GLOBAL INLAND WATER MONITORING FROM SATELLITE RADAR ALTIMETRY – WHAT CAN WE REALLY DO?

Berry, P.A.M. [(1)] & Benveniste, J. [(2)]

[(1)] Newcastle University, Newcastle, NE1 7RU, UK: Philippa.Berry@ newcastle.ac.uk
[(2)] ESA ESRIN, Via Galileo Galilei, Frascati, Italy

ABSTRACT

The series of satellite radar altimeter missions has provided a huge database of altimeter waveforms over the earth's inland water surfaces. This paper outlines the current measurement capability. A comprehensive global analysis shows that waveforms from 22,223 targets have been identified from ERS2; just under 50% of these targets are currently producing useable time series. For EnviSat, 25,363 targets yield 59% of useable time series. This is attributed in part to the dynamic mode-switching capability of the RA-2. The 10-day repeat cycles of TOPEX, Jason1 and Jason2 produce lower numbers; reasons for these retrieval differences are identified and discussed. Using data from CryoSat-2, and 1800Hz 'burst echo' data from EnviSat, the additional potential for inland water measurement from Sentinel-3 is explored. The results demonstrate that the high along track sampling rate of Sentinel-3 SAR FBR waveforms can transforms the measurement technique to a true global monitoring capability for entire river systems.

1 INTRODUCTION

The series of satellite altimeter missions was designed primarily for ocean operation [1] but has acquired a vast database of echoes over the earth's land surfaces, including inland water. Now global datasets are available online [2], [3], [4], [5].
Using a processing scheme developed over many years, thousands of inland water timeseries have been created by retracking waveforms these missions [6], [7], [8]. However, many targets are not captured successfully.

2 GLOBAL GRADING

Assessing the quality of thousands of timeseries manually is clearly not feasible. Accordingly an automated quality assessment has been developed, using a combination of statistical test on waveform parameters (to analyse target stability and quality of data acquisition) and time series analysis to identify environmental signals e.g. from precipitation. These tests allow time series quality to be assessed. [ibid]. The global results for ERS2 and Envisat are given in Tab. 1. It is clear that both altimeters perform well, successfully measuring thousands of targets. Envisat performs better, due to its dynamic mode switching capability, which enabled it to maintain lock on rugged terrain, and then revert quickly to high-resolution 'ocean' mode to take precise measurements.

Table 1 Global Grading Statistics

Mission	Best	Fair	Poor/not captured	Total
ERS2	841	2671	18711	22223
Envisat	1880	6457	17299	25636

Because a subsection of the vast Amazon River system is used later in this paper, the multi-mission outcomes for the whole Amazon basin are given in Tab. 2.

Table 2 Amazon Basin Time Series Statistical Ranking

Mission	Best	Fair	Poor/not captured
ERS2	180	233	374
Envisat	248	209	340
Topex	49	53	158
Jason1	10	21	185

Over the mainly flat terrain, all missions obtain time series. Of note is the good outcome for TOPEX compared with that for Jason-1. Waveform analysis confirms that over still water, where bright quasi-specular echoes are retrieved, there are 'missing' elements in the waveforms; this is a known problem, and affected Jason-1's ability to retrieve good waveforms over these targets.

3 REGIONAL ANALYSES

3.1 The Nile

The Nile is a difficult target for altimeter height retrieval. Surrounded by irrigation zones, which are generally not at the same level as the river surface, the multiple still pools cause off-ranging in all altimeters. Accordingly this is a very good place to examine the relative performance of different missions. Fig. 1 shows the locations of river time series on the Nile from TOPEX, Jason-1 and Jason-2. Quality is denoted by colour, with green being best, yellow good but with one or two outliers/occasional missing cycles, red being not successfully retrieved and blue not captured (many cycles missing). All missions acquire Lake Nasser. However, the results for other targets clearly illustrate the disadvantage of a constrained range window when

Proc. 'ESA Living Planet Symposium 2013', Edinburgh, UK
9–13 September 2013 (ESA SP-722, December 2013)

acquiring inland water targets among many bright reflecting pools. ERS-2 performs well, and Envisat extremely well, changing mode dynamically to measure the Nile in ocean mode and thus producing many 'best quality' timeseries.

