CRUCIAL: Cryosat-2 Success over Inland Water and Land

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Introduction

- CRUCIAL funded in response to ESA ITT ESRIN/AO/1-6827/11/I-NB, to investigate the application of CryoSat-2 data over land and inland water with a forward-look component to the future Sentinel-3 mission.
- Expertise in satellite radar altimetry, generation of inland water and land heights, development of Global Digital Elevation Model and river modelling.
- 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).
- The Earth's land surface is, in general, a relatively poor reflector of Ku band energy, with the exceptions of inland water, salar and ice surfaces.
- Research with EnviSat Burst Echoes has shown that substantial high frequency information content is present at short spatial scales as the small bright reflecting patch at nadir is able to dominate the returned echo. This effect is most strongly seen with inland water.

Cryosat-2 LRM and SAR Mode

- 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 much of the Earth's land surface.
- This is constrained by the availability of SAR Full Bit Rate (FBR) over land as most land/ocean surfaces are tracked in conventional LRM mode.
- Selected SAR (red) and LRM (green) tracks are shown in Fig. 1 (global); Fig. 2 (Amazon Basin); Fig 3. (Mekong); Fig. 4 (Lake Malawi).

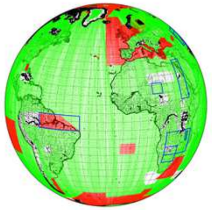


Figure 1: Selected SAR (Red) and LRM (green) track over the Earth. Blank areas SARIN mode

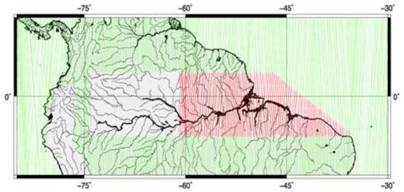


Figure 2. Amazon Basin: LRM (green), SAR (red) and SARIN (blanks) tracks

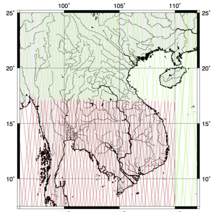


Figure 3. As Fig. 2 for Mekong

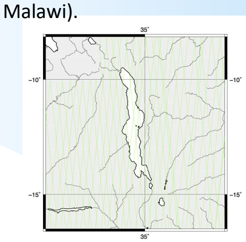


Figure 4. As Fig. 2 for Lake Malawi

SAR Tracks: exemplar Amazon Basin

- 3.5 month of SAR L1B data categorised using waveform shape with water echoes selected using a river mask (e.g. Fig. 5).
- Shape identification gives geographic distribution of water-waveforms and complex echo shapes with water components.
- Study Track A (Fig. 6): Waveform power (Fig.7) with many echoes identified as water echoes (shape class 5 and 10) similar to ocean class SAR returns (e.g. Fig. 8). Large water extent with no discernable interruptions to water flow. Individual waveforms plotted; green line is OCOG medium retrack point (to assess if simple retracking gives reasonable outcome)
- Study Track D (Fig. 9) Brightest echoes often complex shapes, multi-target responses (Fig. 10). Combination of 'simple' quasi-specular returns and complex multi-target echoes (e.g. Fig. 11). These multi-peak echoes more numerous than from previous altimeters
- Results being used to enhance waveform parameterisation in order to weight waveform shapes in height calculation
- Expert system being constructed to carry out these tests and produce weighted height estimates after excluding certain waveform classes. Datasets will be compared with Jason2 time series.

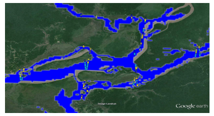


Figure 5. River mask detail

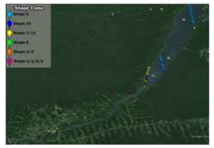
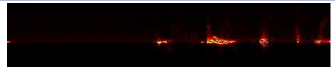


Figure 6. Amazon tributary (track A)

Figure 9. Amazon tributary (track D



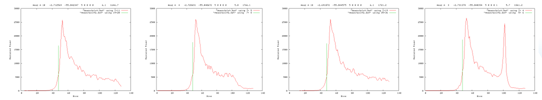


Figure 7: Waveforms power: Track A (left) and below
Figure 8: Representative waveforms:

