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

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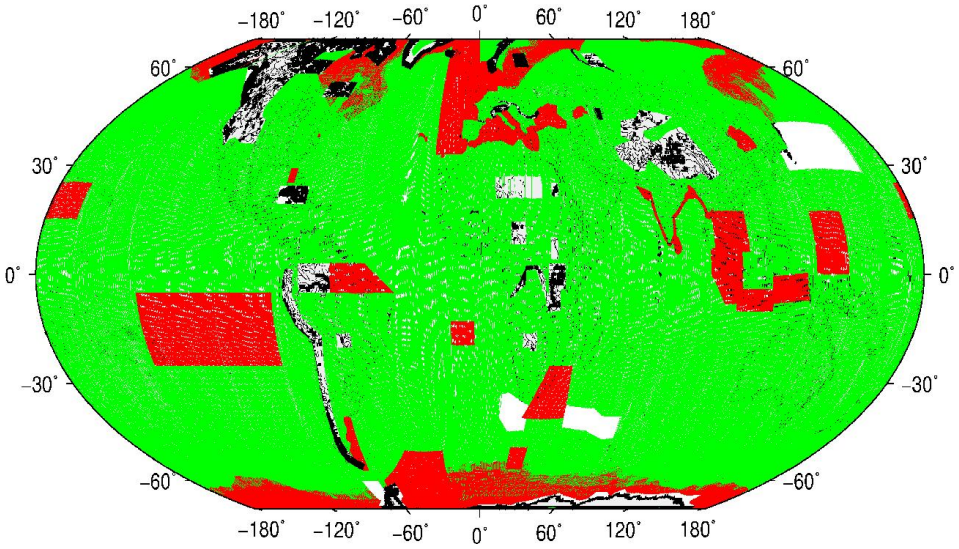
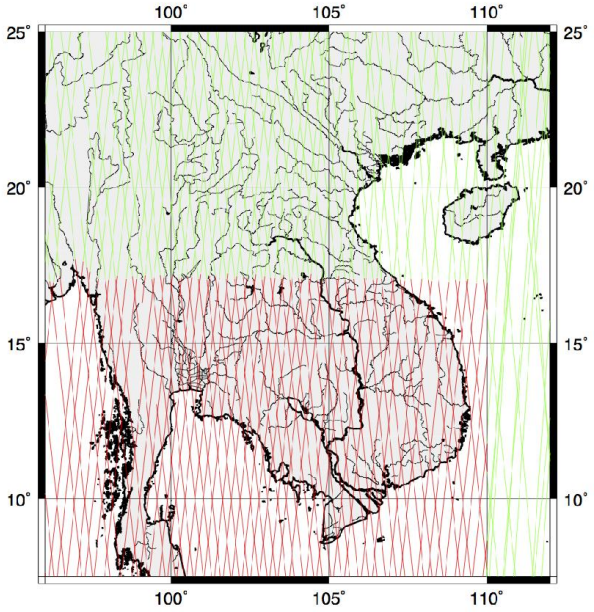
The CRUCIAL Project

- Funded by ESA's **Support To Science Element** (STSE)
- To investigate the application of CryoSat-2 data over inland water with a forward-look Sentinel-3.
  - Previous altimeter missions lost significant amounts of information due to onboard echo averaging.
- Cryosat2 SIRAL (SAR Interferometric Radar Altimeter) operates in one of three modes;
  - Low Resolution Mode(LRM)
  - Synthetic Aperture Radar(SAR)
  - Interferometric Synthetic Aperture Radar(SARIN).
- Here we process SAR Full-Bit Rate (FBR) data to construct and retrack multi-looked waveforms.
- Validation over the Mekong (Newcastle); Amazon(Newcastle); Brahmaputra (DTU)

Cryosat2: FBR SAR data



- Limited SAR FBR availability as most land/ocean surfaces are tracked in conventional LRM.
- SAR (red); LRM (green); SARin (white)

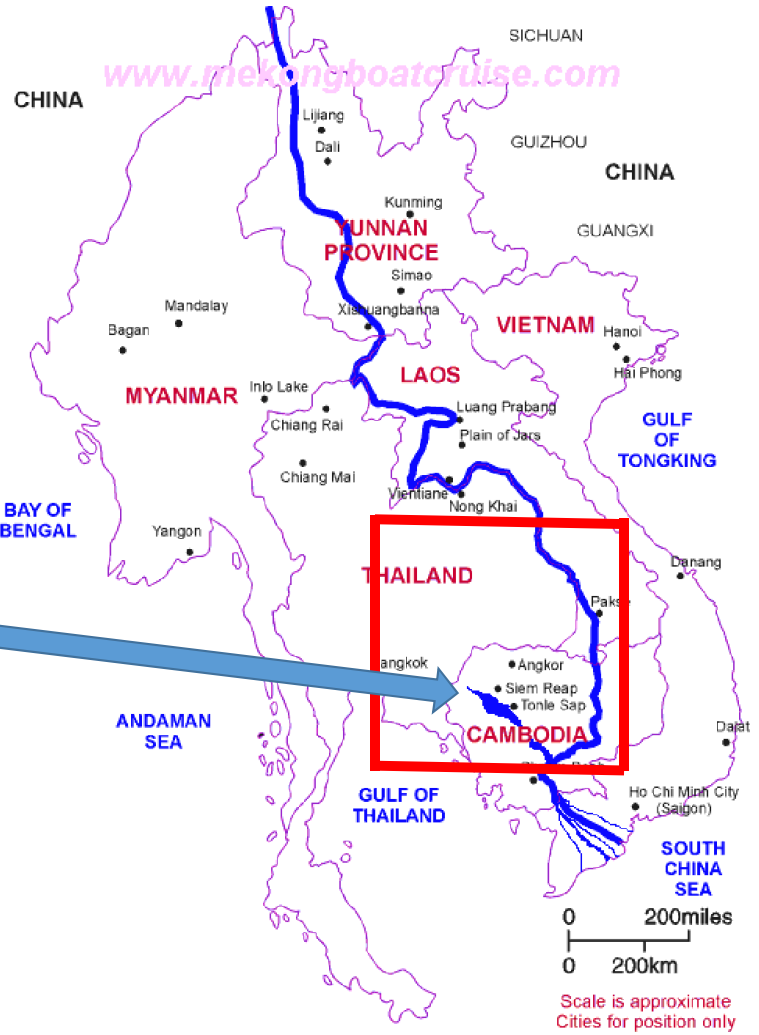


- Selected SAR (red) and LRM (green) tracks over the Mekong Basin.

