# 2011-2014

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# PREFACE

This quadrennial report is the fourth report in the new millennium, which is one of the China National Reports (2011-2015), prepared by the Chinese National Committee for IAPSO for the XXVI IUGG General Assembly of the International Union of Geodesy and Geophysics to be held in Prague, Czech Republic, 22 June - 2 July 2015. This report composes of 15 sections which reviewed the main work done and the major progress made in physical oceanography and air-sea interaction in Mainland China as well as the new trend that the physical sciences of the ocean are becoming multi-disciplinary sciences, since researches into sediment dynamics, ecosystem dynamics and biogeochemistry of the ocean are come into together in China. It should be noted that this report only provides an overview of the subjects mentioned in the 15 papers, but it does show encouraging progress in physical sciences of the oceans in Mainland China over the past four years. It is pleasant to see the fact that some of papers in this report have been written by the younger scientists, which shows that the younger generation of marine scientists in China has grown up.

I would like to take this opportunity, on behalf of the Chinese National Committee for IAPSO, to express my deep appreciation to all the authors for their contributions, and to Mr. Tang Shengquan, who edited all the papers into this report. Finally, the editing of this report was supported by several projects like NSFC 41276008.

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From 2011 to 2014, lots of study about internal tides (IT) with in-situ observation, numerical simulation, as well as satellite remote sensing is done in China.

From the field of in-situ observation, the continental shelf of South China Sea (SCS), including Dongsha Plateau, is highly concerned (Pan et al. 2012, Si et al. 2012, Li et al. 2011, Xu et al. 2013, Guo et al. 2012, Cai et al. 2012, Lee et al. 2012). Xu et al. (2011) presented the evidence for the multimodal semidiurnal IT and showed that the second-mode signals dominate the semidiurnal variations in the northwestern SCS. Both Cai et al. (2012) and Xu et al. (2013) agreed that IT kinetic energy dominated by diurnal period than semidiurnal near Dongsha Plateau. The incoherent (not phase locked with astronomical forcing) IT constituents got much more attentions than ever since Lee et al. (2012) pointed that large irregular fortnightly IT variations near Dongsha Plateau were not phase locked with astronomical forcing. Luzon Strait (LS) is another hot area about IT study (Liao et al. 2012, Xu et al. 2014). Based on two 9-month mooring current observations from autumn 2008 to summer 2009, Xu et al. (2014) suggested that the motions of semidiurnal IT were recognized as seasonally invariant, while diurnal IT showed notable seasonal variation, namely, stronger in summer and winter but weaker in spring and autumn, and IT showing north-south asymmetry and highly coherent nature (~70% of semidiurnal and ~90% of diurnal). The parametric subharmonic instability (PSI) study made progress via in-situ observation recently. Xie et al. (2011) found PSI-induced near-inertial waves for first time in the northeastern SCS (~20N), and Xie et al. (2013) confirmed that PSI of the IT can be effectively enhanced in the reflection of ITs from the boundary. There, PSI is likely to be a strong, rapid nonlinear instability, rather than the classic weakly nonlinear wave-wave interaction.

In the field of numerical simulation of IT, Li et al. (2011) introduced the internal-tide viscosity term based on the z-coordinate model HAMSOM and applied the modified model for the first time with real topography to investigate the M2 internal tides in the LS for its generation and propagation, and revealed that the major IT generation sites are the northwest of Itbayat Island, the southwest of Batan Island and the northwest of the Babuyan Islands. The influences of the changing Kuroshio were investigated through a POM model with idealized settings finished by Jan et al. (2012), differences exist between the modification of the Kuroshio on K1 and M2 baroclinic tides was found. Chiou et al. (2011) also used a POM model but with a real bathymetry to find the source of IT energy off southwestern Taiwan and indicated 95.6% of that energy is remotely generated at the LS and the southeastern Taiwan Strait. MITgcm is widely used in IT simulation (Li et al. 2012, Fan, 2014). Li et al. (2012) used a fully nonlinear, three-dimensional non-hydrostatic model driven by four principal tidal constituents (M2, S2, K1, and O1) for investigating the spatial-temporal characteristics and energetics of IT in LS. Miao et al. (2011) and Chen et al. (2012) presented a three-dimensional isopycnic-coordinate ocean model consists of forward model and adjoint model for the study of IT and applied to SCS successfully. The trend of numerical simulation is using real topography, higher resolution and a better parameterization of dissipation.

Satellite remote sensing is usually combined with in-situ observation to study the influence of Typhoon on the inertial-waves, or for validating numerical simulation results. Sun et al. (2011) indicated that the near-inertial oscillation (NIO) band grows up to a super-dominant constituent of the wave action and the central frequencies of NIO band are blue shifted by using both ADCP mooring data and simultaneous satellite altimeter MADT data. Bai et al. (2013) reported the in-situ documentation of high-frequency internal wave (HIW) activities in the southern Taiwan Strait, and this frequent occurrence of HIW is evidenced by the analysis of a MODIS true color image of the sea-surface roughness.

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# Progress of Ocean-Atmosphere Interaction Studies in China from 2011 to 2015

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During 2011-2015, Chinese scientists made important progress in studying ocean-atmosphere interactions. Their research area extended from the Pacific and Indian Ocean to globe ocean. Some of the research has received marked attention from the world. According to the different time and space scales, the major research results are introduced as follows:

## 1. The ocean-atmosphere interactions over the tropical Oceans

In the recent 5 years, Chinese scientists make great progress in understanding the tropical ocean-atmosphere interactions. For tropical Pacific, a series of studies by Chinese scientists focus on the El Nino - Southern Oscillation (ENSO), the dominant mode in the tropical oceans. The role of westerly wind bursts on El Nino events is investigated, suggesting a close relationship of these wind bursts with both "cold tongue" and "warm pool" El Nino (Lian et al. 2014). A unified perspective on El Nino diversity as well as its causes is proposed, indicating that the westerly wind bursts lead to the asymmetry, irregularity and extremes of El Nino (Chen et al. 2015). For the interannual variability over tropical Indian Ocean, different flavors of Indian Ocean dipole (IOD) mode (Du et al. 2013a, Guo et al. 2015), as well as the "winter predictability barrier" for IOD events are found in observations and models (Feng et al. 2014a, 2014b). Furthermore, the role of the Indo-Pacific SST and rainfall interannual variability on Asian atmospheric circulation in winter is also investigated by Chinese scientists (Zheng et al. 2013).

In addition, Chinese scientists also evaluated the simulation of tropical ocean-atmosphere interactions in coupled models. It is found that the excessive equatorial Pacific cold tongue and double intertropical convergence zone (ITCZ) stand out as the most prominent errors of the current generation of CGCMs (Li and Xie 2012, 2014). On the simulation of ENSO, there is a systematical narrow bias in the simulated meridional width of the SST anomalies of ENSO in CMIP3 models (Zhang et al. 2013), which shows a modest improvement in CMIP5 models (Zhang and Jin 2012). The simulation of interannual ocean-atmosphere modes in tropical Indian Ocean is also evaluated. For the Indian Ocean Basin (IOB) mode, Du et al. (2013b) pointed out that most CMIP5 models reproduce the IOB mode and its close relationship to ENSO, and half of them capture key IOB processes. The magnitude of IOB mode in coupled models are highly related with the thermocline dome in the Southwestern Indian Ocean (Li et al. 2015). Another study evaluated the performance of 21 CMIP5 models in the simulation of the IOD mode (Liu et al. 2014). For the tropical Atlantic, the origin of southeast tropical Atlantic SST biases are investigated by CGCMs (Xu et al. 2014a, b).

**2. The multiscale ocean-atmosphere interaction in the midlatitudes**

From 2011-2015, Chinese scientists made fruitful progress on the ocean-atmosphere interactions in the midlatitudes on different timescales. On the large scale, a framework of SST anomalies and storm track interactions in midlatitudes is built, especially over the North Pacific and North Atlantic. Gan and Wu (2013a, 2015) found significant seasonal and long-term relationships between storm tracks and SST variations in the North Pacific and North Atlantic via a lagged maximum convariance analysis (MCA). They also investigated changes in Northern Hemisphere winter storm tracks during the twentieth century (Gan and Wu 2014), as well as the modulation of ocean-atmosphere feedback over the North Pacific in early winter from global warming (Gan and Wu 2012).

The effects of SST front in the western boundary current region on atmosphere are revealed by a series of studies based on satellite observation. Chinese scientists found that the SST front along the East China Kuroshio affects the local sea surface winds at two different time scales (Liu et al. 2013). The atmosphere response to East China Kuroshio SST front is also investigated, which appears to extend beyond the marine atmospheric boundary layer, with frequent occurrence of cumulus convection (Xu et al. 2011). Furthermore, another study reported that the Gulf Stream SST front has a substantial impact on the marine boundary layer, especially on the low-level cloud (Liu et al. 2014).

**3. The response of ocean-atmosphere interactions to global warming**

During 2011-2015, Chinese scientists have made great achievements and contributions in understanding the dynamics under ongoing global warming. One impressive achievement is revealing the patterns of the seasonal response of tropical rainfall to global warming (Huang et al. 2013). The change of seasonal mean rainfall under global warming combines the wet-get-wetter and warmer-get-wetter trends. Another important achievement is explaining the recent global warming hiatus (Chen and Tung 2014). Scientists found that the slowdown of global warming is mainly caused by heat transported to deeper layers in Atlantic and the Southern oceans. Furthermore, the global fast and slow responses to global warming were proposed (Long et al. 2014). The SST and precipitation patterns are different on the two time-dependent responses.

