CryoSat-2 SAR and SARin Inland Water Heights from the CRUCIAL Project

Philip Moore* (1), Stephen Birkinshaw (1), Marco Restano (2), Américo Ambrózio (3), and Jérôme Benveniste (4)
(1) Newcastle, Civil Engineering & Geosciences, United Kingdom, (2) SERCO c/o ESA, (3) DEIMOS c/o ESA, (4) ESA-ESRIN
***philip.moore@ncl.ac.uk**. CRUCIAL's data available on request (**http://research.ncl.ac.uk/crucial/User_Control_Panel**). Please also CC to **altimetry.info@esa.int**.

1. Introduction

- CRUCIAL is funded by ESA's **Support To Science Element** (STSE), a programmatic component of the Earth Observation Envelope Programme, to investigate the application of CryoSat-2 data over inland water with a forward-look to the Sentinel-3 mission.
- CryoSat-2's primary instrument is SIRAL (SAR Interferometric Radar Altimeter). SIRAL operates in one of three modes; Low Resolution Mode (LRM), Synthetic Aperture Radar (SAR) and Interferometric Synthetic Aperture Radar (SARin).
- Previous satellite radar altimeters lost significant amounts of information due to onboard echo averaging. The high along-track sampling of CryoSat-2 altimeter in SAR/SARin modes offers the opportunity to recover high frequency signals over certain regions of the Earth's surface.
- This poster summarises progress in processing the SAR and SARin Full Bit Rate (FBR) data to construct multi-looked waveforms and comparison against in situ water heights and contemporaneous satellite altimetric missions.

2. CryoSat-2 Mode

- Constrained by the availability of SAR/SARin FBR data as most land/ocean surfaces are tracked in conventional LRM mode.
- As example selected SAR (red) and LRM (green) tracks are shown in Fig. 1 for Amazon Basin.

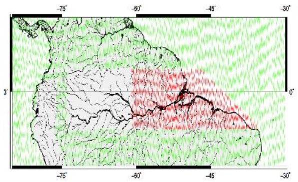


Figure 1. Amazon Basin: LRM (green), SAR (red) and SARIN(blank) tracks. Blank area is SARIN.

3. SAR/SARin FBR: Methodology

Process bursts (Q, I data)

- SAR ~ $80\ Hz, 80\ m$ along-track
- SARin ~ $20\ Hz, 320\ m$ along-track
- Range FFT over 64 pulses in burst
- Form sequence of equiangular ground points at beam angle using coarse approximate steering
- Ground points ~ $300\ m$ along-track for SAR/SARin
- Beam formation and steered to ground points
- Stack beams pointing at ground points
  - max 240 beams in SAR mode and 60 for SARin in stack for multi-look
- Apply slant range correction, tracker range correction, Doppler range correction
- Inland water heights from empirical and OCOG/Threshold retrackers
- Comparison against independent data

4. Empirical Retrackers

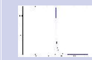
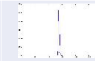
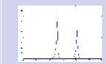
Retracker #	Description	Waveform Shape
1	Specular (still water)	
2	Ocean like (ruffled water)	
3	Ocean like with fall away at high # bins (ruffled waters)	
4	Two specular peaks (strong returns off two patches of still water)	
5	Retracker Type 2 with additional specular peak (ruffled and still water)	

Figure 2. Pictorial representation of inland water empirical retrackers

5. SAR FBR: Mekong

Sequence of multi-look waveforms (Fig. 3) for North-South 19 April 2011 pass across the Mekong (Fig. 4) using a stack of 2N-1 steered waveforms. First 3 waveforms over land/water boundary; next 6 specular waveforms over water; subsequent waveforms increasing degree of off-nadir reflections from Mekong as nadir point moves onto land. Increasing N beyond N=40 had little effect but waveforms noisier for N<40. Fig. 5 plots orthometric heights relative to EGM08 for various N. Slight preference for N=40.

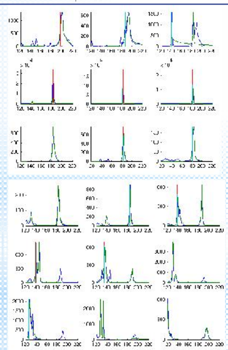


Fig 3. Multi-look waveforms: X axis #bin, Y axis power. Waveform increment across row from top left. N=40

Fig. 4. CryoSat-2 N-S ground track across Mekong.

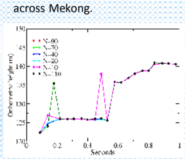


Fig. 5. Variation of heights for pass across Mekong Seconds after 59084 in day.

6. SAR FBR: Tonlé Sap

North-South pass (3 Dec 2011) crossed Tonlé Sap (TS) (Fig.6). Multi-look waveforms (Fig. 7) show double peak (#86) near land and ocean-like waveform in the lake centre (#112). Retracking shows similar results to Mekong with slight preference for N=40 (Fig. 8 & Table 1). Table 2 gives preferred empirical retracker.

Figure 6. Google Earth image of TS and pass on 3 Dec 2011

Multi-look # N	Sum of Square of the errors: Empirical retrackers (m^2)	Sum of Square of the errors: OCOG/Threshold (m^2)
110	0.222	0.251
90	0.225	0.245
70	0.212	0.230
40	0.171	0.196
20	0.184	0.176
10	0.240	0.194

Table 1. Statistics of fit for pass across Tonlé Sap.

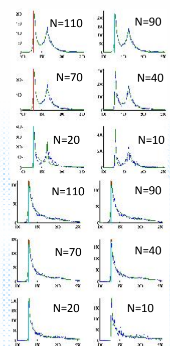


Fig 7. TS waveforms #86 top; #112 lower.