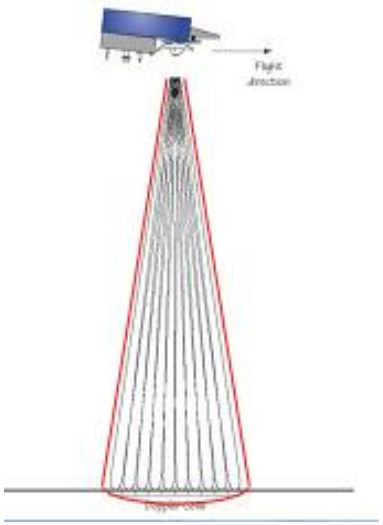
Lower Mekong

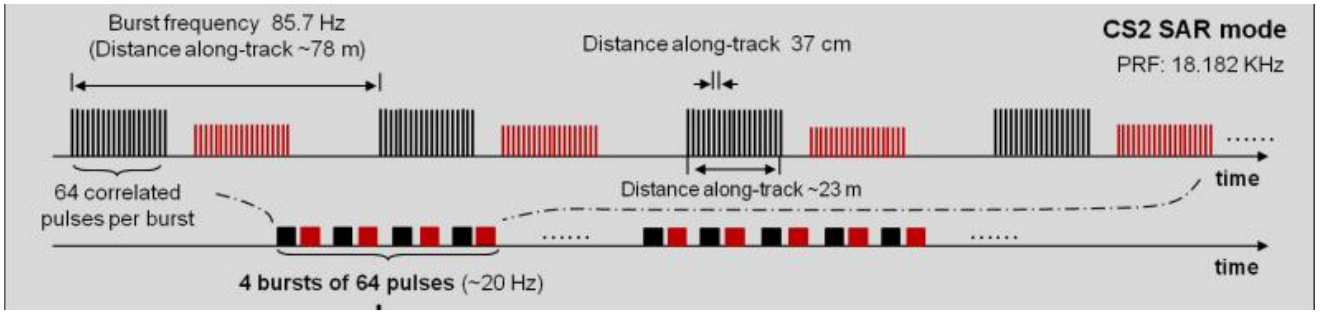
- **Mekong River basin:**
  - eighth largest in the world in discharge (ca. 475 km^3 $year^{-1}$)
  - 12th largest in length (ca. 4800 km).
  - Lower Mekong Basin, downstream of Myanmar/Laos border

- **Tonlé Sap Cambodia**:
  - a combined lake and river
  - flow changes direction twice a year
  - lake expands and shrinks dramatically with the seasons.
    - From November to May (dry season) drains into Mekong River at Phnom Penh.
    - After heavy rains (start June) Tonlé sap backs up to form lake.



FBR SAR data processing 1



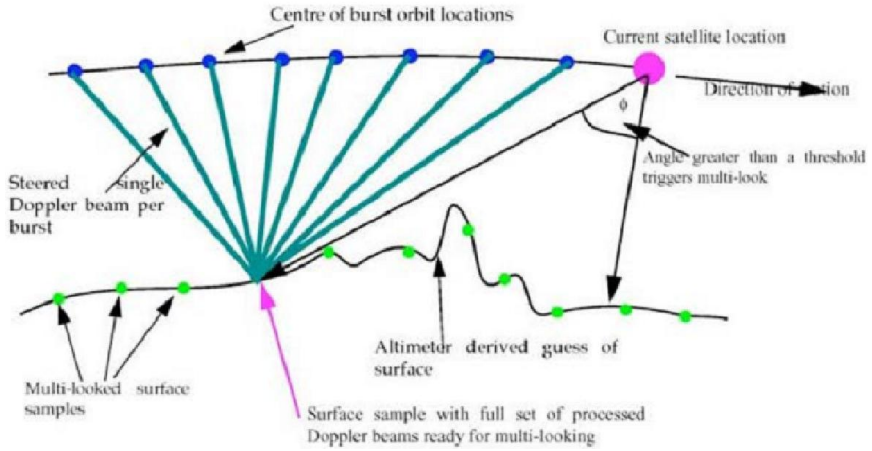


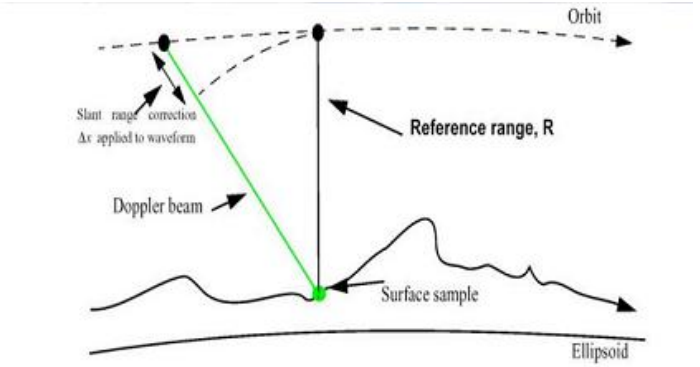
Part 1: Process bursts $\sim 80\ Hz, 80\ m\ along\ track,$

- Q, I data: Coherent range FFT over 64 pulses in burst: Hanning window
- Beam formation steered to nadir direction
- Heights from OCOG/Threshold retracker; orthometric heights using EGM08
- Coarse orthometric surface recovered from mean of inland water heights
- Improved ellipsoidal surface height by reinstating EGM08

Beam forming synthetises a set of 64 Doppler beams per burst, exploiting the Doppler effect due to the satellite motion with respect the ground. Hanning window applied to Doppler burst.

