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21st Century Maritime Silk Road: A Peaceful Way Forward

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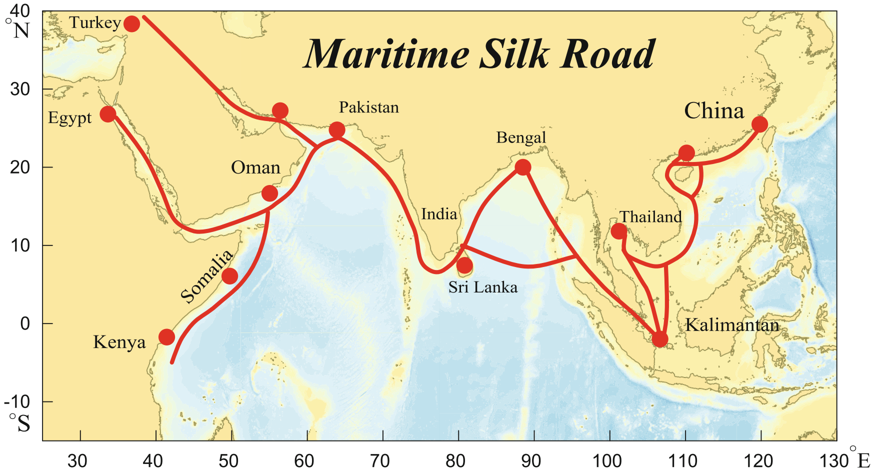

Series Publications on the 21st Century Maritime Silk Road

I. 21st Century Maritime Silk Road: A Peaceful Way Forward
II. 21st Century Maritime Silk Road: Construction of Remote Islands and Reefs
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Preface

The 21st Century Maritime Silk Road (shortened to "Maritime Silk Road" hereafter) proposed by Chinese President Xi Jinping has received increasing attention from many countries and regions. It represents China's consistent theme of peace and development. It is conducive to promoting economic prosperity and regional economic cooperation among countries, strengthening communication between civilizations, and promoting world peace and development. The Maritime Silk Road will open a new chapter of human interconnection, cooperation and win-win scenarios, equality, and mutual assistance. More than 70% of the earth's surface is covered by ocean. The ocean is not only an important regulator of the natural environment but also an important growth point for social and economic development. It is the cradle of human life as well as a resource repository that will bring new opportunities for Chinese national rejuvenation and contributions to the sustainable development of human society. However, challenges and opportunities often coexist. The Maritime Silk Road links the South China Sea and the northern Indian Ocean, involving a large number of countries, a wide range, and long distances. The challenging natural environment, scarcity of electricity and freshwater resources, different political and cultural bases, complex maritime rights disputes, and constant state of conflict greatly increase the difficulty of constructing the Maritime Silk Road. For example, a storm surge in the Bay of Bengal in 1970 caused more than 300,000 deaths. Obviously, understanding the characteristics of the marine environment is a prerequisite for the safe and efficient construction of the Maritime Silk Road. However, relatively weak basic research and scarce marine data seriously restrict the full implementation of the Maritime Silk Road initiative and urgently need to be addressed.

Construction of the Maritime Silk Road includes not only traditional ocean navigation and freight transportation but also the development of marine new energy, island tourism, marine cultural exchange, maritime search and rescue, humanitarian relief, disaster prevention and reduction, anti-piracy escort, anti-terrorism cruises, and several other areas. With the rapid development of human society, the demand for energy has increased accordingly, and along with this, increasingly serious energy and environmental crises have developed. These crises have attracted much attention in recent years. With shortages of conventional energy such as coal and oil, we have begun to focus on new energy resources, researching which resource will be the best for coping with climate change and for mitigating the shortages of conventional energy. This has been a common strategy adopted by several countries. Marine resources will guarantee the survival and sustainable development of the twenty-first-century human society, which will also be a new highlight of the Maritime Silk Road construction. The rational exploitation and utilization of wave energy, offshore wind energy, and other new energy sources will provide a positive contribution to ease the energy crisis of human society, improve the quality of life of residents along the Maritime Silk Road, and enhance the viability of remote islands and reefs. There is an obvious need for "resource evaluation and planning in advance" in energy development. Due to the difficulties of extremely scarce data, the huge amount of computation required, and the difficulty of using the appropriate technology, only a few detailed and systematic energy analyses have been conducted for the Maritime Silk Road, resulting in an insufficient reference for its construction.

An understanding of the characteristics of the marine environment is key to the safety of marine construction, while knowledge of the characteristics of marine energy is the basis of reasonable and efficient energy utilization. In addition, legal counsel is helpful in protecting the rights, interests, and commitment of countries and regions that are participating in the construction of the Maritime Silk Road. We are convinced that there is an urgent need for new insights into the field of coping with the challenging natural environment, the scarcity of electricity and freshwater resources, the different political and cultural bases, and the complex maritime rights disputes that may arise during the construction of the Maritime Silk Road.

Therefore, an in-depth study of the characteristics of the new marine energy, marine environment, remote islands and reefs construction, and legal escort is of great significance and urgently needs to be pursued in order to provide a scientific reference and decision-making support for the construction of the Maritime Silk Road. This book first discusses the significance and opportunities of the Maritime Silk Road initiative, then analyzes the challenges involved in the construction of the Maritime Silk Road and provides corresponding countermeasures. It then focuses on understanding the characteristics of the marine environment; marine resources and their current utilization; important routes, channels, and ports; and the Maritime Silk Road from the perspective of international law. The book also aims to provide a reference to help solve practical problems, such as ocean engineering, marine energy development, remote islands and reefs construction, navigation, disaster prevention and reduction, and legal escort, and thus to contribute to the safe and efficient construction of the Maritime Silk Road. In addition, this book proposes to construct a comprehensive application platform for the Maritime Silk Road that will be practical and convenient and will help decision-making. The book is motivated by the urgent demands of coping with the challenging natural environment, the scarcity of electricity and freshwater resources, the different political and cultural bases, and the complex maritime rights disputes that may arise during the construction of the Maritime Silk Road. This book is written for national decision-makers, researchers, and marine engineering personnel related to the construction of the Maritime Silk Road.

Beijing, China
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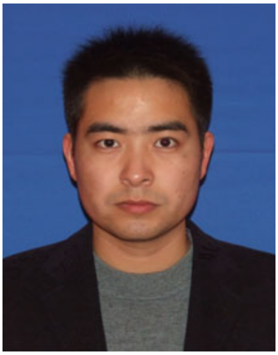
About the Authors



Dr. Chongwei Zheng graduated in 2006 with a bachelor of Oceanography degree from the College of Meteorology and Oceanography at the PLA University of Science and Technology, where he also obtained his master's degree in Physical Oceanography in 2011. He is the creator of Marine Resources and Environment Research Group on the Maritime Silk Road. He was invited as a distinguished expert to the Jiangsu International Sci and Tech Cooperation Center. His research fields cover major areas in physical oceanography, marine new energy evaluation, and climate change. He has published more than 90 papers in many peer-reviewed journals as the first author, including more than 20 papers indexed by SCI or EI (5 papers published in the SCI Top Journals and 1 paper was listed as the "Essential Science Indicators" highly cited paper), as well as more than 40 papers published in Chinese core periodicals. He has published 4 books as the first author. He is the invited reviewer of more than 30 high-impact journals. He has also been invited several times to write review manuscripts on marine new energy evaluation.

Prof. Ziniu Xiao graduated in 1987 with a bachelor of Atmospheric Science degree from the University of Sciences and Technology of China, and he obtained his Ph.D. in Atmospheric Science from the Institute of Atmospheric Physics, Chinese Academy of Sciences, in 2006. He was promoted to Professor in 2001, and he is now the director of State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics, Chinese Academy of Sciences. He is the Chief Scientist of the National Basic Research Program of China Program (No. 2012CB957800). His research fields cover climate change, the Asian monsoon, and solar impacts on the climate system. He has published more than 20 papers in the last 2 years. He has won six National or Provincial Science and Technology Awards.

Dr. Wen Zhou obtained her Ph.D. from City University of Hong Kong in 2004. She was an Alexander Von Humboldt Fellow in 2008. She has been a scientific advisor to HKO since 2008. She is currently Associate Professor in the School of Energy and Environment, City University of Hong Kong. Her research centers on the East Asian monsoon climate, tropical intraseasonal oscillation, and different types of El Niño and their effects on climate. She aims to understand the variability and predictability of the East Asian winter/summer monsoon, and to detect and attribute climate variability and climate extremes over the Asia-Pacific region. She also looks into natural hazards such as floods/droughts, cold surges and heat waves, and sea level rise/storm surges over the Asia-Pacific region and their relationship with different climate drivers in both present and future scenarios. She has published about 130 SCI papers.

Mr. Xiaobin Chen graduated in 2008 with a bachelor of Environmental Engineering degree from the PLA University of Science and Technology, and he obtained his master's degree in Meteorology from the College of Meteorology and Oceanography at the PLA University of Science and Technology in 2013. He has published about 10 papers as the main author or co-author, covering meteorology, wave energy, and oceanic numerical simulation. In 2016, as the fourth author, he published a book titled "Marine environment characteristics profile in China offshore and detailed investigation of wave energy resources" which carries out systematic and elaborate research on the wind and wave climate in the offshore waters of China and provides guidance for new energy development to relieve the energy crisis.

Mr. Xuan Chen graduated in 2010 with a bachelor of Oceanography degree from the College of Meteorology and Oceanography at the PLA University of Science and Technology, where he also obtained his master's degree in Physical Oceanography in 2013. He has published about 30 papers as the main author or co-author, covering statistics, physical oceanography, and oceanic numerical simulation. He is a member of Marine Environment and Resources Research Group on the Maritime Silk Road. In 2017, he and his co-author proposed a new statistical method known as a more general linear regression, a method that sets the field as factors; he and his co-authors described a relationship between the FNP (function of northern pressure gratitude) and equatorial undercurrent; he and his co-authors took the open boundary conditions in the geographical current diagnostics.

Chapter 1
Introduction to the 21st Century Maritime Silk Road

1.1 Maritime Silk Road, Great Peaceful Road

In October 2013, Chinese President Xi Jinping proposed the 21st Century Maritime Silk Road (shortened to "Maritime Silk Road" hereafter) initiative (Fig. 1.1) (China Radio International 2011). At that time, the Belt and Road initiative was officially put forward. In May 2014, in his keynote address at the Conference on Interaction and Confidence-Building Measures in Asia (CICA), President Xi Jinping said that China will work with other countries to accelerate the construction of the "Silk Road Economic Belt" and the "21st Century Maritime Silk Road" as soon as possible, to start the Asian Infrastructure Investment Bank, to more deeply participate in the regional cooperation process, and to propel Asian development and security to achieve complementarity (Xinhua net 2014).

With a mainland coastline of about 18,000 km and more than 3 million km^2 of ocean territory, China is undoubtedly a large marine country. In ancient times, the marine economy was an important part of China's overall economy; the ancient Maritime Silk Road was also an important component of China's economic development. During the flourishing periods of China's Tang, Song, and Yuan dynasties, the starting points of the Maritime Silk Road were composed primarily of Quanzhou, Guangzhou, Ningbo, and other feeder ports (People's network 2015a). As early as the Qin and Han dynasties of China, the Maritime Silk Road existed in an embryonic form. In the middle and late Tang Dynasty, the Silk Road on land was blocked by the war, which caused northern people to move south. As a result, the economic center was moved south (Zhang 2008). At this point, the Maritime Silk Road replaced the Silk Road on land as the main channel of trade between the Song Dynasty and abroad. Due to breakthroughs in maritime technology, as well as unprecedented economic and trade demand, the Maritime Silk Road reached its peak. During Zheng He's voyages in the Ming Dynasty, China's great voyage era also reached its peak. Since then, because maritime economic contributions to the dynasty were not great, pirates and other factors such as the ban on maritime trade, which made China lose

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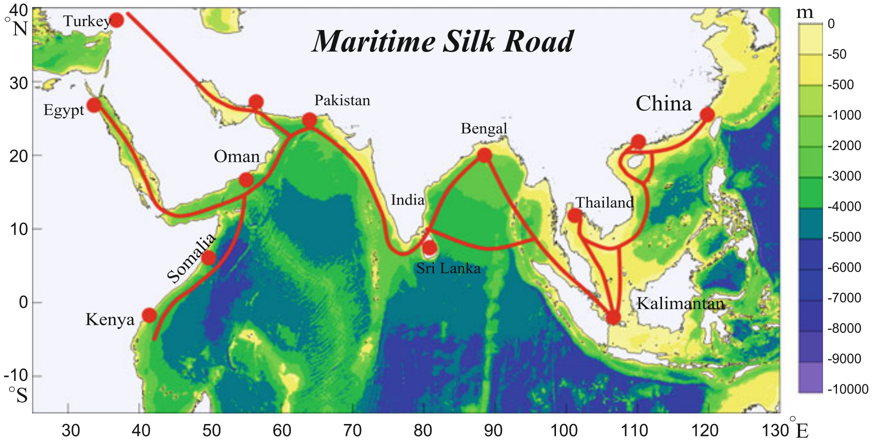

Fig. 1.1 Topography and water depth of the Maritime Silk Road

opportunities for economic development and participation in the world economy, as well as technological changes, caused the ancient Maritime Silk Road to suffer a change from prosperity to decline. It is not hard to see that the Maritime Silk Road has been a peaceful road since ancient times.

The Maritime Silk Road initiative is a powerful means to create a cooperative, peaceful, and harmonious environment for foreign cooperation, which has created a good opportunity and external environment for China's comprehensive deepening reform (CRI Online 2015). This is a new starting point based on history and focusing on the 10th anniversary of the establishment of the strategic partnership between China and the Association of Southeast Asian Nations (ASEAN), under the leadership of the Central Committee of the Communist Party of China (CPC) headed by Chinese President Xi Jinping. To further deepen the cooperation between China and ASEAN and to build a community with a common destiny, a strategic concept for the well-being of the people of the region was put forward (Southcn.com 2014), that is, to tighten mutual interests and strengthen sea lane interconnection. To promote the common prosperity and progress of human society in shipping, marine energy, economy and trade, scientific and technological innovation, the ecological environment, and human communication, there is a need to promote policy communication, road connection, trade flowing, currency circulation and folk mind connection (Qiushi net 2014).

The ocean is a natural link for economic and cultural exchange between countries, and the Maritime Silk Road is the new trade road connecting China with the world under changing global politics and trade patterns. The partners of the Maritime Silk Road include not only the ASEAN countries; other countries and regions interested in the Maritime Silk Road can also be included, which could enhance contacts with border countries and regions; connect the ASEAN countries, South Asia, West Asia, North Africa, and Europe, wherein the market chain comprises major economic sectors; and propel strategic cooperation in the South China Sea, Pacific Ocean, and Indian Ocean economic zones in the economic and trade integration of Asia, Europe, and Africa for the development of long-term goals for the benefit of mankind (People's network 2015b).

1.2 Mutual Benefit, Win-Win Results

Currently, the national economy is entering a new normal in which downward pressure still exists. How to solve the problem of employment and people's livelihoods is still the focus. On one hand, the Belt and Road initiative can implement funding for the Asian Infrastructure Investment Bank (AIIB), which transfers eastern surplus capital and industry to Central Asia, South Asia, Southeast Asia, and African countries and enhances the economic development of countries and regions along the route. On the other hand, through trade to exchange resources, it can further deepen the relationship between China and these other countries and regions. The Belt and Road initiative will create a community with a common destiny, improve the quality of life of residents living along the Belt and Road, and thus enhance the stability and prosperity of the countries and regions along the route.

The Maritime Silk Road includes primarily the South China Sea, the northern Indian Ocean, Southeast Asia, South Asia, and West Asia. The South China Sea is located between the Pacific Ocean and the Indian Ocean and is a primary channel of commercial shipping and oil transport. According to statistics, more than half of the world's supertankers are navigable through the South China Sea. More than half of the world's merchant fleets (in tonnage) pass through the South China Sea each year (Zhang et al. 2014). The Indian Ocean is the link between the Pacific Ocean and the Atlantic Ocean and the bond among Asia, Africa, and Oceania for transport, including oil transport; in includes one-ninth of the world's harbors and one-fifth of the cargo throughput and includes three major routes for international energy transport (Zhang et al. 2014). Countries around the Indian Ocean are South–South countries that lack funds and have a backward basic infrastructure. According to the Asian Development Bank's estimates, in the next 8–10 years, Asia's annual infrastructure funding needs will reach 730 billion US dollars; the World Bank's estimates are about 800 billion US dollars (Yin 2014). The Asian Development Bank and the World Bank's two largest financial institutions have each invested a total of 30 billion US dollars in the infrastructure of Asia. Consequently, Asian infrastructure is facing a huge funding gap (Yin 2014). According to a rough calculation by the US economist Richard Freeman, by 2020, China's GDP may be more than 20 trillion US dollars. Currently, China's foreign investment accounts for about 5% of GDP. If this proportion increases to a reasonable 10%, China's foreign investment will reach 2 trillion US dollars (Bao 2014). Surpluses and deficits just achieve complementarity and mutual benefits between China and the countries and regions along the Belt and Road. At the same time, the countries and regions along the Belt and Road are rich in raw materials and low-cost labor, which is highly suitable for China's surplus production capacity and can help local residents solve employment problems, promote local economic construction, achieve the globalization of capital, and realize the value of assets and investments to achieve common prosperity and progress.

1.3 Challenges and Opportunities Coexist

The Maritime Silk Road connects the South China Sea and the northern Indian Ocean. Since ancient times, the South China Sea has been part of China's territorial waters, termed "the second Persian Gulf," and known as the corridor between the Pacific Ocean and the Indian Ocean. The Indian Ocean is known as the "world sea power center." Obviously, the Maritime Silk Road is not only a major international energy channel but also a resource repository.

Maritime Silk Road construction is not only for traditional navigation and shipping. Under the background of the increasing energy and environmental crisis, the utilization of marine resources will be a powerful guarantee for the sustainable development of mankind, which will also be a new highlight of the Maritime Silk Road. Reasonable exploitation and utilization of wave energy and offshore wind energy will help alleviate the energy and environmental crisis and improve the quality of life of residents along the Maritime Silk Road.

However, challenges and opportunities often coexist. As a link between the South China Sea and the northern Indian Ocean, the Maritime Silk Road involves several countries, a wide geographical area, and long distances, and it faces the difficulties of the complex marine environment, frequent trade frictions, political and cultural differences, political turmoil, and security conflicts, which greatly increase the difficulty of constructing the Maritime Silk Road. Therefore, the recognition of the ocean is a prerequisite. Construction of the Maritime Silk Road faces the following major difficulties.

1.3.1 Challenging Natural Environment

More than 70% of the earth's surface is covered by ocean. As ocean data are difficult to obtain and we understand the ocean less than we understand outer space, our understanding of the ocean is far from meeting the needs of marine construction. Our analysis of the marine environment directly determines the success or failure of marine development and construction.

The ocean is replete with frequent disasters. The threats of typhoons, cold air waves, storm surges, and other threats to navigation, marine construction, and even human life have been widely recognized (Xu and Wu 2007; Zheng et al. 2012a, 2013a, 2014a, b, c). In November 1999, the passenger ship *Dashun* overturned under the impact of a big wave caused by strong cold air on the way from Yantai to Dalian, resulting in more than 200 deaths. In November 1970, a storm surge in the Bay of

Bengal resulted in 300,000 deaths. In the actual process of ocean development, temperature, salt, water current, and other elements have a significant impact on marine construction. High-temperature and high-salt environments are highly corrosive and directly affect the life of marine engineering equipment. Oceanic internal waves can produce a huge horizontal thrust, threatening the normal operation and even safety of anchored or semi-submersible offshore platforms (Yuan et al. 2013). Internal waves often result in the loss of underwater robots, the dislocation of engineering vessels, the collision of offshore structures, cable pull-offs, and other major accidents. On April 10, 1963, the *Long Tail Shark* nuclear submarine suddenly sank 350 km away from Boston Harbor in the Atlantic Ocean, resulting in the death of all 129 people; this accident was caused by strong internal waves. On July 14, 1990, in the Lufeng oilfield located in the South China Sea, an internal wave caused pipeline difficulties in the semi-submersible drilling vessel *South China Sea VI* and the anchored tanker *Ayer Biru* (Miao 2011).

Obviously, just by grasping the characteristics of the marine environment, we can safely and efficiently carry out marine development and construction. However, the existing research on marine environment has systematic deficiencies as well as obvious shortages in spatial resolution and systemic. Systematic deficiencies will lead to an inability to query some of the elements of interest when planning ocean development. Spatial resolution deficiencies will lead to ignorance of some key islands and reefs. Therefore, a systematic study of the climatic characteristics of the marine environment of the Maritime Silk Road, with a high spatial resolution, is necessary to provide a reference for the planning of marine development and construction (such as navigation, marine resource development, remote islands and reefs construction, escort, and ocean engineering). Scientific short-term forecasting and long-term prediction of the marine environment are also needed for marine development and construction. In addition, it is also necessary to enhance our real-time monitoring and observation abilities in the marine environment for maritime search and rescue, disaster prevention and mitigation, and so on. In other words, an all-around, three-dimensional effort to understand the characteristics of the marine environment is an important foundation for the security and efficiency of the Maritime Silk Road initiative.

1.3.2 Scarcity of Electricity and Freshwater Resources

Remote islands and reefs are the important support for human beings towards the deep sea, which have a particularly urgent demand for electricity and freshwater resources, and this has seriously restricted marine development and utilization activities in the deep sea for a long time (Zheng et al., 2014d). In the era of high electrification, most equipment cannot function or is even paralyzed without electricity. Human beings cannot survive without freshwater. Electricity on remote islands and reefs usually relies on a diesel generator, and freshwater depends primarily on shipping supplies. Obtaining these supplies is especially challenging under bad sea conditions. All these difficulties have seriously restricted economic development in the deep sea. In addition, the ecosystem of remote islands and reefs is fragile. Diesel power generation may results in significant pollution. Once the ecosystem of remote islands and reefs is damaged, it is difficult to repair.

Taking advantage of wave energy and offshore wind energy resources in these areas could not only solve the electricity dilemma but also protect the environment of these ecologically fragile islands and avoid the destruction caused by diesel power generation (e.g., pollution). After solving the electricity problem, the problem of seawater desalination can also be solved. Then, the viability and sustainable development of remote islands and reefs can be improved significantly. Better development of remote islands and reefs can promote tourism and the development and utilization of the deep sea, thus contributing to the construction of the Maritime Silk Road. In addition, wave power generation has the advantages of good concealment and strong ability to resist natural disasters. Obviously, marine new energy resources have great potential.

1.3.3 Different Political and Cultural Bases

The Maritime Silk Road involves several countries over a wide range, with obvious differences in customs and religious beliefs. The social culture along the Maritime Silk Road is complex, as it covers today's major religions (Christianity, Buddhism, Islam, and Hinduism) and includes some Indigenous cultures. Cultural differences, especially religious beliefs, have created a precarious situation in the region. In the construction of the Maritime Silk Road, it is necessary to establish a fair and attractive core value concept, which can be widely accepted by the participating countries and regions. And we should also fully respect the habits and customs of all the participating countries and regions. Analyzing the customs, religious beliefs, and other relevant information along the Maritime Silk Road and establishing a standardized database are important. In addition, it is necessary to establish a cultural research group for in-depth exchanges and understanding of contemporary, historical, and marine culture (Wang 2015), to win the public mind and opinion of the countries and regions along the Maritime Silk Road, and to exhibit the amity, sincerity, and inclusiveness of the Chinese nation.

1.3.4 Complex Maritime Rights Disputes

The Maritime Silk Road includes primarily the northern Indian Ocean and the South China Sea. The South China Sea has been part of China's territorial waters since ancient times. Under the instigation of some outside countries, some countries continue to stir up disputes in the South China Sea (Luo and Yuan 2005; He and An 2010). Some countries maintain a high alert regarding the Maritime Silk Road, greatly increasing the challenges facing the Maritime Silk Road initiative. In recent years, China has carried out reasonable and legitimate construction on islands and reefs in its own territorial waters, which was unlawfully disturbed and deemed unjustified by some countries (Zhao and Gong 2016). This requires us to create favorable publicity in the international community, so that more countries and regions can understand the truth. The promotional material should be concise and clear, but not long-winded. For example, all official maps of the countries of the world agree that the South China Sea belongs to China. However, some countries have been tampering with the truth in recent years. A comparison of the earlier official maps (which agree that the South China Sea belongs to China) with altered maps shows the truth at a glance. In the Indian Ocean, India has always regarded itself as the leading country. Anti-piracy escorts in the Indian Ocean and the Maritime Silk Road initiative launched by other countries were regarded as a threat by India (Ye 2016). Therefore, it is particularly important to strengthen regional cooperation and guide the countries and regions involved to participate in the construction of the Maritime Silk Road.

1.3.5 Constant State of Conflict

Rampant piracy, volatile regional situations, and ongoing armed conflicts exist along the Maritime Silk Road. It is particularly important to guarantee the safety of the Maritime Silk Road. Escorts in the Gulf of Aden and the Yemen Evacuation show the great positive contribution of the Chinese Navy to world peace. In the future, remote islands and reefs need to be equipped with security forces to ensure that the legitimate interests of our country and those of international ships and personnel are inviolable. Security should not be carried out by independent implementation, which also needs to strengthen cooperation among the countries and regions along the Maritime Silk Road. The Maritime Silk Road will lead to the common prosperity of humanity. Therefore, in the process of its development, it is necessary to fully mobilize the enthusiasm of countries and regions along the route. When this initiative is deeply implanted in the public mind, and related to vital interests, the relevant countries will be actively involved in the escort of the Maritime Silk Road. In addition, we also need to strengthen legal protection as well as cooperation between legal protection and security forces for the construction of the Chinese-style overseas security model (Li 2015) and thus to contribute to world peace.

1.3.6 Great Opportunity

The challenging natural environment, scarcity of electricity and freshwater resources, different political and cultural bases, complex maritime rights disputes, and constant state of conflict greatly increase the difficulty of constructing the Maritime Silk Road. However, challenges and opportunities often coexist. If we can grasp the inherent law of the ocean, it will provide great benefits. The ocean is not only the cradle of human life but is also a huge resource repository, which includes a wide range of biological resources (fisheries, marine biopharmaceuticals), rich mineral resources (oil, combustible ice, etc.), chemical resources (metals and salts), and also dynamic energy (wave energy, offshore wind energy, tidal energy, temperature-difference energy, salt-difference energy, etc.). With the continuous development of human society, there has been a rapid increase in the demand for energy. Resource crises often result in environmental crises, and even serious armed conflicts. Coal, oil, and other conventional energy resources have become increasingly scarce in today's world. Power supply issues have often restricted the economic development of coastal cities and isolated islands, but their predicament also points to the significant potential of new energy sources. Several countries, including China, advocate the application of clean energy. Energy conservation and emission reduction, as well as development of clean energy, are effective methods to cope with climatic changes and alleviate the energy crisis, which is a common strategy taken by many countries. Currently, the utilization of solar and onshore wind energy has been moving toward industrialization on a large scale, but it is restricted severely by the uneven distribution of different regional resources. Nuclear energy can provide a large amount of energy but carries a large potential threat, as seen in the nuclear leakage caused by the Japanese tsunami in March 2011 and the Soviet Chernobyl nuclear leakage caused by operational errors in April 1986, which caused serious damage. The development and utilization of marine energy resources is now at an early stage, and the advantages of wave energy, such as being safe, pollution-free, renewable, and available in large reserves over a wide distribution, have attracted the attention of developed countries. In January 2011, when Premier Li Keqiang visited the UK, the British demonstrated to him the advanced technology of wave power generation. The electricity dilemma has become a bottleneck that has restricted the sustainable development of every country. Rational development and utilization of new marine resources (offshore wind energy, wave energy, etc.) could be effective in easing the energy and environmental crises (Zheng and Li 2011, 2015a). In addition, shortages of electricity and freshwater are the primary reasons curbing development and construction on deep blue and remote islands and have been a worldwide problem for a long time (Zheng et al. 2013b, c, 2014c). Reasonably carrying out wave power and wind power generation will be a breakthrough in the electricity dilemma, as will solving the seawater desalination problem, which will also be conducive to protecting ecologically fragile islands and thereby improving their viability and sustainable development. At the same time, development and construction on remote islands will promote the development of shipping, thus contributing to marine economic construction.

1.4 Research Status of the Marine Environment, Resources, and Remote Islands and Reefs Construction

The ocean has become increasingly important in several fields such as climate, politics, economy, culture, and shipping (Li 2007, 2010, 2011). Only by deeply grasping the characteristics of the marine environment can we reasonably and efficiently utilize the ocean. Previous researchers have made great contributions to the analysis of the marine environment of the China seas. However, research on the northern Indian Ocean is scarce. In 2012, Zheng et al. (2012b) analyzed the characteristics of the wind and wave climate of the South China Sea and the northern Indian Ocean in advance, by using ERA-40 wind production and hindcast wave data. They found that a southwest wind prevails in the summer and a northeast wind prevails in the winter. Wave and wind direction coincide well in the monsoon region, although in equatorial waters the spring and autumn are transitional seasons. Wind and wave direction differ significantly in the monsoon transition season. The average wind speed during the monsoon transition season is relatively low. Relatively high wind speeds and wave heights occur in summer and winter in the waters off Somalia, in the Bay of Bengal, and in the traditional gale center of the South China Sea. Mei et al. (2010) used 45-year ERA-40 wind production data to drive the WAVEWATCH-III (WW3) wave model. EOF analysis of the wave and wind fields of the northern Indian Ocean and the South China Sea showed that the sea surface wind speed and significant wave height increase linearly, and the sea surface wind speed has a period of about 3 years. In the northern Indian Ocean, tropical cyclones are active primarily in the eastern Arabian Sea and in the eastern and central Bay of Bengal. Tropical cyclones in the Arabian Sea are usually dominated by terrain and move northwest along the Western Ghats before finally landing in southern Pakistan, while tropical cyclones in the Bay of Bengal land in Bangladesh and southern Myanmar (Wu and Luo 2011). Zheng et al. (2013d) used Cross-Calibrated, Multi-Platform (CCMP) wind production data to drive the WW3 wave model to simulate the large waves caused by tropical cyclone "Thane" in the Bay of Bengal in December 2011, providing a reference for short-term numerical forecasting of ocean waves in this area.

Understanding the characteristics of the marine environment is a prerequisite for the safe and efficient construction of the Maritime Silk Road. However, existing studies on the marine environment are relatively weak and are not a good guarantee of the construction of the Maritime Silk Road.

Previous researchers have made great contributions to the analysis of wave and offshore wind energy resources. However, research on the Maritime Silk Road has been scarce until now and has not benefited marine energy development. Zheng et al. (2012c) and Zheng (2014) took the lead in studying the wave energy resources of the South China Sea and the northern Indian Ocean in the hope of providing power resources for marine development and construction in the relevant areas. The results showed that there are abundant wave energy resources in the South China Sea and the northern Indian Ocean; the annual mean wave power density in most of the research areas is above 2 kW/m, and three areas with obviously large values are the traditional gale center of the South China Sea, the waters off Somalia, and the area east of Sri Lanka. In addition, occurrences of wave power density greater than 2 kW/m and greater than 4 kW/m are high. The stability of wave energy in spring, autumn, and winter is better than that in summer, and the stability of wave energy in the South China Sea is better than that in the northern Indian Ocean.

