REMOTE MEASUREMENT AND MONITORING OF INLAND WATER HEIGHTS GLOBALLY USING MULTI-MISSION SATELLITE RADAR ALTIMETRY

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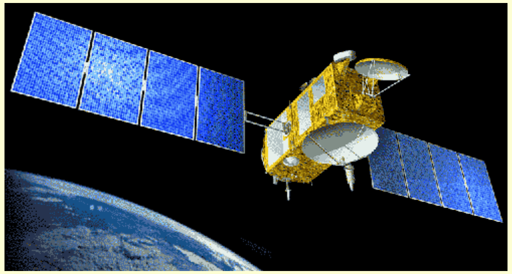
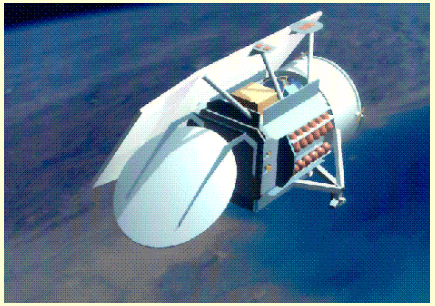
CNFG2, UNESCO, Paris, 17-19 Novembre 2008

Introduction

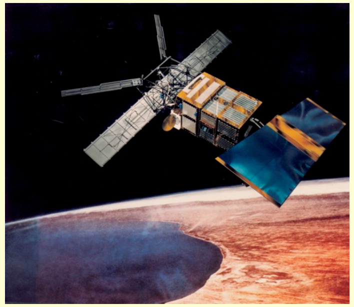
- The effective management of the Earth's inland water is a major challenge facing scientists and governments worldwide.
- However, whilst demand for this often scarce resource continues to grow, the number and distribution of in-situ hydrological gauge stations is steadily falling and many catchments basins in the developing world are now entirely ungauged.

Introduction

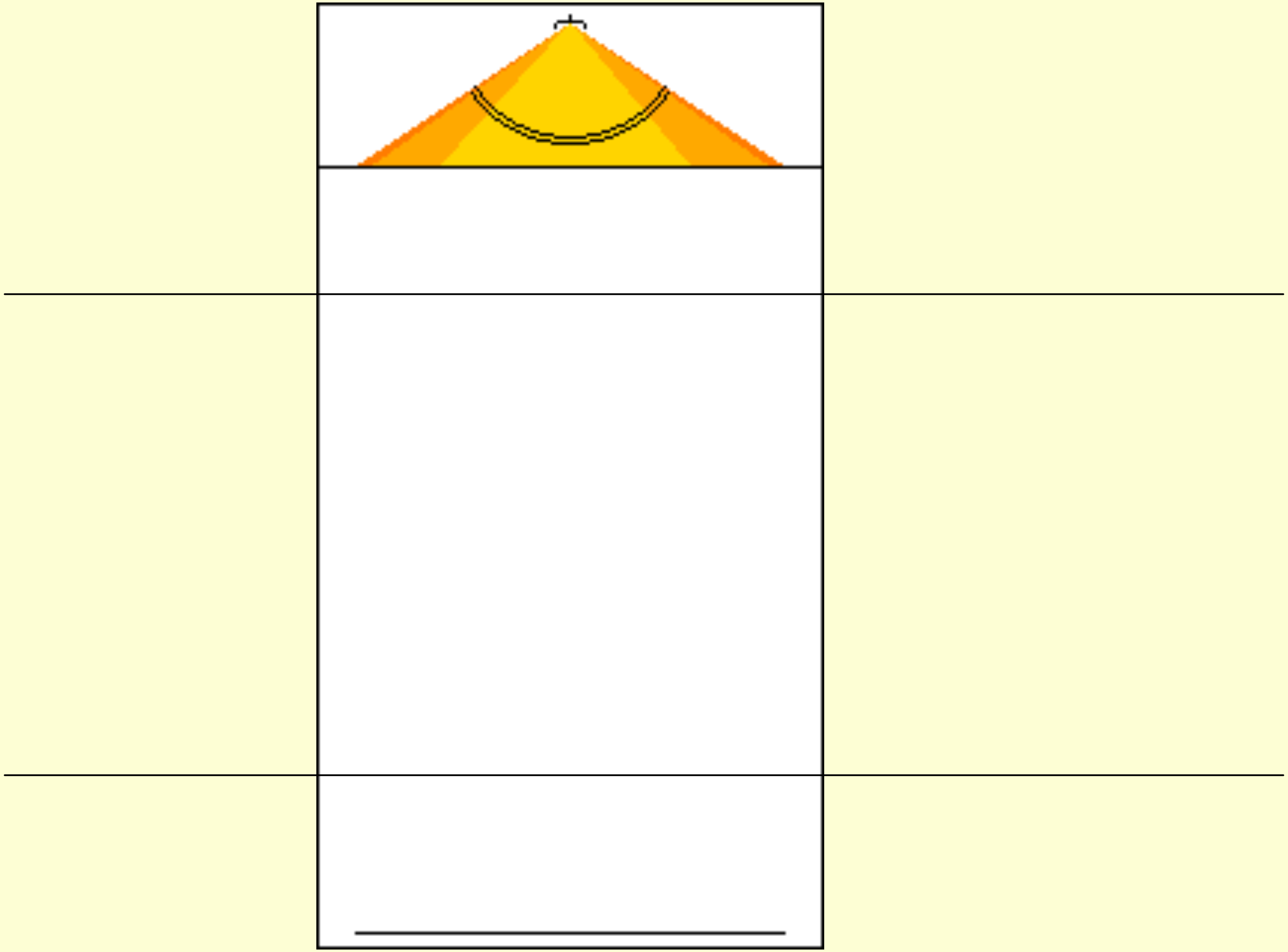




- Satellite radar altimeters have been collecting echo series over inland water for more than 16 years.
- But only a tiny fraction of these data have been successfully mined for ... on r ... ake ...

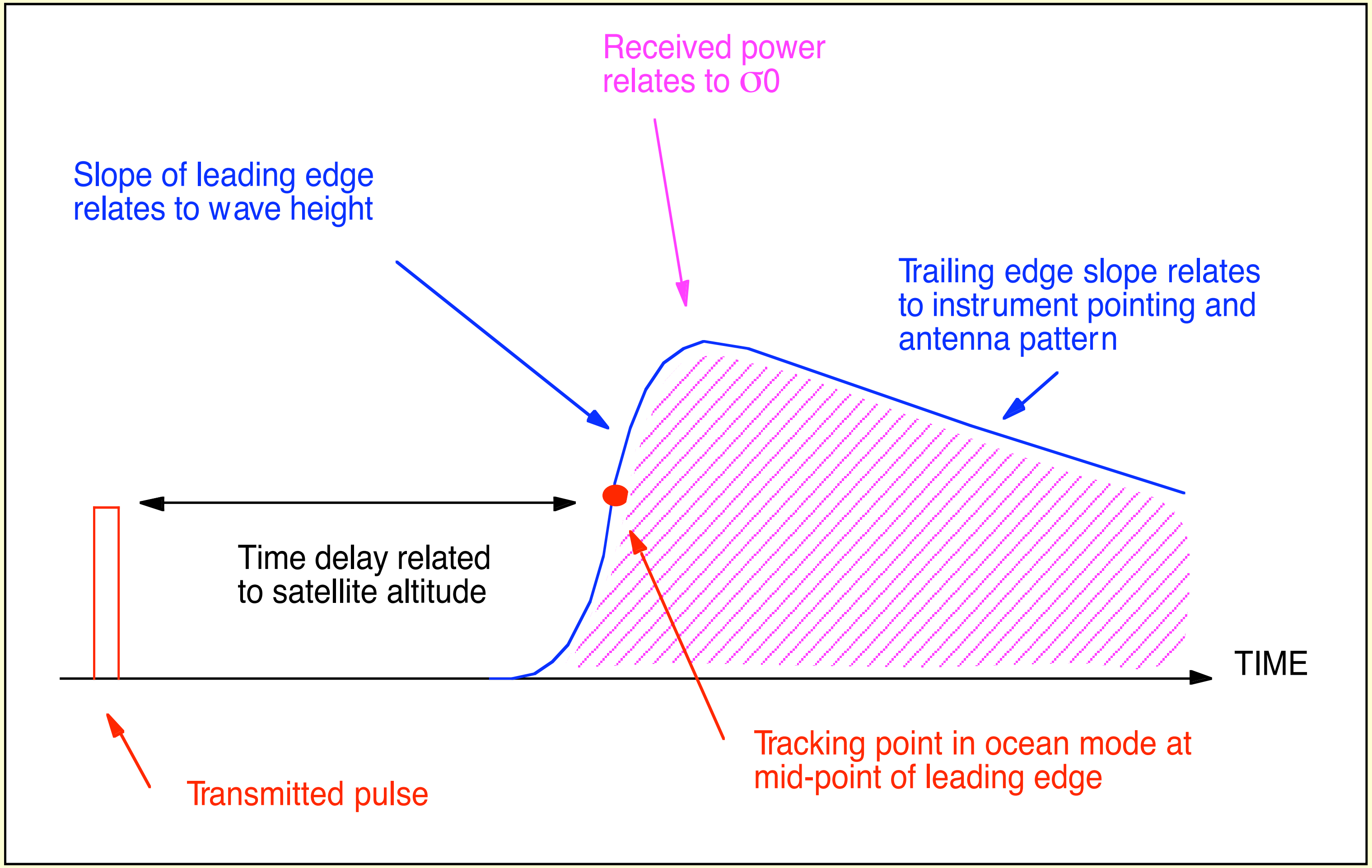


Radar Altimetry Principle

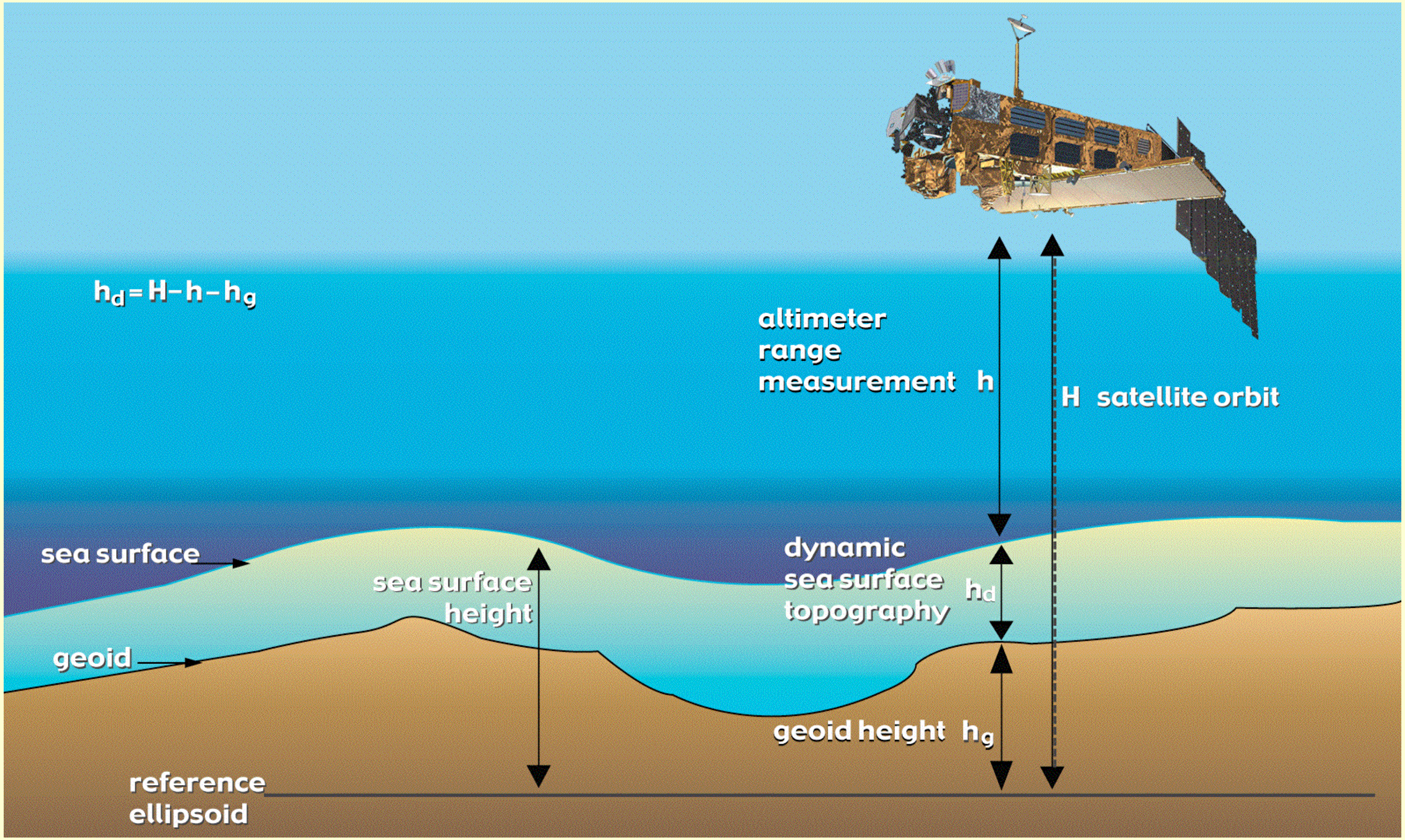


This is an animation

Return Power Waveform



Radar Altimetry Principle



Vertical Datum Applications

- H_i (sea level over ellipsoid) = Horbit - Hrange + E_r

  $= S_g + S_s + S_v + S_t + E_o + E_r$

  with S_g = Geoid signal
  S_s = Stationary signal
  S_v = Variability
  S_t = tides signal
  E_0 = Orbital error
  E_r = remaining errors and corrections
  (solid tides, loading effect, inverse barometer effect,...)

- Leads to different types of oceanographic analysis:
  - Meso-scale dynamic topography (currents, eddies, kinetic energy, ...)
  - Large scale topography/large scale variability (basin gyres, strong currents, mean sea level, mean sea level rise?!,...)
  - stationary signal (mean reference surface, estimation of the stationary dynamic topography)
  - tides study (hydrodynamic models constrained by altimetric data)
  - Assimilation to dynamic models of the oceanic circulation

Vertical Datum Applications

- Glaciology
  - DEM, Delta-DEM
  - Input data for forcing, initialisation or test of ice flow dynamic models
  - Long term monitoring of the topography for seasonal or secular variations.
  - Sea-ice thickness
- Land topography
  - Global DEM obtained from the full 336 days of the ERS-1 geodetic phase (most accurate Global DEM)
- Rivers and Lakes level
  - Long term, global, surface water monitoring
  - Study of the response of lakes to climate for water resources management, fisheries, water quality and conservation

The Basic Radar Altimetry Toolbox

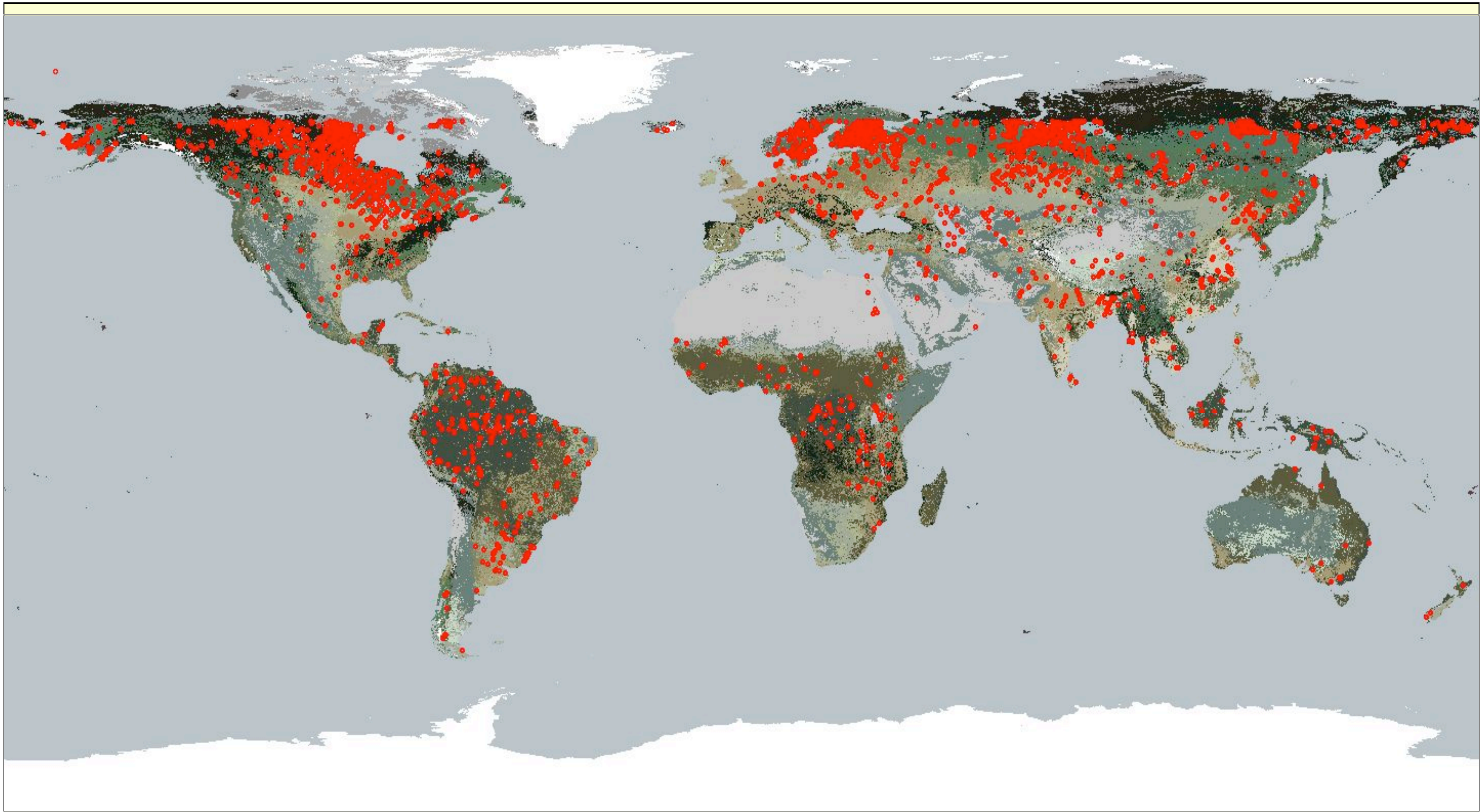
http://earth.esa.int/brat

Current capabilities

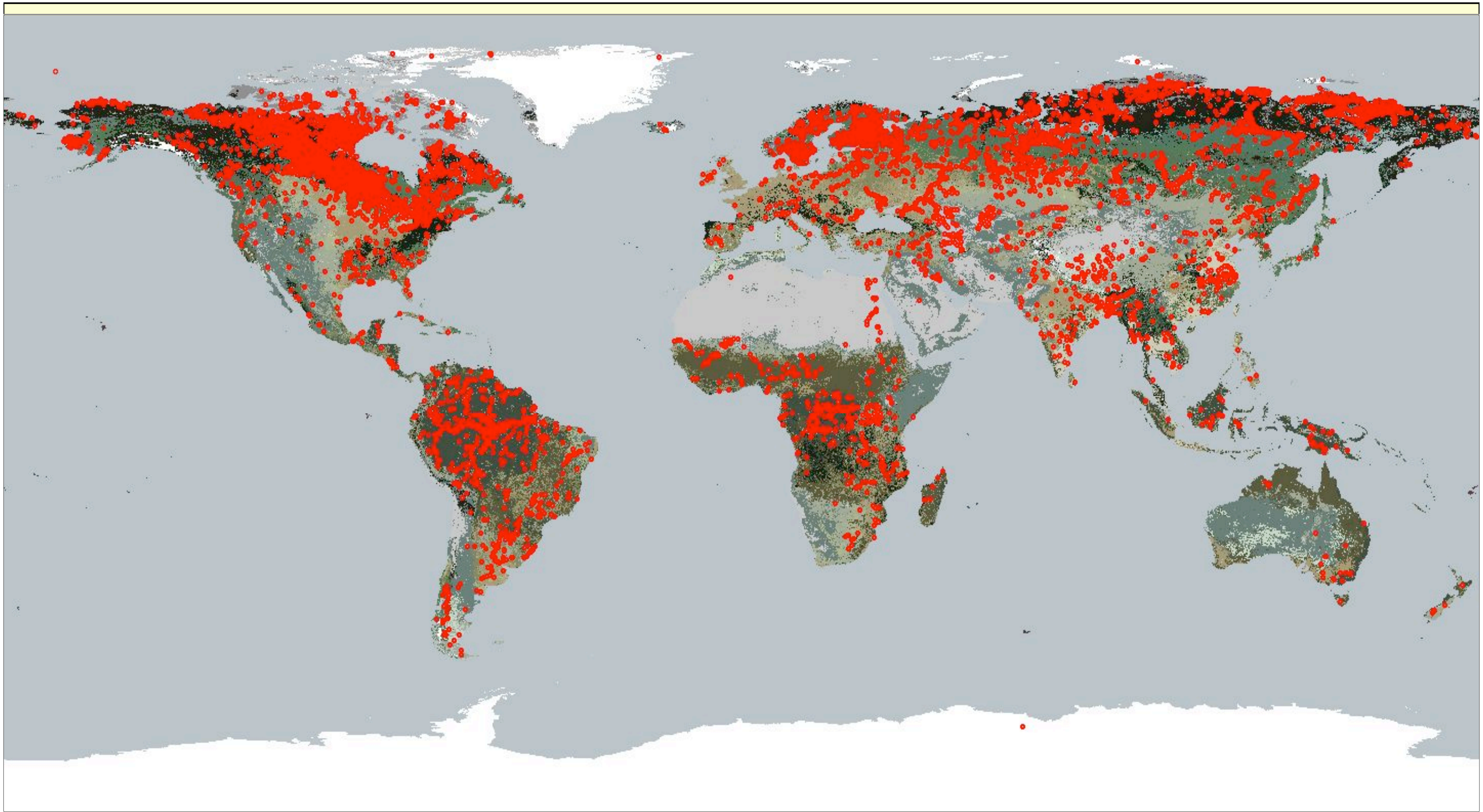
So what can the current generation of altimeters recover over inland water?

