GLOBAL INLAND WATER MONITORING FROM SATELLITE RADAR ALTIMETRY – A GLIMPSE INTO THE FUTURE

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ABSTRACT

The capability of satellite radar altimeters to monitor the height changes of major lakes is well established. However, river systems present far more challenging targets. By retracking altimeter echoes using an expert system approach, river heights can be successfully monitored; this capability is bounded by the along-track sampling rate. However, a glimpse into the potential of future altimeters can be gained from the EnviSat RA-2 Individual Echoes (IEs). These unique echoes, gathered at full 1800Hz along-track sampling rate, allow a detailed investigation of small parts of the earth's river systems. The superb quality of the RA-2 means that these echoes can be retracked at full resolution. This paper presents a global analysis of the inland water monitoring capability of ERS2, EnviSat, TOPEX, Jason1 and Jason2, and uses the RA-2 IEs to demonstrate the potential of SAR mode altimetry to transform the monitoring capability by more than one order of magnitude.

1. INTRODUCTION

The current generation of satellite radar altimeters returns data over much of the Earth's land surfaces, including inland water. A number of factors affect retrieval capability; instrument characteristics, terrain, surface composition and roughness, orbit repeat pattern and along-track sampling rate. Over inland water, the latter constraint critically limits the size of water body that can be reliably monitored. Whilst many lakes are well sampled, rivers present more challenging targets. Although they contain only a small proportion of the total inland water budget, these 'river corridors' are vital for human life, transporting and distributing fresh water throughout the continents

2. ANALYSIS

The first step in quantifying this measurement capability is to assess the ability of the current generation of satellite radar altimeters to measure inland water targets.

In order to achieve this, a global mask of river and lakes locations was derived from the GLCC database [1]. Three years of data from the ERS2 [2], TOPEX [3,4] Jason1 [5] and EnviSat [6] missions were prepared and run over the mask to select data likely to be returned from inland water. Jason2 was excluded from this analysis as a sufficiently long tine series has not yet accumulated. For each target acquired, each of these selected echoes were then assessed using the following criteria.

a. Presence of a leading edge
b. Significant power in the waveform

If at least one waveform passed these criteria for more than 90% of the repeat passes over the target, it was assessed as being successfully acquired. The resulting statistics are summarised in Table 1. The results show very clearly the increased numbers of targets acquired by the ERS2 and EnviSat altimeters, a consequence both of the increased spatial sampling provided by the orbit repeat pattern, and the enhanced ability to maintain lock on rapidly varying underlying terrain.

Table 1 Global target acquisition statistics for current and past altimeter missions

Mission	Global target total
ERS2	22223
EnviSat	25636
TOPEX	7509
Jason1	7200

Acquiring the target does not equate to successful measurement; in order to determine how many of these targets can be effectively monitored using this technique, each time series must be assessed. Using a version of the Berry Expert System configured for inland water echo shapes [7] the echoes were retracked.

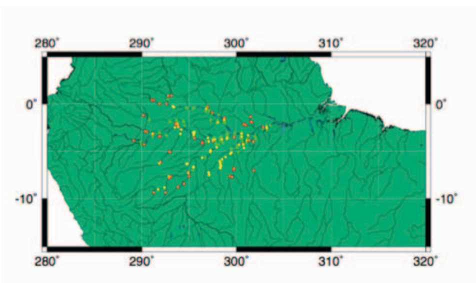


Figure 1 Amazon grading for ERS2 timeseries against nearest gauge data: green good, yellow moderate, red poor

Proc. 'ESA Living Planet Symposium', Bergen, Norway
28 June – 2 July 2010 (ESA SP-686, December 2010)

Table 2 Statistics for Amazon River System

Satellite	Good	Good with a few outliers	Poor
ERS2	180	233	374
EnviSat	248	209	340
TOPEX	49	53	158
Jason1	10	21	185

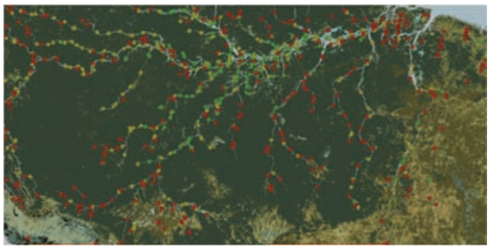


Figure 2 Grading outcome for Amazon River System for ERS2

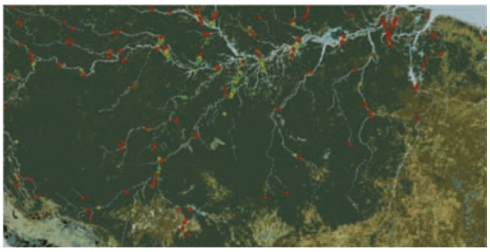


Figure 3 Grading outcome for Amazon River System for TOPEX

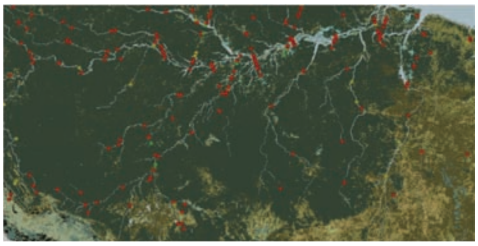


Figure 4 Grading outcome for Amazon River System for Jason1

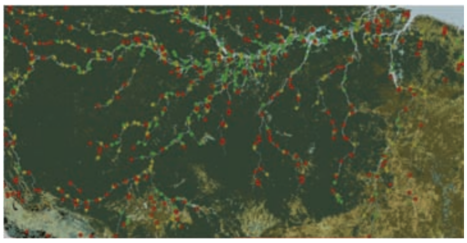


Figure 4 Grading outcome for Amazon River System for EnviSat

The resulting height estimates were combined to yield a mean height value and associated statistics (RMS height difference, number of points included) for each overpass. Time series were constructed, and assessed using an automated grading technique. To illustrate the operation of this grading system, Fig.1 shows part of an ERS2 altimeter validation against the gauge data in the Amazon basin; the outcome of this assessment was used to tune the automated system.