The regional response of ocean-atmosphere interactions to global warming are also investigated in recent 5 years. A series of attribution studies distinguished the contribution of different forcings to the long-term change in Pacific and Indian Ocean (Dong and Zhou 2014, Dong et al. 2014a, b). Especially for the tropical Pacific, the response of the equatorial SST to greenhouse gas forcing in a simple coupled model is investigated, suggesting a robust El Nino-like warming pattern in the tropical Pacific (Jia and Wu, 2013).

In addition to the mean state and seasonal changes, the responses of interannual ocean-atmosphere coupled modes are also studied. As the dominant mode in tropics, the response of ENSO's teleconnection to global warming is investigated based on model experiments (Zhou et al. 2014). The ENSO-forced Pacific-North American (PNA) teleconnection pattern moves eastward and intensifies under global warming. In the tropical Indian Ocean, the responses of IOB and IOD are both studied. For the IOD mode, Zheng et al. (2013) used CMIP5 models to find intensified oceanic feedback and weakened atmospheric feedback, which are counteract each other under global warming. For the IOB mode, studies suggested its amplitude and "capacitor effect" are enhanced under global warming due to the intensified local air-sea interactions (Zheng et al. 2011, Hu et al. 2014).

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# Progress of China in Arctic Physical Oceanography during 2011-2014

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Over the past decade, the Arctic is undergoing rapid change. Although the Arctic sea ice changes are the main feature, the key factor is the change in the Arctic Ocean, for the ocean is the solar energy conversion and storage device. During 2011-2015, Chinese scientist put attached in the ocean variation, and got some series of research activities, which have markedness on the world. According to the different hydrological studies, the major research results are introduced as follows:

**I The upper ocean thermodynamics in Arctic**

1. Heat content and freshwater content in the Canada Basin

In the context of variations of Arctic sea ice, heat content of seawater has undergone significant changes. To analyze the variation and trends of heat content of sea water is benefit for people deepen understanding of the rapidly changing Arctic. CTD data collected during the summers of 2003 and 2008 were used to study upper-ocean (top 200 m) heat content in the Canada Basin (Zhong and Zhao, 2012). The variation of heat content with depth, heat content differences between the summers, principal driving factors, and horizontal spatial scale differences were analyzed. The near-surface temperature maximum ( NSTM) water was also analyzed as an indicator of Arctic Ocean warming.

Freshwater content ( FWC) in the Arctic Ocean has changed rapidly in recent years, in response to the significant decrease in the extent of the sea ice. Research on freshwater content variability in the Canada Basin, the main storage area of fresh water, is important for understanding the input-output of freshwater in the Arctic

Ocean. The FWC in the Canada Basin was calculated using data from the Chinese National Arctic Research Expeditions of 2003and 2008, and from expeditions of the Canadian icebreaker Louis S. St-Laurent from 2004-2007 by Guo et al.(2012). Results showed that the upper ocean in the Canada Basin became continuously fresher from 2003 to 2008, excepting 2006. Contributors to the FWC increase are generally considered to be net precipitation, runoff changes, Pacific water inflow through the Bering Strait, sea ice extent, and the Arctic Oscillation ( AO).

2. Heat flux components in Nordic Seas

Water masses in the Nordic Sea are complex as there are imports of warm and cold ocean current, and a number of recycles. The differences of heat flux components in the four basins were studied to understand the spatial difference of the air-sea interaction in the Nordic Seas (Zhao et al., 2014). As the highly consistent of the averaged SLP of Nordic Seas with AO index, the correlation of the heat fluxes of the four basins with AO index is analyzed to show the influence of oceanic heat on atmospheric movement.

3.

**II The water masses in Arctic**

1.The cold water on the shelf of Bering Sea

The research on the Bering Sea water began from the first CHINARE Arctic Expedition in 1999. Chinese scientists do a lot in this area. Using the high resolution CTD data between 1982 and 2008, Wang and Zhao investigate the property and inter-annual variations of the summer cold water on the northern shelf of the Bering Sea. The results indicate that the waters in this area can be divided into masses by the differences in temperature and salinity. -1°C, 2°C and 4°C isolines can be used properly to identify the boundary of the different water masses. And the distribution range of the cold pool changed between “warm year” and “cold year” on the whole Bering Shelf over the past ten years.

2. Near Sea-surface Temperature Maximum

Near Sea-surface Temperature Maximum (NSTM) is firstly noticed by the Chinese scientists in the Arctic Ocean (Zhao et al, 2003), which is the focus of the upper ocean in Arctic in the past ten years. Cao et al. (2011) studied the fine structure of NSTM using the CTD data by the third CHINARE Arctic Expedition and the ITP data. The annual period of NSTM is shown by this paper, which occurs in summer and disappears in spring in next year. Zhao and Cao (2011) used the CTD data from 1993 to 2010 to study the temperature structure, the temporal and spatial variations. Two clear stages of interannual variation were identified, which was related to the rapid change of the Arctic sea ice.

3. Atlantic Water

The Atlantic Water (AW) is between the surface water and the deep water. The warming of the AW was studied based on the analyses of hydrographic observations in the Canada Basin of the Arctic Ocean during 1985-2006 (Li et al., 2012). It was shown that how the anomalously warm AIW spreads in the Canada Basin during the observation time through the analysis of the AIW temperature spatial distribution in different periods. In 2004, a cold mode of Atlantic Water (AW) entered the western Canada basin, replacing the anomalously warm AW that resided in the basin since the 1990s (Zhong and Zhao, 2014). This slightly colder AW was denser than the 1990s warm mode; it gradually filled most of the western basin by 2009. The enhanced surface stress curl led to the spinup of the Beaufort Gyre and convergence of freshwater. The spinup also resulted in a deepening of the AW core at the center of the gyre and in shoaling of the AW core at the margins of the gyre. The combined effect of density and sea ice retreat that enhanced surface stress curl determined the depth of the AW inside the Beaufort Gyre since 2008. The deepening of the AW core and expanding of the area where the AW deepening occurred had a profound effect on the large-scale circulation in the Arctic Ocean.

4. Double- diffusive staircases in the Canada Basin

Double-diffusive staircases are located between the cold, fresh upper water and the warm, salty Atlantic Water in the Arctic Ocean. There exist extensive double-diffusive mixed phenomena in the Canadian Basin. Double-diffusive staircase is observed in the central Canada Basin and Mendeleyev Ridge by CTD profile data in from the third CHINARE Arctic Expedition in summer of 2008. Zhao and Zhao(2011) found that the distribution of double-diffusive staircase has significant spatial difference. There exists double-diffusive staircase through the depth range of 100-500m. On the basis of double-diffusive flux laws, estimated vertical heat fluxes through the staircase are in the range 0.05-0.22W/m$^2$. Song et al.(2014) found heat flux differences between the upper and lower interfaces were correlated with hear variance of the mixed layer based on the data of Moored Profiler, Ice-Tethered Profilers, and Microstructure Profiler.

**III The front in Arctic**

Ocean front is characterized by a narrow transition zone between the two water significantly different bodies. It is an internal matter of sensitive marine area sports and energy exchange. GIN seas special seabed topography and complex currents determine that it has the typical frontal structure. The spatial distributions and seasonal variations of the main fronts in GIN seas are analyzed by grid data of monthly mean of temperature and salinity by He and Zhao(2011). The fronts show significant diversity in their characteristics and seasonal variations.

During the third CHINARE Arctic Expedition in summer 2008, 33days of current profile, near bottom sea water temperature and salinity data in central Chukchi Sea were collected by a mooring system(CN-1). The observed data showed that near bottom water temperature has two rapid and significant changes. Shu et al.(2011) found that these rapid changes occurred not only in the bottom layer but also the upper layer by the CTD and SST data. The rapid temperature changes were caused by the movement of temperature front.

**IV The currents in the Arctic ocean**

1. The volume transport through Bering Strait

Bering Strait is the only channel connecting the Pacific Ocean and the Arctic Ocean. The Pacific water through the strait is mainly driven by the meridional sea level slop and its inter-annual variation has great influence on the Arctic Ocean. Zhang and Su

(2012) studied the factors related to the inter-annual variability of summer volume transport. The results showed that the SSH in the Laptev Sea, the East Siberian Sea, the Chukchi Sea, south of the Beaufort Sea was negatively correlated to the volume transport of Bering Strait in inter-annual scale while the situation was opposite in the eastern shelf of Bering Sea. They also found that the Ekman transport anomaly should be responsible for the relationship between the sea surface height and the volume flux of Bering Strait. The paper revealed that the summer SLP's inter-annual variation can change SSH via Ekman transport and finally dominant the volume transport through Bering Strait.

2. The currents in Chukchi Sea

Based on the Acoustic Doppler Current Profilers obtained from a shallow mooring deployed in the Central Channel of the Chukchi Sea in the third CHINARE Arctic Expedition 2008, the distribution of sea currents is studied. Wang et al. (2011) analyzed the trend of the vertical structure of currents, profile characteristics and baroclinicity. They also studied the distribution characteristics of residual current and the time-series structures and variations of temperature and salinity in the central channel (Wang et al., 2012). They discussed the relationship between the surface residual current, the wind, the structure of temperature and salinity.

3. Arctic sea-ice drifting patterns

Changes in large-scale sea-ice circulation may havegreat effects on the delicate Arctic environment. Wang and Zhao (2012) studied the spatial and temporal changes of Arctic sea-ice drift by monthly mean sea ice motion vectors and monthly mean sea level pressure (SLP). According to the distinct differences in monthly mean ice velocity field as well as in the distribution of SLP, there are four primary types in the Arctic Ocean: Beaufort Gyre+Transpolar Drift, Anticyclonic Drift, Cyclonic Drift and Double Gyre Drift. The annual occurring times of these types are closely correlated with the yearly mean Arctic Oscillation index.

