OSTST meeting
November 10-12th, 2008
Nice, France

Analysis and Retracking Altimeter Coastal Waveform in China and Neighbouring Seas

Le Yang[1,2*], Mingsen Lin[3], Delu Pan[1]

[1] SOED Lab,Second Institute of Oceanography (SIO), Hangzhou, China
[2] Science Department, Nanjing University of Science and Technology, Nanjing, China
[3] National Satellite Ocean Application Service (NSOAS), Beijing, China

(*yle1024@gmail.com)
November 11, 2008

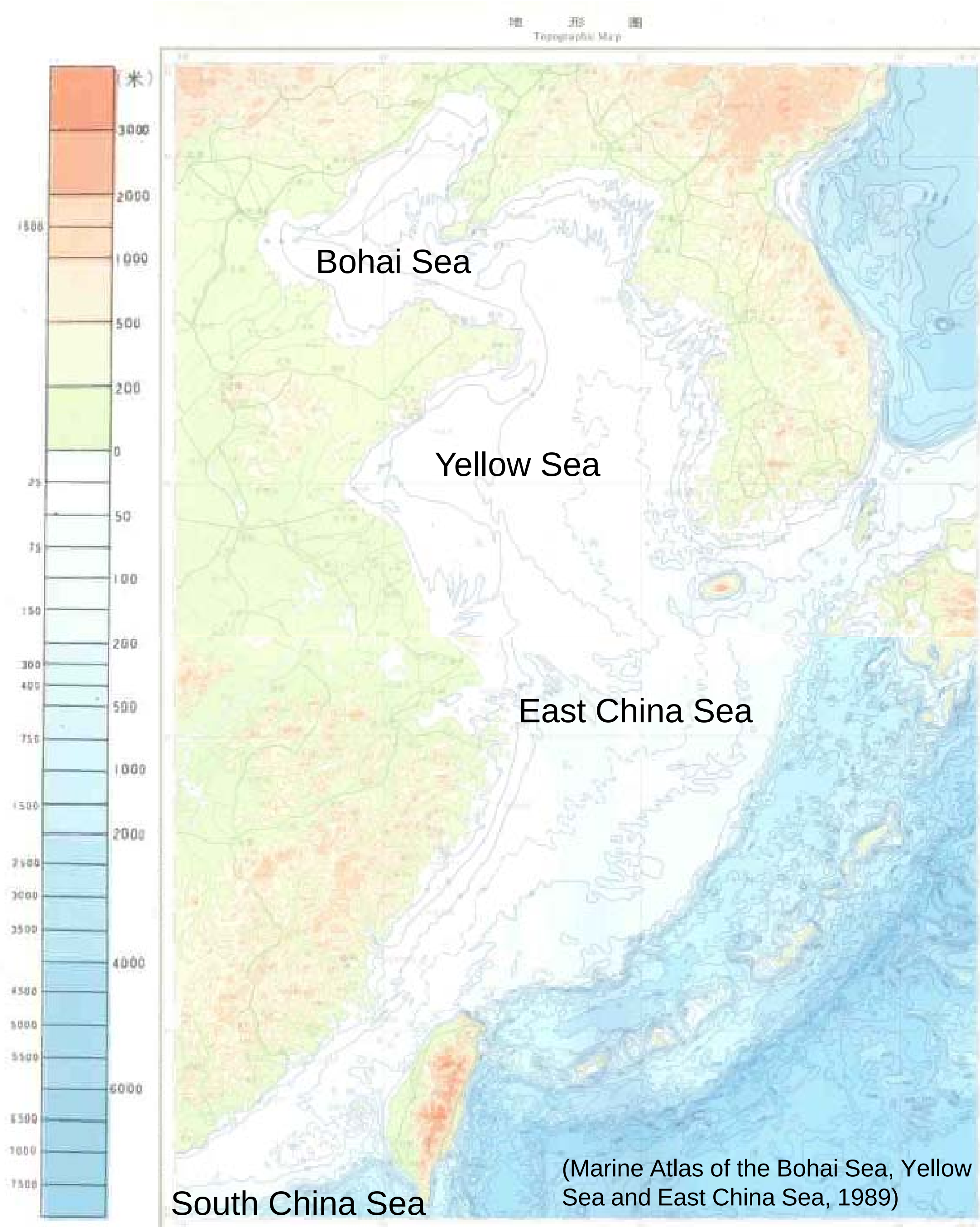
Content

1. Introduction
2. Altimetry Coastal Waveform analysis
3. Retracking algorithms
4. Results
5. Work under way

1. Introduction:

Studying region: China and neighbouring seas (105° E-130° E, 14° N-45° N)

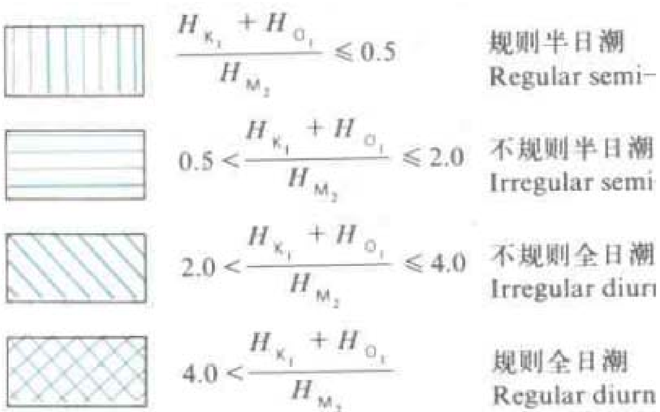
(1) bathymetry;
(2) tide;
(3) coastline.

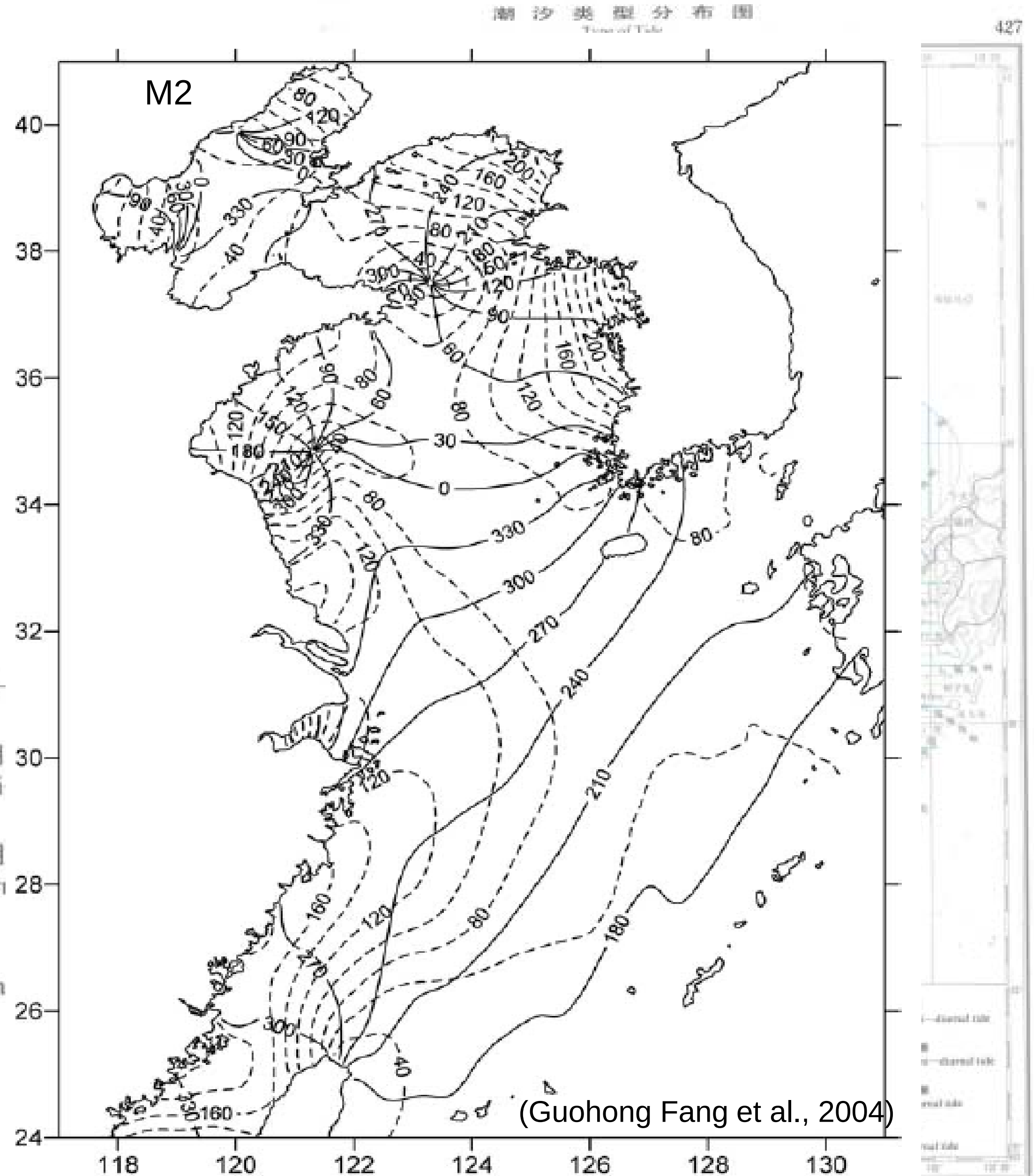


(Marine Atlas of the Bohai Sea, Yellow Sea and East China Sea, 1989)

1. Introduction:
China seas

(2) tide:
- Semi-diurnal tides & Diurnal tides
- Highly variable tides



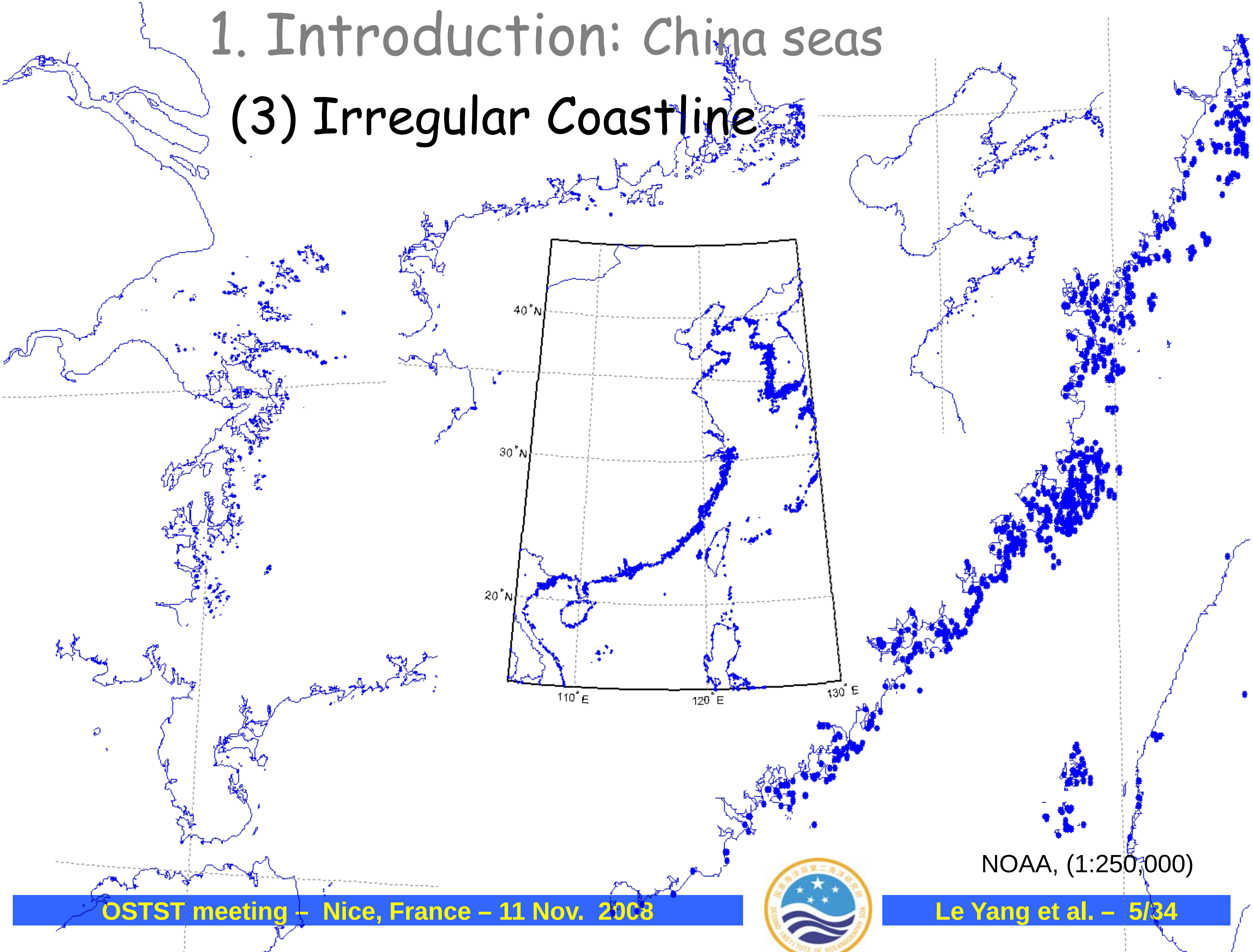


(Guohong Fang et al., 2004)

(Marine Atlas of the Bohai Sea, Yellow Sea and East China Sea, 1989)

1. Introduction: China seas

(3) Irregular Coastline



NOAA, (1:250,000)

1. Introduction :

Why coastal altimetry data are flagged?