Regarding the remote islands and reefs construction, these areas are generally based on reefs and islands and are usually far from the mainland. Shortages of electricity and freshwater are primary difficulties that have been a worldwide problem for a long time. In the era of high electrification and modernization, many devices cannot run without electricity, and the shortage of electricity can even lead to paralysis of the system. Human beings cannot survive without freshwater. The common practice is to use shipped diesel fuel for power generation, which has two obvious disadvantages: (1) bad sea conditions will affect ship supply, and (2) diesel generators cause pollution, which can damage the fragile ecology of islands and reefs. Once the ecology of islands and reefs is damaged, it is difficult to repair. Complete development and utilization of the marine energy resources (wave power generation, offshore wind power, etc.) in the waters surrounding remote islands and reefs according to local conditions will help in achieving electricity self-sufficiency on the reefs. After solving the power problem, the problem of desalination can then be solved. All these tasks must be carried out after completely grasping the characteristics of the marine resources. However, research on the wave and offshore wind energy resources of the Maritime Silk Road is still scarce. Zheng and Li (2015b) have verified the possibility of wave power and offshore wind power generation, which can provide a reference and guidance for remote islands and reefs on the Maritime Silk Road to resolve shortages of electricity and freshwater.

In 2015, Zheng Chong-wei's team presented research termed as "Management and plan for 21st Century Maritime Silk Road" for the first time at home and abroad, with 12 scientific and technical papers published in the *Journal of Xiamen University*, *Ocean Development and Management*, and *Acta Scientiarum Naturalium Universitatis Pekinensis* (Zheng et al. 2015a, b, c, d, 2016a, b, c, d, 2017a, b; Wan et al. 2015; Chen et al. 2016). This series of research first analyzed the importance of the Maritime Silk Road in various fields such as economics, culture, and politics. Then, it systematically and finely analyzed the characteristics of the marine environment (wind climate, wave climate, rough sea occurrence, gale occurrence, extreme wind speed, extreme wave height, ocean current, etc.) based on ocean big data, as well as important routes and port characteristics, geographical features, climate features, and legal escort. The results of this series research can provide a reference for navigation, marine engineering, disaster prevention and reduction, and humanitarian aid. In addition, the spatial and temporal distribution characteristics of renewable energy (wave energy, offshore wind energy, etc.) were also analyzed in the hope of making a contribution to ease the energy and environmental crises and thus to promote sustainable development in the countries and regions involved, improve the quality of life of residents along the route, enhance the viability of remote islands, and thus help China to lead international marine development and construction.

1.5 Structure of This Series Publications

The "Maritime Silk Road" proposed by Chinese President Xi Jinping represents China's consistent theme of peace and development. It opens a new chapter of human interconnection, cooperation and win-win scenarios, equality, and mutual assistance. Construction of the Maritime Silk Road includes not only traditional navigation and shipping but also the development of marine new energy, island tourism, marine cultural exchange, maritime search and rescue, humanitarian relief, disaster prevention and reduction, and several other areas. The Maritime Silk Road will bring new opportunities for Chinese national rejuvenation and contributions to the common prosperity of human society. However, challenges and opportunities often coexist. The Maritime Silk Road links the South China Sea and the northern Indian Ocean, involving a large number of countries, a wide range, and long distances. The challenging natural environment, the scarcity of electricity and freshwater resources, the different political and cultural bases, the complex maritime rights disputes, and constant state of conflict greatly increase the difficulty of constructing the Maritime Silk Road. Obviously, an understanding the characteristics of the marine environment, energy, legal counsel and so on is a prerequisite for the safe and efficient construction of the Maritime Silk Road. However, relatively weak basic research and scarce marine data seriously restrict the full implementation of the Maritime Silk Road initiative and urgently need to be addressed.

This series publications is the first set of marine science monographs on the Maritime Silk Road, including the marine environment analysis, remote islands and reefs construction, marine new energy evaluation, difficulties and countermeasures of location choice of marine new energy, propagation characteristics of swell energy, long-term trends of oceanic parameters and marine new energy, short-term forecasting and long-term prediction of marine new energy, early warning of wave disasters and maritime search and rescue, legal escort, and so on. The mission of this series publications is to improve our cognitive ability to the ocean, thus to improve the capacity of our country for marine construction, enhance the viability of remote islands and reefs, ease the energy crisis facing human society, improve the quality of life of residents along the Maritime Silk Road, and protect the interests and enthusiasm of the countries and regions participating in the construction of the Maritime Silk Road. This series publications is written for national decision-makers, researchers, and marine engineering personnel related to the construction of the Maritime Silk Road.

This series publications first discusses the significance and challenges of the Maritime Silk Road initiative and provides corresponding countermeasures. Then, we focus on the necessity and difficulties of remote islands and reefs construction. According to the electricity and freshwater demand of remote islands and reefs construction, we evaluated the wave and offshore wind energy resources of the Maritime Silk Road, especially the feasibility of wave power generation, and wind power generation in the Gwadar port, Sri Lanka and other important remote islands and reefs, to realize the electricity and freshwater self-sufficiency of these key points and thus to improve their viability. There are many researches on the short-term forecasting and long-term prediction of the oceanic and meteorological parameters. However, the short-term forecasting and long-term prediction of the marine new energy is scarce, which is realized in this series publications to serve the daily operation and mid- to long-term planning of energy development. In addition, a scientific energy classification scheme is closely related to the rationale that informs the choice of power plants location. The traditional wind/wave energy classification schemes consider only partial energy factors. In this series publications, a new energy classification scheme that incorporates a comprehensive consideration of wind/wave energy factors, environmental risk factors, and cost factors is proposed, which is used to zone the potential of offshore wind energy and wave energy resources on the Maritime Silk Road, especially in waters surrounding important remote islands and reefs. This scheme also has practical value for both macro- and micro-scale classifications of marine new energy resources globally. Combining leading and lagging correlation coefficients, the empirical orthogonal function (EOF) method, and wavelet analysis, this series publications proposes a new method to exhibit the exact propagation route, speed, and intraseasonal oscillation of swell energy in order to provide a reference for swell power generation, ocean wave forecasting, and other areas of interest. Based on the above systematic analysis, a big marine resource data regarding the Maritime Silk Road is built to provide base data for our country and our international counterparts.

To promote the safe and efficient implementation of the Maritime Silk Road initiative, according to the demands of marine energy development, port construction, route planning, maritime search and rescue, remote islands and reefs construction, and disaster prevention and reduction, we also analyzed the marine environment of the Maritime Silk Road, systematically including the wind climate, wave climate, ocean current characteristics, long-term trends of oceanic parameters, the threat and characteristics of swell, early warning of wave disasters, and maritime search and rescue. Combining the leading and lagging correlation coefficients, empirical orthogonal function (EOF) method and wavelet analysis, this series publications proposed a new method to exhibit the exact propagation route and speed and intraseasonal oscillation of swell energy, to provide a reference for swell power generation, ocean wave forecasting, and other areas of interest.

This series publications realizes the standardization and visualization of modular data, covering marine new resource development, marine environmental analysis, remote islands and reefs construction, maritime search and rescue, disaster prevention and reduction, legal escort, and other modules. At the same time, we also provide a reserve module to attract more researchers to actively participate in the scientific research of the Maritime Silk Road. Finally, we build a practical, theoretical system that is a query-convenient integrated application platform for the Maritime Silk Road to provide a scientific reference and decision-making support for the national strategy.

This series of books fills in a number of blanks for the Maritime Silk Road, such as remote islands and reefs construction, marine new energy evaluation, marine energy classification, short-term forecasting of wave energy resources, long term prediction of wave energy resources, long-term trend analysis of marine new energy, analysis of the propagation characteristics of swell energy, marine environment analysis, ocean disaster warning, and maritime search and rescue, in the hope of providing a scientific reference and decision-making support for the safe and efficient implementation of the Maritime Silk Road initiative, thus contributing to the sea dream, Chinese dream, and the common prosperity and progress of human society.

1.6 Structure of This Book

In this book, this chapter first discusses the significance of the Maritime Silk Road. It then analyzes the challenges involved in the construction of the Maritime Silk Road and provides corresponding countermeasures. Chapters 2–4 primarily analyze the characteristics of the marine environment, including the wind climate, wave climate, and ocean currents, in the hope of guaranteeing the safe and efficient implementation of the Maritime Silk Road initiative. Chapter 5 presents the characteristics of the marine resources and the utilization status of the countries and regions along the Maritime Silk Road, in the hope of providing a reference for new ocean energy development and thus contributing to easing the energy and environmental crises. Chapter 6 analyzes the characteristics of the important routes, channels, and ports to provide a reference for ocean navigation, freight transport, ship supply, and so on. Chapter 7 presents the Maritime Silk Road from the perspective of international law in providing legal escort to deal with economic disputes, trade friction, maritime rights disputes, and so on. Chapter 8 proposes the building of a practical, theoretical system that is a query-convenient integrated application platform for the Maritime Silk Road to provide a scientific reference and decision-making support for the national strategy. We hope that this book can provide scientific guidance and technological support, assist in decision-making support for the construction of the Maritime Silk Road, and contribute to the common prosperity and progress of human society.

References

Bao SG (2014) One Belt and One Road and China's diplomacy. http://www.qstheory.cn/wp/2014-12/27/c_1113799666.htm

Chen X, Zheng CW, Li XQ et al (2016) Strategic of the 21st century Maritime Silk Road: ocean current. Ocean Dev Manage 33(4):3–7

China Radio International (2011) Search for Maritime Silk Road. http://gb.cri.cn/27824/2011/01/17/3245s3127190_1.htm

CRI Online (2015) International symposium on the 21st century Maritime Silk Road, Quanzhou, Fujian. http://gb.cri.cn/42071/2015/02/12/7551s4873481.htm

He ZG, An XP (2010) The American factor and its influence in the disputes in South China Sea. J Contemp Asia-Pac Stud 1:132–145

Li CY (2007) Cope with the challenge of global environmental change, select the best model for social development. Jiangsu Keji Xinxi 11:5–6

Li CY (2010) The correct understanding and dealing with climate change (1). Hydrol Meteorol Equip 21(6):1–5

Li CY (2011) The correct understanding and dealing with climate change (2). Hydrol Meteorol Equip 22(1):1–4
Li WH (2015) The security model and legal guarantee of Chinese maritime shipping—exemplified by the response to pirates along the Maritime Silk Road in the 21st century. Soc Sci China 6:131–151
Luo L, Yuan SL (2005) Initial research on the South China Sea issue in the China's state security. J Jinan Univ (Humanit Soc Sci) 1:7–11
Mei Y, Song S, Zhou L (2010) Annual variation characteristics of wave fields and wind fields over the Northern Indian Ocean and South China Sea. Mar Forecasts 27(5):27–33
Miao WJ (2011) The effects of the wave to the deepwater floating platform overall performance in analysis. Harbin Engineering University, Haerbin
People's network (2015a) Silk road economic belt and 21st century Maritime Silk Road. http://world1.people.com.cn/GB/8212/191606/374837/index.html
People's network (2015b) Multi-country official thanks China for assistance in evacuating. http://world.people.com.cn/n/2015/0408/c1002-26813718.html
Qiushi net (2014) The 21st century Maritime Silk Road: a great maritime road to realize Chinese dreams. http://www.qstheory.cn/culture/2014-06/16/c_1111154145.htm
Southcn.com (2014) The 21st century Maritime Silk Road. http://economy.southcn.com/e/2014-08/29/content_107551749.htm
Wan JJ, Zheng CW, Cheng XJ et al (2015) Strategic of the 21st century Maritime Silk Road: legal escort. Ocean Dev Manage 32(12):4–9
Wang YH (2015). How do the countries along the line see the One Belt and One Road. http://money.163.com/15/0102/08/AEUJI5PA00253B0H.html
World Wide Web. US pressure on China to try to kill the Asia-Pacific Free Trade Agreement. http://china.huanqiu.com/News/mofcom/2014-11/5189956.html
Wu FD, Luo J (2011) Statistical character analyze of tropical cyclone during 1977–2008 in Northern Indian Ocean. Meteorol Environ Sci 34(3):7–13
Xinhua net (2014) Xi Jinping put forward the strategic concept: One Belt and One Road to open the dream space. http://news.xinhuanet.com/fortune/2014-08/11/c_1112013039.htm
Xu FX, Wu XJ (2007) The harm and distribution of high tiding disaster. China Marit Saf 4:65–66
Ye K (2016) The establish of the strategy pivot countries of 21st century Maritime Silk Road. Master's Dissertation of East China Normal University
Yin L (2014) Asian infrastructure construction faces a major funding shortfall. http://gb.cri.cn/42071/2014/11/25/2225s4778131.html
Yuan QD, Mao JY, Feng LM et al (2013) The isolation of the South China Sea wave impact on offshore installation operations and prevention
Zhang JG (2008) An impact on the economic development in the Tang Dynasty. China Financial and Economic Publishing House, Beijing
Zhang R, Hong M, Li X et al (2014) The South China Sea marine environment risk assessment and emergency response in the Indian Ocean. National Defense Industry Press, Beijing
Zhao Y, Gong HL (2016) The reaction of the U.S. Congress to China's land reclamation in the Nansha Islands. Pac J 24(5):41–51
Zheng CW (2014) The waves comprehensive application and intensive construction. Ocean Dev Manage 31(9):44–53
Zheng CW, Li XQ (2011) Wave energy resources assessment in the China Sea during the last 22 years by using WAVEWATCH-III wave model. Periodical Ocean Univ China 41(11):5–12
Zheng CW, Li CY (2015a) Variation of the wave energy and significant wave height in the China Sea and adjacent waters. Renew Sustain Energy Rev 43:381–387
Zheng CW, Li CY (2015b) Development of the islands and reefs in the South China Sea: wind power and wave power generation. Periodical Ocean Univ China 45(9):7–14
Zheng CW, Pan J, Tian YY (2012a) Atlas of global ocean wind-sea, swell and mixed wave. Ocean Press, Beijing

Zheng CW, Li XQ, Pan J (2012b) Wave climate analysis of the South China Sea and Northern Indian Ocean from 1957 to 2002. J Oceanogr Taiwan Strait 31(3):317–323
Zheng CW, Li XQ, Pan J (2012c) Wave energy analysis of the South China Sea and the Northern Indian Ocean in recent 45 years. Mar Sci 36(6):101–104
Zheng CW, Lin G, Shao LT (2013a) Frequency of rough sea and its long-term trend analysis in the China Sea from 1988 to 2010. J Xiamen Univ (Nat Sci) 52(3):395–399
Zheng CW, Pan J, Li JX (2013b) Assessing the China Sea wind energy and wave energy resources from 1988 to 2009. Ocean Eng 65:39–48
Zheng CW, Su Q, Liu TJ (2013c) Wave energy resources assessment and dominant area evaluation in the China Sea from 1988 to 2010. Acta Oceanol Sin 35(3):104–111
Zheng CW, Lin G, Shao LT (2013d) Analysis of wave field caused by tropical cyclone in the Bay of Bengal. J Mar Sci 31(4):26–35
Zheng CW, Pan J, Huang G (2014a) Forecasting of the China Sea ditching probability using WW3 wave model. J Beijing Univ Aeronaut Astronaut 40(3):314–320
Zheng CW, Shao LT, Li G et al (2014b) Analysis of influence on the security of sea skimming caused by a typhoon wave. J Harbin Eng Univ 35(3):301–306
Zheng CW, Zhou L, Song S et al (2014c) Simulation of the wave field caused by 1307 Typhoon "Soulik". J Xiamen Univ (Nat Sci) 53(2):257–262
Zheng CW, You XB, Pan J et al (2014d) Feasibility analysis on the wind energy and wave energy resources exploitation in Fishing Islands and Scarborough Shoal. Mar Forecasts 31(1):49–57
Zheng CW, Pan J, Sun W et al (2015a) Strategic of the ocean environment of the 21st century Maritime Silk Road. Ocean Dev Manage 32(7):4–9
Zheng CW, Li XQ, Gao ZS et al (2015b) Strategic of the 21st century Maritime Silk Road: wind climate analysis. Ocean Dev Manage 32(8):4–11
Zheng CW, Fu M, Rui ZF et al (2015c) Strategic of the 21st century Maritime Silk Road: wave climate analysis. Ocean Dev Manage 32(10):1–7
Zheng CW, Gao ZS, Zhang Y et al (2015d) Strategic of the 21st century Maritime Silk Road: extreme wind speed and extreme wave height. Ocean Dev Manage 32(11):4–8
Zheng CW, Sun W, Li X et al (2016a) Strategic of the 21st century Maritime Silk Road: important route, crucial node and port feature. Ocean Dev Manage 33(1):4–13
Zheng CW, Li X, Chen X et al (2016b) Strategic of the 21st century Maritime Silk Road: geography and climate characteristic. Ocean Dev Manage 33(2):3–10
Zheng CW, Li X, Chen X et al (2016c) Strategic of the 21st century Maritime Silk Road: marine resources and development status. Ocean Dev Manage 33(3):3–8
Zheng CW, Li CY, Yang Y et al (2016d) Analysis of wind energy resource in the Pakistan's Gwadar Port. J Xiamen Univ (Nat Sci Ed) 55(2):210–215
Zheng CW, Gao Y, Chen X (2017a) Climatic long term trend and prediction of the wind energy resource in the Gwadar Port. Acta Sci Nat Univ Pekinensis (in press)
Zheng CW, Sun W, Chen X et al (2017b) Strategic of the 21st century Maritime Silk Road: construction of integrated application platform. Ocean Dev Manage 34(2):52–57

Chapter 2
Wind Climate Characteristics

As a key factor in navigation, ocean engineering, disaster prevention and reduction, reef runway construction, take-off and landing of carrier planes, analysis of diffusion of pollutants, and so on, the analysis of wind climate is necessary (Zheng, 2013; Zheng and Li 2015; Gao et al., 2017; Zheng et al., 2017). The Maritime Silk Road is located in the monsoon region, where there are obvious seasonal variations (Zheng et al., 2017; Chen et al., 2017). It is also often invaded by tropical cyclones. Therefore, in-depth research on the wind climate of the Maritime Silk Road will make a positive contribution to the development of offshore wind energy as well as disaster prevention and reduction.

Previous studies have made a great contribution to the analysis of the wind climate of the Maritime Silk Road. However, due to several factors such as data and technology, early research has great potential for improvement. In this chapter, 36-year (1979–2014) ERA-interim wind data and ERA-interim gust data from the European Centre for Medium-Range Weather Forecasts (ECMWF) are used to analyze the wind climate of the Maritime Silk Road, in the hope of providing a reference for navigation, ocean engineering, marine energy development, disaster prevention and reduction, and so on.

2.1 Methodology and Data

ERA-interim wind data, hosted at ECMWF, are a new production following ERA-40 data. A high-resolution meteorology model is applied to obtain these data. There has also been great improvement in the assimilation and application of observation data. The time resolution is 6-h intervals. The spatial resolution covers 0.125° × 0.125°, 0.25° × 0.25°, 0.5° × 0.5°, 0.75° × 0.75°, 1.0° × 1.0°,…, 2.5° × 2.5°. In this book, the spatial resolution of 0.125° × 0.125° is used. It covers the time range from January 1979 to December 2014 and a space range of 90°S to 90°N and 0.0°E to 359.875°E. ERA-interim wind data have been proved to have high precision in

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comparison with observation data and are available at http://data-portal.ecmwf.int/data/d/interim_daily/.

ERA-interim gust data are also hosted at ECMWF and have a time resolution of 6 h. The spatial resolution covers 0.125° × 0.125°, 0.25° × 0.25°, 0.5° × 0.5°, 0.75° × 0.75°, 1.0° × 1.0°, …, 2.5° × 2.5°. In this book, the spatial resolution of 0.125° × 0.125° is used. It covers the time range from January 1979 to December 2014 and a space range of 90°S to 90°N and 0.0°E to 359.875°E.

Based on the ERA-interim wind data and ERA-interim gust data, the wind climate of the Maritime Silk Road is analyzed, systematically including primarily the seasonal characteristics of wind speed and wind direction, occurrence of average wind speed greater than class 6, occurrence of gust wind speed greater than class 6, gust index, annual trend of wind speed, extreme wind speed, wind field for the future 40 years, and so on. In addition, the wind rose (co-occurrence of wind speed and wind direction) at the key points of the Taiwan Strait, Beibu Gulf, Xisha Islands, Prince Consort Bank, Malacca Strait, Chittagong, Cape Comorin, Diego Garcia, Gwadar, and the Strait of Hormuz is focused on.

2.2 Seasonal Characteristics of Sea Surface Wind Field

Based on 36-year ERA-interim wind data, the seasonal characteristics of the sea surface wind field (wind direction and wind speed) of the Maritime Silk Road are obtained. To facilitate observations, we use the background color to represent wind speed and unit vector arrows to represent wind direction. as shown in Fig. 2.1. To provide a detail reference for navigation, ocean engineering, marine energy development, disaster prevention and reduction, and so on, we also present the sea surface wind field in each month, as shown in Appendix (1): Sea surface wind field in each month of the Maritime Silk Road.

In February (representing winter), the winter monsoon prevails. The main wind direction in most of the South China Sea and the northern Indian Ocean is northeast. It is worth noting that the wind direction is northwest on the north coast of the Bay of Bengal and west on the north coast of the Arabian Sea. Based on the wind speed, the intensity of the winter monsoon in the South China Sea is obviously higher than that in the northern Indian Ocean. There are two obvious gale centers in the South China Sea: Luzon Strait and the traditional gale center of the South China Sea (southeast of the Indochina Peninsula). Wind speed in most of the northern Indian Ocean is below 5 m/s, with a relatively large area located in the waters off Somalia with about 7 m/s.

In May (representing spring), the southwest monsoon in the northern Indian Ocean becomes more prevalent, and most of the winds are southwest. The monsoon transition in the South China Sea is obvious; the wind direction south of 17°N is southwest, while north of 17°N it is east-northeast. The wind speed is highest in the Bay of Bengal, followed by the Arabian Sea, and lowest in the South China Sea. There are two relatively large centers of wind speed: the waters off Somalia and the area southeast of Sri Lanka.

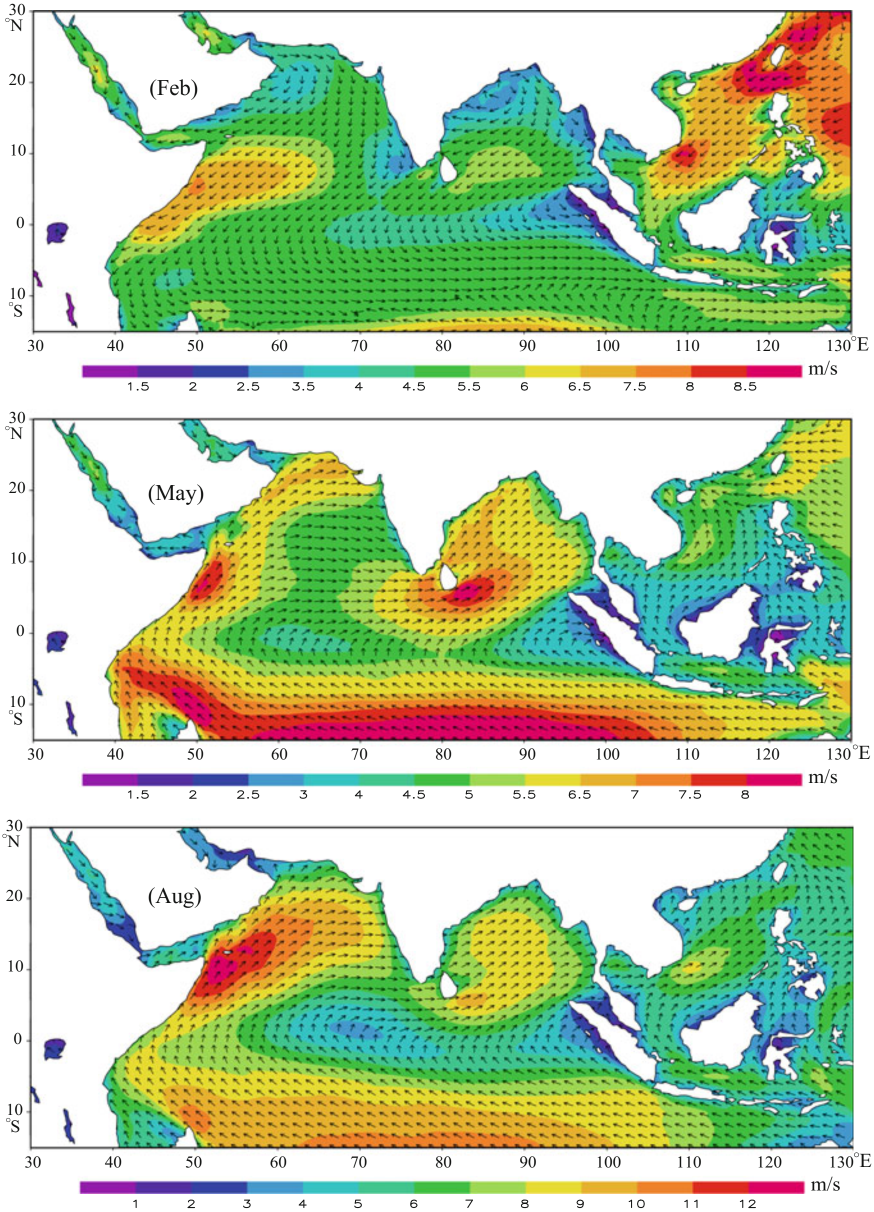

Fig. 2.1 Sea surface wind field of the Maritime Silk Road (after Zheng et al. 2015)

In August (representing summer), the southwest monsoon dominates the Maritime Silk Road. The wind speed is above 7 m/s in most of the Bay of Bengal and above 8 m/s in the Arabian Sea (especially in the waters off Somalia, where the

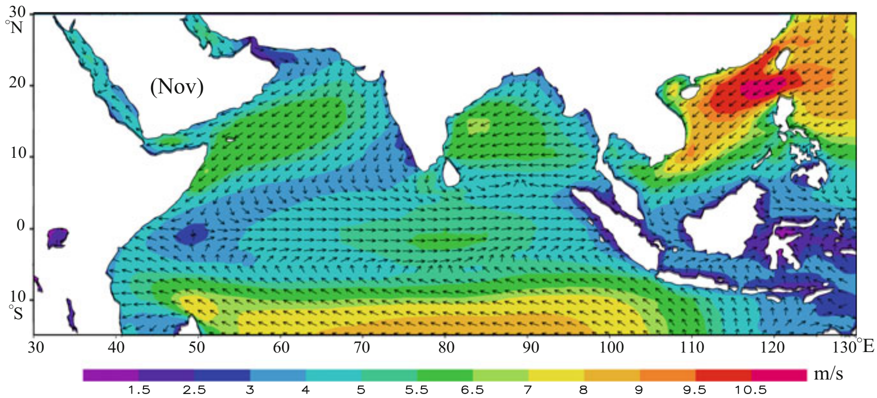

Fig. 2.1 (continued)

average wind speed can reach class 6). The intensity of the southwest monsoon in the South China Sea is obviously lower than that in the northern Indian Ocean. The relatively large center of wind speed above 7 m/s in the South China Sea is southeast of the Indochina Peninsula (the traditional gale center of the South China Sea).

In November (representing autumn), which conventional wisdom regards as the monsoon transition season, the monsoon transition is not as obvious as that in May, as can be seen by comparing Fig. 2.1b, d. It can even be concluded that the conversion from the southwest monsoon to the northeast monsoon is completed in November, for the wind direction in almost all of the Maritime Silk Road is dominated by the northeast. The northeast wind in the north-central South China Sea is strong, with an average speed of above 8 m/s north of 10°N. The average wind speed in the northern Indian Ocean (below 6 m/s) is lower than that in the South China Sea.

2.3 Wind Rose (Co-occurrence of Wind Speed and Wind Direction)

Wind direction (especially strong wind direction) is an important factor for navigation, wind energy development, runway design, and so on. In this chapter, the 6-hourly ERA-interim wind data for the period 1979–2014 are used to count the co-occurrence of wind speed and wind direction (wind rose) on the Maritime Silk Road, as shown in Figs. 2.2 and 2.3. The primary sites of interest include the Taiwan Strait, Beibu Gulf, China's Xisha Islands, Prince Consort Bank, Malacca Strait, Chittagong, Diego Garcia, Gwadar, and Cape Hafun. To provide a detail reference, we also present the wind rose in each month. And the wind rose in Diego Garcia is selected as a case study, as shown in Appendix (2): Wind Rose of Diego Garcia (co-occurrence of wind speed and wind direction).

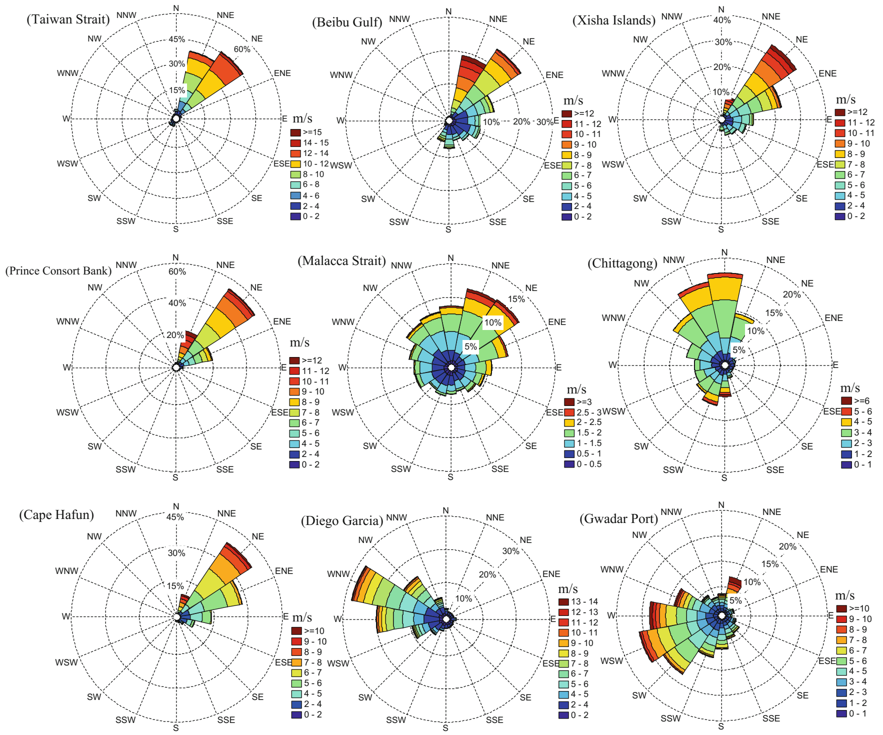

Fig. 2.2 Wind rose (Co-occurrence of wind speed and wind direction) of several key points of the Maritime Silk Road in February (after Zheng et al. 2015)

In February, under the influence of the northeast monsoon, wind direction and strong wind direction are dominated primarily by the northeast, except Chittagong (north-northwest), Gwadar (west-southwest), and Diego Garcia (west to west-northwest). Threatening strong winds include primarily the northeast wind in the Taiwan Strait (the occurrence of wind speed between 10 and 12 m/s is 15%; that between 12 and 14 m/s is 12%), the north-northeast wind in the Beibu Gulf (the occurrence of wind speed between 10 and 12 m/s is 13%), and the northeast wind in the Xisha Islands (the occurrence of wind speed between 10 and 12 m/s is 11%).

