CRUCIAL: Cryosat-2 Success over Inland Water and Land: SAR and SARin Full Bit Rate Altimetric Heights and Validation

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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 data over inland water with a forward-look component to the future 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).
- This poster summarises progress in processing the SAR and SARin Full-Bit Rate (FBR) data to construct multi-looked waveforms.
- 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.

2. Cryosat-2 SAR Mode

- Constrained by the availability of SAR FBR data as most land/ocean surfaces are tracked in conventional LRM mode.
- Selected SAR (red) and LRM (green) tracks are shown in Fig. 1 (Amazon Basin); Fig 2. (Mekong)

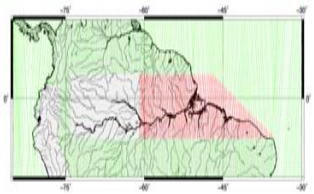

Figure 1. Amazon Basin: LRM (green), SAR (red) and SARIN(blank) tracks. Blank area is SARIN.

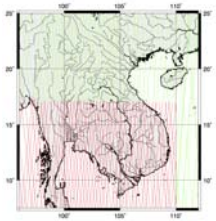

Figure 2. As Fig. 1 for Mekong

3. SAR FBR: Processing Strategy

Part 1: Process bursts (Q, I data)

SAR $\sim 80\ Hz, 80\ m\ along\ track$

SARin $\sim 20\ Hz, 320\ m\ along\ track$

- Range FFT over 64 pulses in burst
- Beam formation and steered to nadir direction
- Heights from OCOG/Threshold retracker
- Orthometric heights using EGM08
- Coarse orthometric surface recovered from polynomial fit to ocean/inland water heights
- Improved ellipsoidal surface height by reinstating geoid

Part 2: Multi-look

($\sim 300\ m\ along\ track$)

- Form sequence of ground points at beam angle using coarse approximate steering
- 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
- Heights from empirical and OCOG/Threshold retrackers

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 still water)	
5	Retracker Type 2 with additional specular peak (ruffles and still water)	

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 loves 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. 4. Cryosat2 N-S ground track across Mekong.

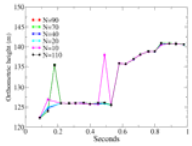

Fig. 5. Variation of heights for pass across Mekong Seconds after 59084 in day.

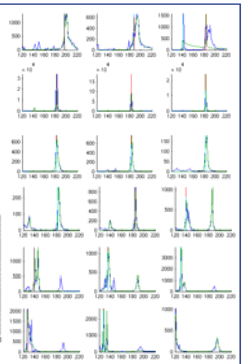

Fig 3. Multi-look waveforms: X axis #bin, Y axis power. Waveform increment across row from top left. N=40

6. SAR FBR: Tonle Sap Cambodia

Tonlé Sap (TS): a combined lake and river. Lake expands/shrinks seasonally. Flow direction changes twice a year. Nov-May (dry season) TS drains into Mekong at Phnom Penh. After start of heavy rain (June) TS backs up to form lake. North-South pass (3 Dec 2011) crossed TS (Fig.6). Note locations for #86 and #112. 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, i.e. little difference for N≥40, slight preference for N=40 (Fig. 8 & Table 1). Table 2 gives preferred empirical retracker.

Multi-look N	Sum of Square of the errors: Empirical retrackers (m²)	Sum of Square of the errors: OCOG/Threshold (m²)
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 Tonle Sap.

	Empirical tracker type			
	2	3	4	5
N=110	30	37	1	0
N=90	26	40	2	0
N=70	18	49	1	0
N=40	5	57	3	3
N=20	5	57	3	3
N=10	8	34	11	15

Table 2. Empirical retracker type Tonle Sap.

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

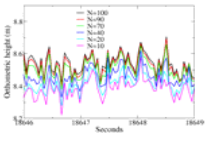

Fig 8. Height across TS (3 Dec 2011) OCOG/Threshold retracker.

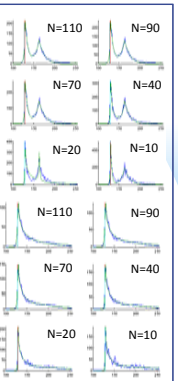

Fig 7. TS waveforms #86 top; #112 lower.

7. Cryosat-2 Validation: Mekong, Tonle Sap & Amazonas

Mekong low water level data (Fig. 8); black squares range of heights at 5 gauges. All data from Mekong River Commission (MRC). To compare against in situ data we selected the nearest gauge to the Cryosat-2 crossing and correct elevation difference from low water level slope. Fig. 9 shows results comparison at Kratie (rms 1.08 m) at chainage 810 km. Note the difference in range between gauge at Kratie and Stung Treng (chainage 659 km) and the range variation upstream and downstream of Kratie in Fig.8. Cryosat-2 Tonle Sap heights compared against USDA OSTM (Fig. 10). Fig 11 shows comparison for gauge at Obidos and Cryosat-2 data on Amazonas (rms 30.6 cm).

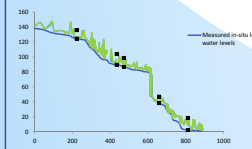

Fig 8. Cryosat-2 (green) and measured low flow elevation (blue) from MRC.

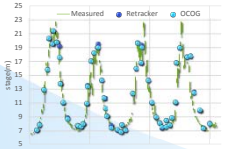

Fig 9. Comparison of Cryosat-2 and gauge data at Kratie.

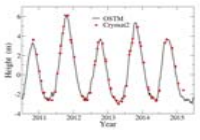

Fig 10. Comparison of Cryosat-2 and USDA OSTM heights across TS

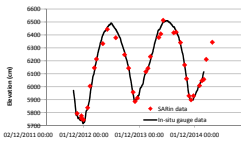

Fig 11. Comparison of Cryosat-2 data and in-situ data at Kratie.

8. Cryosat-2: SARin (Amazonas)

For inland waters Cryosat-2 is in SARin mode across the Amazon and Brahmaputra. 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 ground slope. Here we use both antennae assuming flat terrain. Comparison against data from Tabatinga gauge (Fig. 12) along a river stretch of 160 km. Passes 2hr apart and 150km difference in chainage used to adjust for river slope (-3.95e-5). Fig. 13 compares Cryosat-2 SARin heights against daily gauge data (rms 36 cm). Heights from two antennae near identical.

Fig. 12. Amazonas in the vicinity of The gauge at Tabatinga

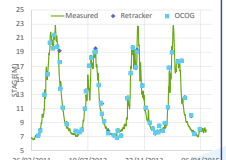

Fig. 13. Comparison of Cryosat-2 and gauge data near Tabatinga, Amazonas.

9. FBR: Discussion

- Retracked waveforms for SAR and SARin data processed from L1A FBR data.
- Retracked heights using empirical retrackers and OCOG/Threshold
  - For specular waveforms OCOG/Threshold performs as well as empirical retrackers.
- Results will include data over
  - Mekong (SAR)
  - Amazon (SAR and SARin)
  - Brahmaputra (SARin)
- Validation using in situ data and OSTM
- Hydrodynamic modelling for Mekong (NCL) and Brahmaputra (DTU)
- Forward look to Sentinel 3.

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