Mass and Energy Exchange in the Tropical Western Pacific Ocean System and Its Impacts: Postprint

Authors: Institute of Oceanology, Chinese Academy of Sciences

Date: 2017-02-08T00:00:00+00:00

Abstract

For a long time, China has primarily focused on research and development in coastal waters while neglecting exploration and research of the deep ocean, resulting in the supporting capacity of marine science and technology being far from adequate to meet the strategic needs of building China into a maritime power. The report of the 18th National Congress of the Communist Party of China explicitly proposed to "enhance the capacity for marine resource development, develop the marine economy, protect the marine ecological environment, resolutely safeguard national maritime rights and interests, and build China into a maritime power." Therefore, venturing into the deep ocean and enhancing the ability to explore and understand the ocean constitute the foundation and guarantee for developing, utilizing, and comprehensively managing the ocean, representing the primary task in building a maritime power. The greatest challenge for China in implementing its maritime power strategy lies in the Western Pacific, which possesses the world' s most complex circulation system, serves as the central region of the Warm Pool, and is the origin of the Kuroshio (a high-temperature, high-salinity western boundary current). The Western Pacific contains the world' s deepest waters, features active seafloor geological processes, complex seafloor environments, and abundant seamounts and hydrothermal systems. Additionally, the Western Pacific is also the region with the highest marine biodiversity globally.

Full Text

Preamble

Strategic Priority Research Programs (Category A) of the Chinese Academy of Sciences

1. Project Background and Significance

For a long time, China has focused primarily on coastal research and development while neglecting deep ocean exploration and investigation. This has resulted in marine science and technology capabilities that fall far short of the strategic requirements for building China into a maritime power. The report from the 18th National Congress of the Communist Party explicitly called for "enhancing the capacity to develop marine resources, developing the marine economy, protecting the marine ecological environment, resolutely safeguarding national maritime rights and interests, and building China into a maritime power." Therefore, advancing into the deep ocean and improving our ability to explore and understand the sea forms the foundation and guarantee for marine exploitation, utilization, and comprehensive management—the primary task of building a maritime power. The greatest challenge to implementing China' s maritime power strategy lies in the Western Pacific, which features the world' s most complex current system and serves as the central region of the warm pool and the origin of the Kuroshio Current (a high-temperature, high-salinity western boundary current). The Western Pacific also contains the world' s deepest waters, with active seafloor geological processes, complex submarine environments, and abundant seamount and hydrothermal systems. Moreover, it represents the region with the highest marine biodiversity globally.

Consequently, in 2013, the Chinese Academy of Sciences launched the Strategic Priority Research Program "Material and Energy Exchange Processes in the Tropical Western Pacific Ocean System and Their Impacts" (hereinafter referred to as the "Marine Program"). Focusing on the tropical Western Pacific Ocean system, the program conducts comprehensive collaborative surveys and research from an "ocean system" perspective. It aims to achieve breakthrough and original results in understanding the evolution patterns of coastal ecosystems under oceanic influence, deep-sea environment characteristics, and resource distribution in the Western Pacific. The program also seeks to promote the development and application of deep-sea research and detection equipment in China, significantly enhance theoretical research capabilities in deep ocean science, and provide scientific foundations for marine environmental information security, strategic resource development, integrated marine management, and disaster prevention and mitigation [Figure 1: see original paper]. Simultaneously, it strives to build an internationally advanced deep-sea scientific research and technology innovation team, promote progress in China' s deep-sea high-tech capabilities, achieve leapfrog development in marine science and technology, and provide scientific and technological support for building a maritime power.

Centered on the core research theme of "material and energy exchange processes in the tropical Western Pacific Ocean system" and its key scientific and technological challenges, the Marine Program established four sub-projects: (1) Mechanisms of variability in the major current systems and the Western Pacific Warm Pool and their climate effects; (2) Impacts of the Kuroshio Current and its variability on China' s coastal ecosystems; (3) Deep-sea marine environment and ecosystems; and (4) Deep-sea exploration equipment development. In 2015, following the Chinese Academy of Sciences' overall requirements for Category A Strategic Priority Research Programs, the program further focused on seven key tasks: (1) Marine environmental security system and its demonstration in key Indo-Pacific Ocean regions; (2) Construction of the Western Pacific major current system observation network and its application in marine environment and climate forecasting; (3) Analysis of causes and countermeasures for coastal ecological disasters; (4) Ecological security and environmental protection for marine ranching; (5) Construction of deep-sea system exploration and technology systems; (6) Comprehensive utilization of deep-sea microbial resources; and (7) Deep-sea equipment development.

