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

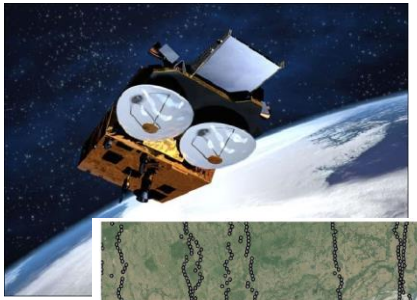
Philip Moore (1), Stephen Birkinshaw (1), Marco Restano (2), Américo Ambrózio (3), and Jérôme Benveniste (4)

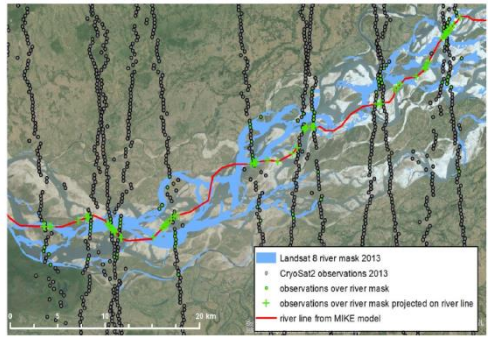
(1) Newcastle, Civil Engineering & Geosciences, United Kingdom (philip.moore@ncl.ac.uk), (2) SERCO c/o ESA, (3) DEIMOS c/o ESA, (4) ESRIN/ESA

The CRUCIAL Project

- **CRUCIAL** is funded by the **ESA's Support To Science Element (STSE) Programme** to investigate the application of CryoSat-2 data over inland water with a forward-look component to the Sentinel-3 mission.

- The high along-track sampling of Cryosat-2 altimeter in SAR/SARin modes offers the opportunity to recover high frequency signals.





Part 1: Process bursts (Q, I data)

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

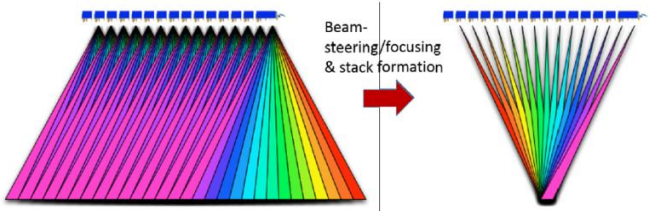
SARin $\sim 20\ Hz, 320\ m\ along\ track$

- 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

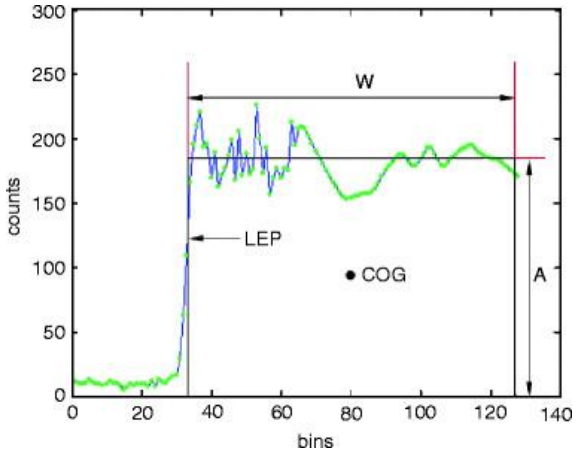
($\sim 300\ m\ along\ track$)

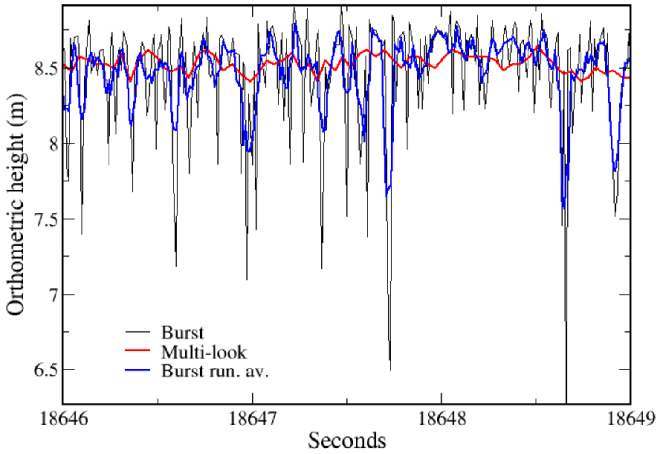
- Form sequence of ground points at beam angle using coarse approximate steering
- Beam formation and steered to ground points
- Stack beams pointing at ground points
  - max 240 beams in SAR mode and 60 for SARin in stack for multi-look
- Apply slant range correction, tracker range correction, Doppler range correction
- Heights from empirical and OCOG/Threshold retrackers