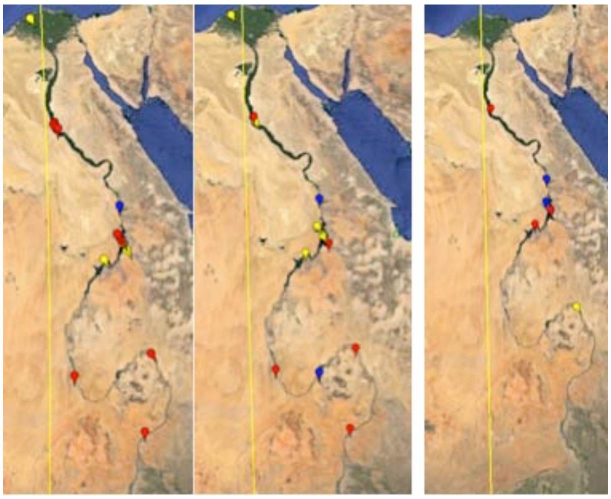

Fig.1 Nile location and quality flags for a) TOPEX, b) Jason-1 and c) Jason-2

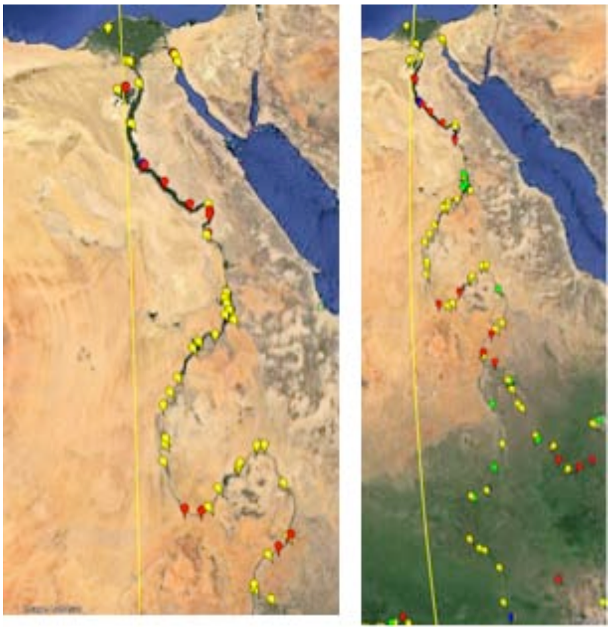

Fig.2 Nile locations and quality flags for a) ERS-2 and b) Envisat

Two example timeseries are shown in Fig.4 and Fig.5 for Envisat. Note the variable numbers of accepted waveforms over Lake Nasser (Fig. 3); initial number in blue, after retracking in green and after filtering in red. The initial along-track RMS is shown in green, the final RMS in red. It is clear that the waveform filtering has significantly reduced the along-track RMS. In contrast, Fig.4 shows an Envisat timeseries over a much narrower part of the river. Here, a variable but small number of points are retained after waveform analysis and filtering, and so the RMS cannot always be calculated. However, a good clear time series is observed.

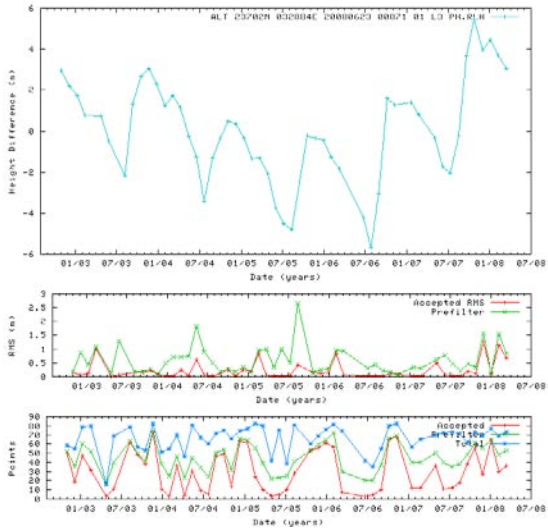

Fig.3 Envisat timeseries over Lake Nasser.

