Jason SWT, November, 2003.

Satellite Radar Altimetry over Inland Waters: Application and Outlook

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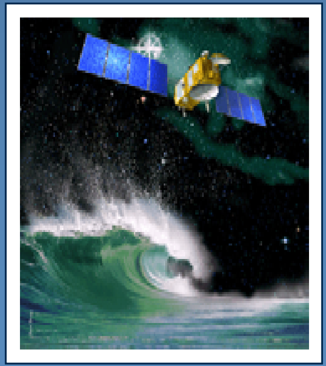
Satellite Radar Altimeters

MISSIONS

1970-1980
GEOS-3, SEASAT

1980-1990
USN GEOSAT

1990-2003
ESA ERS-1, ERS-2
NASA/CNES TOPEX/POSEIDON



Current
USN GFO
ESA ENVISAT
CNES/NASA Jason-1
TOPEX/POSEIDON

Radar Waveforms

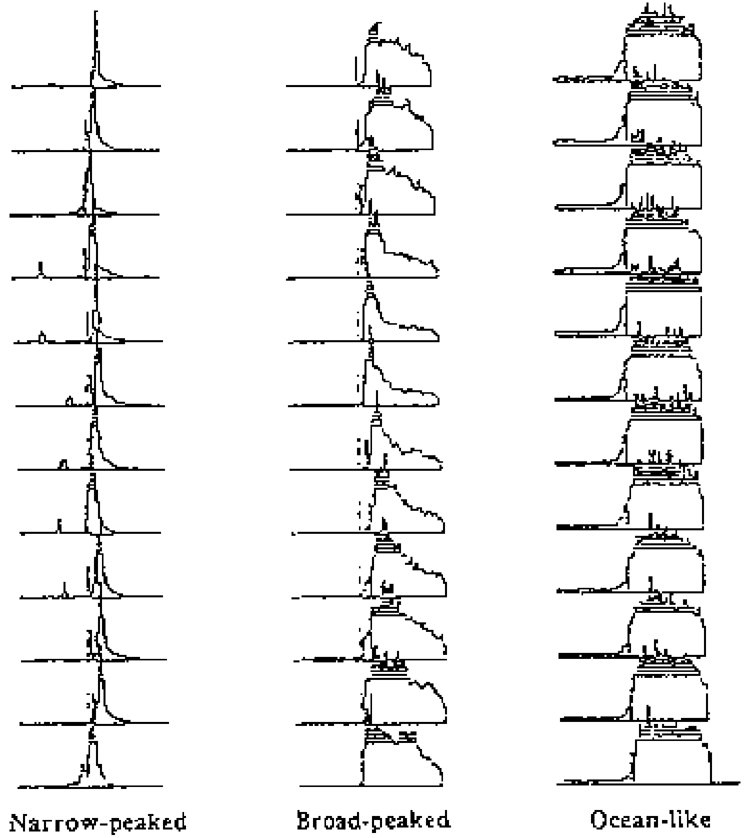
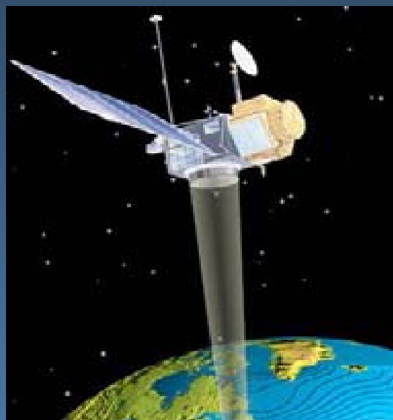
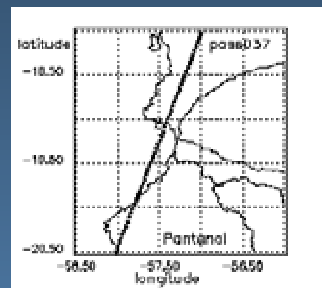


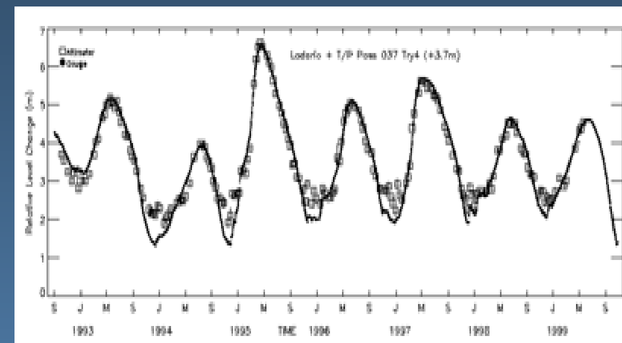
Fig. 1. Three sequences of radar echoes or "waveforms." Each waveform is a representation of power returned as a function of time. Over lakes waveforms are typically ocean-like, but can become broad-peaked or even narrow-peaked under very calm or icy conditions.