In August, the dominant wind direction in the Taiwan Strait, Beibu Gulf, Xisha Islands, Gwadar, and Cape Hafun is south-southwest; in the Malacca Strait and Chittagong it is south; in Diego Garcia it is southeast to south-southeast; in Prince Consort Bank it is west-southwest. Threatening strong winds include primarily south-southwest winds in Cape Hafun (the occurrence of wind speed between 12 and 13 m/s is 25%; that between 13 and 14 m/s can be up to 30%; and that between 14 and 15 m/s is 13%), which can be attributed to the strong southwest monsoon of the waters off Somalia.

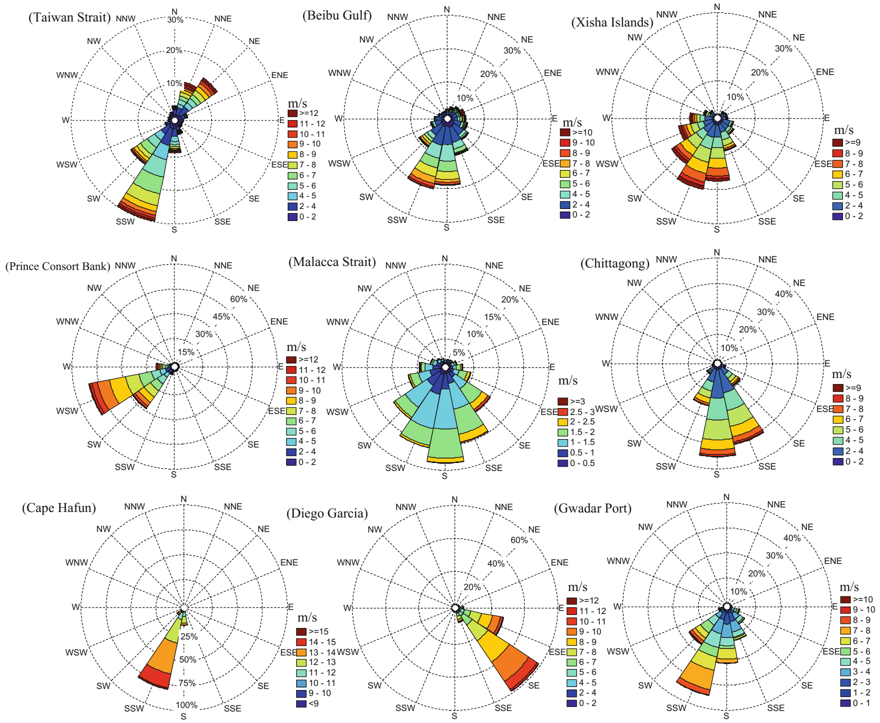

Fig. 2.3 Wind rose (Co-occurrence of wind speed and wind direction) of several key points of the Maritime Silk Road in August (after Zheng et al. 2015)

Here we only present the wind rose in represent month (February and August). In the future work, it is necessary to present the wind rose of key points in each month, to provide detail reference for the related project and research (For example, the Wind Rose of Diego Garcia, as shown in Appendix (3)).

2.4 Occurrence of Strong Winds and Gusts

Strong wind has a significant impact on safety of navigation, ocean engineering, and so on (Zheng 2013; Zheng et al. 2013a, 2014a). In this chapter, 6-hourly ERA-interim wind data for the period 1979–2014 are used to determine strong wind occurrence (occurrence of 10-min average wind speed greater than class 6) (Fig. 2.4). Similarly, strong gust occurrence (occurrence of gust wind speed greater than class 6) is counted based on 6-hourly ERA-interim gust data for the period 1979–2014 (Fig. 2.5). To provide a detail reference, we also present the occurrence of 10-min average wind speed greater than class 6, occurrence of gust wind speed greater than class 6 and

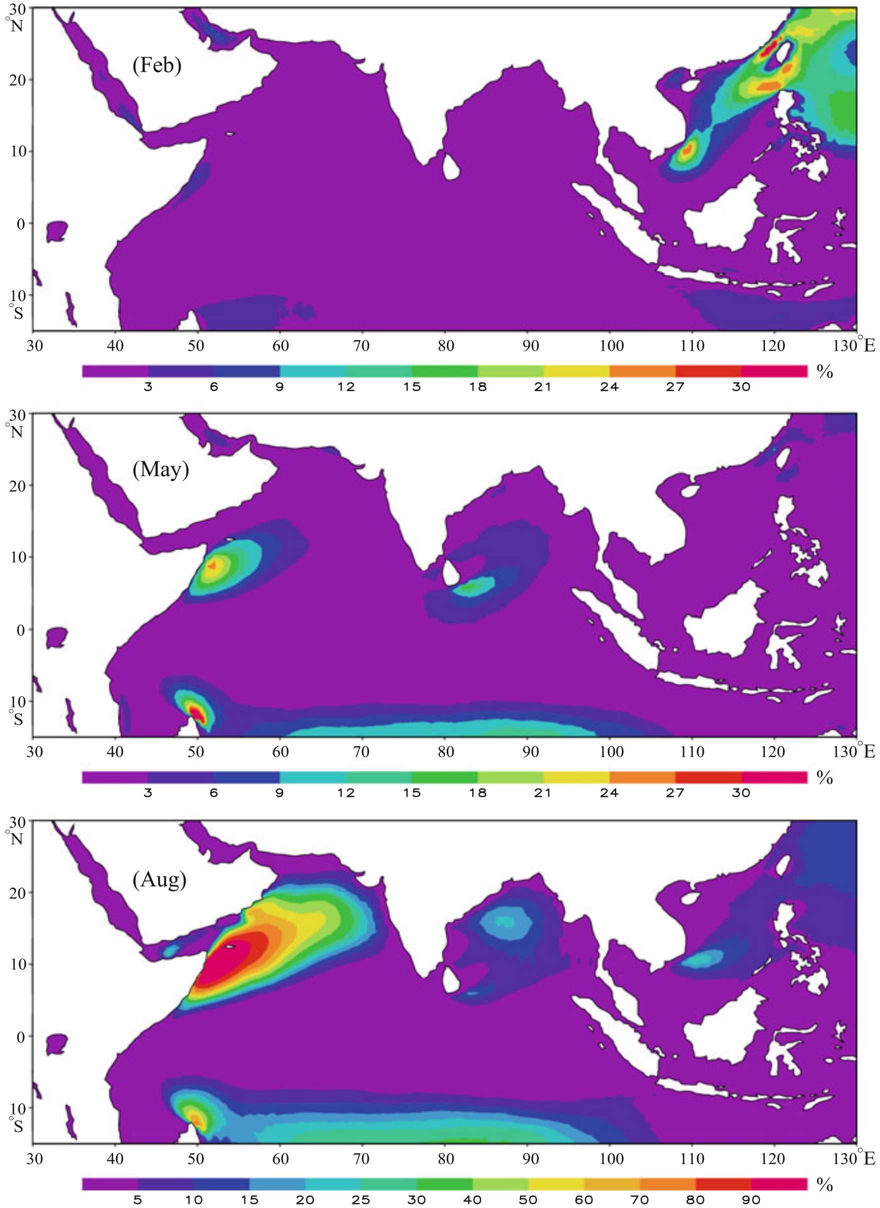

Fig. 2.4 Occurrence of 10-min average wind speed greater than class 6 of the Maritime Silk Road (after Zheng et al. 2015)

occurrence of gust wind speed greater than class 8 in each month, as shown in Appendix (3–5).

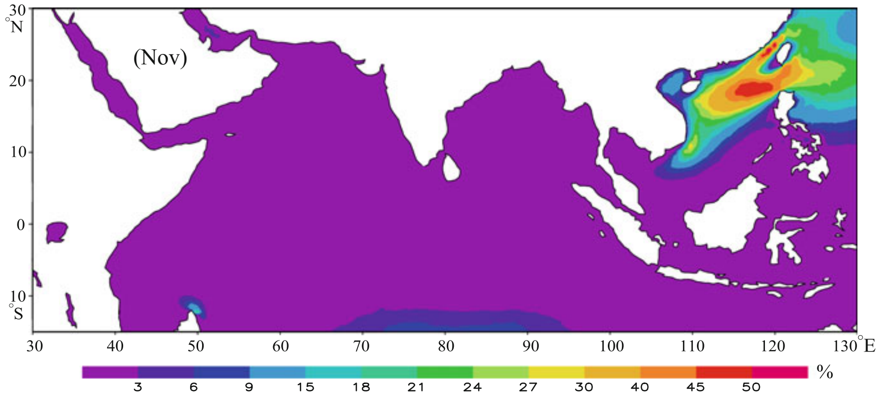

Fig. 2.4 (continued)

Occurrence of 10-min average wind speed greater than class 6 (Fig. 2.4):

The occurrence of wind speed greater than class 6 in the northern Indian Ocean in November and February and in the South China Sea in May is below 5%. In February, the winter monsoon in the South China Sea is strong, resulting in two large-value centers: the waters surrounding Taiwan Island and the traditional gale center of the South China Sea, where the occurrence of wind speed greater than class 6 is above 20%. In May, the occurrences in the South China Sea and the northern Indian Ocean are relatively low. Under the influence of the southwest monsoon, the waters off Somalia and southeastern Sri Lanka are have relatively large occurrences. In August, under the strong southwest monsoon, the occurrence in most of the Arabian Sea is over 40%, and it is even up to 90% in the waters off Somalia. Although the impact of the southwest monsoon in the Bay of Bengal and the South China Sea is also obvious, strong wind occurrence in the Bay of Bengal and the South China Sea is not as high as that in the Arabian Sea. In November, strong wind occurrence in the South China Sea (above 40%) is much greater than that in the northern Indian Ocean.

Occurrence of gust wind speed greater than class 6 (Fig. 2.5):

In February, the occurrence of gust wind speed greater than class 6 in most of the South China Sea is above 25%, even above 55% in the large-value center. In addition, the Persian Gulf, the Red Sea, and the waters off Somalia are areas of relatively large occurrence. In May, the occurrence in the South China Sea is low, whereas the occurrence in most of the Bay of Bengal and the Arabian Sea is relatively high (above 20%). In August, the occurrence in the Arabian Sea and the Bay of Bengal is very high, greater than 90% in the Arabian Sea and greater than 60% in the Bay of Bengal. The occurrence in the South China Sea is relatively low, about 40%. In November, the occurrence in the northern Indian Ocean is generally low, below 10%. The occurrence in the central and northern parts South China Sea is relatively high,

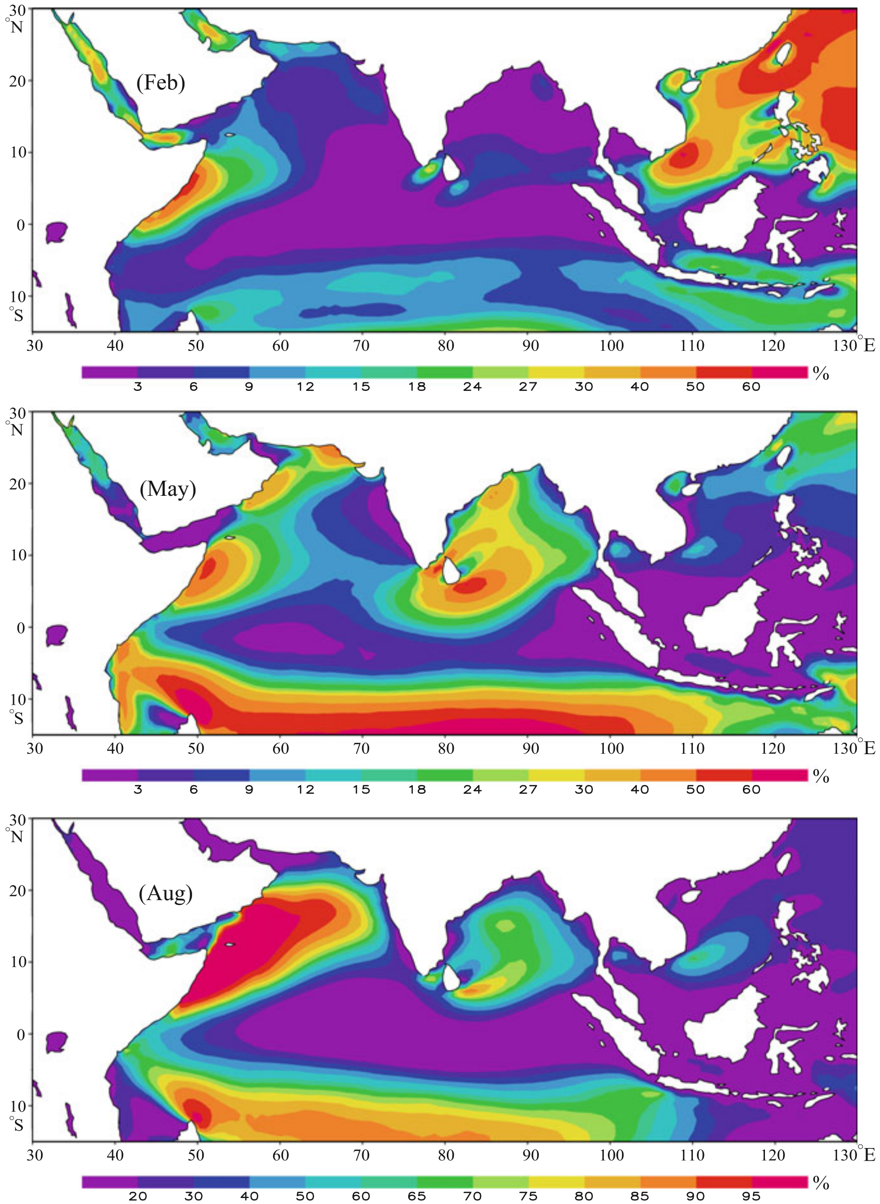

Fig. 2.5 Occurrence of gust wind speed greater than class 6 of the Maritime Silk Road (after Zheng et al. 2015)

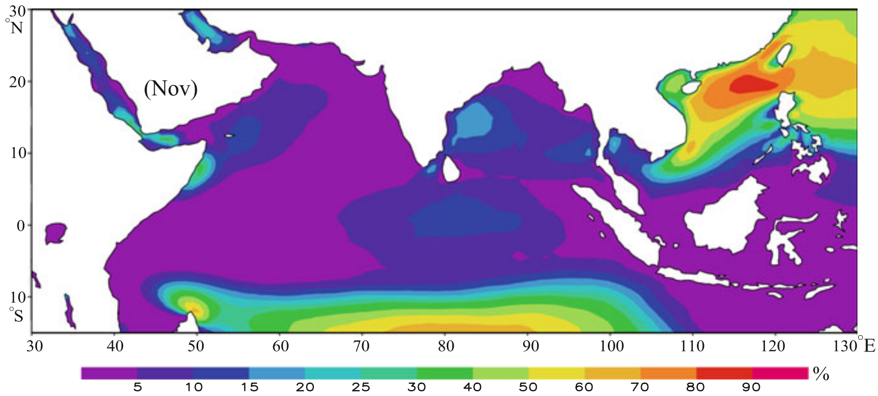

Fig. 2.5 (continued)

greater than 40%, with large-value centers located in the Luzon Strait and its western waters (can be up to 80%).

In this chapter, we discuss only the seasonal characteristics of strong wind occurrence and strong gust occurrence. In future work, it will be necessary to document these occurrences during each month. In addition, an analysis of the long-term trend of strong wind occurrence and strong gust occurrence is needed to provide a reference for the long-term planning of disaster prevention and mitigation, ocean engineering, and so on.

2.5 Gust Index

In numerical forecast products, the forecast wind speed is generally the 10-min average wind speed. In actual navigation and ocean engineering, the impact of gusts is large and cannot be ignored (Zheng et al. 2014b, c). However, general numerical forecast products do not provide gust wind speed. Therefore, it is necessary to statistically analyze the gust index. Combining the forecast wind speed and gust index makes it possible to obtain the forecast gust wind speed. The gust coefficient is defined as the ratio of gust wind speed to the corresponding 10-min average wind speed at a given moment (China Meteorological Administration Department Policies and Regulations 2007). This chapter calculates the gust index of the South China Sea and the northern Indian Ocean during June–July–August (JJA) and December–January–February (DJF). We calculate wind gusts only when the 10-min average wind speed is greater than class 5 (8.0 m/s), as shown in Fig. 2.6.

Figure 2.6a, b show that the gust index of the northern Indian Ocean in JJA is obviously greater than that in DJF, whereas the reverse is true in the South China Sea.

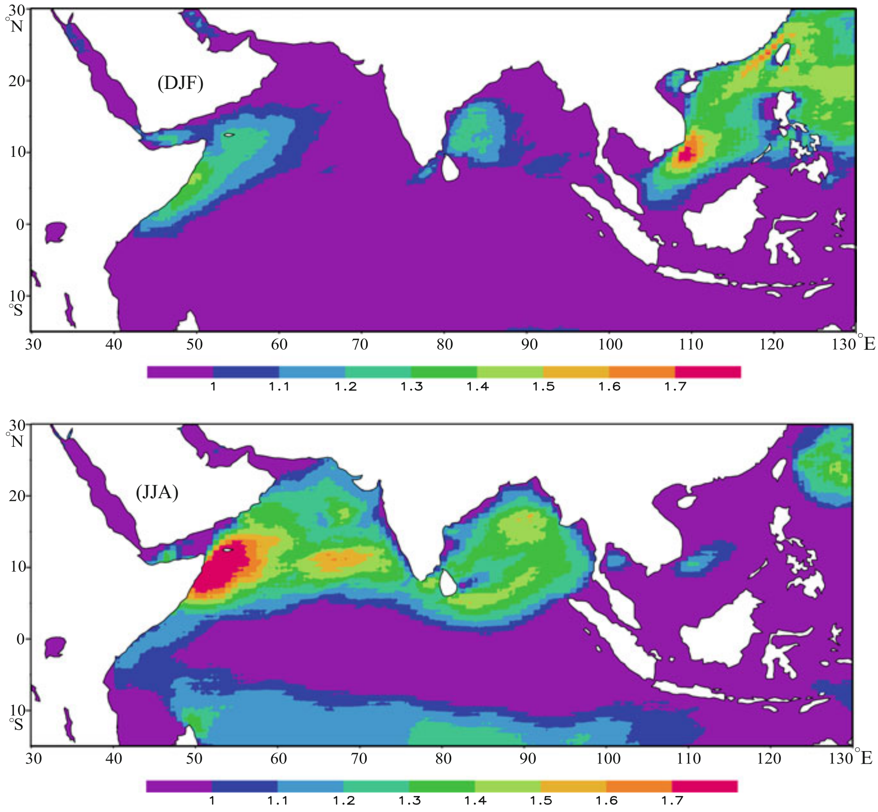

Fig. 2.6 Gust index in DJF and JJA in 2014 of the Maritime Silk Road (after Zheng et al. 2015)

In DJF, the gust index in most of the central and northern South China Sea (except the Beibu Gulf and the Gulf of Thailand) is above 1.3. The gust index in most of the northern Indian Ocean is below 1.2, with areas of relatively large values located in a small region in the western Bay of Bengal (1.2–1.3) and a small region on the Somali coast (1.2–1.4). In JJA, the gust index in most of the Arabian Sea and the Bay of Bengal is above 1.3, with areas of large values on the Somali coast (even up to 1.8). The gust index in most of the South China Sea is below 1.2.

2.6 Annual Trend of Sea Surface Wind Speed

The long-term trend of sea surface wind speed (WS) is important to the development of offshore wind energy resources and is closely related to global climate change analysis. A yearly average value of WS at each 0.25° × 0.25° bin is obtained using the average WS from 0000 UTC January 1, 1979, to 1800 UTC December 31, 1979.

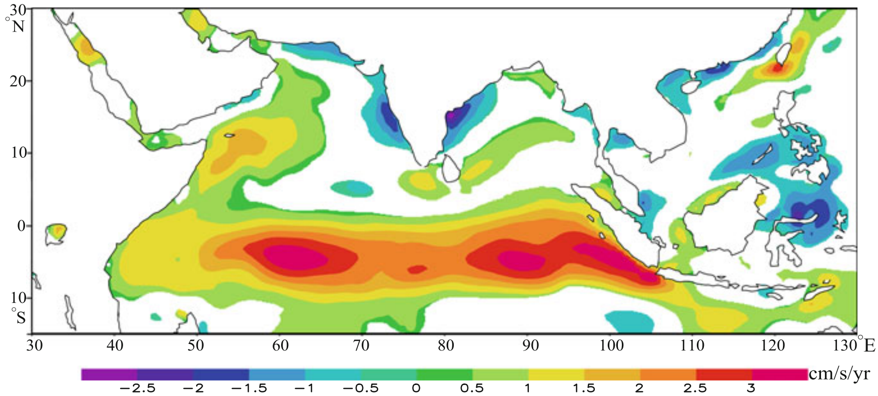

Fig. 2.7 Annual trend of sea surface wind speed after 3-point moving average of the Maritime Silk Road during 1979–2017. Only areas significant at the 95% level are presented

Similarly, a yearly average value of WS at each 0.25° × 0.25° bin for the past 36 years (1979–2014) is obtained. Then, the annual trend of WS of the Maritime Silk Road is analyzed using linear regression and 3-point moving average, as shown in Fig. 2.7.

The WS in most of the South China Sea and most of the northern Indian Ocean does not show significant variation during the past 36 years. Areas with a significant increasing trend are distributed primarily in the waters between 10°S and equator (1.0–3.0 cm/s/year) and in the mid-west of the Arabian Sea (0.5–2.5 cm/s/year). Areas range with a significant decreasing trend of WS are small: the west and east coasts of the Indian Peninsula (−2.5 to 0 cm/s/year), in the Sulawesi Sea (−2.5 to 0 cm/s/year), Palawan island waters (about −1.0 cm/s/year), the Beibu Gulf (about −1.0 cm/s/year), the coast waters of Guangdong Province (about −1.5 cm/s/year), and in other scattered regions.

2.7 Extreme Wind Speed

Extreme wind speed has a significant impact on marine engineering, marine energy development, disaster prevention and reduction, and so on. Previous researchers have presented several studies on China seas, but only a few studies on the northern Indian Ocean, which is not conducive to the efficient and safe implementation of the Maritime Silk Road initiative. In this chapter, ERA-interim gust wind data from ECMWF are used to calculate the annual extreme wind speed with a return period of 100 years (U_{100}), using the Gumbel curve method, as shown in Fig. 2.8.

In the South China Sea, U_{100} in the central and northern regions is above 50 m/s, at times even greater than 55 m/s in the large center. The extreme values in the northern South China Sea could be attributed to the impact of typhoons and cold air, while the extreme values in the central and southern South China Sea could be attributed

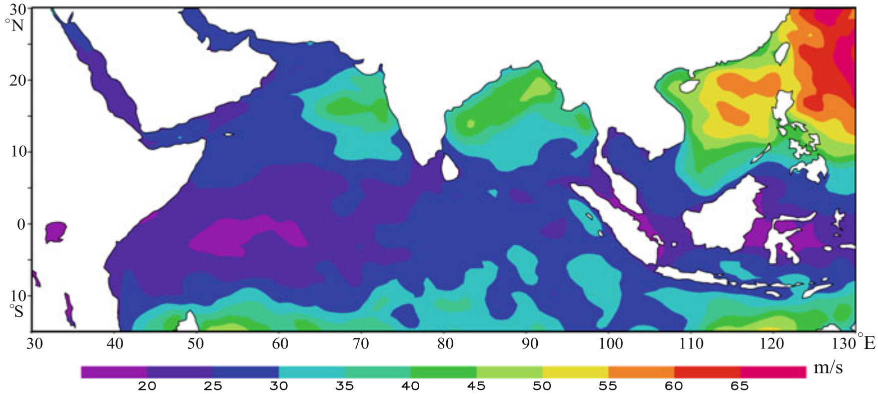

Fig. 2.8 Annual extreme wind speed with a return period of 100 years; unit: m/s

to the impact of local typhoons, resulting in a low extreme value in the south and a large extreme value in the north. The U_{100} values in the Gulf of Thailand and the low latitude waters of the South China Sea are smaller than 30 m/s. In the Arabian Sea, U_{100} in the central and eastern regions (greater than 30 m/s) is much greater than that in the other waters, which could be attributed to the impact of terrain. Tropical cyclones in the Arabian Sea usually occur northwest of the Western Ghats and finally land in southern Pakistan. In the Bay of Bengal, U_{100} is much greater than that in the Arabian Sea; in particular, the area range with $U_{100} > 40$ m/s at the top of the Bay of Bengal is much larger than that in the Arabian Sea. Here, we only present the U_{100}. Similarly, we can calculate the extreme wind speed with a return period of 30 years (U_{30}), extreme wind speed with a return period of 50 years (U_{50}), etc., according to the actual demand of different engineerings.

2.8 Wind Field for the Next 40 Years

Based on the fifth phase of the Coupled Model Intercomparison Project (CMIP5) and the wind production under the representative concentration pathway (RCP) 4.5 scenario from the Intergovernmental Panel on Climate Change (IPCC), the sea surface wind field of the Maritime Silk Road for the next 40 years (2020–2059) is analyzed in this chapter. In addition, the wind field for the next 40 years (future wind field hereafter) is compared with the wind field for 1979–2014 (past wind field hereafter) to provide a reference for wind energy development, disaster prevention and reduction, and so on, as shown in Figs. 2.9 and 2.10. To facilitate observations, we use color to represent wind speed and unit vector arrows to represent wind direction.

In February (representing winter), as a whole, the future wind field shows good agreement with the corresponding month in the past wind field. The agreement of wind direction is better than that of wind speed. There are two obvious large-value

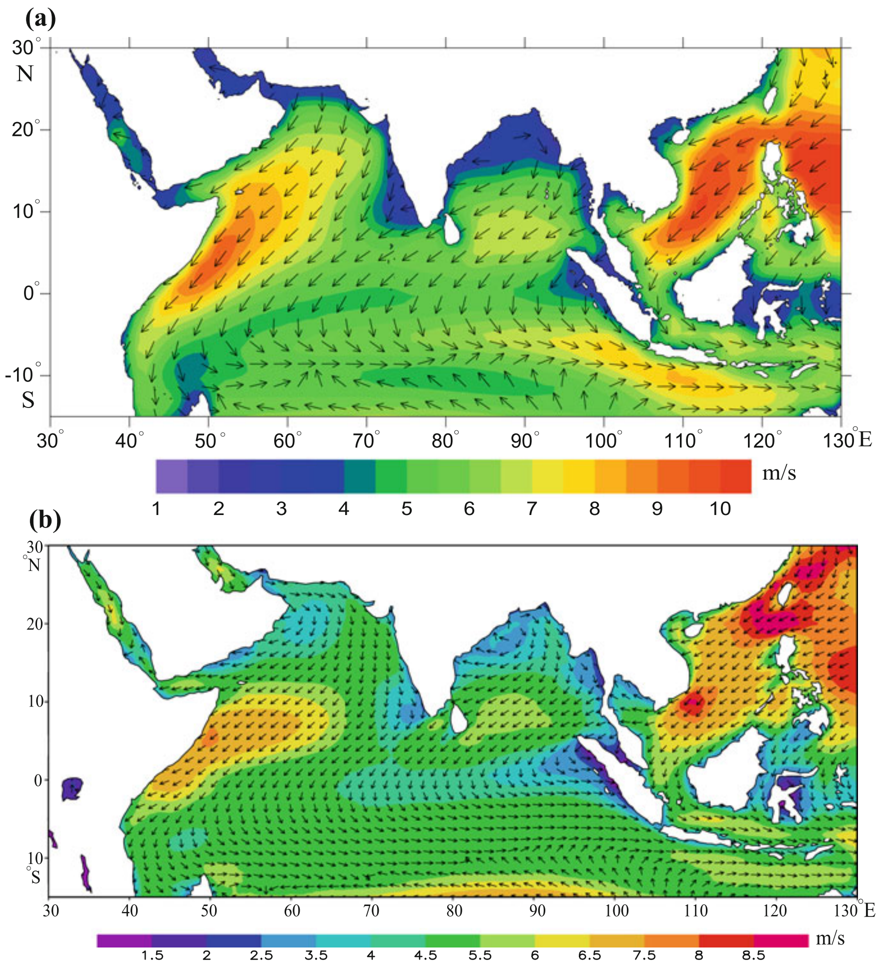

Fig. 2.9 Sea surface wind field of the Maritime Silk Road in February for the next 40 years (2020–2059) (**a**) and for the past 36 years (1979–2014) (**b**); unit of wind speed: m/s

centers of wind speed in the future wind field: the waters off Somalia (>8 m/s) and in the South China Sea (>9 m/s). The central and southern Bay of Bengal have areas of relatively large wind speed (5–7 m/s) for the next 40 years. The prevailing wind direction in the South China Sea and the northern Indian Ocean is northeast for the next 40 years. It worth noting that winter wind speed in the waters off Somalia for the next 40 years is stronger than that in the past 36 years, and the area range of wind speed greater than 7 m/s is also greater for the next 40 years than that in the past 36 years. The winter wind speed in the waters off Somalia for the next 40 years (>8 m/s) is stronger than that in the past 36 years (>6 m/s). The winter wind speed in the Bay of Bengal for the next 40 years is similar to that in the past 36 years.

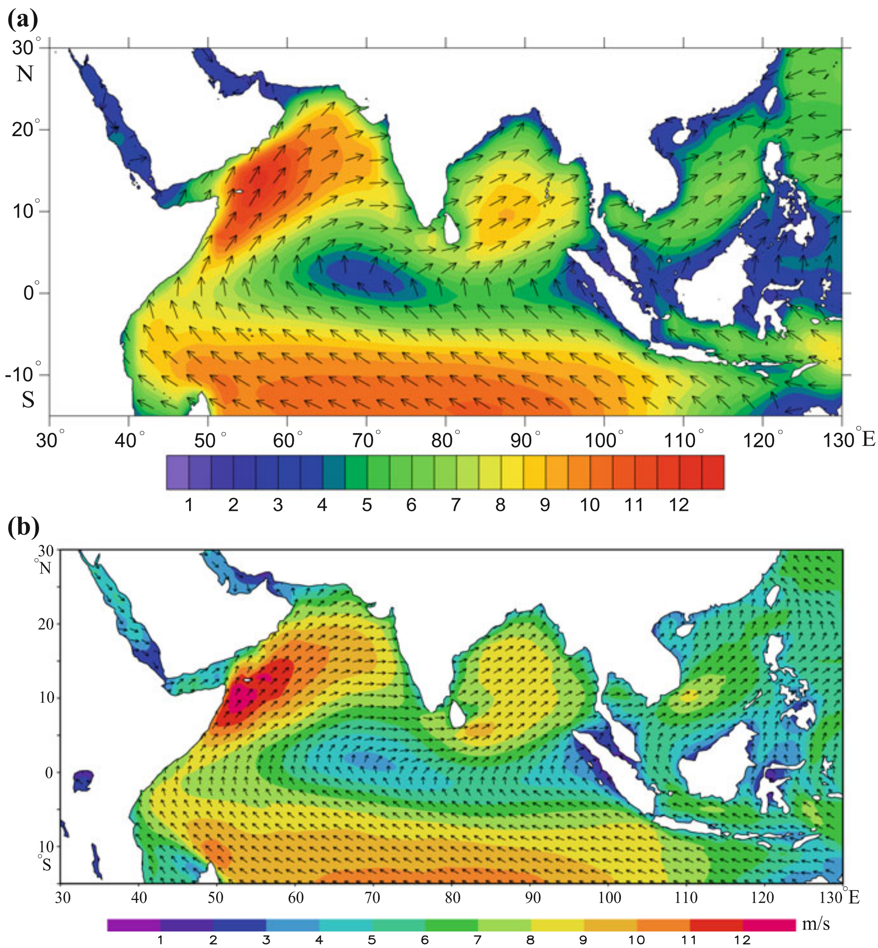

Fig. 2.10 Sea surface wind field of the Maritime Silk Road in August for the next 40 years (2020–2059) (**a**) and for the past 36 years (1979–2014) (**b**); unit of wind speed: m/s

In August (representing summer), as a whole, the future wind field shows good agreement with the corresponding month in the past wind field, and the agreement of wind direction is better than that of wind speed. The agreement between the future wind field and the past wind field in August is better than that in February. For the next 40 years, the wind speed is above 8 m/s in most of the Arabian Sea (even greater than 12 m/s in the large-value center), 5–9 m/s in most of the Bay of Bengal, and 4–7 m/s in most of the South China Sea. The prevailing wind direction in the South China Sea and the northern Indian Ocean is southwest for the next 40 years.

