Current and Future Satellite Radar Altimetry Missions for Hydrology and the River&Lake Project

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European Space Agency

Contributions from:

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Peter Bauer-Gottwein, Danish Technical University

Anny Cazenave & Jean-François Crétaux

Abstract

EGU GIFT-2009 LECTURE

Current and Future Satellite Radar Altimetry Missions for Hydrology and the River&Lake Project

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Since the launch of the altimeters on-board ERS-1 and TOPEX/POSEIDON 17 years ago, significant advances in all facets of Radar Altimetry have resulted in a height accuracy over the open ocean to the cm level. Thanks to advances in the processing of Radar Altimetry data, results are now obtainable over surfaces for which the instruments were not designed. The Radar Altimeter was designed to operate over the oceans and continental ice caps; however echoes are now successfully being processed from within the continental landmasses. Over inland water bodies such as Rivers and Lakes, the measurements of both the Radar Altimeter and Radiometer are degraded by the presence of land; however it is recognized by the global community that useable results can be obtained in Continental Hydrology by dedicated reprocessing of the raw altimeter measurements and careful use of environmental corrections. The European Space Agency has launched a research initiative, "River&Lake", focused on developing two special user products, one aimed at hydrologists and the other at altimeter specialists. This paper will report upon the strategic outlook for exploiting the current and future potential of Radar Altimetry missions. Particular attention is paid to their support to Hydrology, their mission requirements and the potential evolution of the River&Lake products, currently at the stage of a pilot demonstration experiment. Important progress have been made recently in using Satellite data for Hydrology, juxtaposed with in-situ data and the modelling effort.

http://earth.esa.int/riverandlake , http://earth.esa.int/hydrospace07

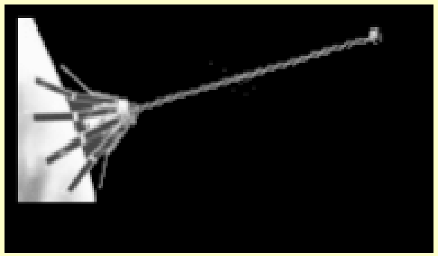
Introduction

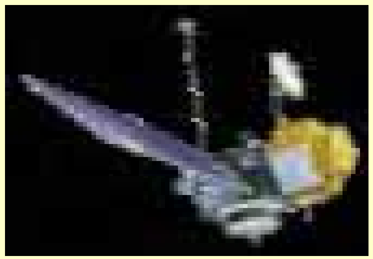
- The effective management of the Earth's inland water is a major challenge facing scientists and governments worldwide.
- However, whilst demand for this often scarce resource continues to grow, the number and distribution of in-situ hydrological gauge stations is steadily falling and many catchments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

Introduction

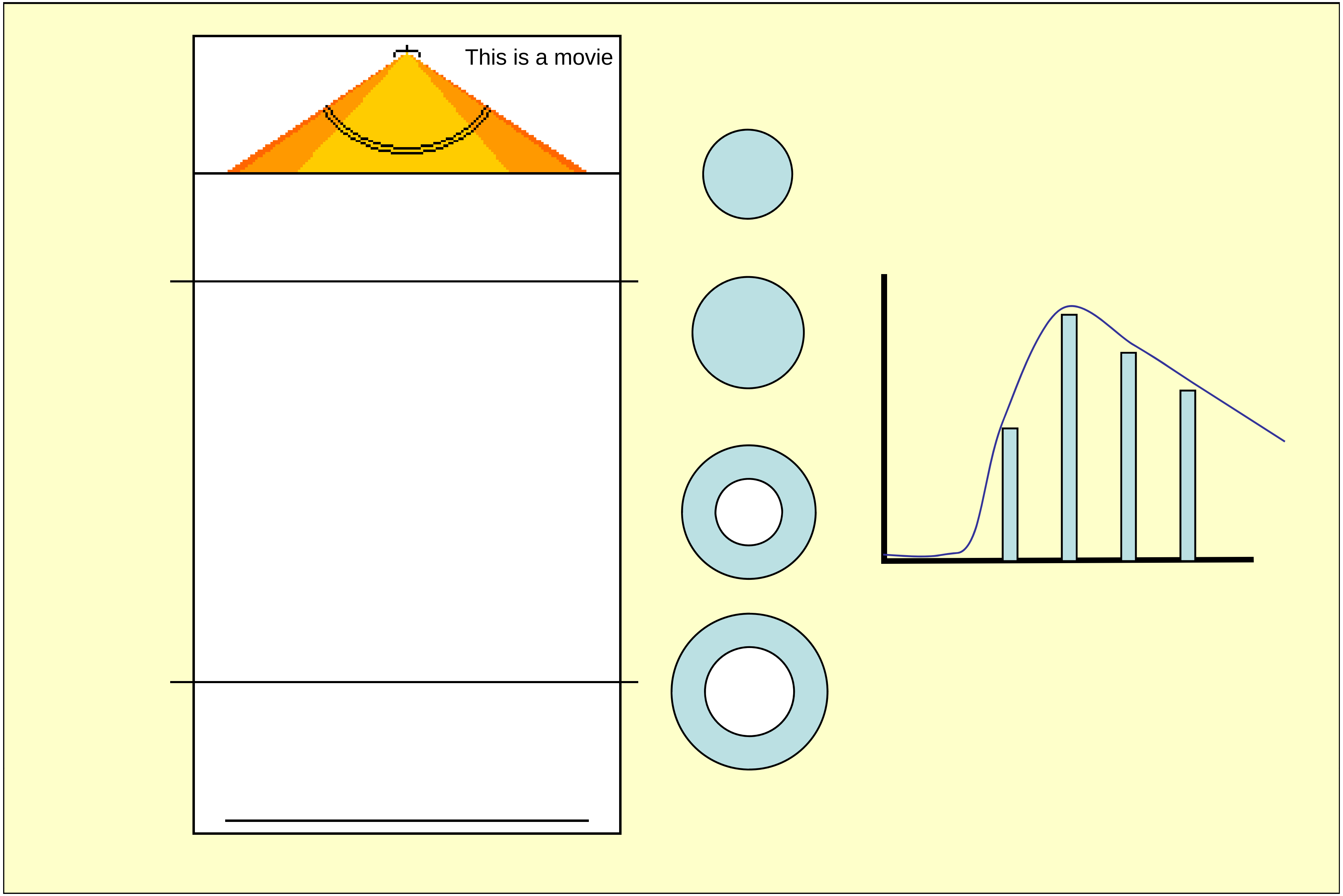


- Satellite radar altimeters have been collecting echo series over inland water for more than 17 years.
- But only a tiny fraction of these data have been successfully mined for information on river and lake heights

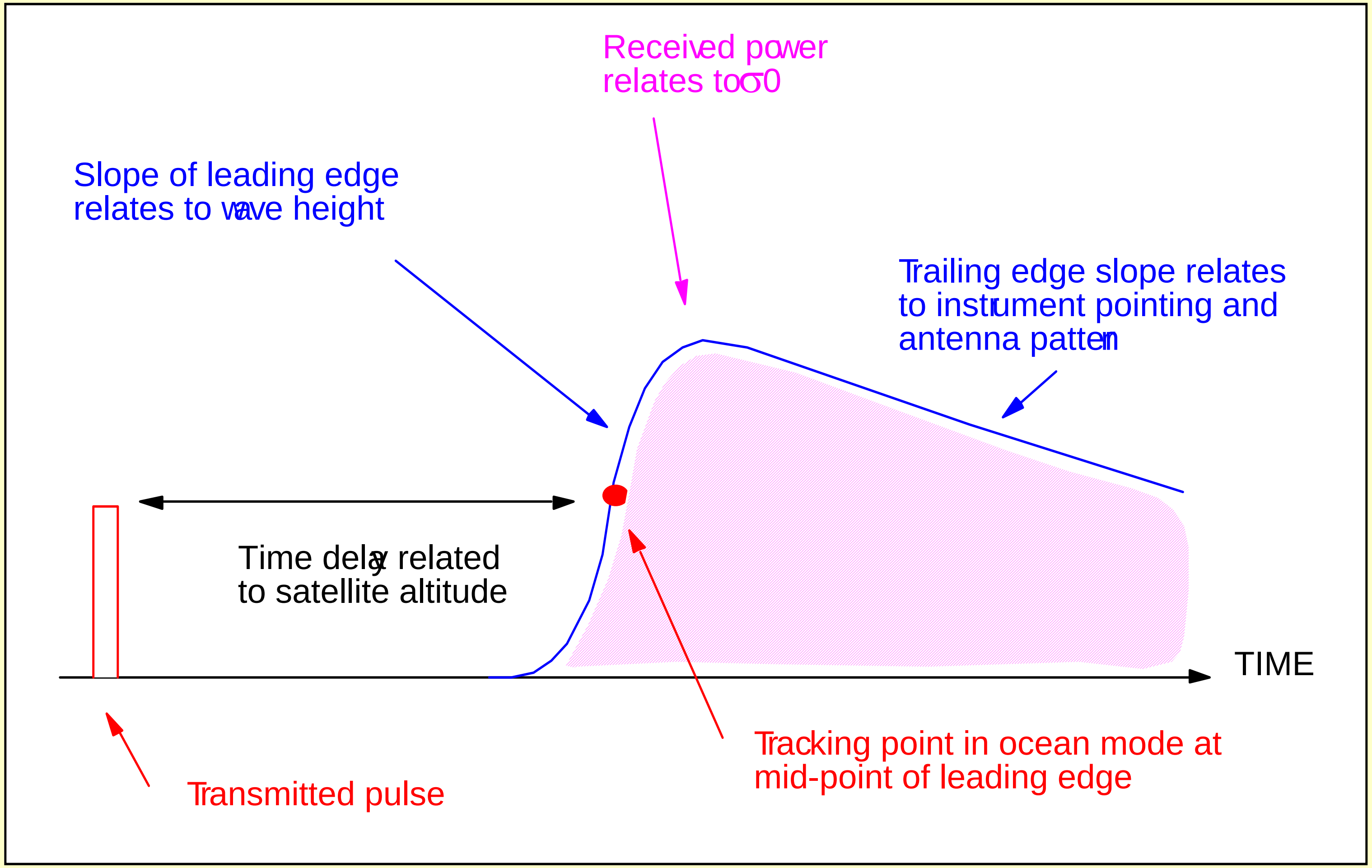




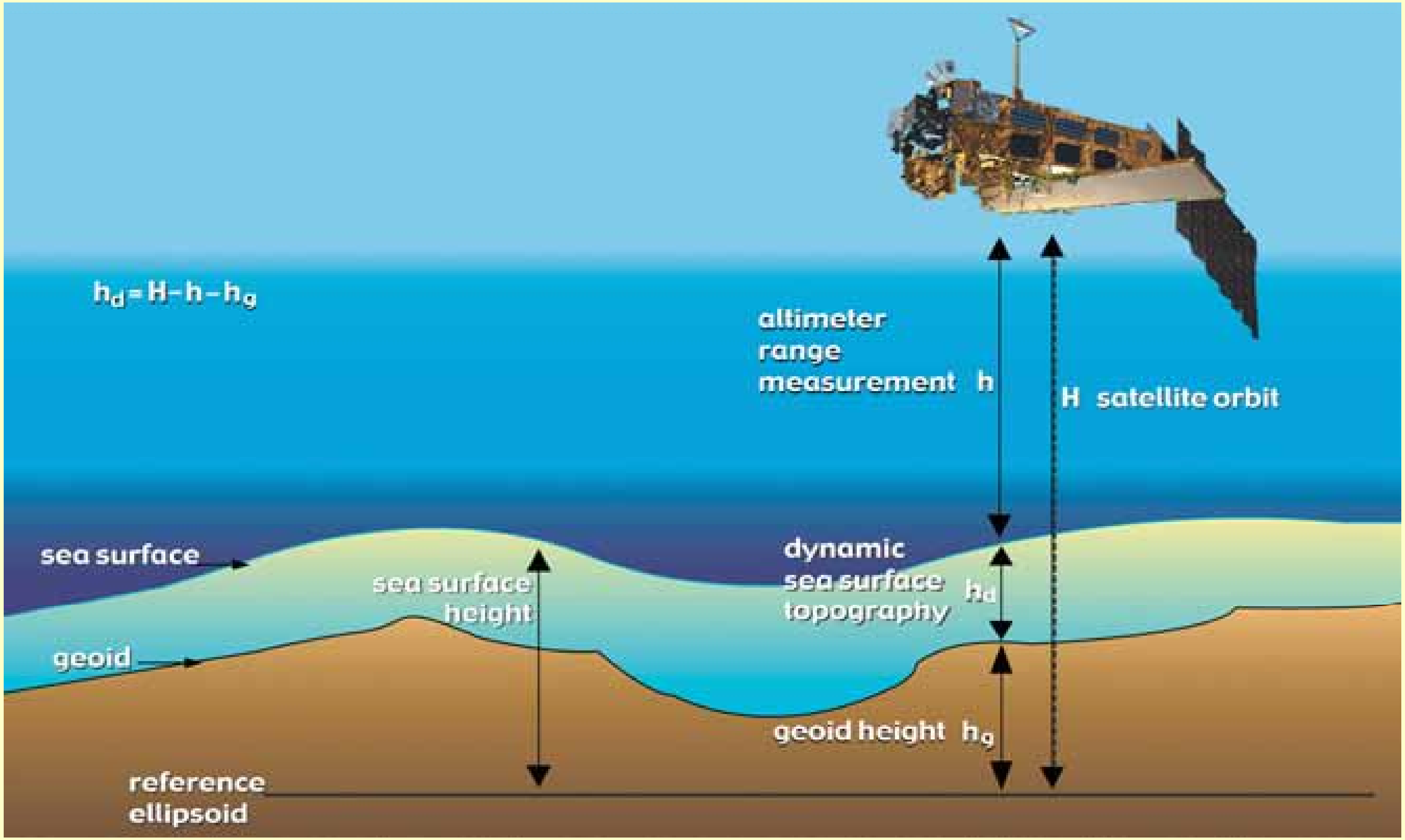
Radar Altimetry Principle



Return Power Waveform



Radar Altimetry Principle



Vertical Datum Applications

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

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

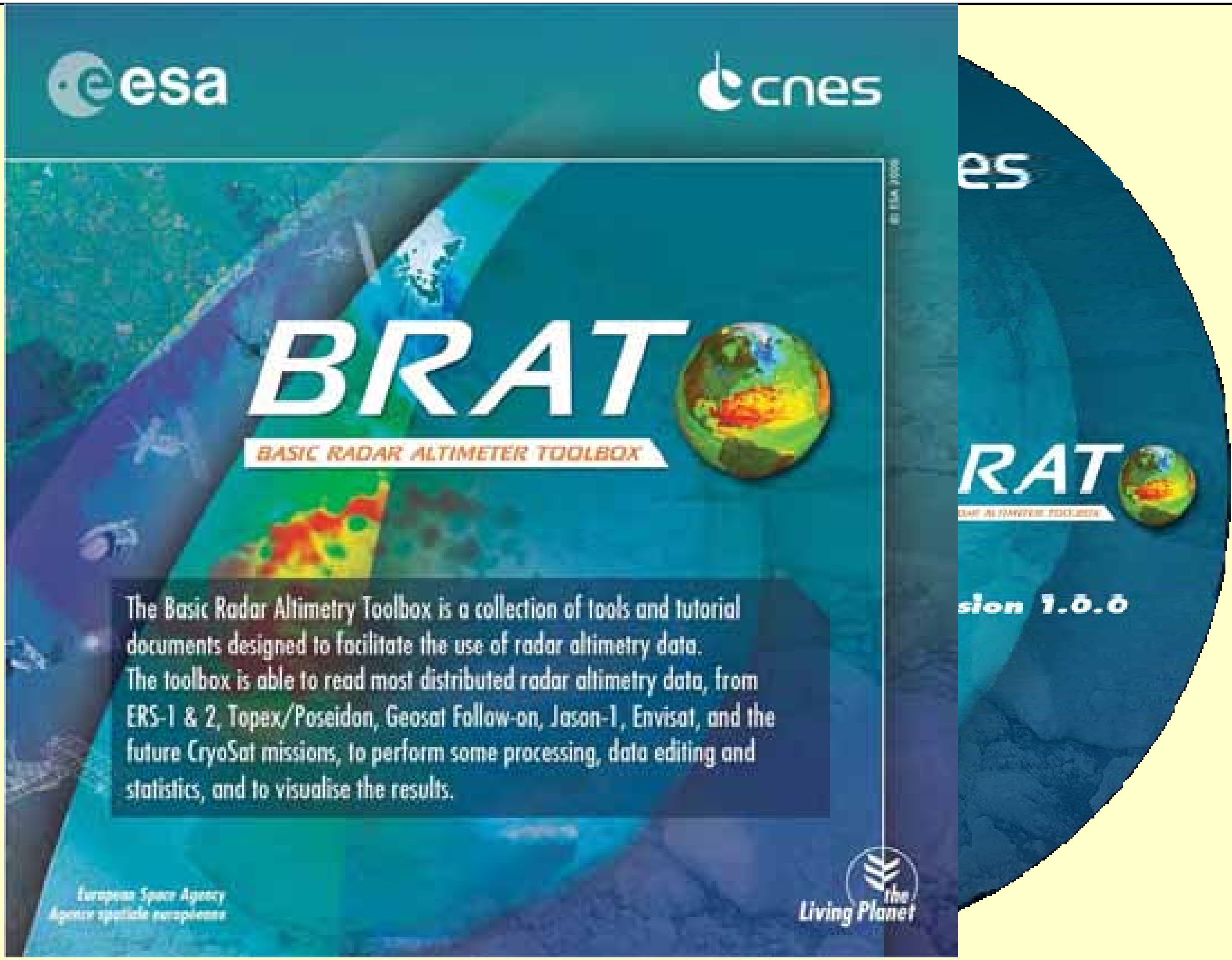
  with
  S_g = Geoid signal
  S_s = Stationary signal
  S_v = Variability
  S_t = tides signal
  E_0 = Orbital error
  E_r = remaining errors and corrections
  (solid tides, loading effect, inverse barometer effect,...)

- 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

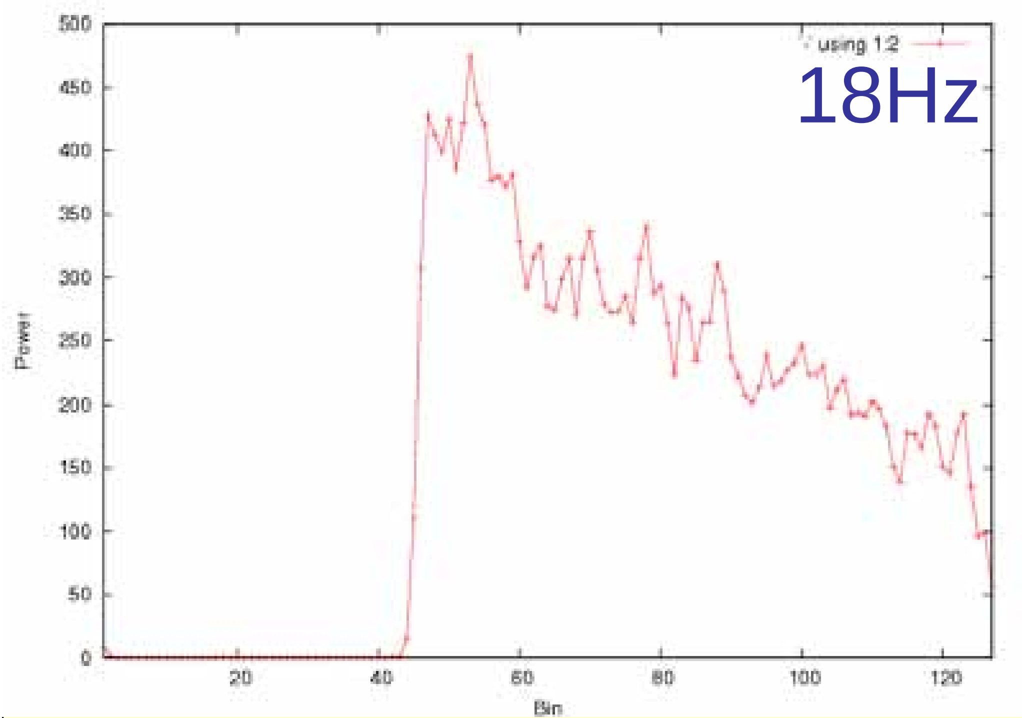
- Glaciology
  - DEM, Delta-DEM
  - Input data for forcing, initialisation or test of ice flow dynamic models
  - Long term monitoring of the topography for seasonal or secular variations.
  - Sea-ice thickness
- Land topography
  - Global DEM obtained from the full 336 days of the ERS-1 geodetic phase (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

The Radar Altimetry Tutorial

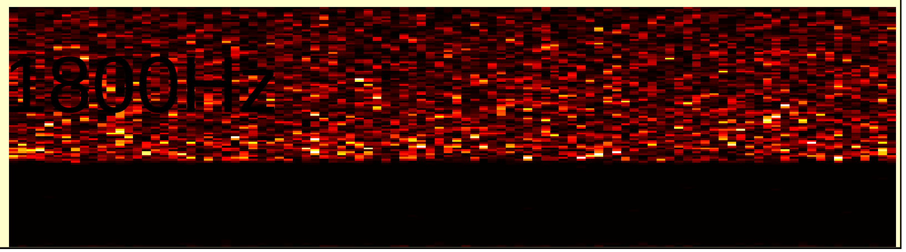


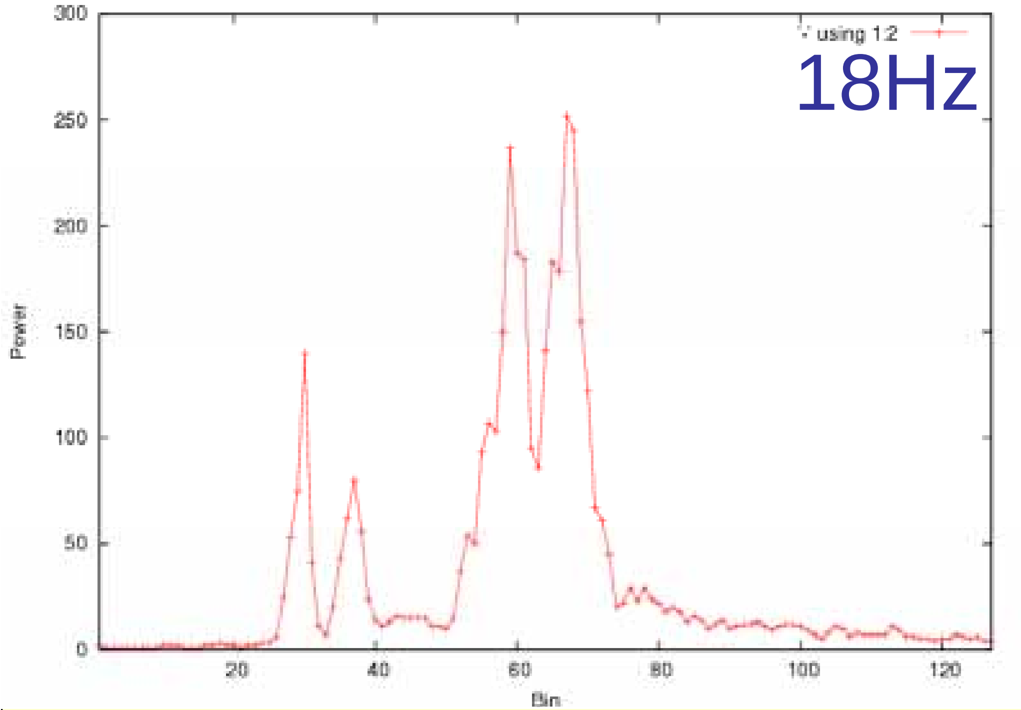
1800Hz

QuickTime™ and a
None decompressor
are needed to see this picture.

Information content of ocean like waveforms

- Top picture shows one EnviSat ocean waveform
- Lower movie shows the 1800Hz waveforms averaged to make the upper picture



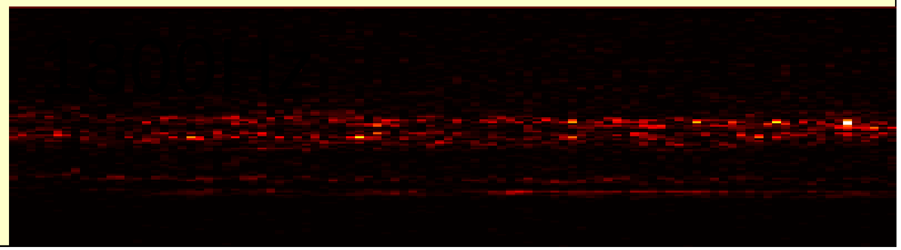


1800Hz

QuickTime™ and a
None decompressor
are needed to see this picture.