Validation

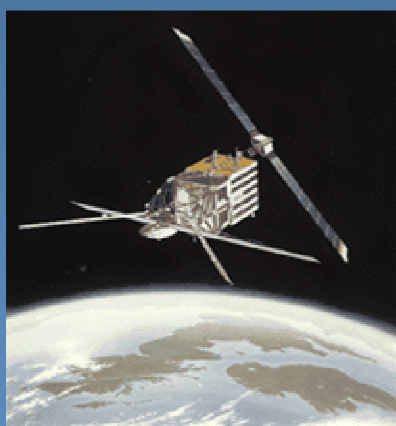


TOPEX/POSEIDON

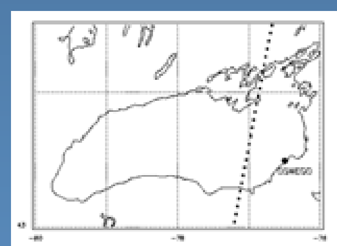


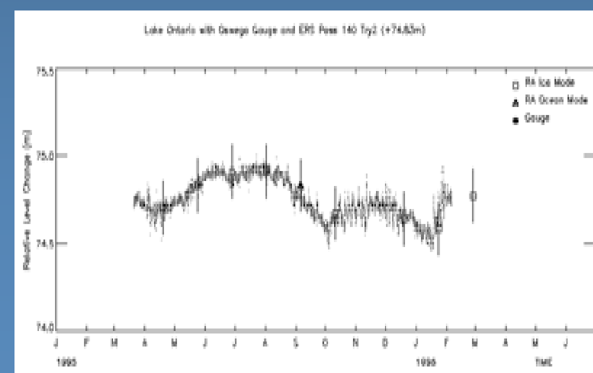


Paraguay River at Ladario



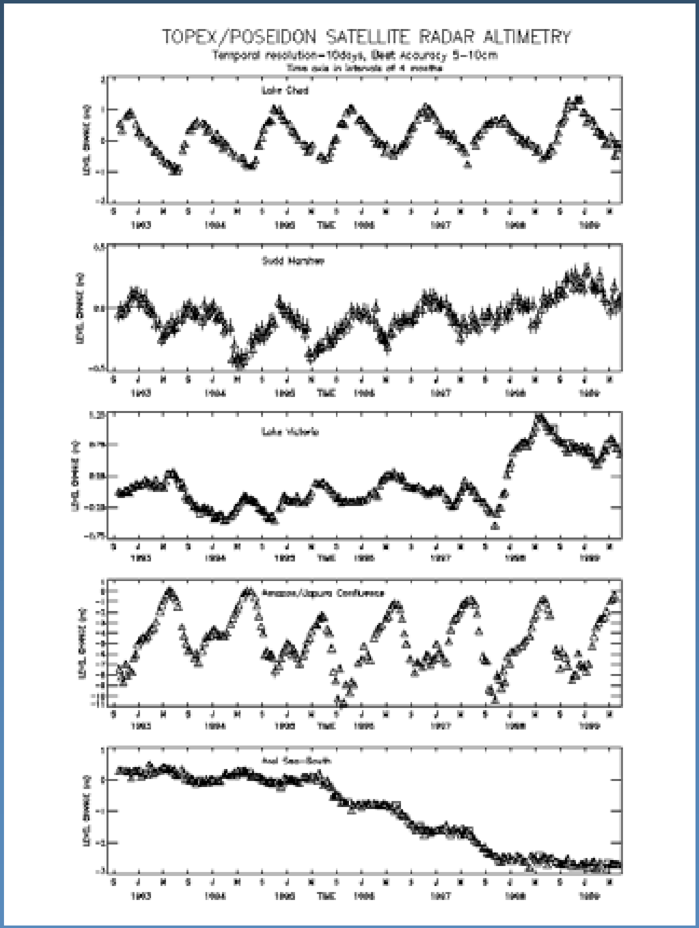
ERS





Lake Ontario

Examples



Lake Chad

Sudd Marshes

Lake Victoria

Amazon/Japura

Aral Sea-South

Advantages and Limitations

ADVANTAGES

The contribution of new 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

Data can only be retrieved along a narrow nadir swath.
The satellite orbit scenario determines the spatial and temporal coverage.
Highly undulating or complex topography may cause data loss or non-interpretation of data.
Height accuracy is dominated by many factors including the size and surface roughness of the target.
Minimum target size is also dependant on many factors.
Retrieved heights are an "average" not a "spot" height at a specific location.
Major wind events, heavy precipitation, tidal effects, ice formation, will effect data quality and accuracy.

Historical Development

SEASAT

R.L. Brooks, 1982 - Mapping of Canadian Lakes

J.G. Olliver, 1987 - Validation with US Lakes and Caspian Sea

Rapley et al., 1987 - Applications over non-ocean surfaces

A. Au et al., 1989 - (and GEOS-3), Caspian and Black Seas

Cudlip et al., 1992 - Preliminary mapping exercises, Sudd Marshes and Amazon Basin

GEOSAT

Guzkowska et al., 1990 - Applications over non-ocean surfaces

Koblinsky et al., 1993 - Amazon Basin, river stage determination

Morris and Gill, 1994 - Variation of Great Lakes water levels

Birkett, 1994 - Great Lakes and Global

ERS-1

Scott et al., 1994 - Tracking mode performance over non-ocean surfaces

TOPEX/POSEIDON - Validation and First looks

Morris and Gill, 1994 - The Great Lakes

Birkett, 1995 - The Great Lakes and Global

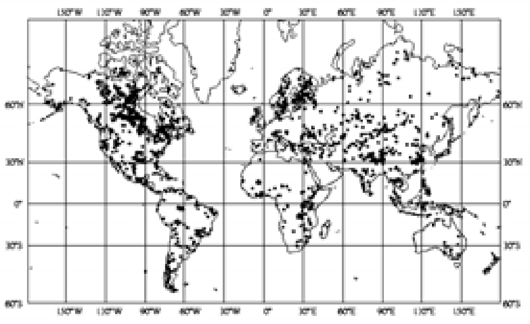
Dalton and Kite, 1995 - Lake Victoria, Africa

Birkett, 1998 - Global Rivers and Wetlands

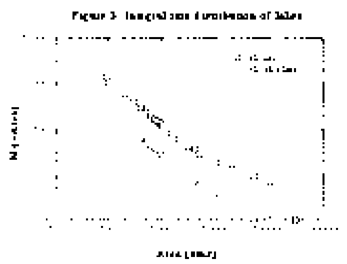
Aridity Index

Detection and Monitoring of Climate Change

Interpretation of short and medium-term lake volume changes in terms of an aridity index.

