Land Hydrology: The contribution of satellite radar altimetry to science investigations and operational programs

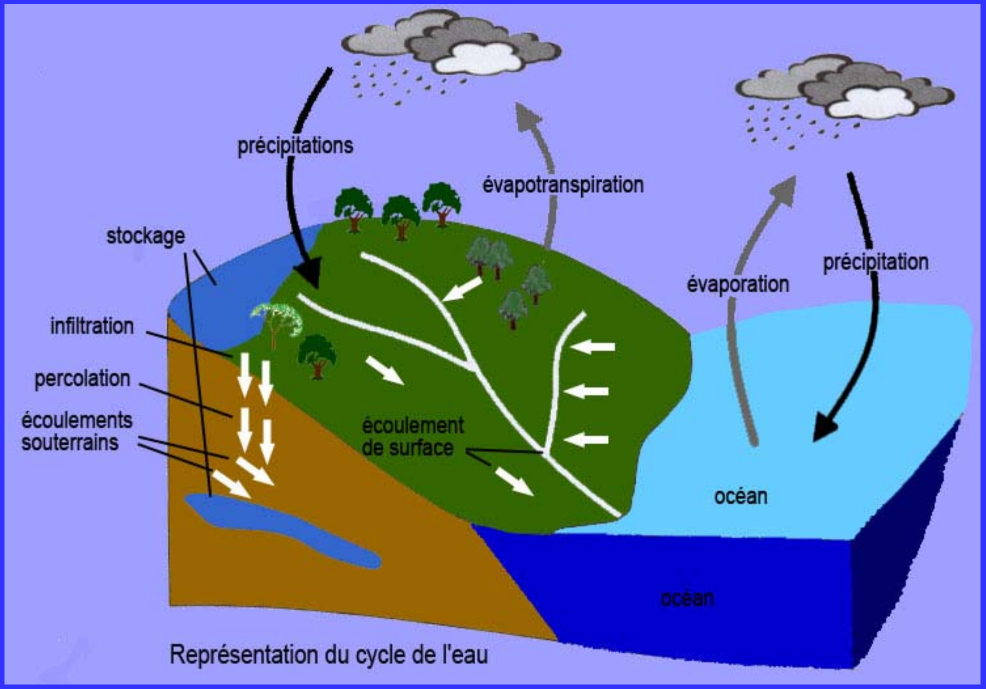
C.Birkett, A. Cazenave, F. Mercier, Frappart, S. Calmant, JF Cretaux, F. Seyler, F.Papa, V. Enjolras, P. Berry, E, Rodriguez, D. Bjerklie, F. Vaz de Almeida, M. Rodell, Zakharova, D.Alsdorf, et al.

Continental Water Cycle

↓

Water exchange between reservoirs:

- Water mass exchanged
- Time scales of exchange
- Reservoirs capacities
- Rate of water renewal inside reservoirs



Processes involved

- Energy transfert between land surface and atmosphere
- Lower atmosphere dynamics
- Gravity effects
- Biological processes
- etc.

Causes of spatio-temporal change of the continental water cycle

- Climate variability (natural and anthropogenic)

- Direct human effects:

  - groundwater mining
  - irrigation
  - dam building
  - urbanization
  - deforestation
  - change in land use

Water Balance Equation (river basin scale)

↓

Water mass balance : $dW/dt = P - E - R$

W: Land water mass (surface and underground waters; snowpack)

P : Precipitation

E : Evapotranspiration

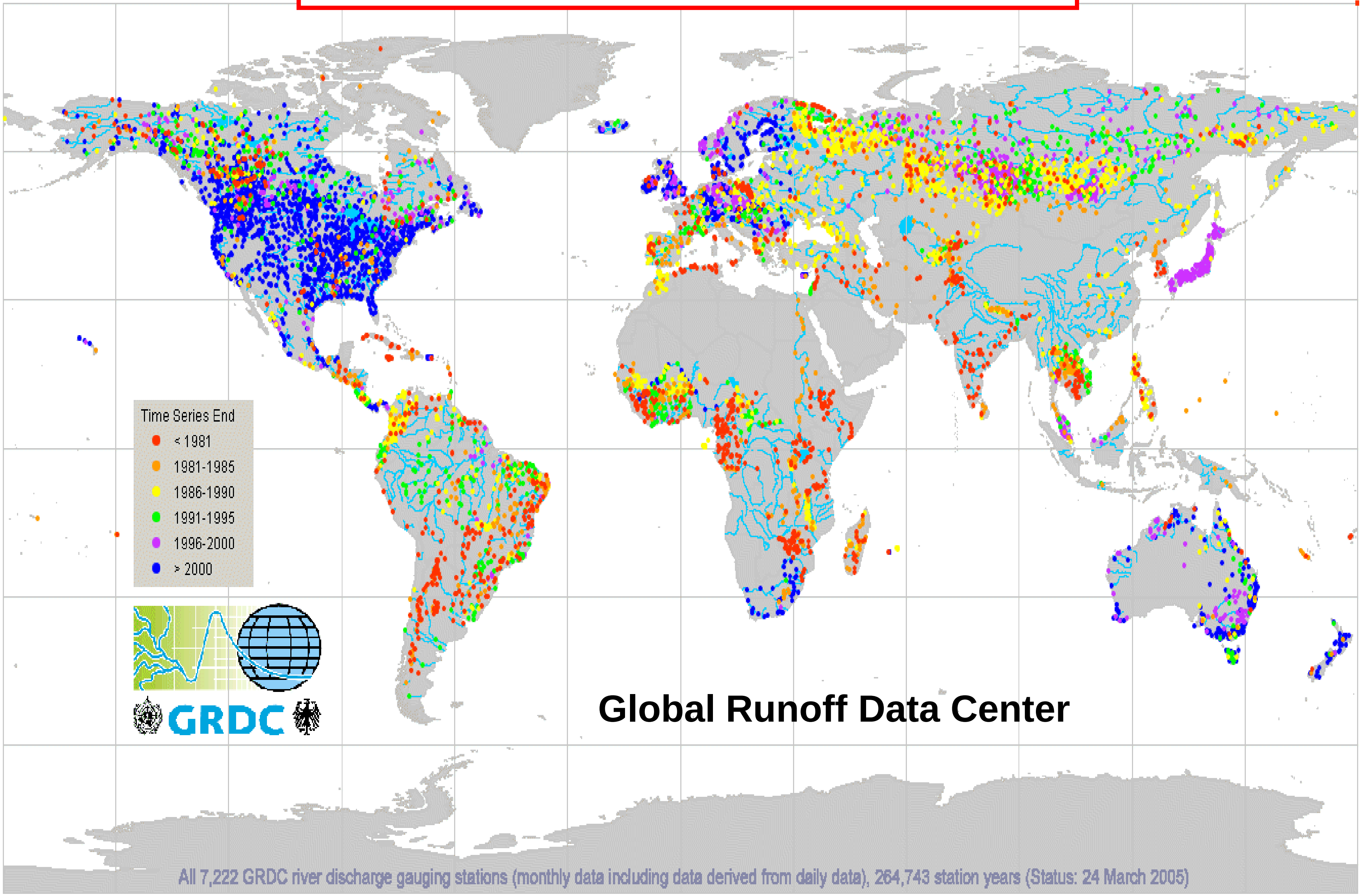
R: Runoff

Applications

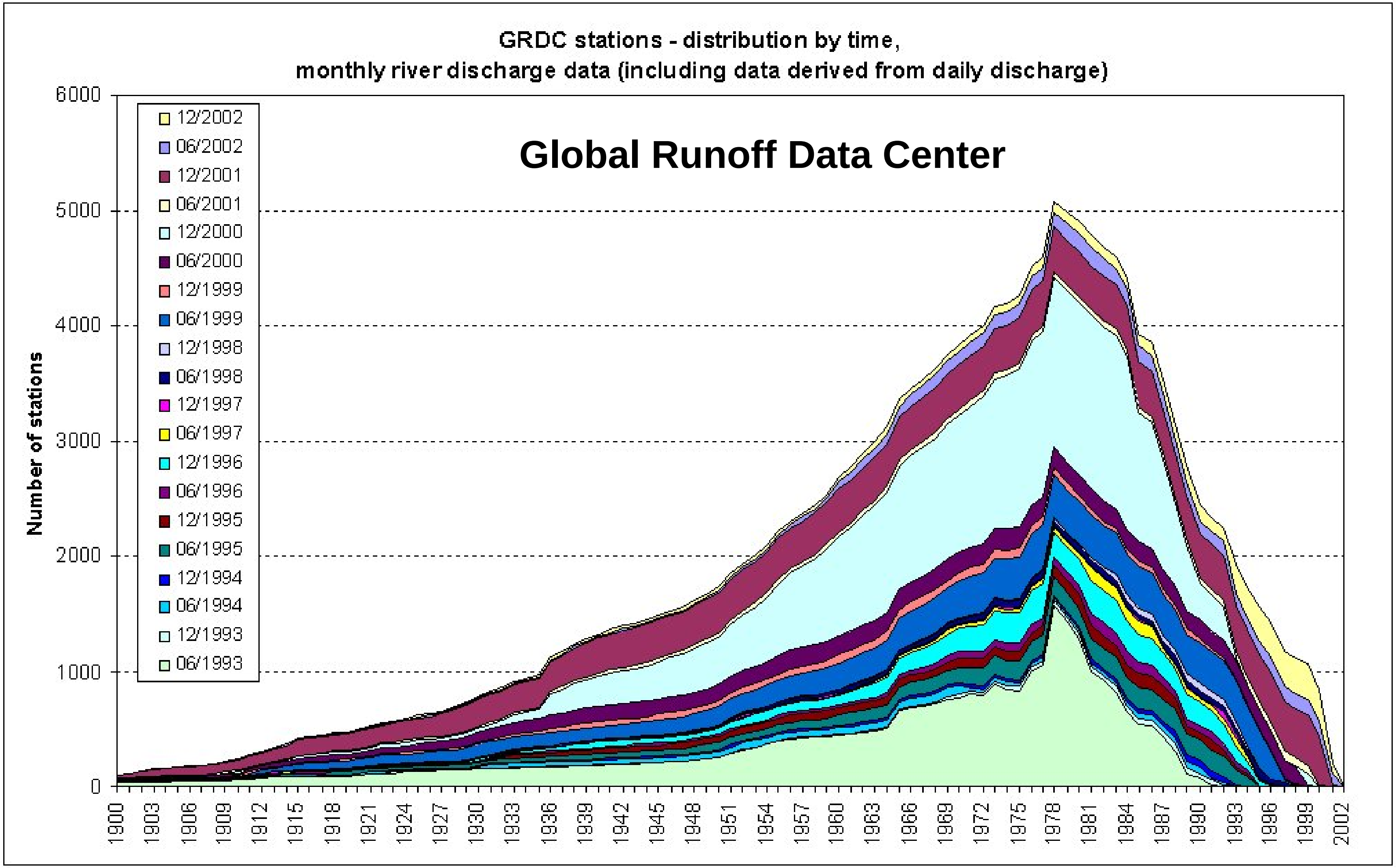
- Weather forecast
- Climate modelling
- Water resources management
- Natural Hazards:
- floods, droughts
- Agriculture (irrigation)
- Hydro-electric energy production
- Fluvial navigation
- Land use and management
- Carbon cycle
- Sediment transport
- Sea level change
- Etc.

River level and discharge knowledge also needed for various applications (water resource management, irrigation, flood/drought prediction, etc.)

