CRUCIAL: Cryosat-2 Success over Inland Water and Land

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Introduction

CRUCIAL was 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. The consortium has expertise in satellite radar altimetry, generation of inland water and land heights, development of Global Digital Elevation Model and river modelling.

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). The primary research focus in this contract is with SAR and LRM data.

From prior research (ESA River and Lakes Contract) it is known that 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 surfaces.

The early research focus in is inland water measurement; the first requirement is to determine where Cryosat-2 retrieves useable echoes.

Cryosat-2 LRM and SAR Mode

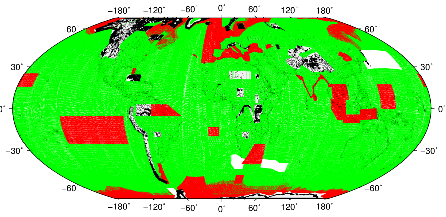

Figure 1. 6 months of SAR (red) and LRM (green) tracks over the Earth. Blank areas are in SARIN mode

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 data (a high rate mode) over land as most land/ocean surfaces are tracked in conventional LRM mode (low rate mode).

Six months of SAR (red) and LRM (green) tracks are shown in Fig. 1 (global); Fig. 2 (Amazon Basin); Fig 3. (Mekong); Fig. 4 (Lake Malawi) and Fig.5 (Brahmaputra). Note that Fig. 2 & Fig. 5 show areas without tracks; these are in SARIN mode.

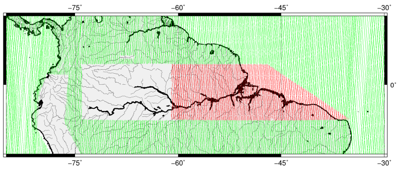

Figure 2. Amazon Basin: LRM (green), SAR (red) and SARIN (blanks) tracks

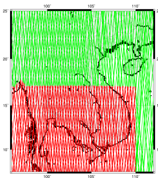

Figure 3. As Fig. 2 for Mekong

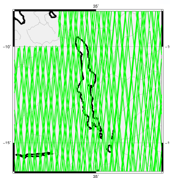

Figure 4. As Fig. 2 for Lake Malawi

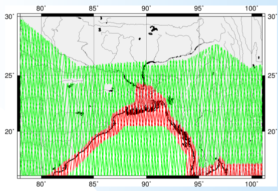

Figure 5. As Fig. 2 for Brahmaputra

SAR Tracks: exemplar Amazon Basin

Figure 6. Amazon tributary (track A): Pin colour as Fig. 12.

Figure 7: Waveforms power: Track A)

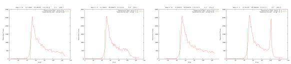

Figure 8: Representative waveforms: Track A

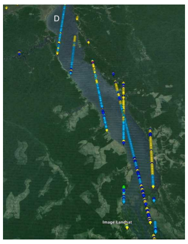

Figure 9. Amazon tributary (track D)

Figure 10: Waveforms power: Track D

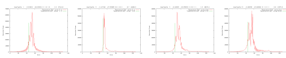

Figure 11: Representative waveforms: Track D

3.5 month of SAR L1B data categorized using waveform shape with water echoes selected using a river mask. 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 are being used to enhance waveform parameterisation in order to weight waveform shapes in height calculation. Datasets will be compared with Jason2 time series.

LRM Tracks: exemplar Lake Malawi

African 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. Cryosat-2 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 (Fig. 16).

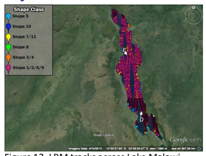

Figure 12. LRM tracks across Lake Malawi

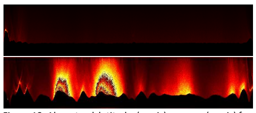

Figure 13. Along-track latitude (x-axis) v power (y-axis) for track D (ocean-like waveforms) and track E (complex waveforms). Note fan-tail not seen in previous missions.

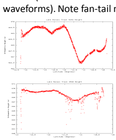

Figure 14.(left) Lake height for tracks D (upper)and E (lower). Along track variation is the geoid

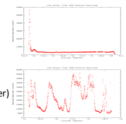

Figure 15 (right) Power amplitude for tracks D (upper) and E (lower).

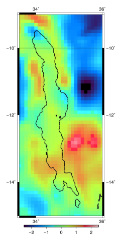

Figure 16. Geoid difference (EGM08-EGM96) over Lake Malawi

Mekong Cryosat-2 and ERS1 Analysis

Cryosat-2 LRM/SAR waveform characteristics over the Mekong to be compared against waveforms from the ERS1 Geodetic Mission.

To date waveform analysis of 6 months of Cryosat-2 data (LRM and SAR) has been performed over the Mekong (Fig. 16). Outcomes now being assessed. However, for full comparison and for tuning Cryosat-2 retracker parameterization a complete year of Cryosat-2 data must be included. Figure 17 shows the ERS-1 waveform analysis.

Example sequence of SAR echoes over Mekong (Fig. 18); the complex multi-target responses predominate are under investigation.

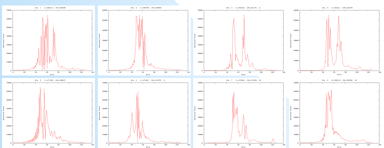

Figure 18: Mekong SAR waveform sequence

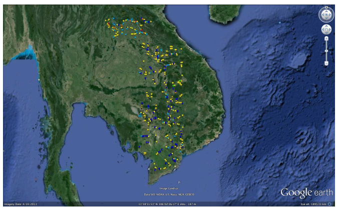

Figure 16. Mekong Cryosat-2 waveform analysis LRM and SAR: pin colour as in Fig. 12

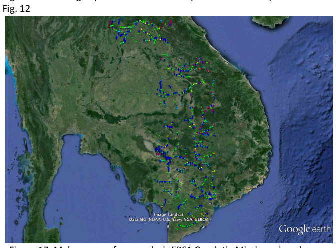

Figure 17. Mekong waveform analysis ERS1 Geodetic Mission: pin colour as in Fig. 12

Cryosat-2 Hydrodynamic Modelling: e.g. Brahmaputra

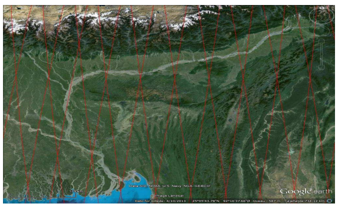

Figure 18. The Brahmaputra and Cryosat-2 crossings in 30 day sub-cycle

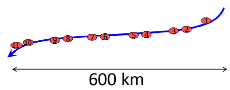

Figure 19. Schematic of cascading Brahmaputra crossings

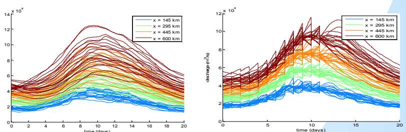

Figure 20. Hydrodynamic runs using synthetic Cryosat-2 heights. No data assimilated (left) and assimilated data (right). Runs assume: Runoff error (20 %); Altimetry error: 0.3 m. Ensemble size: 20

Exact orbit repeat 369 days; Sub-cycles of 30 days (Fig. 18). 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. 19). 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 thus assimilate any altimetric reading (Fig.20)

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

STSE Support To Science Element

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