**V Conclusion**

In the last four years, the studies of the Arctic physical oceanography of China were focused on the rapid changes of the variation of the hydrological phenomena, including the water masses, the fronts, the currents, and so on, which directly reflects the changes in the characteristics of the Arctic. Chinese scientists have made considerable progress in Arctic physical oceanography. By the international cooperation the studies on the Arctic are put into the international Arctic science community and play an important role in promoting the global Arctic research. Structures and mechanisms of various hydrological phenomena are still as the focus in the future research. The research of ocean-atmosphere and climate change in Arctic will also be developed, especially the direct and indirect impact on China's climate.

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# Progress of Marine Biogeochemical Process of Biogenic Elements in China from 2011 to 2015

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As the basis of the biological activity process, biogenic elements have been a popular topic in marine biogeochemistry. In recent 5 years, the researches of C,N,P and biogenic silica in the China marginal sea environments have made further progress. In marine carbon cycle, the southern Yellow Sea SYS behaved as a weak $CO_2$ sink during April to October. The control of temperature on $pCO_2$ was predominant in the offshore SYS and the non-temperature factors were predominant in the shallow nearshore area (Qu et al., 2013;Qu et al., 2014).The TMZ of the Changjing River estuary acted as a source of atmosphere $CO_2$ in February and November and as a sink in May and August.(Li et al.,2015). By analyzing the composition of n-alkane and macroelements in the surface sediments of the central South Yellow Sea, the organic carbon was mainly derived from terrestrial higher plants, which mainly from the input of the modern Yellow River and old Yellow River. Contributions from herbaceous plants and woody plants were comparable (Zhang et al., 2014). For the Yellow Sea it was found that on average approximately 90% of the organic carbon derived from primary productivity was decomposed in the water column and 8% was decomposed in the sediment, resulting in < 4% being permanently buried in the sediment. In contrast, approximately 70% of the organic carbon derived from primary productivity was decomposed in the water column in the East China Sea and 17% was decomposed in the sediment, suggesting that the permanently buried percentage (14%, relative to the primary productivity) was higher in the ECS. The contributions of benthic mineralization to the organic carbon cycle in the ECS and the YS were different (Song et al., 2015).

In the N and P biogeochemical cycle , the particulate P was mainly from phytoplankton and the input of the Changjiang River, while the major source of particulate N was phytoplankton. Phytoplankton production contributed 70% of TPP input and 95% of TPN input in spring and summer, while 64% of TPP input and 89% of TPN input in autumn and winter (Yu et al., 2012). Song and Liu (2015) found the percentage of bioavailable P in TP ranged from 13% to 61% in the sediment of the Yellow Sea and East China Sea. Bioavailable P burial flux that appeared regional differences was affected by sedimentation rates, porosity and bioavailable P content, and the distribution of bioavailable P burial flux were almost the same as that of TP burial flux. In reconstruction of paleoproductivity by biogenic silica, the factors including under saturation of silicic acid in pore water compared with BSi solubility, organic coating in BSi surface and aluminum concentration in pore water have an important influence on BSi preservation and the build-up of silicic acid in sediments (Wu et al., 2014). The dissolution of BSi in sediment can't be neglected in the reconstruction of paleoproductivity. The hydro-dynamic condition affected the diatom cell size distribution and sediment character, and, thus, had a significant influence on the BSi content of different size fractions. So grain size distribution of the bulk sediment should be considered when using BSi as a proxy for paleoproductivity.

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# Progress of Marine Information Technology research in China from 2011 to 2015

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The past five years have witnessed vigorous efforts made by Chinese scholars to promote the progress of marine information technology research, especially after the framework "One Belt, One Road" proposed. In this short survey, we will introduce the recent progress with emphases on marine survey technology, information integration, data mining and visualization. Several suggestions and trends of development are also addressed.

**Marine survey technology**

Recently, China scholars have made a significant breakthrough in marine survey technology. The first Chinese ocean dynamic satellite, HY-2A, is launched on 16 August 2011. It carries four microwave instruments: a radar altimeter, microwave scatterometer, scanning microwave radiometer, and three-frequency microwave radiometer [1]. From 2009, involving the operating ships "Ke Xue" and under construction ships "Xiang Yang Hong 10", there are more than 20 research vessels being operated or under construction, which means that a new heyday of Chinese research ships is coming. "Dongfanghong 3", an under construction research vessel conducted by Ocean University of China, has a displacement of 5000 tons and will be first equipped with the advanced ship-based UAV system. In July 2012, the Chinese manned submersible "Jiaolong" successfully submerged to the depth of 7062 meters, and established the diving depth record of the operational submersibles over the world [2] [3]. "HAIMA", a 4500 m deep-sea ROV project conducted by Shanghai Jiao Tong University [4], underwent sea trial in the South China Sea. It also fulfils the zero breakthrough in Chinese independent developed unmanned deep-sea submersibles. The marine gliders developed individually by Shenyang Institute of Automation, Chinese Academy of Sciences, have been demonstrated in a 30 days sea trial in 2014.

**Marine information integration**

With the progress of marine survey technology, large volumes of marine scientific data characterized by multi-source and heterogeneous have been gathered by the marine institute and its partners. In order to better unearth the data value, the China digital ocean prototype system framework is proposed and accomplishes the distributed information exchange and sharing services [5] [6]. With regard to the marine data integration and sharing problem, data pre-deployment and services framework of marine environmental information management based on cloud computing are studied [7-9]. WebGIS-based browser/server system which uses MapServer and ORACLE Database is also designed for providing convenient marine information sharing service [10]. Effective management of marine big data based on cloud platform and cloud analysis technology will be of paramount importance in the future marine data integration.

**Marine data mining**

Data mining is one of the most important issues in today's marine science. Traditional massive marine data mainly include remote sensing data and model data. By synthetically mining these multi-source data, many major contributions are made in many aspects including revealing dynamics and patterns of climate change [11] [12], studying variability of oceanic and climate system [13] [14], projecting future climate and its impacts [15], finding connection between different oceanic/atmospheric parameters [16], and so on. Many objective algorithms for different oceanic parameters and information extraction methods are also developed aiming to mine oceanographic knowledge from the accumulating Argo data, such as estimating values of ocean parameters [17], detecting tropical cyclone footprint [18], calculating geostrophic circulation [19] and sea deep convection [20], tracking and analyzing mesoscale eddy [21-23], digging new modality [24] and new phenomena in the ocean [25] [26], and so on.

**Marine data visualization**

Marine data visualization draws increasing research attention for its ability to process and present data. By analyzing the data structure and properties, recent researches are mainly concentrated in the Multi-dimensional spatiotemporal data visualization, including octree-based multiresolution data visualization [27], GPU-based spatiotemporal visualization of satellite-derived air–sea $CO_2$ flux [28]. Combined with GIS technology, scientific visualization methods such as color mapping, volume rendering, and line integral convolution are also studied [6] [29] [33]. Visualization engine named i4Ocean is designed to interactively visualize marine environment data [30-33]. The research on marine data visualization is still on the developing stage. Future research should be focused on the integration of interactive visual mining analysis methods of multi-dimensional data and the establishment of knowledge oriented visualization.

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# Progress of Ocean Color Remote Sensing in China from 2011 to 2015

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During 2011 and 2015, ocean color remote sensing in China has made important progress in remote sensing satellite system, atmospheric correction (AC), retrieving algorithm, and its applications. The major progress will be introduced as follows.

## 1. Remote sensing satellite system

In 2014, the development of HY-1C/D satellites and new generation of ocean color sensors was started by China. The spatial and spectral resolutions and detection accuracy of the new generation of observing satellite will be enhanced significantly. It's expected to greatly promote the observation capability with rapid global coverage of Chinese observation satellite.

## 2. Atmospheric correction

The emphasis of AC research is mainly focused on the development of new AC algorithms over turbid waters and evaluation of the AC algorithms of international satellites in the China Seas. For the development of AC algorithms, He et al. (2012, 2013) proposed a new AC algorithm based on ultraviolet bands. Chen et al. (2014) proposed an improved shortwave infrared (SWIR) algorithm based on cross calibration. For the evaluation of AC algorithms, Chen et al. (2014) evaluated applicability of the operational and SWIR algorithms of MODIS in Eastern China Seas. Cui et al. (2014) and Zhao et al. (2014) evaluated the performance of operational algorithms of MODIS, MERIS and SeaWiFS in the Yellow Sea and East China Sea (ECS), and South China Sea (SCS), respectively.

## 3. Retrieving algorithm

The retrieving algorithm is mainly focused on the retrieval of chlorophyll concentration (CHL), suspended particles matter concentration (SPM), and absorption coefficient of colored dissolved organic matter ($a_g$). For CHL retrieval, Le et al. (2012) proposed a new retrieving method for turbid waters based on red-green-bands-ratio. For SPM retrieval, Mao et al. (2012) proposed a SPM retrieving method based on extensive measurements in the ECS. Zhang et al. (2014) proposed a SPM retrieving method in Yellow River Estuary for Landsat satellite. As for the retrieval of $a_g$, Zhu et al. (2011) and Dong et al. (2013) proposed the $a_g$ retrieving method based on QAA with the relationship between particles absorption coefficient and backscattering coefficient. Le and Hu (2013) proposed a new hybrid $a_g$ retrieving method by introduced the CHL retrieving method on the basis of using the relationship model between $a_d$ and backscattering coefficient.