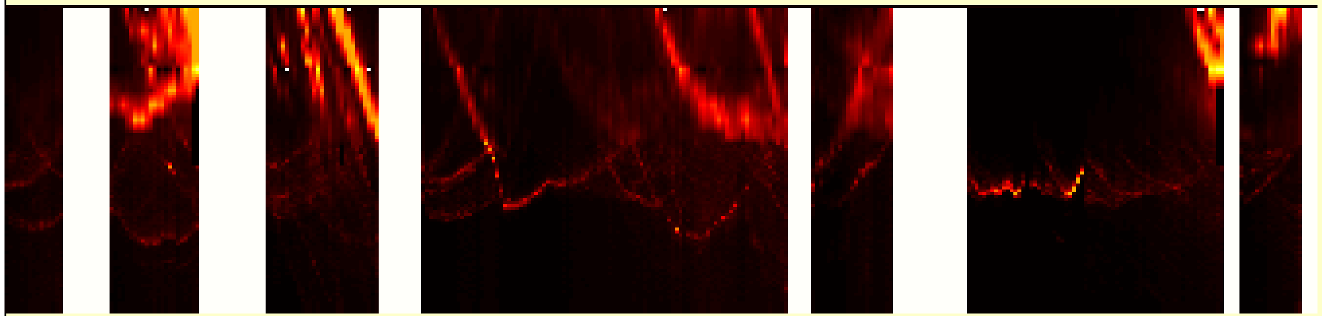
Inland water waveform

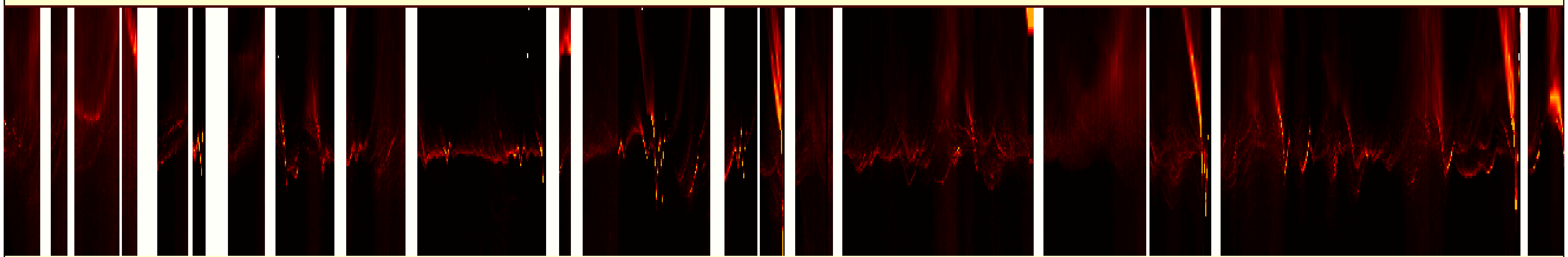
- Inland water waveforms show more coherent features than their ocean counterparts.
- So averaging to 18/20Hz loses significant information.



Retracking

- Key to turning waveforms into useable height measurements is retracking.
- But echoes from inland water complex in nature, as illustrated below in sequences from Jason-1 over the Congo river system (white are data gaps).



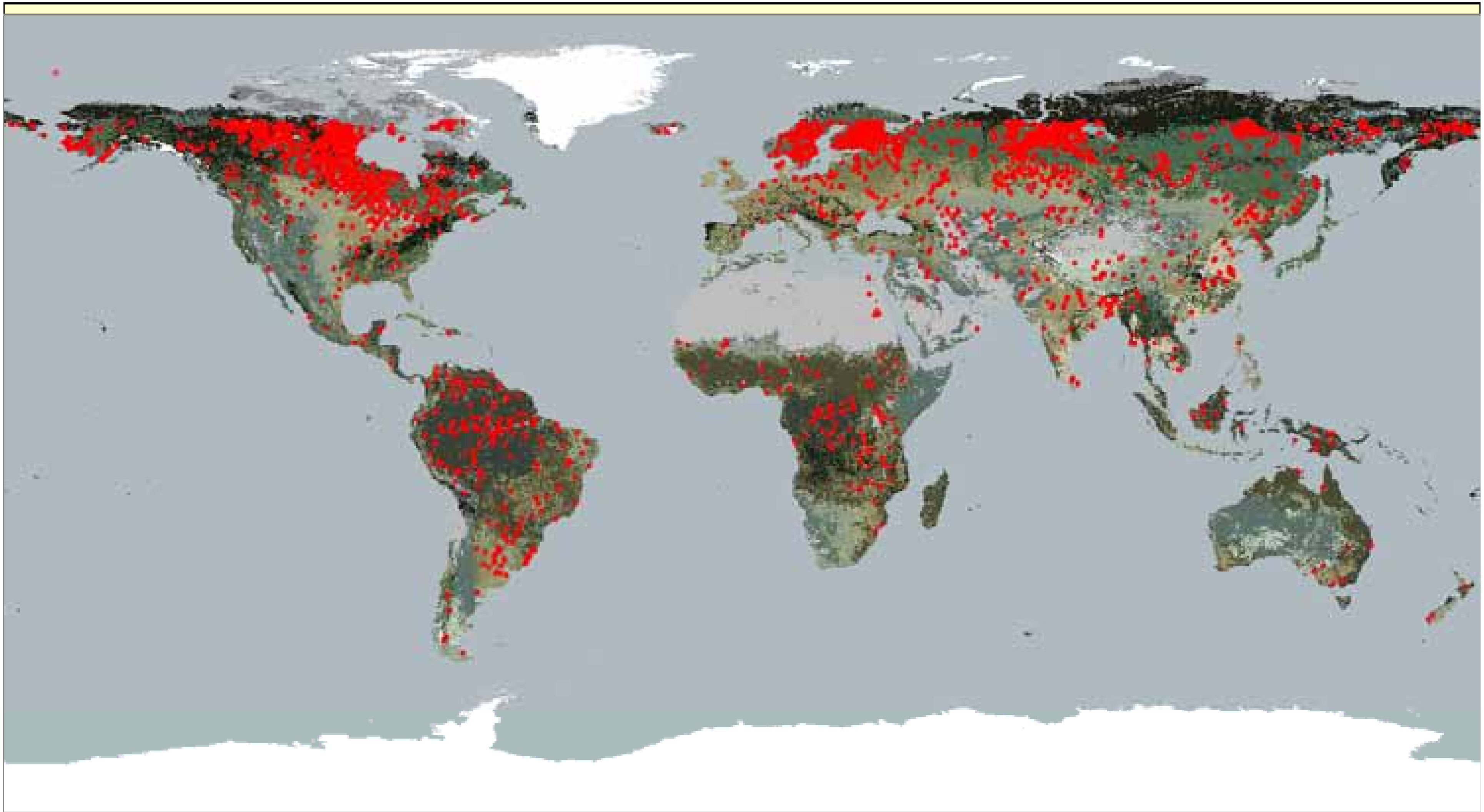


Current capabilities

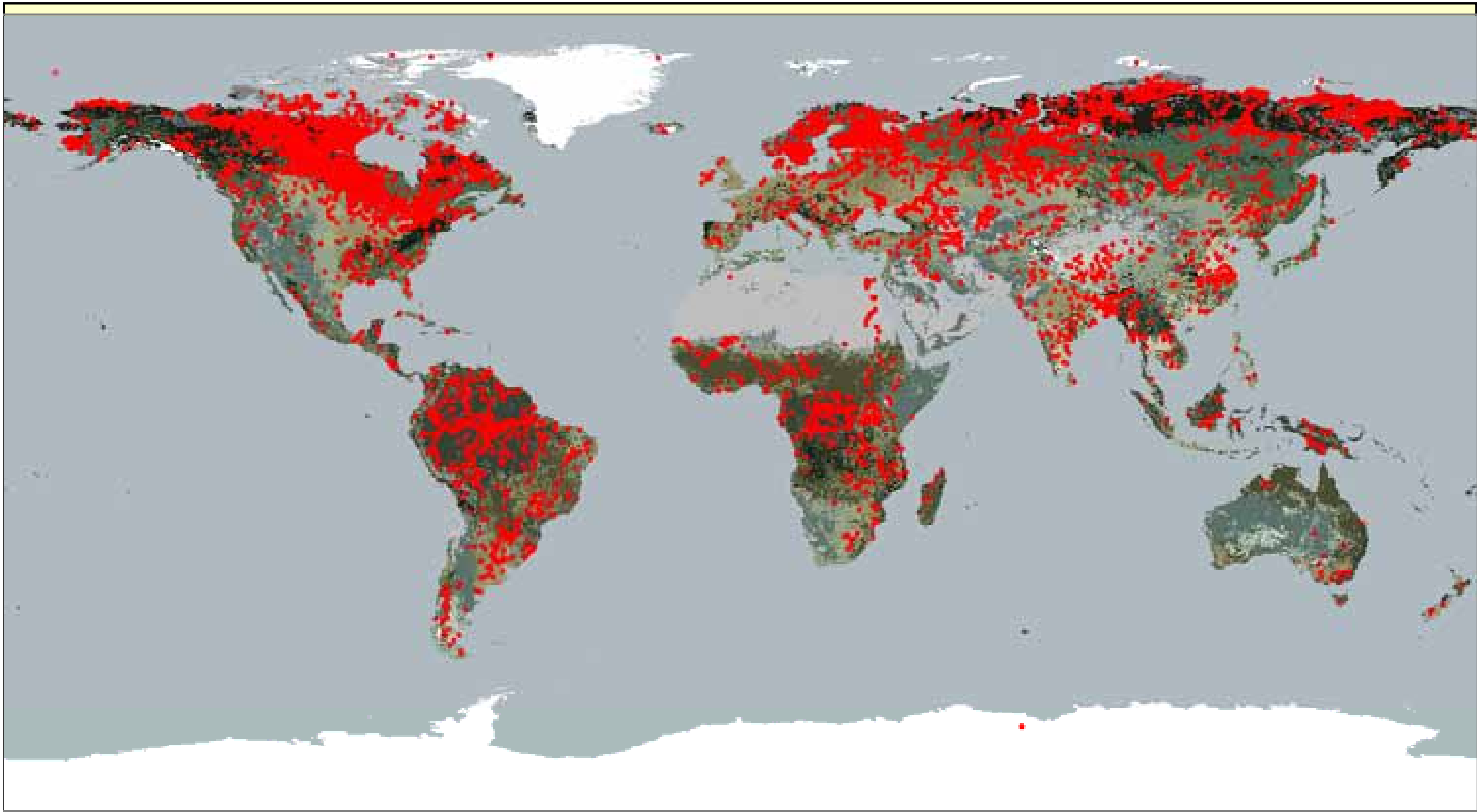
So what can the current generation of altimeters recover over inland water?

- Huge global analysis carried out of waveform recovery over inland water from ERS-2, TOPEX Jason-1/2 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 <u>one red dot for each crossing flagged</u>.

TOPEX Global Targets

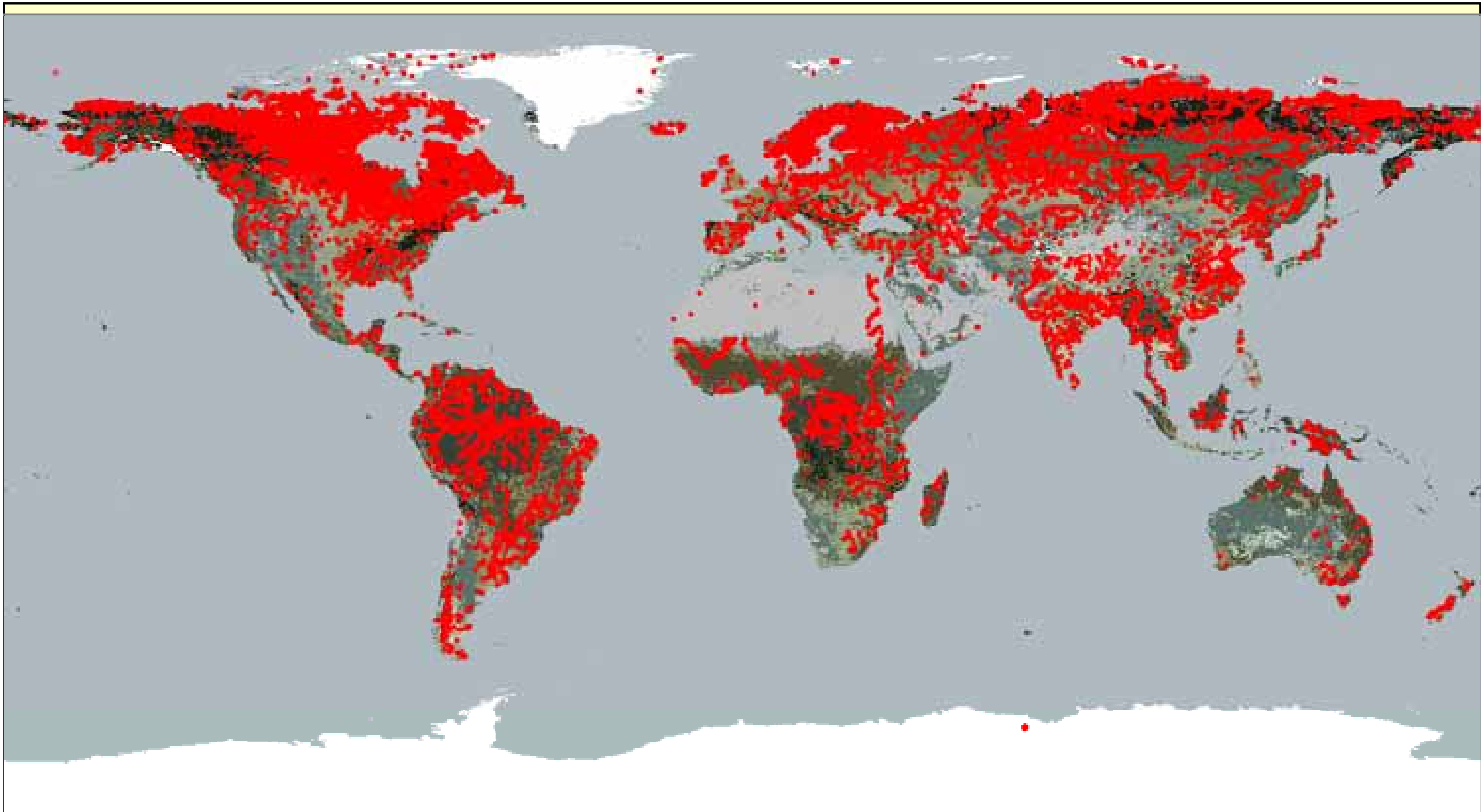


ERS-2 Global Targets



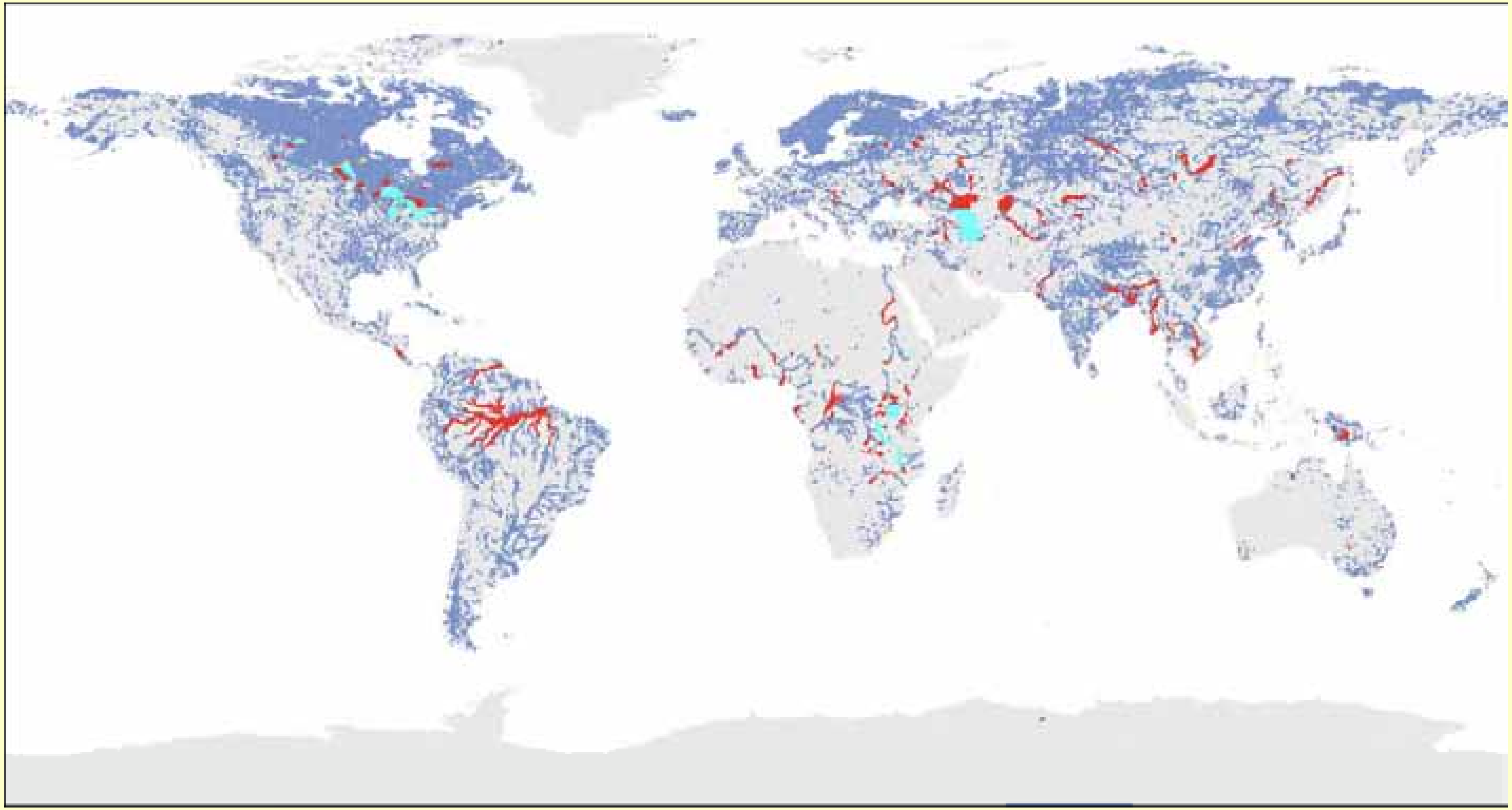
- Increase only partly due to 35 vs 10 day orbit: more to ERS-1/2 RA ability to maintain lock AND the wider ‘ice mode’ range receiving window

Envisat Global Targets



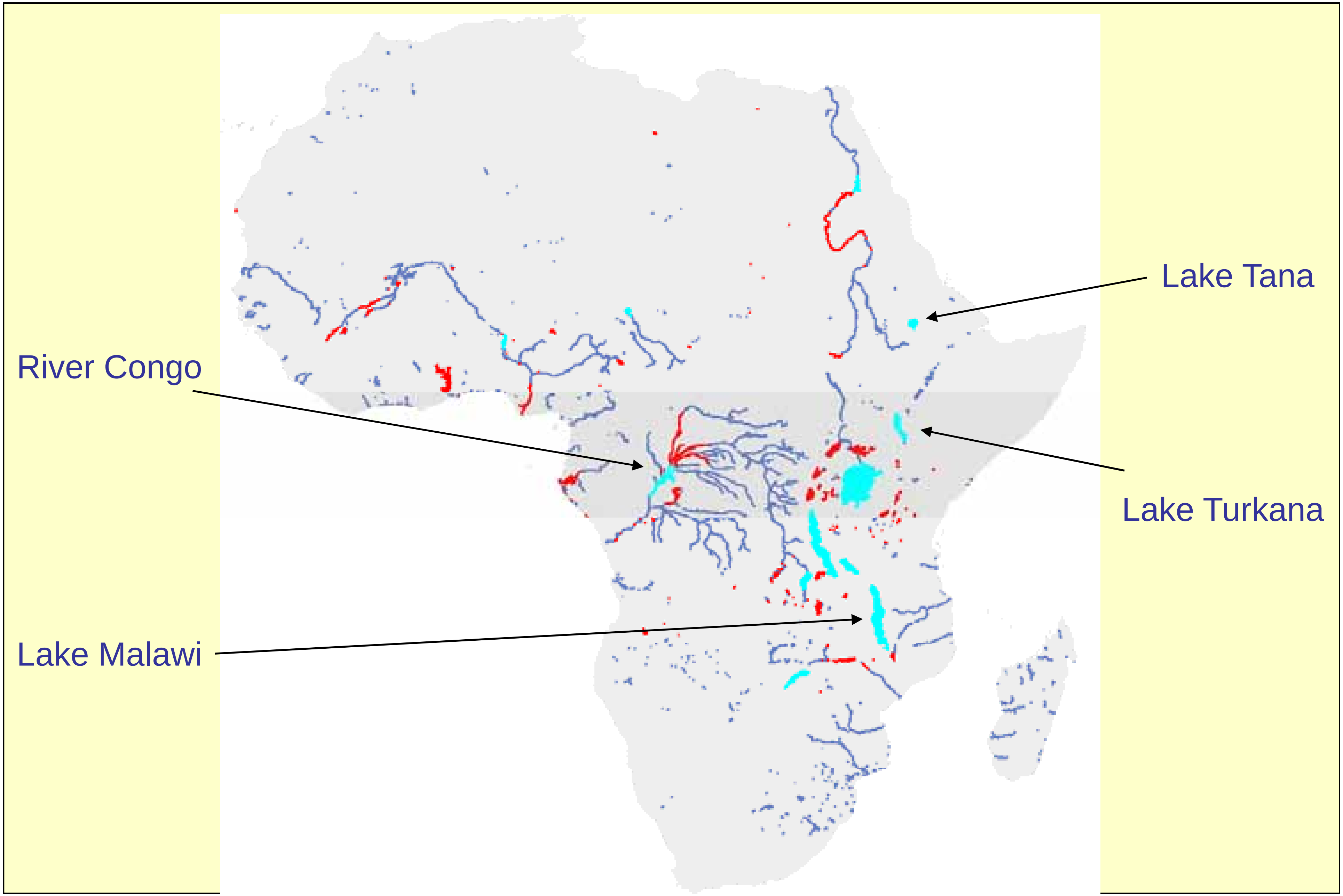
- Even more targets overall, although more ‘drop-out’ of waveforms
  (the self-adaptive tracker is mostly in high-resolution mode)

Global Mask for NRT RA-2 & Jason-1

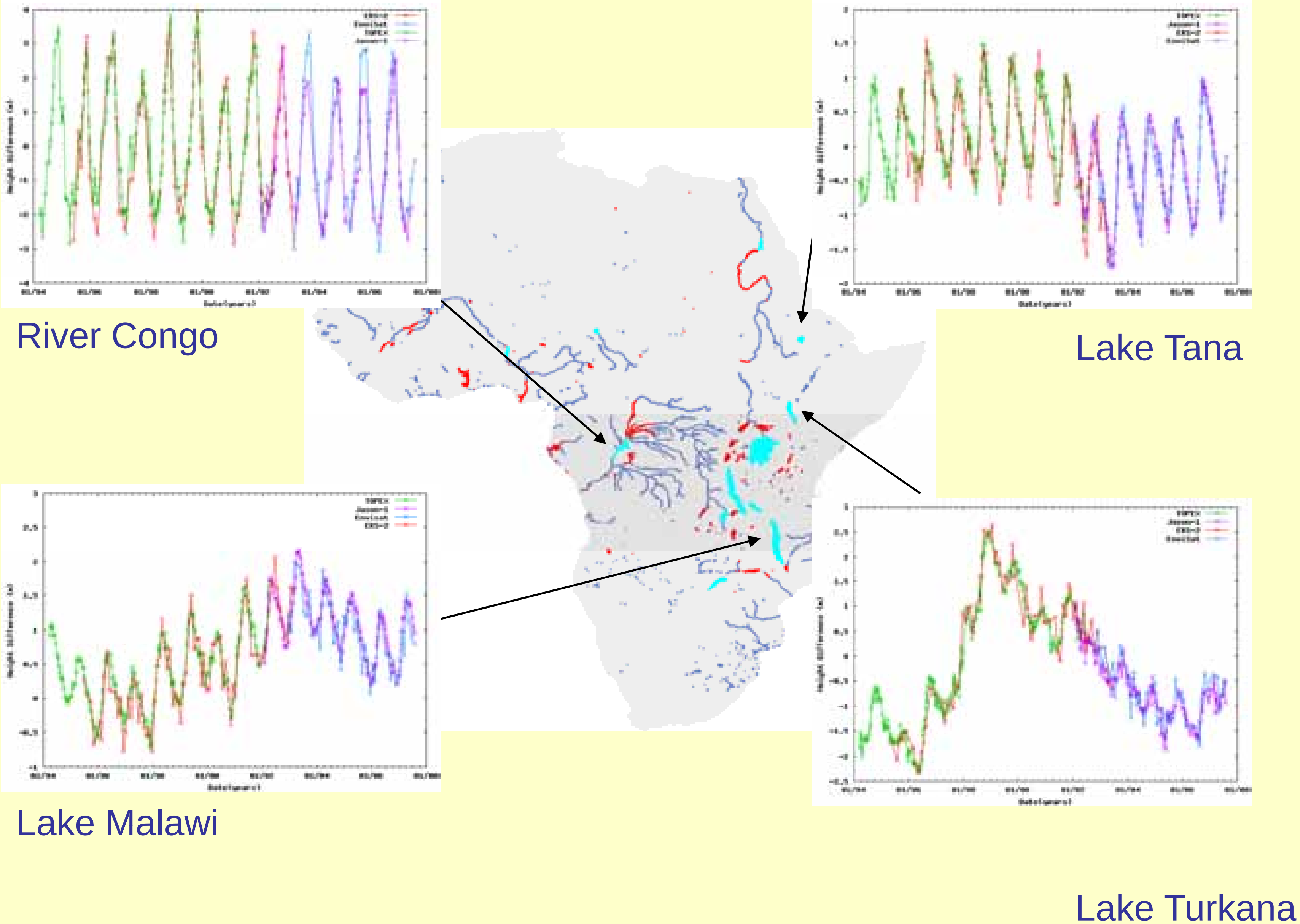


- NRT RA-2 targets red, RA-2 & Jason-1 targets turquoise, potential targets grey-blue. Note: all targets acquired by Jason-1 also seen by RA-2 (better time sampling with both).