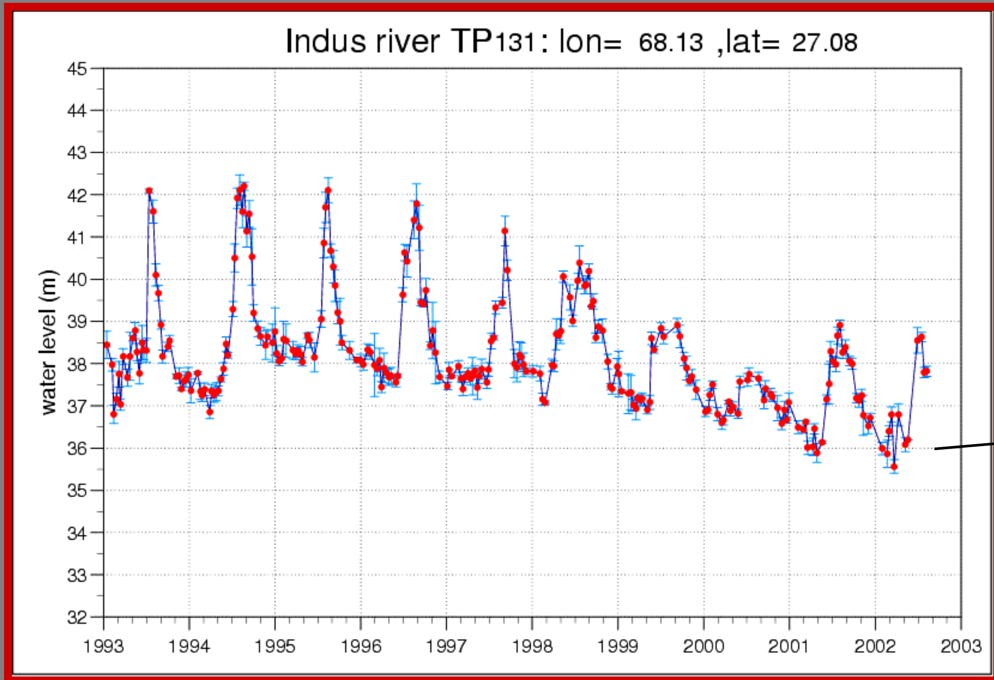
Water level and discharge

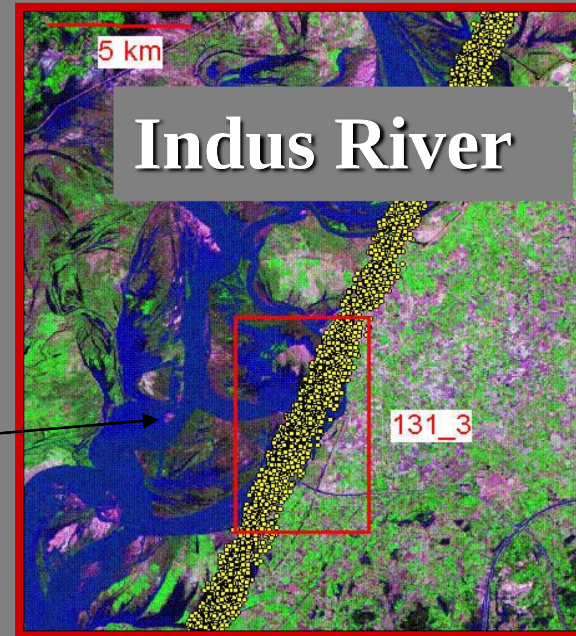


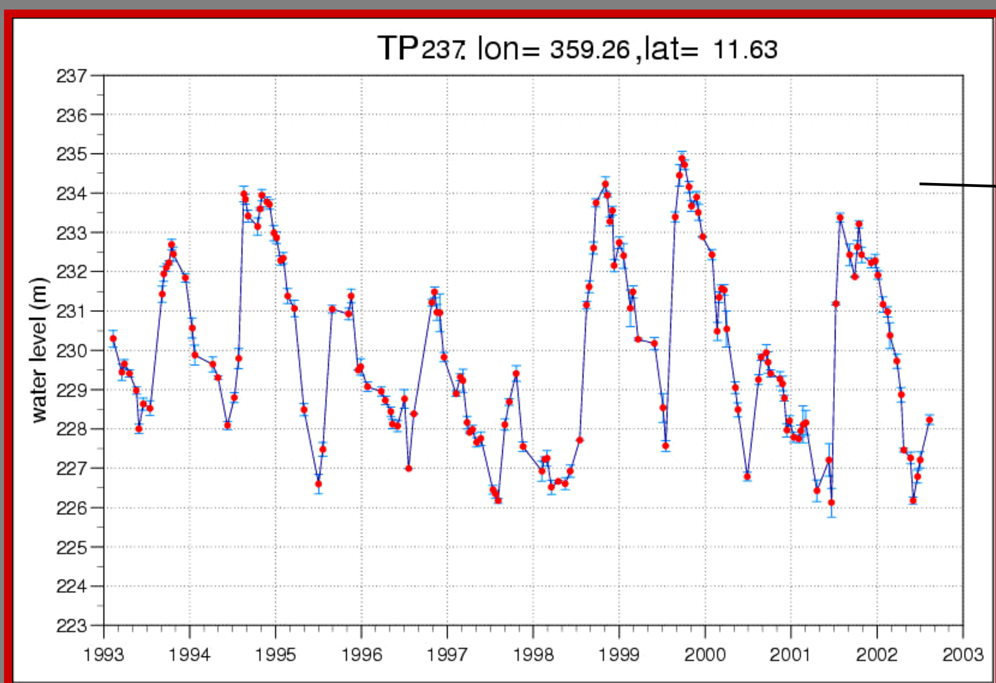
Time distribution of in situ gauges

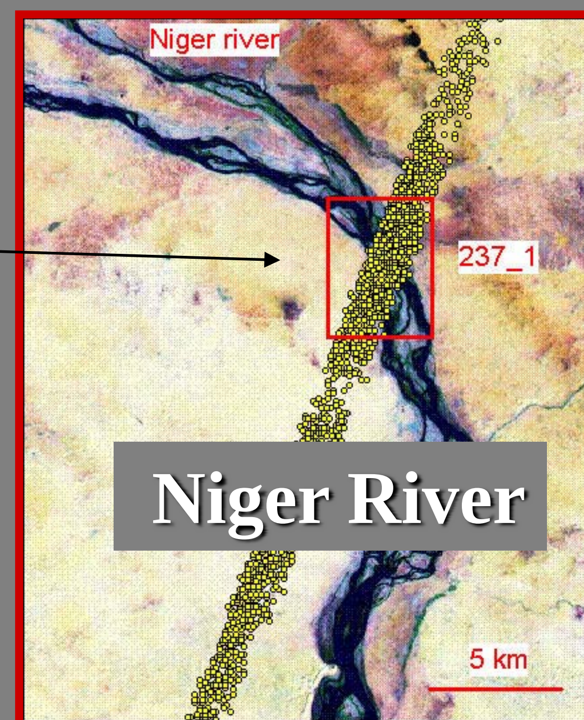


Date

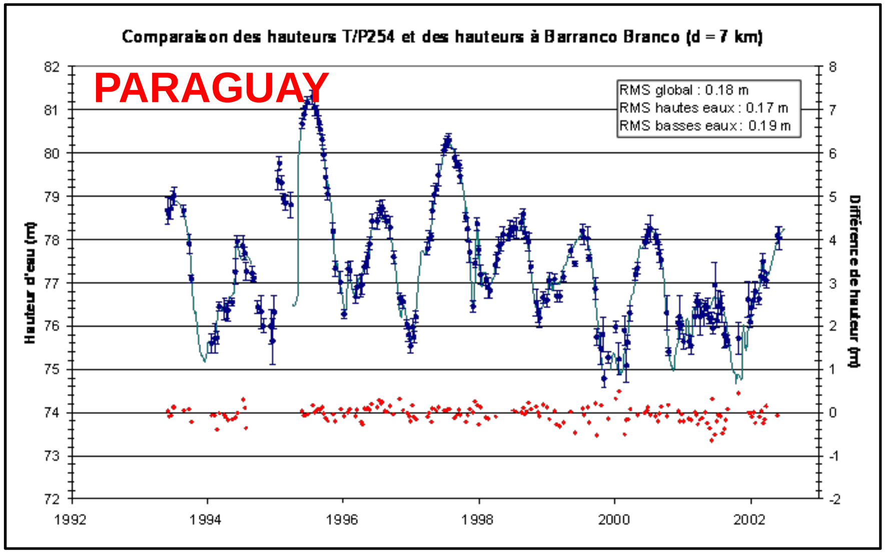

Indus river TP131: lon= 68.13 ,lat= 27.08
water level (m)
45
44
43
42
41
40
39
38
37
36
35
34
33
32
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003

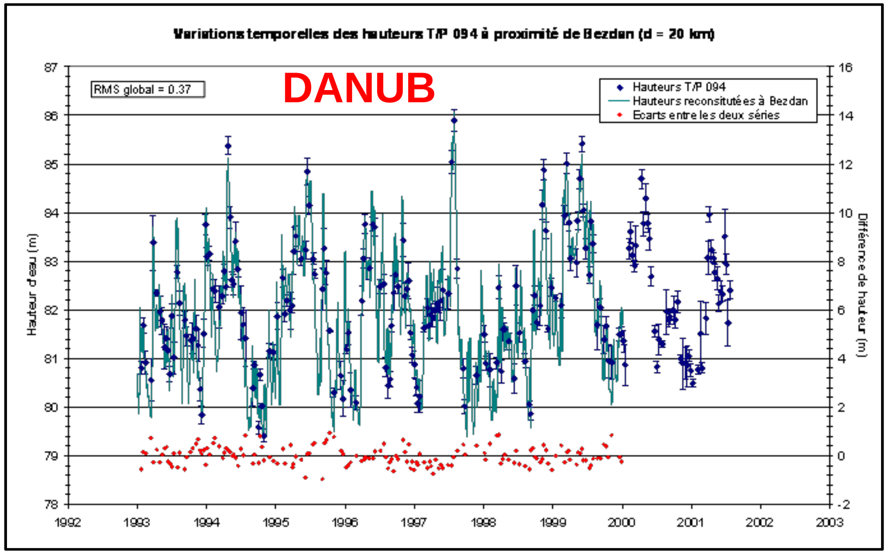

5 km
Indus River
131_3

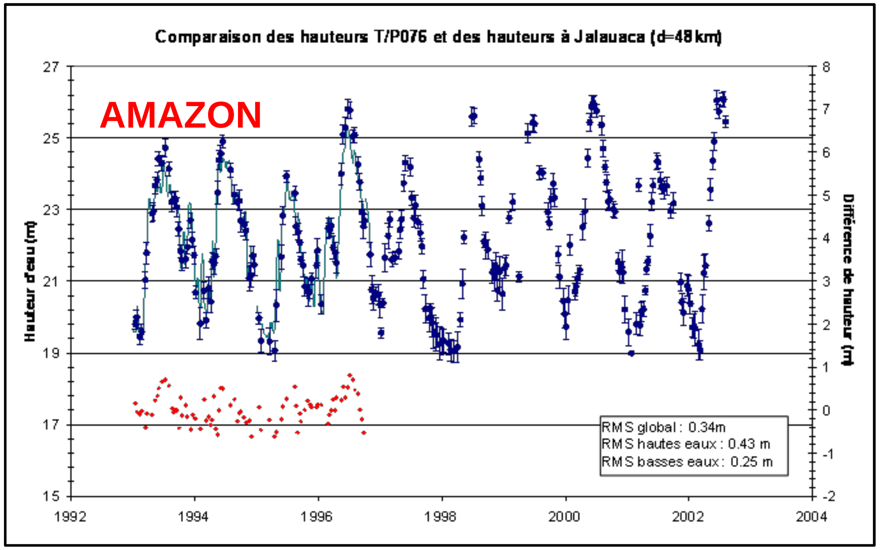

TP237. lon= 359.26 ,lat= 11.63
water level (m)
237
236
235
234
233
232
231
230
229
228
227
226
225
224
223
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003

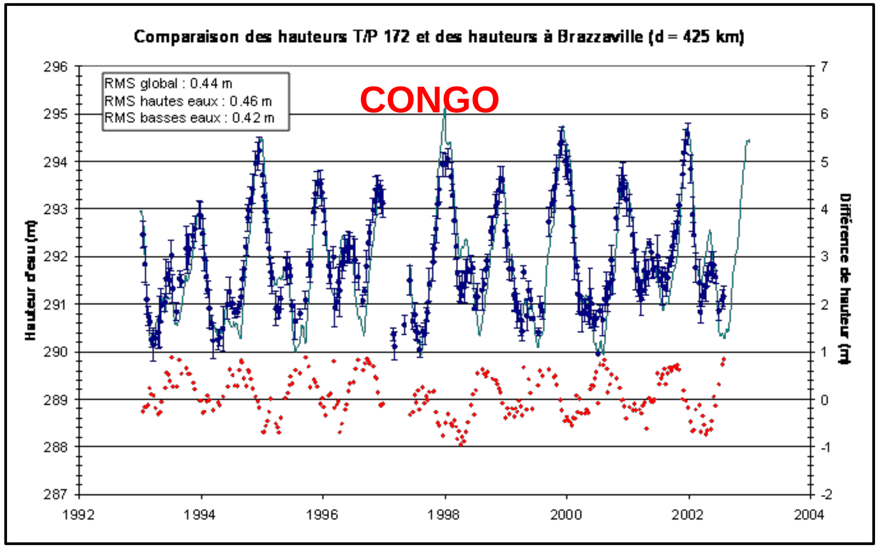

Niger river
237_1
Niger River
5 km

Comparison of altimetry and in situ water levels









1997/1998 Flooding in East Africa

The Daily Afternoon Newspaper for Airline Travelers

The Latest News

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

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

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Robert Clifton Burns, Director

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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.

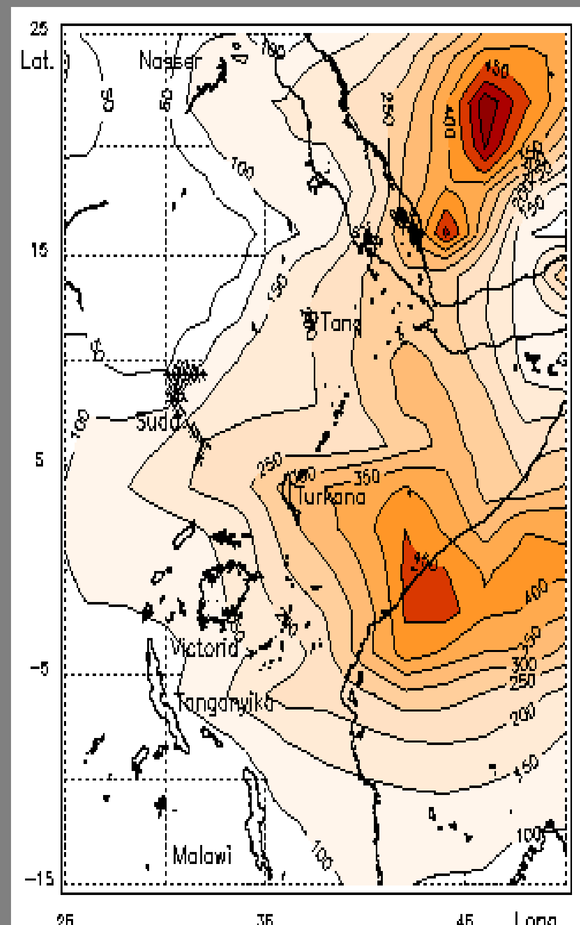
The government has mobilized troops to fight the worst flooding along the Nile River in a half century and is considering evacuating thousands of people in districts near Khartoum.

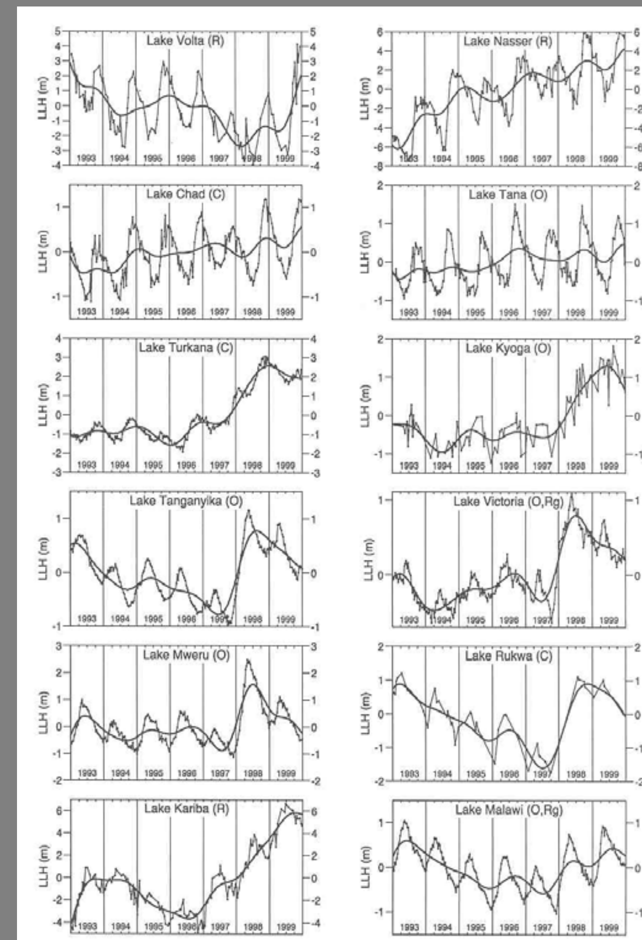
The worst hit regions in Sudan, Africa's largest country, are the Shamalia and el-Nil states north of Khartoum.

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.

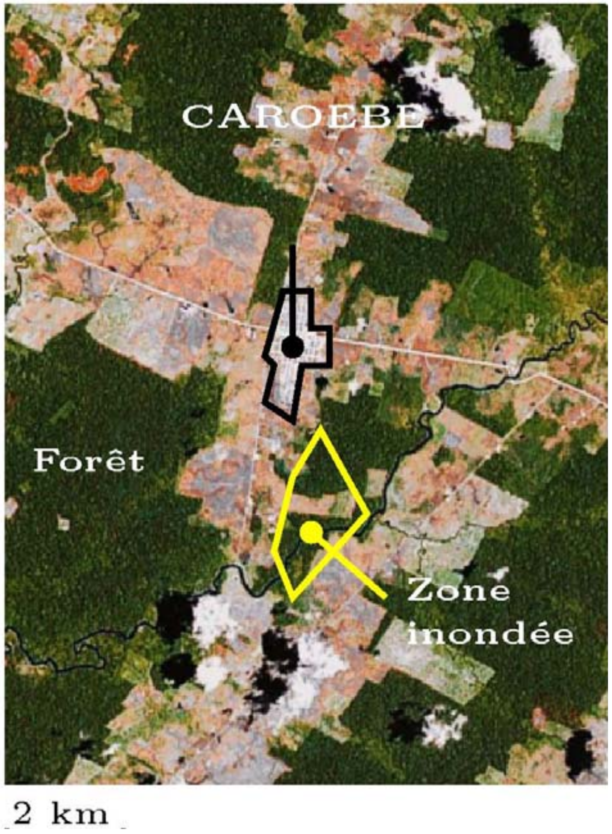


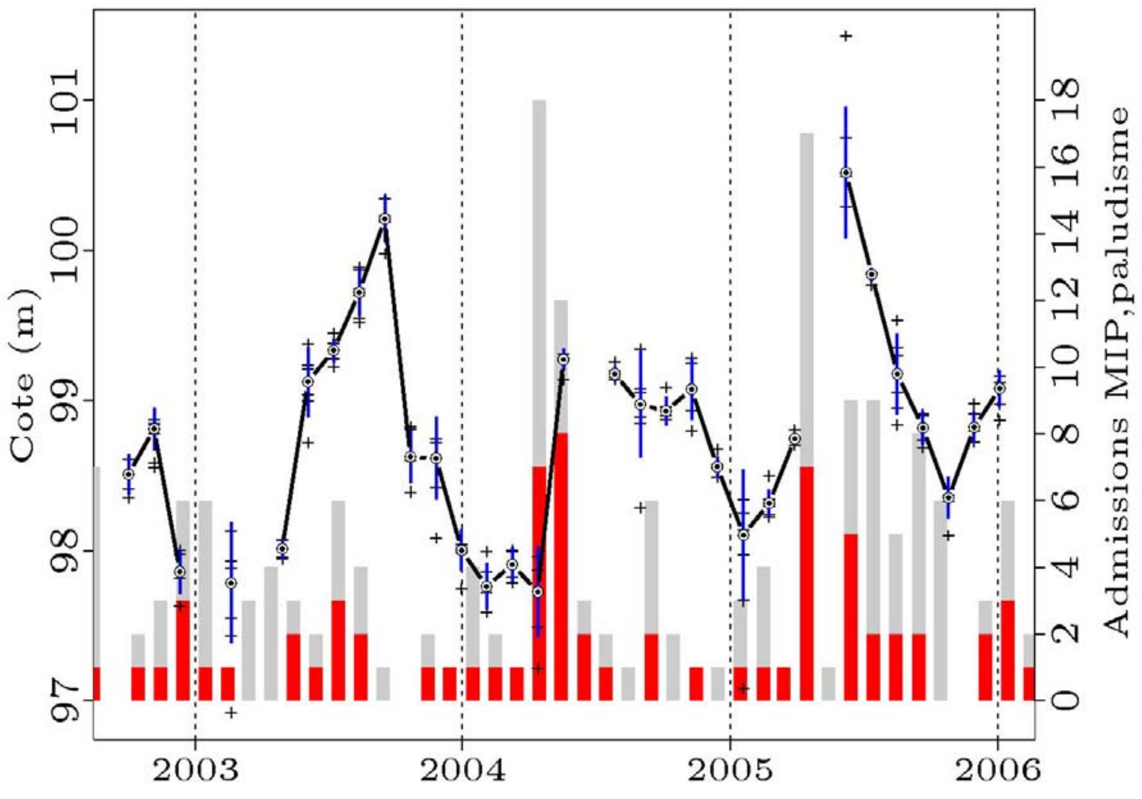


Birkett, Murtugudde and Allan

Mercier, Cazenave and Maheu

Tropical disease and water levels (Amazonia)