- Huge global analysis carried out of waveform recovery over inland water from ERS-2, TOPEX Jason-1 and Envisat.
- Every location where at least 80% of cycles have valid waveforms over the targets was identified and flagged
- Next slides show global plots for TOPEX, ERS-2 and Envisat with one red dot for each crossing flagged.

TOPEX Global Targets

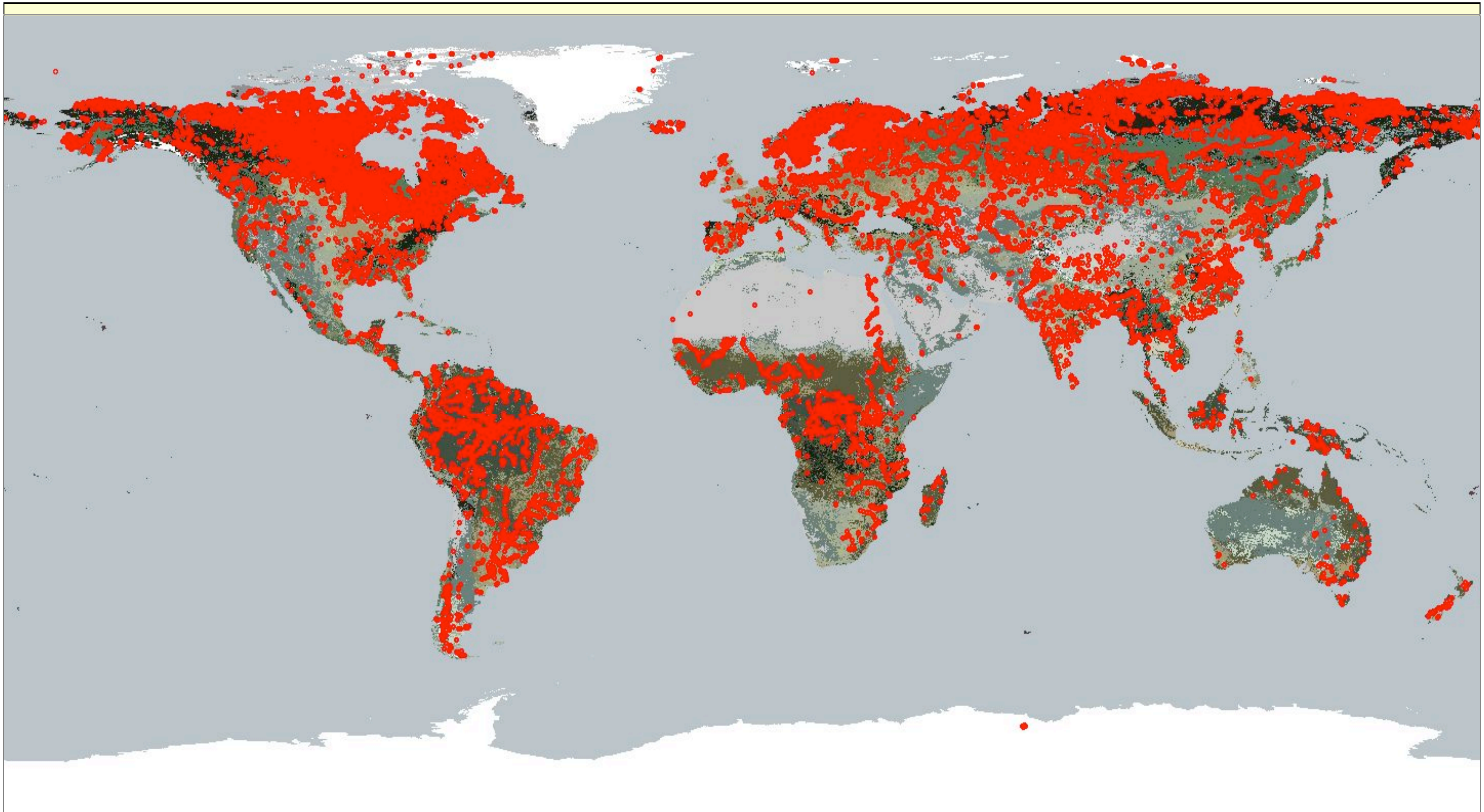


ERS-2 Global Targets



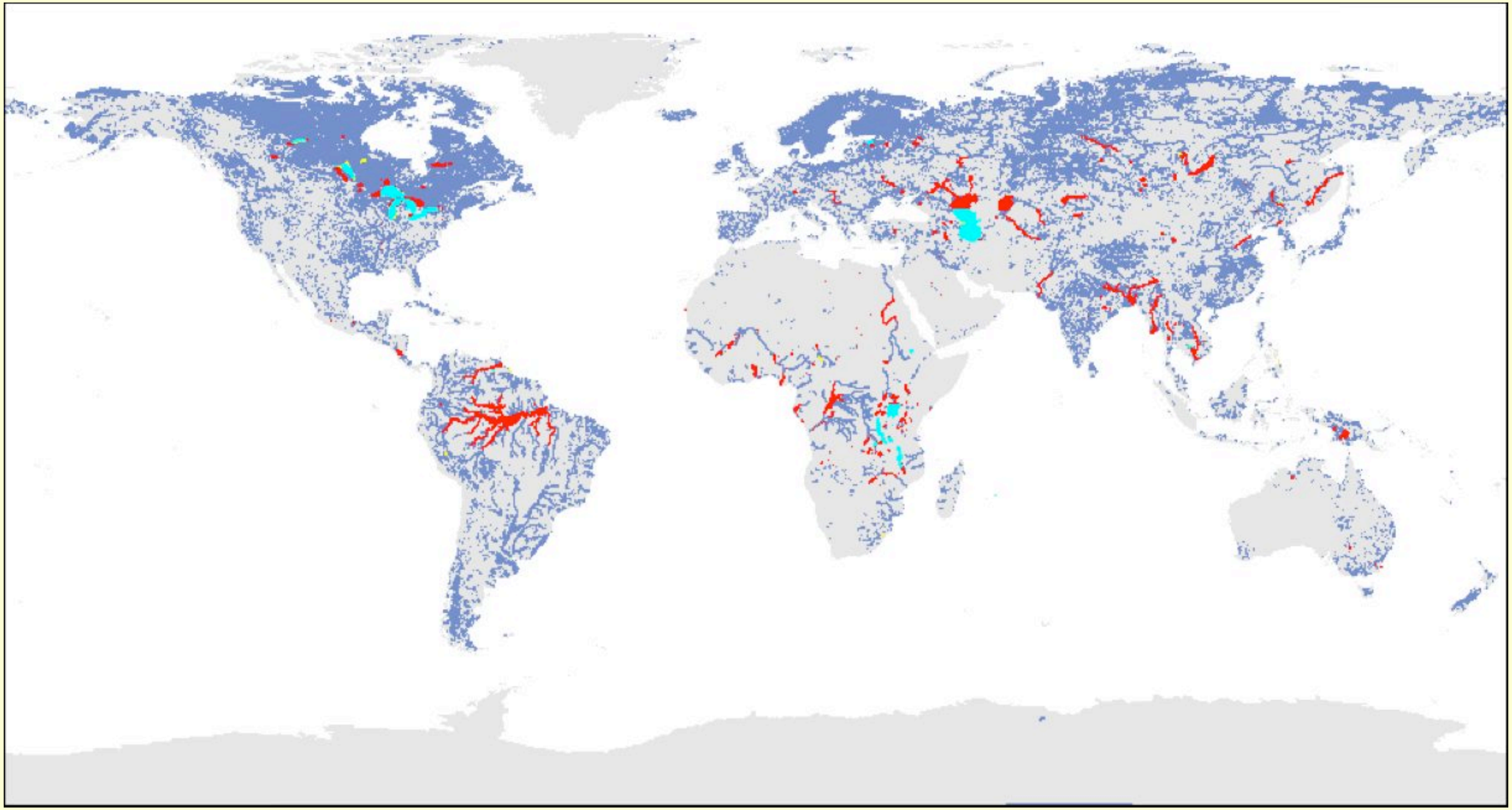
- Increase only partly due to 35 vs 10 day orbit: more to ERS-1/2 RA ability to maintain lock AND the wider 'ice mode' range receiving window

Envisat Global Targets



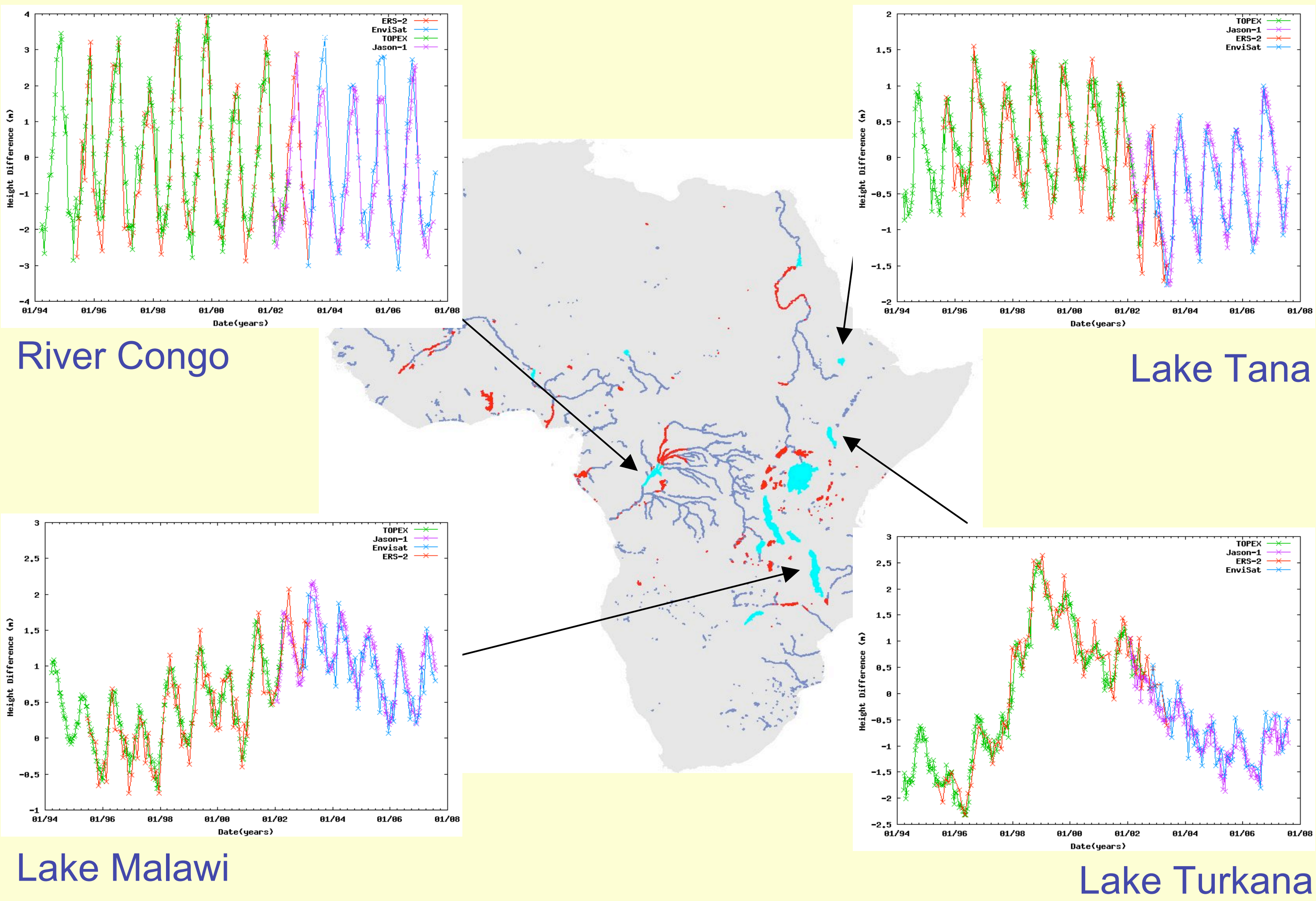
- Even more targets overall, although more ‘drop-out’ of waveforms (the self-adaptive tracker is mostly in high-resolution mode)

Global Mask for NRT RA-2 & Jason-1

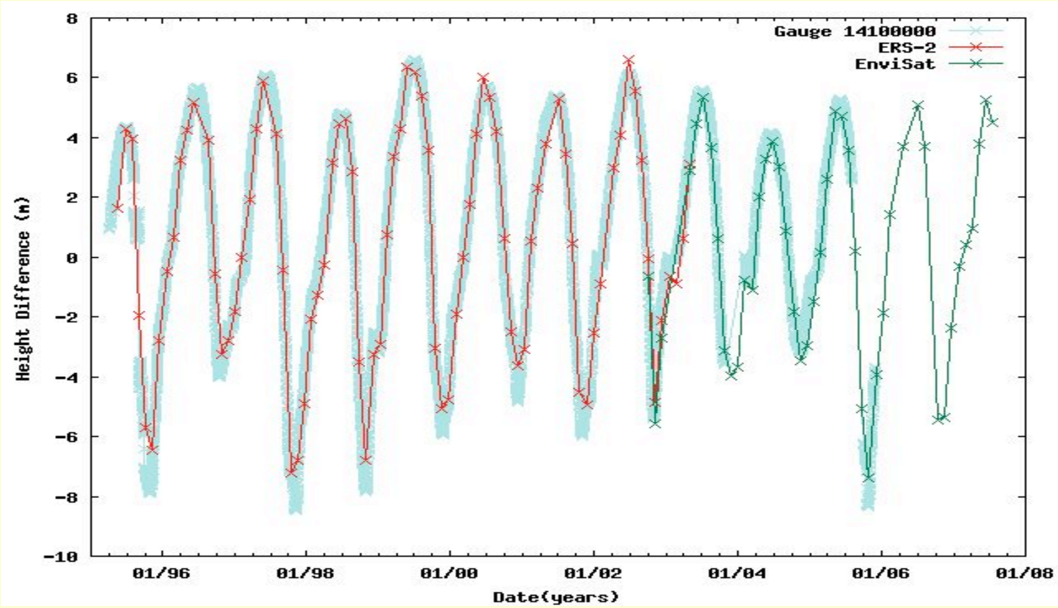


- NRT RA-2 targets red, RA-2 & Jason-1 targets turquoise, potential targets grey-blue. Note: all targets acquired by Jason-1 also seen by RA-2 (better time sampling with both).

New NRT mask over Africa



Example Validation over Amazon basin



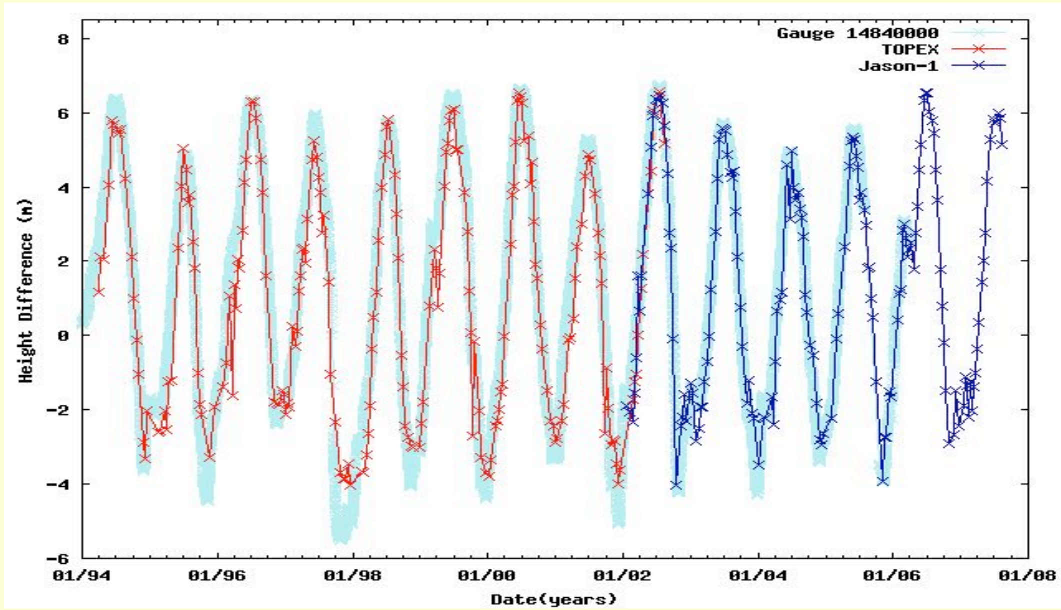
ERS-2 (red): RMS against Gauge: 0.6269m,
Correlation: 0.9878

EnviSat:(green) RMS against Gauge: 0.4724m,
Correlation: 0.9905

- Gauge data plotted in grey-blue

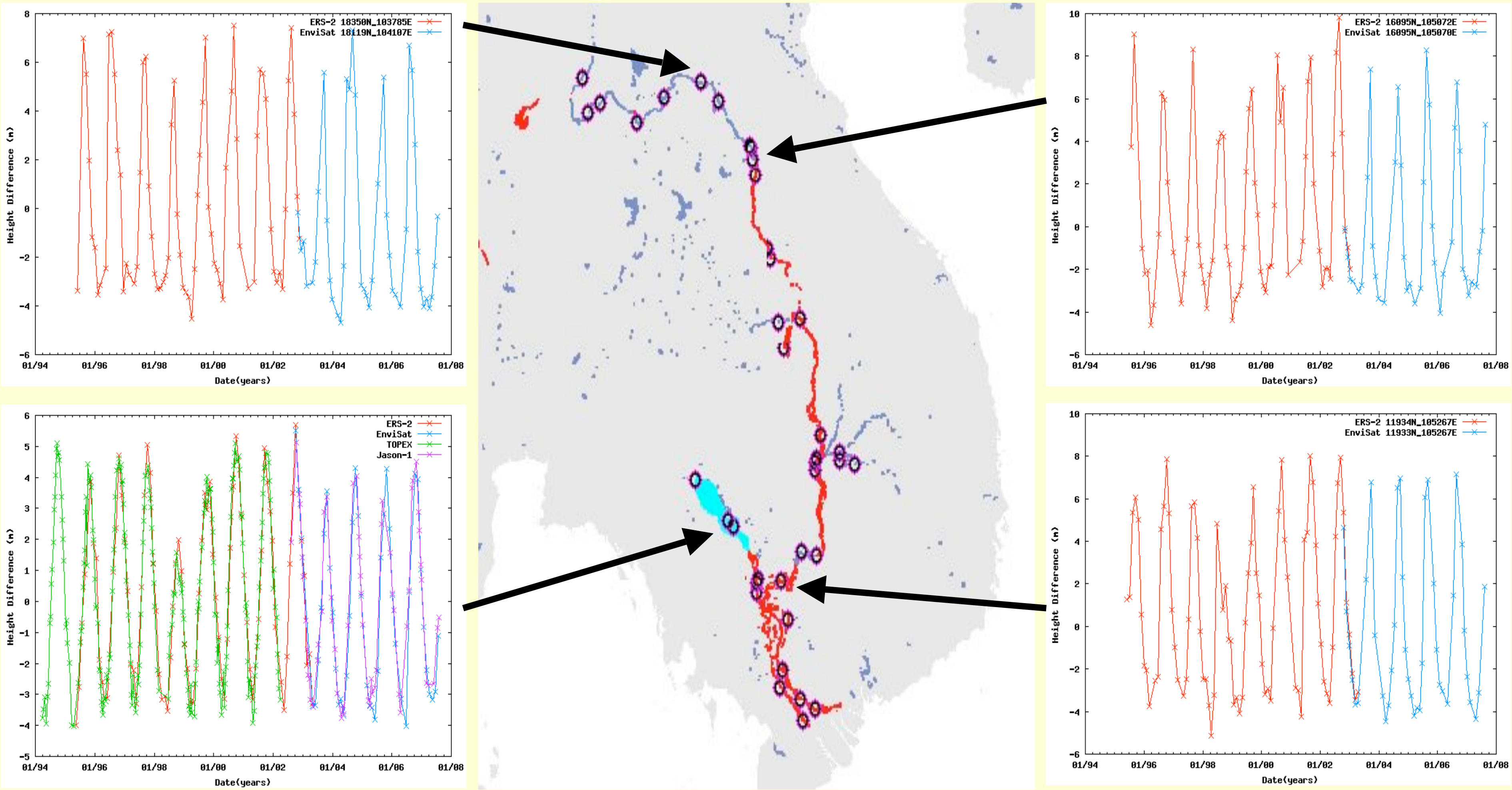
TOPEX (red): RMS against Gauge : 1.8376m,
Correlation: 0.8611