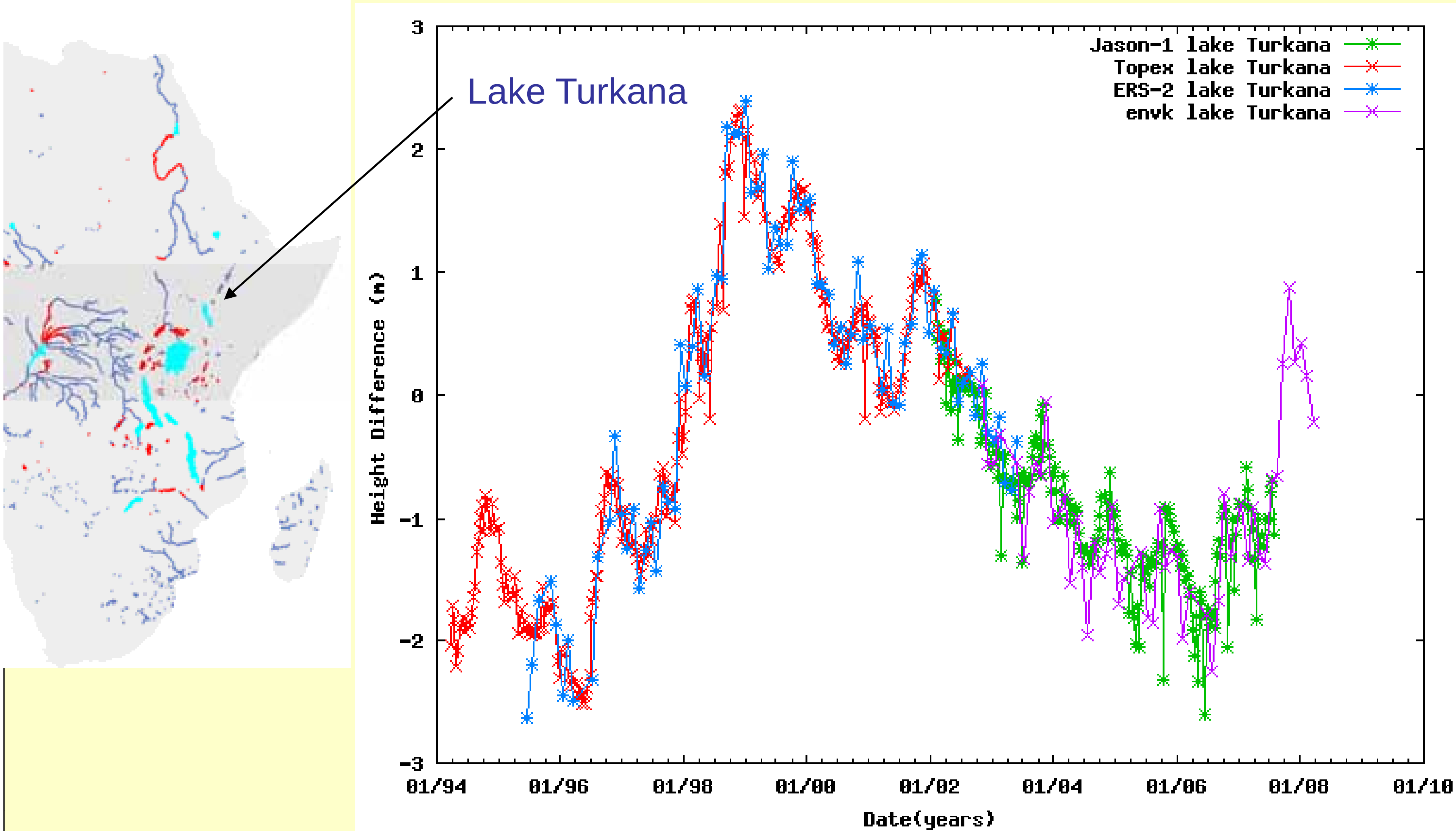
NRT mask : Zoom on Africa



Times Series on the NRT Mask

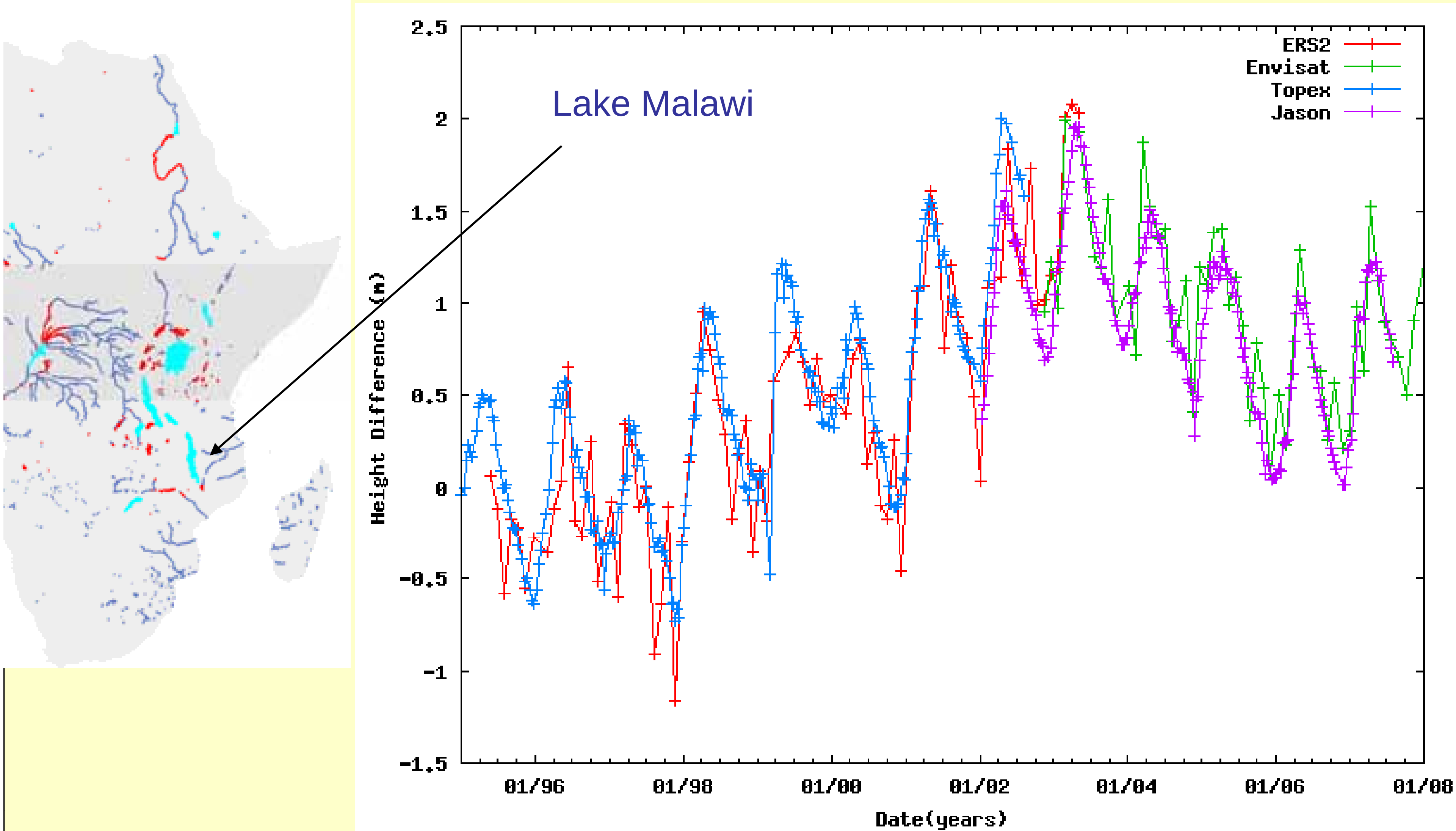


NRT mask over Africa: Lake Turkana



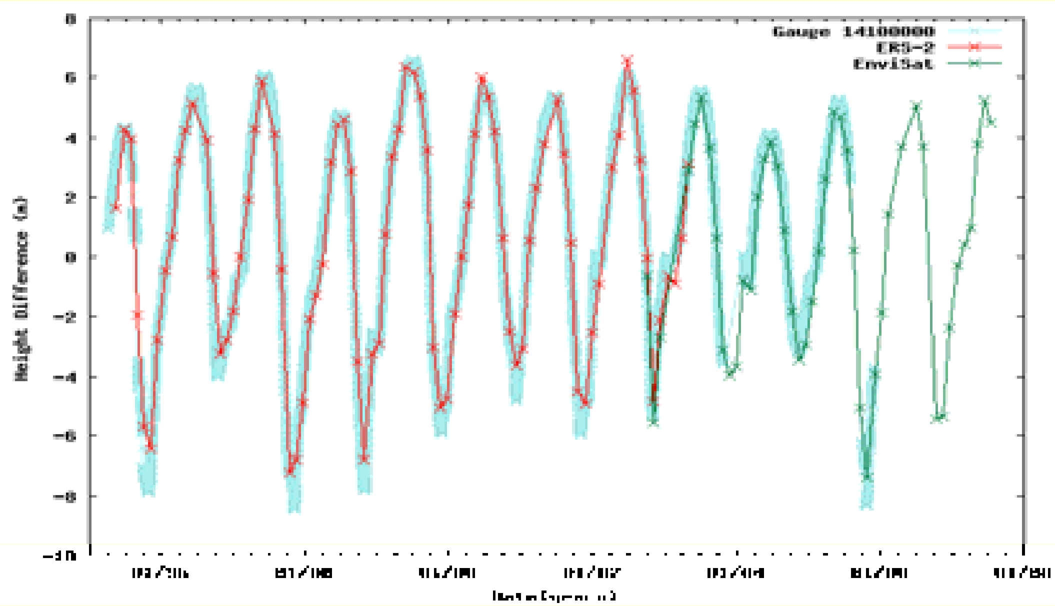
Four Radar Altimeters

NRT mask over Africa: Lake Malawi



Four Radar Altimeters

Example Validation over Amazon Basin



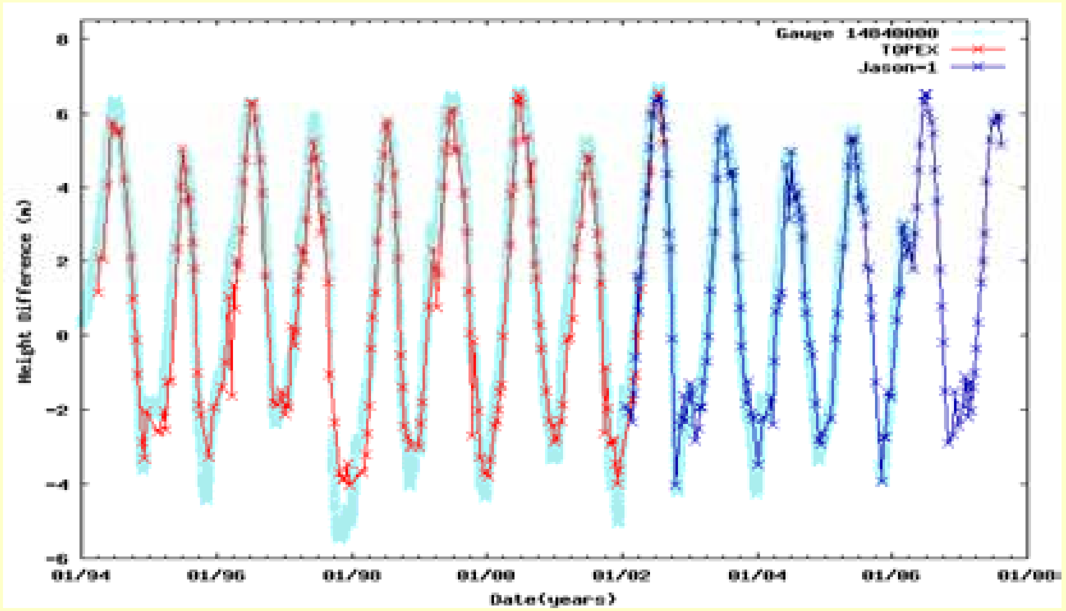
ERS-2 (red): RMS against Gauge:
0.6269m,
Correlation: 0.9878

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

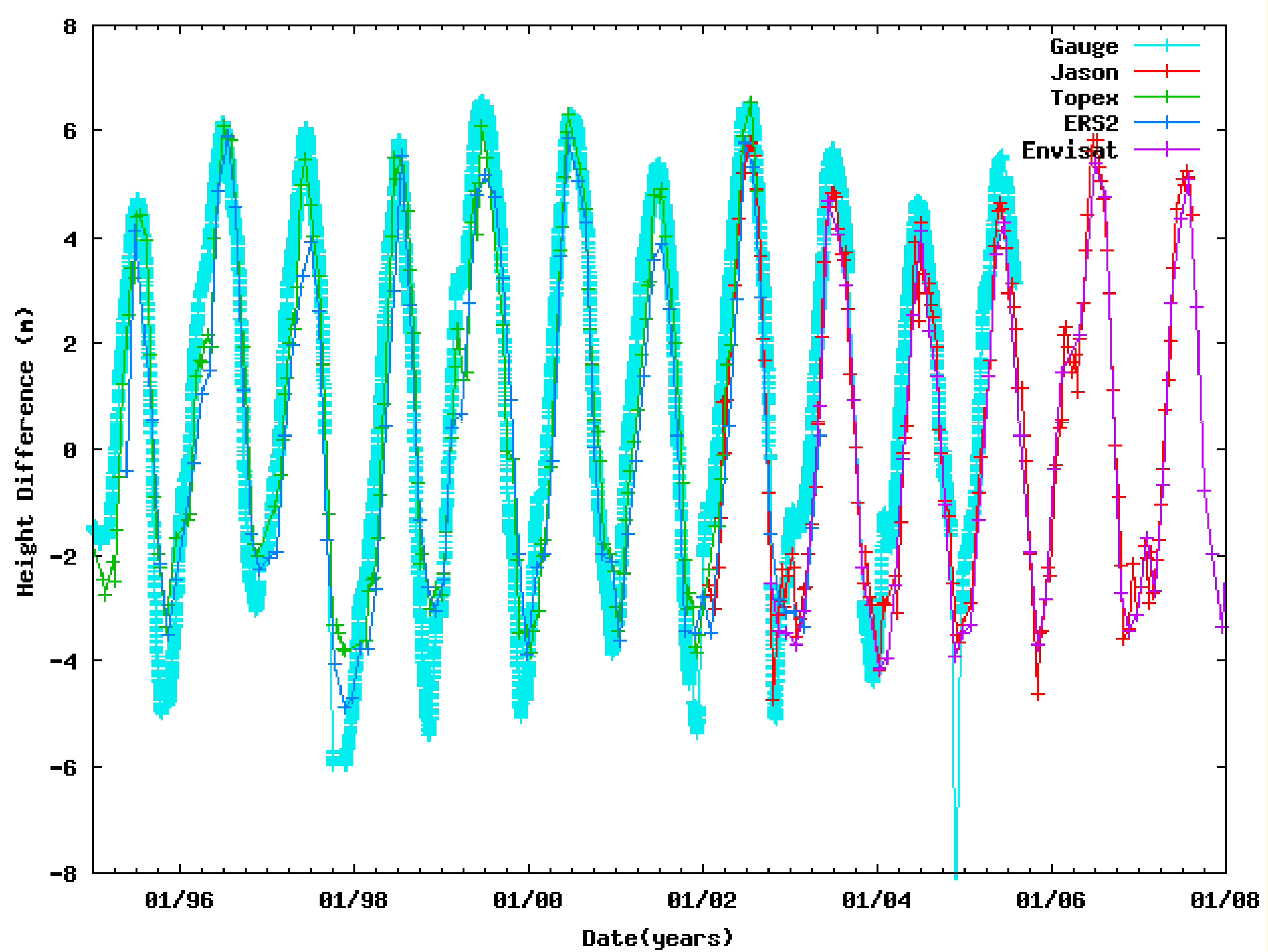
• Gauge data plotted in grey-blue

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

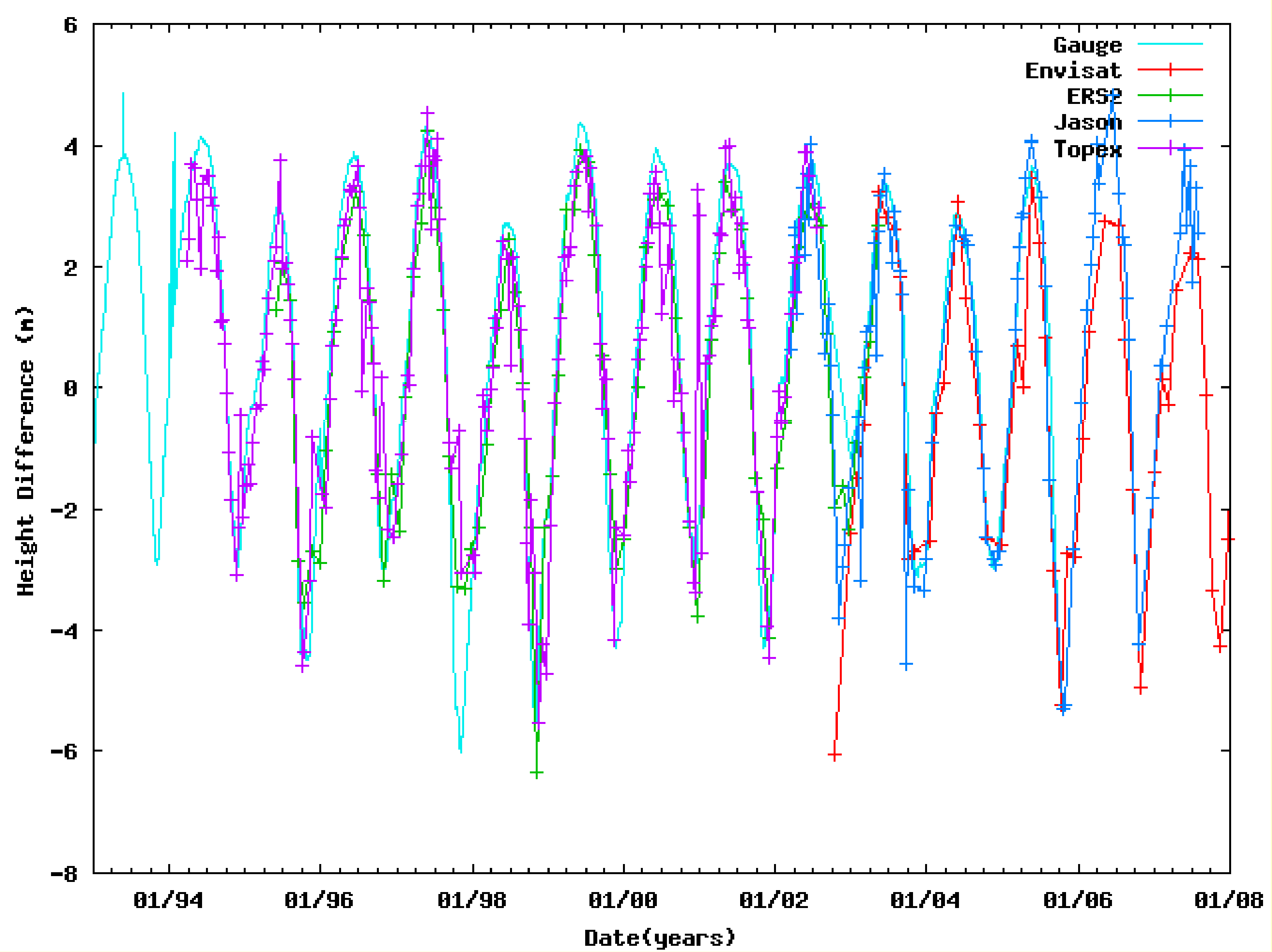
Jason-1 (dark blue): RMS against Gauge:1.2198m,
Correlation: 0.9283