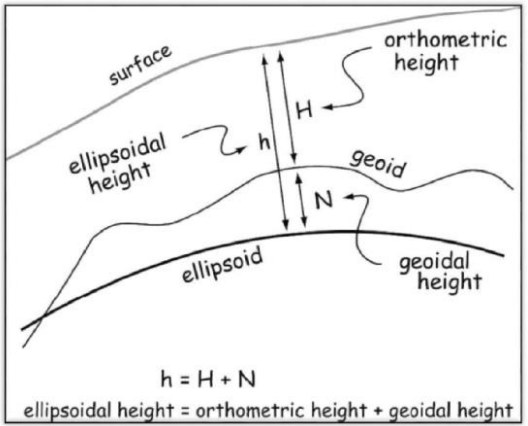


Burst Height (80 Hz) vs. Multi-Look Height (20 Hz)

- The burst echoes heights derived by using the OCOG/Threshold retracker. Also given are heights from the stack forming the multi-look.
- The burst echo heights are considerably noisier than the multi-look data.
- To provide comparability at about 300 m resolution, a running average over 4 burst echo heights is also plotted
- The speckle in the burst echo data affects the recovered heights and only through stacking and forming multi-look waveforms can precise heights be recovered.

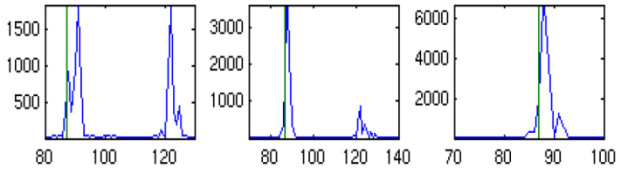


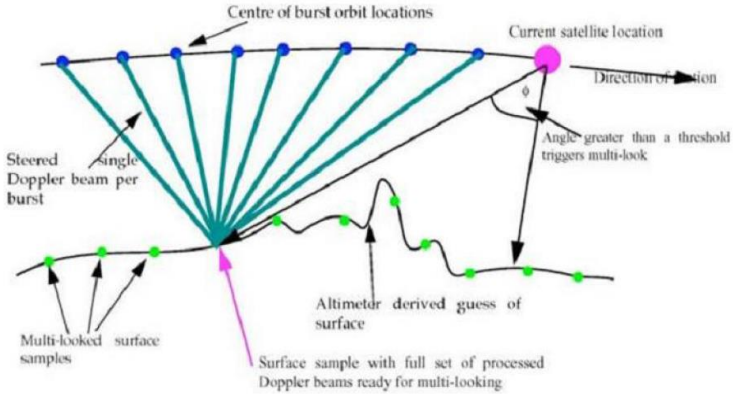


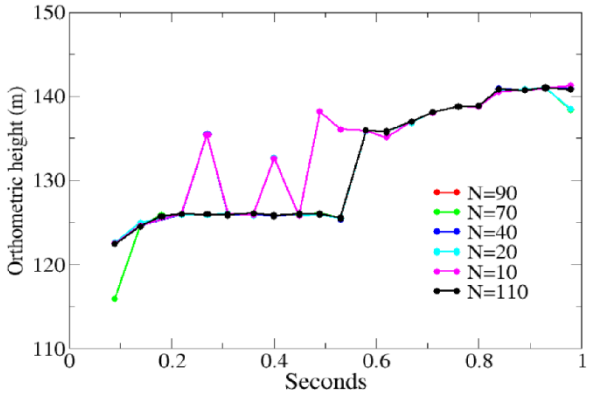


SAR FBR: Mekong – Data Selection

- The Mekong River is the eighth largest in the world in discharge (ca. 475 km3 year-1) and the 12th largest in length (ca. 4800 km).
- Cryosat-2 is in **SAR mode**. SAR data processed using a high resolution river mask (Landsat 8 images & NDWI = (Green-NIR)/(Green+NIR)).
- **The number of looks (N) used in multi-looking the stack has to be determined**.
- For the larger values of N, the number of acceptable heights is 7 or 8 which decreases to 4 for the lower values of N = 10. The orthometric heights for N=110, N=90, N=70 and N=40 are indistinguishable. **N=40 was selected**.







SAR FBR: Mekong – Validation against River Gauges

- SAR FBR heights along the Mekong (N=40).
- Gauges and range identified by lines/circles. Circles at gauge show low water level (Dec-Apr) and high water level (Aug-Sep).
- Gauges at Mukdahan, Khong Chiam, Pakse, Stung Teng, Kratie ordered from low to high chainage. Low water level (Dec-Apr).
- **RMS errors at the Kratie gauge are equal to 67 cm (N=40) and 94 cm (N=110), respectively**.

