Monitoring of lake water level variation from pulse and doppler beam-limited as well as laser altimeters

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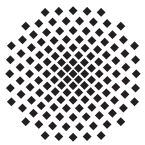

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Motivation

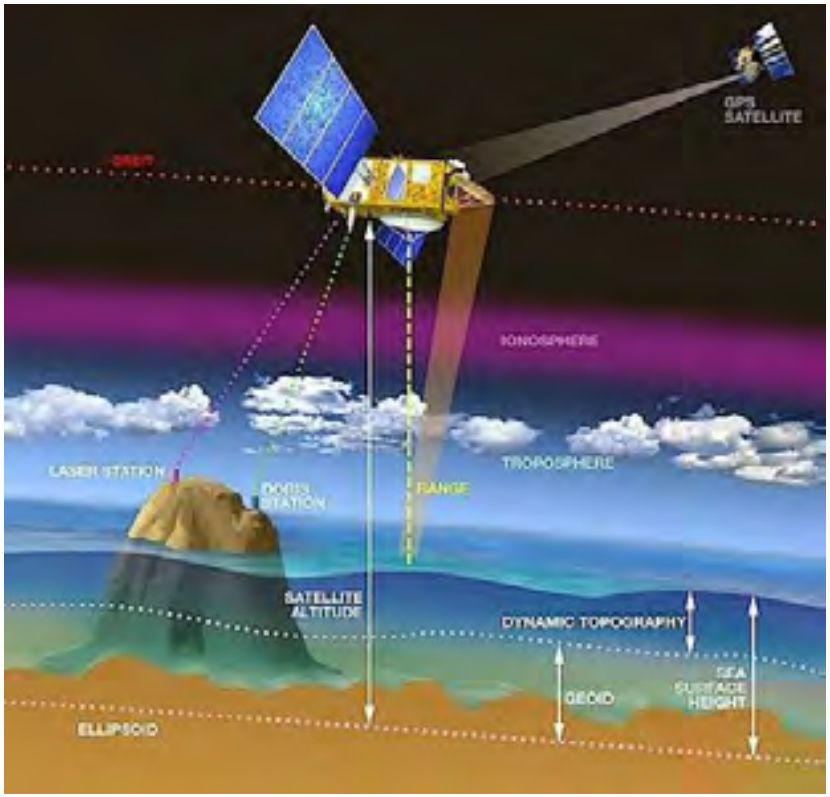
- Evaluate the performance of different kinds of altimeters for monitoring inland bodies
- How much do
  - waveform retracking
    and
  - waveform saturation

  corrections improve the quality of water level monitoring?

Altimetry missions

- Pulse- limited:
  sending separated consequences electromagnetic pulses to the water surface, e.g. Envisat, Jason-2, CS-2 (LRM)
- Doppler beam-limited:
  sending correlated consequences electromagnetic pulses to the water surface and using delay doppler processing, e.g. CS-2 (SAR and SARIn)
- Laser:
  sending separated laser pulses to the water surface, e.g. IceSat, Airborne LiDAR

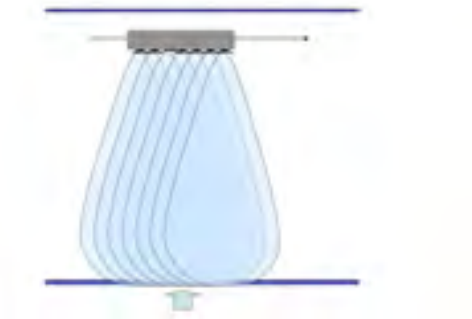
Pulse-limited and doppler beam-limited altimeters

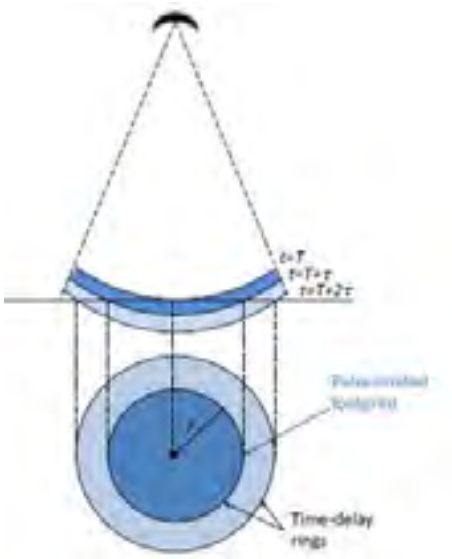


(http://www.altimetry.info)

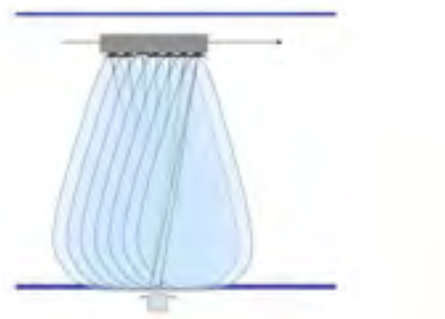
Pulse-limited and doppler beam-limited altimeters

