Understanding and Reflections on China's Marine Science Research Strategy (Postprint)

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Abstract

Through an analysis of key issues in marine research and the current state of marine science development, this article proposes research priorities for China in the fields of coastal waters, deep sea, open ocean, and marine equipment. It recommends strengthening the construction of an automated, intelligent, and unmanned integrated marine perception system within future maritime strategies, to achieve effective transmission, processing, and application of marine information. The article also proposes the concept of conducting marine research from a marine system perspective, emphasizing the need to strengthen research on multi-sphere interactions in the ocean. Through the collaborative development of science and technology, China' s marine scientific research can better serve the implementation of national maritime strategies and the comprehensive management and control of marine systems.

Full Text

Understanding and Reflections on China' s Marine Science Research Strategy

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Abstract

In recent years, marine science in China has developed rapidly. Marine infrastructure and capacity building have achieved significant progress, with numerous research programs and implementation plans being formulated or proposed. This paper analyzes the current status, key challenges, and research strategies of marine science. To better understand the changing ocean and essential ocean variables in coastal and deep sea areas, we identify major gaps in regional and global ocean observing systems, particularly in chemical and biological sensors, geographic coverage, and data collection, sharing, and distribution. We argue for considering interactions between coastal and deep seas, as well as multi-disciplinary and multi-sphere interactions in the ocean. Marine ecosystem health and sustainable development, capacity building of the global ocean observing system, and establishment of ecosystem-based management systems should be top priorities for ocean sciences in China.

Keywords: marine strategy, deep sea, ocean, coastal environment, ocean observation

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Marine research in China has never received such unprecedented attention from the educational and scientific communities as it does today. Within just a few years, dozens of marine institutions have sprung up like mushrooms after rain, with many new marine colleges and research organizations currently under construction or in planning. Marine scientific research vessels and large-scale marine exploration facilities have also been built in large numbers alongside the establishment of these new institutions. In particular, the construction of large modern comprehensive research vessels has, according to statistics, already exceeded Europe in total number. A series of marine-related science and technology programs have been proposed successively, such as deep-sea space stations, transparent ocean, smart ocean, and abyssal exploration initiatives. Amidst this unprecedented enthusiasm for marine research, it is necessary to conduct systematic analysis of marine research strategies and calmly consider how marine science and technology development can meet the needs of national marine strategies, how China can deploy its marine science and technology to keep pace with international marine research, and gradually play a leading role in certain fields.

1. Understanding Several Key Issues in Marine Research

1.1 The Changing Ocean

The ocean is in a constant state of change, and in many cases, the pace of oceanic change exceeds the speed of our cognitive understanding. Many marine phenomena catch us unprepared, leaving fundamental questions such as why they occur, when they will happen, how severe they will be, and whether they are episodic or trend-based often difficult to answer. Some of these changes are perceptible, such as dramatic interannual variations in fish species composition and abundance, fluctuations in harmful algal bloom species and quantities, and fluctuations in zooplankton and benthic organisms. However, many changes remain imperceptible until discovered too late, including alterations in seawater temperature and salinity, shifts in the thermocline, variations in nutrient elements, changes in marine primary productivity, and transformations in marine ecosystem structure and function.

Coral bleaching, mortality, and destruction—exemplified by Australia' s Great Barrier Reef—have become extremely severe. The outbreak of crown-of-thorns starfish (*Acanthaster planci*) has inflicted fatal impacts on coral reefs, yet why these outbreaks occur remains an enigma[1]. Around 2006, outbreaks of sea stars in China' s coastal waters caused significant damage to mariculture, with the underlying causes still unclear. Since 2007, green tides caused by *Ulva prolifera* have erupted annually along the coasts of Jiangsu and Shandong provinces, with many unresolved questions regarding their outbreak mechanisms and biological/ecological characteristics. The proliferation of jellyfish, harmful algal blooms, and *Phaeocystis* blooms in some regions continue to plague enterprises and management agencies.

Much about the ocean remains unknown: How many species inhabit the ocean? Where are they distributed? What are their population sizes? Some marine organisms disappear before we even recognize their existence, while new species simultaneously emerge. Our understanding of the ocean depends heavily on observation and research, and many marine events might not attract attention unless they affect coastal areas and human life. The undeniable reality is that the ocean is perpetually changing, sometimes dramatically, and these changes impact the entire marine system, thereby affecting the ocean environment upon which humans and most of Earth' s flora and fauna depend. The ocean serves as the life support system for all life on Earth, and changes in the marine environment affect this global life support system.

