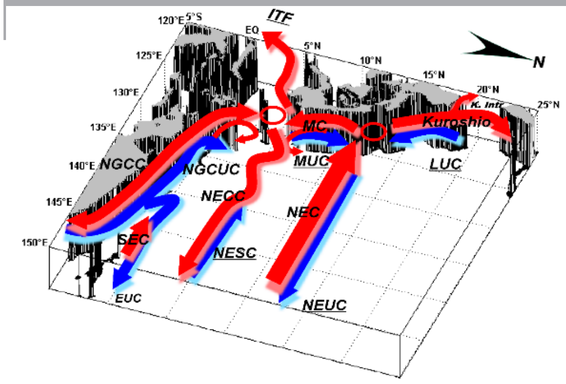
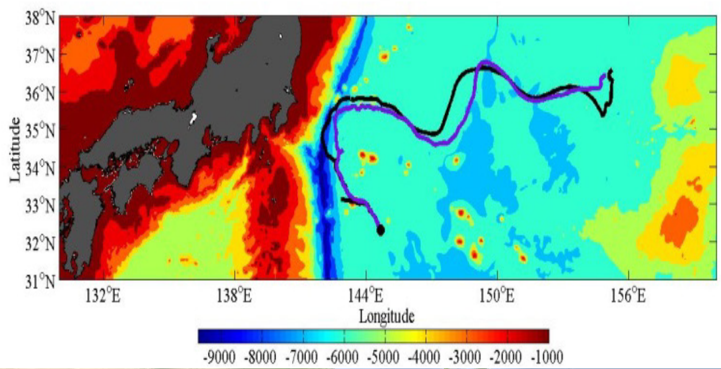
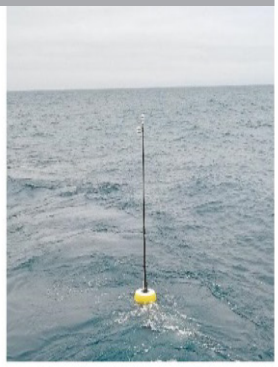
No. 75, November 2018

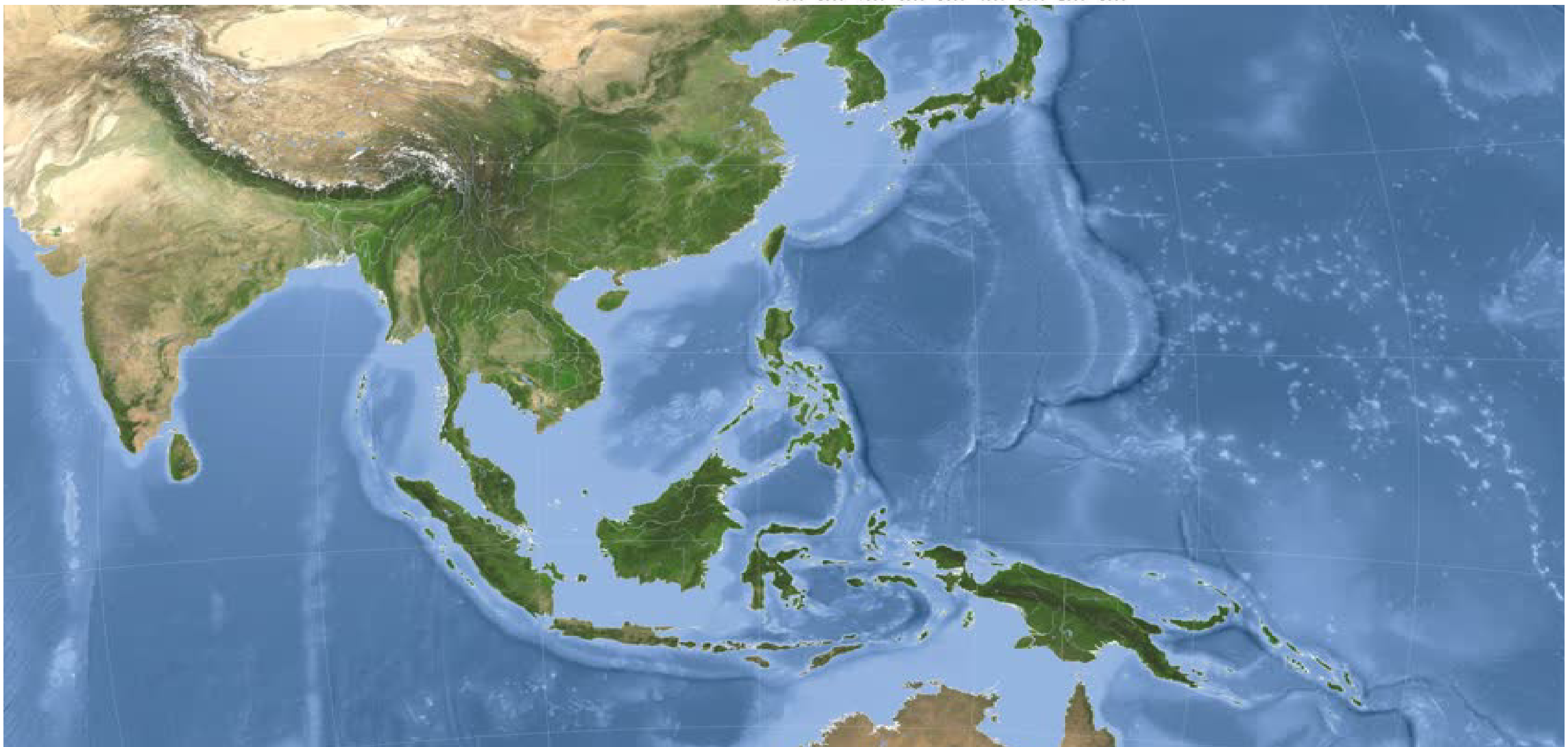
CLIVAR Exchanges

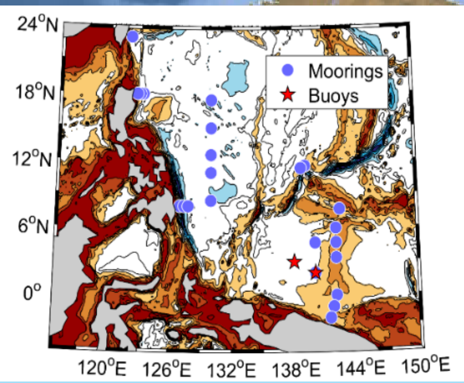
Special Issue: The Contribution of China to Ocean Research











CLIVAR Ocean and Climate: Variability, Predictability and Change is the World Climate Research Programme's core project on the Ocean-Atmosphere System

WORLD METEOROLOGICAL ORGANIZATION
United Nations Educational, Scientific and Cultural Organization
Intergovernmental Oceanographic Commission
International Science Council

Editorial

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The International CLIVAR Project Office was initially hosted at the Max Plank Institute in Hamburg, Germany and in 1998 it moved to the National Oceanography Centre in Southampton, UK. In 2014, WCRP decided to look for a new host for the CLIVAR office, when the First Institute of Oceanography (FIO) located in Qingdao, China was identified as a candidate, the consensus was that this Institution would be the perfect host for CLIVAR.

Why we believe that FIO in particular and China in general is a great home for the International CLIVAR office? Because the contribution of China to Ocean Sciences can rival that of any other country in the world, to put this in context here are some numbers:
Over the last few years the country has invested several billions yuan into Pacific Ocean science; there are hundreds of Marine Science and Technology Research Institutions, in which more than 13,000 scientists and technicians work (30% with PhD); China has recently launched 2 ocean satellites; at least 20 main research vessels are operational; and the country maintains 13 main scientific observations in coastal areas and 3 in the polar area.

In 2017, for the first time, China has overtaken the United States in terms of the total number of science publications, according to statistics compiled by the US National Science Foundation (NSF). China published more than 426,000 studies in 2016, or 18.6% of the total documented in Elsevier's Scopus database. That compares with nearly 409,000 by the United States. Of China's scientific production 30% in Engineering, 7% in GeoSciences (over 30,000 papers). However, there is room to improve in terms of dissemination: Sweden and Switzerland produce the most highly cited publications, followed by the US, the EU, and China.

In summary, Hosting of the International Clivar Project Office contributes to the broad recognition of China as a country internationally leading ocean and climate research and is instrumental in establishing fruitful cooperation between Chinese scientists and the global community of climate researchers from CLIVAR and WCRP.

On occasion of the 60th year anniversary of the First Institute of Oceanography, this special issue highlights some of the recent efforts on oceanographic research being implemented in China.

Climate and Ocean Science in general has evolved a great deal in the past couple of decades and the knowledge that we have been able to generate have no doubt contributed to make our society better prepared to improve our resilience to climate change and variability, but a lot of challenges remain, many scientific questions still remain to be answered, so there is still a great need of fundamental ocean and climate science, and China is prepared to be a key worldwide contributor in the years to come.

Introduction of First Institute of Oceanography

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Introduction

The First Institute of Oceanography (FIO, http://www.fio.org.cn) is a multidisciplinary oceanography institute affiliated to the State Oceanic Administration of China (SOA). The International CLIVAR (Climate and Ocean: Variability, Predictability and Change) Global Project Office (ICPO) is being hosted by FIO since August 2014 when the ICPO moved from Southampton UK to Qingdao China. SOA and FIO are providing full funding and in-kind support to ICPO for an initial term of 5 years (with possibility of renewal), which guarantees its functionality in coordinating world's climate and ocean research activities. Aside from this, FIO also contributes a lot to the world's oceanography and climate research and common welfare in many ways.

Figure 1: Organization structure of FIO

Sixty years' dedication in marine research and service

FIO was initially established in 1958, and was incorporated into SOA system in 1964. Being engaged in basic/applied research in oceanography and social service, FIO aims at enhancing marine S&T and providing technical supports for marine resources management, marine security and economic development. Its key research areas range from China coastal waters/oceans to polar regions, including marine resources and environmental geology, mechanism/forecasting methods of marine hazards, air-sea interaction and climate change, variation of marine eco-environment, and protection/utilization of islands and coastal zones.

After 60 years' development since its establishment, FIO has grown into a domestically and internationally renowned marine research institute. As being illustrated in Figure 1, FIO is now running 8 labs or research centers, which respectively focus on the research of marine science and numerical modeling, marine geology and geophysics, marine physics and remote sensing, air-sea interaction, marine ecology, marine spatial planning, marine engineering, as well as marine policy. FIO is equipped with 3 elite research vessels, two of which with names of Xiangyanghong 01 (Figure 2) and Xiangyanghong 18 (Figure 3) respectively are state-of-the-art and global-level, and a variety of equipment for field survey. Currently, FIO has 532 staff members, including research personnel, administrative members and technical supporting staff. Among the research personnel, there are 68 Research Fellows, 111 Research Associates and 62 Guest Research Fellows invited from domestic and foreign institutes.

Figure 2: R.V Xiangyanghong 01

Figure 3: R.V Xiangyanghong 18

Research highlights on climate and ocean research

Many teams of FIO have focused on climate and ocean research and continuously made significant achievements on various aspects of climate themes.

Numerical models are the core tools for the study of dynamical processes and the forecasting of the ocean environment. Common thermal biases exist in all of the ocean general circulation models (OGCMs), including overestimated SST and underestimated subsurface temperature in summer ((Martin 1985; Kanthaand Clayson 1994; Ezer 2000; Mellor 2001). The common biases are mainly caused by the insufficient vertical mixing in the upper ocean. The First Institute of Oceanography (FIO) focused on the turbulent mixing, especially the surface-wave induced mixing, and developed new types of ocean and climate models.

The Key laboratory of Marine Environmental Sciences and Numerical Simulation (MASNUM) has developed the wave-induced mixing theory, i.e., quantified surface wave-induced mixing and analytically expressed it as a function of the wavenumber spectra of surface waves (Qiao et al., 2004, 2010, 2016). The theory was then validated by the controlled laboratory experiments (Dai et al., 2010) and field observations (Huang et al., 2012). Based on the wave-induced mixing theory, a new OGCM coupled with surface waves, FIO-COM, has been developed (Xia et al., 2006; Qiao et al., 2010, 2011). Numerical results showed that the global mean correlation coefficient in the upper 100 m between the simulated temperature and the Levitus data was enhanced by 31%. An operational forecasting system was run at the Chinese Forecasting Centre, and global reanalysis data with a resolution of 0.1° were produced. A new climate model coupled with surface waves, FIO-ESM, was built and then included in WCRP's 5th phase of the climate model intercomparison project, CMIP5 (Song et al., 2012; Qiao et al., 2013). The results showed that the common bias of the mixed layer depth in the southern ocean was reduced from 38% to 6%, the tropical SST bias was reduced by 50%, and the bias of the summer precipitation in the East Asia monsoon zone was reduced by 27%, which implied that the new model coupled with surface waves could evidently promote the climate simulation and prediction ability.

FIO's scientists also made great contributions to the RAMA program during the past decade by maintaining the subsurface buoy at (8.5S, 107E) and the surface buoy at (8S, 100E), and provided valuable real-time in situ observations to international scientific communities for studies on ocean, atmosphere, and air-sea interaction (Yu et al., 2012). By analysing observational data and numerical simulations, it was found that the first northward propagating intraseasonal oscillation in the eastern Indian Ocean in spring plays a crucial role in triggering the summer monsoon in the Bay of Bengal, which is tightly linked to the subsequent onset of monsoon over the South China Sea (Li et al., 2013). This finding has important implications for the predicting skill of Asian summer monsoon. As another prominent air-sea interaction phenomenon in tropical Indian Ocean, the Indian Ocean Dipole (IOD) event, has been extensively studied by FIO's scientists in the past few years. One of the most important findings is that an IOD independent of ENSO is mostly induced by early onset of summer monsoon, and this type of IOD occurs more frequently since 1980s probably due to the change in mean state of tropical Indian Ocean climate system (Sun et al., 2015).

Figure 4: Deployment of mooring developed by FIO.

Air-sea interaction and its influences on climate and biogeochemical cycles in the Antarctic Ocean became a hot research topic of the FIO's scientists in recent years. By assessing Argo observations, scientists found that the Subantarctic Mode Water (SAMW) has thickened, deepened and warmed between 2005 and 2015, resulting in significant increase in SAMW heat content, which helps to explain the so-called global warming hiatus between 1998 and 2014 (Gao et al., 2017). Wind forcing, rather than buoyancy forcing, is found largely responsible for the observed trends in SAMW. Moreover, projected increases in wind stress curl would drive further deepening of SAMW and increase in heat storage in the Southern Hemisphere oceans. Using observational data from south of Tasmania, it was found that during a period with positive Southern Annular Mode trends, surface water pH and aragonite saturation state in Antarctic Zone decrease in austral summer at rates faster than those predicted from atmospheric CO_2 increase alone, whereas an opposite pattern is observed in Subantarctic Zone (Xue et al., 2018). Together with other processes, the enhanced acidification in Antarctic Zone may be attributed to increased westerly winds that bring in more "acidified" waters from the higher latitudes via enhanced meridional Ekman transport and from the subsurface via increased vertical mixing.

FIO has been making significant efforts in exploring the polar oceans, of both Arctic and Antarctic. More details are elaborated in another article in this Issue.

Active role on the international stage

Over the past decades, FIO has always attached great importance to and positively promoted the international cooperation in marine science and technology. Years of endeavors have witnessed the productive cooperation and stable relationship between FIO and foreign research institutes as well as international organizations in the Northeast Asia, Southeast Asia, South Asia, Africa, Europe, America, and Oceania.

At the present time, FIO has established positive partnership with around 50 research institutes from more than 30 key marine countries and regions. After signing and implementing over 30 inter-institutional cooperation agreements, FIO makes down-to-earth work with partners in marine observation and monitoring, disaster prevention and mitigation, air-sea interaction, marine ecosystem and bio-diversity conservation, marine geology, polar research, integrated coastal management, and ocean engineering, producing fruitful results. Besides, FIO gets actively involved in the activities of international organizations, including Intergovernmental Oceanographic Commission (IOC) and its Sub-Commission for the Western Pacific (WESTPAC), North Pacific Marine Science Organization (PICES), Scientific Committee on Ocean Research (SCOR), Partnership for Observation of the Global Oceans (POGO), and Partnerships in Environmental Management for the Seas of East Asia (PEMSEA). Also, FIO is playing important roles in many important international programs, covering Global Ocean Observing System (GOOS), the International Surface Ocean - Lower Atmosphere Study (SOLAS) Project, World Climate Research Programme (WCRP), Indian Ocean Observing System (INDOOS), etc. Being a success host, FIO has organized a series of big international conventions, such as the PICES 2015 Annual Meeting, CLIVAR Early Career Scientists Symposium, the 10th WESTPAC International Scientific Conference, and China-Southeast Asian Countries Marine Cooperation Forum, etc.