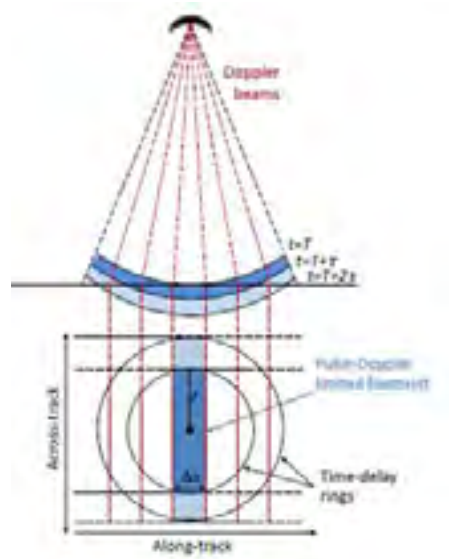
Pulse-limited





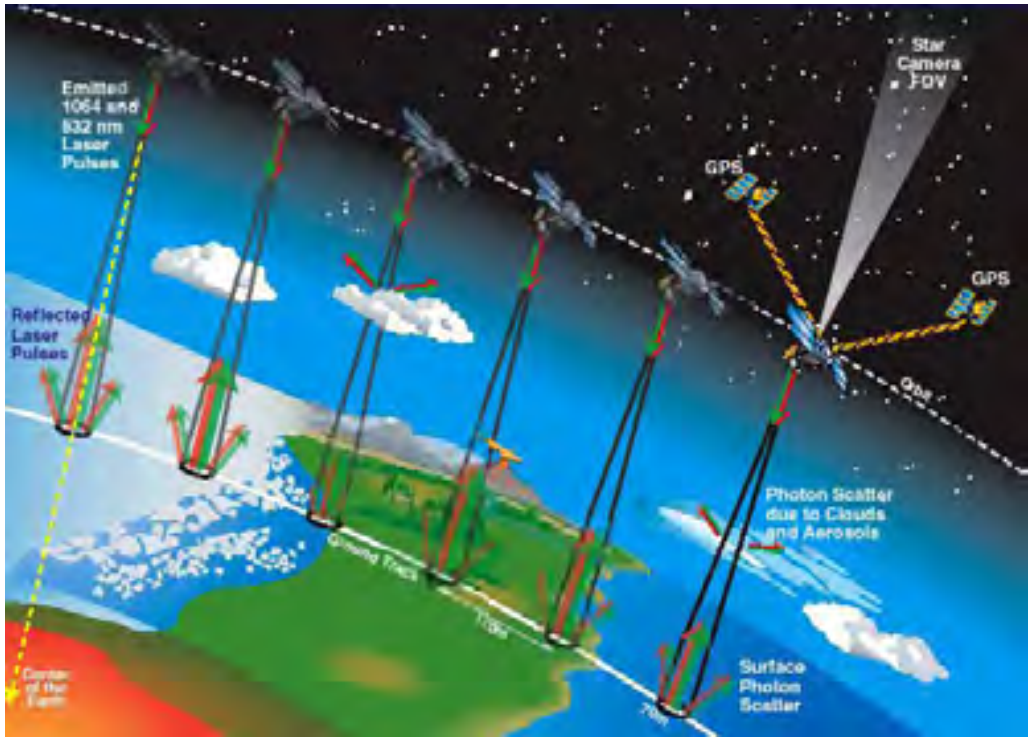
Doppler beam-limited





(CryoSat-2 handbook, 2013)

Laser altimeter



(http://icesat.gsfc.nasa.gov/icesat/links.php)

How can we improve the water level determination?

$$h = f(H, R)$$

H: Satellite orbit height R: Range

- Precise orbit determination

- Increasing precision of range measurements
  - Use more precise range correction, e.g. media and geophysical corrections
  - waveform retracking correction

$$\Delta R_{\text{retracking}} = (G_{\text{r}} - G_0) \times \frac{c}{2}\tau$$

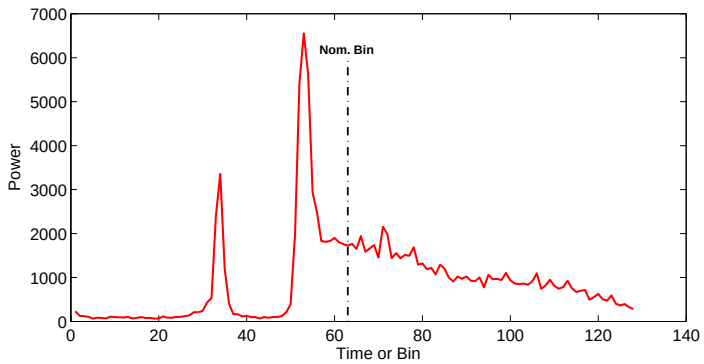
G_{r}: Retracked gate G_0: Nominal retracking gate
c: Light velocity τ: Pulse duration

