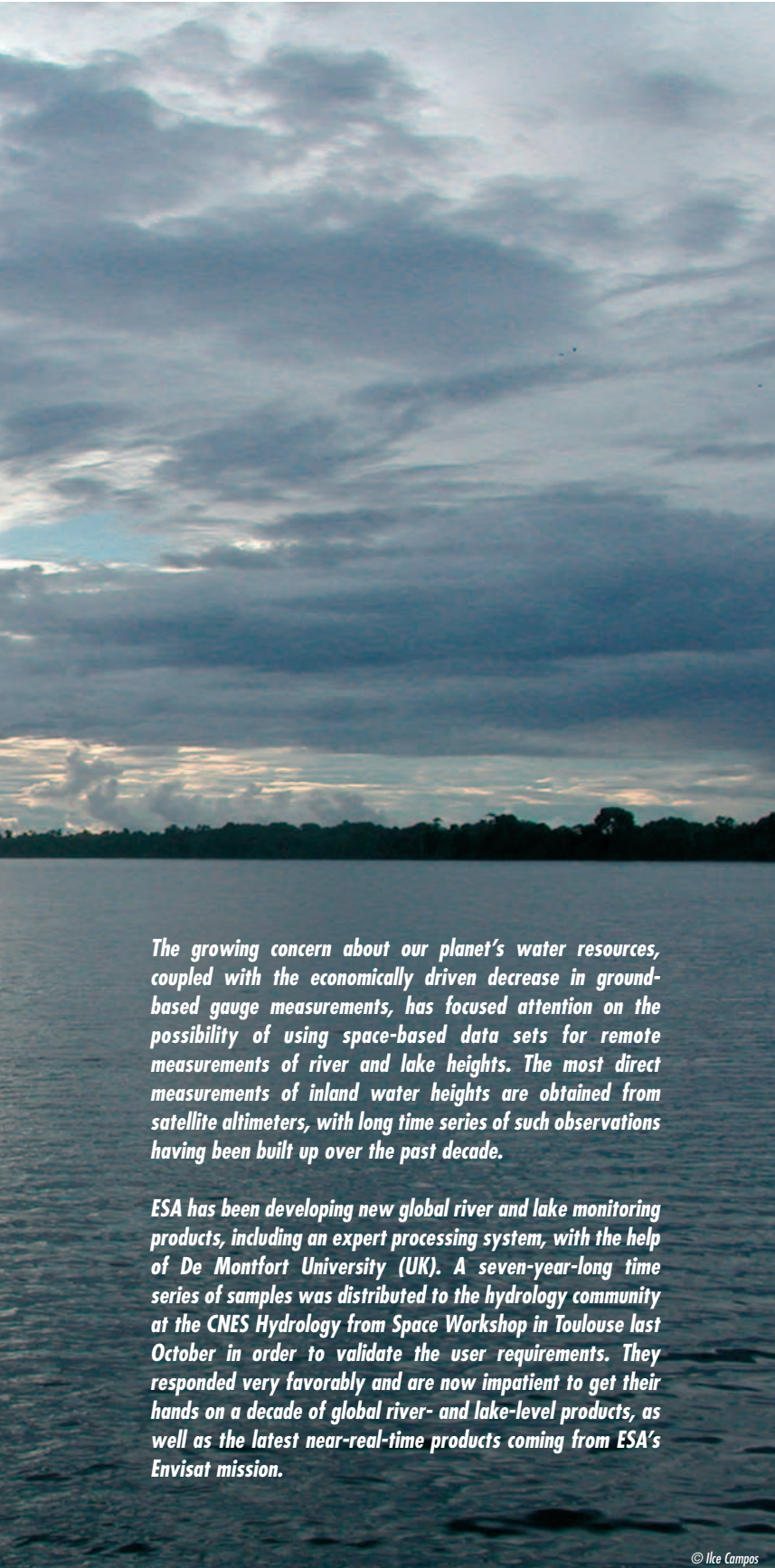


Monitoring River and Lake Levels from Space



The growing concern about our planet's water resources, coupled with the economically driven decrease in ground-based gauge measurements, has focused attention on the possibility of using space-based data sets for remote measurements of river and lake heights. The most direct measurements of inland water heights are obtained from satellite altimeters, with long time series of such observations having been built up over the past decade.