**4. Application of ocean color remote sensing**

The application is mainly focused on the ocean processes and HABs detection. Feng et al. (2014) studied the influence of the Three Gorges dam on total suspended matters in the Yangtze Estuary and its adjacent coastal waters. Lin et al. (2014) studied the variability of phytoplankton size classes associated with a cold eddy in the ECS. Lou and Hu (2014) studied the diurnal changes of a harmful algal bloom in the ECS. Shang et al. (2014) and Tao et al. (2015) proposed the methods of discriminating dinoflagellate from diatom in the East China Sea.

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# Progress of ocean general circulation numerical model in China from 2011 to 2015

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Numerical model is one of the main measures in physical oceanography research and is crucial to the operational marine data products development. In the recent five years, Chinese scientists has made a great progress in ocean general circulation models development.

Yu et al. (2008) proposed the construction method of global ocean triangle mesh. Without open boundaries, the Global Ocean Circulation and Tide Model (GOCTM; Yu, 2008; Yu, 2010; Yu et al., 2010) was developed, which is rooted from Finite-Volume Coastal Ocean Model (FVCOM). It not only can avoid the error caused by the open boundaries. Besides, with encryption in our concerned ocean area, it solves the problem of the difficulties of distinguishing the meso- and micro-scale in the global model and reach a balance between the resolution and calculation. It gained a great success on the simulation of Indonesia tsunami in 2004 (Chu et al., 2013). They also developed the In the latest five years, the GOCTM has been upgraded to Marine and Atmosphere Numerical Simulation System (MANSS). The system is composed by GOCTM and global Weather Research Forecast (Global-WRF). The coupling of air-sea, the tide and circulation of global ocean exhibit some creativities in the model development in China. The combination of visual software and multifunctional information inquiry website makes it more convenient. At present, the system is trying to couple with sea ice model.

The LASG/IAP Climate system Ocean Model (LICOM; Liu et al., 2002) was developed based on the third version of the LASG/IAP OGCM. In the past several years, to reduce the uncertainties of the upper layer temperature, the LICOM was upgraded to LICOM2 in 2012 (Liu et al., 2012). The improvement of the new version include the following: changing the computation of arrays and variables from single precision to double precision; optimizing the parallel performance; correcting bugs in the restart process, etc.

There are also some new under developing models like the pressure coordinates mass conserving ocean general circulation model worked by Yihua Lin from institute of Atmospheric Physics. The other one is the China seas marginal model studied by National Marine Environmental Forecasting Center, National Marine Information Center and Ocean University of China.

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# Progress of ocean sediment research in China from 2011 to 2015

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China's coasts are on the East China Sea, Korea Bay, Yellow Sea, and South China Sea. Understanding the interconnected sediment physical processes of erosion, transportation and deposition of a coastal and oceanic system is of crucial importance for engineering safety and local human social development. During the past engineering applications and practices in China, including port and harbor projects, land reclamation, dam and reservoir constructions, navigational channel development, environmental protection and disaster prevention, many effective experiences and fundamental understanding have been achieved regarding sediment transport and morphodynamics.

（1）With the engineering progress of many important coastal engineering, such as the Yangtze Estuary deepwater navigational channel improvement project *(Wan et al., 2014a)*, HongKong-ZhuHai-Macao Bridge (HZMB) Project *(He et al., 2012)* and Yangshan Port *(Zuo et al., 2012)*, the major processes for the formation of the estuarine turbidity maximum (ETM) have been investigated further. *ECSRC (2013)* studied optimization of the deployment of back-silting-mitigation project in the deepwater navigational channel (DNC) North Passage of the Yangtze Estuary based on near-bed tripod observation and 3D sedimentation modeling. And the main mechanisms of the back-silting in the DNC were preliminarily investigated *(ECSRC; 2014)*, which greatly benefits the daily maintenance of the DNC, one of the most important China's waterway. Residual current *(Liu et al., 2011)* in tidal estuaries and coastal embayments have been recognized as fundamental factors that affects the long-term sediment transport processes. *Song and Wang (2013)* highlighted the importance of drag reduction effect in simulation of the fine sediment transport. *Wu et al. (2012)* demonstrated the variation of ETM is associated with the interaction between stratified flows and cohesive sediments. *Cai et al.(2014)* and *Guo et al.(2014)* emphasized the role of river flow on estuarine morphodynamics. *Wan et al. (2014b)* concluded that both suspended particulate matter availability and local residual flow regime are of critical importance in determining the trapping probability of sediment. *Pu et al. (2015)* proposed a viewpoint that tidal straining circulation is critical for the periodic variation of ETM stratification. Many studies *(Jiang et al., 2012; Dai et al., 2013; Jiang et al., 2013; Ma et al., 2013; Wang et al., 2013a; Wan et al., 2014a)* focused on the response between human invention and hydrodynamic or morphological changes. *Zhou et al. (2013)* and *Shen et al. (2014)* numerically evaluated morphodynamic response induced by sea level rise. *Li et al. (2014)* studied the dependency between bed friction reduction and river discharge increasing. Numerical simulations *(He et al., 2012; Li et al., 2013)* were carried out to study the hydrodynamic and morphological impacts of the HZMB in the Pearl Estuary. *Hu et al., (2014)* analyzed the influence from manual water division operation on the sediment distribution in the Yellow River estuary.

（2）The response and relationship between the Three Gorges Dam (TGD) project and coastal sediment change has been identified by a series studies *(Zhang et al., 2012; Ma et al., 2013; Maren et al., 2013; Qiu and Zhu, 2013; Zhou et al., 2013; Yang et al., 2014)*. Typically, *Yang et al. (2014)* inferred that the estuarine submerged delta would be eroded due to the TGD's sediment retention.

（3）With regard to flow-sediment interactions, many Chinese scientists and engineers have contributed to topics that are closely associated with fine sediment dynamics. With their cohesive nature, fine sediments are prone to aggregation and formation flocculated network structures (flocs) during the settling process, introducing distinct flocculation acceleration and hindered settling phenomenon *(Guo and He, 2011; Shao et al., 2011)*. The presence of salt and suspended particulate matter (SPM) in water column increases mixture density, resulting in longitudinal density variations and baroclinic pressure gradient forcing *(Wu et al., 2012; Wan et al., 2014a)*. The vertical gradient of fluid density creates a stratified water column and introduces buoyancy effect on turbulence, damping the flow turbulence *(Wang et al., 2013b)*. The SSC- and salinity- induced stratification produces a stratified bottom boundary layer, altering the logarithmic velocity profile near the bottom and reducing drag coefficient *(Wang et al., 2011; Song and Wang, 2013)*.

（4）In addition, based on mult-appoach (field survey, laboratory experiment and numerical modeling) and multi-angles from data-driven analysis and process-based modeling, many studies contributed their diversitive attentions on the understanding of wave functions on tidal flats *(Shi et al., 2012; Shi et al., 2014)*, the source and transport mechanisms of land-derived sediments in the Bohai Sea, Yellow Sea and East China Sea *(Bian, 2012)*, the role of tidal pumping using analytical method *(Cai et al., 2012; Yu et al., 2014)*, the long-term morphodynamical process and modeling techniques *(Wang et al., 2013a; Guo et al., 2014)*, Assessment suspended sediment loads *(Zhang et al., 2012)* and so on.

Despite of those studies, several fundamental issues relating to sediment transport in estuarine and coastal areas still need further investigation and exploration. For instance, (1) identify the function and sensitivity of each mutiscale physical processes on estuarine hydro- and sediment dynamics, especially in a large scale coastal and estuarine system; (2) how the hydraulic engineering projects affect the short- and long- term morphological processes; (3) complex interactions between current, wave and sediment; (4) interdisciplinary research between sediment and ecology, meteorology, oceanography, computer science, environics, instrumentalogy, et al.. These above research seem necessary for better understanding of sediment behavior in ocean surroundings. More importantly, they are of critical significance for coastal engineering project and economic development in China.

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# Progress of Physical Oceanography and Regional Air-sea Interaction in the South China Sea from 2011-2015

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Significant progresses have been made in the characteristics of large scale circulation and its variability in the SCS. The spatial distribution of eddies, the formation of strong western boundary current, and their interactions have been thoroughly studied (Chen et al., 2011; Chen and Xue, 2014; Qian et al., 2014). Large scale currents play an important role in the formation and evolution of eddies (Nan et al., 2011; Zu et al., 2013; Chu et al., 2014) and modulate eddy heat and salt transport (Chen et al., 2012a). A positive feedback among eddies, monsoon and ocean front has been revealed (Wang et al., 2012c). The interannual variability of eastward current in summer in the western SCS has been linked to monsoon and El Niño–Southern Oscillation (ENSO) events (Chen and Wang, 2014; Li et al., 2014). The SCS throughflow plays an important role in modulating the variation of the Asian monsoon and ENSO and has significant climate effects (Nan et al., 2013; Yang et al., 2013). It may contribute up to 20% of the Indonesian throughflow in winter (He et al., 2015) and plays an important role on the upper salinity in the northern SCS, especially for the freshening event in 2012 (Zeng et al., 2015).

New understanding has been achieved in the coastal dynamics in the SCS. Upwelling intensity in the northern SCS has been found closely related to large-scale currents (Jing et al., 2011; Shu et al., 2011a; Shu et al., 2011b; Jing et al., 2012; Wang et al., 2012a; Wang et al., 2014a; Jing et al., 2015). The coastal Kelvin wave, propagating northward along the west coast of the Philippines Archipelago through the Mindoro Strait can induce sea level change in the SCS (Liu et al., 2011; Chen et al., 2015).

