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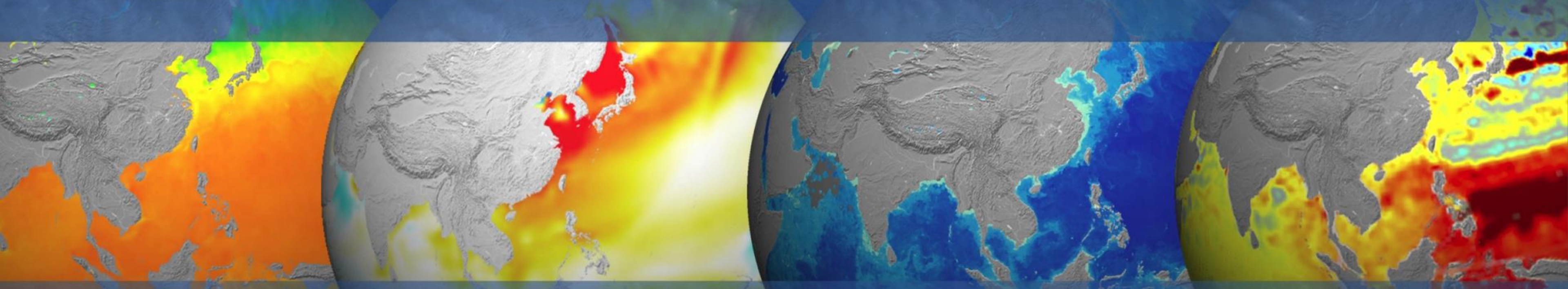

12 to 17 November 2018 | Shenzhen University | P.R. China

Introduction of HY-2 Radar Altimeter and its Data Processing

Hosted by

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- Introduction of HY-2 RA
- HY-2A RA Data processing
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Introduction of HY-2 Satellite

HY-2 Satellite is a series of Chinese marine dynamic environment satellite.

Aim of HY-2 is to obtain the information of sea surface wind, sea surface height, significant wave height and sea surface temperature.

HY-2A was launched on August 15, 2011 (UTC) using a Long March 4B vehicle in the Taiyuan Satellite Launch Center.

Payloads(4): microwave scatterometer, radar altimeter, scanning microwave radiometer, calibration microwave radiometer and etc.

HY-2B Satellite

HY-2B Satellite was launched on October 24, 2018 (UTC) using a Long March 4B vehicle in the Taiyuan Satellite Launch Center.

Payloads: microwave scatterometer, radar altimeter, scanning microwave radiometer, calibration microwave radiometer and etc.

- **HY-2C** Satellite will be launched in 2019.
- **HY-2D** will be continue…

MWR (Microwave Radiometer)

MWR is used to obtain the global sea surface temperature, sea surface wind, the water vapor content, cloud water content, sea ice, rainfall and etc.

Wind speed	- Range: 7-50 m/s - Precision: 2 m/s or 10%(whatever is greater)
Sea Surface Temperature(SST)	- Range: 100-300 K - Precision: 1.0 K
Ice monitoring	- Edge: 15% - Thickness: 2 m
Water vapor	- Precision: 10%

SCAT (Ku-band Scatterometer)

SCAT is a Ku-band pencil-beam conically scanning radar scatterometer to measure sea surface wind vectors.

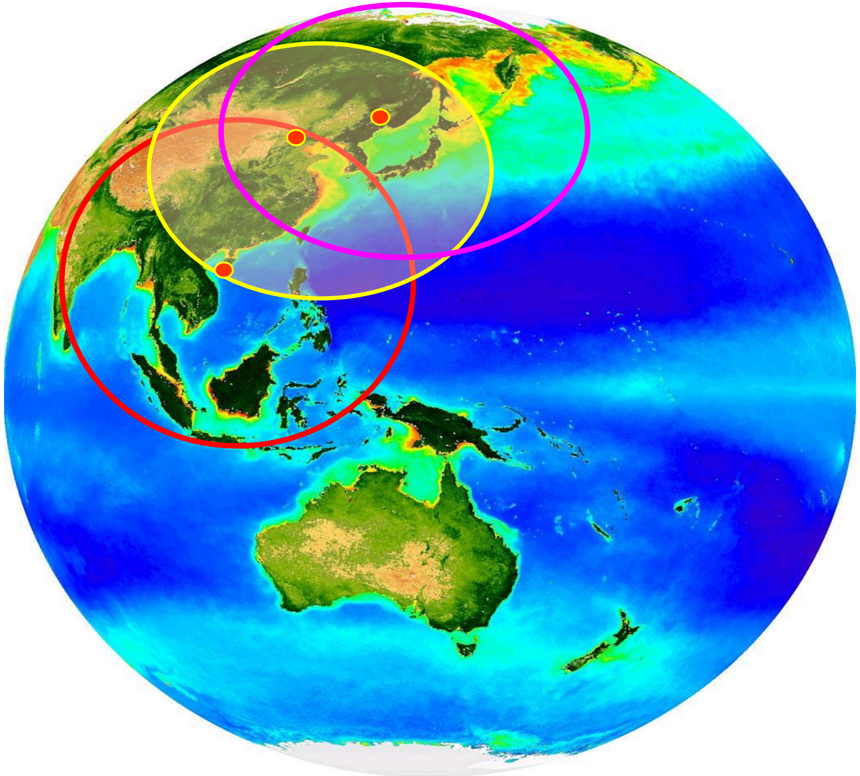
Parameter	Value	Parameter	Value
Center frequency	13.256 GHz	Polarization	HH, VV
Backscattering range	-40~+20 dB	Backscattering precision	0.5 dB
Wind speed range (m/s)	2~24 (after processing)	Wind speed precision	**2 m/s**
Wind direction range	0-360°	Wind direction precision	**20°**
Swath width	**HH: > 1350 km** **VV: >1700 km**	Ground resolution	25 km
Footprint size	Outer beam: 37 x 26 km Inner beam: 33 x 23 km	Local incidence angle	Outer beam: 49° Inner beam: 41°

Introduction of HY-2A RA

RA is used to detect sea surface height (SSH), significant wave height (SWH) and wind speed.

- **SSH precision: < 8 cm (mission specification)**
- **SWH range: 0.5-20 m, SWH precision of < 10 % or 0.5 m (whatever is greater).**

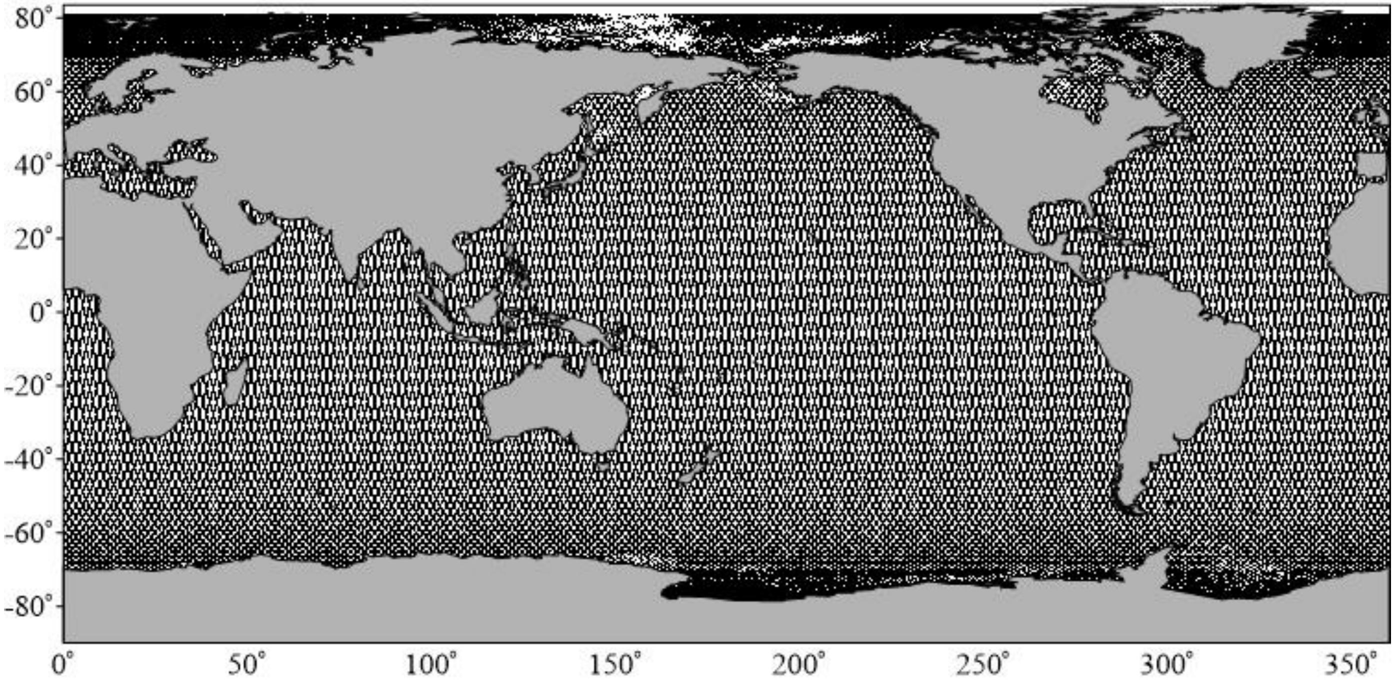
Parameter	Value
Frequency	13.58GHz (Ku-band), 5.25GHz (C-band)
Repeat Cycle	14d/168d
Orbit height	971km
semi-major axis	7341.732 km
inclination	99.34015°
Distance of two neighboring pass	207.64km/17.31km
Local descending time	6:00 am