- The reasons include not only the altimeter measurement itself, but also some geophysical corrections. The proximity of the land also makes it impossible to calculate the wet tropospheric correction, ocean tide correction and atmospheric high-frequency forcing correction accurately, as ones would for the open ocean.

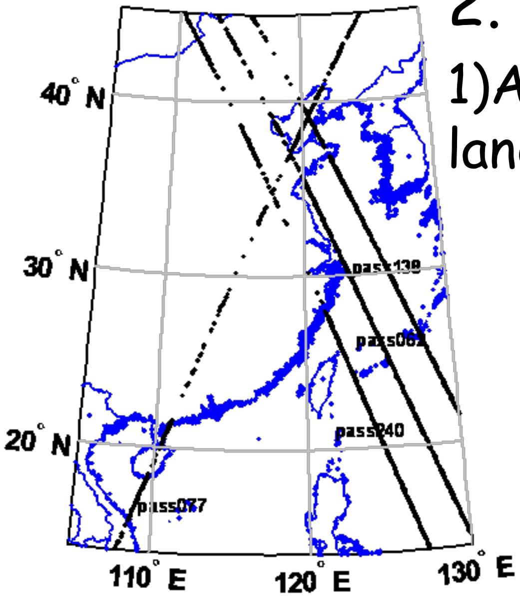
Outline

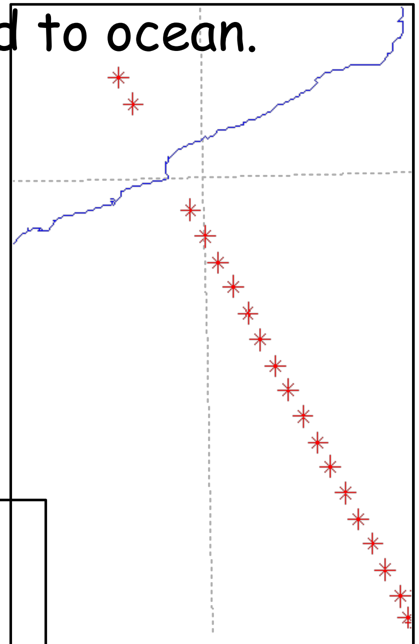
1. Introduction
2. Altimetry Coastal Waveform analysis
3. Retracking algorithms
4. Results validation
5. Work under way

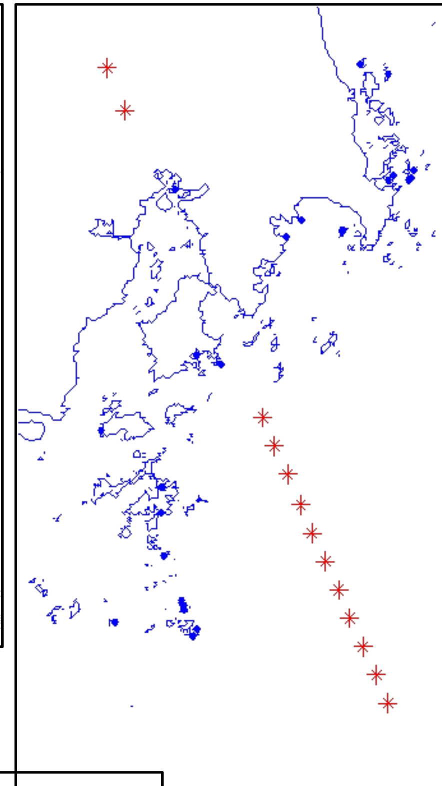
- Altimeter Data: Jason1 SGDR cycle155 to cycle188 (March 2006 to February 2007) over Chinese and neighbouring seas (105° E-130° E, 14° N-45° N).

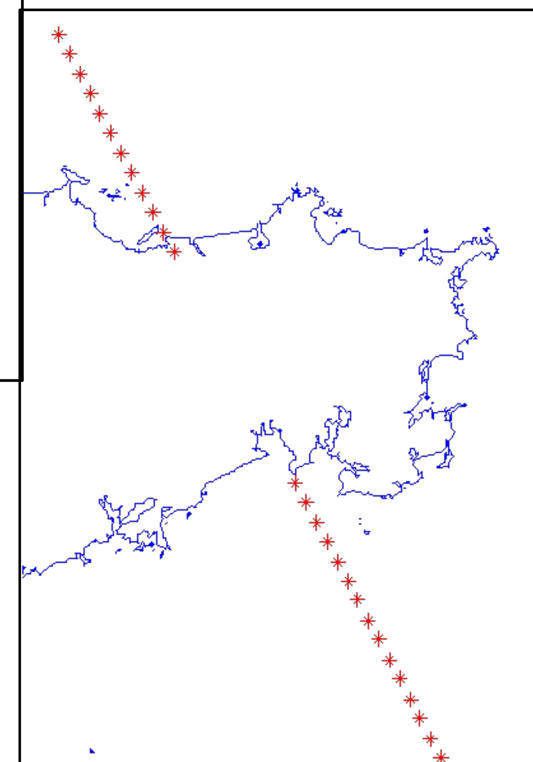
2. Altimetry Coastal Waveform analysis

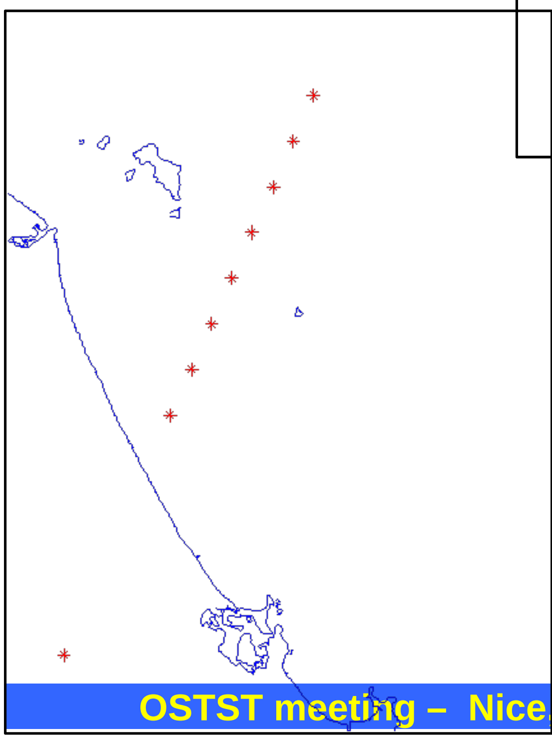
1)Altimeter Jason1 Loss track sometimes, especially from land to ocean.