Some international and regional collaborative projects are initiated and led by FIO scientists and have much international influence. The projects include the Oceanic Forecasting System in Southeast Asian Region (under the auspice of WESTPAC), and Research Project on Marine Endangered Species of China-ASEAN Countries, both of which are funded by the China-ASEAN Maritime Cooperation Fund; as well as Monsoon Onset Monitoring and its Social & Ecosystem Impacts (MOMSEI) under the framework of the Southeast Asian Global Ocean Observing System(SEAGOOS).

Aside from ICPO, another 8 international organizations are hosted by FIO, which include the bilateral research organizations: China-Korea Joint Ocean Research Center (Qingdao), China-Indonesia Center for Ocean and Climate (Jakarta), China-Thailand Joint Laboratory for Climate and Marine Ecosystem (Phuket), China-Australia Joint Research Center of Ocean Engineering (Funded by Ministry of Technology of both countries), FIO-POI Joint Research Center of Ocean and Climate (Vladivostok), FIO-UM Joint Center of Marine Science and Technology (Bachok); and multi-lateral cooperation platforms: UNESCO/IOC Regional Training and Research Center on Ocean Dynamics and Climate (ODC Center), China-PEMSEA Sustainable Coastal Management Cooperation Center (CPC). Cooperating with Indonesia, Malaysia, Thailand, Sri Lanka, and Maldives, FIO has also established many cooperative observation stations and implemented joint research expeditions, setting and maintaining ocean buoys and subsurface buoys together with other countries, so that a regional and global ocean observation collaboration network begins to take shape.

Figure 5: Aero view of FIO Campus

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China's Vision towards the Tropical Pacific Observing System (TPOS) 2020

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Why do we care about the tropical Pacific?

The Pacific Rim countries and beyond suffer from extreme meteorological events on periods ranging from days to years that originate from anomalous conditions in the tropical Pacific. Typhoons frequently impact East Asian countries from June to October. Coastal areas are exposed to various vulnerabilities such as huge surface waves and coastal storm surges caused by typhoons. The China Marine Disaster Bulletin, published annually by the State Oceanic Administration (SOA) of China, showed that the direct economic loss by storm surges was almost 0.9 billion US dollars for China in 2017. The Western Pacific Warm Pool (WPWP), where deep and persistent convection develops, plays a vital role in shaping the global atmospheric circulation and climate regime (Bjerknes, 1969; Graham and Barnett, 1987; Song and Yu, 2013). El Niño and Southern Oscillation (ENSO) events severely influence weather patterns, and hence they substantially impact food security, resource management, ecosystems, public health and economies (Philander, 1983; Cai et al., 2014). Extreme El Niño events draw even more extensive attention (Santoso et al., 2017). To monitor the status and evolution of ENSO, the TAO/TRITON array was successfully implemented during the 1980s and 1990s. This array greatly enhanced the scientific understanding and fit-to-purpose routine prediction of ENSO episodes. However, recent years have experienced a declining trend in TAO/TRITON maintenance (Tollefson, 2014). Although the data return rate rebounded, this issue has been of great concern for the community. Scientists and stakeholders gathered in 2014 to seriously rethink the future of the tropical Pacific observing system (the workshop report can be found online at http://tpos2020.org/wp-content/uploads/TPOS-2020-Workshop-Report-FINAL-300114.pdf), which has heavily relied on TAO/TRITON over the past three decades. The Tropical Pacific Observing System (TPOS) 2020 project was therefore set up to address this development, taking into consideration this new technological opportunity, increased stakeholder involvement, more robust maintenance and a broader scope of international cooperation. China in the past played a critical role in western Pacific Ocean observations during the TOGA and TOGA-COARE eras but unfortunately she discontinued her involvement. In line with continued economic progress, the Chinese oceanographic and climatic communities renewed their concern about the tropical Pacific Ocean, planning an ambitious engagement and active role by consolidating international cooperation and by building up the sustainable TPOS for the coming decades.

Is China ready for TPOS 2020?

Operational forecasting and model development: The Global Framework for Climate Service (GFCS) requires a pivotal and urgent development of an ocean operational service to expand from a synoptic scale to climate scope. The SOA has been promoting its operations system in preparation; for example, using observations from TAO/TRITON, the National Marine Environmental Forecasting Center (NMEFC) issues ENSO predictions (http://www.nmefc.cn) twice a year, in spring (March) and autumn (September). Climate models are a fundamental tool in climate prediction service. Although much effort has been devoted to climate models, they still suffer from various common problems, such as an exaggerated double Inter Tropical Convergence Zone (ITCZ), an overestimated cold tongue in the eastern tropical Pacific, and a spuriously simulated semiannual cycle of sea surface temperature (SST) in the equatorial eastern Pacific (Song et al. 2011, 2012). Some biases are more likely linked to oceanic processes, such as a too shallow oceanic mixed layer depth (MLD) in summertime, both in ocean models and climate models (Fan and Griffies, 2014). The SST bias in climate models in the tropical Pacific Ocean is more than 1 °C, hampering the models' capability to document and predict ENSO variability reliably. One encouraging development in ocean models is the inclusion of explicit oceanic surface waves that consider their impact on air-sea flux and upper ocean stratification in climate models (Qiao et al. 2013), which can dramatically reduce long-lasting common biases in climate models (Song et al. 2012, Fan and Griffies, 2014). Taking into consideration both nonbreaking surface wave-induced mixing and breaking-wave sea spray, it is impressive that the super typhoon simulation is much improved, particularly with a large reduction in typhoon intensity bias (Zhao et al. 2017). Based on such improvements, the FIO-ESM (Earth System Model) is continuously tested in parallel run mode at NMEFC and will be implemented for operational service soon.

New technological developments: Several Chinese teams are working on the development of new ocean technology for the next generation of global ocean observing systems. Several examples are mentioned below. Smart floats: Realizing the critical importance of the deep ocean in regulating Earth's climate, the international community is promoting revolutionary deep ocean observation, including physical, biogeochemical and ecological components. The Deep Ocean Observing Strategy (DOOS) is one such example. Qingdao National Laboratory for Marine Science and Technology (QNLM) is testing one new mobile profiling platform called 'Smart Float', with fast dynamic positioning, a sustainable ocean energy supply and adaptive measuring capacity. The smart float (Fig. 1) integrates the functions of Argo float, glider and AUV into one system that is equipped with a variety of multidisciplinary sensors and that targets depths up to 4000 m.

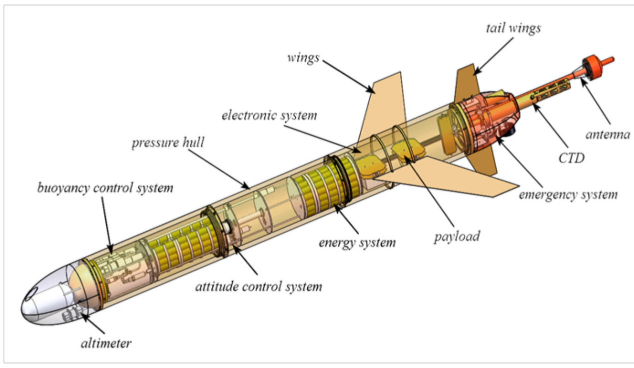

Figure 1: A schematic map of a Smart Float.

Bailong Buoy: The First Institute of Oceanography (FIO) developed its first comprehensive deep ocean buoy named 'Bailong', which can be deployed in the open ocean up to 7000 m deep. Bailong buoy measures sea surface meteorological parameters which can then be used to calculate the air-sea flux using bulk formula and subsurface oceanic temperature and salinity profiles down to a depth of 700 m (Fig. 2). It incorporates the core standards of a PMEL/NOAA TAO buoy and inter-comparisons prove its consistence with TAO within the same level of accuracy (Freitag et al., 2016).

Figure 2: Field photo at the Bailong Buoy location in the tropical ocean.

All the data, including the subsurface data, is transmitted to an office at three-hour intervals via Iridium satellite and then uploaded to GTS. The prototype Bailong buoy was deployed in the southeastern Indian Ocean in 2010. Since then, it has been serving as one component of the RAMA buoy array. Another advantage of Bailong being tested is the integration of multidisciplinary sensors. **Argo and Biogeochemical-Argo:** The classical Argo profiling floats (measuring ocean temperature and salinity in the upper 2000 m) and the novel Biogeochemical-Argo floats (integrating optical, biological and chemical sensors on the floats), allow for comprehensive oceanographic observations at both large spatial and temporal scales. As the leader of China in the international Argo and Biogeochemical-Argo projects, the Second Institute of Oceanography (SIO) is planning to deploy both kinds of floats in the tropical Pacific as a contribution to TPOS 2020, as well as provide comprehensive services such as data receiving, processing and quality-control for floats supported by other institutions. **Submarine Cable Online Observation System (SCOOS):** SCOOS, developed by Zhejiang University, is designed for in situ, online, real-time monitoring of the marine environment (Fig. 3).

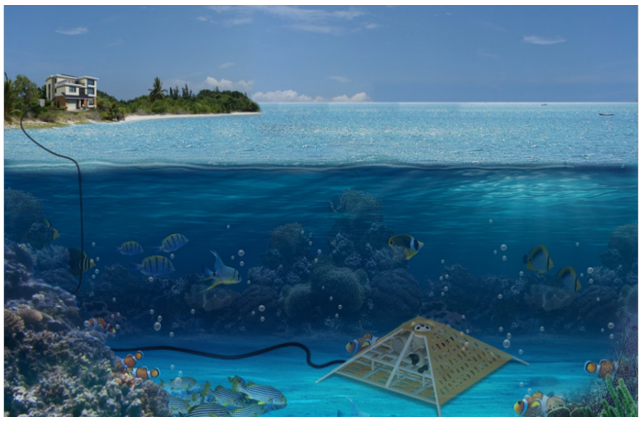

Figure 3: A schematic diagram of SCOOS.

The submarine observation part of SCOOS is deployed at the bottom of the sea and is easy to integrate a wide range of devices and sensors working in real-time to observe temperature, salinity, currents, dissolved oxygen, nutrients, etc. It has real-time two-way communication with a terminal control system on land through a submarine cable for transmitting data which commands and obtains electric power. SCOOS has broad applications for monitoring how the marine environment may respond to El Niño events. **Glider:** A glider equipped with oceanic sensors can serve as a monitoring platform for ocean environment variables. With a high temporal and spatial sampling resolution, glider has been adopted widely in oceanographic studies to understand the dynamics of oceanic processes. Compared to the Slocum glider, Seaglider, and Spray glider designed by American experts in the early 21st century, the Sea-Wing glider (Yu et al., 2011) developed in China is a relatively recent arrival used for oceanographic applications (Qiu et al., 2015). An intensive field observation experiment using 12 Sea-Wing gliders (Fig. 4) equipped with conductivity-temperature-depth (CTD) sensors was conducted in the summer of 2017 to investigate the 3-D structure and time evolution of an anticyclonic eddy in the northern South China Sea (NSCS) (Shu et al., 2018).

Figure 4: The 12 Sea-Wing gliders used in the network observation experiment.

DIF float: A new drifting air-sea interface flux (DIF) float was developed by the National Ocean Technology Center (NOTC). It is a small drifting platform that can be easily deployed. The DIF float measures meteorological parameters 3 meters above the sea surface including surface air temperature, relative humidity and wind vectors. It also measures sea surface hydrological variables including SST and current velocity. The air-sea flux can thus be estimated using bulk formulas. A new testing experiment was designed during a Northwestern Pacific cruise (Fig. 5). Two floats have been collecting oceanographic measurements since May 10, 2018. A preliminary comparison between the DIF float and KEO buoy revealed a similar level of accuracy.

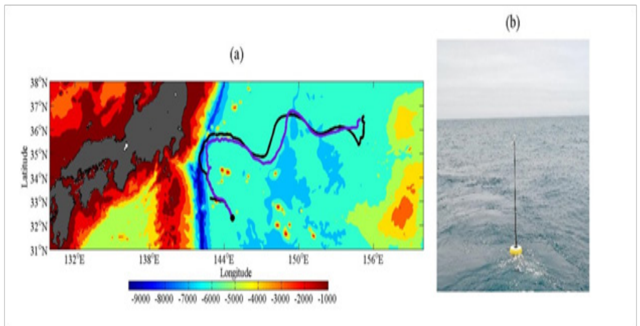

Figure 5: (a) The working trajectories for the testing of the DIF in the Kuroshio extension (KE) region from the May 10 to June 14 (the deadline of writing this paper), 2018. The colored background is the topography from the General Bathymetric Chart of the Oceans (GEBCO). (b) Field photo at the DIF site in the KE east of Japan.

Satellite: In the past few years, China has launched 3 ocean satellites called HaiYang or HY for short: HY-1A, HY-1B and HY-2A. The HY-2A satellite is a Chinese first-generation marine dynamic environment satellite with payloads of altimeter, scatterometer and microwave radiometer, measuring global sea surface height (SSH), sea surface wind and sea surface temperature. Its altimetry data has been incorporated into CLS merged products and has a wide application.

Progress in science: Much attention is being paid to global warming and its uncertainty, which is reflected by the dramatic increase in publications on this topic by Chinese scientists. One example is the concern regarding future extreme El Niño events, which may have a profound influence on summer rainfall patterns over the vast eastern China. Cai and collaborators published two high-impact papers on this topic (Cai et al., 2014, 2015). They found that occurrences of extreme El Niño and La Niña events will increase substantially under global warming. Specifically, the frequency of extreme El Niño events will double in a high emission (4.5 °C warming) scenario. Furthermore, the frequency of extreme El Niño events will continuously increase even if the global mean temperature (GMT) stabilizes in a 1.5 °C warming (low emission) scenario, while extreme La Niña events will change little. Another widely covered topic in China is centered on the Indo-Pacific warm pool. The Chinese Academy of Sciences (CAS) led the project of Northwestern Pacific Ocean Circulation and Climate (NPOCE), endorsed by CLIVAR. This project improved the understanding of the western Pacific Ocean boundary current and its role in climate (Hu et al., 2015) and is regarded as the most successful project in the western Pacific Ocean after TOGA. At the opposite end of the Indo-Pacific warm pool, progress is achieved on monsoon-ocean interactions with relevance to the earliest Asian monsoon onset process over the Bay of Bengal, where the first northward propagating intra-seasonal oscillation (ISO) is identified to trigger the abrupt monsoon onset (Li et al., 2013) and such a process is modulated by ENSO (Li et al., 2018). Another interesting example is the interaction between the tropical Indian Ocean and the tropical Pacific. The Indian Ocean basin mode (IOB) (Xie et al., 2009; Du et al., 2009) has been identified as an important part of the Indo-western Pacific Ocean capacitor, which explains why El Niño stages its last act over the monsoonal Indo-Northwest Pacific (Xie et al., 2016). Surprisingly, it has also been proposed that enhanced SST warming in the tropical Indian Ocean contributes to the La Niña-like state in the tropical Pacific by modulating the Walker circulation cell (Luo et al., 2012). Moreover, the Indo-Pacific region is connected by the Indonesian throughflow (ITF) pathway. Thermocline adjustment in the western Pacific that is forced by climate variability may affect the thermocline structure, the upper ocean temperature and salinity in the region west of Australia (Wang et al., 2015; Zhang et al., 2018). Such notable changes in the ocean will also greatly affect the global distribution of major climate types (Huang et al., 2017) and lead to new trends in wetter and drier weather over the globe (Guan et al., 2017). Another example is research related to ocean heat uptake, where Kosoka and Xie (2016) along with other studies, indicate that the tropical Pacific Ocean plays a vital role in determining and regulating ocean heat uptake, which is the key pacemaker of global surface temperature change. Improvements in estimates of the global and regional ocean heat content (Cheng and Zhu, 2016; Cheng et al. 2017) provide a foundation to understand the key mechanisms regulating the heat redistribution and heat uptake in the tropical Pacific Ocean. It is therefore reasonable to expect that TPOS 2020 will promote the study of the tropical Pacific Ocean and its climate to better meet national, regional and international requirements.

What will be Chinese potential towards TPOS 2020?

Cruises: During the TPOS 2020 Western Pacific Workshop (September 2017 in Qingdao), much discussion was devoted towards the need of enhanced climate observations. The warm-pool boundary dynamics also received a large amount of attention, triggered by JAMSTEC proposals about the eastern and northern edge of the warm pool. More comprehensive plans will be further developed to include topics covering, but not limited to, circulation dynamics, monsoon-ocean interactions, study of typhoons, biogeochemical processes, marine ecosystems and fisheries. Chinese research fleets have experienced significant progress in the past decade, including the Xiang-Yang-Hong series from SOA, the Science series from CAS; the Dong-Fang-Hong series from universities; the Xue-Long series from SOA (dedicated to polar research); and the Da-Yang series from SOA (dedicated to studying marine environmental resources), among others. The national coordination effort will be enhanced to support the pilot projects in the western Pacific Ocean.