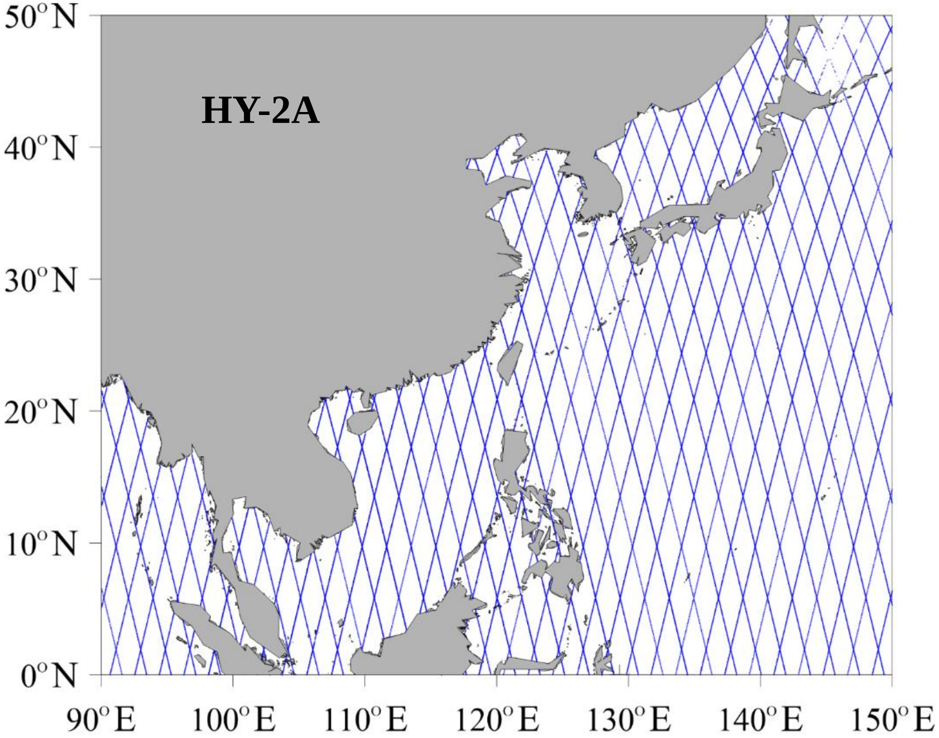


Ground stations

- Beijing
- Sanya
- Mudanjiang

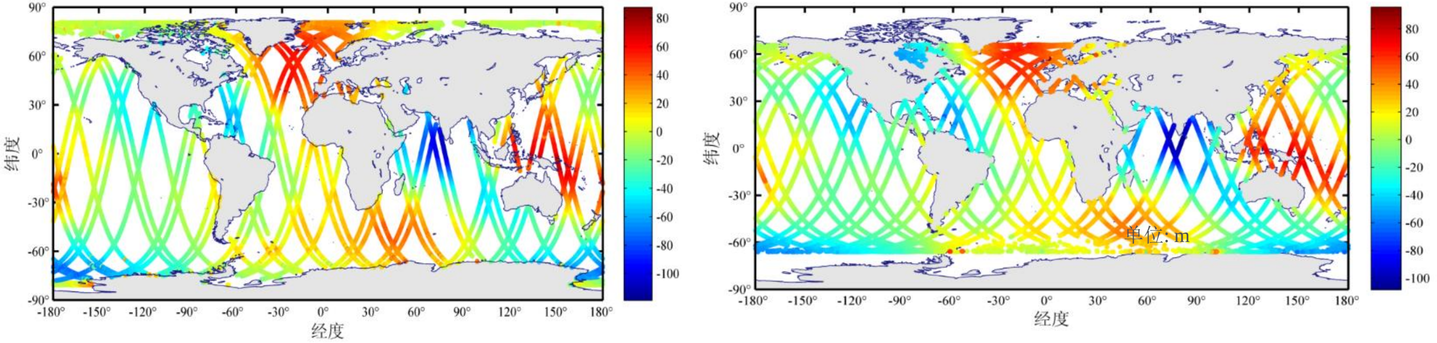
Ground track of HY-2A RA



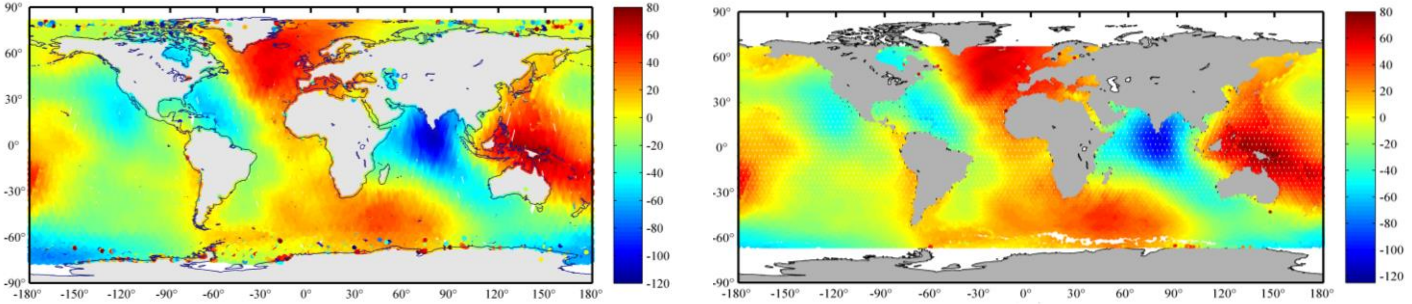


Ground track of altimeters

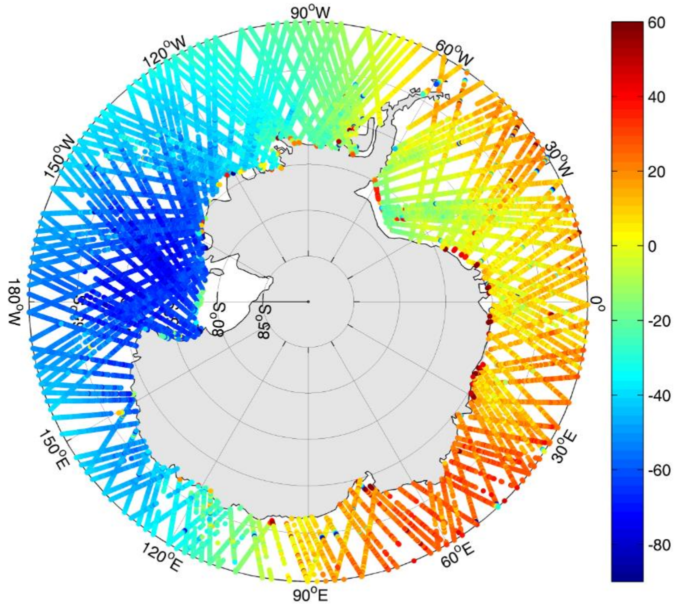
➢ SSH of HY-2A RA

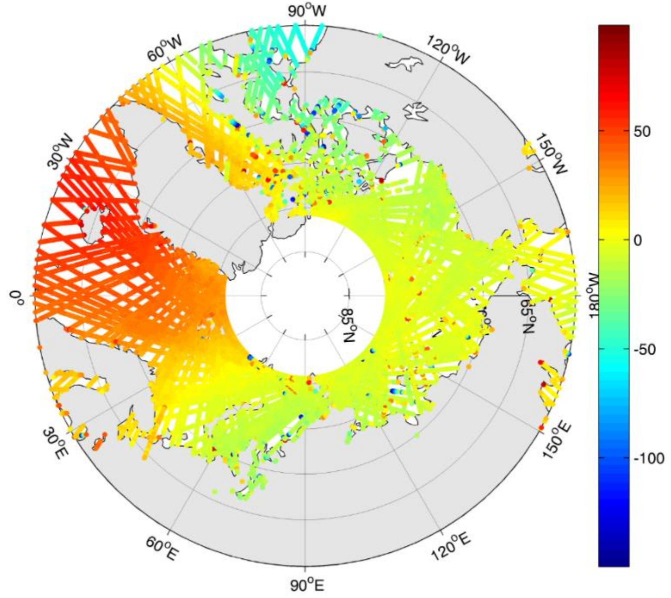


Along-track SSH of HY-2A RA (left) and Jason-2 (right) in the same two days



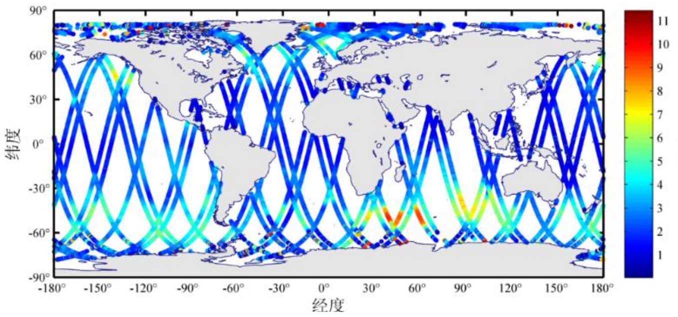
Along-track SSH of HY-2A RA (left) and Jason-2 (right) in the whole cycle

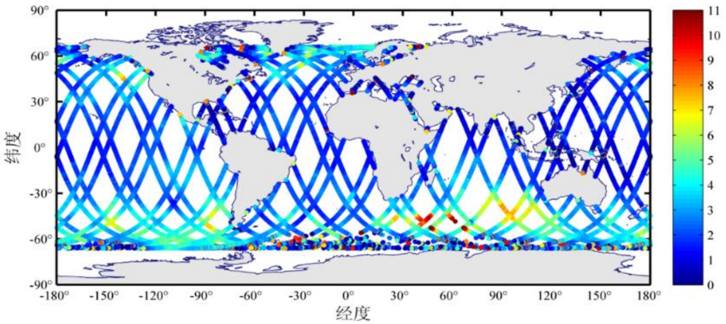




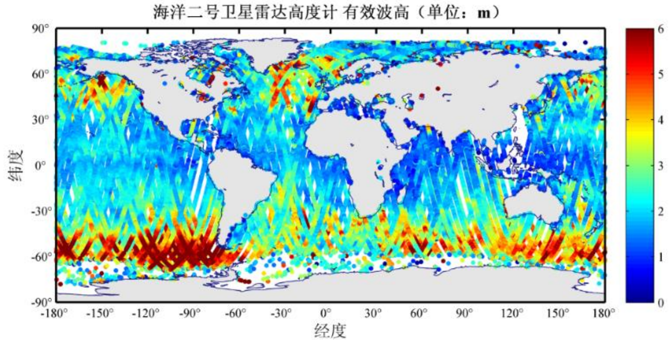
Along-track SSH of HY-2A RA of the whole cycle in the northern and southern polar area

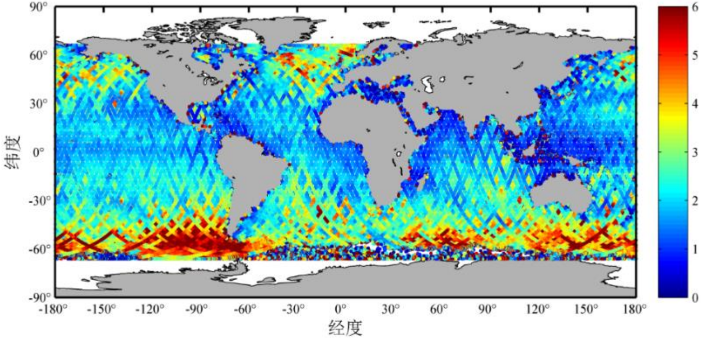
➢ SWH of HY-2A RA



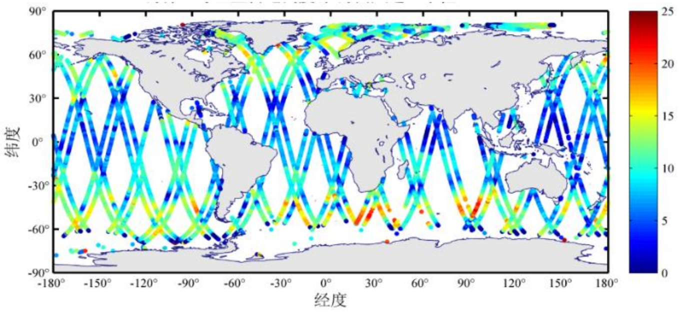


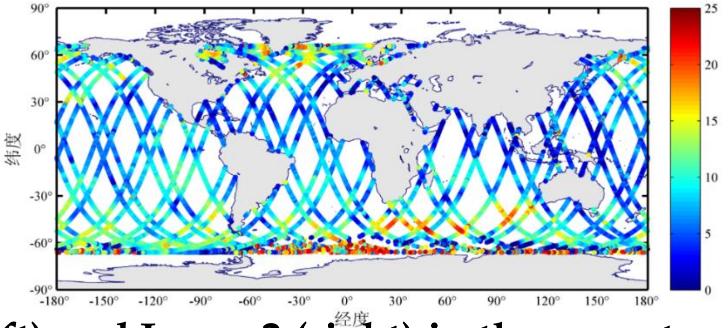
Along-track SWH of HY-2A RA (left) and Jason-2 (right) in the same two days