7. Validation: Tonlé Sap & Mekong

CryoSat-2 and USDA OSTM Tonlé Sap heights compared (Table 2) against downstream gauge at Prek Kdam. A comparison to gauge data near Kratie on the Mekong (Fig. 8 & 9) with slope correction from low water level. Shows large residuals upstream. Restricting CryoSat-2 data -5 to +80 km from gauge gives agreement comparable (Table 3) to ERS-2, Envisat and AltiKa.

Figure 8. Google Earth image overlaid by CryoSat-2 passes near the Kratie gauge (red circle) and the two Envisat/AltiKa crossing points

Satellite	#	RMS v Prek Kdam(cm)
OSTM	99	42.6
Cryosat-2	26	42.1

Table 2. Residuals to gauge data for pass across Tonlé Sap.

Data Provider	Satellite	Period	RMS (cm)
CRUCIAL	CryoSat-2		54.0
DAHITI	Envisat	Jul 2002 – Nov 2010	47.2
DAHITI	Altika	Jun 2013 – Nov 2014	62.0
River&Lakes	ERS-2	Apr 1995 – Jun 2003	70
River&Lakes	Envisat	Jul 2002 – Mar 2006	65

Table 3. Residuals to gauge for Mekong passes near Kratie.

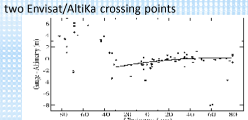


Figure 9. Differences between gauge heights at Kratie and the CryoSat-2 heights modified for river slope.

8. CryoSat-2: SAR (Amazon)

Residuals with Óbidos gauge-2 have RMS 36.1 cm. Manacapuru about 650 km upstream from Óbidos has RMS 53.6 cm after adjusting for river slope. Compared against TOPEX/Poseidon (Birkett et al., 2002) (mean ~1.1 m RMS for 1992-1999 with best results 0.4–0.6 m RMS) CryoSat-2 at Manacapuru falls within Birkett et al. (2002) best results while the CryoSat-2 result at Obidos is superior by a factor of two.

Source	Satellite	Crossing	Date	Sigma (cm)	#
DAHITI	ENV+ALTIKA	ENV1	May 2002 - Jun2016	37.4	92(2)
	ENV		May 2002 – Oct 2010	40.2	77(0)
	ALTIKA		May 2013 – Jun 2016	17.4	15(2)
	ENV+ALTIKA	ENV2	May 2002 – Jun 2016	56.4	103(2)
	ENV		May 2002 – Oct 2010	57.7	78(0)
	ALTIKA		May 2013 – Jun 2016	26.3	25(2)
CRUCIAL	CryoSat-2	Various	Oct 2012 – Apr 2015	36.1	34(0)
	CryoSat-2		Oct 2012 – Apr 2015	34.9	34(0) slope adj
	CryoSat-2		Oct 2012 – Apr 2015	27.3	32(2) slope adj + 2.5σ

Table 4. Comparison of altimetry against the Óbidos gauge on the Amazon . Final column gives number of accepted measurements with rejected points in parenthesis.

Figure 10. Google Earth image overlaid by CryoSat-2 passes across the Amazon near the Óbidos gauge (red circle) and the two Envisat/AltiKa crossing points

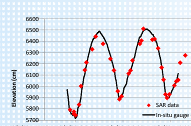


Figure 11. FBR SAR heights (N=40, empirical retrackers) at Óbidos using both a 2.5σ rejection level and slope adjustment (RMS 27.3 cm).

Figure 12. : Google Earth image overlaid by CryoSat-2 passes across the Amazon near the Manacapuru gauge (red circle) and the two Envisat/AltiKa crossing points

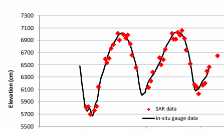


Figure 13. FBR SAR heights (N=40, empirical retrackers) at Manacapuru using both a 3σ rejection level and slope adjustment (RMS 53.6 cm).

9. CryoSat-2: SARin (Amazonas)

For inland waters CryoSat-2 is in SARin mode across the Amazon near Tabatinga. Q and I data is collected from the two antennae. Burst points about 310 m along-track steered to ground points. Coherence between waveforms from antennae can be used for across-track angle. Here we use both antennae assuming flat terrain. Comparison against data from Tabatinga gauge (Fig. 14) along a river stretch of 160 km. Passes 2hr apart and 150km difference in chainage used to adjust for river slope. Figure15 compares CryoSat-2 SARin heights against daily gauge data (rms 36 cm). Heights from two antennae near identical.

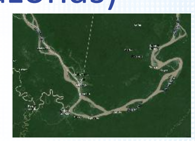


Figure 14. Amazonas in the vicinity of gauge at Tabatinga

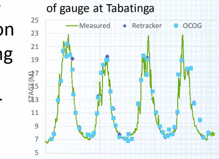


Figure 15. Comparison of CryoSat-2 and gauge data near Tabatinga, Amazonas.

10. Discussion

- Retracked waveforms for SAR and SARin data processed from L1A FBR data.
- Retracked heights using empirical retrackers and OCOG/Threshold
- Validation using in situ data and other altimetric satellites
- CryoSat-2 inland water heights more accurate that T/P, OSTM, ERS-2 and Envisat but less accurate than SIRAL/AltiKa
- Forward look to Sentinel-3 (S3). Note that SARvatore/SARvatore L2 (S3) products include indication on waveforms in the stack used to form the multi-look waveform

Acknowledgements: The authors thank the European Space Agency for funding the study, the MRC for Mekong in situ data and USDA and DAHITI for other altimetric heights.

http://research.ncl.ac.uk/crucial/