CRUCIAL: Cryosat-2 Success over Inland Water and Land

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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'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 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 mode 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)

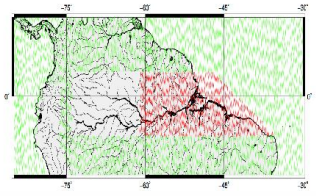


Figure 1. Amazon Basin: LRM (green), SAR (red) and SARIN(blank) tracks. Blank area is SARIN.

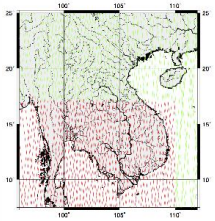


Figure 2. As Fig. 1 for Mekong

3. SAR FBR: Processing Strategy

Part 1: Process bursts

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

- Q, I data
- Range FFT over 64 pulses in burst
- Beam formation and steered to nadir direction
- Heights from OCOG/Threshold retracker
- Orthometric heights using EGM96
- Coarse orthometric surface recovered from polynomial fit to ocean/inland water heights
- Improved ellipsoidal surface height by reinstating EGM96

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 multi-look)
- Apply slant range correction, tracker range correction, Doppler range correction
- Heights from OCOG/Threshold retracker
- For illustration 2 FBR passes are presented (1) oceanic pass (1 Jan 2013) (2) a pass (23 Aug 2013) across the Rio Tapajos, a tributary to the Amazonas

4. SAR FBR Tracks: Ocean

S-N track off the coast of Chile/Peru (Fig. 3). Multi-look waveforms: 81 look angles centred on beam with smallest angle to nadir. 14000 bursts gave 3645 locations for multi-look points. log10 power of waveforms given in Fig 4. The slope in leading edge due to choice of datum for slant range correction. The waveforms #2000, 2100,...2700 in Fig. 5 are typical of ocean returns. Figure 6 shows heights above EGM96 from individual bursts (OCOG/threshold retracker with threshold=0.3) and the multi-look waveforms (threshold=0.4). The orthometric heights are uncorrected for SWH and inverse barometric correction. The main variations are residual commission and omission effects in EGM96 and sea-surface topography.

Fig. 3. Cryosat2 ground track

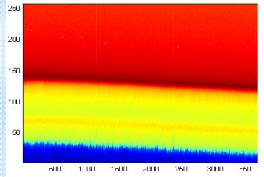


Fig 4. Multi-look waveform power. Units. X axis #waveform, Y axis log10 power

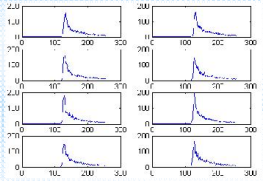


Fig 5. Individual waveforms 2000-2700 (100) Units. X axis #bin, Y axis power

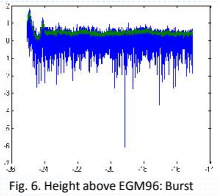


Fig. 6. Height above EGM96: Burst Heights (blue); multi-look heights (green)

5. SAR FBR Tracks: Rio Tapajos/Amazonas

Fig. 7&8 show river system and Cryosat-2 ground track of 23 Aug 2013. Satellite travelling S-N across small tributary into Rio Tapajos, the broad Rio Tapajos, Rio Arapiuns, and then 4 braids (?) of the flooded Amazon. Fig. 9 plots log10 of waveform power. The 7 inland water targets identified by Amazonas river mask. Slope in maximum waveform power probably an artefact of EGM96 geoid. Figure 10 shows individual waveforms (#20,40, …, 160) across the Rio Tapajos. Waveform #20 is over land, #40 - #120 "ocean-like"; #140 double peaked and #160 complex from land reflection.

Fig 7 Rio Tapajos/Amazonas

Fig.8. Google Earth image of 4/10/13

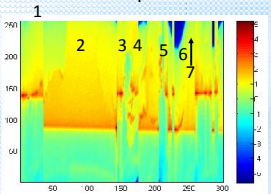


Fig 9. Multi-look waveform power. Units. X axis #waveform, Y axis log10 power

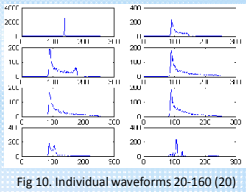


Fig 10. Individual waveforms 20-160 (20) Units. X axis #bin, Y axis power

6. Cryosat-2: Tapajos FBR Multi-look Results

Fig. 11 shows orthometric height (relative to EGM96). The blue line are heights for the full pass; cerise points those identified over inland water using river mask. Land targets are evident while inland water outliers occur due the river braids. Table 1 and 2 summarise the multi-look results. Outliers identified uses a 2 sigma rejection criterion. Question marks are attached to inland waters were uncertainty exists as to whether static or flowing water.

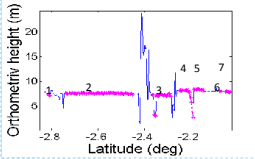


Fig. 11. Orthometric heights relative to EGM96. Land/inland water heights (blue); inland water Masked (cerise). The numbers refer to different inland water surfaces

		Sigma (cm)	# used	# rej	Mean (m)
1	Trib Tapajos?	13.2	3	0	7.30
2	Tapajos	4.72	96	12	7.63
3	Arapiuns	16.9	27	4	7.29
4	Amazonas	7.97	6	0	8.20
5	Amazonas	9.59	22	9	8.34
6	Amazonas?	0.85	3	0	8.01
7	Lake?	1.56	7	2	7.98

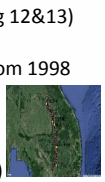
Table 1. Inland water height statistics relative to EGM96 from retracked multi-look waveforms. Heights rejected using 2σ.

	RMS (cm)
Ocean #500-3645	6.3

Table 2. RMs of multi-look ocean heights after polynomial fit to data excluding waveforms at ground points 1-500 to avoid geoid deficiency. The RMS value contains commission and omission geoid errors due to EGM96.

7. Cryosat-2 Hydrodynamic Modelling: Mekong

- Mekong SAR L1B water levels from data from DTU Space (Fig 12&13)
- Mask Using Landsat 8 data (Fig 14)
- Mekong River commission **low water level** data every km from 1998
- Compare against measured in-situ data (Fig 15)
- 5 in-situ gauges. Data to Nov 2012. (Fig 16)
- For each Cryosat crossing select the nearest gauge
- Low water level slope to correct elevation difference (Fig 17)



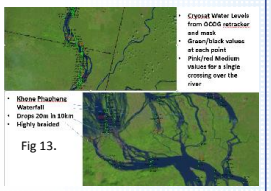


Fig 13.

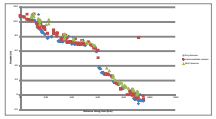


Fig 12. Medium Cryosat2 water levels for each river crossing. OCOG Retracker

Fig 14. Mekong river from Landsat imagery

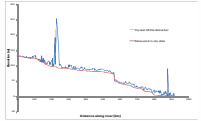


Fig 15. Cryosat-2 (blue) and measured low flow elevation (red) from

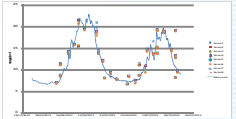


Fig 17. Comparison of Cryosat-2 data and in-situ data at Kratie. Data DTU

8. FBR: Next Steps

- Fine tune process
- Process extended period of data for
  - Mekong
  - Amazon
  - Brahmaputra
- Utilise waveform shape for analysis and filtering to identify inland water points and eliminate land points
- Utilise retracker optimised for inland waters
- Validation using in situ data and Jason-2
- Hydrodynamic modelling
- Forward look to Sentinel 3.

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