FBR SAR data processing 2



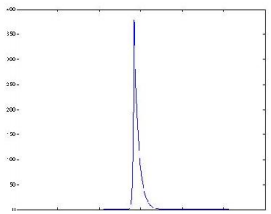
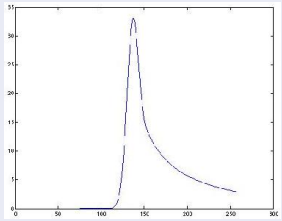
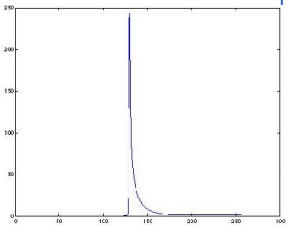


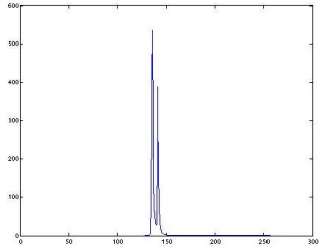
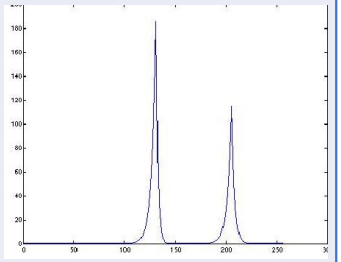
Part 2: Multi-look

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

- Form ground points using approximate steering
- Inland water locations identified by inland water mask
- Beam formation and steerage 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
- Stacked beams – cosine weighting
- Heights from empirical retrackers

In the approximate beam steering, beams in the fan are steered by the same angle.

Retracker #	Parameters fitted	Description	
Simple waveform shapes			
1	4	Specular: (still water)	
2	5	“Ocean-like”: (ruffled water)	
3	7	“Ocean-like” with fall away in power at high # bins: (ruffled water)	

Retracker #	Parameters Fitted	Description	
Double peak waveform shapes			
4	8	Twin specular peaks (strong returns off two still water Patches)	
5	9	Retracker type 2 with additional specular peak (ruffled and still water)	

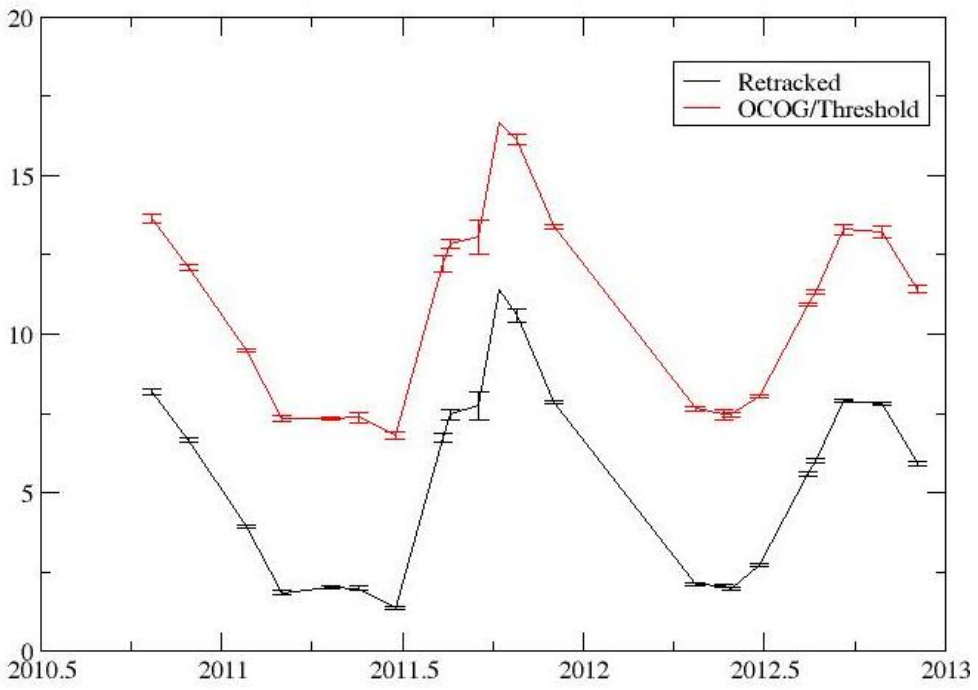
Retracker chosen to minimise Normalised Residual Error (NRE)

$$NRE = \sum_{i=1}^{256} (P_i^{obs} - P_i^{\mathrm{mod}})^2 \Big/ \sum_{i=1}^{256} (P_i^{obs})^2$$

where P_i^{obs}, P_i^{mod} are observed and fitted power for bin i.