Surface buoys, subsurface moorings and Argo floats: A total of 12 stations are planned (Fig. 6), including 12 surface buoys with 6 coexisting subsurface moorings. The buoys cover the western Pacific Ocean with a “丁” (a T-like Chinese characterpronounced “ding”) configuration, whose Chinese meaning is the ordinal number '4th', coincidently representing the 4th Chinese regional ocean observation initiative after those in the coastal region, polar region and the Indian Ocean.

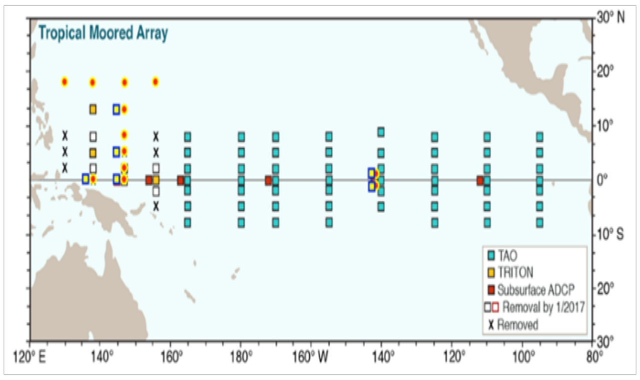

Figure 6: The proposed Chinese engagement (version 1) in TPOS 2020, where the red dots with yellow circles represent SOA's surface buoy sites, and the yellow squares with blue frames denote SOA's subsurface ADCP mooring sites.

In fact, it is the tropical part of the Chinese Big-Cross ocean observation plan that covers the tropical to mid-latitude western Pacific Ocean. The “丁” array targets the study of ENSO development, particularly westerly wind bursts and the Madden Julian Oscillation (MJO) revitalization over the equatorial western Pacific Ocean, typhoon genesis and propagation, and the northwestern Pacific monsoon. In essence, the “丁” array endeavors to link the western equatorial Pacific Ocean, where ENSO is triggered, to the central-to-eastern region, where ENSO peaks, and further evaluate the impacts of ENSO in east Asia through investigating monsoon-ocean interactions and typhoon genesis/development over the northwestern Pacific Ocean. To supplement the fixed time-series observations, Argo floats will be deployed in the tropical Pacific Ocean with the aim of doubling the present Argo density, which in turn will improve products, such as the Roemmich-Gilson Argo product (Roemmich and Gilson, 2009). Swells are frequent in the central eastern equatorial Pacific (Chen et al., 2002). Swell-related information, including wave height, period, direction and spectra could be collected by the "丁" array. It could also improve the accuracy of wave climate prediction and thus be of benefit to sea-navigation and ocean engineering. Surveys using underwater gliders are also planned in connection to fixed observatories, particularly in extreme environments (e.g., typhoons).

Satellites: SOA's HY-2A satellite is currently in orbit and it has been working for almost 7 years. According to the plan shown in Fig. 7, 3 satellites, including HY-1C, HY-2B and the Chinese-French Oceanic Satellite (CFOSAT), will be launched in 2018. HY-1D and HY-2C will be launched before 2020. The new HY-1 series satellites will provide daily observation of ocean color and sea surface temperature on a global scale. CFOSAT will observe ocean surface wind and waves simultaneously. With the adoption of an open data policy, SOA is expecting stronger cooperation and coordination with the international satellite community.

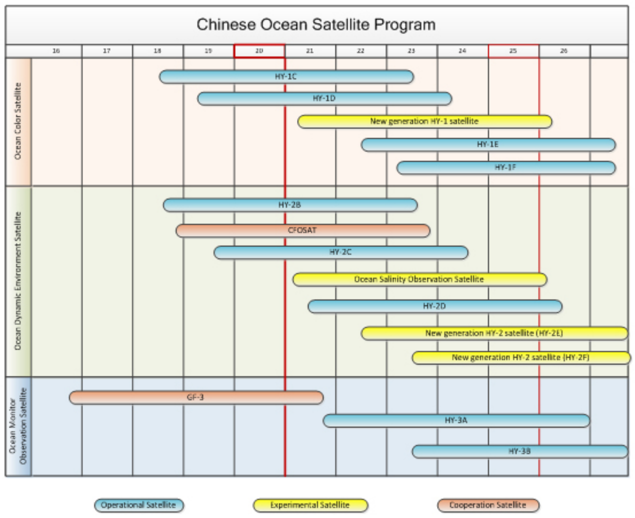

Figure 7: Timeline of the Chinese Ocean Satellite Program development program, including three categories: ocean color satellites (HY-1), ocean dynamics environment satellites (HY-2) and ocean monitor observation satellites (HY-3).

How do we move forward?

In close collaboration with the TPOS 2020 international scientific committee, SOA is ready to establish a national coordination mechanism in the form of the National Advisory Committee for TPOS 2020 Implementation (NACTI) to promote western Pacific Ocean observation, research and operational services. NACTI will incorporate momentum from various agencies in China, including the SOA, CAS, Ministry of Education (ME), and QNLM. QNLM is a new marine science and technology boost towards the frontiers and takes advantage of complementary teams from different agencies. It is expected that QNLM will support new technologies and implement studies to optimize the observations. Operational marine observation and forecasting will be led by SOA through its institutes and operational centers. The National Ocean Technology Center (NOTC) is leading the planning of the Chinese Global Ocean Observing System (C-GOOS), whose component in the Pacific Ocean fits well with TPOS 2020. All the in situ observation will be delivered to the National Marine Data and Information Service (NMDIS), where the data are quality controlled and distributed to the public in a free and open policy.

C-GOOS - from space to the ocean interior: C-GOOS aims to establish a 3-D real-time observing system from space to in situ, which will support TPOS 2020 in the Pacific basin. SOA seeks the global use and the widest application of its satellite data, particularly considering the deployment of 5 new satellites before 2020. One target collaborative project using a Chinese satellite is required to demonstrate its application in the TPOS science. The proposed 12 buoy/mooring stations will merge with those from PMEL/NOAA and JAMSTEC as the new TAO/TRITON/Bailong array. SOA, together with its partners such as PMEL and JAMSTEC, promote the development of the core TPOS Array with its specifications under DBCP/JCOMM guidance, which calls for extensive technological exchange and cooperation among the organizations. Together with regular service and pilot study cruises, the data collected by SOA and other Chinese agencies will be made public after following the quality control in the IOC data policy. In parallel, C-GOOS keeps Chinese streamlined in the South China Sea (SCS) and Indian Ocean (IO). TPOS 2020 also benefits from such a balanced component in the SCS and IO, considering that tropical IO and tropical Pacific Ocean are inter-connected in many aspects. The SOA will continue to support IndOOS, in particular its RAMA development and maintenance. Towards that goal, SOA's collaborative IO network, including its oversea centers in Malaysia, Thailand, Indonesia, Sri Lanka and its partners with Maldives, Kenya and Madagascar, will be sustained and enhanced. CAS will also continue its IO observations and studies, contingent on its successful cooperation with Sri Lanka and productive annual open cruises since 2010 to the eastern IO sponsored by the National Natural Science Foundation (NSFC).

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Recent Progresses in the Western Pacific Ocean Circulation and Climate Study from IOCAS and Contribution to NPOCE/CLIVAR

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Introduction

The ocean is a key part of the Earth climate system. The western Pacific Ocean (WPO) is unique in that it holds the largest warm pool with highest sea surface temperatures in the world's oceans. The high surface temperatures drive strong atmospheric deep convection. Even a small change of the western Pacific warm pool can trigger strong climate fluctuations. El Niño Southern Oscillation (ENSO), East Asian Monsoon and tropical cyclones are affected by the WPO (Figure 1).

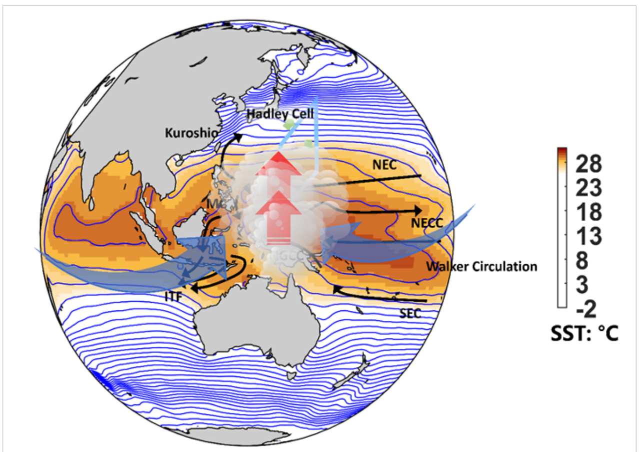

Figure 1: Background ocean and climate system in the tropical northwestern Pacific Ocean. Blue contour lines and color indicate annual mean SST during 2004–2014 from HadISST dataset. Major ocean circulations in the upper layer and overlying atmospheric circulations are schematically depicted. MC: Mindanao Current; NEC: North Equatorial Current; NECC: North Equatorial Countercurrent; SEC: South Equatorial Current; NGCC: New Guinea Coastal Current; ITF: Indonesian Throughflow.

As the origin of major currents, the western Pacific strongly interacts with the ambient oceans and marginal seas. Although significant advances have been made over the past decades, understanding of the mean circulation in the region remains incomplete, and variability of the low latitude western boundary currents (WBCs) is largely unknown. A lack of in-situ observations severely hinders our ability to understand the physical and dynamical process in the tropical ocean and the associated climate impact.

To better observe, simulate, and understand the dynamics of the northwestern Pacific Ocean circulation and its role in modulations of regional and global climate, the "Northwestern Pacific Ocean Circulation and Climate Experiment" (NPOCE) was launched in 2010 (Hu et al., 2011; Wang and Hu, 2010). NPOCE is an international program endorsed by the Climate and Ocean - Variability, Predictability and Change (CLIVAR), a core project of the World Climate Research Programme. A total of 19 institutions from 8 countries including Australia, China, Germany, Indonesia, Japan, Korea, Philippines and United States participate in this program. The NPOCE scientific issues are addressed through five research themes: 1. Western boundary currents; 2. Interaction with ambient circulation systems; 3. Roles in warm pool maintenance and variability; 4. Regional air-sea interaction and climatic impacts; and 5. Ocean biogeochemistry, acidification, ecosystem, and paleo-oceanography. By integrating coordinated observations and modeling, the NPOCE aims to provide a more complete depiction of the structure and variability of the ocean circulation and to improve prediction of their climatic impacts.

After an 8-year successful implementation, the NPOCE community has made remarkable achievements in advanced observing and better understanding the WPO ocean circulation and climate system. As a lead institution initiating the NPOCE program, the Institute of Oceanography of Chinese Academy of Sciences (IOCAS) has contributed to the NPOCE during more than a decade with numerous in situ observation projects and plenty of research resources. This paper aims to summarize the major processes from IOCAS as a contribution to the NPOCE/CLIVAR program.

Advances in WPO Observation

Since the NPOCE was launched in 2010, great progress has been made through collective effort in field experiments, including a series of cruises to the NPOCE domain. In 2010, scientists from the IOCAS and Ocean University of China successfully deployed three subsurface moorings in the Philippine trench at 8ºN and 18ºN, including one at 6100-m off Mindanao. From these moorings, four years of direct current observations were obtained for the first time in history.

Since 2014, mooring arrays consisting of more than 30 subsurface moorings and 2 buoys have been built up in the tropical western Pacific Ocean and Indonesian seas by the IOCAS under the WPOS (Western Pacific Ocean System: Structure, Dynamics and Consequences) project supported by the Chinese Academy of Sciences (Figure 2).

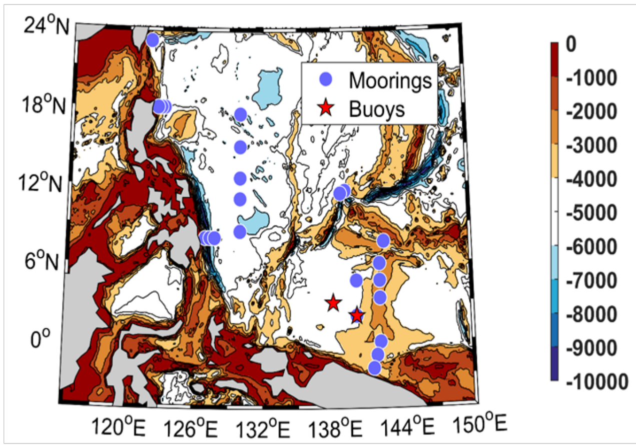

Figure 2: Tropical western Pacific Ocean observation system deployed and maintained by the IOCAS as a contribution to the NPOCE program.

In 2017, 10 subsurface moorings were upgraded with real time data transmission. To maintain the mooring arrays, the IOCAS performs at least one western Pacific cruise every year. Besides the mooring arrays, numerous CTD casts were also made and ARGOS drifters were deployed. With these efforts in field observations, the NPOCE community has significantly advanced the scientific research of the ocean circulation and climate.

WPO ocean circulation structure and basic features

Direct current measurements and densified hydrographic observations have confirmed the existence of the undercurrent system in the Philippine Sea, which includes the Mindanao Undercurrent (MUC) (Zhang et al., 2014; Wang et al., 2015; Hu et al., 2016), Luzon Undercurrent (LUC) (Hu et al., 2013; Wang et al., 2014a; Wang et al., 2015) and North Equatorial Undercurrent (NEUC) (e.g., Wang et al., 2015; Zhang et al., 2017) (Figure 3). Based on in situ observations, a new undercurrent named North Equatorial Subsurface Countercurrent (NESC) was discovered (e.g., Yuan et al., 2014) and directly observed with ADCP observations (Wang et al., 2016c). The spatial structure and multi-time scale variability of the Pacific western boundary currents and their climatic impacts were fully reviewed by Hu et al. (2015).

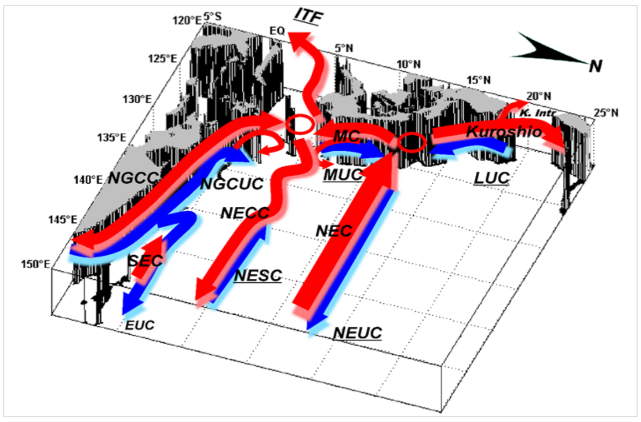

Figure 3: Three-dimensional structure of northwestern Pacific Ocean circulations, where selected new achievements are highlighted by underlines: discovering and directly observing of NESC (Yuan et al., 2014; Wang et al., 2016c), confirming existence of MUC (Zhang et al., 2014; Wang et al., 2015; Hu et al., 2016), LUC (Hu et al., 2013; Wang et al., 2015) and NEUC (Wang et al., 2015); salinity-effect mechanism of interannual to decadal variability of ITF (Hu and Sprintall, 2016, 2017).

Based on data from Argo profiles and other historic hydrographic observations, it has been observed that the MUC is located between 6.5°N and 10.5°N with two northward velocity cores greater than 10 cm s-1, the LUC has a core southward velocity exceeding 2 cm s-1 under the Kuroshio at 18°N and 16.25°N sections, while the NEUC has two to three cores with velocity larger than 1 cm s-1 (Wang et al., 2015). Water mass analyses suggest that the MUC feds the southern part of NEUC with the South Pacific water and South/North Pacific water mixture, and the LUC carrying the North Pacific water flows into the northern NEUC, with the climatological circulation pattern according to the geostrophic balance (Wang et al., 2015). ADCP mooring observations at 2°N, 140°E and 4.7°N, 140°E have provided direct evidence for the existence of NESC, and reversals of the EIC and NESC were observed in May and June from westward to eastward, respectively (Wang et al., 2016c). Mooring measurements at the Maluku Channel during December 2012–November 2016 show that the mean transport through the upper Maluku Channel is about 1.04–1.31 Sv northward (Yuan et al., 2018).

The low-latitude Pacific Ocean circulation is found to be significantly different from the classical Sverdrup gyre circulation (Yuan et al., 2014). The Argo geostrophic meridional transport is found to deviate from the Sverdrup minus Ekman meridional transports in dipole gyres off the east Philippine coasts (Zhang et al., 2013; Yuan et al., 2014), which are important for the zonal currents through the continuity equation. The non-Sverdrup gyres are suggested to be forced by oceanic nonlinearity associated with mesoscale eddy activities and tropical instability waves rich in the area. The roles of the non-Sverdrup circulation in shaping the surface and subsurface circulation of the western Pacific Ocean are yet to be disclosed.