ESA has been developing new global river and lake monitoring products, including an expert processing system, with the help of De Montfort University (UK). A seven-year-long time series of samples was distributed to the hydrology community at the CNES Hydrology from Space Workshop in Toulouse last October in order to validate the user requirements. They responded very favorably and are now impatient to get their hands on a decade of global river- and lake-level products, as well as the latest near-real-time products coming from ESA's Envisat mission.

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The great majority of the World's population lives alongside, and is often dependent upon, continental water bodies. Inland water bodies – rivers, lakes, wetlands and floodplains – play important roles in a variety of interdisciplinary applications. They are a source of both water and protein, often a means of navigation and for the production of hydroelectric power, and have been shown to be good proxy indicators of local and regional climatic change. Many catchment areas are regions of great biodiversity and are often focal points in terms of environmental and conservation issues. Routine monitoring of these basins has further importance for regional and continental-scale hydrological, biochemical and climatological studies concerning, for example, the measurement of river discharges, the production of wetland methane, and the estimation of evaporation losses for land/atmosphere interactions.

Changes in the stored volumes of surface water also have geodynamical implications for the Earth's rotation and gravity, and for estimating the global water mass in relation to sea-level changes. With synergistic inundation extent measured by remote-sensing imagers, radar or optical, the monitoring of both surface level and area has relevance for studies of water-related epidemics such as malaria, cholera, and tuberculosis and the financial losses and human suffering therefrom.

The Rationale

ESA's ERS-1 and ERS-2 missions and the Topex/Poseidon satellite have been acquiring radar-altimeter data for more than ten years now. With the recent successful launch of Jason-1 and ESA's Envisat, this time series will be prolonged into the future, as well as being processed in near real time. It means that there is a wealth of long-term hydrological information at hand, but extracting meaningful products from the radar-altimeter signal echoes is a complex process due to the unpredictable nature of the echo's shape over continental surfaces. This is precisely why ESA launched the development of a new ready-to-use hydrological product as part of its 'River and Lake Project'.

The project's main objective is to provide the scientific community with easy-to-use, effective and accurate river and lake level measurements from both the ERS and Envisat satellite altimeters. The hydrologist's requirements pose a very interesting challenge, because the traditional satellite products have been radically different from those based on ground data, with both the vertical precision and temporal sampling being more limited.