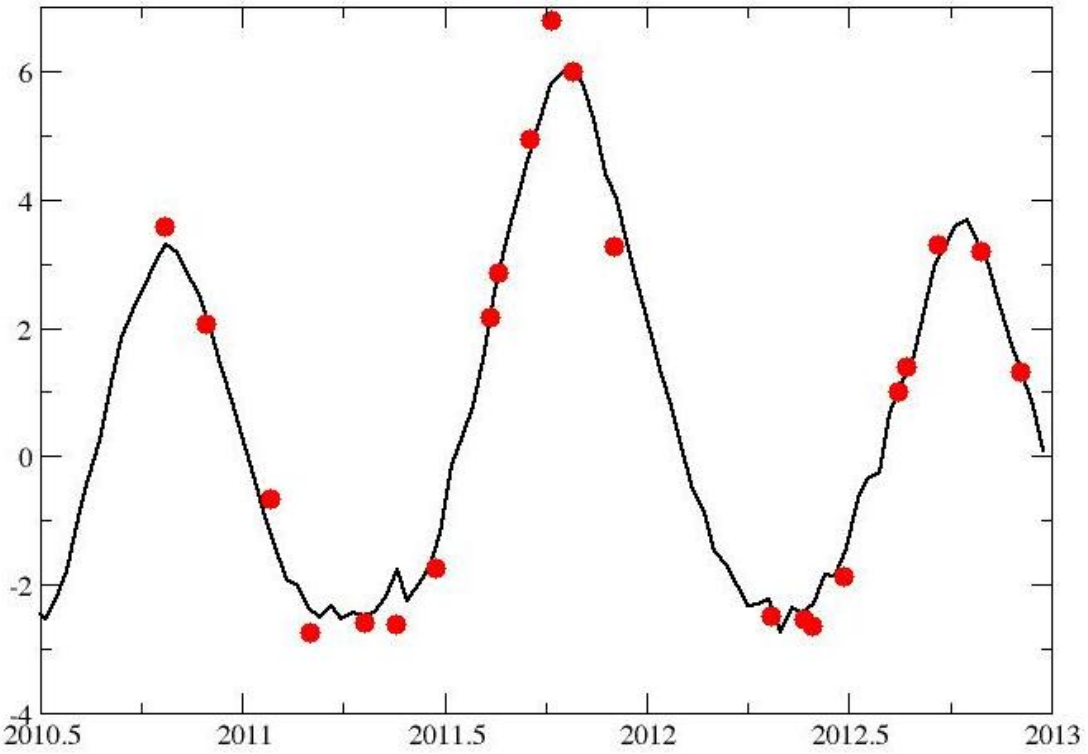
Tonle Sap: Comparison of Retrackers v OCOG/Threshold

Date	Retracked Ht (m)	Sigma (m)	#	OCOG/Threshold Ht (m)	Sigma (m)	#	Total data
2010.808	8.179	0.072	69	8.642	0.129	75	98
2010.908	6.662	0.047	65	7.108	0.107	87	94
2011.068	3.935	0.043	67	4.474	0.048	61	90
2011.167	1.849	0.080	88	2.340	0.080	80	97
2011.300	2.008	0.051	55	2.337	0.049	58	84
2011.379	1.985	0.057	76	2.374	0.164	98	114
2011.479	2.862	0.064	25	3.254	0.115	24	41
2011.612	6.757	0.221	20	7.076	0.418	26	26
2011.632	7.458	0.166	3	7.846	0.121	3	3
2011.711	9.536	0.049	32	9.845	0.180	40	64
2011.765	11.386		1	11.655		1	
2011.817	10.582	0.220	20	11.132	0.171	18	20
2011.916	7.862	0.053	60	8.394	0.082	68	83
2012.308	2.122	0.049	55	2.494	0.242	84	87
2012.387	2.071	0.052	64	2.458	0.164	78	92
2012.408	1.969	0.053	63	2.464	0.076	61	89
2012.487	2.726	0.040	33	3.043	0.050	37	61
2012.619	5.602	0.071	63	5.924	0.044	46	108
2012.639	6.004	0.064	17	6.314	0.069	20	20
2012.718	7.904	0.056	84	8.299	0.175	118	143
2012.823	7.789	0.052	54	8.233	0.182	77	103
2012.923	5.919	0.059	71	6.421	0.103	70	82



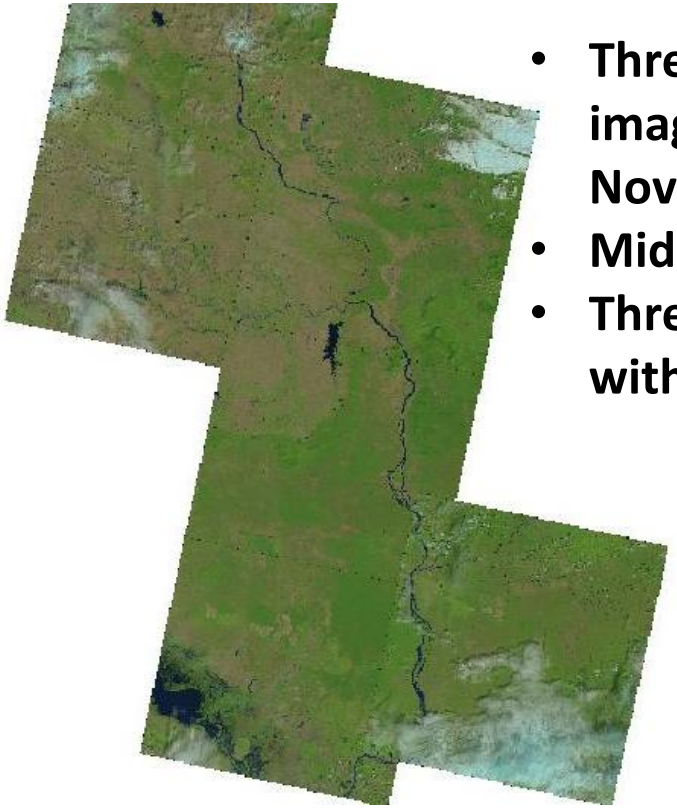
Heights and sd's: OGOG/Threshold offset by 5m

Comparison of USDA OSTM heights and Cryosat-2 heights over Tonle-Sap (units metres)

