Global scale Land Hydrology Monitoring Using Satellite Altimetry

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Abstract

The new generation of altimeter-bearing satellites, Envisat and Jason-1, bring enhanced monitoring capability, with currently increased temporal sampling when combined with existing missions, and increased spatial sampling from the three tracking modes on Envisat, which allows data to be retrieved over widely varying topographic surfaces. Combined with the multi-satellite historical record, this provides a unique time-series of water flow over the earth's land surface.

This paper combines data from Envisat, ERS-1, ERS-2 and Topex to investigate the historical record, demonstrate the current abilities of altimeters to monitor the global land surface water flow, and illustrate the future potential of this technique.

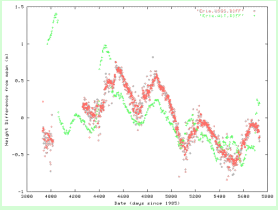
Validation study over the great lakes

To optimise the recovery of height information from satellite altimeters over inland water, it is necessary to reprocess the individual echoes, to allow for the effects of surrounding topography, still water, sandbars and islands (Berry et al, 1997). In order to validate these retracked data a region was required for which a ground based data set was available. The area chosen for the study was the great lakes where lake level data were available from the United States Geophysical Survey. These data are observed hourly and combined to provide a single value for each 24 hour period.

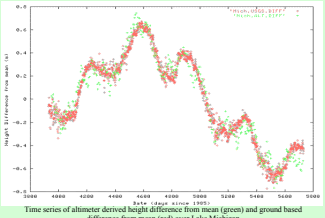
For the purpose of the comparison with the USGS data the altimeter data were processed to extract the height data using the same iterative process as was developed for use over Rivers. The data for each lake were then combined into a single file; outlying values were removed using a statistical filter. A running mean for the altimeter data was then calculated and the correlation coefficient, mean difference and standard deviation of the mean difference were calculated for the two data sets as shown below.

Lake	Correlation Coefficient	Mean Difference	Standard Deviation
Michigan	0.968197	0.003222	0.093054
Huron	0.922437	1.10E-02	0.149035
Erie	0.737992	0.003342	0.244425
Superior	0.787312	1.79E-04	0.154704

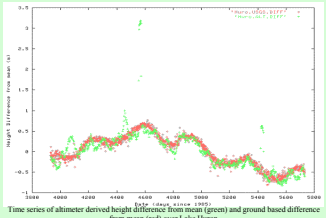
Table summarising the results of the comparison between the altimeter data and the USGS lake level data.



Time series of altimeter derived height difference from mean (green)and ground based difference from mean (red) over Lake Erie



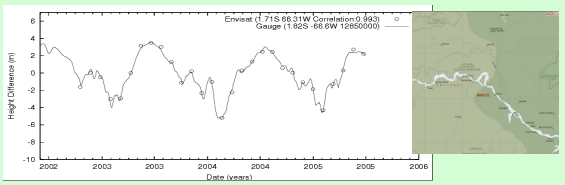
Time series of altimeter derived height difference from mean (green) and ground based difference from mean (red) over Lake Michigan



Time series of altimeter derived height difference from mean (green) and ground based difference from mean (red) over Lake Huron

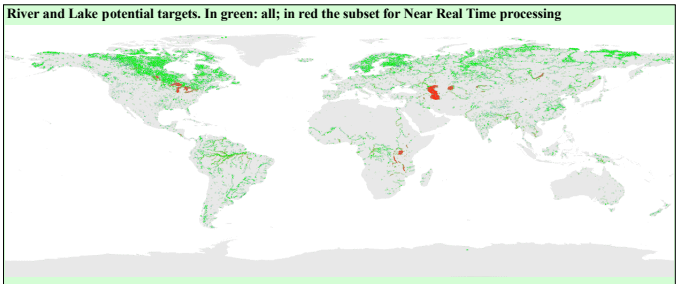
Validation Study over Rio Japurá (South America)

Having demonstrated that retracking individual altimeter echoes over inland water, heights can be successfully retrieved, even from rivers in complex terrain, it was decided to explore the potential application of this technique to recovery of height data along some of the worlds major river systems to determine the extent to which this method could be used to monitor water resource utilisation for rivers which cross national boundaries. As an example, the time series of one of the three main tributaries of the Amazon river, the Japurá river, were generated.

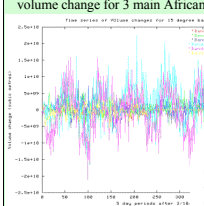


Time series of altimeter derived river surface height over the Rio Japurá

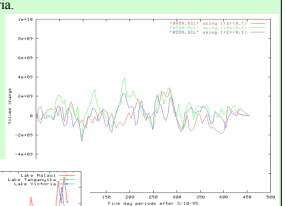
River and Lake potential targets. In green: all; in red the subset for Near Real Time processing



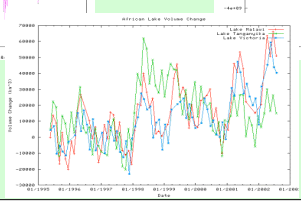
The map above also includes the lakes covered of ERS-2 and Envisat, after data have been retracked. The two first graphs below show relative **lake volume change** for the Northern hemisphere, in 15 degree bands of latitude, then in 5 degree bands for 46 to 60 North. Both seasonal and inter-annual variations are evident. The last graph shows lake volume change for 3 main African lakes: Malawi, Tanganyka, Victoria.



