Methodology and Validation of SAR and SARin Full Bit Rate Altimetric Waveforms and Heights from the CRUCIAL Project

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1. Introduction

- CRUCIAL is funded by the ESA's **Support To Science Element** (STSE) a programmatic component of the Earth Observation Envelope Programme, to investigate the application of CryoSat-2 (CS2) data over inland water with a forward-look component to the future Sentinel-3 mission.
- This poster summarises the methodology to process FBR L1A Doppler beams to form a waveform product using ground cell gridding, beam steering and beam stacking.
- Validation for Amazon and Mekong (2011-2015) against gauge data and other altimeter missions.
- SARin processing include comparison of heights from the two antennae, extraction of slope of the ground surface and validation against ground data where appropriate.

2. Methodology

- Data: Cryosat-2 L1A FBR I (in-phase carrier) and Q (quadrature-phase carrier)
- Geophysical corrections included to form the height above reference ellipsoid.
- Azimuthal FFT applied to burst echoes and heights retracked using(OCOG/Threshold) retracker to form ground surface.
- Approximate steering of beams to equiangular ground points
- Multi-look beams stacked and slant range and tracker bin corrected.
- 2N+1 waveforms Hamming windowed to form multi-look waveform
- Empirical retrackers formulated for inland water applications

3. Number of Looks: SAR Tonlé Sap

Pass across Tonlé Sap (TS) 3 Dec 2011 (Fig. 1). Burst echo heights (Fig. 2) show need for multi-look waveforms. Effect of number of looks in stack on multi-look waveform (Fig. 3) and heights Fig. 4. Consistency across 68 points (i.e. lowest variation) for N=40 (Table 1) and for additional passes in Table 2.

Fig.1: Pass across Tonle Sap 3 Dec 2011

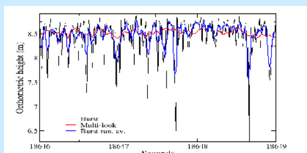

Fig.2: Burst (≈80 m), burst running average (≈320 m), and multi-look heights (≈300 m)

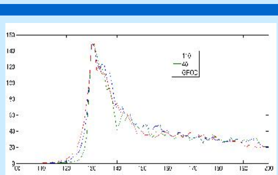

Fig.3: Multi-look waveforms with N=110 and N=40 and GPOD's CS2 waveform

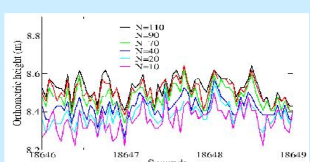

Fig.4: Multi-look heights with N

Multi-look N	Sigma Empretrackers (cm)	Sigma OCOG/Threshold (cm)
G-POD: SAMOSA2	7.39	
G-POD: retracked	5.88	7.18
120	5.69	6.14
110	5.72	6.08
70	5.58	5.81
40	5.01	5.38
20	5.20	5.09
10	5.94	5.35
5	9.20	7.66

Table 1: Sigma (cm) for 68 points across TS: Varying N & GPOD

Date	Sigma (cm) N=110	Sigma (cm) N=70	Sigma (cm) N=40	Sigma (cm) N=20
2011-11-04	3.91	3.94	3.83	4.78
	4.23	4.05	3.89	4.19
2011-12-03	5.72	5.58	5.01	5.20
	6.08	5.81	5.38	5.09
2011-12-10	4.88	4.18	4.52	5.42
	5.38	5.30	5.04	5.24
2014-11-12	4.08	3.74	3.64	4.14
	4.89	4.45	4.57	5.25

Table 2: Sigma for (cm) for passes across TS for varying N. Empirical retrackers (top) : OCOG/Threshold lower.

Comparison of CryoSat-2 , OSTM (USDA) and gauge at Prek Kdam downstream of OSTM ground track. Altimetry corrected for a 12-day time lapse against gauge data. RMS differences between gauge and OSTM (99 values) 42.6 cm; CryoSat-2 42.1 cm (26) values. Fig. 5, shows midpoint of CryoSat-2 across Tonlé Sap with time series in Fig. 6.

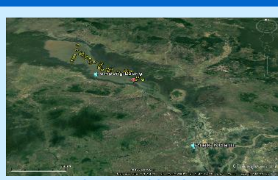

Fig.5: Locations of midpoint of CryoSat-2 passes across TS, Prek Kdam and OSTM crossing

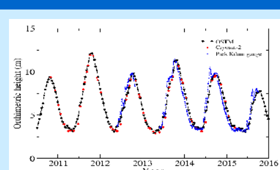

Fig.6: Prek Kdam gauge time series with CryoSat-2 and OSTM heights.

4. SAR: Mekong at Kratie

Time series of CryoSat-2 heights and gauge data at Kratie on the Mekong (Fig. 7). Statistics of differences (Table 2) for different altimeter missions, studies, operating period, number of points and chainage from gauge. CryoSat-2 chainage values denote maximum distances upstream and downstream of gauge.

