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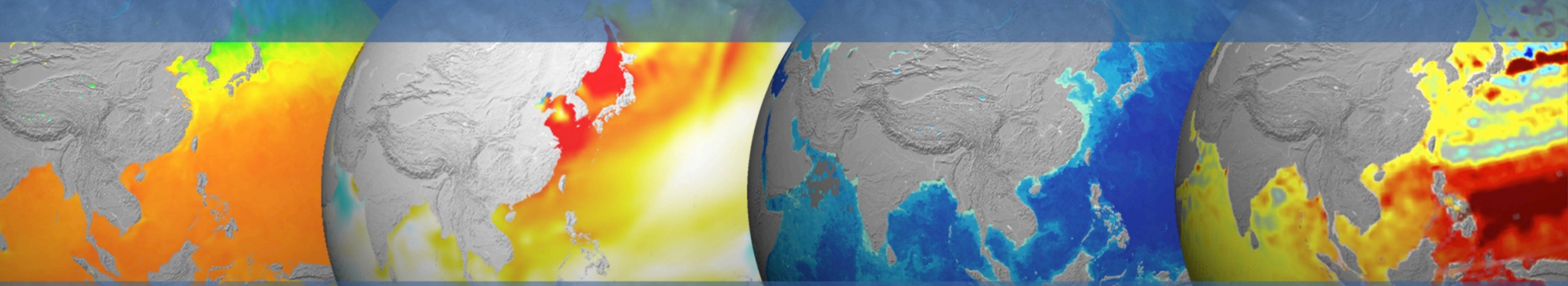


12 to 17 November 2018 | Shenzhen University | P.R. China

Application of altimetry in the China Seas

Hosted by

Jungang Yang (杨俊钢), First Institute of Oceanography, State Oceanic Administration

outline

1. Ocean tide
2. Ocean wave
3. Sea level change
4. Ocean circulation and mesoscale eddy
5. Marine gravity anomaly

Aims of the Topic

What can do?

Introduce the main applications of altimeter data in the ocean research.

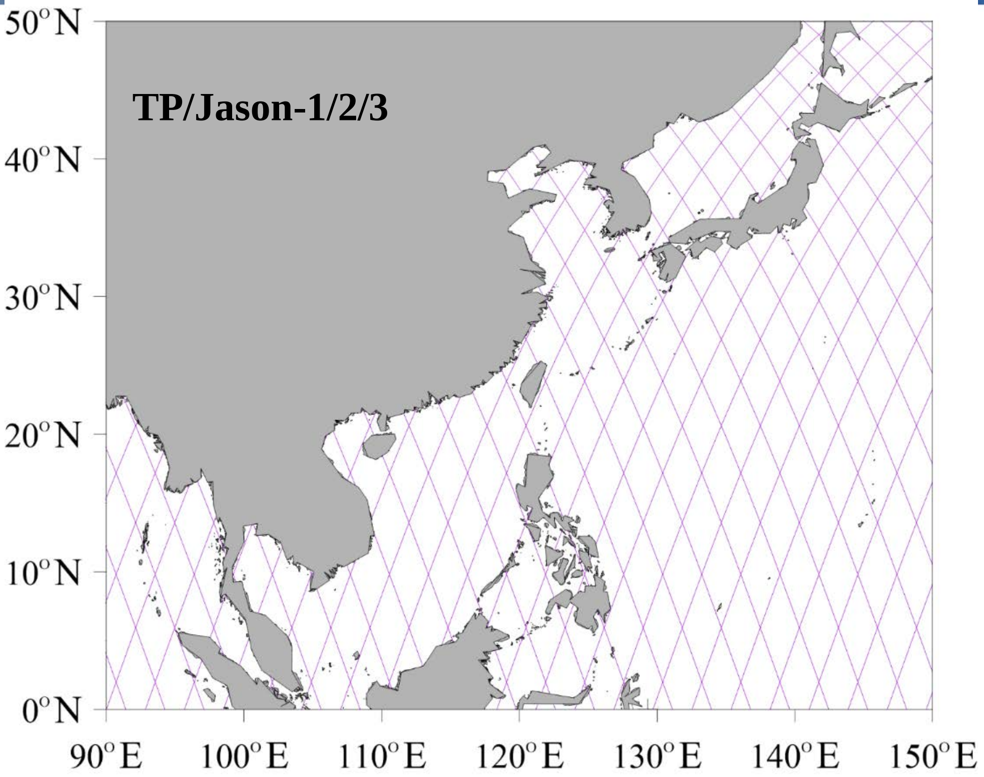
How to do?

Introduce the basic method or technical flow for the applications of altimeter data.

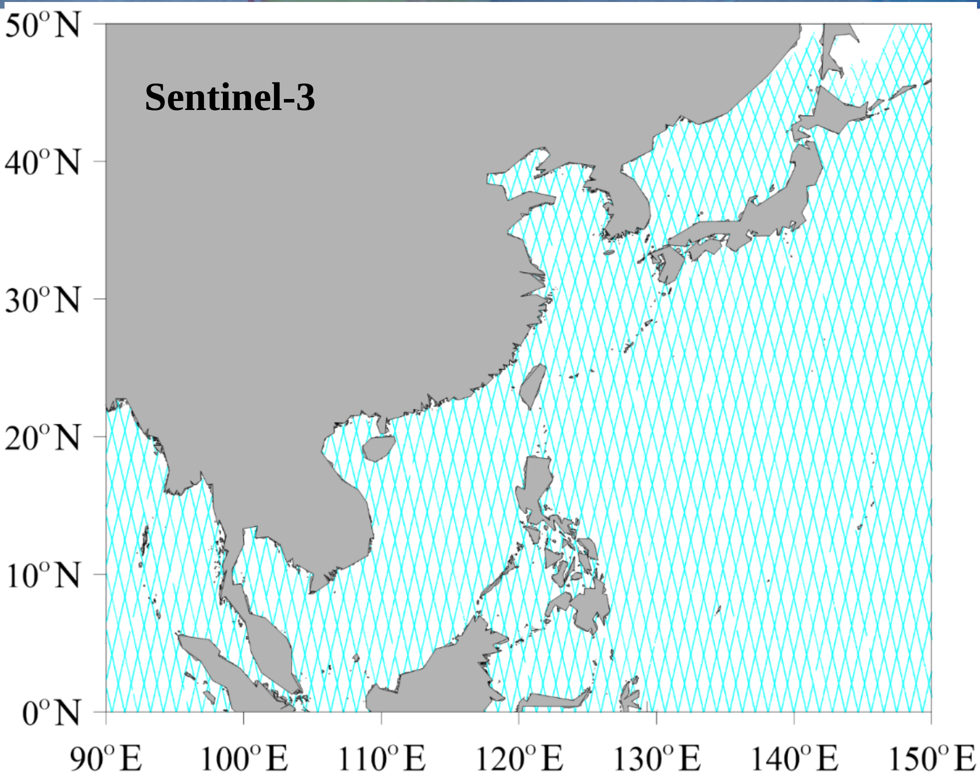
What have done?

Give a review about the altimeter application in the China Sea.

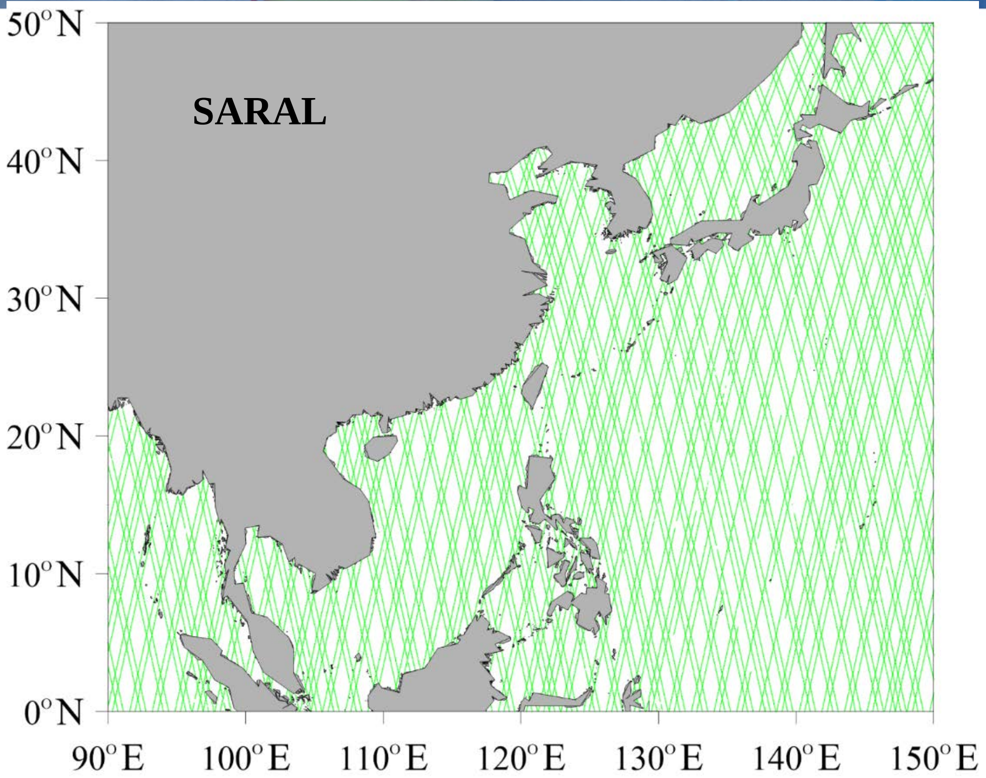
Satellite	Country/Organization	Orbit/km	inclination/°	Repeat Cycle/d	Period
T/P	USA/France	1336	66	9.9156	1992.9.25~2005.10.8
ERS-1	ESA	799	98.55	35/30	1991.8.1~1996.6.2
ERS-2	ESA	799	98.55	35/30	1995.4.29~2010.9.13
GFO	USA	880	108	17	2000.1.9~2008.9.7
Jason-1	USA/France	1336	66	9.9156	2002.1.15~2012.12.11
Envisat	ESA	799	98.55	35/30	2002.5.14~2012.4.8
Jason-2	USA/France	1336	66	9.9156	2008.7.4~
Cryosat-2	ESA	717	92	369	2010.7.16~
HY-2A	CHINA	973	98	14	2011.10.01~
SARAL	India/France	800	98.55	35	2013.3.14~
Jason-3	USA/France	1336	66	9.9156	2016.2.12~
Sentinel-3	ESA	814.5	98.65	27	2016.12.24~
HY-2B	CHINA	973	98	14	2018.10.25~