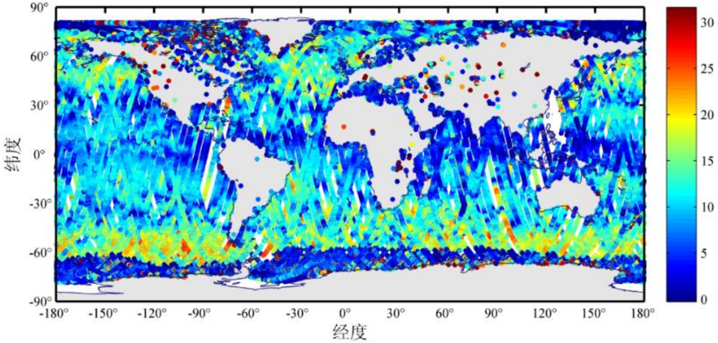


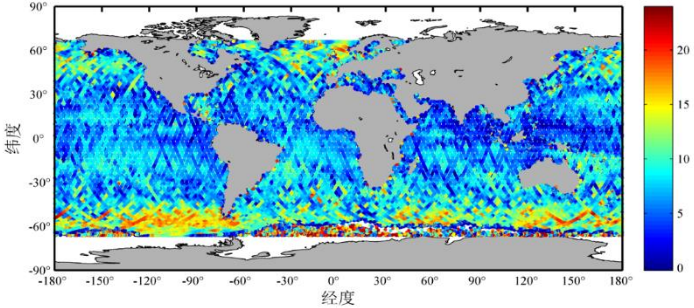
Along-track SWH of HY-2A RA (left) and Jason-2 (right) in the whole cycle





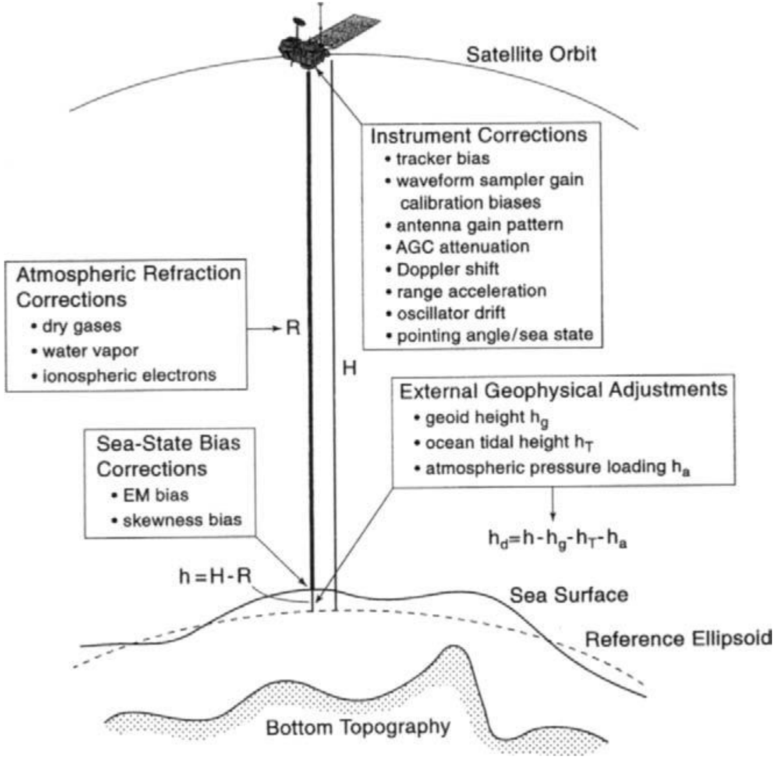
Along-track wind speed of HY-2A RA (left) and Jason-2 (right) in the same two days





Along-track wind speed of HY-2A RA (left) and Jason-2 (right) in the whole cycle

HY-2A RA Data processing



- Precision orbit determination
- Atmospheric correction
- Sea state bias (SSB) correction
- Geophysical adjustment correction
- Significant Wave Height (SWH) inversion
- Wind Speed inversion

1. Precision orbit determination (POD)

POD is determination of satellite centroid with high precision in a specific reference coordinate system.

- SLR (Satellite laser ranging) : measure the round trip time of the laser pulse from the ground observation point to the satellite equipped with the reflector.
- DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite): broadcasts a radio beacon from the ground station to the satellite and measures the Doppler shift and calculate the distance of the satellite.
- GPS :determine the location and time of satellite by GPS satellite constellation.

For HY-2A RA: Combination of DORIS and GPS improve the orbit precision.

2. Atmospheric correction

The electromagnetic pulse emitted by the altimeter is subjected to the refraction effect of the atmosphere during the propagation process, resulting in a delay in the pulse transmission and range error.

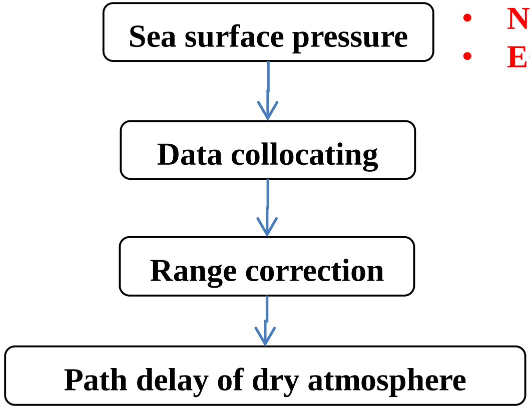
Atmospheric corrections include:

- **Dry tropospheric correction (干对流层校正)**
- **Wet tropospheric correction (湿对流层校正)**
- **Ionospheric correction (电离层校正)**

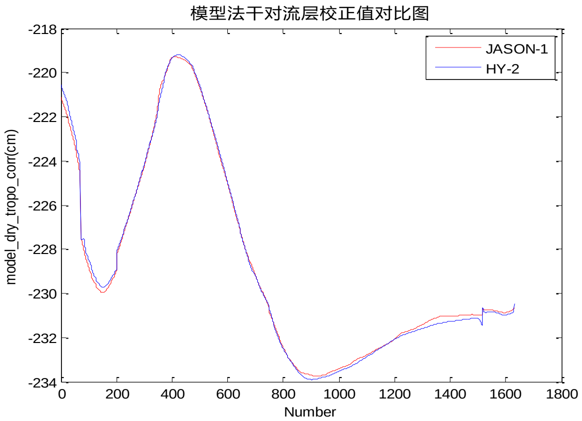
Dry atmosphere affects refractive index of atmosphere, causing pulse delay. It is the major part of tropospheric correction and typical value is 190-250 cm.

Algorithm: $$PD_{dry} = 0.2277\,P_0\left(1 + 0.0026\cos 2\varphi\right)$$

P_0 is Sea surface atmospheric pressure. φ is latitude of ground point.



- NCEP
- ECMWF



Validation by Jason-1 data

➢ Wet tropospheric correction

Atmospheric water vapor and cloud liquid water cause pulse delay. The water vapor correction is the main part and typical value is 0-50cm. Typical value of cloud liquid water correction is less than 1 cm.

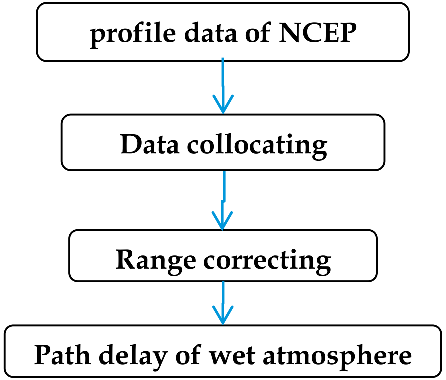
Two kinds of wet tropospheric correction are given in HY-2A RA data.

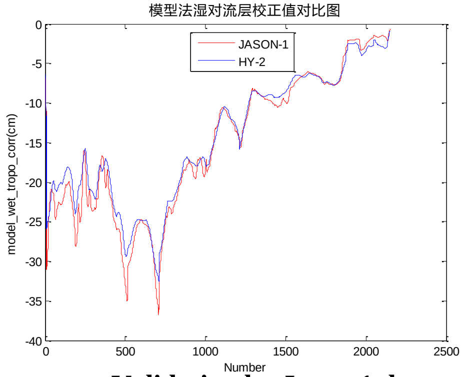
- **Meteorological model method:** calculate path delay by NCEP or ECMWF data.
- **Calibration radiometer method:** calculate path delay by calibration microwave radiometer data.

Atmospheric temperature and humidity, cloud liquid water data from NCEP or ECMWF data are used to calculate correction.

water vapor part: $PD_V = 1.763*10^{-3}\int_0^H (\rho_V(z)/T)dz$ cloud liquid water: $PD_L = 1.6\int_0^H \rho_L(z)dz$

ρ_V, ρ_L, T are density profile of water vapor, cloud liquid and atmospheric temperature profile data. H is the altitude of satellite.





Validation by Jason-1 data

Calibration radiometer model method

① Retrieve cloud liquid water content and wind speed by calibration radiometer brightness temperature.

② Calculate initial value of correction PD^g according to wind speed.

③ Calculate middle value of correction PD^1 and PD^2 according to PD^g and wind speed.

④ Obtain the water vapor correction PD^f by weighing average of PD^1 and PD^2.

⑤ Wet tropospheric correction is equal to the sum of water vapor and cloud liquid water correction.

➢ Ionospheric correction

Refraction occurs when electromagnetic waves pass through the ionosphere, which causes range error 0.2cm-40cm. Ionospheric correction is calculated by total electron content (TEC).

$$\Delta H_{ion} = \frac{40.3}{f^2}\int_0^{h_0} n_e(z)dz = \frac{A}{f^2}TEC$$

Dual-frequency method: calculate TEC by the SSH of Ku and C band.