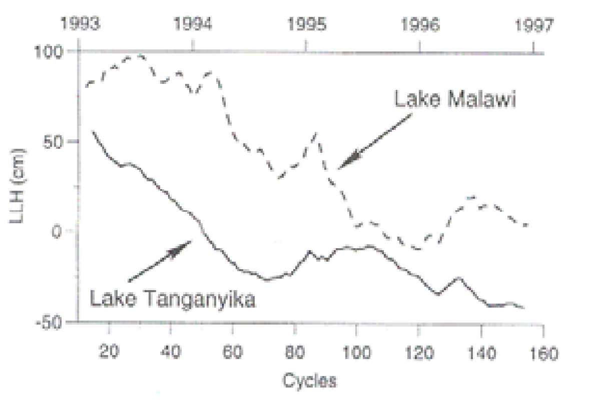


GLD Distribution of lakes >100km2



$$C \equiv \frac{1}{A_C}\left(\frac{R}{E_L - P_L}\right)$$

Lake volumes respond to changes in precipitation integrated over their catchment basins. This response is particularly marked for closed lakes. T/P crosses over ~350 large lakes, of which ~50 are ‘closed’. However, even reservoirs and open lakes respond to climatic variations.



Water level residuals after removing the annual cycle for lakes Tanganyika and Malawi. Derived from T/P for 1993-1996.

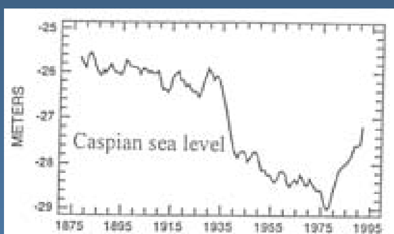
Ponchaut and Cazenave, 1998

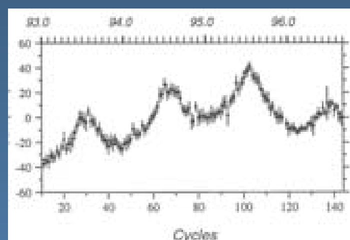
Mason et al., 1994, Birkett, 1995, Birkett and Mason, 1995

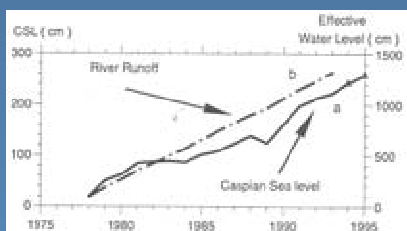
Case Studies

Caspian Sea

Decadal Variations in Sea Level





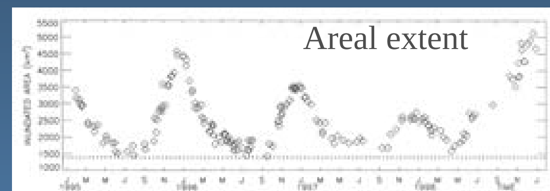


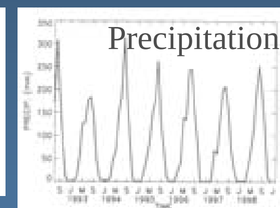
Post 1975 sea level rise via traditional gauge measurement confirmed by T/P observation, and observation of rating equation

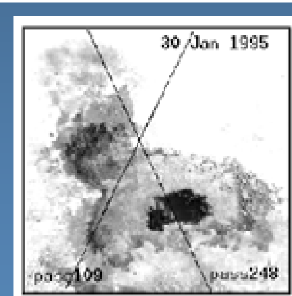
Cazenave et al., 1998

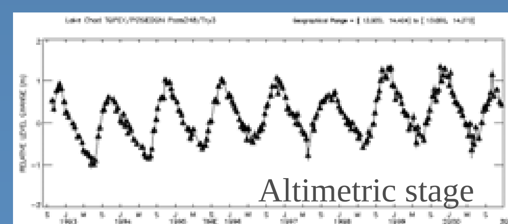
Lake Chad

Seasonal Inundation: Impact on Livelihood Choices









Synergy between elevation, areal extent, and precipitation together with up-river observations may allow seasonal prediction of inundation extent, magnitude and duration.

Birkett and Sarch, 2000

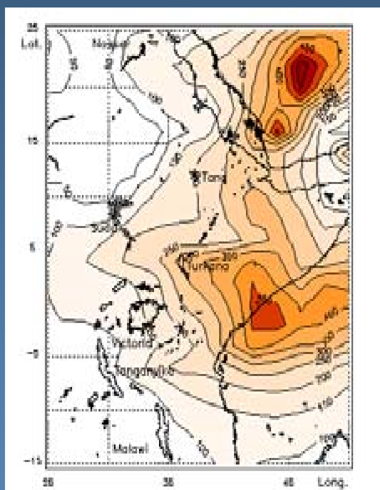
Application: Flooding

1997/1998 Flooding in East Africa

The Latest News

"Includes news from Europe and Asia that America will read at dawn"

4 p.m. Edition, Thursday, September 10, 1998



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.

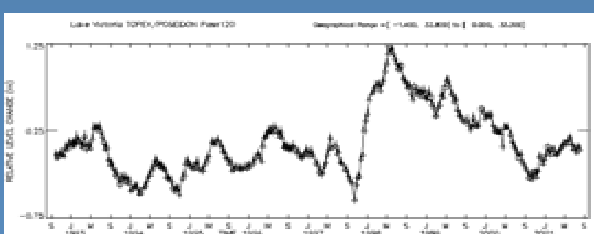
The government has mobilized troops to fight the worst flooding along the Nile River in a half century and is considering evacuating thousands of people in districts near Khartoum.

The worst hit regions in Sudan, Africa's largest country, are the Shamalia and el-Nil states north of Khartoum.

