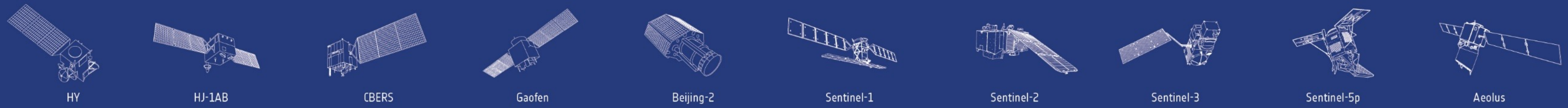

2023 DRAGON 5 SYMPOSIUM

3rd YEAR RESULTS REPORTING

11-15 SEPTEMBER 2023

[PROJECT ID. 58900]

[MARINE DYNAMIC ENVIRONMENT MONITORING IN THE CHINA SEAS AND WESTERN PACIFIC OCEAN BY SATELLITE ALTIMETERS]

< DAY 4, 14 SEP 2023>

ID. 58900

PROJECT TITLE: MARINE DYNAMIC ENVIRONMENT MONITORING IN THE CHINA SEAS AND WESTERN PACIFIC OCEAN SEAS BY SATELLITE ALTIMETERS

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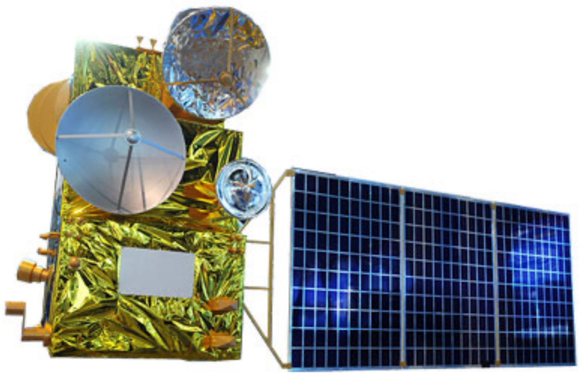
PRESENTED BY: JUNGANG YANG, FIRST INSTITUTE OF OCEANOGRAPHY, MNR, CHINA

1. The project's objectives

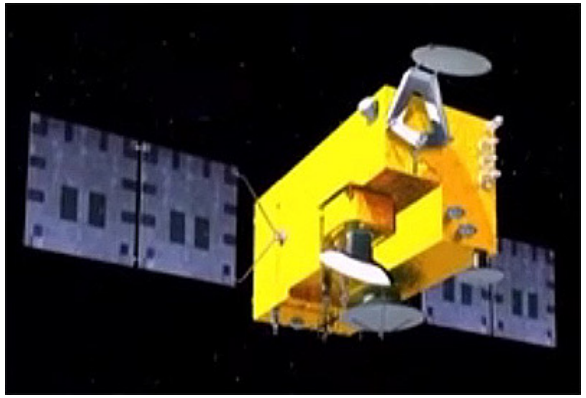
- To combine European and Chinese altimeters to improve the abilities of data applications and the ocean dynamic monitoring abilities in the China seas.
- To develop the reprocessing method of Sentinel-3, HY-2 series in the China seas, to merge these satellite altimeters to grid SSH and SWH data with high spatial resolution.
- to applicate these data in the study of ocean wave, ocean current and mesoscale eddies in the China seas and western Pacific Ocean.

Sentinel-3A
Launched on 16 Feb. 2016

Sentinel-3B
Launched on 25 Apr. 2018



HY-2B
Launched on 25 Oct. 2018



HY-2C: 21 Sep. 2020
HY-2D: 19 May 2021

EO Data Delivery

Altimeter data of Sentinel-3A/3B and Sentinel-6(launched on 21 Nov. 202), Sentinel-1A/B SAR data from Europe and altimeter data of HY-2 series satellites from China are used in this study.

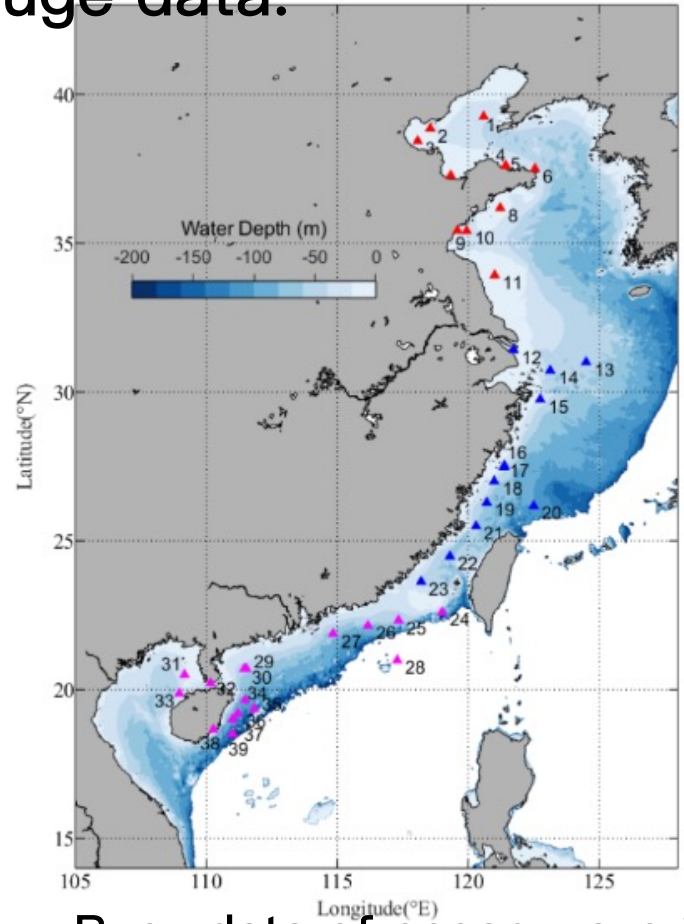
Copernicus Sentinels data	No. Scenes
1. SENTINEL-3A/B SRAL Altimetry	all achieved data until to 2023 From FTP
2. SENTINEL-1A/B Wave (WV)	all achieved data until to 2023 From FTP
3. SENTINEL-6 POSEIDON-4 L2	all L1 & L2 achieved data until to 2023 From FTP
Total:	
Issues: From FTP	

Chinese EO data	No. Scenes
1. HY-2A ALT	all achieved data until to 2021 From FTP
2. HY-2B ALT	all achieved data until to August 2023 From FTP
3. HY-2C ALT	all achieved data until to August 2023 From FTP
3. HY-2D ALT	all achieved data until to August 2023 From FTP
Total:	
Issues: From FTP	

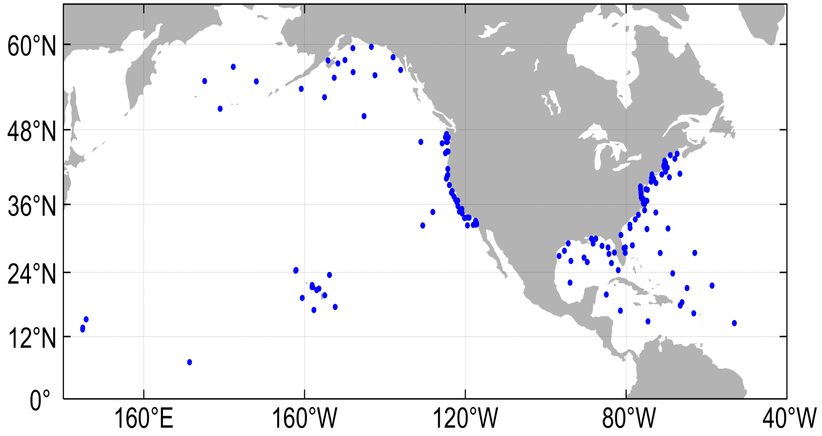
In addition, Jason-2/3, SARAL altimeter data and CFOSAT SWIM data were used in this study.

Detail the in-situ data measurements and requirements

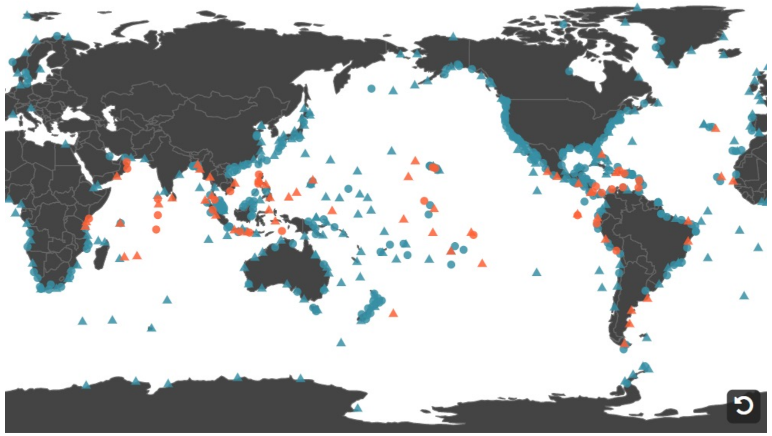
In-situ data: Ocean wave data from buoys and tide gauge data.



Buoy data of ocean wave in the coastal area of the China Sea



NDBC buoy data of ocean wave



Tide gauge data from UHSLC (University of Hawaii Sea Level Center)

European Young scientists contributions in Dragon 5

Name	Institution	Poster title	Contribution including period of research
Bjarke Nilsson	Technical University of Denmark – National Space Institute	High Resolution Ocean Wave Characteristics From ICESat-2 Following The CRYO2ICE Realignment	Analysis, validation, data curation, writing During the period of 2021-2024
Bjarke Nilsson	Technical University of Denmark – National Space Institute	Consolidating ICESat-2 Ocean Wave Characteristics With CryoSat-2 During The CRYO2ICE Campaign	Analysis, validation, data curation, writing During the period of 2021-2024
Mads Ehrhorn	Technical University of Denmark – National Space Institute	Predicting Future Sea Level from Satellite Altimetry	Analysis, model creation, data handling, writing During the period of 2021-2024

Chinese Young scientists contributions in Dragon 5

Name	Institution	Poster title	Contribution including period of research
Jie Sun	First Institute of Oceanography, Ministry of Natural Resources	Study on Wet Tropospheric Correction of HY-2C Altimeter based on Multi-source Data	Analysis, validation, data curation, writing During the period of 2021-2024
Jiaju Ren	First Institute of Oceanography, Ministry of Natural Resources	Analysis of Seasonal Variations of Internal Tides in the Luzon Strait by Multi-satellite Altimetry Data	Analysis, validation, data curation, writing During the period of 2021-2024
Fengjia Sun	First Institute of Oceanography, Ministry of Natural Resources	Retrieval of the Wide Swath Significant Wave Height from HY-2C Scatterometer based on Deep Learning	Analysis, validation, data curation, writing During the period of 2021-2024
Zhiheng Hong	First Institute of Oceanography, Ministry of Natural Resources	The Improvement of HY-2B Satellite Altimetry Range Corrections in Coastal Area	Analysis, validation, data curation, writing During the period of 2021-2023
Jiaju Ren	First Institute of Oceanography, Ministry of Natural Resources	Optimization Of Waveform Retracking Algorithm For Sentinel-3 SAR Altimeter In Coastal Altimetry	Analysis, validation, data curation, writing During the period of 2021-2023

Study on Coastal Waveform Retracking and Range Correction Reprocessing of HY-2B Altimeter

Jungang Yang[1], Ole Baltazar Andersen[2], Zhiheng Hong[1], Yongjun Jia[3], Wei Cui[1], Chenqing Fan[1], Shengjun Zhang[4]

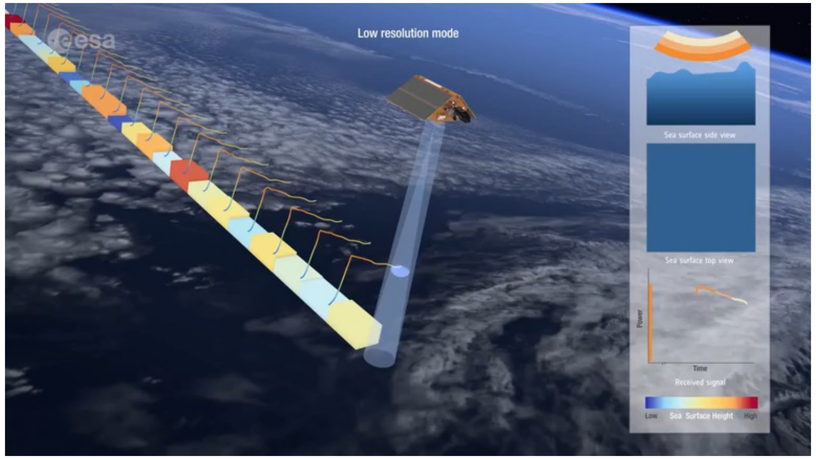
[1]First Institute of Oceanography, MNR, Qingdao, China;

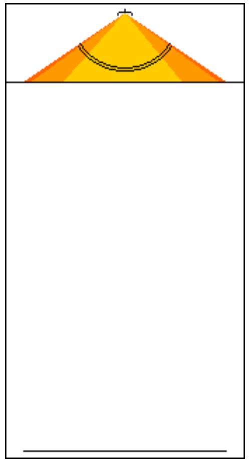
[2]Technical University of Denmark, Lyngby, Denmark;

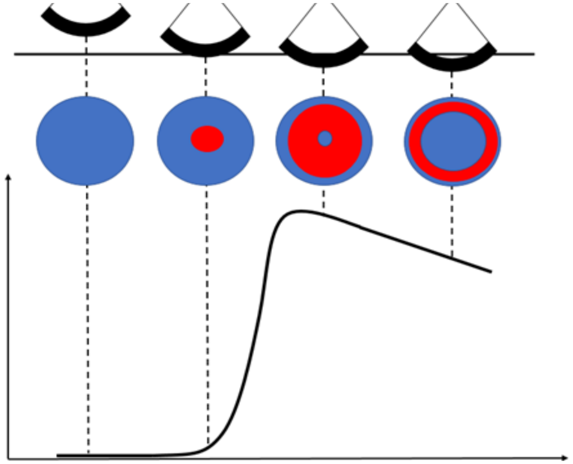
[3]National Satellite Ocean Application Service, MNR, Beijing, China;