Jason-1 (dark blue): RMS against Gauge:1.2198m,
Correlation: 0.9283

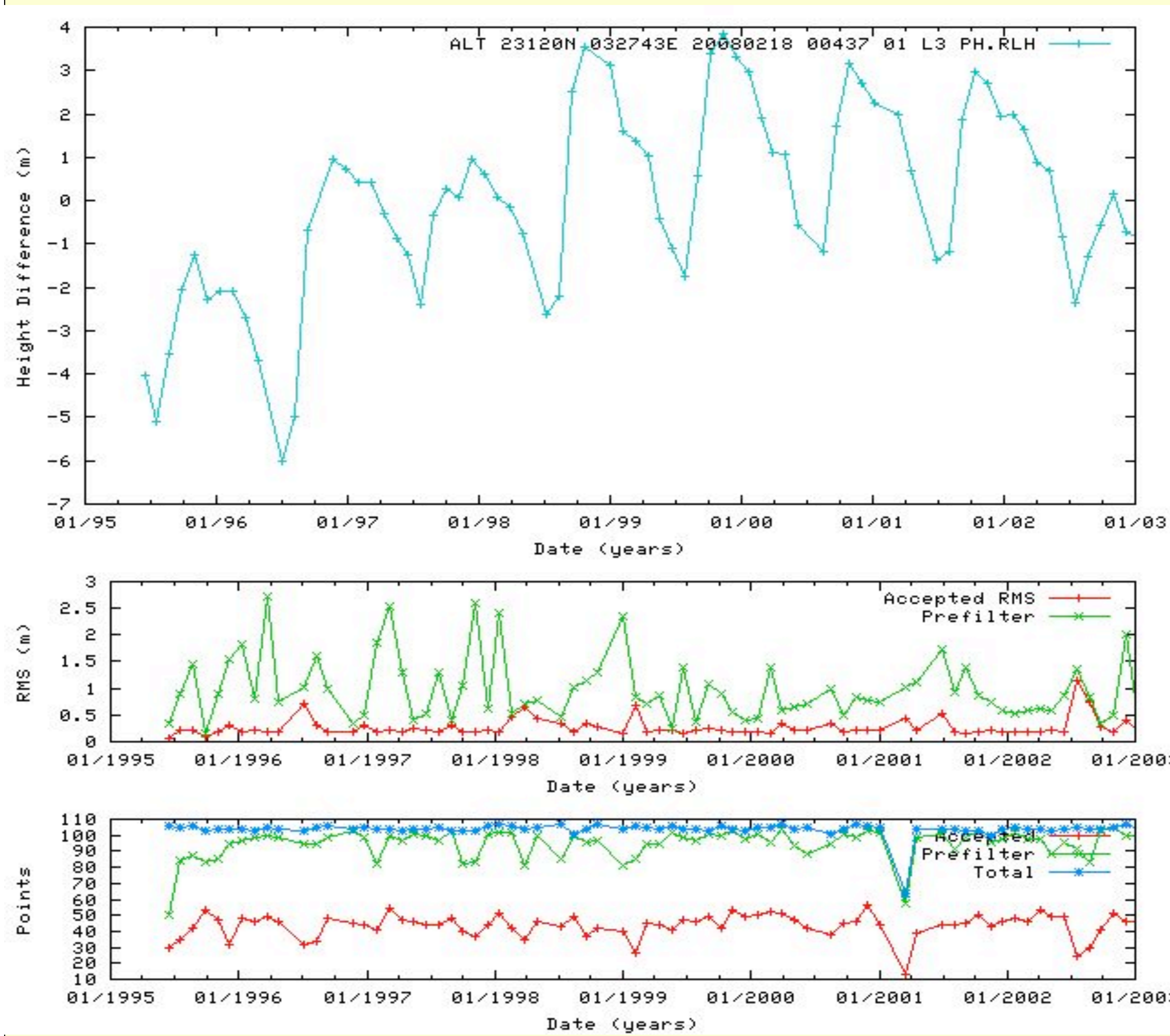


Mekong and Tonle Sap

Multi-mission data over Tonle Sap (ERS-2 + Envisat + TOPEX + Jason-1) and on Mekong (ERS-2 + Envisat: each circle is time series)



ERS-2 Statistics over Lake Nasser



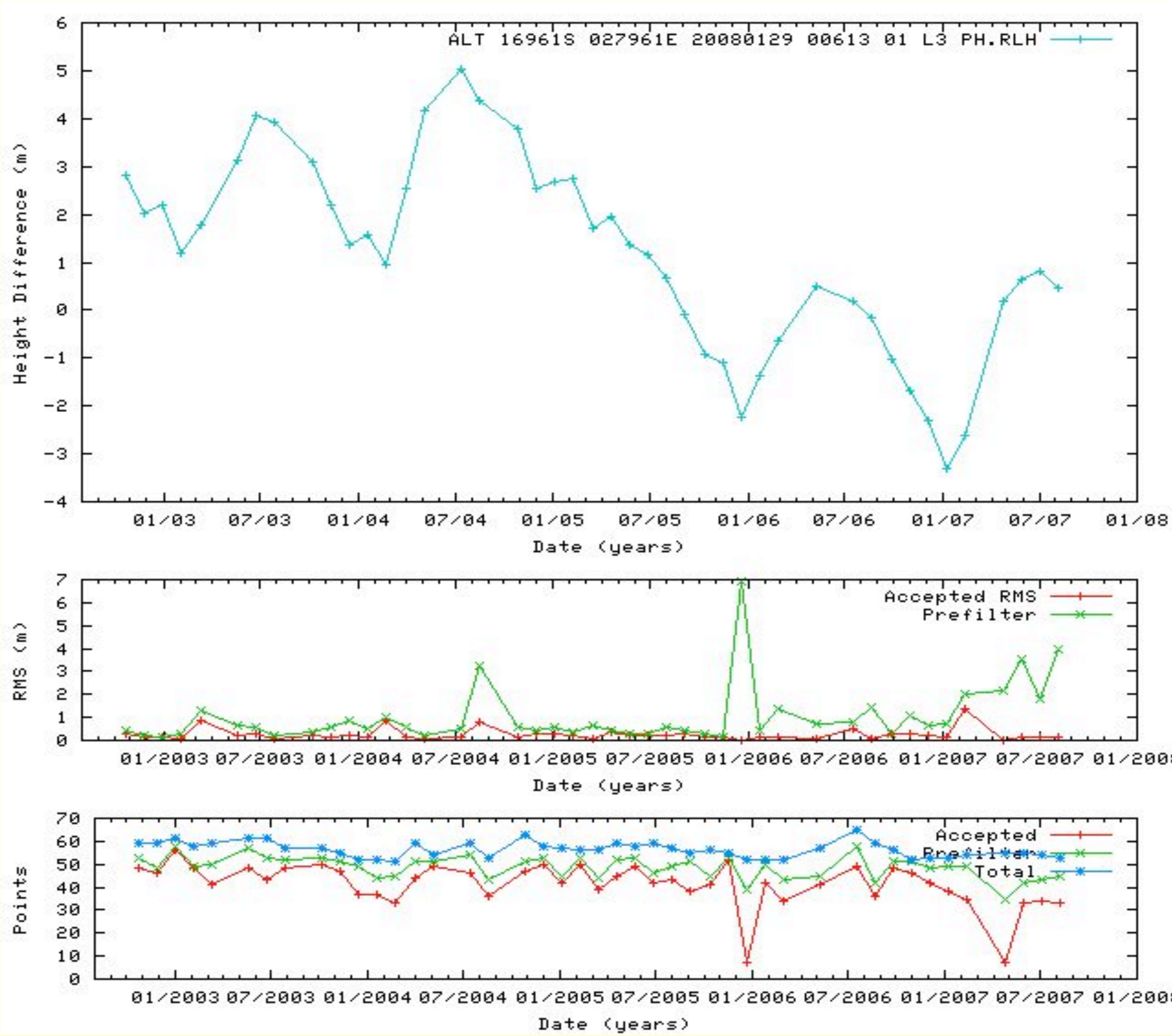
Top graph shows one time series over lake Nasser from ERS2.

Second graph shows pre-filtered along-track RMS (green) and NRT system output RMS (red).

Bottom graph shows number of points

a) from mask subset
b) After initial selection
c) As output from system

Envisat Statistics over Lake Kariba

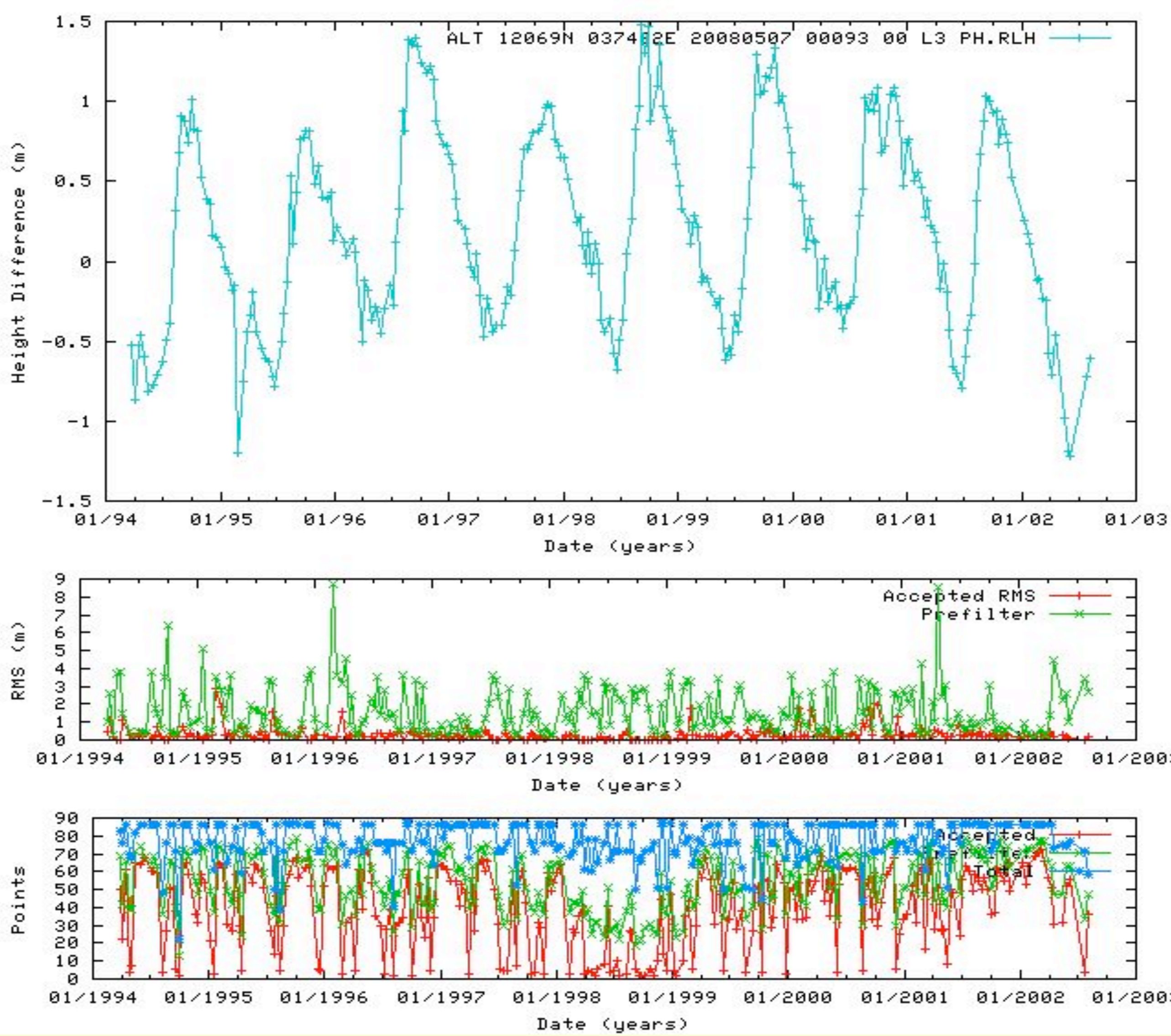


Statistics for Envisat over Lake Kariba

Plots as last slide

Note low loss of waveforms but reduction in RMS

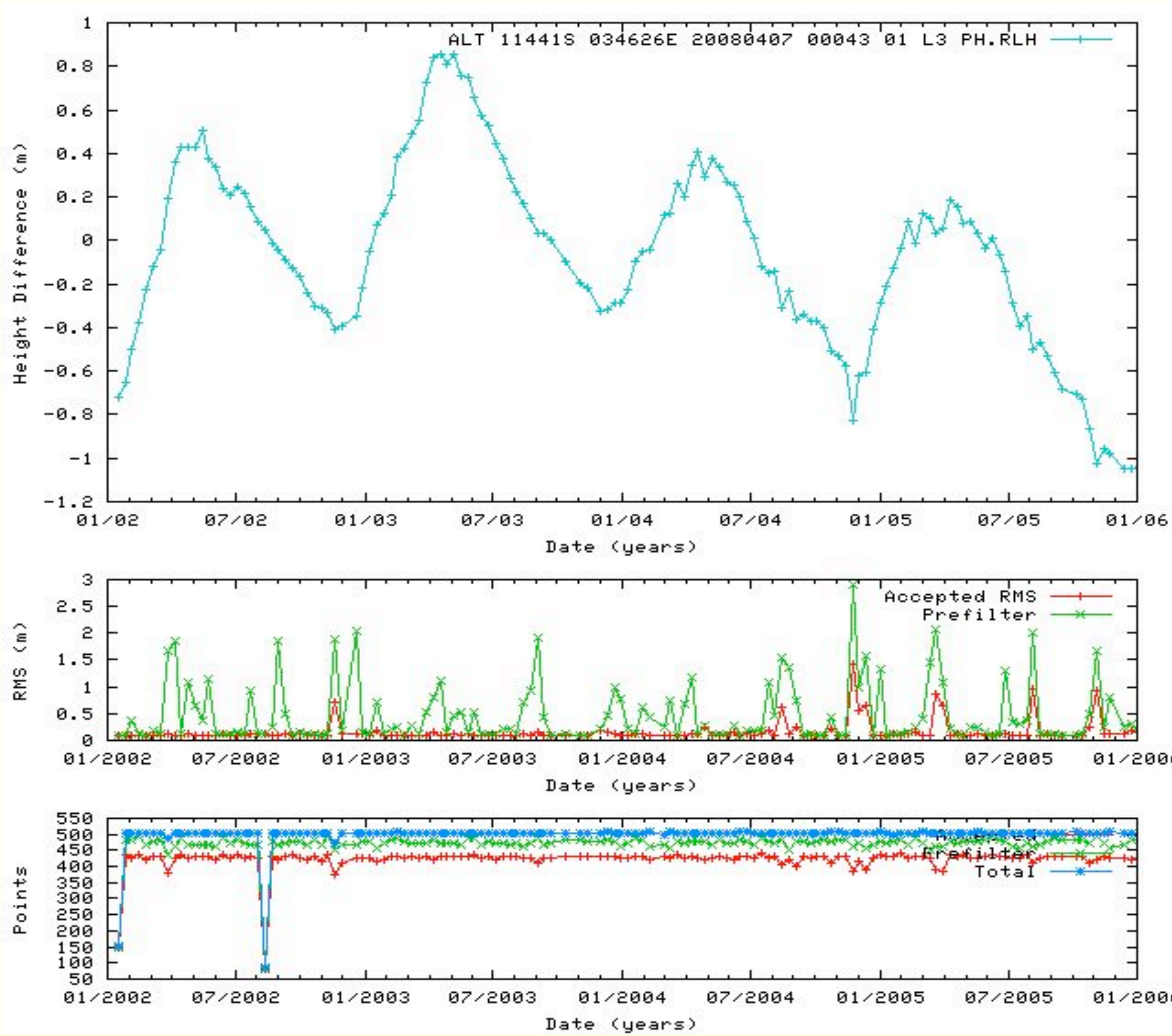
TOPEX Statistics over Lake Tana



Statistics for TOPEX from Lake Tana.
Again, note substantial improvement in along-track RMS after system processing and retracking

More waveforms rejected from TOPEX but RMS improves dramatically

Jason-1 Statistics over Lake Malawi



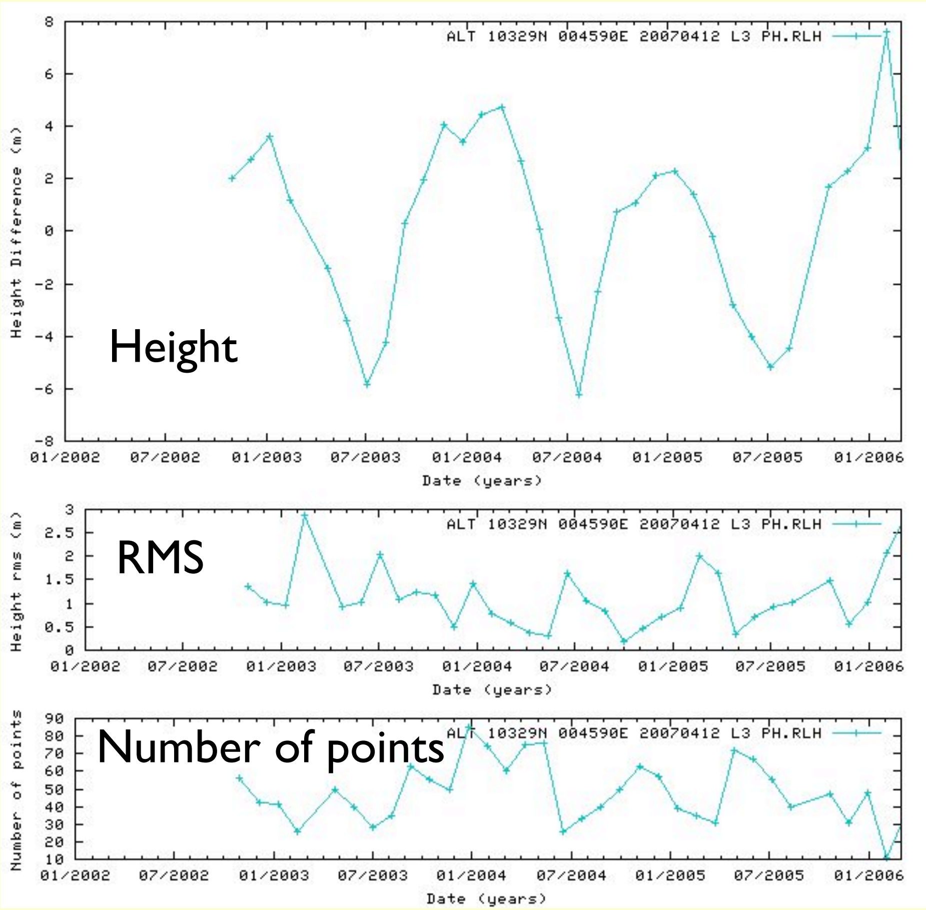
Statistics for Jason-1 from Lake Malawi

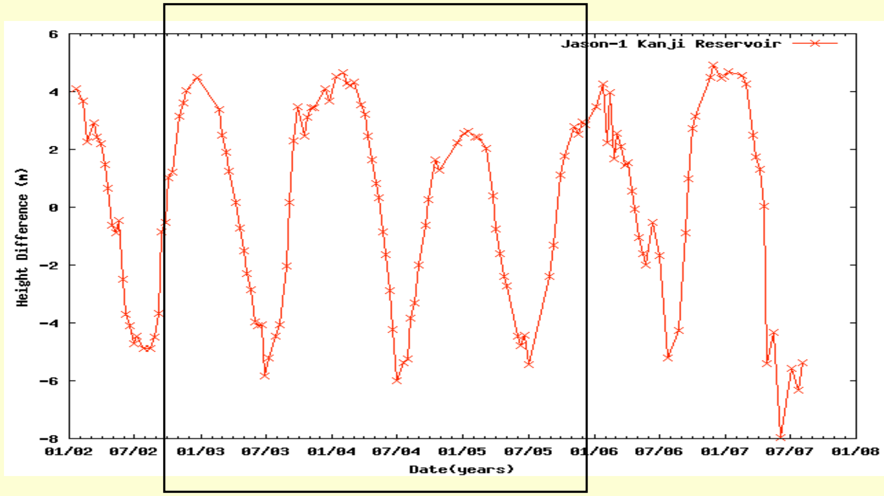
Here, far fewer waveforms rejected but RMS greatly reduced.

This often seen with Jason-1: retracking greatly enhances height retrieval

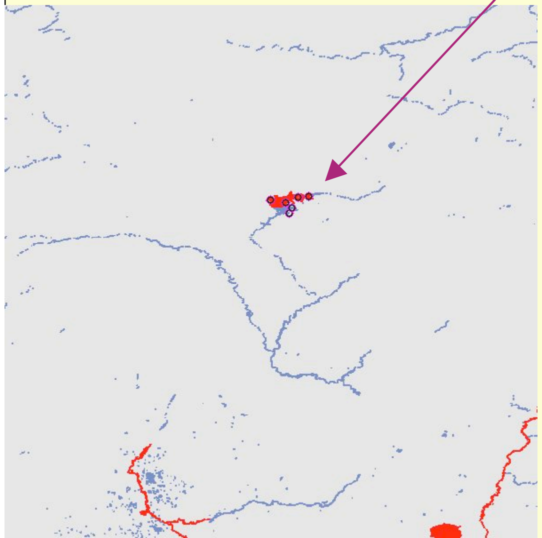
Kainji Reservoir - Niger River

Time series from Envisat (left) and Jason1 (right).