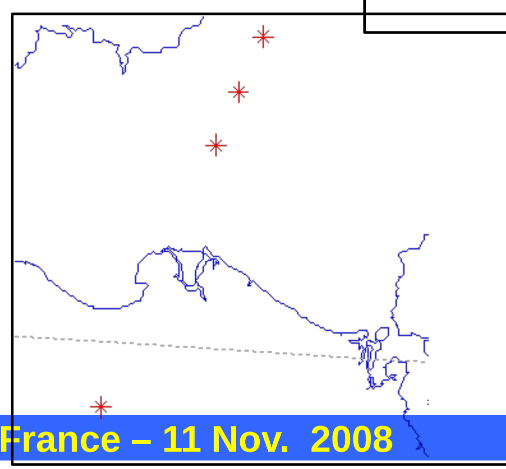




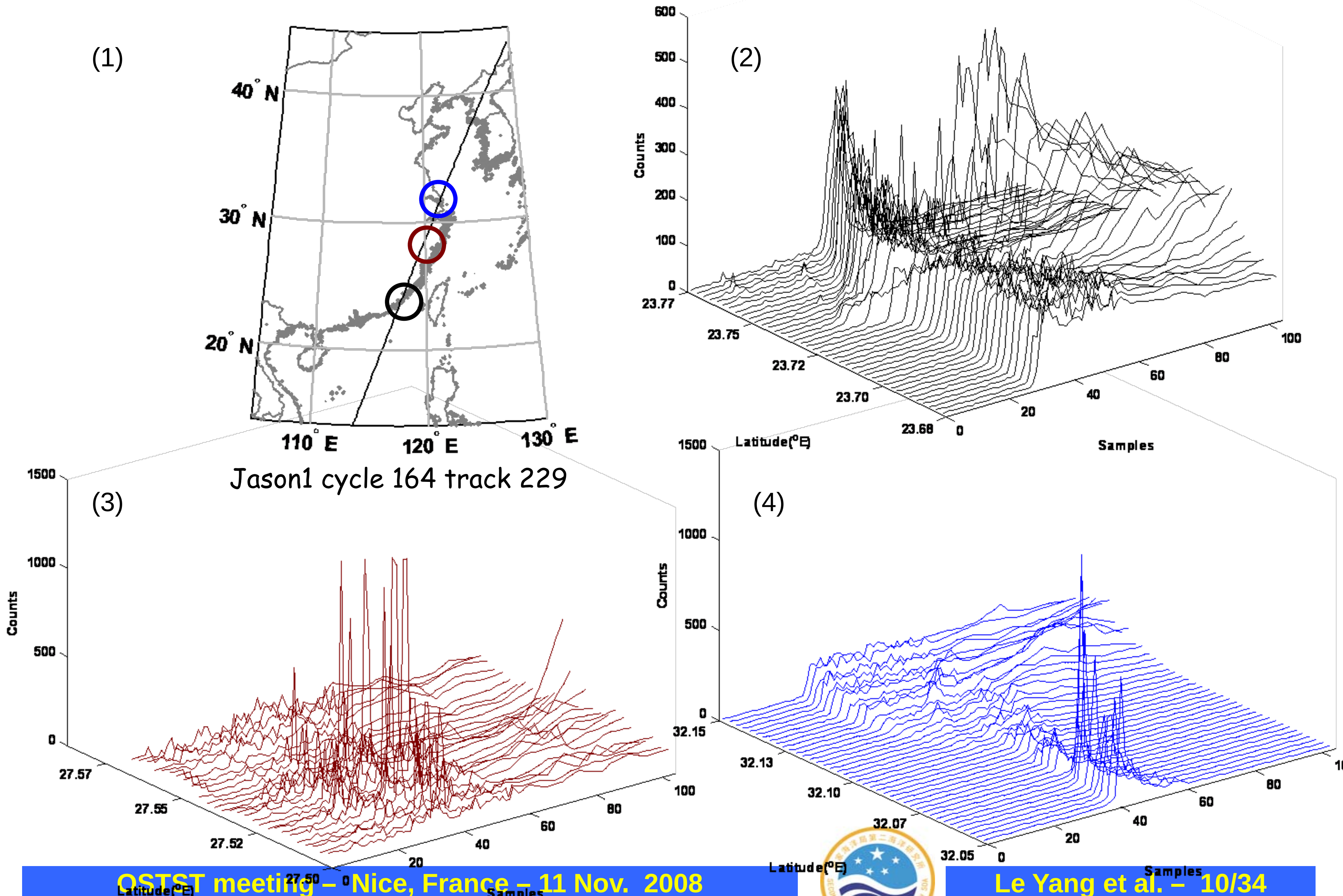


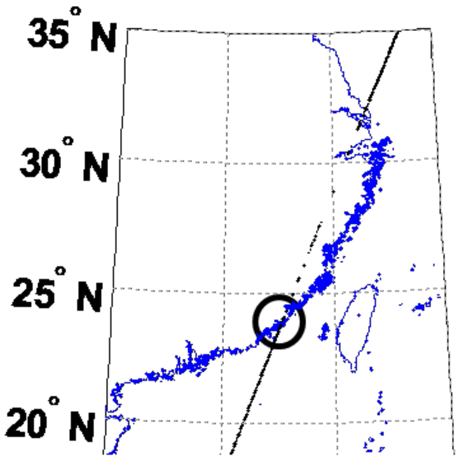


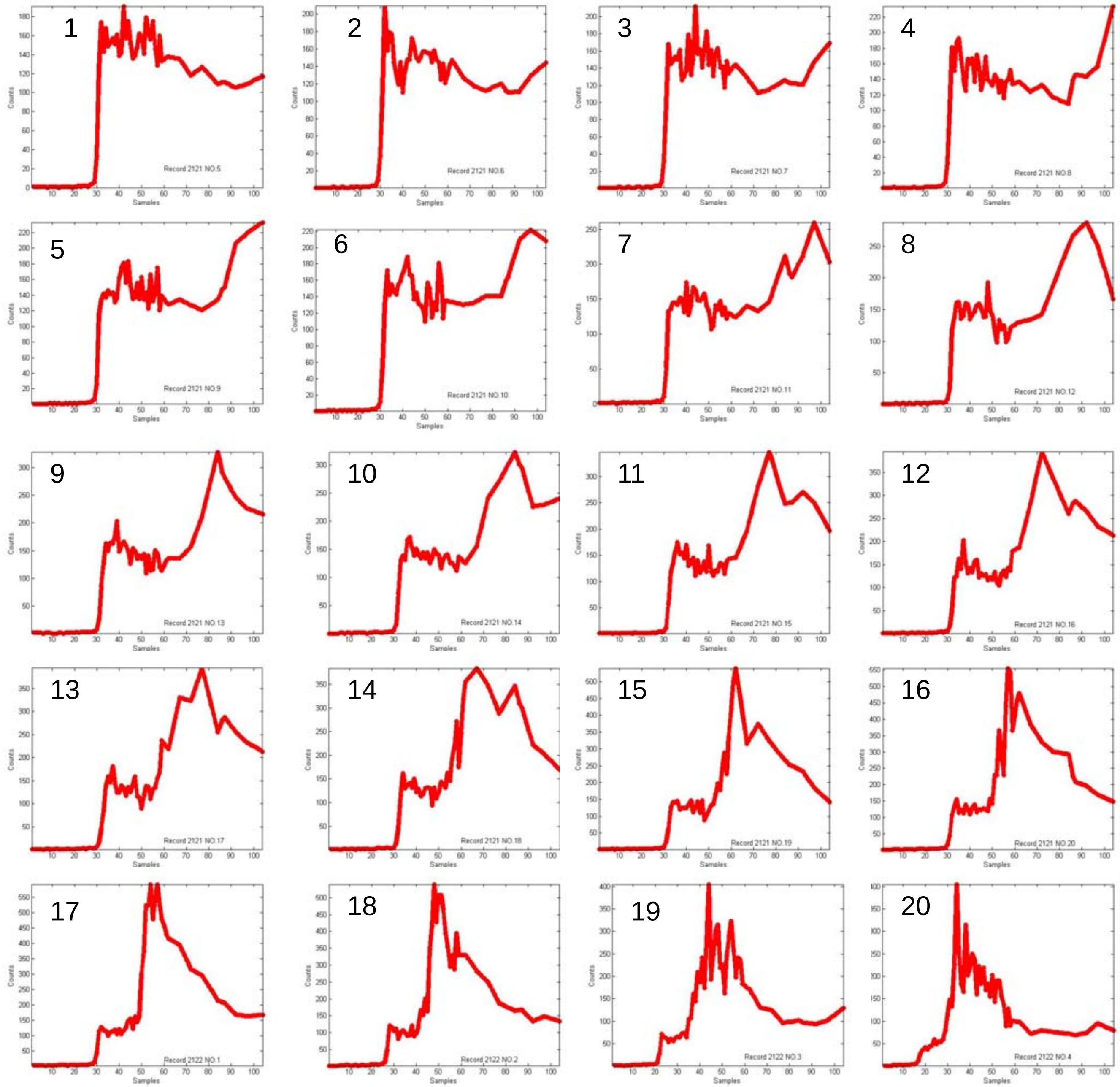




2. Altimetry Coastal Waveform analysis







Jason-1 Cycle164Pass229

Record2121No.5-Record2122No.4

Waveform Interval:

0.05s,350m

===============

Radiometer Flag on: 94.4km

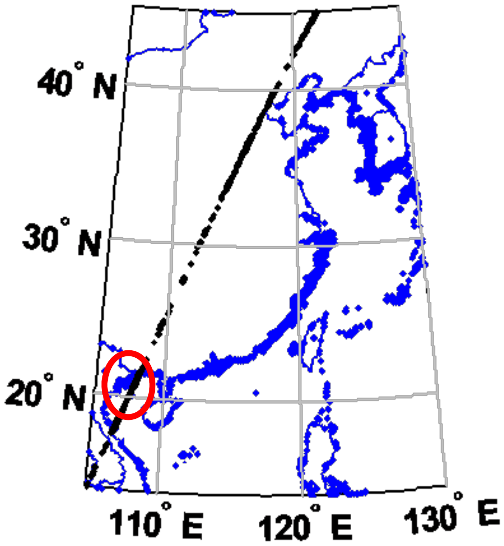
Altimeter Flag on: 11.8km

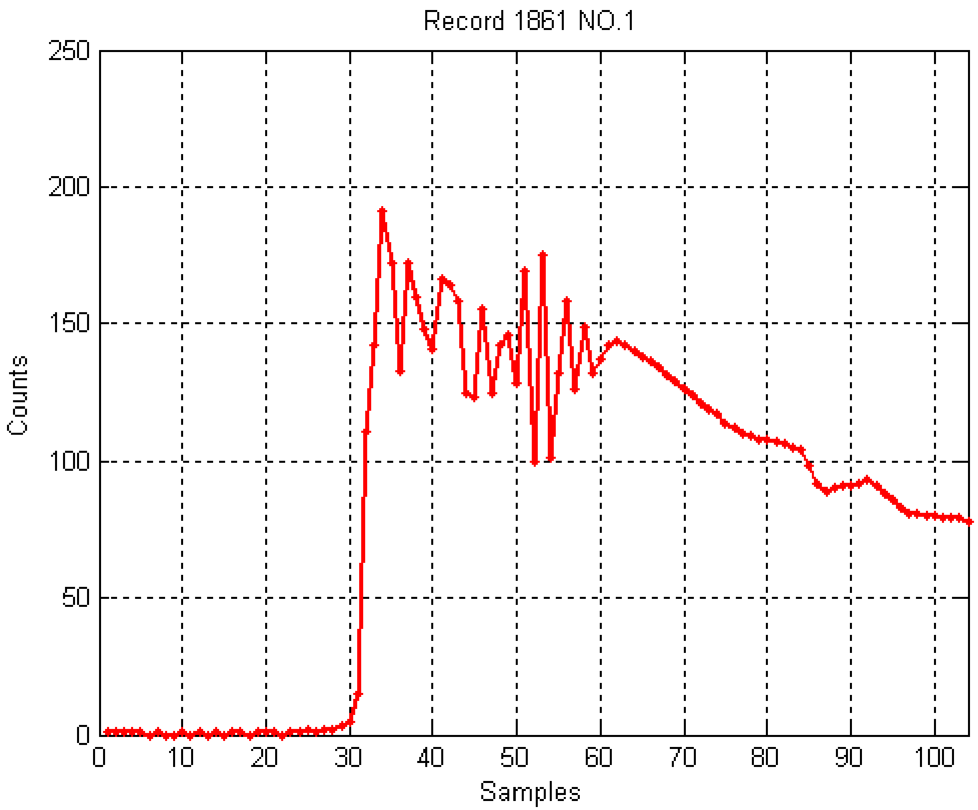
1：10.63km，

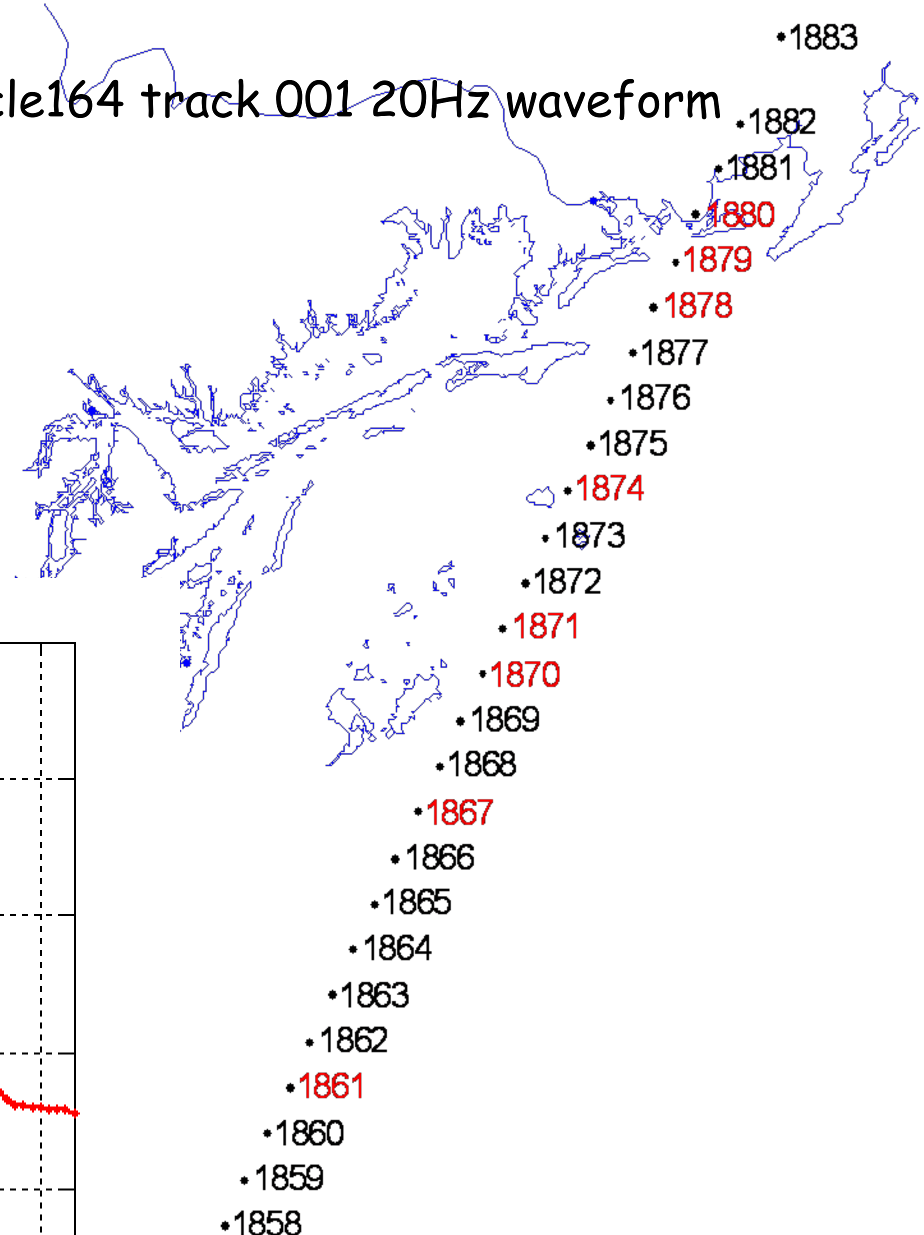
17：5.90km，

20：5.03km，

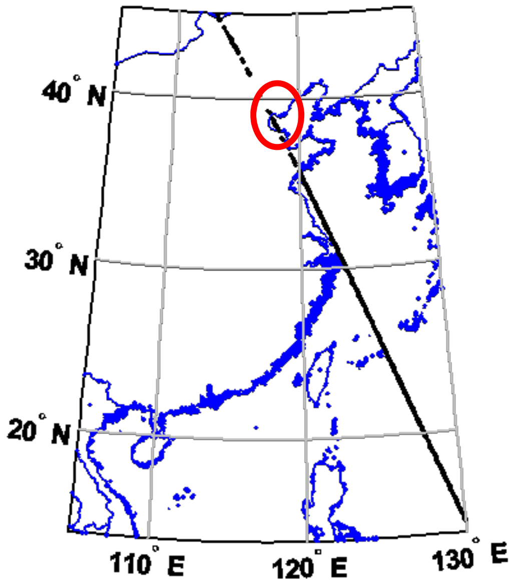
Jason1 cycle164 track 001 20Hz waveform

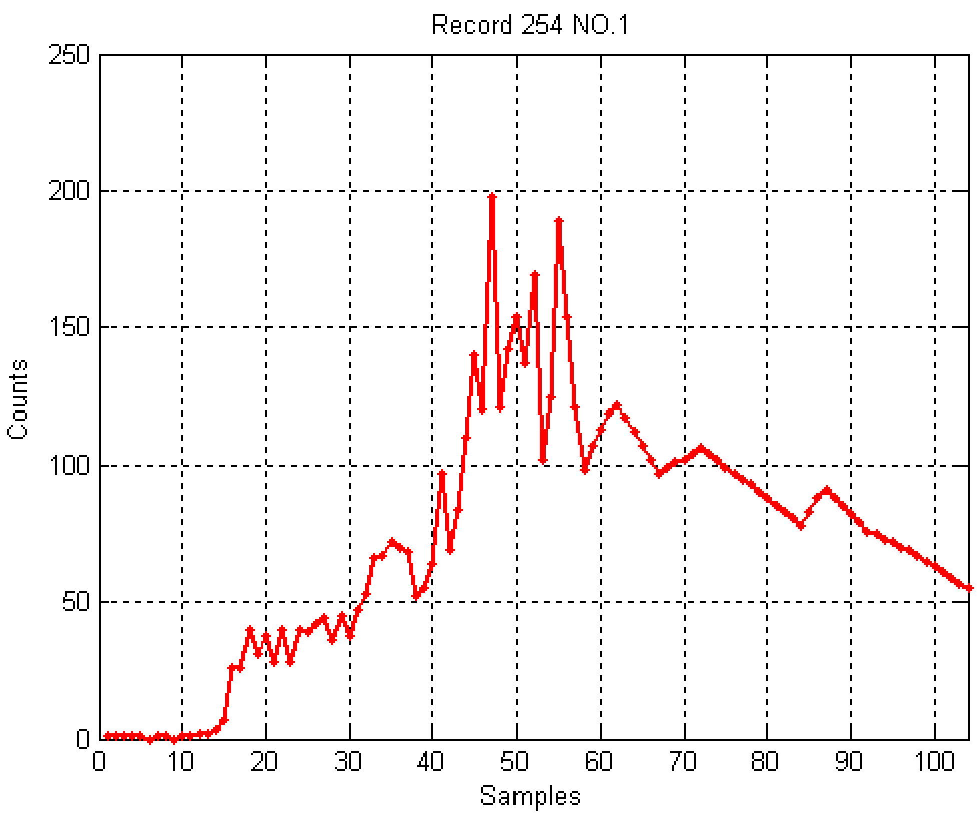


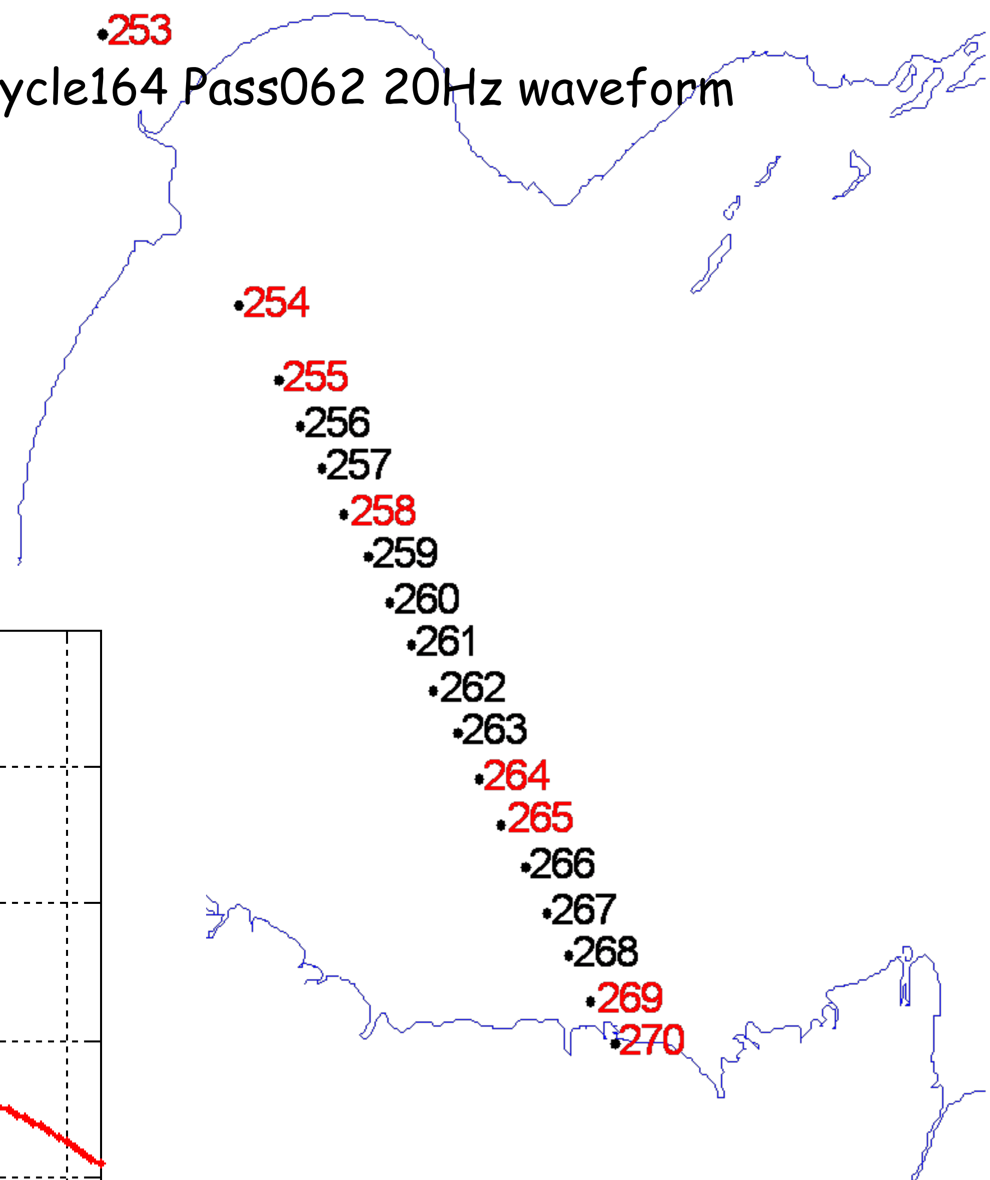




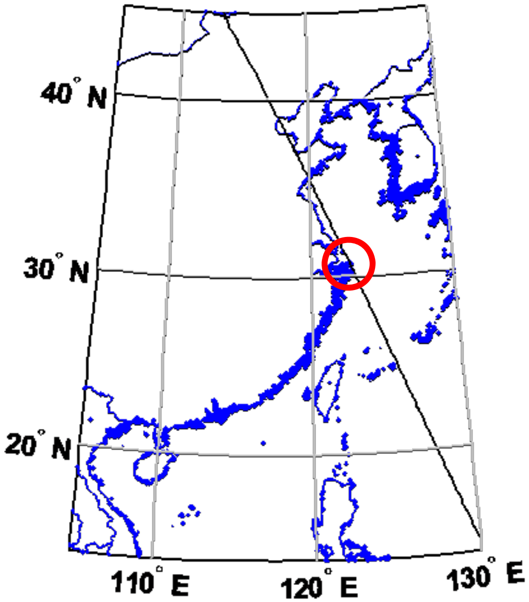
Jason1 Cycle164 Pass062 20Hz waveform

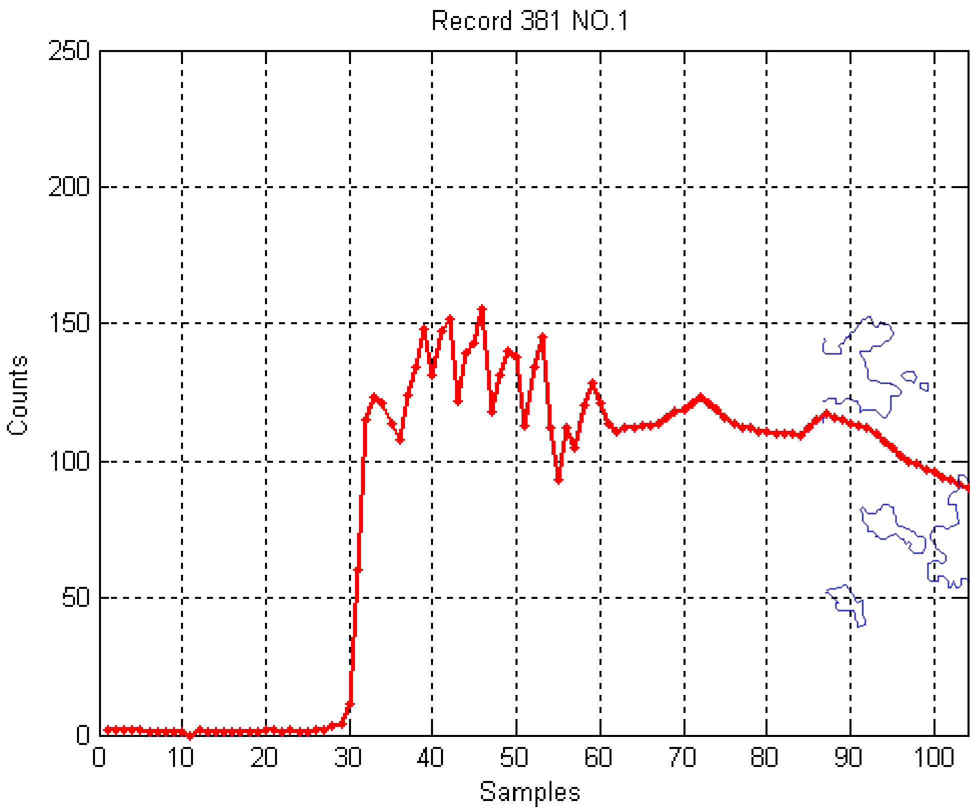


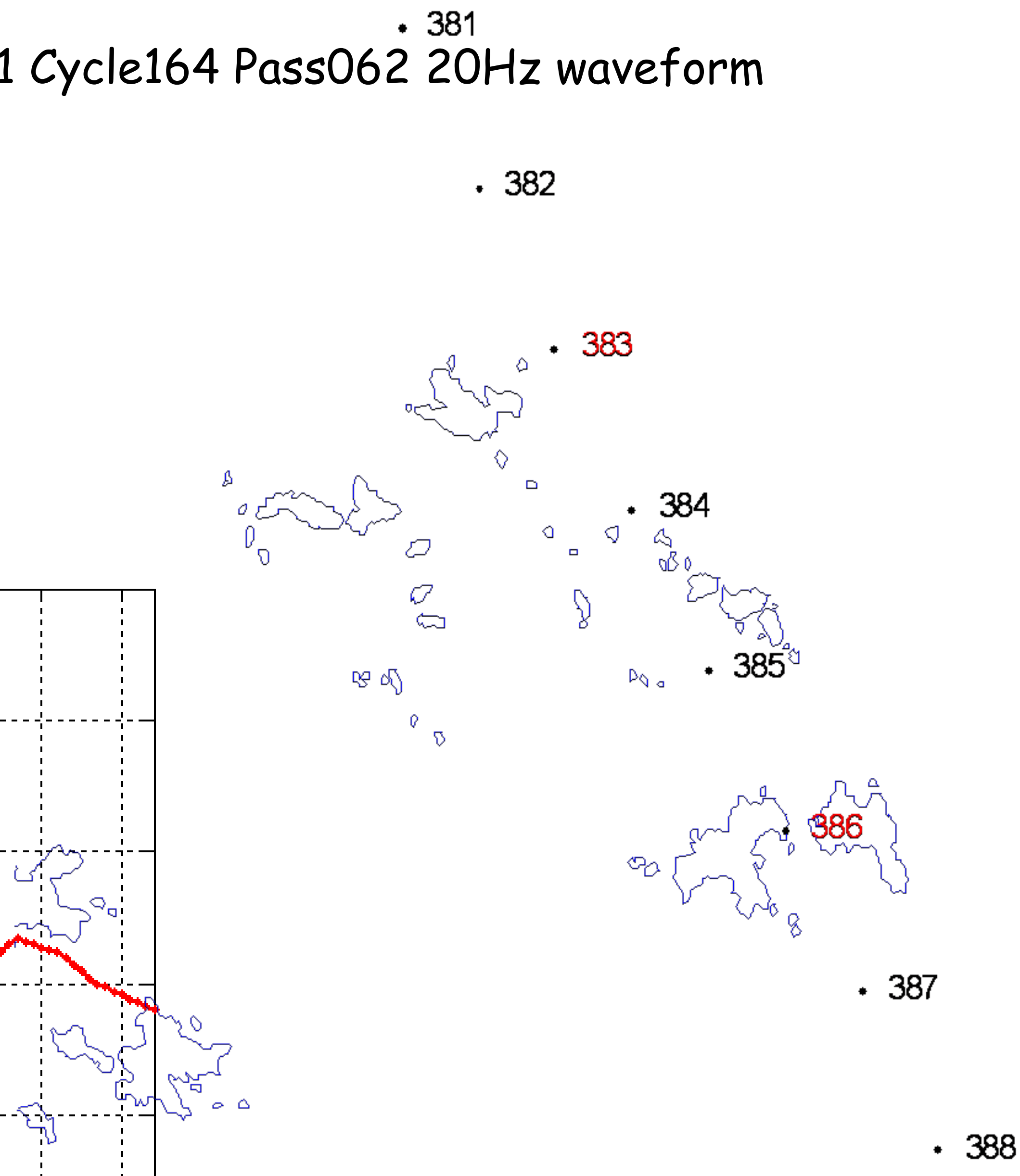




Jason1 Cycle164 Pass062 20Hz waveform







2. Altimetry Coastal Waveform analysis

Summary

- Loss data sometimes, especially from land to ocean (5~10km).
- Strong land returns contaminate the altimetry waveforms (~10km): Ocean to land & land to Ocean.
- Irregular coastlines result in discontinued flagged altimeter records.
- Many flagged 20Hz waveform data can be used by employing waveform retracking algorithms.