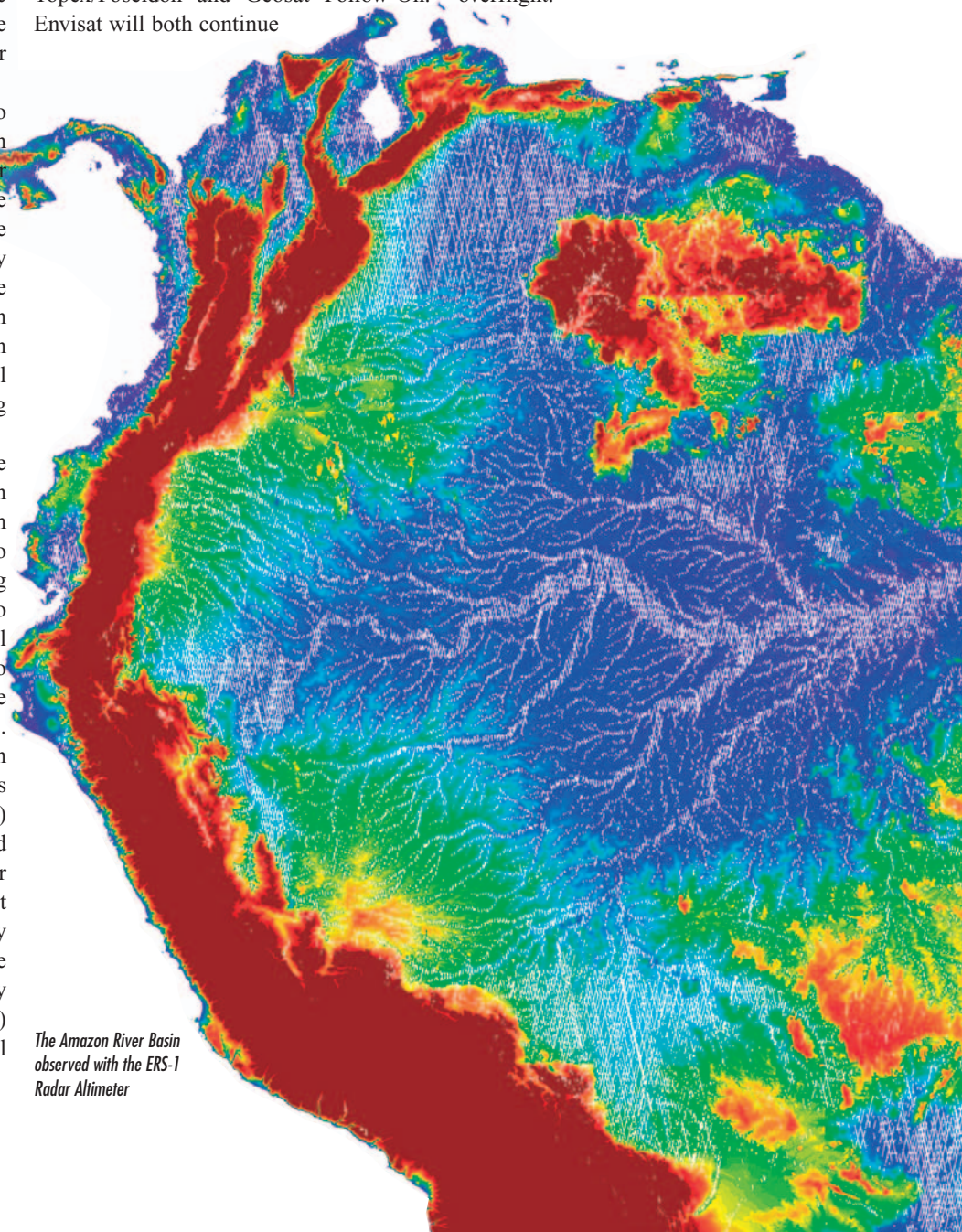
This new development will enable the valuable hydrological data encoded in satellite altimeter echoes returned from rivers and lakes to be translated into accurate height estimates, thus permitting time series of more exact water heights to be produced. Of the many potential applications of radar altimetry to hydrology, the simplest in concept is the monitoring of river and lake levels. Previous work on extracting such information from satellite data was constrained by mission limitations (Seasat) and a combination of data limitations and instrument and pointing difficulties over land surfaces (Geosat). This meant that only very limited applications of altimetry for surface hydrology could be demonstrated over land, with the primary targets being wetlands (for direct mapping) and large lakes (for water-level determination).

Considerable work has been done with Topex, which has also demonstrated the usefulness of such data, but only over a small number of selected targets. One key constraint for hydrological applications from these missions is that their altimeters, originally designed for ocean measurements, can 'keep track' only over very limited areas on land.

The major advance in land coverage provided by the inclusion of an 'ice mode' in the ERS-1 and ERS-2 Radar Altimeters has vastly increased the capabilities for monitoring the Earth's river and lake systems, compared with altimeters equipped only with an 'ocean mode', e.g. Topex/Poseidon and Geosat Follow-On. Envisat will both continue

this valuable data stream and, potentially, extend it, as an additional tracking mode allows successful radar-echo capture over even rougher terrain.

The system developed by De Montfort University (UK) for ESA uses both ERS and Envisat data to produce two types of products: a River-Lake Hydrology (RLH) product and a River-Lake Altimetry (RLA) product. The first goal is to obtain 7 years of processed data for specific targets, then to propose the world-wide coverage of large rivers and lakes over 7 years, and finally to make all RLH and RLA products available to hydrologists in near-real-time, i.e. less than 3 hours after the satellite's overflight.



The Amazon River Basin observed with the ERS-1 Radar Altimeter

The Role of Satellite Radar Altimetry

Water bodies represent important economic and cultural resources, but also much economic activity and development takes place close to the shorelines of lakes and can be adversely affected by flooding. Moreover, lake volumes respond to changes in precipitation integrated over their catchment basins and so can act as important, though indirect, indicators of climate change on both regional and global scales. Major river systems are important targets for research covering a wide range of applications, such as transport, flooding hazards, water and food resource management, as well as studies of the hydrological cycle and the impact of land use and climate change.

For certain major rivers and wetlands, hydrological information can often be difficult to obtain, due to the inaccessibility of the region, the sparse distribution of gauge stations, or the slow dissemination of data. Satellite radar altimeters have the potential to provide accurate height measurements not only for lakes, but also for large rivers such as the Amazon, which has been a primary target of environmental studies over the last 10 years.