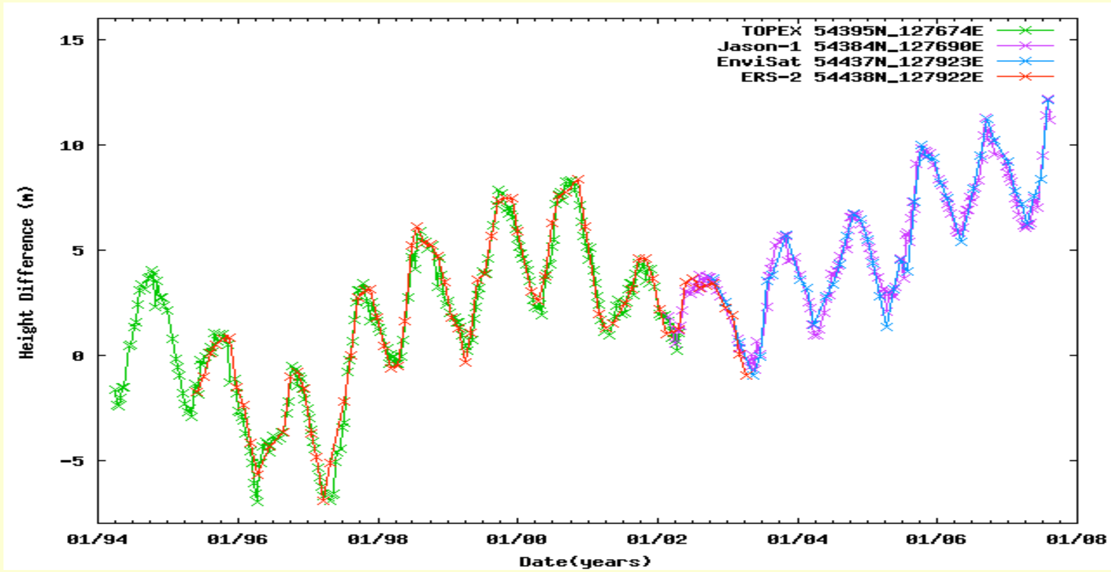


Zeyskoye Vodokhranilishche

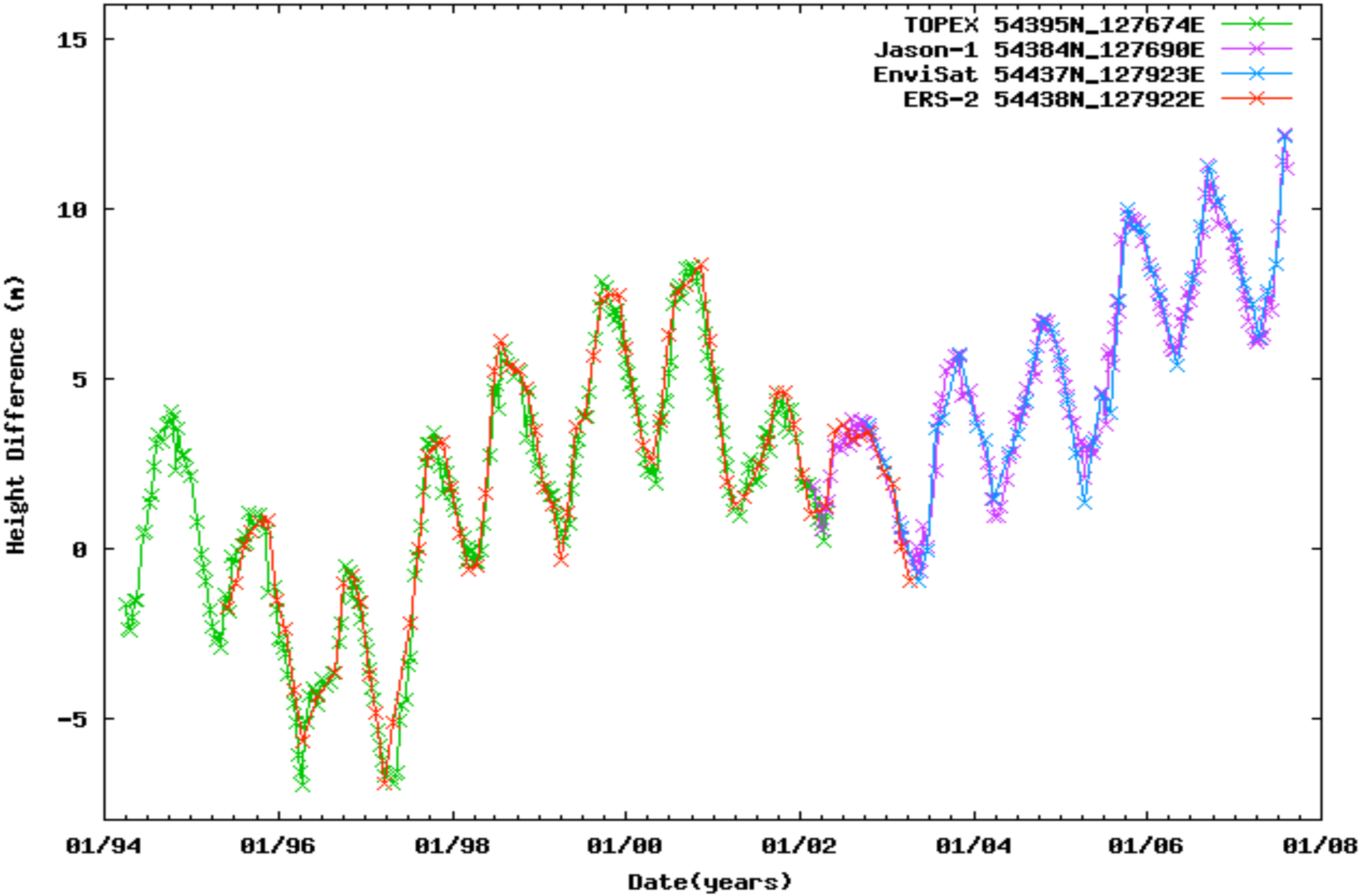


Reservoir Zeyskoye Vodokhranilishche, Russia, water level with 12 year combined timeseries derived from retracked ERS-2, EnviSat, Topex and Jason-1waveform data.   Excellent agreement is achieved over this fairly complex target.

Note the very good data from Jason-1 over this reservoir.   *(click to zoom)*



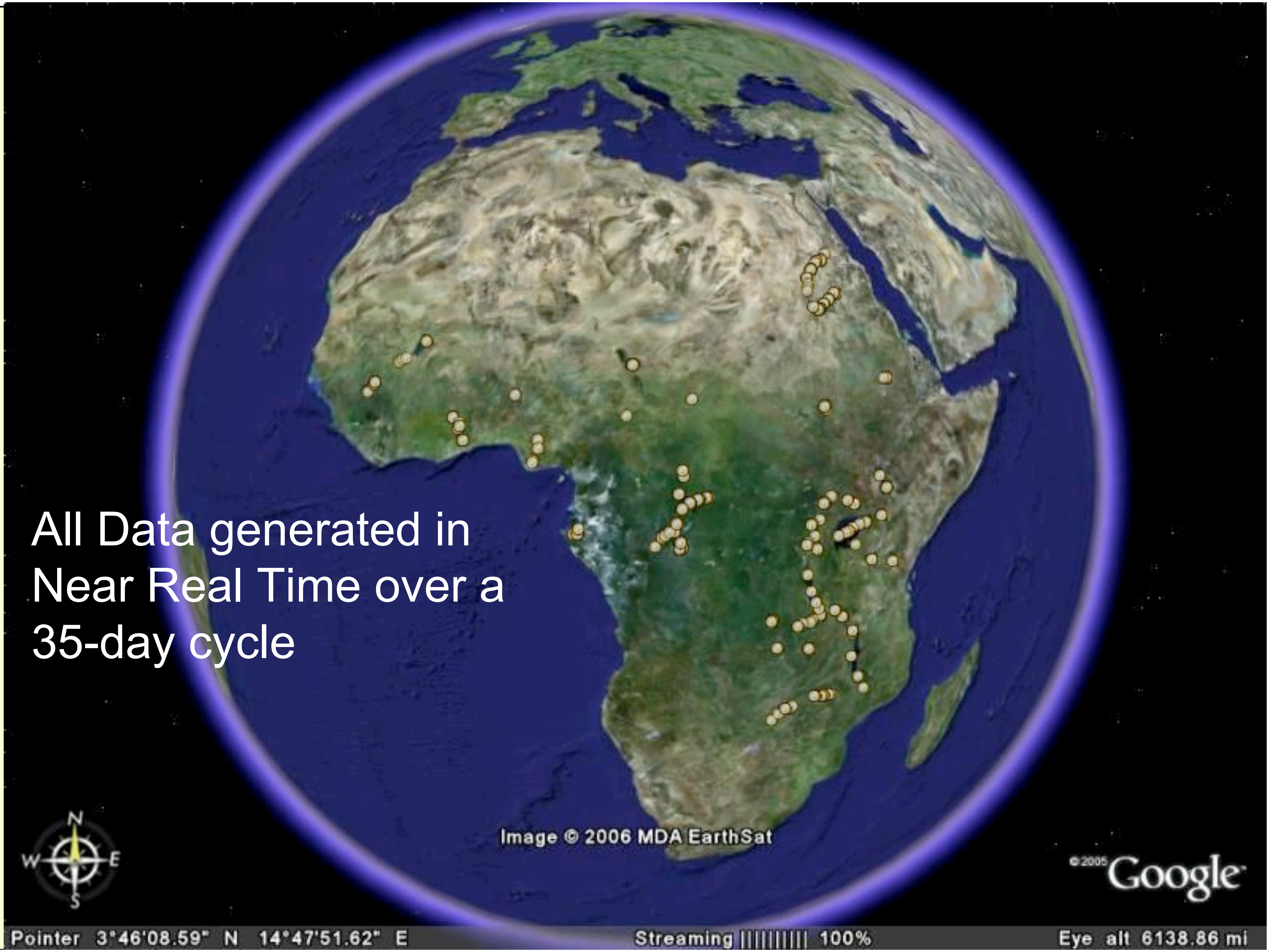
Zeyskoye Vodokhranilishche



Near-Real Time Products

6 measurements per day over Africa, <u>ONLY</u>!

Near-Real Time Products



All Data generated in Near Real Time over a 35-day cycle

Near-Real Time Products

esa

Need Denser Time Sampling !

⇒ A Swath Altimeter (WaTER, HM, SWOT)
- 2D maps will give slope!

⇒ A Constellation of Nadir Altimeters

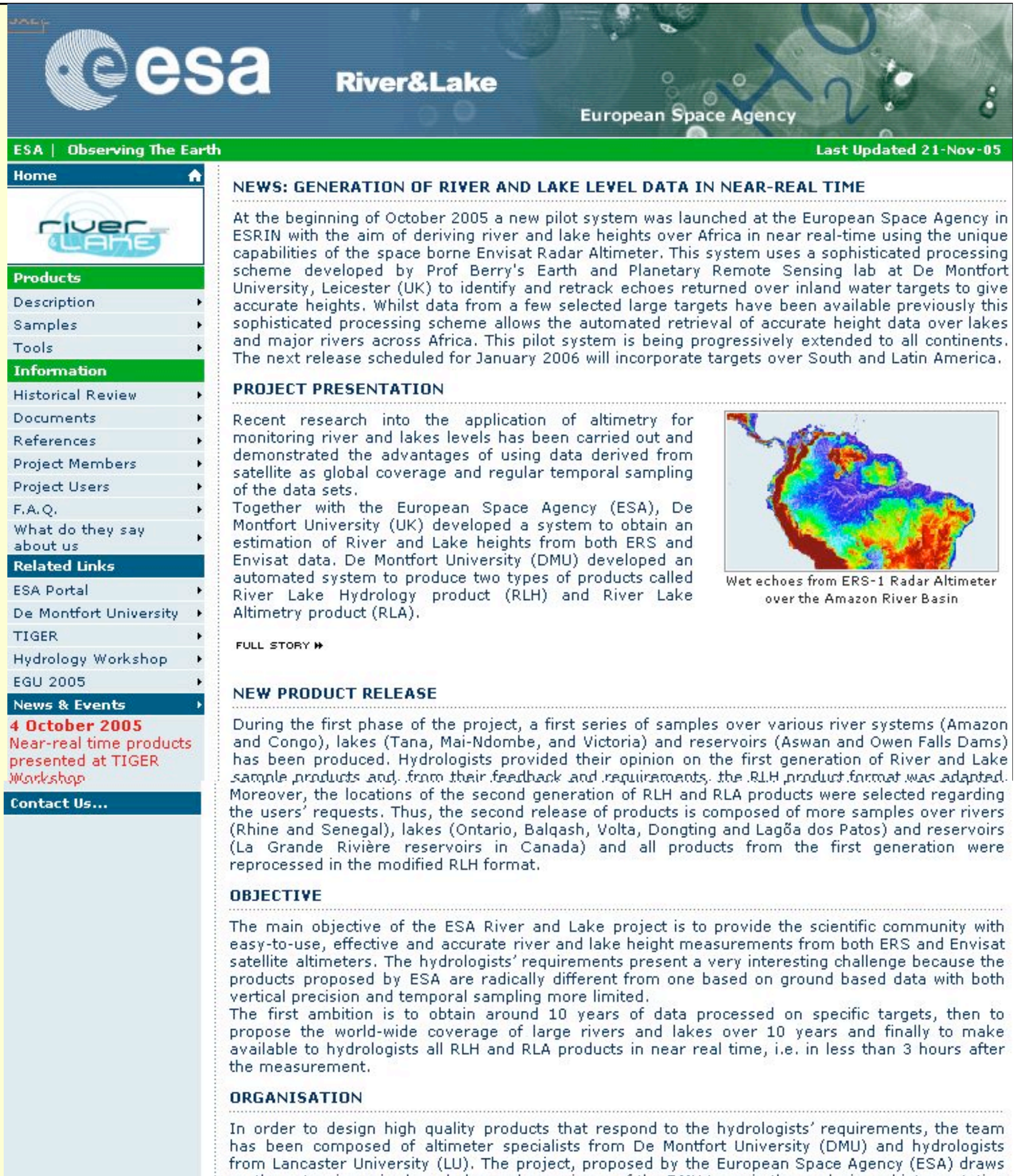
All Data generated in
Near Real Time over a
35-day cycle

Location of data since 25 October

"River & Lake" Website

Information and Data Products Request:

http://earth.esa.int/riverandlake



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river LAKE

Products
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- Project Users
- F.A.Q.
- What do they say about us

Related Links
- ESA Portal
- De Montfort University
- TIGER
- Hydrology Workshop
- EGU 2005

News & Events

4 October 2005
Near-real time products presented at TIGER Workshop

Contact Us...

NEWS: GENERATION OF RIVER AND LAKE LEVEL DATA IN NEAR-REAL TIME

At the beginning of October 2005 a new pilot system was launched at the European Space Agency in ESRIN with the aim of deriving river and lake heights over Africa in near real-time using the unique capabilities of the space borne Envisat Radar Altimeter. This system uses a sophisticated processing scheme developed by Prof Berry's Earth and Planetary Remote Sensing lab at De Montfort University, Leicester (UK) to identify and retrack echoes returned over inland water targets to give accurate heights. Whilst data from a few selected large targets have been available previously this sophisticated processing scheme allows the automated retrieval of accurate height data over lakes and major rivers across Africa. This pilot system is being progressively extended to all continents. The next release scheduled for January 2006 will incorporate targets over South and Latin America.

PROJECT PRESENTATION

Recent research into the application of altimetry for monitoring river and lakes levels has been carried out and demonstrated the advantages of using data derived from satellite as global coverage and regular temporal sampling of the data sets.
Together with the European Space Agency (ESA), De Montfort University (UK) developed a system to obtain an estimation of River and Lake heights from both ERS and Envisat data. De Montfort University (DMU) developed an automated system to produce two types of products called River Lake Hydrology product (RLH) and River Lake Altimetry product (RLA).

Wet echoes from ERS-1 Radar Altimeter over the Amazon River Basin

FULL STORY

NEW PRODUCT RELEASE

During the first phase of the project, a first series of samples over various river systems (Amazon and Congo), lakes (Tana, Mai-Ndombe, and Victoria) and reservoirs (Aswan and Owen Falls Dams) has been produced. Hydrologists provided their opinion on the first generation of River and Lake sample products and, from their feedback and requirements, the RLH product format was adapted. Moreover, the locations of the second generation of RLH and RLA products were selected regarding the users' requests. Thus, the second release of products is composed of more samples over rivers (Rhine and Senegal), lakes (Ontario, Balqash, Volta, Dongting and Lagõa dos Patos) and reservoirs (La Grande Rivière reservoirs in Canada) and all products from the first generation were reprocessed in the modified RLH format.

OBJECTIVE

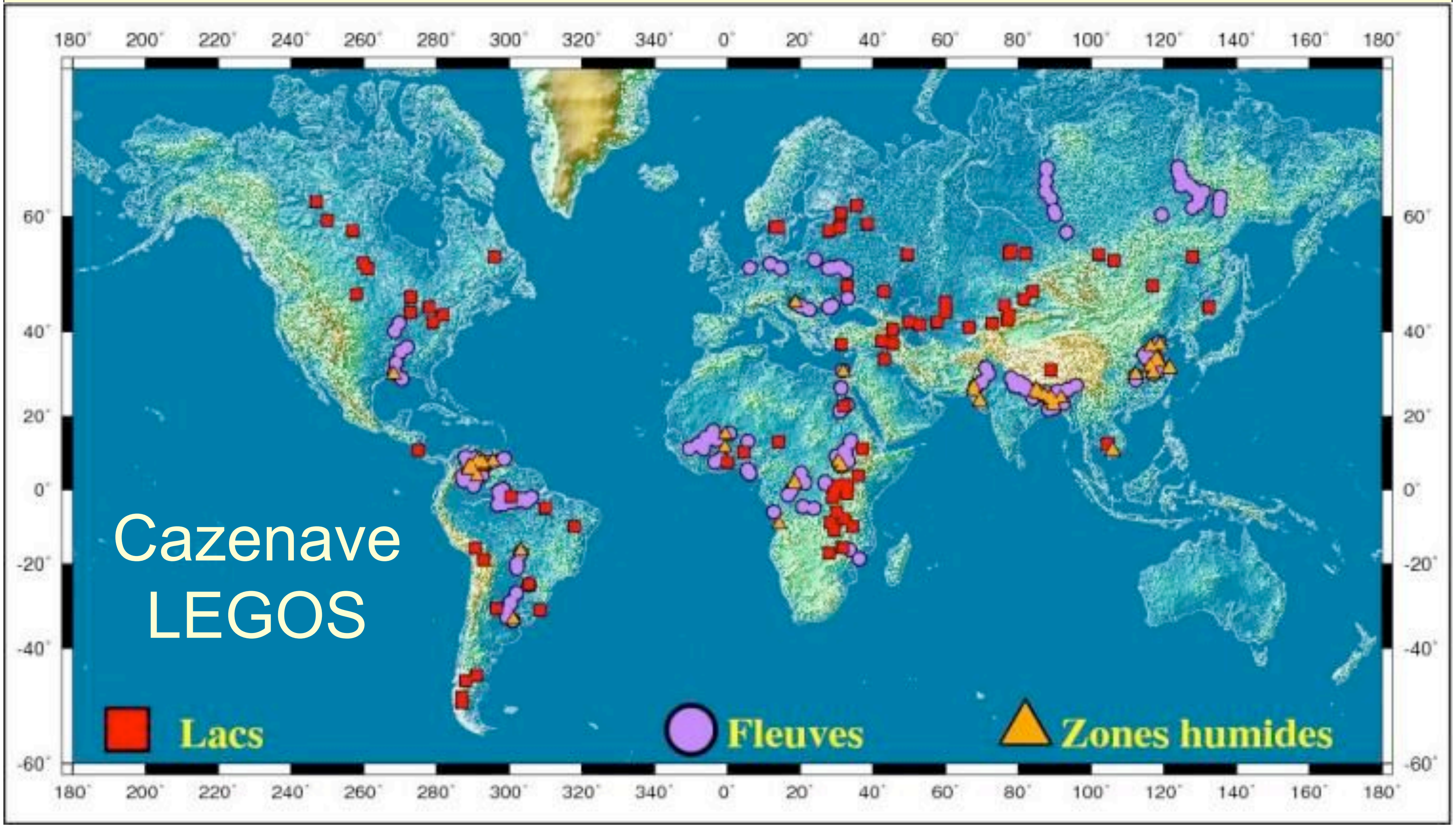
The main objective of the ESA River and Lake project is to provide the scientific community with easy-to-use, effective and accurate river and lake height measurements from both ERS and Envisat satellite altimeters. The hydrologists' requirements present a very interesting challenge because the products proposed by ESA are radically different from one based on ground based data with both vertical precision and temporal sampling more limited.
The first ambition is to obtain around 10 years of data processed on specific targets, then to propose the world-wide coverage of large rivers and lakes over 10 years and finally to make available to hydrologists all RLH and RLA products in near real time, i.e. in less than 3 hours after the measurement.