Example Validation over Amazon Basin

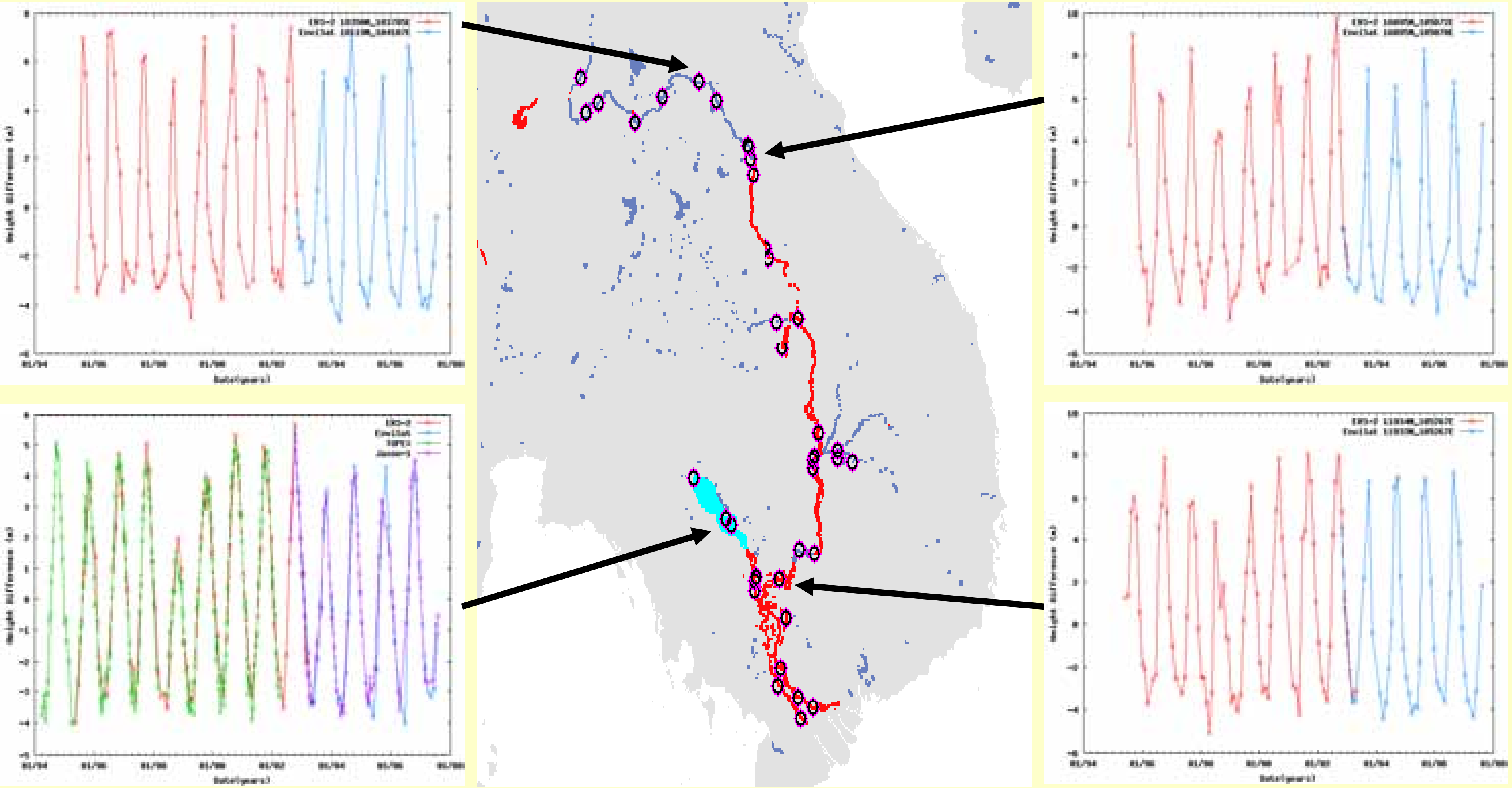


Example Validation over Amazon Basin

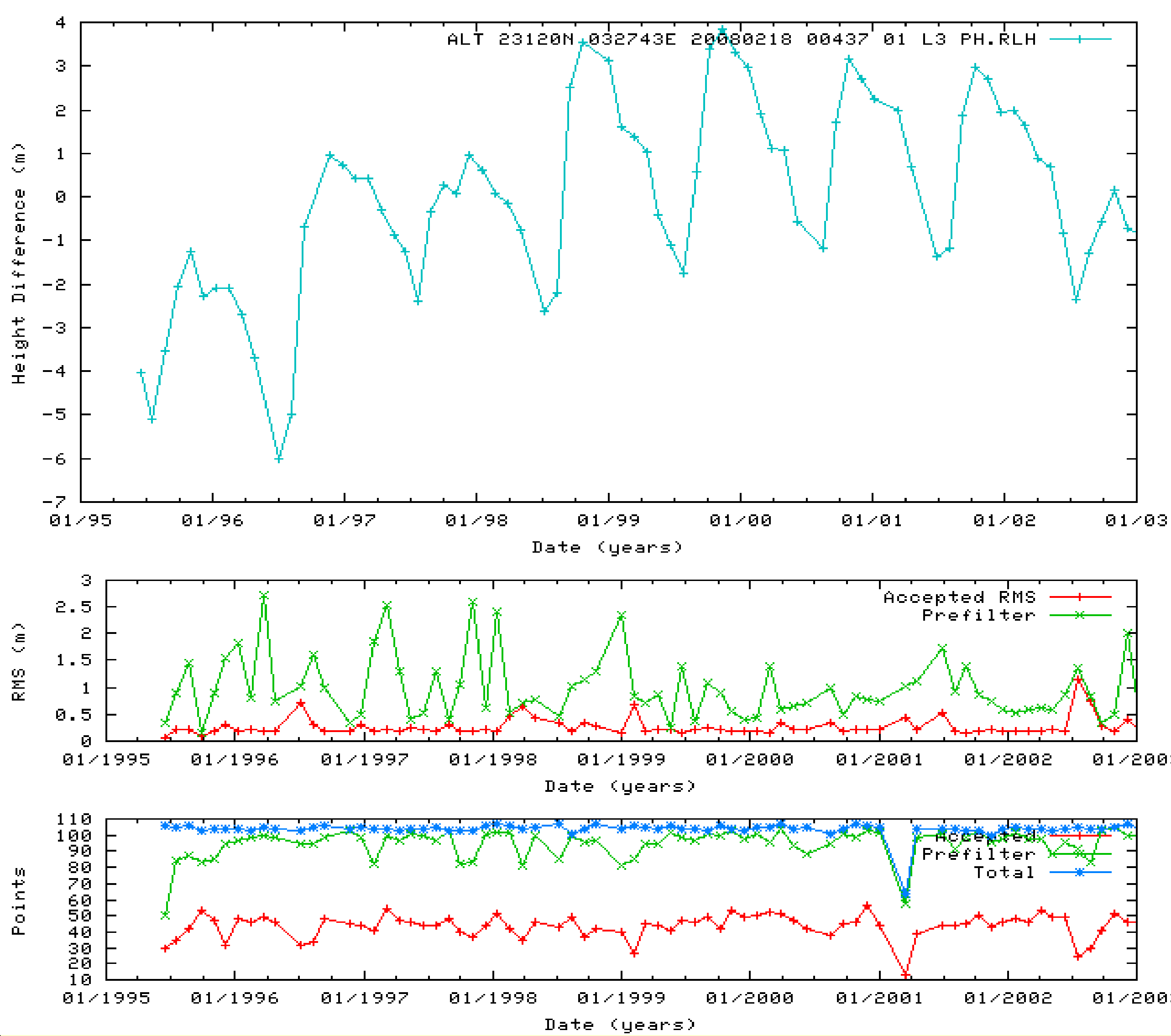


Mekong and Tonle Sap

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



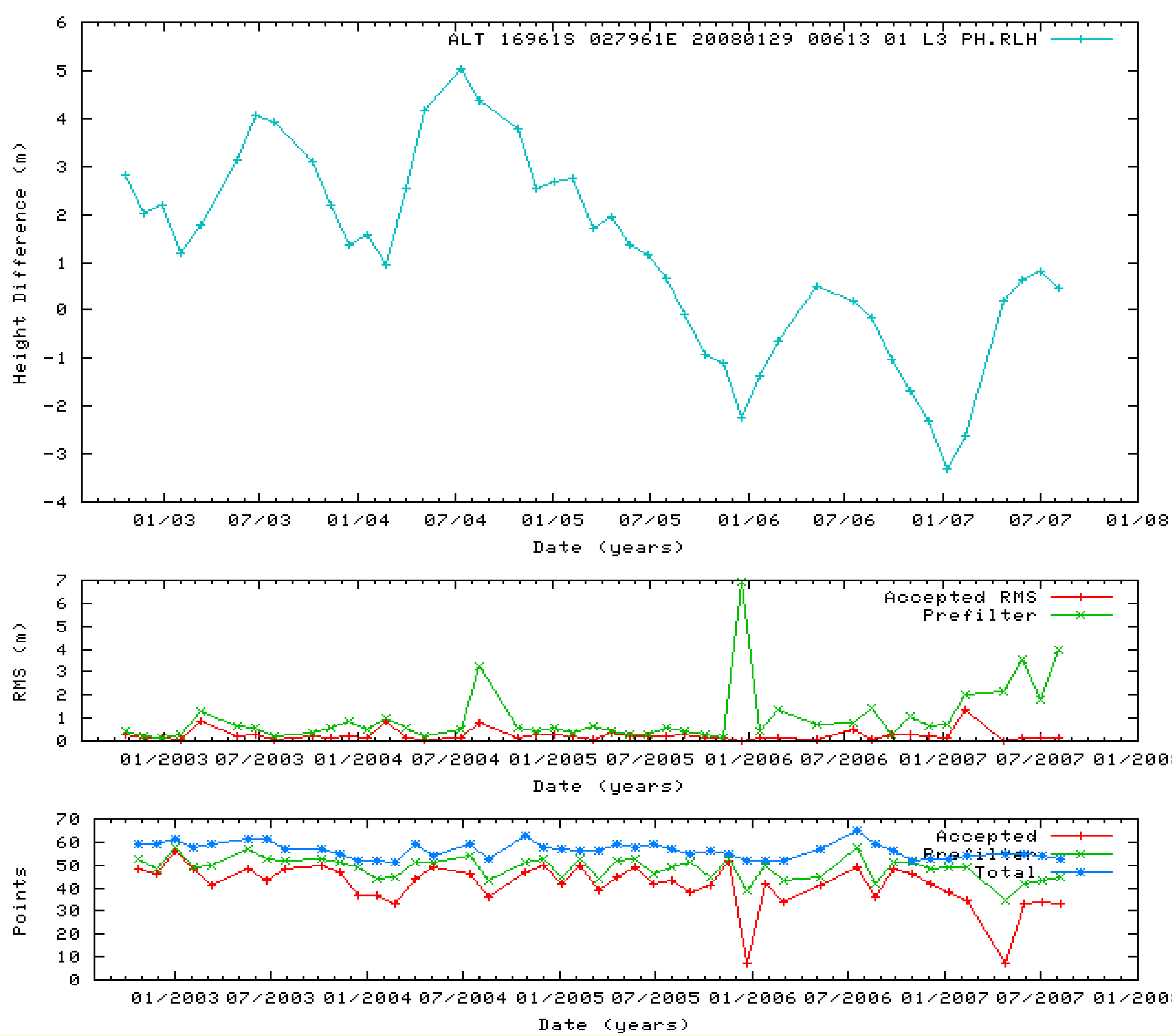
Top graph shows one time series over lake Nasser from ERS2.

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

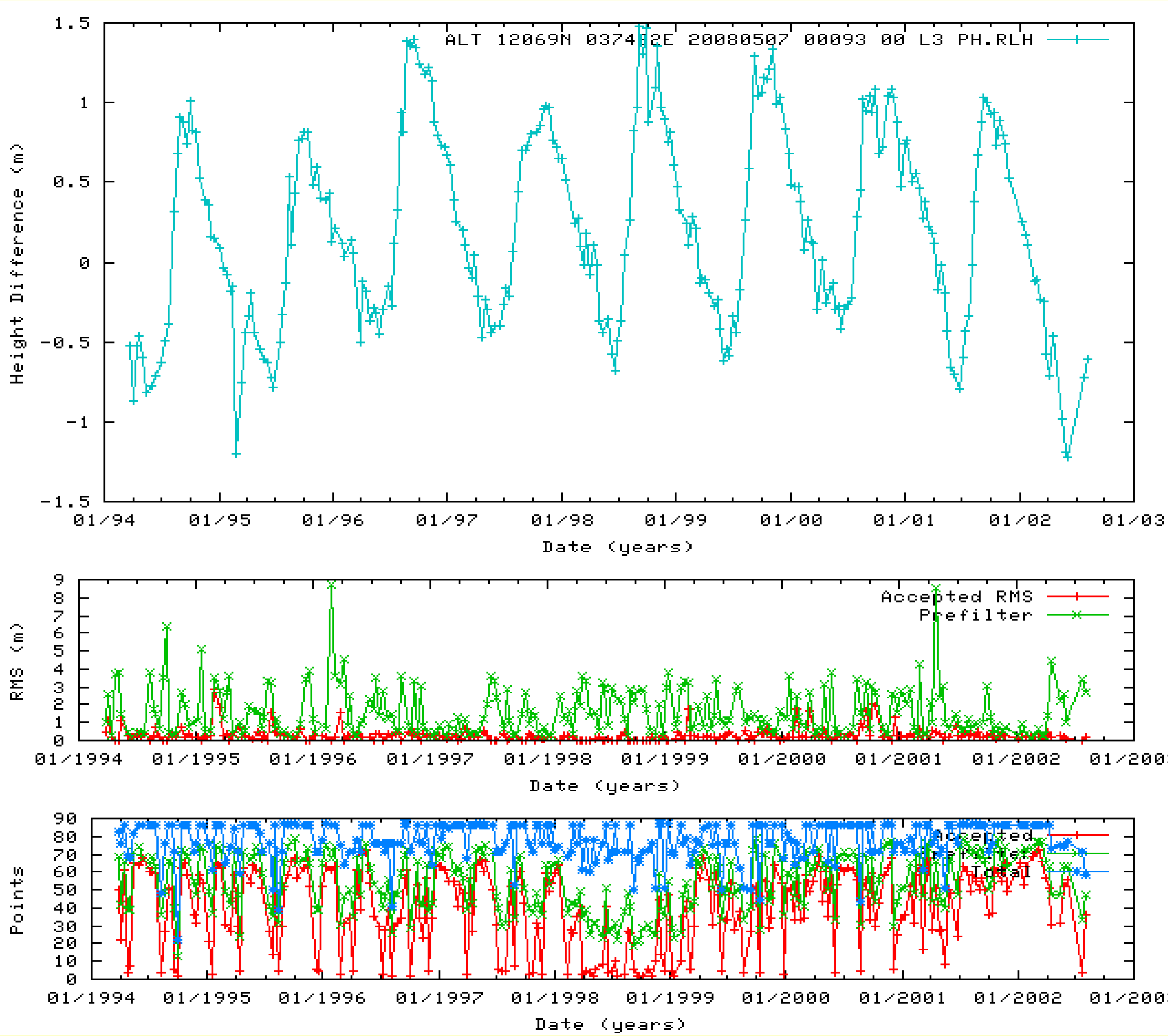


Statistics for Envisat over Lake Kariba

Plots as last slide

Note low loss of waveforms but reduction in RMS

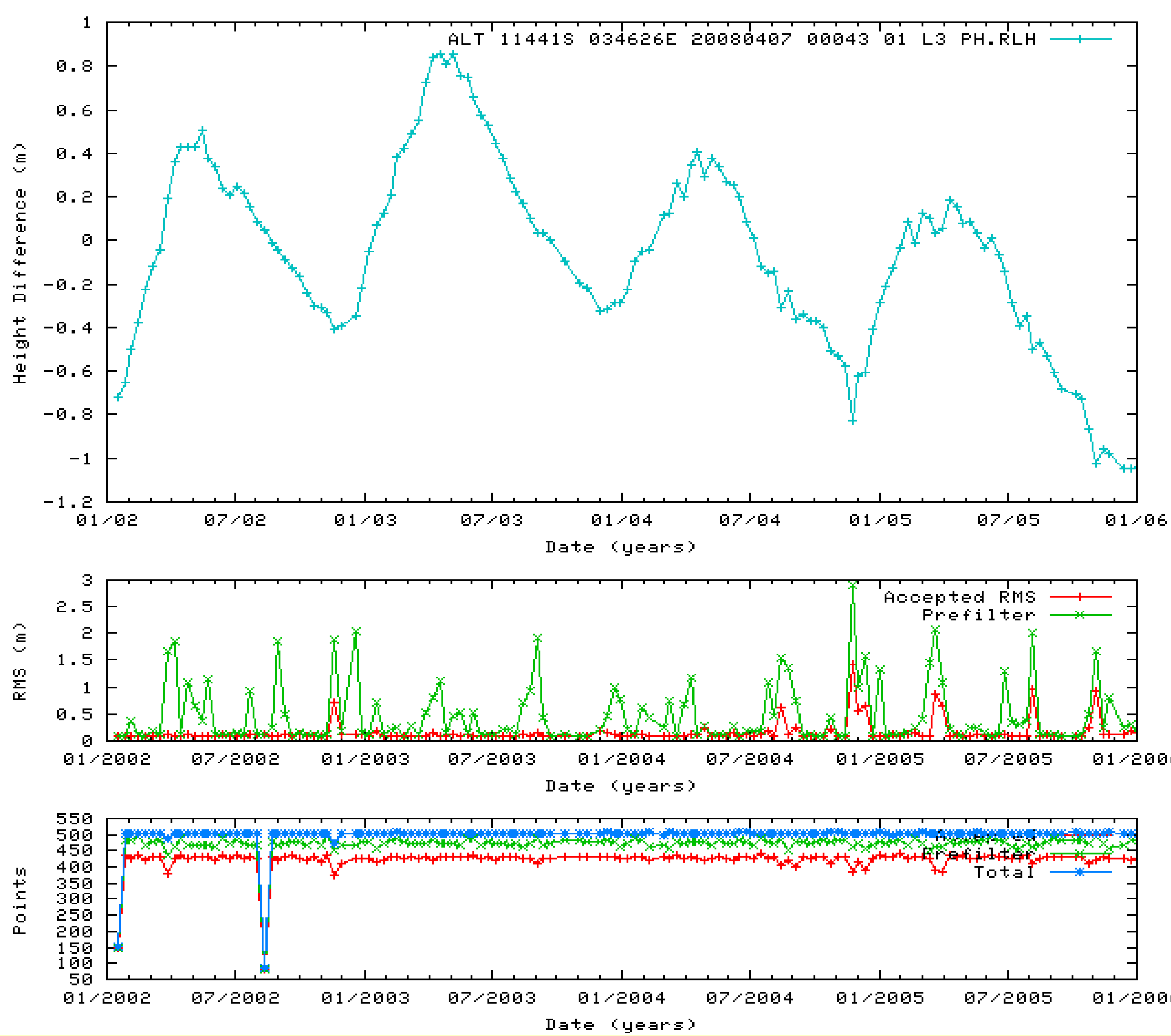
TOPEX Statistics over Lake Tana



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

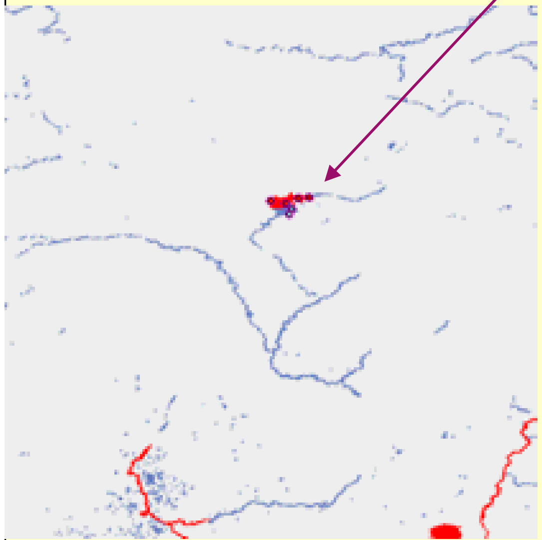


Statistics for Jason-1 from Lake Malawi

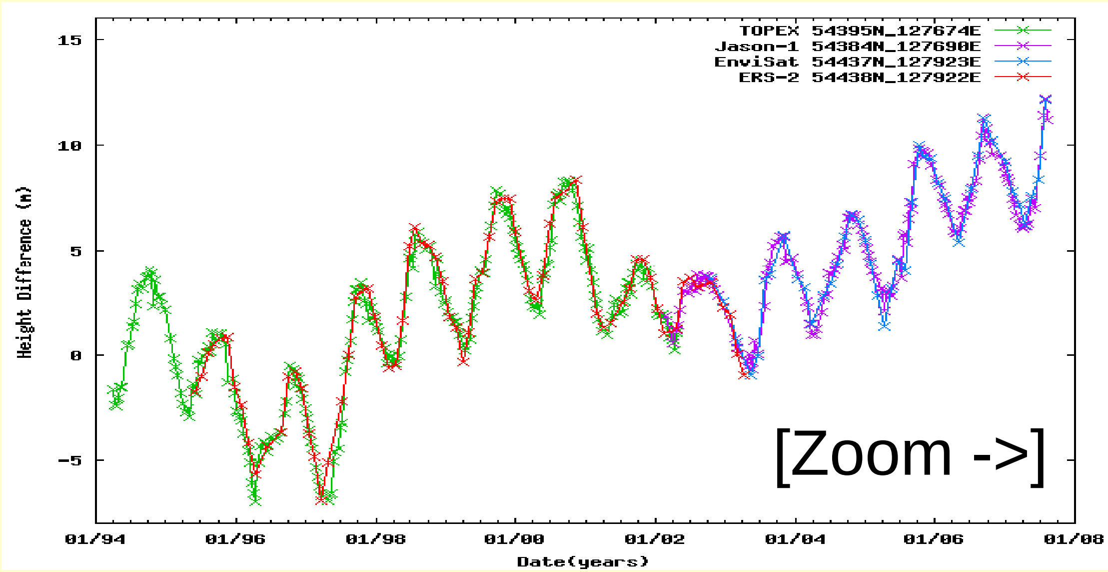
Here, far fewer waveforms rejected but RMS greatly reduced.

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

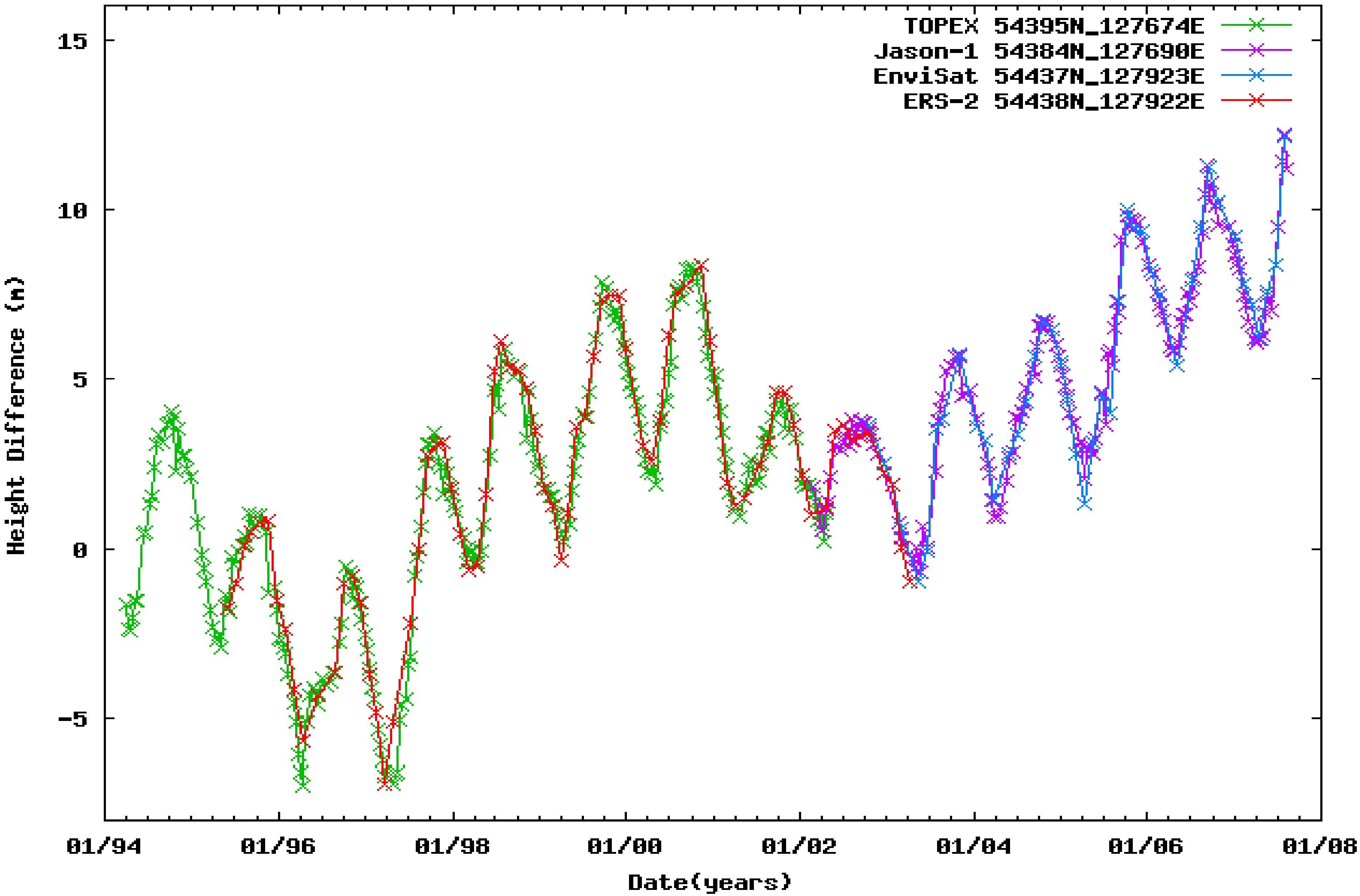
Zeyskoye Vodokhranilishche



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.