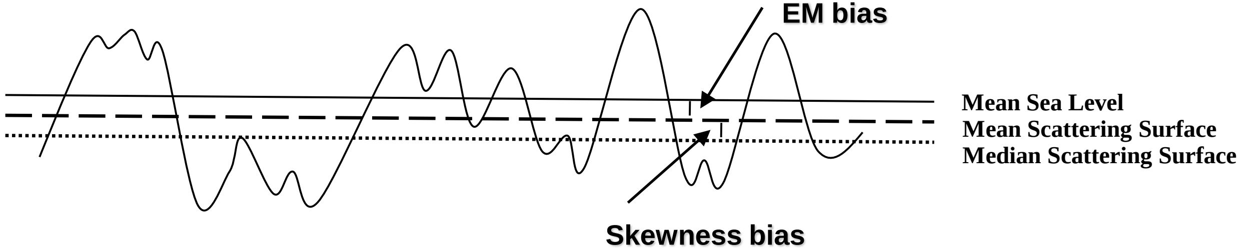
$$\Delta h_{ion} = \frac{A}{f^2}TEC = \frac{h_C - h_{Ku} + b_{Ku} - b_C}{K-1}$$

IRI model method: calculate TEC by the IRI (International Reference Ionosphere) model.

$$\Delta h_{ion} = \frac{40.3}{f^2}TEC$$

3. Sea state bias (SSB) correction

SSB correction is bias in the estimate of mean sea level because of differences between the distributions of the scatterers and the SSH. SSB includes electromagnetic (EM) bias and skewness bias.



SSB is the largest error influence in the range measurement.

$$SSB_m = SWH[a_1 + a_2 SWH + a_3 U + a_4 SWH^2 + a_5 U^2 + a_6 SWHU]$$

⬇

$$SSB = SWH(a_1 + a_2 SWH + a_3 U + a_6 SWH \cdot U)$$

- **constant model**
- **two-parameter model**
- **three-parameter model**
- **five-parameter model**
- **six-parameter model**

➢ Ocean tide

Ocean tide: the cyclic rise and fall of seawater, caused by slight variations in gravitational attraction between the Earth and the moon. 10-60cm in open sea，1-10m in coastal area.

Ocean loading tide： Vertical elastic motion of solid earth under the influence of seawater gravity caused by ocean tides, mm~cm.

- GOT00.2 model
- FES2004 model

➢ Solid earth tide

The solid earth tide (~cm) is due to the cyclic rise and fall of the earth's crust by the sun and lunar gravity, calculated by Cartwright model.

$$h_{solid} = \Delta h_m + \Delta h_s + \Delta h_c$$

Lunar component: $$\Delta h_m = h_2 \frac{M_m}{M_e} \frac{A_e^2}{D_m^3} (\frac{3}{2}\cos^2\theta_m - \frac{1}{2})$$

Solar component: $$\Delta h_s = h_2 \frac{M_s}{M_e} \frac{A_e^2}{D_s^3} (\frac{3}{2}\cos^2\theta_s - \frac{1}{2})$$

Earthly component: $$\Delta h_c = 0.202 h_2 (\frac{3}{2}\sin^2\psi - \frac{1}{2})$$

➢ Pole tide

Pole tide (<1cm) is due to the small perturbations of earth rotation axis. This entails a varying elastic response of the earth's crust.

The expression of pole tide:

$$h_{pole} = 32\sin(2\times lat)(m_1\cos(lon) + m_2\sin(lon))$$

$$m_1 = x_p - \bar{x}_p \quad m_2 = y_p - \bar{y}_p$$

(x_p, y_p) $(\bar{x}_p, \bar{y}_p)$ **are coordinate of pole point and its mean.**

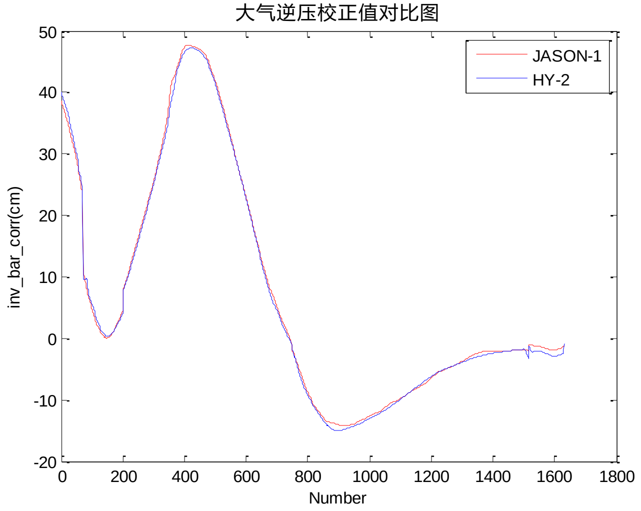
➢ Inverse Barometer (IB) Correction

As atmospheric pressure increases and decreases, the sea surface tends to respond hydrostatically, falling or rising respectively. Generally, a 1-mbar increase in atmospheric pressure depresses the sea surface by about 1 cm.

$$IB = -0.948 \times (P - \overline{P})$$

P **is sea surface atmospheric pressure**

$\overline{P}$ **is time varying mean of sea surface atmospheric pressure**



Validation by Jason-1 data

➢ High Frequency Response Correction

High frequency oscillation is the response of sea level to the dynamic part of atmospheric pressure and wind.

➢ Geoid

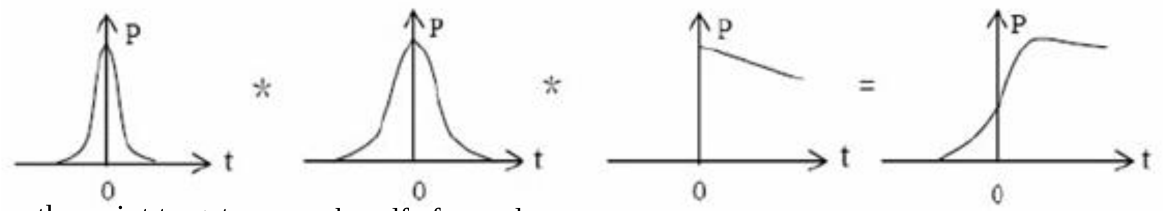
Geoid height is calculated from the EGM2008 model.

➢ Mean Sea Surface (MSS) and Bathymetry

MSS is calculated from MSS_CNES-CLS model (2′×2′).
The value of bathymetry is determined from ETOPO1 (1′×1′).

According to Hayne(1980) model, the return power is given by a three fold convolution:

$$W(t) = P_{FS}(t) * q_s(t) * p_\tau(t)$$



the point target response

the pdf of specular points on the sea surface

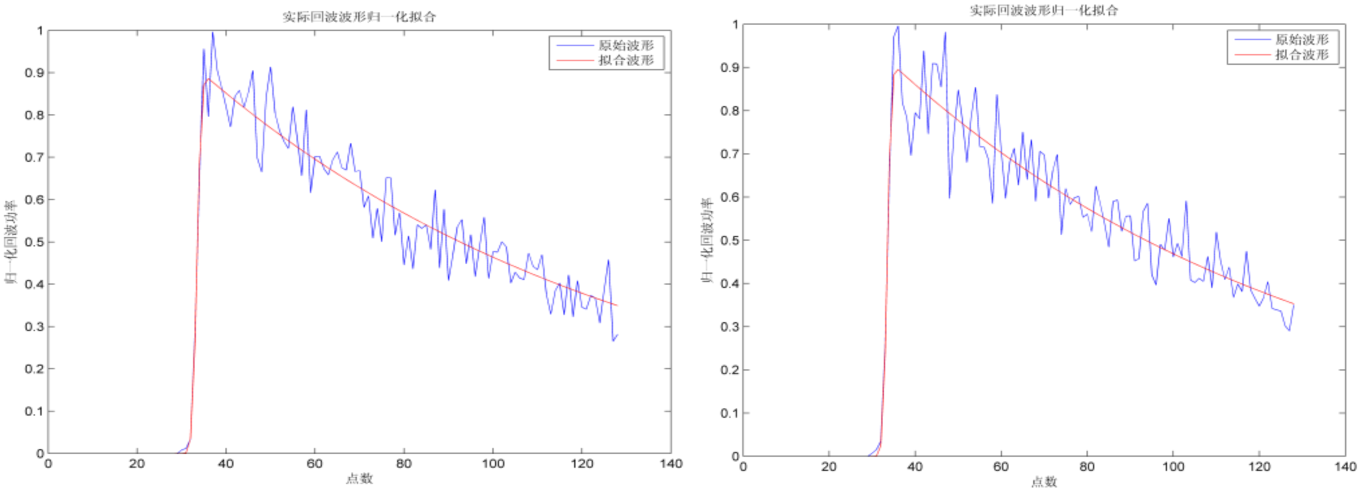
the flat surface response

$$W(t) = \frac{P_u}{2}\exp[-d(\Gamma + \frac{d}{2})]$$
$$\left\{\left[1 + erf(\frac{\Gamma}{\sqrt{2}})\right]\left[1 + \frac{\lambda_s}{6}(\frac{\sigma_s}{\sigma_c})^3 d^3\right] - \frac{\sqrt{2}}{\sqrt{\pi}}\exp(-\frac{\Gamma^2}{2})\frac{\lambda_s}{6}(\frac{\sigma_s}{\sigma_c})^3(\Gamma^2 + 3d\Gamma + 3d^2 - 1)\right\}$$

$$W = f(t_0, P_u, \sigma_c, \zeta)$$ **4 parameters are obtained by fitting the waveform.**

$$SWH = 2 * c * \sigma_s \qquad \sigma_s^2 = \sigma_c^2 - \sigma_p^2 \qquad \sigma_p = 0.513T$$ T=3.125ns

HY-2A RA introduces antenna pointing angle to improve SWH inversion accuracy.