We cannot simplistically attribute the causes of ocean change to just "global climate change and human activities." Understanding oceanic changes, comprehending their causes, and finding countermeasures constitute the core issues of marine research—questions that marine scientists cannot evade, as they directly determine what should be studied in marine science and how research should be conducted.

1.2 The Mysterious Ocean

It is estimated that humans have explored and understood only about 5% of the ocean to date, meaning that 95% remains unknown, primarily the deep sea. Our understanding of many marine phenomena remains superficial, including marine matter and energy transfer in relation to climate change; the relationship between ecosystem structure and functional changes; heat loss from the ocean[2]; dissolved oxygen variations in seawater; ocean acidification; changes in marine biodiversity; the disappearance of large predatory fish—data show that

90% of large fish in the global ocean have already vanished[3]; the proliferation of gelatinous organisms such as jellyfish and tunicates[4]; marine geological processes; deep-sea extreme environments and life; and microorganisms in the deep seabed. All these issues await in-depth exploration and research, as they are intimately connected to human survival and development.

2. Experiences and Reflections on Marine Science Research

2.1 Coastal Ocean Research

China's coastal waters face numerous problems, with coastal environmental security under severe threat. The frequency and extent of harmful algal blooms continue to increase, becoming a normalized phenomenon. Since 2007, green tides have erupted annually in the Yellow Sea, jellyfish populations have surged dramatically, impacting fishery resources as well as coastal industrial facilities and tourism. Some marine biological outbreaks pose serious threats to nuclear power plant safety, while fishery resources teeter on the brink of collapse. Coastal resources and environments directly affect blue economy development and social stability in coastal regions. These coastal issues cannot be ignored or avoided in marine research.

Hypoxia in coastal zones and nearshore waters may deliver devastating blows to aquaculture, and the ecological problems caused by nitrogen increase in coastal waters are no less severe than those from ocean acidification. Our research on marine ecosystem carrying capacity falls far short of meeting the needs for sustainable development of marine resources and environments. Conducting research solely in coastal waters may be insufficient to resolve current marine problems; collaborative studies between adjacent open oceans and coastal waters are necessary. The key issue in this regard is the impact of Kuroshio variability on China' s coastal waters—what is the nature of this relationship, how large is the influence of Kuroshio' s interannual variation, and particularly, research on Kuroshio' s input flux to China' s coastal waters should be strengthened. The Yangtze River estuary and the Jiangsu-Shandong shoals serve as source areas for ecological disasters in the Yellow Sea and East China Sea, but the marine environments in these two regions are extremely complex, influenced by both terrestrial material discharge and adjacent oceanic changes. The lack of long-term observation data, particularly continuous and three-dimensional integrated observations, makes it difficult to understand many ecological problems occurring in these areas. Only by combining the influence of adjacent oceans on China' s coastal waters with changes in the coastal waters themselves can we unlock the key to ecosystem evolution in China' s coastal seas.

The construction of marine three-dimensional observation networks, establishment of comprehensive coastal ecological environment simulation systems, development of integrated ecosystem carrying capacity assessment models, and creation of integrated fishery resource assessment models constitute core issues in coastal resource and environmental research. Coastal ocean research involves challenges in the marine research evaluation system. Because coastal research often addresses regional issues and involves complex problems, publishing in top-tier international journals is relatively difficult, representing an important reason why many researchers avoid or are unwilling to conduct coastal ocean studies. Therefore, coastal research should not be judged solely by publications; the key lies in whether it can solve practical problems.

On the other hand, many problems in China's coastal waters are largely management issues. Terrestrial material discharge, overfishing, and coastal environmental changes are important factors causing coastal resource and environmental problems. Solving coastal issues depends heavily on establishing an integrated ecosystem-based management system.

2.2 Deep Sea Research

Many key issues in marine science are intimately related to the mysterious deep sea. Regarding ocean and climate issues, even slight heat changes in the ocean can cause dramatic global climate shifts. However, we know very little about global ocean heat transfer and balance. One critical problem is that we currently understand only surface ocean heat variations, while knowing very little about the deep ocean. The lack of observational data and understanding of heat transfer rates and temperature change rates at different depths directly affects our comprehension of ocean-climate relationships. Without solving these problems, we cannot fundamentally address global climate change.

Ocean carbon cycling has long been a concern. As the largest carbon reservoir, how much carbon the ocean can absorb, along with marine carbon fluxes, biogeochemical carbon cycles, and the relationship between the ocean’ s biological pump and global climate change and marine food web dynamics, are all areas where we lack understanding of deep ocean conditions. This deficiency in deep-sea knowledge prevents us from fundamentally achieving in-depth understanding of ocean carbon cycling.