ORGANISATION

In order to design high quality products that respond to the hydrologists' requirements, the team has been composed of altimeter specialists from De Montfort University (DMU) and hydrologists from Lancaster University (LU). The project, proposed by the European Space Agency (ESA) draws

Hydroweb: Selection of rivers and lakes

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

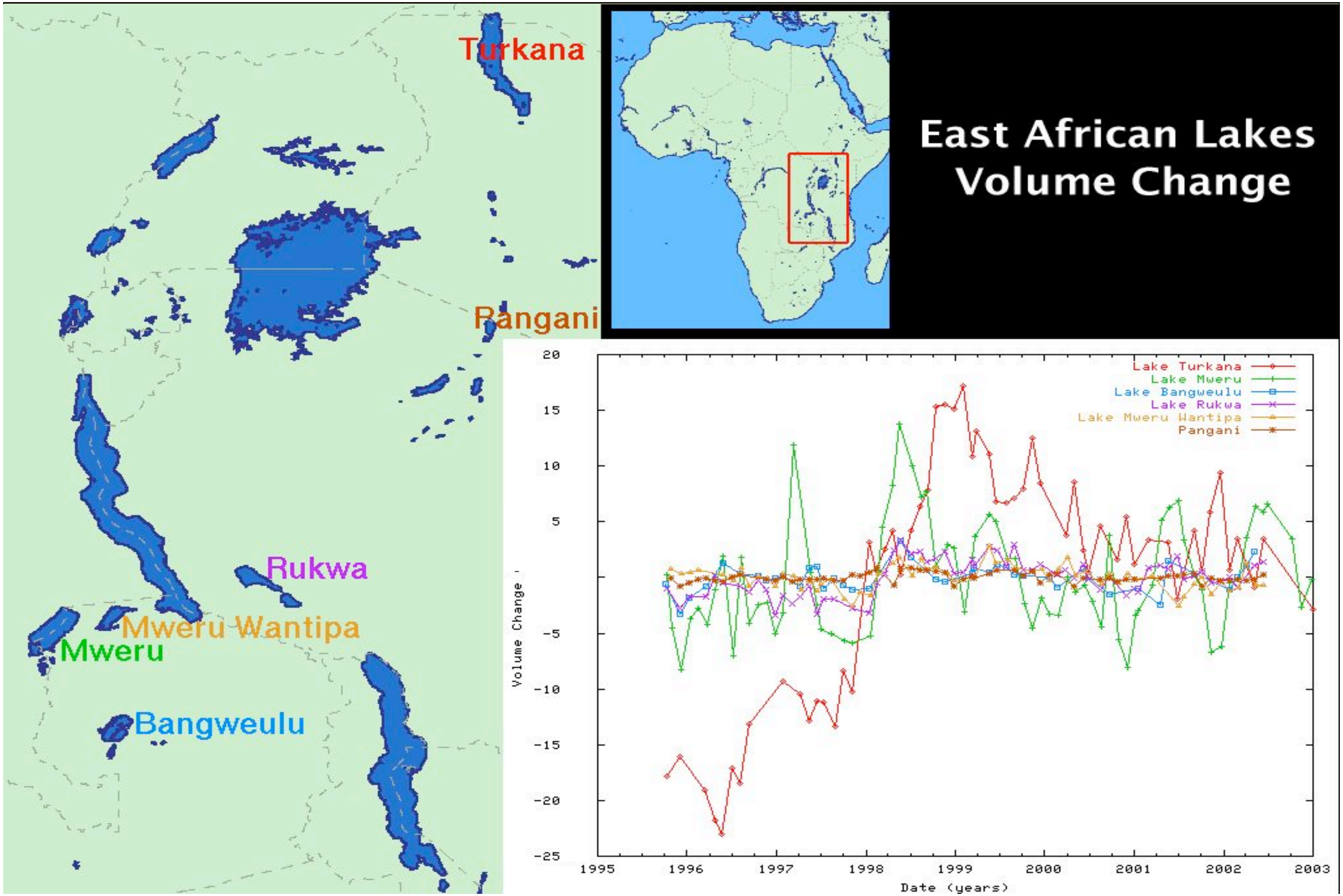


USDA: Reservoirs and Lakes

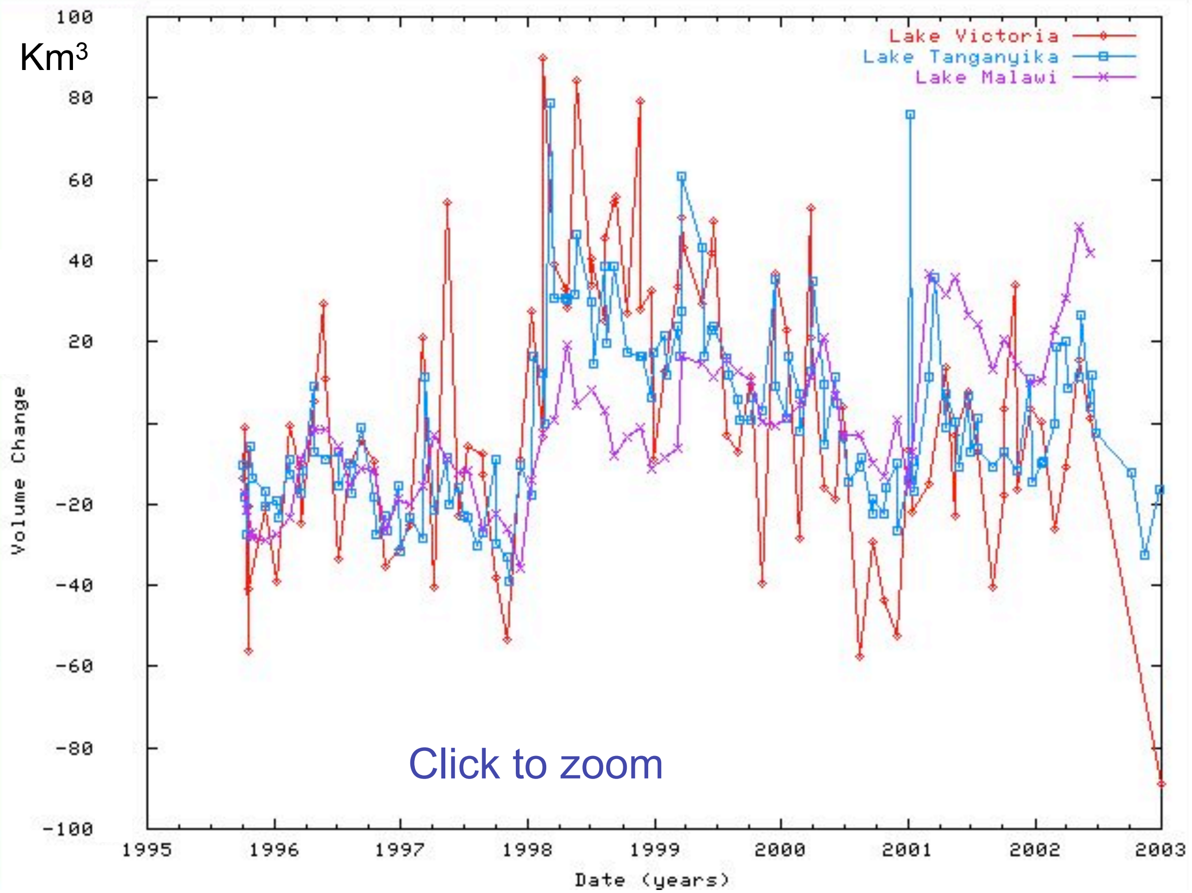
http://www.pecad.fas.usda.gov/rssiws/global_reservoir/index.cfm

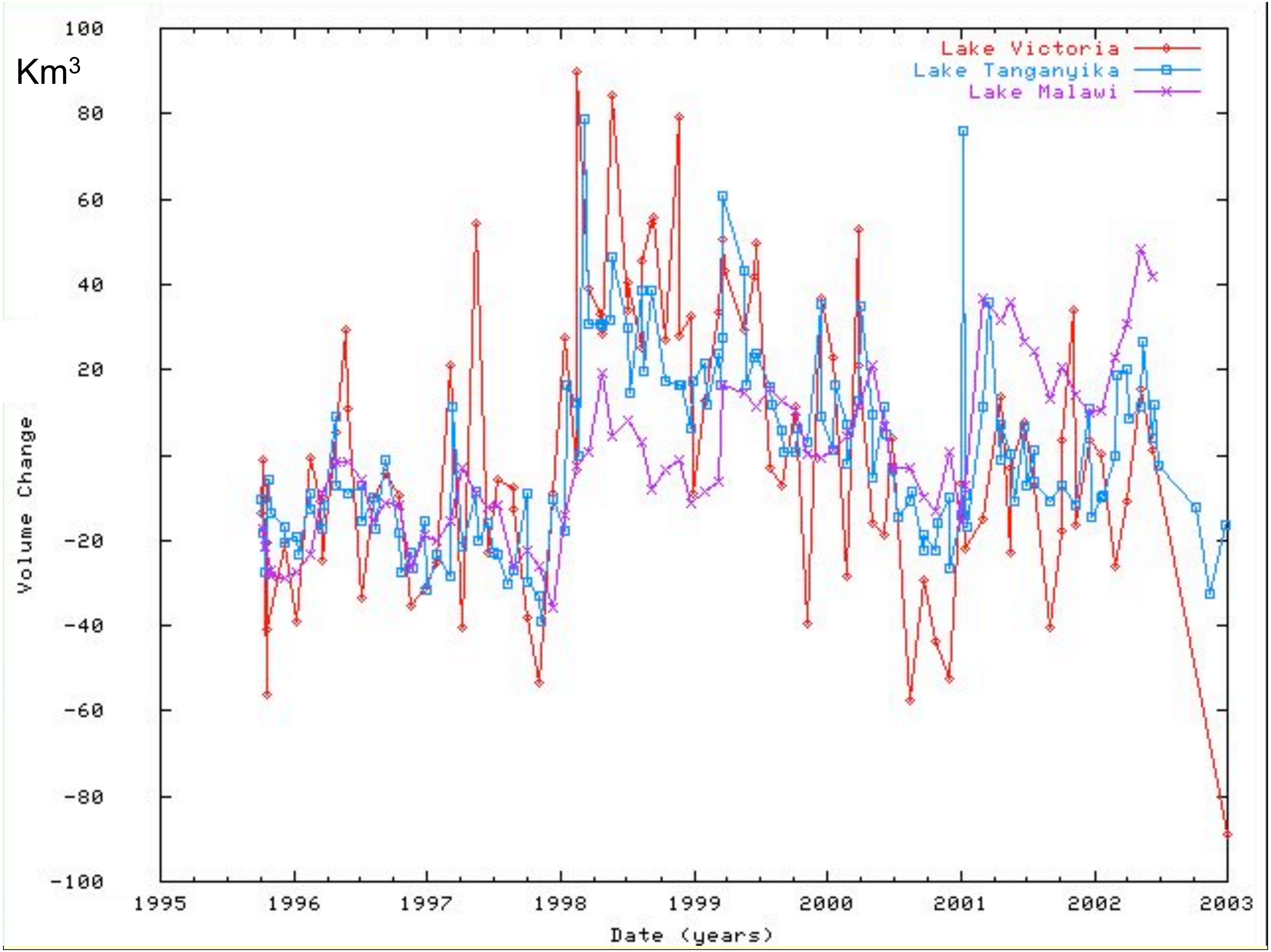
Birkett
USDA

Lake Volume Variation (km^3)



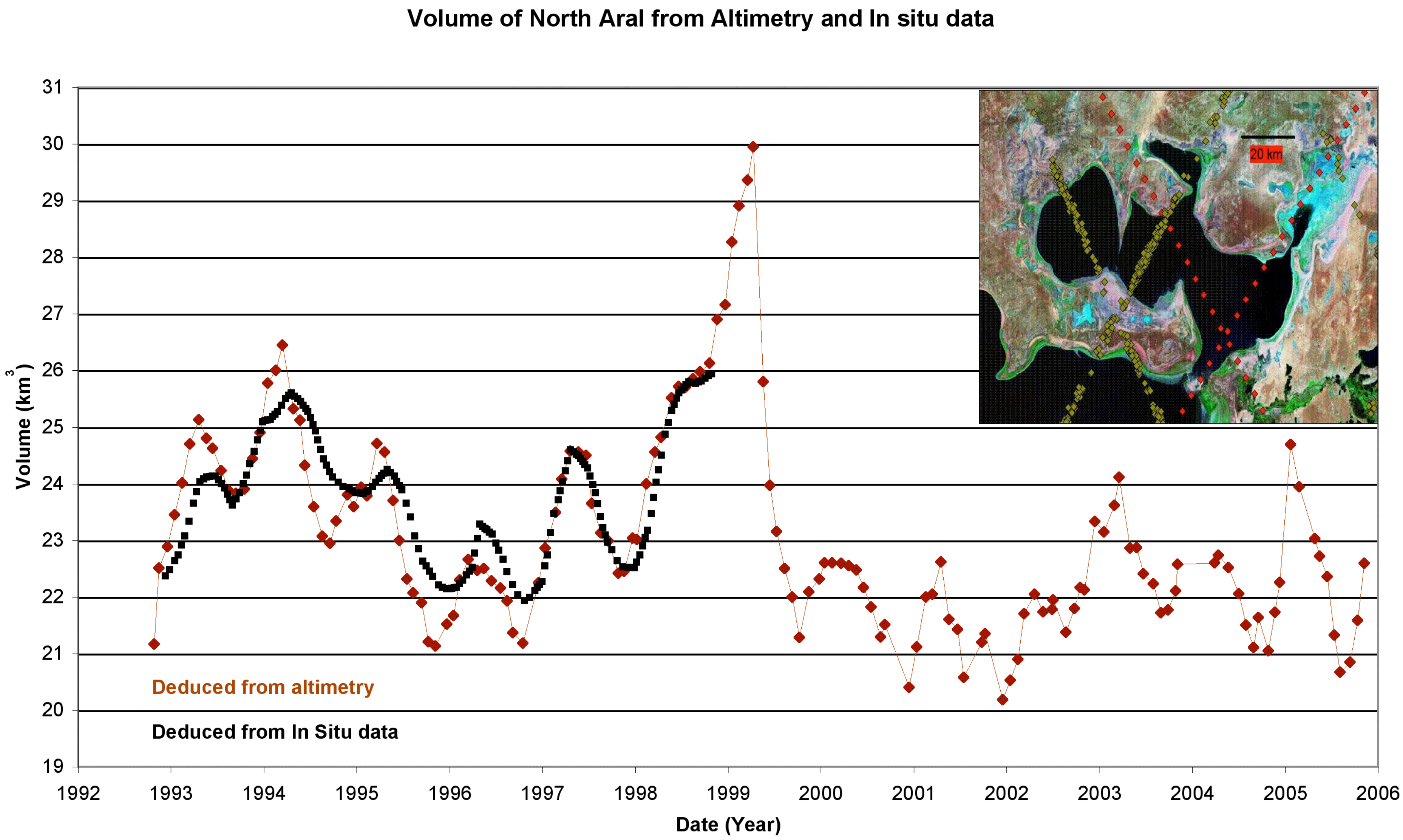
East African Lakes Volume Change





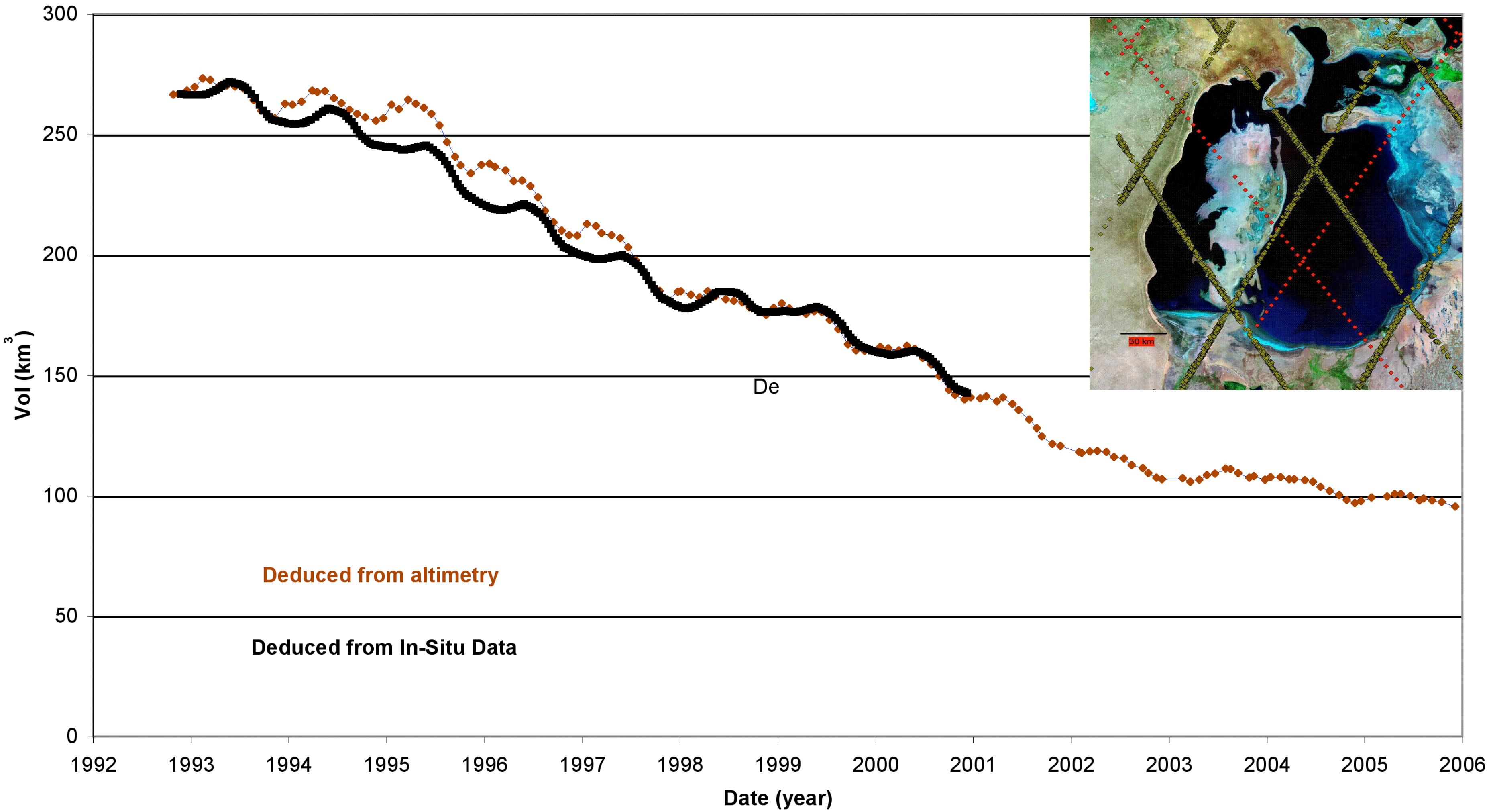
Km3
100
80
60
40
20
-20
-40
-60
-80
-100
Volume Change
Lake Victoria
Lake Tanganyika
Lake Malawi
1995
1996
1997
1998
1999
2000
2001
2002
2003
Date (years)

North Aral Sea - Cazenave & Crétaux



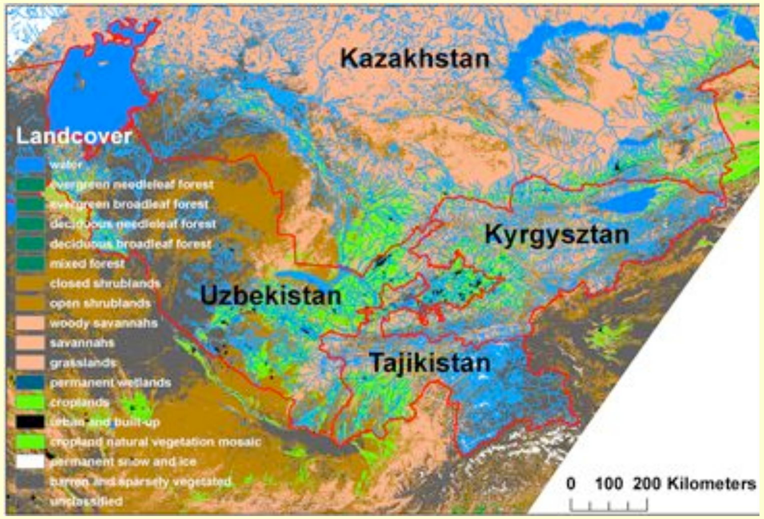
South Aral Sea - Cazenave & Crétaux

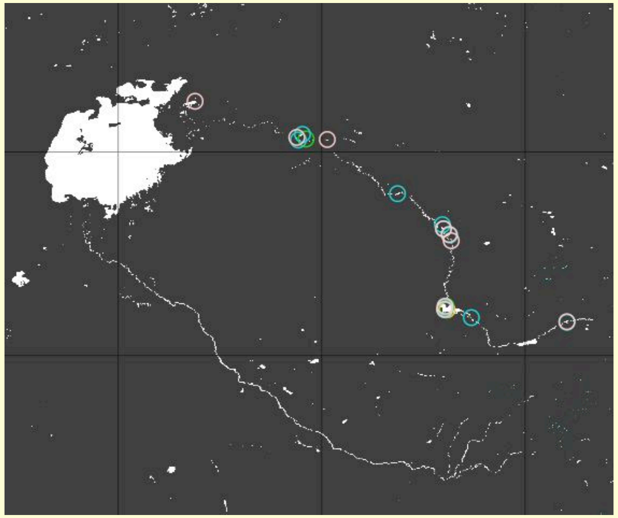
South Aral volume variation



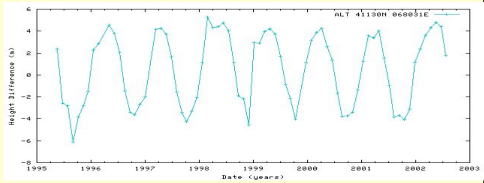
Syr Darya

The Syr Darya River Basin is shared between the four central Asian republics of Kyrgyzstan, Tajikistan, Uzbekistan and Kazakhstan. The total surface area of the Basin is 780,000 km2 (below left). The runoff regime in the basin is snow-melt dominated and most of the runoff is generated in the mountainous parts of the catchment, which rise to altitudes of more than 7000 meters above mean sea level. The Syr Darya river is the Northern tributary to Lake Aral and contributed about 30% to the total inflow into Lake Aral in the near-natural state.