North Pacific Tropical Water mainly subducts in the northeastern Pacific Ocean, spreads in the North Equatorial Current (NEC), and then splits into the Kuroshio region and tropical Pacific region and Indian Ocean through western boundary pathway or interior pathway (Nie et al., 2016). A large number of thermocline-mixing events occurring down to the lower half of the thermocline and the lower flank of the Equatorial Undercurrent (EUC) due to lower Richardson numbers, which might provide an important perspective in understanding the thermocline dynamics (Liu et al., 2016).

WPO ocean circulation variability and dynamics

With the intensified NPOCE observations and accumulated in situ and remote observations, the multiple time scale variability of the WPO current and undercurrent system has been identified, which will be introduced below from intraseasonal to decadal time scales.

Significant intraseasonal variability (ISV) is observed in the western tropical Pacific and Indonesian waters from in-situ measurements and remote observations (e.g., Hu et al., 2013; Zhang et al., 2014; Wang et al., 2016a; Yuan et al., 2018). Moored ADCP measurements show that the equatorial current system, including the North Equatorial Countercurrent (NECC), South Equatorial Current (SEC), EUC, Equatorial Intermediate Current (EIC), North Intermediate Countercurrent (NICC), and NESC, also have significant ISV (Wang et al., 2016c). The period of intra-seasonal oceanic variability in the tropical western Pacific Ocean increases with latitude and is symmetrical about the equator (Hu et al., 2018). Observed oceanic ISV is associated with westward propagating mesoscale eddies and Rossby waves due to dynamic instabilities (Hu et al., 2013; Hu et al., 2018). The Madden-Julian Oscillation is an important forcing in shaping the oceanic ISV in the tropical western Pacific Ocean through (Wang et al., 2016a; Hu et al., 2018).

Prominent semi-annual variability of sub-thermocline meridional flow along the Mindanao coast was revealed for the first time using ADCP mooring observations (Wang et al., 2016b). It is shown that the Antarctic and North Pacific Intermediate Waters are alternating transported by northward and southward undercurrents near the Mindanao coast and hence the sub-thermocline meridional flow plays an important role in the intermediate water exchange in northwest tropical Pacific (Wang et al., 2016b).

Interannual to decadal variability of WPO ocean circulations is linked to ENSO and PDO-related dynamics, and a better understanding of mechanisms and their influence is proposed. For example, the salinity effect in the Indonesian Throughflow (ITF) (Hu and Sprintall, 2016, 2017), salinity anomaly transported by NEC (Li et al., 2013), and directly observed interannual variability of the MUC (Hu et al., 2016). New mechanisms associated with buoyancy forcing are proposed to understand variability of ITF.

Salinity variability in the ITF outflow region associated with fresh water input within the Indonesian seas is found to be an important factor that causes significant ITF variation on interannual to decadal time scales (Hu and Sprintall, 2016; 2017). The ITF acts as an Indo-Pacific oceanic channel through transport anomalies related to IOD and ENSO and is suggested to play an important role in the climate variations in the tropical Pacific Ocean (Yuan et al., 2011; 2013; Xu et al., 2013). The precursory relation between IOD and ENSO at the one year time lead has been suggested to be controlled by the interannual variability of the ITF, which contributes to the predictability of nearly 50% of the cold tongue SSTA variability (standard deviation) with one year lead time. The IOD-ENSO precursory relation at the one-year lead time has decadal variability, due to the decadal variations of the thermocline depth in the eastern Pacific Ocean, which modulate the coupling of the tropical Pacific Ocean and atmosphere (Xu and Yuan, 2014).

The MUC and MC was directly observed for about 4 years for the first time and their depth-dependent interannual variability were investigated using the ADCP measurements east of the Mindanao Island at 7°59′N, 127°3′E. Diagnostic analysis accompanying with numerical experiments imply that wind forcing in the western Pacific Ocean is a driving agent in conditioning the interannual variability of MC and MUC through westward-propagating Rossby waves while local Ekman pumping also plays a role (Hu et al., 2016). Penetration of western boundary currents into the Sulawesi Sea is found to be sensitive to gap width and WBCs strength due to hysteresis procedure related to nonlinear collision (Wang and Yuan, 2012 2014).

The NEC is found to transport interannual variations of sea surface salinity, which are generated in the central Pacific due to ENSO-related atmospheric freshwater forcing and ocean advection changes, towards the WPO and causes sea surface salinity variations in the Philippine Sea (Li et al., 2013). The NECC is found to have pronounced interannual-to-decadal variations in terms of intensity, position and path length, as a response to ENSO cycle and its decadal change through Kelvin and Rossby wave dynamics (Zhao et al., 2013).

Repeated shipboard acoustic Doppler current profiler measurements during 1993–2008 indicate that the NEC transport has intensified during the 16 years (Hu and Hu, 2014).

Decadal variability in the NEC transport and bifurcation is mainly related to decadal wind forcing in the tropical western Pacific (Zhai et al., 2013, 2014; Hu and Hu, 2014). The decadal variations of the zonally and vertically integrated meridional geostrophic transport in the interior tropical North Pacific Ocean are found to precede the Pacific decadal oscillation (PDO) by

1–3 years, but the Sverdrup transports differ from the meridional transport significantly probably due to nonlinearity (Zhou et al., 2018).

Western Pacific warm pool and climatic impacts

ENSO-related warm pool variability and dynamics is an important focus for both the NPOCE and IOCAS. Sea surface temperature structure inside the western Pacific warm pool (WPWP) is usually of distinct homogeneity, but it is found that the WPWP significantly splits into two parts, which is named WPWP split phenomenon (Hu et al., 2017). Oceanic dynamics related to enhanced upwelling and western propagating upwelling Rossby waves account for the WPWP split, which seems to intensify following El Niño events (Hu et al., 2017). Hu and Hu (2012) defined the WPWP heat center and found that longitude of the WPWP heat center leads the Niño-3 index by about 3–4 months and hence probably is a good predictor for ENSO events. Jia et al. (2017) found that the Niño-4 SST variation explains approximately half of the variance of the WPWP heat content and almost all the variance of the east-west migration of the WPWP. Intraseasonal variability in the tropical Pacific subsurface temperature is investigated and suggested to play an important role in the two types of ENSO events (Feng et al., 2016).

Temperature variance budgets in the mixed layer of the Niño-3 and Niño-4 regions suggest that thermocline and zonal advective feedbacks are the most important positive feedbacks for generating ENSO SST variance, and thermodynamic damping is the largest negative feedback for damping ENSO variance (Guan and McPhaden, 2016). It is shown that thermocline feedbacks experienced a substantial reduction from 1980 to 1999 and into the 2000s, while negative feedbacks likewise weakened after 2000, particularly thermal damping in the Niño-3 region and the nonlinear sink of variance in both regions (Guan and McPhaden, 2016).

The western tropical Pacific Ocean acts to modulate the South China Sea summer monsoon onset and plays as a good predictor of the latter (Feng and Hu, 2014). An effective precursor for the prediction of the July Niño 3.4 index with a lead time of 2-4 months were identified in the WPWP by a regression analysis to surface current and the July Niño 3.4 index (Wang et al., 2017).

Summary

TOGA and WOCE in the 1980’s and 1990’s were responsible for the most prosperous period in the history for ocean circulation and climate study in the western Pacific Ocean. However, after that there was a stagnant period until 2010 when NPOCE was launched. Remarkable progress has been made by the NPOCE community over the past decade or so. We must give the credit to the international collective effort of the NPOCE body and the productive scientist community.

Under the greenhouse warming scenario, humankind is faced with serious challenges related to climate change and extreme weather and climate events. Better and quantified understanding of the ocean circulation and climate change in the northwestern Pacific Ocean is still an essential issue that we must settle in order to be better prepared to face the challenges ahead.

Acknowledgments

F.W. was supported by the National Natural Science Foundation of China (Grants 41730534, 41421005, and U1406401), the Strategic Priority Research Program of the Chinese Academy of Sciences (grant XDA11010204), the Qingdao National Laboratory for Marine Science and Technology (2015ASTP), the National Program on Global Change and Air-Sea Interaction (grant GASI-IPOVAI-01-01), and the National Key Research and Development Program of China (2017YFA0603200). S.H. was supported by the National Natural Science Foundation of China (Grant 41776018) and the CAS Key Research Program of Frontier Sciences (QYZDB-SSW-SYS023). We are grateful to Dr. Jose Santos and an anonymous Guest Editor for their helpful comments and suggestions.

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A review of the comprehensive investigation over the tropical Indian Ocean in China.

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Introduction

The Indian Ocean is not unfamiliar to China. As early as 600 years ago when Zheng He commanded expeditionary voyages to the West, the hard-working Chinese people started to explore the Indian Ocean and its surrounding waters through various means. However, the scientific exploration and investigation of the Indian Ocean by Chinese scientists have been missing over a long period after the founding of the New China (People's Republic of China). China's climate is a typical monsoon climate. The summer flood season is controlled by the Asian summer monsoon system, which shows significant changes at multiple temporal scales. The oceanic dynamics and thermodynamics of the Indian Ocean are important factors affecting the Asian monsoon system. Therefore, a comprehensive research helps to understand and predict the environmental variability in the Indian Ocean and its impact on the Asian summer monsoon. It also provides important support to disaster prevention, disaster mitigation, and responses to climate change in China's flood season.

A Review: Research of the Indian Ocean

In November 2007, the First Institute of Oceanography (FIO), State Oceanic Administration, took the lead in carrying out ocean and climate observations in the Indian Ocean. A one-week Indian Ocean observation was conducted via the Sino-Indonesian joint voyages. The first deep sea submersible system was deployed during that week, which was a zero-breakthrough for China to fulfill the long-term observation of the dynamic environment in the Indian Ocean. On May 13th 2010, the institute successfully deployed buoys (named "White Dragon") in the Indian Ocean for the first time through the China-Indonesia collaboration. It was the third type of deep sea buoy system officially used in the Indian Ocean following the "The Research Moored Array for Africa-Asia-Australian Monsoon Analysis and Prediction" (RAMA) by the United States and Japan. However, the continuous observations of fixed-points by buoys and submersibles are not enough to meet the high demands necessary to systematically understand the marine environment of the Indian Ocean. Since 2010, the expeditions for marine surveys funded by the National Natural Science Foundation of China have been carried out successively in northeastern Indian Ocean, however, the comprehensive investigation of the tropical southeastern Indian Ocean had not been implemented.

Under the support of the National Program on Global Change and Air-Sea Interaction by the State Oceanic Administration, the "Comprehensive Investigation of the Southern Waters of Eastern Indian Ocean" led by the First Institute of oceanography (FIO) was implemented in an orderly manner in 2013. Marine scientific researchers from physical oceanography, marine meteorology, marine biology, marine chemistry, and marine optics have conducted multidisciplinary surveys in the tropical southeastern Indian Ocean, using FIO's marine research vessels. The comprehensive surveys of the marine environment were conducted in four seasons (spring, summer, autumn, and winter), in 2013, 2016 and 2017, through the collaboration of research centers and laboratories of FIO: Center for Ocean and Climate Research, Laboratory of Marine Science and Numerical Modeling, Marine Ecology Research Center, and Laboratory of Marine Physics and Remote Sensing, with North China Sea Branch of State Oceanic Administration, National Ocean Technology Center, National Center of Ocean Standards and Metrology, and the China Meteorological Administration.

A series of surveys with a total voyage of over 50, 000 nautical miles were carried to systematically acquire the comprehensive environment database of the southeastern Indian Ocean, which allowed to deepen our understanding of the dynamic environment and ecosystem in these sea areas.

Introduction of the voyages to the Indian Ocean

A comprehensive environment survey of the southeastern Indian Ocean was carried out by China in the spring expedition from March 11 to May 12, 2013. "Xiang Yang Hong 09" research vessel undertook the 64-day expedition and completed the survey covering 89 stations. 41 young researchers participated in the expedition with an average age of merely 33 years. The surveys, including ocean surface and internal section observations, meteorological key element profiling observations, deep-sea mooring submersible system observations, meteorological chemistry and marine chemistry observations, marine biological comprehensive surveys, and marine optics and microwave remote sensing observations, were conducted in this sea area for the first time. The surveys provided important data to reveal the characteristics and mechanisms of the Wyrtki current variability in the Indian Ocean (Duan et al., 2016, Wu et al., 2018), obtained the bacteria that significantly kill the pathogenic ciliates in aquaculture fishery, and revealed the distribution characteristics of the low-oxygen area in the southeastern Indian Ocean.

The summer expedition voyage lasted for 55 days, from July 13th to September 5th, 2016. It completed a comprehensive survey covering 102 stations. The observations were conducted by using the survey ship "Hai Ce 3301". Thirty-six researchers participated in the cruise. The surveys primarily included physical oceanography and marine meteorology, marine and atmospheric boundary layer, marine chemistry, marine biology, and marine optics. It explored the basic background fields of the southern waters of the eastern Indian Ocean and atmospheric environment during the monsoon season in South Asia.

The autumn expedition was carried out by the "Xiang Yang Hong 01" vessel with 40 researchers from October 19th to December 30th, 2016 (See Figure 1).

Figure 1: The group photo of 2016 cruise.

It was the first expedition for the vessel. It successfully completed the surveys and sample collections from 99 stations. During this cruise, CTD cranes were applied for the first time to carry out the high frequency and long-time automatic operation. The satellite-ground optical observations of the Indian Ocean were completed simultaneously for the first time in conjunction with the measurement from "Tiangong-2". During the expedition, the public open days were held in the Maldives and Cambodia, and the first Sino-Cambodian joint marine scientific investigation was conducted, which greatly promoted the marine science and technology collaborations between China and the coastal countries along the "21st Century Maritime Silk Road".

The winter expedition was undertaken by the "Xiang Yang Hong 18" vessel with 29 researchers from November 17th, 2017 to February 5th, 2018. It was the first expedition for the vessel to cross the equator towards the southern hemisphere to conduct surveys. The expedition created a new record for China who successfully completed the comprehensive surveys in the Indian Ocean using the minimum tonnage research vessel to fulfill the high demanding tasks (97 stations) during long working hours (80 days) by minimum personnel. The survey successfully observed the characteristics of the multi-element variability in the core regions of the tropical cyclone off the equator, observed the abnormal changes in the thermocline in the tropical southeastern Indian Ocean, and further understood the characteristics of the low-oxygen area of the Indian Ocean. During the expedition, sampling of marine microplastics was carried out, and the deep-sea submersible and buoy systems were successfully deployed and recovered by making good use of the limited space on the deck.

The series of the comprehensive surveys of the southeastern Indian Ocean provided an important database for the complete, systematic, and in-depth study on the temporal and spatial distribution characteristics, formation and variation mechanisms of the key elements of the studied sea areas. It cultivated and trained many researchers for oceanic investigations, expanded and deepened the maritime collaborations between China and the countries along the coasts of the Indian Ocean, and made a significant contribution towards the construction of the "21st Century Maritime Silk Road".

Besides the cruises in recent years, I suggest that the investigation results and new understandings about the Indian Ocean are involved to enrich the manuscript. The author can find the post publications in http://www.clivar.org/publications/exchanges.

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MOMSEI: exploring the monsoon onset and its social and ecosystem impacts. An IOC/WESTPAC Regional Cooperation Effort

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1 Why monsoon onset matters?

It is well known that most Asian countries (which include over two thirds of the world's population) are under the regime of the Asian Monsoon, as it is reflected by the dominant rainfall pattern over a wide region of Asia and its nearby oceans with its most intensive centers over the west coast of India, the northern Bay of Bengal (BoB), the western Philippines and over the northwestern Pacific Ocean (Fig.1). The Monsoons are one of the largest climate systems on earth. The inextricable relationship between the human beings and the monsoon climate persists throughout a long history and in the evolution of the local societies, cultures, religions and civilizations. Such a remarkable linkage between people and the monsoon climate attracts much attention, not only from the point of view of scientific research, but also of the human-nature interactions, particularly in the context of sustainable development. For example, Fu and Manton (2018) recently reviewed the 10-yr progress of the Monsoon Asia Integrated Regional Study (MAIRS) project, which is significantly characterized by its human-monsoon focus.