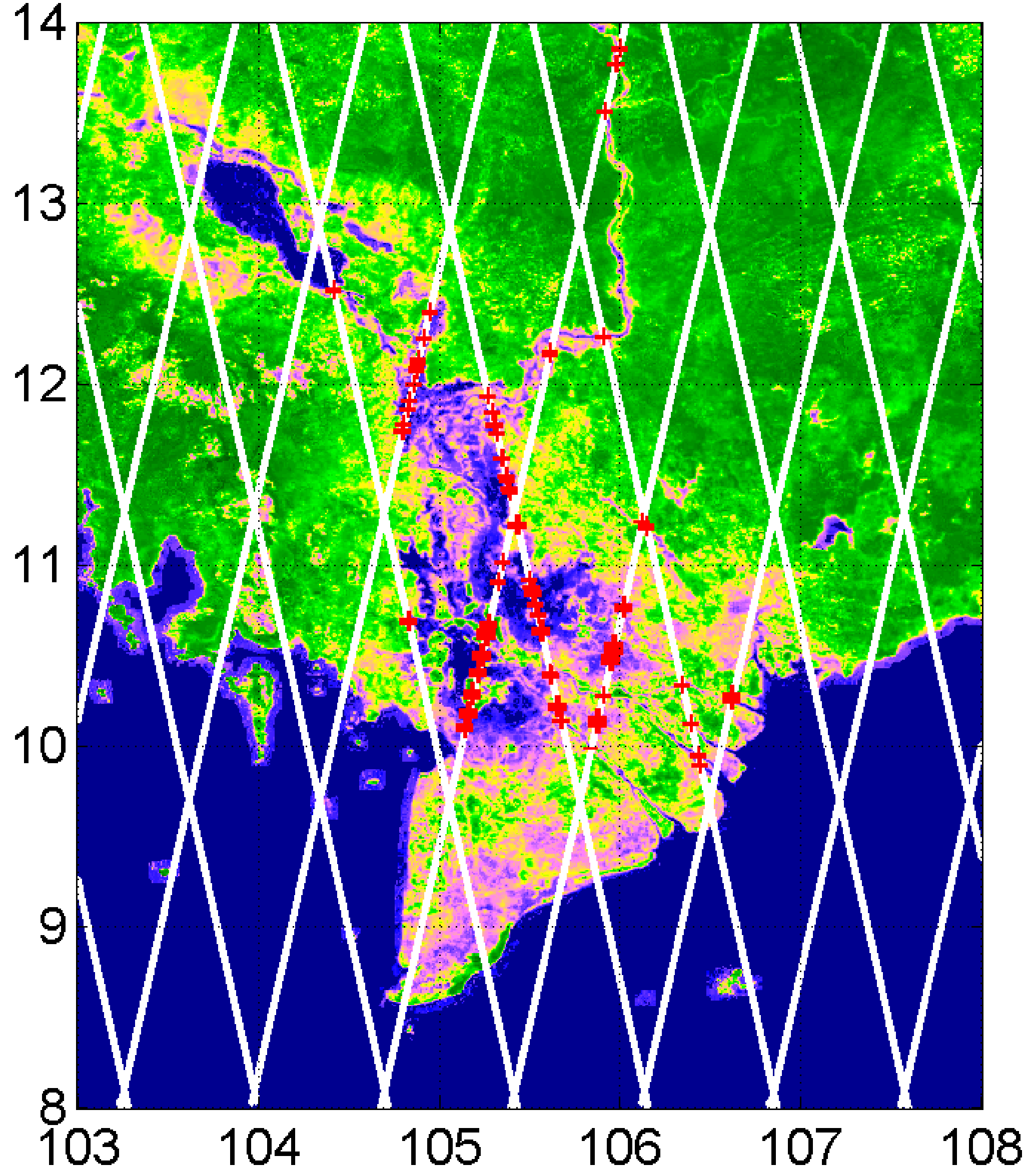




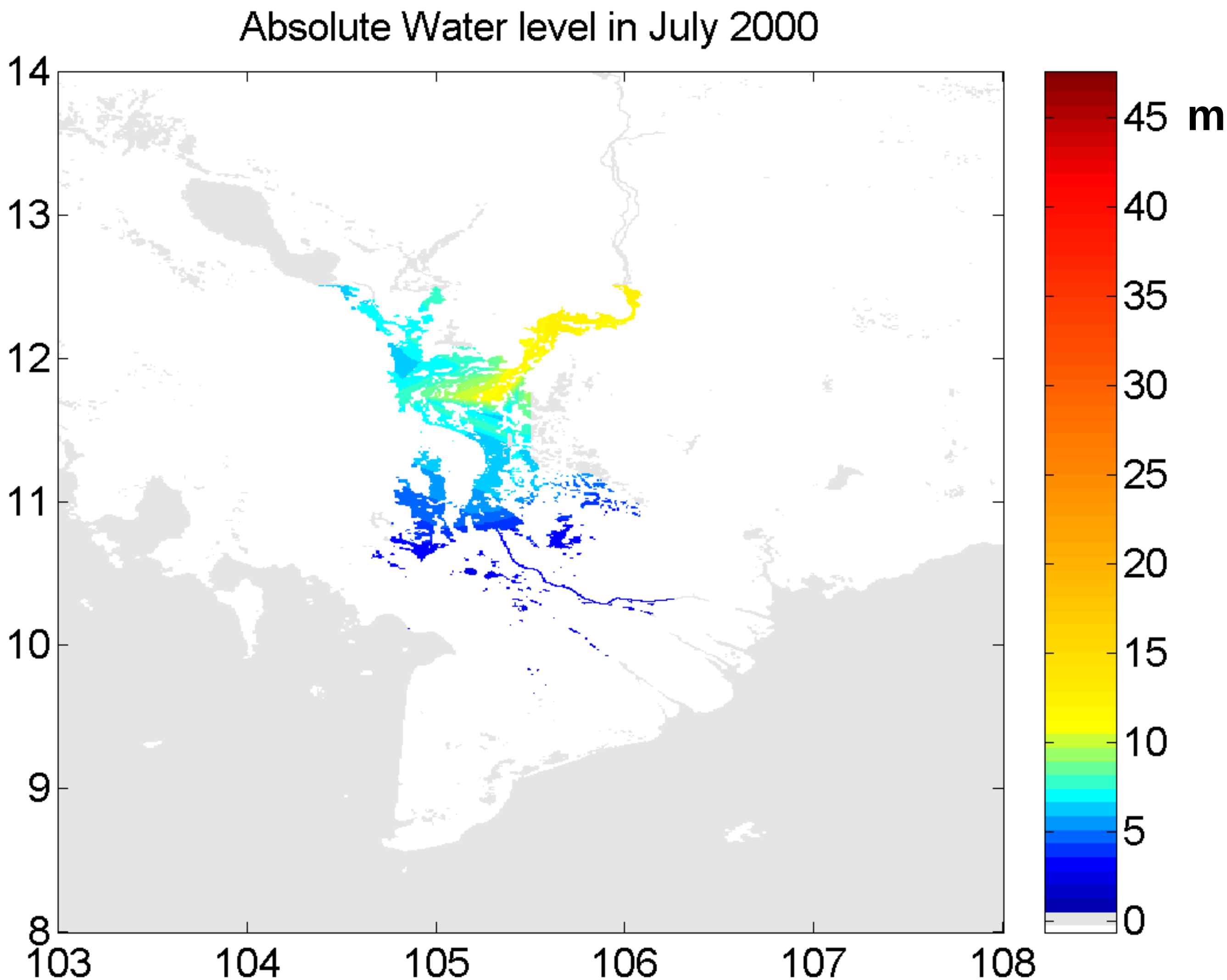
E. Roux/F.Seyler (LMTG)

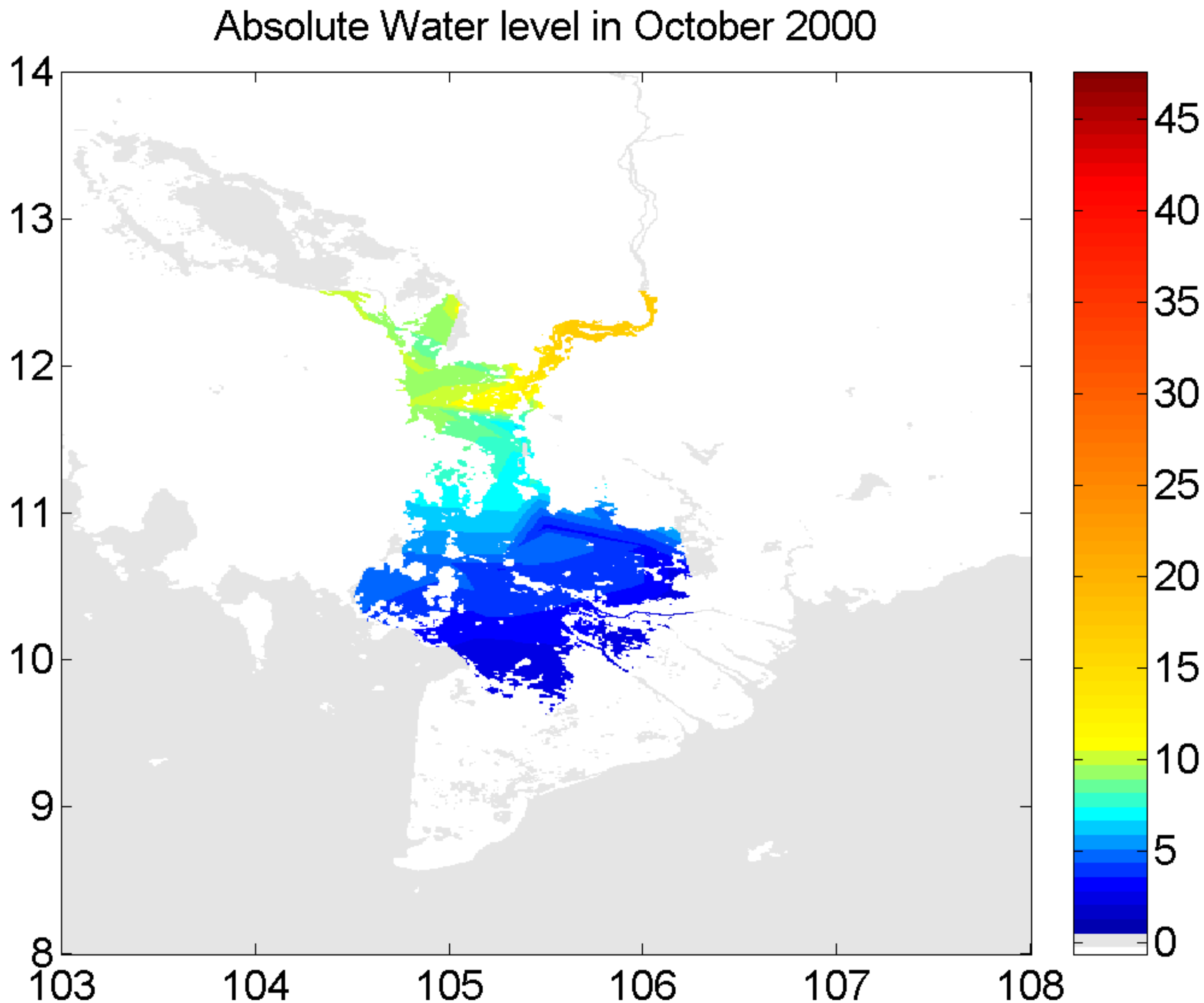
Seasonal flood monitoring in the Mekong Basin

ERS/ENVISAT altimetry + SPOT/VGT imagery



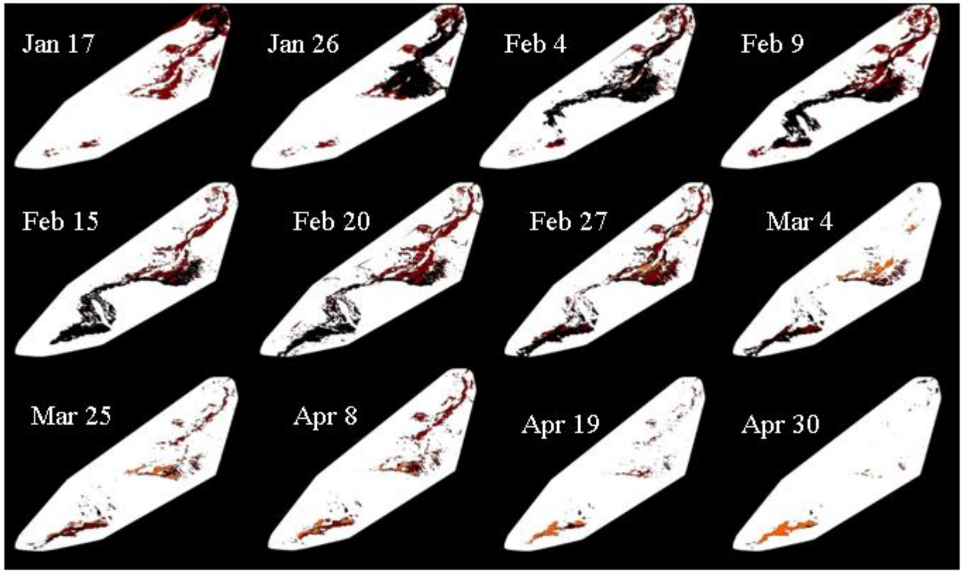
Frappart et al., 2006


Absolute Water level in July 2000
14
13
12
11
10
9
8
103
104
105
106
107
108
45
40
35
30
25
20
15
10
5
0
m



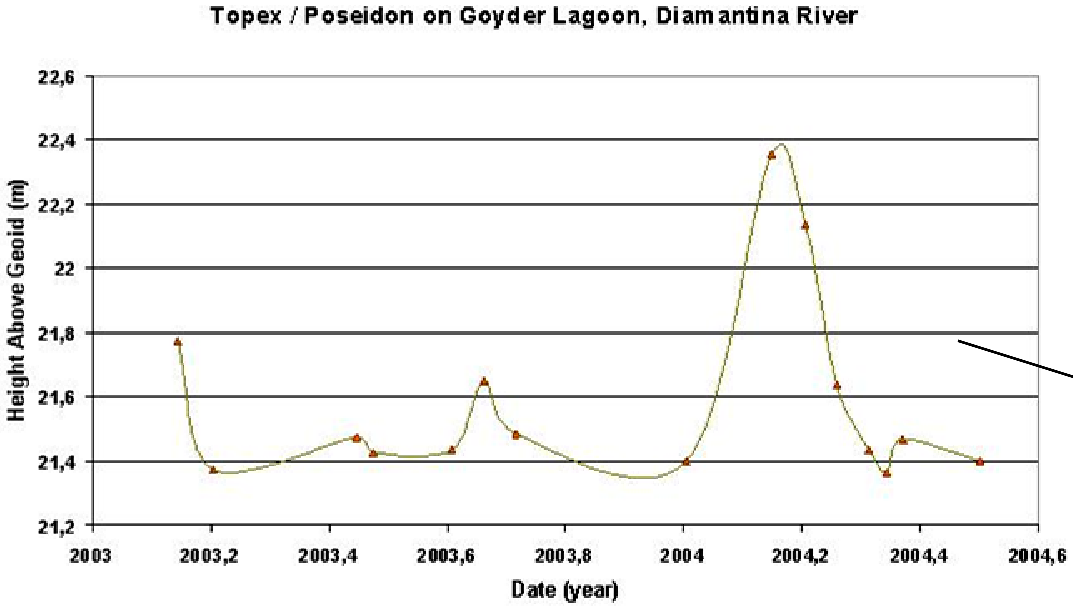
Absolute Water level in October 2000
14
13
12
11
10
9
8
103
104
105
106
107
108
45
40
35
30
25
20
15
10
5
0

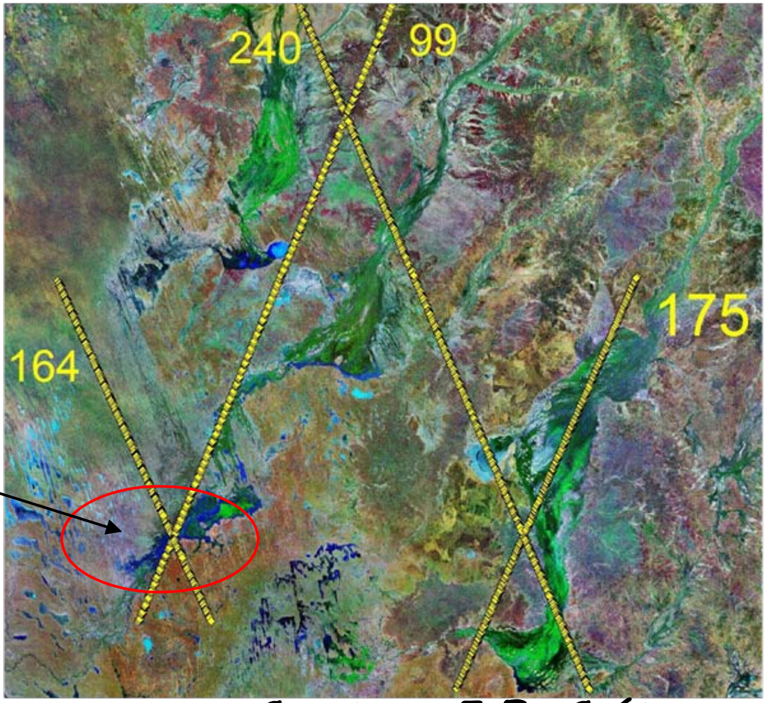
Monitoring of the 2004 flood event along Diamentina River (Australia) using MODIS images and Topex altimetry



Sequence of flood on Diamantina river in 2004 From Modis data

Black: water, Red: Aquatic Vegetation, Orange: Vegetation, White: dry land





Courtesy J.F. Crétaux

Potential GRACE Based Prediction of Lake Chad Water Levels

Due to an arid climate, Lake Chad and its tributaries are the primary source of water for residents of that region. These people alternate between fishing and farming, depending on river flows in a given year.