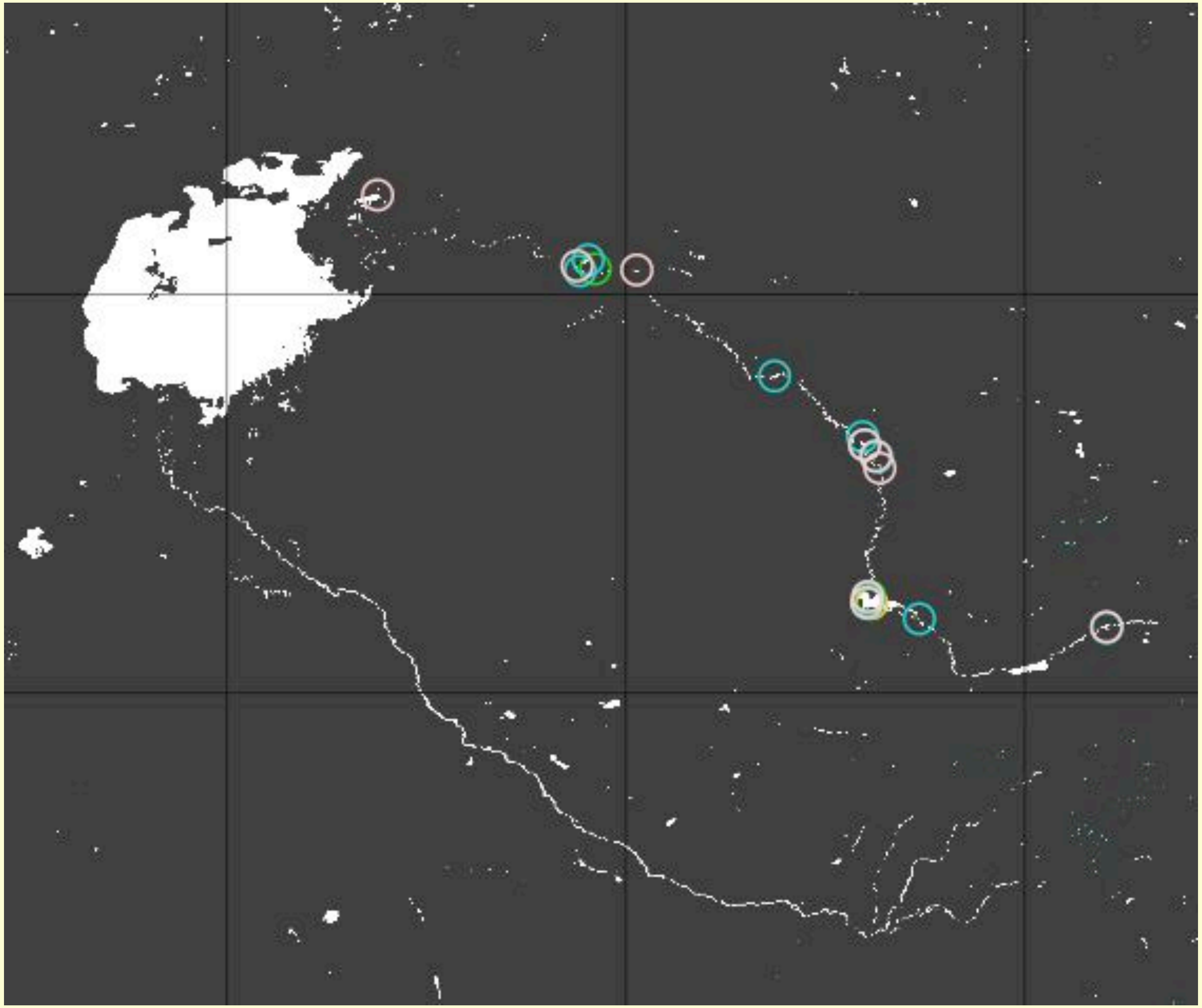


Locations of altimeter time-series:
EnviSat (light blue),
ERS2 (pink)
Topex (gold) and
Jason-1 (green).



Project is to model the Syr Darya river basin, incorporating multi-mission satellite radar altimetry

Syr Darya



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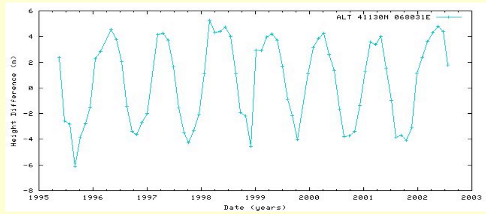
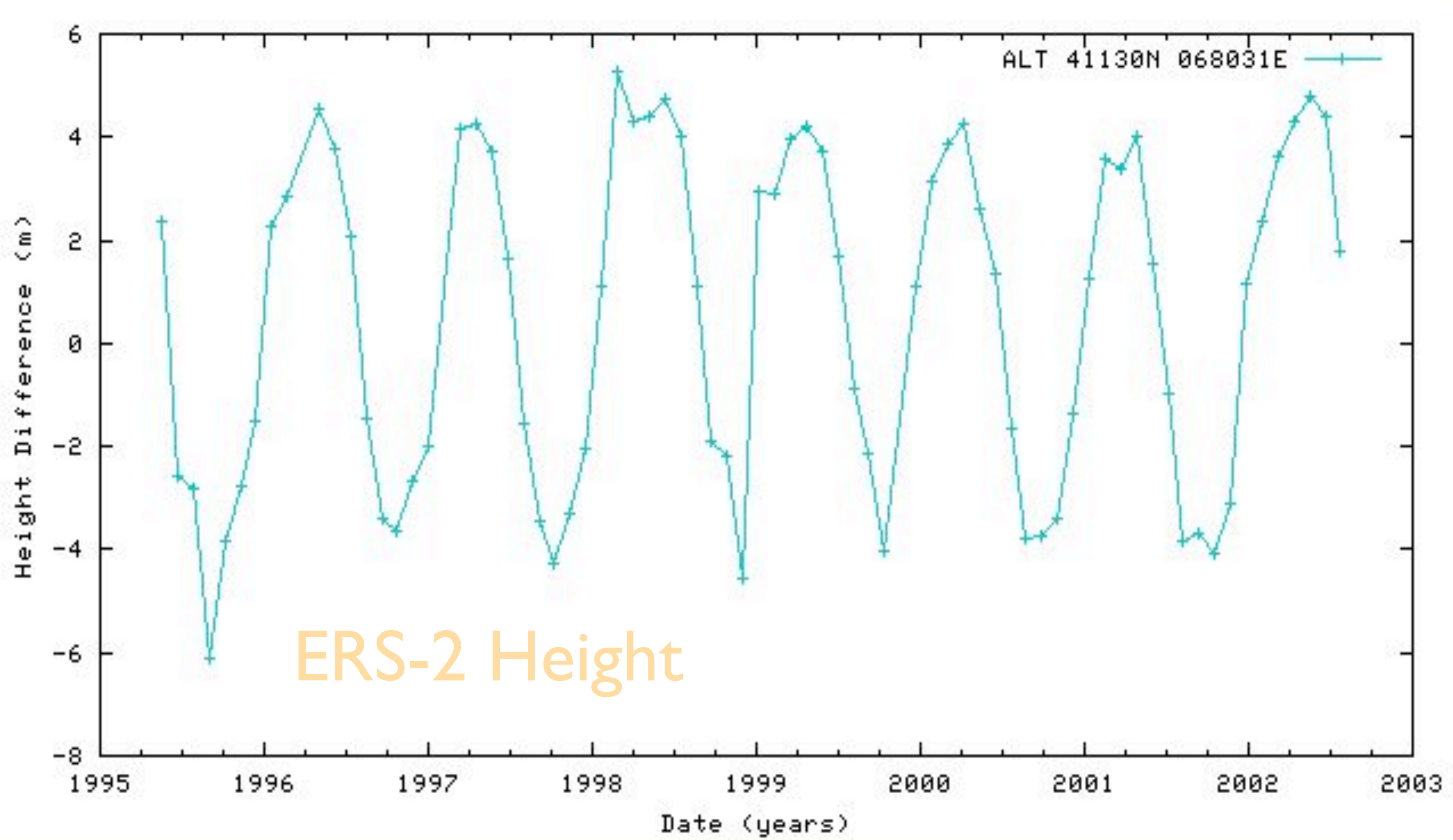
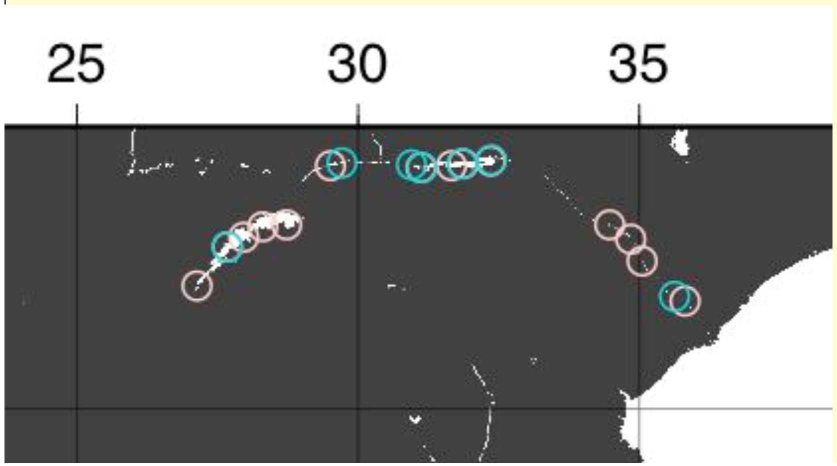


Syr Darya: ERS-2 (1995-2003)

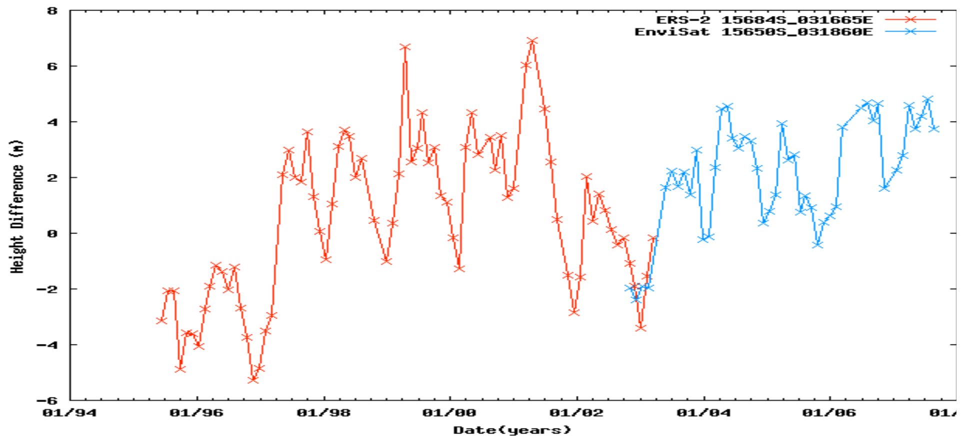


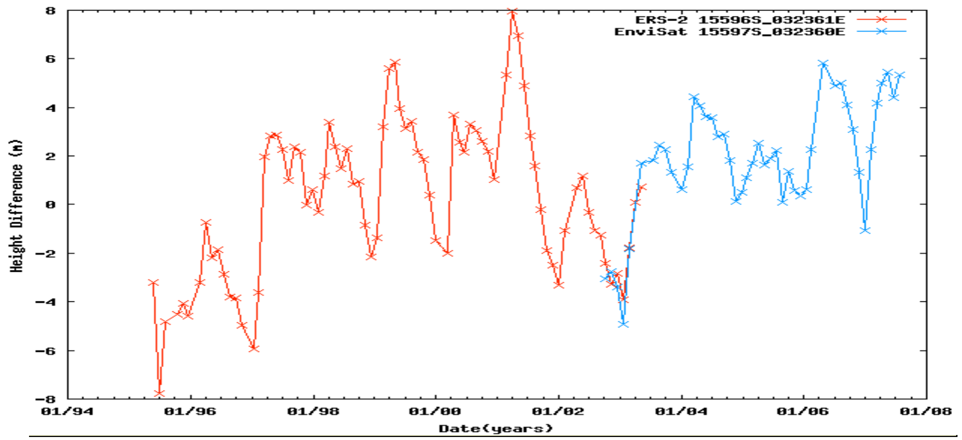
Zambesi

- The Zambezi River is the fourth largest in Africa, flowing eastward for more than 2’800 km from the Kalene Hills in northern Zambia to its mouth at the Indian Ocean in Mozambique. It has an approximate catchment size of 1’570’000 km2.
- One of Africa’s most heavily dammed river systems

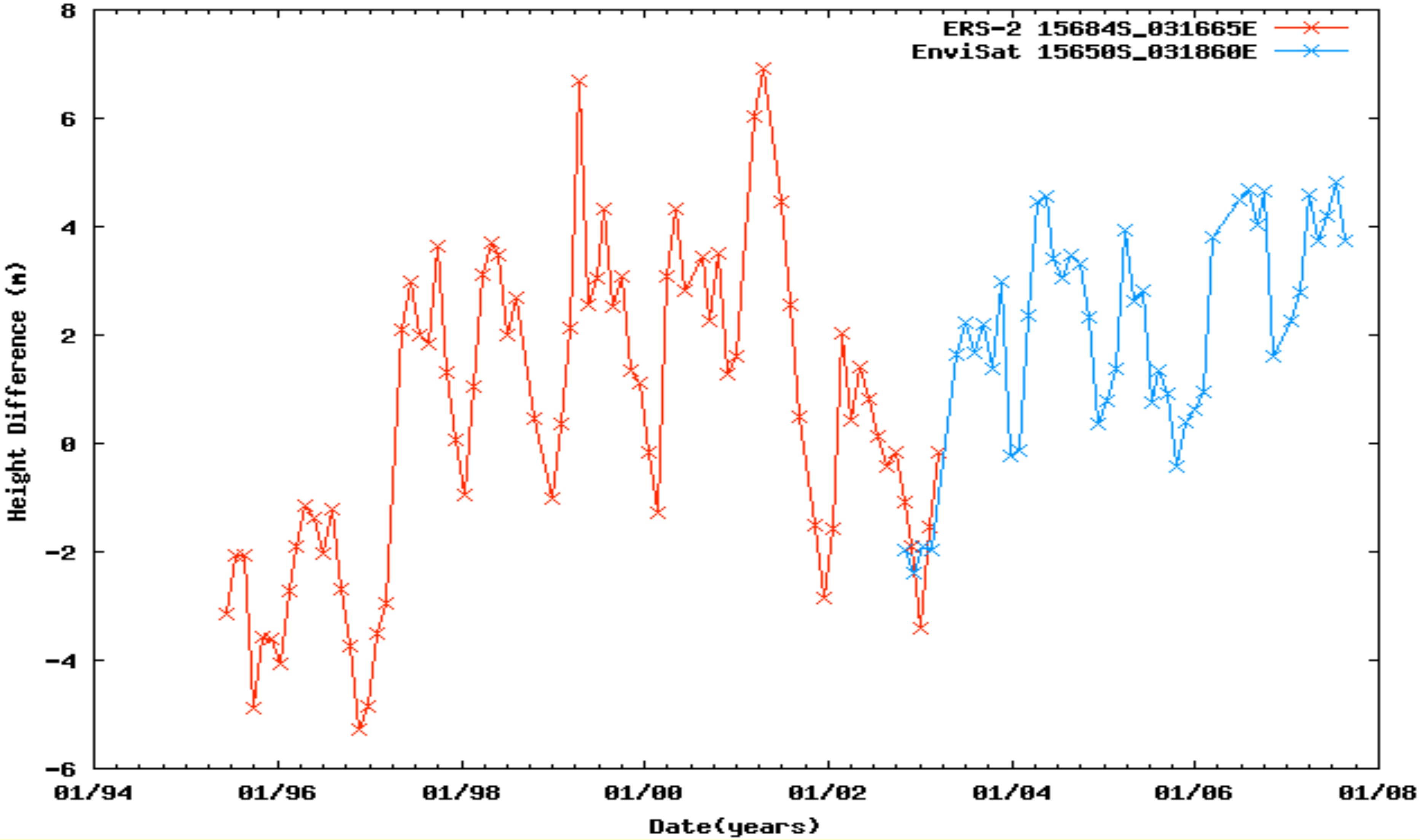


Combined time-series from ERS-2/ Envisat and Topex/Jason-1 (where possible!) will be used. Below (click to zoom) are two combined ERS-2/ Envisat time-series over the Zambesi.