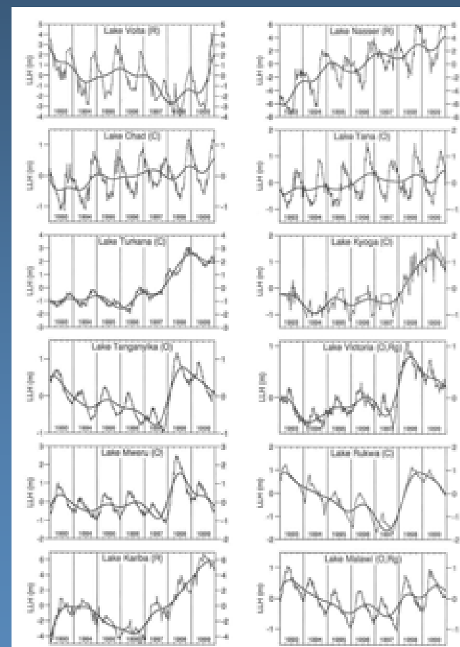
On Tuti Island, located in the Blue Nile, a few hundred yards from where the river meets the White Nile, more than 10,000 inhabitants have been battling the surging river for three days. A 2.5-mile-long wall of sandbags has been erected to save thousands of homes.

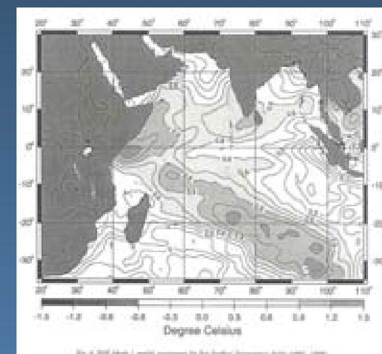
Sudan has flooding problems in September, when the rivers peak and seasonal rains begin.

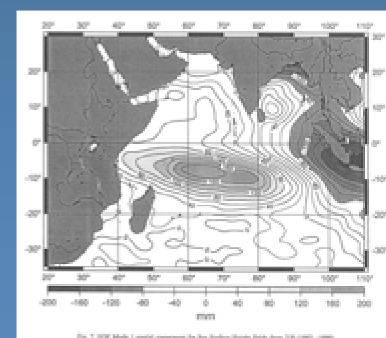
Meanwhile, air drops and feeding centers operated by international agencies hoping to alleviate a famine in southern Sudan are relieving some suffering, but people are still dying at an alarming rate, the United Nations.