By observing variations in water stored in the uplands which drain to Lake Chad, GRACE satellite observations may soon enable forecasts of these river flows.

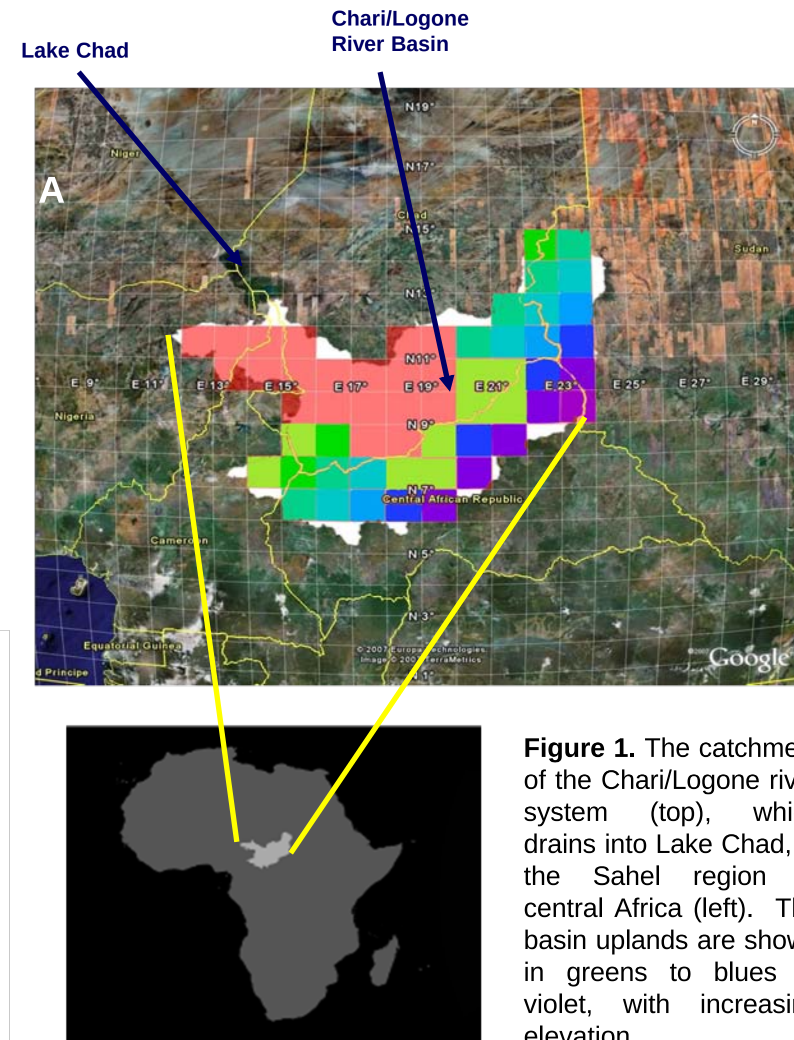


Figure 1. The catchment of the Chari/Logone river system (top), which drains into Lake Chad, in the Sahel region of central Africa (left). The basin uplands are shown in greens to blues to violet, with increasing elevation.

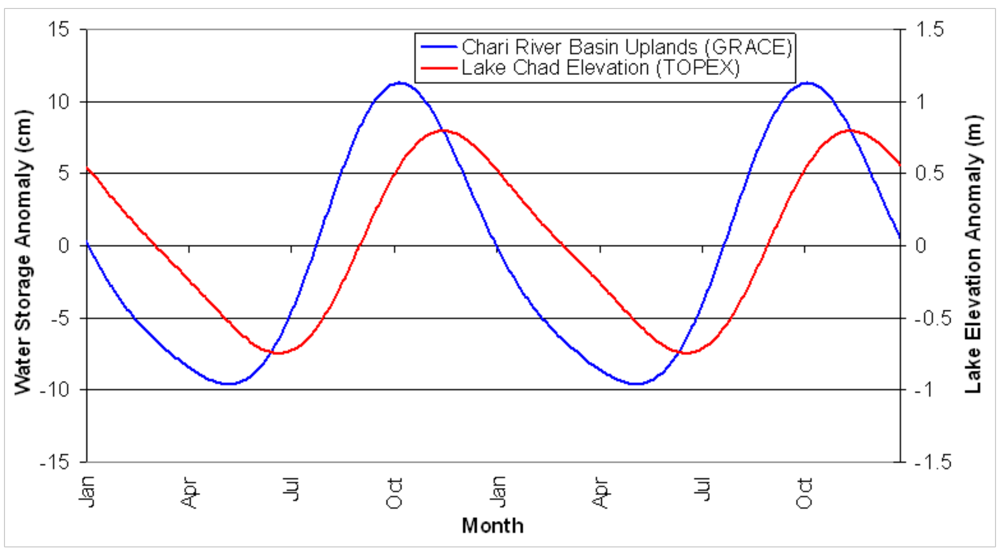
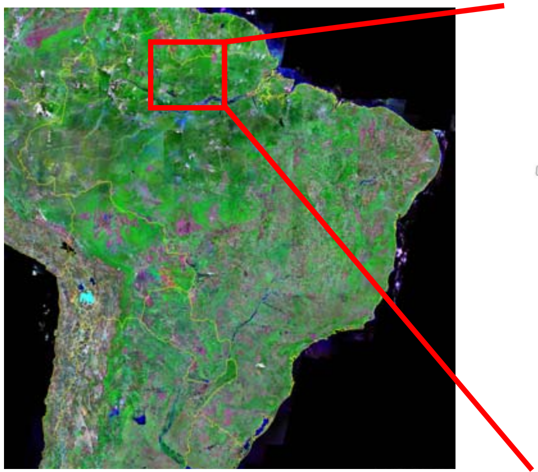
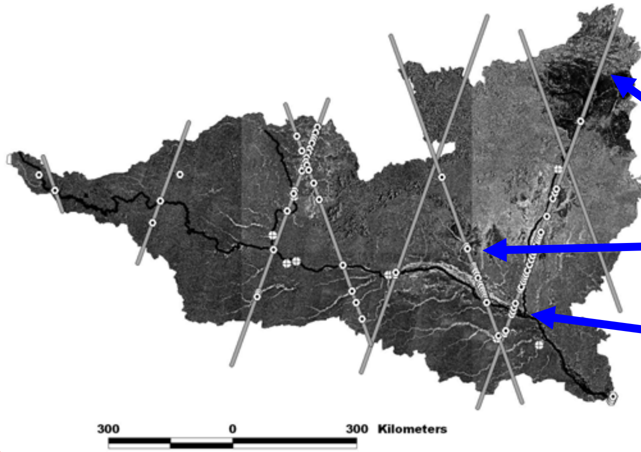


Figure 2. Annual cycles of terrestrial water storage anomalies in the uplands of the Chari and Logone River basins (from GRACE satellite observations) and Lake Chad elevation anomalies (from TOPEX/Poseidon satellite altimetry).

Matt Rodell, NASA/GSFC
Altimetric Levels from CropExplorer/Birkett

Surface water volume change from multi-satellite techniques: Combining surface water extent and altimetry-derived water height





Rio Negro basin

Altimeter track (T/P)

Altimeter station

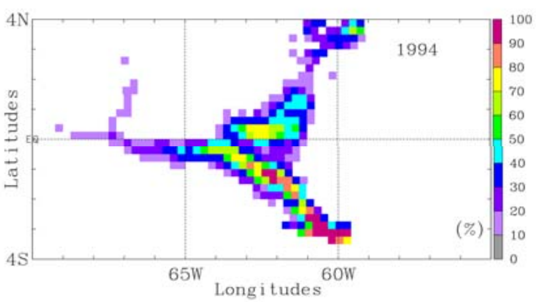
In situ gauge station

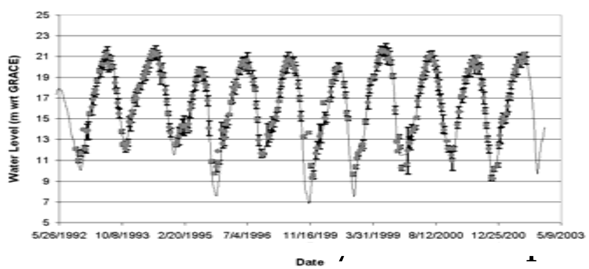
floodplains/inundation using multi-satellite technique

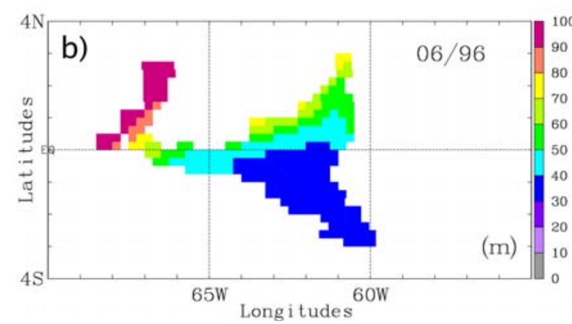
+

water level time series Topex/ Envisat

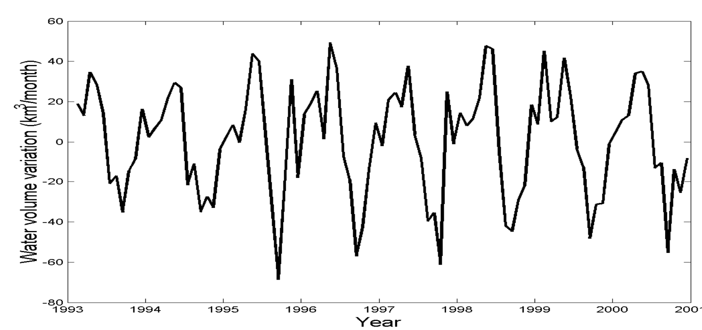
water level variation maps





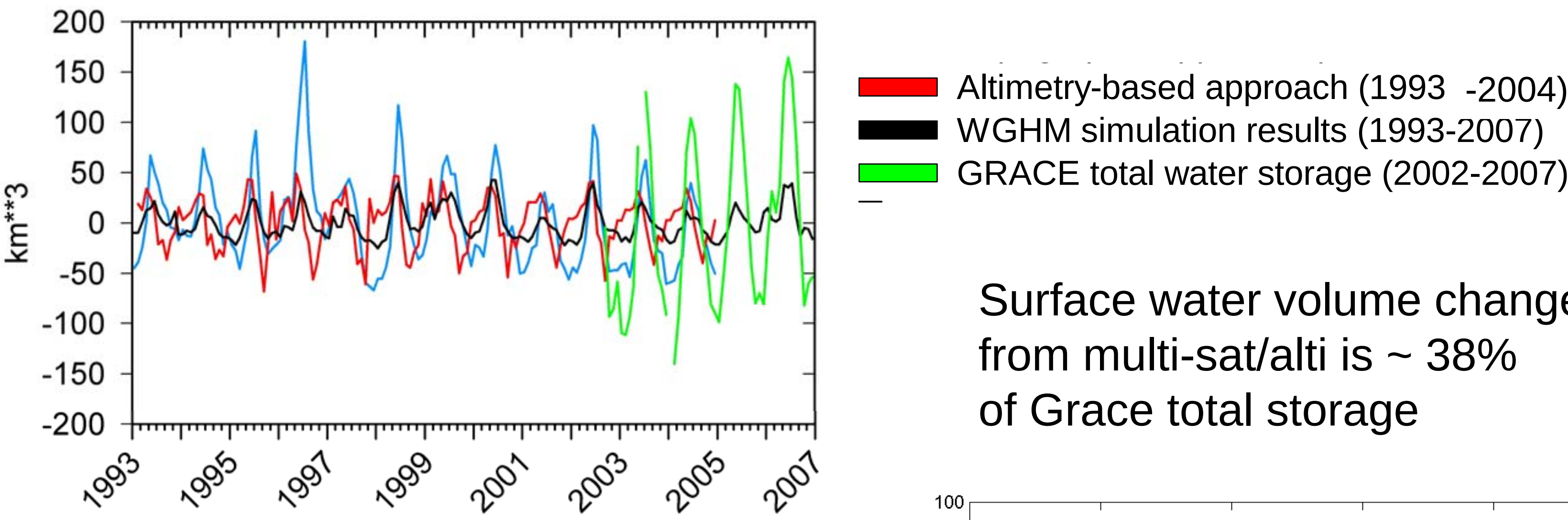


Computation of surface water volume variations

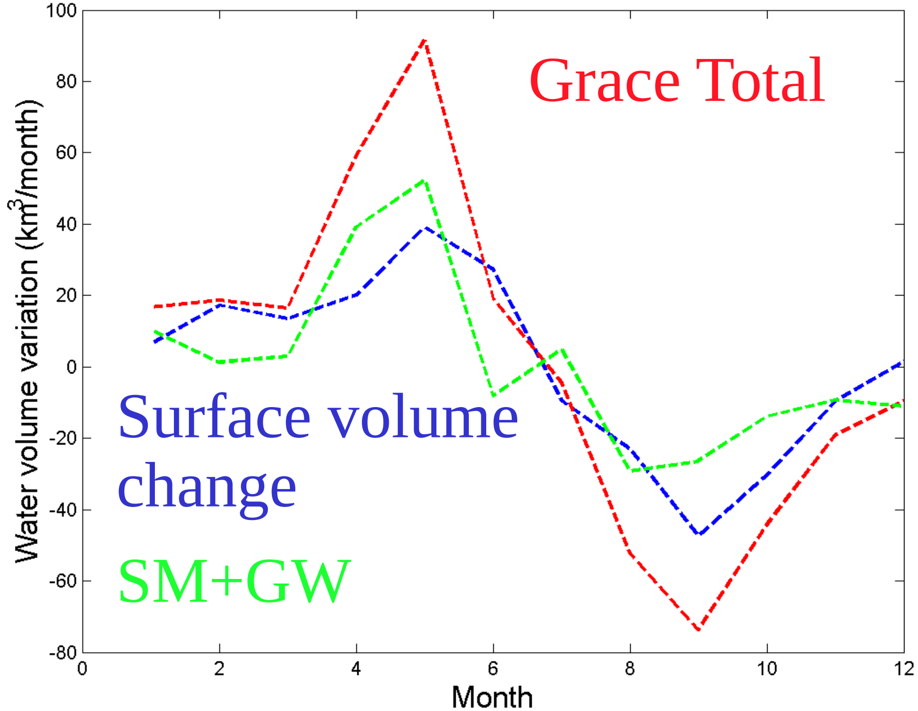


Papa et al., 2006, 2008 GRL, 2007, JGR
Prigent et al., 2007 JGR; Frappart et al., JGR, 2008

Surface water volume change from multi-satellite techniques: Combining surface water extent and altimetry-derived water height