  - Waveform saturation correction: $E_{\text{received}} > E_{threshold}$, E: Energy

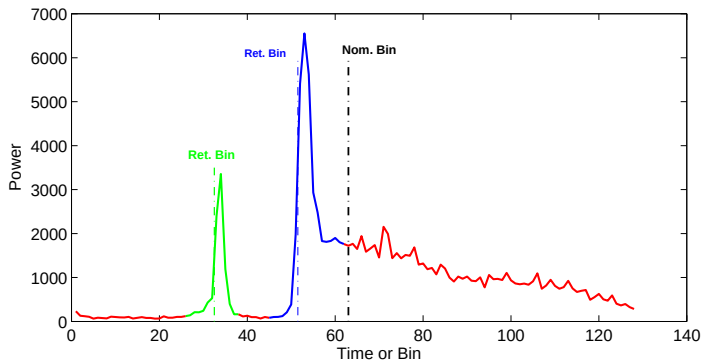
Waveform

The reflected signal from water surface back to the satellite, waveform, can be considered as:

- Full-waveform



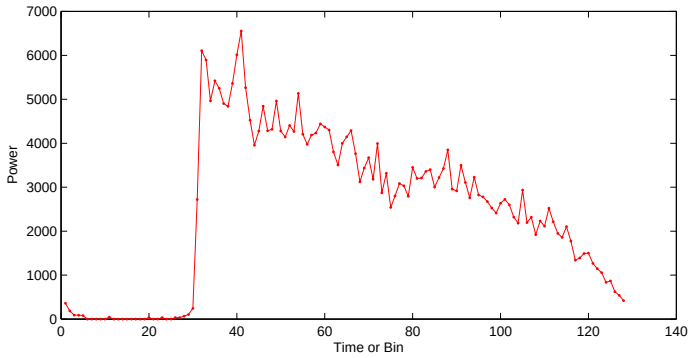
- Sub-waveform



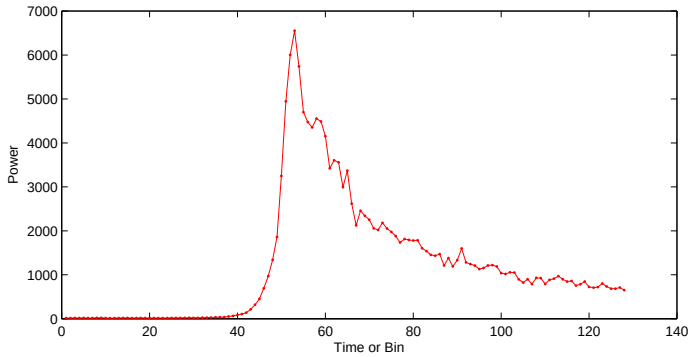
Pulse-limited (CS-2 LRM), Qinghai lake, August 2010

Waveform of different altimeters

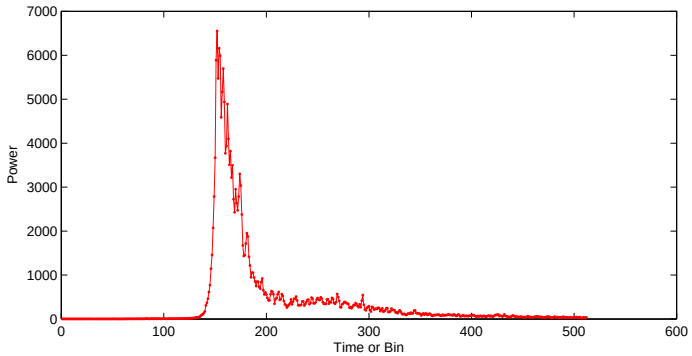
- Pulse-limited



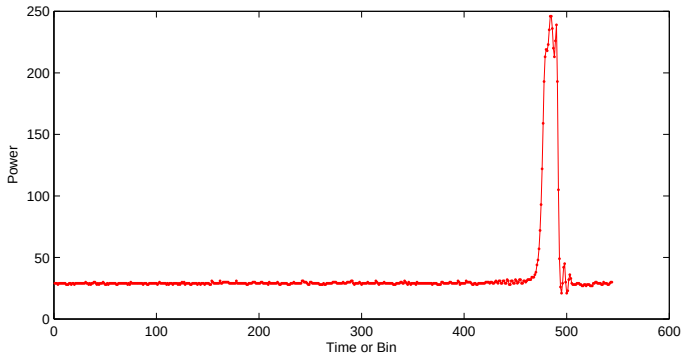
- Doppler beam-limited (SAR)



- Doppler beam-limited (SARIn)