Birkett, Murtugudde and Allan, GRL, 1999





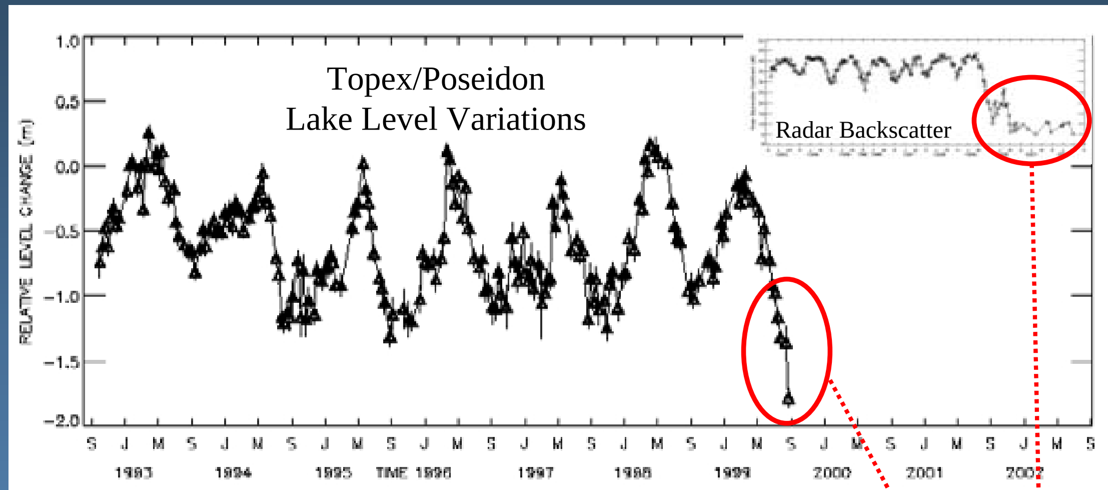


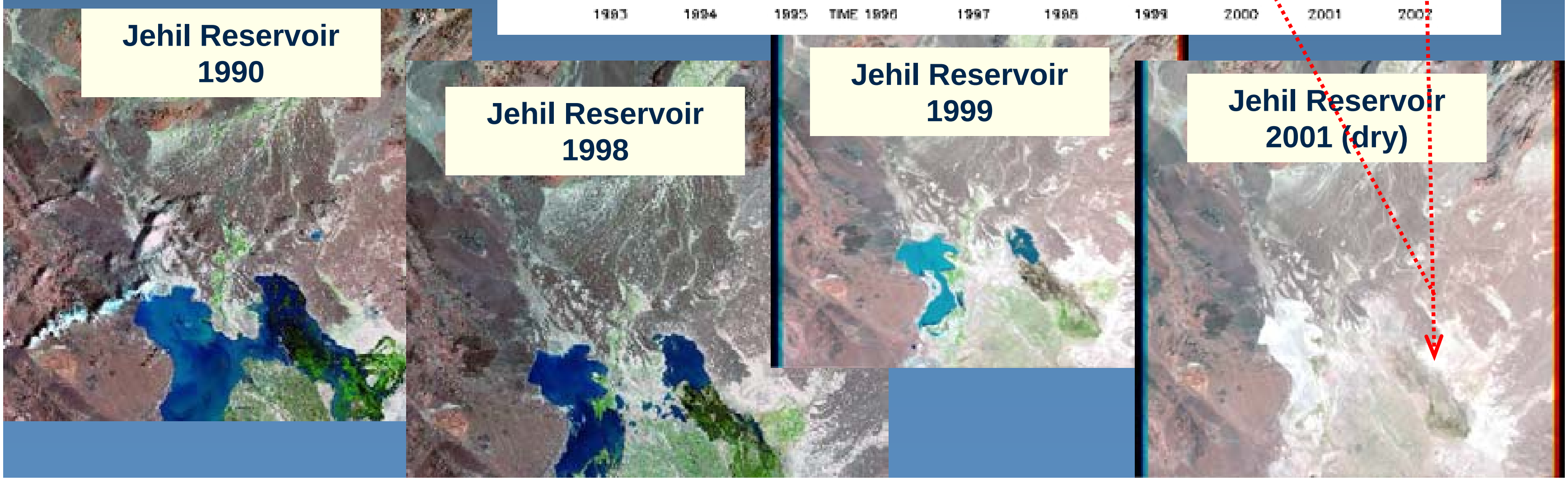
Mercier, Cazenave and Maheu, GPC, 2002

Application: Drought

UMD/USDA/USGS

Jehil Reservoir, Afghanistan

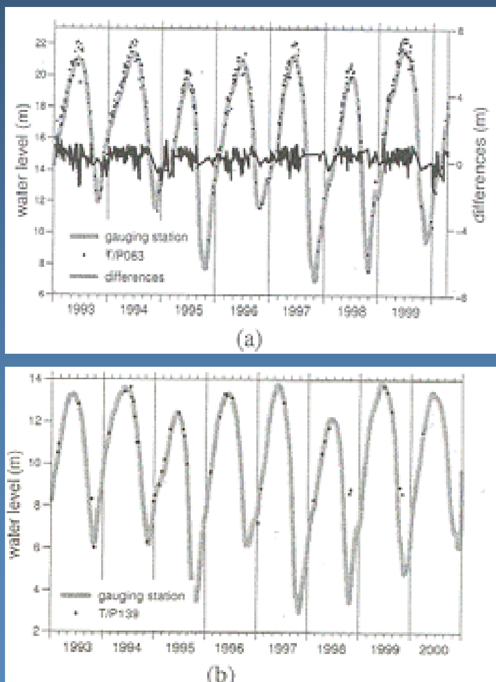




Application: Rivers/Wetlands

Seasonal/Inter-annual Variability, Propagation speeds and ENSO effects

Amazon Basin

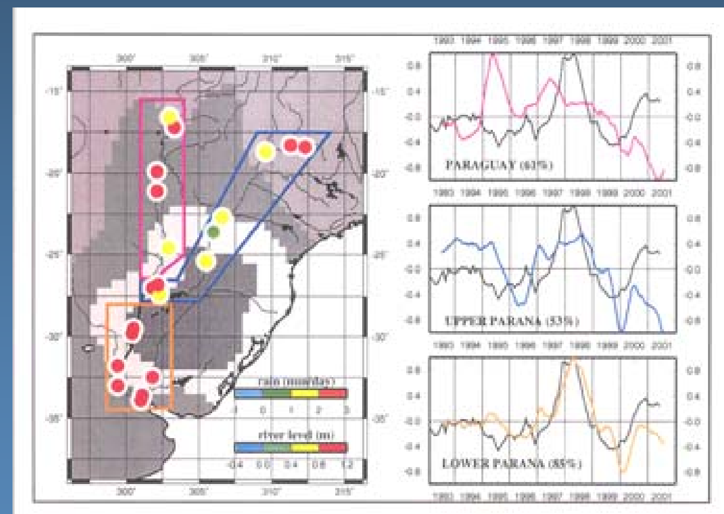


Comparison of the T/P-derived water level time series (dots) and reconstructed time series from the in situ gauging information. Results from Tracks 63 and 139 are shown.

Campos, Mercier, Maheu, Cochonneau, Kosuth, Blitzkow, Cazenave, 2001

La Plata Basin

Parana, Paraguay, Uruguay



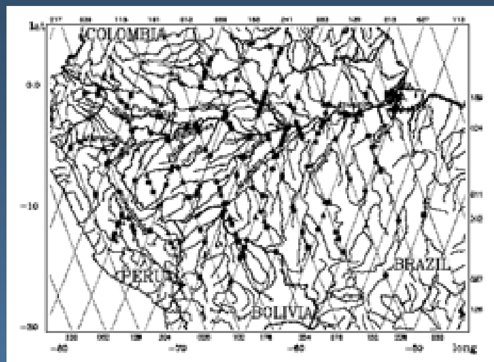
Leading mode of precipitation in the La Plata basin and of normalized water level time series. Principal component of precipitation (black), normalized elevation (colored) for 3 sub-basins. Surface water propagation speeds ~ 0.1m/s

Maheu, Cazenave, Mechoso, 2003

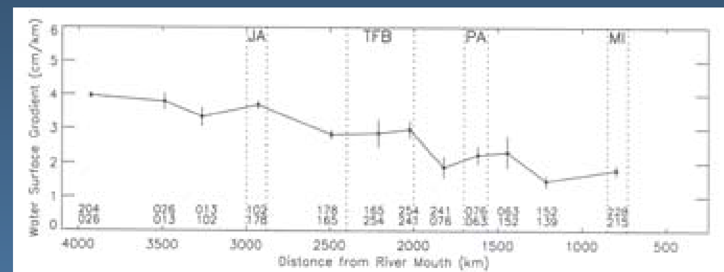
Application:River Dynamics

Birkett, Mertes, Dunne, Costa, 2002

T/P
Ground Tracks
Over the
Amazon Basin

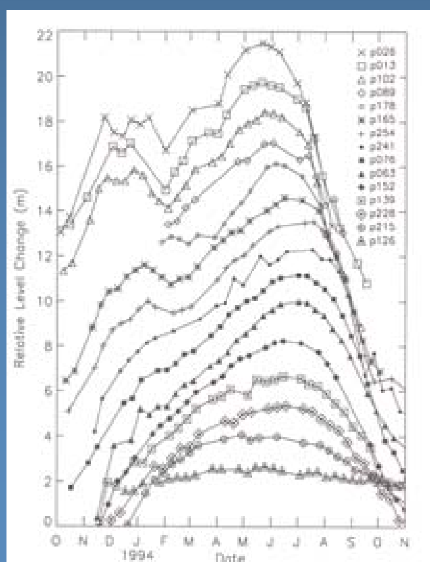


Water-surface gradient Amazon Main stem
June 1, 1993-1999



B.