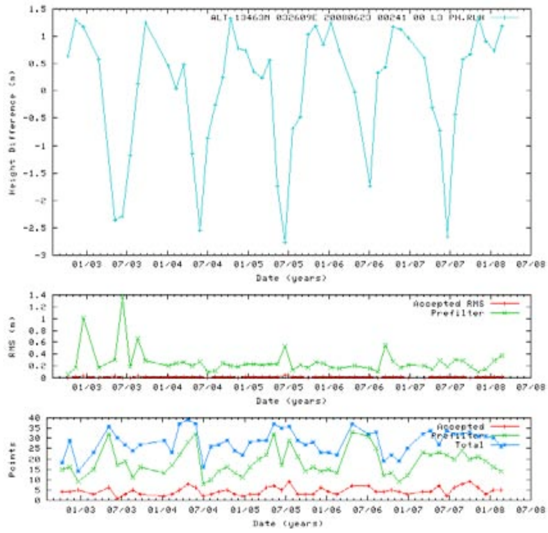

Fig.4 Envisat timeseries from higher Nile

3.2 Amazon Tributary

Fig.5 ERS2 timeseries location and quality in subset of Amazon basin

Cryosat-2 SAR data are available over part of the Amazon basin, this area has been selected for closer study using existing mission data. Fig.5 and Fig.6 show the locations and quality of timeseries from ERS2 and Envisat respectively over a small part of the Amazon basin. Fig.7 shows an ERS2 timeseries from the smaller tributary. For both missions, even with only one good echo from many cycles, a good timeseries is retrieved.

Fig.6 Envisat timeseries and quality in subset of Amazon basin

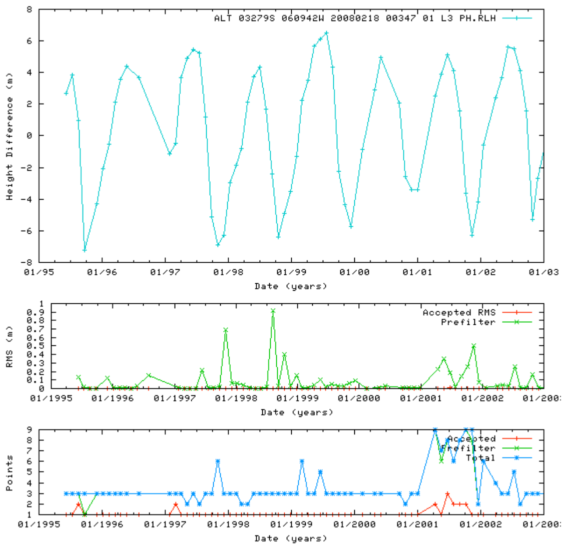

Fig.7 ERS-2 time series from smaller tributary

Thus although this subset of the Amazon basin contains many bright targets, so that for many cycles only one echo is retrieved which is not affected by off-ranging or land components, both ERS-2 and Envisat effectively monitor the river levels in both the larger and smaller tributaries. As a CryoSat SAR mode track crosses this region, this is analysed later in the paper.

Analysis of the Envisat Individual Echoes (IEs) shows that the high PRF allows recovery of good timeseries from small numbers of echoes over the Amazon [9], [10].