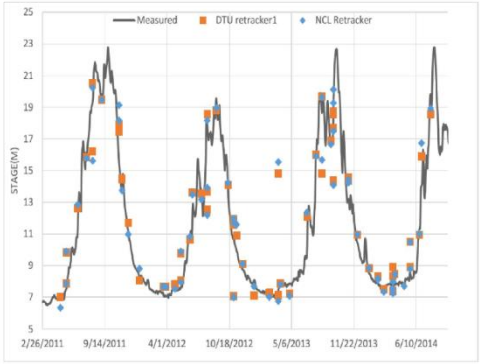


Figure 19: Comparison of Kratie gauge data with heights from near-by altimetric points from NCL (this study; N=110) and DTU. RMS 91.9 cm (NCL, empirical retrackers) and 96.8 cm (DTU).

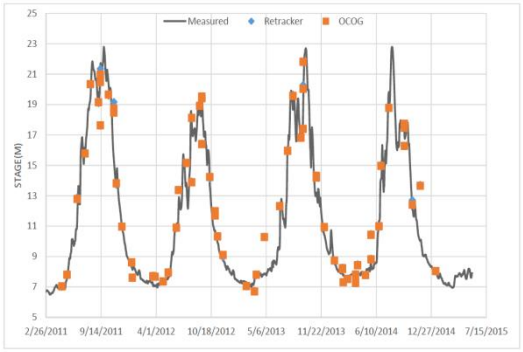
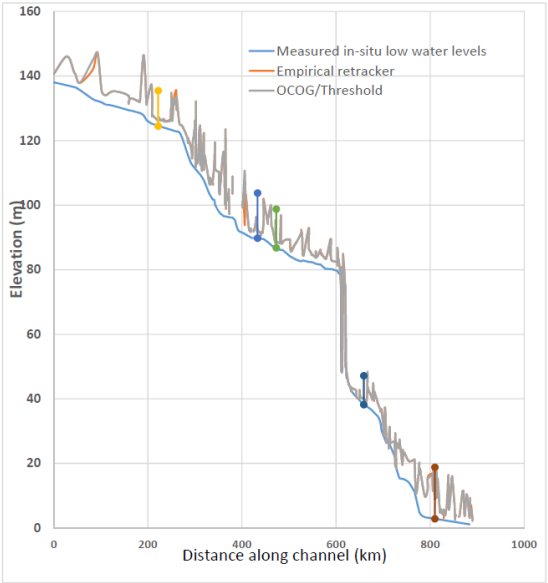


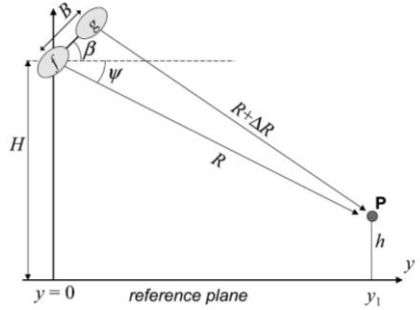
Figure 20: Comparison of Kratie gauge data with heights from near-by altimetric points from NCL (this study) waveforms using N=40. RMS 67.8 cm (empirical retrackers) and 66.9 cm (OCOG/Threshold) using 3σ rejection level.

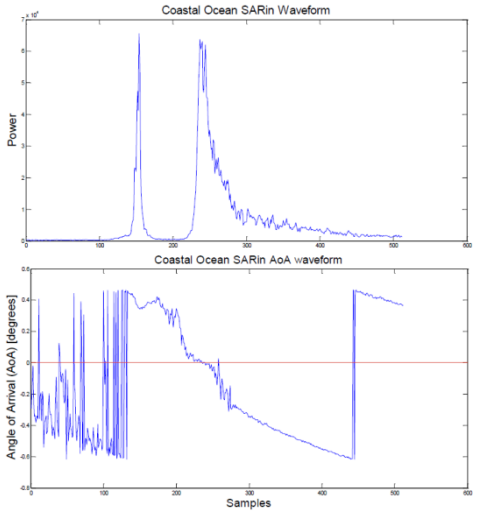


#	Site	Latitude (deg)	Longitude (deg)	Low water level (m)	Range (m)	Chainage of gauge (km)	Chainage range altimetry (km)
013402	Mukdahan	16.540	104.737	124.5	11	222	158-321
013801	Khong Chiam	15.318	105.500	89.8	14	433	338-441
013901	Pakse	15.117	105.800	86.8	12	473	446-615
014501	Stung Teng	13.545	106.017	38.2	9	659	650-740
014901	Kratie	12.240	105.987	2.85	16	810	741-890

SARin for Inland Water

- Waveforms transmitted from two antennae illuminating the same surface area.
- If the satellite roll is accounted for, heights from the two antennae should be near identical over flat terrain and inland waters.
- Coherence between waveforms from antennae can be used for ground slope.
- Unrealistic to attempt to determine the river slope from SARin unless all systematic errors are accounted
- The angle of arrival (AoA) can be used to identify off nadir clutter returns.