Seasonal Stage
Variations
along the
Main Stem

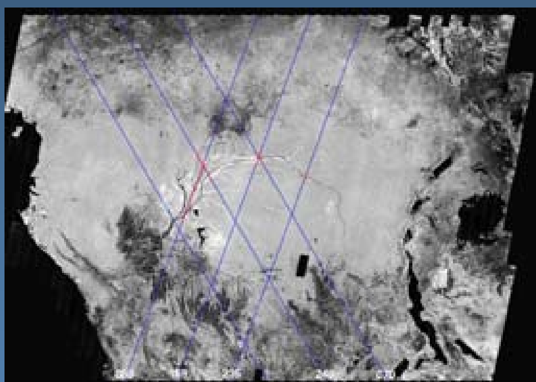


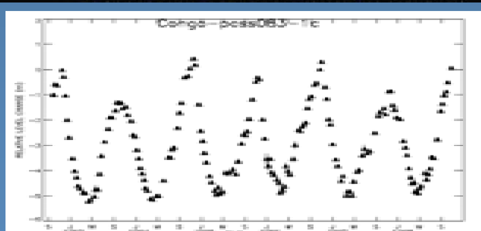
Variation of altimetric water-surface gradient as a function of Surface elevation during the passage of the annual flood wave (1995-1996) at Manacapuru. Gradient is deduced from a satellite pass-pair defining a river reach.

Application: Validation tool

JERS-1 SAR

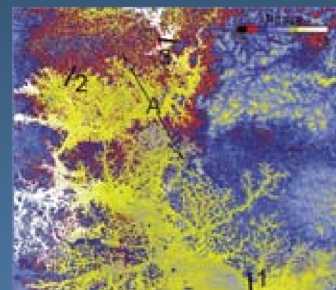
Congo River



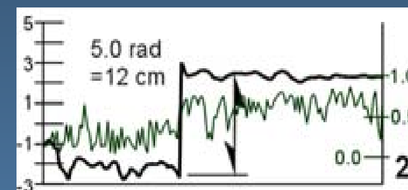


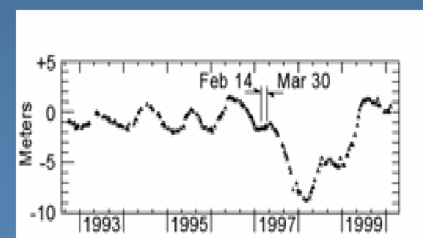
Utilizing radar altimetry and historical gauge data
For validating the hydrological significance of the
JERS-1 SAR (GRFM) mosaics in central Africa.
Rosenqvist et al., IJRS, 23, 2002.

Interferometric SAR



Balbina Reservoir

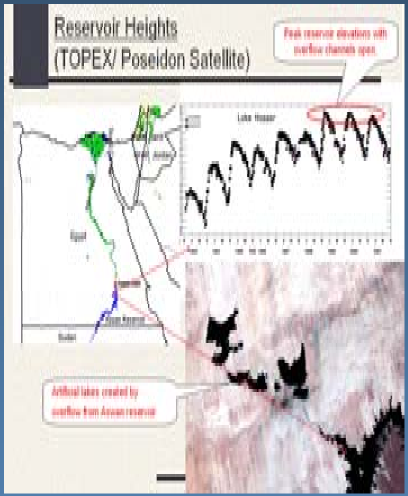


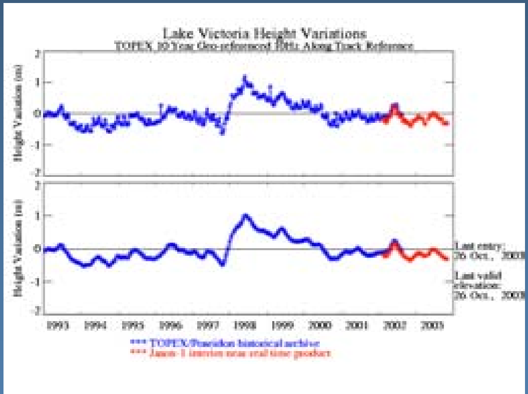


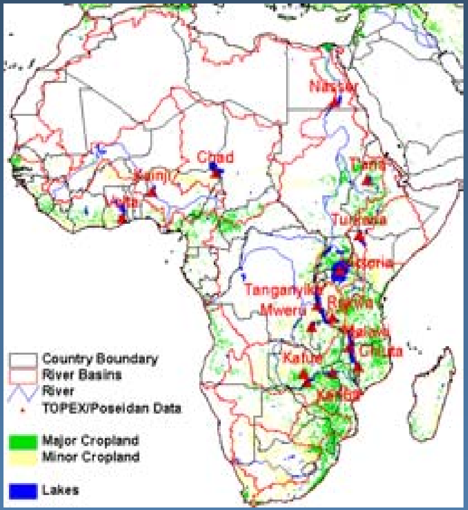
JERS-1 Interferogram spanning February 14 – March 30, 1997. “A” marks location of T/P altimetry profile, yellow =lake surface, blue= land. Inundated vegetation allow “double-bounce” travel path of radar pulse. In-SAR level changes 12 +/- 2 cm T/P level changes 21 +/- 10 cm.
Alsdorf, et al., GRL, 28, 2001.