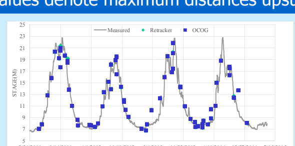

Fig.7: Kratie gauge time series with CryoSat-2 retracked heights (N=40) . RMS differences 67.8 cm (emp. retrackers) and 66.9 cm (OCOG). 3σ rejection criterion.

Data Provider	Satellite	Period	Chainage (km)	RMS (cm)	#
This study	Cryosat-2	Mar 2011 – Mar 2015	-5,6	43.7	13(1)
	Cryosat-2		-5,11	44.7	17(1)
	Cryosat-2		-5,26	50.5	28(1)
	Cryosat-2		-5,40	62.9	38(1)
	Cryosat-2		-5,50	64.1	47(2)
	Cryosat-2		-5,80	59.9	56(4)
DAHITI	Altika	Jun 2013 – Nov 2014	8	29.7	11(4)
	Altika		43	40.9	14(4)
	Envisat	Jul 2002 – Nov 2010	78	42.9	83(7)
	Envisat		43	48.8	34(3)
River&Lakes	ERS-2	Apr 1995 – Jun 2003	8	70	69(12)
	Envisat	Jul 2002 – Mar 2006	8	65	26(3)

Table 2: Statistics of altimetric differences against Kratie gauge data. ERS2, ENVISAT and AltiKa in repeat orbit; CS2 crossings between chainage range. # is no accepted with rejected measurements in parenthesis.

5. SARin: Amazon at Tabatinga

CS2 in SARin mode over Amazon near Tabatinga gauge (Fig. 8). Heights from two antennae agree at cm level (Fig. 9) over Amazon floodplain. Two passes cross east and west of gauge separated by about 24 hours in time and over 100 km in distance providing an altimetric measure of river slope.

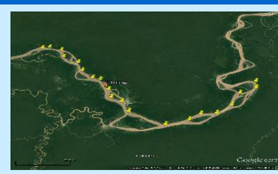

Fig.8: Amazon near Tabatinga gauge (red marker) with centre points of stretch considered (yellow markers)

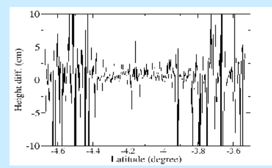

Fig.9: OCOG/Threshold SARin height differences from two antennae. Amazon 5 May 2012.

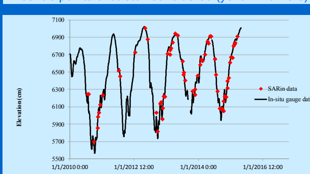

Fig.10: OCOG/Threshold SARin height comparison against Tabatinga gauge data. RMS 29.9 cm.

Fig.12: Google earth plot of 5 May 2012 ascending pass across Amazon. Direction of flight given by arrow.

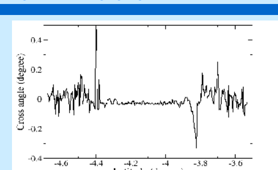

Fig.11: SARin cross-angle from two antenna. Amazon 5 May 2012.

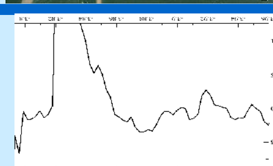

Fig.13: cross-angle of points from Fig. 12: Negative values corresponds to water target left of ground track.

Correcting the time series of CS2 heights for river slope gives a RMS difference of 29.9 cm (Fig 10). Analysis of cross-power between waveforms from the two antennae weighted by the coherence gives the cross-angle (Fig. 11) the off pointing of the antennae from nadir to the resultant of summed reflectance from the water targets in the slice of the altimeter footprint. Amazon centred at lat 4.2°S. Fig. 12 and Fig. 13 show an ascending pass across the Amazon and the derived cross angle in degrees. A positive cross-angle implies dominant reflectance to right of flight direction with converse for a negative cross-angle. The main body of the Amazon is first to the left and then to the right of the ground track giving the positive early cross-angle values, the large negative values before returning to near zero as the river meanders out of range cross-track. The zero cross-track angle may be offset and requires precise knowledge of the satellite roll angle. Often the cross-angle is noisy due to the saturated ground acting as a water reflector but these plots and generally show the expected trend.

Conclusions

- Burst echoes are too noisy and inland water targets require multi-looked waveforms
- The precision of the derived heights depends on the looks in the multi-look with N=40 (i.e. 81 out of a possible 240 looks) being a good choice.
- Comparison of CS2 against in situ and altimetric data complicated by non-repeat orbit. CS2 performed as well as OSTM across TS despite the assumption of the same time lapse compared to gauge data.
- Comparisons on the Mekong difficult and requires consideration of distance from gauge. General conclusion: CS2 performing as well as ERS-2 and ENVISAT, while AltiKa gives the lowest RMS (29.7 cm) for a crossing 7 km from the gauge. But
- RMS against Tabatinga gauge 29.9 cm. SARin heights from antennae identical.
- Cross-power between SARin antennae dominated by water reflectance with positive cross-angle when reflectors on right hand side of ground track.