Zeyskoye Vodokhranilishche

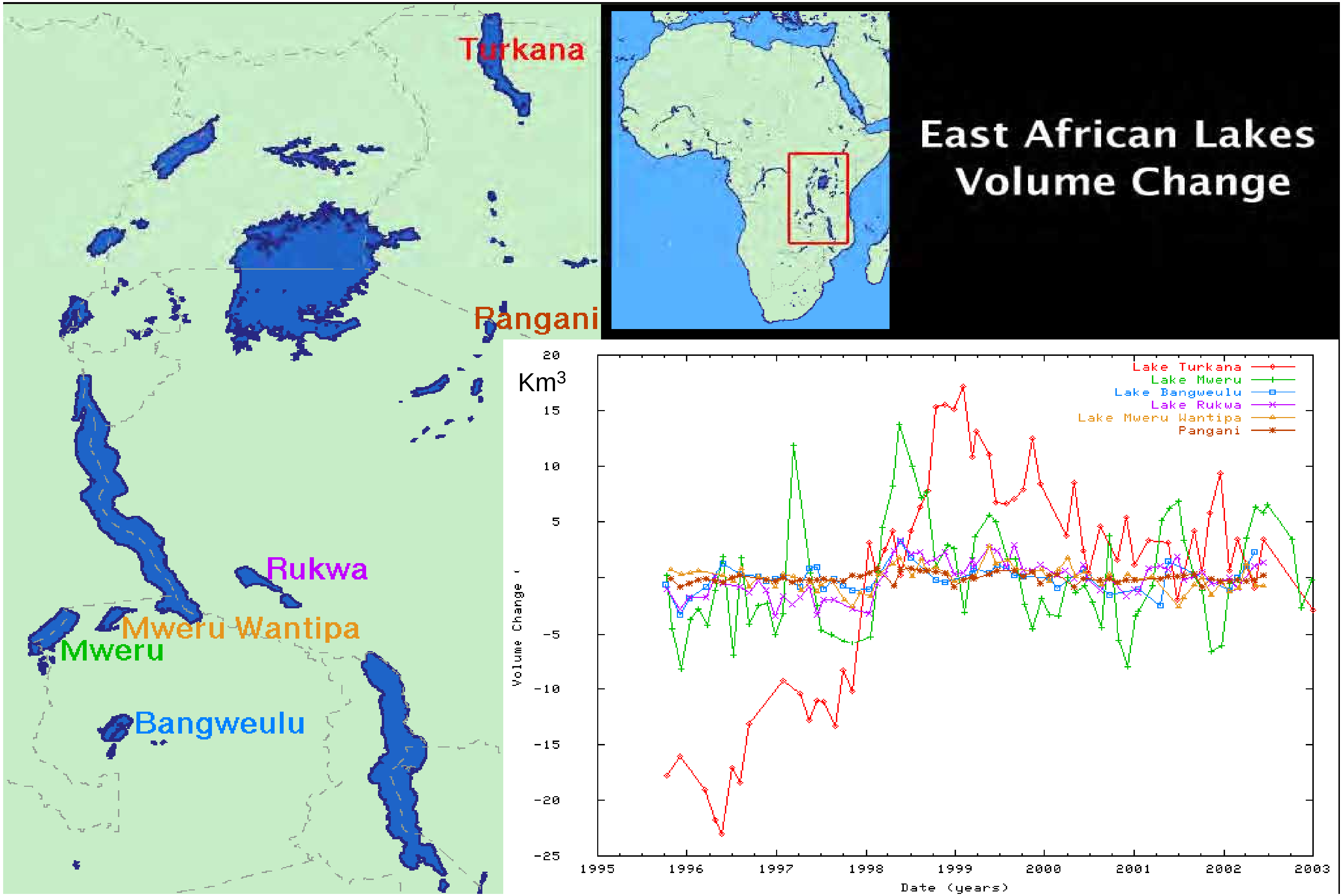


NEAR-REAL TIME PRODUCTS

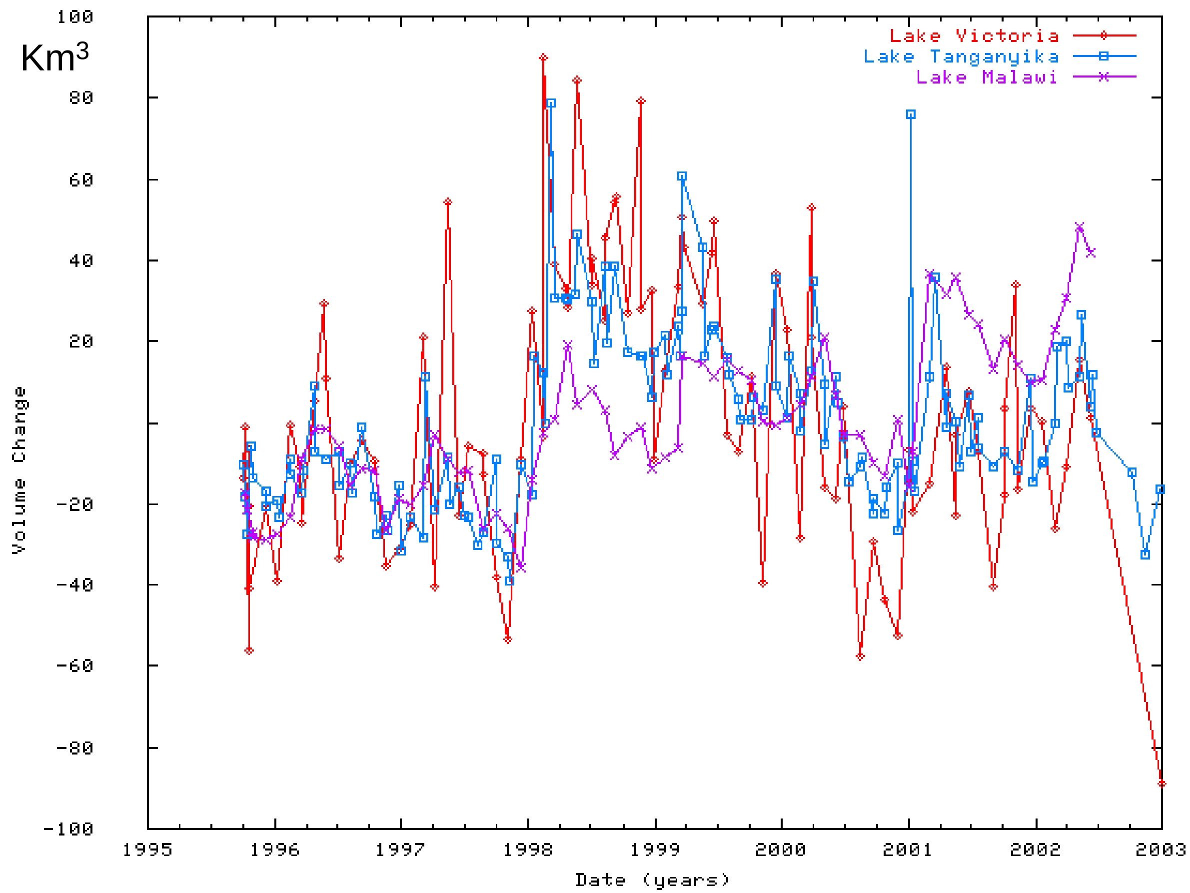
6 measurements per day over Africa, only!

NEAR-REAL TIME PRODUCTS

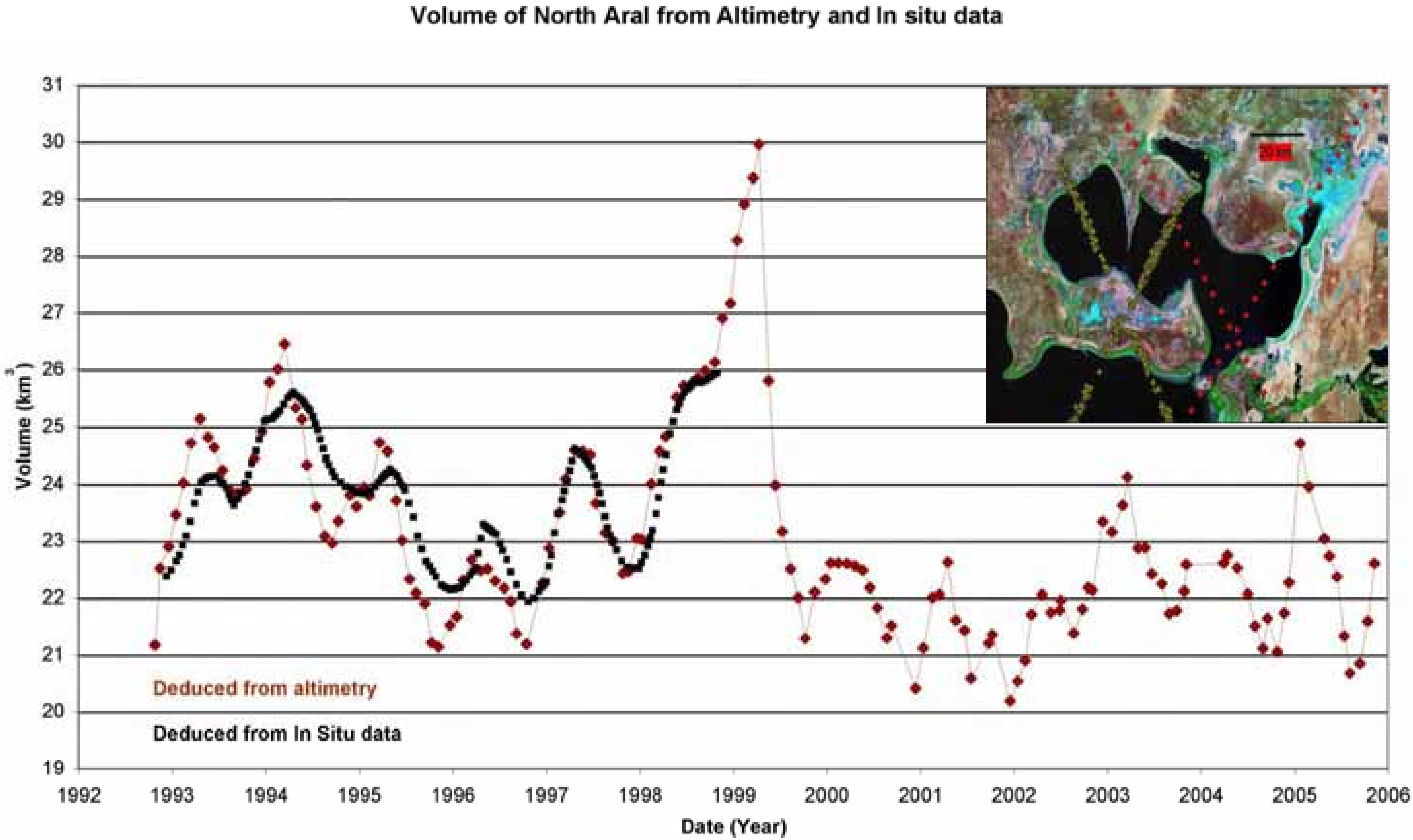
Lake Volume Variation (km^3)



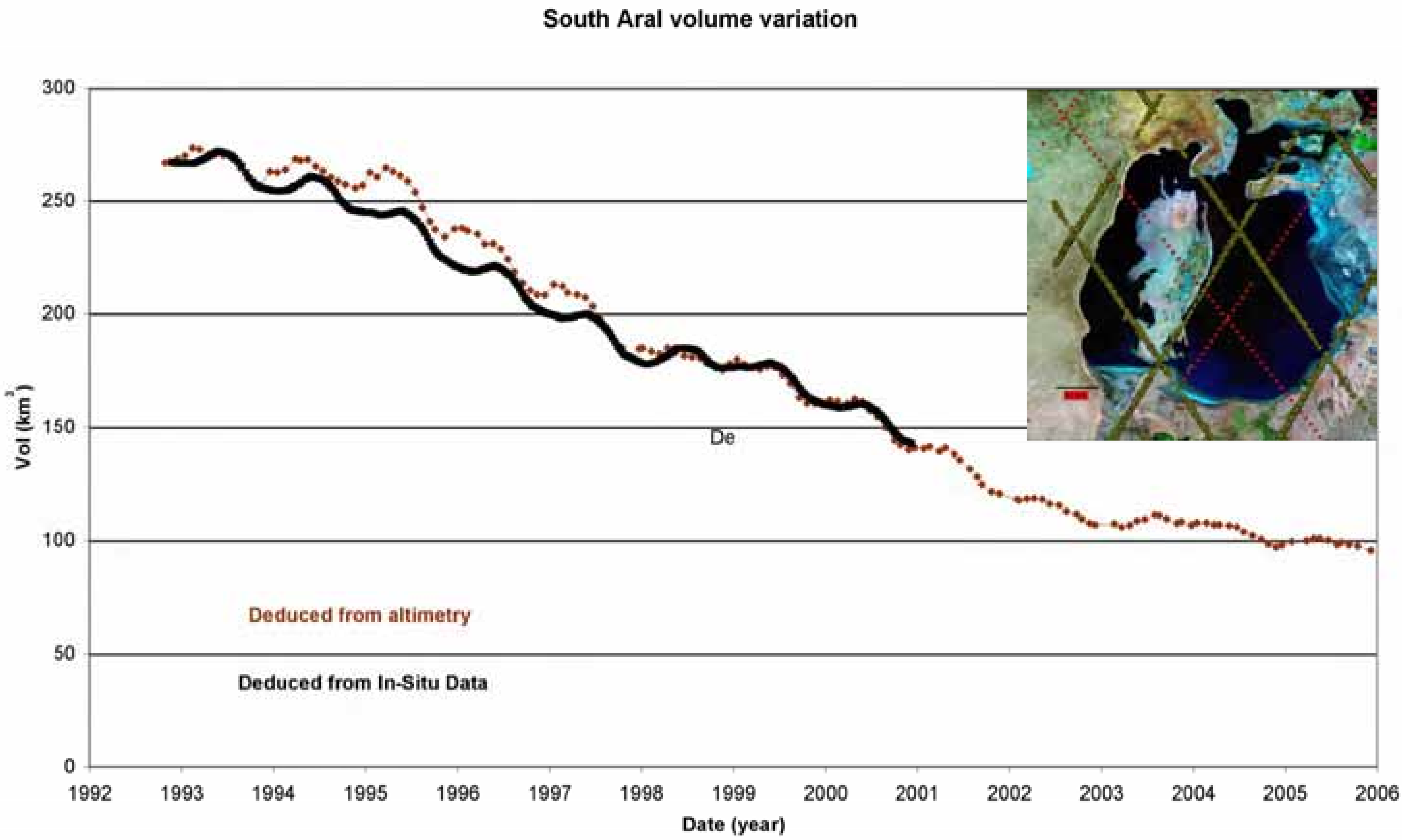
East African Lakes Volume Change



North Aral Sea - Cazenave & Crétaux

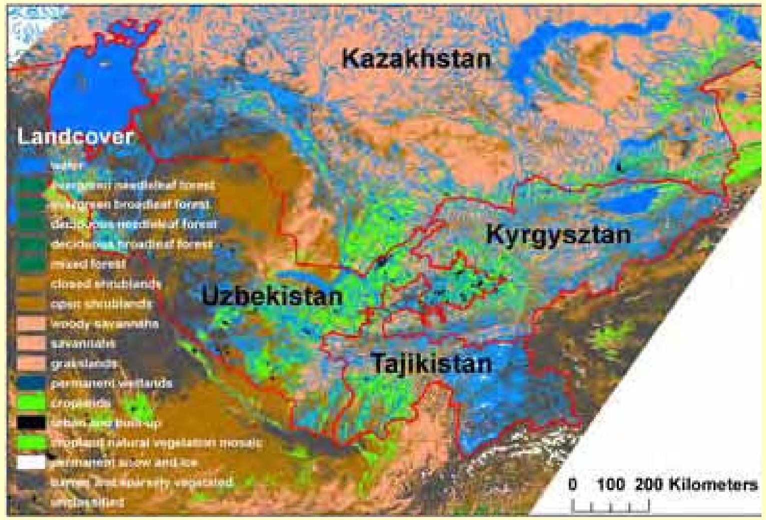


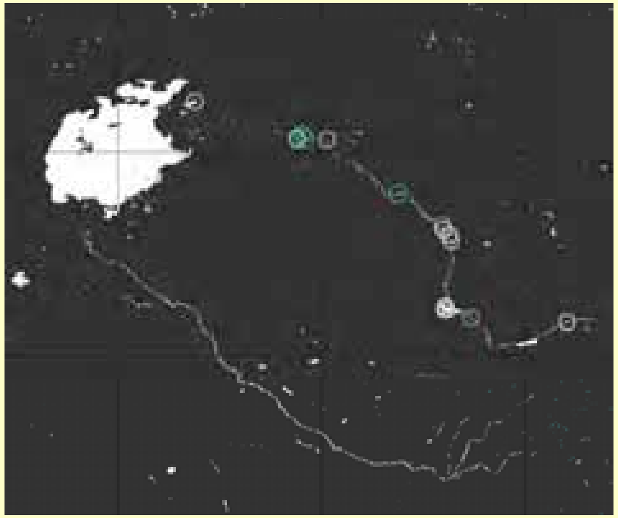
South Aral Sea - Cazenave & Crétaux



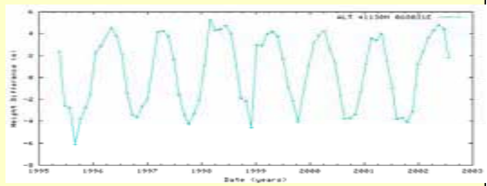
Syr Darya Modeling and Assimilation

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.



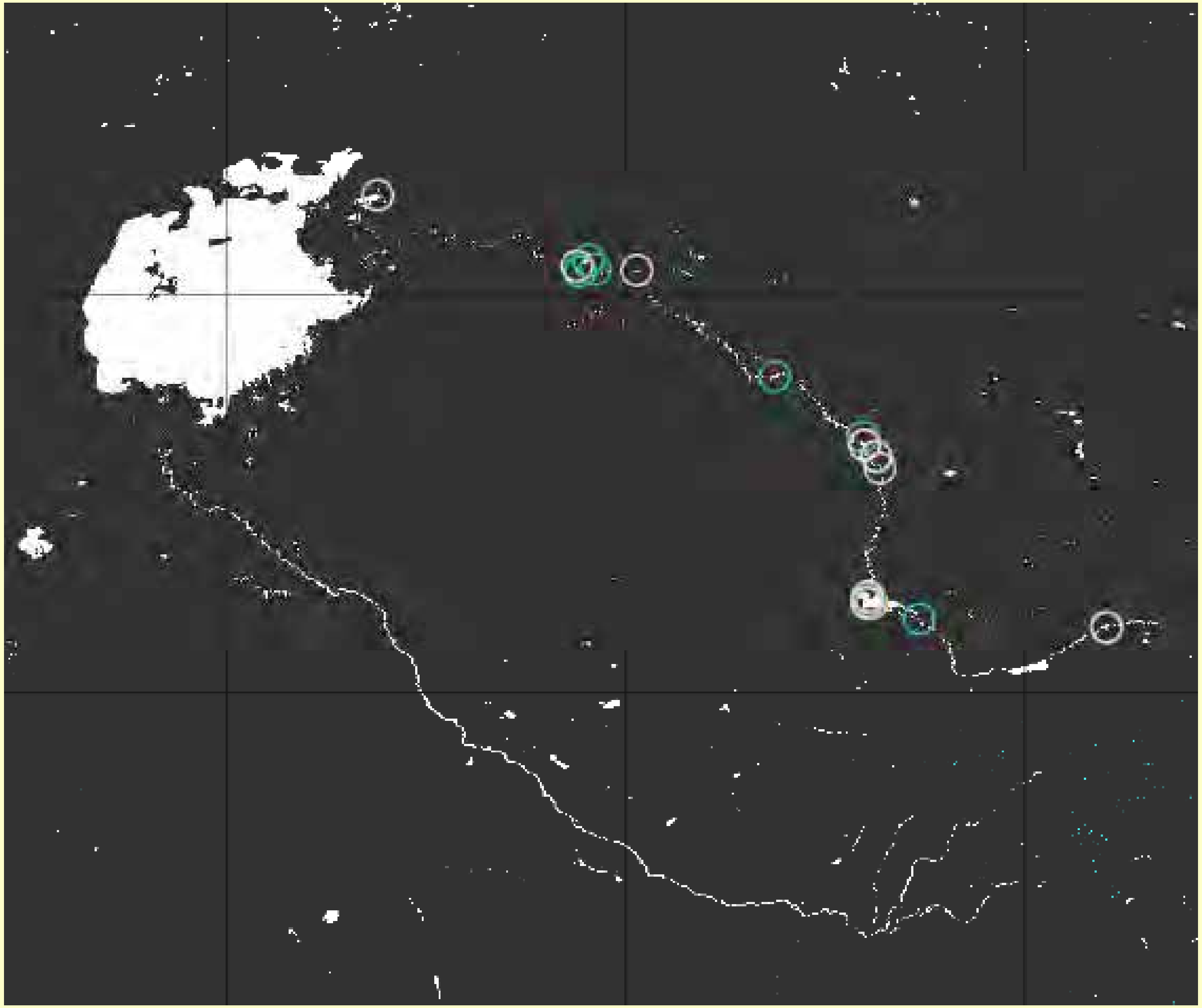


Locations of altimeter timeseries: EnviSat (light blue), ERS2 (pink) Topex (gold)

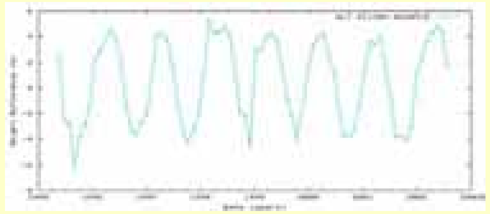


This part of the project will model the Syr Darya river basin, incorporating multi-mission satellite radar altimetry