Surface water volume change from multi-sat/alti is ~ 38% of Grace total storage



GRACE: groundwater +surface water+SM

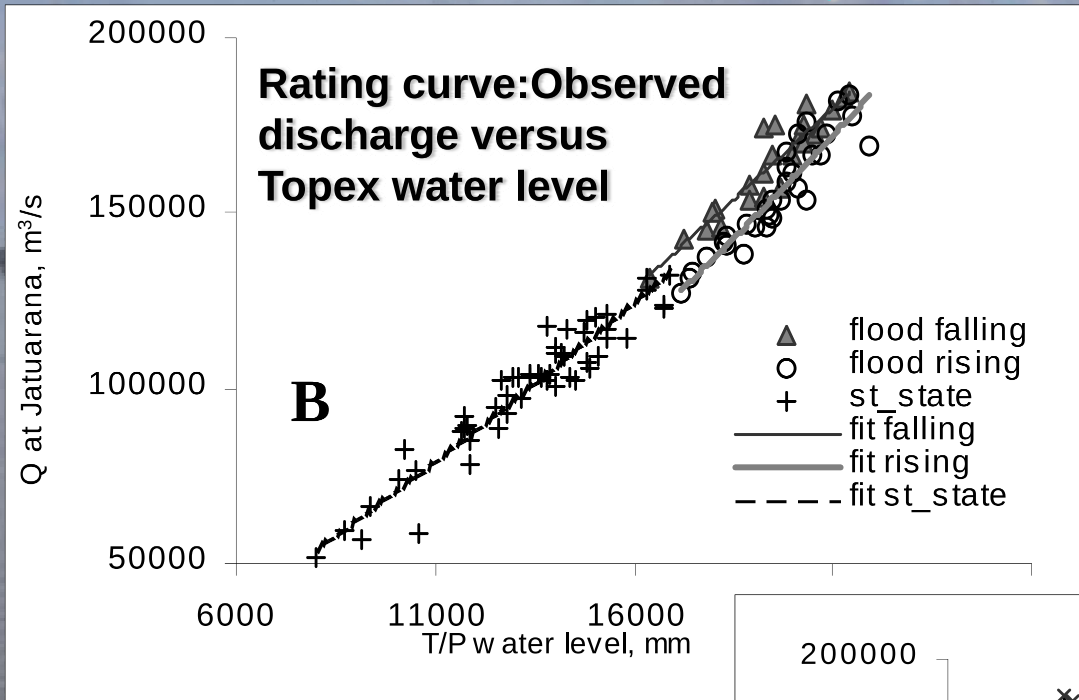
Multi-sat+altimeter: surface water volume

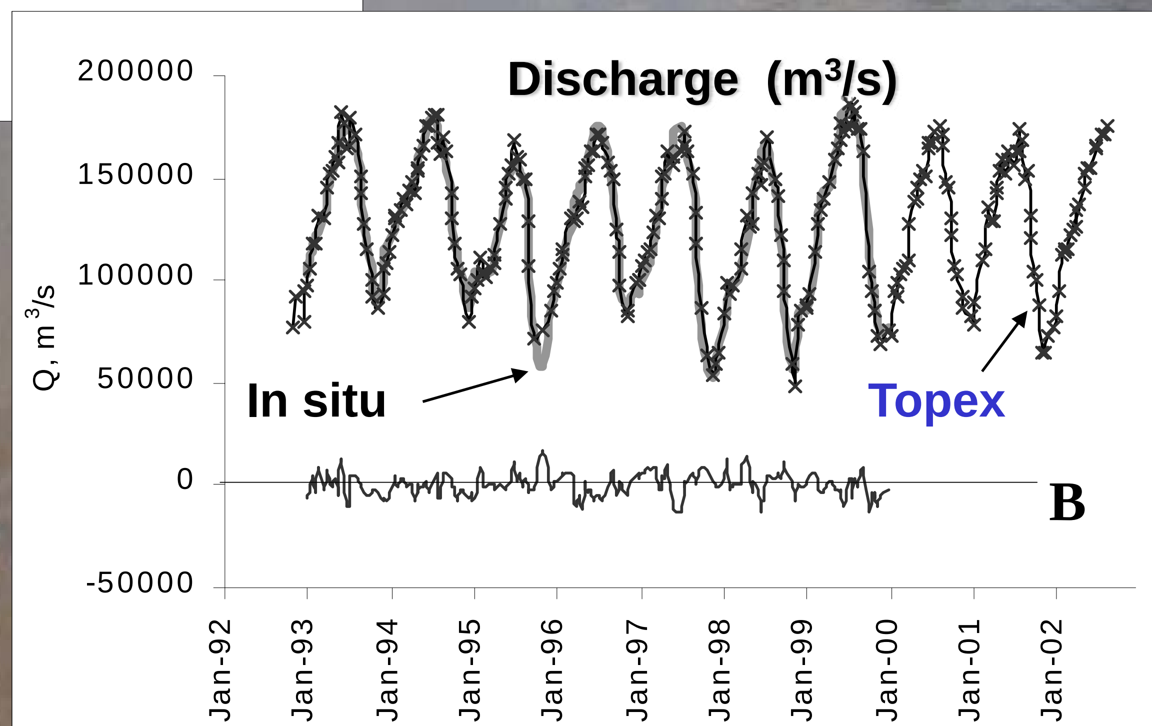
Decomposition of the GRACE signal to extract soil moisture+ ground water

More opportunities with SMOS, SMAP

Longer time series thanks to Jason2

Amazon River; Jatuarana station

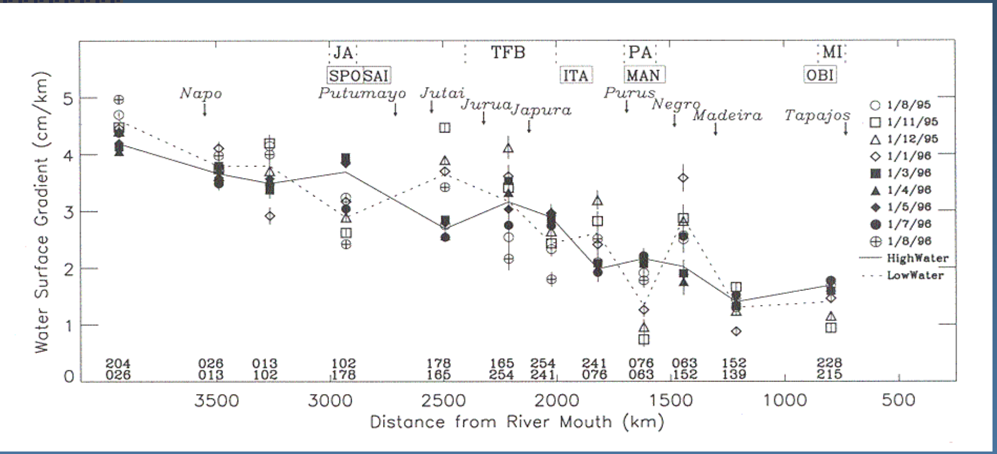




Zakharova et al., 2005

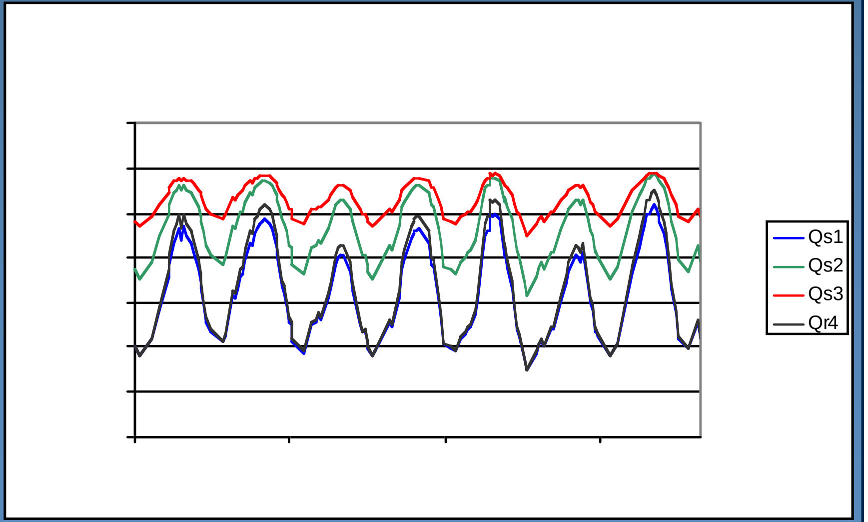
Surface Water Dynamics and Discharge Determination along the Amazon River

(Example by Chin, Jasinski, Birkett, Bjerklie)



Amazon River : surface water slope from the Topex NRA

River slope from altimetry + Manning's equation = discharge



Qs1: Variable slope from depth from Oltman, 1968

Qs2: Depth/slope relation with range of slope values taken from Birkett, 2002.

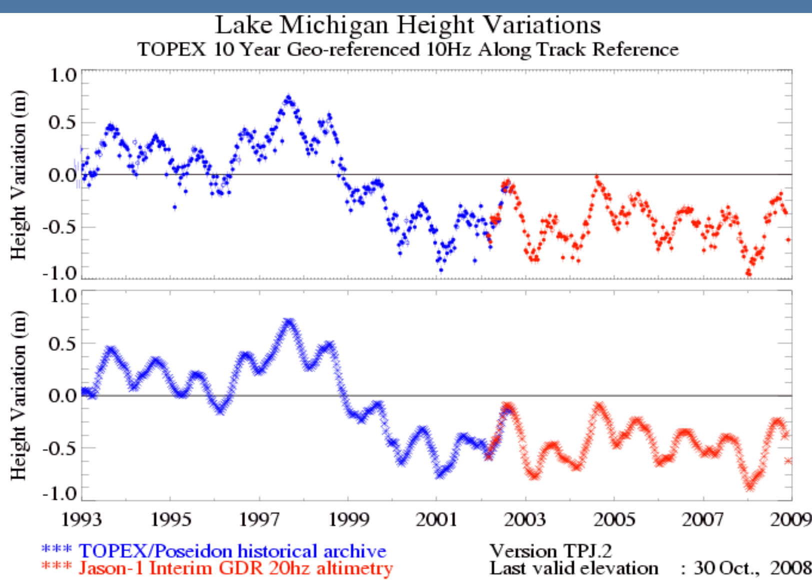
Qs3: Constant slope 1.5cm/km from Birkett, 2002

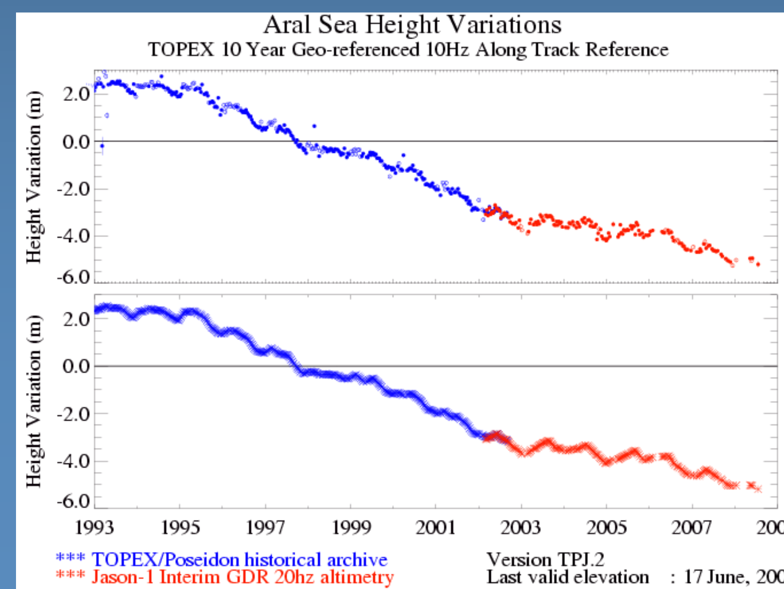
Qs4: Depth/discharge rating from Oltman,1968

Near Real Time Monitoring of Reservoirs and Lakes: Crop Irrigation and Water Resources

(Birkett, Beckley, Doorn, and Reynolds)

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

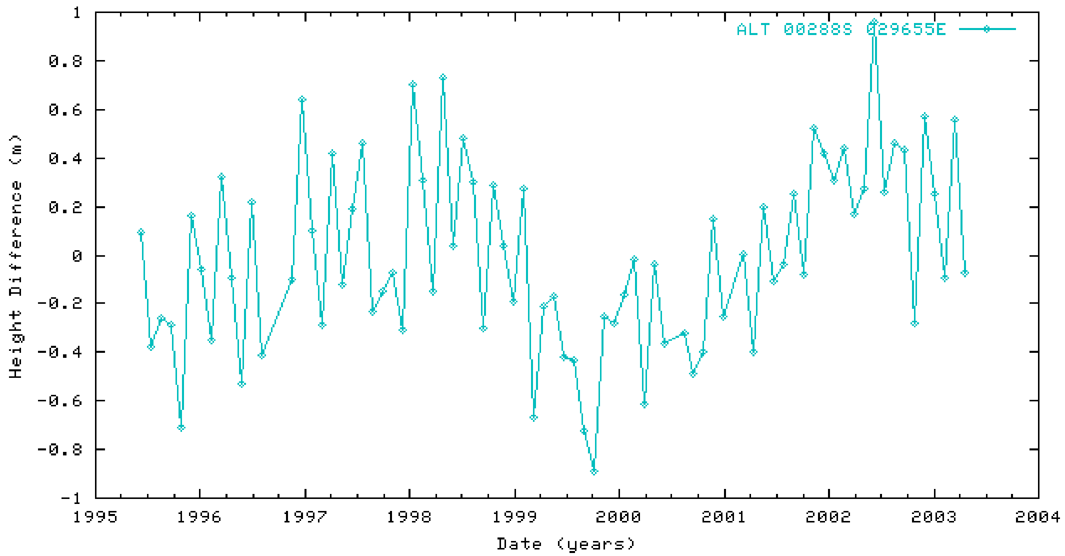


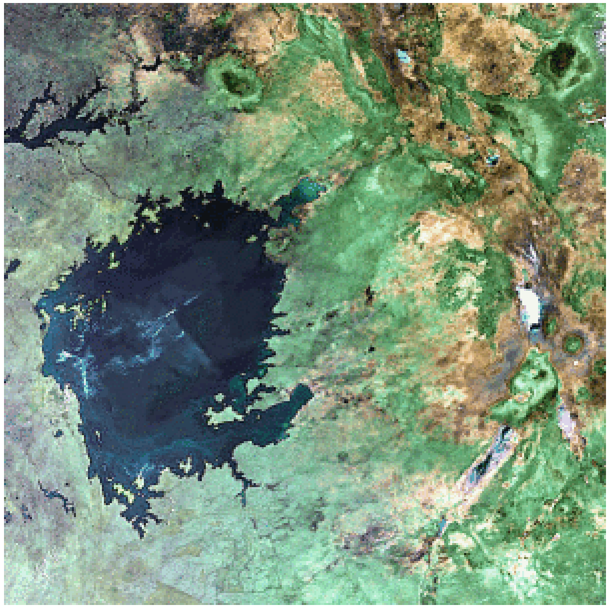


Rivers and Lakes ESA Data Base (P.Berry, UK) mainly ERS1/2 and ENVISAT

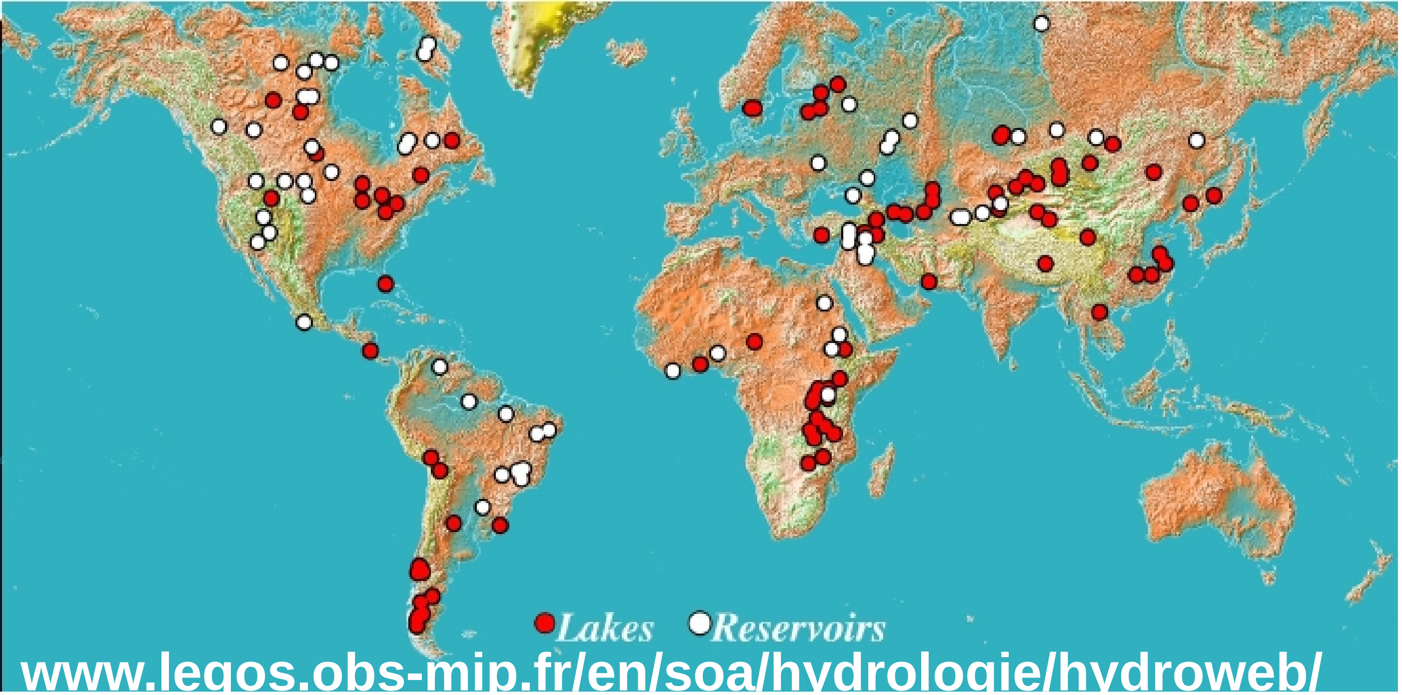
http://earth.esa.int/riverandlake

Lake Edouard (Africa)