3. Retracking algorithms

3.1 standard waveform processing algorithm: Ocean fitting algorithm

3.2 waveform retracking algorithms:

- **3.2.1 Ice-1/OCOG**
- **3.2.2 Ice-2**
- **3.2.3 Sea Ice/Threshold**
- **3.2.4 Beta5/9**

3.1 Ocean fitting algorithm

(Brown,1977) convolution expression of the surface return power:

$$W(t) = P_{FS}(t) * q_s(t) * p_r(t)$$

(Hayne,1980) Anylitcal expression of the return waveform: （ Ingoring the non-guassian distribution of sea surface,ie $\lambda_s = 0$ ）

$$W(t) = A\exp(-v)[1 + erf(u)]$$

其中 $v = a((t - t_0) - \frac{a}{2}\sigma_c^2), u = \frac{(t - t_0) - a\sigma_c^2}{\sqrt{2}\sigma_c}, a = \alpha - \frac{\beta^2}{4}$

$$\alpha = \frac{\ln 4}{\sin^2(\theta/2)} \frac{c}{h} \frac{1}{(1 + h/R)} \cos(2\xi)$$

$$\beta = \frac{\ln 4}{\sin^2(\theta/2)} [\frac{c}{h} \frac{1}{(1 + h/R)}]^{1/2} \sin(2\xi) \quad A = Au * \exp(\frac{-4\sin^2(\xi)}{\gamma})$$

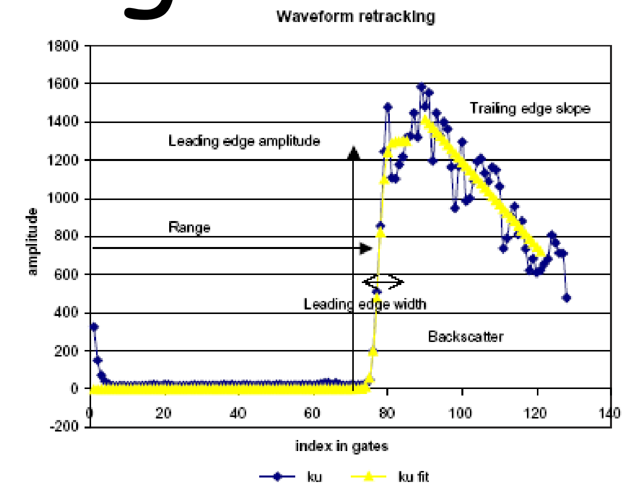
h-Satellite altitude (m)

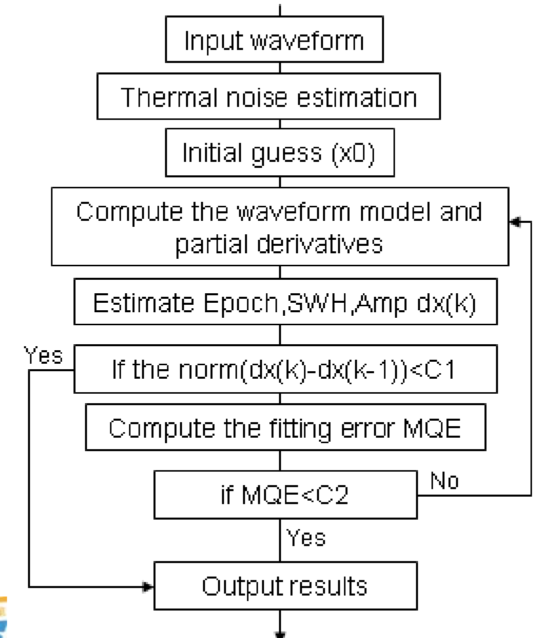
R-Radius of the Earth (m)

θ-Antenna beamwidth at 3 dB

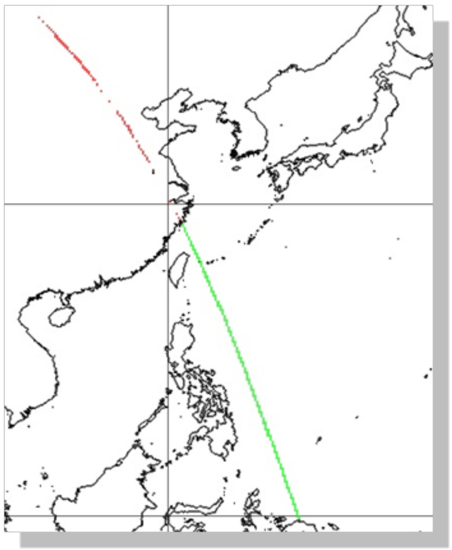
ξ-off nadir angle

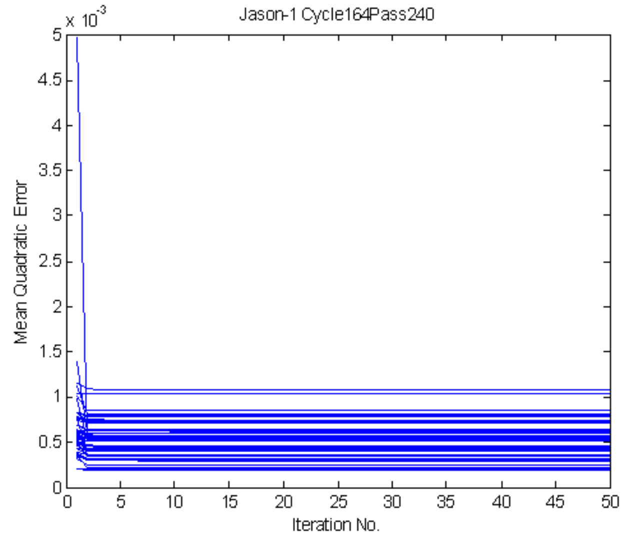
σ_c-$\frac{SWH}{2*c}(s)$, SWH-Significant waveheight (m)

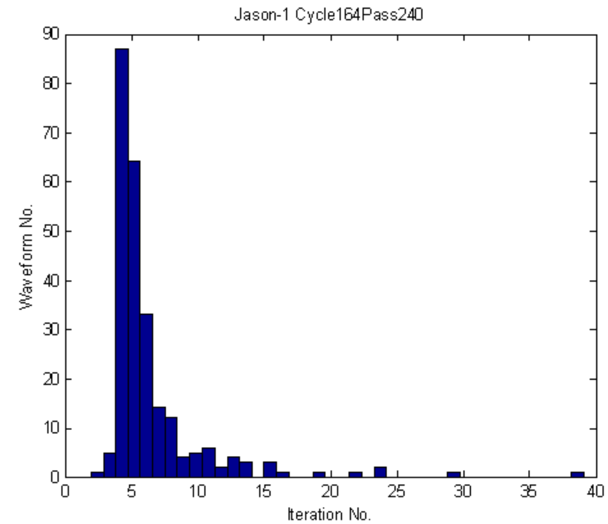


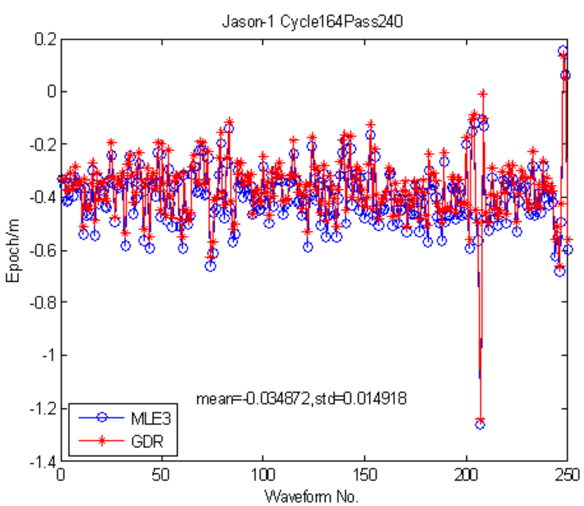


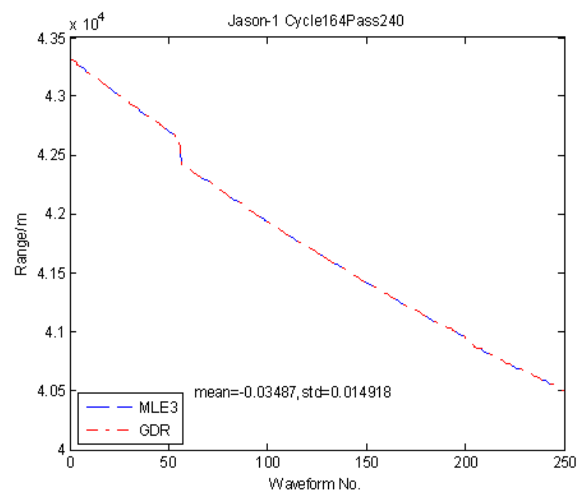
Cycle164Pass240(2006-06-28 19:06-20:02) 1Hz Ocean return waveforms results using least square fitting and Hayne 1980 model:

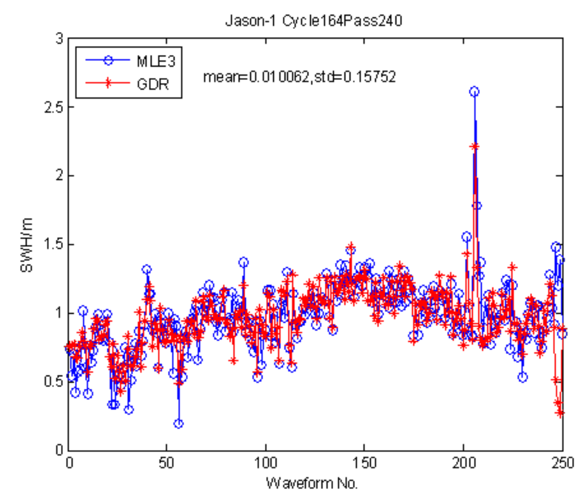












3.2 waveform retracking algorithm

- Altimeter waveform retracking consists in ground-processing altimeter waveforms to obtain better range estimates than those obtained with on-board tracking algorithms.
- The algorithm retrieves the point of the radar echo corresponding to the effective satellite to ground range.
- Many specific retrackers exist, most were initially developed for ice surface: OCOG (Wingham, 1986; Bamber,1994), Ice-2 (Legresy and Remy, 1997), Beta5/9 (Martin, 1983) , S/V (Davis, 1993), Threshold (Laxon, 1994).
- Those retracker are widely employed to retrieve ranges for other surfaces, such as Land, Inland lake and river, and Coastal water.
- OCOG, Ice-2, Beta5,Threshold algorithms are compared for china and neighbouring coastal seas.