Another major concern in marine science is ocean acidification. As the ocean absorbs carbon dioxide, it undergoes changes itself, with seawater pH alteration being a critically important phenomenon. We need to understand to what depth ocean acidification affects the ocean, and to what extent pH changes impact marine organisms. Given the ocean’ s vast capacity, studying the gradients and rate changes of ocean acidification from surface to deep waters represents an important research direction.

The reduction of dissolved oxygen in seawater significantly impacts marine ecosystems, yet deep seawater dissolved oxygen originates from surface waters. The quantity variations of dissolved oxygen in the deep sea, oxygen transfer from surface to deep waters, and its relationship with marine environmental changes remain unclear. Dissolved oxygen variation is one of the most important driving factors of marine ecosystem change, closely related to marine biodiversity, ecosystem dynamics, and future ocean predictions.

Deep-sea biodiversity, the status and variation patterns of deep-sea food webs, and their relationships with global climate change and human activities—particularly concerning deep-seabed mining and other deep-sea activities—are urgent issues requiring resolution. Biological baseline surveys of potential deep-seabed mining areas serve as an important driver for deep-sea biological research, especially for seafloor organisms. Such research is crucial for environmental assessment of future deep-seabed mineral resource exploitation.

In deep-sea research, the depth we should focus on is also a very important question. Different concepts of deep sea lead to different research strategies. Currently, most people advocate using 200 m water depth as a deep-sea standard because 200 m is the seawater compensation depth and the boundary of the euphotic zone, so many marine surveys and observations are set at 200 m. We have relatively little data for waters deeper than 200 m, meaning we should strengthen observations of regions below 200 m. Many advocate setting deep sea at 1,000 m because seawater temperature becomes relatively stable and water movement weakens after 1,000 m depth, believing that only beyond 1,000 m is truly deep sea. From a marine research perspective, we often need to observe the entire water column, and different disciplines and scientific questions have different requirements for observation depth. The greatest challenge in marine research lies in the deep sea, where many issues are at the international frontier. Without deep-sea understanding, we cannot have definitive knowledge of ocean problems. Most unknown events in the ocean occur in the deep sea, and many strategic resources exist there. Deep-sea exploration and research reflect future strategic positioning and benefit for future generations. Deep-sea research involves national territory expansion, strategic resource exploration, marine technology development, and earth science advancement—an ideal field for organic integration of science and technology and interdisciplinary marine research across multiple spheres. Deep-sea research also reflects a nation’ s scientific and technological level and comprehensive national strength, so future competition in marine science will largely manifest in deep-sea exploration and research.

2.3 Marine Equipment Development

Marine exploration and research depend heavily on the development of marine detection and research equipment. The key is to develop practical equipment that meets scientific research needs. Scientific research vessels and deep-sea submersibles have played irreplaceable roles in marine exploration and research. However, facing a changing ocean, relying solely on research vessels for ocean observation is far from sufficient from the perspective of marine perception and understanding. Greater emphasis should be placed on the development and application of long-term automatic observation equipment. The development of long-range remote-controlled detection and sampling equipment will greatly advance the exploration of marine extreme environments and life. Currently, hot topics and bottleneck issues involve the development of chemical and biological sensors. Deep-sea Argo floats, ocean gliders, AUVs (Autonomous Underwater Vehicles), and intelligent seafloor observation networks equipped with chemical and biological sensors represent the focus of global ocean observation, particularly for deep-sea observation.

3. Future Ocean and Marine Research Strategy

3.1 Building an Automated, Intelligent, Unmanned Marine Comprehensive Sensing System

Facing the unpredictable marine environment, mysterious seafloor world, and increasingly serious marine resource and environmental problems, we must address critical questions: How should we deploy marine research forces? How can we seize key issues in marine science to produce influential, breakthrough results that support national marine economic development, maintain marine environmental security, enhance marine disaster prevention and mitigation, achieve sustainable development of marine resources and environment, and maintain healthy marine ecosystems? Humans do not live in the ocean, and our perception and understanding of the sea depend largely on advances in marine observation and detection technology and equipment development. The application of marine acoustic technology and the development of acoustic devices represent a typical case of technology driving marine science progress.