In this chapter, the sea surface wind field of the Maritime Silk Road under the RCP4.5 scenario for the next 40 years (2020–2059) is analyzed. Using this method, the characteristics of the future wind field under different scenarios (RCP2.6, RCP6.0, and RCP8.5) can also be analyzed. In addition, only wind speed and direction are analyzed in this chapter. It is necessary to analyze strong wind direction, strong wind occurrence, extreme wind speed, and other important factors in future work.

2.9 Summary

In this chapter, ERA-interim wind data and ERA-interim gust data from ECMWF are used to analyze the wind climate of the 21st Century Maritime Silk Road, including primarily the seasonal characteristics of wind direction and wind speed, the occurrence of 10-min average wind speed greater than class 6, the occurrence of gust wind speed greater than class 6, the gust index, the long-term trend of sea surface wind speed, and so on. CMIP5 wind data are used to analyze the characteristics of the future (2020–2059) wind field of the Maritime Silk Road. Important conclusions are as follows:

Seasonal characteristics of the wind field
In February, the primary wind direction is northeast in the South China Sea and north-northeast in the northern Indian Ocean. The intensity of the winter monsoon in the South China Sea is obviously higher than that in the northern Indian Ocean. In May, south of 17°N in the South China Sea and the northern Indian Ocean the transformation from the northeast monsoon to the southwest monsoon is complete. North of 17°N in the South China Sea is the monsoon transition period. In August, the southwest monsoon is the strongest in the Arabian Sea and smaller in the Bay of Bengal and South China Sea. Conventional wisdom regards November as the monsoon transition season. We found that the conversion from the southwest monsoon to the northeast monsoon is completed in November, and the wind direction on almost all of the Maritime Silk Road is dominated by the northeast.

Strong wind direction occurrence
In February, strong wind direction occurrence is dominated primarily by the northeast; in August, it is dominated primarily by the southwest and south. Threatening strong winds include primarily south-southwest winds in Cape Hafun (the occurrence of wind speed between 12 and 13 m/s is 25%; that between 13 and 14 m/s can be up to 30%; and that between 14 and 15 m/s is 13%), which can be attributed to the strong southwest monsoon in the waters off Somalia.

Occurrence of 10-min average wind speed greater than class 6
The occurrence of wind speed greater than class 6 is below 5% during the autumn and winter in the northern Indian Ocean and during spring in the South China Sea. In autumn and winter, the areas of large wind speed are distributed in the South China Sea. In summer, the occurrence in the Arabian Sea is above 40%, even up to 90% on the Somali coast.

Occurrence of gust wind speed greater than class 6

In February, the occurrence in most of the South China Sea is above 25%. In May, the occurrence in the South China Sea is low, whereas the occurrence in most of the Bay of Bengal and the Arabian Sea is relatively high (above 20%). In August, the occurrence in the Arabian Sea and the Bay of Bengal is very high, greater than 90% in the Arabian Sea and greater than 60% in the Bay of Bengal. The occurrence in the South China Sea is relatively low, about 40%. In November, the occurrence in the northern Indian Ocean is generally low, below 10%. The occurrence in the central and northern South China Sea is relatively high, greater than 40%.

Gust index

The gust index of the northern Indian Ocean in JJA is obviously greater than that in DJF, whereas it is the reverse in the South China Sea. In DJF, the gust index in most of the central and northern South China Sea is above 1.3. The gust index in most of the northern Indian Ocean is below 1.2. In JJA, the gust index in the Bay of Bengal and Arabian Sea is above 1.3. The gust index in the South China Sea is below 1.2.

Long-term trend of wind speed

The wind speed in most of the South China Sea and most of the northern Indian Ocean does not show significant variation during the past 36 years. Areas with a significant increasing trend are distributed primarily in the waters between 10°S and 0° (1–4 cm/s) and in the southwestern Arabian Sea (1–2 cm/s). Areas with a significantly decreasing trend are distributed primarily on the west and east coast of the Indian Peninsula, in the Sulawesi Sea, and in other small regions.

Extreme wind speed

Areas of relatively large extreme wind speed are distributed primarily in the northern South China Sea, the northern Bay of Bengal, and the eastern Arabian Sea. The extreme wind speed in the South China Sea is obviously greater than that in the northern Indian Ocean.

Future wind field

Under the RCP4.5 scenario, the wind fields in February and August for the next 40 years (2020–2059) show good agreement with the corresponding month for the past 36 years (1979–2014). The agreement in August is better than that in February. The agreement of wind direction is better than that of wind speed. The winter wind speed in the waters off Somalia and in the South China Sea for the next 40 years is stronger than that in the past. The winter wind speed in the Bay of Bengal and the summer wind speed in the South China Sea and the northern Indian Ocean for the next 40 years are similar to those in the past.

References

Chen X, You XB, Zheng CW (2017) Instruction to mathematic structures of ekman current. Lambert Academic Publishing

China Meteorological Administration department policies and regulations (2007) Meteorological industry standard assembly

Gao ZS, Zheng CW, Shi WL (2017) Wave climate and wave energy resource in the China Seas [M]. Lambert Academic Publishing

Zheng CW, Li CY (2015) Development of the islands and reefs in the South China Sea: wind climate and wave climate analysis. Periodical of Ocean Univ China 45(9):1–6

Zheng CW, Zhuang H, Li XQ et al (2012) A comparison study on the global change trend of SST analyzed based on two data sets. Adv Mar Sci 30(2):171–176

Zheng CW (2013) Statistics of gale frequency in global oceans. J Guangdong Ocean Univ 33(6):77–81

Zheng CW, Lin G, Shao LT (2013a) Frequency of rough sea and its long-term trend analysis in the China Sea from 1988 to 2010. J Xiamen Univ (Nat Sci) 52(3):395–399

Zheng CW, Zhou L, Song S et al (2013b) Long term trend of global sea surface temperature from 1870 to 2011. Oceanologia et Limnologia Sin 44(5):1123–1129

Zheng CW, Zhou L, Song S et al (2014a) Simulation of the wave field caused by 1307 Typhoon "Soulik". J Xiamen Univ (Nat Sci) 53(2):257–262

Zheng CW, Pan J, Huang G (2014b) Forecasting of the China Sea ditching probability using WW3 wave model. J Beijing Univ Aeronaut Astronaut 40(3):314–320

Zheng CW, Shao LT, Li G et al (2014c) Analysis of influence on the security of sea skimming caused by a typhoon wave. Journal of Harbin Engineering University 35(3):301–306

Zheng CW, Li XQ, Gao ZS et al (2015) Strategic of the 21st century Maritime Silk Road: wind climate analysis. Ocean Dev Manag 32(8):4–11

Zheng CW, Li CY, Pan J (2016) Global oceanic wind speed and wind energy climate features and trends. Lambert Academic Publishing

Zheng CW, Gao CZ, Zhang R (2017) Global oceanic wave energy resources evaluation [M]. Lambert Academic Publishing

Chapter 3
Wave Climate Characteristics

The ocean wave has a significant impact on the safety and cost of navigation, wave energy resources development, seawall design, ocean engineering, island and reef construction, disaster prevention and reduction, air-sea interaction, global climate change and so on. Previous researchers have made a great contribution to the wave climate analysis of the China seas (Zheng and Li 2015a; Zheng et al. 2012, 2015a). However, there are few studies on the wave climate of the northern Indian Ocean, so there is no detailed reference for the construction of the Maritime Silk Road (Zheng et al. 2015b, c; Zheng and Li 2015b). In this chapter, the wave climate (systematically including the seasonal characteristics of wave direction and wave height, wave rose (co-occurrence of wave height and wave direction), rough sea occurrence, the annual trend of significant wave height (SWH), extreme wave height, the future wave field, etc.) of the Maritime Silk Road is analyzed based on ERA-interim wave reanalysis data from the European Centre For Medium-Range Weather Forecasts (ECMWF) and WW3 hindcast wave data forced by the CMIP5 wind data to provide a reference for navigation, ocean engineering, wave energy development, disaster prevention and reduction, and so on.

3.1 Data and Methodology

Using ERA-interim wave reanalysis data from ECMWF, the wave climate of the Maritime Silk Road is analyzed, including primarily the seasonal characteristics of wave direction and wave height, co-occurrence of wave direction and wave height (wave rose), rough sea occurrence, the long-term trend of SWH, and so on. The time resolution of the ERA-interim wave reanalysis data is 6 h. The spatial resolution covers 0.125° × 0.125°, 0.25° × 0.25°, 0.5° × 0.5°, 0.75° × 0.75°, 1.0° × 1.0°,…, 2.5° × 2.5°. In this book, the spatial resolution of 0.125° × 0.125° is used. The time range is from January 1979 to the present and the geographical range is 90°S–90°N

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Springer Oceanography, https://doi.org/10.1007/978-981-10-7977-1_3

and 180°W–180°E. These data have high reliability and are widely used (Dee et al. 2011; Kent et al. 2013).

Using the CMIP5 projection wind data from the IPCC to drive the third-generation wave model WW3, we also obtained a 3-hourly hindcast global wave field for the next 40 years (2020–2059) to analyze the characteristics of the future wave field of the Maritime Silk Road. In addition, the wave field for the next 40 years (shortened to future wave field hereafter) is also compared with the wave field for 1979–2014 (shortened to past wave field hereafter), to better serve mid- to long-term planning for navigation, ocean engineering, disaster prevention and reduction, and other activities related to ocean waves.

3.2 Seasonal Characteristics of Wave Field

The seasonal characteristics of wave direction and SWH for the past wave field are presented in Fig. 3.1. To facilitate observations, we use the background color to represent wave height and unit vector arrows to represent wave direction. To provide a detail reference, we also present the wave field in each month, as shown in Appendix(6): Wave field in each month of the Maritime Silk Road.

In February (representing winter), cold air processes have a more obvious impact on the South China Sea than on the northern Indian Ocean, which agrees with the findings of Zheng et al. (2015c). The SWH in most of the South China Sea is greater than 1.4 m, even greater than 1.8 m in the large center. The SWH in north of 10°N in the northern Indian Ocean is below 1.2 m, but much larger south of 10°N; it even reaches 2.0 m at 10°S. This can be attributed to the impact of swells from the southern Indian Ocean. The wave direction in most of the South China Sea is northeast, but in the Beibu Gulf it is east-southeast.

In May (representing spring), the wave direction in the whole northern Indian Ocean is south. There is no obvious rule of wave direction in the southern South China Sea. The wave direction is southeast in the central South China Sea and east in the northern South China Sea. Zheng et al. (2015c) have pointed out that the northern Indian Ocean completes the transition to the southwest monsoon during this month, whereas the South China Sea transitions from the northeast monsoon to the southwest monsoon. The SWH in most of the northern Indian Ocean is above 1.2 m, much greater than that in the South China Sea (0.4–1.0 m). It is worth noting that the waves in the northern Indian Ocean show an obvious northward propagation judging from the contours of SWH.

In August (representing summer), under the impact of the strong southwest monsoon, the wave direction in the South China Sea and northern Indian Ocean is southwest. The SWH in most of the Arabian Sea is greater than 2.2 m, even reaching 3.6 m in the waters off Somalia, followed by the Bay of Bengal (1.4–2.8 m), and then the South China Sea (1.2–1.8 m in the north-central region, about 0.6 m in the low-latitude waters, the Gulf of Thailand, the Beibu Gulf, and offshore of the Indochina Peninsula). In addition, the SWH in the east of the Indian Peninsula, in the Red Sea, and in the Persian Gulf is also small, about 0.6 m.

In November (representing autumn), the wave direction is northeast in the South China Sea, south in the east-central Bay of Bengal, east in the western Bay of Bengal and the west-central Arabian Sea, and south in the eastern Arabian Sea. During this month, the gradually prevailing cold air has a significant impact on the South China Sea, a smaller impact on the Arabian Sea, and no impact on the Bay of Bengal. The SWH in the South China Sea is much greater than that in the northern Indian Ocean. The SWH in the north-central South China Sea is above 1.2 m, with a large center of about 2.4 m located in the northern South China Sea. The SWHs in the Bay of Bengal and the Arabian Sea are 1.0–1.6 m and 0.6–1.4 m, respectively.

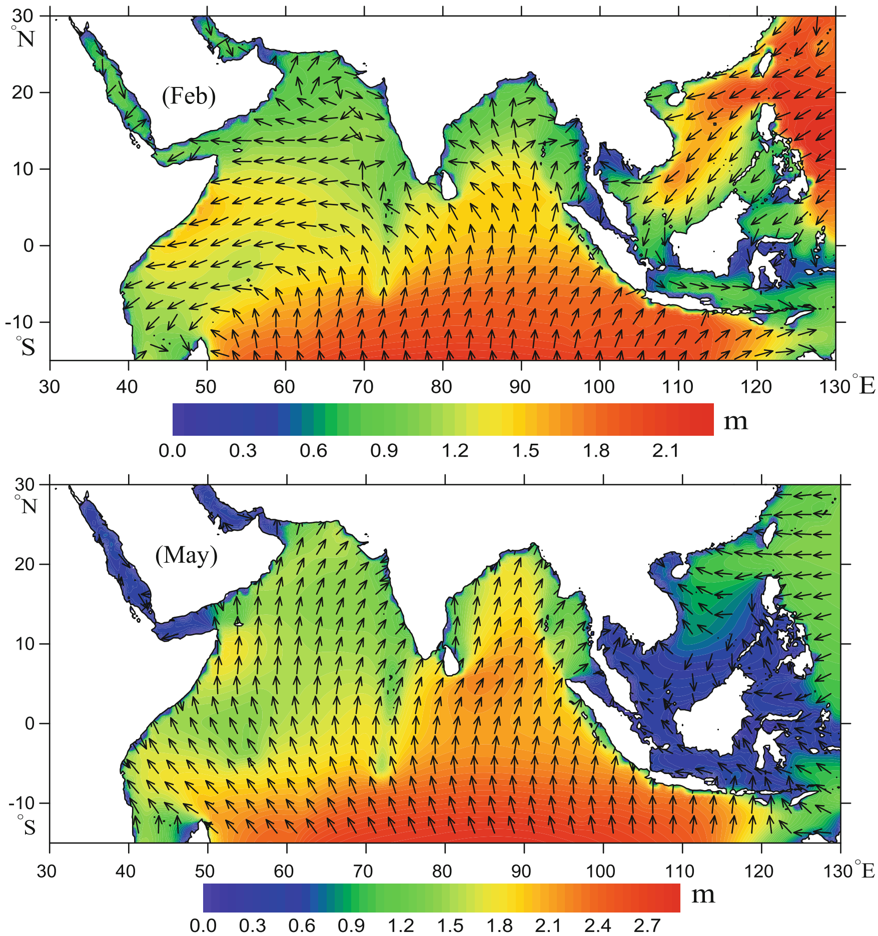

Fig. 3.1 Wave field of the Maritime Silk Road (after Zheng et al. 2015d)

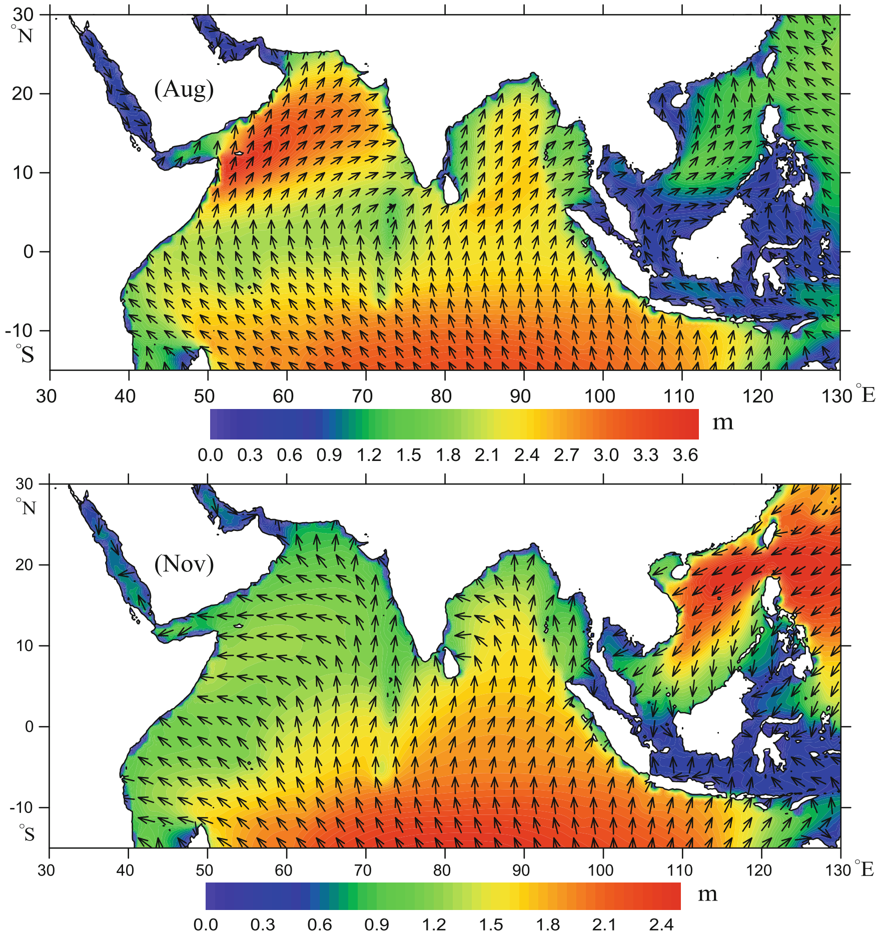

Fig. 3.1 (continued)

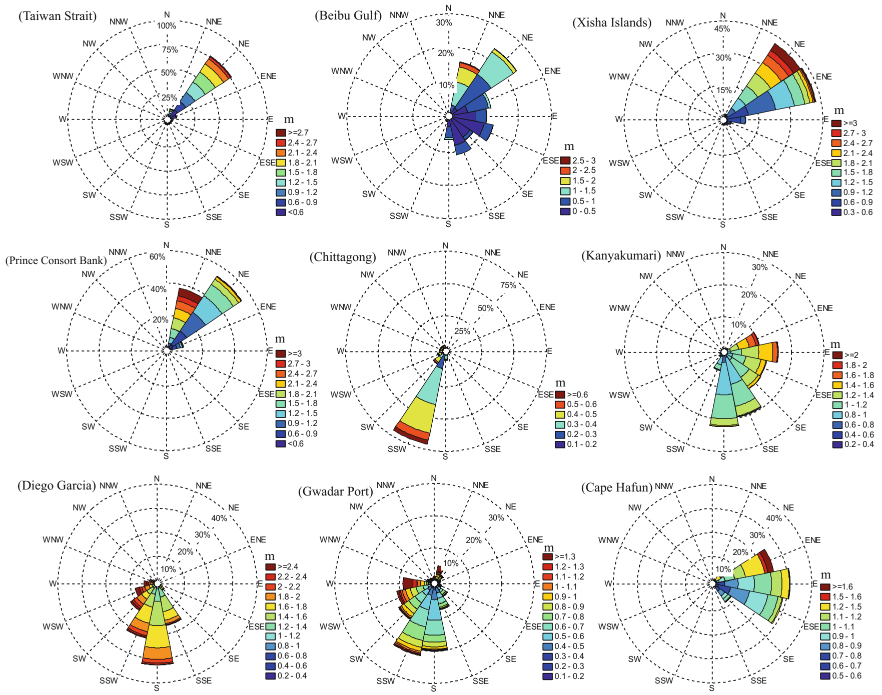

Fig. 3.2 Wave rose (combined wave direction and significant wave height) of several key points of the Maritime Silk Road in February (after Zheng et al. 2015d)

3.3 Wave Rose (Co-occurrence of Wave Height and Wave Direction)

Based on the 6-hourly SWH and wave direction data for the period 1979–2014, the co-occurrence of wave direction and wave height (wave rose) of some key points on the Maritime Silk Road is counted, as shown in Figs. 3.2 and 3.3. To provide a detail reference, we also present the wave rose in each month. And the wave rose in Diego Garcia is selected as a case study, as shown in Appendix(7): Wave rose of Diego Garcia (co-occurrence of wave height and wave direction).

In February, the most frequent strong wave direction is northeast (NE) at several key points in the South China Sea. The most frequent strong wave direction is south (S) at several key points in the northern Indian Ocean.

In August, the most frequent strong wave direction is S or southwest (SW) at most of the key points. Diego Garcia is located south of the equator. Under the impact of cross-equatorial flow, the wave direction in Diego Garcia is dominated by south-southeast (SSE) and southeast (SE). SWH greater than 3.0 m also comes from these two directions. During this month, attention should be directed toward strong waves from the south-southwest (SSW) in the Taiwan Strait, from the S in China's Xisha

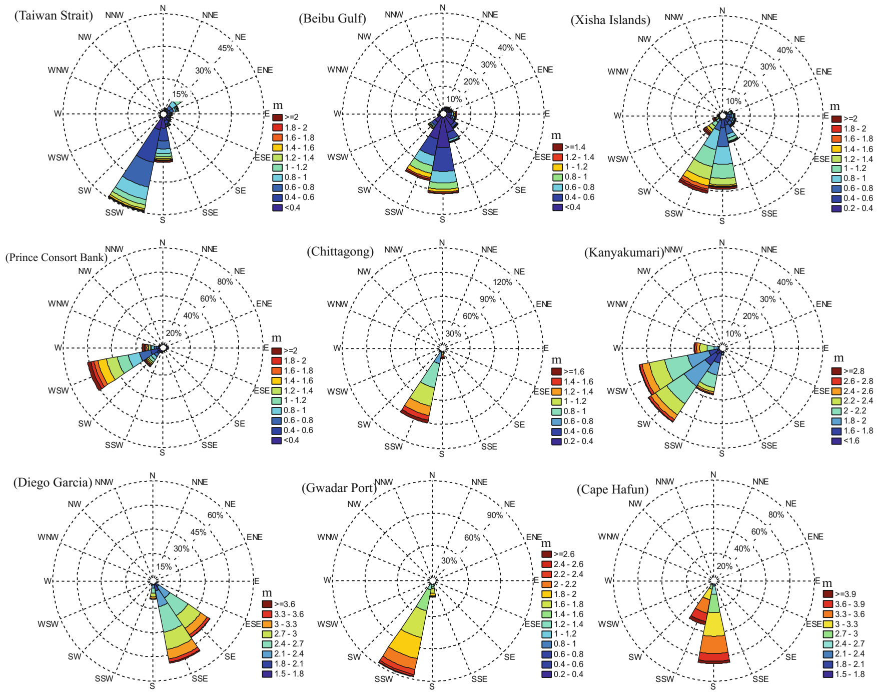

Fig. 3.3 Wave rose (combined wave direction and significant wave height) of several key points of the Maritime Silk Road in August (after Zheng et al. 2015d)

Islands, from the SSW in Chittagong, from the SW and west-southwest (WSW) in Kanyakumari, from the S, SSE, and SE in Diego Garcia, from the SSW in Gwadar, and from the S and SSW in Cape Hafun.

3.4 Rough Sea Occurrence

Big waves have a significant negative impact on navigation, ocean engineering, disaster prevention and reduction, and so on (Zheng et al. 2013, 2014). Based on 6-hourly ERA-interim wave data for the period 1979–2014, the rough sea occurrence (occurrence of SWH greater than 2.5 m) in each season and the annual mean value are counted, as shown in Figs. 3.4 and 3.5. To provide a detail reference, we also present the rough sea occurrence in each month, as shown in Appendix(8).

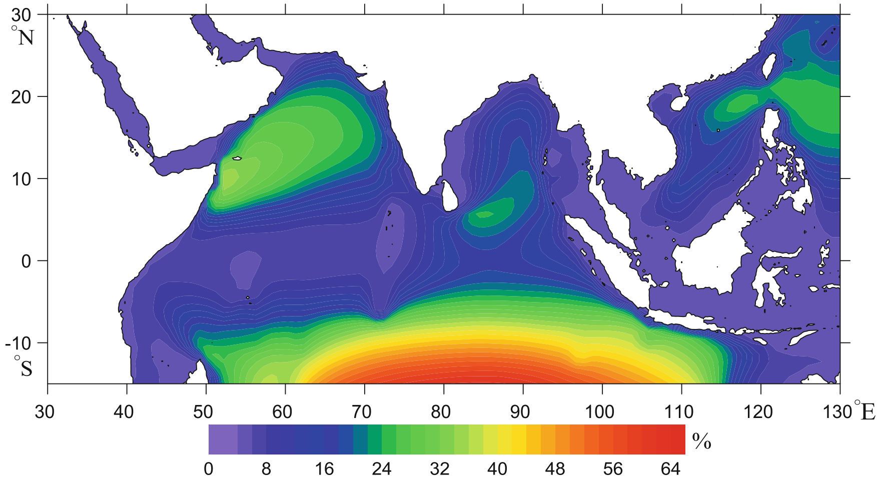

Fig. 3.4 Annual rough sea occurrence (occurrence of SWH greater than 2.5 m) of the Maritime Silk Road

3.4.1 Annual Rough Sea Occurrence

Based on 6-hourly ERA-interim wave data for the period 1979–2014, the multi-year average annual rough sea occurrence at each 0.125° × 0.125° bin is counted, as shown in Fig. 3.4. The rough sea occurrence in the Arabian Sea (10–40%) is much greater than that in the Bay of Bengal and the South China Sea. The contours of rough sea occurrence in the Arabian Sea exhibit a northeast-southwest shape, with large areas located in the waters off Somalia, which can be attributed to the effect of the strong southwest monsoon. The rough sea occurrence in the north-central South China Sea is 10–30%, with large areas located in the Luzon Strait and its western waters (25–30%). The rough sea occurrence in the Beibu Gulf, the Gulf of Thailand, and the low-latitude waters of the South China Sea is below 10%, and it is about 15% in the central Bay of Bengal. There is a relative large value region of rough sea occurrence between the Sri Lanka and Sumatra (of 20–30%). The rough sea occurrence in the Bay of Bengal is caused primarily by the northward propagation of swells in the southern Indian Ocean.

3.4.2 Seasonal Difference of the Rough Sea Occurrence

Based on 6-hourly ERA-interim wave data from 0000 UTC February 1, 1979, to 1800 UTC February 28, 1979, the rough sea occurrence (occurrence of SWH greater than 2.5 m) at each 0.125° × 0.125° bin in this month is counted. Similarly, the rough sea occurrences in each February for the past 36 years (1979–2014) are counted. Then the multi-year average rough sea occurrence in February is obtained. Using the same method, the rough sea occurrences in four representative months (February, May, August and November) are obtained, as shown in Fig. 3.5.

Rough sea occurrence in February: Cold air does not have a significant impact on the northern Indian Ocean, resulting in a low rough sea occurrence of below 10%. The occurrence in the north-central South China Sea is greater than 10%, whereas it is greater than 20% in the traditional gale center of the South China Sea and in the Luzon Strait.

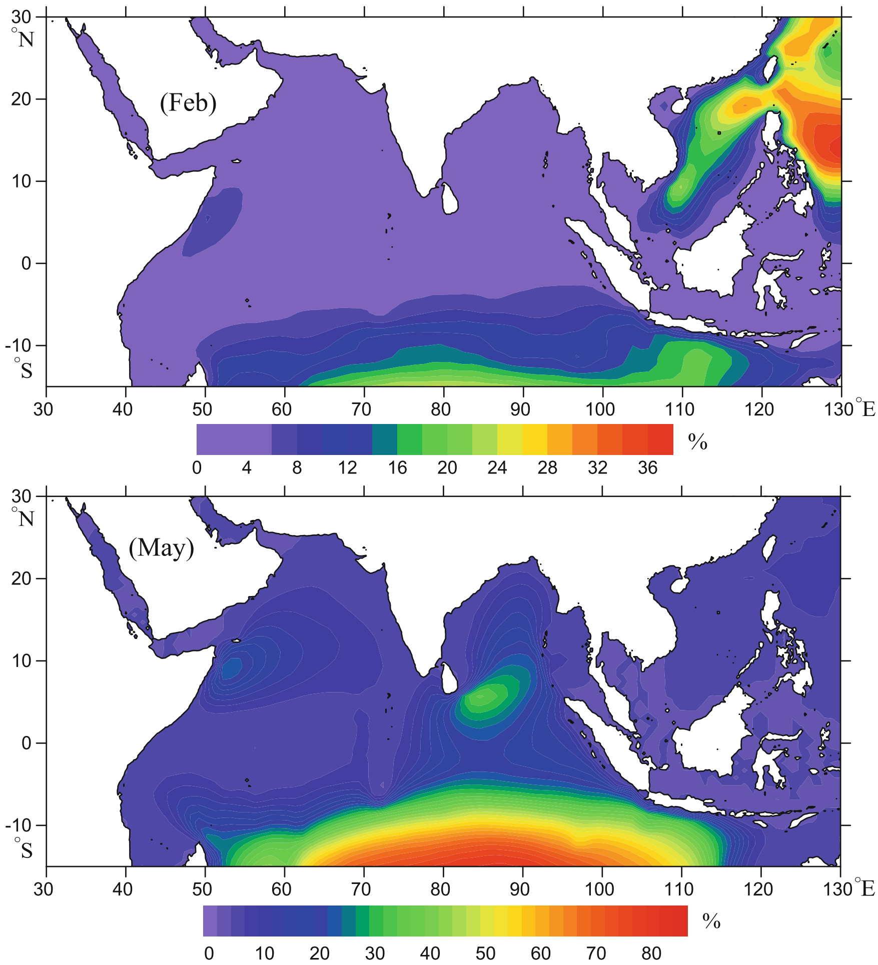

Fig. 3.5 Rough seas occurrence (occurrence of SWH greater than 2.5 m) in representative month of the Maritime Silk Road

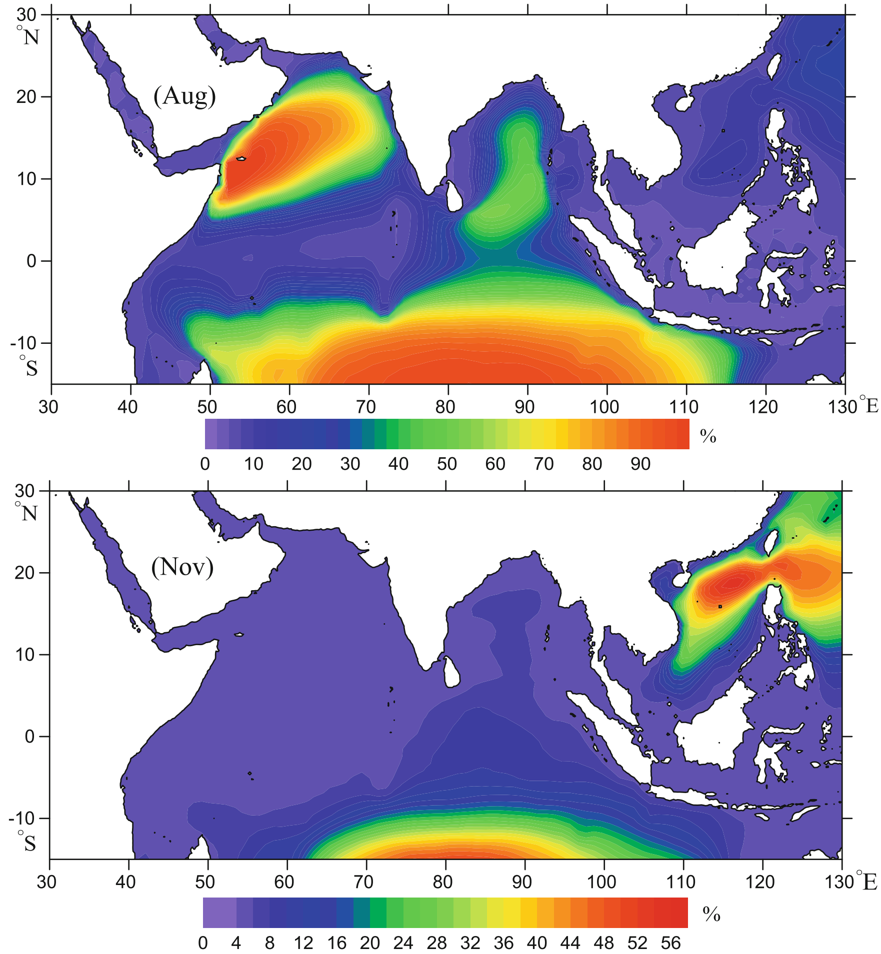

Fig. 3.5 (continued)

Rough sea occurrence in May: The rough sea occurrence in the South China Sea is below 10%. The highest occurrence is in the south-central Bay of Bengal, which is attributed to the northward propagation of swells in the southern Indian Ocean. In addition, there is a relatively large area northeast of Somalia, which is caused by the gradually prevailing southwest monsoon.