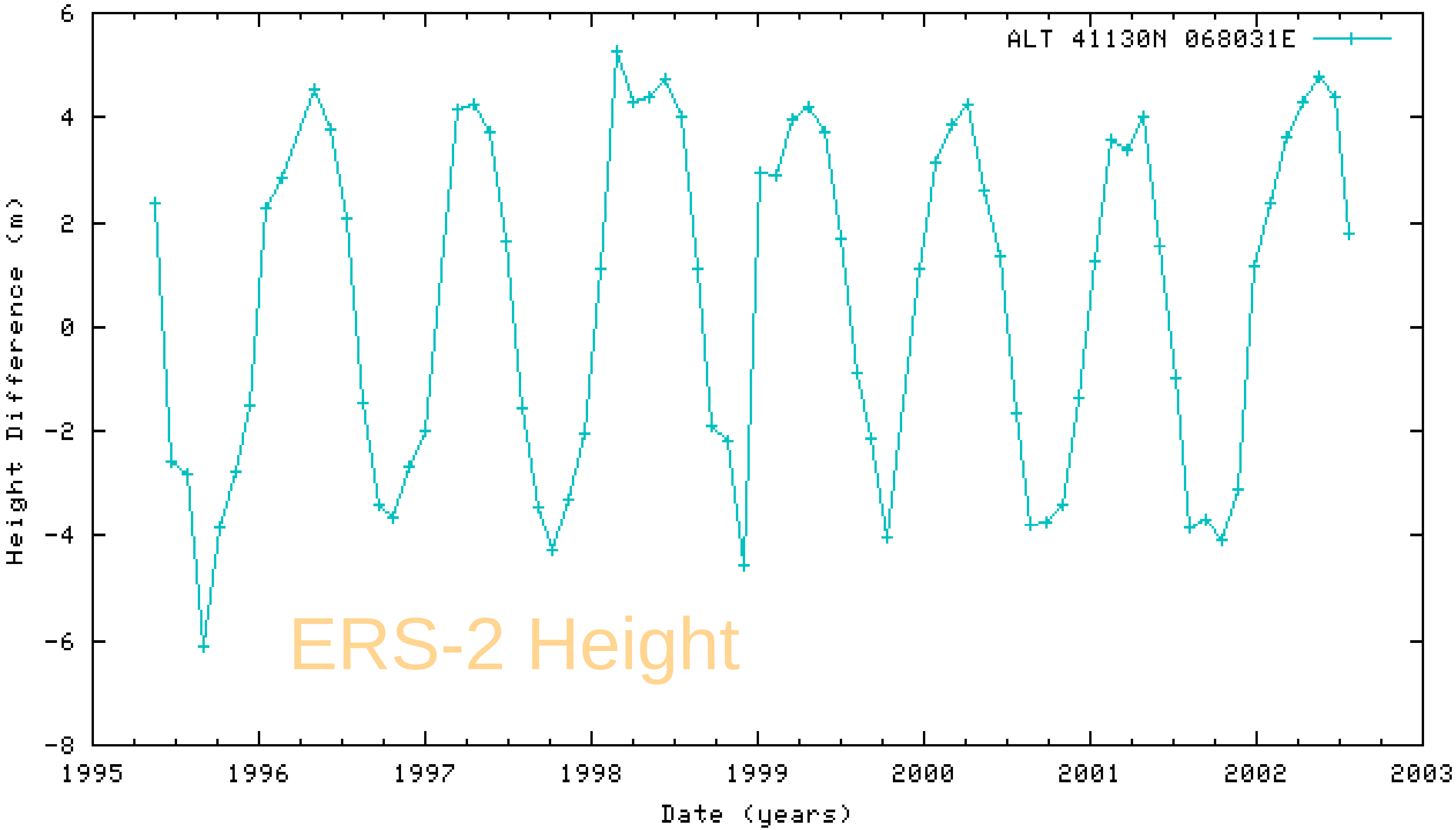
Syr Darya



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

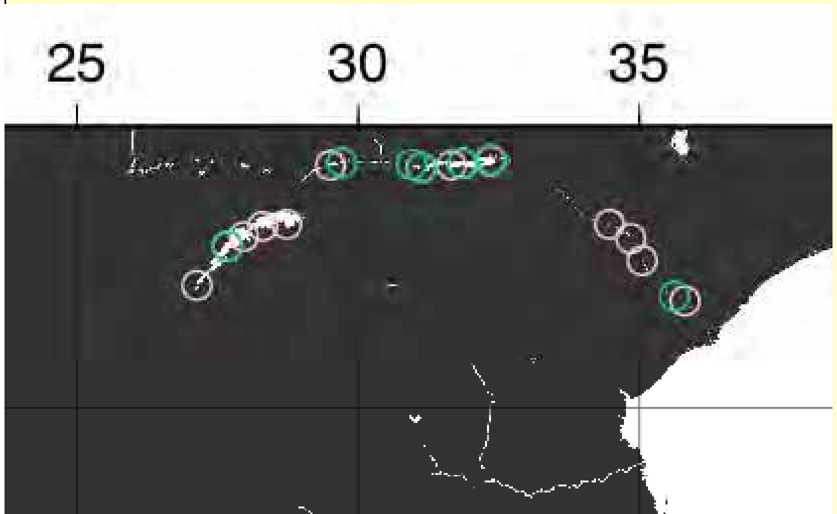


Syr Darya

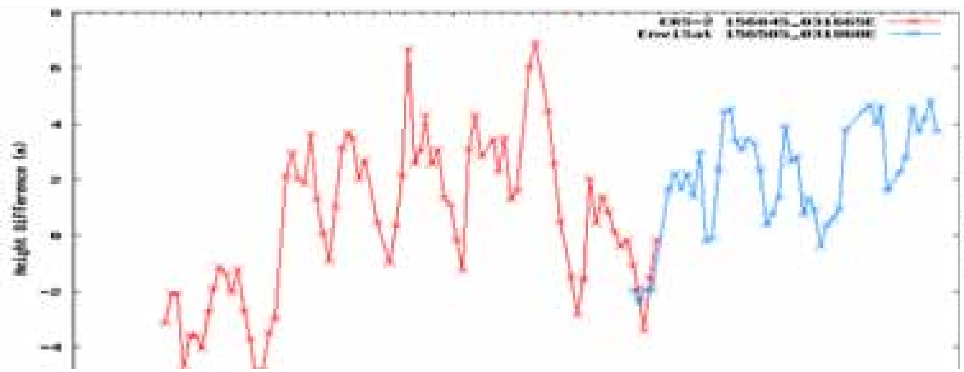

ALT 41130N 068031E
Height Difference (m)
6
4
2
0
-2
-4
-6
-8
1995
1996
1997
1998
1999
2000
2001
2002
2003
Date (years)
ERS-2 Height

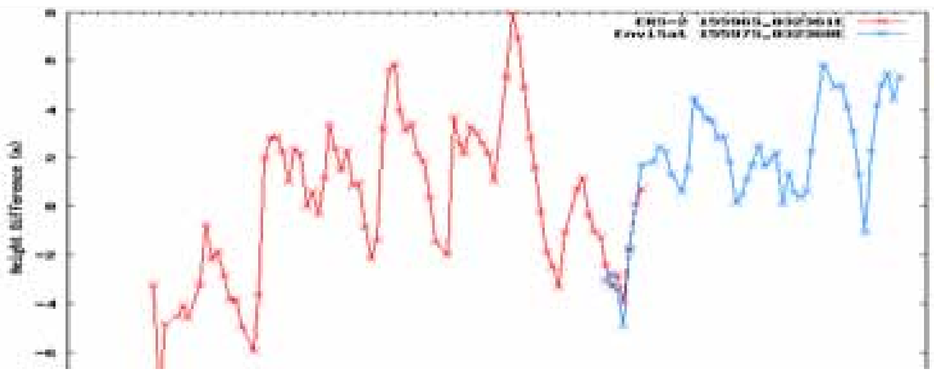
Zambesi Modeling and Assimilation

- 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

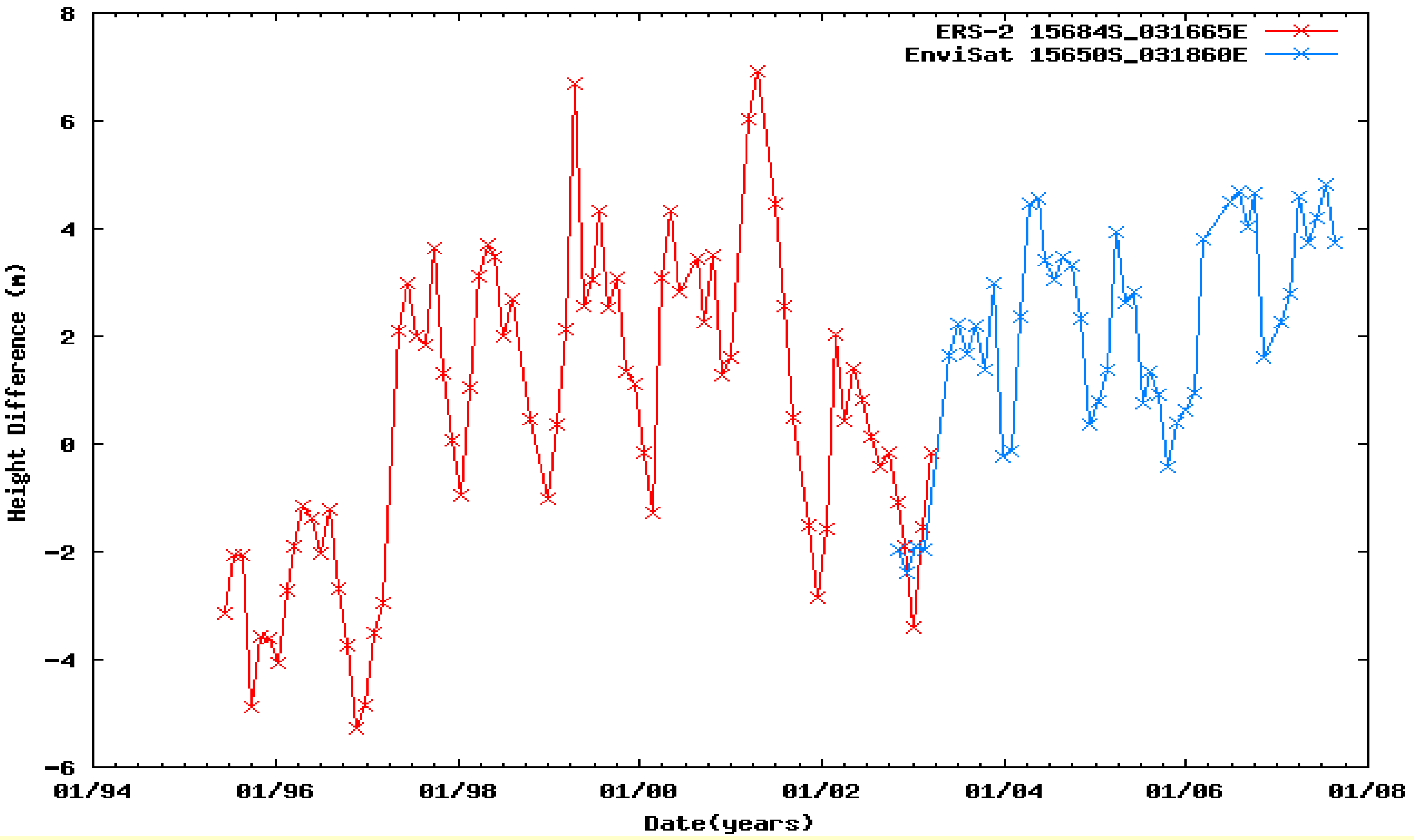


Again, combined timeseries from ERS2/EnviSat and Topex/Jason-1 (where possible!) will be used in modeling this river basin. Below are two combined ERS2/EnviSat timeseries over the Zambesi.



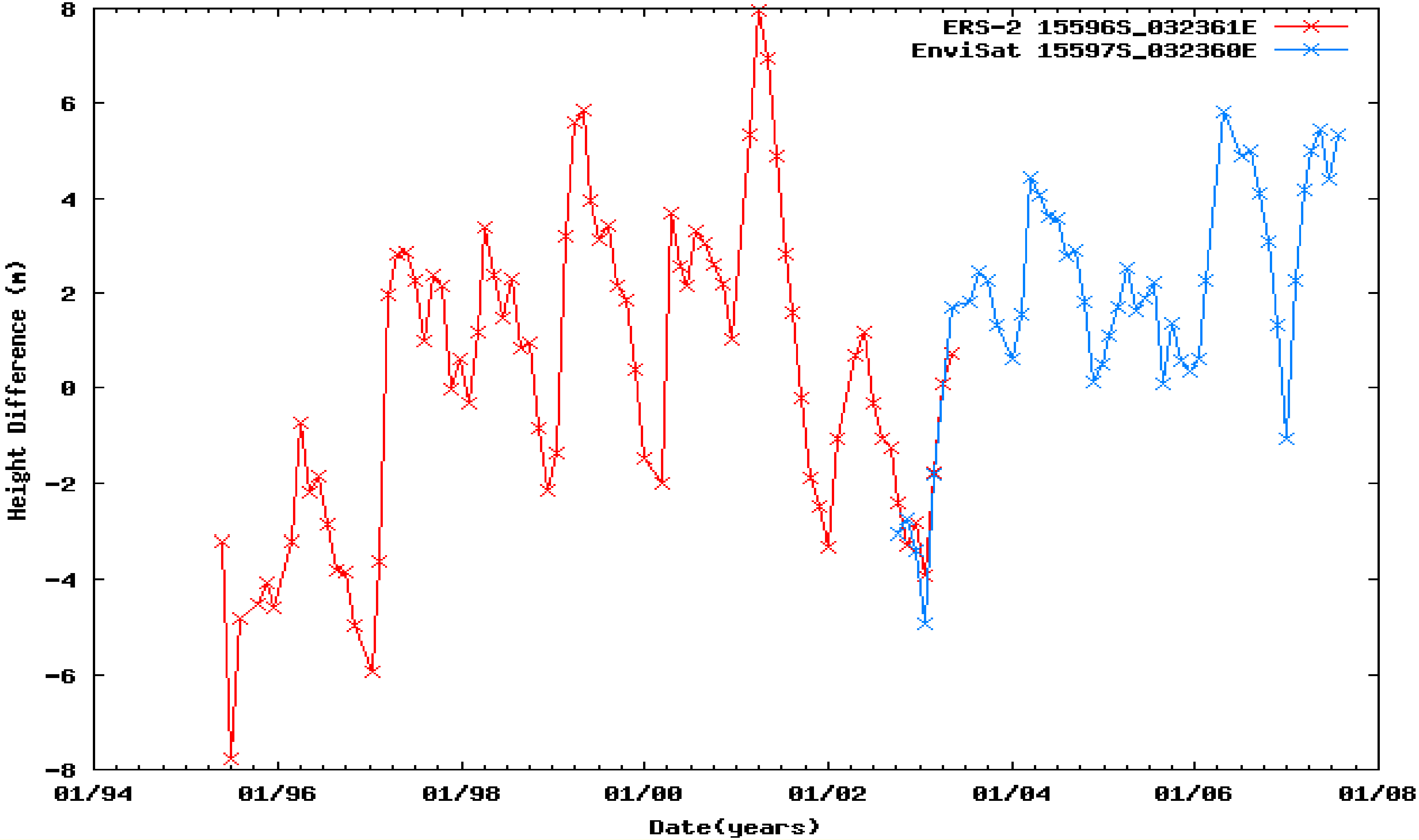


Zambesi



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



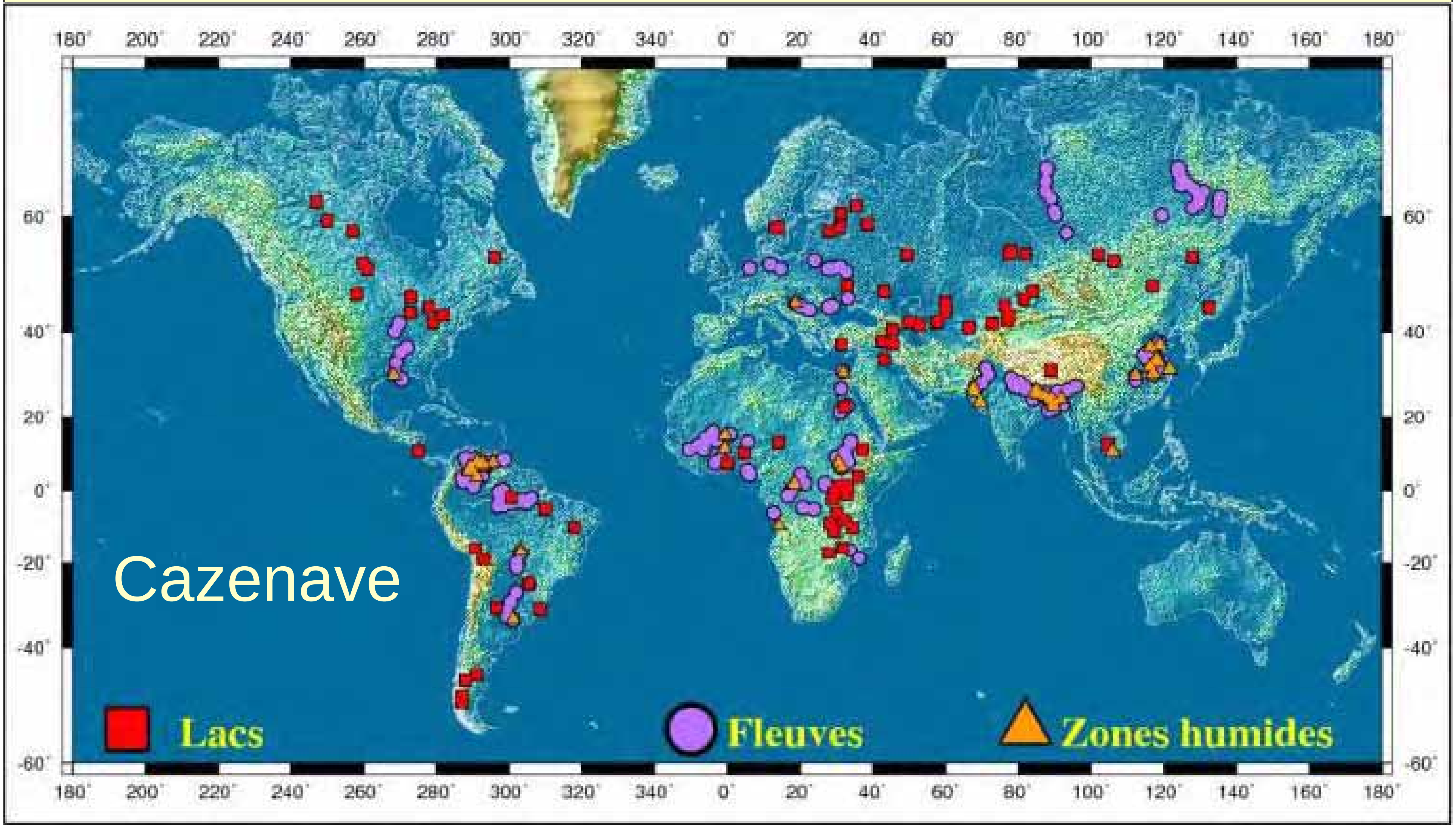
ERS-2 15596S_032361E
EnviSat 15597S_032360E
Height Difference (m)
8
6
4
2
0
-2
-4
-6
-8
01/94
01/96
01/98
01/00
01/02
01/04
01/06
01/08
Date(years)