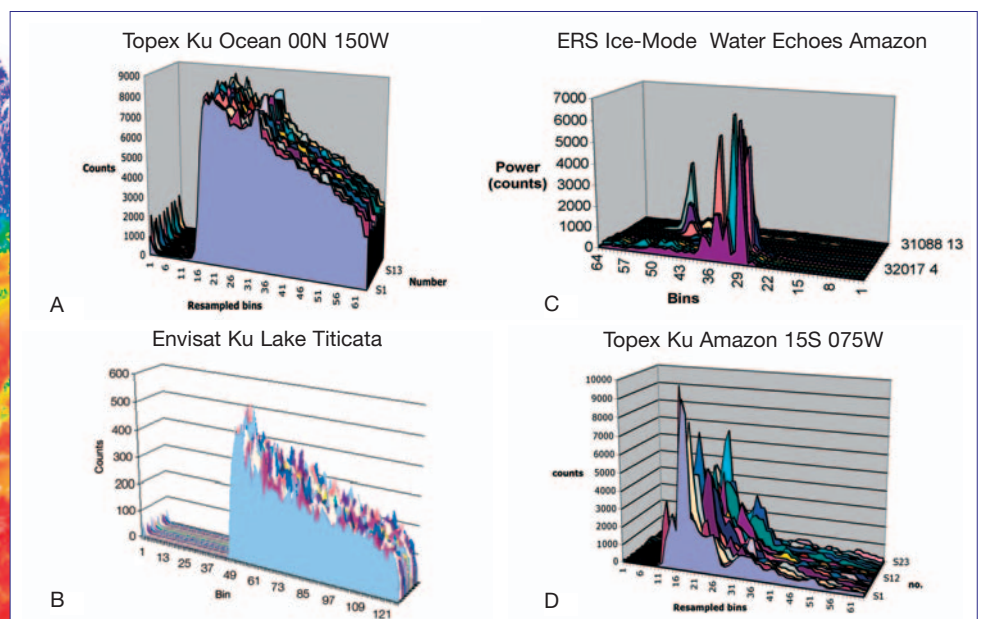
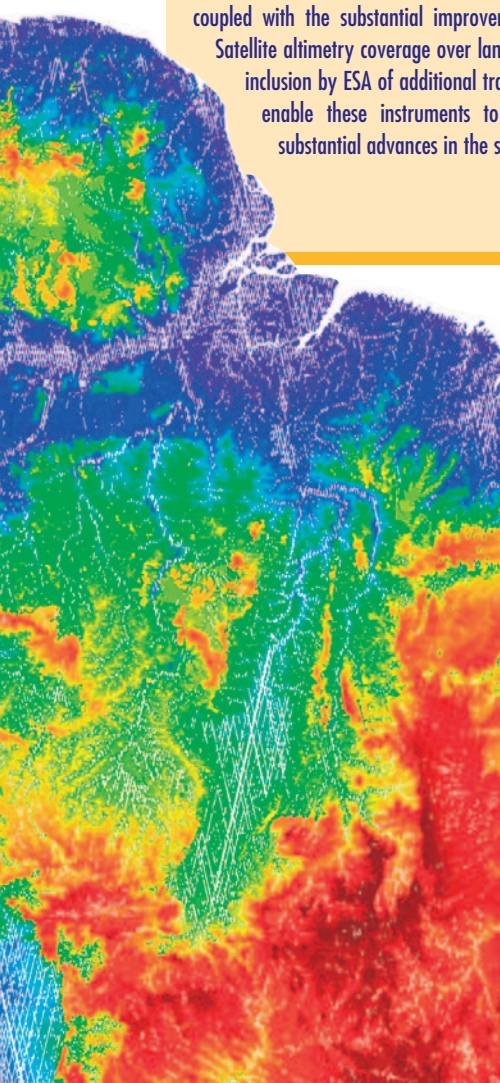
Research into the application of altimetry for monitoring river and lake levels has been carried out since 1982. It has highlighted the advantages of using data derived from satellites due to their global coverage and regular temporal sampling of the processed data, but has also identified the difficulties in interpreting radar-altimeter measurements made over inland waters. In general, the great improvement in altimeter measurement accuracy that has occurred over the past decade has been due to the progress in altimeter instrumentation, coupled with the substantial improvement in the precision of satellite orbit calculations.