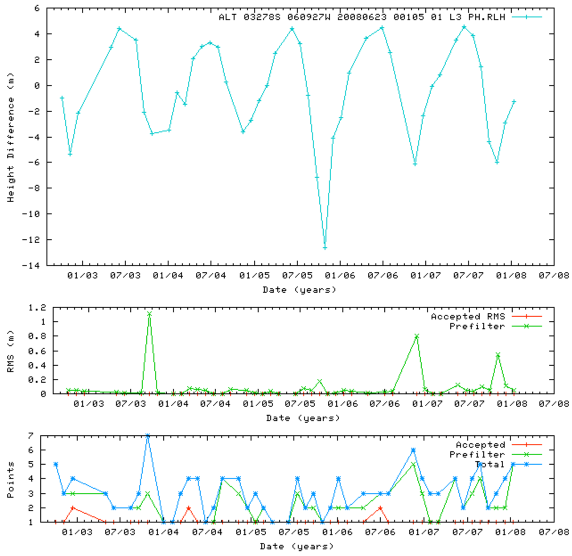

Fig.8 Envisat time series from larger tributary

4 CRYOSAT

Analysis of both LRM and SAR data [11] over inland water globally is underway. Here, one example from each mode of CryoSat operation is presented.

4.1 Nile

Analysis of the long CryoSat LRM track over Africa shown in Fig.9 indicated generally good waveform capture over the flat desert terrain. Over the Nile the results are more complicated. Fig.10 shows the height profile crossing the Nile floodplain, together with the waveform rescaled amplitude. Here the floodplain itself is clearly seen, with high amplitudes from the bright surface, corresponding to a reduction in orthometric height. Waveform shape analysis is also shown; this shows that over the bright target two waveform classes overwhelmingly predominate (7 and 11). These classes denote complex multi-target waveforms, from which precise height estimates are problematic.

Fig.9 CryoSat LRM track over Nile

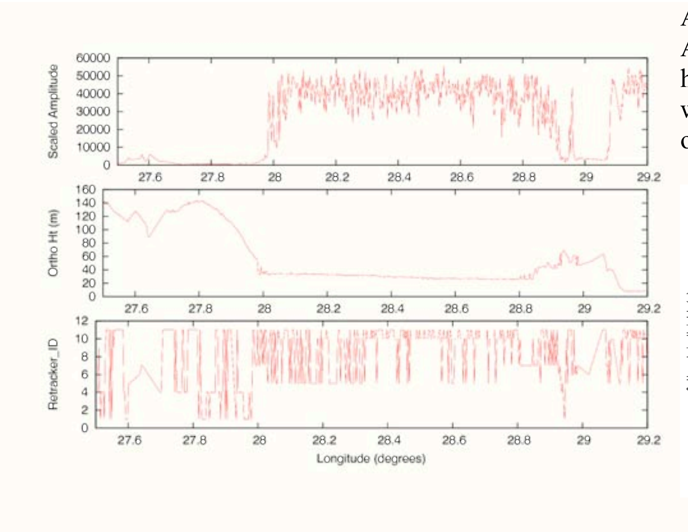

Fig.10 Cryosat LRM track over Nile floodplain

Comparison with other 'ocean mode' altimeters shows some consistency here. A similar result is obtained over the Nile delta (Fig. 11).