“River & Lake” Products Website

Information and Data Products available via http://earth.esa.int/riverandlake

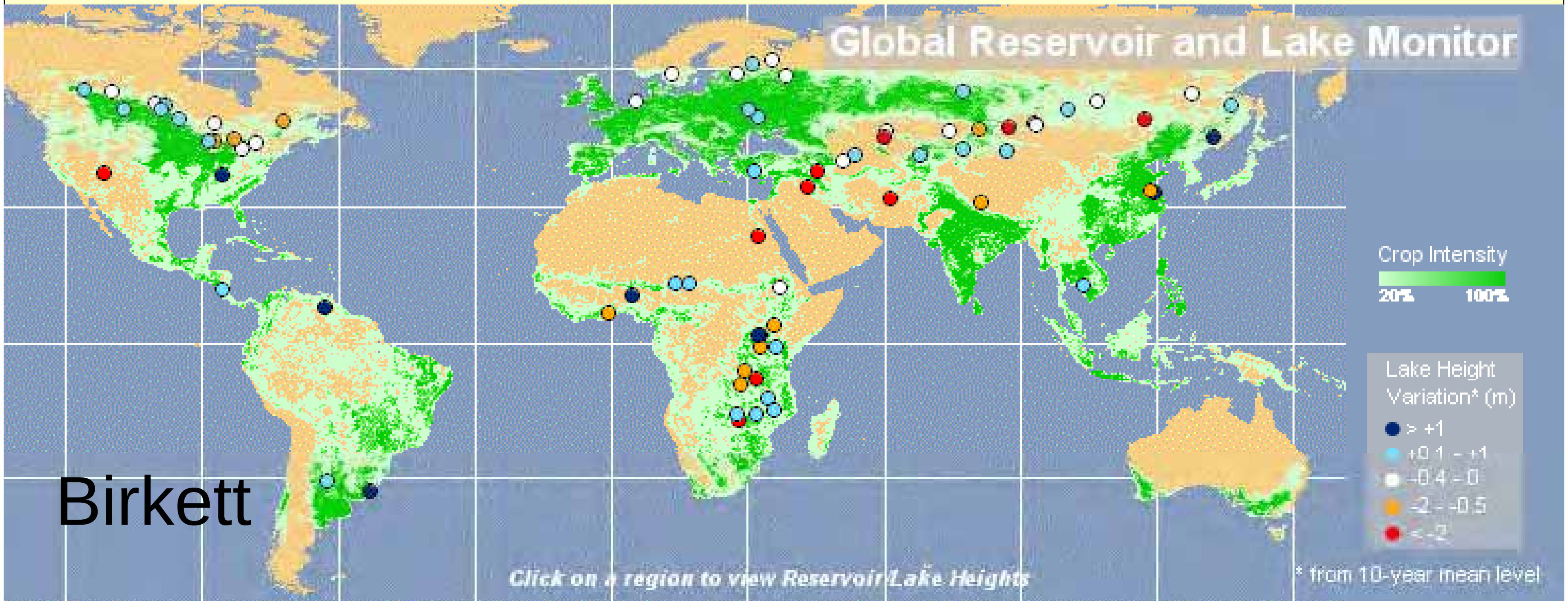
Global selection of rivers and lakes

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



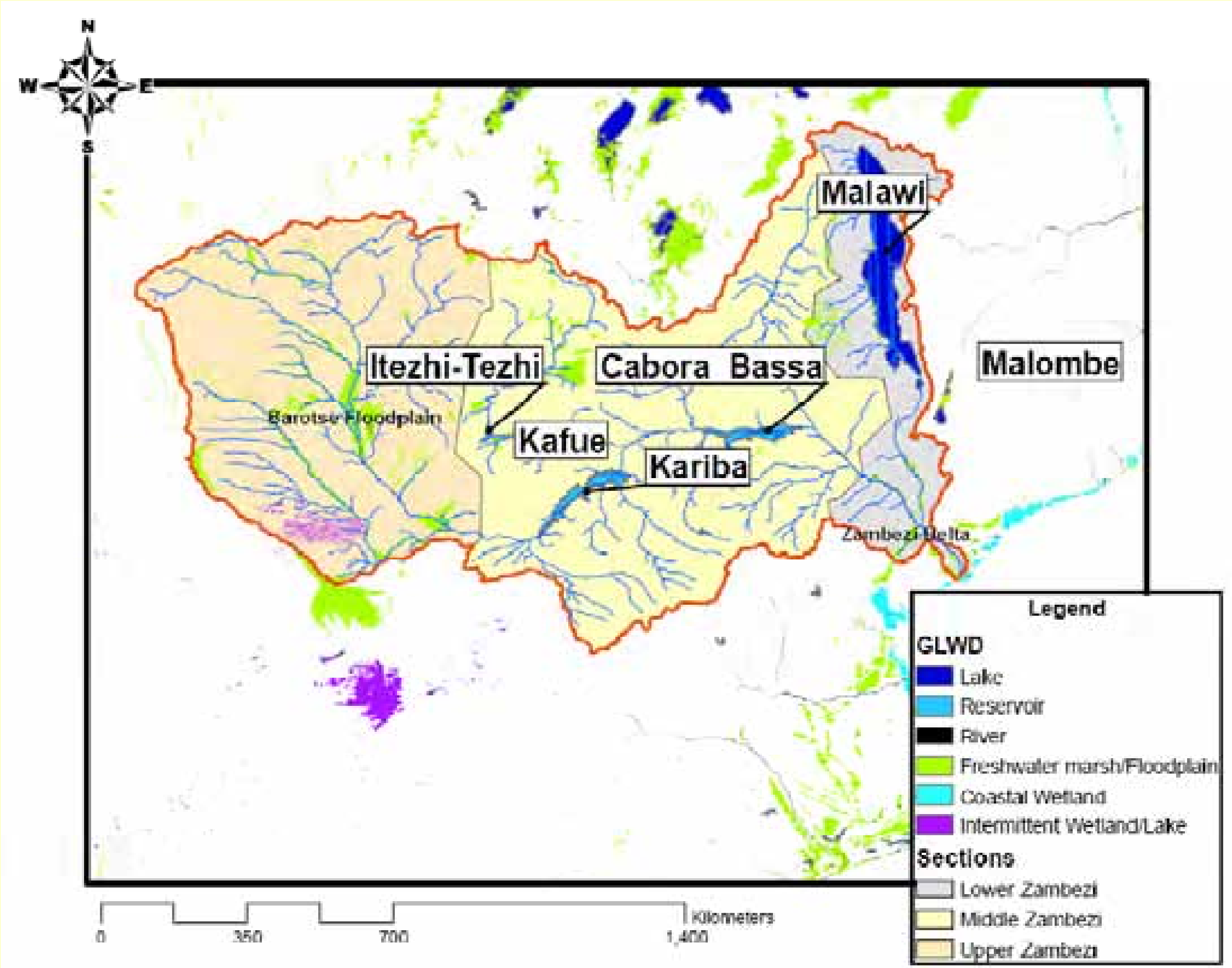
Global selection lakes

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

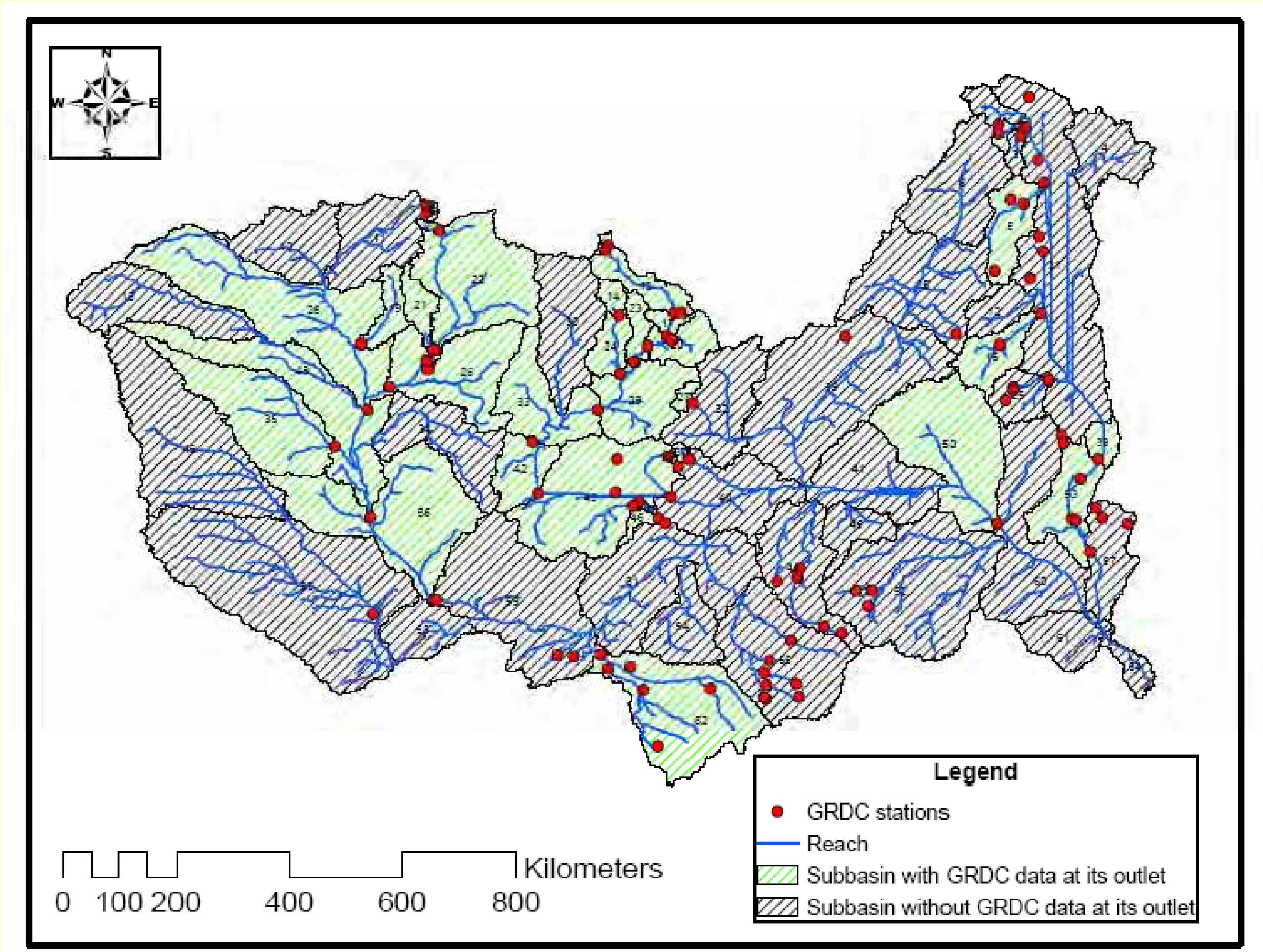


Birkett

Zambezi River Basin



Zambezi SWAT Model Setup

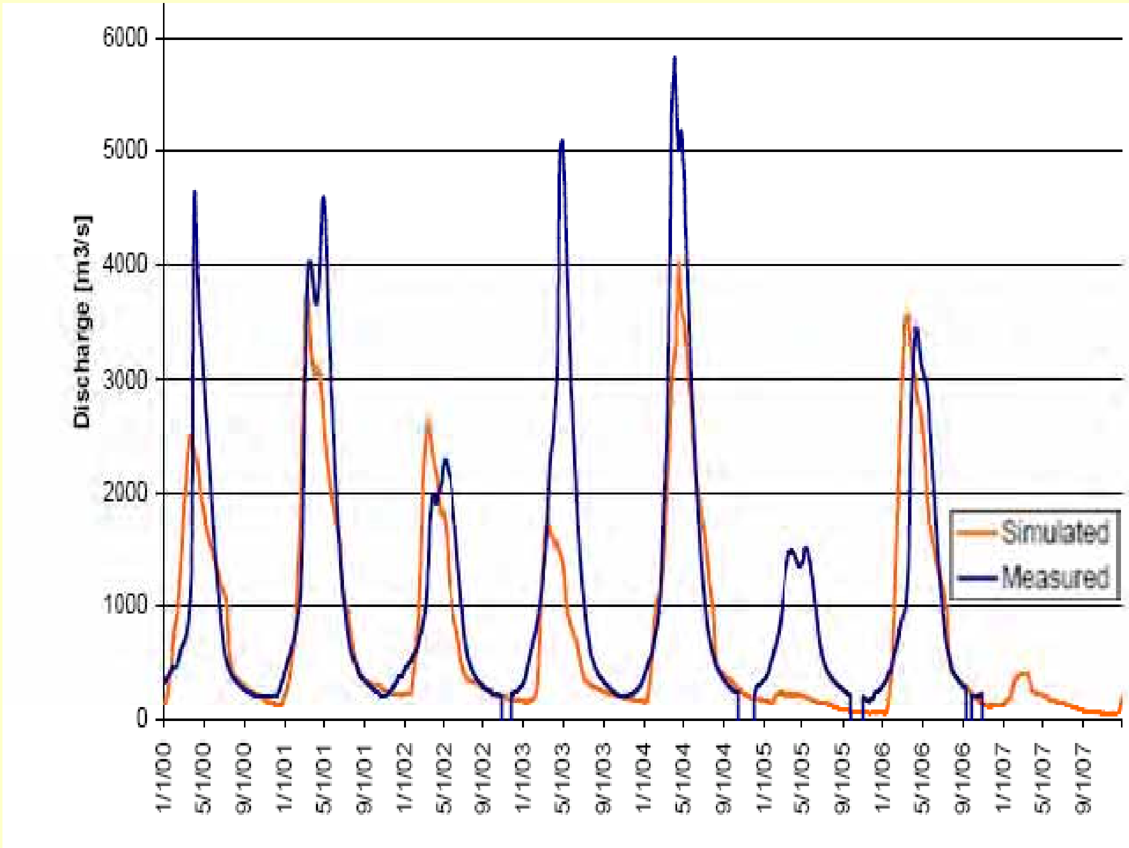


SWAT: Soil & Water Assessment Tool

SWAT is a public domain model actively supported by the USDA Agricultural Research Service at the Grassland, Soil and Water Research Laboratory in Temple, Texas, USA.

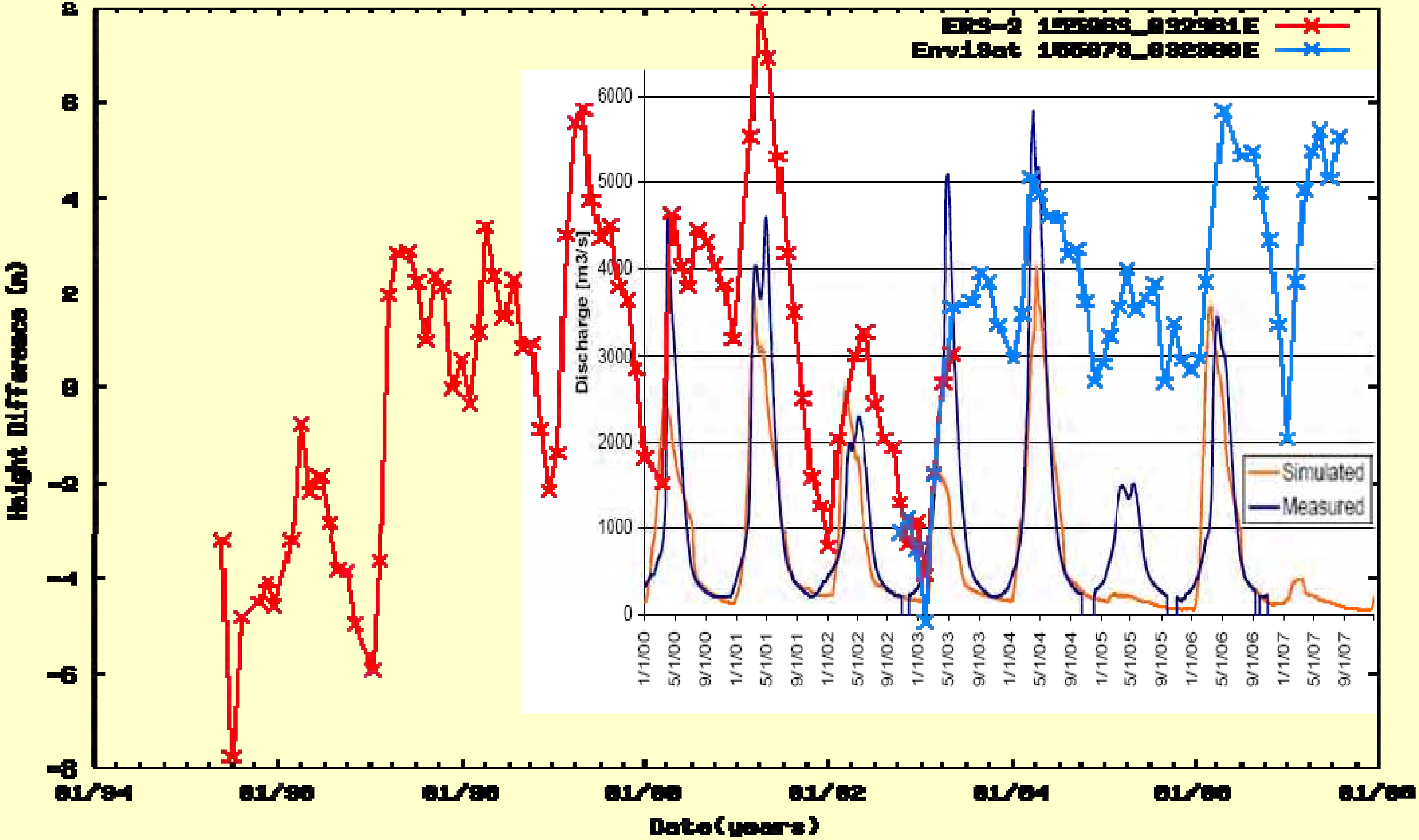
http://www.brc.tamus.edu/swat/

Zambesi



Sample model performance on discharge

Zambesi



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

esa

World Meteorological Organization
Working together in weather, climate and water

IRD
Institut de recherche pour le développement

Cemagref

DE MONTFORT UNIVERSITY
LEICESTER • BEDFORD

E.A.P.R.S.

LEGOS

TETIS

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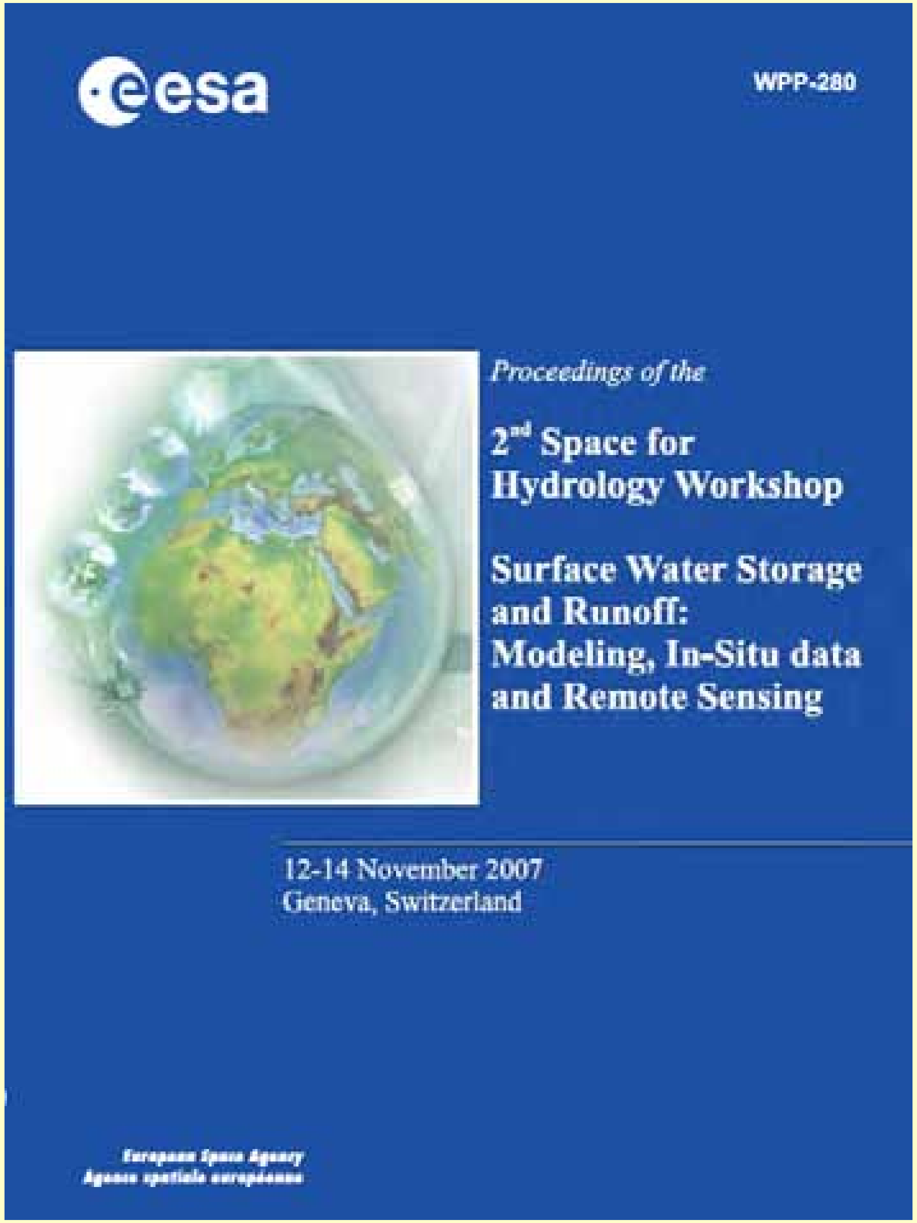
2nd Space for Hydrology Workshop Attendance

- 80 Abstracts
- 38 Posters
- 34 Oral
- 188 Co-authors
- 103 Participants, 27 countries
- 5 Dedicated sessions

- Several communities together
  - Modeling,
  - In situ data,
  - Space sensors and data
  - Meteorology
  - Geodesy

http://earth.esa.int/hydrospace07

2nd Space for Hydrology Workshop



Following the plenary discussion session, recommendations were drafted and issued in the proceedings;

Reported in the conclusions of WPP-280.

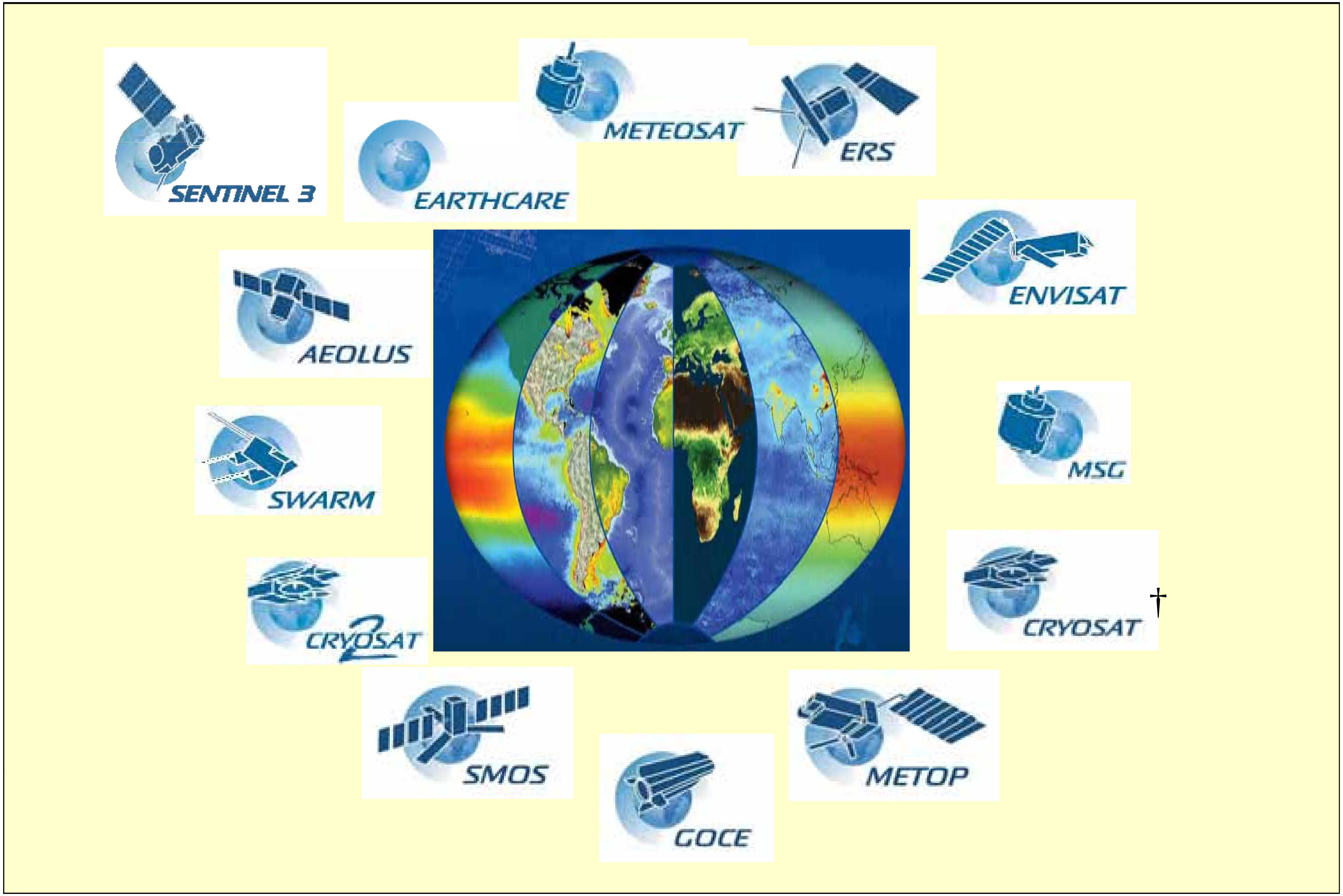
Stay tuned for the

3rd Space for Hydrology

Workshop!

ESA Earth Observation Programme and Missions Status

ESA's Earth Observation Toolkit



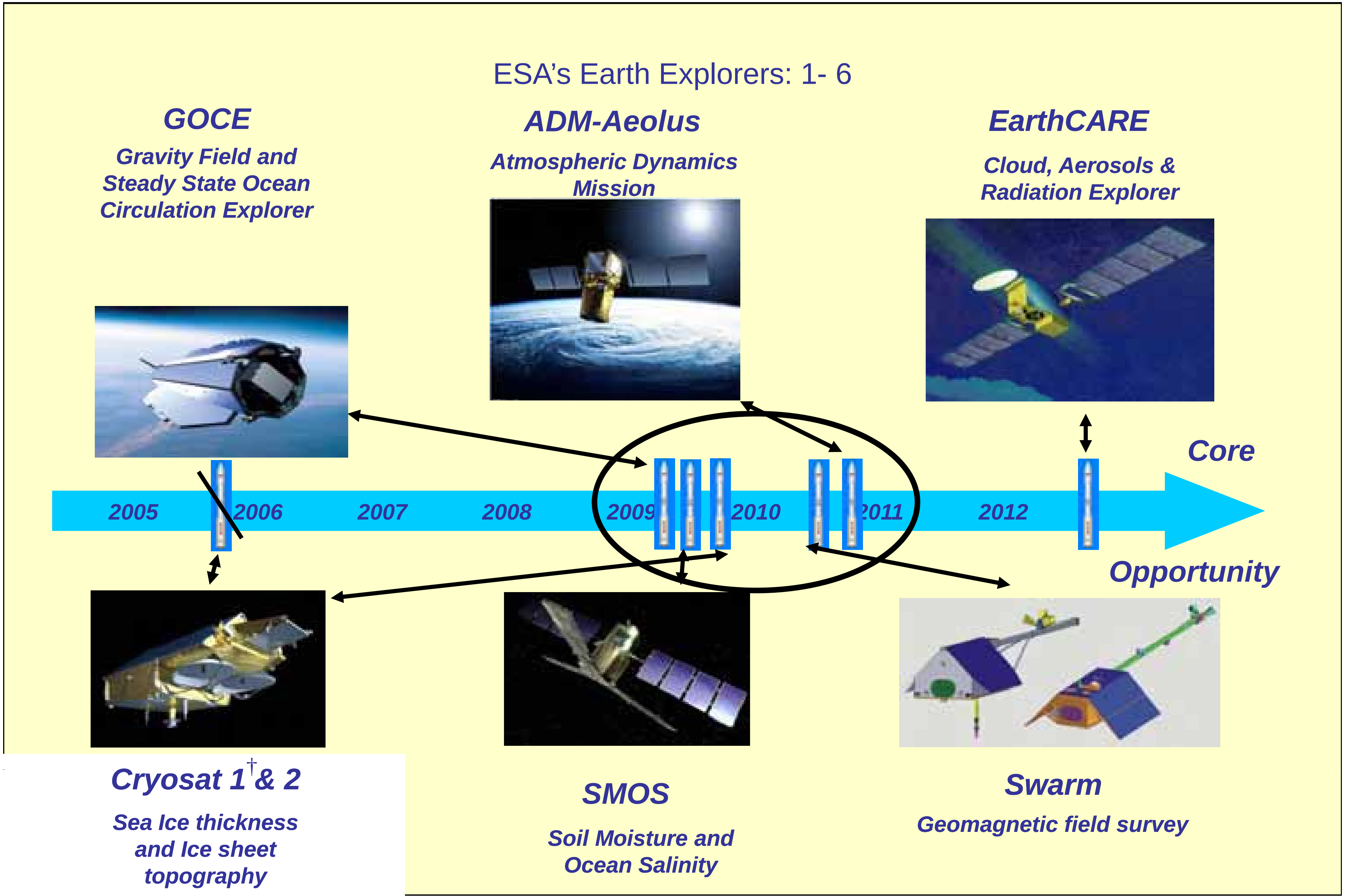
Forthcoming Attractions

- ESA's Living Planet Programme contains the Earth Explorer line of "science-driven" missions

- Approved Earth Explorer Missions:

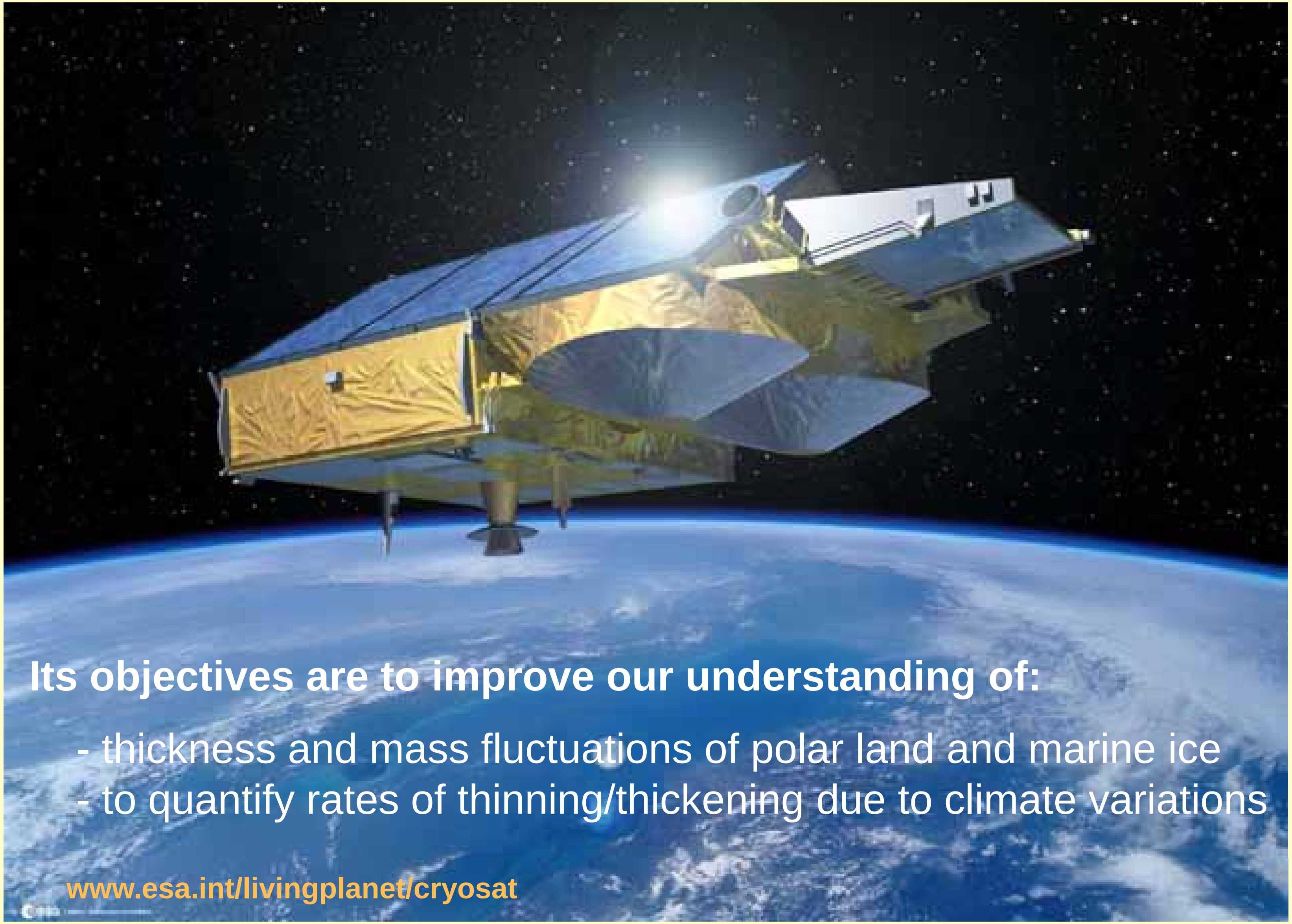
► GOCE	(Launched 17 March 2009)
► SMOS	(planned mid-2009 launch)
► CryoSat-2	(planned end-2009 launch)
► Swarm	(planned mid-2010 launch)
►ADM-Aeolus	(planned end-2010 launch)
► EarthCare	(planned end-2012 launch)