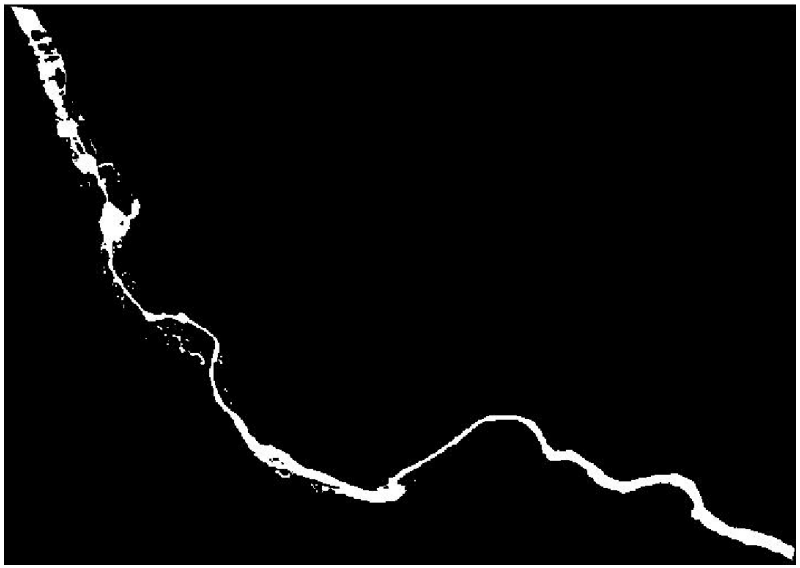


USDA heights from OSTM black curve; Crosat2 FBR data (red circles)

River Mask



- Three Landsat8 images from November 2014
- Mid-season Flows
- Three images within one week



- Mask Using Landsat 8 data
- Two Stages
  - Approximate river mask
  - Actual water bodies using Landsat images

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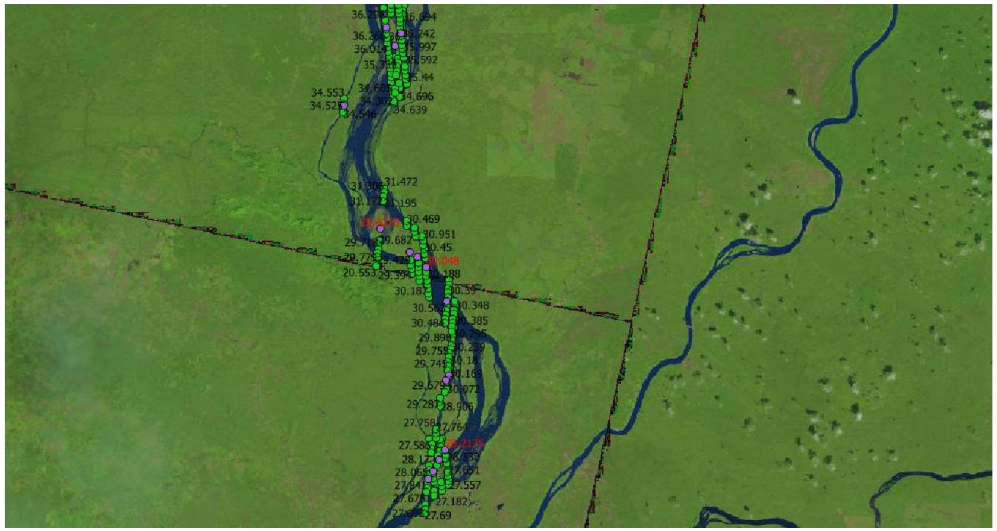
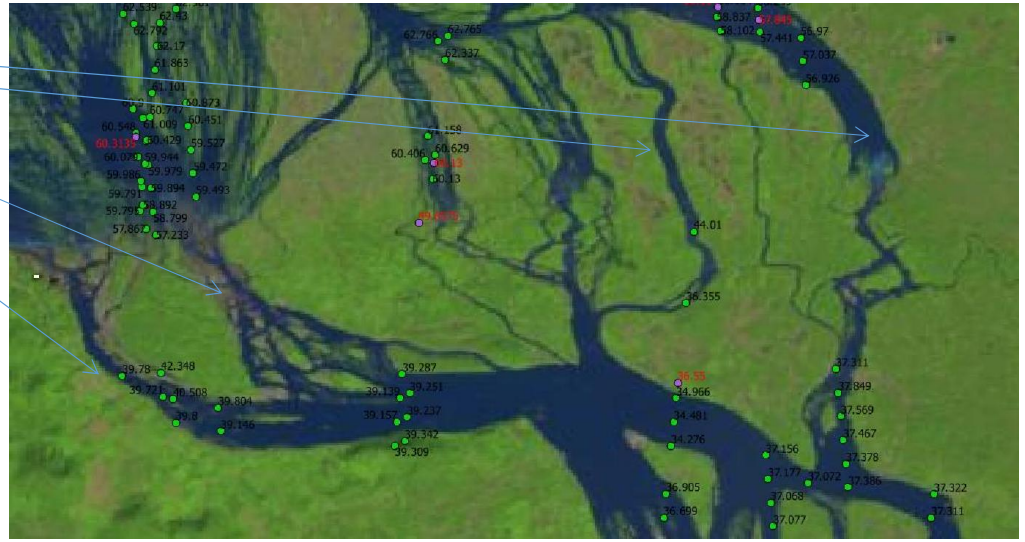