Besides the surface circulation, studies on middle and deep circulation have been advanced. Midlevel current deflection around Dongsha Islands is related the Joint Effect of Baroclinicity and Relief (Wang et al., 2013a), which has also been proved be the dominant forcing for the formation of SCS warm current at the north SCS shelf (Wang et al., 2010). The existence of deep cyclonic circulation in the SCS has been confirmed (Wang et al., 2011) and found to be not only related to the deep inflow but also influenced by the entrainment of the middle and upper layer inflow from Luzon Strait (Lan et al., 2013; Shu et al., 2014; Zhou et al., 2014; Lan et al., 2015; Wang et al., 2015; Zhang et al., 2015).

With the significant increase of marine meteorological observations in the SCS (Wang et al., 2013b; Zeng et al., 2015; Yang et al., 2015), studies of regional air-sea interactions have been brought to a new level. Interannual sea surface temperature (SST) anomalies in the SCS are strongly influenced by ENSO events with a double-peak feature of SST in the SCS following an El Niño event in the Pacific (Wang et al., 2006). Significant different SST warming modes in the SCS during eastern and central Pacific El Niño has been discovered (Liu et al., 2015). SST perturbations associated with eddies, oceanic fronts and other oceanic processes have been found to induce adjustment of the marine atmospheric boundary layer and to result in perturbations of surface wind (Huang et al., 2011; Chow and Liu, 2012; Liu et al., 2012; Shi et al., 2014). The variations of tropical cyclone activities in the SCS on intraseasonal (Yang et al., 2014; Yuan et al., 2014), interannual (Chen et al., 2011; Du et al., 2011; Wang et al., 2014b), and interdecadal scales (Yang et al., 2012; Chen et al., 2012b; Li et al., 2014; Ha and Zhong, 2015) have been well investigated. Using the observations from Xisha Stations, it is found that MABL during tropical cyclone passages experience significant changes (Wang et al. 2012b).

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# Progress in Studies on Influences of Physical Processes on Coastal Ecosystems in China from 2011 to 2015

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In recent five years, studies on influences of physical processes on coastal ecosystems have made notable progresses in China. The influences of physical processes have been found for each trophic level, each kind of eco-disaster and in each coastal sea of China, through observations and ecosystem modelling.

Nutrients loads from the Changjiang (Yangtze) River show an increasing trend in dissolved inorganic nitrogen (DIN), decreasing significantly in $SiO_3$-Si concentrations over the past fifty years while the $PO_4$-P concentration has been fluctuating and maintaining the same level since year 2000. Some researchers deducted that increased river nutrient loads have led to increased Harmful Algal Blooms (Shi et al., 2013; Li et al., 2014). In offshore areas, circulation and turbulent mixing are the main physical processes to provide nutrients for algae growth. Kuroshio has very important influence to the nutrients inventory in the Yellow, East and South China Seas. Yellow Sea Warm Current in winter and the northward expansion of the Changjiang Diluted Water are the main nutrients source for the central of Yellow Sea (Yuan et al., 2013).Two areas, one located northeast of Taiwan and one southwest of Kyushu, were found to bemajor source regions of oceanic nutrients for the shelf of East China Sea (Zhao and Guo, 2011). Huge amount of phosphate is continuously transported to the area off the coast of Zhejiang by a near-shore branch of the Kuroshio Current that upwells to the surface water just off the coast of Zhejiang (Yang et al., 2013). Stratification and the northward extension of the Taiwan Warm Current control the occurrence and evolution of hypoxia adjacent to the Changjiang estuary (Wang et al.， 2012). Kuroshio intrusion through Luzon Strait and diapycnal mixing are also the key process affecting the nutrients in the upper layer of the northern South China Sea (Du et al., 2013). All these processes could influence the dissolved inorganic carbon distribution at the meantime of transport nutrients ( Qu et al., 2014; Zhai et al., 2014) and determine whether a coastal sea acts as a source or sink for atmosphere $CO_2$ (Lu et al.，2012；Dai et al.，2013). In addition to mixing in water column, bottom boundary turbulence also controls the sediment re-suspension and further influences the light attenuation (Wang et al., 2014) that limits the photosynthesis near shore. Dynamics in bottom boundary layer and diffusive boundary layer dominate the variation of mass exchange fluxes at the sediment-water interface (Wang et al., 2012; 2013).

Physical processes determine the seasonal variation of phytoplankton ( Liu et al., 2015) and its diel vertical change (Liu et al., 2012) in the southern Yellow Sea. Intense wind mixing triggers and influences the distribution of spring phytoplankton bloom in the central of Yellow Sea ( Xuan et al., 2012), while advection of cool water to the middle layer leads to the subsurface maximum Chl-a concentration after spring phytoplankton bloom in the same area (Han et al., 2011).Wind drift at the surface drives the green macro-algae to Qingdao (Qiao et al., 2011) while tidal front combined with wind determine the gathering of giant jelly fish (Wei et al., 2015) in summer in the Yellow Sea, both being heavy eco-disaster in recent years. The cold dome, Yellow Sea Cold Water Mass at the bottom of the central trough, is the refuge of zooplankton to over summer; the duration of both stratification and spring algae bloom cause the variability of the *C. Sinica* biomass and community (Wang et al., 2014). In the East China Sea, high primary production in the Changjiang Estuary, coast of Zhejiang Province and northeast of Taiwan is related to upwelling while plankton community is related to water masses (Zhao et al., 2015; Xu and Gao, 2011). In the South China Sea, it was found that typhoons cause increase of Chl-a concentration (Wang et al., 2014 ) and the cyclonic(anti-cyclonic) mesoscale eddies cause increase (decrease) of the algae biomass (Xiu et al., 2013).

Intensity of the Yellow Sea Warm Current influences the overwinter field distribution of most migration fish species and also alters the early recruitment and annual biomass of anchovy (Wang et al., 2013). Fifty years of fishery catchment data show that the inter-annual variation of hairtail in the East China Sea is tightly related to precipitation, monsoon, sea surface temperature and the number of tropical cyclones after taking out the factor of overfishing (Wang et al., 2011). A study on aquaculture in the semi-enclosed Sanggou Bay suggests that the damping of tidal current by the kelp 'forest' leads to reduction of water exchange, lack of nutrients and limitation of aquaculture capacity (Shi et al., 2011). Scenario predictions of nutrients in the Yellow and East China Seas are made under future climate change suggested by IPCC AR5 and future river nutrient loads estimated by the Ecosystem Millennium Assessment. This suggests that the increase of river loads is the main reason for future nutrient rising while variations of advection and mixing could raise the nutrient concentration in the Yellow Sea (Zhao et al., 2015).

Further research on the roles played by physical processes in the evolution of ecosystem in coastal seas of China keeps on going in order to improve the ability of prediction. Due to the lack of longterm monitoring of coastal ecosystems, some oceanographers are searching the impacts of climate change on ecosystems from sediment records, but facing difficulties in separating the changes due to natural and anthropological causes. Dramatic human activities such as land reclamation may have long lasting effects on coastal ecosystem along side with the changes associated with global climate change. Carbon cycling and $CO_2$ fluxes at air-sea interface influenced by physical processes in coastal seas of China continue to be a hot research topic.

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# Progress of the influence of Kuroshio on its neighboring Chinese Seas and the Ryukyu Current studies in China from July 2010 to May 2015

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On progress of the influence of Kuroshio on its neighboring Chinese Seas and the Ryukyu Current studies, a lot of the works were made and reviewed by the Chinese scientists during July of 2010- May of 2015. In this paper these works will be reviewed and can be divided into three aspects, namely the Kuroshio intrusion into the South China Sea (SCS) and circulations around the Luzon Strait, Variability of Kuroshio and its interaction with the East China Sea (ECS), Interaction between the Ryukyu Current and Kuroshio in the East China Sea.

**1. The Kuroshio intrusion into the South China Sea and circulations around the Luzon Strait**

1.1 The seasonal and interannual variation of the Kuroshio intrusion, and the mechanisms on the Kuroshio intrusion

Based on current measurements at two mooring stations M2 from 25 April to 12 June, 2008 and M1 from 24 April to 11 June, CTD and wind data obtained in the Luzon Strait (LS), a three-dimensional diagnostic model with modified inverse method was used to study the regional circulation from April 23 to 26, 2008 (a La Nina year). Yuan et al. (2012a) indicated that the modeled VT of the westward Kuroshio intrusion across the upper layer of LS in during spring 2008 was much less than that in spring 1992 (an El Nino year) and normal years. That is to say, the westward intruding VT of Kuroshio across the upper layer of the LT may be closely related to the El Nino (or La Nina) phenomenon, being higher during El Nino and lower during La Nina, and it may be also related to the mesoscale variability in the

LS.

On the basis of Acoustic Doppler Current Profiler (ADCP) measurements of current and hydrographic data obtained in October 2008, a diagnostic model of ocean circulation with a modified inverse method is used to study the circulation in Luzon Strait. Satellite-based geostrophic velocity calculated from the merged absolute dynamic topography is also used and compared with the in situ data. Yuan et al. (2012b) revealed that during the period of observations there were two branches of the Kuroshio current. The main stream of the Kuroshio was located at 122°10′ E to 122°40′ E near the southern boundary of the study region and confined to the upper 700 m, while its western branch was located at 121°00′ E to 121°35′ E and confined to the upper 400 m. The Kuroshio water intruded into the South China Sea through the northern boundary of the study region east of 120°45′ E. At the 1000 m depth, the flow was dominated by southwestward or westward flow in the area north of 20º30' N, while the flow was mostly southeastward in the area south of 20º30' N. The volume transport across the longitudinal section 120°45′ E between about 20.00° N and 21.20° N south of Taiwan during the period of observations was about 4 × 106 m3 s-1. One Argo float was tracked as it moved across Luzon Strait, reflecting the westward flow at both the surface and 1000 m depth.