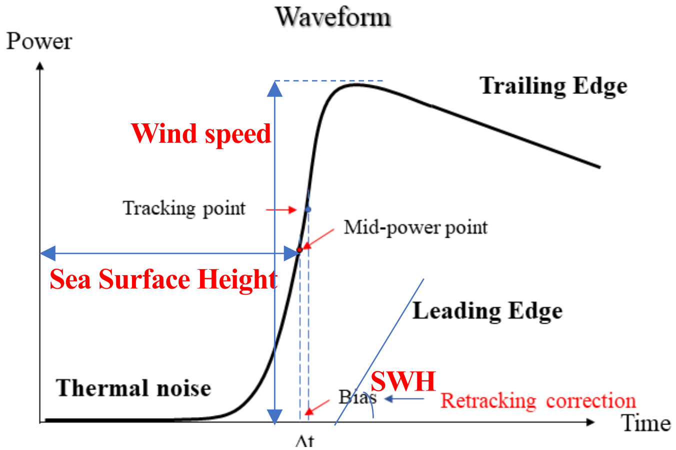
[4]School of Resources and Civil Engineering, Northeastern University, Shenyang, China

The principle of satellite altimeter



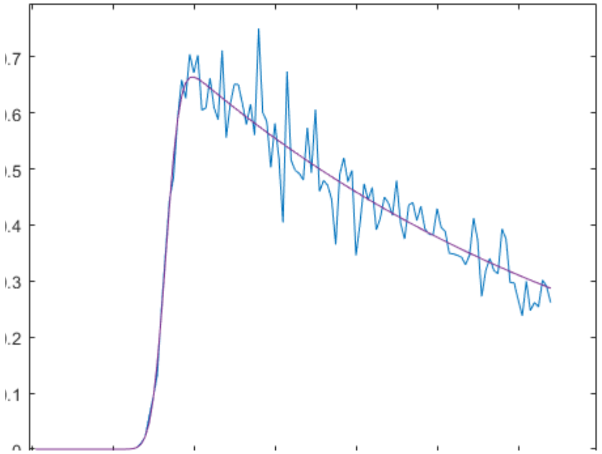




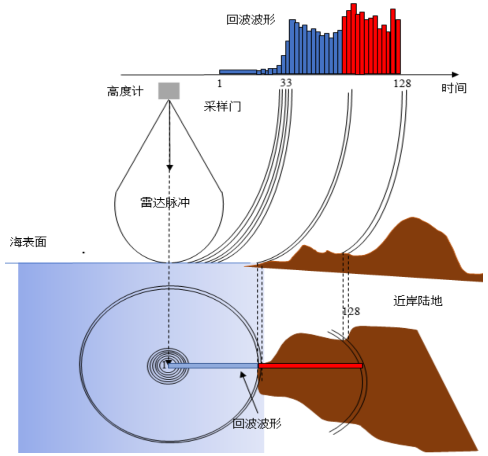


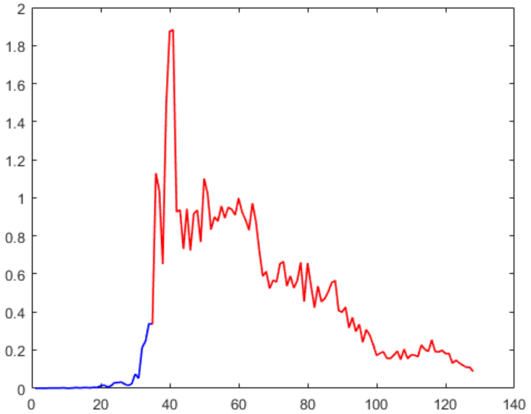
Satellite altimeter can obtain:

Sea Surface Height(SSH), Significant Wave Height(SWH) and Sea Surface Wind(SSW).



Ideal waveform



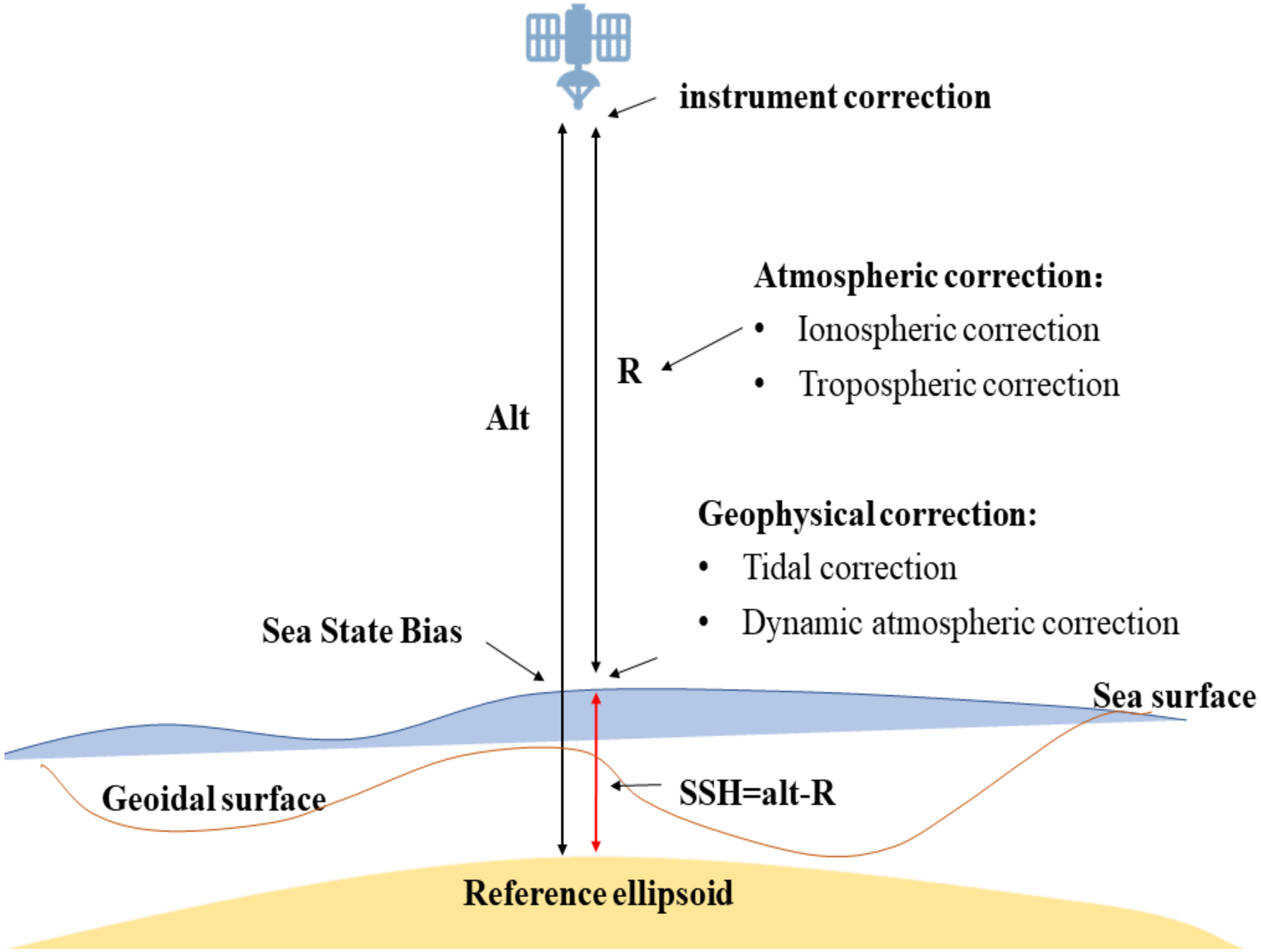


polluted waveform

Waveform Retracking:

correct the range measurement of altimeter.

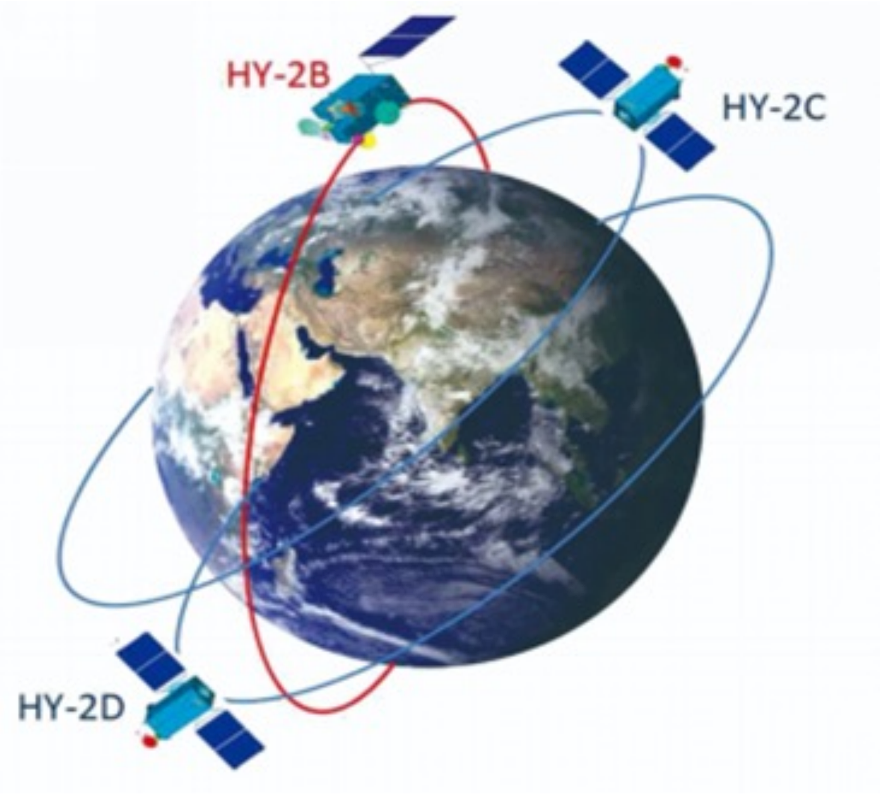
Range Corrections: correct the Delay of Range Measurement.



- Ionosphere correction.
- Calibrated Microwave Radiometer(CMR) is used to correct wet tropospheric path delay.
- Sea State Bias (SSB) correction is relate to the wind and wave.
- Ocean tide in the coastal areas is difficult to predict accurately.

HY-2 series satellite missions

HY-2 Series satellites are global ocean dynamic environment monitoring satellites of China and are equipped with altimeter, radiometer and scatterometer.



HY-2 series altimeters

Three satellites networked-observation

	HY-2A	HY-2B	HY-2C	HY-2D
Sponsor	China's National Satellite Ocean Application Service (NSOAS)			
Launch Date	16-Aug-2011	25-Oct-2018	21-Sep-2020	30-May-2021
Inclination	99.35 degrees	99.35 degrees	66 degrees	66 degrees
Altitude	971 km	971 km	957 km	971 km
Period	14 days	14 days	10 days	10 days

The main work

Improving HY-2B altimeter data in coastal area

Waveform retracking

Reprocessing range corrections

Waveform retracking for HY-2B altimeter

- waveform retracking in the coastal area
- Validation of retracking results

Reprocessing of range corrections for HY-2B altimeter

- Sea State Bias (SSB) correction
- Ionospheric Correction
- Wet Tropospheric Correction
- Ocean Tide Correction

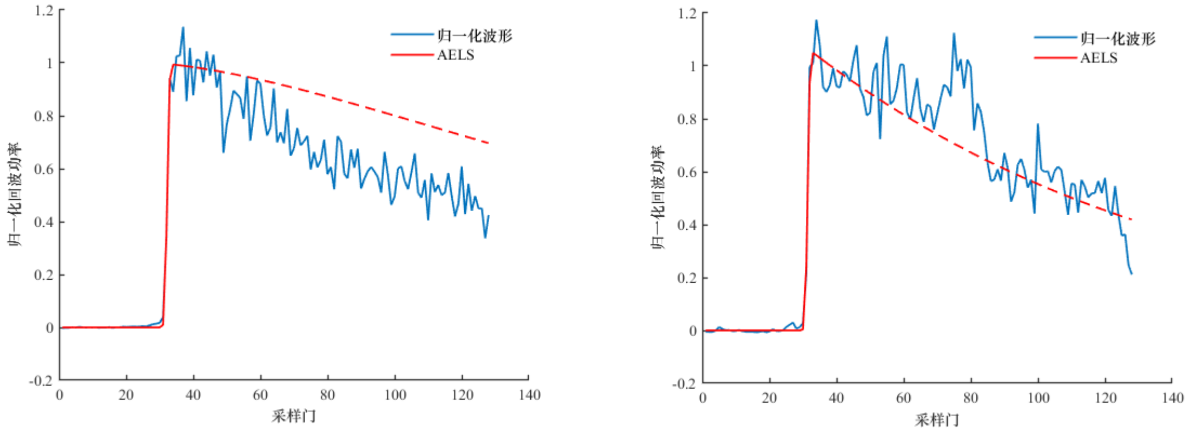
Reprocessing of HY-2B altimeter data in the coastal area of China

- Reprocessing HY-2B Altimeter data
- Analysis of reprocessed data

The existed waveform retracking method in the coastal area

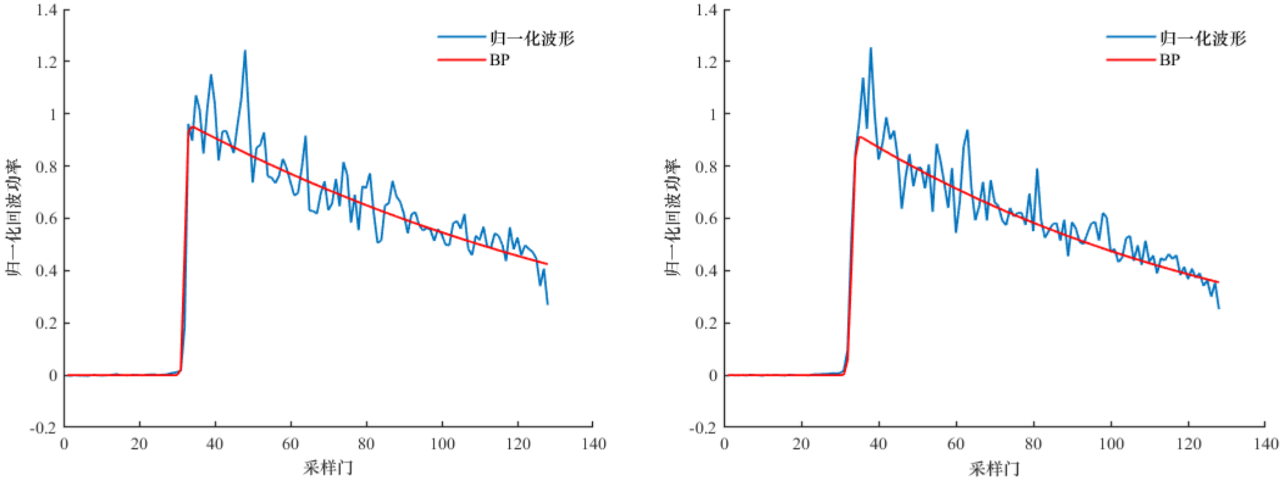
➢ ALES Waveform Retracking

The ALES algorithm adaptively adjusts the width of the fitted-subwaveform based on sea surface height and wave height information.