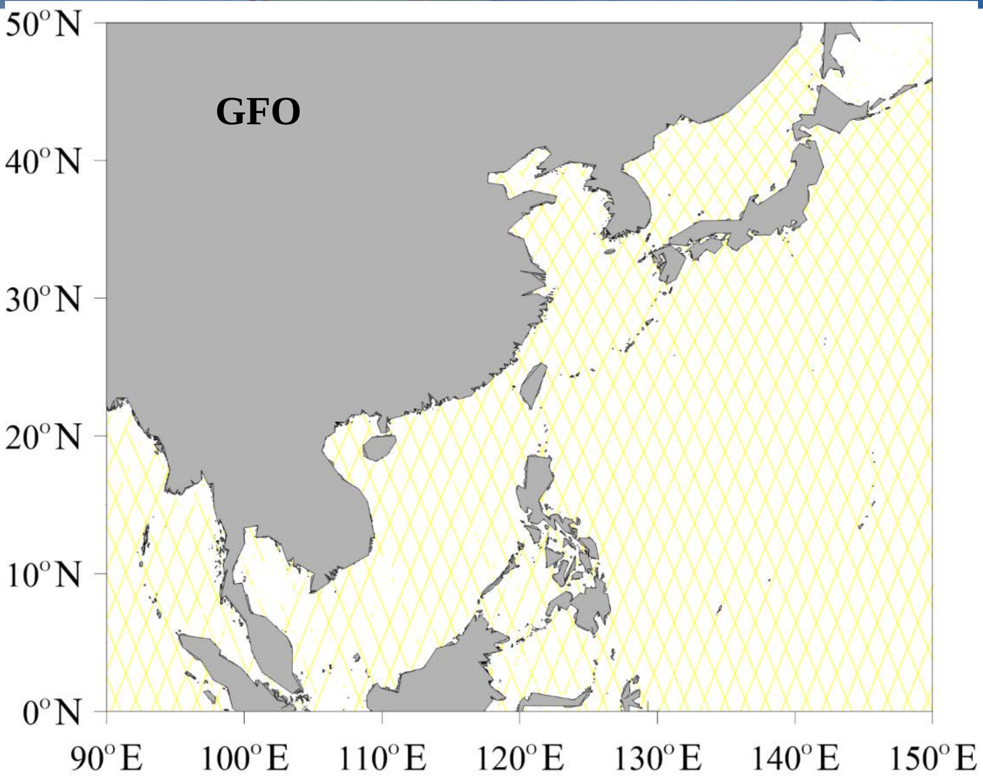
Ground track of altimeters



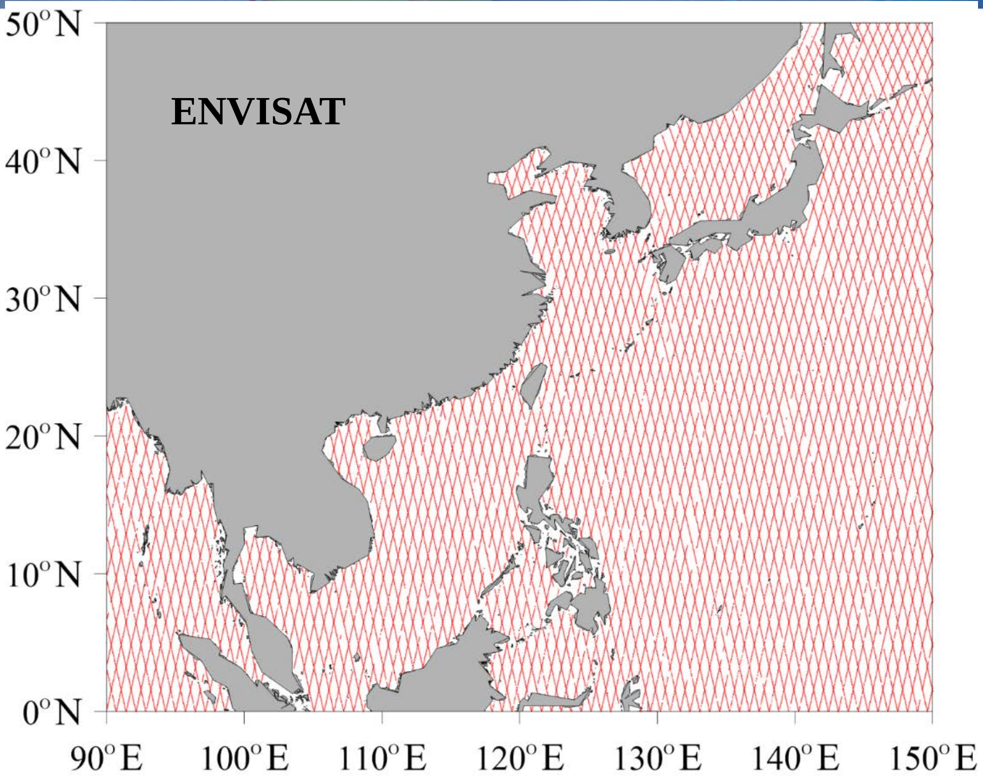
Ground track of altimeters



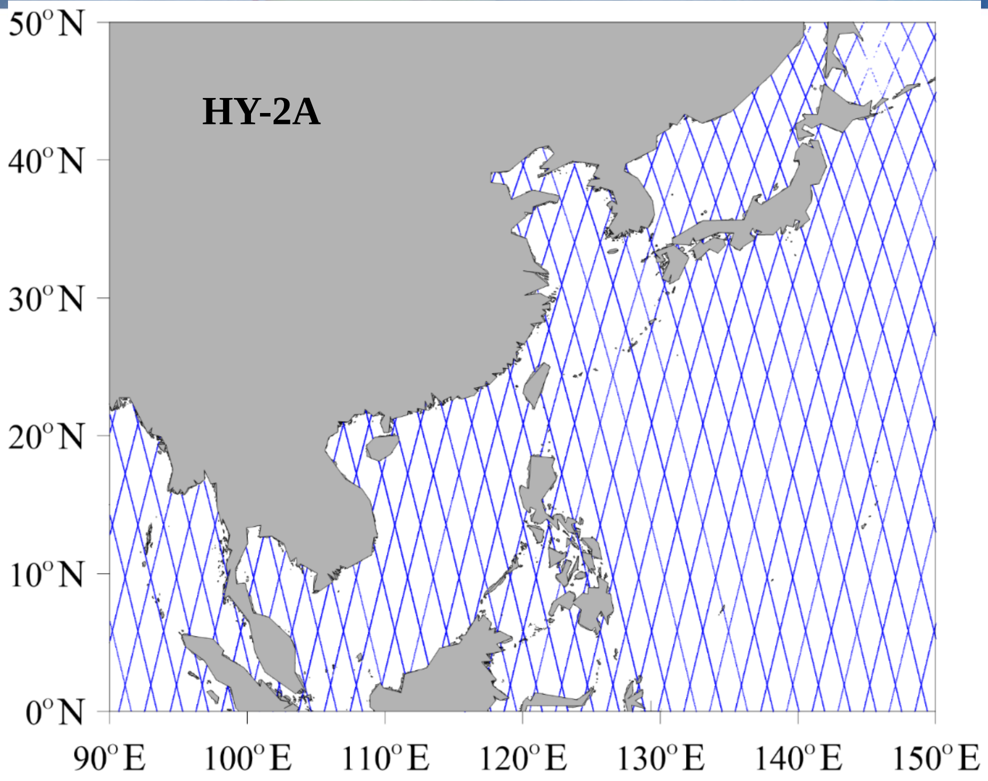
Ground track of altimeters



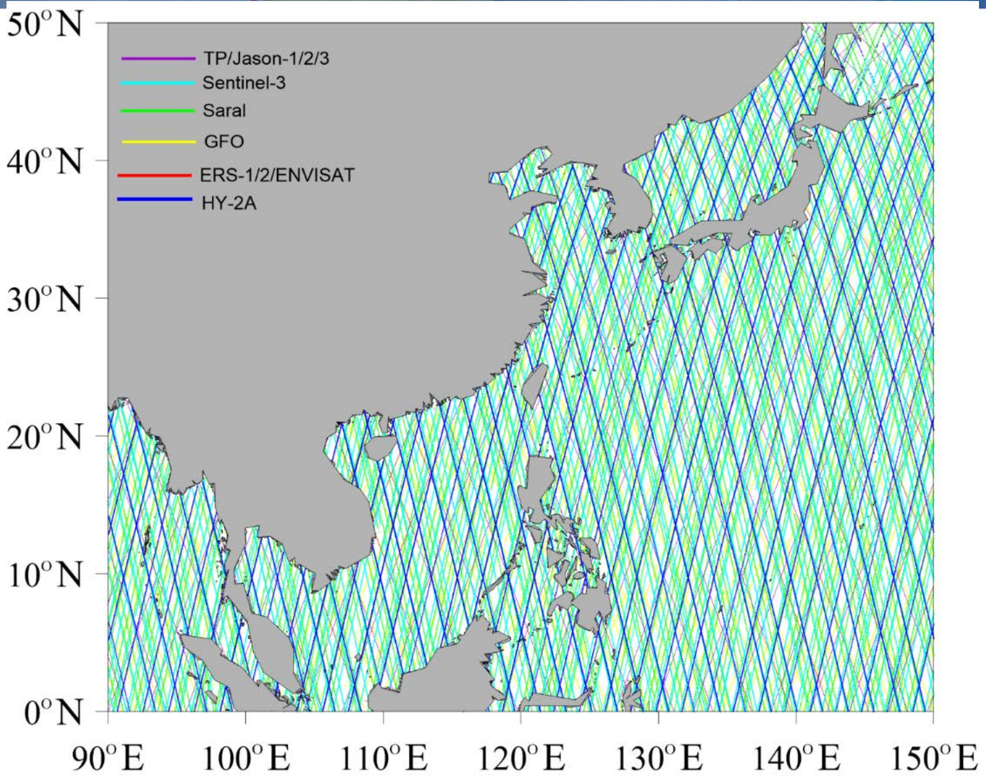
Ground track of altimeters



Ground track of altimeters



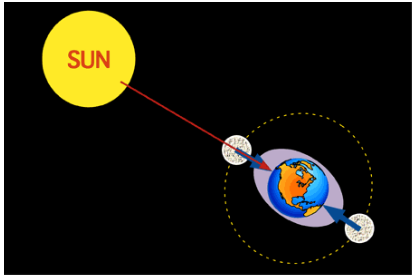
Ground track of altimeters

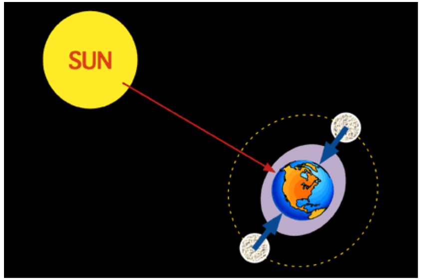


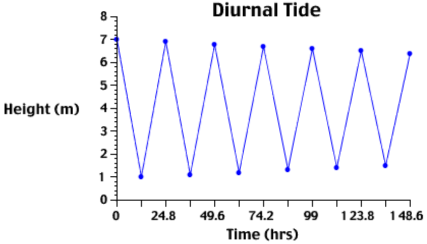
Ground track of altimeters

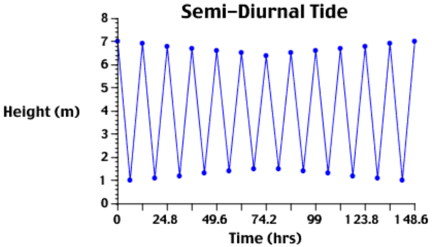
1. Ocean Tide

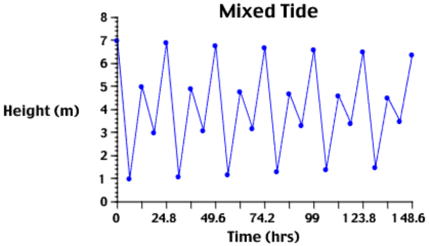
Ocean tide is of importance in the study on oceanography, geophysics and geodesy.

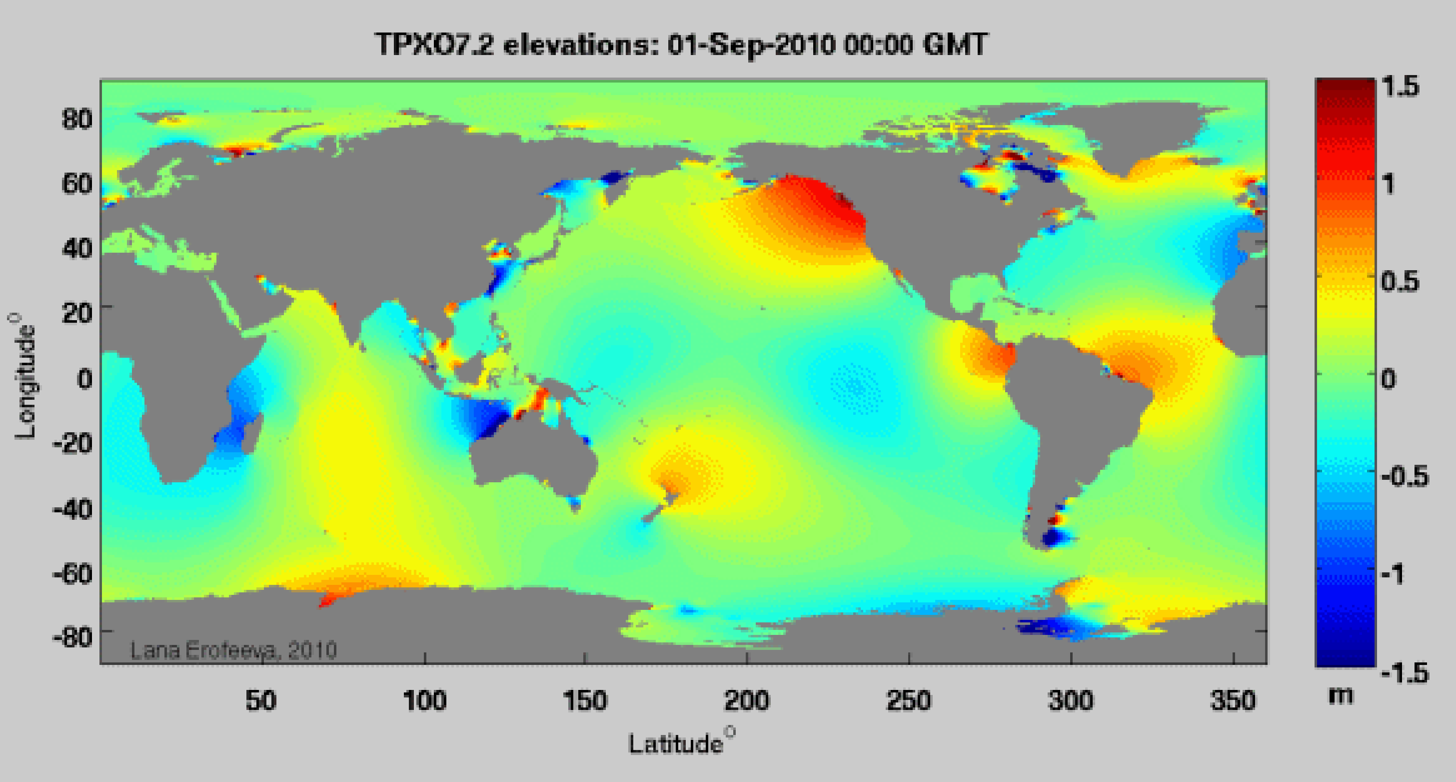






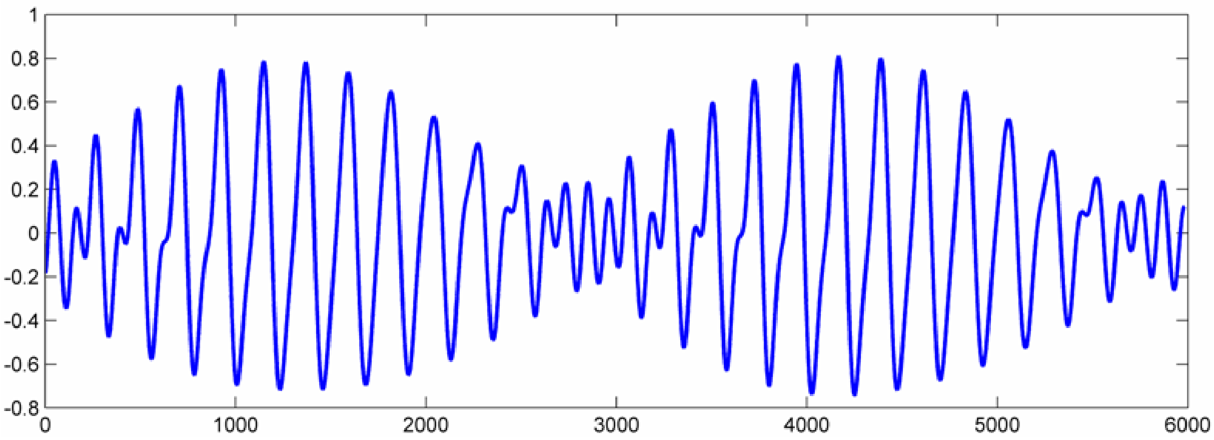





TPXO7.2 elevations: 01-Sep-2010 00:00 GMT
80
60
40
20
0
-20
-40
-60
-80
Longitude°
50
100
150
200
250
300
350
Latitude°
1.5
1
0.5
0
-0.5
-1
-1.5
m
Lana Erofeeva, 2010

(1) Extraction of tide with altimeter data

Based on the time series of altimeter data, the harmonic constants of ocean tide can be extracted by two methods.



➢ Harmonic Analysis Method(调和分析法)

Ocean tide elevation can be regarded as the sum of several tidal constituents of different frequencies.

$$\xi(\vec{x},t)=\sum_{i=1}^{N} f_i(t)A_i(\vec{x})\cos[\omega_i t+V_i+u_i(t)-G_i(\vec{x})]$$

Where, $f_i(t)$, $u_i(t)$ are the nodal corrections of tidal constituents.