Based on current measurements recorded at Mooring Station N2 (20°40.441′N, 120°38.324′E), hydrographic data and Argo observations in the period starting from July 2009, a diagnostic model with a modified inverse method is used to study the circulation in the Luzon Strait (LS). A number of new circulation features in the LS were found by Yuan et al. (2014a) as follows. (1) Both observed and modeled currents showed that the intruded Kuroshio flow northwestward through the LS into the South China Sea (SCS) in the upper 400 m during July 2009. (2) The diagnostic model confirms that the Kuroshio is located in the area east of 121°20′E and west of 122°20′E at 20°00′N. The Argo float 1 went into the area of the western Kuroshio. The Argo float 1 was tracked as the flow moved northwestward into the SCS across the LS in July and August, 2009, reflecting the northwestward flow at both the surface and 1000 m depth, which coincided with modeled currents. These results confirm the northwestward Kuroshio intrusion into the SCS across the LS in summer 2009 for the first time. (3) From the dimensional analysis for the equation of stream function, it is seen that the joint effect of the baroclinity and relief (JEBAR) and the β-effect are two important mechanisms on the Kuroshio intrusion into the SCS in this period. This summer Kuroshio intrusion results from the weaker upstream Kuroshio transport in summer 2009 (El Niño initiating period) due to inertia effects and is associated with a weak volume transport across the LS (2.15 × 106 m3 s−1 westward). (4) After comparison of the dynamics of the Kuroshio intrusion during October 2008 and summer 2009, it is clear that these were influenced by the seasonal variability due to the monsoon winds and the interannual variation resulting from the weak upstream Kuroshio transport affected by the ENSO due to inertia effects.

Yuan et al. (2014b) analyzed the observed subtidal currents, 1/12˚ global HYCOM model results and the observed time series to interpret seasonal and interannual patterns in the behavior of the Kuroshio intrusion around the Luzon Strait (LS). The observations included current measurements conducted at mooring station N2 (20°40.441′ N, 120°38.324′ E) from July 7th, 2009 to March 31st, 2011, surface geostrophic currents derived from the merged absolute dynamic topography and the trajectory of an Argo float during the winter of 2010-2011. Results from mooring station N2 confirmed the seasonal changes in the Kuroshio intrusion and the variation of the Kuroshio intrusion during El Niño event from July, 2009 to April, 2010 and La Niña even from June, 2010 to March, 2011. The strongest Kuroshio intrusion occurs in the winter, with successively weaker currents in spring, autumn and summer. Comparison of relative differences ($\Delta_{max}(z)$) in the maximum absolute value of monthly average zonal velocity components |Umax (z)| showed that the Kuroshio intrusion was stronger during the 2009-2010 winter (El Niño) than the 2010-2011 winter (La Niña). Furthermore, the relative differences ($\Delta_{max}(z)$) in deeper layers exceed those of the surface layer. Circulation patterns in surface geostrophic currents and the Argo float trajectory confirmed the results of mooring station N2. The

Kuroshio intrusion velocity variation modeled using the 1/12˚ global HYCOM model resembled the observation on both seasonal to interannual scales. Modeled variation in the zonal mean velocity anomaly was also consistent with Niño3, Niño4 and North Equatorial Current (NEC) bifurcation latitude indices, indicating concurrent impacts of the ENSO influence. Monsoon winds strongly affect the seasonal variation while the weak upstream Kuroshio transport induced by El Niño, strongly affects the interannual variation, such as 2009-2010 winter. In 2010-2011 winter, the impact of winter monsoon forcing still exists in the LS. However, the stronger upstream Kuroshio transport during this period did not allow the Kuroshio to penetrate into the LS deeply. This explains why the 2009-2010 winter Kuroshio intrusion (El Niño event) was stronger than that of the 2010-2011 winter (La Niña event).

Yang et al.(2013) pointed out that a northward shift of the North Equatorial Current (NEC) Bifurcation Latitude (NECBL), a weakening of the Kuroshio Current (KC) or a strengthening of the Mindanao Current (KC) would enhance the Luzon Strait transport (LST) into the South China Sea (SCS). This relationship between the LST and the NEC-KC-MC was consistent with observations. The analytical result was tested by a set of idealized numerical simulations.

Inferred from the satellite and in situ hydrographic data from the 1990s and 2000s, the Kuroshio intrusion into the South China Sea (SCS) had a weakening trend over the past two decades (Nan et al., 2013). They simulated using the Regional Ocean Modeling System (ROMS) Pacific model and showed that 1) the strength of the Kuroshio intrusion into the SCS decreased from 1993 to 2010 with a negative trend, −0.24 sverdrups (Sv) yr−1 (1 Sv ≡ 106 m3 s−1), in the total Luzon Strait transport (LST). 2) The Kuroshio transport east of Luzon Island also had a negative trend, which might also be linked to the weakening Kuroshio intrusion.

Based on the hydrographic data obtained during September 1994, the improved Princeton Ocean Model using a generalized topography-following coordinate system together with a modified inverse method was applied to study the circulation in September. The main dynamical features were summarized by Wang et al. (2012) as follows: (1) The Kuroshio had two branches with the main Kuroshio existing above 800 m and the western part existing above 400 m level. (2) The non-linear term was important and cannot been neglected in the momentum equations in the northern part of the Luzon Strait under the baroclinity field. The westward intrusion path of the Kuroshio in the northern part of the Luzon Strait from the non-linear dynamics was more curved than that from the linear dynamics. However, the non-linear term was less and negligible around Luzon Strait under the homogeneous density field. (3) Among the levels above 400m, the circulation was mainly dominated by the basin-scale cyclonic gyre. (4) In the computational domain west of 121°E, the circulation below 800 m was mainly dominated by the basin-scale anti-cyclonic gyre.

1.2 The influence of Kuroshio on Currents in the Luzon Strait and circulation in the northern South China Sea

Several observations including Argos satellite-tracked drifters, Argo profilers and altimetry satellite data and the computed results using a reduced gravity model both were analyzed to understand the upper layer circulation in the Luzon Strait (Wang et al., 2012). The observations showed that the Kuroshio had a relatively stable pattern with some of Kuroshio water entering the South China Sea in winter. Circulation in the Luzon Strait was mainly controlled by the Kuroshio and the monsoon wind, which had different roles. The Kuroshio could induce a cyclonic gyre west of the Luzon Strait in either summer or winter which was stronger and extends more westward as the Kuroshio becomes stronger. The monsoon wind could drive a cyclonic gyre in the Luzon Strait in summer. In winter, an anticyclonic gyre and a cyclonic gyre were produced southwest of Taiwan Island and northwest of Luzon Island respectively, resulting in a strong westward current in the middle of the Luzon Strait.

The velocity profile was figured out using the LDEO LADCP processing software during the cruise of Luzon Strait in April 2008 from data of LADCP and ship-mounted ADCP (SADCP). Yang et al. (2012) pointed out that the core of intruding Kuroshio flows through station C2, C7, C8 and C9, respectively and the positions of core agree basically with those in spring 1992. At station C2 the Kuroshio is located in the upper layer from sea surface to 400m with the maximum westward speed 77cm/s, and its speed decreases with the increase of water depths. At station C7, C8, C9, the Kuroshio is located in the layer from surface to 500m, depth of the Kuroshio becomes shallow gradually when it intrudes into the South China Sea.

Current observations of internal tides from ADCP and measurements of the velocity structure in the thermocline in Luzon Strait were presented (see Liao et al., 2011, 2012). For example, the statistics for current, vertical variation of the inertia-gravity waveband, parametric subharmonic instability (PSI), and current shear were analyzed (Liao et al., 2012). They found that 1) barotropic flow primarily consisted of a nearly circular mixed tide. Diurnal tides were strongest and showed smooth variance with fortnightly spring-neap cycle, indicative of the astronomical tide-generating force. However, the semi-diurnal band power exhibited a high-frequency oscillation as a result of non-linear interactions. The high-frequency band power with high values during the spring tide oscillates with the tidal cycle. Near-inertial wave motions showing random variance may be caused by changes in the wind forcing at the sea surface or by random forcing. 2) Baroclinic velocities exhibited strong shear structure. 3) Strong non-linear interactions among internal waves existed, and the semi-diurnal (M2) plays a key role in these interactions. 4) The polarization relations were used to diagnose observational internal tidal motions. A mooring system was located at a depth of about 3300 m west of the Luzon Strait, the observed upper ocean current, temperature and salinity at a high frequency were analyzed for more than nine months (Li et al., 2014).

The seasonal upper circulation in the northern South China Sea from altimetry data and a connected single-layer and two-layer model was investigated (Cai et al., 2012). They pointed out that the water exchange via the LS, the Kuroshio intrusion brings about a net inflow into the SCS, and the monsoon has a less effect, whilst the water transports via the Sunda Shelf and the Sibutu Passage are the most important influencing factors, thus, the water exchange of the SCS with the Pacific via the LS changes dramatically from an outflow of the SCS in summer to an inflow into the

SCS in winter.

Zeng at al. (2014) pointed out that in 2012 the freshening of up to 0.4 psu in the upper-ocean of the northern SCS was confirmed by in situ observations. This freshening in 2012 was caused by a combined effect of abundant local freshwater flux and limited Kuroshio intrusion.

Evolution of an anticyclonic eddies (AEs) southwest of Taiwan were studied (Zu et al., 2013) Energy analysis was utilized to study the evolution process of the AE, and it showed that the barotropic instability (BTI) and baroclinic instability introduced by the Kuroshio intrusion flow appear to be the main energy sources for the AEs. Generally, the BTI of Kuroshio intrusion contributes more than the direct wind stress work to the increase of the eddy kinetic energy for the generation and growth of the AEs.