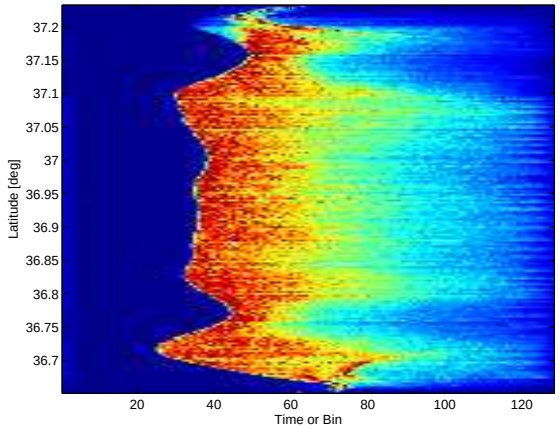


- Laser

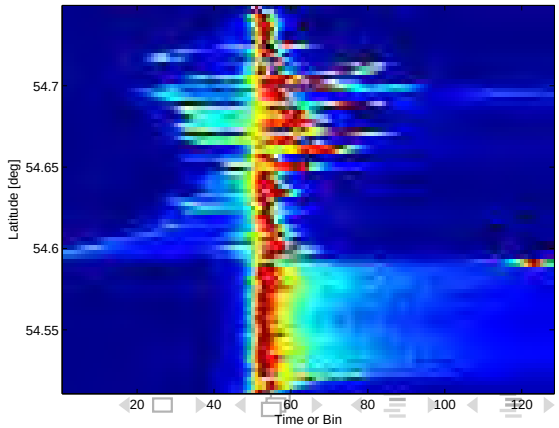


Along track waveform variations

Qinghai lake: Pulse-limited altimeter (CS-2 LRM), September 2012

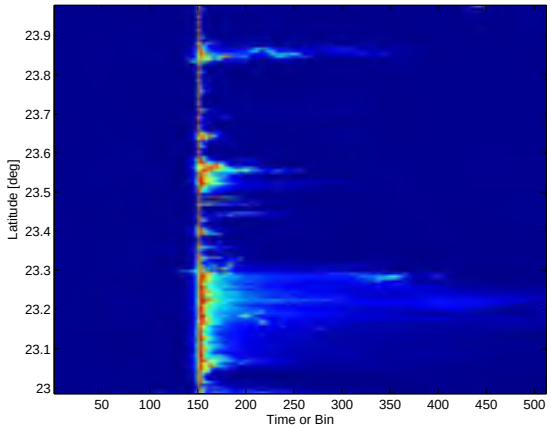


Lough Neagh lake: Doppler beam-limited (CS-2 SAR), April 2012



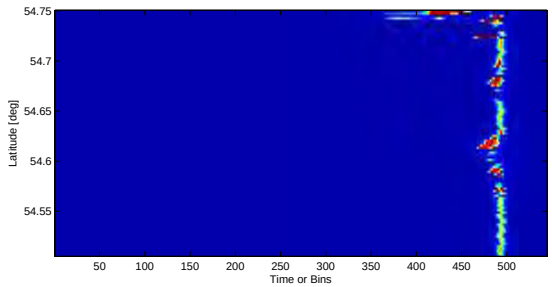
Along track waveform variations

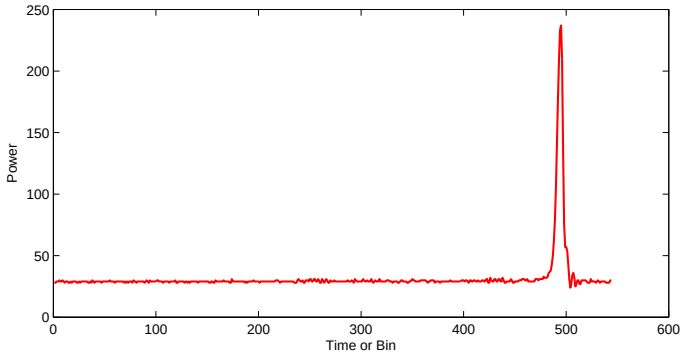
Nasser lake: Doppler beam-limited (CS-2 SARIn), August 2011