2. Progress

2.1. Leapfrog Development of Deep Ocean Observation Capabilities

(1) First large-scale subsurface mooring observations in the tropical Western Pacific. The program constructed the world' s largest subsurface mooring array in the Western Pacific boundary current and equatorial current system, comprising 18 full-depth moorings [Figure 2: see original paper]. This achievement enables long-term continuous observations of flow volume, velocity, and structure of the Western Pacific boundary and equatorial currents, providing unprecedented long-cycle, multi-layer, high-frequency, full-depth scientific data for systematically and quantitatively investigating major scientific questions. These include the influence of tropical Western Pacific circulation on warm pool variability, characteristics of deep circulation and its relationship with large-scale circulation, and deep water mixing processes and their impacts on circulation variation. The program has thus established China's core position in global research on this ocean region.

(2) Establishment of an internationally advanced deep-sea research platform. Relying on the research vessel *Kexue* (Science) [Figure 3: see original paper], the program pioneered a deep-sea environmental detection technology system in China that combines macroscopic and microscopic, underway and fixed-point, gradient and in-situ approaches. It achieved breakthroughs in key technologies including 10,000-meter deep-sea fixed-point detection, 6,000-meter deep-sea exploration and sampling, 4,500-meter deep-sea precision detection and sampling, 1,000-meter water column profile underway detection, 30-meter deep-sea sediment coring, and 20-meter rock coring. The platform possesses comprehensive capabilities for three-dimensional, synchronized, and precise detection of deep-sea topography, seafloor environment, and water column conditions, reaching an internationally advanced level overall. The program also constructed deep-sea in-situ long-term continuous monitoring and experimental platforms [Figure 4: see original paper], successfully implementing in-situ cultivation experiments on organism adaptation to extreme environments. This truly achieves the leap from "laboratory simulation experiments → marine mobile laboratories → deep-sea in-situ laboratories." The research collective for deep-sea exploration and platform system construction received the 2015 CAS Outstanding Scientific and Technological Achievement Award.

(3) Successful development of autonomous deep-sea observation platforms. Experimental applications of autonomous underwater platforms such as underwater gliders and autonomous underwater vehicles (AUVs) [Figure 5: see original paper] have significantly enhanced the efficiency and capability of real-time, rapid acquisition of marine environmental information based on China' s independently developed equipment. Three "Haiyi" underwater gliders successfully completed high-precision observations in the strong current region of the Northwest Pacific, obtaining 343 vertical profile multi-parameter observation datasets. The 4,500-meter AUV was deployed in the South China Sea, acquiring detailed topographic maps of extensive cold seep areas and thousands of high-definition seafloor images. The 1,000-meter AUV achieved a new Chinese record for longest continuous underwater operation at over 7 days, with maximum working depth exceeding 800 meters, reaching an internationally advanced level.

(4) Groundbreaking theory that smooth oceanic crust subduction is more likely to trigger catastrophic earthquakes. Researchers discovered for the first time that subduction faults generating large earthquakes are weaker than those undergoing creeping slip, proposing that the roughness of subducting oceanic crust controls the strength and seismic activity of subduction faults. Smooth subducting crust leads to weaker faults capable of producing major earthquakes. This research provides novel insights into the geological conditions for large earthquake occurrence and plays an important role in understanding the physical mechanisms of subduction zone earthquakes and in earthquake and tsunami disaster prevention and mitigation. The findings have been published in *Science*.

2.2. Breakthroughs in Frontier Basic Research

(1) Leading research on Western Pacific boundary currents and their interaction with climate, historically establishing China' s dominant and leading position in international frontier research on the tropical Western Pacific. The program investigated strong mixing processes in the equatorial Pacific cold tongue region, revealing their occurrence patterns —findings that provide important insights for El Niño and ENSO mechanism research and numerical model improvement. These results were published in *Nature Communications*. A review article titled "Pacific western boundary currents and their roles in climate," led by the program' s research team, was published in *Nature*, marking the first time *Nature* has published a review on Pacific circulation and climate research and the first such marine science review by Chinese scientists in this journal.

(2) Revealing the impact of the Kuroshio Current on typical coastal ecosystems in China and deepening scientific understanding of the

causes and processes of coastal ecological disasters. Through collaborative research on the Kuroshio and China' s coastal environment, the developed numerical model accurately simulated the influence of Kuroshio branches on the disaster-prone areas adjacent to the Yangtze River estuary, demonstrating simulation capabilities unmatched by other current models. Related results have been published in JCR Tier 1 journals such as *JGR* and *JPO*. Focusing on harmful algal blooms and jellyfish blooms that have severely impacted China' s coastal waters in recent years, the program systematically summarized previous research findings, revealing the origin and early development processes of green tides in the South Yellow Sea and proposing a conceptual model for their early development. It also elucidated the key processes, controlling mechanisms, ecological environmental effects, and development trends of jellyfish blooms.