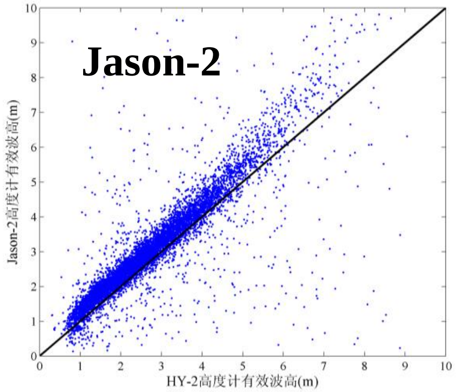


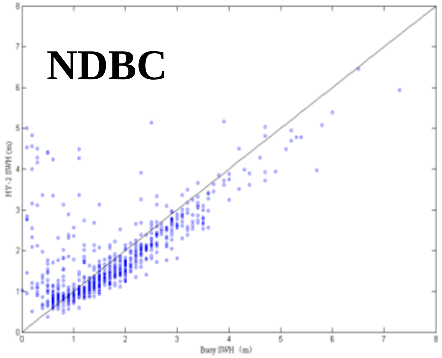
Example of waveform fitting for two observation points of HY-2A RA

Validation

- comparison with Jason-2 at the crossovers: standard deviation is 0.46m.
  - Data period：5th Oct. 2011 – 8th Jun. 2012
  - Temporal difference: 2h

- comparison with NDBC buoys: RMS is 0.32m.
  - Data period: Jan. – Jun. 2012
  - Spatial and temporal difference are 50km and 30min





6. Wind Speed Inversion

Wind speed is inversed by backscattering coefficient by Geophysical Model Function (GMF) - MCW model.

$$U_{10} = \frac{Y - a_{U_{10}}}{b_{U_{10}}} \qquad Y = \left[1 + \exp^{-\left(\vec{W_y}\vec{X} + \vec{B_y}\right)}\right]^{-1} \qquad \vec{X} = \left[1 + \exp\left(-\left(\vec{W}_x \vec{P}^T + \vec{B_x}^T\right)\right)\right]^{-1}$$

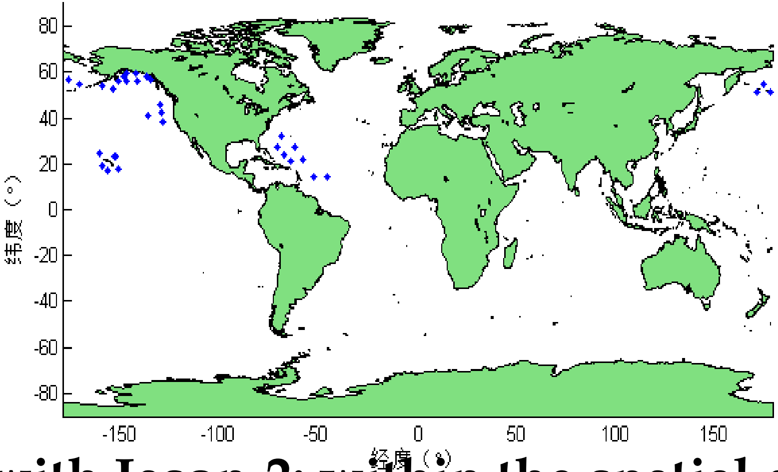
$$\sigma_0 = (AGC - 14.512385)/0.930235$$

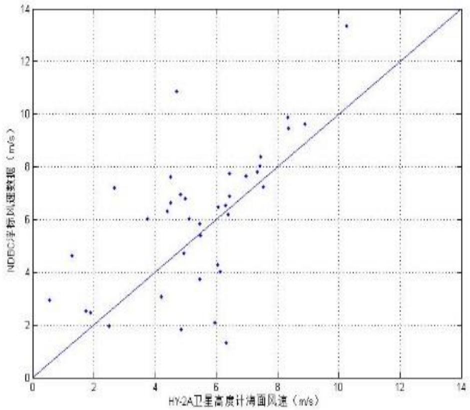
AGC is the value of Automatic gain control.

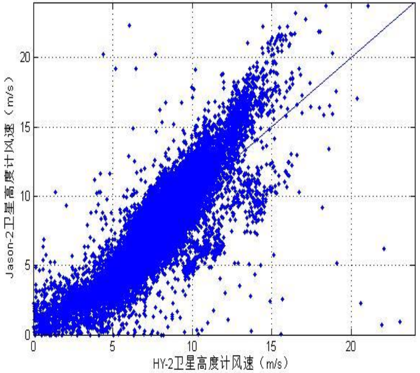
$$U_{10} = f\left(SWH, \sigma_0\right)$$

need to input SWH and Sigma0.

Validation







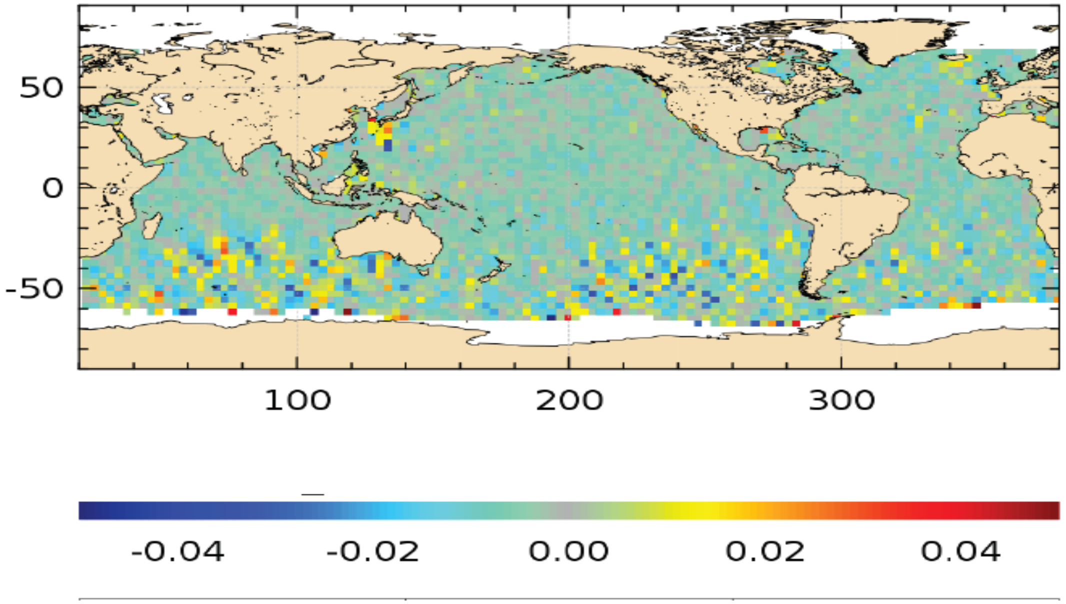
- comparison with Jason-2: within the spatial and temporal scale of 50km and 30min, RMSE is 1.91m/s。
- comparison with NDBC: RMSE is 1.98m/s。

➢SSH comparison

Differences de SSH	Nbre de points	.	Ecart-type	.
	HY-2A	Jason-2	HY-2A	Jason-2
Global	5485	10123	8.9 cm	7.0 cm
Global avec EO			7.8 cm	
Selection (Lat/Bat/VarOce)	2635	4647	6.2 cm	5.5 cm
Selection (Lat/Bat/VarOce) avec EO			5.9 cm	

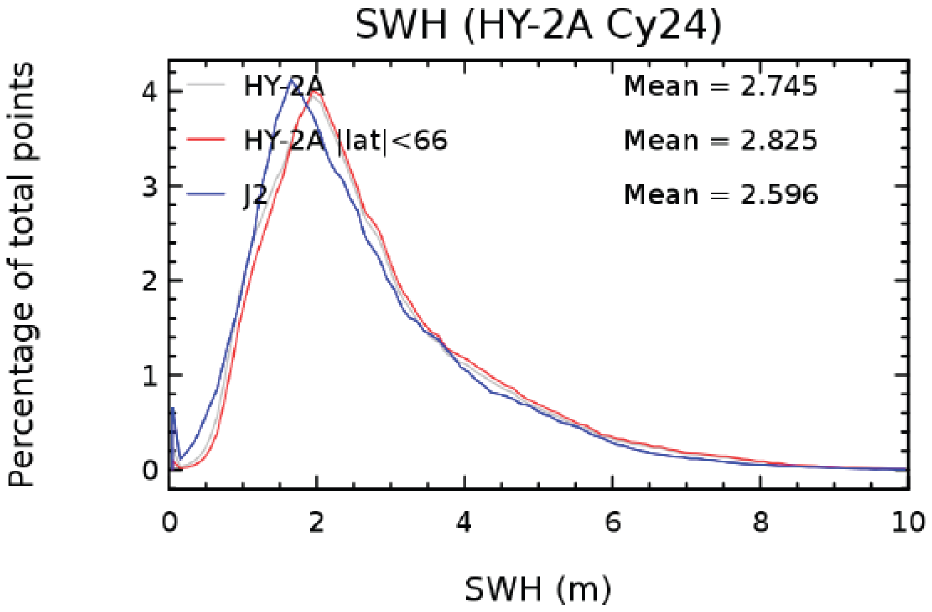
Refer to the report from CNES: The accuracy of HY-2A RA SSH is 6.2 cm and Jason-2 is 5.5 cm in the same longitude and latitude range.

➢SLA comparison



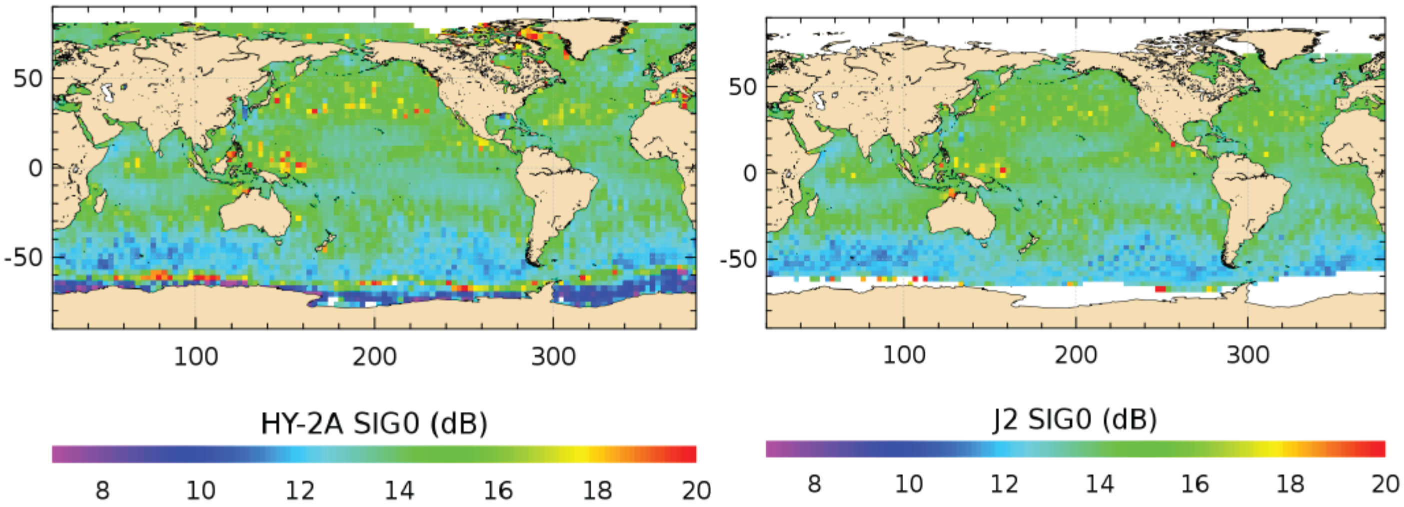
The average global SLA difference between HY-2A RA and Jason-2 is less than 1 cm.