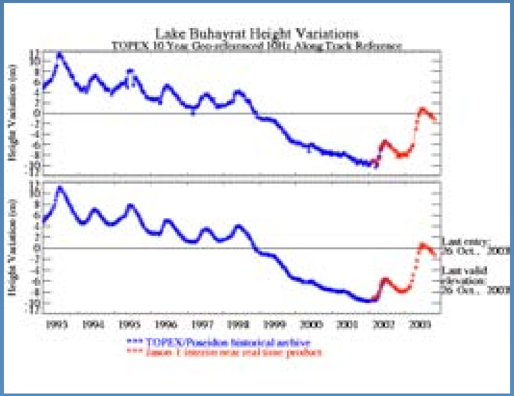
Application:
Near Real Time Global Monitoring

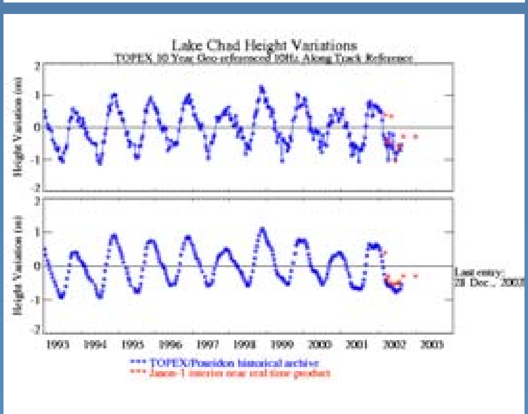
Jason-1

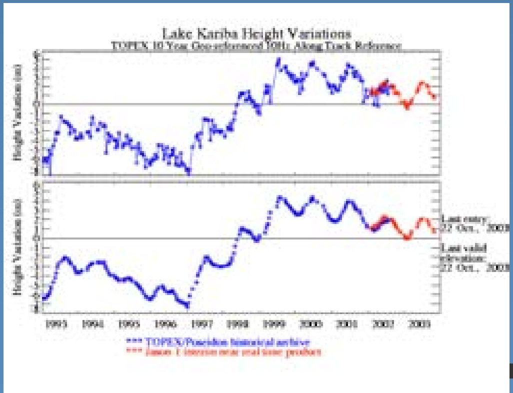












NASA: Outgrowth of the NASA ESE post-2002 Mission Planning. One of 3 THP working groups (soil moisture, cold-land processes).
Funded: NASA Terrestrial Hydrology Program Manager-Jared Entin.

- Science Questions

e.g. The ability to predict the Land Surface Branch of the Global Hydrologic Cycle

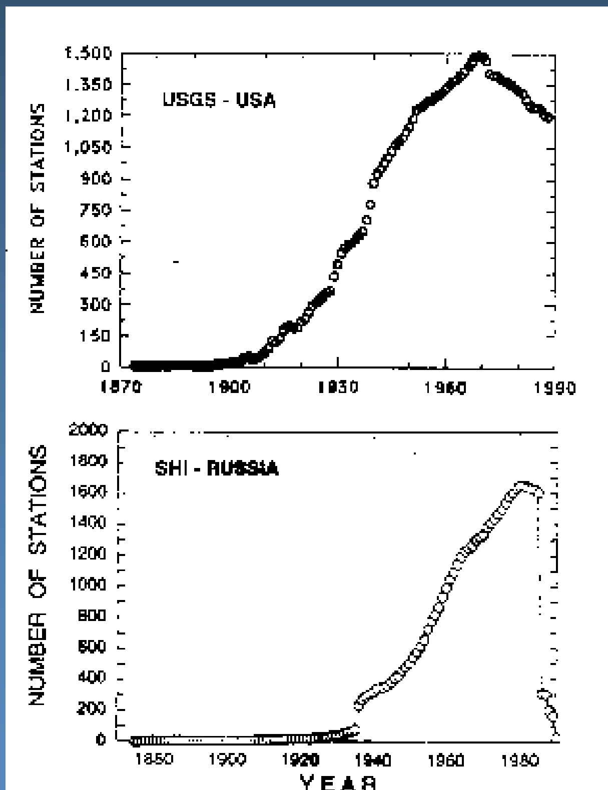
* Stream flow is the spatial and temporal integrator of hydrological processes thus is used to verify GCM predicted surface water balances.
* Unfortunately, model runoff predictions are not in agreement with observed stream flow.

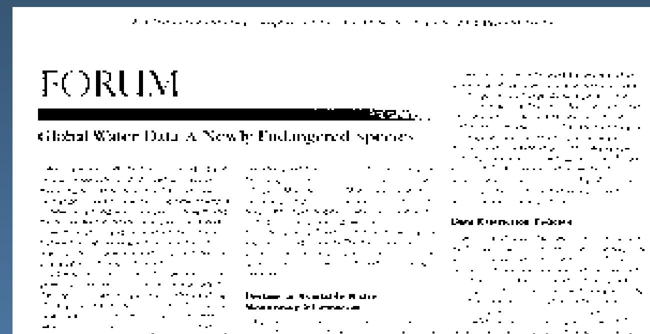
e.g. What is the role of wetland, lake and river water storage as a regulator of biogeochemical cycles, such as carbon and nutrients

- Global Water Management and Assessment Issues
- Lack of Discharge and Water Storage Measurements
- A Global Decline in Gauge Networks
- A Need for Satellite-based Observations
- Potential Space-borne Solutions