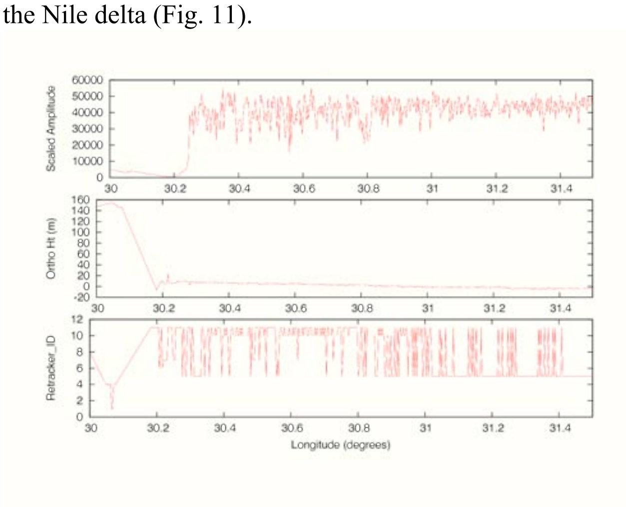

Fig.11 CryoSat LRM track over Nile delta

4.2 Amazon

Fig.12 CryoSat SAR track over subset of Amazon basin

An example analysis of a SAR track over part of the Amazon basin is shown in Fig.12. Fig.13 shows the height profile obtained on initial retracking of the waveforms. Spikes are evident; these mainly arise from off-ranging.

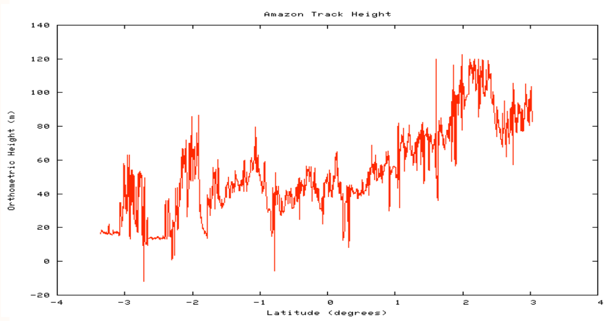

Fig.13 Unfiltered orthometric height profile from CryoSat SAR track in Fig.12 showing snagging

The rescaled waveform amplitudes are shown in Fig.14. This shows multiple bright targets, with clear correlation between the off-ranging and bright targets, as expected. Waveform shape analysis is shown in Fig. 15. The shape classes are seen to oscillate between class 7 and 11 over much of the profile, indicating complex multi-spike waveforms from multiple bright targets.

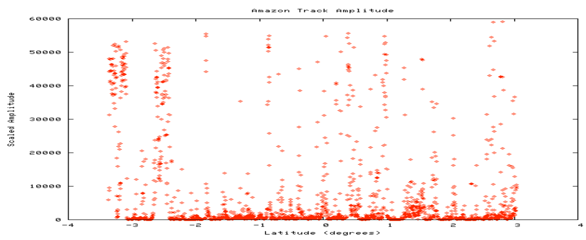

Fig.14 Unfiltered rescaled amplitude from CryoSat SAR track in Fig. 12 showing multiple bright targets

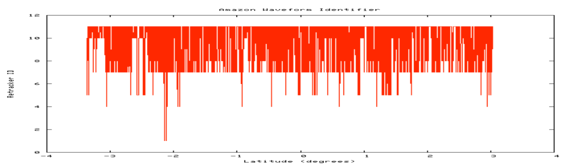

Fig.15 Waveform shape analysis for CryoSat SAR track in Fig. 12 showing complex multi-target waveform shapes

However, several other waveform classes are observed over part of this track. By identifying and selecting only waveforms corresponding to identified classes of inland water shapes, heights corresponding to these waveforms were selected and the results are shown in

Fig. 16. Here, two coherent extents of echoes are observed at the left of the plot. These correspond to the locations of the two tributaries overflown. This is an encouraging result, and work continues on waveform selection and retracker enhancement for the 'water' waveform classes.

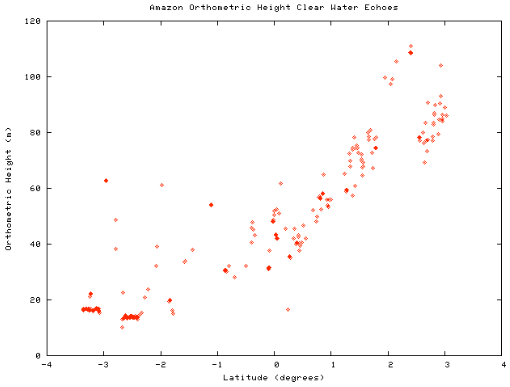

Fig.16 Orthometric heights from inland water identified SAR waveforms over Amazon tributaries