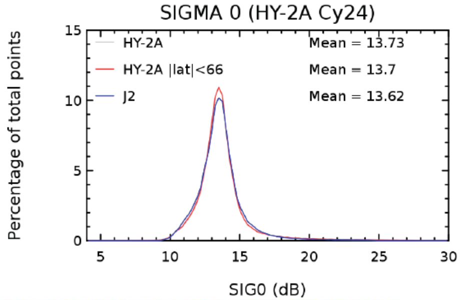
➢SWH comparison



The average SWH difference between HY-2A RA and Jason-2 is less than 23 cm.

➢Sigma0 comparison

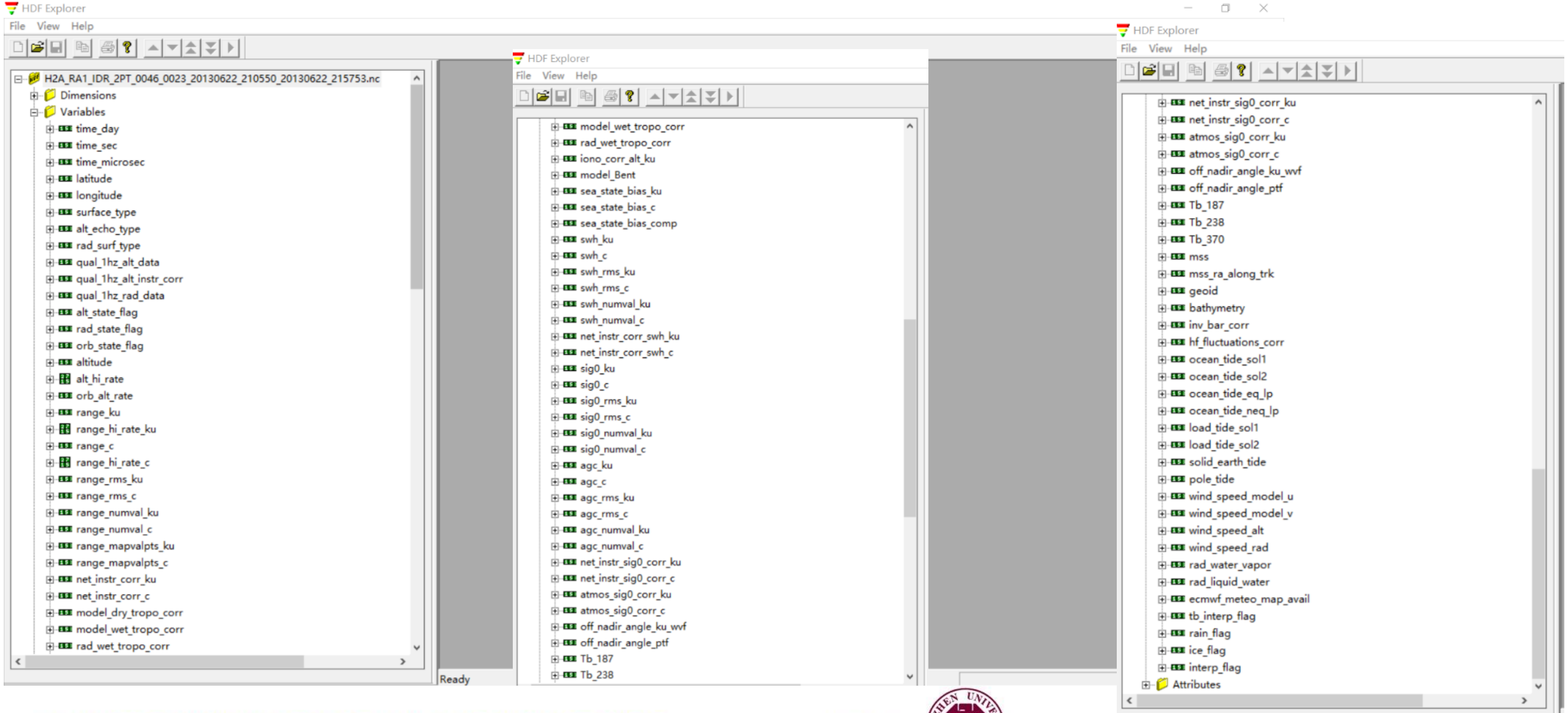


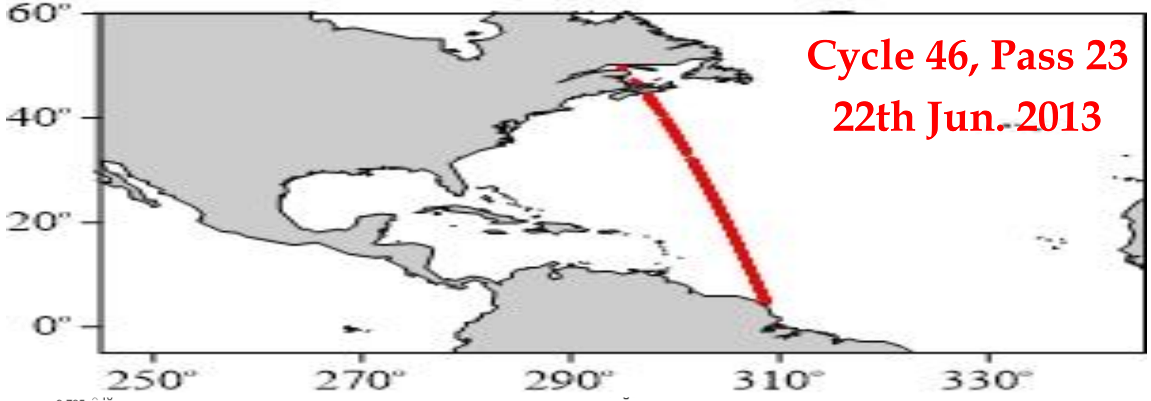


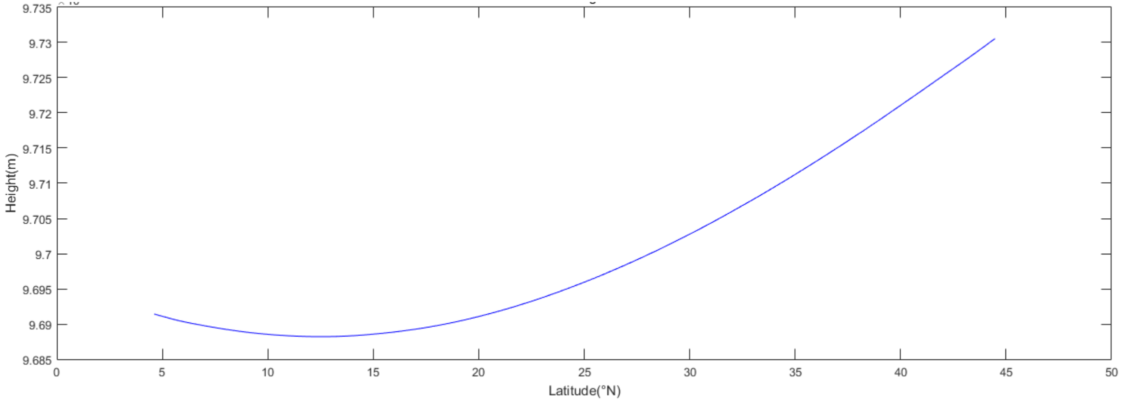
The average Sigma0 difference between HY-2A RA and Jason-2 is less than 1 dB.

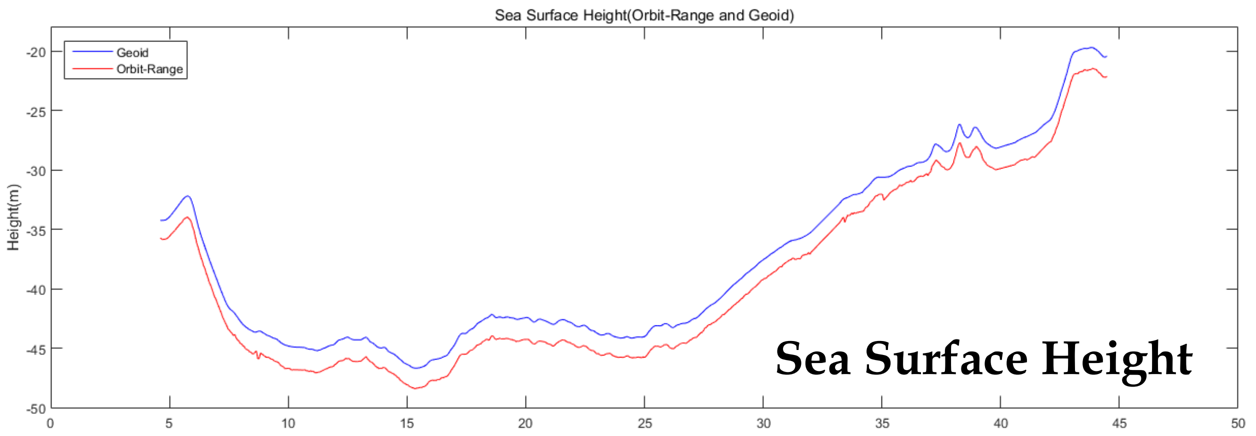
HY-2A RA Data example

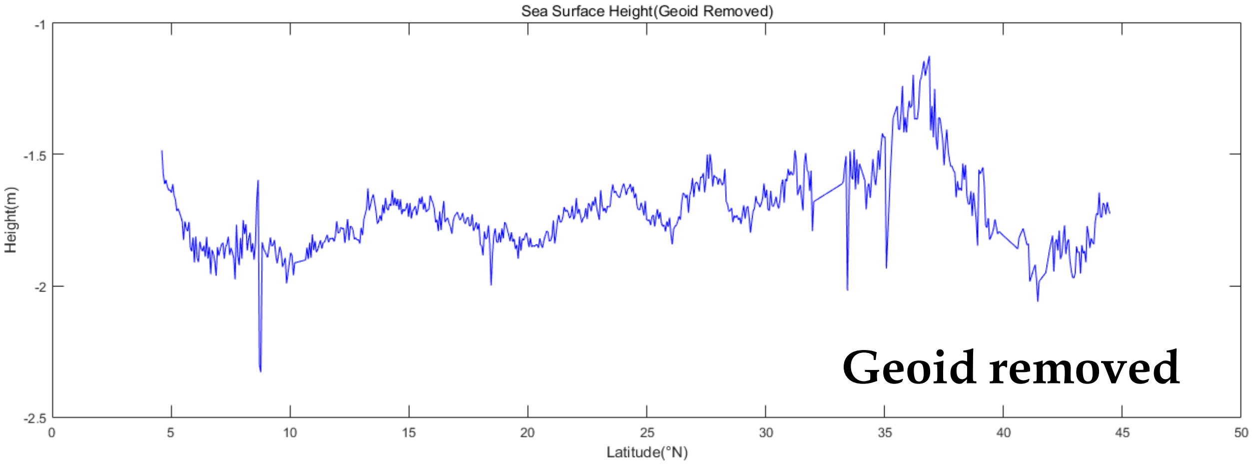
H2A_RA1_IDR_2PT_0046_0023_20130622_210550_20130622_215753.nc