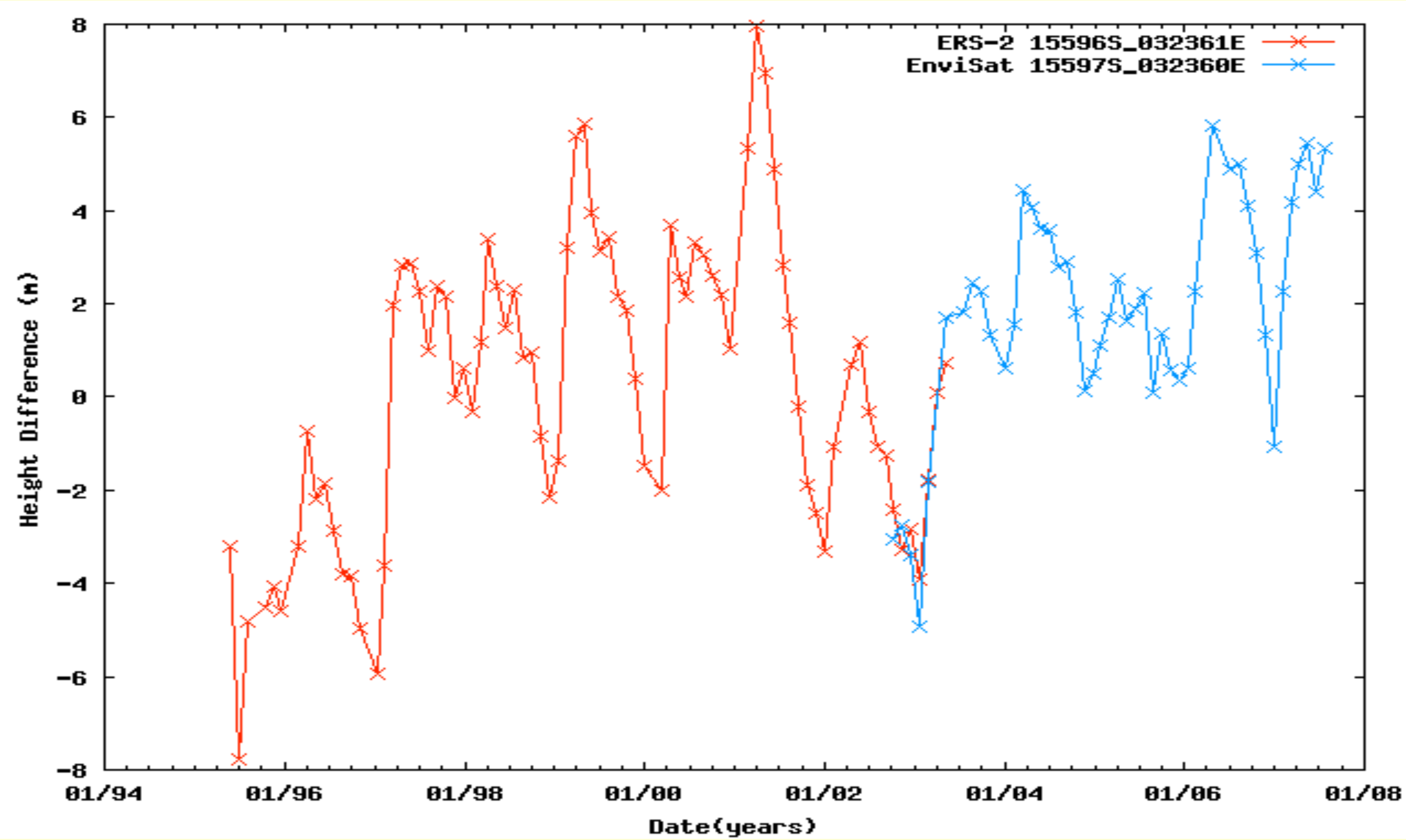


Zambesi



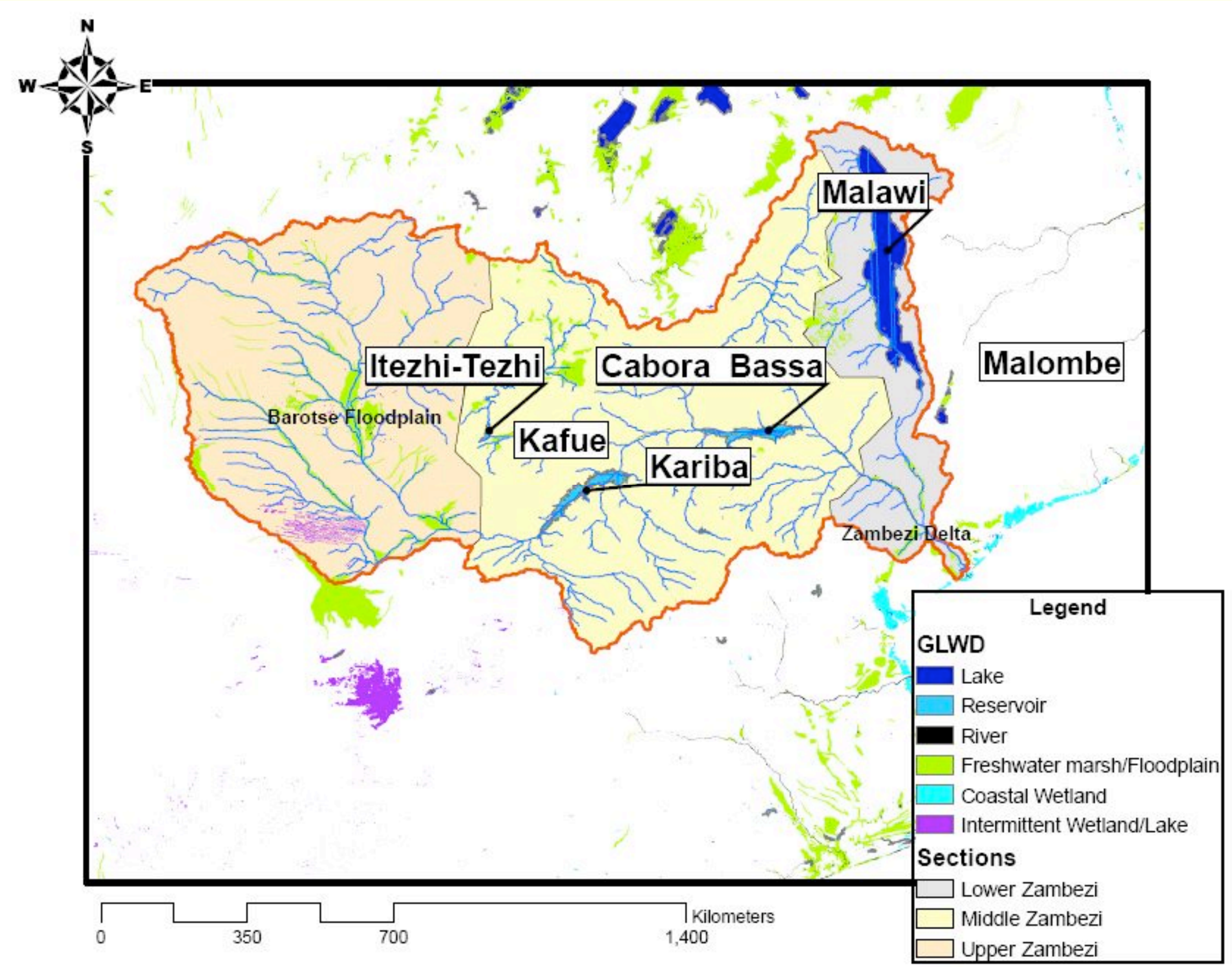
ERS-2 15684S_031665E
EnviSat 15650S_031860E
Height Difference (m)
8
6
4
2
0
-2
-4
-6
01/94
01/96
01/98
01/00
01/02
01/04
01/06
01/08
Date(years)

Zambesi

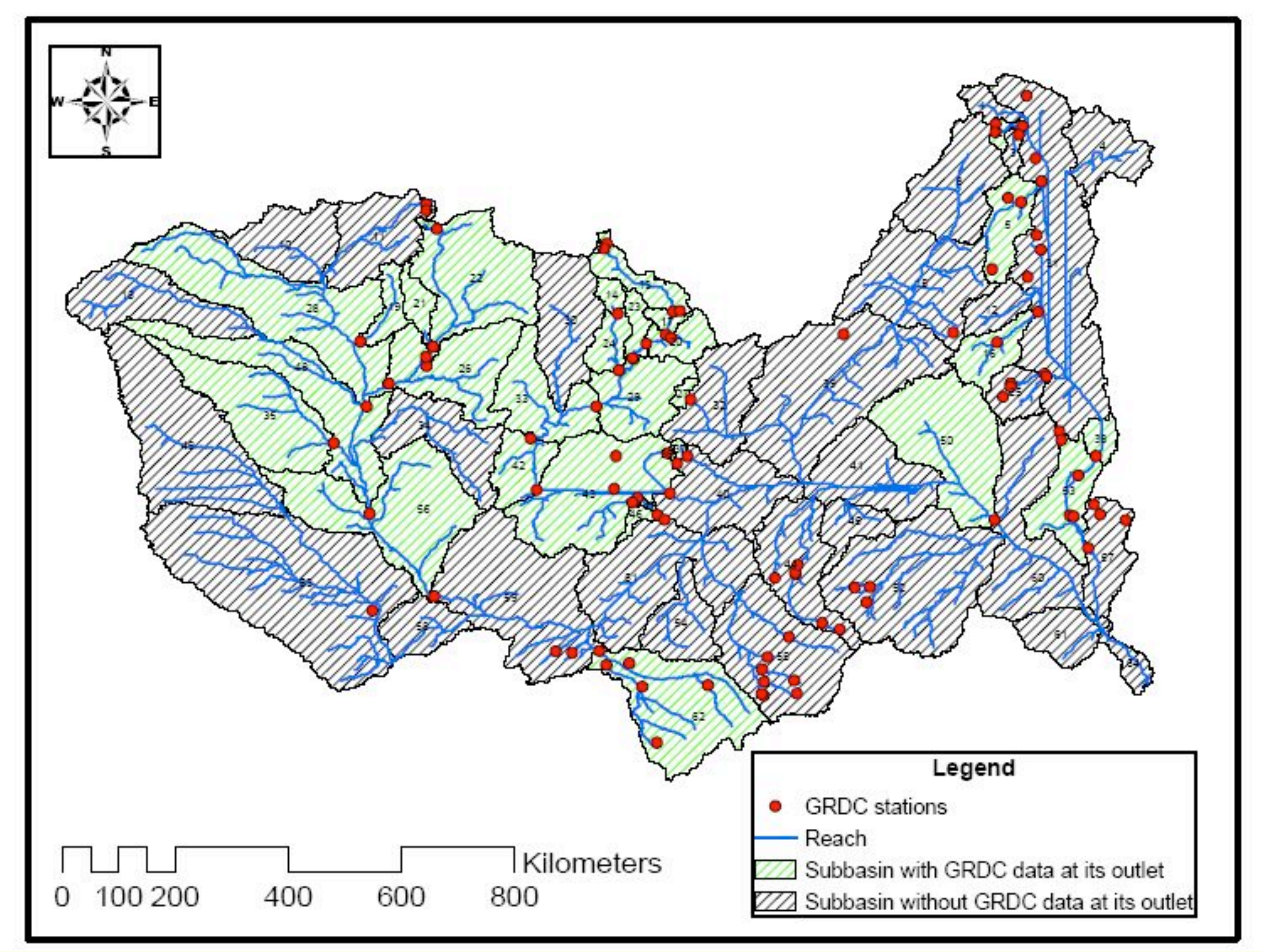


ERS-2 15596S_032361E
EnviSat 15597S_032360E
Height Difference (m)
8
6
4
2
0
-2
-4
-6
-8
01/94
01/96
01/98
01/00
01/02
01/04
01/06
01/08
Date(years)

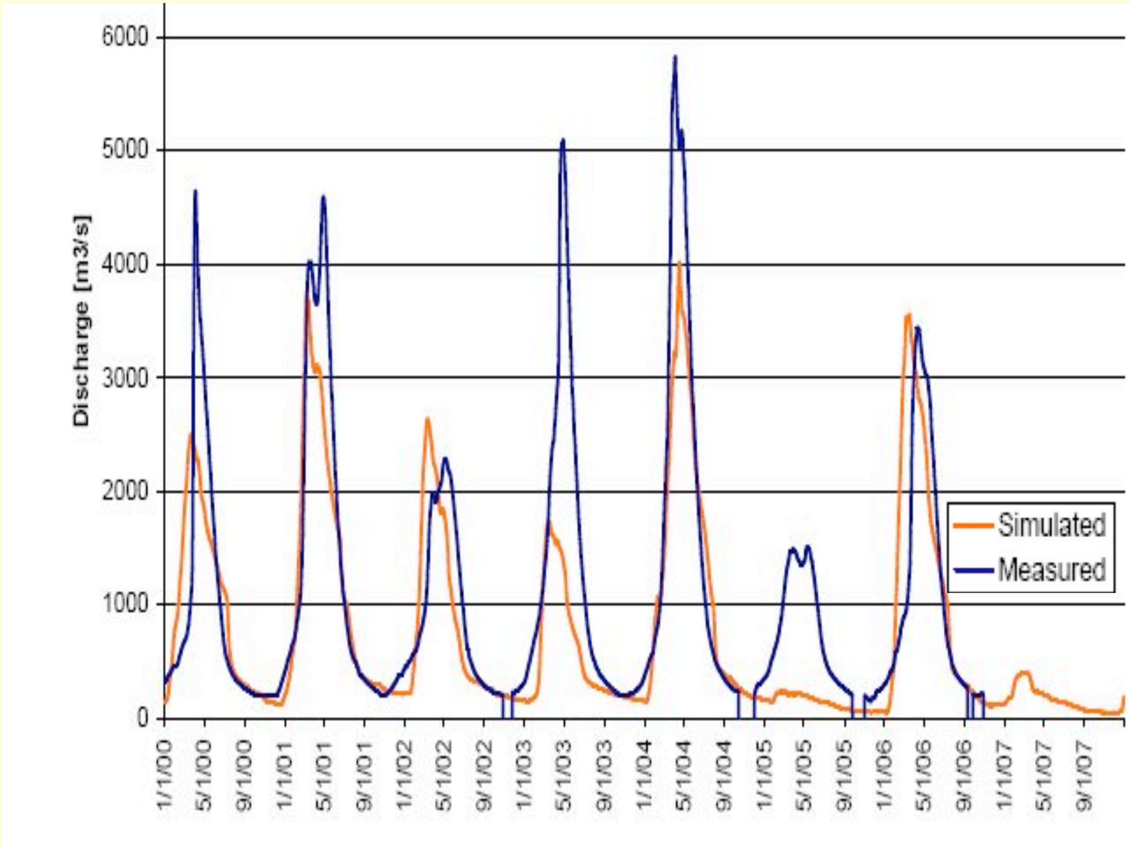
Zambezi River Basin



Zambezi SWAT Model Setup

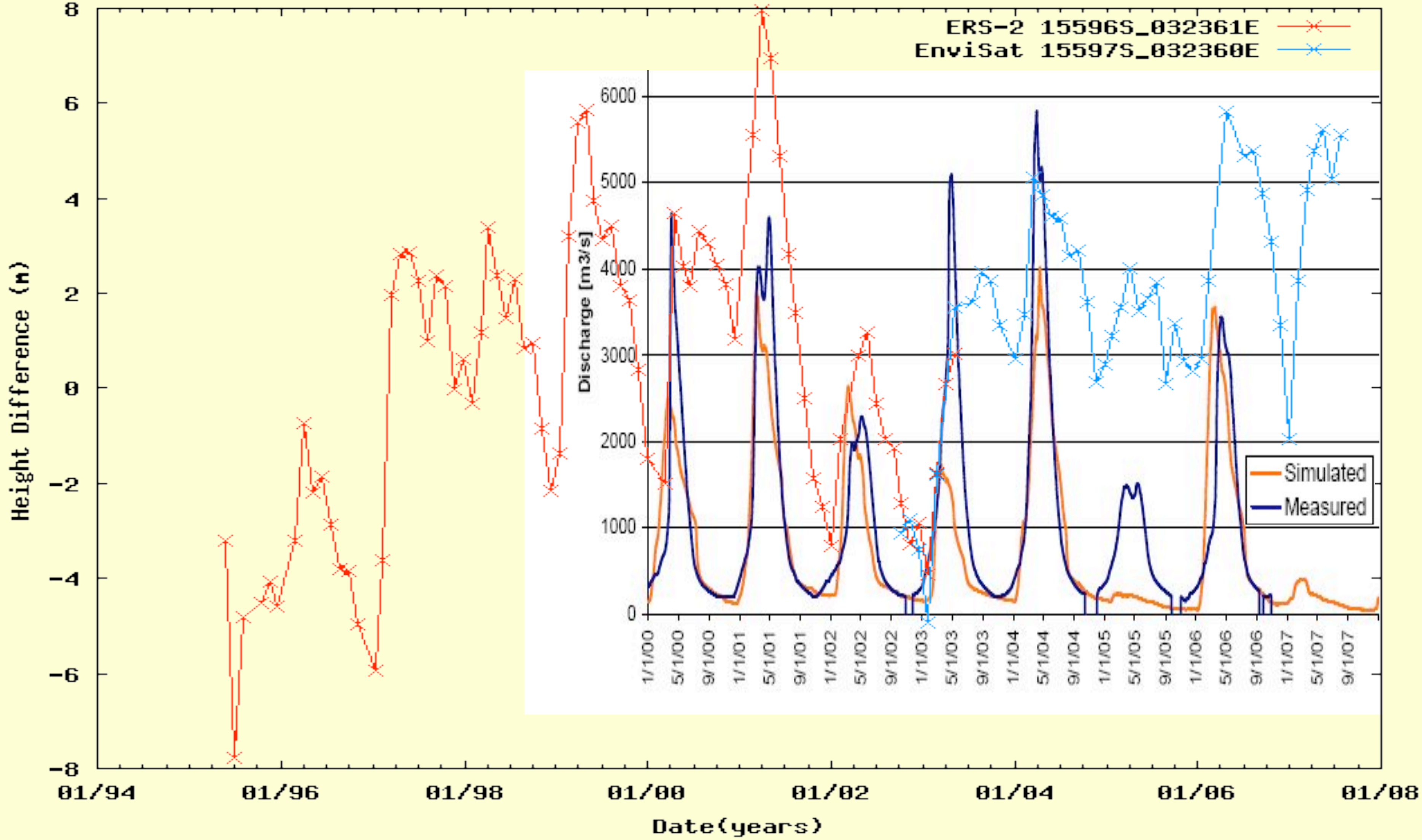


Zambesi River Basin Model



Sample model performance on discharge

Zambesi



visual comparison of 1 river-crossing stage and catchment discharge
next step is to model stage-discharge relations

Water Storage in the Amazon Basin from GRACE gravity and Satellite Altimetry

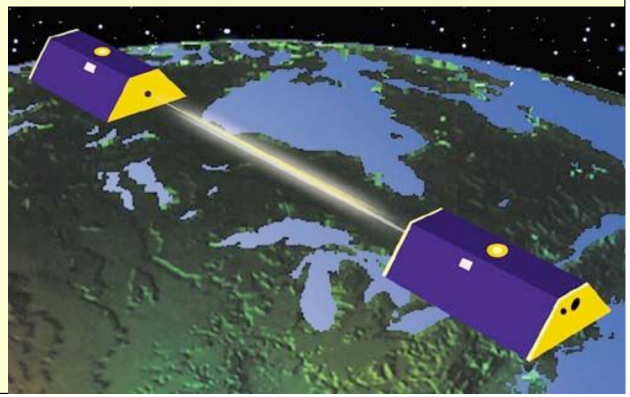
Goal is to study variation of water-storage in the Amazon.

Ultimate goal is to use Altimetry and GRACE to get ”sub-surface” terrestrial water storage.

NASA/GSFC GRACE Mascon registers the total amount of water and it’s changes.

The EAPRS retracked ERS-2/Envisat satellite altimetry register the changing heights of the water in the rivers and tributies.

We compare the variation on monthly-annual scales.



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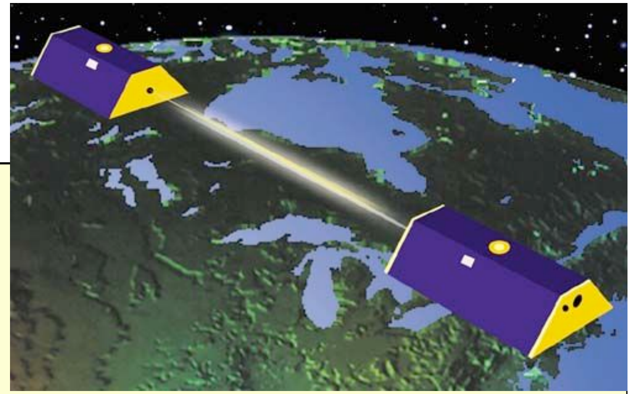
NASA/GSFC GRACE MASCONS



- Processed GRACE level 1B Data from July 2003 - Dec 2004
- Upgraded atmospheric series, improved ocean tide models, improved processing.
- Mascons solved on a 4ºx4º grid **every ten days**, where sufficient data were available to construct a solution.
- Apply a spatial & temporal constraint of the form: $e**(2-d_{ij}/D-|t_{ij}|/T)$ where d_{ij} and t_{ij} are the distance and time differences between the mascons, where T and D are the correlation time and distance .
- Used T=10 days & D= 250 km.
- Mascons are computed relative to a mean background field. The 10-day regional Amazonas mascon estimates are based on two multi-period solutions: (1) July - Jan. 2004; (2) Feb. - October 2004.

  => There is a total of 52 10-day solutions in the Amazon.