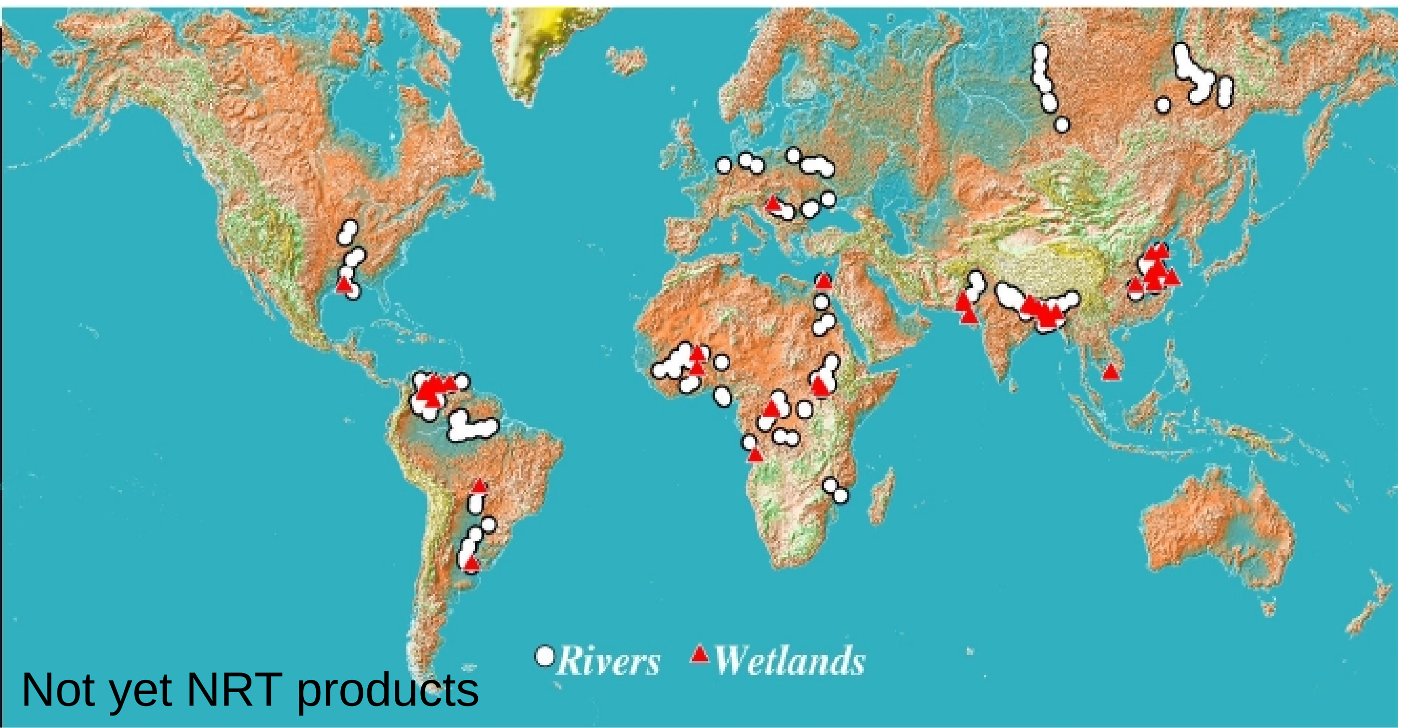




Also: near real time water levels from ENVISAT in some regions



www.legos.obs-mip.fr/en/soa/hydrologie/hydroweb/



Not yet NRT products

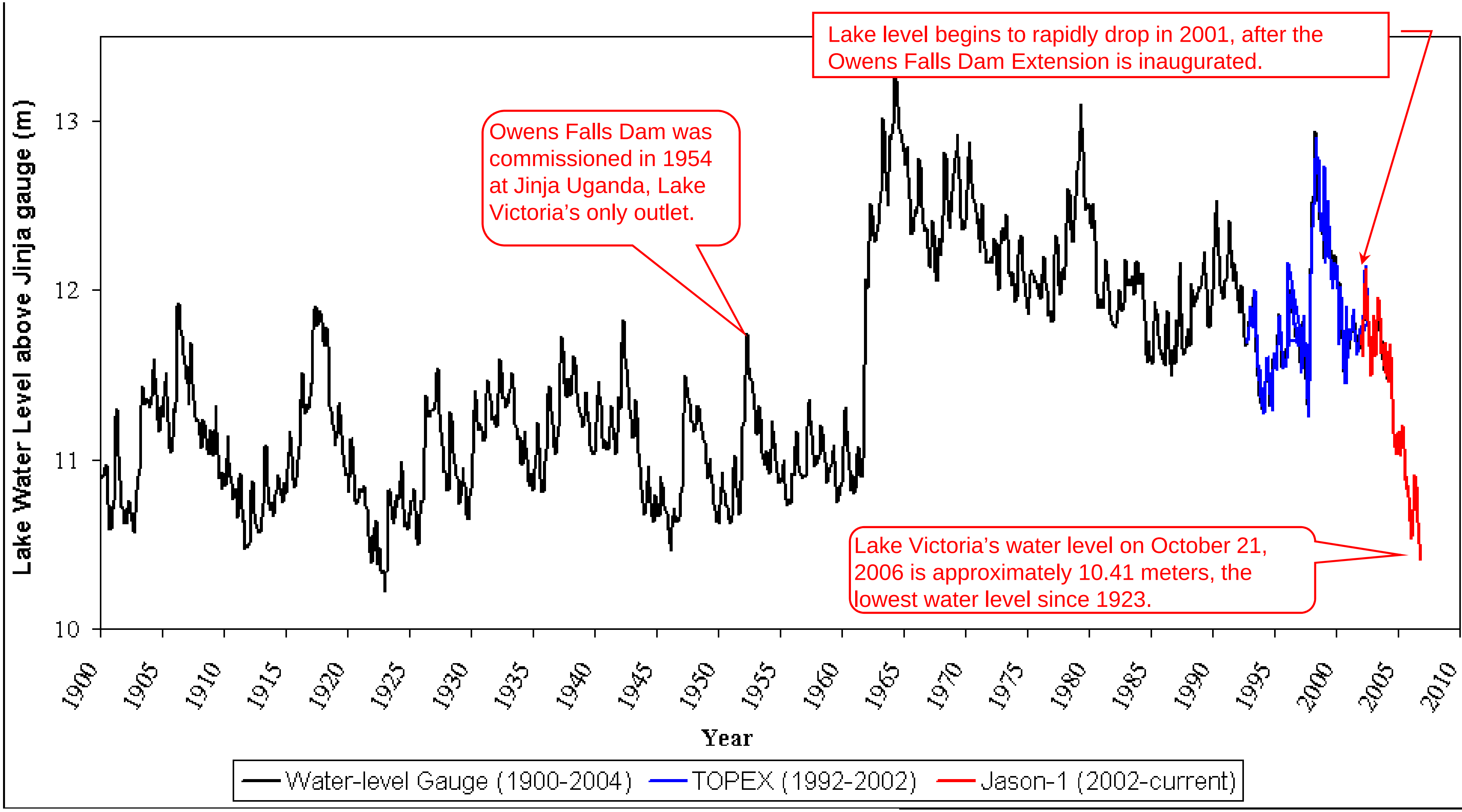
HYDROWEB data base: Altimetric water level +total water volume In major river basins from GRACE

↓

100 lakes,
50 reservoirs,
250 sites on rivers,
several sites on wetlands,
30 largest river basins

LEGOS
JF Cretaux/MC Gennero

Historical Water Level Elevations for Lake Victoria



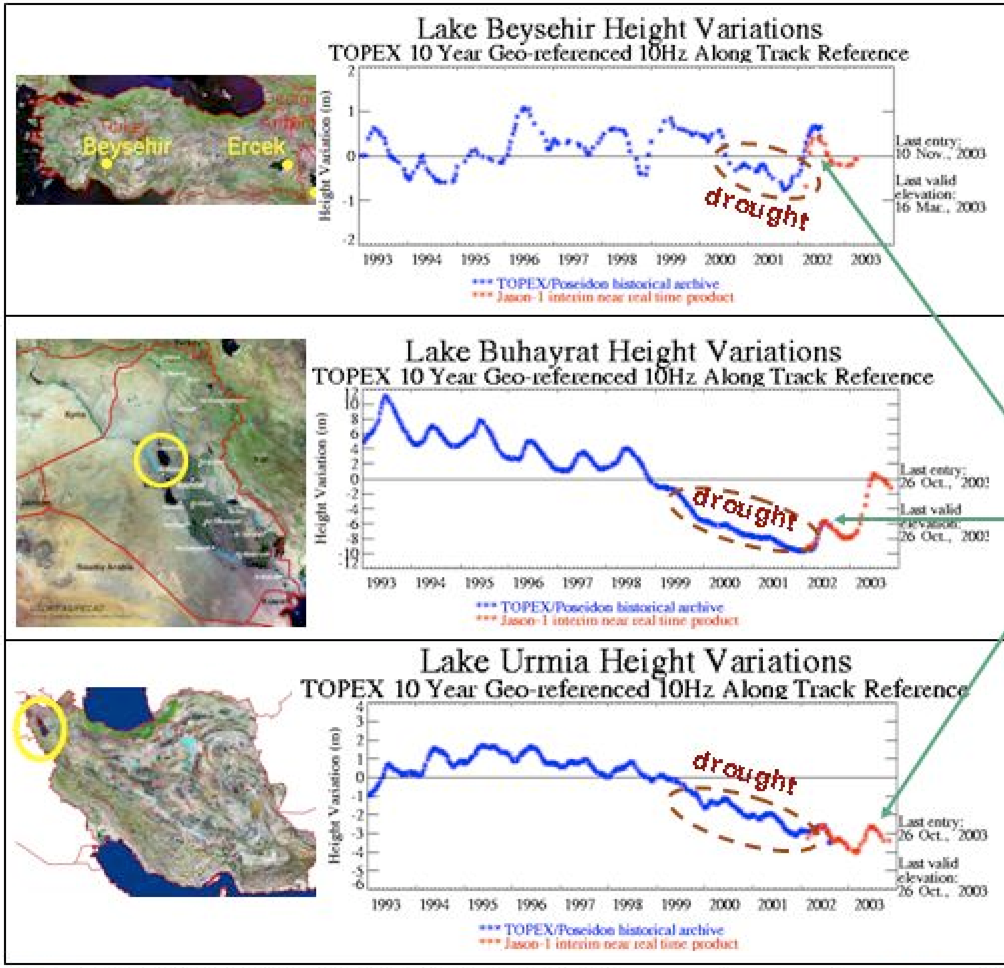
Data Source:
Historical water level gauge data from Jinja, Uganda (near Lake Victoria's outlet).
Satellite radar altimeter data from USDA/NASA/UMD at:
http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/

U.S. Department of Agricultural (USDA)
Foreign Agricultural Service (FAS)
Impact Analysis Division (IAD)
International Production Assessment (IPA)

Courtesy of C. Birkett

Production Estimates and Crop Assessment Division
Foreign Agricultural Service

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.

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

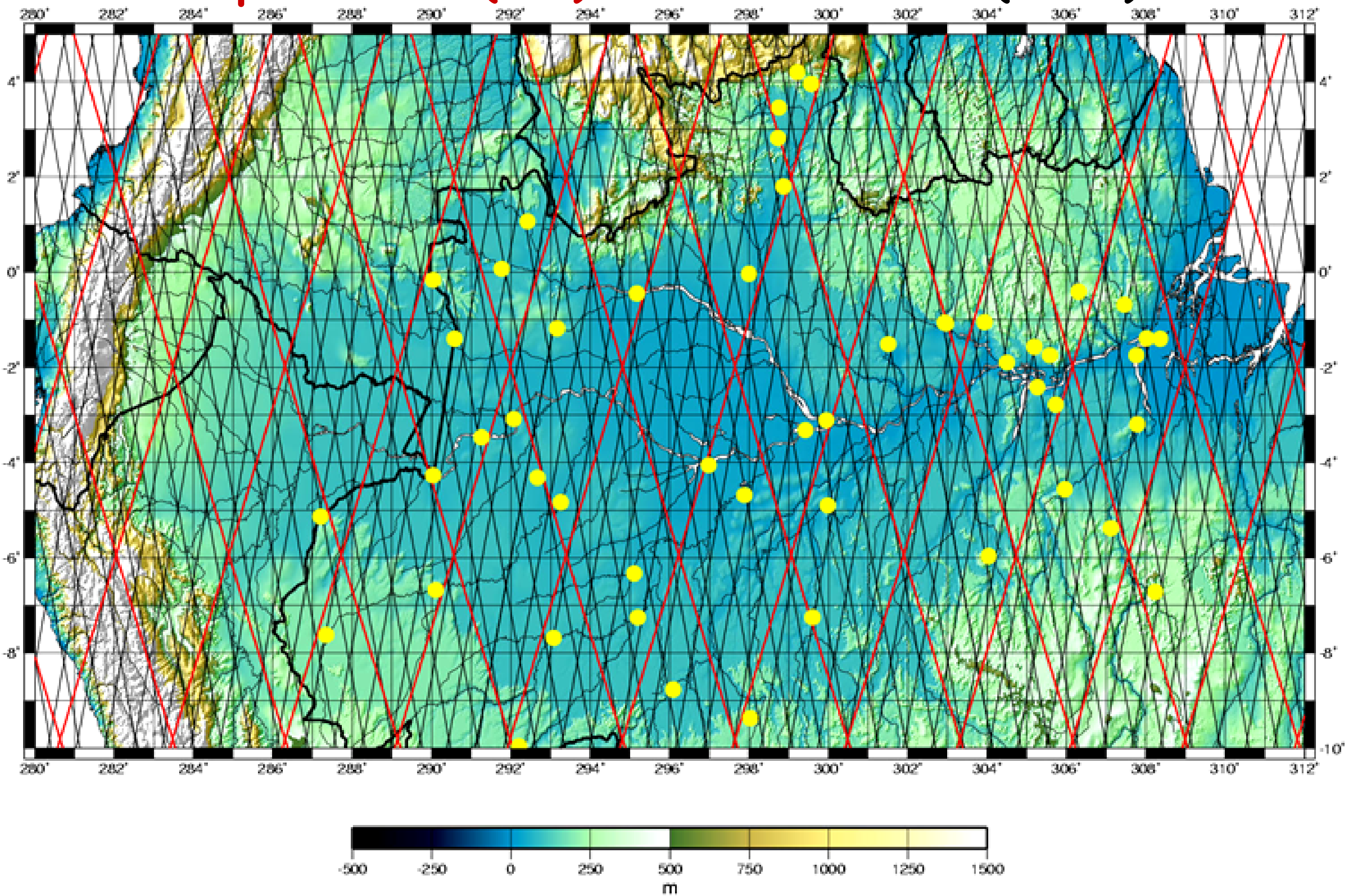
Production Estimates & Crop Assessment Division (PECAD)
Foreign Agricultural Service (FAS)
U.S. Department of Agriculture (USDA)
http://fas.usda.gov/pecad/pecad.html

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

Problems....