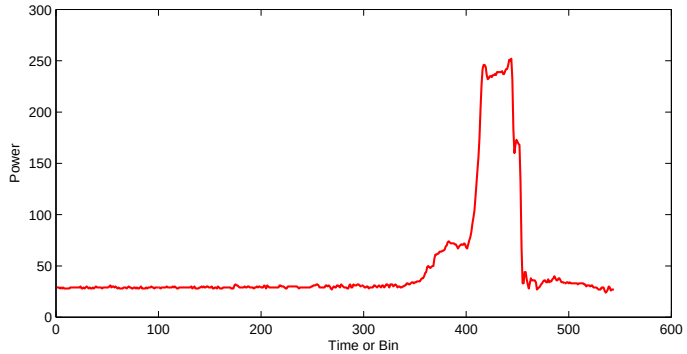
Along track waveform variations

Lough Neagh lake: Laser (IceSat), October 2004



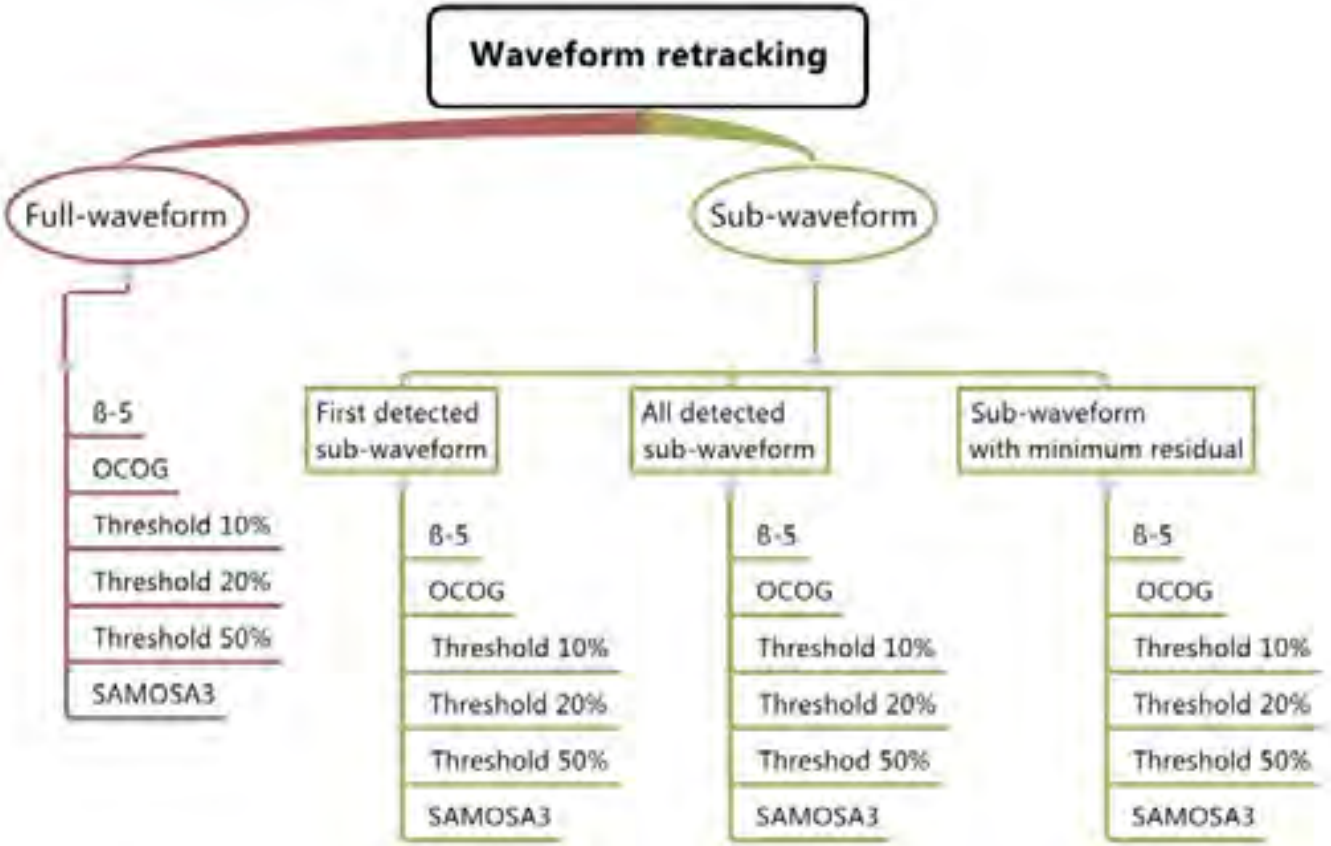


Unsaturated waveform



Saturated waveform

Waveform retracking scenarios



Retracked water level changes

- Defining water level time series for each pass of satellite over the lake and rejecting outliers using linear trend
- Combining all of the short water level time series from each satellite over pass to build a long time series
- Rejecting outliers from the long time series using following model:

$$h(t_i) = a + bt_i + ct_i^2 + d\sin\left(\frac{2\pi}{T}t_i\right) + e\cos\left(\frac{2\pi}{T}t_i\right)$$

a, b, c, d, e : Unknown parameters
T : Annual period
h : Observed water height

- Validation in front of available in-situ gauge data

Data and area of study

- Data:
  - Envisat: GDR, May 2002- Apr 2012
  - IceSat: Campaign L2 and L3 (GLA01 and GLA14), Oct 2003- Oct 2010
  - Jason-2: gdr-d, Jul 2008- Jun 2014
  - CS-2: L1b, L2I and L2 from Oct 2010- Jan 2014
- Area of study:

Lake	Surface area (km^2)	Depth (m)	Latitude	Longitude
Qinghai	4298	21	$38.9°$	$100.12°$
Lough Neagh	392	10	$54.6°$	$-6.4°$
Nasser	5250	25.2	$22.7°$	$32.5°$

  - Qinghai lake: Pulse-limited (CS-2 LRM), Envisat
  - Lough Neagh lake: Pulse-limited (Envisat), Doppler beam-limited (CS-2 SAR), Laser (IceSat)
  - Nasser: Doppler beam-limited (CS-2 SARIn), Pulse-limited (Jason-2)

Spatial and temporal resolutions

Repeat orbit of different missions

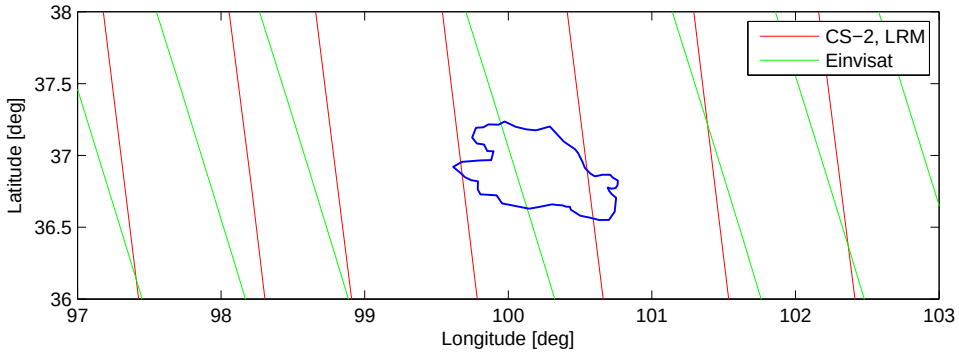
Mission	β^1	α^2 (day)	Sub-cycle (day)	Inclination
Envisat	501	35	16	98.60°
IceSat	1354	91	33	94°
Jason-2	127	10	3	66.00°
CS-2	5344	369	30, 85	92.00°

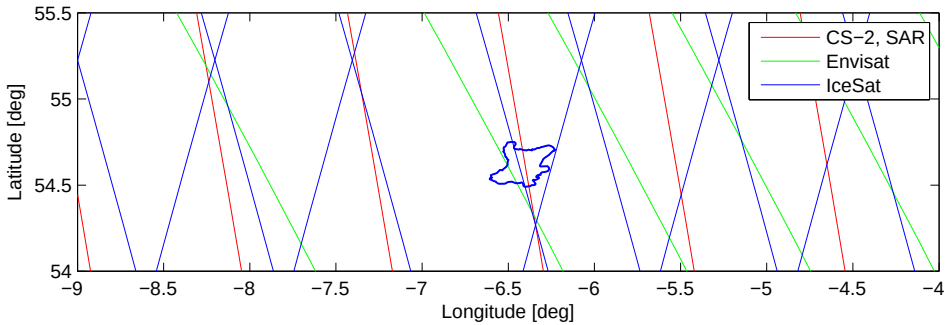
1: Number of revolution 2: Repeat cycle

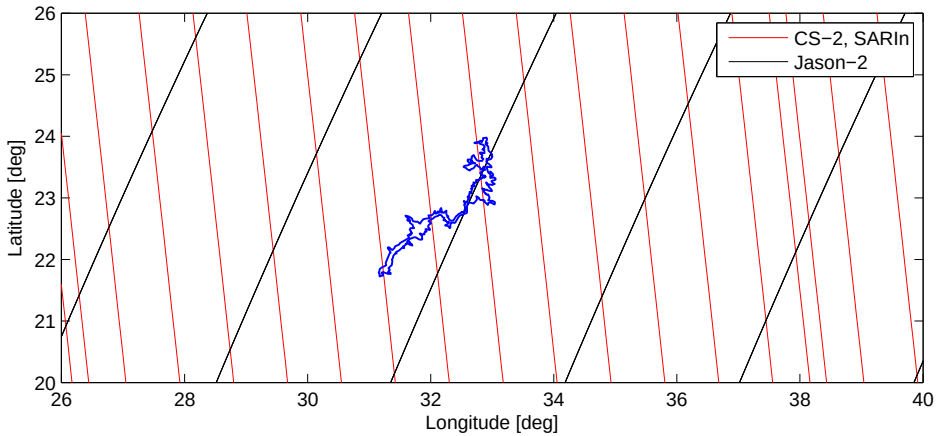
Ground track separation at the equator (km)

Mission	10 days	Sub-cycle	Full repeat cycle
Envisat	280.0	174.0	80.0
IceSat	269.3	81.6	29.6
Jason-2	315.5	1051.8	315.5
CS-2	277.0	92.2, 32.5	7.5