Rough sea occurrence in August: Under the impact of the strong southwest monsoon, rough sea occurrence in the whole Arabian Sea is greater than 40%, even reaching 90% in the waters off Somalia. The rough sea occurrence in the Bay of Bengal is smaller than that in the Arabian Sea, above 30% in the south-central region. Despite the impact of the southwest monsoon, the rough sea occurrence in the South China Sea is much smaller than that in the Arabian Sea and the Bay of Bengal.

Rough sea occurrence in November: The occurrence in the whole northern Indian Ocean is low, below 10%. Under the impact of gradually prevailing cold air processes, the rough sea occurrence in the north-central South China Sea can be greater than 20%, even greater than 50% in the Dongsha Islands.

3.5 Long-Term Trend of Rough Sea Occurrence

3.5.1 Annual Trend of Rough Sea Occurrence

Based on 6-hourly ERA-interim wave data from 0000 UTC January 1, 1979, to 1800 UTC December 31, 1979, the rough sea occurrence (occurrence of SWH greater than 2.5 m) in each 0.125° × 0.125° bin for the year 1979 is counted. Using the same method, the rough sea occurrence in each year for the past 36 years (1979–2014) is obtained. Then, the annual trend of rough sea occurrence in each 0.125° × 0.125° bin for the past 36 years is calculated by using linear regression, as shown in Fig. 3.6.

For the past 36 years, the rough sea occurrence in more than half of the research region exhibits a significant increasing trend. The areas with significant increasing trends are distributed primarily in the northern South China Sea (~0.09–0.33%/yr; here and in the following, the % is the rough sea occurrence, not the variation rate of the rough sea occurrence), a small region in the Bay of Bengal (~0.03–0.09%/yr), the northern Arabian Sea (~0.06–0.21%/yr), a large region from Somalia to Diego Garcia (~0.03–0.27%/yr), and a west-east belt east of Diego Garcia (about 0.12%/yr). Only some scattered areas exhibit a significant decreasing trend in rough sea occurrence. Areas without significant variations are located primarily in the south-central South China Sea and to the west and east of the Indian Peninsula.

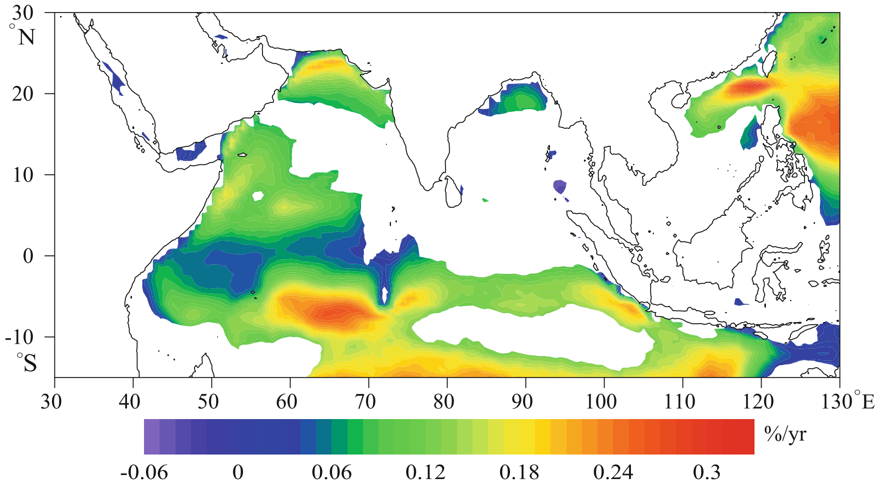

Fig. 3.6 Annual trend of rough sea occurrence (occurrence of SWH greater than 2.5 m) of the Maritime Silk Road for the period 1979–2014 (after Zheng et al. 2016)

3.5.2 Monthly Trend of Rough Sea Occurrence

Based on 6-hourly ERA-interim wave data from 0000 UTC January 1, 1979, to 1800 UTC January 31, 1979, the rough sea occurrence at each 0.125° × 0.125° bin in this month is counted. Similarly, the rough sea occurrences in each January for the past 36 years are counted. Then the long term trend of rough sea occurrence in January for the past 36 years is calculated by using linear regression. Similarly, the long term trends of rough sea occurrence in each month for the past 36 years are calculated (Figures omitted).

In January, the rough sea occurrence in the north-central South China Sea exhibits a significant increasing trend of ~0.4–0.7%/yr. There is no significant variation in the other waters. In February, most of the research region does not exhibit significant variation. Only a small region in the Dongsha Islands and one to the west of Sumatra exhibit a significant increasing trend. In March, rough sea occurrence in the northern South China Sea exhibits a significant increasing trend of ~0.2–0.6%/yr, whereas it does not exhibit significant variation in the south-central South China Sea and the northern Indian Ocean. In April, no significant variation exists in the whole research region. In May, only the central Bay of Bengal exhibits a significant increasing trend of ~0.3–0.5%/yr; there is no significant trend in other waters. In June, the northern Arabian Sea has a significant increasing trend of ~0.4–1.0%/yr. The areas with significant decreasing trends are located primarily in the central Bay of Bengal (~−0.8 to −0.4%/yr) and the central South China Sea (~−0.4–0.0%/yr). In July, rough sea occurrence in most of the South China Sea exhibits no significant variation. The north coast of the Bay of Bengal exhibits a significant increasing trend of 0.4%/yr. Most of the Arabian Sea shows a significant increasing trend, except the waters off

Somalia. In August, no significant variation exists in the whole research region. In September, the northern South China Sea and a small region in the northern Bay of Bengal show a significant increasing trend, of ~0.2–0.4%/yr. The increasing trend in the Arabian Sea is strong, above 0.5%/yr, even reaching 1.2%/yr in the large-value center. In October, the South China Sea and the Arabian Sea have no significant variation, whereas the north-northwest of the Bay of Bengal exhibits a significant decreasing trend. In November, no significant variation exists in the whole research region. In December, the waters off the Dongsha Islands, a small area northeast of Sri Lanka, a small area off the coast of Somalia, and a wide region southwest of Sumatra have a significant increasing trend.

3.5.3 Dominant Month of the Long-Term Trend

Zheng et al. (2013) pointed out that the long-term variation of rough sea occurrence in different waters is usually dominated by different seasons. In Table 3.1, we present the monthly and annual long-term trends of rough sea occurrence in the South China Sea, the Bay of Bengal, and the Arabian Sea and the dominant month of the long-term trend. Obviously, rough seas occur in the South China Sea primarily in January, March, and September; in the Bay of Bengal they occur mostly in July, September, and October; and in the Arabian Sea they occur mostly in June, July, and September.

3.6 Annual Trend of Significant Wave Height

The long-term trend of significant wave height (SWH) has a significant impact on wave energy resource development, global climate change, and so on. Using the method of Zheng et al. (2013) and Zheng and Li (2015c), the annual long-term trend of SWH in each $0.125° \times 0.125°$ bin of the Maritime Silk Road for the past 36 years (1979–2014) is calculated based on ERA-interim wave data, as shown in Fig. 3.7.

For the past 36 years, the increasing trend of SWH in the South China Sea is greater than 0.4 cm/yr, much greater than that in the northern Indian Ocean. The increasing trend in the northern South China Sea and southeast of Taiwan is above 0.6 cm/yr, even reaching 0.8 cm/yr in the large center. The Beibu Gulf and the Gulf of Thailand do not exhibit significant variation. Almost the whole Bay of Bengal and a wide area west of the Indian Peninsula do not exhibit significant variation in the long-term trend of SWH. The SWH in the western Arabian Sea and between 15°S and 0° in the Indian Ocean exhibits a significant increasing trend, of 0.1–0.4 cm/yr. Only some scattered waters exhibit a significant decreasing trend.

Table 3.1 Monthly and annual long-term trends of rough sea occurrence in the South China Sea, the Bay of Bengal, and the Arabian Sea and the dominant month of the long-term trend

	South China Sea	Bay of Bengal	Arabian Sea
January	~0.4–0.7%/yr in the north-central region	——	——
February	——	——	——
March	~0.2–0.6%/yr in the northern region	——	——
April	——	——	——
May	——	~0.3–0.5%/yr in the central region	——
June	~ −0.4 to −0.0%/yr in the central region	~ −0.8 to −0.4%/yr in the central region	~0.4–1.0%/yr on the coast of the northern region
July	——	0.4%/yr on the coast of northern region	~0.4–1.3%/yr on the edge of the Somali gale area
August	——	——	——
September	~0.2–0.4%/yr in the northern region	~0.2–0.4%/yr in a small area of the northern region	>0.5%/yr in most of the region
October	——	~0.0–0.2%/yr in the north-northwestern region	——
November	——	——	——
December	——	——	——
Annual	~0.09–0.33%/yr in the northern region	~0.03–0.09%/yr in a small area of the northern region	~0.06–0.21%/yr in the north, ~0.03–0.27%/yr from Somalia to Diego Garcia
Dominant months	January, March, September	July, September, October	June, July, September

Note "——" means without significant variation

3.7 Extreme Wave Height

Extreme wave height is one of the primary considerations of seawall design, ocean engineering, and island reef construction. In this chapter, the ERA-interim wave data from ECMWF are used to calculate annual extreme wave height with a return period of 100 years (H_{100}) using the Gumbel curve method, as shown in Fig. 3.8.

In the South China Sea, the H_{100} in the central and northern regions (above 10 m) is greater than that in the southern region, with a large center of about 12 m located in the Luzon Strait and its western waters. The extreme values in the northern South China Sea could be attributed to the impact of typhoons and cold air, while the

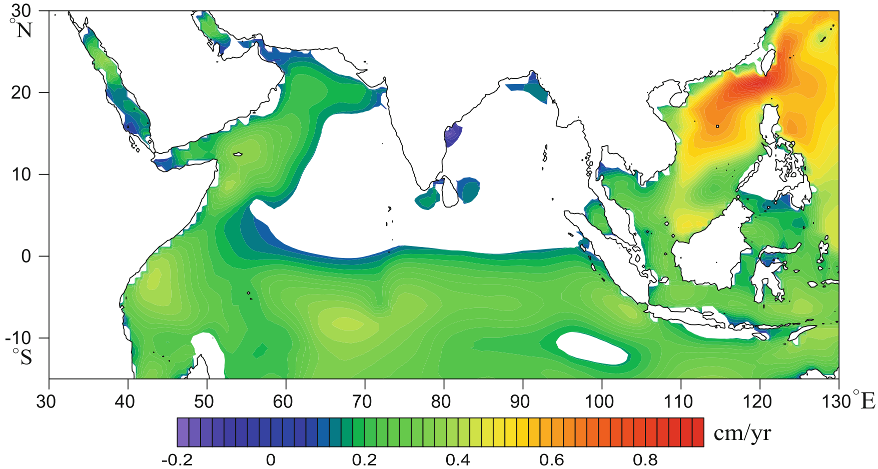

Fig. 3.7 Annual long-term trend of significant wave height for the period 1979–2014. Only areas significant at the 95% level are presented

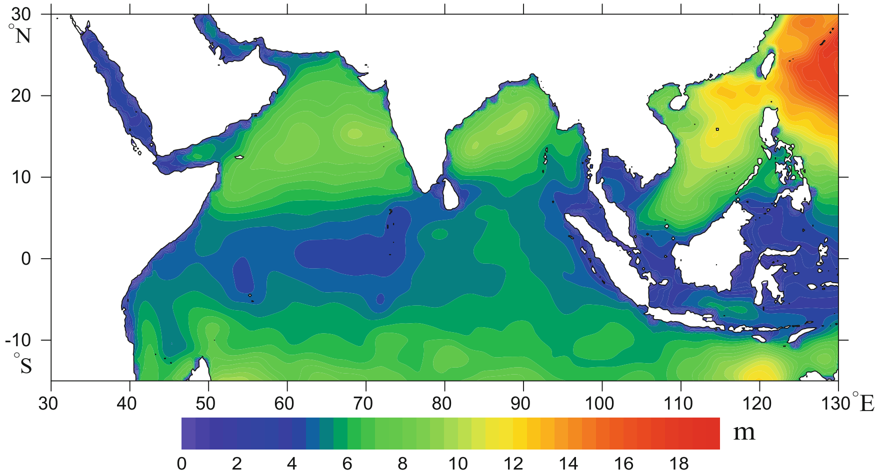

Fig. 3.8 Annual extreme wave height with a return period of 100 years

extreme values in the southern South China Sea could be attributed to the impact of local typhoons, resulting in a low extreme value in the south and a large extreme value in the north. In the Arabian Sea, the H_{100} in most of this area is above 5 m. The extreme value in the east is obviously greater than that in the west. In the Bay of Bengal, the H_{100} in most of this area is above 5 m. The extreme value in the northwest is obviously greater than that in other waters. It is worth noting that the area range with H_{100} > 9 m in the Bay of Bengal is much larger than that in the Arabian Sea. Here, we only present the H_{100}. Similarly, we can calculate the extreme wave height with a return period of 30 years (H_{30}), extreme wave height with a return period of 50 years (H_{50}), etc., according to the actual demand of different engineerings.

3.8 Wave Field for the Next 40 Years

Zheng (2017) obtained the wave field of China seas using CMIP5 projection wind data from the IPCC to drive the third-generation wave model WW3. Then, the wave energy resources were projected. Referring to their method, using the CMIP5 projection wind data to drive the WW3 wave model, we obtain a 3-hourly hindcast global wave field for the next 40 years (2020–2059) to analyze the characteristics of the future wave field of the Maritime Silk Road. In addition, the future wave field is compared with the past wave field, as shown in Figs. 3.9 and 3.10. To facilitate observations, we use color to represent the SWH and unit vector arrows to represent the wave direction.

In February (representing winter), as a whole, the future wave field agrees well with the corresponding month for the past wave field. For the next 40 years, the area range of SWH greater than 1.2 m is obviously larger than that for the past. The SWH in the South China Sea for the next 40 years (>1.6 m) is greater than that for the past (1.2 m), which is consistent with the sea surface wind field (Fig. 2.9).

In August (representing summer), as a whole, the future wave field agrees well with the corresponding month for the past wave field, especially in the Arabian Sea. The SWH in the Bay of Bengal and the South China Sea for the next 40 years is greater than that for the past.

In this chapter, the wave field of the Maritime Silk Road under the RCP4.5 scenario for the next 40 years (2020–2059) is analyzed. Using this method, the characteristics of the future wave field under different scenarios (RCP2.6, RCP6.0, and RCP8.5) can also be analyzed. In addition, only wave height and direction are analyzed in this chapter. It is necessary to analyze strong wave direction, rough sea occurrence, extreme wave height, and other important factors in future work to provide a detailed reference for wave power generation, ocean navigation, disaster prevention and reduction, and so on.

3.9 Summary

In this chapter, ERA-interim wave data from ECMWF are used to analyze the wave climate of the 21st Century Maritime Silk Road, including primarily the seasonal characteristics of wave direction and wave height, the combined wave direction and significant wave height (wave rose), rough sea occurrence, the long-term trend of SWH, and so on. CMIP5 wind data and the WW3 numerical wave model are used

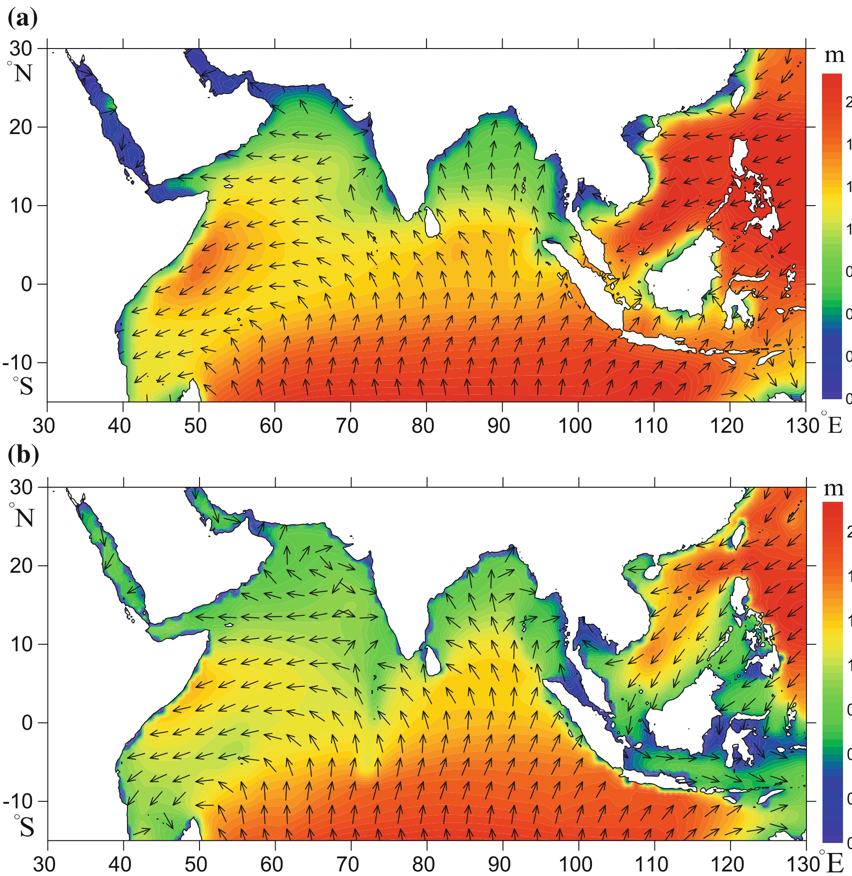

Fig. 3.9 Wave field of the Maritime Silk Road in February for the next 40 years (2020–2059) (**a**) and for the past 36 years (1979–2014) (**b**); unit of significant wave height: m

to analyze the characteristics of the future (2020–2059) wave field of the Maritime Silk Road. The important conclusions are described below.

In February, cold air processes have a more obvious impact on the South China Sea than on the northern Indian Ocean. The SWH in the South China Sea (>1.4 m) is much greater than that in the northern Indian Ocean. The wave direction is northeast in the South China Sea and south in the Bay of Bengal, with a clockwise rotation in the Indian Ocean north of 10°N, and to the east south of 10°N. In May, the SWH in the northern Indian Ocean (>1.2 m) is much greater than that in the South China Sea (~0.4–1.0 m). The wave direction is south in the northern Indian Ocean, southeast in the central South China Sea, and east in the northern South China Sea. In August, the SWH is highest in the Arabian Sea (>2.2 m), followed by the Bay of Bengal (~1.4–2.8 m), and smallest in the South China Sea. The wave direction is southwest in most regions. In November, the SWH in the South China Sea (>1.2 m in the north-

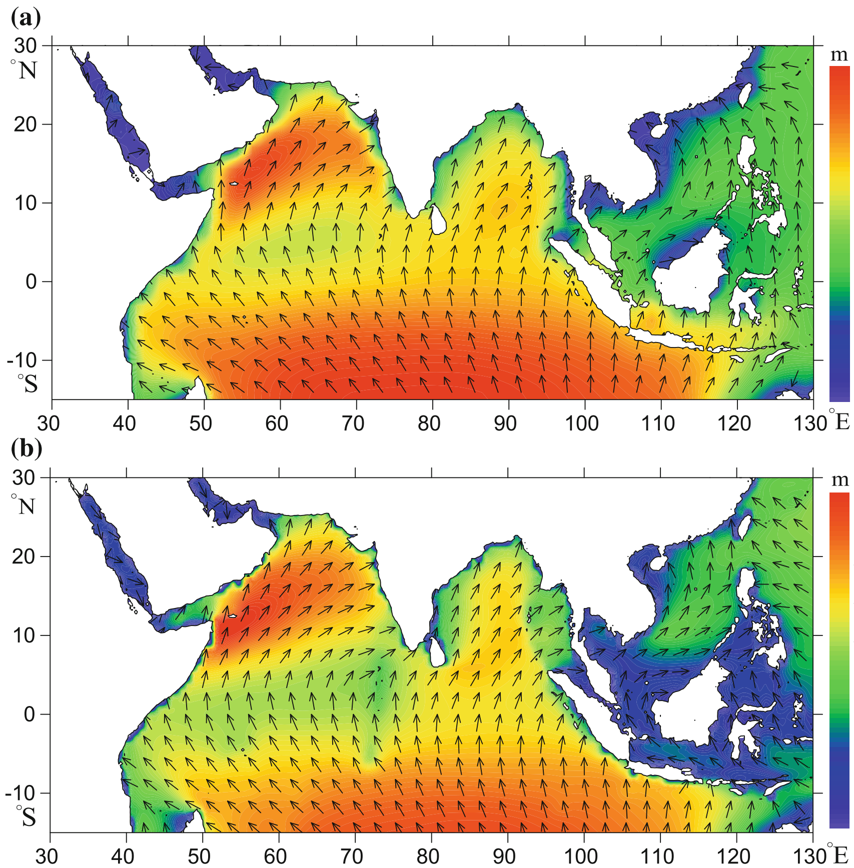

Fig. 3.10 Wave field of the Maritime Silk Road in August for the next 40 years (2020–2059) (**a**) and for the past 36 years (1979–2014) (**b**); unit of significant wave height: m

central region) is much greater than that in the northern Indian Ocean (~1.0–1.6 m in the Bay of Bengal and ~0.6–1.4 m in the Arabian Sea).

In February, the most frequent strong wave direction is NE at several key points in the South China Sea, and S at several key points in the northern Indian Ocean. In August, the most frequent strong wave direction is S or SW at most of the key points of the Maritime Silk Road.

In February and November, rough sea occurrence in the northern Indian Ocean (<10%) is much smaller than that in the South China Sea. In May, rough sea occurrence on the Maritime Silk Road is below 10%. In August, rough sea occurrence in the Arabian Sea is greater than 40% (even > 90% in the waters off Somalia), followed by the Bay of Bengal, and then the South China Sea.

For the period 1979–2014, the areas with significant increasing trends in rough sea occurrence are mainly distributed in the north of the South China Sea

(0.09–0.33%/yr), a small region in the Bay of Bengal (0.03–0.09%/yr), the north region of the Arabian Sea (0.06–0.21%/yr), a large region from the Somali to the Diego Garcia (0.03–0.27%/yr) and the a west-east belt region in the east of the Diego Garcia (about 0.12%/yr). The rough sea occurrence in most of the Bay of Bengal and central-east region of the Arabian Sea does not exhibit significant variation for the past 36 years. The rough seas occur in the South China Sea primarily in January, March, and September; in the Bay of Bengal they occur mostly in July, September, and October; and in the Arabian Sea they occur mostly in June, July, and September.

For the period 1979–2014, the SWH in most of the South China Sea exhibits a significant increasing trend of above 0.4 cm/yr. Almost the whole Bay of Bengal and a wide area west of the Indian Peninsula do not exhibit significant variation in the long-term trend of SWH. The SWH in the western Arabian Sea and between 15°S and 0° in the Indian Ocean exhibits a significant increasing trend, of ~0.1–0.4 cm/yr. Only some scattered waters exhibit a significant decreasing trend.

The large area of the extreme wave height on the Maritime Silk Road is distributed primarily between 10°N and 20°N. Extreme wave height in the South China Sea is greater than that in the northern Indian Ocean. Extreme wave height with a return period of 50 years is above 10 m in the central and northern South China Sea, above 7 m in most of the Arabian Sea, and above 5 m in most of the Bay of Bengal.

Under the RCP4.5 scenario, there is good agreement between the wave fields for the next 40 years (2020–2059) and those for the past 36 years (1979–2014), especially the wave field in August in the Arabian Sea. The winter wave field in the waters off Somalia and in the South China Sea for the next 40 years is stronger than that in the past. The summer wave fields in the South China Sea and the Bay of Bengal for the next 40 years are stronger than those in the past.

References

Dee DP, with 35 co-authors (2011) The ERA-Interim reanalysis: configuration and performance of the data assimilation system. Quart J R Meteorol Soc 137:553–597

Kent EC, Fangohr S, Berry DI (2013) A comparative assessment of monthly mean wind speed products over the global ocean. Int J Climatol 33(11):2520–2541

Zheng CW, Li CY (2015a) Development of the islands and reefs in the South China Sea: wind power and wave power generation. Periodical of Ocean Univ China 45(9):7–14

Zheng CW, Li CY (2015b) Development of the islands and reefs in the South China Sea: wind climate and wave climate analysis. Periodical of Ocean Univ China 45(9):1–6

Zheng CW, Li CY (2015c) Variation of the wave energy and significant wave height in the China Sea and adjacent waters. Renew Sustain Energy Rev 43:381–387

Zheng CW, Lin G, Sun Y et al (2012) Analysis of wave characteristics in the Pacific Ocean during the last 45 years. J Trop Oceanography 31(6):6–12

Zheng CW, Lin G, Shao LT (2013) Frequency of rough sea and its long-term trend analysis in the China Sea from 1988 to 2010. J Xiamen Univ (Nat Sci) 52(3):395–399

Zheng CW, Pan J, Xin Li et al (2014) Relationship between El Niño and frequency of the rough sea in the China Sea and adjacent sea area from 1988 to 2009. Mar Sci Bull 33(2):140–147

Zheng CW, Chen X, Li CY (2015a) Observation analysis of wave climate in of Korean Peninsula waters. Periodical of Ocean Univ China 45(9):21–27

Zheng CW, Pan J, Sun W et al (2015b) Strategic of the ocean environment of the 21st century Maritime Silk Road. Ocean Dev Manag 32(7):4–9

Zheng CW, Li XQ, Gao ZS et al (2015c) Strategic of the 21st century Maritime Silk Road: wind climate analysis. Ocean Dev Manag 32(8):4–11

Zheng CW, Fu M, Rui ZF et al (2015d) Strategic of the 21st century Maritime Silk Road: wave climate analysis. Ocean Dev Manag 32(10):1–7

Zheng CW, Xia LL, Luo X et al (2016) Characteristics of the rough sea occurrence in South China Sea and North Indian Ocean. J PLA Univ Sci Technol (Nat Sci Edition) 17(3):284–288

Zheng CW (2017) Projection of wave energy resource: a case study of the China seas. J Mar Sci Technol (under review)

Chapter 4
Ocean Current Characteristics

As a basic motion of all the world's oceans, ocean currents play an important role in the development of marine fisheries, surface primary productivity, material transportation, humanitarian assistance such as the placement and arrangement of mines, buoy movement, determining the location of underwater equipment, and so on. Intensive study (Zheng and Li 2015a, b; Zheng et al. 2015) of the surface winds, waves, currents, and other marine environmental factors can provide a scientific basis for sociological marine construction activities and humanitarian assistance (Zheng et al. 2013, 2014a, b). Cold and warm currents have an influence on the coastal climate, as during the Younger Dryas event about 11–10 Ka BP. In addition, areas where cold and warm currents intersect are the world's most famous fishing grounds, as these areas are rich in nutrients. In the polar seas, currents also influence navigation by affecting the motion of sea ice.

The Indian Ocean, one of the world's four oceans, has a complicated boundary. It lies west of the Atlantic Ocean and east of the Pacific Ocean; moreover, through the Gulf of Aden, the Persian Gulf to the northwest connects to the Red Sea, and the Malacca Strait and other waterways connect to the South China Sea. Recently, the Indo-Pacific region (IPR), the Indonesian Through Flow (ITF), and the Agulhas current (Fang et al. 2002; Yu et al. 2003; Hermes et al. 2007) have become hot spots for studying climate change. There are few research papers on Indian Ocean currents, and the scattered papers that do exist are focused on hot spots such as the ITF or on the effects of the IPR on the climate of China. Currently, the chief resource on the characteristics of the marine environment of the Indian Ocean is *Regional Oceanography* by Godfrey. In this chapter, three chapters of these characteristics are summarized.

Surrounding the Indian Ocean are the Indian subcontinent, Africa, Asia, Australia, and the South Pole. With these complicated surroundings, the monsoon is significant in the Indian Ocean. The Malacca Strait and the Gulf of Aden are very important for global maritime traffic. On the basis of the reanalysis of current data, this chapter briefly introduces the characteristics and seasonal variations of currents in the Indian

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Springer Oceanography, https://doi.org/10.1007/978-981-10-7977-1_4

Ocean and the South China Sea (~20°S–30°N, ~30°E–130°E) to make a contribution to national marine construction and strategic planning.

4.1 Data

The ocean current data referenced in this section are from the Simple Ocean Data Assimilation (SODA) developed by the University of Maryland (Carton and Giese 2005). The current characteristics of the seas along the Maritime Silk Road are analyzed in this section, including both annual and seasonal characteristics.