5 DISCUSSION

This global analysis shows that previous altimeters did well over benign terrain except when snagging on bright targets. Loss of data due to terrain drop-out and snagging on bright targets is greatly reduced with Envisat, as this altimeter has the capability to switch mode to re-acquire the target, and then quickly return to 320MHz mode to measure the water surface precisely. A glimpse into the capability of instruments with a higher PRF is seen from the Envisat IEs, where inland water timeseries are recovered from a few IEs over a small Amazon tributary. Looking toward the future, CryoSat LRM waveforms show performance over land and inland water with similarity to previous 'ocean mode' altimeters. Initial statistics show about 40% of waveforms are successfully captured over flat to moderately varying terrain

SAR waveforms require different retracking but the information is not 'concentrated' in the waveform leading edge over inland water targets: an anomalously high proportion of very complex echo shapes are found. Further analysis is underway. From this work it is clear that the higher PRF of SAR FBR data has great potential; much more data at this PRF is required from Sentinel-3.

6 REFERENCES

1 Fu L-L & Cazenave.A (2001), *Satellite Altimetry and Earth Sciences. A handbook of Techniques and Application*, Academic Press, International Geophysics Series, Vol. 69, San Diego, USA.

2 Capp, C.A. (2001), *Altimeter Waveform Product ALT.WAP Compact User Guide*, Issue 4.0, PF-UG-NRL AL-0001, Infoterra Ltd., UK.

3. Benveniste, J. , et al., (2002), ENVISAT RA-2/MWR Product Handbook. *Frascati, Italy: Eur. Space Agency. Issue 1.2, PO-TN-ESR-RA-0050.*

4. Zanife, O.Z. J.P. Dumont, J. Stum, T. Guinle (2004), SSALTO Products Specifications - Volume 1: Jason-1 User Products, Issue 3.1, SMM-ST-M-EA-10879-CN, CLS/CNES, Toulouse, France.

5. Algiers, J., et al. (1993), TOPEX Ground System Software Interface Specification, (SIS-2) Altimeter Sensor Data Record (SDR) - Alt SDR Data (NASA), March, 1993, JPL D-8591 (Rev. C), TOPEX 633-751-23-001, Rev. C

6. Berry, P.A.M., Garlick, J.D., Freeman, J.A. and Mathers, E.L. (2005), Global Inland Water Monitoring from Multi-Mission Altimetry Geophysical Research Letters, 32 (16), L16401, DOI: 10.1029/2005GL022814.

7. Salloway, Mark, Berry, Philippa A.M., Smith, Richard G., Benveniste, Jérome (2012). Global Inland Water Monitoring in Near RealTime: Current Capabilities. Proceedings of ESA 20 Years Of Progress In Radar Altimetry Symposium, Venice, August 2012.

8. Berry, P.A.M., Salloway, M. K., Smith, R.G. & Benveniste, J. (2011), Global inland water monitoring from satellite radar altimetry a glimpse into the future. IAHS-AISH Publication 343, p.g. 104-109, IAHS Publ. 343 (2011) ISBN 978-1-907161-18-6

9. Berry, P.A.M., Benveniste, J., Freeman, J.A. & Rogers, C. (2007). Global analysis of Envisat RA-2 burst mode echo sequences. *IEEE Transactions on Geoscience and Remote Sensing* **45**(9), pp. 2869-2874.

10. Berry, P. A. M.; Smith, R. G.; Salloway, M. K.; Benveniste, J., (2011). Global Analysis of EnviSat Burst Echoes Over Inland Water. *IEEE Transactions on Geoscience and Remote Sensing,* Issue 99, pp.1-6.doi: 10.1109/TGRS.2011.2170695

11. CRYOSAT Product Handbook: http://emits.esa.int/emits-doc/ESRIN/7158/CryoSat-PHB-17apr2012.pdf