Cryosat2 passes across Mekong

- **Khone Phapheng Waterfall**
- **Drops 20m in 10km**
- **Highly braided**



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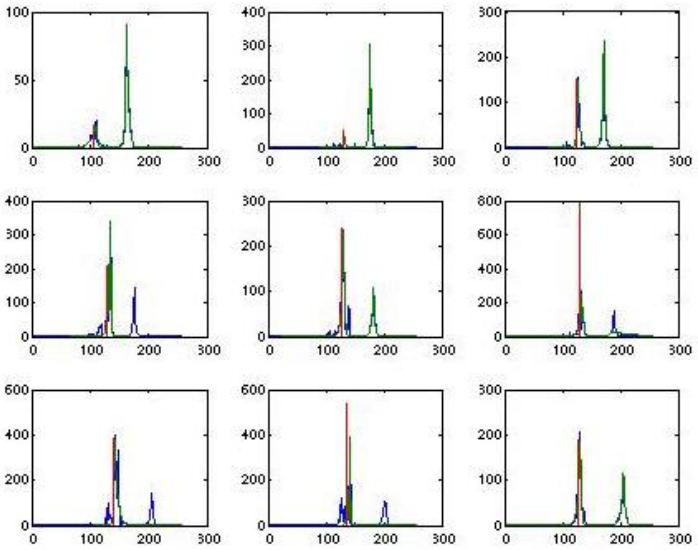
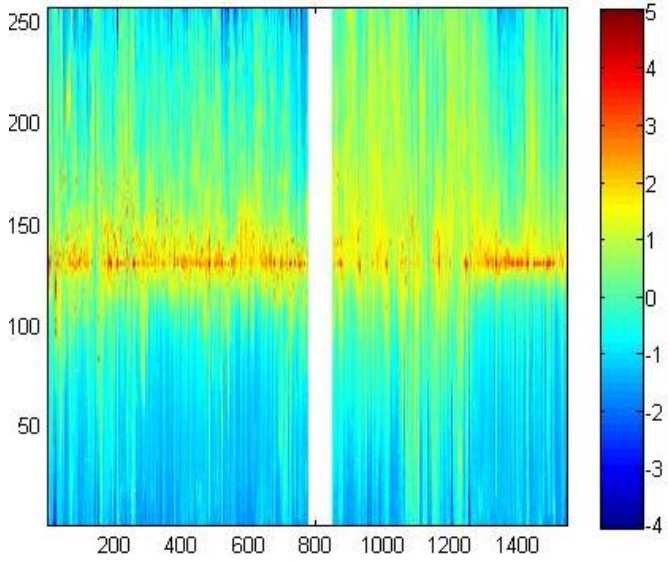
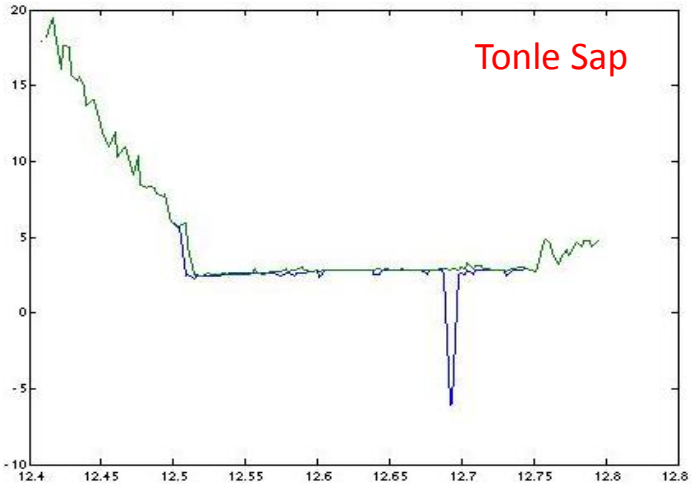
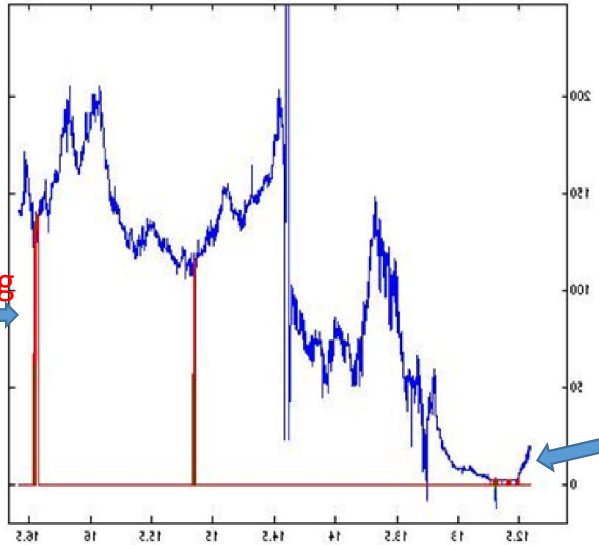
Waveforms from Mekong





Power (log10) of multi- looked waveforms of N-S pass across Mekong and Tonle Sap





Orthometric height (m). **Blue** curve from bursts

Mekong

Tonle Sap

- Compare Cryosat2 data with in-situ data
- 5 in-situ gauges. Data up to November 2012.
- 18 months overlap
- For each Cryosat2 crossing select the nearest gauge
- Correct for different elevation using low water level slope