Satellite altimetry coverage over land surfaces has also been greatly improved due to the inclusion by ESA of additional tracking modes in the ERS and Envisat altimeters, which enable these instruments to cope with rapidly changing surfaces, leading to substantial advances in the study of ice, land and inland waters.

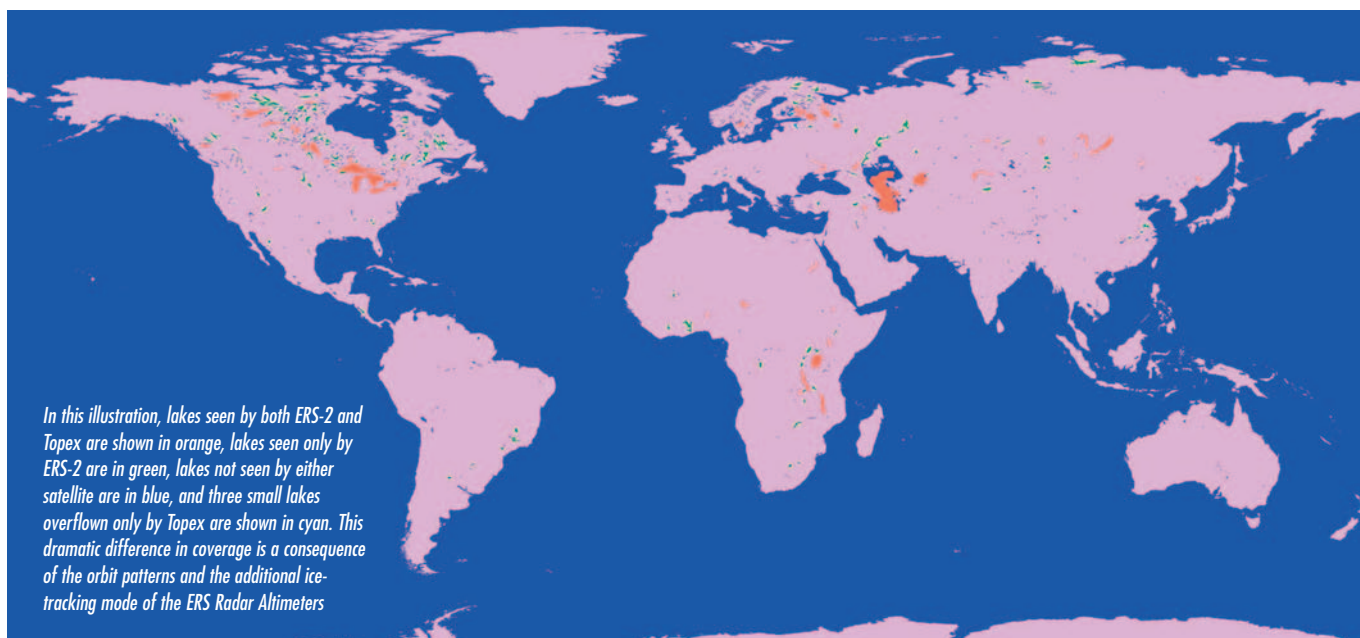
Sifting the Data

To optimise the recovery of inland water data from spaceborne altimeters, and gain access to the unique time series of inland water heights contained in the ERS and Envisat radar signals, it is necessary to reprocess the individual echoes to obtain an accurate 'range to surface'. The task is complicated by the wide variety of echo shapes returned, especially in the presence of land 'contamination'. In fact, several factors affect the accurate recovery of height data from inland water echoes. The first and in many ways the most serious limitation is the presence of very bright components within the echo resulting from still pools. Further complications include the presence of islands and sandbars within the water body, the surrounding still water from, for example, irrigation and rice paddies, and the effect of surrounding terrain. All of these factors affect the echo shape and complicate retrieval of the range from the satellite to the water surface.

The accompanying figure shows four sequences of echo shapes to illustrate the differences between the echoes from large lakes and oceans, and the rapidly varying radar returns from rivers and smaller lake systems: they are typical ocean returns from Topex, returns from Envisat over a large lake (Lake Titicaca), and two series