  => There is 195 blocks in the greater Amazon region

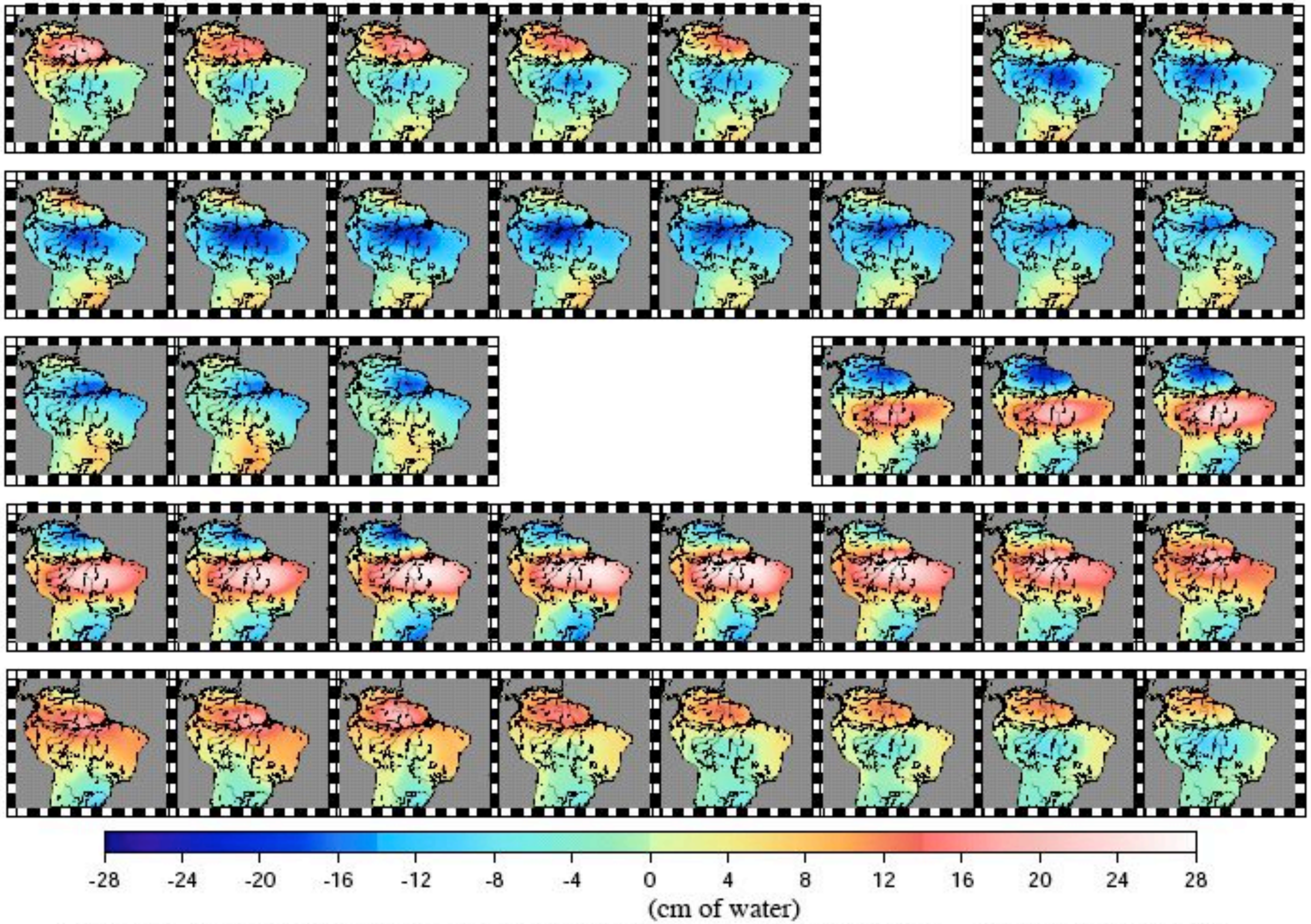
2003-
0706

2003-
0926

2003-
1216

2004-
0306

2004-
0526



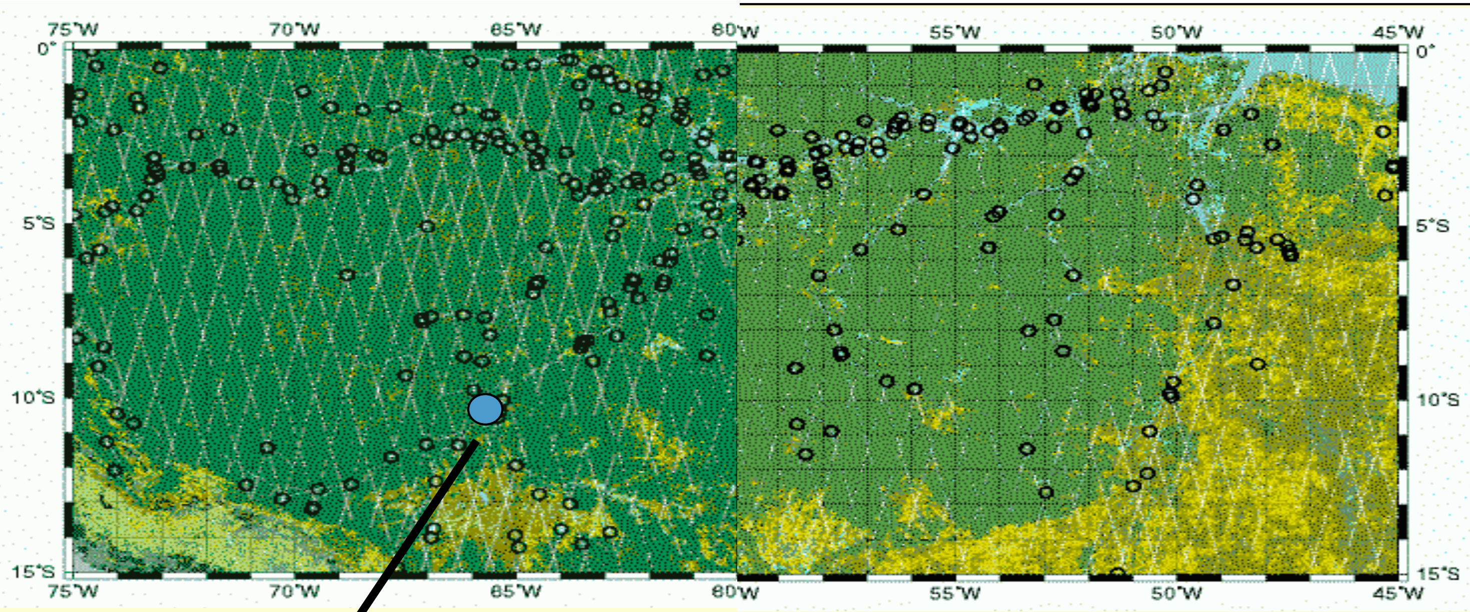
South America Mascon solutions: July 2003 - August 2004

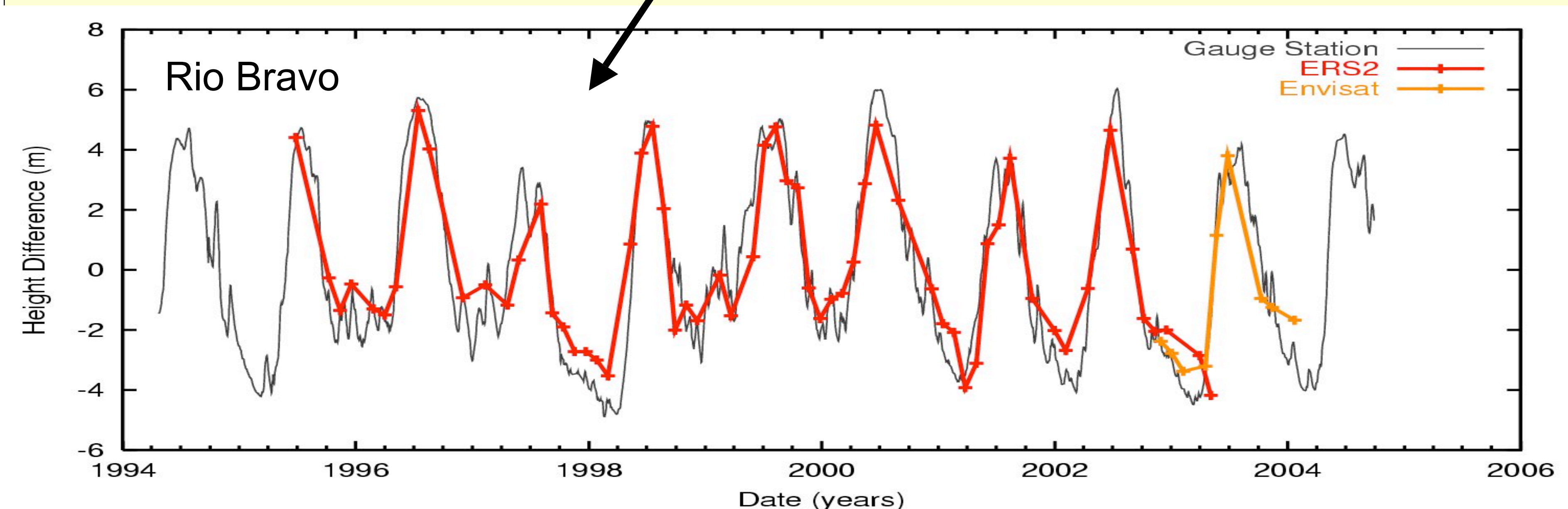
(wrt July 2003-July 2004 mean)

Altimetric Time-Series

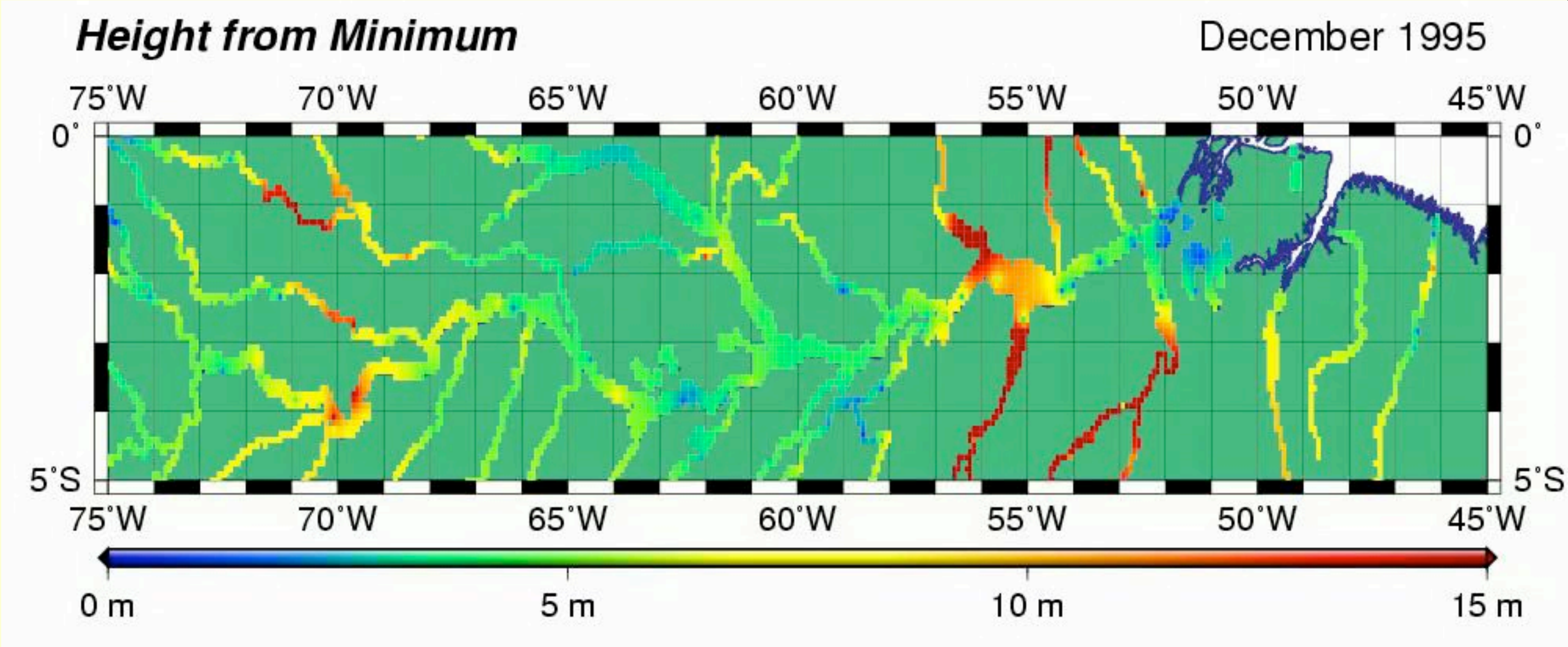
192 time series with 95% temporal coverage in the Amazon.

Interpolate to 10 days sampling

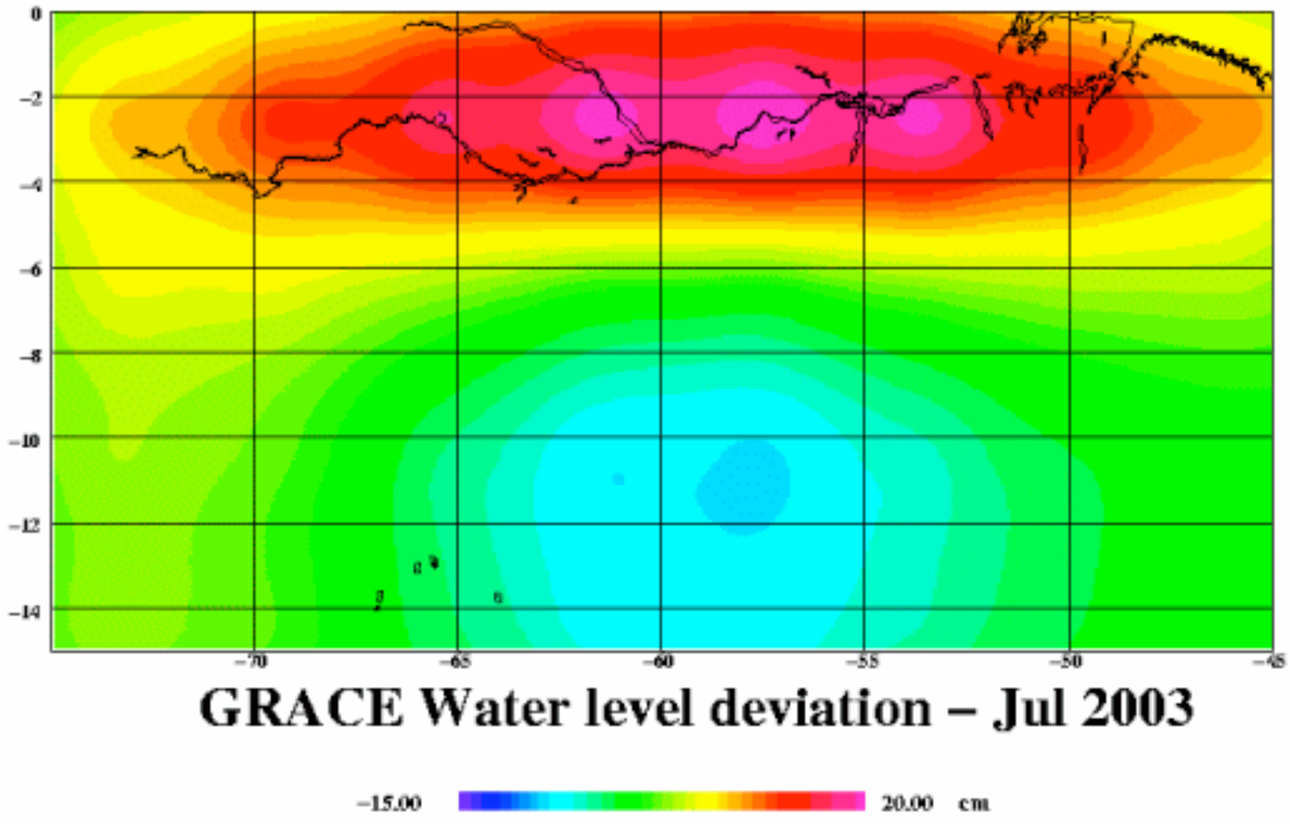




Altimetric Time-Series Animation

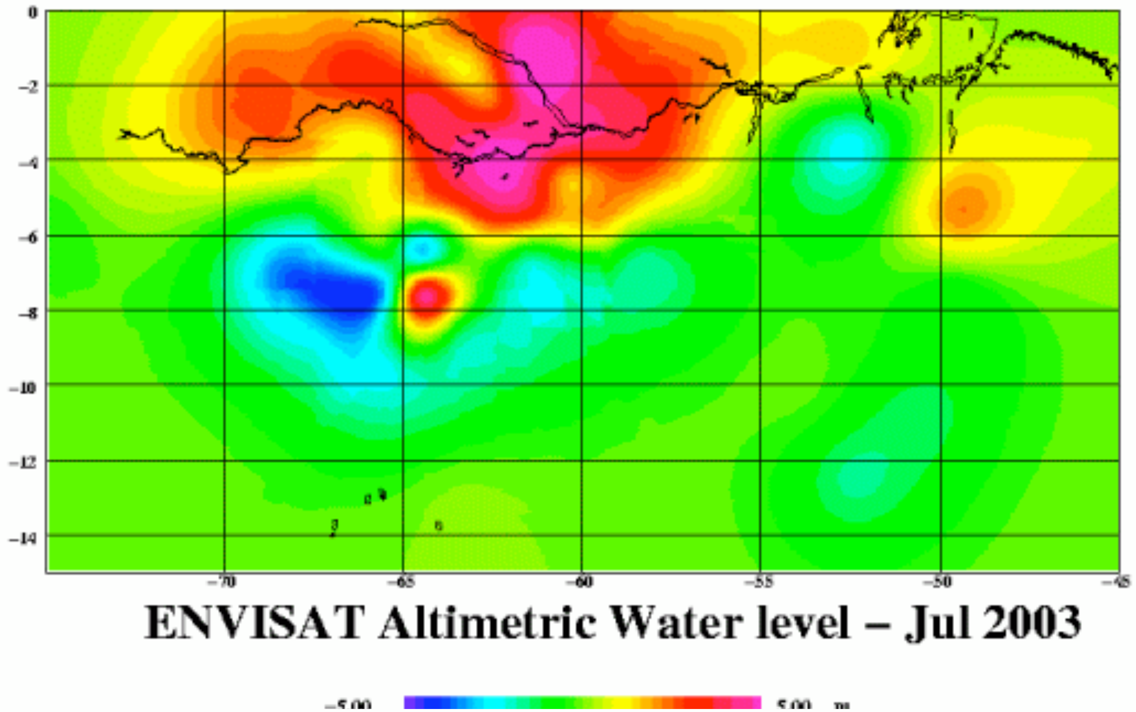


Water level time-series from GRACE



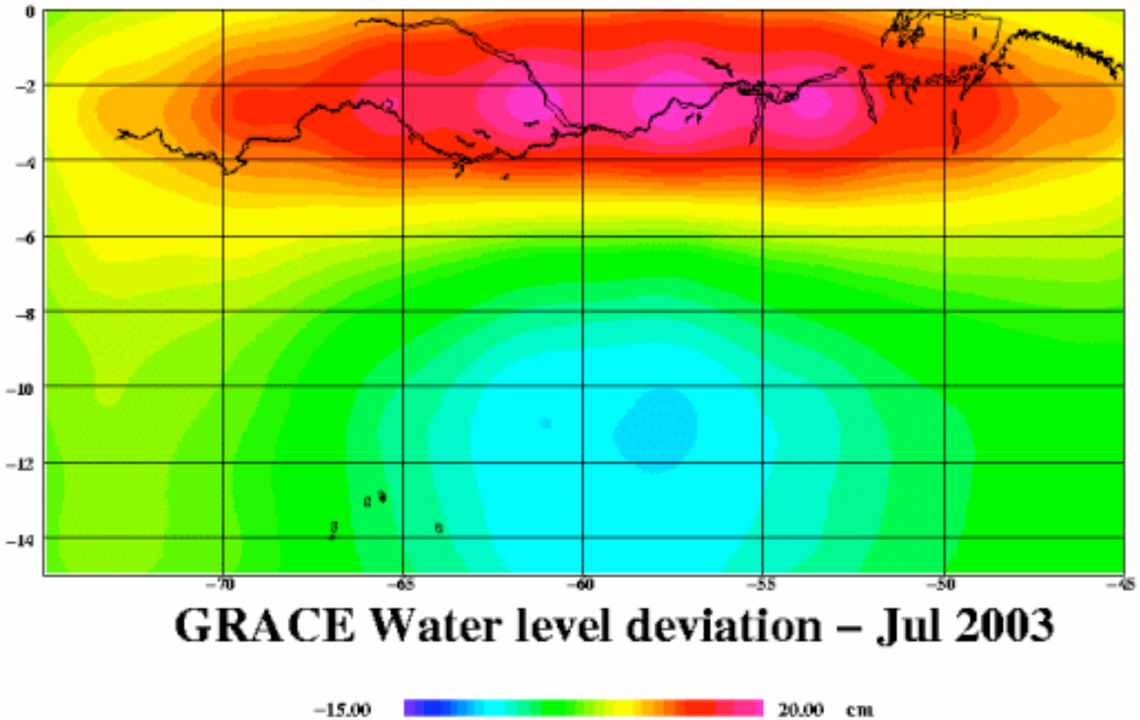
This is an animation

- ERS
- ENVISAT



This is an animation

- GRACE



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Water Storage in the Amazon Basin from GRACE gravity and Satellite Altimetry

esa

Comparison of 1.5 years simultaneous ”high resolution” water mass observations from GRACE gravity and satellite altimetry in the Amazon drainage region & rivers with 10 days temporal resolution.

- The high resolution GRACE MASCONS shows the ”propagation” of water
- The altimetric observations from ERS-2+ENVISAT shows it too.
- Altimetry and GRACE agree on phase/time of maximum annual water level
- Simplified model shows fairly similar magnitude of the two distinct sources

Conclusions

- A huge amount of waveforms are already acquired over inland water targets globally, since 1992.
- Processing these complex echoes to retrieve decadal time-series of height changes has already recovered information over hundreds of targets worldwide.
  ADAPTED RETRACKING IS ESSENTIAL
- With applications ranging from near-real-time monitoring for water resource management to decadal climate change indicators, and spatial scales which both allow correlations with GRACE data, and permit monitoring of hundreds of river systems, the unique contribution of satellite radar altimetry to global inland surface water monitoring and the importance of continued measurements is evident.
  INCREASED TIME SAMPLING IS ESSENTIAL

Conclusions (2)

- As in-situ gauges falls out of repair, more and more catchments are becoming ungauged, whilst the demand on water continues to escalate.
- Using the remote measurement capability of altimetry, particularly the near-real-time capability, it is now possible for water resource managers to access both the NRT data and its context -decadal historical information.
- The global monitoring capability, now being achieved using multi-mission satellite radar altimetry, reveals changing patterns of use, as stress on water resources increasingly depletes drainage basins beyond their capability to recharge.
- The technology can be applied as well in the oceanic coastal zone (similar difficulties in retrieval due to contamination by surrounding land)

Conclusions (3)

- The scientific challenge is to fully extend to the global inland water bodies and the coastal ocean the success of altimetry in monitoring the global open ocean. To satisfy hydrologist requirements we need:-
  1) better techniques on current instruments;
  2) better instruments for the future;
  3) better spatial/temporal sampling
     (this will require new technology or constellations as proposed by CEOS Strategic Implementation Team)
  4) integration of measurement and forecast systems
     (satellites, river gauges, discharge and current meters, tide gauges, hydrographic measurements, models).

Conclusions (4)

- In Hydrology and coastal altimetry cooperation is essential at EU level, but even globally, as the problems are global and the expertise needed is interdisciplinary and geographically distributed.
- The best excellences need to be networked and complementarities exploited. This is actually happening and needs to be sustained with adequate funding.
- Europe however is leading the field of altimetry for hydrology and coastal zone oceanography (important investments) and should endeavour to retain this role as a key player on the international scene.

Conclusions (5)

- Concerning instrument data processing and auxiliary corrections, an active network is required for gathering local data,
  - for altimeter measurement corrections and validation,
  - to be patchworked into a global product,
  - for inland water, estuaries and oceanic coastal zone.