➢ Brown-Peak（BP）Waveform Retracking

According to the shape characteristics of the polluted waveform, the BP Algorithm determines the polluted gates by the Adaptive Peak Detection and then fits waveform by weighted least squares.



The proposed waveform retracking method

Waveform Retracking by Determining the Effective Trailing Edge and the Low Noise Leading Edge

- Confirming Main Part of Waveform.
- Low Noise Leading Edge and Effective Trailing Edge Detection.
- Waveform Fitting.

Waveform Model

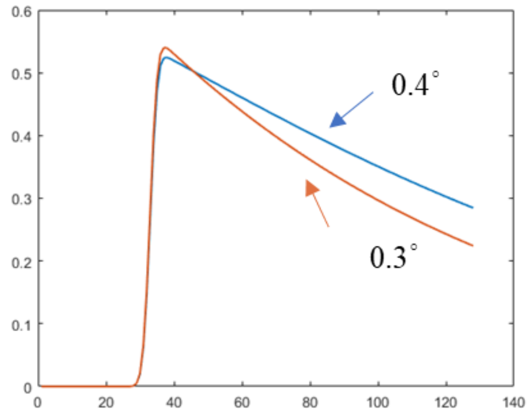
$$W(t) = a_{\xi} P_u [1 + erf(u_1)] \cdot \exp(-v_1) - \frac{a_{\xi} - P_u}{2} [1 + erf(u_2)] \cdot \exp(-v_2) + T_n$$

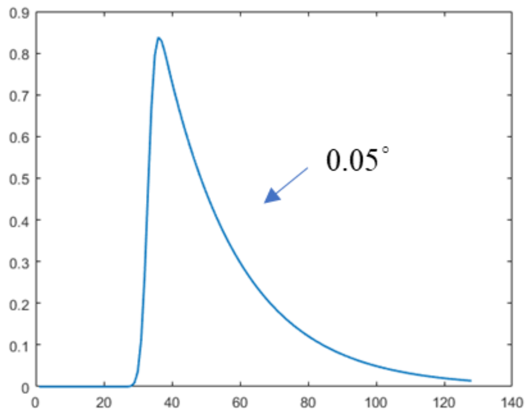
$$a_{\xi} = \exp(-\frac{4\sin^2 \xi}{\gamma}) \qquad \gamma = \sin^2(\theta_0) \frac{1}{2\ln(2)}$$

$$erf(x) = \frac{2}{\sqrt{x}} \int_0^x e^{-t^2} dt$$

$$u_1 = \frac{t - \tau - a_1 \sigma_c^2}{\sqrt{2}\sigma_c} \qquad v_1 = \alpha_1 (t - \tau - \frac{a_1 \sigma_c^2}{2}) \qquad \alpha_1 = \delta - \frac{\beta^2}{8}$$

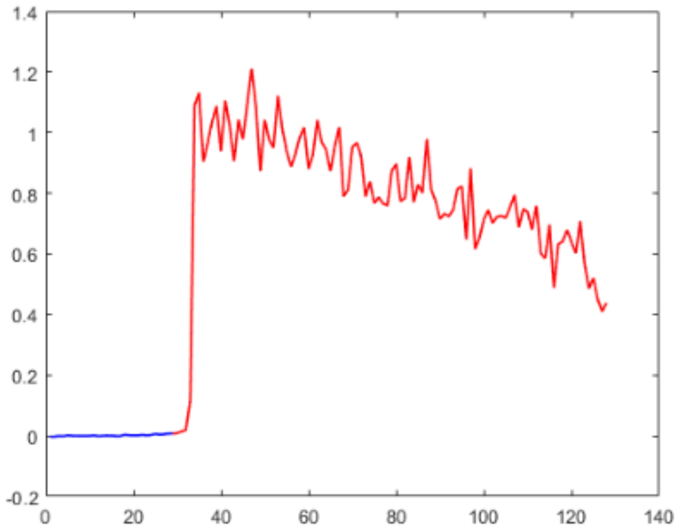
$$u_2 = \frac{t - \tau - a_2 \sigma_c^2}{\sqrt{2}\sigma_c} \qquad v_1 = \alpha_2 (t - \tau - \frac{a_2 \sigma_c^2}{2}) \qquad \alpha_2 = \delta$$



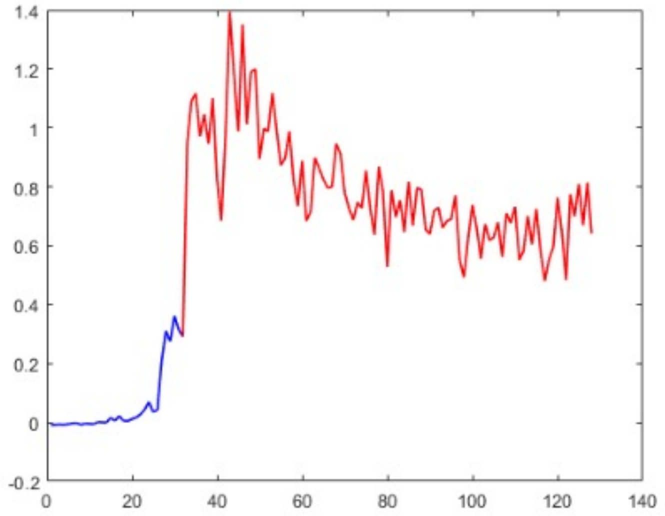


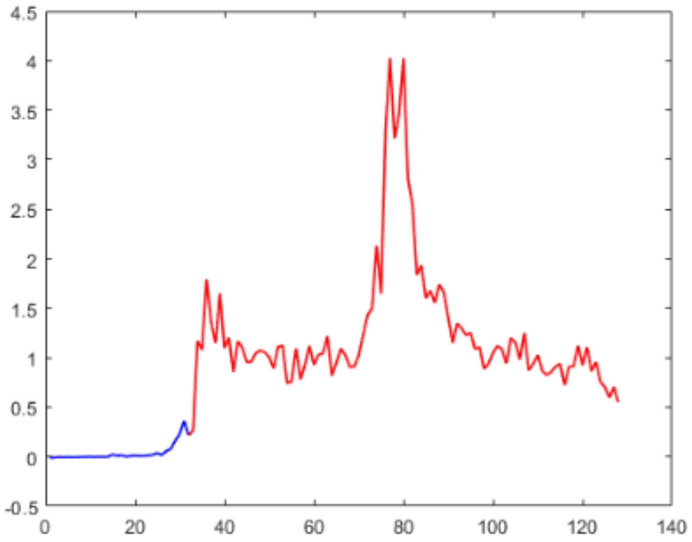
Confirming Main Part of Waveform

- Avoid power contamination at the starting position of the waveform leading edge.
- Improve the fitting precision of SWH.
- the main part of the waveform is determined by searching under a power threshold.



Waveform over the open sea





Waveform over the coastal ocean

Determining of Low Noise Leading Edge of Waveform

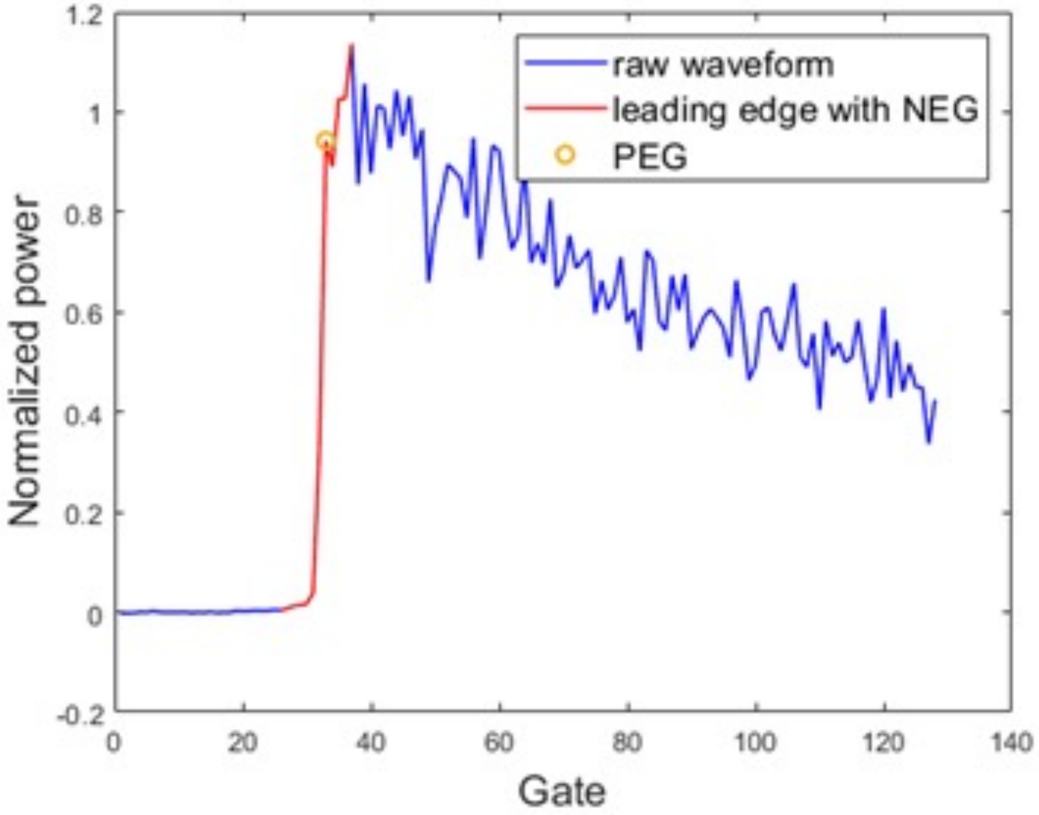
- Removing the Noisy Gates of Leading Edge
- Determining the Stop Gate of Leading Edge

- First Reference Gate： with Rising Power of Trailing Edge
- Second Reference Gates

$$P_{second} \le P_{first} - (i - first) \times 0.0065$$

- Reliable Reference Gate to Calculate Leading Edge Power

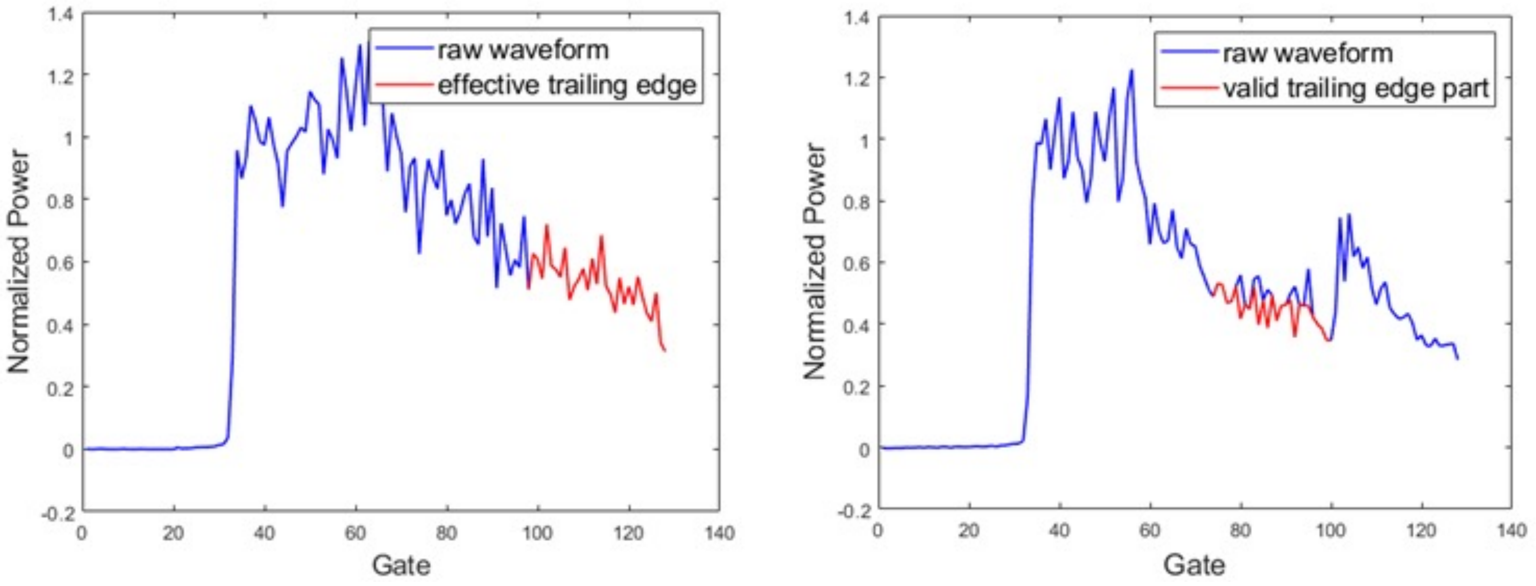
$$C = P_{first} - P_{sec} - (\sec - first) \times 0.008$$



