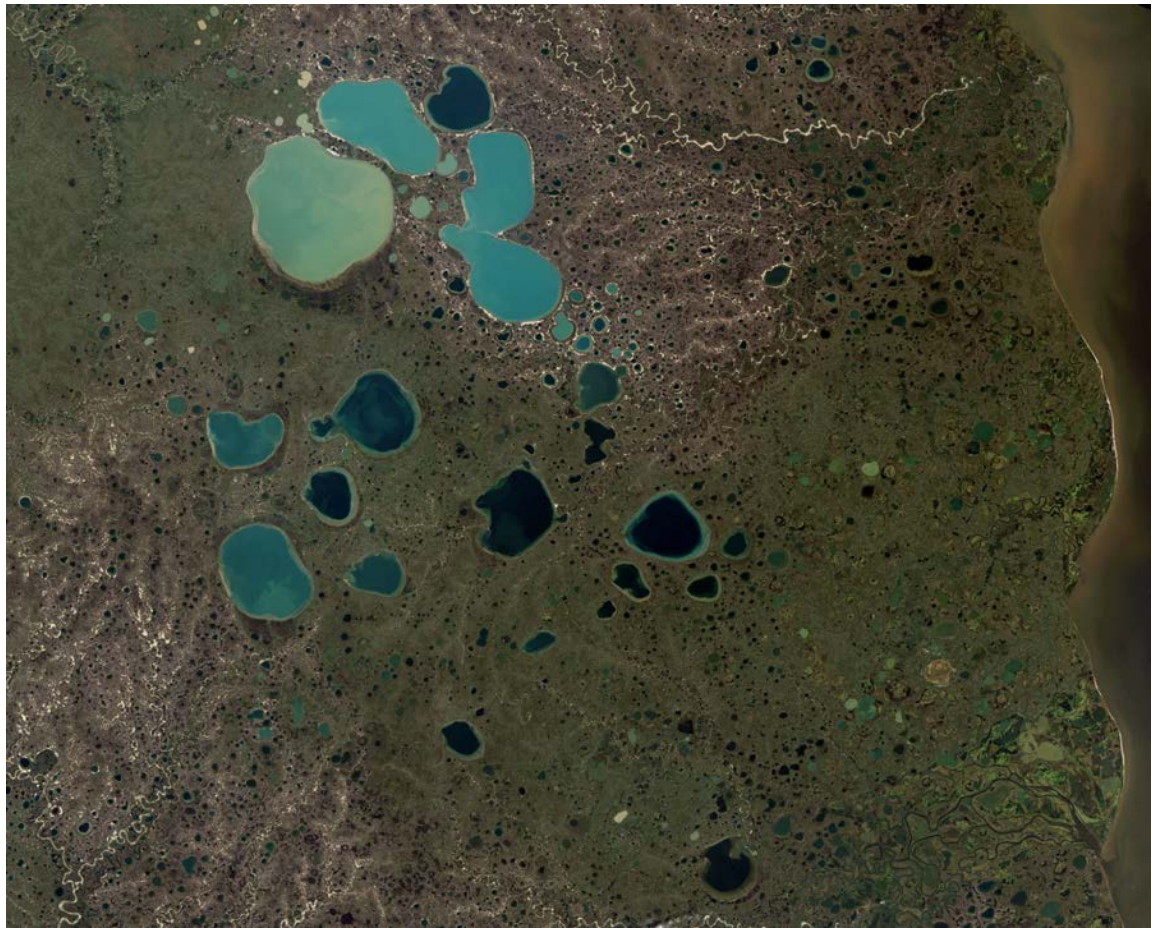
References

Birkett, C., 1995: The contribution of TOPEX/POSEIDON to the global monitoring of climatically sensitive lakes, J. Geophys. Res., 100, 25,179-25,204.

Birkett C. and B. Beckley, 2010: Investigating the Performance of the Jason-2/OSTM Radar Altimeter over Lakes and Reservoirs, Marine Geodesy, 33:S1, 204-238, DOI:10.1080/01490419.2010.488983.

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

Contacts

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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!