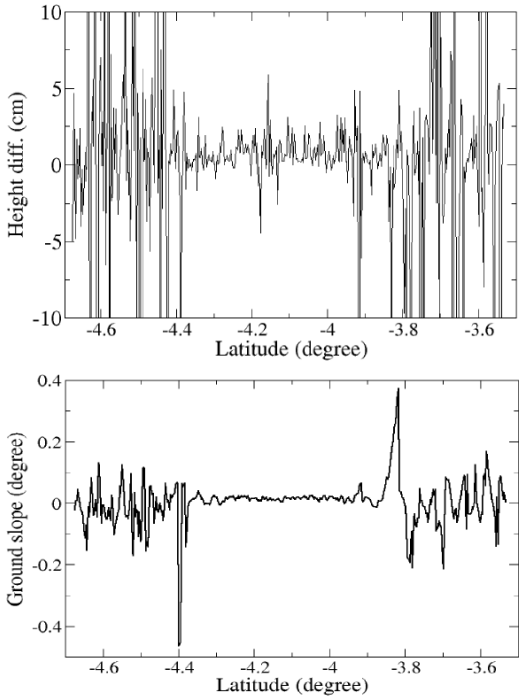
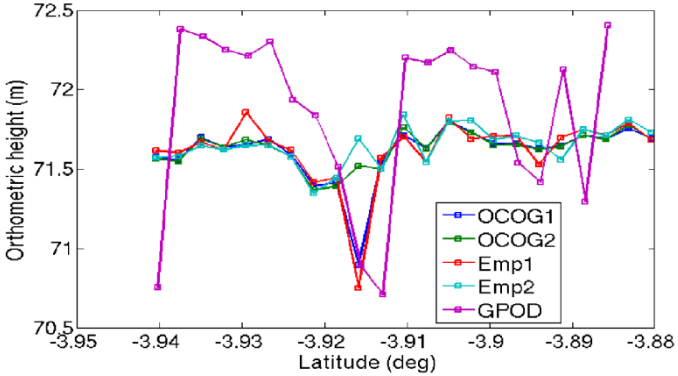


Figure 22: (Upper) Difference between heights from two antennae; (lower) ground slope across. SARin Amazonas 5 May 2012. (Latitude -4.2° corresponds to longitude 70.179°W)

SARin FBR: Amazon – Validation against River Gauges

- 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 at Tabatinga, an **RMS of 36 cm has been obtained (N=60)**.
- Heights from two antennae are nearly identical.



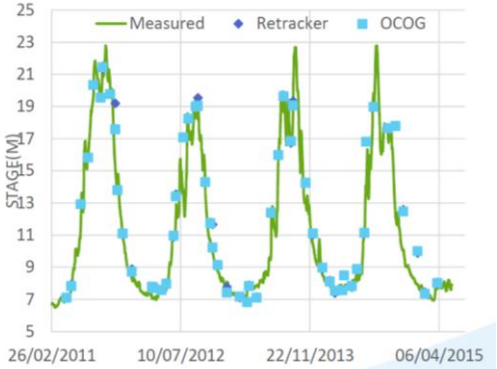


Fig. 13. Comparison of Cryosat-2 and gauge data near Tabatinga, Amazonas.

Figure 38: Google earth image of Amazon near Tabatinga. Gauge marked in red. Yellow markers denote centre line of stretch considered for Cryosat-2 crossings.

Conclusions

- CryoSat-2 measures river stage in both SAR and SARin modes.
- The burst echo heights (80Hz) are considerably noisier than the multi-look data (20Hz).
- The number of looks (N) used in multi-looking the stack has to be optimized.
- The SARin mode allows both to infer the ground slope (Coherency) as well as to reduce the presence of clutter (AoA).
- Results include data over Mekong (SAR), Amazon (SAR and SARin) and Brahmaputra (SARin)
- Hydrodynamic modelling for Mekong (NCL) and Brahmaputra (DTU)

- **CRUCIAL web site : http://research.ncl.ac.uk/crucial/About**
- **Request for data can be sent to: philip.moore@newcastle.ac.uk**