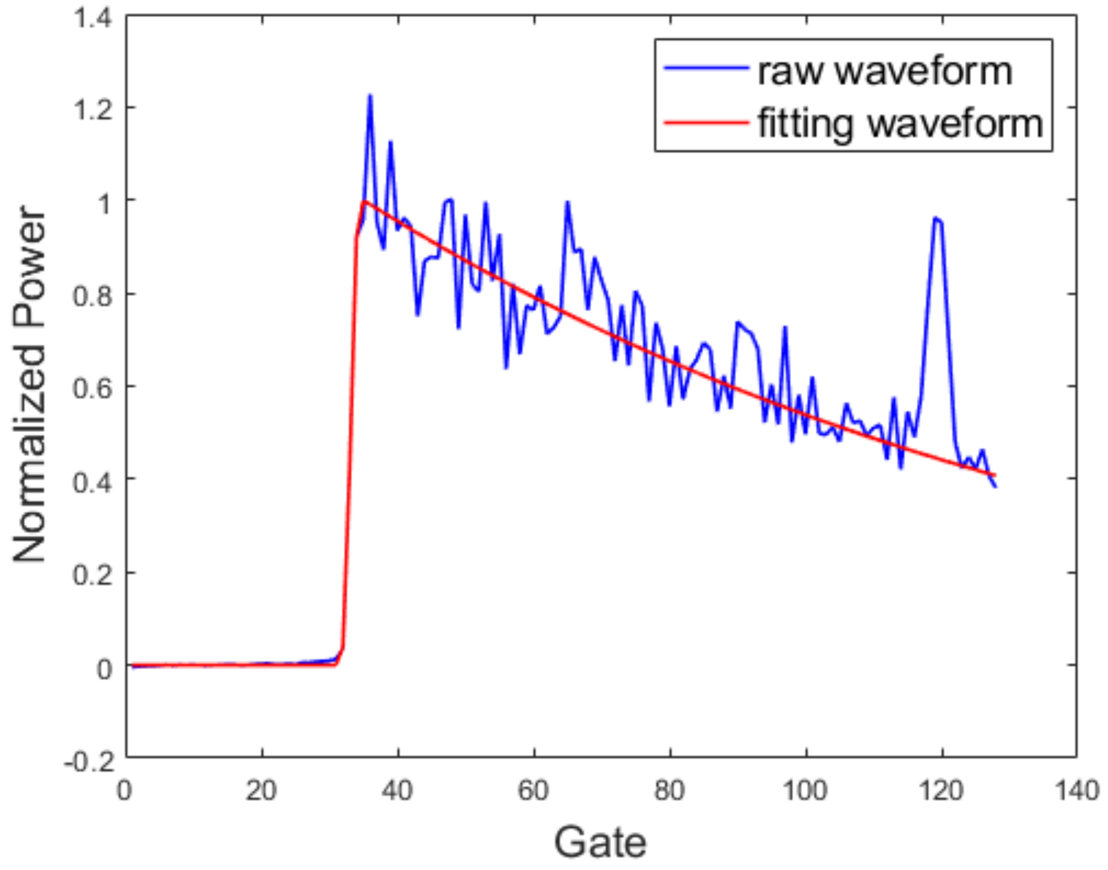
Determining Effective Trailing Edge of Waveform

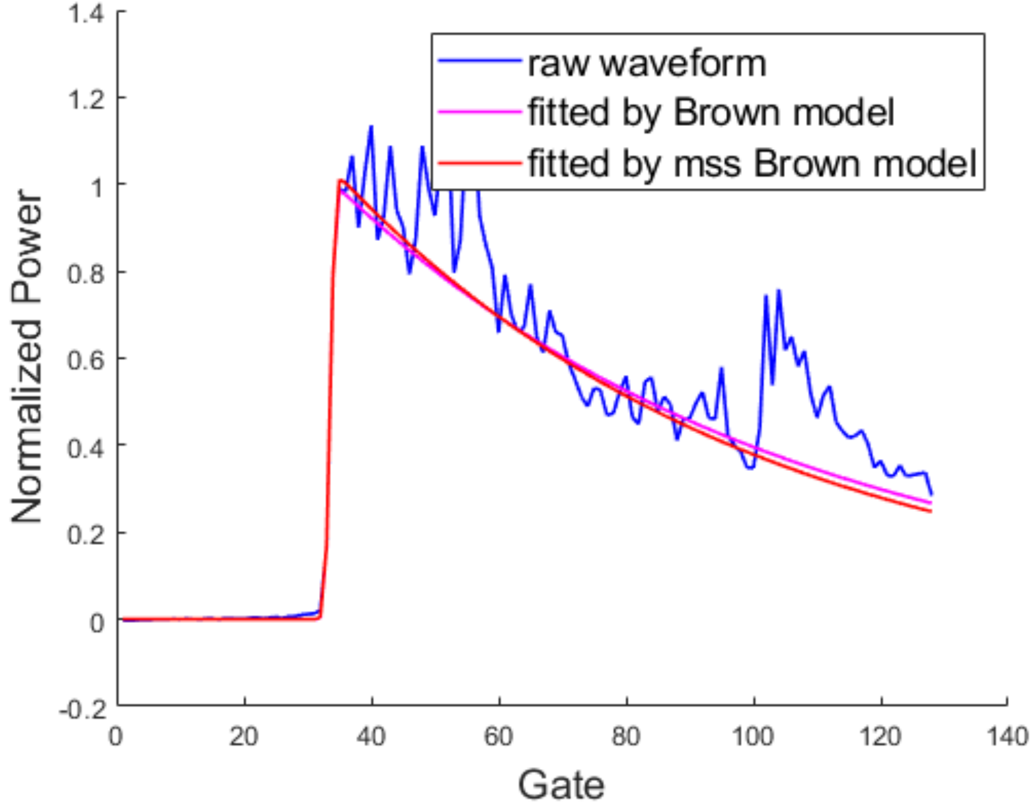
The effective trailing edge of waveform is identified by the power slope between each gate and the fixed gate.

- Judgement of power decreasing
- Exclusion of large range
- Searching effective trailing edge



Waveform Fitting





Validation of retracking results

➢ Waveform Data in coastal area

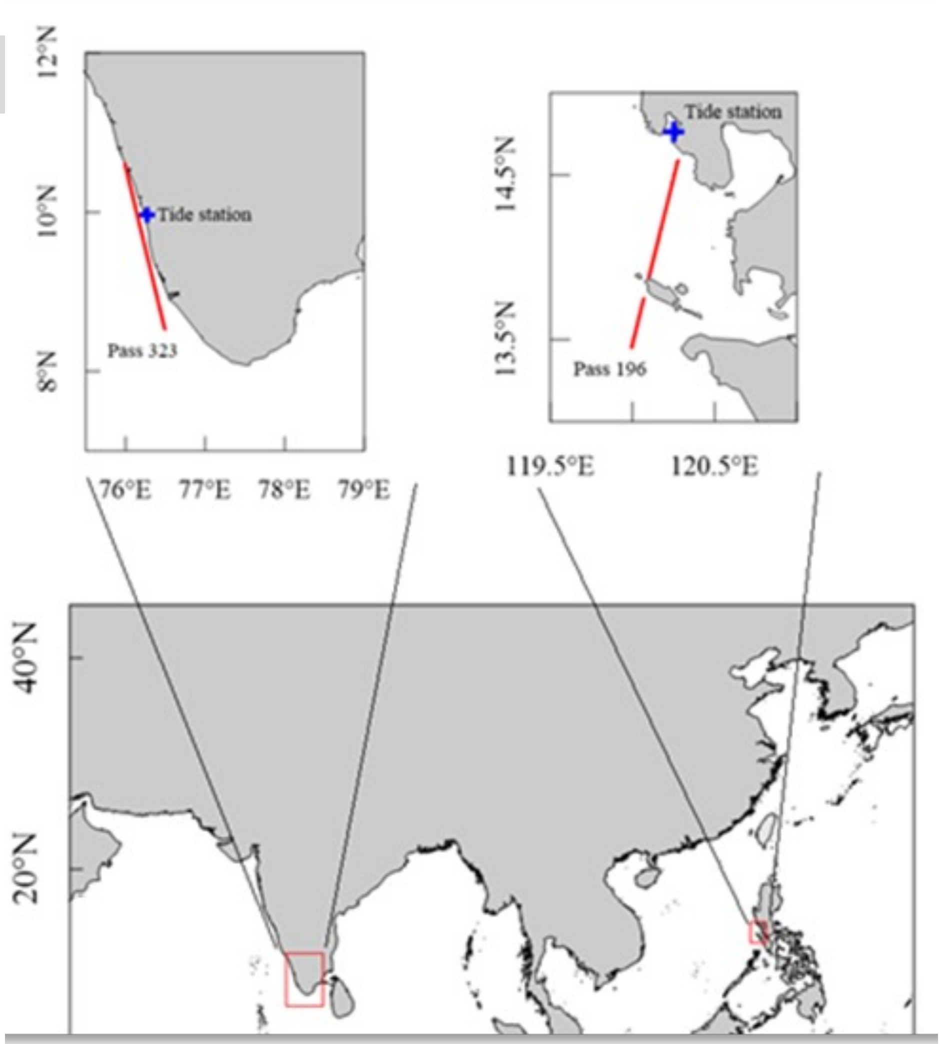
HY-2B 323 Pass / HY-2B 196 Pass

➢ Tide gauge observation

PSMSL Data (ID 174 / ID 382)