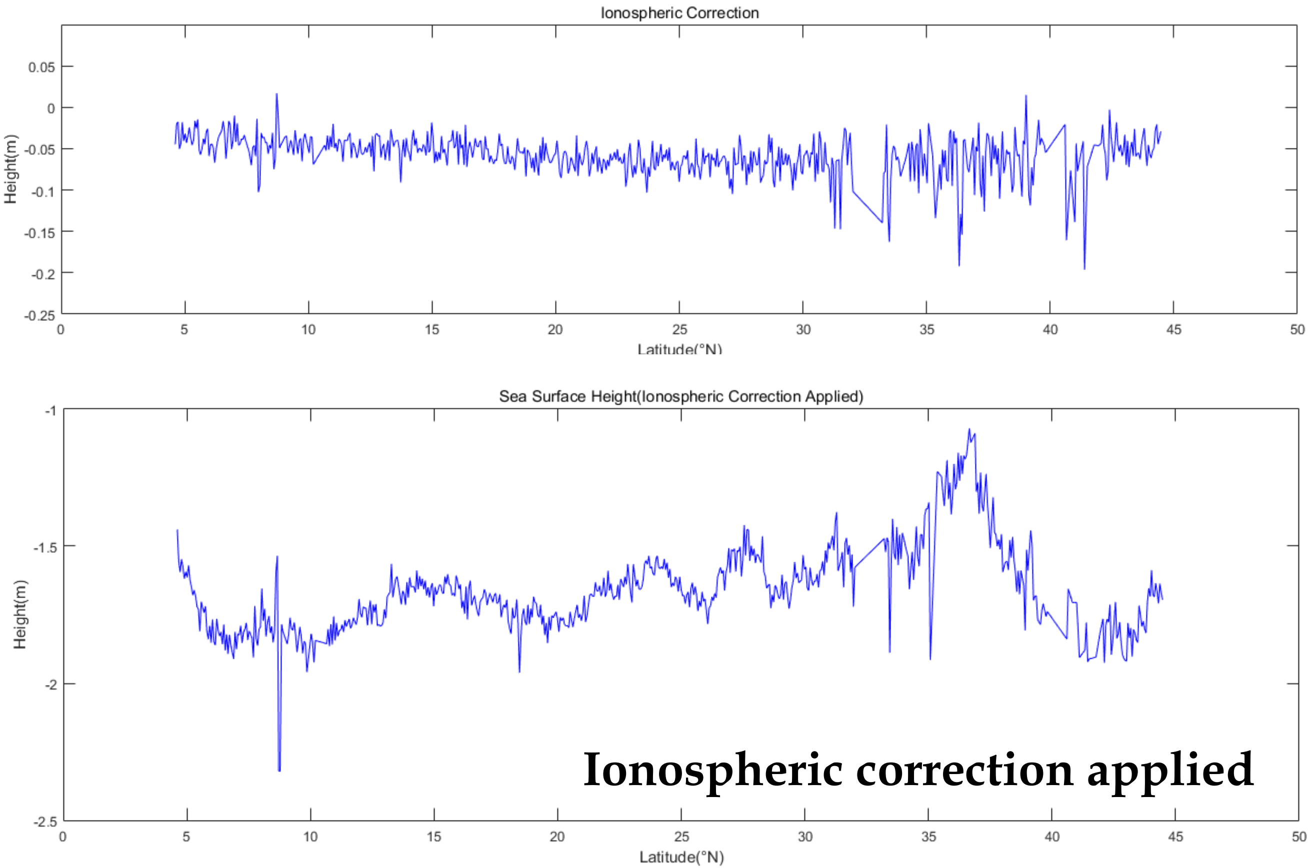



Cycle 46, Pass 23
22th Jun. 2013
60°
40°
20°
0°
250°
270°
290°
310°
330°

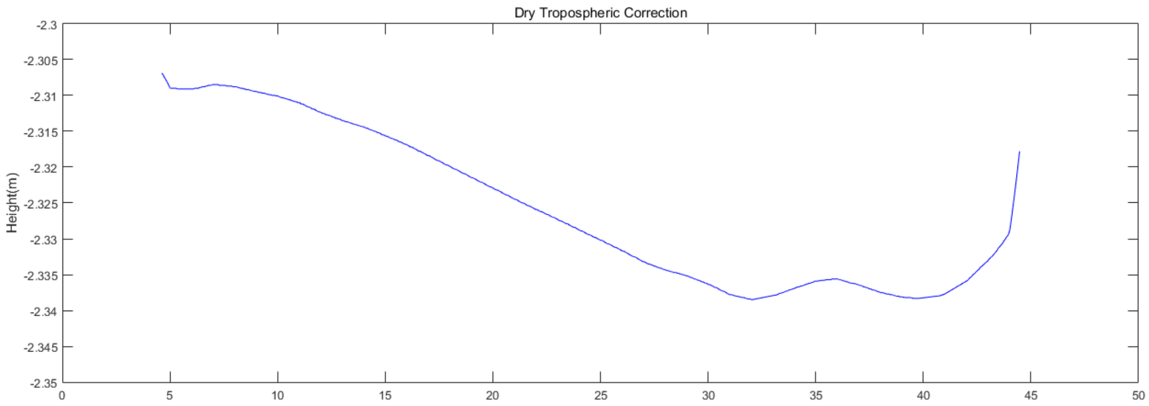

Height(m)
Latitude(°N)
9.735
9.73
9.725
9.72
9.715
9.71
9.705
9.7
9.695
9.69
9.685
0
5
10
15
20
25
30
35
40
45
50

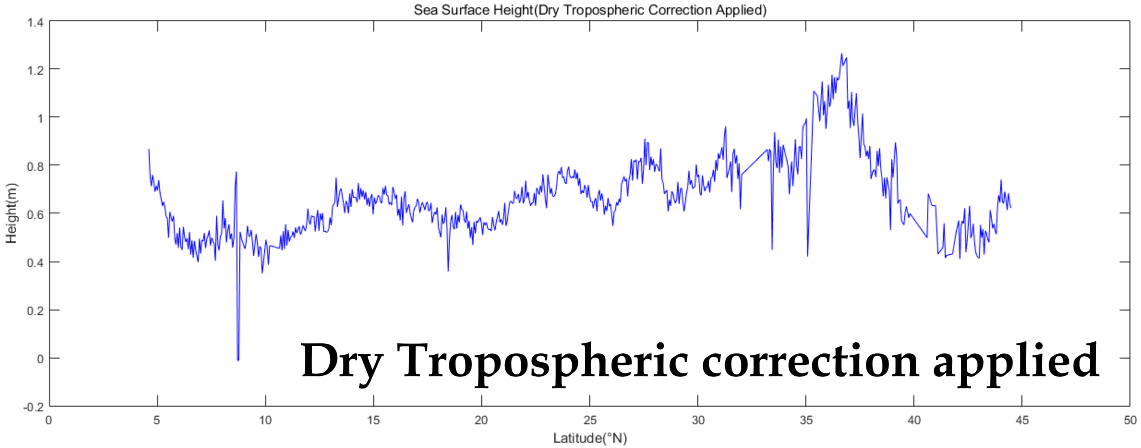

Sea Surface Height(Orbit-Range and Geoid)
Geoid
Orbit-Range
Height(m)
Sea Surface Height