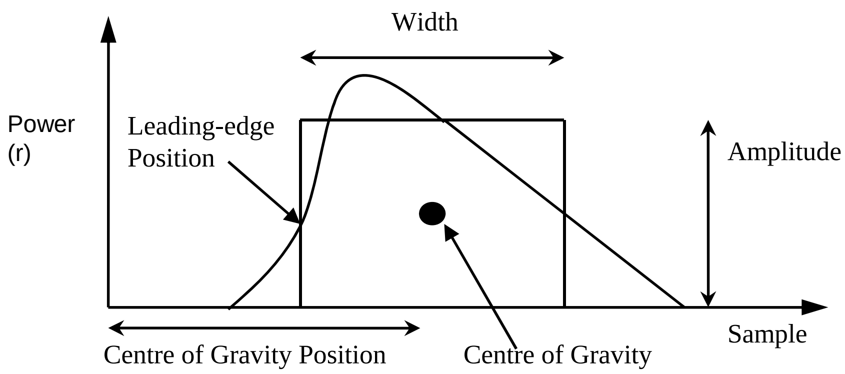
3.2 waveform retracking algorithms

3.2.1 OCOG algorithm

OCOG: Offset Center of Gravity algorithm

- calculate the centre of gravity and width of a rectangular box using all the samples in the waveform;

$$Amplitude = \sqrt{2 \times \sum_{i=1}^{i=60} \left(0.5 \times r^2(i) \times r^2(i)\right) \Big/ \sum_{i=1}^{i=60} r^2(i)}$$



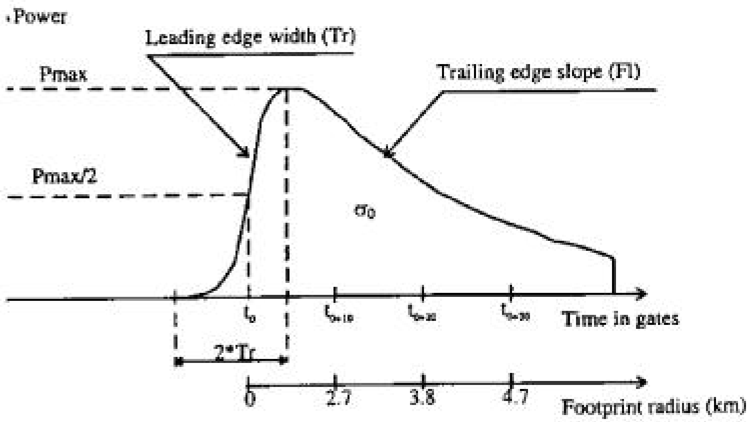
$$Width = \frac{\left(\sum_{i=1}^{i=60} r^2(i)\right)^2}{\sum_{i=1}^{i=60} r^4(i)}$$

$$C\ of\ G\ Position = \frac{\sum_{i=1}^{i=60} i \times r^2(i)}{\sum_{i=1}^{i=60} r^2(i)}$$

(Wingham, 1986; Bamber,1994)

3.2 waveform retracking algorithms

3.2.2 Ice-2 algorithm



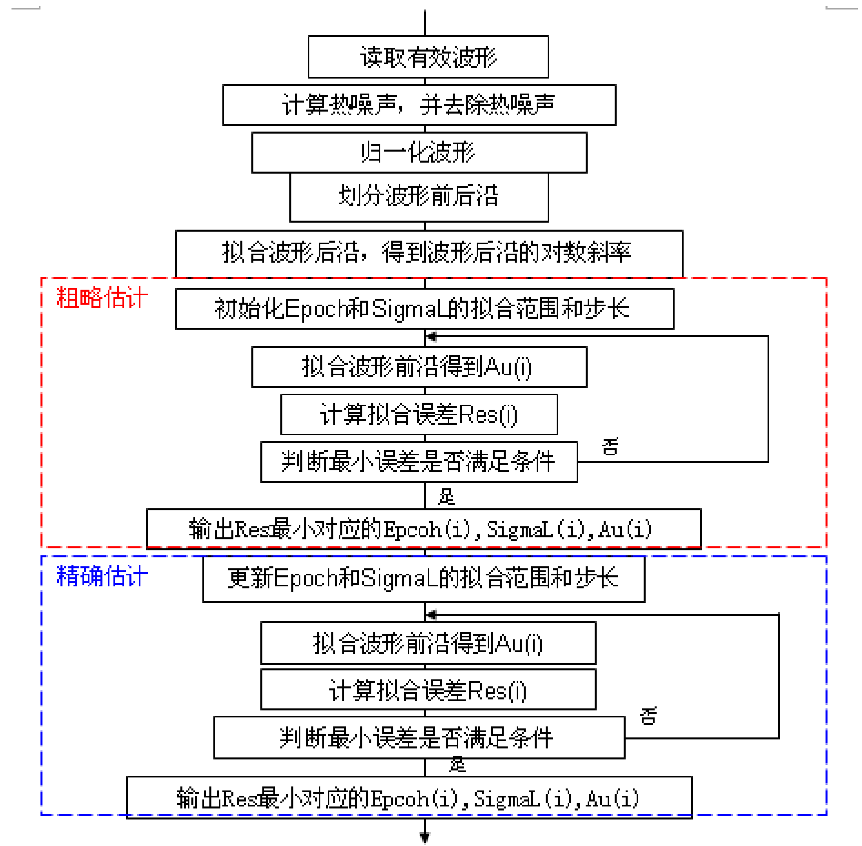
(Hayne,1980) Anylitcal expression of the return waveform:

$$W(t) = A\exp(-v)[1+erf(u)]$$

$$v = a((t-t_0)-\frac{a}{2}\sigma_c^2), u = \frac{(t-t_0)-a\sigma_c^2}{\sqrt{2}\sigma_c}, a = \alpha - \frac{\beta^2}{4}$$

$$\alpha = \frac{\ln 4}{\sin^2(\theta/2)}\frac{c}{h}\frac{1}{(1+h/R)}\cos(2\xi)$$

$$\beta = \frac{\ln 4}{\sin^2(\theta/2)}[\frac{c}{h}\frac{1}{(1+h/R)}]^{1/2}\sin(2\xi)$$

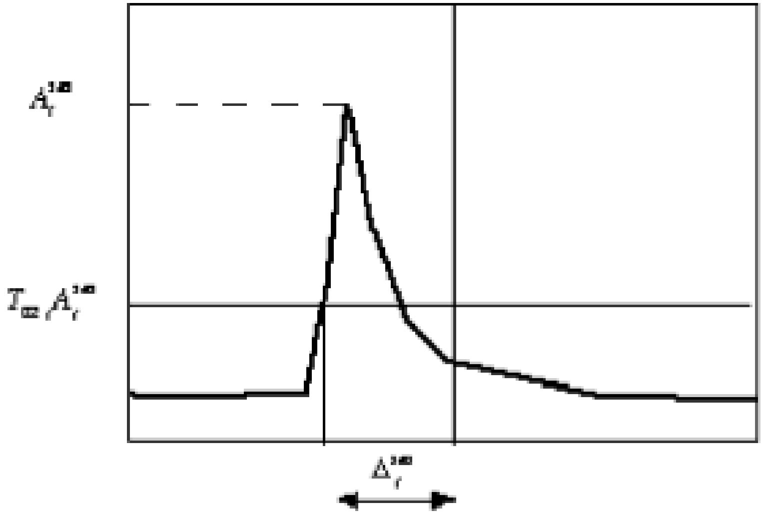


(Legresy and Remy, 1997)

3.2 waveform retracking algorithms

3.2.3 Threshold algorithm

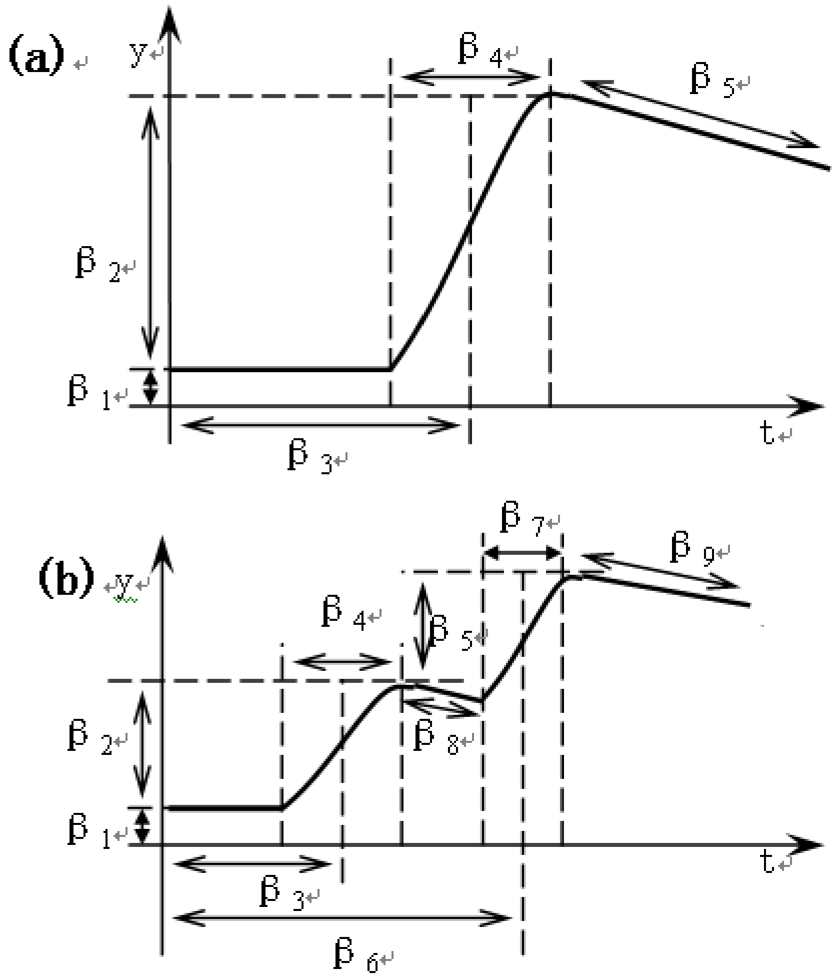
- The straightforward Threshold algorithm identifies the amplitude by finding the maximum value of the echo. The retracking point of the waveform is determined by linear interpolation where the radar echo is greater than a threshold of the waveform amplitude.



(Laxon, 1994)

3.2 waveform retracking algorithms

3.2.4 Beta5/9 algorithms



$$y = \beta_1 + \beta_2 \cdot \exp(-\beta_5 \cdot Q_1) \cdot P(\frac{t-\beta_3}{\beta_4})$$

$$y = \beta_1 + \beta_2 \cdot \exp(-\beta_5 \cdot Q_1) \cdot P(\frac{t-\beta_3}{\beta_4}) + \beta_5 \cdot \exp(-\beta_9 \cdot Q_2) \cdot P(\frac{t-\beta_6}{\beta_7})$$

$$Q_1 = \begin{cases} 0 & t < \beta_3 - 2\beta_4 \\ t-(\beta_3 - 2\beta_4) & t \geq \beta_3 - 2\beta_4 \end{cases}$$

$$Q_2 = \begin{cases} 0 & t < \beta_6 - 2\beta_7 \\ t-(\beta_6 - 2\beta_7) & t \geq \beta_6 - 2\beta_7 \end{cases}$$

$$P(z) = \int_{-\infty}^{z} \frac{1}{\sqrt{2\pi}} \exp(-\frac{q^2}{2}) dq$$

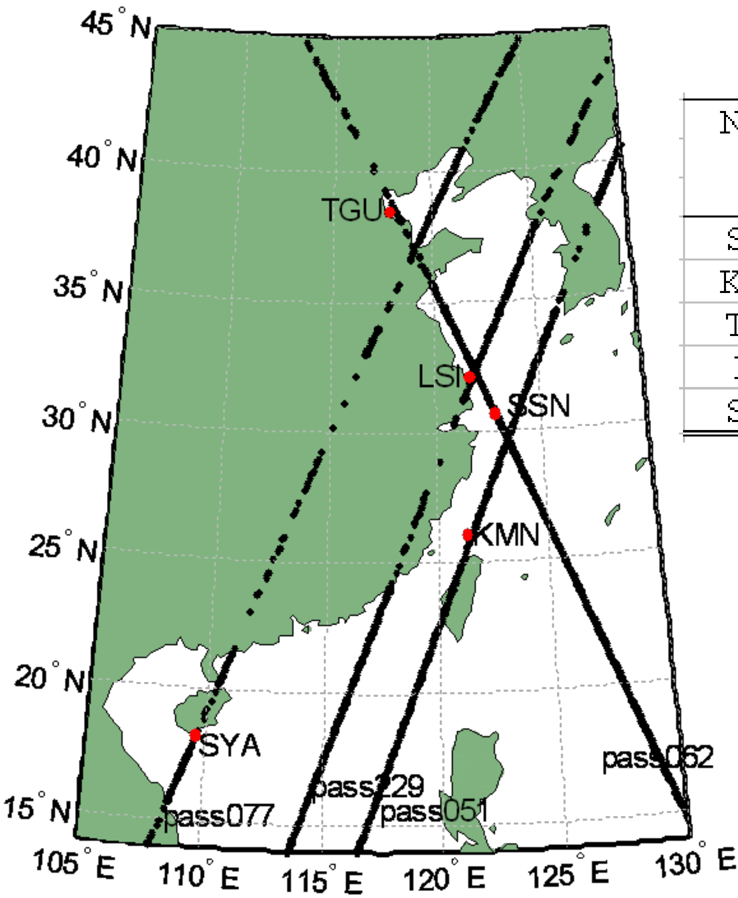
(Martin, 1983)