➢ Period of Data

- Pass 323: 2019.02.16 - 2019.11.09
- Pass 196: 2019.01.28 - 2020.08.10

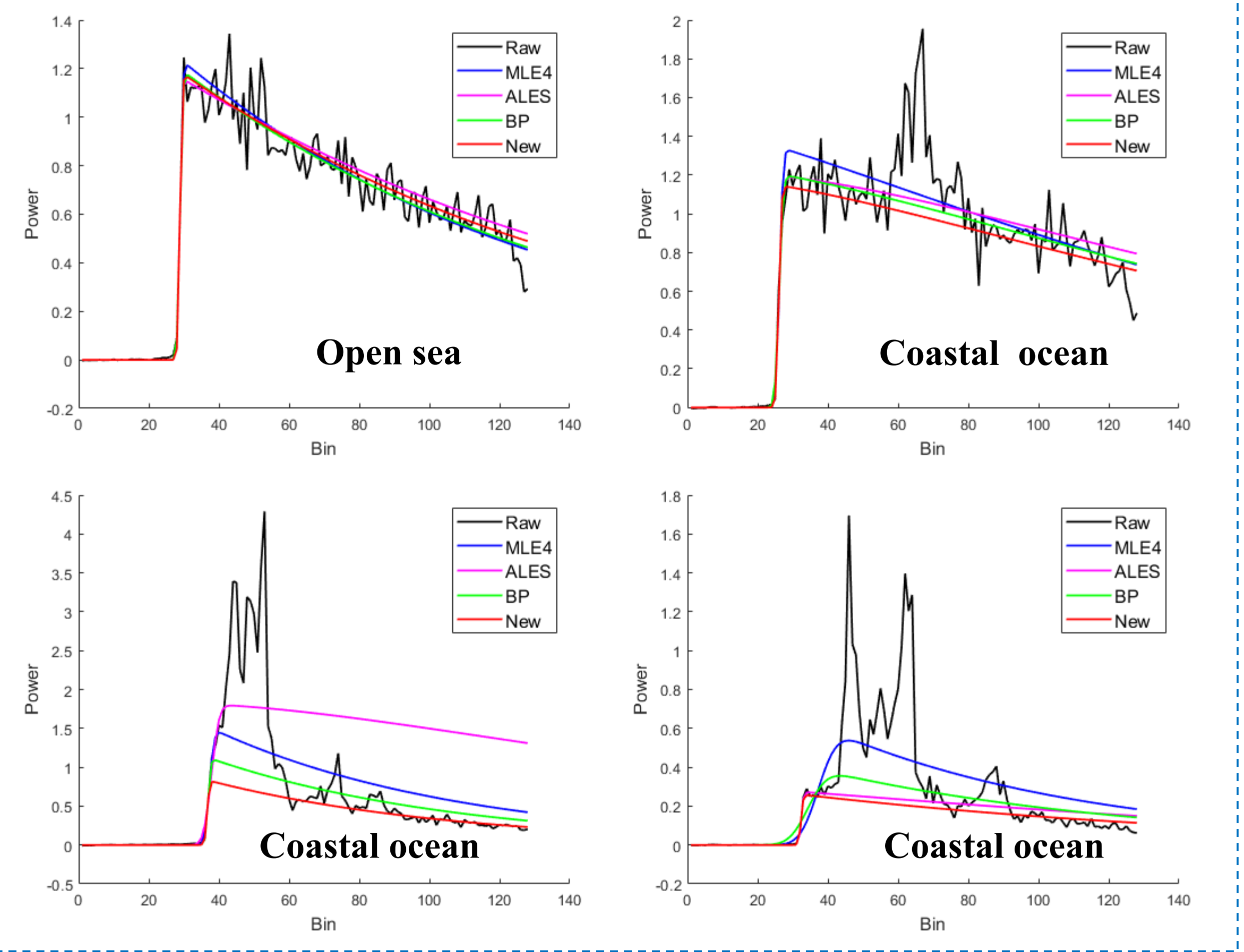


➢ Retracking Algorithm

- MLE (SGDR)
- ALES
- BP
- The proposed method

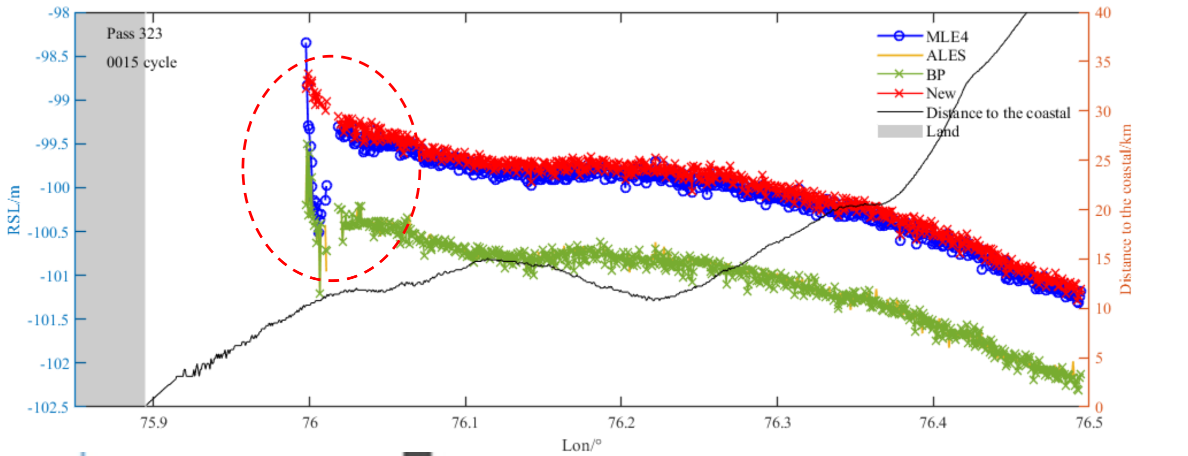
Qualitative Analysis

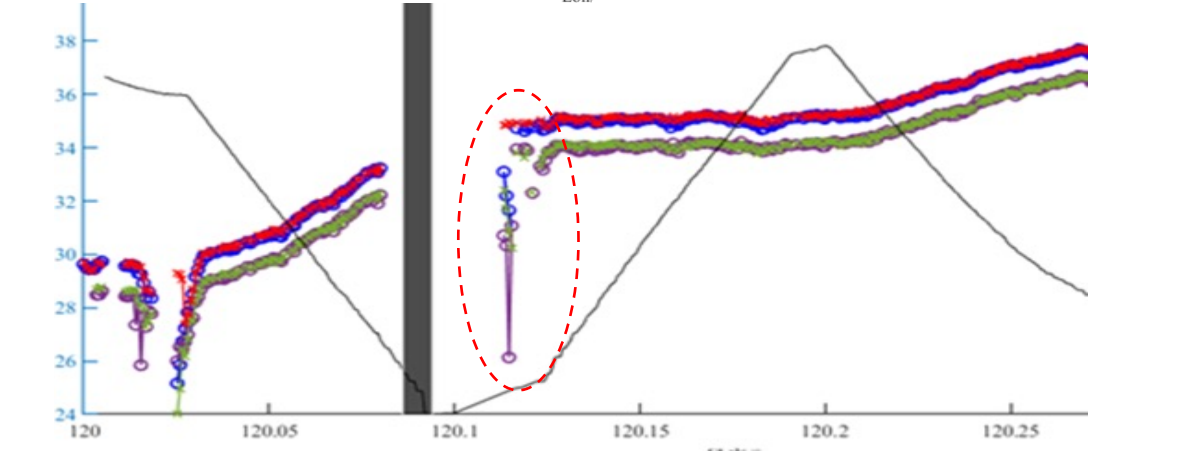
➢ Waveform Fitting



➢ Raw Sea Level (RLS) Comparison

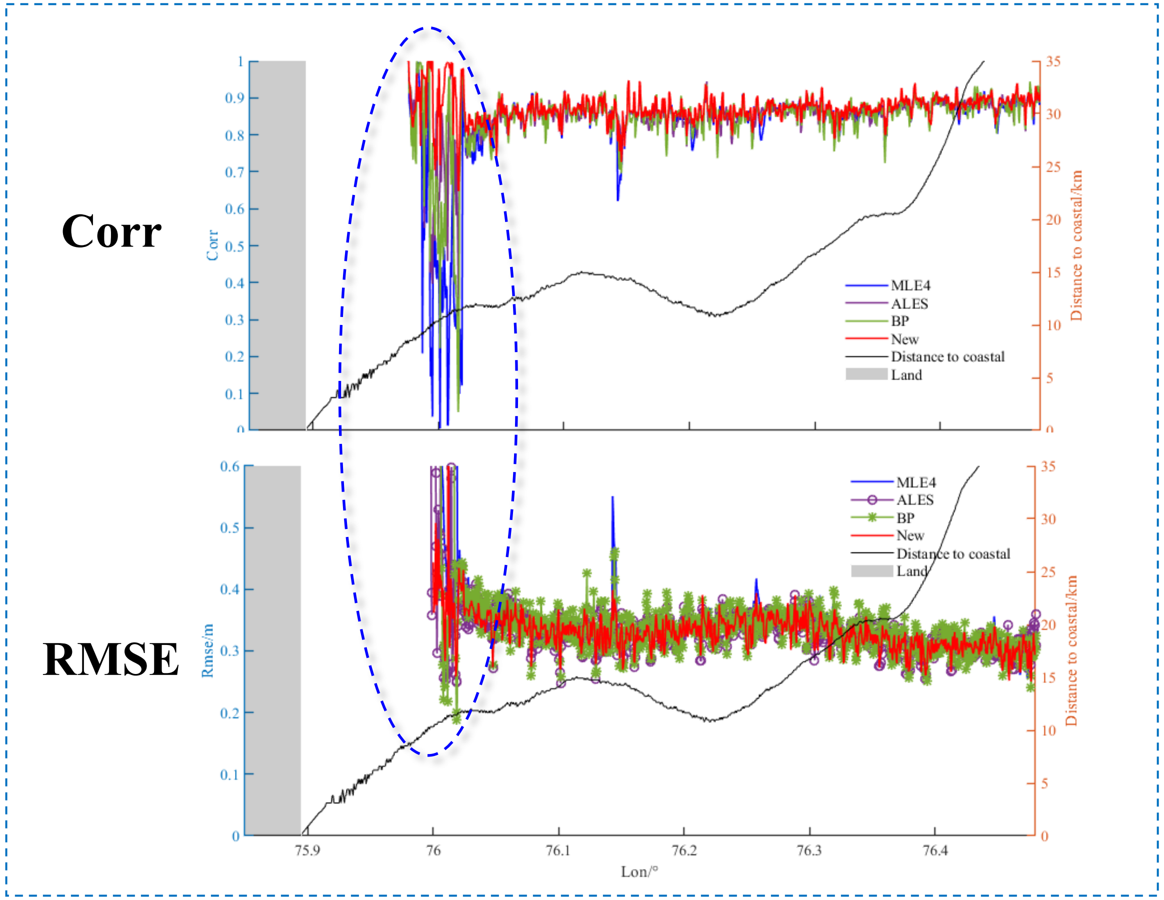
RSL = Alt – Range (Retracked)



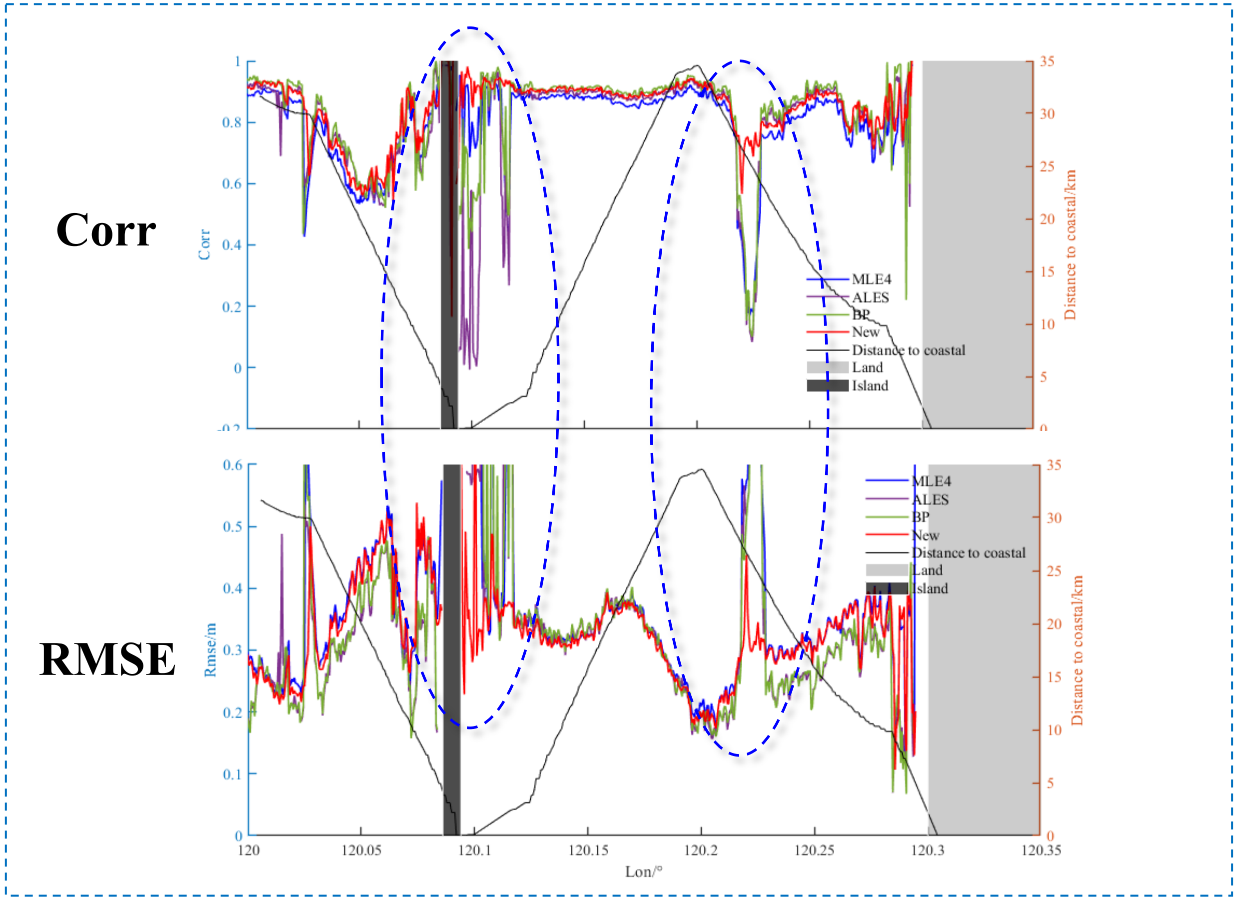


Quantitative Analysis

➢ Pass 323



➢ Pass 196



Range corrections

Sea State Bias (SSB) correction

Developing the local high frequency SSB model for the Correction of 20Hz SLA Data.

- Cross Points

FG Model

$$SSB = -0.064\ SWH(9.8\ SWH/Wind^2)^{0.11}$$

NP Model

$$SSB = SWH(-0.0859-0.0021\ SWH+0.0031\ Wind-5.6233*10^{-5}\ Wind^2)$$

- Adjacent Points

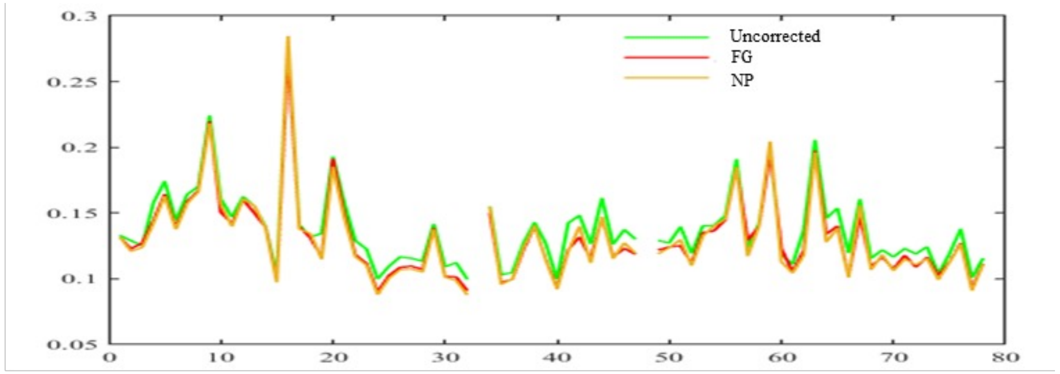
FG Model

$$SSB = -\ 0.063\ SWH(9.8\ SWH/Wind^2)^{0.04}$$

NP Model

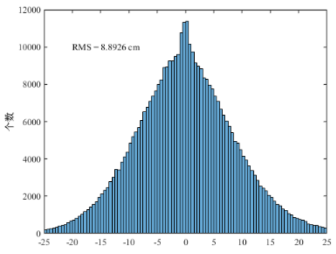
$$SSB = SWH(-0.0509-0.0008\ SWH+0.0004\ Wind-2.2106*10^{-4}\ Wind^2)$$

STD/m



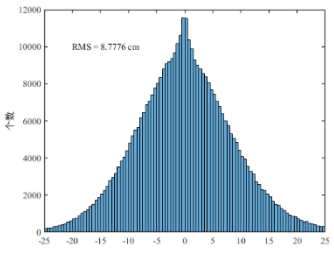
Cycle (Pass 043)

FG cross



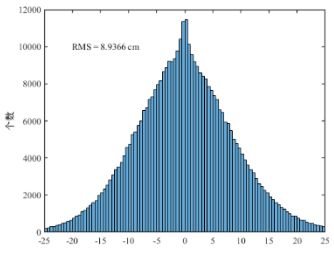
8.9cm

NP cross



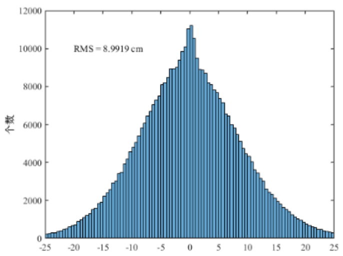
8.8cm

FG adjacent



8.9cm

NP adjacent



8.9cm

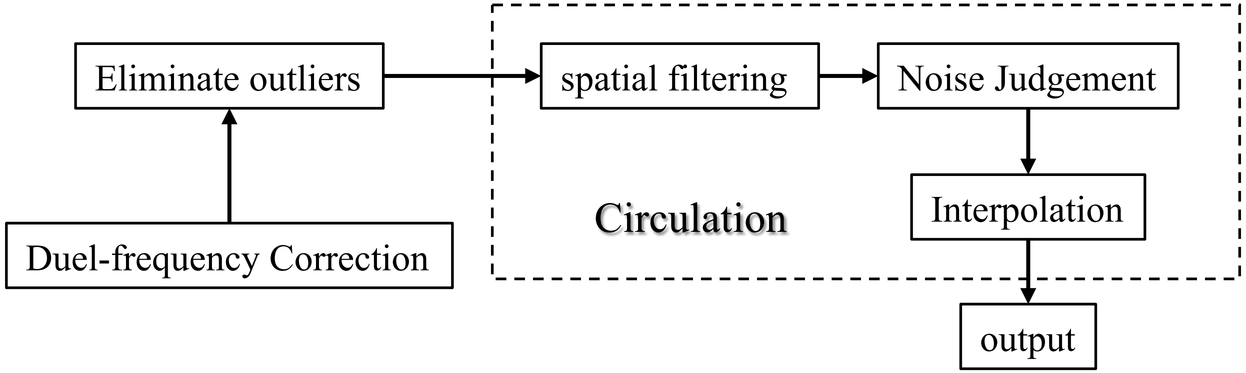
NP Model by Cross Point is more Suitable for Reprocessed SLA Data