$A_i(\vec{x}), G_i(\vec{x})$ **are the amplitude and phase lag of tidal constituents. V_i is the astronomical phase, and ω_i is the frequency of the tidal constituents.**

➢ Orthogonalized Convolution Method(正交响应法)

Ocean tide elevation is expressed as the sum of a series of orthotides.

$$\xi(t)=\sum_{n=2}^{\infty}\sum_{m=0}^{n}\sum_{k=-K}^{K}[u_n^m(k)a_n^m(t-k\Delta t)+v_n^m(k)b_n^m(t-k\Delta t)]$$

The orthotides expression of Groves and Reynolds(1990):

$$\xi(t)=\sum_{m=1}^{2}\sum_{j=0}^{2}[U_j^m P_j^m(t)+V_j^m Q_j^m(t)]$$

U_j and V_j can be obtained by least square method.

$$H\cos g=H_1=(-1)^m H_0 X(\omega)$$
$$H\sin g=H_2=(-1)^m H_0 Y(\omega)$$

$X(\omega)$, $Y(\omega)$ can be calculated by U_j and V_j. H_0 is the amplitude of astronomical equilibrium tide potential. H and g are the harmonic constants of tidal constituents.

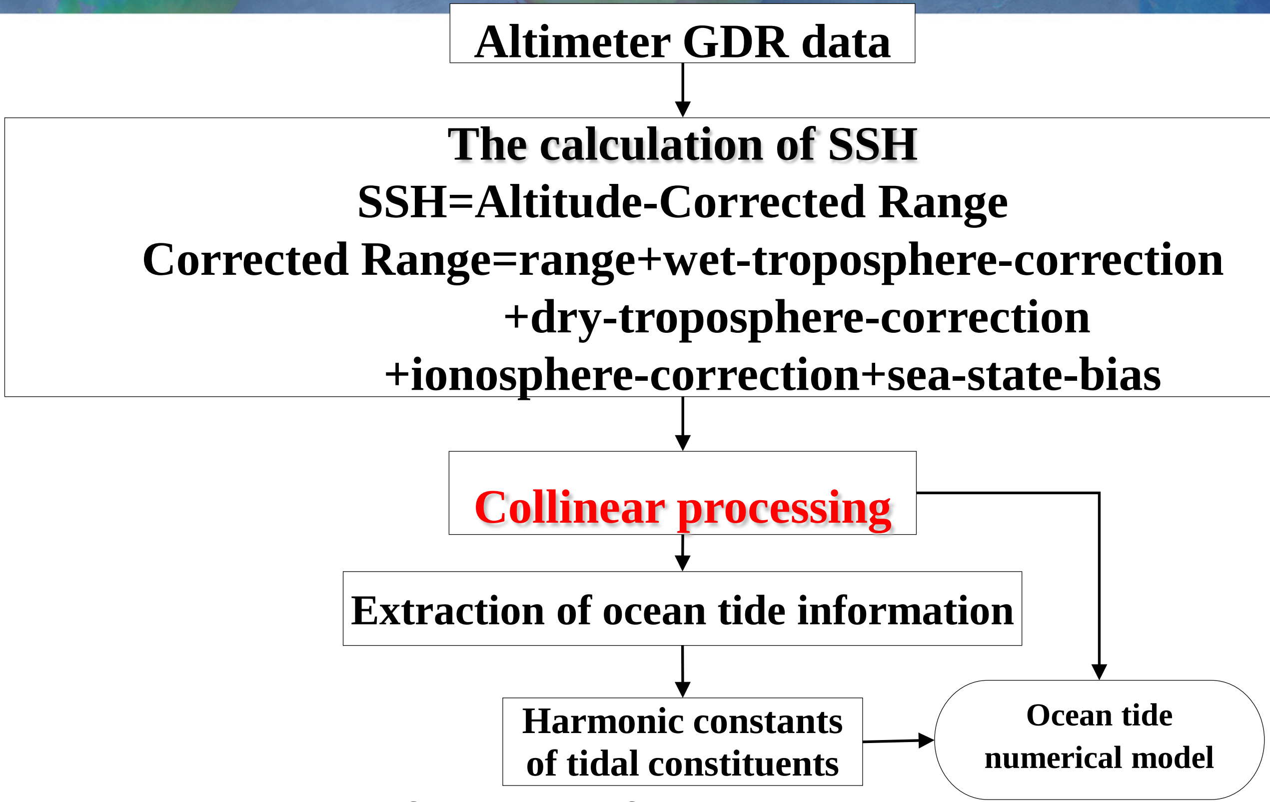
(2) Combination of altimeter data with numerical model

➢ **example: 2-D ocean tide numerical model**

$$
\begin{cases}
\dfrac{\partial \zeta}{\partial t} + \dfrac{\partial (Hu)}{\partial x} + \dfrac{\partial (Hv)}{\partial y} = 0 \\
\dfrac{\partial u}{\partial t} + u\dfrac{\partial u}{\partial x} + v\dfrac{\partial u}{\partial y} - fv = -g\dfrac{\partial \zeta}{\partial x} - \dfrac{C_b u}{H} \\
\dfrac{\partial v}{\partial t} + u\dfrac{\partial v}{\partial x} + v\dfrac{\partial v}{\partial y} + fu = -g\dfrac{\partial \zeta}{\partial y} - \dfrac{C_b v}{H}
\end{cases}
$$

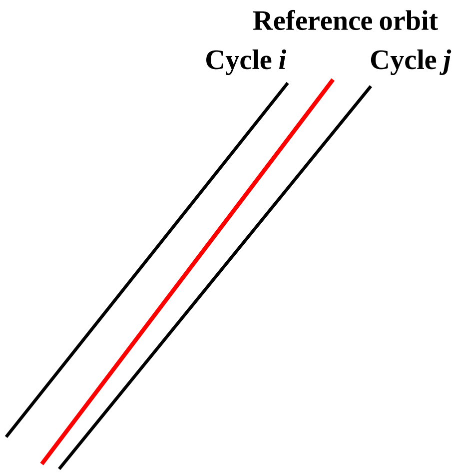
Where, u,v are the east and north components of tidal current. ζ is tidal elevation. f is Corolis parameter. C_b is the bottom friction coefficient. g is the gravity acceleration. H is water depth.

solving the above numerical model, altimeter data can be used as the input of water elevation ζ in the open boundary.



The basic technical flow chart of altimeter data application in the ocean tide study

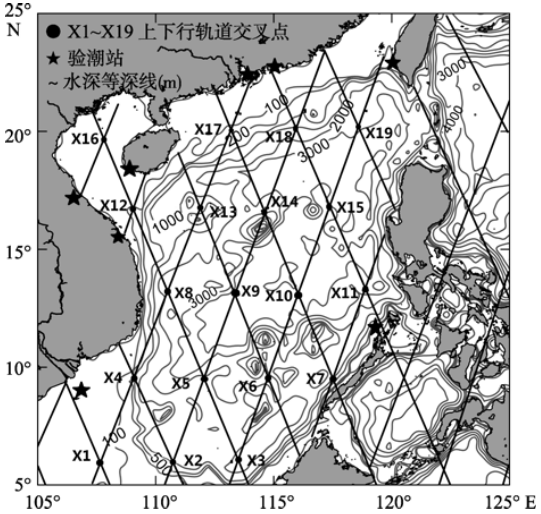
Collinear processing: using interpolation method to process the altimeter data of each cycle into a reference ground track with the fixed ground points. That makes to obtain the time series of SSH observations at the same ground track point.



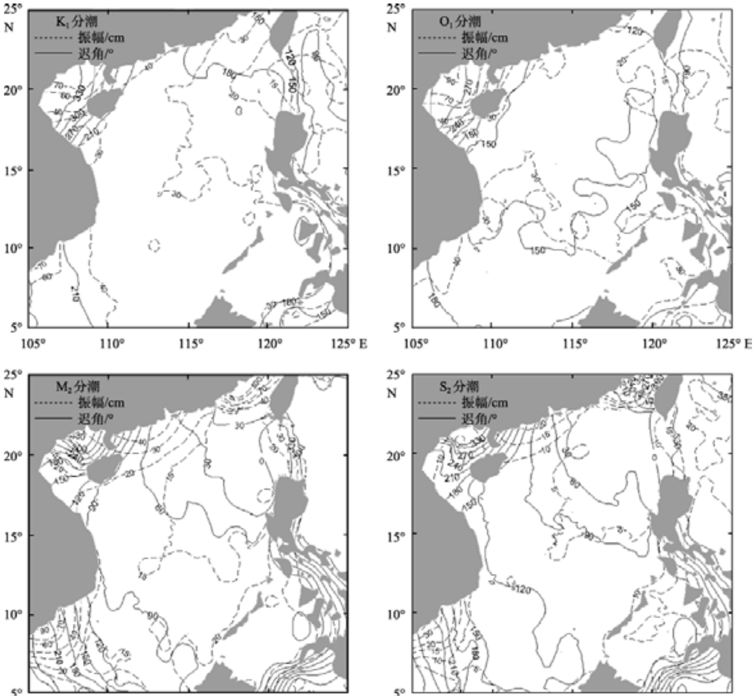
Processing the same pass in different cycles

1.2 The application in the China Seas

- **10 years (1992~2002) of T/P data is performed to derive the semidiurnal and diurnal tides in the South China Sea.**



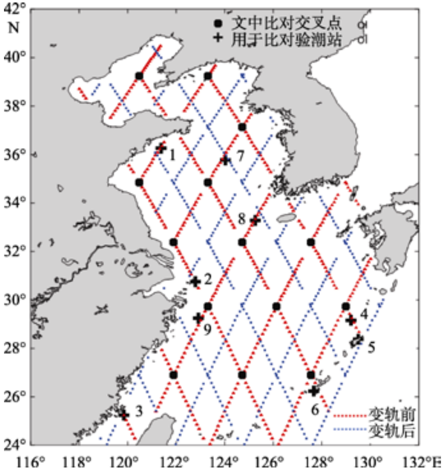
cotidal charts

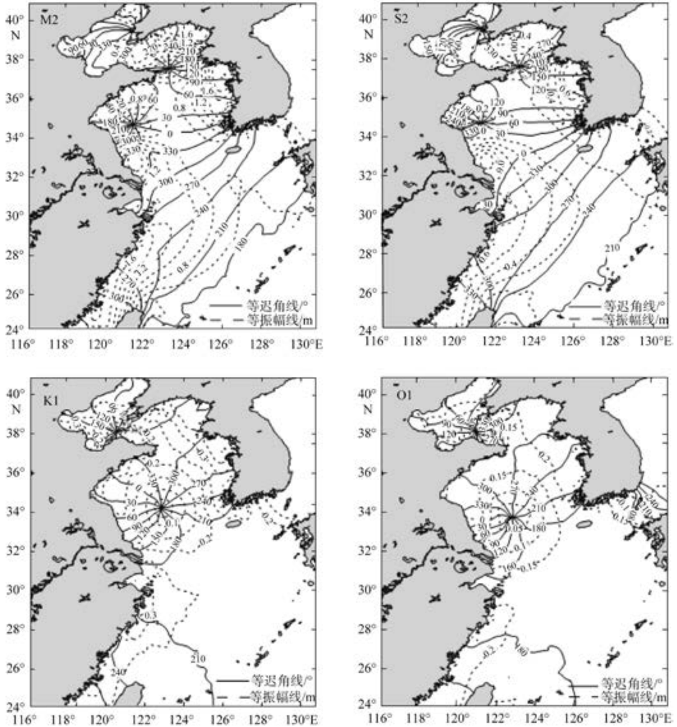


Comparisons with TPXO7.2 is less than 3 cm in amplitudes and 7° in phase lags.

Yunxia ZHAO, et. al., 2012, Marine Sciences, Vol.36(5).(In Chinese)

- The harmonic analysis of 8 tidal constituents in the East China Sea, Yellow Sea, Bohai Sea was performed by combining of 19 years altimeter data of T/P and Jason-1.



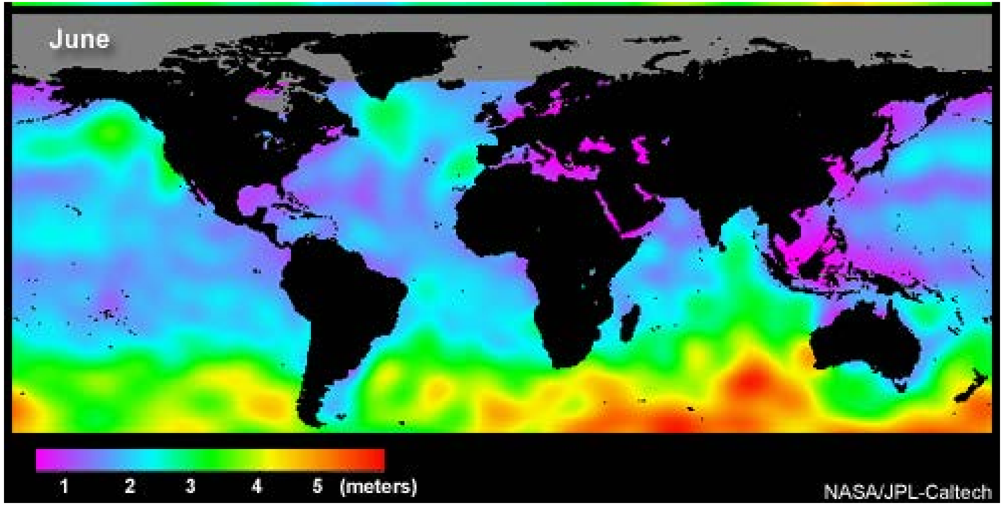


The RMSE of Amplitude is 1.0~1.8 cm and that of phase lag is 4.1°~7.8°,

Changwei ZHONG, et. al., 2013, Marine Sciences, Vol.37(10).(In Chinese)

2. Ocean Wave

Ocean wave is one of the basic parameter of sea state, and it reflects the local ocean and weather condition.