(3) Achieving new understanding of deep-sea environments and biodiversity, establishing the foundation for China to independently conduct comprehensive deep-sea scientific research. The program pioneered in-situ detection of hydrothermal vent fluid temperature gradients, identifying over 20 hydrothermal vents in the Manus Basin (with maximum temperatures of 344°C) using independently developed deep-sea hydrothermal vent fluid temperature gradient meters and Raman spectrometers to obtain temperature gradient distributions and chemical composition data around vents [Figure 6: see original paper]. The program discovered one new family, three new genera, and 23 new species of deep-sea macroorganisms, including the new family Probathylepadidae Ren & Sha, 2015, within the Scalpelliformes order of crustacean Thoracica—the first family-level taxonomic unit discovered and named by Chinese scientists in crustacean thoracicans [Figure 7: see original paper].

2.3. Significant Benefits from Innovative Technologies

(1) Independently developed ENSO prediction model achieves real-time El Niño event forecasting. The independently developed IOCAS ICM (Institute of Oceanology, Chinese Academy of Sciences Intermediate Coupled Model) has been included by the International Research Institute for Climate and Society (IRI) at Columbia University for integrated analysis and application [Figure 8: see original paper]. This marks the first time a Chinese domestic institution' s air-sea coupled model has provided ENSO real-time forecast results for the international academic community.

(2) Establishment of a harmful algal bloom emergency response technology system. Addressing coastal red tide disasters in China, the program developed modified clay emergency response technology with independent intellectual property rights. This innovation solved key bottlenecks affecting clay-based red tide mitigation and improved removal efficiency for micro-algal blooms. Centered on three major tasks—"protecting key engineering projects,""preserving landscape and recreational waters," and "securing major events"—the technology has been promoted in China' s coastal waters. In 2015, the technology was applied to emergency response of *Phaeocystis globosa* blooms in the cooling water intake area of the Fangchenggang Nuclear Power Plant in Guangxi, providing safety assurance for coastal nuclear power cooling water sources.

(3) Establishment of an ecosystem-based marine ranching management model to boost marine agricultural development. The program established the development concept of "ecology first, ranch construction before harvesting." Through ecological niche complementarity and multi-species matching, it constructed a three-dimensional ecological aquaculture system and developed "algae-shellfish-sea cucumber" and "algae-fish-sea cucumber" ecological enhancement models. The management system covers all production elements including personnel, vessels, marine environment, aquaculture conditions, and marine organisms, forming a seamless, comprehensive information modern marine ranch management system. An IoT-based seamless, full-information quality safety traceability platform was constructed for the industrial chain, achieving a processing chain "from ocean to workshop, from seedling to product" that provides farmers with various services including product quality control, information traceability, risk early warning, and production information [Figure 9: see original paper].

3. Recommendations for Future Deployment in Related Fields

The 21st century has ushered humanity into a new era of comprehensive marine development and utilization. The ocean has become a strategic space for competition among nations in political, economic, and military domains, directly relating to national sovereignty, survival, and development. China' s marine science and technology endeavors are currently experiencing an excellent period of rapid development, with both opportunities and challenges. To achieve the strategic goal of building a maritime power, China needs to accelerate the formulation and implementation of its marine science and technology development strategy.

3.1. Innovate Organizational Mechanisms and Optimize Marine Field Layout

Facing international frontiers, major national needs, and the main battlefield of national economy, we should follow the development approach of "coordinating land and sea, coordinating coastal and open ocean, coordinating science and technology, and coordinating technology and social development." Focusing on three major fields—coastal environment, deep ocean, and marine resources—and oriented toward major outputs, we should strengthen marine technology capabilities as support and employ innovative management models. This requires strengthening the integration of domestic innovative units in marine science and technology and adjusting and optimizing marine research layout. Key directions deserving attention include: ocean and climate, ecosystem health, biological resource development and utilization, open ocean and coastal interactions, land-sea interactions, biodiversity, carbon cycling, biogeochemistry, heat transfer, marine geological processes, strategic resource development, deep biosphere, extreme environments, chemosynthetic ecosystems, and other related fields.