Ionosphere Correction

➢ **Duel-frequency Correction**

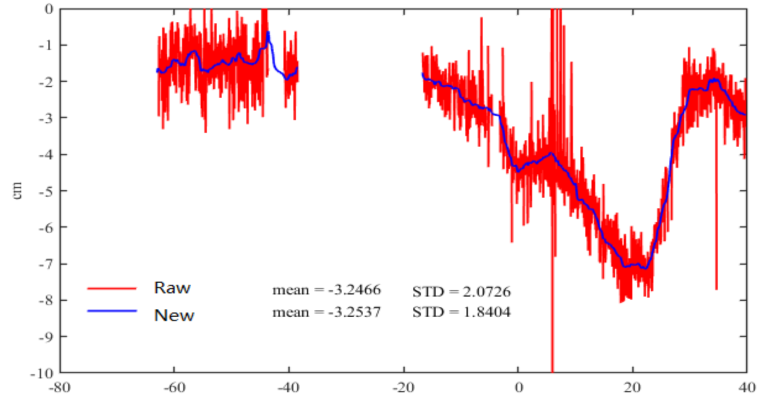
$$\delta f = \frac{f_C^{\,2}}{f_{Ku}^{\,2} - f_C^{\,2}} \qquad Iono = \delta f[(Range_{Ku} + SSB_{Ku}) - (Range_C + SSB_C)]$$

Process Flow

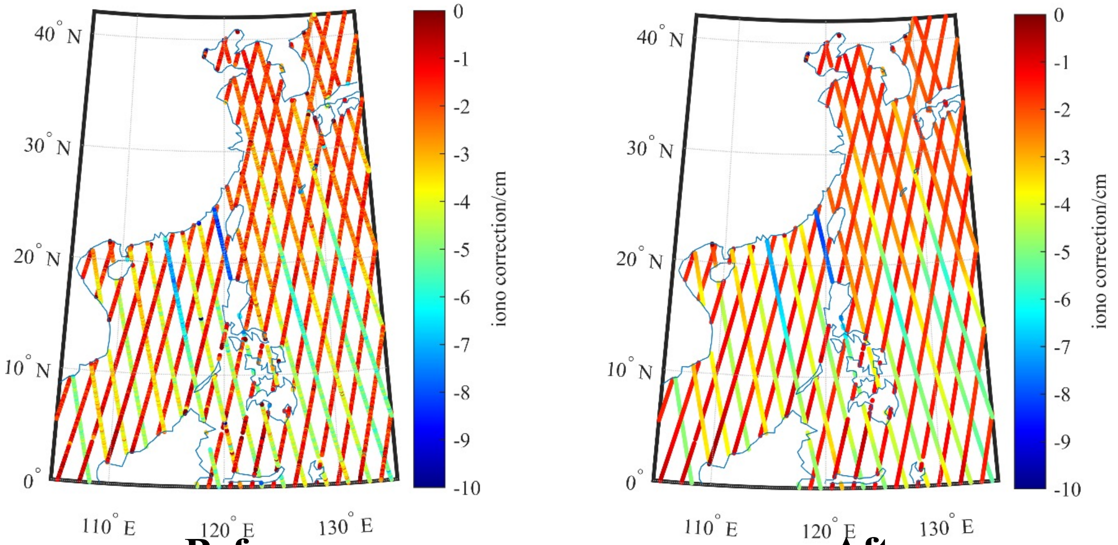


Lanczos Filter（150km）➡ Retain Low Frequency Signal

- One Pass Data Processing Result



- One Period Data Processing Result



Before **After**

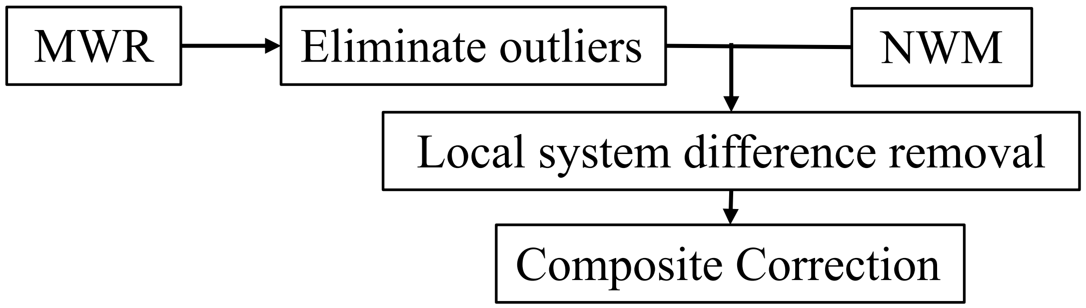
Wet Tropospheric Correction

- Model

$$\Delta h_{vap} = -[22.1\times 10^{-6}\int_{Z_s}^{Z_{sat}} \frac{P_w}{T}dz + 3.73\times 10^{-1}\int_{Z_s}^{Z_{sat}} \frac{P_w}{T}dz]$$

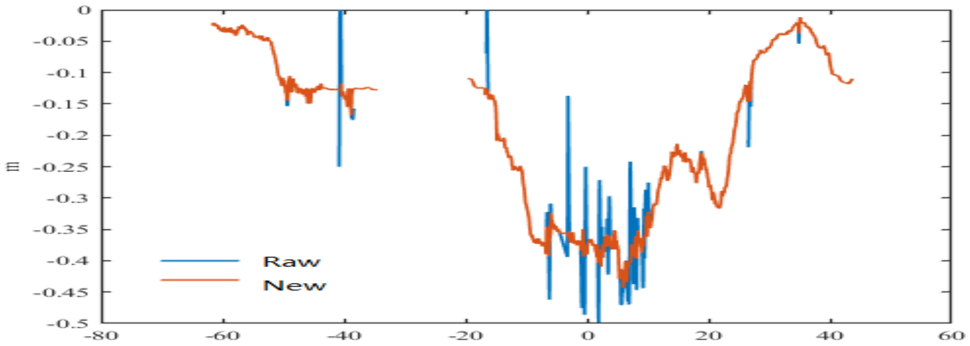
Process Flow

Composite Correction with Numerical Model and Radiometer Observations

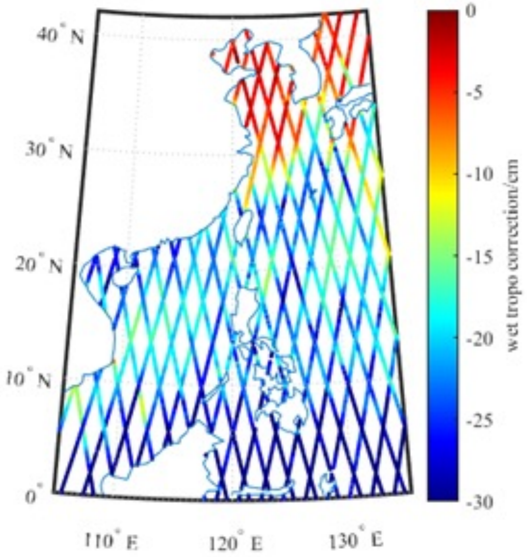


Local Processing → Retain more Valid MWR Observation

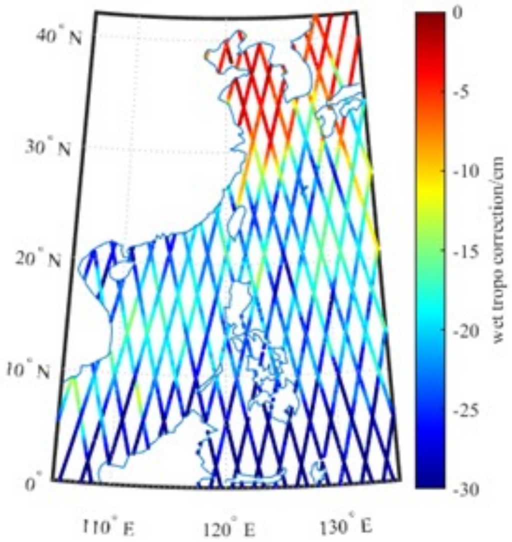
- One Pass Data Processing Result



- One Period Data Processing Result



Before



After

Ocean Tide Correction

Calculating ocean tide with coastal harmonic constant of X-TRACK.

- **Harmonic Analysis**

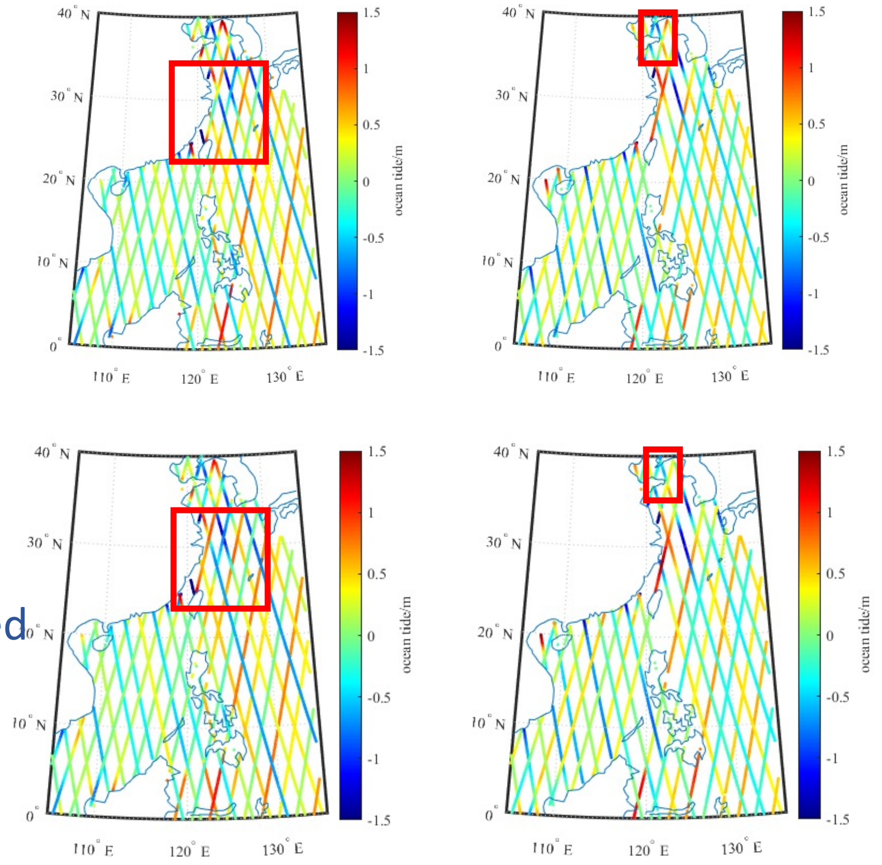
$$h(t) = H_0 + \sum_{i=1}^{8} f_i H_i \cos[w_i t + (V_{0i} + u_i) - g_i]$$

- **Tidal Component**： M2, S2, N2, K2, K1, O1, P1, Q1

	V0（°）	ω（°/h）
M2	360-2s+2h1	28.98410424
S2	360	30.00000000
K2	360+2h1	30.08213728
N2	360-3s+2h1+p	28.43972954
K1	90+h1	15.04106864
…	…	…

SGDR

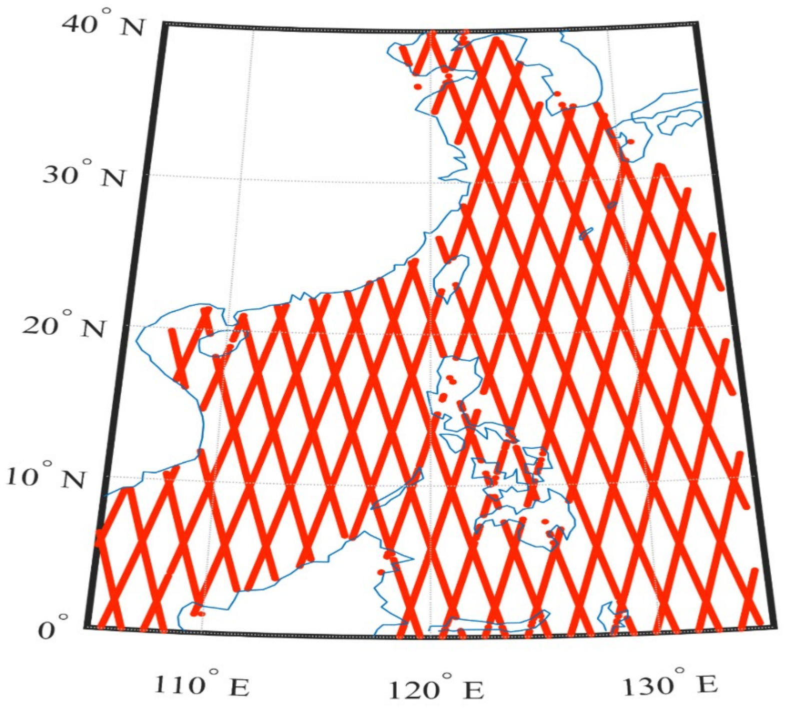
Reprocessed



Improving consistency in coastal area

HY-2B Altimetry Data reprocessing

- **Data**: **HY-2B SGDR/GDR (37 Passes)**
- **Range**: **105~135 ° E, 0~42 ° N**
- **Time Series**: **2018.11 - 2022.6（73~79 Cycles）**