2.1 Application in the ocean wave study

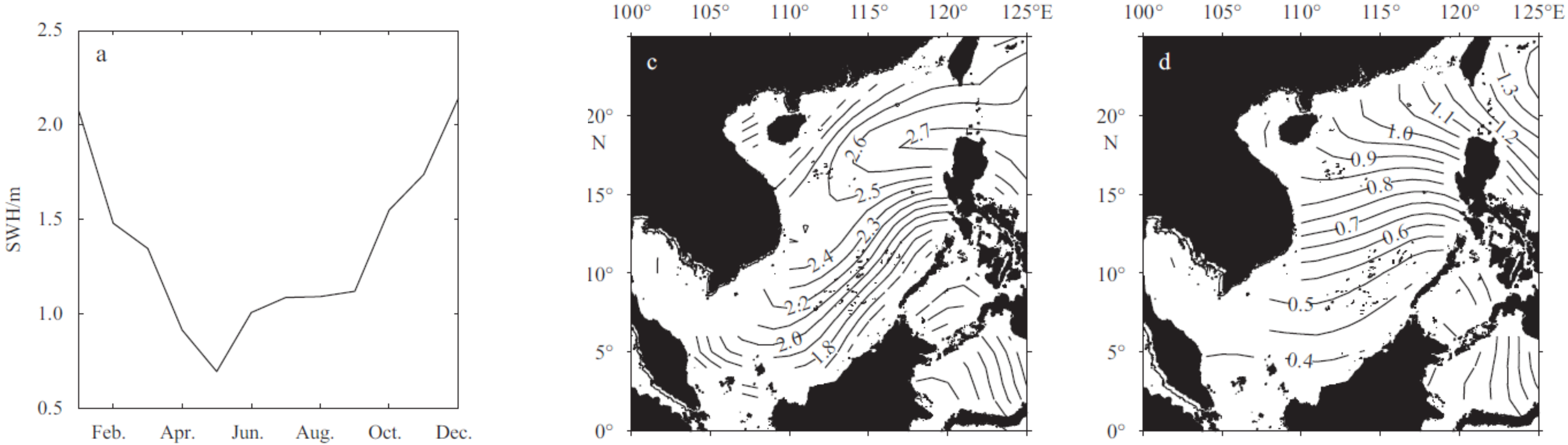
Wave/wind observation: obtain SWH, sea surface wind speed and monitor sea state. Statistic characters analysis of ocean wave.

Extreme SWH estimation： extreme SWH in many return years can be estimated by using altimeter data.

Model validation： validate the result of numerical simulation and the statistic distribution model of ocean wave.

Ocean wave data assimilation： assimilate SWH data into the numerical ocean wave model (WAM, SWAN or WAVEWACTH III) by the optimal interpolation or other methods.

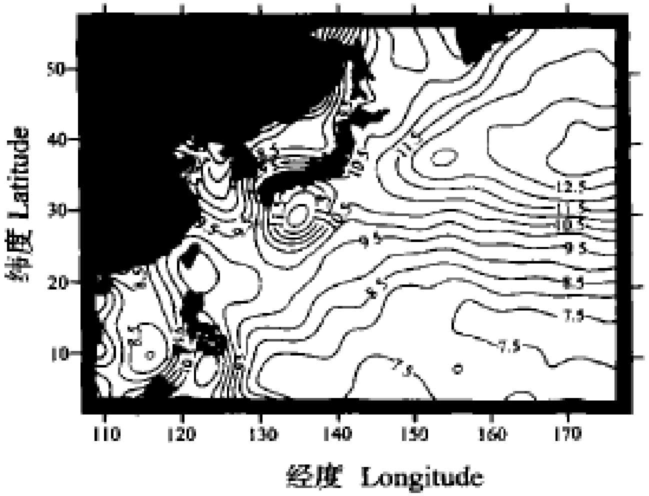
- **The seasonal variability of the SWH in the South China Sea is investigated using the gridded daily altimeter data for the period of September 2009 to August 2015.**



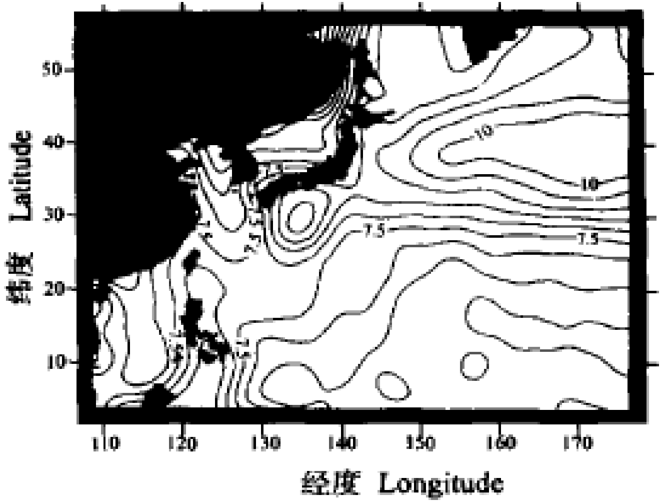
maximum **minimum**

SU Hui et al. Acta Oceanol. Sin., 2017, Vol. 36, No. 11, P. 38–50.

- The estimation of extreme SWH using T/P data, the results were compared with those calculated by traditional method and observed data.

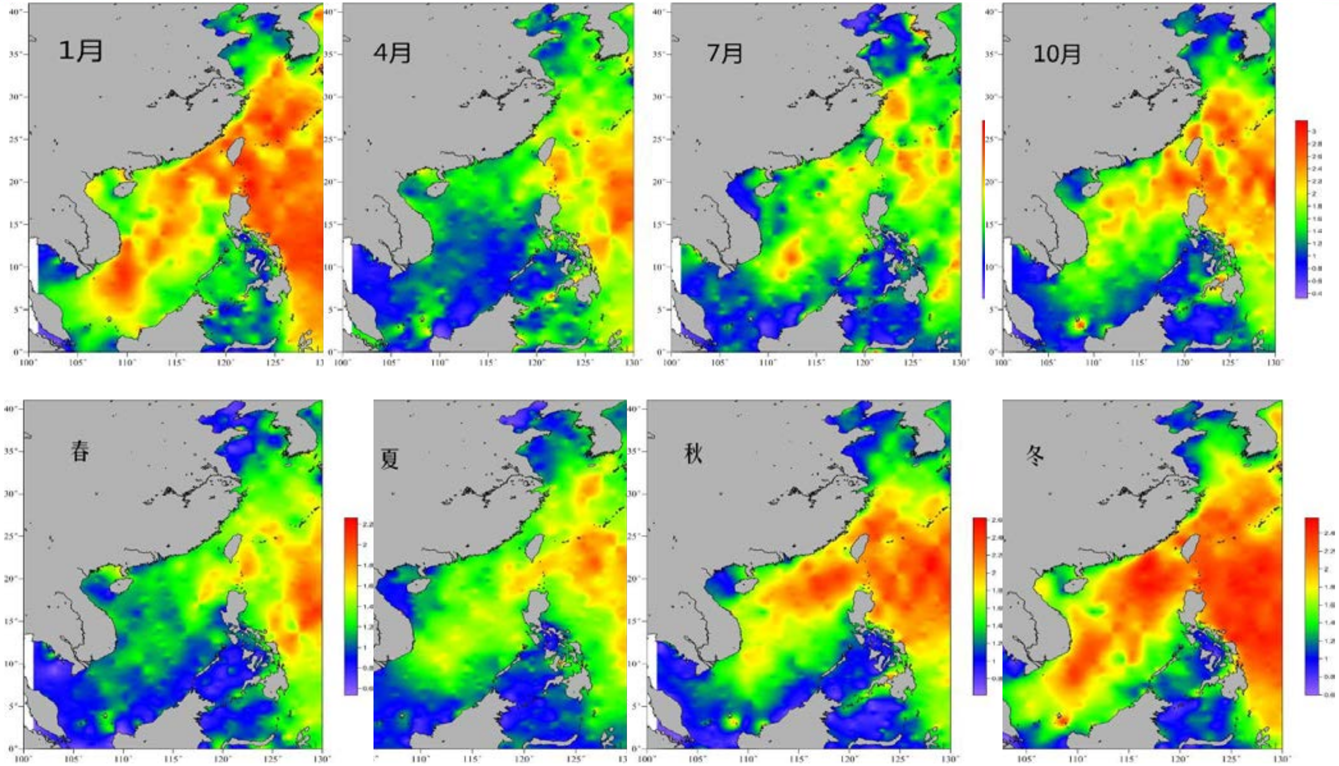


Threshold of SWH (100 Return Years)



Threshold of SWH (50 Return Years)

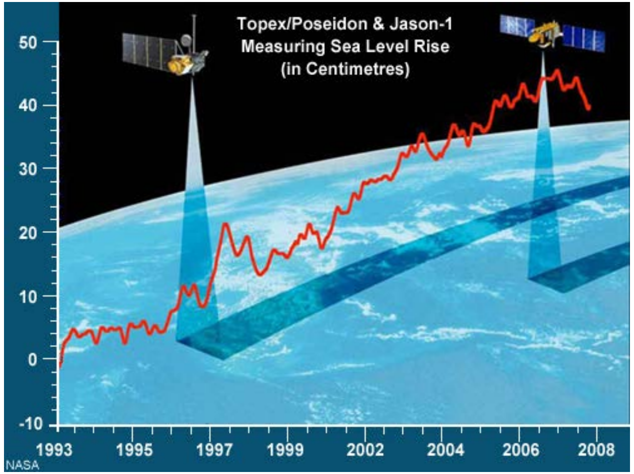
Han Shuzong，2003. Journal of ocean university of Qingdao, 33(5), 657-664.

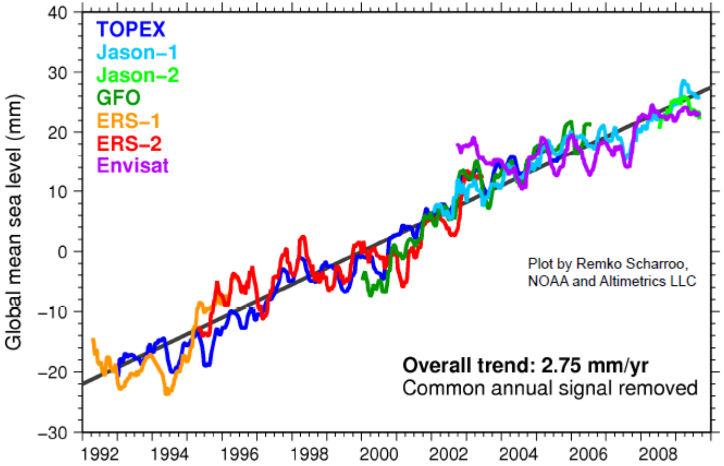


Monthly and seasonal mean distribution of SWH in the China Sea based on Jason-1 data

3. Sea Level Change

- The study on sea level change is the important section of the global change study. This study aims to understand the variation of sea level, to forecast the future and its impacts on the environment of human living.
- Altimeter supplies the unique data for the study on the global sea level change, which make up the shortcoming of tide gauge data.





3.1 Application in the sea level change study

Altimeter data can be used in the study on:

- **The trend of sea level rise.**
- **The sea level rise rate.**
- **Analyzing the main reasons of sea level change in combination with other data, such as SST, tide gauge, glacier or ice sheet data.**

Altimeter GDR data

↓

Data quality control and SSH calculation
GDR data edit criteria, shallow water data(<200 m) and high RMS variability(>40cm) data are eliminated

↓

collinear processing
Coregistering each cycle to a reference ground track.

↓

Calculation of $mss(\Phi, \lambda)$
$mss(\phi,\lambda) = \sum_{i=1}^{N} h_i(\phi,\lambda) / N$, Φ/λ is latitude/longitude; N is the number of repeat cycles.

↓

Calculation of $\Delta h_i(\Phi, \lambda)$
$\Delta h_i(\phi,\lambda) = h_i(\phi,\lambda) - mss_i(\phi,\lambda)$

↓

Calculation of $\Delta msl_i(\Phi, \lambda)$
$\Delta msl_i = \sum_{\lambda}\sum_{\phi} \Delta h_i(\phi,\lambda) w(\phi) \Big/ \sum_{\lambda}\sum_{\phi} w(\phi)$
$w(\phi) = \sin\beta(\phi)/\sin\beta(0)$ is weight factor.

↓

MSL: $MSL = \sum_{i=1}^{N} \Delta msl_i$

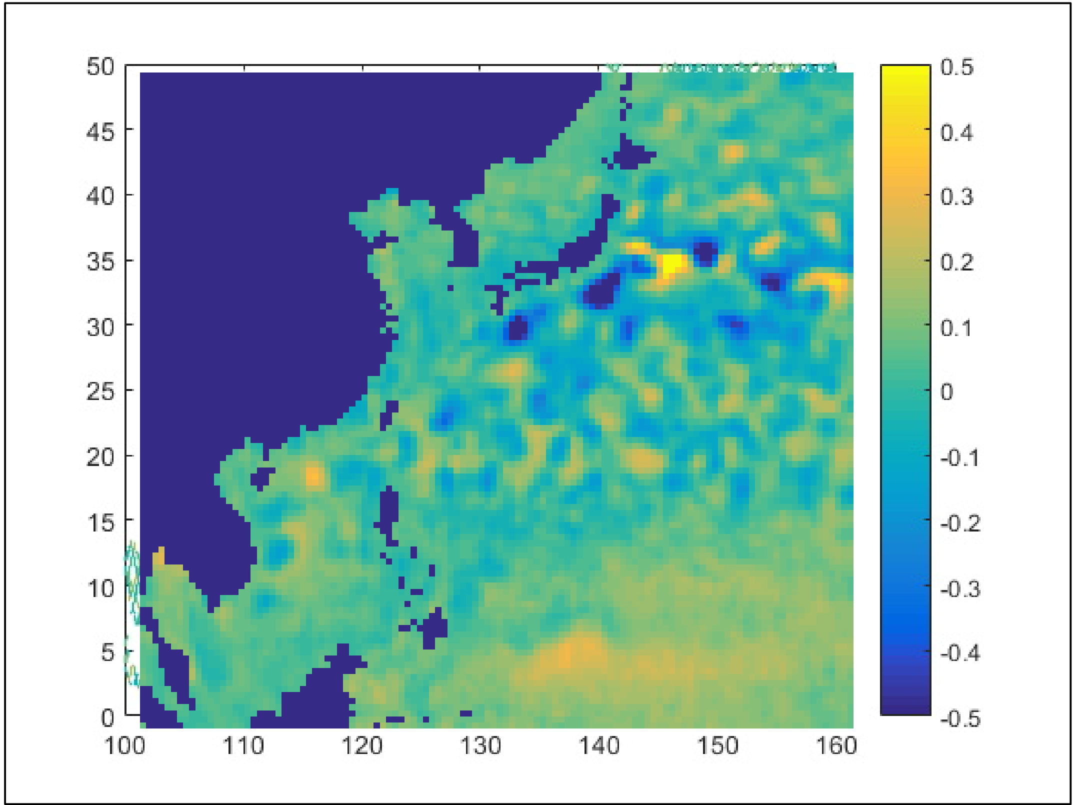
$$w(\phi) = \sin\beta(\phi)/\sin\beta(0)$$

$$\beta(\phi) = \frac{\pi}{2} - \tan^{-1}\left|\frac{V_S \sin\alpha \pm V_e \cos\phi}{V_S \cos\alpha}\right| \qquad \sin\alpha = \left|\frac{\cos I}{\cos\phi}\right|$$