Content

1. Introduction
2. Altimetry Coastal Waveform analysis
3. Retracking algorithms
4. Results
5. Work under way

4 Results

4.1 Jason1-Ground Comparison of SSH

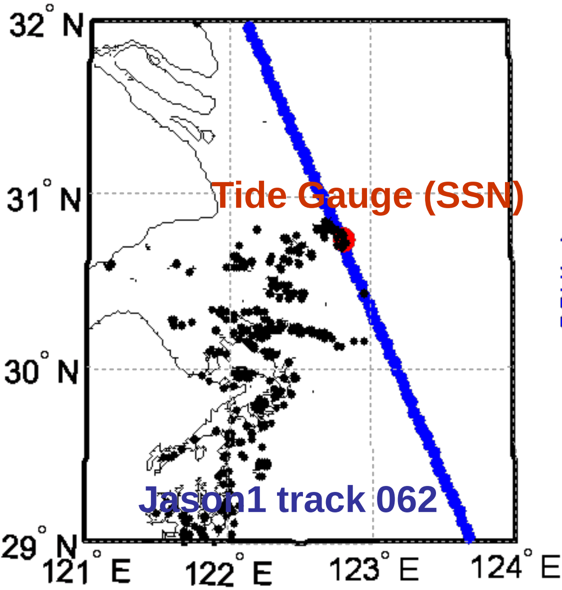


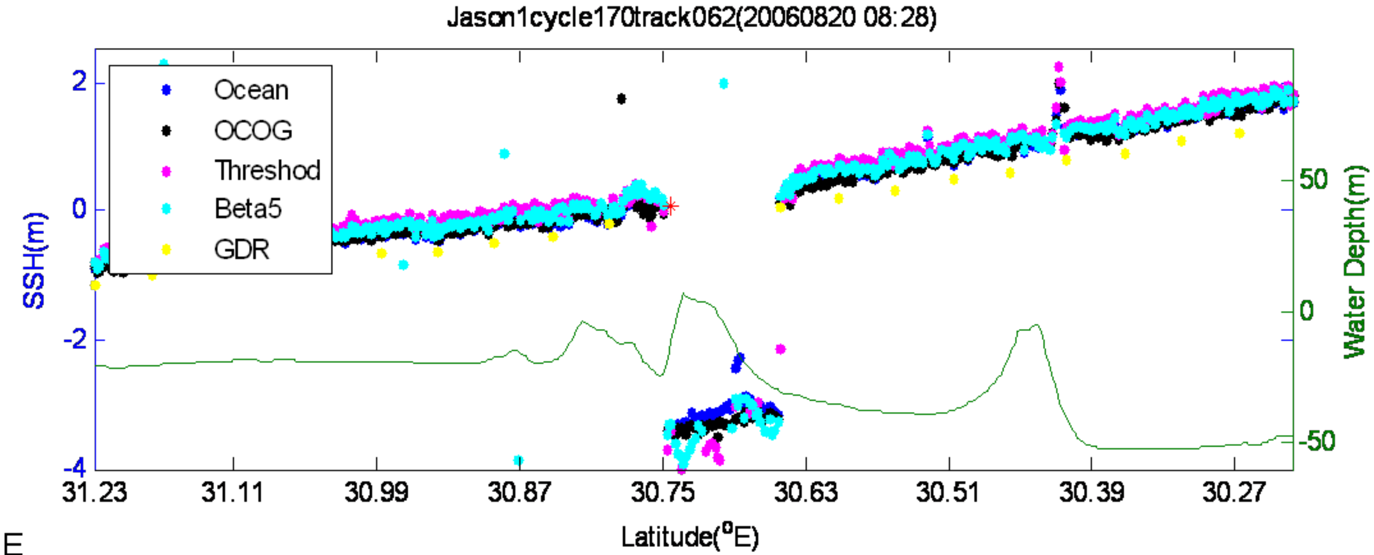
Name	Latitude (°N)	Longitude (°E)	Distance to Land (km)	Jason1 track No.	Distance to Jason1 track (km)
SSN	30.75	122.8	1.897	062	4.08
KMN	26.08	121.28	83.792	051	19.63
TGU	38.55	117.82	17.858	062	21.39
LSI	32.13	121.62	5.754	077	34.28
SYA	18.23	109.53	0.053	138	3.73

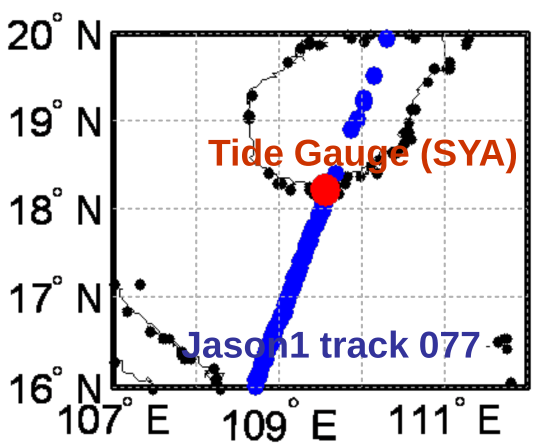
$$SSH = H_{alt} - H_{range} - \Delta H_{atm} - \Delta H_{ss} - \Delta H'_{tide}$$

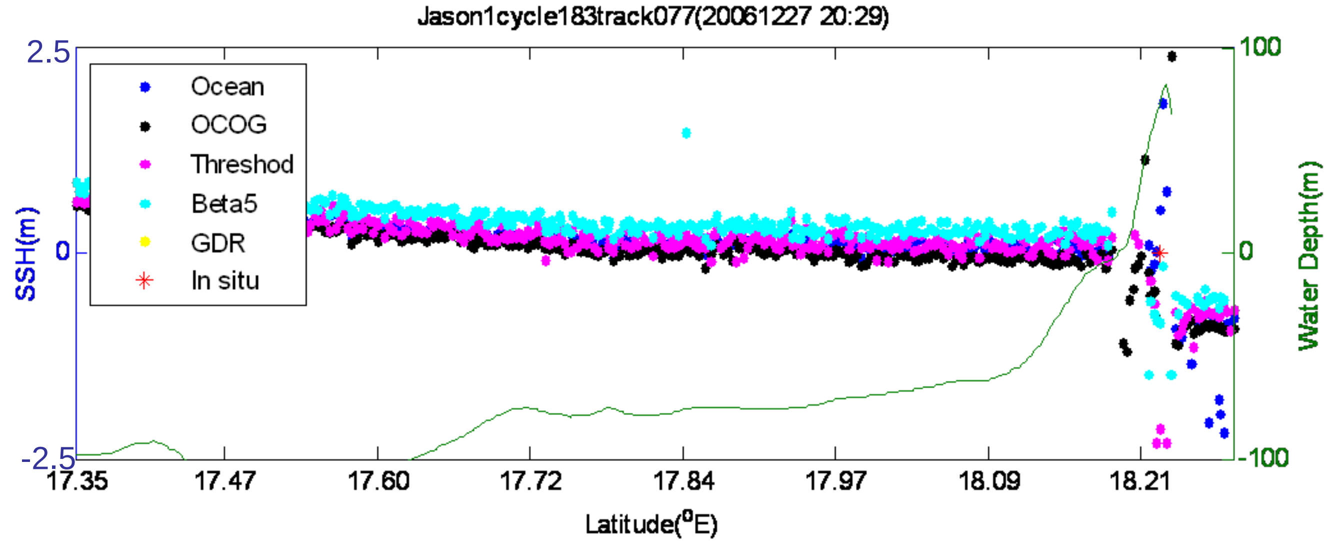
$$\Delta H_{atm} = h_{wet\_tropo} + h_{dry\_tropo} + h_{iono}$$

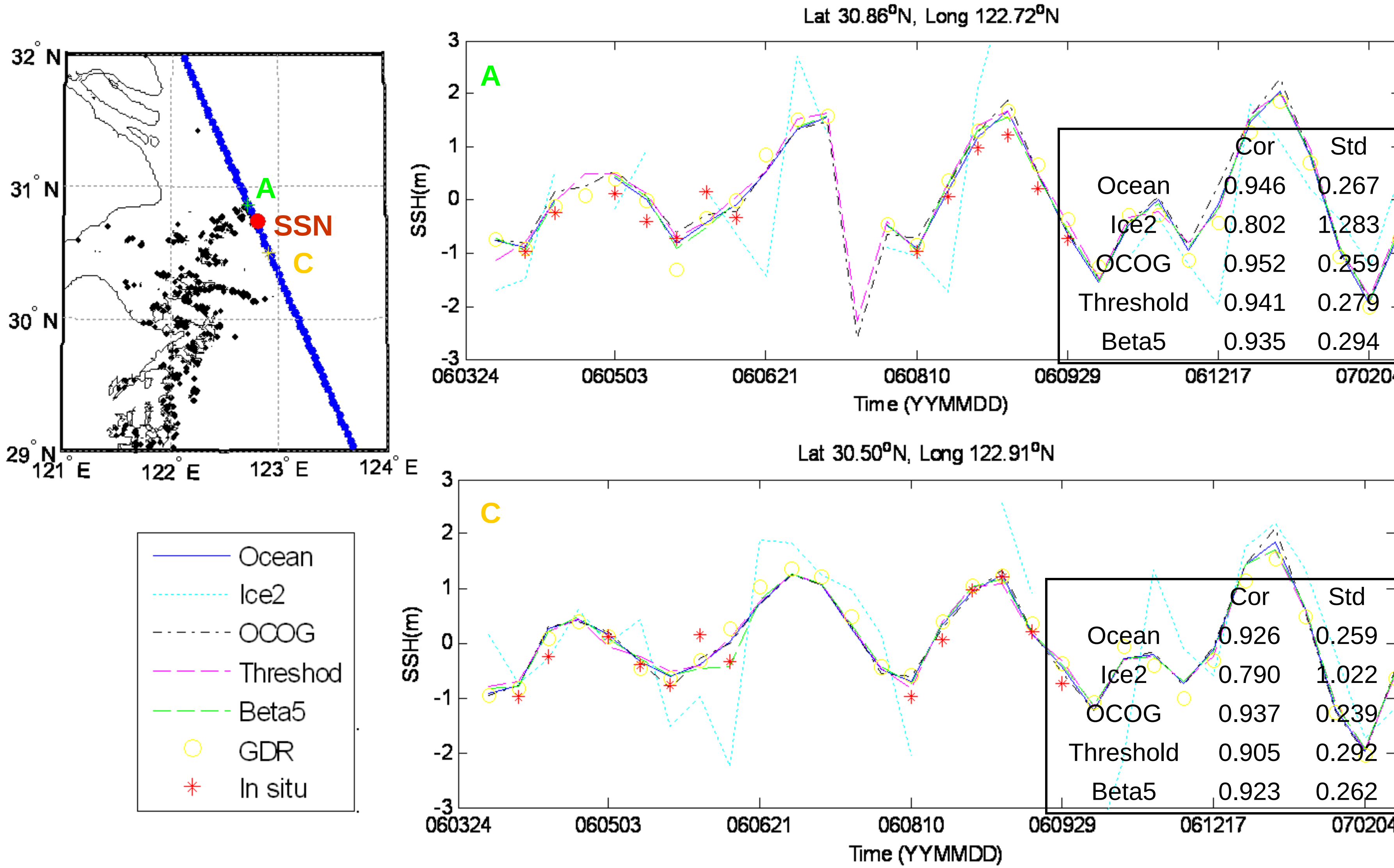
$$\Delta H'_{tide} = h_{solid\_earth\_tide} + h_{loading\_tide} + h_{pole\_tide}$$


32° N
31° N
30° N
29° N
121° E
122° E
123° E
124° E
Tide Gauge (SSN)
Jason1 track 062