- **Process Flow**

Waveform Retracking

- Coastal Waveform by Determining the Effective Trailing Edge and the Low Noise Leading Edge

Coastal Range Correction

- SSB Correction
- Iono Correction
- Tropo Correction
- Ocean Tide Correction

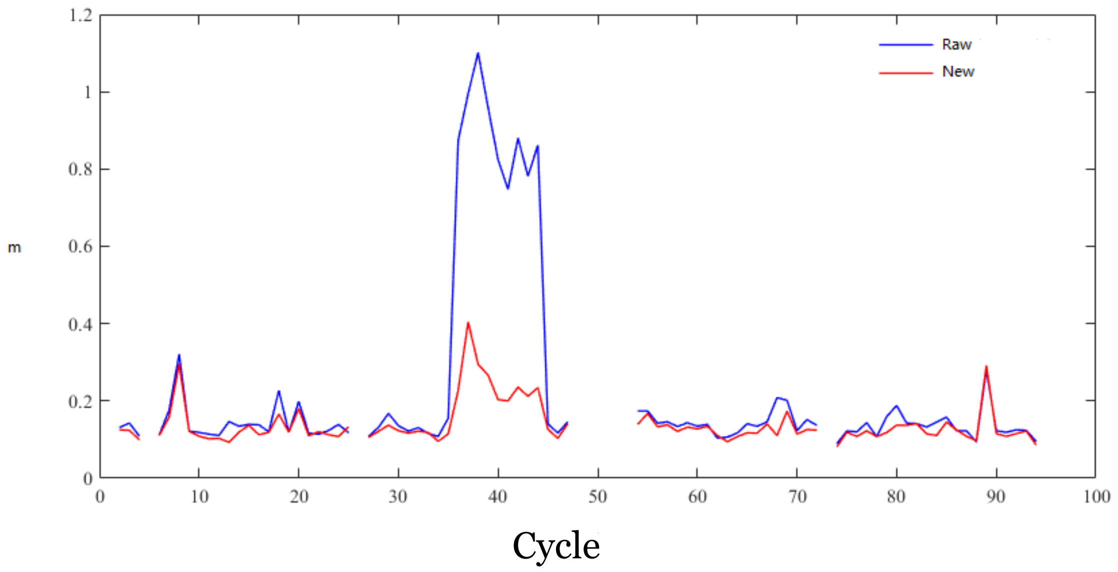
Altimetry Dataset

- 1/20Hz SLA Data
- All Parameters Record

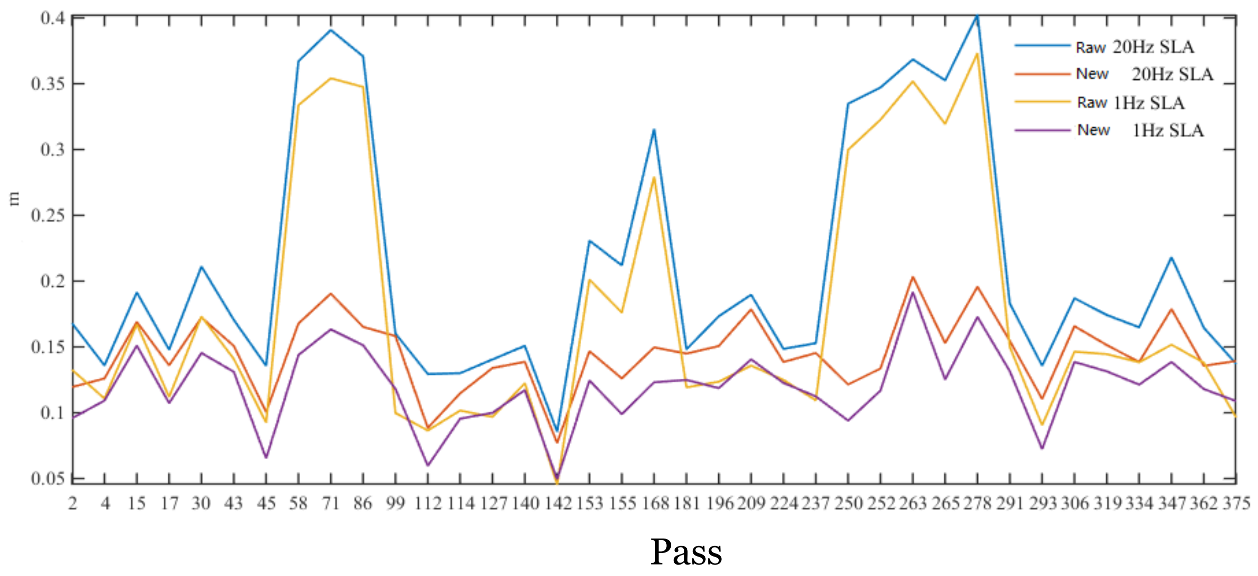
Analysis of reprocessed HY-2B altimeter data

➢ Comparison with original SGDR Data

- period-mean value of SSH difference at cross point



- Period-mean standard deviation



- Reprocessed data have less error observation than HY-2B altimeter SGDR data
- Reprocessed data are more stable than HY-2B altimeter SGDR data

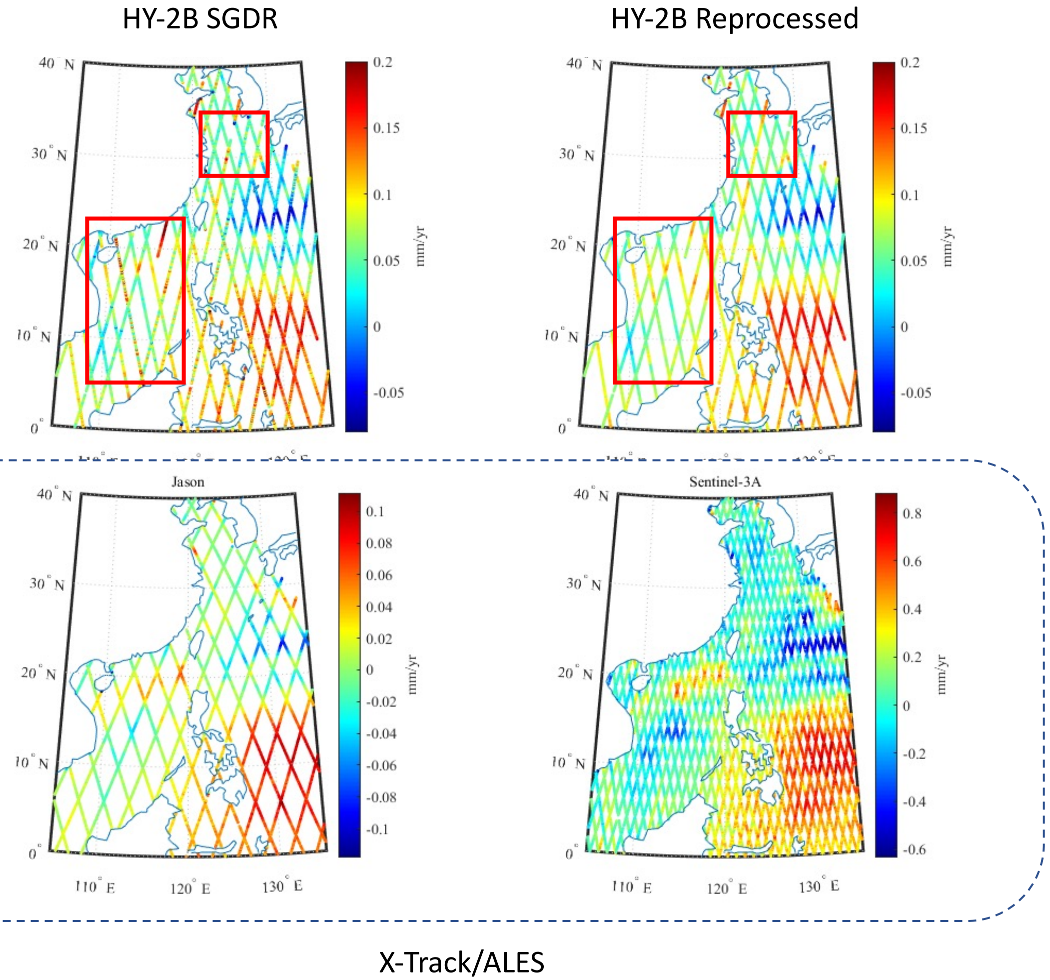
➢ Comparison with X-track/ALES Data

• Data Processing

	Reprocessed Dataset	X-TRACK/ALES
Retracking	The proposed method	ALES
SSB	Local Model	Non-parameter Model
Iono	Improved	Improved
Wet Tropo	Composite	GPD+/MWR
MSS	CLS-2015	Improved
Ocean Tide	Improved by X-TRACK Tide	FES2014

The deviation of the reprocessed dataset is smaller and the availability is higher than the SGDR Data, the SLA variation is more consistent with the X-Track/ALES product.

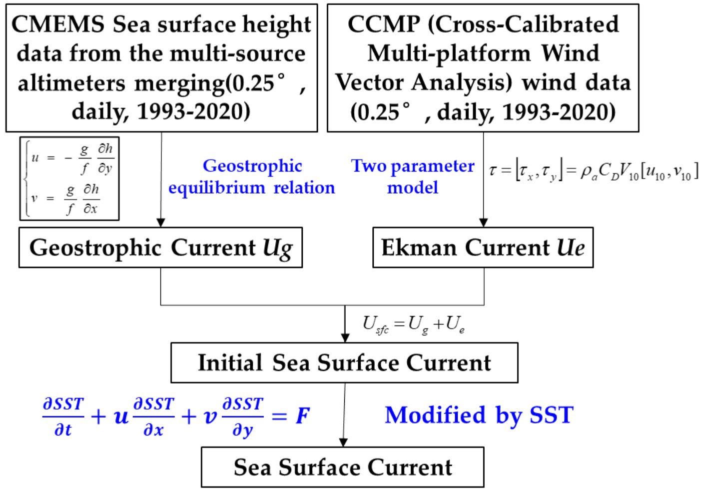
• Comparison of SLA Change

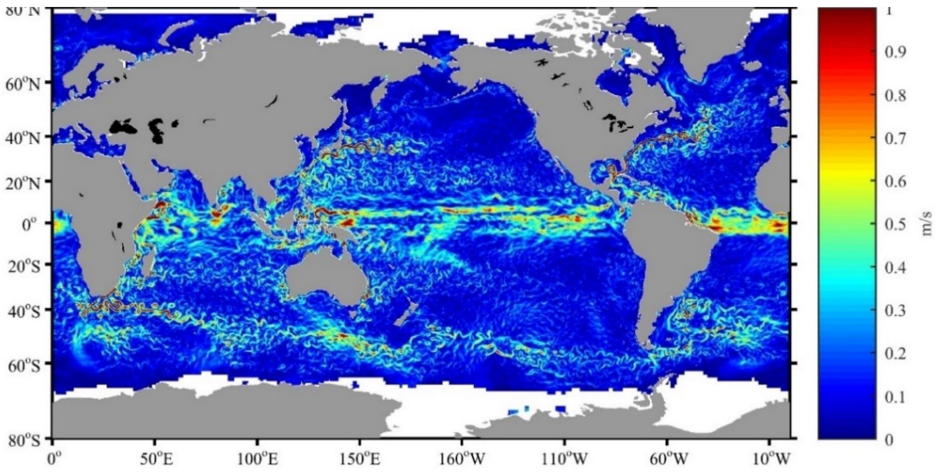


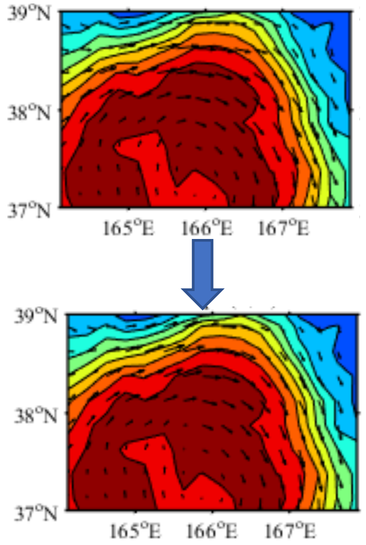
Project results after 3 years of activity

Study on ocean current

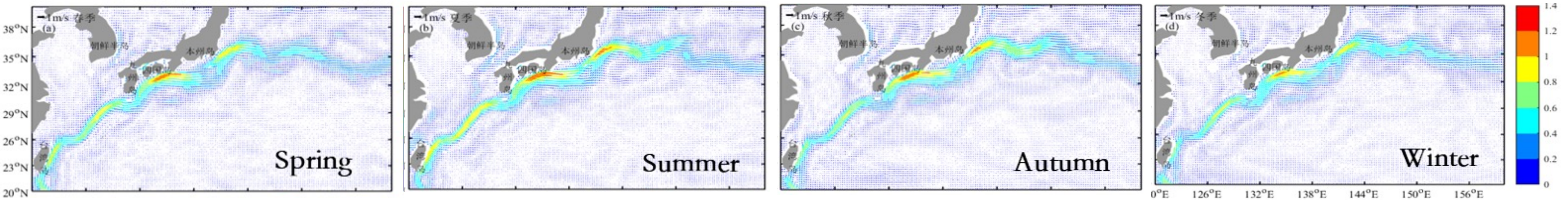
- **Generation of sea surface current data by combing the altimeter, sea surface wind and SST.**







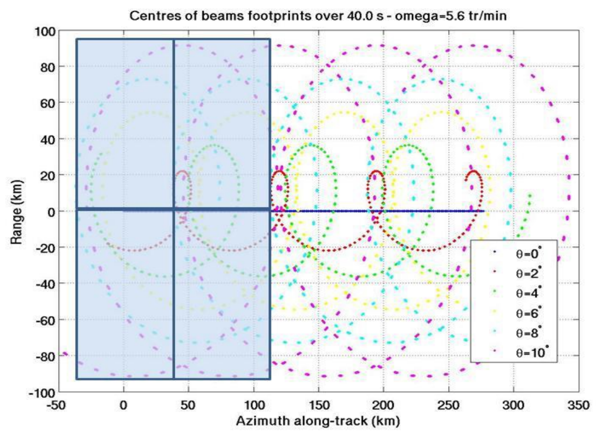
- **Sea surface current data application on the Kuroshio.**