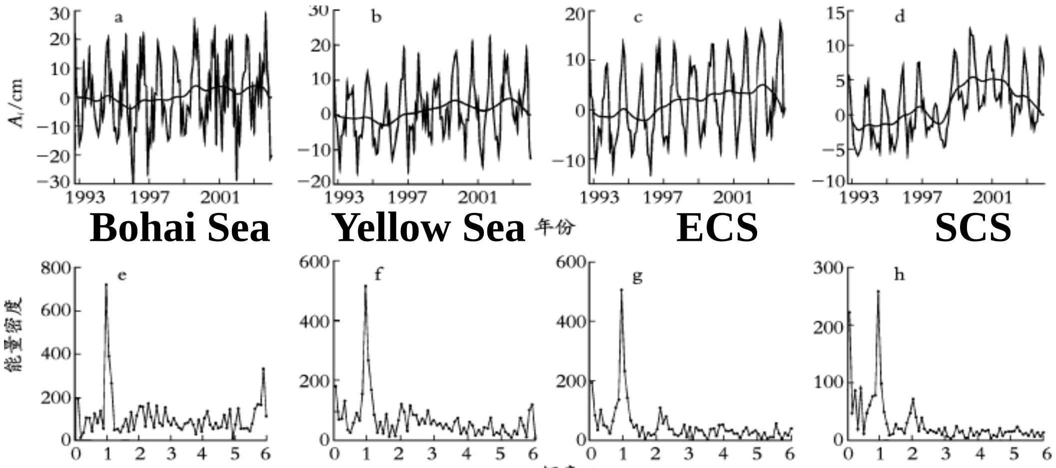
Where, V_S is ground speed of satellite. V_e is earth rotation speed in the equator. I is Satellite orbit inclination, and is positive when I<90° , is negative when I>90° .

The technical flow chart of altimeter data application in the sea level change study

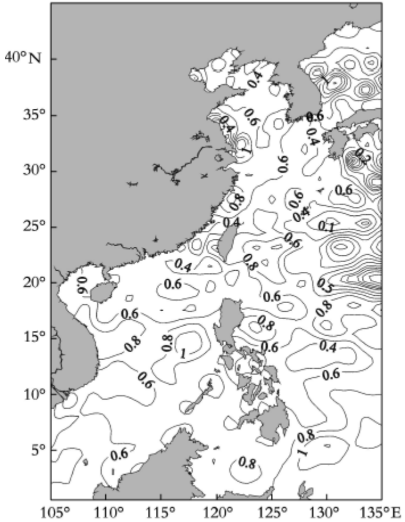
Along track SLA ----→ gridding SLA



- **The period characteristics and rise rate of the sea level in the China Sea were analyzed based on T/P and Jason-1 data from 1992 to 2004, the rise rate was 0.593cm/a.**



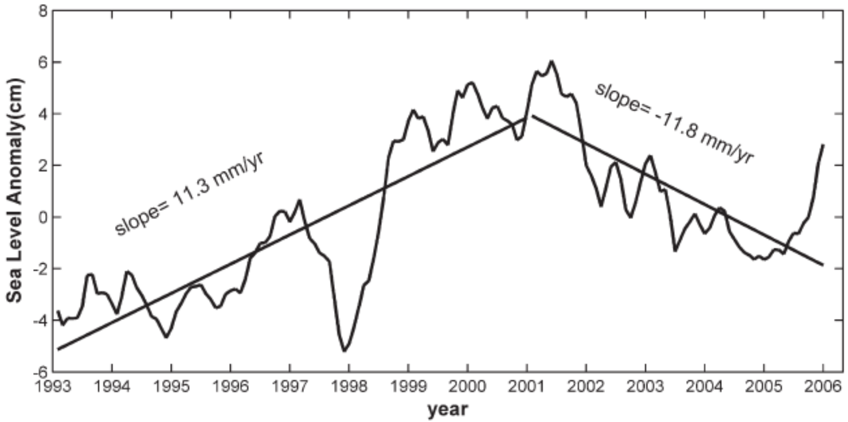
Sea level anomaly and frequency analysis results from Oct . 1992 to Jan. 2004



Spatial distribution of rise rate (cm/ a)

Qiao Xin, 2008. Marine Science, 32(1), 60-64.(In Chinese)

- Sea surface variability in the South China Sea was analyzed to show that the rise rate and fall rate from 1993 to 2006 were 11.3 mm/yr and 11.8 mm/yr respectively.

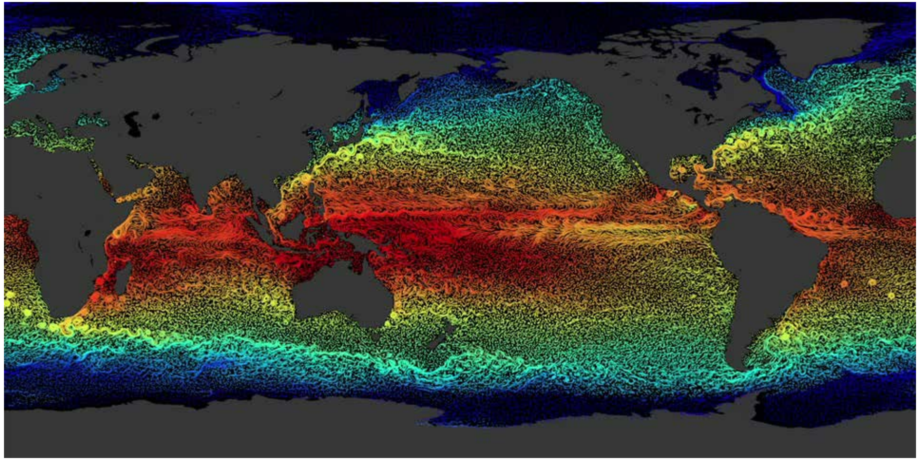


Time evolution of the SCS mean sea level anomaly from January 1993 to December 2005

Xuhua Cheng, 2007. Global and Planetary Change, 72, 227–233.

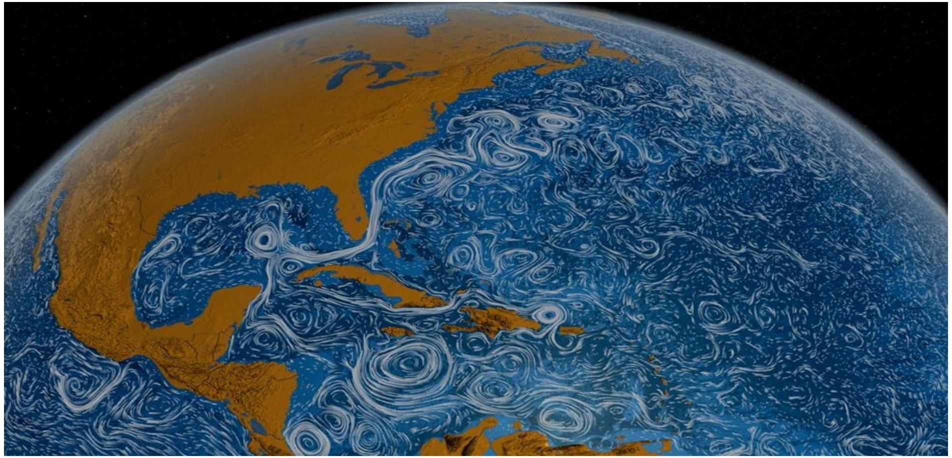
4. Ocean circulation and mesoscale eddy

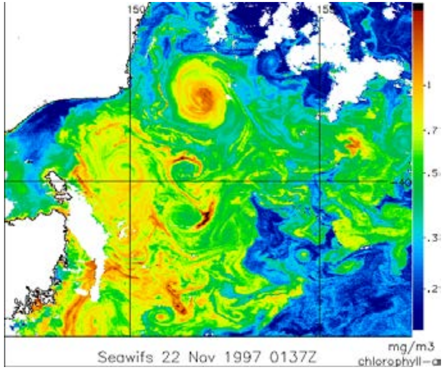
- Ocean circulation and mesoscale eddy are the important forms of sea water movement, and they are important means of transport of mass and energy in the ocean.
- Based on altimeter data, the global ocean circulation and mesoscale eddy were understood.

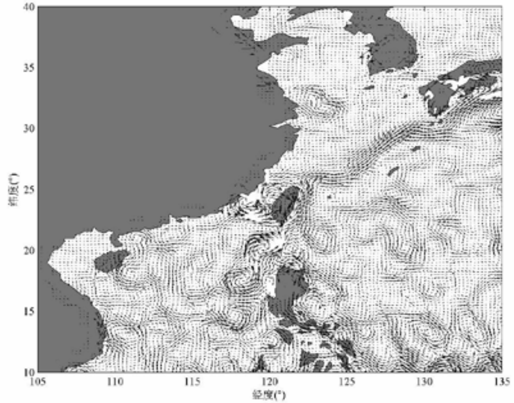


Mesoscale Eddy

- Large bodies of swirling water
- Nearly everywhere in the global oceans
- Temporal scale： ten days ~ several months
- Spatial scale： ~100 km



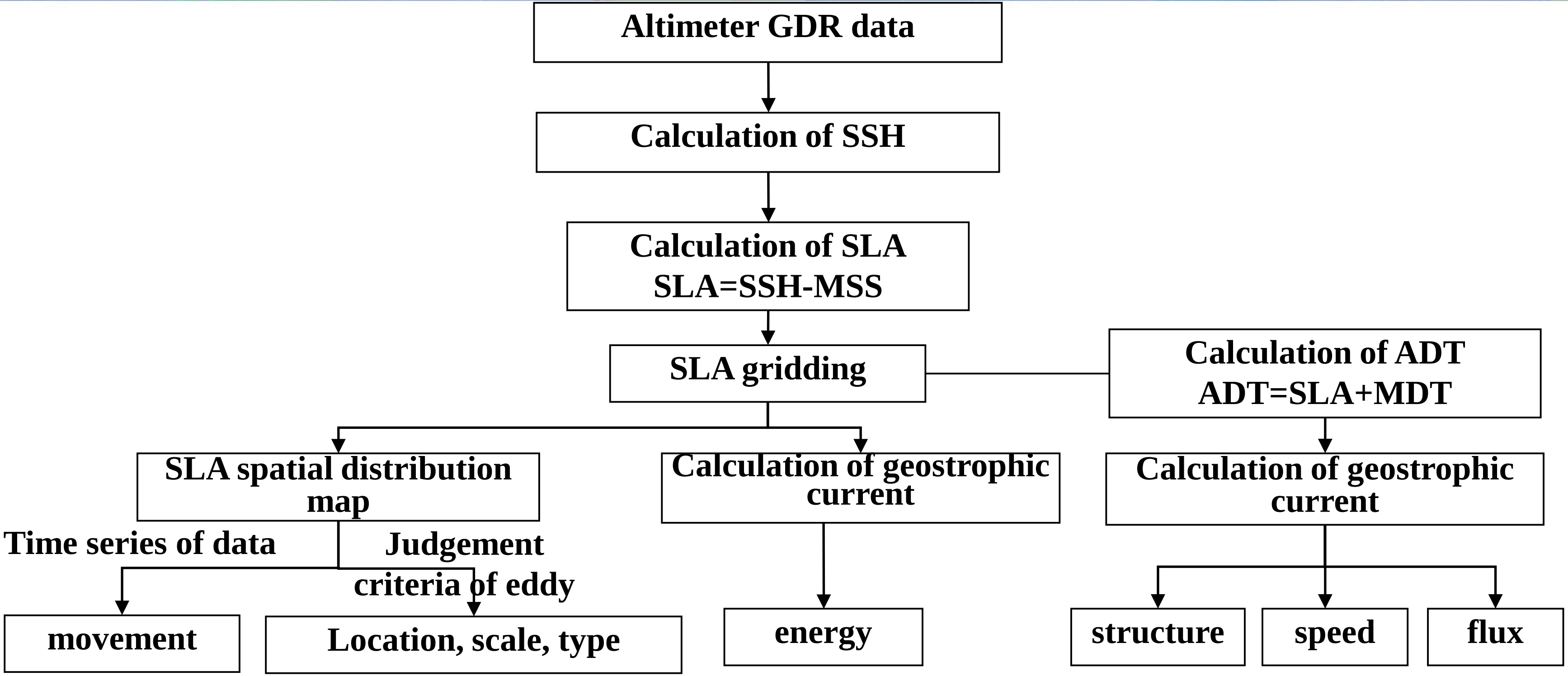




4.1 Application in the ocean circulation and mesoscale eddy study

With altimeter data, we can study:

- **Structure, speed and flux of ocean circulation.**
- **Annual variability of ocean current.**
- **Characters, movement and energy of mesoscale eddy.**
- **Data assimilation to the numerical model.**



The technical flow chart of data application in the ocean circulation and mesoscale eddy study

Calculation of geostrophic current

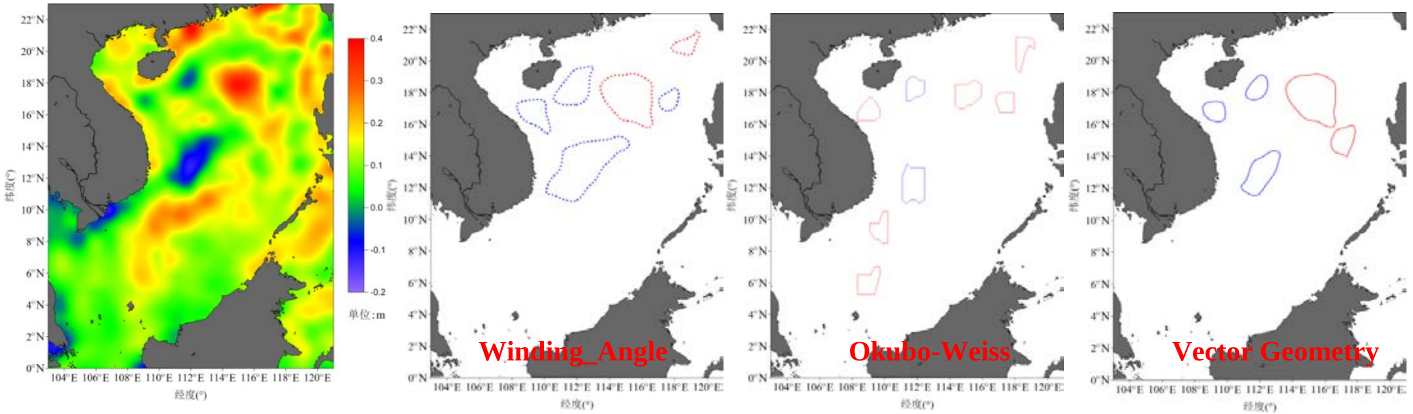
According to geostrophic balance，the pressure gradient force is equal to Corolis force.

$$\begin{cases} u = -\dfrac{g}{f}\dfrac{\partial h}{\partial y} \\ v = \dfrac{g}{f}\dfrac{\partial h}{\partial x} \end{cases}$$

Where, *u*, *v* is the east and north component of geostrophic current. *f* is Corolis parameter. *g* is gravitational acceleration. *h* is ADT.