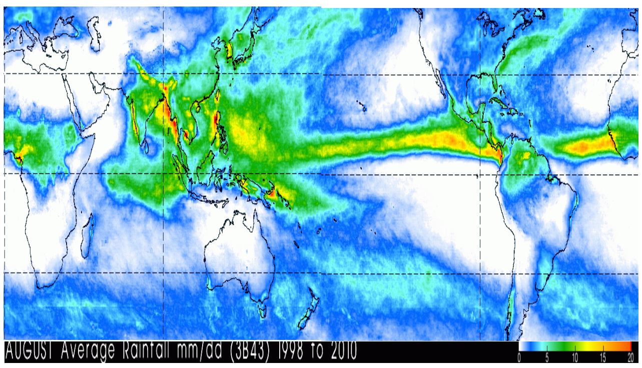

Figure 1: The mean rainfall in August over the 1998-2010 period from Tropical Rainfall Measuring Mission, TRMM (from https://pmm.nasa.gov/TRMM)

The abrupt onset is a salient feature associated with the monsoon seasonal cycle, representing the transition from dry to wet season and the dramatic change of wind direction from northeasterly to southwesterly. On the basis of the present understanding, we need to further explore the following questions: (1) through what process does the monsoon phase transition occur, particularly considering its sharp transition? (2) what is the role of the ocean in monsoon onset in addition to the established framework of the land-atmosphere interaction? (3) how the three-stage Asian monsoon onset (earliest onset over BoB, followed by South China Sea (SCS) and finally over India) is configured? On the applications side, we need to address some serious social concerns, taking into account the knowledge not only on the total monsoon rainfalls, but also on their exact starting dates, including: (1) how well can we predict the monsoon onset? (2) how much the monsoon onset varies from one year to another, and why? (3) what are the social and marine ecosystem impacts when the monsoon onset deviates from its normal date?

To tackle the above scientific questions and the relevant applications, a regional collaborative project entitled Monsoon Onset Monitoring and its Social and Ecosystem Impacts (MOMSEI) was initiated in 2009 by the Intergovernmental Oceanographic Commission (IOC) Sub-Commission for the Western Pacific (WESTPAC), as a pilot study under its Southeast Asian Global Ocean Observing System (SEAGOOS).

2. Understanding the air-sea processes associated with monsoon onset

The governing mechanisms of Asian monsoon onset have been much studied and the most relevant processes include the elevated heating and mechanical forcing of the Tibetan Plateau, the mid-latitude forcing, and the tropical low frequency forcing, as reviewed and discussed in Wu and Zhang (1998). However, some unresolved questions remain, including the role of local air-sea interaction, the mechanism behind the monsoon onset sequence, and the relative contribution between the tropical forcing and mid-latitude forcing. Within the MOMSEI framework, the oceanic preconditioning and the dominant role of tropical perturbations in triggering the monsoon onset are examined, as briefed below.

2.1 Ocean helps precondition the earliest monsoon onset over BoB

The Asian monsoon is traditionally regarded to be driven by the land-sea thermal contrast between the Asian continent and its adjacent oceans, where the Tibetan Plateau plays the dominant role as the elevated heating source (Fu and Fletcher, 1985; Li and Yanai, 1996). The observations however reveal a much more complex picture (See Fig. 2). For example, Asian monsoon's three-stage onset (Wang and Linho, 2002) is hardly to be explained based on the above conceptional framework, where the local air-sea interaction is overlooked. Even though the Arabian Sea, BoB and SCS are almost on the same latitude, the monsoon onset in those areas does exhibit a non-simultaneous pattern.

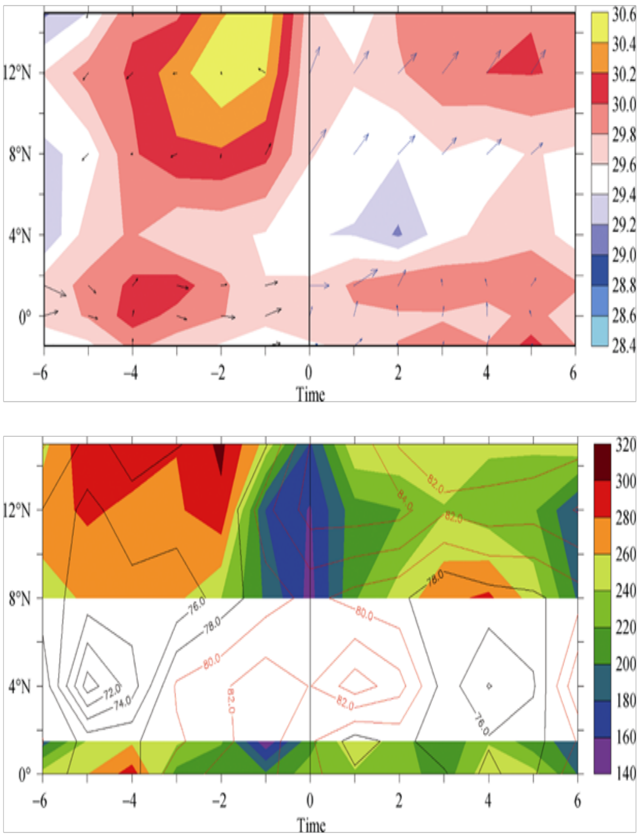

Figure 2: Composite map during the monsoon onset process along 90°E in the Bay of Bengal. Upper: SST (shaded, units: °C) and wind (vector, units: m s−1), lower: shortwave radiation (shaded, units: W m−2, blank area indicating missing data) and sea surface atmospheric relative humidity (contour, units: %, red/black contour for values over/below 80%). The horizontal axis represents the relative time (units: pentad) with reference to the monsoon onset date (time zero). (from Yu et al., 2012)

It has become clear that the local air-sea interaction helps set up the monsoon onset order. BoB SST peaks before the monsoon onset (Liu, 2009; Jiang and Li, 2011), which provides the precondition for the monsoon onset. Based on the buoy data from RAMA/IndOOS (McPhaden et al., 2009), the composite multi-variable evolution map of monsoon onset (fig.2) clearly shows the oceanic pre-condition (Yu et al., 2012). SST peaks in central BoB, followed by the northward propagation of the atmospheric convection system. It is proposed that monsoon onset over BoB is a phase-lock between local SST precondition and the first northward propagating atmospheric intra-seasonal oscillation (FNISO) (fig.3), whose structure differs from the boreal summer intra-seasonal oscillation and is identified by Li et al., 2013, thus it is clear that the monsoon onset over BoB is triggered by FNISO.

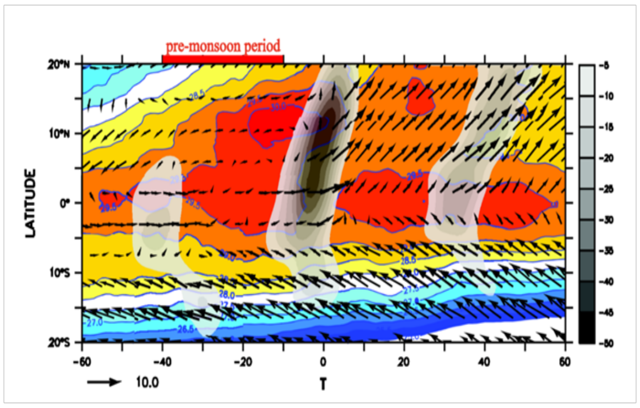

Figure 3: Composite time-latitude map of surface winds (vectors, m s−1), SST (color shading and contour, °C) and 20–70-day outgoing longwave radiation anomalies (grey shading, W m−2) averaged over 85°–95°E associated with the monsoon onset over Bay of Bengal during 1990–2009. The horizontal axis is the relative time, with day 0 representing the monsoon onset date. (from Li et al., 2015a)

2.2 Monsoon onset favors the super cyclone development

The intra-seasonal nature of monsoon onset provides the favorable time window and background environment for the BoB cyclone genesis. It has been observed (Li et al., 2013) that 5 of the 7 historical super BoB cyclones occurred during the FNISO, which triggered the monsoon onset (Fig.4). The other 2 historical super BoB cyclones occurred with the second bounce of northward propagating intra-seasonal oscillations. Diagnosis also reveals that the dominant process that anchors the super cyclones within FNISO is the mid-level moisture increase associated with the FNISO development (Li et al., 2105b).

Cyclone Nagis (2008) exhibited such kind of scale interaction between the synoptic process and intra-seasonal convection, Nagis landed on Myanmar on May 2, 2008, when the BoB monsoon was marching northward. The strong atmospheric convection background provided the optimal environment for cyclone development and finally it became a category 5 super cyclone and caused tremendous disaster in the region. The new understanding of such close linkage between cyclone and monsoon onset over BoB brings the attention to the highly risky window of extreme disaster. Not only the climate prediction, but also the weather forecast should open their eyes widely during this period.

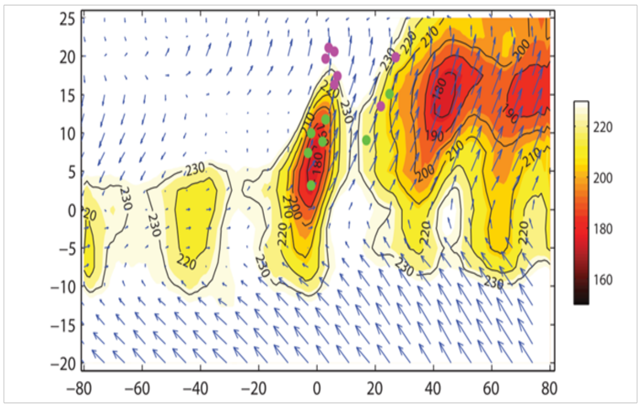

Figure 4: Composite time–latitude diagram of outgoing longwave radiation (OLR, contour and shaded, W/m2) and 850 hPa wind (vector, m/s) averaged over 80°–100°E with reference to the BoB monsoon onset. The green and purple dots indicate the genesis and peak latitudes of cyclones respectively. (from Li et al., 2013).

3. Extending monsoon onset prediction to marine ecosystem application

It is well understood from Fig.2 that the BoB SST reaches its maximum temperature before the monsoon onset and persists for about one month. Such an extreme warm ocean loads heavy thermal pressure to the marine ecosystems. Southeast Asian Seas are widely known for its rich diversity, such as coral reef. It is known that coral reef lives within some optimal temperature range, if the ocean temperature exceeds a certain threshold (i.e. 29.5°C - 30°C) and persists for too long (i.e. more than one month), the coral becomes bleached due to the expulsion of the symbiotic algae. This close relationship between ocean temperature and coral bleaching provides opportunities to extend the application of climate prediction into the marine ecosystem conservation. Learning from the coral bleaching event in 2010 (Khokiattiwong and Yu, 2012), MOMSEI tries to understand the fact that BoB usually exhibits the late monsoon onset in the El Niño decay year, which extends the persisting time of the SST warm anomalies over BoB, its adjacent seas and hence increases the thermal pressure on the coral reef. The year 2010 witnessed the significant late monsoon onset and serious coral bleaching in the Andaman Sea, which was even worse than the bleaching even in 1998.

Fig. 5 suggests that the El Niño Southern Oscillation (ENSO) delays/advances the following BoB monsoon onset during its warm/cold phase mainly through modulating the vertical wind shear over the northern Indian Ocean, which further suppresses the intra-seasonal convection activities (Li et al., 2018). Following the BoB monsoon onset conceptional model (Yu et al., 2012), i.e., the phase-lock between BoB SST precondition and the FNISO, the suppressed intra-seasonal convection activity leads to the delayed monsoon onset.

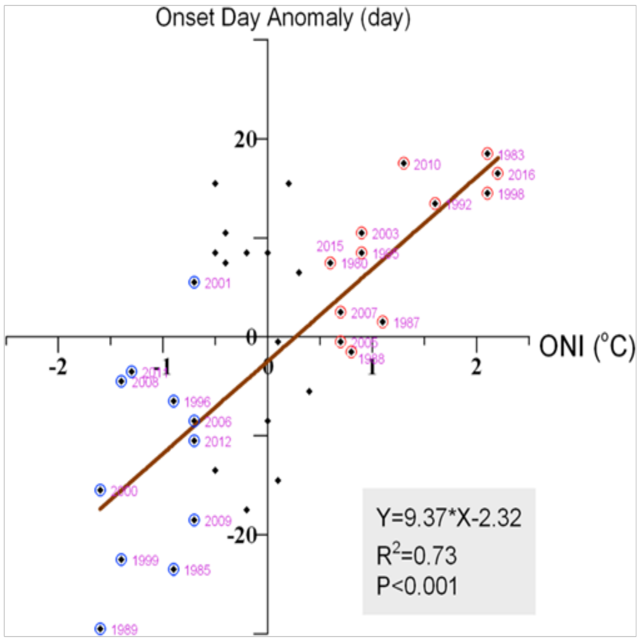

Figure 5: Composite relationship between monsoon onset anomalies and the Oceanic Nino Index (ONI) from 1979 to 2016. The linear regression of 24 ENSO years on the ONI is statistically significant above the 99.9% confidence level based on Student's t test. Warm (cold) ENSO years are indicated by red (blue) circles. (from Li et al., 2018)

4. Summary and outlook

MOMSEI has improved our understanding on the monsoon onset over the BoB region by providing the intra-seasonal view of seasonal transition. The oceanic precondition of monsoon onset is highlighted and the scale-interactions are emphasized. At the high frequency end, FNISO favors the cyclone genesis and development. At the low frequency end, ENSO modulates FNISO and hence leads to the delayed (advanced) monsoon onset following its warm (cold) phase. The late monsoon onset over BoB produces high social impacts, one of which is the massive coral bleaching.

MOMSEI is driven by the strong social requirements and its initial success demonstrates its value in setting up the knowledge chain from observation to understanding and further to the social impacts. It is clearly well taken by MOMSEI team that much is to be explored to decipher the rather complex Asian monsoon.

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Long-term trend observations in the Antarctic Ocean during the Chinese Polar Program period

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Introduction

As the coldest part of the Earth system, the Antarctic region has a significant influence on the global climate change. The Antarctic system includes a complex ecosystem with interactions among the atmosphere, ocean, land, ice, snow and living organisms. Nowadays, more and more countries pay attention to polar research to detect and interpret climate change, in order to enhance the ability of humans to adapt to those changes.

The first Chinese Antarctic Research and Expedition (CHINARE) was carried out in 1984 and the first Chinese Antarctic scientific expedition station (the Great Wall station) was constructed at the Antarctic Peninsula during that cruise. The second Chinese Antarctic station (the Zhongshan station) was constructed in 1989 in Prydz Bay and thence two kinds of investigation modes named "one ship-one station" and "one ship-two stations" were applied in CHINARE. Thus, most of the research activities carried on by China are focused around the Antarctic Peninsula and Prydz Bay stations. Different observations in physical oceanography, meteorology, geology, biology, glaciology and space physics have been carried out gradually in Chinese Antarctic research. During 2007-2008, China implemented the Prydz Bay-Amery ice shelf and Dome A(PANDA)observational plan which was one of the key plans in the International Polar Year (IPY) programme, in this way CHINARE has played an important role in the international polar programmes.

Chinese oceanic science in the Antarctic started from scratch and has been developing gradually in the last 30 years. Chinese Antarctic research in physical oceanography and meteorology made obviously progress and got some fundamental results in several aspects. For example, multiple observational data of temperature, salinity and current in the Southern Ocean (SO) were obtained. The accumulated CTD section data over 20 years in Prydz Bay is the most all-sided data sets in this region and basal structures of water mass and circulation in Prydz Bay and Antarctic Peninsula as well as their adjacent areas have been recognized; the structure and variability of oceanic fronts along the cross sections in the Antarctic Circumpolar Current region were studied based on observations and remote sensing data; model projections had been used in the Prydz Bay and the whole SO.

However, until a few years ago, Chinese Antarctic research was still weak compared to well-developed countries in polar science, such as United States of America, Russia, Japan and Australia. Some problems restricted our development in polar research in the past, including: lack of specific objectives in the initial design; feeble ability in macro-control; scattered and random observations; few scientific papers at high impact journals; small and unstable research team; lack in shipping time, etc. This situation meliorated when the Chinese Polar Environment Comprehensive Investigation and Assessment Program began in 2011.

Chinese Polar Program

The Chinese Polar Program was set up initially for a seven year period, it was established with the goal of detecting environmental changes in the Antarctic Ocean and studying interactions in the Ice-Ocean-Atmosphere system, shedding light on the Antarctic bottom water formation and transport, overturning circulation, providing services for research on global climate changes, resources exploitation and utilization, and environmental estimation, it provided the platform for the first comprehensive large-scale polar research in China. Aspects such as subjects, team size, observational area and instruments were highly improved. Seven Antarctic cruises (28th-34th) were carried out during 2011-2018, with emphasis areas around Prydz Bay and the Antarctic Peninsula. Those were signs that Chinese polar research was becoming a general and systemic business work.