Amazon Basin

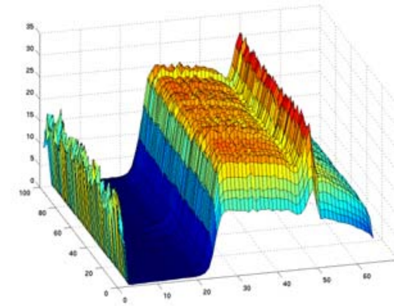
Nadir-viewing radar altimetry coverage
Topex/Jason (red) and ERS/Envisat (black)

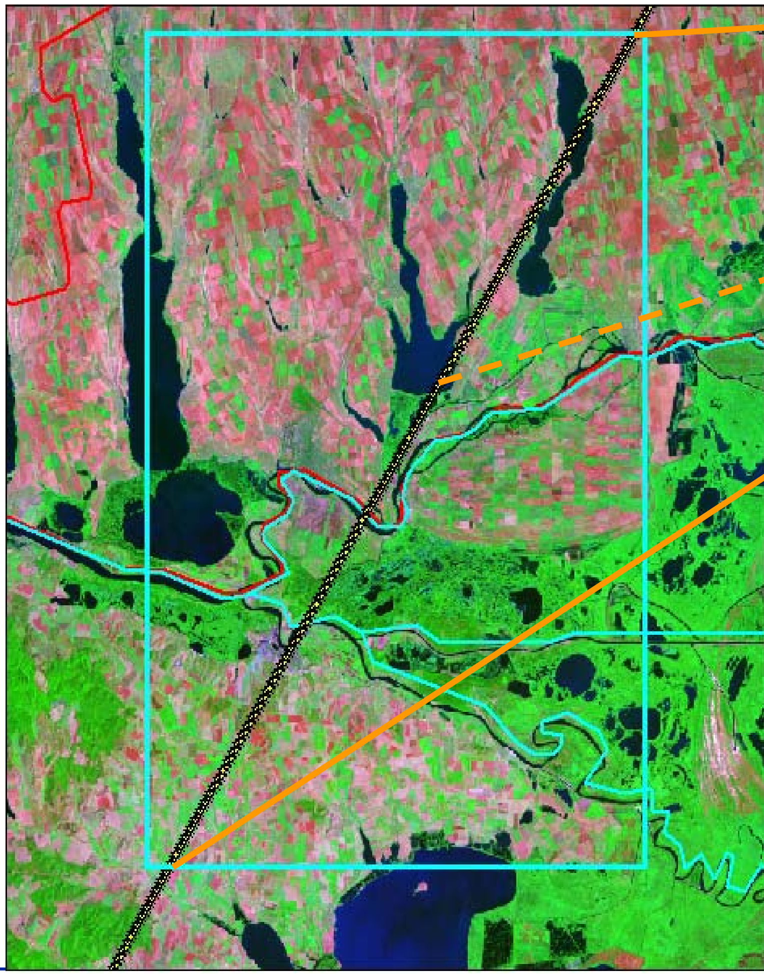


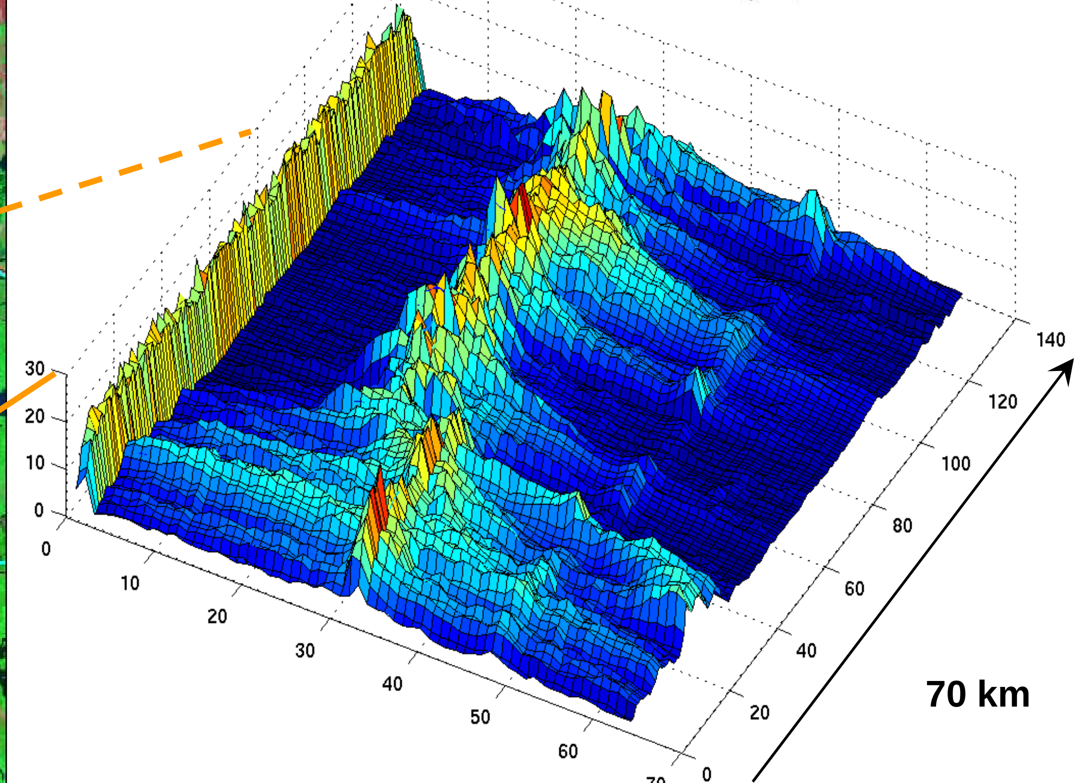
• in situ gauges

Radar waveforms on rivers

Example 3: Danub (track 033)







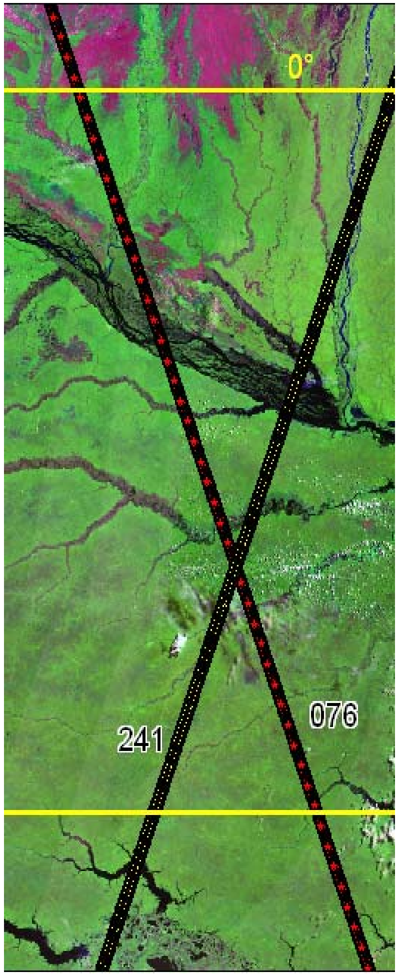
Courtesy of F. Mercier

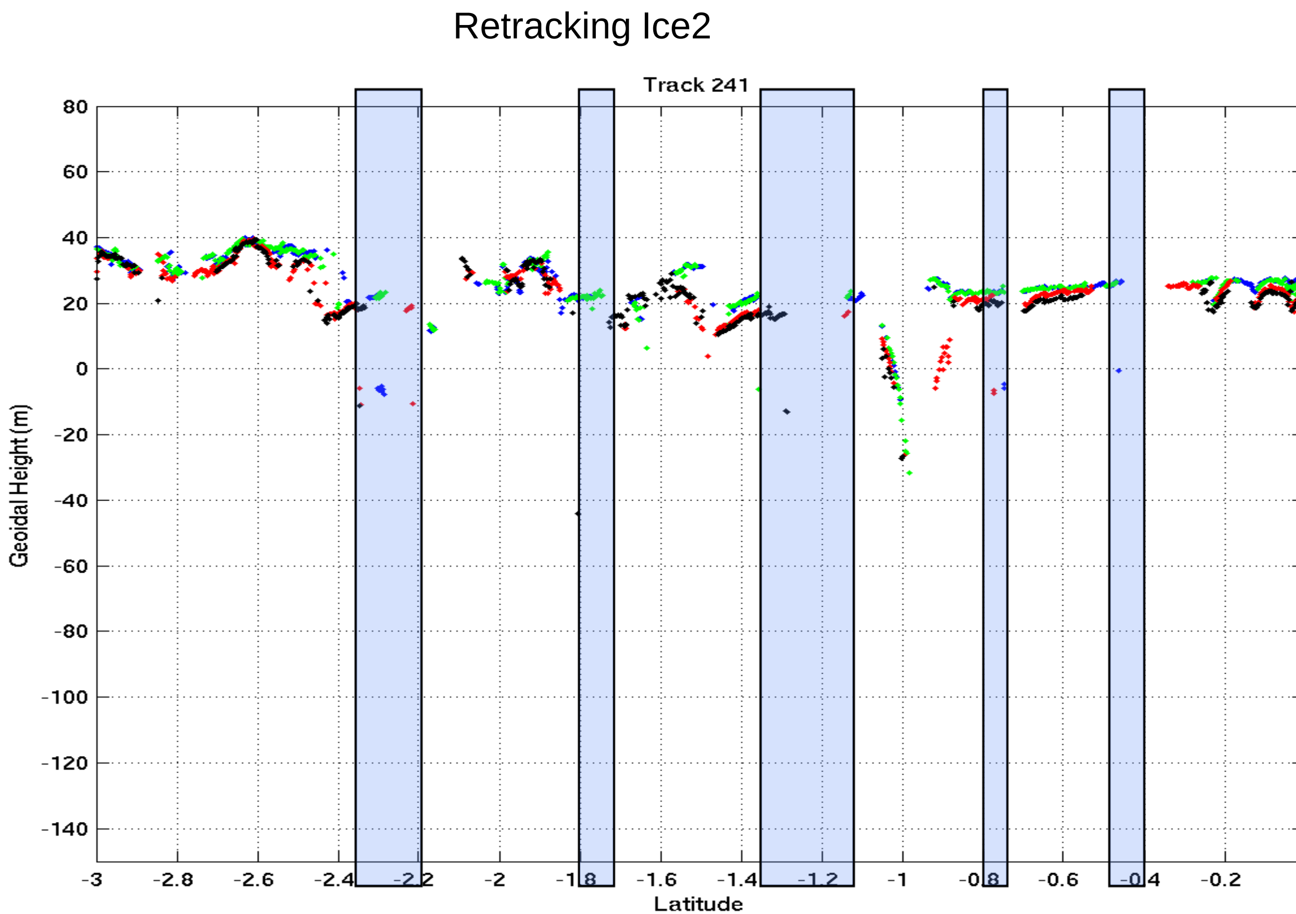
Retracking efforts

- P. Berry (expert system)
- CLS (use of ENVISAT trackers; application to Topex)
- New methods:
  - Wavelets (F. Frappart)
  - Enjolras/Rogriguez method

Retracking of Jason-1 waveforms using Ice2

Amazon: Negro , Trace 241





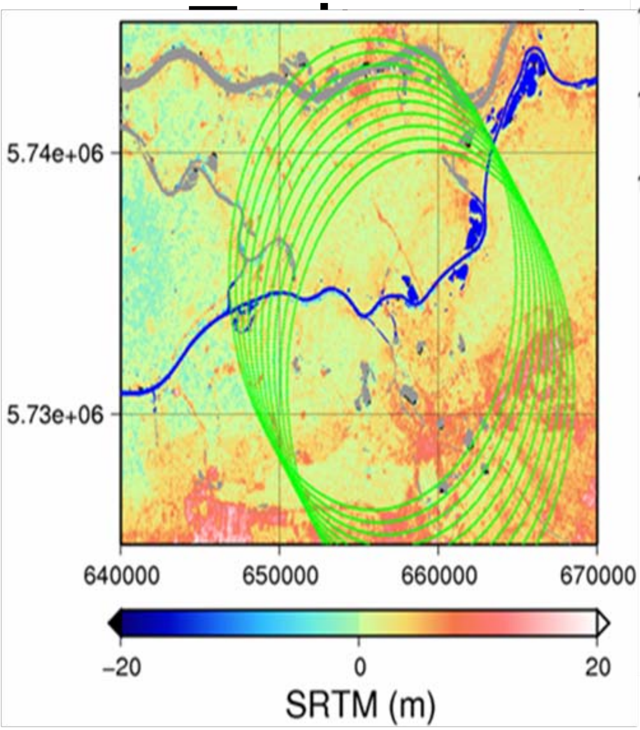
Courtesy of F. Mercier

V. Enjolras/E. Rodriguez waveform fitting method

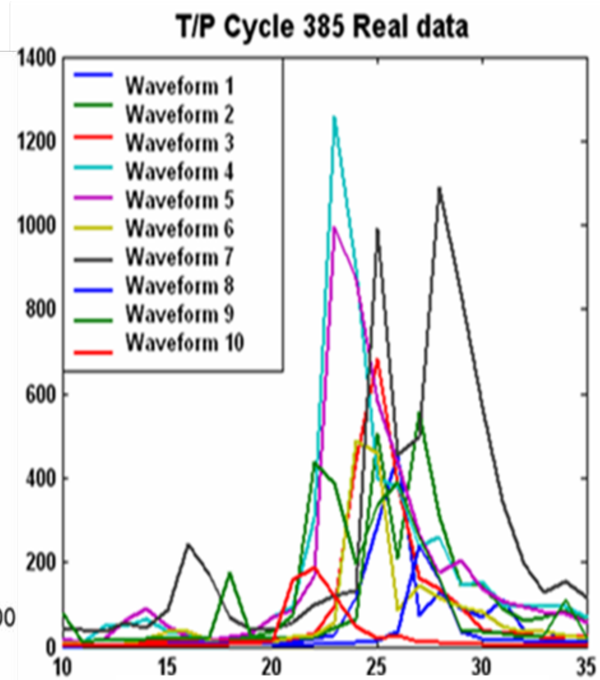
(use of the whole set of waveforms at satellite-river intersection)

- Simulation of radar waveforms on rivers using SRTM DEM, water/non water mask based on Landsat/MODIS images, CIA world data bank for river location, radar characteristics (system point target response, altimeter antenna pattern, instrument thermal noise…) and target parameters (water height)
- Simulated waveforms are generated for a large range of parameters values (water height, radar cross section)
- A least-squares adjustment is performed to extract the best fitting parameters
- Applications to Meuse (Europe) and Lena (Siberia) rivers