Eddy detection Method

➢ **Winding Angle, Okubo-Weiss parameter, Vector Geometry**

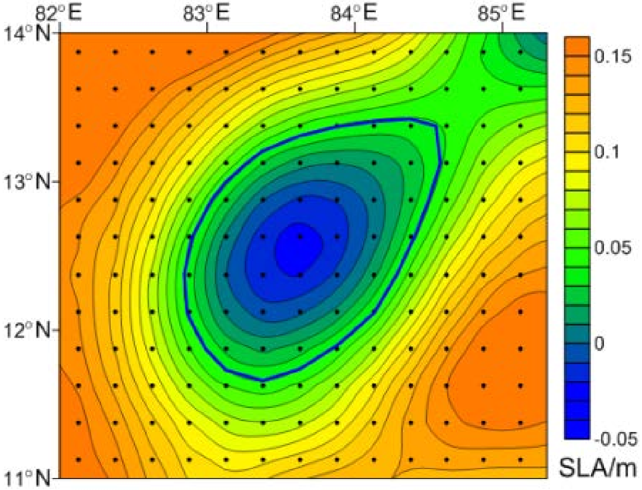


The Winding Angle presents the best performance, similar to the results by other scientists (Chaigneau et al., 2010; Souza et al., 2011).

➢ Winding Angle method

① to identify the local SLA maximum or minimum as the center of eddy.

② to select outermost closed SLA contour associated to each eddy as the eddy edge.



Eddy characteristic

The eddy radius *R* is defined as the equivalent radius of a circle with the same area *A* as the closed contour of the eddy borders，

$$R = \sqrt{A/\pi} \; .$$

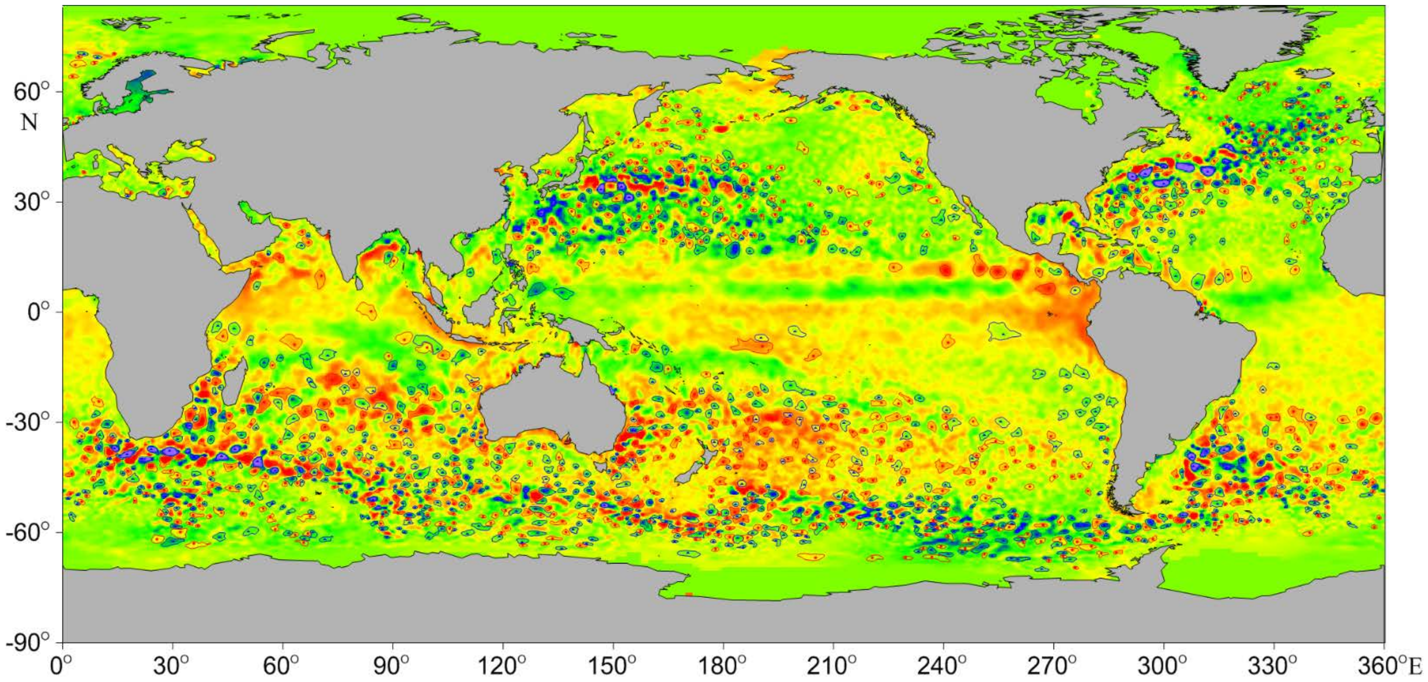
The amplitude is defined as the SLA difference between the center and bourder of mesoscale eddy,

$$Amplitude = |SLA_{\max} - SLA_{\mathrm{border}}| \; .$$

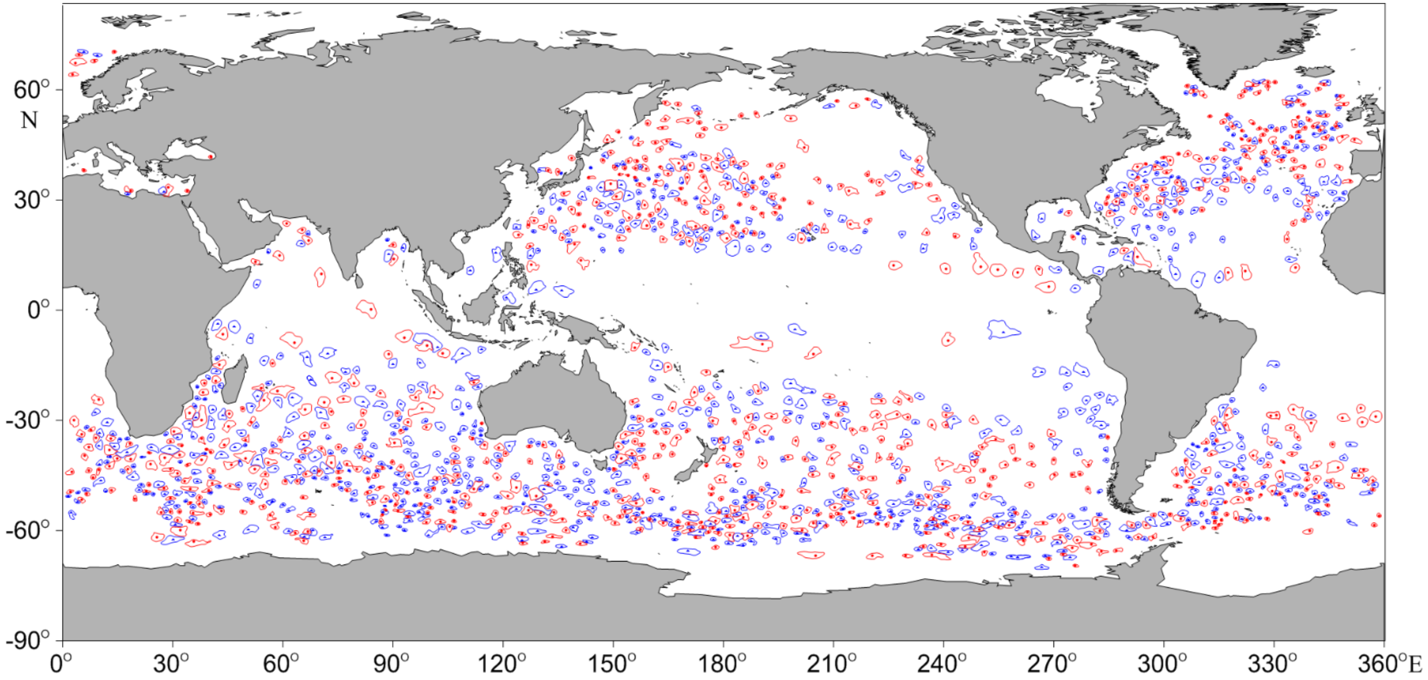
The eddy intensity is characterized by the eddy kinetic energy EKE,