The automated system was then run for all timeseries in the Amazon basin for each mission. Results from this analysis are shown in Table 2, and the results are displayed graphically in Figs.2, 3 4. and 5
Investigating the causes for the many poor graded time series revealed that failure to capture the target consistently was a major factor with smaller river targets; this in turn was identified as due in part to limitations in the selections mask. A detailed study over the Zambesi river system confirmed that improving the mask enhanced the retrieval capability by one order of magnitude and enabled good results to be obtained even when only one echo was consistently returned. At this point, the retrieval capability becomes limited by the along-track sampling rate.

3. BURST ECHOES

Fortunately, there is a dataset that allows investigation of the effect of a higher along-track sampling rate. The EnviSat RA-2 returned a small percentage of data at the full 1800Hz sampling rate [8] these data include information from river systems. With only one second of data (sampling about 7 km of the underlying terrain) every 180 seconds, the first challenge is to find river targets present in the burst echo datasets; one obvious place to start looking is the Amazon basin, and a typical set of burst echo locations is shown in Fig. 6.

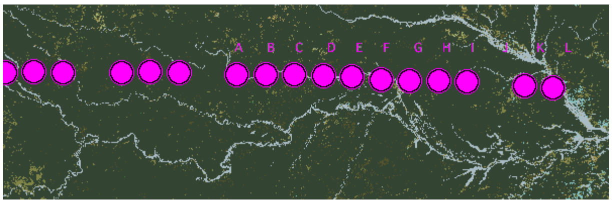
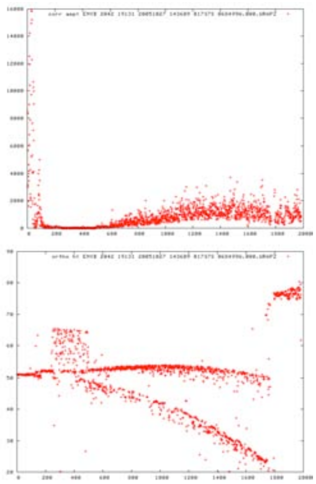


Figure 6 Burst echo locations over part of Amazon basin from cycle 42

Although the Japurá river appears to have a series of bursts sampling along its length, comparison with Google Earth revealed that only one of these bursts could positively be identified as located over the major river; the comparison was impeded by the dense canopy which prevented identification of much of the river course. Analysis of the bursts using a version of the Berry Expert System (BES) [9] confirmed that water was present in all the bursts, often as very still bright pools. Statistics from the waveform analysis are included in Table 3.

Table 3 Statistics from waveform analysis of bursts from Figure 1

Label	No of rejected echoes	Flat surface	Still Water echoes type 1+2+3	Google Earth comparison
A	0	1353	480 + 0 +50	Not river
B	123	806	97+15+36	River
C	33	681	419+16+207	Not river
D	0	920	457+5+159	Not river
E	8	797	590+20+182	Not river
F	44	999	624+18 + 14	Canopy
G	32	436	237 +17+219	Canopy
H	1	1057	169+17+201	Canopy
I	2	739	181+0 +218	Canopy

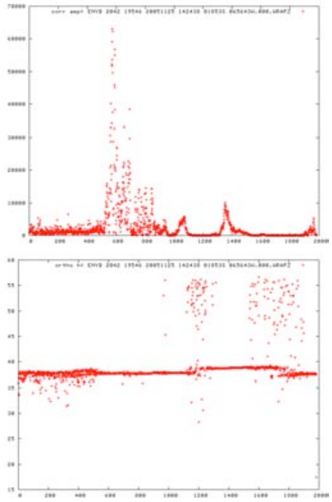


(a)

(b)

Figure 7 Waveform amplitude (a) and height (b) for location B plotted against echo number

Here, the bright water target is seen at the extreme left edge of the plots in Fig. 7; the flat water surface is clearly apparent, with varying heights from complex and noisy echoes towards the right of the height plot.
The endemic occurrence of pools of still water is seen in the echo analysis in Table 3; whilst these echoes are not identified with the tributary itself, they do clearly indicate the presence of very bright still water. To illustrate this, Fig. 8 shows the results from burst F, beneath the rain forest canopy.



(a)

(b)

Figure 8 Waveform amplitude (a) and height (b) for location F plotted against echo number

Here, a very bright target is seen around burst 490 in the sequence; inspection of similar plots for other bursts confirms that the findings are similar for all bursts where still water echo shapes are identified by the BES.

4. DISCUSSION

The current generation of satellite radar altimeters has acquired a huge database of echoes over the earth's inland water surfaces. This dataset is only now being mined to identify the thousands of inland water targets from which echoes are returned. Whilst optimal time series of height variation are only retrieved currently from a small percentage of these targets, there remains a substantial untapped potential which can be realized by enhancing the echo analysis and height retrieval systems. Ultimately, however, the size of target that can be measured is limited by the along-track sampling. Here, the EnviSat burst echoes give a glimpse into the huge enhancement in monitoring of inland water heights that is available with a higher along-track sampling rate. With the next generation of satellite radar altimeters (CryoSat2, Sentinel3) designed to return a far higher along-track sampling, the future capabilities of this technique are set to increase substantially.

5. REFERENCES

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2. ACKNOWLEDGEMENTS

The authors wish to thank the European Space Agency for supply of ERS2 and EnviSat data, CNES for supplying Jason1 data and JPL for supply of TOPEX data.