The area in this study covers the South China Sea and the northern Indian Ocean, located at ~20°S–30°N and ~30°–130°E. The data time span covers from January 1987 to December 2007 with an interval of about a month; the horizontal resolution is 0.5° × 0.5°, and the vertical resolution is 40 layers. Table 4.1 presents information about each layer.

4.2 Annual Average Current Characteristics

In the upper marine main thermocline, motion is significantly affected by wind, and the upper ocean is also where high-frequency motion tends to cluster. Surface currents have an important effect on material transport and navigation; the annual average surface currents for 21 years are shown in Fig. 4.1.

Table 4.1 Water depth (*unit* m) of each layer for SODA

Layer	Depth/m	Layer	Depth/m	Layer	Depth/m
1	5	15	229	29	2625
2	15	16	268	30	2875
3	25	17	318	31	3125
4	36	18	381	32	3375
5	47	19	466	33	3625
6	58	20	579	34	3875
7	70	21	729	35	4125
8	83	22	918	36	4375
9	97	23	1139	37	4625
10	112	24	1379	38	4875
11	129	25	1626	39	5125
12	149	26	1875	40	5375
13	171	27	2125		
14	198	28	2375		

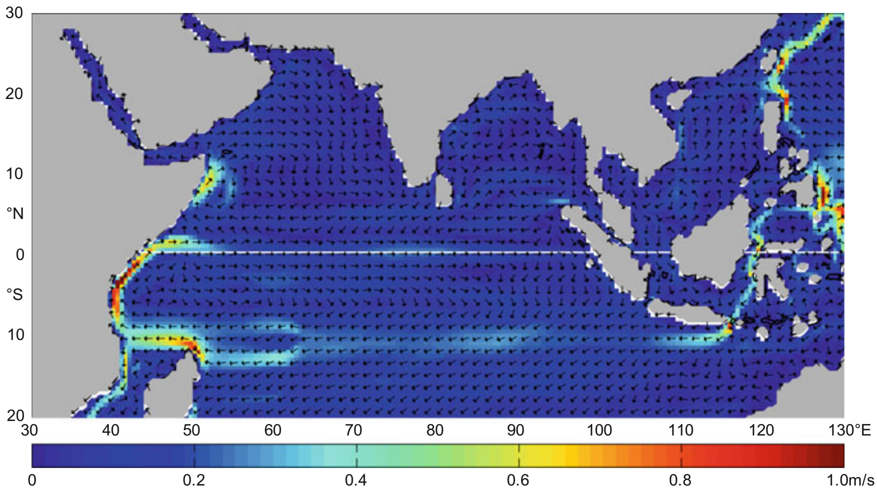

Fig. 4.1 Multiyear mean sea surface flow field (m/s)

The value of surface currents in the research area is about 0.1 m/s. However, in near-shore areas, according to the law of conservation of mass and the influence of boundaries, the maximum velocity can increase up to over 1 m/s, particularly in equatorial areas (eastern), on the western boundary, and in the western area from ~7° to 20°S. In the boundary flow region, on the west side of the Mozambique Strait, the primary direction of currents is south, and the direction of the current near the west side is nearly north, but the flow is complex on the east side of the strait. There are three eddies to the north of the strait—one anticyclonic eddy and two cyclonic eddies—but there is one cyclonic eddy to the south, so that there is a saddle at 16°S. North of 10°S on the eastern coast of Africa, the direction of the currents is north, and the maximum flows are concentrated in the near-shore areas. In the coastal areas of China and the northwestern Pacific Ocean, 10°N is the cutoff point for flow direction; north of the cutoff point, the direction of the flow is north, but it is opposite south of the cutoff point. South of the cutoff point, there is another cutoff point at 5°N near Sonsorol Island; the westward flow turns south between Kalimantan Island and Sulawesi Island, and through the Nusa Tenggara Islands, this flow turns west near 115°E.

After considering the significant influence of atmospheric forces on the upper marine motion, the mean flow (MF) averaged from the surface to a depth of 1000 m is analyzed in this chapter. The direction distribution of the MF is similar to that of the surface flow field (Fig. 4.2), and the MF velocity is weak, with a maximum of about 0.35 m/s. In contrast to the weak velocity distribution, the flow direction distribution is relatively stable. Except in the South China Sea, the influence of strong currents is relatively deeper. In addition, due to the influences of the western boundary and topography, there are some significant flow vortices in the coastal area, such as in the

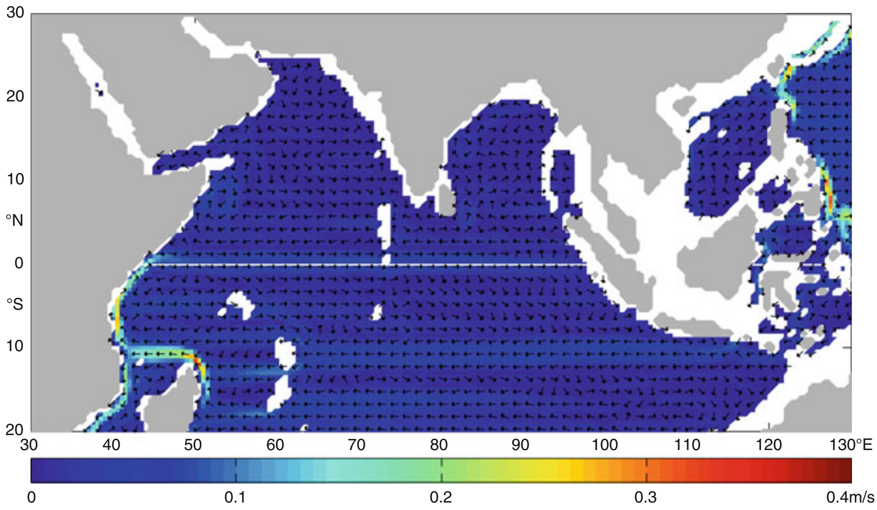

Fig. 4.2 Multiyear mean MF field (m/s)

Mozambique Strait. In this strait, the MF direction distribution is more consistent and stable, and there is flow direction shear in the west-central strait.

4.3 Seasonal Average Current Characteristics

In this section, we consider the following four months as typical of each season: February for winter, May for spring, August for summer, and November for autumn. To provide a detail reference, we also present the ocean current (averaging from 5 to 1000 m of the under water) and upper ocean current (5 m of the under water) in each month, as shown in Appendix (9–10).

As shown in Fig. 4.3, in the spring and autumn, the equatorial system of the Indian Ocean is relatively developed, as the developed field flows in the low-latitude area of the northern Indian Ocean in winter. In contrast, in the western part of the study area, the flow field is more stable. In September, the Indian Ocean equatorial current begins to appear; the current velocity increases from October to November, up to December, and then, under the influence of the monsoon, the current begins to weaken, and a flow on the north side of the equatorial current begins to appear and develop with a direction opposite to that of the equatorial current; in the following January, the northern equatorial current disappears, and the south has an weak eastward flow until April.

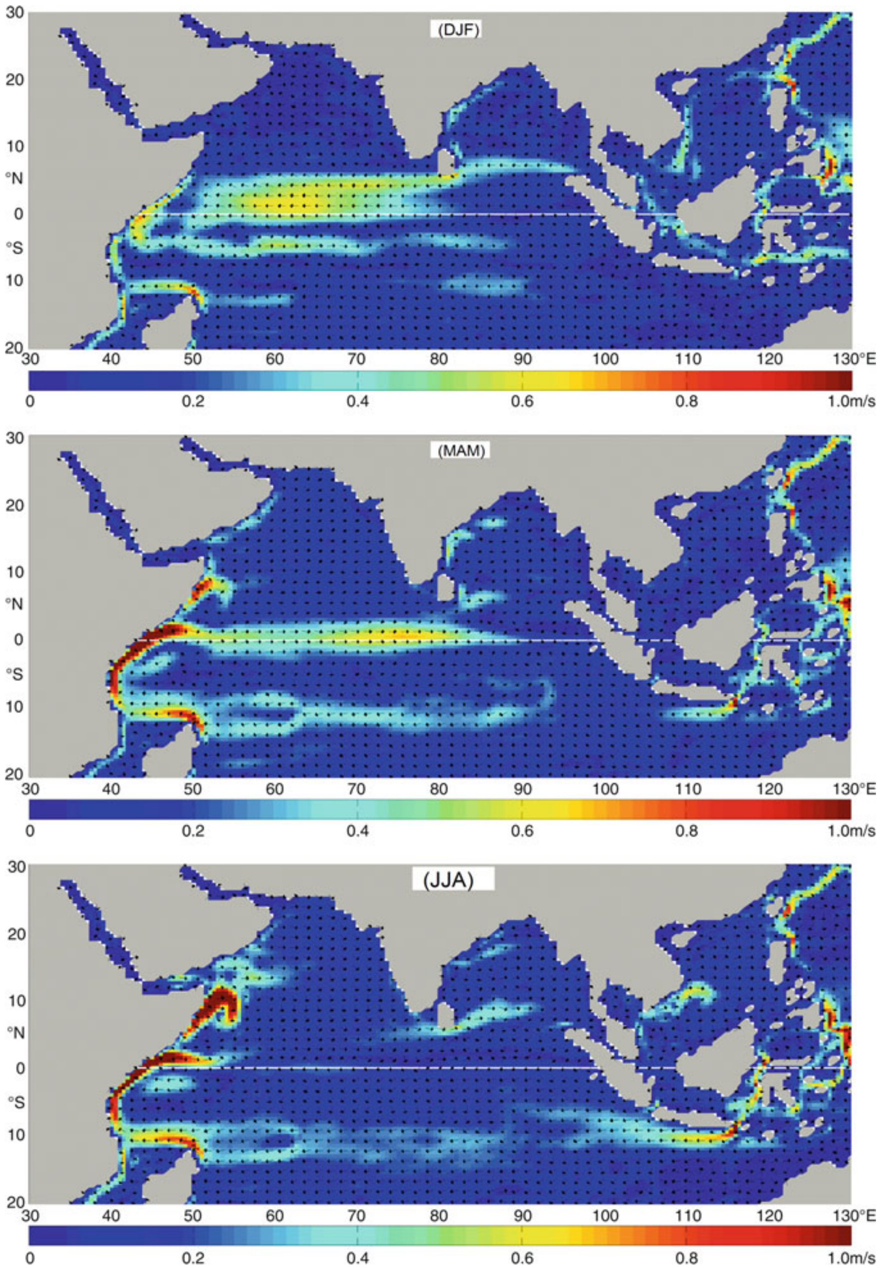

Fig. 4.3 Surface average flow field of each season (m/s)

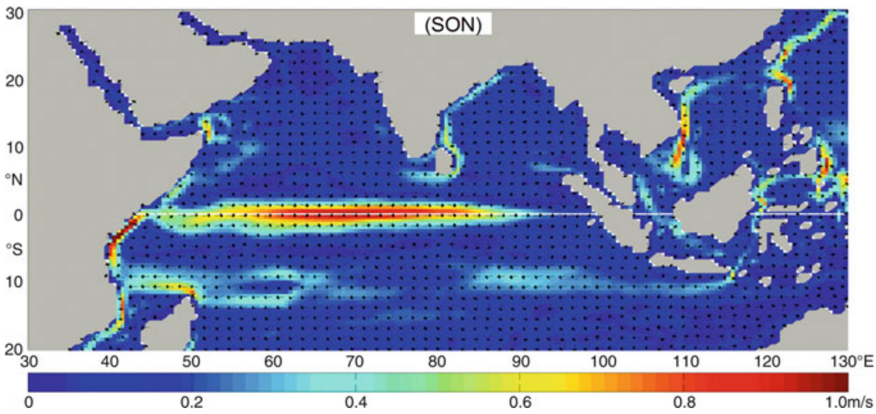

Fig. 4.3 (continued)

Currents near the African coast

In April, the coastal flow system is divided into a northern and a southern branch at the northern end of the Mozambique Strait, and the northern flow is further divided into an eastward and a northward branch at the equator until October; up until November, the northern equatorial current turns south and then converges with the flow south of the equator, while the north becomes weak. At 5°N latitude, the coastal flow is divided into two branches until April. From May to September, the coastal flow covers a wide area and develops a maximum velocity of over 1.8 m/s; in contrast, the equatorial flow system is weaker, with a maximum velocity of over 0.8 m/s.

In the South China Sea, due to the combined effect of the monsoon, topography, and Kuroshio current, along the edge of eastern Guangdong to the south of Hainan Island and the west side of Vietnam, the flow has greater velocity and runs parallel to the terrain from south of Taiwan to south of Hainan Island, where the flow turns to the south. The monsoon has a significant influence on the currents of the South China Sea; after October, the northeast monsoon gradually affects the South China Sea until the following March. In the southern South China Sea, due to the interaction of the boundary topography and the currents, an anticyclonic eddy appears and becomes significant, with a deep influence in November. In summer, with the influence of the southwest monsoon, the currents in the South China Sea weaken and are significantly affected by the Kuroshio current, whose seawater transport and seasonal variations have an important influence on driving the currents in the South China Sea (Su 2005).

On the south side, where the terrain is complex, there are the Sulawesi Sea, the Java Sea, and the Banda Sea, which contain several islands. These seas extend in all directions, and under the influence of this terrain, the currents in these areas are changeable. These areas are in the confluence of the Pacific and Indian Oceans; in winter, two currents from both the east and west sides of Kalimantan Island flow to the Java Sea. Along the Nusa Tenggara Islands, there is an eastern flow on the west side, after the eastern flow to the Java Sea, at about 115°E. This flow is divided into two branches, one out from the Java Sea and the other continuing eastward; the currents on the east side of the island converge with those on the west. Up until spring, the currents on the west side of the island weaken and disappear, but the currents on the east are maintained. At the same time, a flow is formed on the west side of Sulawesi Island, on the south side of which both flows converge and then flow out from the south side of the Java Sea at about 115°E. This is also the period when this outflow begins to strengthen; during summer, flows on both sides of Sulawesi Island continue to strengthen, and it is at this time that the flows reach their peak. In autumn, due to the establishment of the currents on the west side of Kalimantan Island and the disappearance of the currents on the east side of Sulawesi Island, the flow from the Java Sea to the Indian Ocean begins to weaken. These currents reach their peak in summer, with a maximum velocity of about 1.0 m/s.

In the Malacca Strait, the direction of the surface flow is always along the strait from the South China Sea to the Indian Ocean in each typical month, and the surface flow is strong in autumn and winter. In spring and summer, as there is a western flow in the Indian Ocean near the coast of the Indian subcontinent from ~5°–10°N, both currents converge at the exit of the strait.

The surface average flows for each season are shown in Fig. 4.3; a significant feature is that the eastward flow at the northern end of the Mozambique Strait is stable throughout the year. This phenomenon also exists in the MF without a significant change at the surface. On the west coast of Africa, the MF is also stable south of the equator, but the northern flow appears only in summer and autumn and is weak in winter and spring. In the region of ~50°–55° E and ~5°–10°N, there is a cyclonic flow vortex at the surface in spring, and the center of the vortex in the MF is slightly north of the surface; until summer, the intensity of the flow vortex is enhanced with the strengthening of the boundary flow, and the center stretches northward; in autumn, the vortex disappears. The vortex is similar to surface flows near the African coast, and the depth of influence of the equatorial currents has obvious seasonal variation (Fig. 4.4).

To further understand the characteristics of the equatorial currents and the African coastal currents, the surface flow field of the Indian Ocean in the equatorial region (Fig. 4.5) and at 50°E (Fig. 4.6) was selected for analysis in this chapter. From April to October, the currents in the eastern equatorial region are strong, whereas the equatorial currents are inactive in summer. In addition, the direction of the equatorial currents also has seasonal variation. In the region of ~55°–75°E, from January to March, the currents' direction is primarily westward; in April, the direction turns eastward, until it stretches west in June. In July, the direction turns westward, and this shift lasts for only 2 months; after that, the equatorial currents' direction remains primarily eastward. In the eastern equatorial region, the seasonal variation is simplified to two types as follows: from December to the following March, the currents are weak and southwestward, and during the other months they are strong and northeastward.

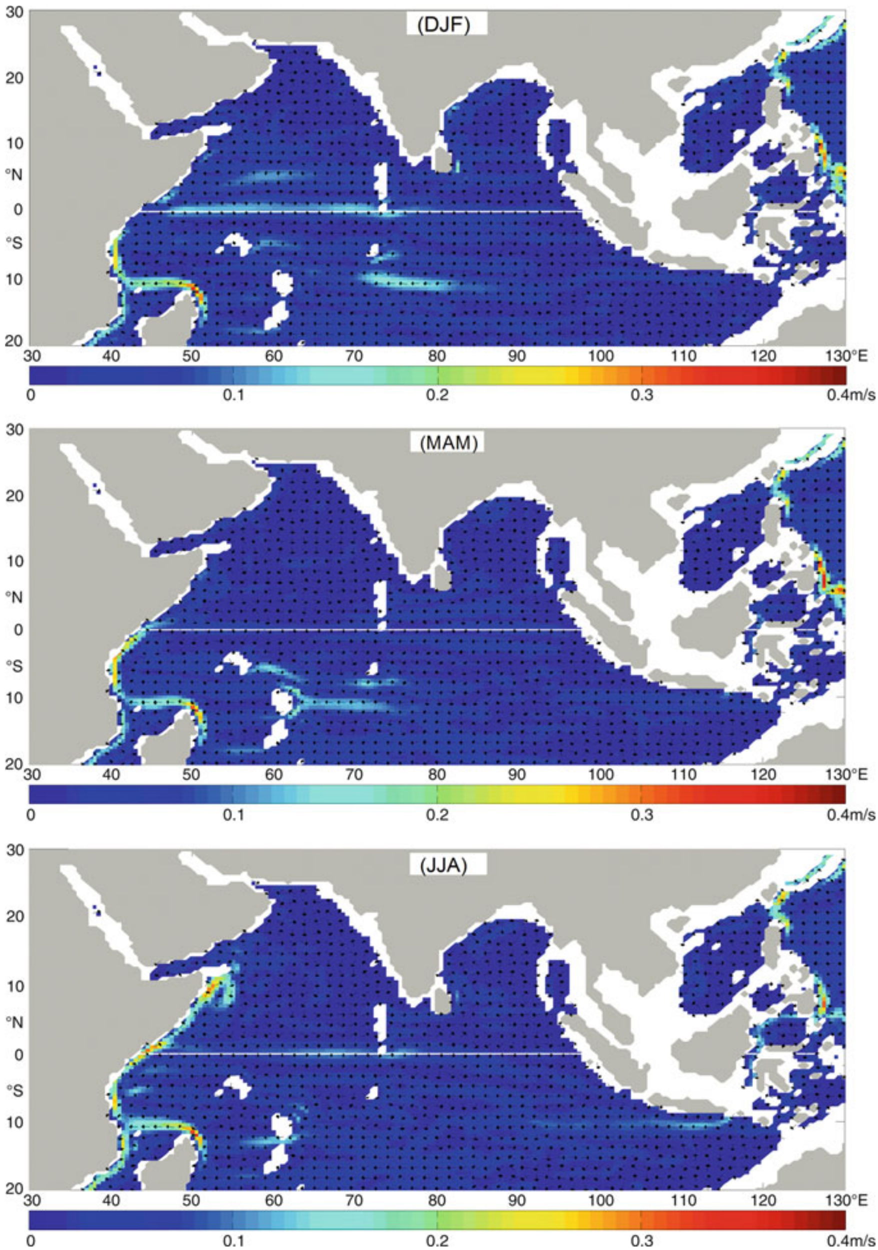

Fig. 4.4 Average MF field of each season (m/s)

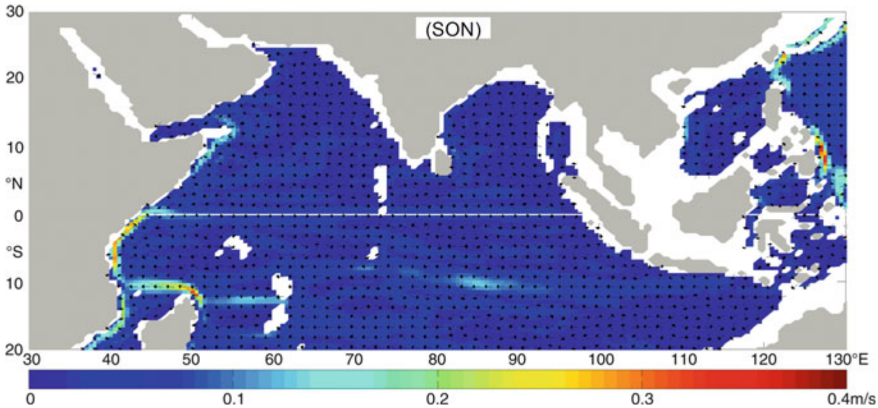

Fig. 4.4 (continued)

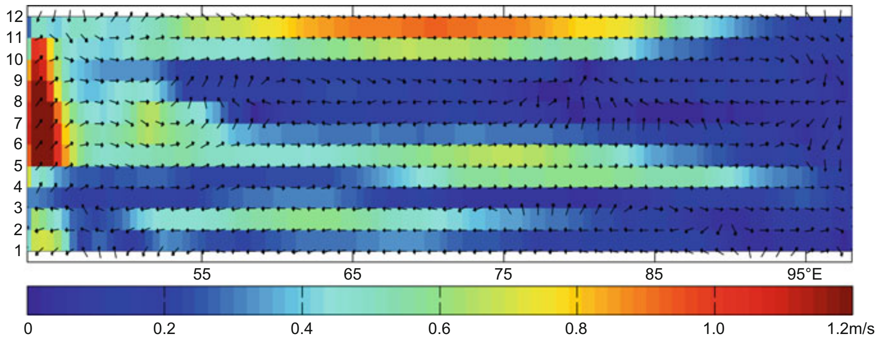

Fig. 4.5 Temporal and spatial distribution of surface flow (m/s)

Compared with the boundary currents, during the period of weak currents, the direction of the lower equatorial currents is primarily in the longitudinal direction, and at a depth of 70 m, the direction turns eastward. In addition, in the upper area of the weak currents, the reverse change in flow direction indicates that this is a zero-velocity region with no vertical shear of velocity.

As can be seen from Fig. 4.6, the currents are relatively stable on the eastern side of Madagascar; in the upper layer, the direction of the currents is similar to that at the surface, and the intensity of this flow is weaker in winter. In the north, with the increase in depth, the currents at the equator and in the low latitudes of the Northern Hemisphere show a southbound extension trend, and strong currents with a shallower depth of influence occur from about April to September. At a depth of 200 m, there is a relatively strong current in the low latitudes of the Northern Hemisphere, which is quite different from that near Madagascar. In addition, in the equatorial area, there

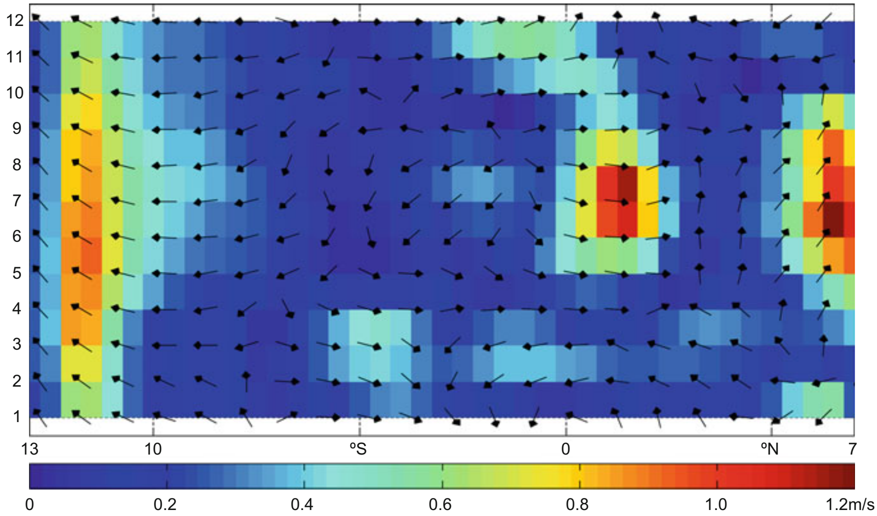

Fig. 4.6 Temporal and spatial distribution of surface flow at 50°E (m/s)

is a change in flow direction from March to April, and a vertical change in flow direction exists primarily from January to March, during which there is no velocity distribution in the equatorial area.

4.4 Summary

In this chapter, the upper flow field characteristics of the South China Sea and the northern Indian Ocean were analyzed based on the SODA dataset. The analysis included annual and seasonal characteristics. The primary characteristics of the upper flow field are as follows:

(1) In the South China Sea, the seasonal variation in the flow field is remarkable and is influenced by the combined effect of the monsoon, the Kuroshio current, and topography. During the northeast monsoon, there is a flow along the coast of eastern Guangdong to south of Hainan Island, and the changes in this flow have an influence on areas of the southern South China Sea, such as the Java Sea.

(2) There are obvious seasonal changes in the flows on the east side of Sulawesi Island and the west side of Kalimantan Island. When the flows are strong, both are southerly. Currents from the Java Sea are perennial, and the velocities reach the greatest values in summer, with a maximum of about 1.0 m/s.

(3) There are obvious seasonal variations in the flows in the equatorial Indian Ocean and on the east coast of Africa, and there is a flow direction shear in the lower-

velocity region of the upper sea. The maximum velocity of the coastal current appears in May–September, at more than 1.8 m/s, whereas the maximum velocity of the equatorial flow is above 0.8 m/s in November.

Sometimes, we will focus on the co-occurrence of flow velocity and direction of some important key point. In this book, we present the current rose to exhibit the co-occurrence of flow velocity and direction. And the Eluanbi station (south of Taiwan Island, 120.8°E, 21.9°N) is taken as a case study, as shown in Appendix (11).

References

Carton JA, Giese BS (2005) SODA: A reanalysis of ocean climate. Available at http://www.atmos.umd.edu/~carton/pdfs/carton&giese05.pdf

Fang GH, Wei ZX, Huang QZ et al (2002) Volume, heat and salt transports between the southern South China Sea and its adjacent waters, and their contribution to the Indonesian throughflow. Oceanologia ET Limnologia Sinica 33:296–302

Hermes JC, Reason CJC, Lutjeharms JRE (2007) Modeling the variability of the greater Agulhas current system. J Clim 20:13

Su JL (2005) Overview of the South China Sea circulation and its dynamics. Acta Oceanol Sin 27(06):1–8

Yu YQ, Zhou ZY, Zhang XH (2003) Indonesia hydrographic shut down the influence of the climate: a numerical simulation research. Chin Sci Bull 48(suppl):60–64

Zheng CW, Li CY (2015a) Development of the islands and reefs in the South China Sea: wind climate and wave climate analysis. Periodical of Ocean Univ China 45(9):1–6

Zheng CW, Li CY (2015b) Development of the islands and reefs in the South China Sea: wind power and wave power generation. Periodical of Ocean Univ China 45(9):7–14

Zheng CW, Lin G, Shao LT (2013) Frequency of rough sea and its long-term trend analysis in the China Sea from 1988 to 2010. J Xiamen Univ (Natural Science) 52(3):395–399

Zheng CW, Pan J, Huang G (2014a) Forecasting of the China Sea ditching probability using WW3 wave model. J Beijing Univ Aeronaut Astronaut 40(3):314–320

Zheng CW, Shao LT, Li G et al (2014b) Analysis of influence on the security of sea skimming caused by a typhoon wave. J Harbin Eng Univ 35(3):301–306

Zheng CW, Chen X, Li CY (2015) Observation analysis of wave climate in Korean Peninsula waters. Periodical of Ocean Univ of China 45(9):21–27

Chapter 5
Marine Resource Characteristics and Current Utilization

Under the background of a shortage of conventional resources (such as coal and oil) and overfishing of inshore fishery resources, countries all over the world are paying special attention to energy crisis. China has also been paying special attention to energy crisis, as realized through equal trade. In addition, China also actively promotes the development and utilization of renewable energy, which is undoubtedly an effective method to deal with climate change and ease the energy crisis. Since ancient times, the ocean has been the cradle of human life, and it is also a huge treasure house of resources, including the following: a wide range of biological resources (including fisheries, marine biopharmaceuticals, etc.), rich mineral resources (such as oil and gas), chemical resources (metals and salts), and inexhaustible power resources (such as wave energy, tidal energy, ocean current energy, etc.). Exploitation of marine resources can strongly guarantee the survival of human society and sustainable development during the 21st century (Zheng and Li 2015; Zheng et al. 2015a, b, c; Acero et al. 2017); it will also be a highlight of the construction of the 21st Century Maritime Silk Road.

The Maritime Silk Road binds the South China Sea and the northern Indian Ocean and opens a new chapter in human cooperation, mutual assistance, and win-win scenarios. A thorough understanding of the resources involved in the relevant seas will be conducive to the efficient and rational exploitation and utilization of marine resources. In this chapter, the characteristics of marine resources in the South China Sea and the Indian Ocean are analyzed, which will contribute to the construction of the Maritime Silk Road, benefit international marine development and construction, and promote the sustainable development of human society.

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5.1 Resource Overview in the South China Sea

5.1.1 Mineral Resources

The South China Sea, known as "the second Persian Gulf," is rich in mineral resources such as oil, gas, and rare metals (Wang and Ma 2003; Li 2015; American Security Project 2012). The strata of the South China Sea are rich in Mesozoic and Cenozoic sedimentary seabeds with an estimated area of 750,000 km^2, of which 581,000 km^2 are located in the nine-dotted line rich in oil, gas, and mineral resources (Li 2015). There are seven oil and gas resource basins (the Bohai basin, the South China Sea basin, the East China Sea basin, the Beibu Gulf basin, the Yinggehai basin, the Zhujiangkou basin, and the Taiwan shoal basin) in China's offshore area, and the following three are in the South China Sea: the Pearl River Mouth basin with about 40–50 million tons of crude oil, the Yinggehai basin with about 4–5 million tons of crude oil, and the Northern Gulf basin with about 4–5 million tons of crude oil (Wang and Ma 2003). In addition, in the Zengmu Reef basin, there are tertiary sedimentary rocks with a thickness of 4000–9000 m and an area of about 250,000 km^2; according to estimates, this region's total oil and gas reserves are about 13.7 billion tons, and oil and gas resources estimated at more than 4 billion tons are kept in Wanan Tan. The South China Sea also contains gas hydrates (combustible ice) (Wang and Ma 2003).

In the South China Sea, there is quite a difference in estimates of oil and gas reserves; the minimum estimate for these reserves is about 7700 million barrels, and the maximum is about 213 billion barrels, which is nearly 27 times the minimum estimated reserves, and these reserves constitute about 80% of Saudi Arabia's crude oil reserves (American Security Project 2012). The estimation of oil and gas reserves in the South China Sea by Hainan Province is as follows: oil and gas reserves are about 70,780 million tons, which include 29,190 million tons of oil and 58,000,000,000,000 m^3 of natural gas (Li 2015). The estimation by the US Energy Information Administration is as follows: oil reserves are about 11,000,000,000 barrels, and natural gas reserves are about 190,000,000,000,000 ft^3 (Insider Secrets 2014). The estimation of natural gas reserves is about 266,000,000,000,000 ft^3, which is estimated to constitute 60–70% of the region's hydrocarbon reserves. In addition, rich natural gas reserves rather than oil are found by relevant countries such as Brunei, Indonesia, Malaysia, Thailand, Vietnam, and the Philippines. Regarding oil estimation, there is considerable divergence in gas reserve estimations. As far as China is concerned, the estimation of the South China Sea gas reserves is different, from 900,000,000,000,000 ft^3 to 2,000,000,000,000,000 ft^3 (Li 2015). The valuation of estimations from Hong Kong (2009) is shown in Table 5.1.