Various observations were used to detect the variation and long-term trend of ocean, atmosphere and sea ice in recent cruises. Section observations in crucial region, cross section observations in the SO and long-term observations were the three basal kinds of modes used in the Antarctic investigation. Observations during the 28th, 30th, 32nd and 34thexpedition were performed in the northwestern Weddell Sea, east of the Antarctic Peninsula. New 911plus CTD equipped with with double sensors were used for the first time onboard the R/V Xuelong during the 28th CHINARE, improving data accuracy and quality, while direct micro-structure measurements were performed for the first time in the 30th cruise. The investigation around Antarctic Peninsula in the largest scale ever was carried on during this cruise. Based on data collected from cruises, Antarctic bottom water export from Weddell Sea can be estimated precisely and energy dissipation and exchange processes can be illustrated. Relative warm water observed in the Powell Basin is named Weddell Deep Water (WDW) or Warm Deep Water (WDW). Weddell Sea is one of the most important formation regions of Antarctic Bottom Water (AABW). Weddell Bottom Water (WBW) and Bransfield Strait Bottom Water (BSBW) are the two main AABWs around this region (Figure 1). As for Prydz Bay, characterized by a broad shelf and the existence of Amery Ice Shelf, direct observations conducted during the 29th, 31stand 33rd cruises aimed at finding potential bottom water formation, cross shelf water exchanges and ocean-ice shelf interaction. From the data collected it was observed that the water masses present in Prydz Bay mainly contain relative warm and fresh Antarctic Summer Surface Water (AASSW) and Antarctic Winter Water (WW) in the upper layer, relative warmer Circumpolar Deep Water (CDW) in the deep layer, salty and dense Antarctic Bottom Water (AABW) in the bottom layer, regional Shelf Water (SW) on the continental shelf, relative saltiest High Salinity Shelf Water (HSSW) and relative coldest Ice Shelf Water (ISW) formed near the Amery Ice Shelf (AIS) (Figure 2). These three cruises are the largest scale investigation in Prydz Bay ever implemented, and the former was set up as the first official cruise for the Chinese Polar Program. Based on these observational data in Prydz Bay, several aspects have been conducted, involving dense shelf water export and its contribution to bottom water formation, decadal changes of shelf water properties (compared to the historical data) and 3-D structure circulation in Prydz Bay.

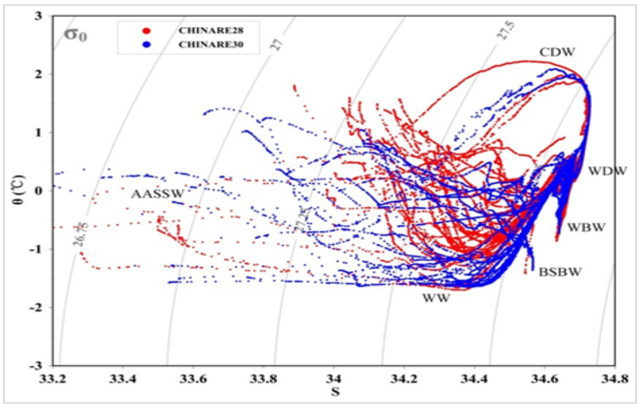

Figure 1: θ-S diagram based on CTD profiles around the Antarctic Peninsula obtained by the 28th and 30th CHINARE.

The Chinese government has given much more importance and support to polar science in recent years. Those seven cruises (28th-34th) laid the foundation for future Antarctic science development in China and will make a contribution for international cooperation on Antarctic research in the years to come.

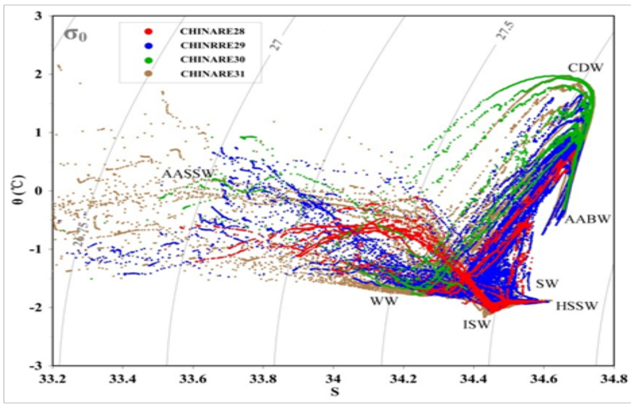

Figure 2: θ-Sdiagram based on CTD profiles in Prydz Bay obtained by the 28th-31st CHINARE.

Primary results

Many aspects of CHNIARE have been highly improved during the Chinese Polar Programs period. Using extensive observations as well as other data collected, Chinese scientists have got some new recognitions and results in the Antarctic physical oceanography and meteorology. Some representative improvements and primary results include: (1) The observational area, object, technique, and instruments used in the Antarctic physical oceanography and meteorology have been highly improved (Gao et al., 2016). (2) The standardization and stabilization of mooring observational system provide new insights in ocean circulation and variability of water mass around the Antarctic continental shelf and slope (Willianms et al., 2016; Shi et al., 2016). (3) Meteorological observations played a key role in the international rescue, when Russian vessel Akademik Shokalskiy and R/V Xuelong were trapped in the Commonwealth Bay in January 2014 (Zhang et al., 2014). (4) Using observational data collected south of Tasmania during 14 austral summer cruises in the period 1993-2011, the response of sea surface fugacity of carbon dioxide to the Southern Annular Mode shift were examined (Xue et al., 2015). (5) Historical surface drifter observations collected from the Southern Ocean are used to study the near-surface structure, variability, and energy characteristics of the Antarctic Circumpolar Current (Gao et al., 2013). (6) The application of new methods in our long-term observation such as elephant seals instrumented with CTD enriches seasonal data in the Antarctic. (7) Drifting buoy, LADCP, CTD and mooring measurements provided a deeper insight in 3-D circulation in Prydz Bay. (8) The new Chinese Polar Program promotes the development of multi-discipline research involving Physical Oceanography, Biology, Chemistry, and Geology. (9) Using Argo observations to assess changes in thickness, depth and heat content of the Subantarctic Mode Water (SAMW) layer. And highlighted that model projected increases in wind stress curl would drive further deepening of SAMW and increase in heat storage in the southern hemisphere oceans (Gao et al., 2018).

Six overarching challenges in Antarctic and Southern Ocean science were identified by the Southern Ocean Observing System (SOOS) report (Rintoul et al., 2012): freshwater and heat balance, overturning circulation stability, ice sheet melt and sea level rise, future of sea ice, carbon and biogeochemistry, and impact on ecosystems. These scientific challenges need an integrated international network of various platforms and techniques, such as CTD/LADCP sections, Argo floats, underway measurements, animal-borne sensors, gliders, and ice tethered platforms. The Chinese Polar Program provided the first comprehensive polar investigation in large-scale for China. All the subjects, team size, observational area and instruments in the polar science were highly improved. Chinese Antarctic expedition works as a part of integrated observing system in the southern ocean and make its specific contribution to monitoring environmental changes in Antarctic regions.

Advice and prospect

Chinese Antarctic research has been highly successful in recent years, which was largely due to the systemic and efficient organization. Here a few experience and advices are summarized, which should be considered for future work:(1)All the Antarctic cruises of CHINARE were organized during the austral summer, with too much material transportation works. We would better try to attend austral winter cruise via international cooperation or hiring other research vessel, in order to achieve more observations during the cold season. (2) Under the situation of lacking shipping time and sparse data sets in the SO, we advise to enhance the long-term and new kind observations, such as buoy, mooring array, Seal sensor and AUV, to increase the spatial and temporal series of Antarctic data. (3) Although some Chinese outstanding oceanographers focus on polar research, we still run short of talent, especially early career scientists in physical oceanography and meteorology. We should encourage more and more young scientists to attend CHINARE, and contribute their strength to the polar enterprise. (4) More Chinese scientists should work hard and join the international ongoing efforts. The linked scientific achievements will get Chinese scientists and international cooperators a better access for future research opportunities.

There are ample opportunities for collaboration in the future, especially with the Southern Ocean Region Panel (SORP) of the Climate and Ocean - Variability, Predictability and Change (CLIVAR), core project of the World Climate Research Programme.

Acknowledgements

This work was supported by the National Key R&D Program of China (2018YFA0605701), the Basic Scientific Fund for National Public Research Institutes of China (2018S02), and the NSFC grants (41876231, 41706220, U1606405).

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Dynamics of the North Pacific Intermediate Water during the last glaciation

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Introduction

The global meridional ocean circulation (MOC) is a crucial player in controlling climate changes through regulating the redistributions of heat, salinity, CO2 and freshwater in the global ocean. Only limited sites are favorable for deepwater formation in the world ocean, including the Nordic Sea, Labrador Sea, Ross Sea and Weddell Sea. Under the influence of various unfavorable factors, including low evaporation and net influx of freshwater caused by summer East Asian Monsoon and moisture transfer from the Atlantic to Pacific (Broecker, 1989; Emile-Geay et al., 2003), the surface salinity of high North Pacific is markedly lower than that of the North Atlantic, which inhibits the formation of deep water in the North Pacific (Talley, 1993). In this scenario, a intermediate-depth water mass with low salinity is formed in the marginal seas of northwestern North Pacific. However, the past variations in North Pacific Intermediate Water (NPIW), including its source regions, ventilation and intensity, pathway, remain elusive over glacial cycles.

The instrumental data show that a low-salinity water mass, the NPIW, widely spreads in the subtropic Pacific at a water depth of 300-800 m, which is deduced to derive from the continental margins of high-latitude North Pacific (Sea of Okhotsk and Alaska Gulf) during the formation of sea ice in winter season(Talley, 1993; You et al., 2000). The modern state of NPIW is characterized by low salinity (33.8) and low density (26.4-27.2 sigma). Moreover, the NPIW contains also abundant dissolved iron derived from the Sea of Okhotsk and the pronounced silicate and phosphate, which has significant impacts on marine ecosystem along its downstream.

Source and nature of modern NPIW

Being an important component of global MOC, the low-density NPIW is believed to originate mainly from the Sea of Okhotsk (Talley, 1993). Subsequently, You et al. (2000) found Alaska Bay also made a bit contributions to the formation of NPIW. On the basis of direct hydrological observation in the polynyas of the northwestern Sea of Okhotsk, Shcherbina et al. (2003) concluded that the dense shelf water produced through brine rejection is the precursor of NPIW, which corroborates previous inference (Talley, 1993). Furthermore, Itou et al. (2003) suggested that the NPIW consists of three distinctive water masses with different density (the dense shelf water from the Sea of Okhotsk, the western subarctic Pacific waters and the warm waters from the Sea of Japan). These three different water masses are fully mixed and then spread toward the south along the isopycnal surface. You (2003) argued that there is no shortcut in extending southward for NPIW, but moving eastward to the East Pacific and gradually sinking along the boundary between the subarctic and subtropic Pacific and eventually returning back to the western Pacific (Figure 1). This indicates that the climatic signals of high-latitude northern Pacific can propagate into mid- and low-latitude areas through this oceanic tunnel, NPIW. However, nowadays the spatial distribution of NPIW in the eastern and western Pacific is asymmetrical. NPIW can enter the Celebes Sea in the western Pacific, whereas it dominates in the subtropic eastern North Pacific.

Due to the modern low-salinity lid and permanent halocline stratification of the subarctic North Pacific, NPIW cannot outcrop in the surface subarctic Pacific ocean. As a consequence, both eastern and western margins of the North Pacific and tropical Pacific are potential regions for upwelling of the NPIW. Given abundant nutrients carried by the NPIW, it is reasonable to deduce that the NPIW plays a significant role in shaping nutrient- and carbon- dependent marine ecosystem at its downstream. Some unique phenomena have been reported and it may be related to the ventilation of NPIW, such as occurrence of oxygen minimum zone in the eastern North Pacific (Schmidtko et al., 2017) and CO2 efflux to the atmosphere in the South China Sea (Dai et al., 2013). However, further studies are needed to elucidate the role of NPIW in shaping regional marine ecosystem and climatic changes.

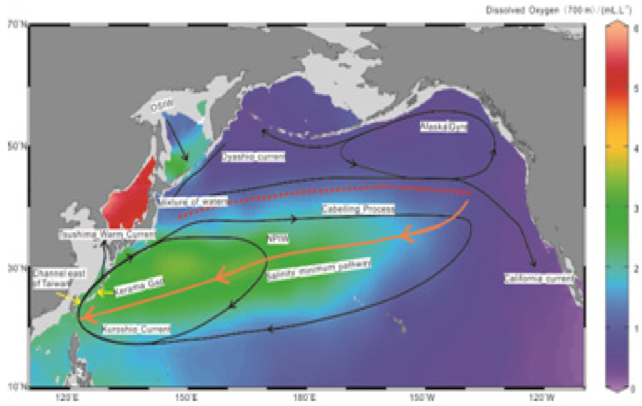

Figure 1: Schematic map of surface oceanic circulation in the North Pacific and North Pacific Intermediate Water, superimposing on the distribution of dissolved oxygen concentration at a water depth of 700m

Variations in formation source and ventilation of the glacial NPIW

The source region of the NPIW varies at orbital and millennial timescales. Today, NPIW is mainly originated from the Sea of Okhotsk, but high abundances of radiolarian species (C.davisiana) during the last glacial maximum suggests intensified ventilation, which was caused by the displacement of the formation source of the NPIW to the Bering Sea (Ohkushi et al., 2003). Subsequently, observations of radiogenic neodymium isotopes in Fe-Mn oxyhydroxides of the Bering Sea sediments at the intermediate depth during glacial periods was explained by subduction of the surface water off northeastern Kamchatka to the intermediate depth due to brine rejection (Horikawa et al., 2010). The gradients of carbon and oxygen isotopes of foraminifera between the Okhotsk and the Bering seas also are invoked to indicate that active formation of NPIW also occurred in the Bering Sea during the last glacial and stadials (Rella et al., 2012).

Intensified ventilation in NPIW has been widely reported during the last glacial period. Higher δ13C of benthic foraminifera suggests well ventilated water occurred at adeeper-water depth of 1500-2300 m during the glacial period than that of present day (Keigwin, 1998; Matsumoto et al., 2002). Concentrations of sedimentary redox sensitive elements (Mo, U and Mn) in cores retrieved from the North Pacific also recorded dramatic changes in bottom water oxygen related to ventilation in NPIW during the last deglaciation (Jaccard and Galbraith, 2012; Jaccard and Galbraith, 2013) and pointed out that the maximum penetration depth of NPIW is less than 2300 m during Heinrich Stadial 1 (Jaccard and Galbraith, 2013; Max et al., 2014). However, other studies suggest much deeper penetration of NPIW during the early deglaciation (Okazaki et al., 2010; Rae et al., 2014). Using a combination of paired radiocarbon ventilation age records with model simulation, Okazaki et al. (2010) suggested that deep water extending to a depth of ~2500 to 3000 meters was formed in the North Pacific. Subsequently, Rae et al. (2014) provided the first evidence of local deep water formation to 3600 m in the North Pacific using paired radiocarbon and boron isotope data from foraminifera. If these observations are correct, it means that the North Pacific played a more crucial role in regulating poleward oceanic heat transport, thus global climate than previous thought during the period of weakening or collapse of the Atlantic Meridional Overturning Circulation (AMOC).

During the warming period of the last deglaciation, Bolling-Allerod (B-A, 14.7-12.9 ka), several lines of evidence indicate the presence of a weakened NPIW, which was coeval with peak in productivity and intensified Oxygen Minimum Zone (OMZ) in the North Pacific (Cartapanis et al., 2012; Crusius et al., 2004). However, recent studies noted that, besides for the NPIW, intensified wind-driven upwelling due to the presence of large ice sheets over North America during the B-A can result in enhanced productivity and OMZ intensification (Gray et al., 2018). During the last deglaciation, an increase in atmospheric CO2 is deemed as a main driver in pushing the climate out of the glacial state. CO2-rich deepwater upwelling in the subarctic Pacific would contribute to deglacial CO2 rise (Jaccard and Galbraith, 2018).

The far-reaching impacts of NPIW's variation on marine environment downstream and far away from its formation areas is also evidenced. Several records from the northeastern Pacific showed that the presence of laminated layers results mainly from suppressed NPIW and enhanced export productivity during the deglacial warming intervals (Crusius et al., 2004; Jaccard and Galbraith, 2012). Both redox sensitive elements and benthic planktic assemblage and benthic foraminiferal d13C in sediments from the Okinawa Trough also indicate coupling changes between the concentrations of sedimentary oxygenation and the intensity of NPIW (Jian et al., 1996; Li et al., 2005). Likewise, reduced export productivity on millennial time scales over the last 90 thousand years thousand years ago (ka) recorded in the middle Okinawa Trough was attributed to subdued supply from the deep water upwelling duo to increased penetration of NPIW (Li et al., 2017). Sedimentary magnetic properties in the northern South China Sea indicated an increased intensity in deep current during the Younger Dryas (YD) and Heinrich Stadial 1(HS1) (Zheng et al., 2016), which is also related to enhanced formation of NPIW at that time. A similarity between foraminiferal δ13C records from the Bering Sea and the Eastern Tropic Pacific indicates that past changes in northern component waters could have exerted additional impacts on glacial nutrient availability and biological productivity in the tropical Pacific (Max et al., 2017). All these lines of evidence suggest a crucial role of NPIW under glacial boundary in shaping basin-scale environment variations and marine ecosystem.