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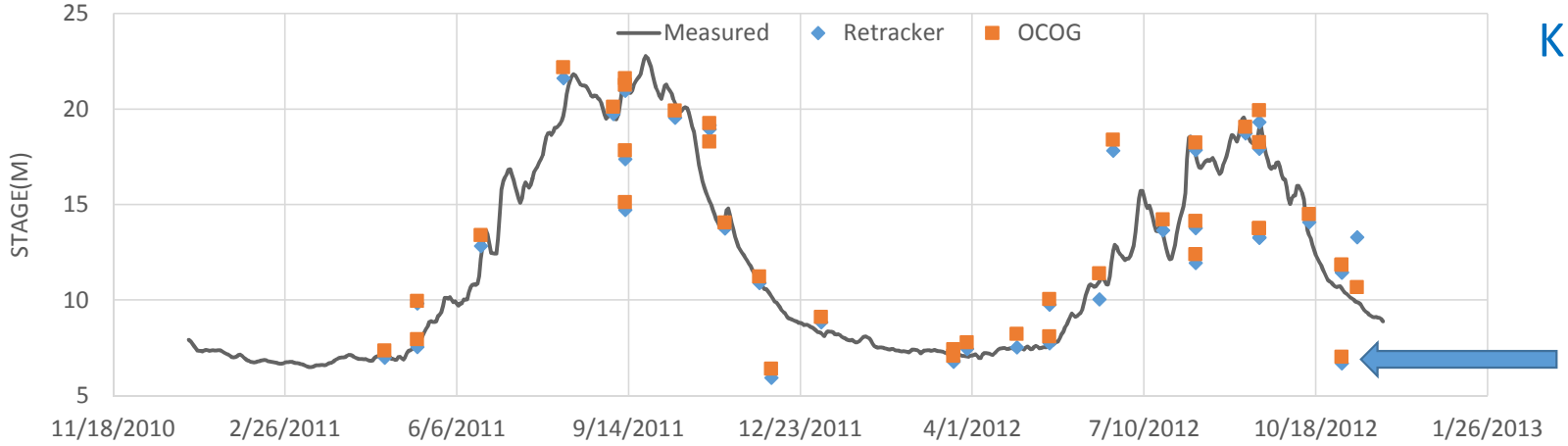
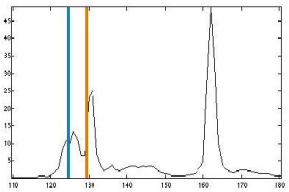
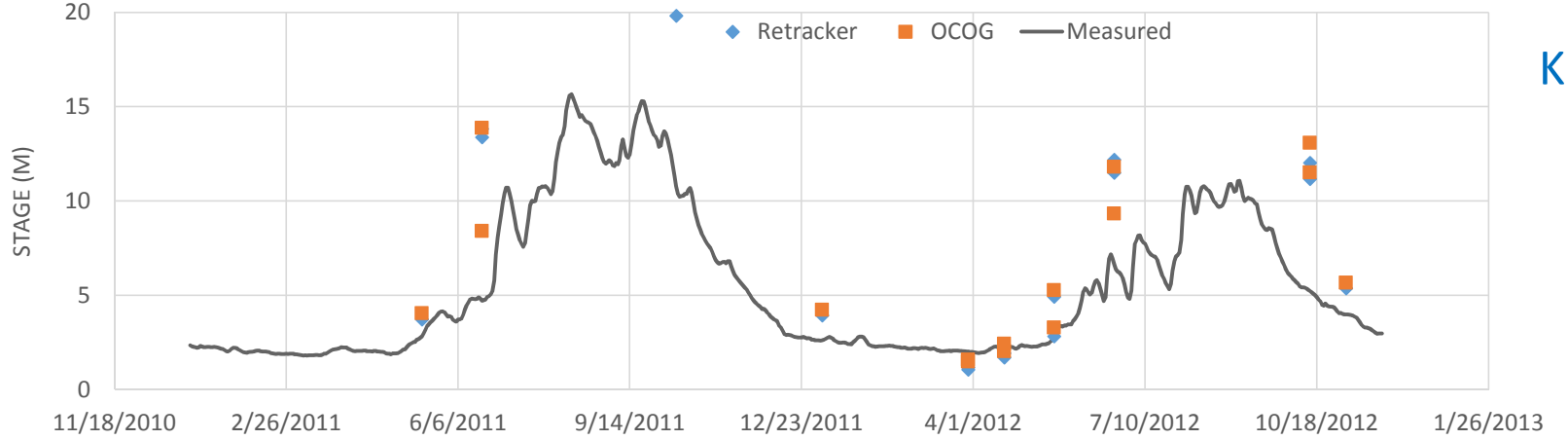
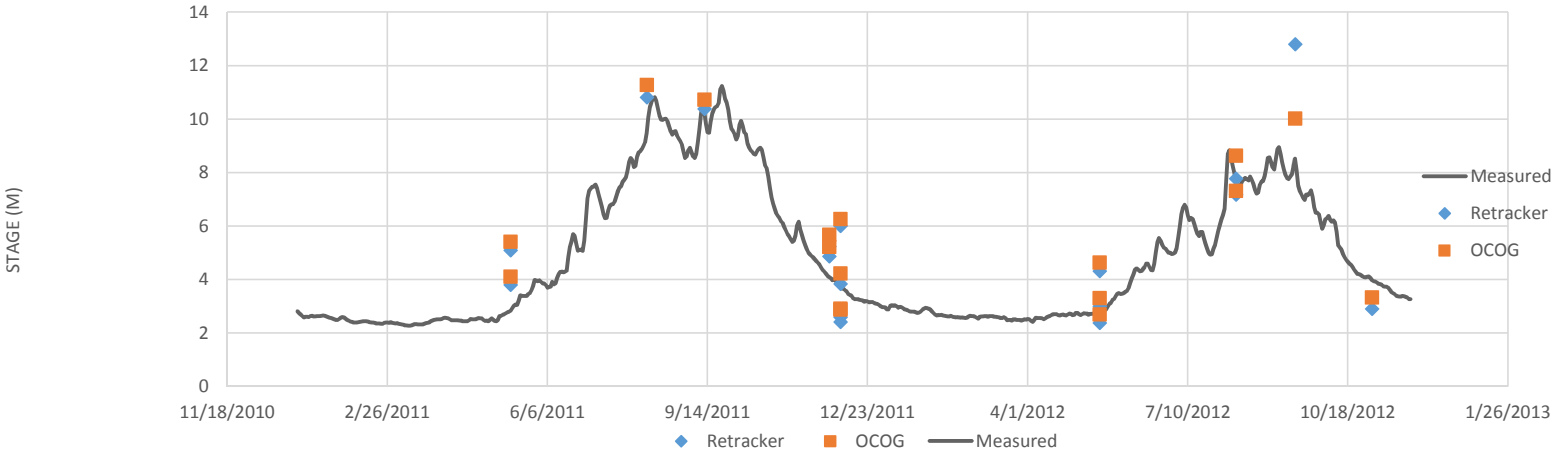