Jason1cycle170track062(20060820 08:28)
Ocean
OCOG
Threshod
Beta5
GDR
SSH(m)
Water Depth(m)
Latitude(°E)
31.23
31.11
30.99
30.87
30.75
30.63
30.51
30.39
30.27
2
0
-2
-4
50
0
-50

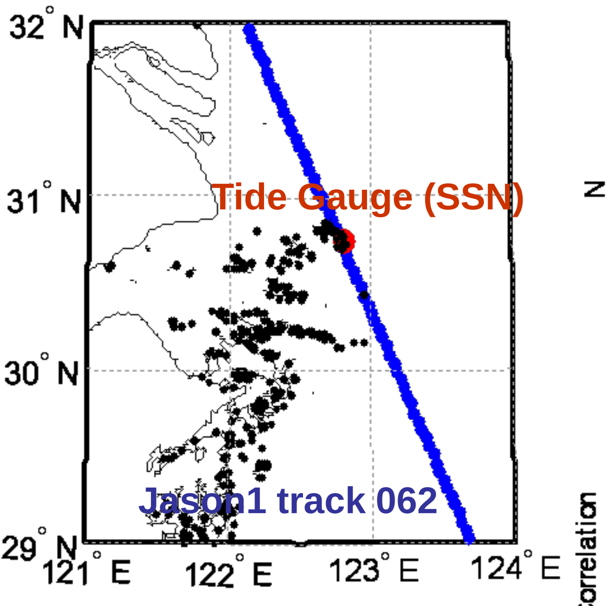

20° N
19° N
18° N
17° N
16° N
107° E
109° E
111° E
Tide Gauge (SYA)
Jason1 track 077


Jason1cycle183track077(20061227 20:29)
Ocean
OCOG
Threshod
Beta5
GDR
In situ
SSH(m)
Water Depth(m)
Latitude(°E)
17.35
17.47
17.60
17.72
17.84
17.97
18.09
18.21
2.5
0
-2.5
100
0
-100

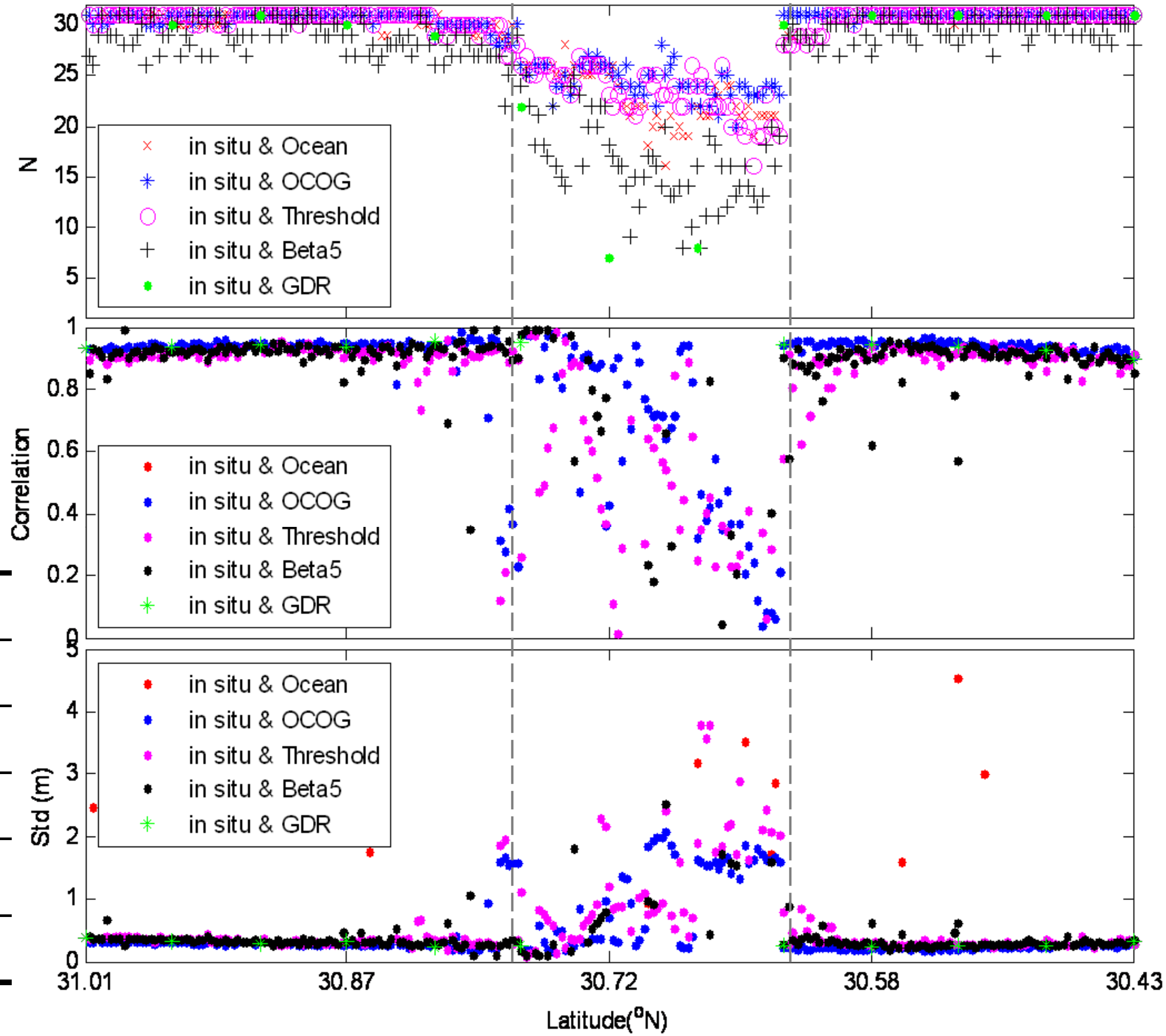


A	Cor	Std
Ocean	0.946	0.267
Ice2	0.802	1.283
OCOG	0.952	0.259
Threshold	0.941	0.279
Beta5	0.935	0.294

C	Cor	Std
Ocean	0.926	0.259
Ice2	0.790	1.022
OCOG	0.937	0.239
Threshold	0.905	0.292
Beta5	0.923	0.262



	N(31)	Cor	Std
Ocean	30.7	0.899	0.336
Ice2	27	0.431	1.257
OCOG	30.7	0.889	0.355
Thres-hold	30.7	0.868	0.387
Beta5	29.1	0.877	0.372



4 Results

4.2 Jason1-Ground Comparison of SWH

The retracking algorithms can only provide the Range from satellite to ocean surface, many corrections (wet tropo, dry tropo, iono, SSB…) are needed to derived SSH, while the altimetry Significant Wave Height (SWH) is determined by the waveform leading edge slope of the ocean return signal and not affected by the atmospheric and ocean conditions.

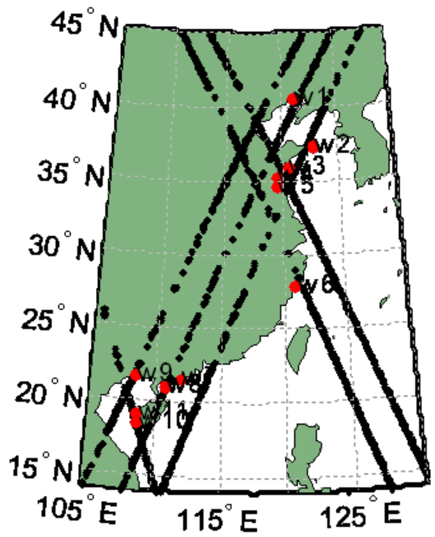
Corrected SWH = SWH + Instrument Correction

In order to compare the retracking algorihtms independently, we calculated the Epochs using five retracking algorithms and additional SWHs using Ocean fitting algorithm again.

4 Results

4.2 Jason1-Ground Comparison of SWH

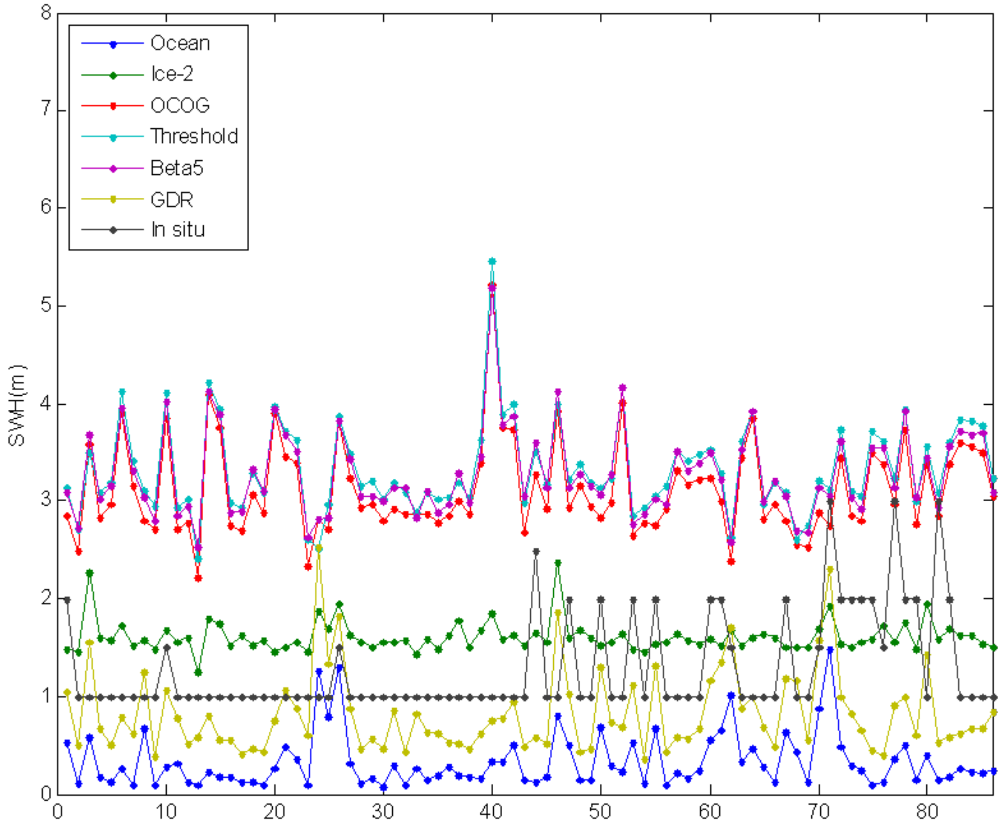
- Co-located altimetry data are selected when the closet approach of altimeter ground track is less than 1 hour, and averaged over 50km along track.



No.	Name	Latitude (°N)	Longitude (°E)	Jason1 track No.
w1	HLD	40.70	120.98	077
w2	CST	37.38	122.68	153
w3	XMD	36.05	120.42	062
w4	RZH	35.40	119.55	062
w5	LYG	34.78	119.43	062
w6	WZH	28.00	120.88	240
w7	ZPO	21.58	111.82	077
w8	NZU	20.95	110.58	077
w9	FCN	21.62	108.33	001
w10	YGH	18.52	108.68	038
w11	DFG	19.10	108.63	038

4 Results

4.2 Jason1-Ground Comparison of SWH



- The SWH from OCOG, Threshold, and Beta5 retracking algorithms are systematically higher.
- The SWH from the Jason1 GDR products are much close to the in situ data.
- This could be explained by the large time and space windows(1 hour,50km) of comparison, while the altimetry waveforms are affected by land when the distance to land is around 10 km.
- However, because of the limited number of comparing data (86), more in situ data are needed to make a solid conclusion.

Conclusions

- The altimetry sea surface heights are unusable where the distance to land is 50 to 100 km. However, the distance where the altimeter measurement itself is affected is only around 10 km to land.
- Coastal ocean return waveforms do not conform to the Brown model as the coast is approached (~10km).
- By employing retracking algorithm with 20 Hz waveform, higher sampling ratio data can be derived (but noisy).
- The Ocean algorithm is the most accurate when the distance of altimeter nadir measured point is more than 10 km from the nearest land. But the standard Ocean fitting algorithm cannot be used in the coastal altimeter waveform processing.
- Among the four retracking algorithms, OCOG retracking algorithm is appropriate considering both the accuracy and valid result percentage of the Jason1-in situ SSH comparisons.

5. Work under way

- Waveform recognition and extraction: If the leading edge contributed by the ocean surface could be distinguished and extracted properly, the only one retracker (ocean retracker) is needed.
- Further validate the retracking algorithms with longer term in situ data, and Jason1-Ground Comparison of SSH and SWH.
- Analyse Multi-satellite data (Jason1/Jason2/Envisat RA2).
- Investigate Land effects on altimetry waveform.

Thank you!