3.2. Develop Advanced Technologies and Enhance Independent Innovation Capacity

Always centering on "enhancing marine science and technology innovation capacity and international competitiveness, and building a national marine science and technology innovation system," we should focus on improving marine research standards, cultivating key core technological innovation capabilities in marine science, and breaking through weak links restricting China' s marine science and technology innovation. We must forward-deploy strategic issues and frontier technology research; deepen coastal research, expand into open oceans, strengthen security assurance, and support development. Breakthroughs are needed in key technologies including sustainable development of coastal ecological environments, deep-sea resource exploration and development, and marine three-dimensional integrated observation systems. We should form a multi-level, organically integrated strategic deployment and accelerate the industrialization and operationalization of relevant achievements to lay the foundation for building a maritime power.

3.3. Improve Resource Allocation and Provide Stable Support for Scientific Development

A comprehensive national-level marine research institution with international vision should possess large-scale marine equipment with R&D and updating capabilities, the capacity to conduct deep-sea and open ocean research, the ability to perform long-term studies, the capability for comprehensive integration and system integration, and big data processing capacity, along with thorough understanding of global and regional ocean issues. Therefore, we should increase investment in marine science and technology, support the construction, equipment renewal, and operational funding of key research institutions, strengthen comprehensive marine scientific surveys and investigations, construct satellite ground stations, enhance research, development, and application of satellite ocean information, strengthen surface and subsurface buoy observations, continue supporting the construction of marine science laboratories, improve technical equipment, strengthen operational management, and enhance utilization efficiency.

3.4. Strengthen Team Building and Construct an Innovation Talent Highland

Talent cultivation and development constitute the strategic core of marine science and technology advancement. To strengthen team building and construct an innovation talent highland, efforts should focus on four aspects: (1) At the institutional and policy level, establish mechanisms conducive to talent development and create favorable environments for talent growth; (2) Cultivate and develop marine science and technology talent, particularly leading talent, to continuously expand marine S&T research forces; (3) "Bring in"and "go global,"using talent as the carrier to promote improvements in marine science and technology innovation; (4) Emphasize the cultivation of talent innovation capabilities and comprehensive qualities, strive to stimulate talent enthusiasm, initiative, and creativity, value collaborative innovation, and build a first-class science and technology think tank.

3.5. Implement Special Project-Driven Approaches to Promote Leapfrog Development

We should develop marine science and technology plans and implement the "China Marine Science and Technology Action Plan." Focusing on major research fields of Chinese marine science and technology, we should deploy key projects, conduct long-term observations and research, and establish overall and phased goals. Particularly important is the deployment of major special projects in marine high-tech fields. According to the characteristics and patterns of different R&D tasks, we should conduct full-chain innovative design with specific objectives, clear boundaries, and defined cycles, implementing them in an integrated manner. We should strengthen coordination among projects, talent, and infrastructure construction, establish an effective China marine innovation system, and promote the establishment of industry-university-research collaboration mechanisms among marine research institutions, education, and enterprises to drive overall enhancement of China' s marine science and technology innovation capacity.

Affiliation: Institute of Oceanology, Chinese Academy of Sciences

Due to climate change and multiple pressures from human activities, China is experiencing dramatic, negative changes in its marine ecosystems—changes that are critical to the social and economic sustainable development of China' s vast coastal regions. The Institute of Oceanology, Chinese Academy of Sciences, focuses on the succession mechanisms of marine ecosystems and has successfully achieved multiple research results regarding causes and potential mechanisms of coastal environmental degradation, ecosystem structure and function, and prediction, restoration, and mitigation of marine disasters such as harmful algal blooms (red tides) and jellyfish outbreaks. Additionally, relying on the research vessel *Kexue*, the institute has constructed an internationally advanced marine comprehensive detection system, undoubtedly providing China with opportunities to explore the deep sea and participate in and lead major international scientific research projects in oceanography/climate, marine geology, and biodiversity.

John Gunn is Co-Chair of the Global Ocean Observing System (GOOS), Director of the Australian Institute of Marine Science, and a member of the Australian National Marine Science Committee and Integrated Marine Observing System Board. He possesses extensive management and development strategy experience across marine research fields including marine ecological fisheries, coastal systems, marine physics and chemistry, atmospheric chemistry, and climate science. As Chief Scientist of the Australian Antarctic Program, he played a key role in developing the "Antarctic Science Strategic Plan 2011–2021" and previously served as Deputy Director of the CSIRO Oceans and Atmosphere Institute. He has published over 150 peer-reviewed publications, articles, and reports, delivered more than 100 conference and symposium presentations, and enjoys an international reputation in surface fish ecology and the development of marine biological observation technology and systems.

Note: Figure translations are in progress. See original paper for figures.