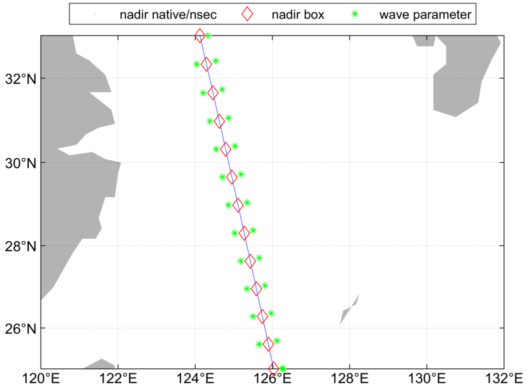
Multi year seasonal average flow field

Study on ocean wave

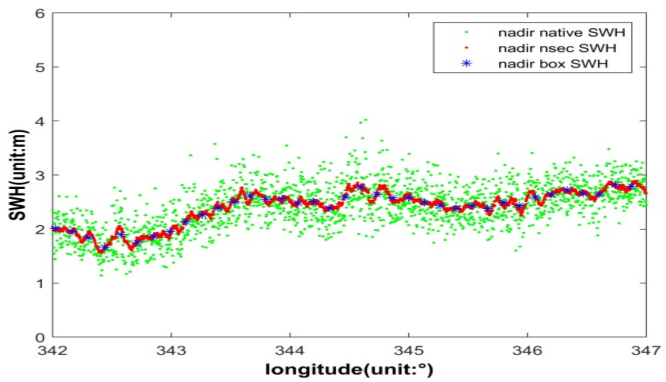
➢ **Evaluation of CFOSAT SWIM ocean wave**



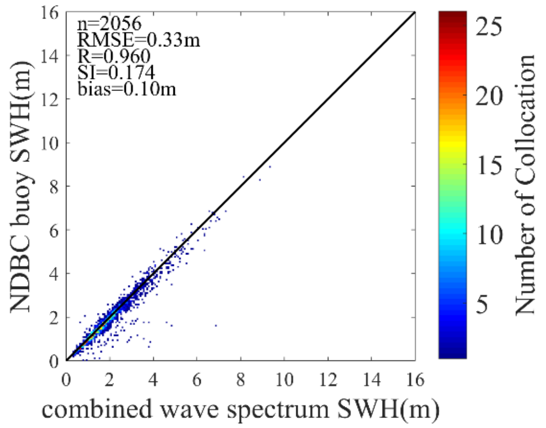
SWIM working principle

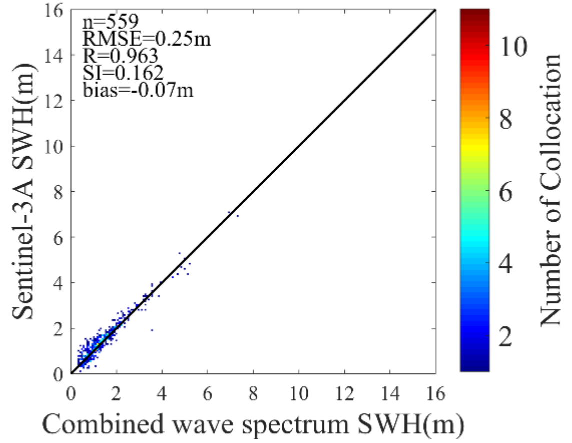


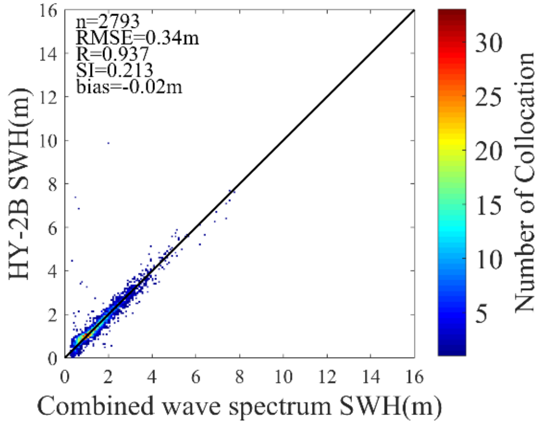
Example of the location of nadir and off-nadir SWH data



Example of the comparison of three kinds of nadir SWH

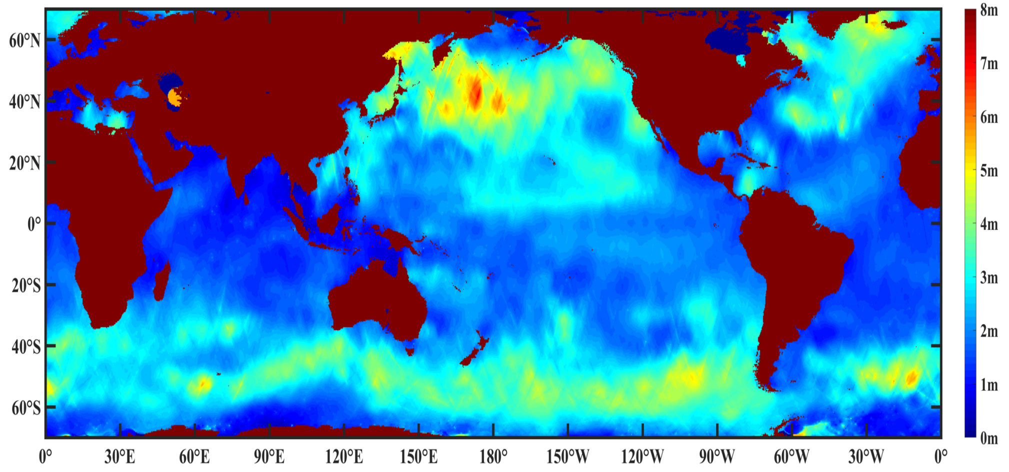




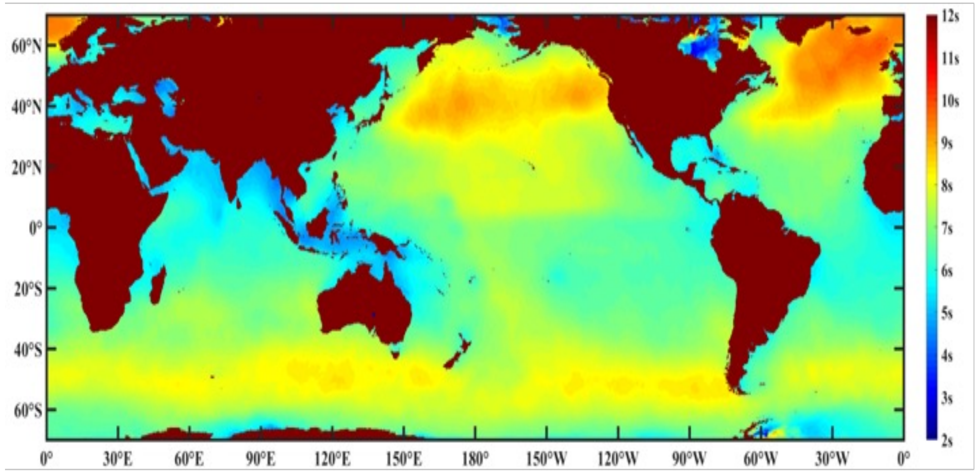


	n	bias	RMSE	R
Buoy	2056	0.10m	0.33m	0.960
Jason-3	13348	0.04m	0.28m	0.981
HY-2B	2793	-0.02m	0.34m	0.937
HY-2C	7209	-0.15m	**0.27m**	0.989
Sentinel-3A	559	-0.07m	**0.25m**	0.963
Sentinel-3B	567	-0.10m	**0.25m**	0.963
SARAL	9731	-0.02m	0.62m	0.933

➢ The merging of global SWH and MWP data

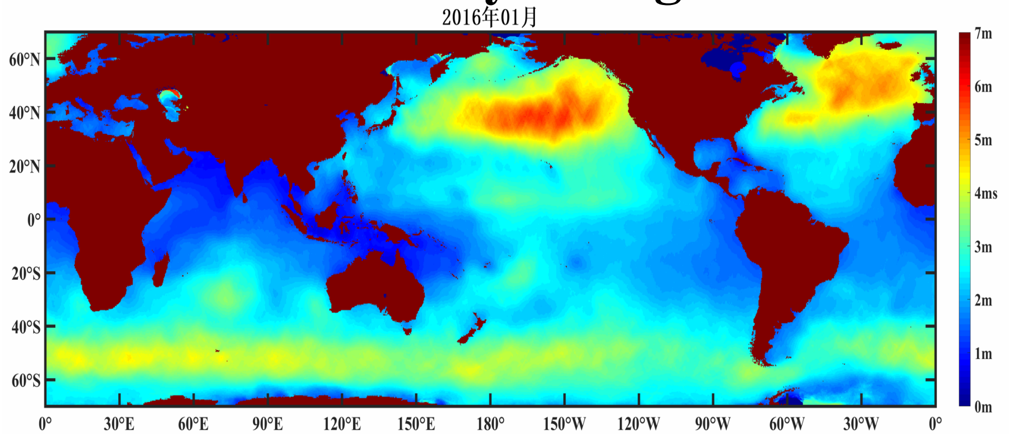


The global distribution of SWH

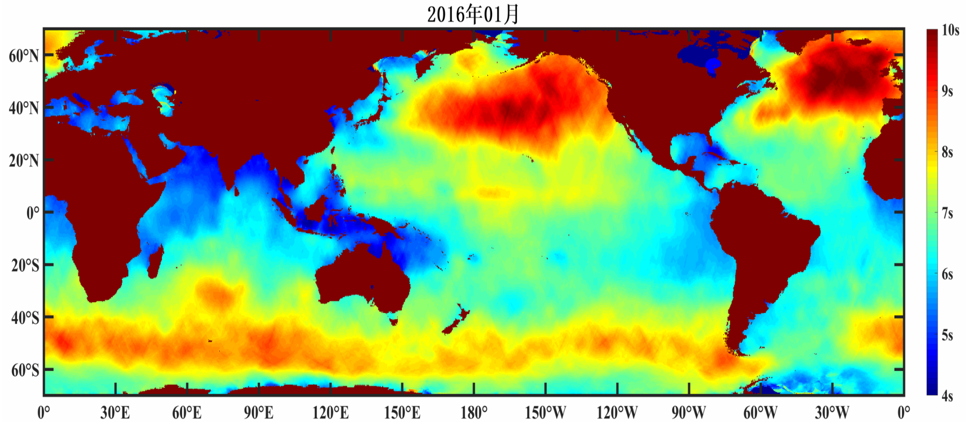


The global distribution of MWP

➢ Characteristics analysis of global ocean wave



The distribution of global ocean wave monthly SWH

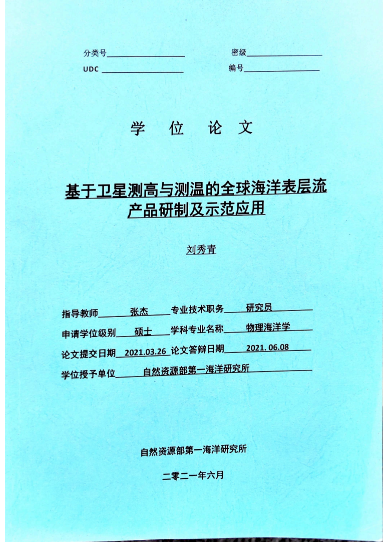


The distribution of global ocean wave monthly MWP

Training of young scientists on the project

Five young scientists from FIO take part in the study, and two had graduated.

- Xiuqing LIU: graduated Major, data oceanic application on ocean circulation.
- Guozhou Liang: graduated Master, Major: data application on ocean wave.
- Zhihong Heng: Master Student, retracking of waveform.
- Fengjia Sun: Master Student, ocean wave.
- Jie sun: Master Student, tropospheric correction of altimeter.



Two young scientists from DTU space take part in the study.

The Chinese young scientists have be trained on the data processing of altimeters and data processing and application on waveform retracking, ocean wave and ocean current. The European young scientists contributes to the data processing of altimeter on ocean wave.

Thesis Titles are:

- Application and Evaluation of Surface currents Product Generation Method Based on Satellite Altimetry and Satellite Temperature Measurement.
- Comprehensive Research on Global Ocean Waves Multi-parameter Based on Multiple Satellite Microwave Remote Sensing Measurements.
- Study on Coastal Waveform Retracking and Reprocessing of Range Correction for HY-2 Satellite Altimeter.

Publications after 3 years of activity

1. Yang Jungang, Jia Yongjun, Fan Chenqing, Cui Wei. 2023. Preliminary results of the global ocean tide derived from HY-2A radar altimeter data. Acta Oceanologica Sinica, 42(2): 65–73.
2. Hong, Z.; Yang, J.; Liu, S.; Jia, Y.; Fan, C.; Cui,W. Coastal Waveform Retracking for HY-2B Altimeter Data by Determining the Effective Trailing Edge and the Low Noise Leading Edge. Remote Sens. **2022**, 14, 5026.
3. Cui,W.; Yang, J.; Jia, Y.; Zhang, J. Oceanic Eddy Detection and Analysis from Satellite-Derived SSH and SST Fields in the Kuroshio Extension. Remote Sens. **2022**, 14, 5776.
4. Liang, G.; Yang, J.;Wang, J. Accuracy Evaluation of CFOSAT SWIM L2 Products Based on NDBC Buoy and Jason-3 Altimeter Data. Remote Sens. **2021**, 13, 887.
5. Nilsson, B., Andersen, O. B., Ranndal, H., and Rasmussen, M. L.: Consolidating ICESat-2 ocean wave characteristics with CryoSat-2 during the CRYO2ICE campaign, EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-10395.

The planning of the following year

- To continue data applications on ocean wave, ocean current and mesoscale eddy in the study area.
- spatial-temporal characteristics analysis of marine dynamic environment in the China seas and western Pacific Ocean, such as ocean wave, ocean circulation and mesoscale eddies.

Thanks for your attentions