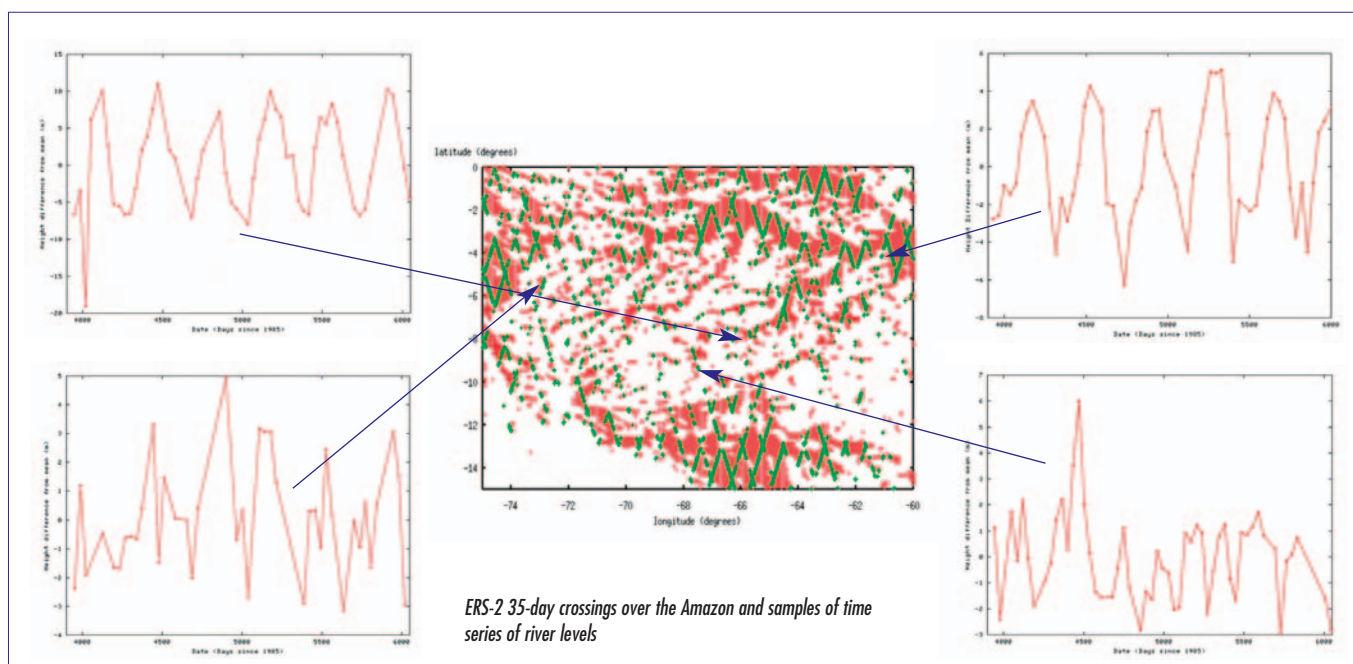
Envisat Radar Altimeter return-echo shapes over rivers