When people see or talk about the ocean, one of the first questions that comes to mind is: “How deep is the ocean?” This seemingly ordinary question has actually troubled humanity for a long time, and even now we have not truly determined or precisely measured the average depth of the ocean. Because the ocean is so vast, it is difficult to conduct very precise measurements of global ocean depth, yet this question is crucial for ship navigation, underwater military environments, and calculation of global seawater volume. In the past, ropes were used to measure ocean depth, but as depths increased, this method proved ineffective due to influences from ocean currents and other factors, and it could not be used for large-scale measurements of the vast ocean. Therefore, people invented devices using acoustic principles to measure ocean depth. When a spherical device hits the seafloor, it produces sound, and we can determine ocean depth by measuring the time required for the sound to reach the surface. In 1925, German scientist Haber installed an “echo sounder”on the research vessel *Meteor*, hoping to obtain more detailed ocean data with this new equipment. After using the echo sounder for measurements, people were surprised to discover that in some areas of the mid-Atlantic, the ocean was not as deep as imagined but rather “shallow,”leading to the discovery of the Mid-Atlantic Ridge. The *Meteor* collected over 70,000 data points, providing important impetus for subsequent deep-sea and ocean exploration. Today’ s seafloor mapping equipment also basically works on acoustic principles. From this seemingly simple technical issue, we can see how important technological progress is for marine science development.

The invention and application of CTD (Conductivity, Temperature, and Depth profilers) have enabled large-scale physical oceanographic observations, leading to new understanding of many ocean dynamic issues and physical phenomena. Some believe that without CTD invention, understanding of ocean circulation and basin-scale ocean dynamic processes would be impossible, and CTDs are now indispensable in ocean observation systems. The invention of deep-sea submersibles has enabled deep-sea exploration and discovery of hydrothermal vent communities, enhancing understanding of deep-sea extreme environments and life. Satellite remote sensing technology and ocean color satellites allow global-scale observation and study of the surface ocean. The invention of marine buoys and moorings enables understanding of both surface and deep oceans, while Argo floats allow large-scale monitoring of ocean conditions. Development of these instruments and equipment has been driven by marine research needs, and only through organic integration of science and technology can they truly function effectively.

Marine observation is undoubtedly crucial for marine research. Over the past decades, marine observation has received global attention, achieving substantial progress in observation methods, scope, technology, and precision, but primarily for physical environments. Observation of marine chemical and biological environments remains very backward, especially biological environment observation, with few detectors meeting practical standards. Therefore, we currently understand the changing global marine physical environment relatively well, as most current long-term ocean observation networks focus on physical oceanography. In other words, with sufficient investment, obtaining marine physical environment information is not problematic. Chemical and biological sensors represent the bottleneck for establishing long-term ocean observation networks. Most chemical and biological environment data currently come from research vessel-based surveys, which cannot meet the needs of modern marine science development in the rapidly changing ocean environment.

Human exploration of life is endless. The search for intelligent life in the universe and life on other planets has opened a new era of deep space exploration, and the same applies to marine life exploration. The application of molecular biology, genetic technology, and imaging technology; development of marine biological chips; combination of new sensor technology with biotechnology; integration with unmanned underwater vehicles; and organic integration of marine life science with information science will enable deeper understanding of marine life and the mysterious ocean—something that cannot be achieved by relying solely on manned submersibles and research vessels.

Future marine research will enter an era of automation, intelligence, and unmanned operation. In laboratories, deep-sea extreme environments can be explored, sampled, and observed in situ through remote control technology, making the deep sea no longer mysterious. The establishment of intelligent marine observation networks and automated marine detection systems, combined with artificial intelligence technologies such as ocean simulators and supercomputers, will provide better understanding of key ocean processes, environmental changes, and ecosystem structure and function dynamics. Ecosystem-based integrated marine management will become a reality, and the ocean’ s supporting role for economic and social development will become more prominent.

In summary, a core issue for future marine science development is ocean perception, and establishing a marine information system is the foundation and guarantee for perceiving, understanding, and comprehensively managing the ocean. Marine information system establishment includes several key links: ocean information acquisition, transmission, processing, and application. We must fully recognize the special characteristics, complexity, and difficulties of the marine environment and seawater medium. Some problems already solved in land, atmospheric, and space detection become bottlenecks in ocean observation. Development of new marine detectors, especially chemical and biological sensors, and effective transmission, processing, and application of marine information will be frontier core issues in future marine science and technology development. Considering the cost, risk, efficiency, and vastness of ocean exploration, the status and role of research vessels in modern marine research will gradually diminish, while automatic unmanned detectors, marine remote sensing technology, and remote-controlled sampling technology will become future trends in marine science development.

