(Part 1) Satellite-based determination of Reservoir and Lake Surface Water Heights

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Radar Echoes and Surface Elevation

The 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.
Satellite Radar Altimeter Missions
Ku- and Ka-band frequencies. Lake/reservoir surface water level products are generally derived from the long-term “repeat-track” missions which fall into 2 groups having different temporal sampling.
(Other missions include GEOS-3, Seasat, Geosat, GFO, CryoSat, and HY-2A)

10-day Temporal sampling over a 21year period, 1992 to the present day

35-day temporal sampling over a 19yr period, 1994 to the present day.
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).
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.

The NASA/CNES series
- 10-day resolution
  - Sampling ~380 water bodies
  - Including ~90 reservoirs

The ESA/ISRO/CNES series
- 35-day resolution
  - Sampling ~1065 water bodies
  - Including ~230 reservoirs

Common
- Sampling ~315
Validation of Altimetric Height Variations

Comparison with daily or hourly gauge (in situ) data over the same time period.

Early Pioneering Examples of Satellite Radar Altimetry

Demonstrating application of the altimetric technique to the derivation of water level variation for large lakes, wide river channels and large expanses of inundated wetland.
Radar Altimetry - Advantages and Limitations

ADVANTAGES
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.
Determined surface heights are 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.

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 (4-20cm rms large open lakes) is dominated by the size and surface roughness of the target.
Major wind events, heavy precipitation, tidal effects, ice formation, will effect data quality and accuracy.
Minimum target size (50-100km²) is also dependant on many factors and the retrieved heights are an "average" not a "spot" height at a specific location.
Continental Water Monitoring – Web based sources

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

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

http://www.legos.obs-mip.fr/soa/hydrologie/hydroweb/

http://tethys.eaprs.cse.dmu.ac.uk/RiverLake/shared/main

http://openadb.dgfi.badw.de/index.php?id=85
The need to monitor agricultural (seasonal) and hydrological (long-term) drought.

USDA integrates a wide variety of data sets.

Information is input into a monthly ‘lockup’ process which sets global Crop Condition/Production numbers and provides an ‘Early Warning of Events’.

Output information is shared between USDA and US Gov agencies for various Decision Support Protocols.

Estimates drive or influence markets, price discovery, trade and foreign policies, agriculture production, and farm and food programs.

Missing Input - The VOLUME of stored water for irrigation potential considerations.

**USDA Requirements:** “The monitoring of water levels within all large globally-distributed lakes and reservoirs between 40°S-52°N to an accuracy of 10-20cm rms making both archival (20yrs) and near real time data products (1-2weeks) available to the USDA and the public via a freely-accessible web interface”.
USDA/FAS Crop Explorer
A portal for data sets that assist agriculture-based decisions
http://www.pecad.fas.usda.gov/cropexplorer/

Multiple satellite, ground-based and modeled data sets, including water surface heights for lakes and reservoirs
A “Lake Status” map, based on a ~10-year mean, provides a guide to the current storage situation and so helps to assess long-term drought or high-water level conditions.
The Global Reservoir and Lake Monitor – Product Access
http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/

End-users select by lake to retrieve a water surface height product.
The Global Reservoir and Lake Monitor – Product Format

Products are in graphical (gif) and ascii text format and show the relative variations in surface water level over the lifetime of the missions. Example shown for the 10-day resolution NASA/CNES instrument suite over Lake Michigan, USA.
The USDA/NASA Global Reservoir and Lake Monitor
http://www.pecad.fas.usda.gov/cropexplorer/

Preliminary archival products from the ESA/ENVISAT (2002-2010) mission.

**Lake Chardarinskoye Height Variations**
Envisat Pass 825 Cycle 22 Geo-referenced 20Hz Along Track Reference

**Lake Murray Height Variations**
Envisat Pass 462 Cycle 15 Geo-referenced 20Hz Along Track Reference

- **Lake Chardarinskoye**
  - Reservoir: Chardarinskoye Reservoir
  - Country: Kazakhstan
  - Area: ~500km²
  - Latitude: 41.13
  - Longitude: 68.13

- **Lake Murray**
  - Reservoir: Lake Murray
  - Country: Papua New Guinea
  - Area: ~650km² (variable)
  - Latitude: -7.00
  - Longitude: 141.50

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*** Envisat MWR GDR 20hz altimetry
Version Env.1
Last valid elevation: 3 Aug., 2010

*** Envisat MWR GDR 20hz altimetry
Version Env.1
Last valid elevation: 22 July, 2010
Middle East and Turkey:
Warmer Than Normal and Plenty of Moisture

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.


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
Venezuela to Ration Water Because of Low El Nino Rainfall

October 22, 2009

Venezuelan President Hugo Chavez urged citizens to curtail 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.

Lake Guri Height Variations

Jason-2 Geo-referenced 20Hz Along Track Reference Pass 152 Cycle 69

2010 Drought
Approaching the reservoir "Dead Level"

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.

In fact, the National Electricity Corporation (Corpoelec) informed the authorities of state-run energy reduction.

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 Venezuela 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 Executive branch of government has already outlined two scenarios for operating the Guri hydroelectric plant if the reservoir drops to such a level.

The peak oil crisis: countdown at the Guri

by Tom Whipple

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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 5,800 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 Nino, 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 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.

Version TPJ0.2
Last valid elevation: 13 Oct., 2013

*** TOPEX/Poseidon historical archive
*** Jason-1 Interim GDR 20Hz altimetry
*** OSTM Interim GDR 20Hz altimetry (Ice mode)
Application: Flood Monitoring
Lake Victoria - case study region

1997/1998 Flooding in East Africa

Rainfall rate over the Nile Basin for the period October 1997 to January 1998. 100%=mean rate
Excessive 2007 snowmelt led to water release out of the Kajakai Reservoir spillway which resulted in large scale inundation of the floodplain. From 2008, the NASA 10-day products are aiding water managers via supplementing the often-sporadic fall/winter in situ data (no 35-day ground tracks exist across Kajakai).
The Future – The Global Reservoir and Lake Monitor
Many hundreds of lakes and reservoirs will be added, the GRLM continuing to supply both archival and near-real time water level measurements.
Lake level product users span a variety of different organizations including FAS foreign resource analysts, international governments, lake development agencies, conservation groups....

Interests include impoundment effects, water resources, energy supply, fish productivity, regional security, climate change....

The GRLM will continue to enhance and expand existing lake level products. In addition, the scope may be broadened to consider the operational delivery of new products that include lake areal extents, reservoir water storage, and perhaps river channel discharge. The production of such new products are under research development.
Striving to improve…..
the current limitations on target size
the acquisition of data in mountainous terrain
the accuracy of the surface water levels
the delivery time of the lake level products to end users

Many research teams are working to maximize the potential of the current altimetric data sets.

Others look to improvements via instrument design modifications.
The Future: The Launch of Additional Enhanced Instruments

Providing continuity and new swath-based data sets

- **ESA**
  - Sentinel-3
  - 2014

- **NASA/CNES**
  - Jason-3
  - 2015

- **ESA/EUMESTSAT/CNES/NASA/NOAA**
  - Jason-CS
  - 2017

- **NASA**
  - SWOT
  - 2020
To Conclude

The University of Maryland, NASA, and USDA/FAS welcome all comments and discussions on the altimetric lake level products within the Global Reservoir and Lake Monitor.
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Thank You!

Sponsored by:

NASA grants NNX08AT88G, NNX12AJ85G, and NNX13AH15

And the USDA/FAS Office of Global Analysis