The South China Sea is also rich in placer mineral resources. According to the definition of the International Association for Theoretical and Applied Chemistry, rare metals are the 15 lanthanide elements as well as scandium and yttrium. These metals are commonly used for the production of special metal materials, aircraft, rockets, and atomic energy and in other fields where these elements are the key

Table 5.1 Potential oil and gas reserves in the South China Sea (Li 2015; Insider Secrets 2014; University of Hong Kong 2009)

Region	Potential storage (million barrels)
Southern China	1500
South of Hainan Island	210
Gulf of Tonkin	95
South Vietnam	2847
Sunda Shelf	180
Borneo/Sarawak	9260
The Philippines	409

materials. The South China Sea is rich in minerals such as zircon, monazite, niobium tantalite, xenotime, and quartz sand, which are distributed primarily on coastal islands along the beach and coastal areas. Among them, on the coast of Hainan Island, rare metal resources include primarily zircon, ilmenite, monazite, rutile, and xenotime.

5.1.2 Biological Resources

The South China Sea is rich in biological resources such as fisheries and biopharmaceuticals. In terms of fishery resources, there are nearly 400 million tons in the South China Sea, comprising about one-third of the world's marine species, which can provide 10% of the world's catches. There are several varieties of aquatic resources, whereas the number of single species is less; for example, there are nearly a thousand types of fish, and the primary economic varieties include sea bream, blue round scad, sardines, gold line fish, and so on. In addition, the South China Sea is still rich in tuna, bonito, swordfish, sharks, and other oceanic fish; shellfish, shrimp, crabs, and algal resources are also found in abundance. Areas around Xisha, Nansha, and Zhongsha are rich in turtles, sea cucumber, and hawksbill. Harvesting accounts for 20.3% of China's marine capture. Fisheries trade with neighboring countries around the South China Sea is important. Considering the Philippines as an example, from 2009 to 2013, the export of fishery products from the Philippines to China increased from USD 49,000,000 to USD 129,000,000. In 2013, the value of fishery products imported from China to Philippines was USD 60,000,000 (The Diplomat 2015).

5.1.3 Chemical Resources

Seawater contains more than 80 types of chemical elements, and among them, hydrogen, oxygen, deuterium, and uranium are common elements with exploitation and utilization value. The dissolved oxygen content in the waters of the Xisha Islands is

5.14–7.11 mg/L, and the oxygen saturation is 68–100%. The dissolved oxygen content in the waters of the Nansha Islands is 6.22–6.79 mg/L, and the oxygen saturation is 101–108%. The dissolved oxygen content and oxygen saturation of the Nansha and Zhongsha Islands are all up to Class I water quality standards. The Nansha and Zhongsha Islands are ideal areas for the electrolysis of seawater for the extraction of hydrogen and oxygen resources. The metal uranium is the primary fuel for nuclear power generation. The total uranium energy of only Xisha seawater is equivalent to a 2.5×10^5 kW power plant providing about 15 billion years of electricity. The nuclear energy reserves of deuterium in the Xisha Islands reach 1.5×10^{21} kWh, equivalent to a 2.5×10^5 kW power station providing 750 billion years of electricity, which is about 50 times that of uranium nuclear energy (Hainan Local Chronicles net 2009).

5.1.4 Dynamic Power Resources

Zheng et al. (Zheng 2011; Zheng et al. 2013a) carried out a detailed statistical analysis of the power resources in the South China Sea (Table 5.2).

5.2 Resource Overview in the Indian Ocean

5.2.1 Mineral Resources

Oil and natural gas resources are the most important resources in the Indian Ocean and are distributed primarily in the Persian Gulf. In addition, oil and natural gas are found in the continental shelf near Australia, the Bay of Bengal, the Red Sea, the Arabian Sea, and the east coast of Africa and around Madagascar. In the Persian Gulf, submarine, oil-proven reserves constitute about 12 billion tons, and natural gas–proven reserves comprise about 71 billion m^3; both resources account for one-fourth of the proven reserves in the Middle East. The Indian Ocean is the world's largest offshore oil-producing area, accounting for one-third of the total offshore oil production (Song and Bai 2009). Ore deposits in the Indian Ocean are dominated by manganese nodules, which are distributed primarily on the bottom of the deep-sea basin, with large reserves in the western Australian and middle Indian Ocean basins. In addition, a considerable amount of heavy placer is found in the offshore waters of the Indian Peninsula, around Sri Lanka, and in western Australian waters.

In 1976, the United States Central Intelligence Agency plotted the distribution of the Indian Ocean's natural resources (U.S. Central Intelligence Agency 1976; Cartoko 2010) (Fig. 5.1). In 2015, in the Indian Ocean basin, a large area of rare earth-rich sediments was first found by our scientists, and two rare earth-rich sedimentary regions were preliminarily extrapolated (Xinhua Net 2015). The development of the

Table 5.2 Dynamic resources of the South China Sea (Zheng 2011; Zheng et al. 2013a)

Source type	Spatial distribution
Wind energy	The period of effective wind speed in the South China Sea (3–20 m/s) is about 5000–7500 h/a, and the effective wind power density is 150–500 W/m^2, making this a region rich in wind energy resources. The latest research shows that the frequency of wind speed available for wind energy development in most of the South China Sea that is rich in wind energy resources can reach more than 75%; the annual average wind power density of the Xisha Islands is 180–285 W/m^2, the annual effective wind energy storage is 1050 kWh/m^2, and the wind energy of the Xisha Islands is higher than that of the Nansha Islands
Wave energy	Wave energy resources in the South China Sea are optimistic in the following ways: the wave power density in most of the sea is 2–16 kW/m, and large areas are located along the line from the Luzon Strait to southeast of the Indochina Peninsula. From 1988 to 2009, wave power density in most the South China Sea linearly increased year by year at the rate of 0.05–0.55 (kW/m)/a. The frequency of wave power density greater than 2 kW/m is more than 60% in most of the South China Sea. The wave energy is more stable, the coefficient of variation Cv of each month is basically less than 0.9, the monthly index Mv is less than 6, and the seasonal variation index Sv is less than 4. The northern South China Sea has a relative advantage in wave energy resources
Ocean current energy	Ocean current energy in the South China Sea exists in 23 waterways, accounting for 25% of the total number of coastal waterways. In the Xisha, Nansha, and Zhongsha Islands, there are monsoon currents; strong currents exist in the Xisha Islands, east of Hainan Island, and in the Bashi Strait. The South China Sea is rich in sea current energy; the maximum power density is 4.35 kW/m^2
Tidal energy	Due to terrain and the criss-crossing waterways, around the reefs near the Nansha Islands, tidal trends are more acute. The maximum tidal range in the Nansha area is up to 3 m, and the reefs are mostly atolls, whose lagoons are unique tidal energy development zones
Temperature and salinity energy	Differences in temperature and salinity in the surface layer of the South China Sea are not significant, but the vertical difference in water temperature is high. In a sea area of about 1.54 million km^2 in the South China Sea with a depth greater than 500 m, temperature-difference energy can reach 18.99×10^{20} J per year, which is about 600 billion kW, occupying an important position in the country. Salt-difference energy reserves are similar to those of temperature, as near the Pearl River estuary, the sea salinity difference energy is 24.552 million kW. Utilizing the osmotic pressure energy of the salinity difference for energy generation is one of the objectives of the comprehensive utilization of marine energy

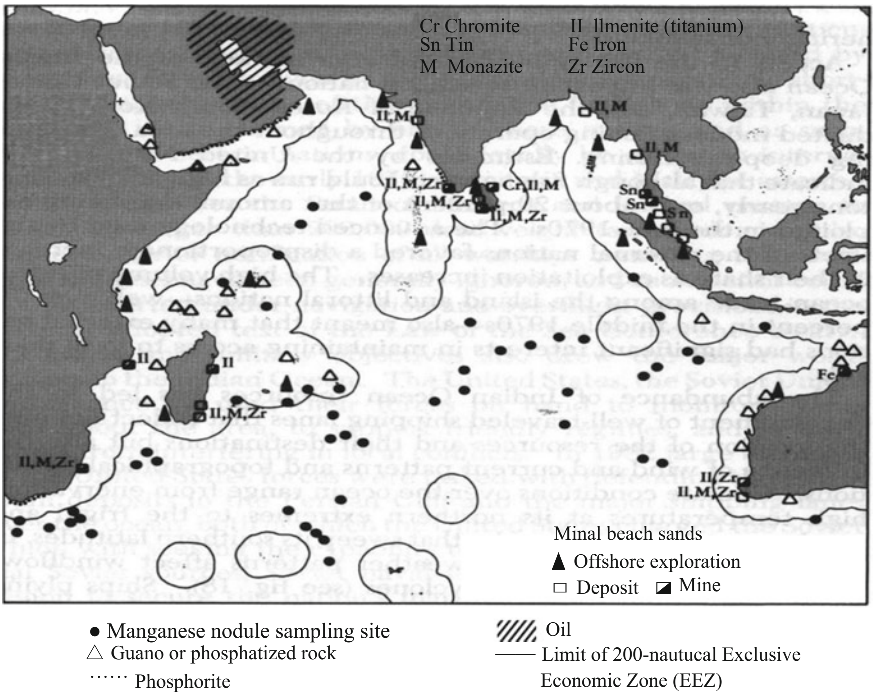

Fig. 5.1 Spatial distribution of natural resources of the Indian Ocean. (after U.S. Central Intelligence Agency 1976)

oil and gas industry in the countries on the periphery of the Indian Ocean is shown in Table 5.3.

Wet crust resources on the Indian Ocean seamount are 111.6 × 10^8 t, and dry crust resources are 80.4 × 10^8 t. The amount of dry resources on the Indian Ocean seamount is (81.5–163.0) × 10^8 t; the amounts of manganese, cobalt, nickel, copper, and molybdenum in the Indian Ocean seamount are (11.9–23.9) × 10^8 t, (0.2–0.5) × 10^8 t, (0.3–0.5) × 10^8 t, (0.1–0.2) × 10^8 t, and (0.03–0.07) × 10^8 t, respectively; and the amount of platinum metal is 2648–5296 t (Zhang et al. 2015).

5.2.2 *Biological and Chemical Resources*

The Indian Ocean is rich in fish, with about 2200 species of fish in only the western Indian Ocean, and there are also rare and endangered animals such as dugongs, coelacanths, turtles, sharks, and more than 350 species of corals. The Indian Ocean also contains one-fifth of the world's unique biological resources. Fishing yields about 500 million tons, much less than in the Pacific and Atlantic. In the Indian Ocean,

Table 5.3 Oil and gas industry developments in the countries peripheral to the Indian Ocean

Singapore	Singapore is one of the major oil refining centers in Asia, with nearly 1.3 million barrels of crude oil refining capacity. The three major refineries include ExxonMobil with 58 million barrels of crude oil refining per day, the British Shell Group in Pulau Bukom with 43 million barrels of crude oil refining per day, and Singapore Refining Company (SRC) with 285,000 barrels of crude oil refining per day. Singapore's natural gas resources are all dependent on imports (China Macroeconomic Information Network 2004)
Myanmar	There are large reserves of oil and natural gas in the inland and coastal areas. According to statistics from the Myanmar Ministry of Energy, in Myanmar, there are a total of 49 onshore oil blocks and 26 offshore oil blocks, with 3.2 billion barrels of crude oil reserves and 89 trillion ft^3 of natural gas reserves (the People's Republic of China embassy in Myanmar Federal Republic 2013). Today, 18 oil fields have been developed on land and 3 natural gas fields offshore. According to data from the US Energy Information Administration, toward early 2013, the proven crude oil reserves were about 50 million barrels and natural gas reserves were about 10 trillion ft^3. In 2012, the Myanmar Ministry of Energy announced that it had 140 million barrels of crude oil reserves and 22.5 trillion ft^3 of natural gas reserves. Crude oil production is 1.96 million barrels per day; natural gas production is 1.475 billion ft^3. Offshore of Myanmar, proven oil reserves with exploitability comprise 35 million barrels, and the amount of natural gas reserves is 10 trillion ft^3. In Myanmar offshore areas, 1.2 million barrels of crude oil and 1.05 billion ft^3 of natural gas have been exploited per day The China-Myanmar crude oil pipeline starting point is in Madeira; the China-Myanmar natural gas pipeline starting point is in Kyaukpyu, via Rakhine State, Magu province, Mandalay province, and Shan State, by Ruili in China into our country. The crude oil pipeline is 771 km long, and the natural gas pipeline is 793 km long (Fabi 2012)
Bangladesh	Bangladesh has few oil, coal, and hydropower resources, but it has abundant natural gas resources on land and sea. Therefore, the energy supply for Bangladesh's industrial production and the whole economy lies mainly in natural gas resources. According to the latest report, Bangladesh has proven natural gas reserves of 20.42 trillion ft^3, and its long-term reserves are 41.8 trillion ft^3. Bangladesh's financial status and technology make the country unable to independently exploit natural gas, so it has to rely on foreign investors
India	India has 26 sedimentary basins with an area of 3.14 million km^2. Most of the sedimentary basins are located in the sea, of which land and shelf areas with a depth of less than 200 m comprise 1.79 million km^2; basin areas with a depth greater than 200 m comprise 1.35 million km^2. Oil and gas resources have been found primarily in the Mumbai high basin on the western sea, Andhra Pradesh on the eastern Bay of Bengal, Gujarat, Odisha, and Assam, seven of which have activities. As of April 2013, India's recoverable oil and gas reserves were 4.07 billion tons of oil equivalent, the cumulative production was 1.96 billion tons of oil equivalent, and the remaining reserves were 21.1 million tons of oil equivalent (Yu 2015)

(continued)

Table 5.3 (continued)

Sri Lanka	According to the BBC, Sri Lanka has never produced oil. The country resumed oil exploration after the end of the civil war in 2009. The government of Sri Lanka has announced the discovery of natural gas fields and "oil traces" in the Gulf of Manal Bay. Companies are welcome to explore and exploit (Xinhua Net 2012)
Mehmood Kot	In Pakistan, 36.18 trillion ft^3 of exploitable natural gas have been identified, and 13.07 trillion ft^3 have been mined and depleted. Proven crude oil industry reserves are estimated at 668 million barrels. Due to continuous mining, it is estimated that there are remaining reserves of 252 million barrels. There are four refineries in Pakistan, one in Mehmood Kot in the northern region, one in the central region, and two in the port city of Karachi (the People's Republic of China, the Commercial Counsellor's Embassy in the Islamic Republic of Pakistan 2003)
Iran	Iran is a major oil exporter, with an oil export revenue of USD 23.6 billion during the 2000–2001 fiscal year. According to the USGS (2000), oil and gas resources to be discovered in Iran include 39.654 billion barrels onshore and 13.461 billion barrels at sea, 176.198 trillion m^3 of natural gas onshore and 138.37 trillion m^3 at sea, and 7.768 billion barrels of liquid natural gas onshore and 61.87 billion barrels at sea. According to the US *Oil and Gas Journal* report, as of January 1, 2003, Iran's remaining proven recoverable oil reserves were 12.288 billion tons, and its remaining proven recoverable natural gas reserves were 23 trillion m^3
Saudi Arabia	Saudi Arabia is the world's largest oil reserve country. According to the US *Oil and Gas Journal* in December 2012, as of the end of 2012, the remaining proven oil reserves in Saudi Arabia were 36.361 billion tons, accounting for 16.2% of the world's total reserves. In addition, Saudi Arabia and Kuwait neutral-zone reserves comprise 343 million tons. Proven recoverable natural gas residual reserves are 8.15 trillion m^3, ranking fourth in the world. Oil revenues account for more than 70% of national revenue, and oil export revenues account for about 90% of total exports (Liu and Jia 2013)

most fishing occurs along the coast of the Indian Peninsula, and the important fish include mackerel, sardines, and flounder. Near the South African coast, the important species include tuna, flying fish, and turtles. The cephalopod resources in the western Indian Ocean have great potential. India is a major fish supplier, and in 2006, India exported more than 600,000 tons of fish for more than USD 1800 million in income. The west coast of India is rich in bait and the water flows gently, so there are several important fishing grounds. The SmartFish Program also shows that the waters of the eastern Arabian Sea are the most productive in the region, accounting for 60% of the total catch in the western Indian Ocean.

The Indian Ocean is also rich in chemical resources, including metal ores and manganese nodules, and it also contains heavy sand, rutile, zircon, monazite, diamond, phosphate nodules, and sludge rich in a variety of metals (iron, zinc, copper, lead, silver, and gold); the average content of iron in sludge is 29%, and the enrichment of zinc is 8.9% (Cartoko 2010).

5.2.3 Dynamic Power Resources

Domestic research on the Indian Ocean's dynamic power resources is extremely rare. Zheng et al. (2012a) studied the wave energy resources of the South China Sea and the northern Indian Ocean and found that the average annual wave power density in most areas is greater than 2 kW/m, and large values lie in the South China Sea, the Bay of Bengal, and the waters near Somalia. The occurrences of wave power density greater than 2 kW/m and greater than 4 kW/m appear high. The wave energy in this area is stable; the stability of the wave energy is better in spring, autumn, and winter than that in summer, and the stability of the South China Sea is better than that of the northern Indian Ocean. The annual average wind power density and wave power density of the Maritime Silk Road are calculated using ERA-interim data from the European Centre for Medium-Range Weather Forecasts (ECMWF), as shown in Fig. 5.2.

Annual average wind power density

The largest value is located in the Arabian Sea (most areas are available, with wind energy density of more than 100 W/m^2, more than 300 W/m^2 in eastern Somalia, and even more than 600 W/m^2 in the large center), followed by the South China Sea (more than 100 W/m^2 in most areas; two large-value areas lie in the Luzon Strait and to the west and in the traditional gale center of the South China Sea). The lowest values are distributed in the Bay of Bengal (100–300 W/m^2) and the equatorial east-central Indian Ocean and the equatorial waters of the South China Sea (less than 50 W/m^2).

Annual mean wave power density

The largest value is located in the Arabian Sea (8–18 kW/m), followed by the Bay of Bengal (6–16 kW/m), and then the South China Sea (2–12 kW/m). In this chapter, the wave power density is slightly lower than that simulated by Zheng et al. (2012a). The abundant wave power and wind power density in the Arabian Sea can be attributed to the strong southwest monsoon, and that in the Bay of Bengal is due to the northward propagation of swells in the southern Indian Ocean, while it is caused by cold air in the South China Sea.

5.3 Overview of Wave Energy Resources

As early as 2012, Zheng et al. (2012a) used ERA-40 wind field data from 10 m above the sea surface to drive the current international advanced third-generation numerical wave model WW3 to obtain wave datasets for the South China Sea and northern Indian Ocean from September 1957 to August 2002. This was the first study to carry out research on the wave energy of the Maritime Silk Road.

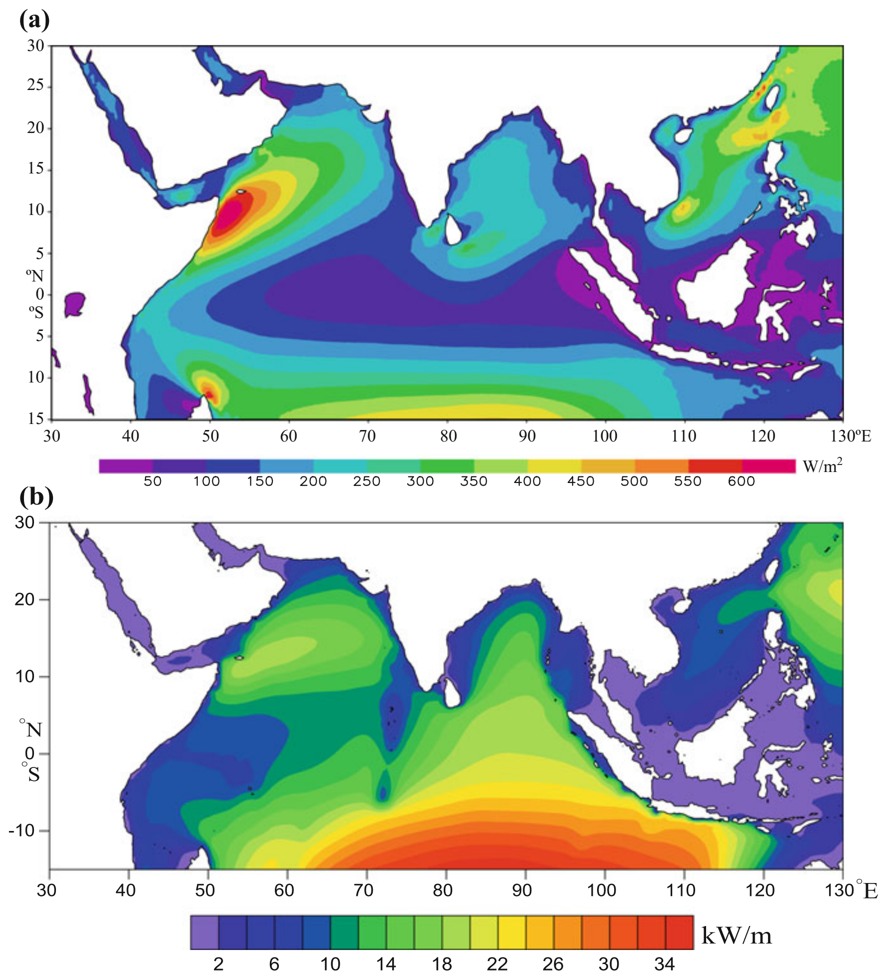

Fig. 5.2 Annual mean wind power density (**a**) and wave power density (**b**) of the Maritime Silk Road

5.3.1 Seasonal Characteristics of Wave Energy

In this chapter, the wave energy resource assessment formula used by EPRI (Electric Power Research Institute) (Zheng et al. 2012b, 2013b) is adopted as follows:

$$P_{\rm w} \approx 0.42 H_{1/3}^2 T_{\rm p} \quad \text{or} \quad P_{\rm w} \approx 0.5 H_{1/3}^2 \overline{T} \tag{5.1}$$

where $H_{1/3}$ is the significant wave height, $T_{\rm p}$ is the peak period, and T is the average period; $T_{\rm p} = 1.2\overline{T}$. Based on 3-hourly simulated wave data from the South China Sea and the northern Indian Ocean from September 1957 to August 2002, the 3-hourly wave power density during this period is calculated.

Wave energy is generally considered to be available when the wave power density is greater than 2.0 kW/m. As shown in Fig. 5.3, the wave energy resource in the South China Sea and northern Indian Ocean can be exploited all year round. In the spring, the wave power density is concentrated primarily in most of the South China Sea (2.0–2.5 kW/m), most of the Bay of Bengal (about 2.0 kW/m), eastern and southeastern Sri Lanka (2.0–2.5 kW/m), and the waters near Somalia (about 2.0 kW/m). The values of wave power density of several large centers are close to each other. In summer, large areas are concentrated in the South China Sea (3.0–5.0 kW/m), the Bay of Bengal (about 10.0 kW/m), and the Arabian Sea (10.0–50.0 kW/m). In autumn, the wave power density in the northern Indian Ocean is 2.0–4.0 kW/m, and larger in the South China Sea (2.0–12.0 kW/m). In winter, the wave power density in the northern Indian Ocean is concentrated primarily around 2.0–4.0 kW/m. At the same time, the wave power density in the South China Sea is the highest of the year, at 4.0–18.0 kW/m. Regarding the annual mean values, the three largest centers are the Arabian Sea (6.0–14.0 kW/m), the Bay of Bengal (about 4.0 kW/m), and the South China Sea (4.0–8.0 kW/m). In terms of geography, in the northern Indian Ocean, the wave power densities in spring, autumn, and winter are similar, at about 2.0 kW/m; in summer, the value is the largest, at about 10.0–50.0 kW/m. The wave power density in the South China Sea gradually increases from spring to winter; the minimum in spring is 2.0–2.5 kW/m, and the maximum in winter is 4.0–18.0 kW/m.

5.3.2 Occurrences of Wave Energy Levels

In wave energy assessment, the occurrence of different levels of wave power density is an important index to measure the abundance of energy, which is helpful in site selection for wave power generation. Wave energy is considered to be available when the wave power density is greater than 2.0 kW/m (Zheng et al. 2014a, b). Wave energy is considered to be rich when the wave power density is greater than 20 kW/m (Zheng et al. 2014a, b). In this section, the occurrences of wave power density greater than 2 kW/m, greater than 4 kW/m, greater than 6 kW/m, greater than 8 kW/m, greater than 10 kW/m, greater than 15 kW/m, and greater than 20 kW/m are counted separately, as shown in Fig. 5.4. It is easy to see that both the frequencies greater than 2 kW/m and those greater than 4 kW/m are high. The large areas of occurrence of wave power density greater than 2 kW/m are concentrated primarily in the middle of the South China Sea (about 50%), in eastern and southeastern Sri Lanka (50–55%), and in the waters near Somalia (50–60%). The occurrence in the equatorial Indian Ocean is relatively low, about 30%. The spatial distribution of the occurrence of wave power density greater than 4 kW/m is similar to that of the occurrence of wave power density greater than 2 kW/m.

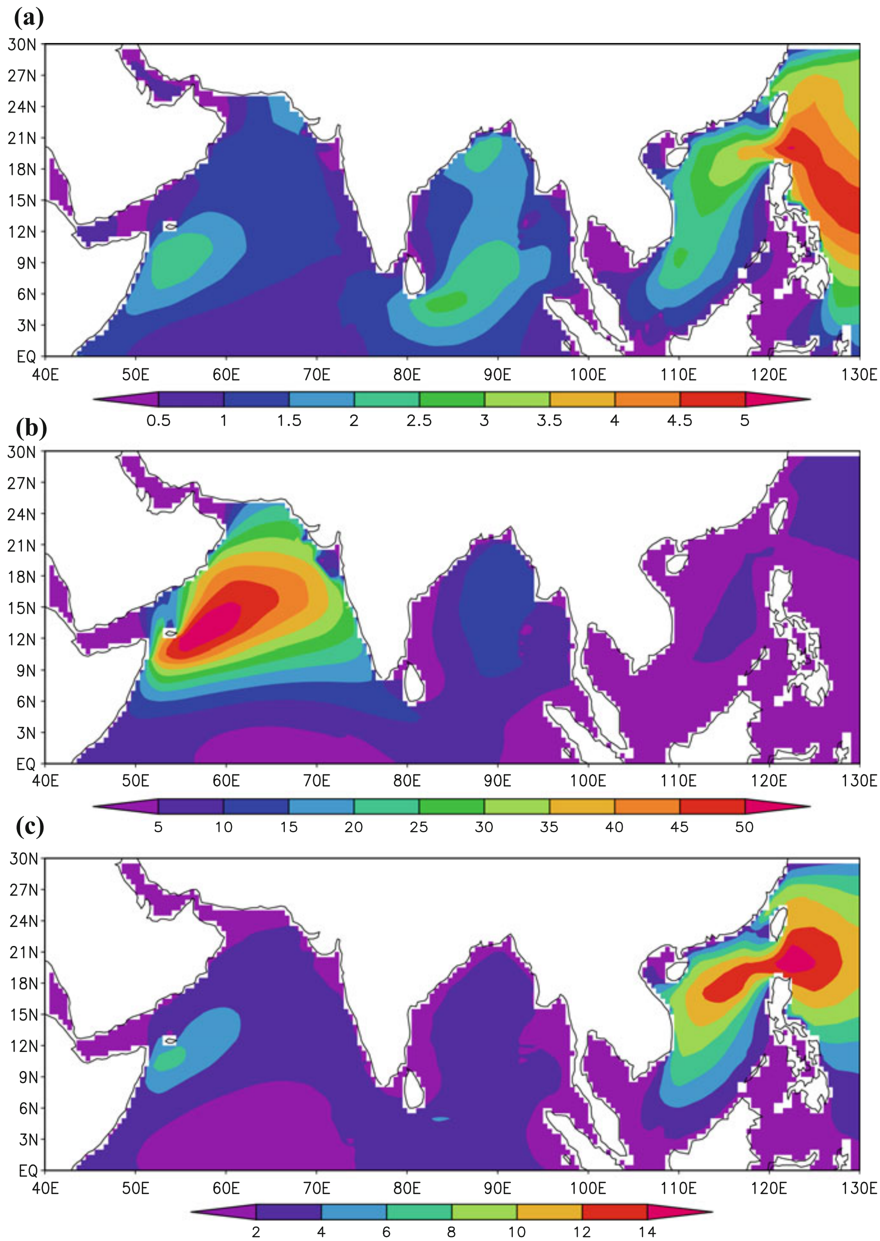

Fig. 5.3 Wave power density in MAM (**a**), JJA (**b**), SON (**c**), DJF (**d**), and annual mean (**e**) of the Maritime Silk Road. (after Zheng et al. 2012a)

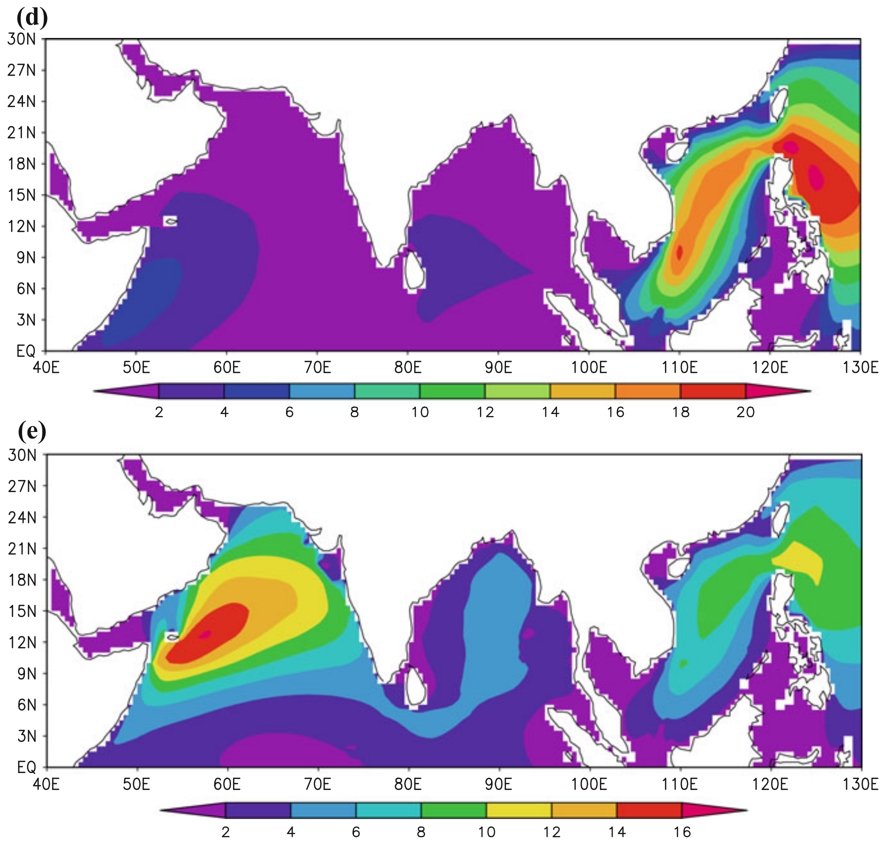

Fig. 5.3 (continued)

5.3.3 Stability of Wave Energy

The development and utilization of wave energy requires a focus not only on wave energy levels but also on wave energy stability. The more stable the wave energy, the more conducive it is to the acquisition and conversion of wave energy. In unstable situations, power generation equipment may be destroyed. In this section, the stability of the wave power density in different months is determined by calculating the coefficient of variation (C_v) of different months at each grid point, as shown in Fig. 5.5. The smaller the coefficient of variation, the better the stability. The coefficient of variation is calculated as follows (Cornett 2008):

$$C_{\mathrm{v}} = \frac{S}{\bar{x}} \tag{5.2}$$

where C_{v} is the C_v, S is the standard deviation, and $\bar{x}$ is the mean value.