Ground track after 30 days revolution



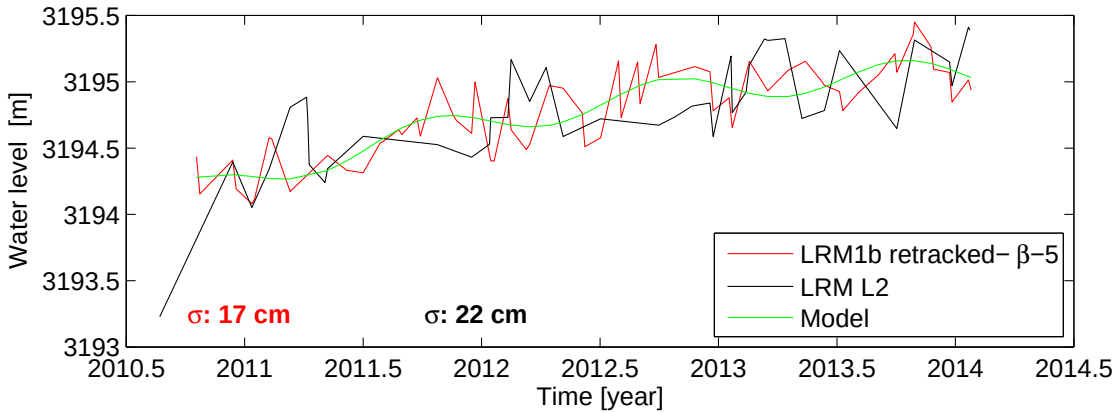




Water level from pulse-limited altimeter

Table: Standard deviation (cm) of water level from different retrackers

retracker	full-waveform	sub-waveform		
		first	mean-all	min-residual
Envisat ice-1	**17–21**[1]	–	–	–
CS-2 ESA	22	–	–	–
CS-2 β-5	**17**	169	150	164
CS-2 OCOG	132	169	150	153
CS-2 Threshold 10%	100	163	157	163
CS-2 Threshold 20%	101	173	157	163
CS-2 Threshold 50%	101	169	157	160

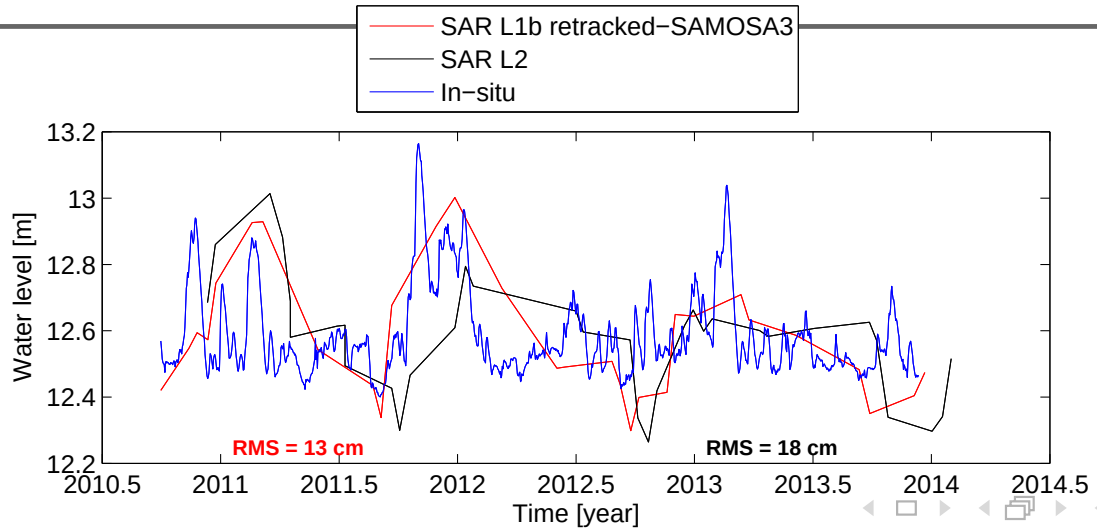


1- Roohi et al., Capability of pulse-limited satellite radar altimetry to monitor inland water bodies, EGU 2014