Ground-Based Gauge Networks

Vörösmarty et al., EOS Trans, 2001





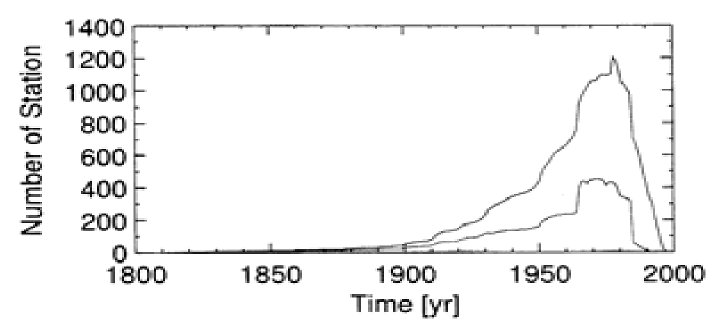
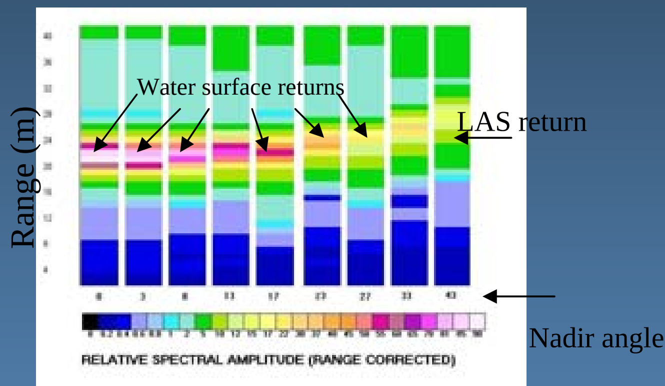


Figure 1. Time series of discharge gaging stations held by the WMO Global Runoff Center (top curve) a central repository for observations of continental runoff (Fekete et al. 1999) and that held within the University of New Hampshire RivDIS database (bottom curve, Vörösmarty et al., 1996a). Abandonment of stations, closure of previously open data sets, and delays in data processing conspire to limit the real-time value of these data sets.

New/Applied Technologies:
Doppler Lidar and Radar Interferometry

River stage and surface velocity

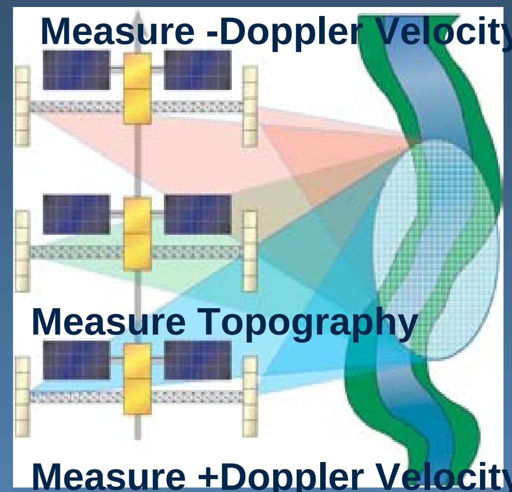


2µm coherent detection lidar
4-6 mJ (330 nsec pulse), 80 Hz rep rate
water cooled, ~7-10% total system efficiency, 10 cm two axis scanner, side door mounted, GUI for instrument control& data display

Single shot data used to obtain 400 shot average at ~3 degrees off nadir

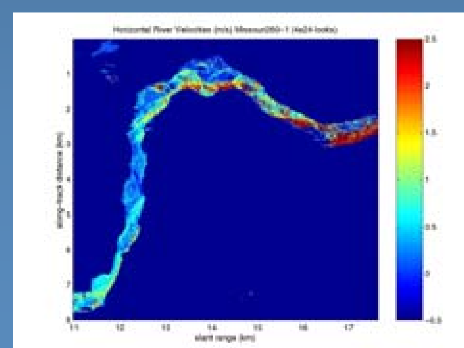
Airborne Doppler lidar returns from water surfaces
G.D. Emmitt and C. O’Handley, SWA.

River velocity, width, &slope



Only relative height/slope changes are measured. Assumes meter accuracy DEM can be used for calibration.

JPL



Example of measurement of the radial component of surface velocity using along-track interferometry

Rodriguez et al

Current Missions:
Improved Performance over Inland Water?

ICESAT/GLAS
Inland Water Level CAL/VAL

Objectives:

- Validate water level elevations in vicinity of river and lake gauges
- Assess signal quality as a function of water surface state & off-nadir angle
- Assess retrieval of along channel water slope

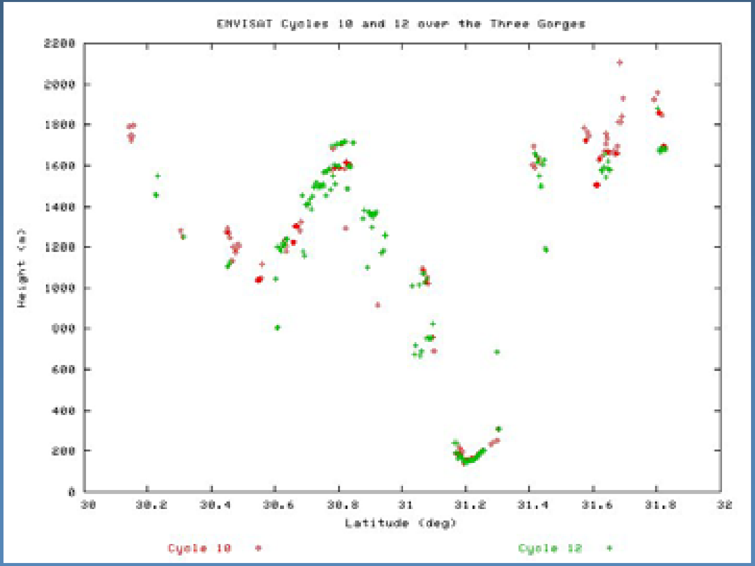
8-day Path Mode Targets:

Lower Mississippi River
Lower Missouri River
Columbia River Reservoir
Sacramento River
Great Salt Lake
Upper Nile River
Lake Nasser/Aswan Dam

Standard Land Nadir Mode:

Amazon River main stem, Everglades
Lakes Ontario +Chad, Paraguay +Yangtze Rivers

ENVISAT



Stage variation within the Three Gorges Dam
P.Berry, 2003 (DMU, p.c.)