Links between the NPIW and AMOC

AMOC is regarded as one of main drivers in triggering millennial-scale climate oscillations during the last glacial period (Broecker, 1998). However, both proxy-based and model simulations results indicate slowdown or collapse of the AMOC during HS1 and the YD due to freshwater input from icebergs into the northern North Atlantic (McManus et al., 2004). Intensified deep convection occurred in the North Pacific Ocean during these periods, which could be responsible for the poleward heat transport. However, reconstructions of sea surface temperature and sea ice in the subarctic western Pacific show prominent cooling and expanded sea ice cover during these cold intervals (Max et al., 2012), ruling out any significant northward heat transport in the Pacific Ocean at this time.

Several studies have revealed an out-of-phase relationship between NPIW's ventilation and AMOC's intensity. However, it is not clear how the AMOC's intensity influence the changes in ventilation of NPIW. The formation of NPIW is constrained by several factors, such as sea surface temperature, sea surface density and sea ice coverage in the marginal seas of high-latitude North Pacific. Previous studies reported that a weakened AMOC could result in reduced northward transport of heat, cooling North hemisphere and increased sea ice cover (Lynch-Stieglitz, 2017). The subsequent consequences led to variations in position and strength of the Aleutian Low and Siberian High, thus promoting the expansion of sea ice coverage in the Bering Sea (Okumura et al., 2009), and ultimately strengthening the formation of NPIW. An intrinsic connection between the formation of NPIW and the intensity of AMOC thus can be established through atmospheric teleconnection.

On the other hand, accompanied by a weakened AMOC, the Intertropical Convergence Zone (ITCZ) would shift southward, which decreases the intensity of summer East Asian Monsoon and resultant precipitation over the North Pacific. Likewise, decreased net moisture transport from the Atlantic to the Pacific via Isthmus of Panama also occur. Both these processes could enhance sea surface salinity in the tropical and subtropical Pacific. This process has been confirmed by the reconstruction of sea surface salinity using planktic foraminiferal δ18O in the subtropic area (Rodríguez-Sanz et al., 2013). Along with the weakening of the AMOC, strengthened Pacific Meridional Ocean Circulation (PMOC) would inevitably bring low-latitude high-saline waters to high latitude oceans, increase sea surface salinity and promote the formation of NPIW.

Model simulations also suggest that the closure of the Bering Strait would increase the salinity in the North Atlantic and reduce the salinity in the North Pacific, inducing a Pacific-Atlantic seesaw in meridional overturning circulation (Hu et al., 2010; Saenko et al., 2004). However, a recent proxy-based study using foraminiferal δ18O and δ13C reveal an enhanced formation of NPIW during extreme glacial period but fail to recur an orbital-scale Pacific-Atlantic seesaw (Knudson and Ravelo, 2015) that was predicted in the model simulation. This study further noted that the closure of the Bering Sea could affect the wind direction, brine rejection and the location of Aleutian Low, which in turn is favorable for NPIW's formation (Knudson and Ravelo, 2015).

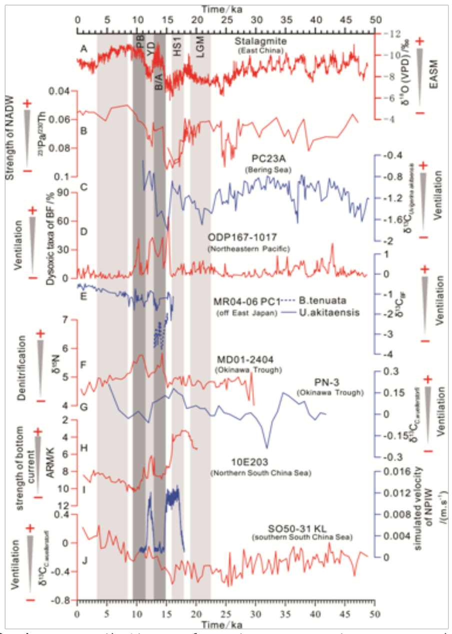

Figure 2: A compilation of various proxies recorded in the North Pacific indicating ventilation variation at mid-depth and compared to the strength of East Asian Summer Monsoon (Wang et al., 2001) and North Atlantic Deep Water (McManus et al., 2004).

Links between high- and low-latitude through NPIW and East Asian Monsoon

The intense seasonal temperature contrast between sea and land shapes the unique Asian monsoon system, namely the summer and winter East Asian Monsoon (EAM). The summer EAM carries large amounts of water vapor from the low-latitude oceans to the hinterland of Asia, and controls the amount of runoff that is delivered into the sea. Previous studies have revealed that increased discharge of Amur River into the Sea of Okhotsk not only reduces the formation of sea ice in the Sea of Okhotsk in the coming year, but also transfers a large amount of dissolved and particle matters to the Sea of Okhotsk. The observational data in the open sea of the western subarctic Pacific show that NPIW contains high concentrations of dissolved Fe, and it is speculated that it may be related to the input of Sea of Okhotsk Intermediate Water(Nishioka et al., 2014).

During the B-A warm period with enhanced summer EAM (Wang et al., 2001) and melting frozen soil (Crichton et al., 2016), the delivery of nutrients and Fe buried through Amur River into the Sea of Okhotsk would have increased significantly, which would exert an important effect on maintaining the productivity blooms of the subarctic Pacific and suppressed ventilation of NPIW. Synchronously, reduced formation of NPIW can inhibit the supply of nutrients from NPIW to mid- and low-latitude oceans. This feedback loop is also applicable during the cold glacial interval, but in an opposite way. Thus a feedback loop between the NPIW and summer EAM and a coupling process between high- and low- latitudes could be established.

Summary and Outlook

As an important component of global overturning circulation, the NPIW is widely distributed in the subtropic Pacific and is characterized by low salinity, high nutrients and oxygen. During the stadial and glacial periods, the source of NPIW with enhanced intensity is assumed to be derived mainly from the Bering Sea. In particular, the signal of enhanced NPIW can be detected in distant low-latitude oceans at extreme cold intervals, such as the eastern tropic Pacific, South China Sea, etc. During the warm period, weakened NPIW formation can facilitate the expansion of a Minimum Oxygen Zone in the Northern Pacific and enhanced export productivity. The variations in ventilation, penetration depth and formation region of NPIW over glacial cycles are closely related to the intensity of AMOC. A general feedback loop between high- and low-latitude climate process through summer East Asian Monsoon and NPIW can be established. All lines of evidence suggest the crucial role of NPIW in regulating regional environment and global climate at a degree higher than previously thought.

Although a great body of research has been done on the evolution of NPIW on orbital and millennial timescales, there are still many issues to be resolved for NPIW in the development of research approaches, observation and mechanistic understanding and its environmental and climatic effects. Some aspects for future research of NPIW are needed to draw attention, which are summarized as follows:

(1) Development of new proxies for the reconstruction of NPIW. Due to shallow carbonate compensation depth in the North Pacific, traditional proxies related with carbonate shells used for reconstruction of subsurface water are facing challenge. It is thus urgent to develop new proxies to reconstruct past variation of NPIW in future studies.

(2) Response of NPIW to regional environment and global climate. Specific questions include: What is the timing of NPIW variations? Is there a deep water formation in the North Pacific? Where was the southern boundary of the impacts of NPIW during the Ice age? How does the state of NPIW, such as ventilation, formation area, intensity and expansion pathways, respond to regional and global climate changes on orbital and millennial time scales? What causes such variations of NPIW?

(3) The role of NPIW variation in regional environment and global climate: What role does the NPIW play in atmospheric CO2 fluctuations under different climatic states? What is the effect of NPIW ventilation on the environment of its downstream? What is the effect of the change in the nature of the NPIW on the process of the nutrients biogeochemical cycles?

To comprehensive understand the dynamics of NPIW and its effects, we need an international cooperation because the NPIW dominates vast areas covering the whole North Pacific, from the Bering Sea to the tropic Pacific and from NW Pacific to the Eastern Tropic Pacific. Moreover, a combination of proxy-based observation and model simulation is inevitable to enhance our understanding of the dynamics and roles of NPIW.

Acknowledgments

Financial support was provided by the National Program on Global Change and Air-Sea Interaction (GASI-GEOGE-04), by the National Natural Science Foundation of China (Grant Nos.: 41476056, 41876065, U1606401) and by the Basic Scientific Fund for National Public Research Institutes of China (No.2016Q09) and Taishan Scholars Program of Shandong.

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Introduction of the UNESCO/IOC Regional Training and Research Center on Ocean Dynamics and Climate (UNESCO/IOC-ODC)

Xunqiang Yin[1]

1. The First Institute of Oceanography, State Oceanic Administration, China

Introduction

The Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (UNESCO/IOC) Regional Training and Research Center (RTRC) on Ocean Dynamics and Climate (ODC) was officially established through one agreement signed by IOC and the host institute, the First Institute of Oceanography, State Oceanic Administration (FIO, SOA) of China at the Eighth Intergovernmental Session of UNESCO/IOC Sub-Commission for the Western Pacific (WESTPAC-VIII) in Bali, Indonesia on 11 May 2010. And it was officially inaugurated on 9 June 2011 in Qingdao. ODC center is the first RTRC and also the first training and research center under the framework of IOC in China, the cooperation agreement with the work plan for 2015-2020 has been renewed in 2015. ODC center aims to promote the international cooperation and enhance the research capacity and capability in WESTPAC region on ocean dynamics, air-sea interactions, climate change and numerical modeling through the provisions of international workshops and annual training courses to junior scientists and doctoral/master students mainly from the developing member states of IOC in the Western Pacific.

ODC center is hosted by the First Institute of Oceanography (FIO) and has established a Scientific Committee, Administration Department and Technique Support to ensure the daily operation. Professor Fangli Qiao, Secretary General and Deputy Director General of FIO, serves the ODC center as the Director, and Dr. Xunqiang Yin from FIO, serves as the Deputy Director. The Scientific Committee is composed of well-known experts and scholars in the field.

Since its inauguration in 2011, ODC center has organized eight training courses with the subjects of Ocean Models (10-16 June 2011); Ocean Dynamics (16-22 July 2012); Air-Sea Interaction and Modeling (12-23 August 2013); Climate Models (3-14 November 2014); Climate Change (7-18 September 2015); Ocean Dynamics and Multi-scales Interaction (5-16 September 2016); Development of Coupled Regional Ocean Models (12-23 June 2017) and Ocean Forecast System (25 June-7 July 2018). Till now, a total of 359 young scientists from 43 countries have participated in these training courses and acquired valuable knowledge from famous experts worldwide.

Figure 1: Inauguration of ODC center in FIO on 9 June 2011

Training activities

Training course and practice

ODC center is built to provide advanced training and education for young scientists, to promote cooperation among experts and trainees within and outside regional ocean research, and to initiate cutting-edge research on ocean and climate model development, in the following, we briefly describe the eight training courses that ODCCenter has hosted in Qingdao:

The first training course on Ocean Models; June, 2011

The first ODC training course was focused on ocean models and covered the basic concepts of numerical modeling in ocean and atmosphere, the application of MPI in Princeton Ocean Model (POM), ocean data

Figure 2: Organizational structure of ODC center

assimilation, the grid system of ocean models, wetting and drying algorithms and the tutorial of POM, the three-dimensional wave-current coupled sediment transport model, modeling of marine ecosystems and carbon cycle, Lagrangian particle trajectory and individual-based biophysical models, air-sea interactions, wave-tide-circulation coupled models and the modeling of estuarine circulation. Ten world-leading ocean scientists on ocean numerical model were invited to provide lecturers to 69 trainees from Australia, Indonesia, Korea, Malaysia, Peru, Russia, Thailand, Vietnam, United States and China.

The second training course on Ocean Dynamics; July, 2012

Seven lecturers from United States and China participated in this course. The topics included small scale dynamics and ocean model introduction, wave-circulation interaction and its application, large-scale ocean dynamics, carbon cycle and marine ecosystem, ocean-atmosphere interaction, ENSO and impacts of climate on extreme events, introduction of adaptive data analysis methods, and mesoscale ocean dynamics based on satellite Data; 67 trainees from Russia, Korea, DPR Korea, Japan, Qatar, India, Thailand, Vietnam, Singapore, Malaysia, Indonesia, Mauritius, Peru, Cambodia and China attended this training course.

The third training course on Air-Sea Interaction and Modeling; August, 2013

For this course, following suggestions from trainees and IOC/WESTAPC, the training course was extended to two weeks. Five outstanding scientists of climate and modeling were invited as lecturers, three from United States and two from China. Their lectures contained interdisciplinary information and knowledge: the ensemble empirical mode decomposition methods and applications, atmosphere-ocean interaction processes and the inter-annual variability of monsoon, intraseasonal variability of the ocean, the development of new ocean and climate models and applications to operational ocean forecast system, and sea surface wave dynamics and applications to the coupled atmosphere-wave-ocean modeling system. There were fewer trainees (33) compared to the previous two training courses. However, the number of countries that participated in the training course (15) was similar to the previous courses: Cameroon, DPR Korea, Ecuador, Egypt, Indonesia, Iran, Malaysia, Myanmar, Pakistan, Republic of Korea, Sri Lanka, Thailand, Turkey, Vietnam and China.

The fourth training course on Climate Models; November, 2014

This training course invited 7 lecturers and focused on climate models, and covered the climate prediction and large-scale features associated with long-term changes in Asian monsoon and ENSO, ocean models and AR5-related research activities, the key roles of surface wave in ocean and climate systems, land surface processes and modeling, the evaluation of climate models, the earth system model and data assimilation in ocean and climate models. There were 35 trainees from 13 countries (Ecuador, Indonesia, Korea, Malaysia, Myanmar, Nigeria, Ni-Vanuatu, Pakistan, Philippine, Sri Lanka, Thailand, Vietnam and China).

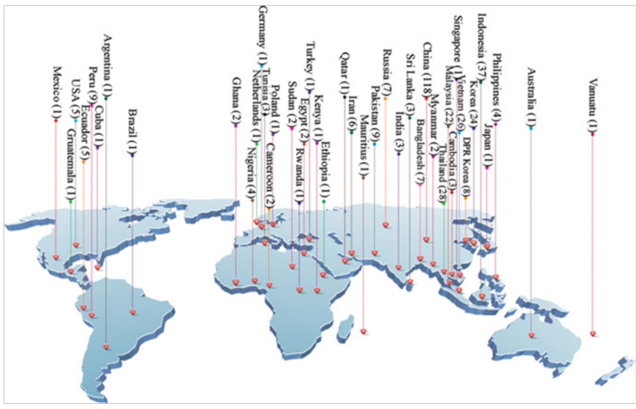

Figure 3 : Geo-distribution of trainees during 2011-2018

The fifth training course on Climate Change; September, 2015

This training course focused on Climate Change and included topics on the role of wind waves in modulating the fluxes between ocean and atmosphere, the essential effects of surface waves in climate system, the monsoon under climate change, climate variability and change in the tropics, Land-climate interactions, the MOC circulation: its representation in climate models and the role of mesoscale and submesoscale variability, and the sea level changes and its projections. ODC center invited 7 lecturers from Germany, Italy, United States and China to deliver lectures to 35 trainees from 16 countries (Bangladesh, Cambodia, DPR Korea, Ghana, Indonesia, Iran, Japan, Korea, Malaysia, Nigeria, Peru, Sudan, Thailand, Tunisia, Vietnam and China).

The sixth training course on Ocean Dynamics and Multi-scales Interaction; September, 2016

This training course invited seven professors from United States and China to give lectures on basic knowledge of ocean dynamics, the interaction of wave-tide-circulation and application in upwelling system of coast areas, Rossby/Kelvin waves and meso-scale eddies from Deep Ocean to marginal seas, and the background, laboratory experiments and in situ observations of Surface Wave-induced mixing. 37 trainees from 16 countries (Bangladesh, Cambodia, Ecuador, Ghana, India, Indonesia, Iran, Korea, Malaysia, Pakistan, Peru, Sudan, Thailand, Tunisia, Vietnam and China) attended this training course.

The seventh training course on Air-Sea Interaction and Modeling; June, 2017

The topic of this training course was the development of coupled regional ocean models. The training course introduced the knowledge on the issues associated with regional ocean models and demonstrations of various tools to help setting up and running tools, the ocean circulation model and turbulence, the transport of sediment and transport of contaminants and coupling of biota, hydrodynamics and sediments in regional models, physics and fundamentals of regional ocean modeling and modeling ocean circulation and ecosystem in the South East Asia Seas, wave-tide-circulation coupling theory and application in regional ocean models, ocean model development and applications based on FESOM, and history of surface wave model development. Seven professors from Italy, German, Ukraine, United States and China were invited to deliver lectures, 36 trainees from 16 countries (Bangladesh, DPR Korea, Indonesia, Iran, Korea, Malaysia, Nigeria, Pakistan, Peru, Philippines, Russia, Rwanda, Thailand, Tunisia, Vietnam and China) attended.