New retracking method developed by V. Enjolras & E. Rodriguez

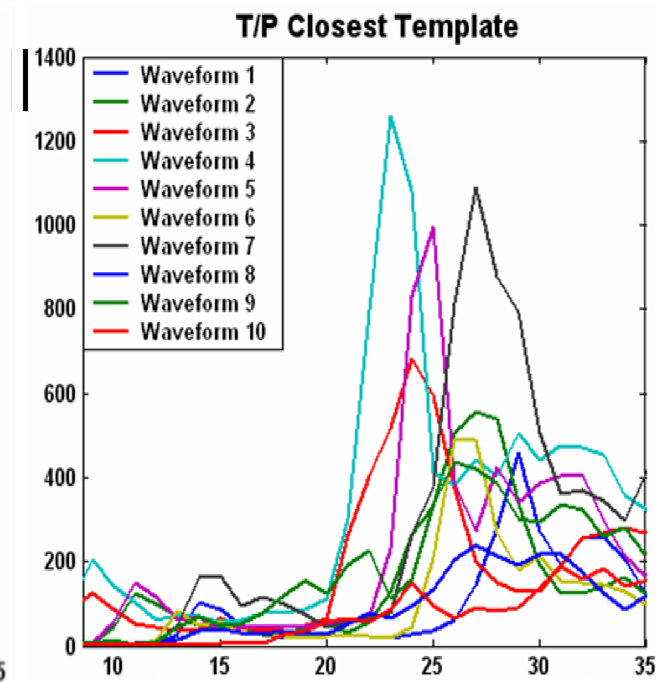


Meuse River



Range gate

Actual Topex waveforms

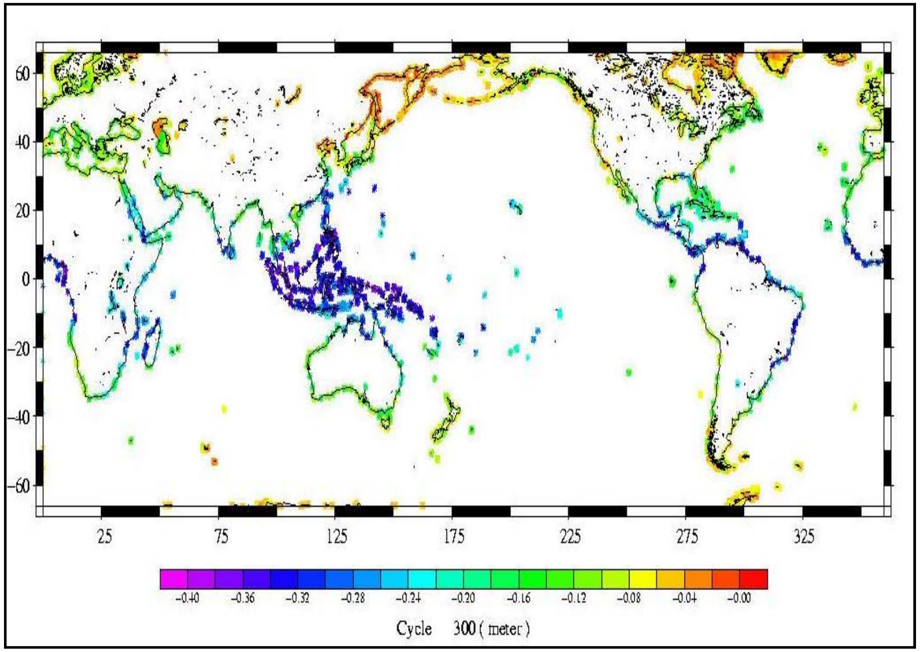


Range gate

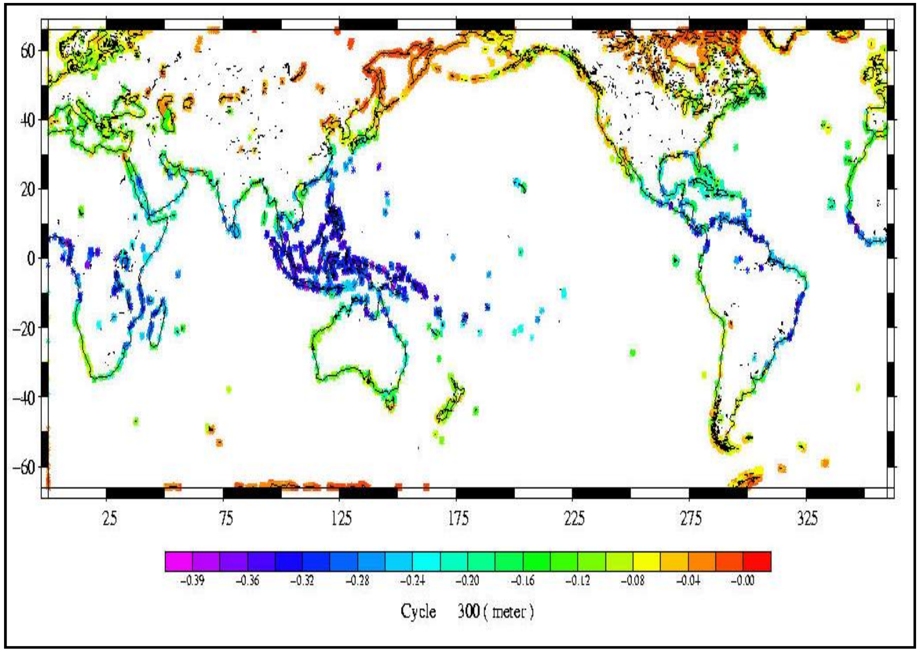
Simulated waveforms

Courtesy of V. Enjolras

wet tropospheric correction on land
Topex/Poseidon MGDRs



TMR

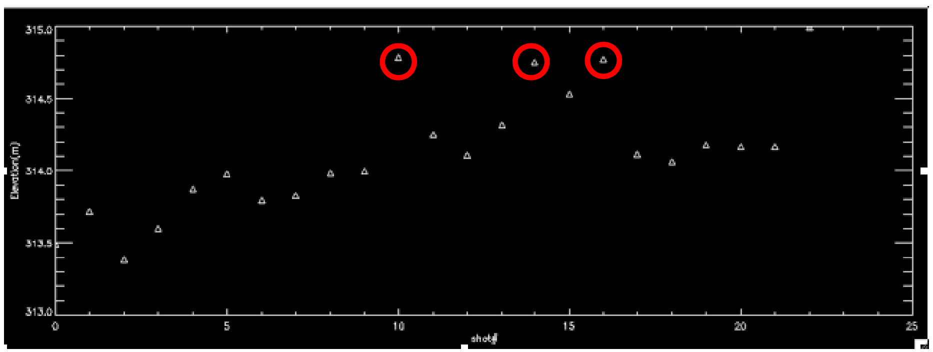


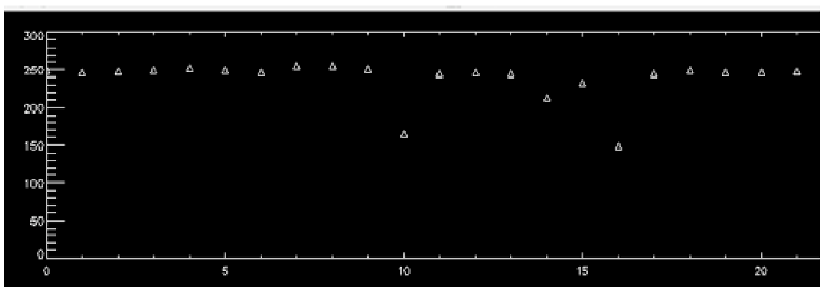
ECMWF model

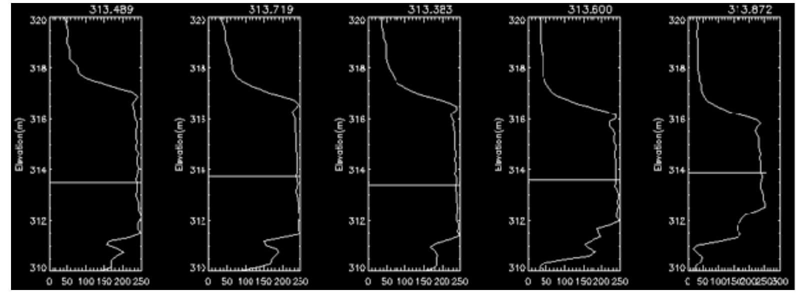
ID Saturated Waveforms

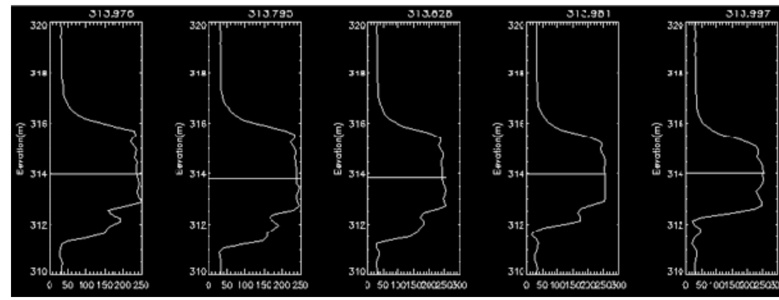
Lake Mead

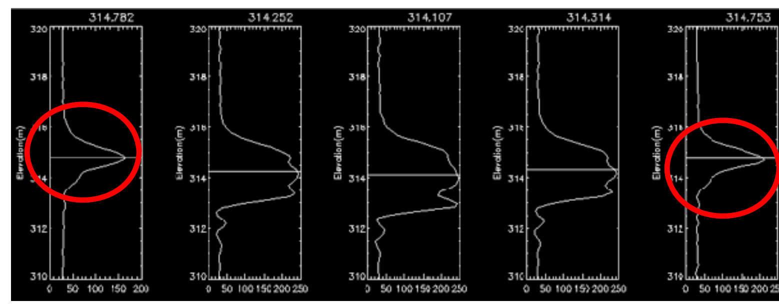
2119_002_0370_2_02_0001(10 Apr 2007, 23:01:27**)**

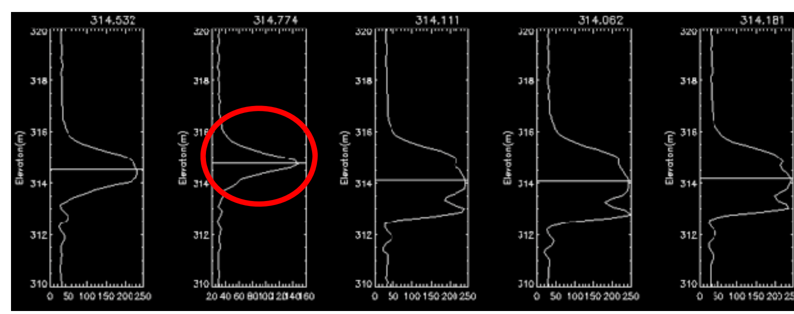






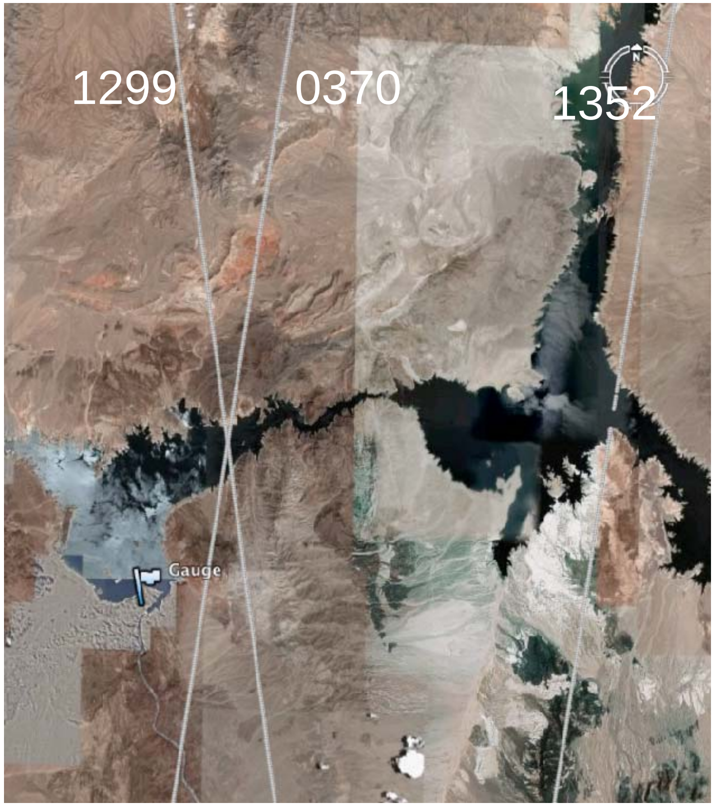


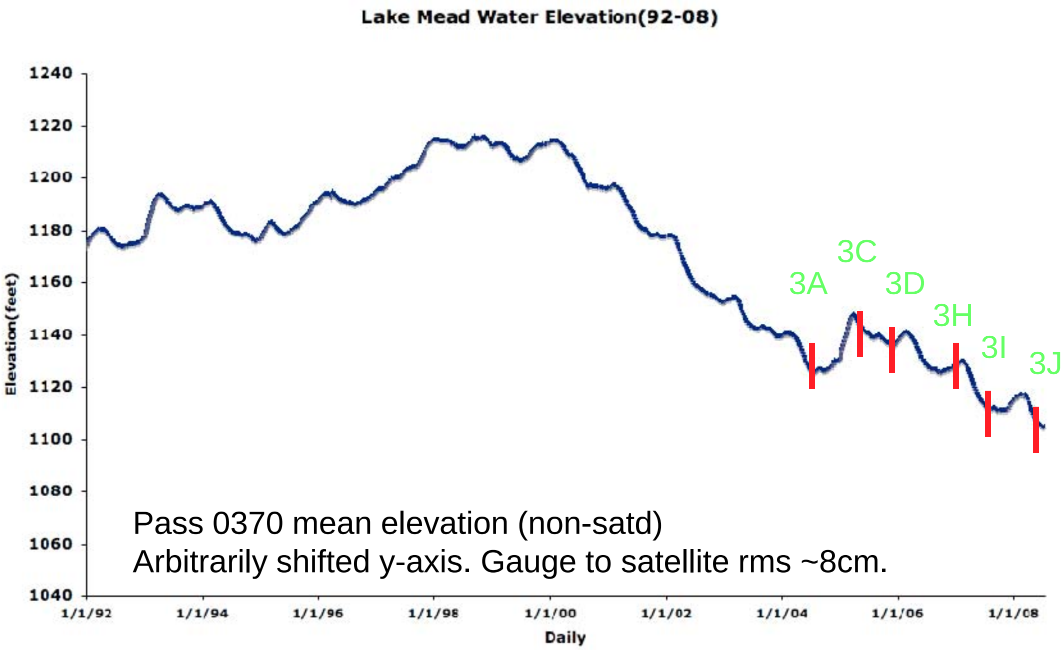




L3H GLA01,05,06
Elevtn (top), illuminated area (below)

Preliminary validation of GLAS elevation: comparison to gauge data for Lake Mead.





Birkett, Hofton and Li

Note:GLAS data and gauge data should be converted into the same reference frame of Geoid. Gauge data is from Bureau of reclamation (http://lakemead.water-data.com/).

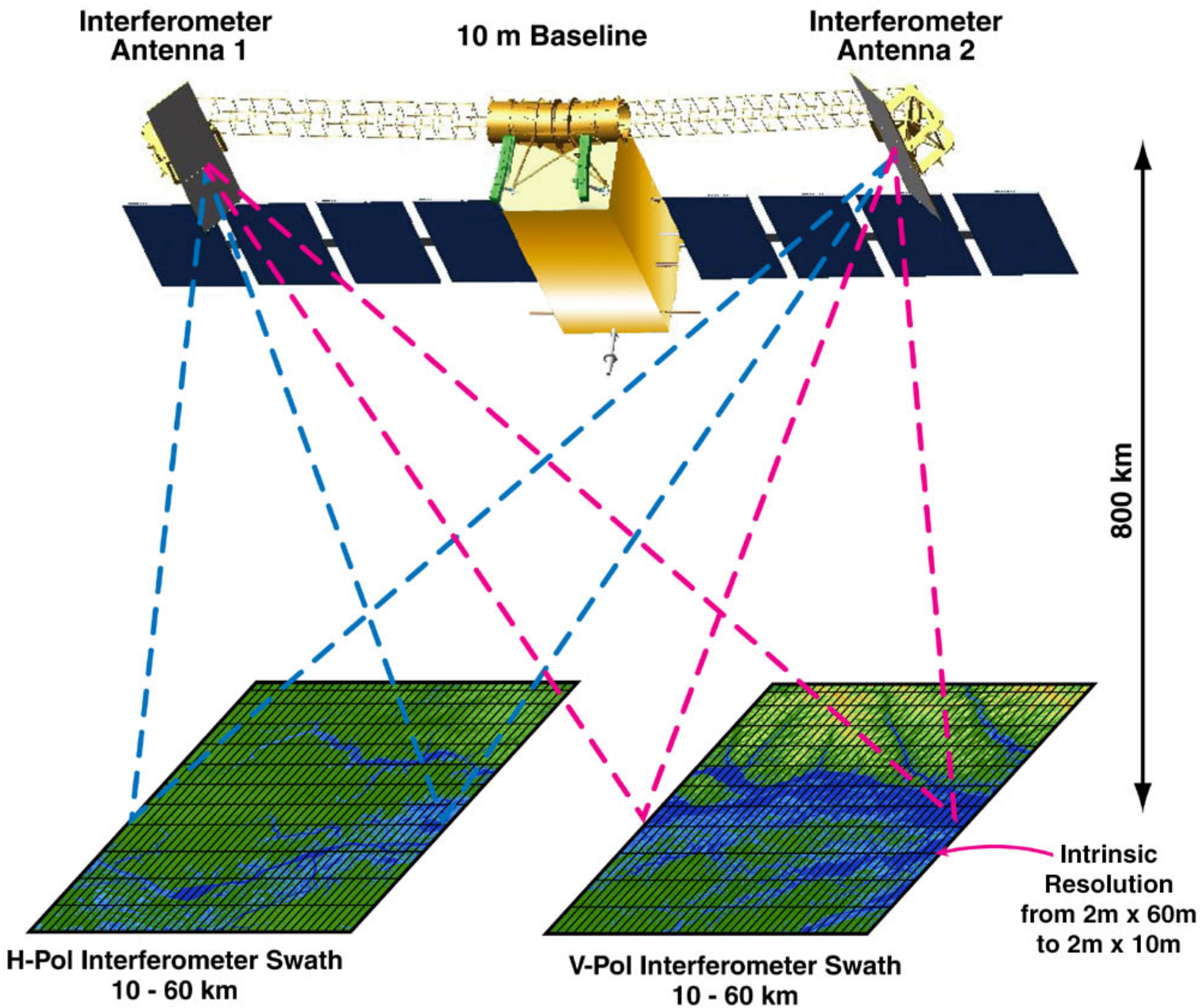
Why 2-D (wide-swath) altimetry is required

- Profiling altimeters miss too many rivers and lakes whereas imaging methods sample all of the world's water bodies.

- Profiling altimeters
  - 10-day repeat: i.e. Topex/Jason, misses ~45% of rivers and 80% of lakes
  - 35-day repeat: i.e., ERS/ENVISAT, misses ~20% of rivers and ~55% of lakes

- Swaths from an interferometric radar altimeter
  - 10-day repeat: misses ~7% of the rivers and lakes
  - 16-day repeat: samples all (misses only ~1% of rivers and lakes)

Courtesy of D. Alsdorf/ E. Rodriguez



The Solution

KaRIN: Ka-band Radar Interferometer.

SRTM, WSOA heritage. Maps of h globally and ~weekly.

Courtesy of E. Rodriguez (JPL)