$$EKE = \frac{1}{2}\left(u'^2 + v'^2\right).$$

Mesoscale eddies detection results

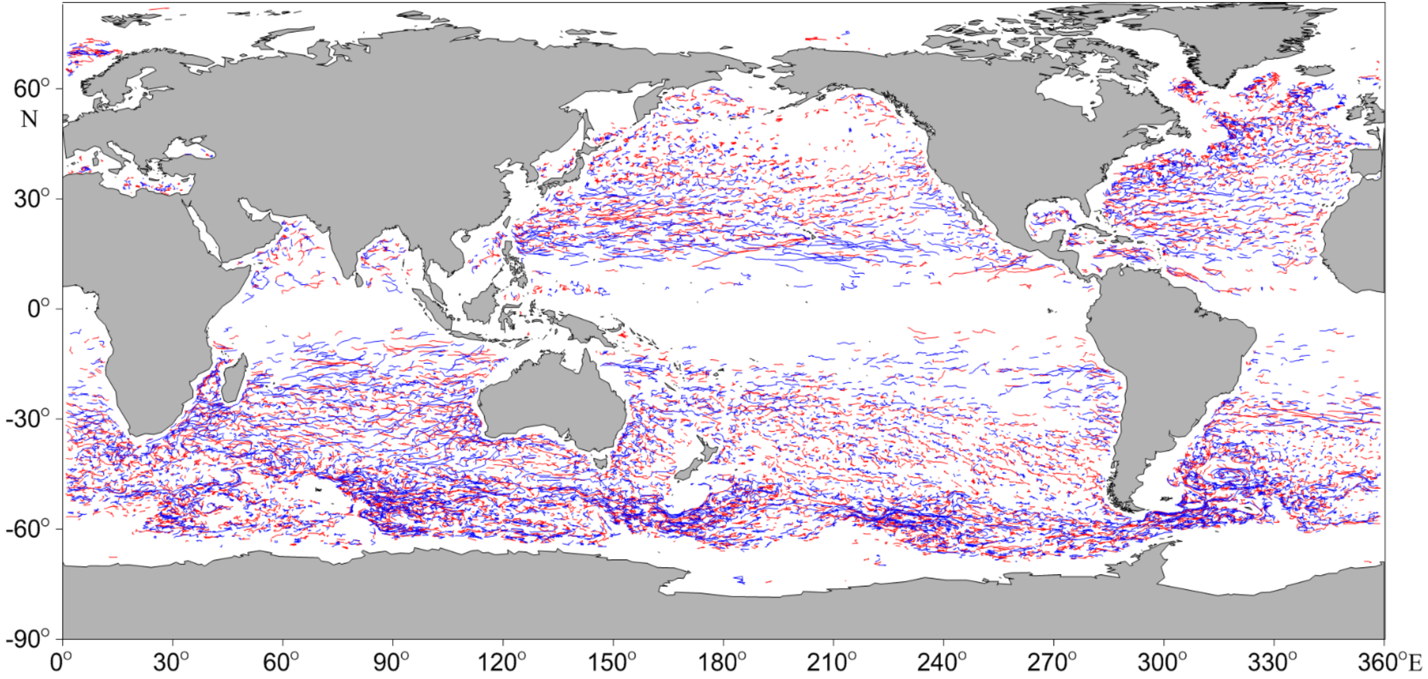


SLA on May 3, 2011

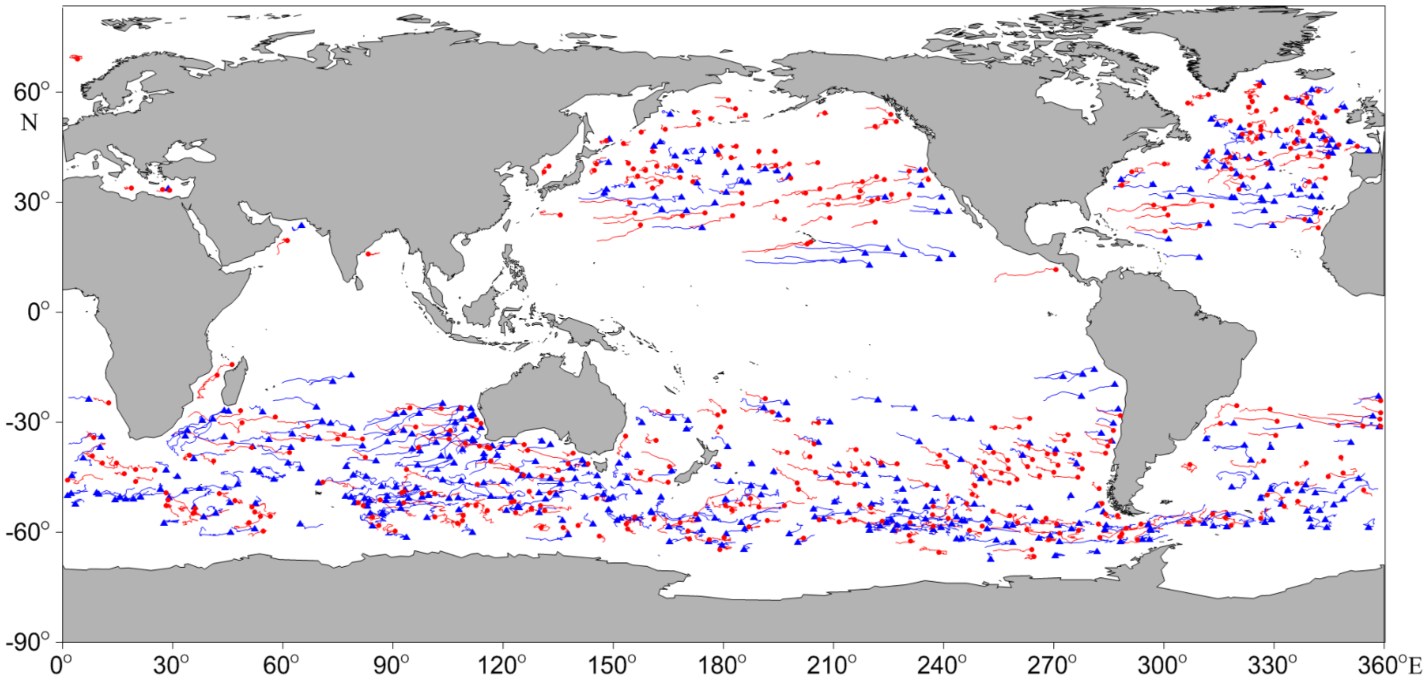


Eddy detection result on May 3, 2011

Eddy Tracking result

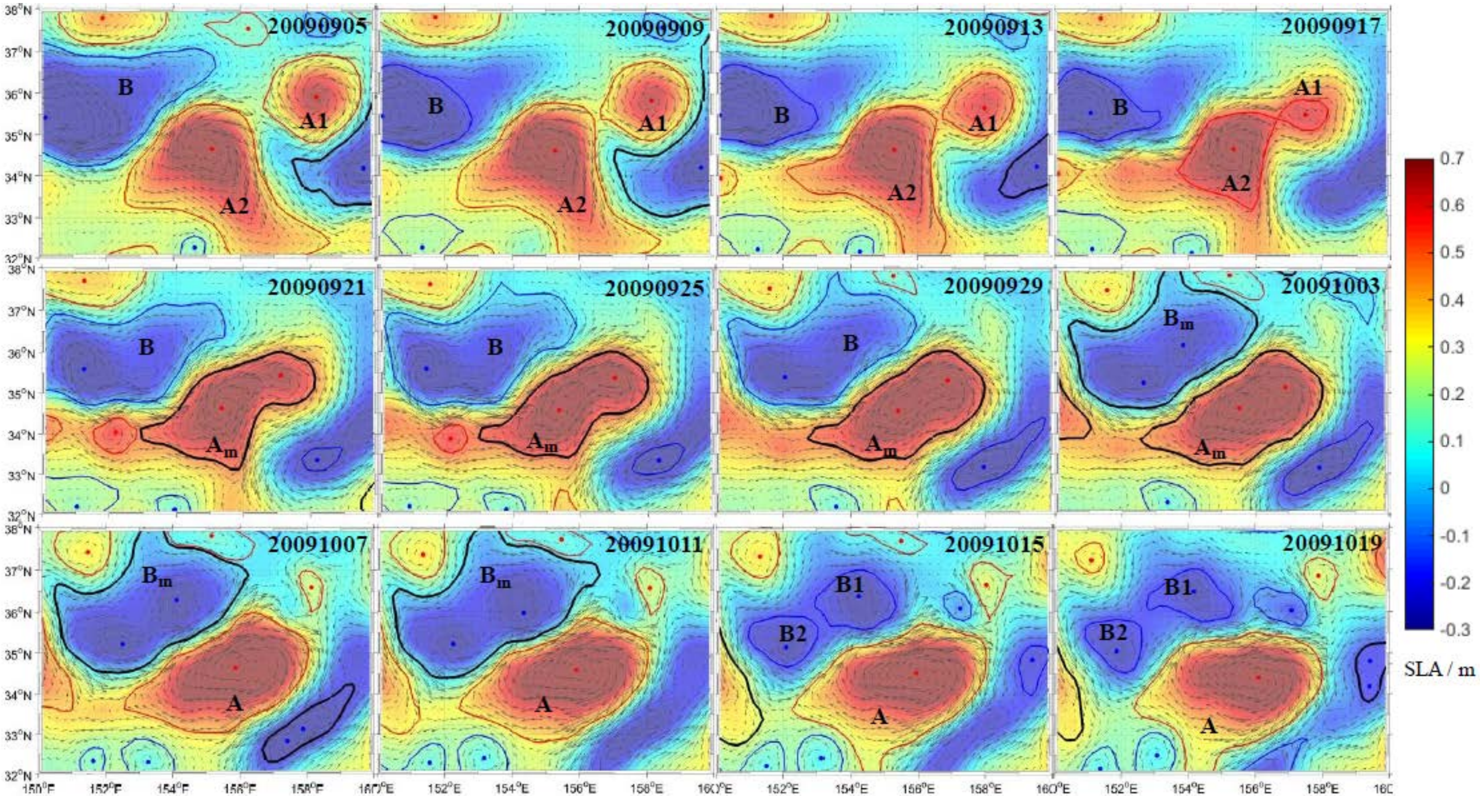


The propagation trajectories of cyclonic and anticyclonic eddies > 30d on 2011

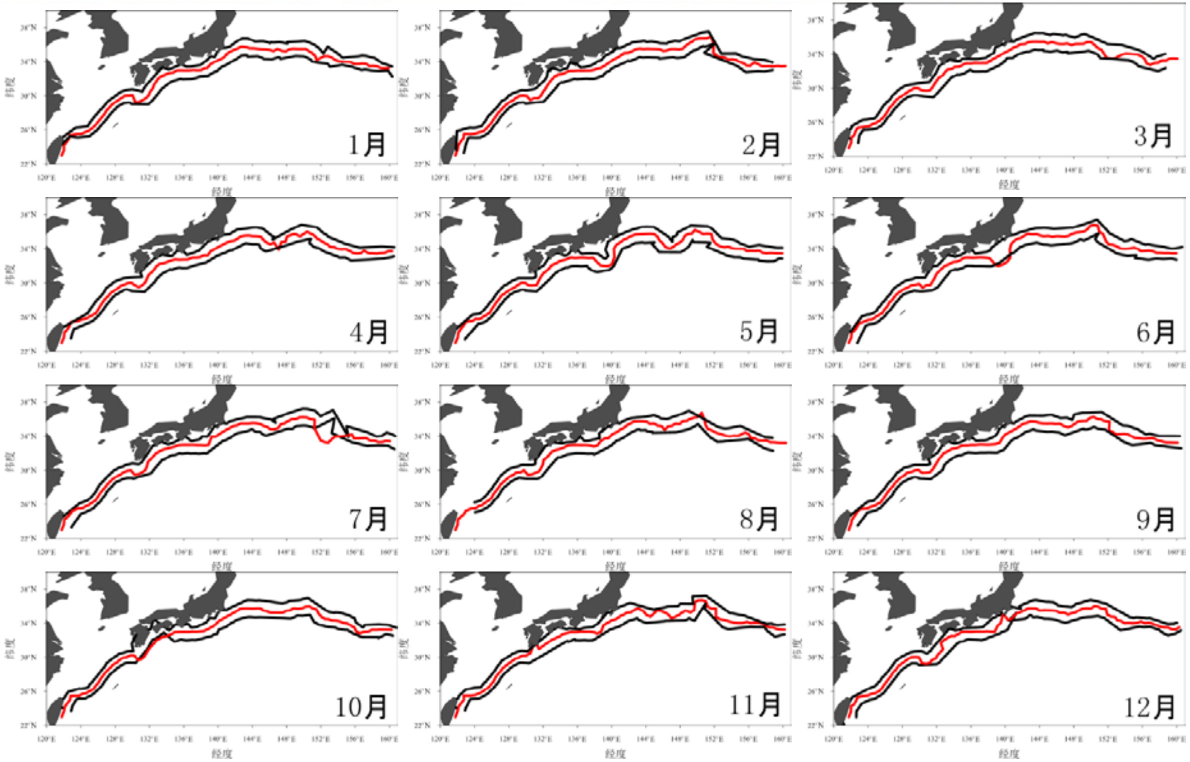


The propagation trajectories of cyclonic and anticyclonic eddies >180d on 2011

Multicore eddy evolution

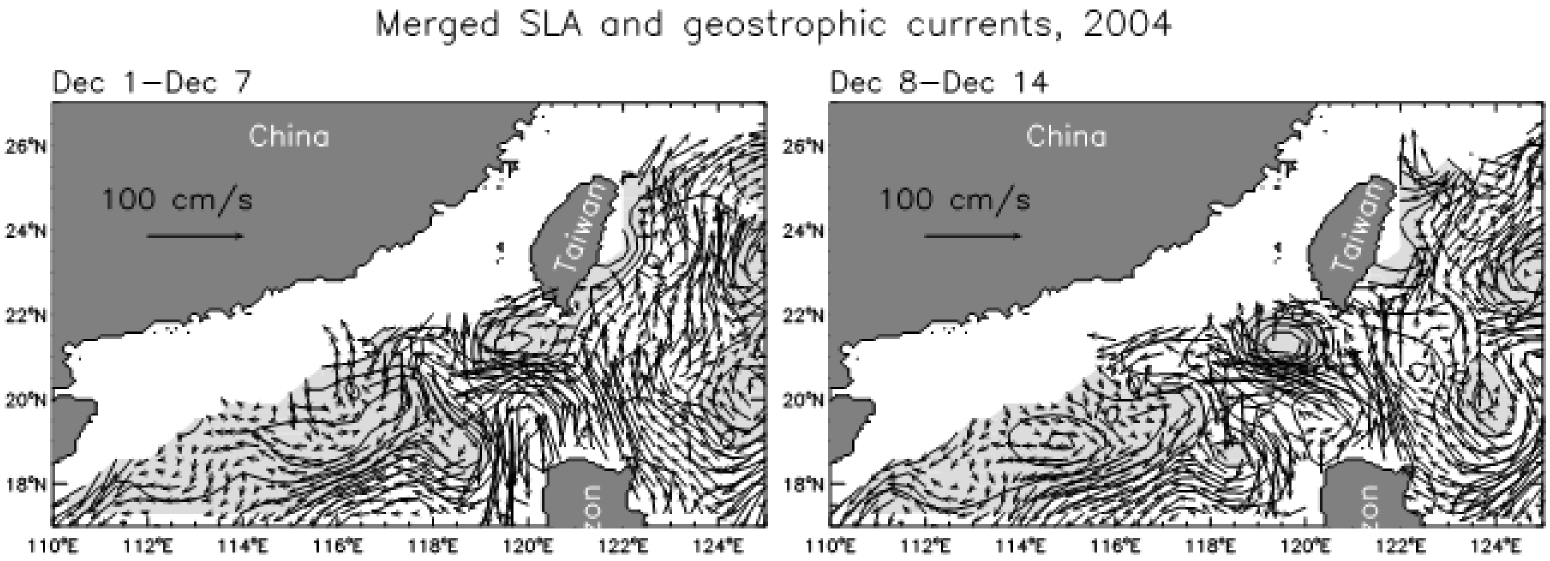


4.2 The application in the China Seas



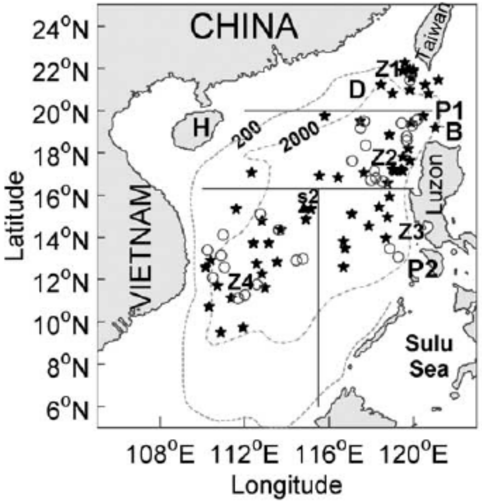
Annual average of the Kuroshio

- altimeter data, combining with Satellite ocean color and SST data, are used to study the surface Kuroshio path in the Luzon Strait area.

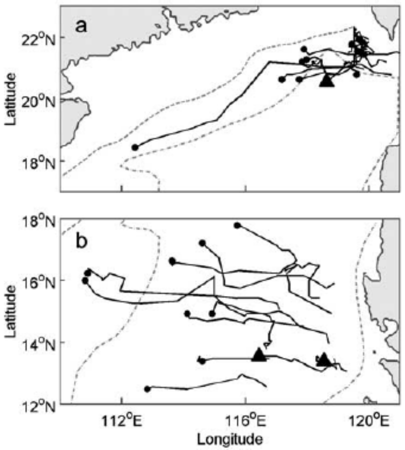


Dongliang Yuan, 2006. JGR, 111, C11007, doi:10.1029/2005JC003412.

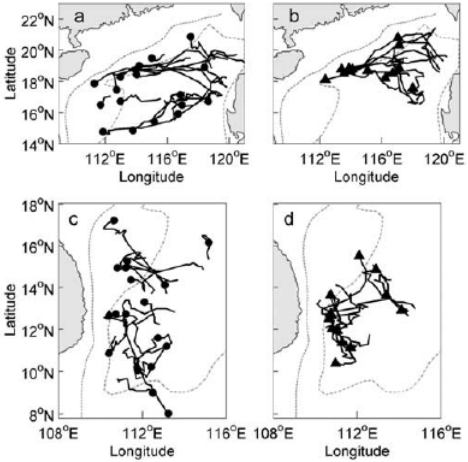
- **A composite time series (1993–2000) of SSHA from several satellites is used to identify eddies in the SCS. The eddy lifetime, radius, strength, and straight-line travel distance are estimated.**



Study area



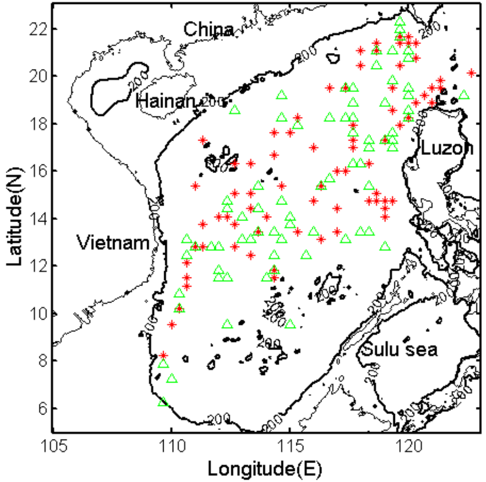
Tracks of eddies generated in (a) Z1 and (b) Z3.