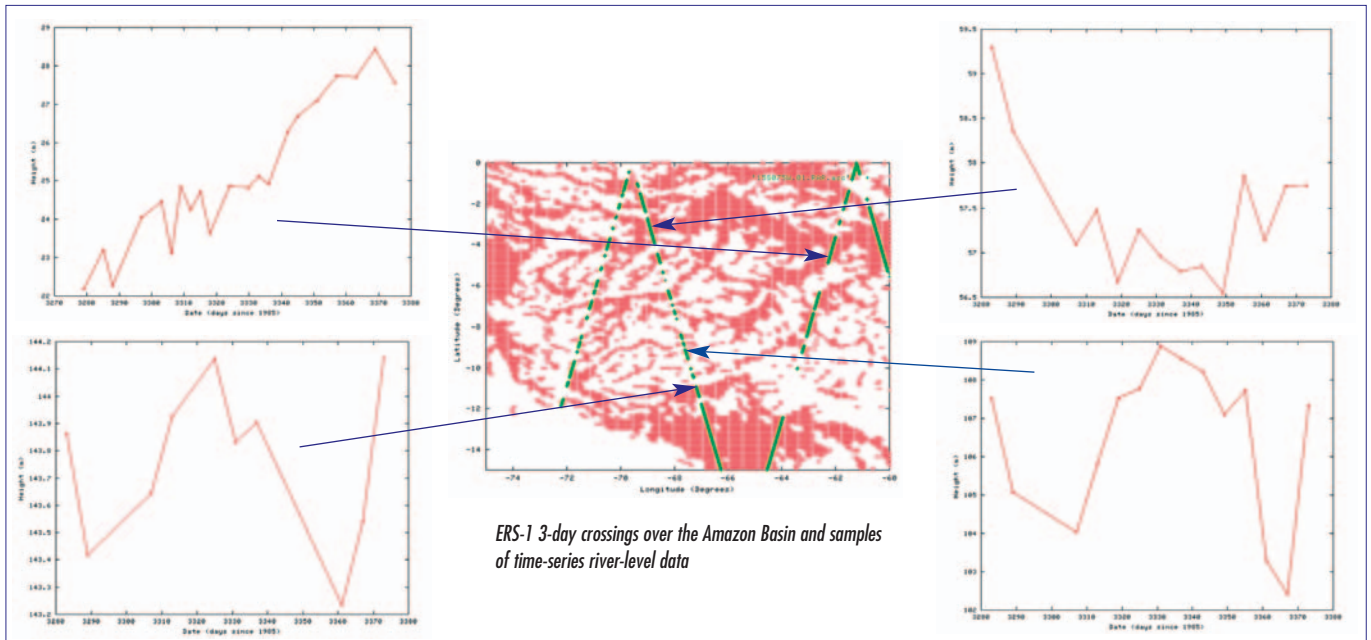


of returns from inland water/land composites over the Amazon Basin from ERS-2 and Topex. This diversity in echo shapes means that it has not been possible to design just one retracking algorithm to reprocess all waveforms optimally. Rather, a suite of such algorithms is required, and this is the approach that has been implemented for ERS-1/2, Envisat and Topex data using the expert system developed at De Montfort University.

Over rivers, ERS-2 shows significantly better performance than Topex, thanks to the Ice mode. The accompanying figure shows a typical 35-day cycle of ERS-2 crossings (green) superimposed on the Amazon Basin bright-targets map developed from the ERS-1 geodetic mission (red). Four sample time series of river-height variations derived from the ERS-2 retracked dataset are also shown. The large annual variation is clear.

To illustrate the relative performance of a higher sampling frequency with an ice-mode altimeter, the next figure shows a similar map for ERS-2 three-day crossings (green) over Amazon Basin bright targets. Again, time-series data have been included to illustrate the satellite altimetry's potential for identifying rapid temporal variations in river and stream height when using a satellite with a short orbit-repeat pattern.



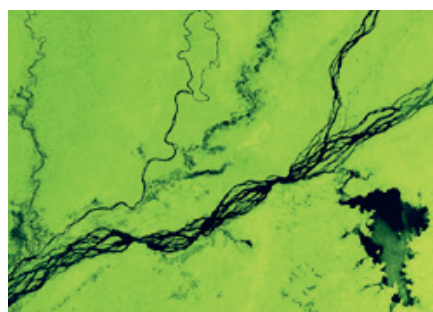
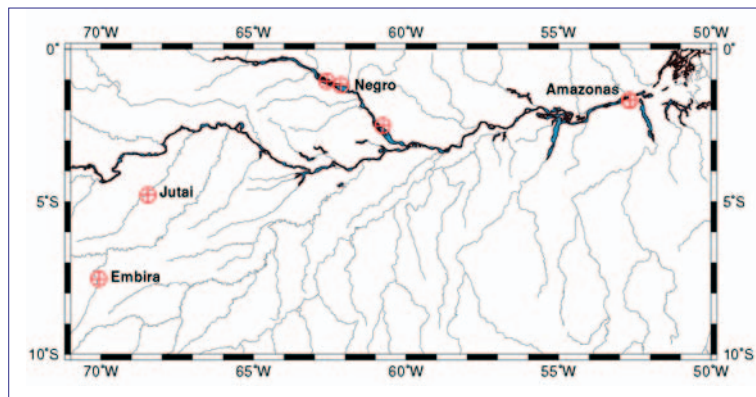


The Two New Products

As mentioned above, two novel types of product have been designed and are currently available as samples. The River-Lake Hydrology (RLH) product, intended for hydrologists with no special knowledge of radar altimetry, is grouped by river/lake crossing point (one product per crossing point). The RLH product is distributed in XML format, which makes access and visualisation very simple. The River-Lake Altimetry (RLA) product, designed for radar-altimetry experts, is grouped by satellite orbital revolution. A detailed product description can be found in the Product Handbook, downloadable from the River and Lake Project web site (<http://earth.esa.int/riverandlake>).