Sea Surface Height(Geoid Removed)
Height(m)
Latitude(°N)
Geoid removed

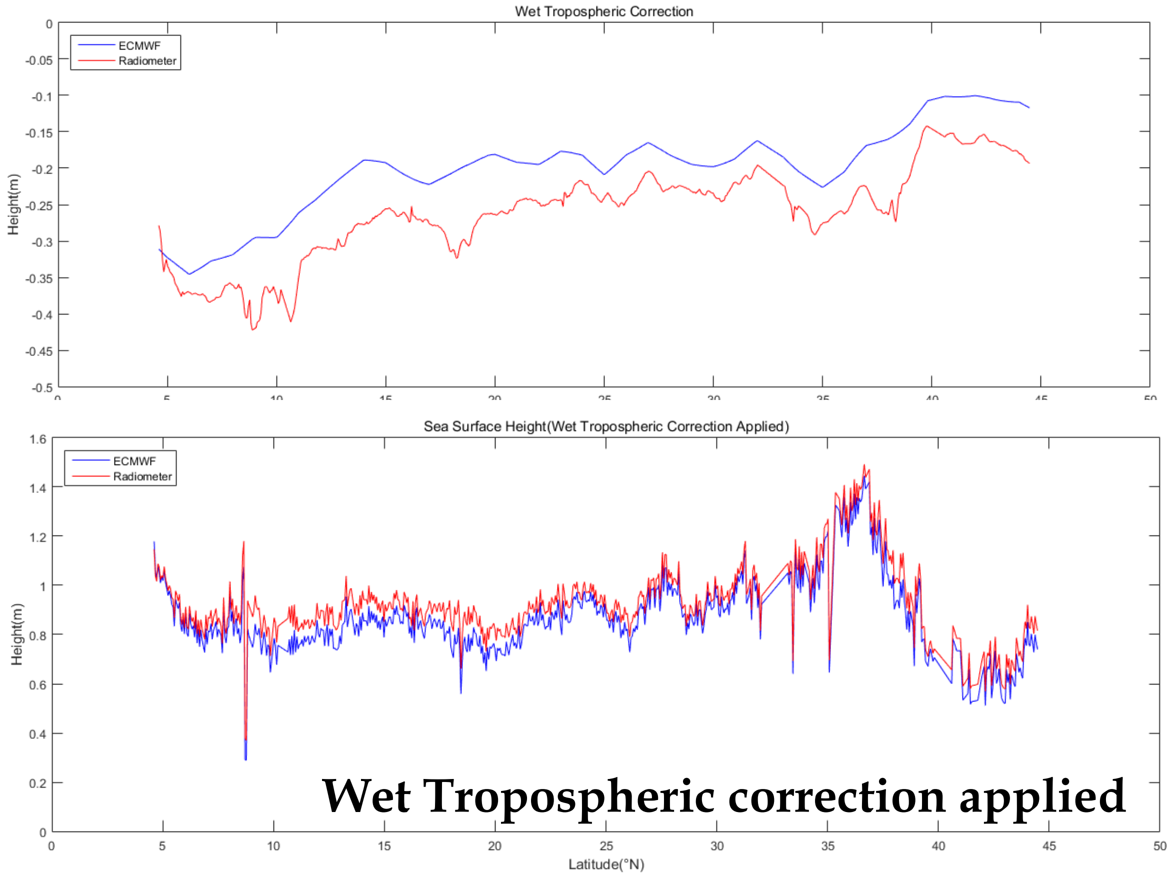


Ionospheric correction applied

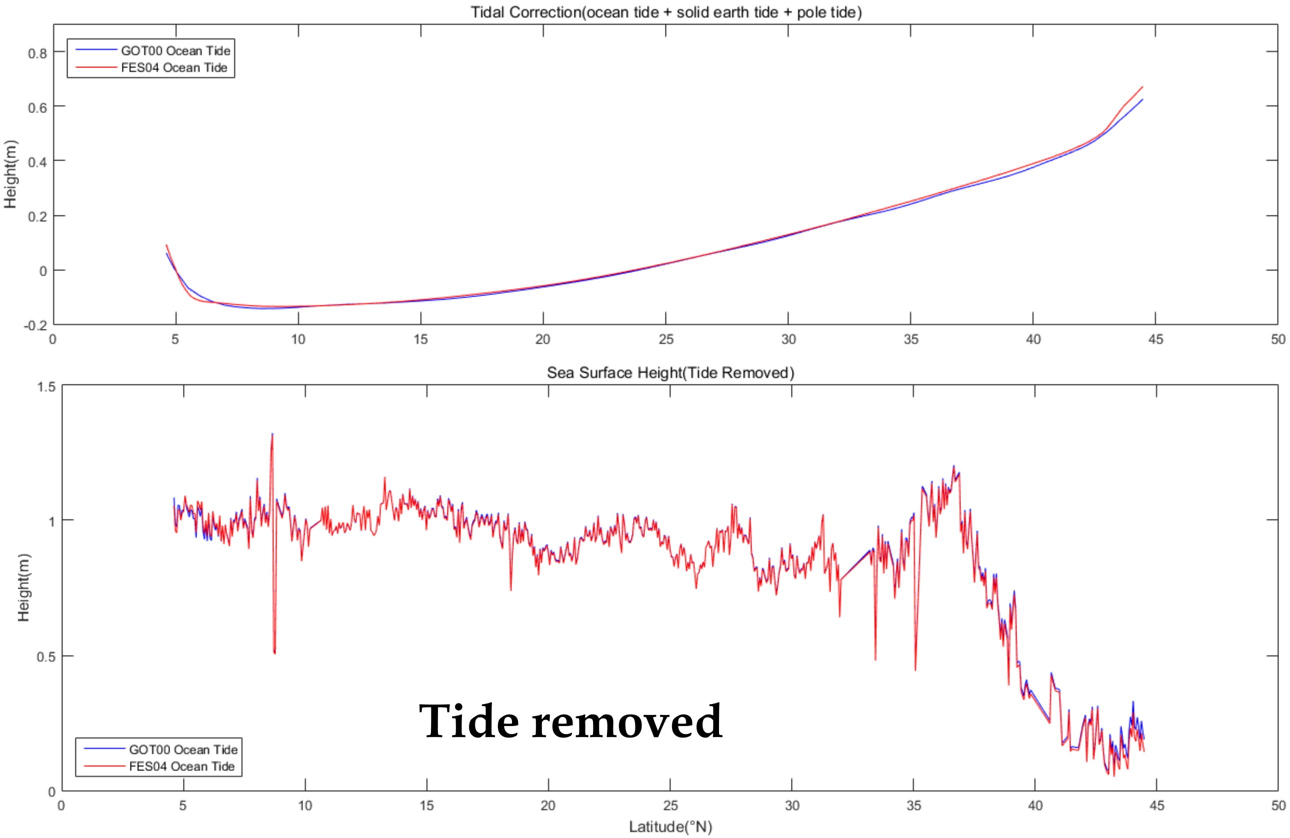




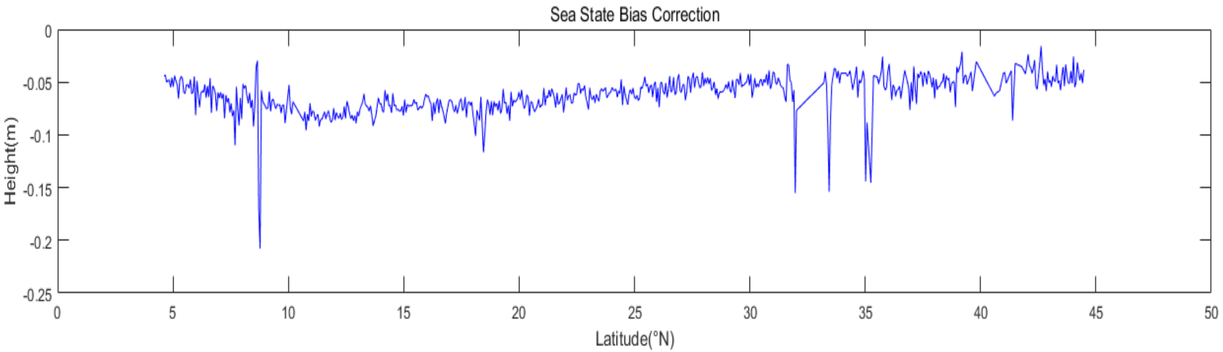
Dry Tropospheric correction applied

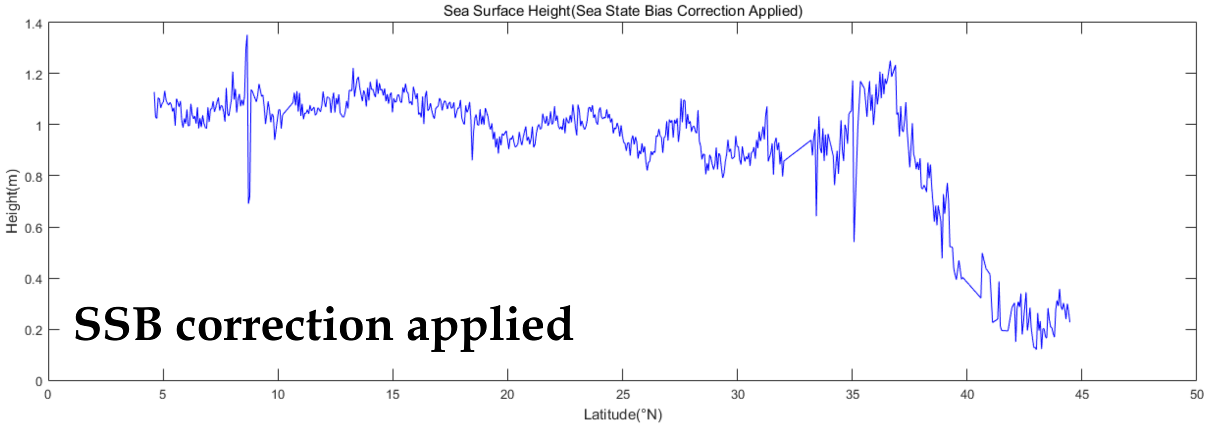


Wet Tropospheric correction applied

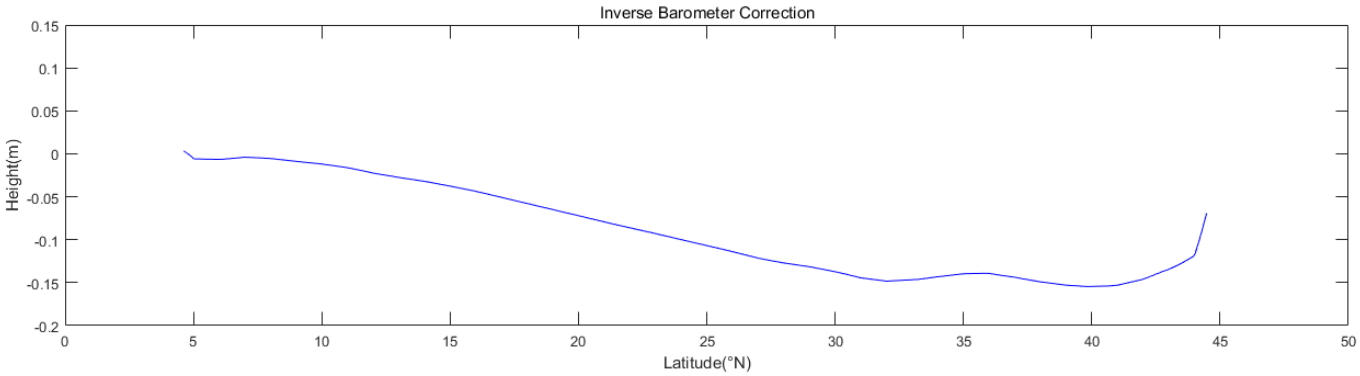


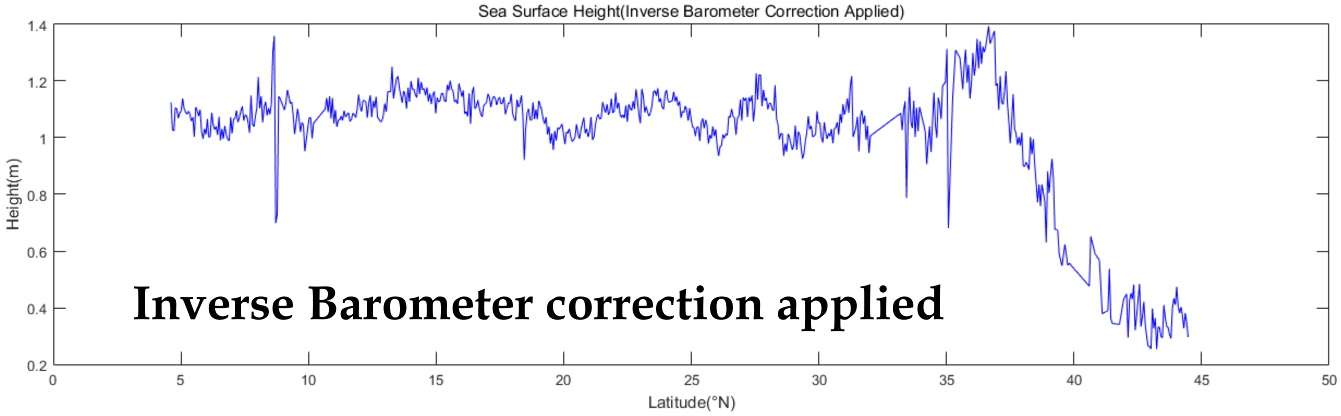
Tidal Correction(ocean tide + solid earth tide + pole tide)
GOT00 Ocean Tide
FES04 Ocean Tide
Height(m)
Sea Surface Height(Tide Removed)
Tide removed
GOT00 Ocean Tide
FES04 Ocean Tide
Height(m)
Latitude(°N)





SSB correction applied


Inverse Barometer Correction
Height(m)
Latitude(°N)


Sea Surface Height(Inverse Barometer Correction Applied)
Height(m)
Latitude(°N)
Inverse Barometer correction applied

Data application of HY-2 data

http://www.nsoas.org.cn/portal/article/1420428121582.html
ftp://ftp2.nsoas.org.cn

Thanks for your attention!

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