A variable-grid global ocean circulation model (MITgcm) was employed to study the effects of wind and Kuroshio intrusion on the Luzon cold eddies (LCEs) in the northern South China Sea (SCS) (He et al., 2015). Study findings showed that there are two cold eddies northwest of the Luzon Island. Their results showed that the upper layer LCE was mainly induced by the winter wind stress curl in the SCS and generated northwest of the Luzon Island in late November, but it may have been weakened by the Kuroshio intrusion. The contributions of both wind stress curl and Kuroshio intrusion to the generation of the lower layer LCE were roughly equal.

## 2. Variability of Kuroshio and its interaction with the East China Sea

### 2.1 Overview of studies on the Kuroshio in the East China Sea

The hydrographic observations along two transects (PN and TK) from 1955-2010 were collected to calculate the geostrophic part of the Kuroshio based on thermal-wind relation (Wei et al., 2013a; Wei et al., 2013b). The estimated annual mean Kuroshio volume transport (KVT) across the PN transect is 22.48 Sv, peak in winter followed by summer but weak in autumn, which is consistent with that of mooring observations presented by Andres et al. (Andres et al., 2008). There is a dominant interannual variability of KVT is 2–5 year and a weak 20-year decadal variability.

Feng et al. (2010) analyzed the Argos drifter data obtained from the selected area (21o -33o N, 120 o -132 o E) in 1979-2008 and learned the characteristics of Kuroshio across the three sections in the East China Sea. The three sections are the SS section locating in the sea area northeast of Taiwan, representing the south segment of Kuroshio in the East China Sea (ECSK), the PN section representing the middle segment of ESCK , and the TT section locating in the sea area between Kyushu and the Amami Islands. It was learnt from the statistical results that the main features and the seasonal variations of the ECSK segments respectively across the sections can be better reflected in the Argos drifter data. Especially at the middle segment of ECSK, the current speed was stronger, the current width was wider, and the current flowing-volume was greater. All those features at the middle segment of ECSK were the most significant and the most stable.

Wu et al. (2010) used the long term observation data in the main part of East China Sea Kuroshio and revealed that the Kuroshio upper layer temperature experienced slight rise while salinity decreased in the past 50 years. In winter, Kuroshio upper layer temperature was closely related to the surface temperature in east China, and large area in east China showed positive correlation to the Kuroshio upper layer temperature. In summer, the increase of the precipitation causes the increase of diluted Yangtze River water into the shelf sea, thereby results in the salinity decrease of Kuroshio in the upper layer.

Based on the 33 year data of Argos drifting buoy whose sail located at depth of 15 m from February 1979 to M arch 2012, Yu Long et al. (2014) plotted annual mean and monthly mean Kuroshio current fields at 15 m depth. The results showed that 1) the annual mean path of the Kuroshio was roughly a quarter of a circle whose center was at (13o30’ N，142 o 00’ E)and radius was about 2235 km. 2) The Kuroshio axis overall deviated to the Kuroshio s 1eft boundary. 3) The Kuroshio velocity in general to increase from south to north. 4) Monthly mean current fields showed that February, May, August and November were important transition periods of the Kuroshio's path.

5) The Kuroshio's path and axis were curviest during winter months and its intrusion to margina1 seas was obvious; While during summer months, the Kuroshio's path and axis were relatively straight with northward flow along 1eft side of the Kuroshio； Spring and autumn were transitional periods．

Using high resolution data, the surface current variation within half-year time scale in active region of the Kuroshio in East China Sea was studied (Wang et al, 2014). The major results were as follows: (1) The northeast Taiwan area and near Tokara Strait region were two regions with the most remarkable variation of the surface current of Kuroshio in East China Sea (ECS). (2) There were the surface current variations within half-year time scale in two regions, the quasi-periodic transformation between anomalous cyclonic vortex and anomalous anticyclonic vortex was basic feature of the surface current variation. (3) In northeast of Taiwan area, the 50 to 70 days oscillation of the Kuroshio in East China Sea is mainly originated from the Kuroshio mesoscale fluctuation. Analogously, the 50 to 70 days oscillation of the Kuroshio in East China Sea is mainly originated from the Kuroshio mesoscale fluctuation at upper reaches of the Kuroshio.

2.2 The Kuroshio intrusion into the East China Sea and their water exchange and the dynamic impacts

Problem is whether the Kuroshio intrusion could affect nearshore regions off the Changjiang River Estuary remains unclear. Zhou et al. (2015) presented their observational data along with simulations that supports such possibility. Stronger than typical cross-shelf exchanges at the shelf break and flows through the Taiwan Strait delivers saline water to the 32°N north of the Changjiang River mouth in an enhanced intrusion year like 2006. A few new places at the southern shelf break at 26°-28°N were also identified in their studies, where persistent and vigorous cross-shelf exchanges occur throughout the year 2006. With weak seasonality, cross-shelf exchange at the shelf edge is largely determined by the along-shelf geostrophic balance, in which barotropic feature is relatively significant in comparison to the baroclinic part.

Zeng et al. (2012) and Huang et al. (2015) presented their observational data on coastal circulations in the western East China Sea, which is based on an array of four bottom-mounted current profiles deployed during 28 December 2008 to 12 March 2009. Two parallel alongshore seasonal mean currents have been revealed, i.e. the nearshore southwestward Zhe-Min coastal current and the offshore northeastward Taiwan Warm Current, which have also shown their competitive roles during the observations. Cross-shore movements are found closely dependent on the along-shore component but significantly weaker than the latter. The current profile at the four stations indicates that the more distant in the offshore direction the more barotropic feature, except for thin boundary layers which are affected by frictions at surface and at bottom.

Qu et al. (2010) classified the dynamic impacts exerted by Kuroshio on the shelf-water in the East China Sea into two components , i.e. the direct intrusion and the strong shear of Kuroshio. The dynamic response of the East China Sea shelf-water to the strong shear of Kuroshio is studied. It is shown in the calculation results that the current loop induced from the shear and the water upwelling are limited into the sea area closely adjacent to the shear. These results are consistent with the satellite images in which a cold eddy is located in the sea area northeast of Taiwan.

Song et al. (2011) studied the variability of the Kuroshio in the East China Sea (ECS) in the period of 1991 to 2008 using a three-dimensional circulation model, and calculated Kuroshio onshore volume transport in the ECS at the minimum of 0.48 Sv in summer and the maximum of 1.69 Sv in winter. Based on the data of WOA05 and NCEP, The modeled result indicated that the Kuroshio transport east of Taiwan Island decreased since 2000. Lateral movements tended to be stronger at two ends of the Kuroshio in the ECS than that of the middle segment. In addition, they applied a spectral mixture model (SMM) to determine the exchange zone between the Kuroshio and the shelf water of the ECS. The result revealed a significantly negative correlation (coefficient of −0.78) between the area of exchange zone and the Kuroshio onshore transport at 200 m isobath in the ECS.

The self-organizing map method was applied to satellite-derived sea-level anomaly fields of 1993–2012 to study variations of the Kuroshio intrusion northeast of Taiwan Island (Yin et al., 2014). Four major features were revealed, showing significant seasonal variability of the intrusion. In general, the intrusion increased (decreased) with a high (low) sea-level anomaly at the edge of the East China Sea shelf in winter (summer). Open-ocean mesoscale eddies played an additional role in modulating the seasonal variation of the intrusion

2.3 Downstream increasing of nutrient transport by the Kuroshio

The Kuroshio carries large masses of water and amounts of heat as well as a variety of dissolved materials including nutrients, and have a significant influence on the climate and marine ecosystems in the vicinity of their path. Quantitation of nutrient transport by the Kuroshio is an important step to understand the nutrient element cycle on a basin scale. Based on absolute geostrophic velocity, which was calculated using repeated hydrographic data of 39 cruises from 2000 to 2009 by the Japan Meteorological Agency and nitrate concentrations measured in the same areas from 1964 to 2009, Guo et al. (2012 and 2013) obtained the temporally averaged nitrate flux and nitrate transport of four sections across the Kuroshio from the East China Sea (sections PN and TK) to an area south of Japan (sections ASUKA and 137E). In addition, Guo et al. (2012 and 2013) examined section OK east of the Ryukyu Islands in order to understand how the Ryukyu Current contributed to the transport of nutrients by the Kuroshio south of Japan. The mean nitrate flux showed a subsurface maximum core with values of 9.6, 10.6, 11.2, 10.5, and 5.7 mol m-2s-1 at sections PN, TK, ASUKA, 137E, and OK, respectively. The depth of the subsurface maximum core changes among these five sections and was approximately 400, 500, 500, 400, and 800 m at sections PN, TK, ASUKA, 137E, and OK, respectively. The mean downstream nitrate transport was 204.8, 165.8, 879.3, 1230.4, and 338.6 kmol s-1 at sections PN, TK, ASUKA, 137E, and OK, respectively. The transport of nutrients in these sections suggested the presence of the Kuroshio nutrient stream from its upstream to downstream regions. The deep current structure of the Ryukyu

Current (section OK) contributed to the same order of nitrate transport as did the Kuroshio from the East China Sea (section TK) to the area south of Japan; however, the former only had one-fifth the volume of transport than the latter.