Water level from doppler beam-limited altimeter SAR

Table: RMS (cm) of water level from different retrackers

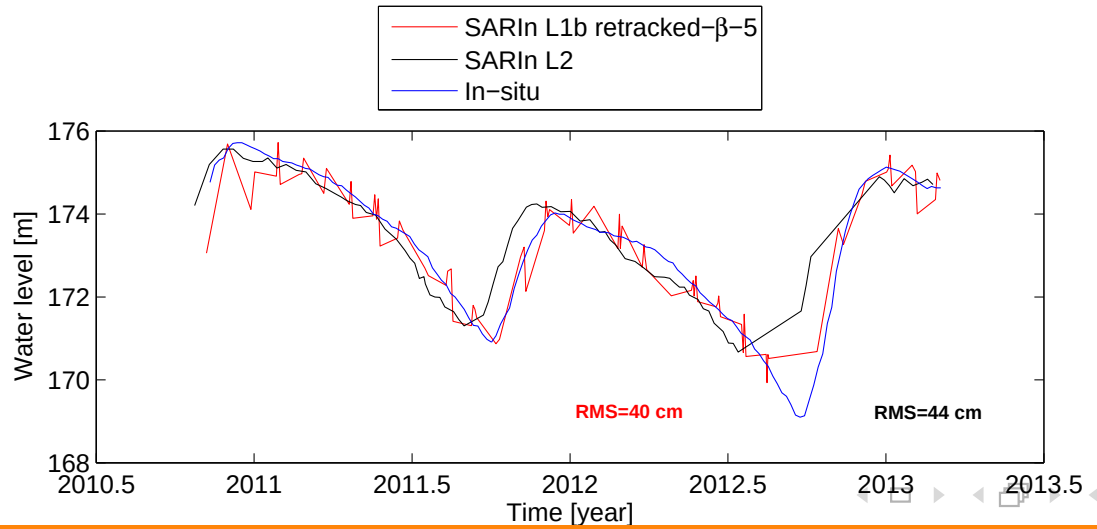
retracker	full-waveform	sub-waveform		
		first	mean-all	min-residual
Envisat ice-1	32	–	–	–
CS-2 ESA	18	–	–	–
CS-2 β-5	19	48	74	77
CS-2 OCOG	20	48	38	88
CS-2 Threshold 10%	19	21	**11**	22
CS-2 Threshold 20%	62	32	12	26
CS-2 Threshold 50%	22	47	17	24
CS-2 SAMOSA3	**15.5**	**13**	–	–



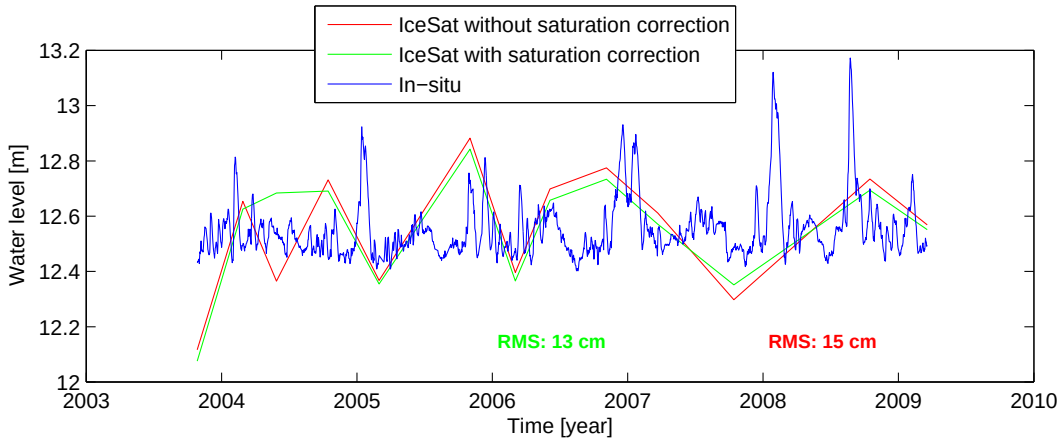
Water level from doppler beam-limited altimeter SARIn

Table: RMS (cm) of water level from different retrackers

retracker	full-waveform	sub-waveform		
		first	mean-all	min-residual
Jason-2 ice	54	–	–	–
CS-2 ESA	44	–	–	–
CS-2 β-5	97	**40**	92	64
CS-2 OCOG	89	96	104	94
CS-2 Threshold 10%	87	65	93	53
CS-2 Threshold 20%	71	79	92	72
CS-2 Threshold 50%	51	102	92	94



Water level from laser altimeter



Conclusion and discussion

- Obviously waveform retracking techniques can improve the quality of altimetry data especially over the shallow water bodies.
- Waveform saturation correction can improve the quality of water level measurement.
- The quality of water level depends on the waveform retracking techniques and type of altimeters.
- For Qinghai lake the full-waveform outperforms the sub-waveform and Envisat shows better performance than CS-2 (LRM).
- For Neagh lake SAMOSA3 and threshold 10% with the accuracy of 10–15 cm are the best retrackers for doppler beam-limited altimeter, CS-2 SAR.
- Laser altimeter (IceSat) provides an RMS of 13 cm for water level in the case of using waveform saturation correction.
- Doppler beam-limited altimeter (CS-2 SAR) has better performance than laser altimeter and laser altimeter has better performance than pulse-limited altimeter (Envisat) over Neagh lake.

Conclusion and discussion

- For Nasser lake the first detected sub-waveform retracked by β-5 is the best reacking scenario for doppler beam-limited altimeter.
- Doppler beam-limited altimeter (CS-2 SARIn) has better performance than pulse-limited altimeter (Jason-2) over this lake.

Many thanks for your attention