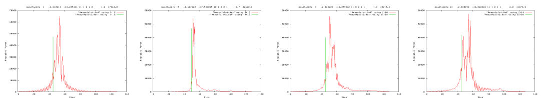


Figure 10: Waveforms power: Track D (left) and below
Figure 11: Representative waveforms:

LRM Tracks: exemplar Lake Malawi

- Rift valley lake: substantive terrain variation in surrounding area: good target for prior altimeter missions
- Good validation time series from Jason2, therefore identified as CRUCIAL validation test target for height retrieval prior to involvement of river modellers. Cryosat2 not returning data over much rough terrain
- LRM tracks (Fig. 12) put through expert system tuned for Cryosat-2 LRM waveform shape recognition.
- High proportion of complex (land/water) multi-target echoes, often due to snagging on bright targets (Fig 13) in addition to problems/complexities resembling those from 'ocean mode' altimeters.
- Lake heights (Fig. 14) and power (Fig.15) for Tracks D and E (Fig. 12). Track D "ocean-like"; Track E complex waveforms. Height variation in Fig. 14 due to geoid variation relative to EGM96 model. No real improvement with EGM08.

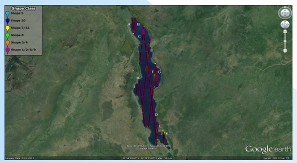


Figure 12. LRM tracks across Lake Malawi

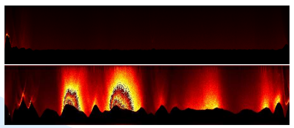


Figure 13. Along-track latitude (x-axis) v power (y-axis) for track D (ocean-like waveforms) and track E (complex waveforms). Note fan-tail not seen in previous missions.

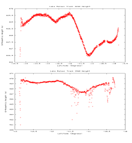


Figure 14. Lake height for tracks D (upper)and E (lower). Along track variation is the geoid

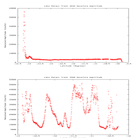


Figure 15. Power amplitude for tracks D (upper)and E (lower).

Cryosat-2 Hydrodynamic Modelling: e.g. Brahmaputra

- Exact orbit repeat 369 days; Sub-cycles of 30 days (Fig. 16)
- Non-repeat orbit: no virtual station time series and cannot convert altimetry to depth
- Daily measurements for about 10 days per sub-cycle. 20 days per sub-cycle without any data. Measurements cascading in downstream direction (Fig. 17). Spatial distance between measurements ≈50 km, i.e. measurements proceed slower than a flood wave
- Objective to simulate water level everywhere in the river and can thus assimilate any altimetric reading (Fig. 18)
- Approach based on Saint Venant and Manning equations: Requires accurate river bottom elevation and river cross sections
- The hydrodynamic model is non-linear: Ensemble Kalman Filter

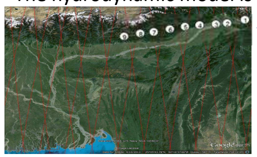


Figure. 16. The Brahmaputra and Cryosat-2 crossings in 30 day sub-cycle

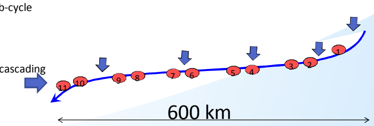


Figure 17. Schematic of cascading Brahmaputra crossings

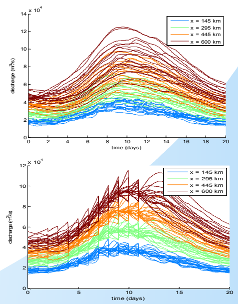


Figure 18. Hydrodynamic runs using synthetic Cryosat-2 heights. No data assimilated (upper) and assimilated data (lower). Runs assume: Runoff error (20 %); Altimetry error: 0.3 m. Ensemble size: 20

Acknowledgements: The authors thank the European Space Agency for funding the study through Contract 4000109110/13/I-NB