To familiarise the hydrology community with these novel products and to gather feedback concerning their suitability and use, a set of 22 representative seven-year-long time-series samples were distributed at the Hydrology from Space Workshop in Toulouse (F) last October. The 22 products focused on two regions:

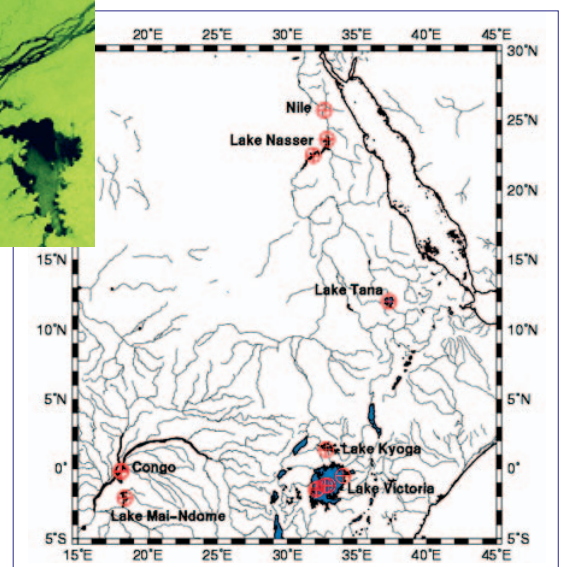
- Africa: Lake Nasser, the River Nile including the Aswan Dam, Lake Tana, Lake Kyoga, Lake Victoria, Lake Mai-Ndombe and the River Congo.
- South America: Amazon Basin.



The River Congo as seen by Envisat's Advanced Synthetic Aperture Radar (ASAR)

The accompanying location maps for both regions have the related product crossing points highlighted and the corresponding product samples can be downloaded at [http:// earth.esa.int/riverandlake](http://earth.esa.int/riverandlake).

Maps of the African and South American sample-product locations





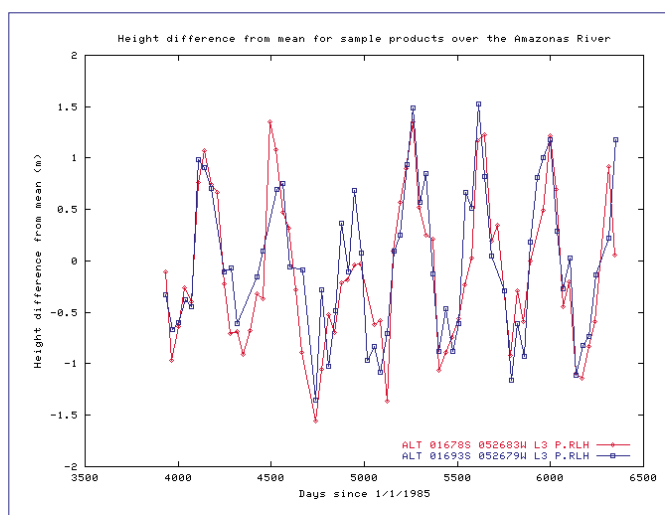
The shrinking Aral Sea, as seen by Envisat's MERIS instrument. Its water level has dropped 13 metres since the 1960's

Three New Processing Tools

To help the hydrology community to access and process the two new products, software tools have also been developed and made available. A software library, written in the C programming language, helps users to incorporate the reading/writing of RLA products into their own programs. A new Graphical User Interface tool realised in IDL (Interactive Data Language) facilitates the plotting of both the RLA and RLH products. An RLH Demonstration Viewer, written in Java and therefore platform-independent, allows scatter, line and area plots to be made of more than one RLH product at a time. The River-Lake Viewer also includes a zoom facility and the possibility to export plots in Portable Network Graphics format.

Future Plans

Whilst the decade-long archive of satellite data is being processed, more samples for other geographical regions, focusing on specific user needs, will be prepared and distributed next April. The Envisat ground segment will be enhanced with the near-real-time river and lake level processor to provide products to the hydrology community in less than three hours after measurement. A second Hydrology from Space Workshop will be organised next year, as was strongly recommended by the participants in the first workshop, along with the establishment of a European scientific working group on Hydrological Observations from Space. The Working Group's objective is to promote the application of existing space observations to problems in hydrology and formulate the requirements for future spaceborne hydrology missions, as well as to organise the necessary ground-based observations to support the validation of the space-data products. The Working Group will also promote communication between ESA and the scientific communities represented within its membership.



Sample products over the River Amazon, which clearly show not only the annual cycle in water level, but also the year-to-year variation, which have both ecological and climatological consequences