3.2 Conducting Marine Research from an Ocean System Perspective

Many hot topics exist in marine science, ranging from resources and environment to exploration of the unknown world, including sustainable utilization of marine biological resources, marine environmental security, marine ecosystem health, marine biodiversity conservation, marine biogeochemical cycles, and deep-sea extreme environments and life. Each aspect is important, but can we conduct systematic research on the same platform? The Chinese Academy of Sciences’ Marine Pilot Project, “Material and Energy Exchange in the Tropical Western Pacific Ocean and Its Impact,” has made some explorations in this regard.

Marine science has the characteristics of big science—almost all processes found on land exist in the ocean. Marine disciplines are also extremely complex, encompassing physics, chemistry, biology, and geology, with coastal zones, nearshore waters, open oceans, and deep seas all being important. From another perspective, not only are different parts of the ocean connected, but different marine disciplines are also interrelated. For example, in marine ecology research, physical, chemical, biological, and geological environments are all indispensable. Therefore, marine science research represents a comprehensive integration of physical oceanography, chemical oceanography, biological oceanography, and marine geology. Can we combine these disciplines to conduct research around the same question on the same platform? Can we link the open ocean, deep sea, and coastal waters to form an organic whole for comprehensive systematic research? What topic can express such integrated research? In the design of the CAS Marine Pilot Project, we conducted beneficial explorations (Figure 1[Figure 1:

see original paper] and Figure 2[Figure 2: see original paper]).

First, in terms of region selection, we focused on the tropical Western Pacific because this region is crucial for implementing China' s marine strategy and is also scientifically important, mainly manifested in the following aspects: (1) This is the region with the highest global sea surface temperature—the warm pool. Temperature variations in this region affect East Asian and even global climate; (2) This is the birthplace of the Kuroshio Current, which, as an important western boundary warm current in the Pacific, transports heat and materials from low to high latitudes, and Kuroshio variability affects China' s coastal environment; (3) The seafloor of the Western Pacific is very active, with numerous seamounts, hydrothermal vents, and cold seeps, which are significant for exploring marine extreme environments and life, as well as for integrated interdisciplinary research between earth science and oceanography.

What topic can express the research content and involved issues: transfer, transformation, and conversion of marine energy and matter; the role of ocean circulation in transporting heat and materials; air-sea interactions; interactions between shelf marginal seas and adjacent oceans; relationships between deep-sea and middle/upper ocean layers; and exploration of deep-sea extreme environments and life? We ultimately chose the topic "Material and Energy Exchange in the Tropical Western Pacific Ocean and Its Impact." Research on tropical Western Pacific circulation and climate, the relationship between Kuroshio variability and China' s coastal environment, and deep-sea exploration fundamentally concern marine energy and matter exchange. Energy is mainly manifested in ocean heat transfer and exchange, while matter is mainly manifested in the transfer and transformation of particulate organic matter, marine organisms, and dissolved substances in seawater.

As one of the ten Category A pilot projects of CAS, the Marine Pilot Project focuses on air-sea interactions in the tropical Western Pacific (Figure 3[Figure 3: see original paper]), impacts of Kuroshio variability on China's coastal ecological environment (Figure 4[Figure 4: see original paper]), exploration and research of deep-sea extreme environments and life (Figure 5[Figure 5: see original paper] —Figure 7[Figure 7: see original paper]), and marine equipment development based on marine research objectives (Figure 8[Figure 8: see original paper]).

3.3 Emphasizing Multi-sphere Interaction Research in Oceans

The ocean is interconnected, and many marine phenomena are not isolated but closely interrelated, such as interactions between coastal and open oceans, land-sea interactions, and air-sea interactions. Interactions between different Earth spheres are particularly prominent in the ocean domain, including interactions between the lithosphere, hydrosphere, atmosphere, and biosphere. Ocean exploration and research should focus on flux studies across three interfaces: The air-sea interface involves ocean-atmosphere interactions, with heat and water vapor exchange relating to many international frontier issues such as ocean circulation and climate, ocean carbon cycling, and ocean acidification. The land-sea interface: variations in coastal ecosystems depend largely on terrestrial material discharge, with eutrophication, expansion of hypoxic zones, changes in coastal biological resources, and marine environmental security largely resulting from interactions between land and ocean, and between coastal and open oceans. The seafloor interface: deep-sea extreme environments and life such as hydrothermal vents, cold seeps, seamounts, and abyssal plains remain largely unknown to us and represent frontier issues in earth science, involving coordination and interdisciplinary collaboration across geology, geophysics, geochemistry, and marine life sciences. Exploration of strategic resources such as new oil and gas resources, mineral resources, pharmaceutical resources, and genetic resources, as well as research on the origin, adaptation, and evolution of deep-sea life, will become hot areas of scientific exploration in marine science.

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