Kratie

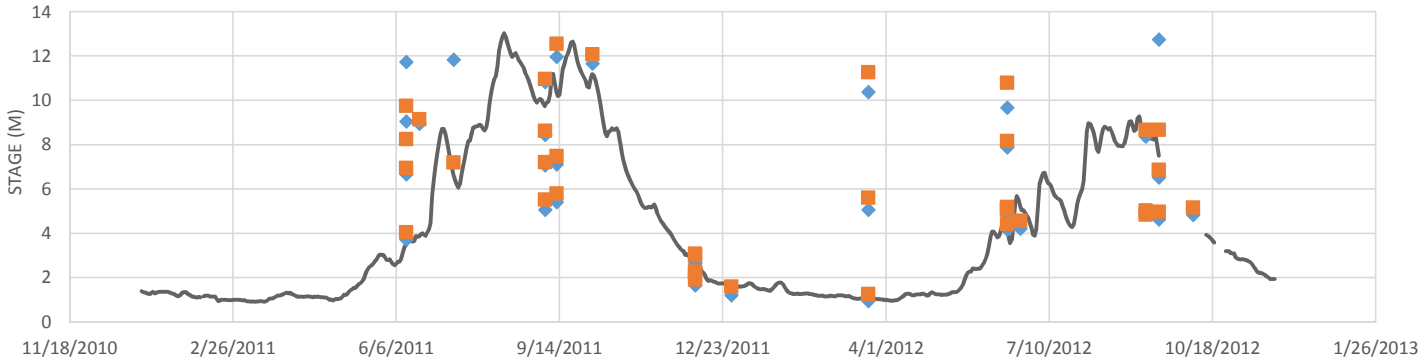




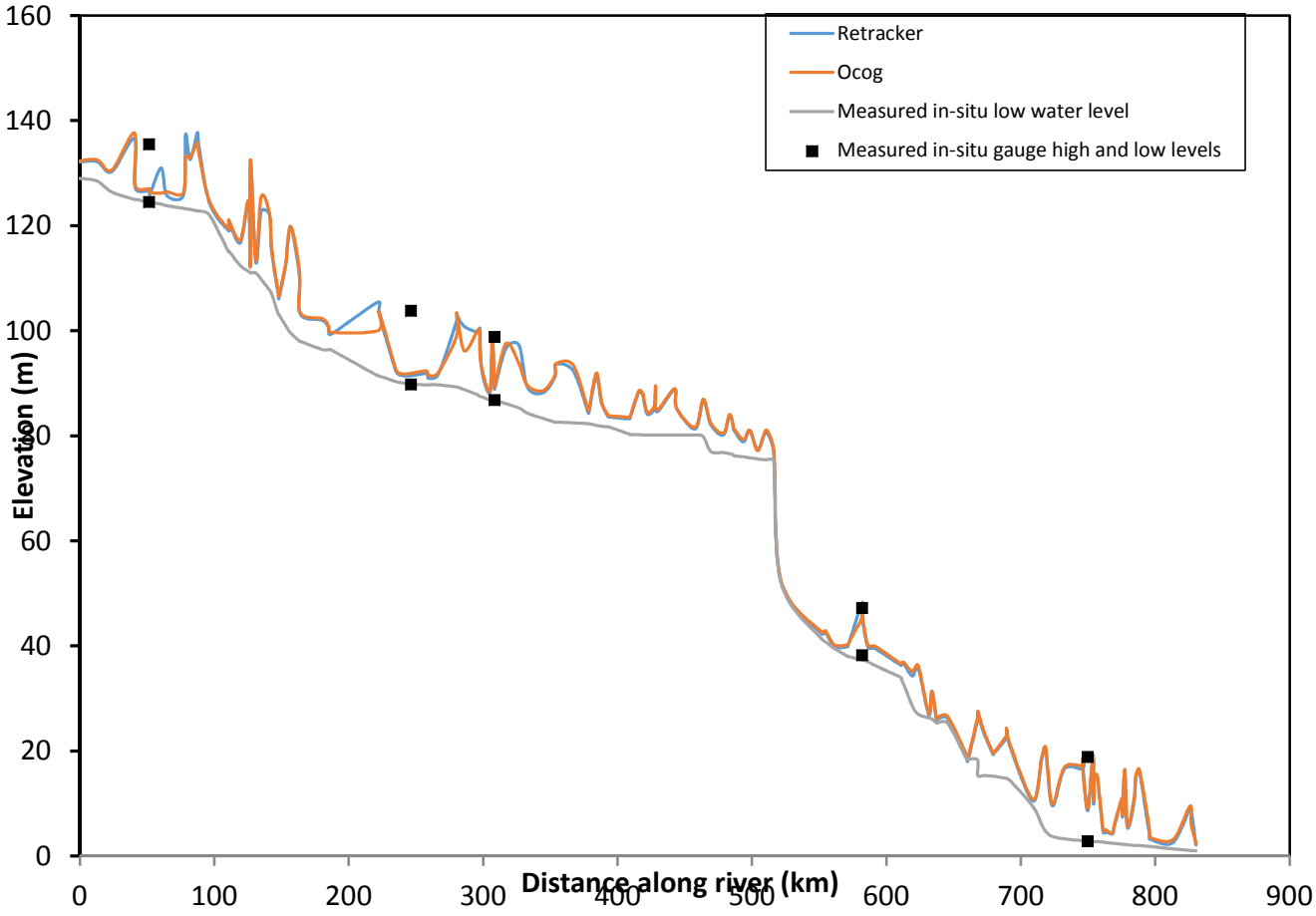
Khong Chiam



Stung Treng



Pakse



Low water level data every km from 1998 (Mekong River commission)

High water slope different from low water slope (Kratie range 16m, Stung Treng 9m)

SAR FBR Processing: Next steps

- Different mask for different seasons
- Processing options – off nadir water reflections
- Refinement of retrackers
- Use of Cryosat2 data for hydrological modelling