Time series showing the total lake volume change in 15-degree bands of the Northern Hemisphere as seen by ERS-2

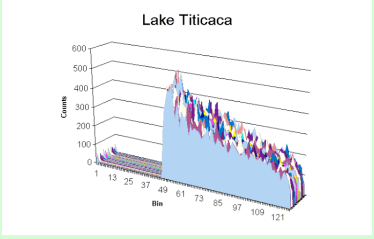


Time series showing the total volume change in three five degree bands as seen by ERS-2

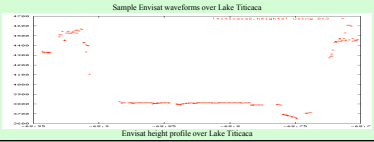


Lake volume change for three main African lakes

Envisat



Sample Envisat waveforms over Lake Titicaca



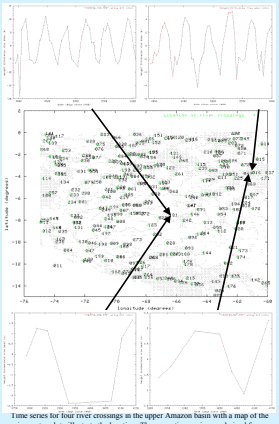
Envisat height profile over Lake Titicaca

The Envisat RA-2 has three tracking modes which were designed to switch dynamically in response to the severity of the underlying terrain. This has enabled acquisition of data over inland water bodies located in mountain ranges. The upper picture shows waveforms collected over Lake Titicaca, high in the Andes, in the high resolution mode (allowing calculation of very accurate heights).

The lower picture shows a height profile over part of the Andes: the flat central section is Lake Titicaca.

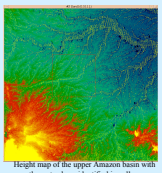
Coupled with the fast delivery processing capability of both Envisat and Jason-1, the potential now exists for monitoring of river and lake heights on a global scale and in near-real-time.

Results Over River and Lakes Systems Using Retracked Data



Time series for four river crossings in the upper Amazon basin with a map of the river network to illustrate the locations The upper time series are derived from ERS-2 heights, whilst the lower time series are derived from ERS-1 heights.

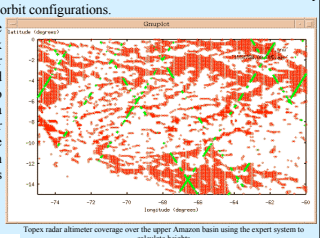
With the use of the expert system to retrack data it becomes possible to use the altimeter height data to study rivers located within more extreme terrain than was previously possible. With this increase in the available altimeter data it became necessary to improve the maps used to identify river targets for study; the figure below illustrates the potential for using the Geodetic Mission phase of the ERS-1 mission to identify rivers.



Height map of the upper Amazon basin with the wet echoes identified in yellow

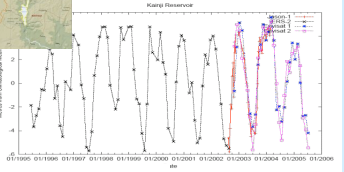
The figure to the left shows the coverage which has been provided over the Amazon basin by retracking ERS-2 ice mode data. Sample time series illustrating the benefits of the relative lengths of the time series from ERS-1 and ERS-2 are also included. As would be expected, the longer time series given by the use of ERS-2 data in a consistent repeat pattern are particularly valuable; however, useable heights can be extracted from most of the ERS-1 mission at a variety of different orbit configurations.

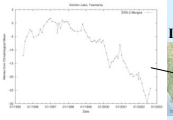
The plot to the right shows the coverage obtained over the upper Amazon basin using a single year of retracked Topex altimeter data. As would be expected this coverage is poorer than that for ERS-1/2 but this is compensated by the increased temporal coverage from the ten-day repeat pattern. The two time series below illustrate that using retracked altimeter data it is possible to extract height values even at the time of year when the river level is at its lowest.This is found to be generally true with Topex data: the only additional limitation over ERS altimeters is the ocean-only mode, which restricts the acquisition of data from inland water in rough terrain



Topex radar altimeter coverage over the upper Amazon basin using the expert system to calculate heights

Time series of the Kainji lake, reservoir on the Niger river, as seen by different altimeters,



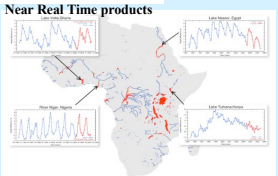


Lake Gordon, Tasmania

River & Lake web site

The River & Lakes website is available at the following URL:

Near Real Time products



NRT system demo is on since October 2005. It was stopped since March 2006, and restarted November 2006. NRT data is available within 3 days through the above R&L web site.

Very good agreement with SGDR data, meaning that the NRT heights are accurate within a few cm.

Outputs will be assessed and mask upgraded to include additional sites periodically.

The following **African rivers** are processed in near real time by the River&Lake system : Senegal, Niger/Benue, Volta, Nile, Congo, Zambezi, Limpopo and Orange. The following **African lakes** are processed in near real time by the River&Lake system: Albert, Aswuan, Bangweulu, Cahora Bassa, Chad, Chilwa, Ndombe, Edward, George, Kainji, Kariva, Kivu, Kyoga, Lac de Buyo, lac de Kossou, lac de lagdo, lac de Manantali, lac de Selingue, Malawi, Mbakaou, Mweru, Mweru Wantipa, Nasser, Niangay, Nyasa, Shiroro, Tana H'ay'k, Tanganyika, Turkana, Victoria

Conclusions: The ERS2 measurements have allowed generation of long time series of inland water heights over Africa. ENVISAT continues this valuable time series. Additionally, its Near-Real Time capability allows generation of heights within 2-3 days of measurement. The spatial sampling permits data over a huge number of inland water targets to be gathered; the drawback is the low temporal sampling which permits annual and seasonal variations to be observed but does not allow high frequency changes to be identified. These data are provided by ESA to Users: work continues to enhance this pilot system and recover heights from all the available water crossings worldwide.

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