2.4 Application of satellite remote sensing on the terrestrial material transport by the Kuroshio intrusion into the East China Sea

As controlled by the mixing between Kuroshio and Changjiang river, Bai et al. (2013) found the conservative behavior of colored dissolved organic matter (CDOM) in the East China Sea, and developed a robust algorithm to estimate the sea surface salinity from satellite-derived CDOM. Based on the satellite-derived salinity, Bai et al. (2014) analyzed the variations of summertime Changjiang River plume over 1998-2010, and found no significant long-term trend of plume area change in summertime and concluded that the interannual variation was probably regulated by natural variation rather than anthropogenic effects, such as construction of the Three Gorges Dam. Using a 14 yr (1998-2011) time series of satellite ocean color data, He et al. (2013) revealed a doubling in bloom intensity in the Yellow Sea and Bohai Sea which might induced by the rapid increase of nutrient in these regions; while no significant long-term increase or decrease were found in the Changjiang Estuary, which was consistent with the finding of no significant long-term trend of Changjiang river plume area analyzed by Bai et al. (2014). Moreover, taking the Kuroshio and Changjiang river as two end-members to quantify the horizontal mixing for total dissolved inorganic carbon and total alkalinity, Bai et al. (2015) have developed a mechanistic semi-analytic algorithm (MeSAA) to estimate sea surface pCO2 in the East China Sea from satellite data. In addition, using the daily satellite-derived water transparency, He et al. (2014) found clear signals of terrestrial material transport to the southern Okinawa Trough triggered by the Typhoon Morakot in August 2009, indicating that episodic cyclone driven terrestrial material transport could be another source of mud in the southern Okinawa Trough.

3. Interaction between the Ryukyu Current and Kuroshio in the East China Sea

The self-organizing map (SOM) was used to study the linkage between the two western boundary currents, the Kuroshio Current and the Ryukyu Current, through the Kerama Gap (Jin et al,. 2010). Four coherent ocean current patterns, extracted from a numerical model output for the Kerama Gap area, were used to describe the variability of the Kuroshio current axis and the mesoscale eddies in the Ryukyu Current system. The temporal evolution of these four patterns showed a robust cycle with an average period of 120 days. The shift of the Kuroshio current axis was found to be a dominant factor in determining the water exchange in the Kerama Gap, and the eddies associated with the Ryukyu Current were also important in affecting the strength of eddies in the Kerama Gap. The interaction between the Kuroshio Current and the Ryukyu Current through the Kerama Gap as revealed by the SOM provided new insights in understanding the water exchange between the East China Sea and the northwest Pacific.

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# Progress of internal Solitary Waves Research in China from 2011 to 2015

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In recent five years, internal solitary waves (ISWs) became the hot topics in the field of wave dynamics. More and more Chinese scientists are engaged in ISWs studies. This report summarized research progress of ISWs in the past five years, which included four aspects, namely, remote sensing images, in situ measurements, numerical simulations and theoretical methods.

Based on plenty of SAR images during more than 5 years, Wang et al. (2012) and Guo et al. (2014) interpreted the spatial and temporal characters distribution of ISWs in the South China Sea (SCS) and East China Sea (ECS), respectively. Li et al. (2013) presented new satellite observations of ISW refraction at Dongsha in the SCS and indicated that the refracted ISW wavelength and crest length were about 1/3 and 1/2 of corresponding incident ISW before they reach the atoll. Moreover, the phase speeds of ISWs were captured from satellites images by Liu et al. (2014), who then compared it with theoretical values predicted by T-G Equation and found the spatial and temporal variation of phase speeds.

With the progress of field experiments, in-situ measurements plays an essential role in the ISWs investigation. Based on mooring data, Huang et al. (2014) suggested that south of the Batan Island is probably the main source region of the type-a ISW, while the south of Itbayat Island and south of the Batan Island is likely the main source region of the type-b ISW. Lv et al. (2013) using the onboard X-band radar and ADCP, captured the velocity of the NLIWs around Dongsha Atoll which could reach 3.04 m/s and the propagating direction (297 degree). He also indicated that surface signal of IWs were related not only to amplitude, but also to currents and depth of mixing layer. Zha et al. (2012) proposed a method to estimate the force and torque exerted by IWs on a submerged cylindrical pile, through marine X-band radar images and in-situ buoyancy frequency data. After tracing the passage of the ISW, the Froude number decreases monotonically with depth in the upper layer, and then increases slightly with depth again till the bottom (Xu et al., 2011).

It is evident that the capability of numerical simulation has been substantially improved in recent years. Li et al., (2011) applied a 2-D non-hydrostatic MITgcm to indicate that barotropic tidal motion over sells could result in the generation of depressions solitons in the northwestern SCS for the first time. Operating the same model, Guo et al. (2012) successfully demonstrated that the eastern ridge in the LS could efficiently radiate tidal beams, which then nonlinearly superimposed on beams generated by the western ridge. Furthermore, the analysis of tidal excursion and topographic Froude number clearly illustrated that the generation of IWs in the northeast of Taiwan Island is subject to mixed lee wave mechanism (Fan et al., 2014). Meanwhile, Li et al. (2014) assessed several factors affecting NLIWs in the SCS, such as the distance between two ridges, the role of rotation, stratification and the Kuroshio effect. Based on a 3-D ocean current diagnostic model, Liao et al. (2014) showed the linear phase speed and dispersion parameter varied weakly with season and density stratification.

At present, theoretical researches shows increasing development. Lin et al. (2012) analyzed the internal wave generation via the gravity collapse mechanism, compared appropriate conditions between KdV and eKdV theory, and found a rapid conversion from the potential energy to kinetic energy during the generation phase. By calculating the wave phase speed and characteristic half-width of ISWs, Cai et al. (2014) found that finite-depth theory was more available to investigate ISWs in the SCS than shallow-water theory and the nonlinearity for IWs was stronger in summer than that in winter. In addition, the effects of the high-order nonlinearity and the earth's rotation on the fission of ISWs in the northern SCS are investigated by using the vKdV model and its varied modifications in a continuously stratified system

(Zhang et al., 2013). In a gravitational stratified fluid tank, Du et al. (2013) demonstrated the experimental criterion of the instability and breaking is amplitude parameter larger than 0.4 and the severe energy loss of ISW is a symbol of the breaking.

Eventually, Guo et al. (2014) reviewed ISWs researches and dynamic processes in the SCS with the summary of different investigation approaches before 2011, gave some hints on the ISWs' research for the future.

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# Progress of Oceanic Remote Sensing by Satellite Altimetry Studies in China from 2011 to 2015

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Satellite altimetry is one important operational technique of the oceanic remote sensing. Altimeter can achieve sea surface height(SSH), significant wave height(SWH) and sea surface wind speed which can be used in the observations, forecasts and studies of ocean dynamic process. Chinese first oceanic dynamic environment satellite - HY-2 satellite with a sun-synchronous orbit at an altitude of ~970km, which employed a Ku/C bands radar altimeter, was launched on 16 August, 2011, and the orbit is determined by SLR, GPS and DORIS systems. It has the repeat cycles of 14 days for the first two years with oceanographic purpose and 168 days geodetic cycles for the third year of the mission (Jia et al., 2014a).

For the SSH data processing of HY-2 radar altimeter, referring to the data processing of T/P, Jason-1/2 altimeter, dry troposphere correction modeling method, wet troposphere correction method from model and radiometer(Hu et al., 2011; Wang et al., 2014; Zheng et al., 2014a, 2014b), dual-frequency and modeling ionosphere correction method(Zhang et al., 2012), sea state bias correction method combining the parameter and non-parameter model(Zhou et al., 2012; Li et al., 2012; Ren et al., 2013; Wang et al., 2014a), ocean tidal corrections method form global tide model GOT00.2 and FES2004, solid earth tide and polar tide correction method from IERS model are developed. For the SWH and wind speed extraction of HY-2 radar altimeter, the SWH extraction algorithm based on the Barrick echo model and wind speed extraction algorithm based on the modified MCW model are developed(Fan et al., 2014; Wang et al., 2014b). In addition, Instrument errors such as Doppler error and acceleration error, time tag bias and the error caused by the inconsistent of the height direction of the satellite orbit and the satellite antenna pointing are studied (Wang, 2013; Xu et al., 2014), and the validations and calibrations of HY-2 radar altimeter data are carried out(Zhang et al., 2013; Wang et al., 2013; Jia et al., 2014b). The standard deviation of HY-2 SSH at crossovers is about -2±8.6 cm, and the error of SWH is 0.31m compared with NDBC buoys (Jia et al., 2014a).

In the oceanic application studies of altimeter data, ocean tide, ocean tide, mesoscale eddy, ocean current, sea level change and marine gravity are studied. The mean wave period is studied by the altimeter data (Miao et al., 2012). The harmonic constants of semidiurnal and diurnal tide in Chinese Sea (Zhao et al., 2012; Zhong & Yang, 2013) and global ocean (Song et al., 2014) are extracted by TOPEX/Poseidon and Jason-1 data. The variability of Kuroshio in the East China Sea are studied by ERS-1/2, ENVISAT and HY-2 altimeter data, the main axis location and width of mainstream of Kuroshio are extracted and analyzed(Zhao et al., 2014).With more than 20 years altimeter data including ERS-1/2, Envisat RA-2 and HY-2A altimeter, the spatial and temporal characters of mesoscale eddies in the South China Sea are analyzed, and the location, type, radius, movement of mesoscale eddies are derived in the South China Sea (Yang et al., 2014). A 2′×2′ resolution mean sea surface model over China sea and its adjacent sea areas(0°-45°N, 100°-140°) is built(Zhang et al., 2012) and the characters of sea level change in the East China Sea are analyzed by the altimeter data(Wang et al., 2014). In addition, the 2′×2′ gridding gravity anomalies data over China Sea and its vicinity are determined by combining Geosat, ERS-1/2, Envisat, T/P, Jason-1/2 satellite altimeter data, and the error is 5.251mGal compared to the ship-measured data (Wang, 2012).

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