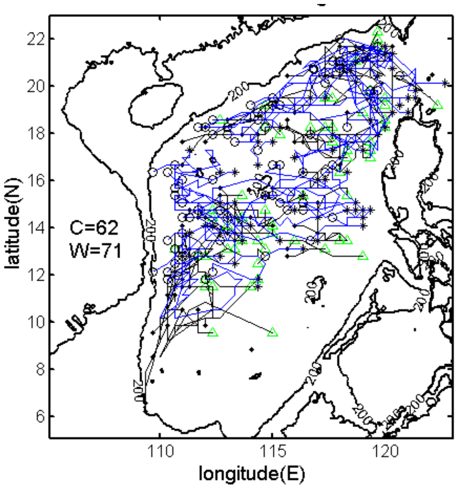
Tracks of eddies generated in Z1 (a, b) and Z4 (c, d).

Guihua Wang et al., 2003. GRL, 30(21), doi:10.1029/2003GL018532.

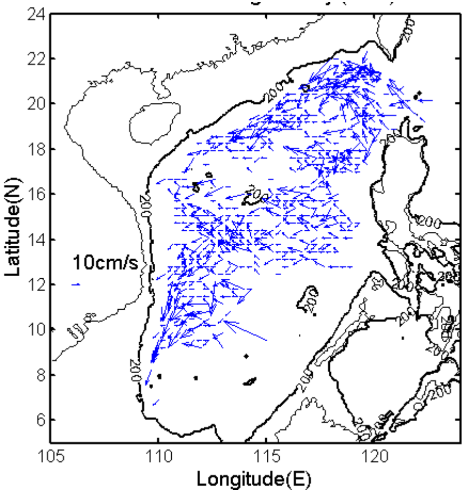
- **Based on T/P and ERS-1/2 merged data, the mesoscale eddies in the SCS from 1993 to 2001 were identified and tracked, and theirs characters of generation and movement were analyzed.**



The location of eddies. * is warm eddy. Δ is cold eddy.

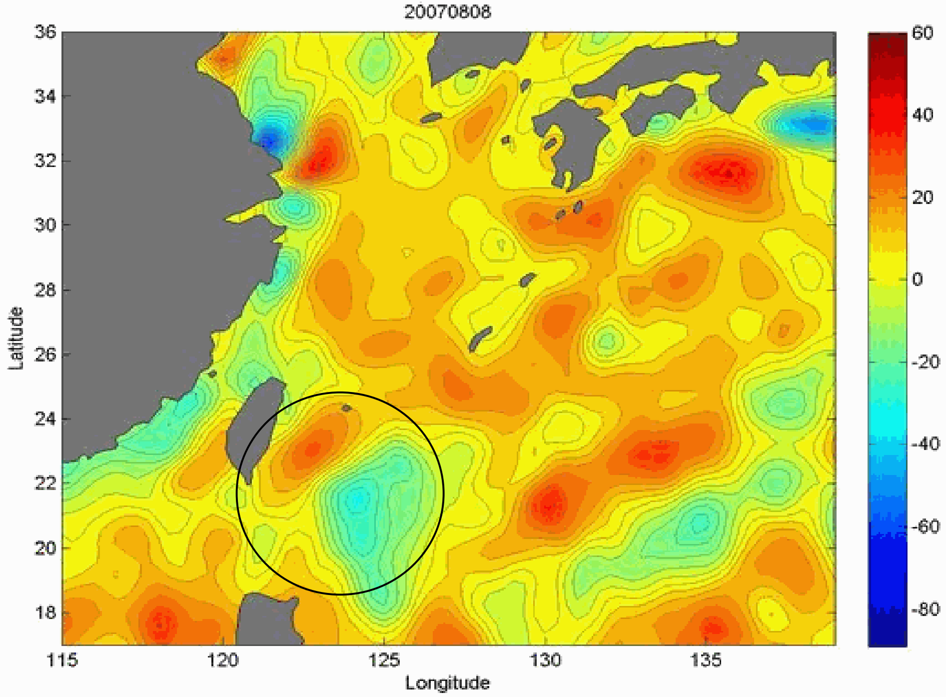


Western moving path

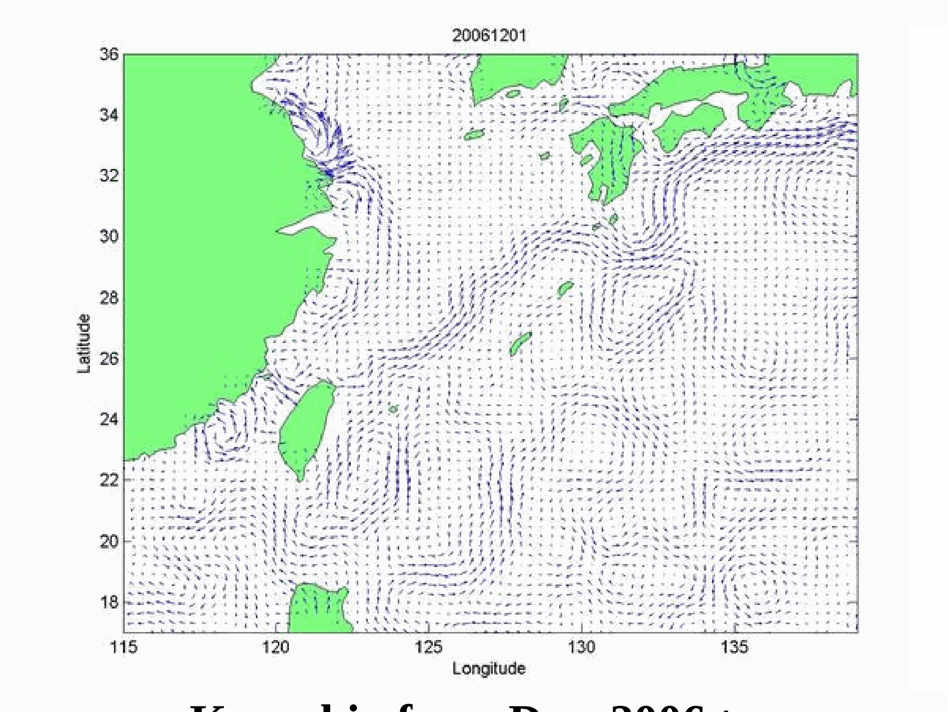


Speed of western moving

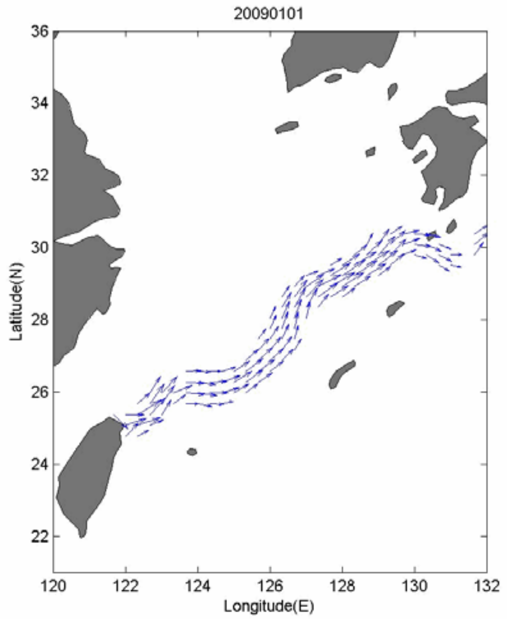
Lin Pengfei, 2005. Master Dissertation, Institute of Oceanology, CAS.



The evolvement of a cold eddy in the eastern Luzon strait during 2007.8.8-2007.10.10



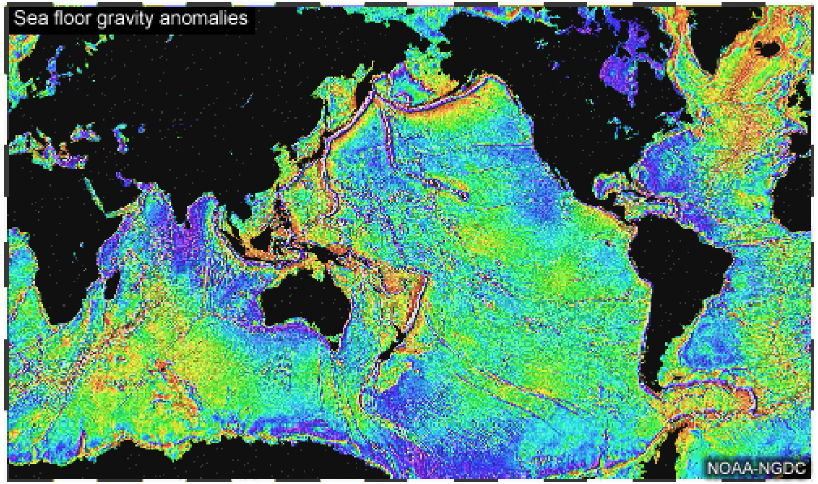
Kurushio from Dec. 2006 to Jan. 2007



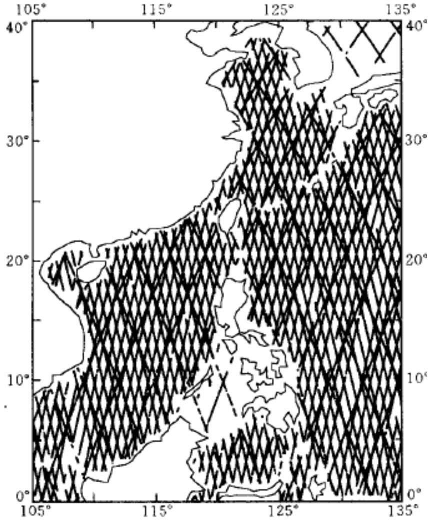
The main current variability of Kuroshio in 2009

5. Marine Gravity Anomaly

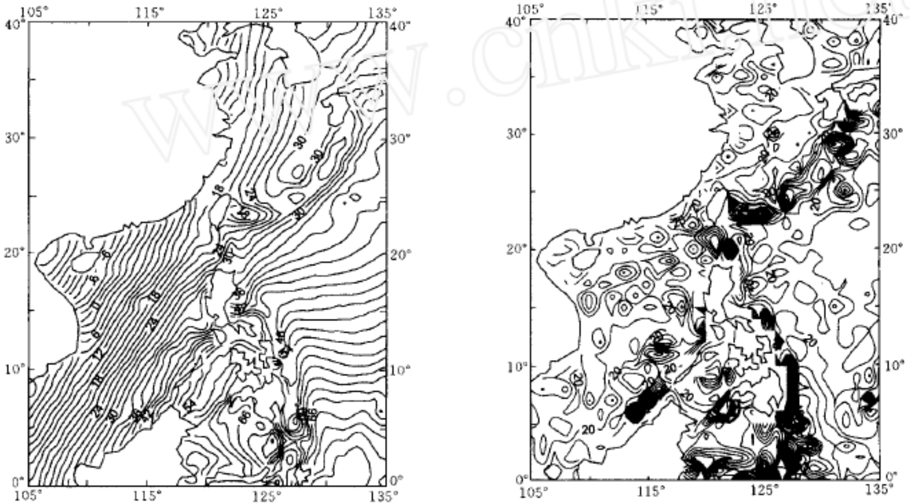
- The determination of the marine gravity field is very important for studying the global gravity field.
- Satellite altimetry has been the important mean to obtain the information of marine gravity field now.



- **Based on T/P and ERS-1 data, the 30′×30′ gravity anomalies in the China Seas and its vicinity are recovered. The precision was 3.5mGal.**



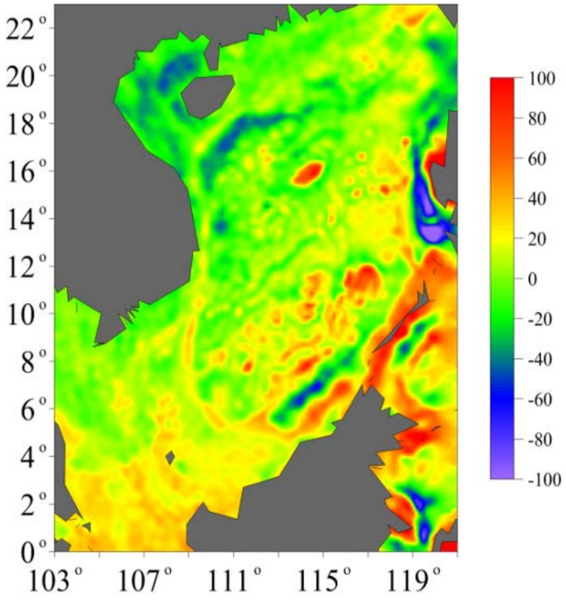
Ground tracks of T/P and ERS-1



Geoid undulations (left) and gravity anomalies in the region of China seas and vicinity

Hsu Hou-tse et al., 1999. Chinese Journal of Geophysics, 42(4), 465-471.

- **gravity anomalies inversion by multi-source altimeters data (Geosat, T/P, ERS-1/2, Envisat, Jason-1/2/3, HY-2A RA).**



Compare to in-situ measurement data, the RMSE is less than 5.8 mGal.

Summary

Ocean Tide

- extract harmonic constants of tidal constituents.
- Assimilate altimeter data into the numerical ocean tide model.
- The application in the China Sea: extracting diurnal, semidiurnal and other tidal constituents based on altimeter data.

Summary

Ocean Wave

- Analyze statistic characters of ocean wave.
- Estimate extreme SWH.
- Validate the statistic distribution and numerical model.
- Assimilate altimeter SWH data into the ocean wave model.

Summary

Sea Level Change

- Trend and rate of sea level rise.
- Analyze the main reasons of sea level.
- Altimeter data assimilation of the numerical model.

Summary

Ocean Circulation and Mesoscale Eddy

- Structure, speed and flux of ocean circulation.
- Annual variability of ocean current.
- Characters, movement and energy of mesoscale eddy.
- Application in the China Seas: Kuroshio, surface circulation and mesoscale eddies in the SCS, ECS and Yellow sea, and the data assimilation of the numerical model .

Summary

Marine Gravity Anomaly

- Recover the gravity anomaly with satellite altimeter.
- The gravity anomalies of different spatial resolution in the China seas were recovered by combining multi-altimeter data.

Thanks for your attention!

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