- *5 7th explorer in pre-phase A, selection process on-going*
  - *Earth Explorer User Consultation meeting, 20-21 January 2009, Lisbon*



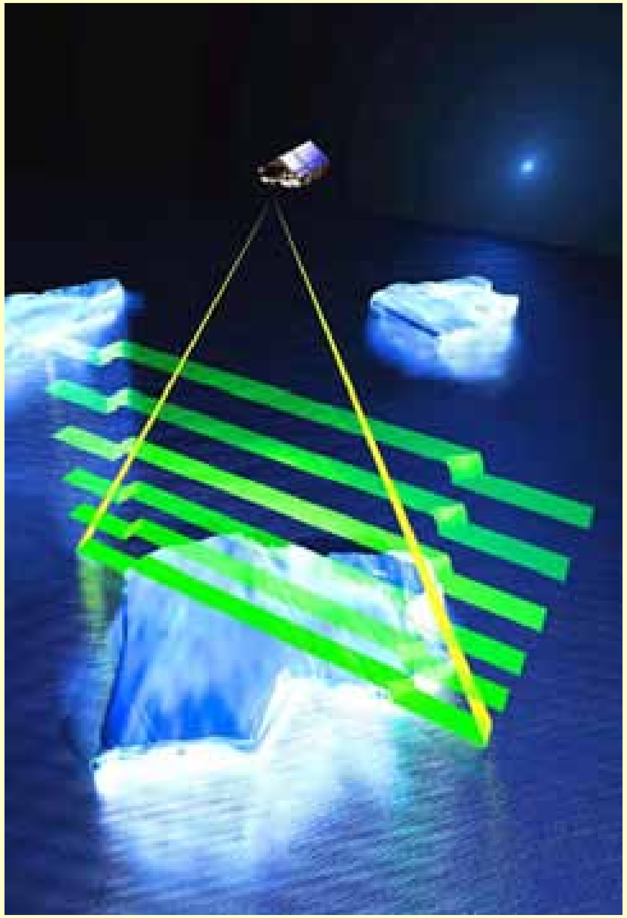
ESA's Earth Explorers: 1- 6
GOCE
Gravity Field and Steady State Ocean Circulation Explorer
ADM-Aeolus
Atmospheric Dynamics Mission
EarthCARE
Cloud, Aerosols & Radiation Explorer
Core
2005
2006
2007
2008
2009
2010
2011
2012
Opportunity
Cryosat 1† & 2
Sea Ice thickness and Ice sheet topography
SMOS
Soil Moisture and Ocean Salinity
Swarm
Geomagnetic field survey

CryoSat-2: ESA’s Ice Mission



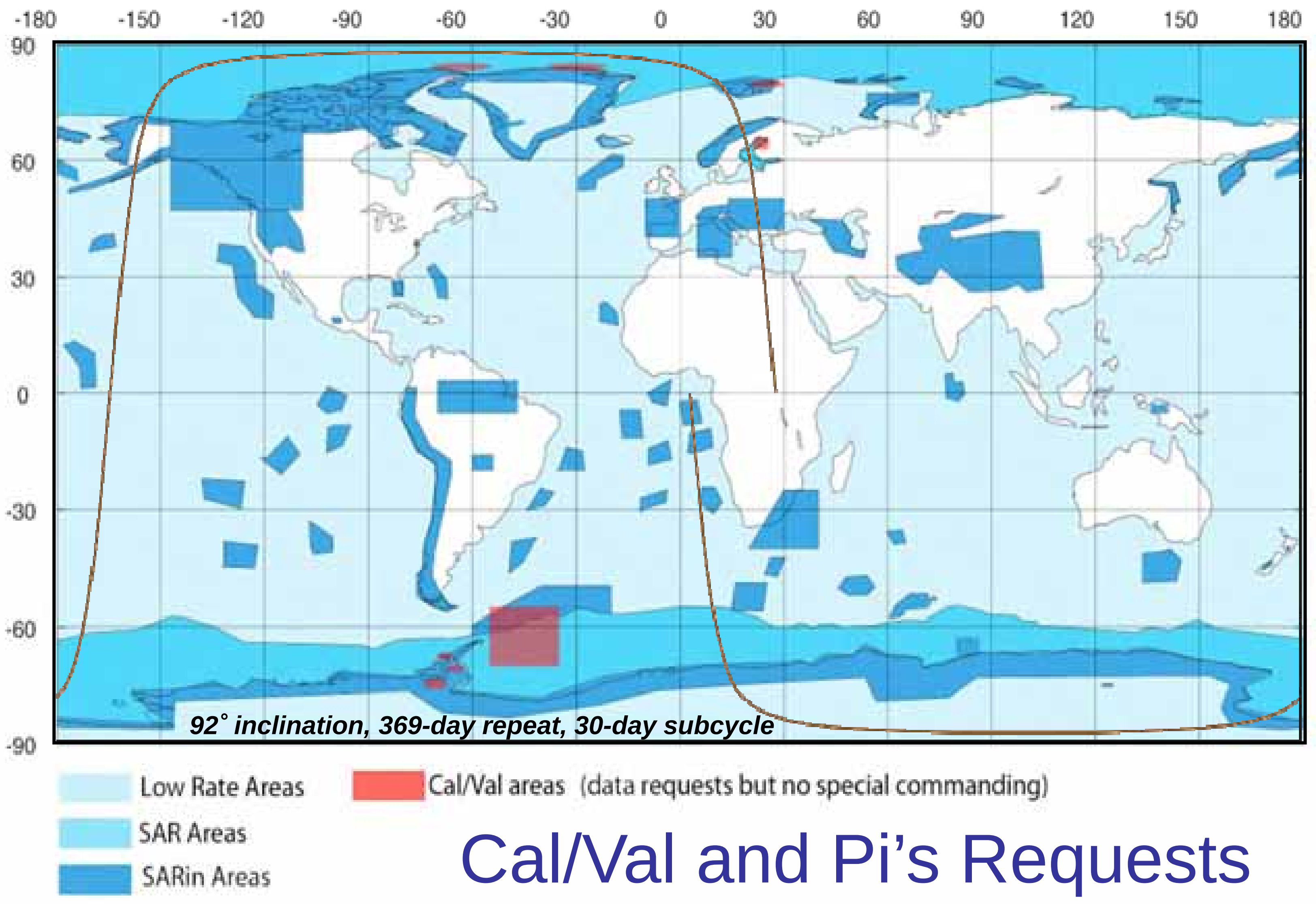

CryoSat will carry a new generation Altimeter

CryoSat's High-Resolution



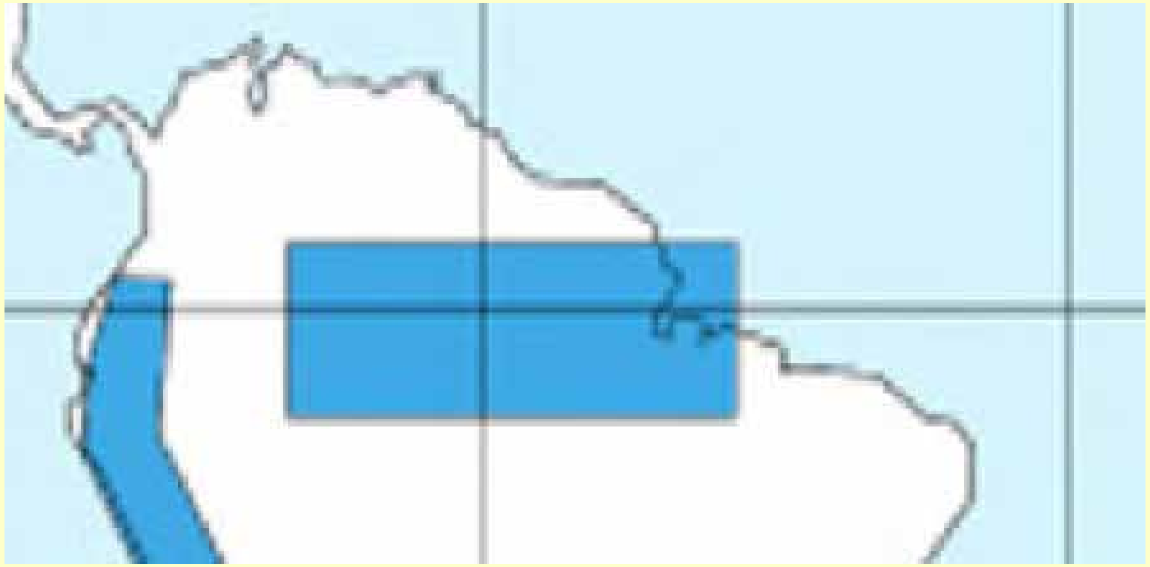
- Transmits bursts of 64 pulses: sequential echoes are correlated
- Satellite moves 250 m between bursts
- Aperture Synthesis technique gives 250 m along-track resolution, much higher than conventional altimeters (ERS-2/Envisat RA-2)
- SAR Mode used over sea-ice to measure ice-floe freeboards and retrieve thickness

SIRAL Mode Operation



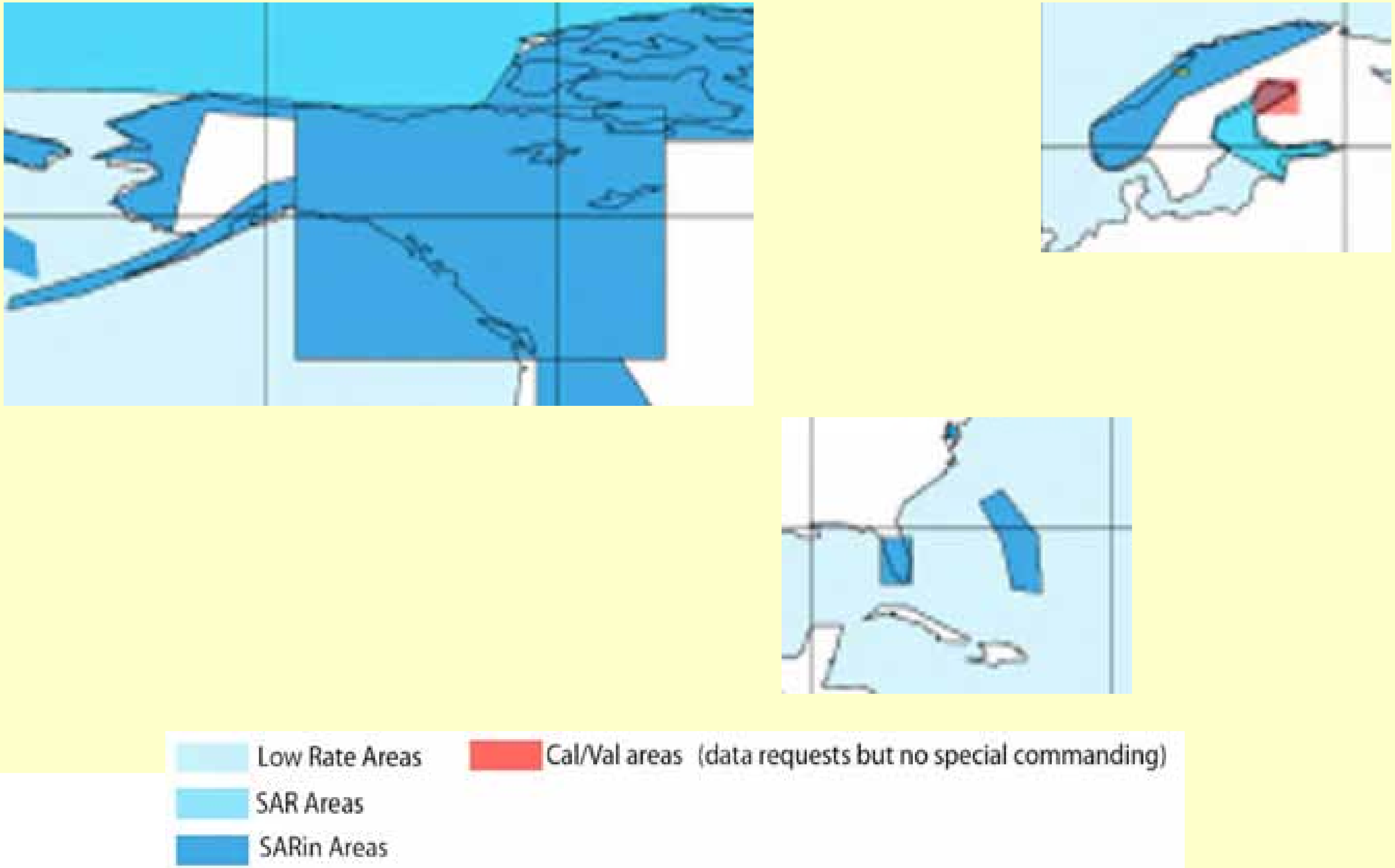
Cal/Val and Pi's Requests

SIRAL Mode Operation



Low Rate Areas
Cal/Val areas (data requests but no special commanding)
SAR Areas
SARin Areas

SIRAL Mode Operation



Sentinel-3

will carry a new generation Altimeter, similar to CryoSat but with no interferometry mode

Global Monitoring for Environment and Security

Sentinel-3 is one element of the overall GMES system providing 2 days global coverage earth observation data for sea and land applications with real-time products delivery in less than 3 hours.

Operational oceanography & global land applications

Acquire data to feed ocean/atmosphere models and to derive global land products and services.

- Sea/land colour data, in continuation of Envisat/Meris.
- Sea/land surface temperature, in continuation of Envisat/AATSR.
- Sea surface and land ice topography, in continuation of Envisat altimetry.
- Along-track SAR for coastal zones, in-land water and sea ice topography.
- Vegetation products by synergy between optical instruments.

Mission duration

A series of satellites, each designed for a lifetime of 7 years, shall be launched to provide an operational service over 15 to 20 years. Furthermore, two satellites shall operate at any time to fulfil the mission requirements.
(Only one satellite is in development at this moment)

Mission orbit

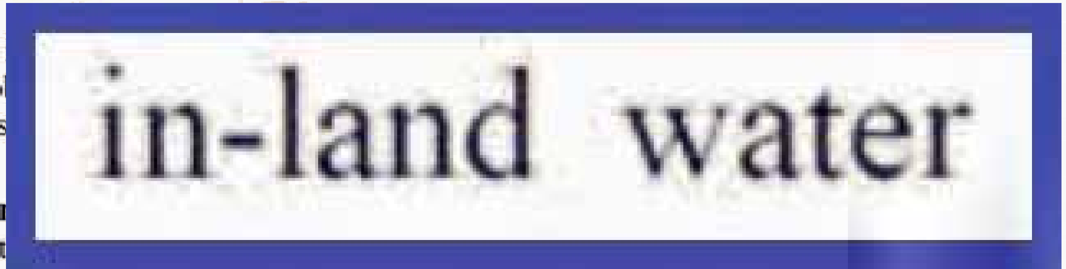
Type: Frozen, sun-synchronous low earth orbit
Repeat cycle: 27 days (14+7/27 orbits per day).
Average altitude: 814.5km over geoid
Mean solar time: 10h00 at descending node.
Inclination: 98.65°
Launcher: VEGA/Kourou (Eurockot/Plesetzk backup)

Spacecraft configuration

Launch mass: 1198kg (with maturity margins + 10% system margin, 95kg hydrazine in 130kg tank)
Stowed dimensions: (H) 3712 mm (W) 2202 mm (L) 2172 mm
Attitude control: Gyroless, 3 axis stabilised platform with 3 star tracker heads, 4 reaction wheels and magnetic off-loading.
Geodetic pointing and yaw sterring
Orbit control: 8x1N hydrazine thrusters for in-plane and out-out plane manoeuvres.
130kg hydrazine tank
3 meter accuracy real-time onboard orbit determination based on GPS and Kalman filtering.
Power: 2.1 kW rotary wing with 10 m^2 triple junction GaAs European solar cells.
LiIon battery, 160Ah
Communications: 64kbps uplink, 1Mbps downlink S-band command and control link (with ranging).
2x225Mbps X-band science data downlink.
330Gbit solid state mass memory.
Autonomy: Position timeline and onboard sun ephemeris for >2 weeks nominal autonomous operations.

Global Monitoring for Environment and Security

Sentinel-3
2 days glo
applications



Operatio

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Sentinel-3
2 days glo
applications

in-land water

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LAUNCH : End 2012

Sentinel-3
2 days glo
applications

in-land water

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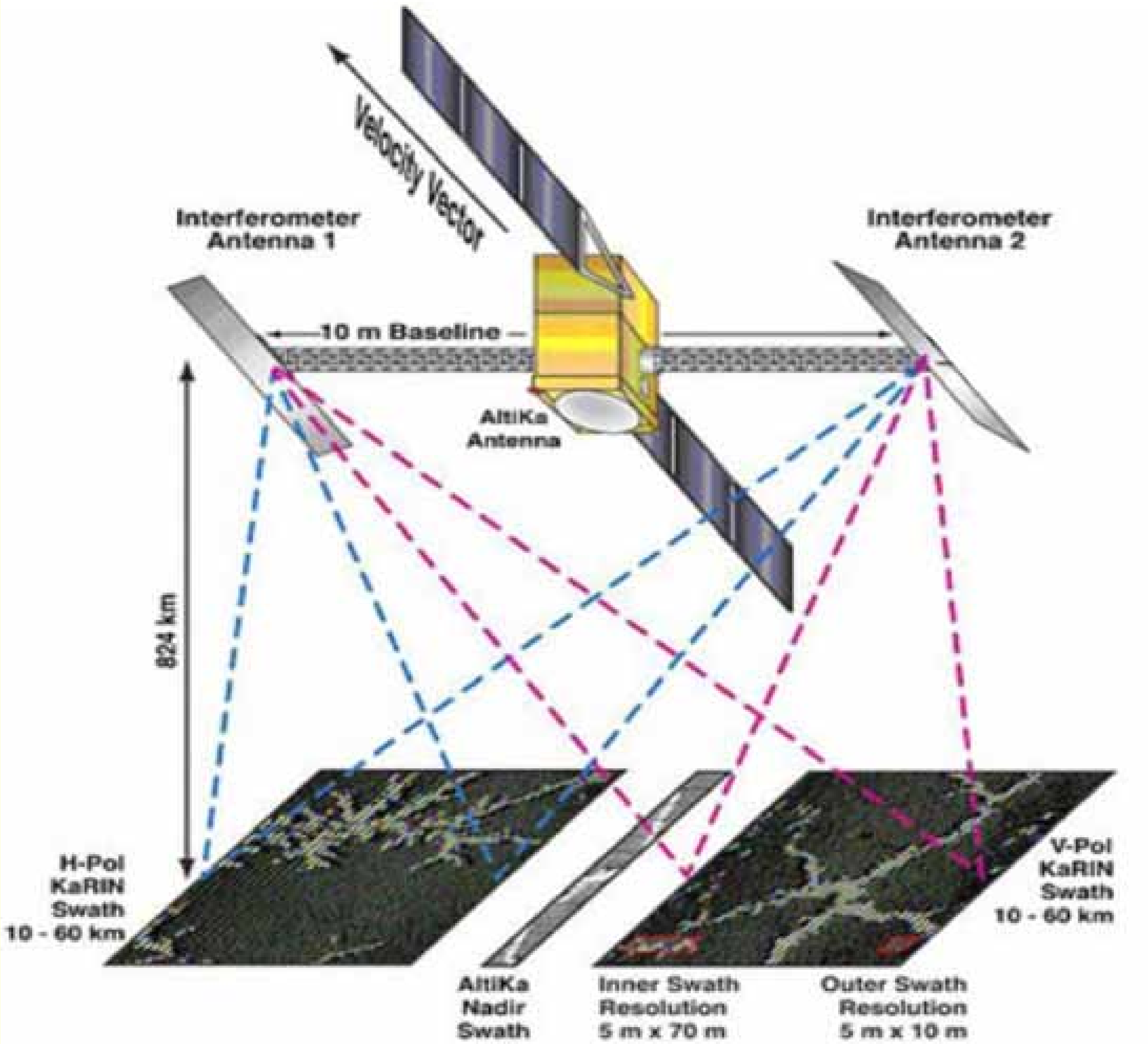
SWOT in 2016


Velocity Vector
Interferometer
Antenna 1
Interferometer
Antenna 2
10 m Baseline
AltiKa
Antenna
824 km
H-Pol
KaRIN
Swath
10 - 60 km
V-Pol
KaRIN
Swath
10 - 60 km
AltiKa
Nadir
Swath
Inner Swath
Resolution
5 m x 70 m
Outer Swath
Resolution
5 m x 10 m

Conclusions (1/5)

- A huge amount of waveforms are already gathered over inland water targets globally.
- 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.

Conclusions (2/5)

- As the existing network of in-situ gauges falls out of repair, more and more catchments are becoming ungauged, whilst the demand on this increasingly scarce resource continues to escalate. Using the remote measurement capability of altimetry, particularly the near-real-time capability, is now beginning to allow water resource managers access to both the NRT data and its context, in the form of 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 basin resources beyond their capability to recharge.
- The technology can be applied as well in the oceanic coastal zone (similar difficulties in making the measurement due to contamination by surrounding land)

Conclusions (3/5)

- 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 processing 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) and
  - 4) integration of measurement and forecast systems (satellites, river gauges, discharge and current meters, tide gauges, hydrographic measurements, models).

Conclusions (4/5)

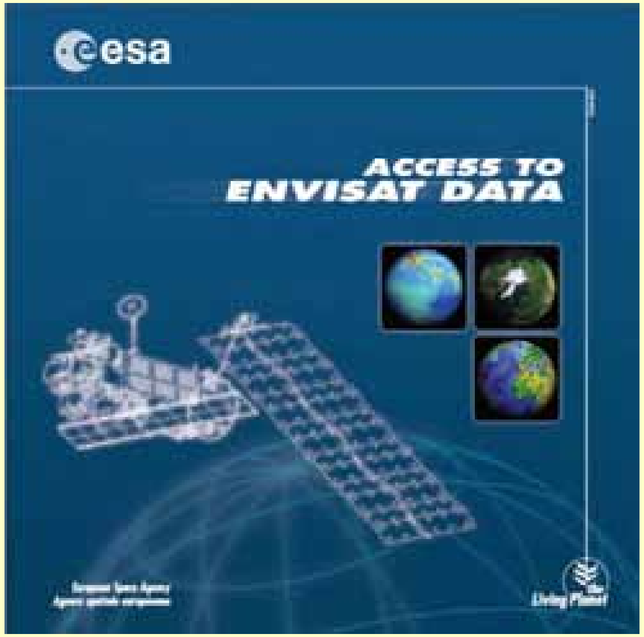
- In Hydrology and coastal altimetry cooperation is essential at EU level, but even globally, as the problems are global and the expertise needed is interdisciplinary and geographically distributed.
- The best excellences need to be networked and complementarities exploited. This is actually happening 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 (5/5)

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

ESA EO Data Access

http://earth.esa.int



eohelp@esa.int