The eighth training course on Air-Sea Interaction and Modeling; July, 2018

The course covered all the components of the ocean forecast system, including circulation, tide, wave models and their coupling in coastal regions, data assimilation and the interpretation of the forecasted results. This training course was organized back to back with the first CLIVAR-FIO summer school on past, present and future sea level changes. Fourteen experts from Australia, France, German, Italy, UK and China were invited to provide lectures and related practices. There were 47 trainees from 27 countries (Argentina, Bangladesh, Brazil, Cameroon, Cuba, Ecuador, Egypt, Ethiopia, Germany, Guatemala, India, Indonesia, Iran, Kenya, Korea, Malaysia, Mexico, Netherlands, Nigeria, Pakistan, Philippines, Polish, Russia, Sri Lankan, Thailand, United States, Vietnam and China).

Other activities related to training courses

ODC center introduced practical activities in 2013 as homework and decided to do some hand-on practice during the class since 2016. The time of practice in class has been gradually increased every year. In 2018, the time of practice was approximately equal to that of lectures. The practices have included topics like particle trajectories, 1D-model and Ekman layer, harmonic analysis and tidal prediction and 2D model and tides, in situ observations and methods of related data analysis, visualization of results from regional ocean forecast, a global model simulation, and date assimilation in regional ocean forecast model. Through these training, the trainees could initially grasp how to use some basic software which would be useful for their future career. In order to effectively promote cooperation, ODC center strives to establish a stage for experts to share brilliant scientific ideas and points of view, and an open platform for young scientists to explore ocean and climate. To that end, trainee reports, group discussions and group reports have been implemented.

Figure 4 : Participants from the Different Training courses

(1) Trainee report
All the trainees are required to give a presentation that covers their main research focus, their institutions' work areas and preliminary ideas for cooperation with other countries in the region. The trainee report contributes to establishing a research network and identifying possible areas of cooperation among the trainees.

(2) Group discussion and group report
To provide more chances for the trainees to work together and to share prospective ideas with each other, all the trainees are divided into several groups. A group leader and a secretary is elected from each group with the tasks to help ODC center conduct their respective group discussions and prepare group reports. Trainees in each group need to complete their homework together during the group discussion. In addition, a conclusion report, which summarizes the knowledge trainees have learnt from the training course, results of trainees' assignments and suggestions for the cooperation in the future, is to be finished before the end of the training course. These activities have created a pleasant learning environment and provided more opportunities for trainees and experts to communicate.

(3) Best Trainee Award
Trainees who have successfully completed this training course were issued a certification during the completion ceremony. The group leaders and group secretaries were also issued a special certification because of their great contributions to this training course. Additionally, 3-4 trainees were issued the Best Trainee Award every year based on their performance at the end of the training course.

Research activities
ODC center has also conducted several international workshops and joint researches, such as the international forum on the Role of the Oceans in Multi-decadal climate Variability in 2013, the joint WCRP/CLIVAR and IOC/WESTPAC workshop on Advancing Ocean Climate Observation and Studies in the Indo-Pacific in 2016, the joint research on Sri Lanka Regional Ocean Modeling in 2017, and the joint research with University Malaysia Terengganu on the Marine Environment Numerical Prediction and Research in Malaysian Seas in 2018.

Joint workshops

- On the occasion of the 5th training course, a joint workshop between WCRP/CLIVAR and IOC/WESTPAC was held. It focused on "Advancing Ocean Climate Observation and Studies in the Indo-Pacific" and aimed to take stock of previous achievements in ocean observations, modeling and ocean climate studies, build and enhance networks among ocean and climate research communities in the region, exchange strategic directions and further synergize efforts between WESTPAC and CLIVAR by identifying areas of common interest and means of cooperation. All the trainees of ODC training course were invited to attend this workshop to expand their views on the front study of climate change.
- During the 10th WESTPAC International Scientific Conference (17-20 April 2017) entitled "Advancing Ocean Knowledge, Fostering Sustainable Development: from the Indo-Pacific to the Globe", more than 600 representatives from 22 WESTPAC member countries and other international organizations participated. ODC previous trainees who attended the 10th WESTPAC International Scientific Conference were invited to participate in a lunch seminar, in total,. 22 trainees attended this conference and gave oral (14) or poster (8) presentations.

Joint research
(1) Joint research of China and Malaysia on ocean modeling
From 26 August to 6 September, 2013, Dr. Siew Jing Huey and Dr. Halimatun Muhamad from the Research Centre for Tropical Climate Change System of Malaysia participated in a joint research project on ocean modeling with the MASNUM (Key Lab of Marine Science and Numerical Modeling, SOA, China) Modeling Group at the FIO. Dr. Changshui Xia, Dr. Xunqiang Yin and Dr. Feng Shan from the FIO also joined in this research effort. To begin the basic information, usage and coupling of the ocean surface wave, tide and circulation models were discussed in detail and the research project was outlined. Subsequently, a coastal model of the Malay Peninsula Eastern Continental Shelf was constructed and implemented. Finally, the preliminary results of this coastal model were analyzed and discussed. This joint research, was a fruitful experience for all involved as the cooperative effort enhanced the

insights gained from the numerical models and the sharing of knowledge.

(2) Joint research on Sri Lanka regional ocean modeling

During 3-20 January 2017, two young scientists from the National Aquatic Resources Research and Development Agency (NARA) finished a joint research on Sri Lanka regional ocean modeling at FIO. As an important step of long term cooperation between FIO and NARA, Dr. Akila Harishchandra and Ms. Kashmila Madusha Samankumari were invited by ODC center for a joint research to build up the numerical ocean model for Sri Lanka region together with experts in FIO. During this period, Prof. Yanfeng Wang, Dr. Xunqiang Yin, Dr. Changshui Xia, Dr. Feng Shan, Dr. Yiding Zhao, Dr. Zhenhua Chen, Mr. Shumin Jiang and Ms. Pan Han from FIO participated in this activity. In the first two weeks, some problems on physical oceanography, geophysical fluid dynamics, computer programming, ocean governing equation and numerical differential method in ocean models were discussed in detail. Then the joint research group focused on the set up of circulation and wave models for Sri Lanka region. Finally, primitive modeling results have been obtained and a further cooperation plan in this field has been made. When Dr. Akila Harishchandra and Ms. Kashmila Madusha Samankumari returned back to their country, they applied this regional model in the forecasting for Sri Lanka.

(3) Joint research on the marine environment numerical prediction and research in Malaysian seas

During 9-13 July 2018, Dr. Ernest Kok from Universiti Malaysia Terengganu attended the training courses on marine numerical model that were organized by FIO in Qingdao under the auspices of ODC center. The subject and schedule of this training were made specifically for Dr. Ernest Kok, according to his educational background and academic training experiences. The training courses mainly included background knowledge of ocean dynamics, programming language of Fortran, control equations of earth fluid mechanics, numerical discrete method and ocean circulation mode of Princeton Ocean Model. After the training, Dr. Ernest Kok expressed fully gratitude to all the organizers for their help and hoped to apply the knowledge to the marine environment numerical prediction and research in Malaysian seas.

Summary

Since the establishment, ODC center has operationally run successfully and smoothly in the past years. Eight training courses with 359 trainees from 43 countries attending have been carried out. These activities have not only promoted the capacity building in ocean and climate science, but also enhanced the cooperation among IOC member states. In addition, a solid technical support was provided to several international cooperation projects, such as the OFS (Ocean Forecast Systems) and MOMSEI (Monsoon Onset Monitoring and its Social and Ecosystem Impacts).

The ODC center will continue to host research activities and annual training courses. The subject of the training course in 2019 will be climate dynamics and air-sea interaction, which aims to improve our thorough comprehension of the basic theory of climate dynamics and the interaction between the equatorial and mid-latitudes. And the subject of the training course in 2020 will be development and application of coupled regional climate models. It will provide a deep understanding on regional climate model and practice on numerical simulation of regional climate.

Introduction of the High Performance Computing Center at the First Institute of Oceanography

Xinfang Li[1], Ying Bao[1], Zhen Jia[1]

1. The First Institute of Oceanography, State Oceanic Administration, China

Introduction

The High Performance Computing Center of the First Institute of Oceanography, State Oceanic Administration (FIO-HPCC) was established in February 2010. The main responsibilities of FIO-HPCC include the construction and service of high-performance computing platforms, the construction and service of data managing and sharing platform. The high-performance computing platform is an important part of FIO's public technical support. It provides service for the numerical modeling and large-scale data processing by providing computing resources.

The total area of FIO-HPCC is 330m2, and the main computer room is about 180m2. The key environmental equipment of FIO-HPCC has reached the first level of the Chinese professional equipment room. Up to date, there are more than 10 high-performance computing servers in the computer room, including IBM X240 blade clusters, HP BL280 blade clusters, SGI UV2000 server and many other world-renowned server manufacturers' computing devices, the total computing capacity has reached 50 trillion times per second. The computer room has 12 storage devices, including HP P10000 series, HP EVA series, Sugon ParaStor series and other types of disk arrays, and the total storage capacity has exceeded 4PB(Fig.1).

The computing resources of FIO-HPCC are mainly used to run numerical models such as Community Earth System Model (CESM), First Institute of Oceanography Earth System Model (FIO-ESM), Marine Science and Numerical Modeling(MASNUM) Surface Wave Model, Weather Research and Forecasting Model (WRF), among others. Some calculation results, which are related to global climate change (Song et al. 2007; Huang et al., 2008; Song et al., 2011; Song et al., 2011; Qiao et al., 2013; Bao et al., 2016), Bohai oil spill, Yellow sea Enteromorpha(Lv et al.2008; Qiao et al 2011), Japan Fukushima nuclear leakage (Qiao et al., 2011) and other relevant domestic and foreign issues, have been achieved in FIO-HPCC.

FIO-HPCC provides an important support for the development of the First Institute Oceanography-Earth System Model (FIO-ESM) (Qiao et al., 2013) which is implemented by the numerical modeling group of FIO and is composed of a coupled climate system model and a coupled carbon cycle model. FIO-ESM is the first climate model that includes a surface wave model (Fig.2). The inclusion of wave model in FIO-ESM leads to the coupling between surface waves and ocean circulation by introducing the non-breaking wave-induced vertical mixing into the ocean circulation model. Results of sensitive runs of FIO-ESM shown that the sea surface temperature and mixed layer depth can be drastically improved. The FIO-ESM has participated in the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Taylor et al., 2012) and performed well compared to the observations. The historical simulation results of FIO-ESM show that the performance of surface air temperature, sea surface temperature, and seasonal variation of sea ice area in the Arctic are at the top of nearly 50 CMIP5 models. Based on the FIO-ESM global carbon cycle model, a more realistic approach named accumulative contribution is proposed to quantify the historical contribution of CO_2 emissions to climate change in different countries. The Ensemble Adjusted Kalman Filter (EAKF) assimilation scheme is

Figure 1: The Environment of FIO-HPCC

introduced into FIO-ESM and the results show that the assimilation can effectively improve the simulation of temperature in the upper ocean, atmosphere circulation (Chen et al., 2015), and Arctic sea ice (Shu et al., 2015), which suggests that this EAKF system can provide a reasonable initial condition for short-term climate prediction. The EAKF assimilation and prediction system of FIO-ESM has finished the climate hindcast experiment for the last 20 years, and is applied to short-term climate prediction including El Niño-Southern Oscillation (ENSO) prediction (Song et al., 2015;Fig.3) and sea ice forecast in Arctic.

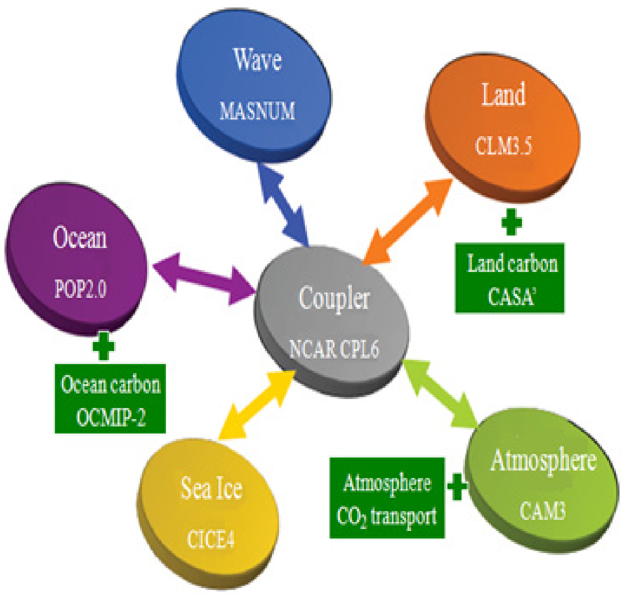

Figure 2: The Frame of FIO-ESM

Main application

The high-performance computing center also assisted in supporting a series of emergency management, as it is described in what follows:

In March 2006, an oil spill occurred in the Bohai Sea of China. However, due to the complicated and varied marine environment, the oil-concentrated area drifted with the wind and currents, which made it more difficult to track and deal with the oil spill. The Ocean numerical modeling group of FIO successfully predicted the drifting route of the spilling oi, based on the numerical prediction model and the high-performance computing center servers, which allowed the accurate tracking and timely disposal of the oil spill.

In June 2008, The Enteromorpha broke out in the Yellow Sea of China, and it drifted to the seacoast of Qingdao under the influence of oceanic and atmospheric environmental factors, which directly threatened the sailing match of the 2008 Olympic Games. Based on the resources of the FIO-HPCC, the ocean numerical modeling group of FIO proposed the "sea channel of enteromorpha" by using the particle tracing method, which provided key scientific and technological support for decision-making of the interception, salvage and emergency treatment of the Enteromorpha, and effectively guaranteed the progress of the Olympic Sailing Games.

In March 2011, after the Fukushima nuclear leakage in Japan, the forecast of the nuclear leakage diffusion and transport was fully supported by FIO-HPCC. Within 7 days after the leaking, the numerical modeling group of FIO made predictions of the diffusion of nuclear materials in the atmosphere and seawater, and published the first scientific paper on the prediction of Japan's nuclear leakage (Qiao et al., 2011). The prediction results were verified by the subsequent related observations and provided an important support for the prediction and prevention of nuclear leakage.

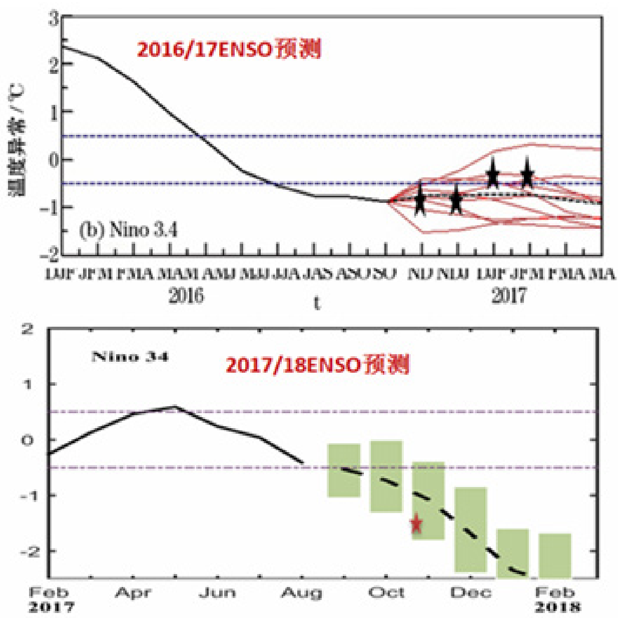

Figure 3: The Forecast Results of ENSO

Conclusion

High performance computing center is an important support for the development of ocean numerical model and an important foundation for ocean scientific research. With the development of large data and artificial intelligence technology, we will strengthen the supporting role of high-performance computer technology in data processing, scientific computing, product applications and other aspects to better serve the development of marine science. We hope that one day we can really use mathematical methods to calculate ocean and weather changes.

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No. 75, November 2018

The CLIVAR Exchanges is published by the International CLIVAR Project Office ISSN No: 1026-0471

Editor: Jose Santos

Guest editor: Dejun Dai

Layout and Designing: Harish J. Borse, ICMPO at IITM, Pune, India

Production, Printing and Mailing of this issue by ICMPO with the support of IITM and Ministry of Earth Sciences, India.

WCRP is sponsored by the World Meteorological Organization,the International Council for Science and the Intergovernmental Oceanographic Commission of UNESCO.

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