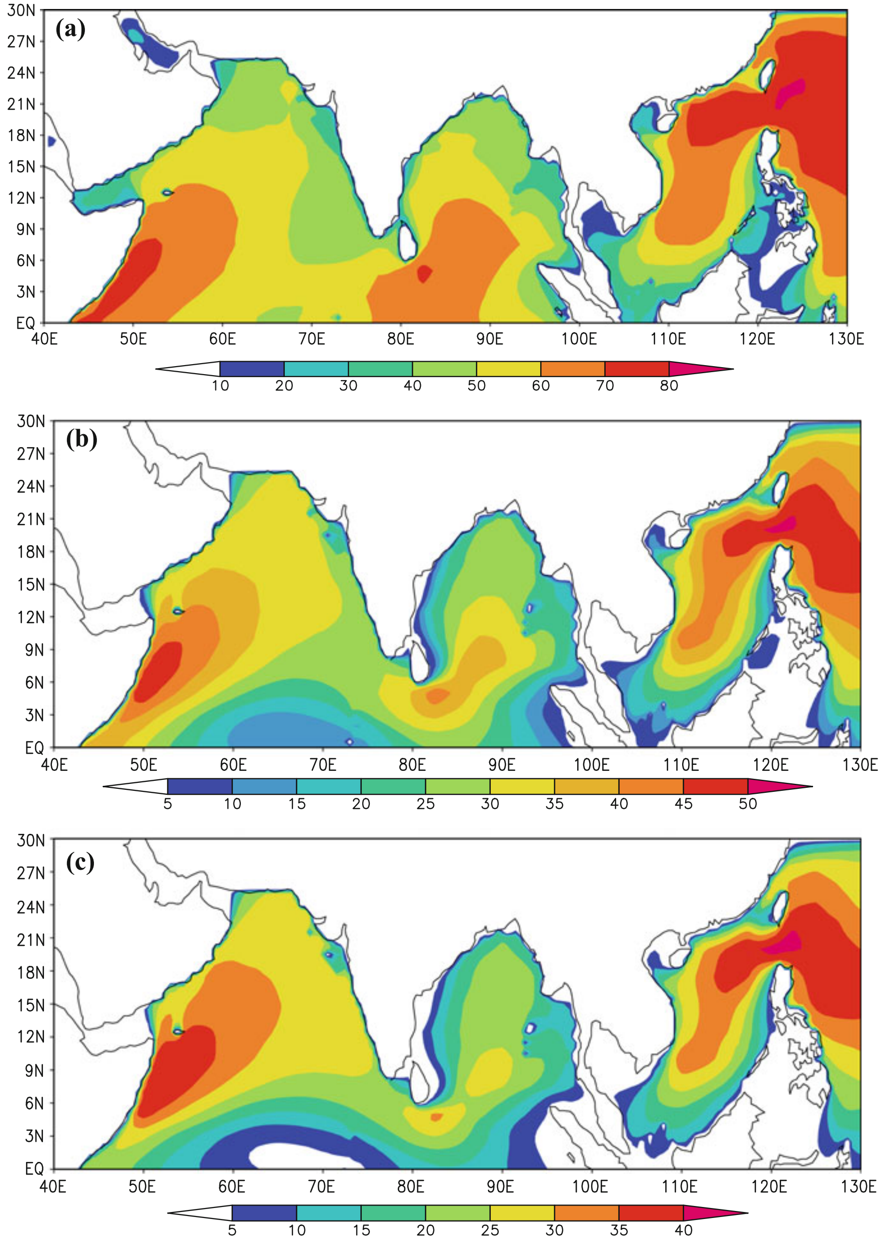

Fig. 5.4 Occurrences of wave power density greater than 2 kW/m (**a**), greater than 4 kW/m (**b**), greater than 6 kW/m (**c**), greater than 8 kW/m (**d**), greater than 10 kW/m (**e**), greater than 15 kW/m (**f**), and greater than 20 kW/m (**g**) of the Maritime Silk Road; unit: %

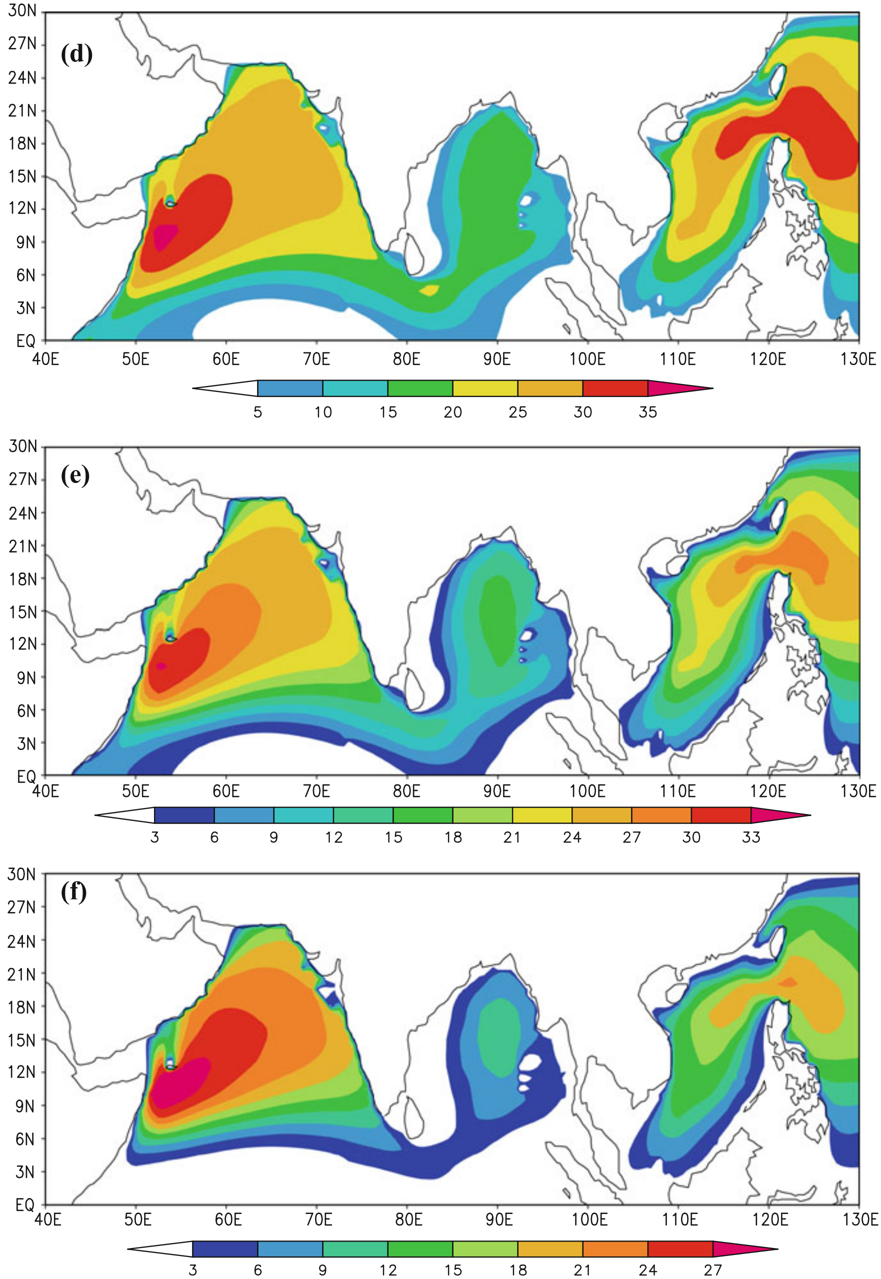

Fig. 5.4 (continued)

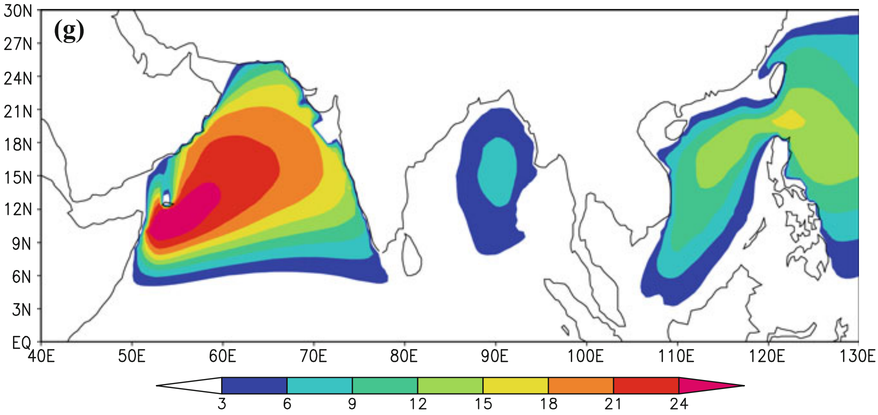

Fig. 5.4 (continued)

Stability of wave power density in the northern Indian Ocean

In spring, the energy is more stable, and the coefficient of variation of the wave power density is less than 0.6 in most areas. In summer the stability is the worst, as it is impacted by tropical cyclones, and the stability is the worst near the Bay of Bengal and Somalia; the stability of the remaining waters is relatively good. In autumn the stability is the best, and the coefficient of variation is below 0.3. In winter, the stability is also better, with a coefficient of variation of less than 0.6, and the stability in the eastern Arabian Sea is slightly lower, with a coefficient of variation of about 0.8.

Stability of wave power density in the South China Sea

The wave power density is stable throughout the year. The coefficients of variation for the wave power density in spring, autumn, and winter are all less than 0.4, and in the summer the stability is slightly worse, with a coefficient of variation of about 0.3–0.6.

In general, the stability of wave power density in the South China Sea and the northern Indian Ocean is good. The stability in the South China Sea is better than that in the northern Indian Ocean. The stability is better in spring, autumn, and winter than it is in summer.

5.3.4 Summary

The wave power density of the South China Sea and the northern Indian Ocean has three large centers: the South China Sea, the area near eastern Sri Lanka, and the waters off Somalia. The wave power density of the northern Indian Ocean is about 2 kW/m in spring, autumn, and winter and 10–50 kWm in summer, which is the largest. The wave power density in the South China Sea gradually increases from

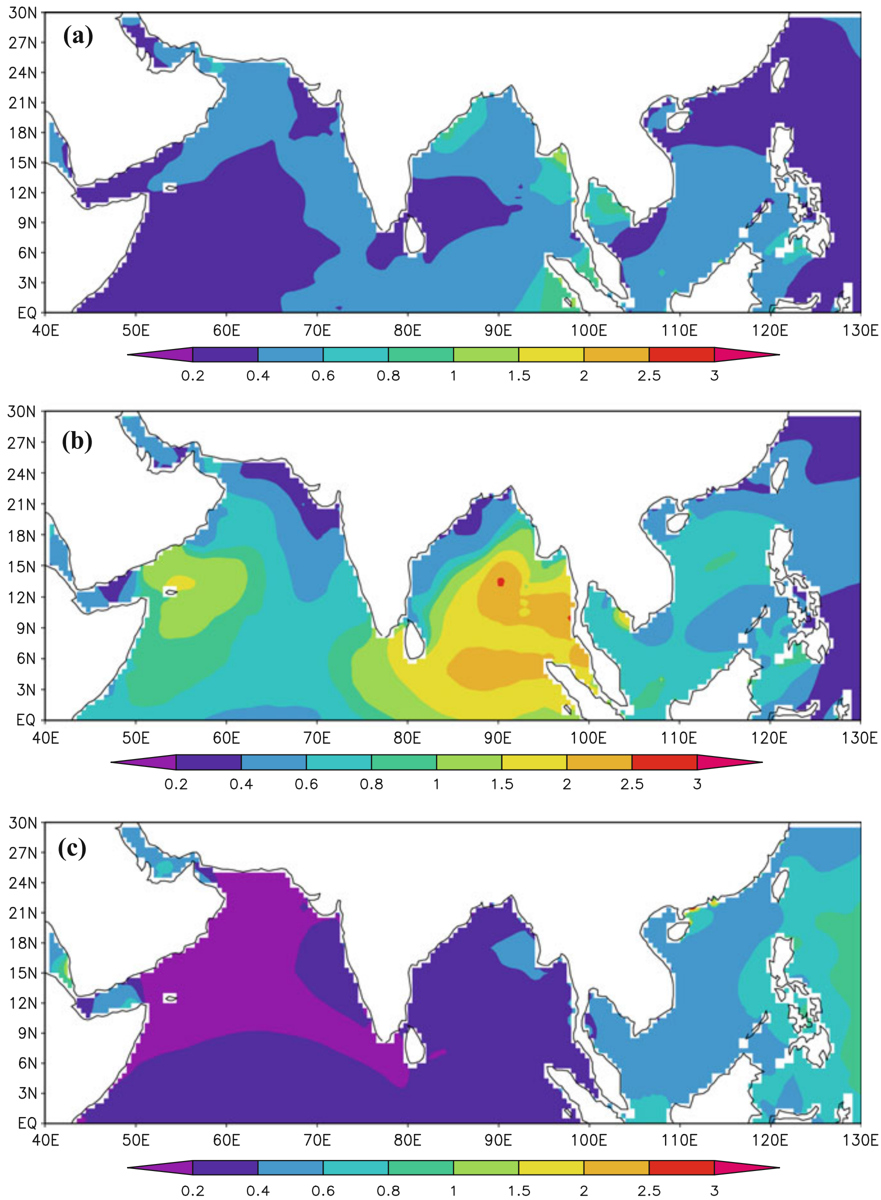

Fig. 5.5 Coefficient of variation of wave power density in January (**a**), April (**b**), July (**c**), and October (**d**) of the Maritime Silk Road. (after Zheng et al. 2012a)

spring to winter; it is about 2–2.5 kWm in spring, which is the least, about 3–5 kW/m in summer, about 2–12 kW/m in autumn, and about 4–18 kW/m in winter, which is the largest. The occurrence of wave power density of more than 2 kW/m and more

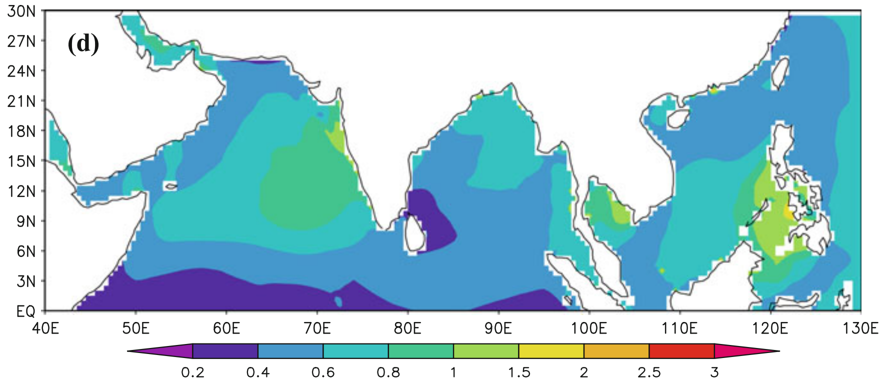

Fig. 5.5 (continued)

than 4 kW/m in the whole South China Sea and northern Indian Ocean is higher, which is conducive to the development and utilization of wave energy resources. The stability of the wave power density in the South China Sea and the northern Indian Ocean is good. The stability is better in spring, autumn, and winter than it is in summer; the stability of the South China Sea is better than that of the northern Indian Ocean. In the South China Sea and the northern Indian Ocean, most areas contain abundant wave energy with better stability. The development of wave energy resources, such as wave power generation and seawater desalination, will have broad prospects.

5.4 Prospects

The mineral, biological, chemical, and power resources of the Maritime Silk Road are tentatively catalogued. The Maritime Silk Road is also rich in irreplaceable navigational resources. Even today, with the development of air and inland transportation, navigational transportation still plays an indispensable role; 90% of global commercial trade and 65% of the total oil trade are based on navigational transportation. Moreover, half of the world's container transport corridors pass through the Indian Ocean, and 40% of global trade passes through the Malacca Strait. The Indian Ocean holds one-sixth of the world's cargo throughput and nearly one-tenth of the cargo turnover. Obviously, the Indian Ocean is already a "sea lifeline" for both the Orient and the West. The South China Sea is a very important maritime gateway linking China and the rest of the world, as well as the maritime corridor between the Pacific and Indian Oceans. Annually, more than 40,000 ships pass through the South China Sea. For Japan, South Korea, and Taiwan, more than 90% of oil imports rely on the channel in the South China Sea; through this channel, the transport of liquefied natural gas accounts for two-thirds of the world's total trade volume. From China there are nearly 40 routes to foreign countries, of which more than half pass through the South China Sea.

Development and utilization of marine resources will effectively ease the resource and environmental crises. Limited to the professional level, especially in mineral resources and biology, we can thus build a framework and research ideas. We hope that more researchers will participate in scientific research relevant to the Maritime Silk Road, which will contribute to the "Sea Dream" and the "Chinese Dream." In future work, we need to address the following aspects: (1) a systematic and detailed statistical analysis of the temporal and spatial distribution of various resources; (2) short-, medium-, and long-term forecasts of the various resources; (3) the establishment of a three-dimensional monitoring network and early warning platform, which will be convenient for easy real-time control; (4) a comprehensive evaluation system of resources, environment, economy, and national defense; (5) site evaluation that can demonstrate the feasibility of resource development at important sites and be supportive of the Maritime Silk Road construction.

References

Acero WG, Gao Z, Moan T (2017) Numerical study of a novel procedure for installing the tower and rotor nacelle assembly of offshore wind turbines based on the inverted pendulum principle. J Mar Sci Appl 3:243–260

American Security Project (2012) Resources in the South China Sea. http://www.americansecurityproject.org/resources-in-the-south-china-sea/. Posted By Xander Vagg on 4 Dec 2012

Cartoko (2010) Indian Ocean. Natural resources. http://www.cartoko.com/2010/05/indian-ocean-natural-resources/

China Macroeconomic Information Network (2004) The present situation analysis to oil and gas industry in Singapore. http://www.macrochina.com.cn/xsfx/wbhj/20040726066948.shtml

Cornett AM (2008) A global wave energy resource assessment. In: Proceedings of the eighteenth international offshore and polar engineering conference, Vancouver, Paper No. ISOPE-2008-TPC-579

Fabi R (2012) West's energy firms await more reforms in Myanmar. Reuters. http://uk.reuters.com/article/2012/03/28/uk-myanmar-oil-idUKBRE82ROPN20120328, 28 Mar 2012

Globalsecurity.org. South China Sea Oil and Natural Gas http://www.globalsecurity.org/military/world/war/spratly-oil.htm

Hainan Local Chronicles net (2009) Natural renewable energy. Available at http://www.hnszw.org.cn/data/news/2009/06/43652/

Insider Secrets (2014). Why oil and gas in the South China Sea won't be developed. http://oilprice.com/Energy/Energy-General/Why-Oil-and-Gas-in-the-South-China-Sea-Wont-Be-Developed.html, 17 July 2014

Li G (2015) China sea oil and gas resources. http://www.ciis.org.cn/english/2015-05/11/content_7894391.htm

Liu ZJ, Jia QS (2013) Saudi Arabia oil and gas resources present situation and policy review. Land Resour Inf 6:42–44

People's Republic of China embassy in Myanmar Federal Republic (2013) Economy of Burma. http://mm.china-embassy.org/chn/ljmd/zzjj/t924655.htm

People's Republic of China, the commercial counsellor's embassy in Islamic Republic of Pakistan (2003). Pakistan's oil and gas industry. http://pk.mofcom.gov.cn/article/ztdy/200305/20030500094435.shtml
Song DX, Bai J (2009) Geopolitical strategy under the perspective of the Indian Ocean. South Asian Stud 3:31–45
The Diplomat (2015) China and the South China sea resource grab [EB/OL]. http://thediplomat.com/2015/02/china-and-the-south-china-sea-resource-grab/, 22 Feb 2015
University of Hong Kong, Swire Institute of Marine Science (2009) Hydrocarbons in the South China Sea. ftp.fisheries.ubc.ca/l.teh/destructive%20fishing/South%20china%20sea.pdf
U.S. Central Intelligence Agency (1976) Indian Ocean Atlas. Washington, pp 16–17
Wang Y, Ma JS (2003) Characteristics of submarine geomorphology, natural resources distribution and border intermittent lines of the South China Sea. J Nanjing Univ (Natural Science) 39(6):797–805
Wu Q (2012) The status quo of the plundering of oil and gas resources in the South China Sea. http://finance.sina.com.cn/china/20120516/114112077175.shtml, 16 May 2012
Xinhua Net (2012) India wants to monopoly offshore oil and gas fields in Sri Lanka. http://news.xinhuanet.com/world/2012-03/14/c_122834388.htm
Xinhua Net (2015) We first discovered accumulates rich rare earth deposits in the Indian Ocean basin. http://www.sd.xinhuanet.com/xhsksd/2015-06/18/c_1115662351.htm
Yu GM (2015) India's oil and gas industry present situation and development trend. http://wenku.baidu.com/link?url=kZGtwdKuqU1Re5CSL1ynLcx9m888tf3Dxj7DF45VAnubCIblgGuowLtSFoSEY_wT8G8UQIJdstkuReV5nvclOd90ebtnY7LZvq3lpLd6gZK
Zhang FY, Zhang WY, He XW et al (2015) Resource estimation of co-rich crusts of seamounts in the three oceans. Acta Oceanol Sin 1:88–105
Zheng CW (2011) Wave energy and other renewable energy resources in South China Sea: advantages and disadvantages. J Subtrop Resour Environ 6(3):76–81
Zheng CW, Li CY (2015) Important role of ocean in the development of modern society. Ocean Dev Manage 32(9):4–12
Zheng CW, Li XQ, Pan J (2012a) Wave energy analysis of the South China Sea and the northern Indian Ocean in recent 45 years. Mar Sci 36(6):101–104
Zheng CW, Zhuang H, Li X, Li XQ (2012b) Wind energy and wave energy resources assessment in the East China Sea and South China Sea. Sci China Technol Sci 55(1):163–173
Zheng CW, Su Q, Liu TJ (2013a) Wave energy resources assessment and dominant area evaluation in the China Sea from 1988 to 2010. Acta Oceanol Sin 35(3):104–111
Zheng CW, Pan J, Li JX (2013b) Assessing the China Sea wind energy and wave energy resources from 1988 to 2009. Ocean Eng 65:39–48
Zheng CW, Shao LT, Shi WL et al (2014a) An assessment of global ocean wave energy resources over the last 45 a. Acta Oceanol Sin 33(1):92–101
Zheng CW, Zhou L, Jia BK, Pan J, Li X (2014b) Wave characteristic analysis and wave energy resource evaluation in the China Sea. J Renew Sustain Energy 6:043101. https://doi.org/10.1063/1.4885842
Zheng CW, Pan J, Sun W et al (2015a) Strategic of the ocean environment of the 21st century Maritime Silk Road. Ocean Dev Manage 32(7):4–9
Zheng CW, Li XQ, Gao ZS et al (2015b) Strategic of the 21st century Maritime Silk Road: Wind climate analysis. Ocean Dev Manage 32(8):4–11
Zheng CW, Fu M, Rui ZF et al (2015c) Strategic of the 21st century Maritime Silk Road: wave climate analysis. Ocean Dev Manage 32(10):1–7

Chapter 6
Characteristics of Important Routes, Channels, and Ports

To better serve the Maritime Silk Road, the characteristics of important routes, nodes, and ports are analyzed in this chapter, including geographical position, climatic conditions, hydrological characteristics, commercial value, and humanistic background.

6.1 Important Routes

6.1.1 Near-Sea Shipping Line

Near-sea shipping line refers to the line from Chinese ports to the key ports of neighboring countries. There are six primary routes as follows:

(1) **China–Vietnam**

The important ports include Hanoi and Haiphong. China exports primarily steel, equipment, cotton, and other products to Vietnam, while it imports primarily coal, oil, fruits, vegetables, and other supplies from Vietnam.

(2) **China–Philippines**

The important ports are Manila, Cebu, and others. Manila is the Philippines' largest port; it is also the political, economic, cultural, and transportation center. Cebu is the second-largest port in the Philippines, which is rich in materials and minerals. China exports primarily textiles, coal, and clothing to the Philippines, while it imports primarily electronic devices, raw steel, bananas, and other supplies from the Philippines.

(3) **China–Singapore, Malaysia**

The primary ports are the port of Singapore, Kuantan, Port Klang, Port of Penang, Malacca, and others. The important imported products of China are fossil fuels,

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organic chemicals, natural rubber, plastics and their products, machinery, electronics, and so on. The primarily exported products of China are iron and steel products, machinery, electronics, ships, furniture, and so on.

(4) **China–Thailand, Cambodia**

The primary ports are Laem Chabang, Bangkok, Songkhla, and others. The major imported products of China are agricultural products, plastic products, rubber products, machinery, electronics, and so on. The primary exported products of China include organic chemicals, iron and steel, machinery, electronics, and optical medical equipment.

(5) **China–Indonesia**

The major ports are Jakarta, Surabaya, Semarang, and others. The primary imported products of China are fossil fuels, animal and vegetable oils, miscellaneous chemical products, and rubber and rubber products. The major exported products of China include machinery and equipment, steel, and base metals and products. Today, China has become Indonesia's largest trading partner, and hence this route has become busier.

(6) **China–North Kalimantan**

The important ports include Brunei's Bandar Seri Begawan, Malaysia's Miri, Kuching, and others. The major imported products of China are electromechanical products, fossil fuel, animal oil, mechanical equipment, and rubber and its products. The primary exported products of China include electromechanical products, mechanical equipment, crude steel, copper and its products, optical instruments, textiles, and so on. China has been Malaysia's largest trading partner for a long time, and in recent years, trade between China and Brunei has also increased rapidly within this route.

6.1.2 Ocean-Going Shipping Line

The ocean-going shipping line of the Maritime Silk Road refers to the routes from China's ports to the key ports in the following areas: the Bay of Bengal, the Arabian Sea, the Persian Gulf, the Red Sea, and the Mediterranean Sea.

(1) **China–Bay of Bengal**

The primary ports are Yangon, Chittagong, Kolkata, and Chennai. In bilateral trade, China's exports to Bangladesh include textiles, machinery, equipment, chemicals, fertilizers, seeds, and consumer goods, while China's imports from Bangladesh are primarily jute and its products, raw materials and processed leather, shrimp, and frozen food. Myanmar's exports to China are timber, agricultural products, and mineral products, and imports from China include complete sets of equipment and electromechanical products, textiles, motorcycle accessories, and chemical products. India's major exports to China include cotton, mineral products, copper and its products, organic chemicals, and building materials. India's imports from China are primarily mechanical and electrical products, mechanical equipment, organic chemicals, cultural relics, and fertilizers.

(2) **China–Sri Lanka**

The major port is Colombo. Sri Lanka's exports to China include primarily plant fiber and its products, tea, rubber and its products, (non-) knitted products, and (non-) crocheted dresses. Sri Lanka's imports from China are primarily electromechanical products, mechanical equipment, knitted fabrics, cotton, and steel products.

(3) **China–Arabian Sea, Persian Gulf**

The major ports are Mumbai, Karachi, Abbas, Dubai, Khalk Island, Kuwait, Doha, and Basra. The route takes up about half of China's offshore oil transportation and is the lifeline for China's energy imports. In addition, this route is also the primary trade lane for China, India, and Pakistan. Thus, this route plays an extremely important role in the construction of the Maritime Silk Road and in China's energy supply.

(4) **China–Red Sea**

The major ports are Aden, Jeddah, Aqaba, Sudan, and others. China's exports to Yemen include primarily textiles, electromechanical products, grain and oil foods, and light industrial products, while the primary import of China from Yemen is crude oil. From the perspective of trade commodity structure, China's imports from Saudi Arabia are mainly petroleum and petrochemical products, and China is Saudi Arabia's third-largest export destination. China's exports to Saudi Arabia are primarily clothing, IT products, home appliances, and so on. China is Saudi Arabia's second-largest source of imports. Currently, Saudi Arabia is one of the most important and stable overseas suppliers of crude oil. Sudan is also rich in oil and mineral resources; about two-thirds of oil exports are transported to China, accounting for about 6% of China's oil imports. Sudan is China's third-largest trading partner in Africa. China is Sudan's largest trading partner. Thus, this route plays an extremely important role in the construction of the Maritime Silk Road and in China's energy supply.

(5) **China–East Africa**

The major ports are Mogadishu, Mombasa, Dar es Salaam, Maputo, and Port Louis. China's major exports to Kenya are mechanical equipment, household appliances, textiles, daily necessities, hardware, tools, building materials, pharmaceuticals, chemical raw materials, and so on, and imports from Kenya include primarily animal leather, logs, sawn wood, sisal, and so on. China's exports to Tanzania are primarily foodstuffs, vehicles, textiles, light industrial products, chemical products, mechanical equipment, electrical equipment, steel, and so on, and imports from Tanzania include dried seafood, raw leather, logs, crude copper, and wooden handicrafts. China's major exports to Mozambique are mostly electromechanical products, steel, vehicles, and other transport equipment, and the major imports from Mozambique are primarily logs, minerals, and other primary products. With the rapid trade growth between China and Mozambique and between China and Tanzania, the cargo volume of the route is also increasing.

(6) **China–Mediterranean**

The major ports on the north and south shores of the Mediterranean Sea are Aosa, Constance, Varna, Istanbul, Rijeka, Venice, Genoa, Marseille, Barcelona, Valencia, Alexandria, Tripoli, Benghazi, Tunisia, Algiers, and others. Currently, the EU is China's largest trading partner and export market, the largest source of technology imports, and the fourth-largest real investor. Moreover, China is the EU's second-largest trading partner, and the economic and trade ties between China and the EU are the best in history. The EU has been China's largest trading partner for 11 consecutive years, and China has been the EU's second-largest trading partner for 12 consecutive years. In 2014, the bilateral trade volume between China and the EU exceeded USD 600 billion. As this route is significantly shorter and more secure than the routes around the Cape of Good Hope, this route has played an important role in increasing the maritime trade and transport between China and the EU.

In summary, the China–Persian Gulf route, the China–Red Sea route, the China–Indonesia route, and the China–North Kalimantan route play an important role in the marine transport of China's imported energy. Other routes, especially the China–Mediterranean route and the China–Singapore and Malaysia routes, are important in strengthening China's foreign trade.

6.2 Important Channels

In the previous section, we briefly analyzed the important routes of the Maritime Silk Road, which also contain some important nodes such as the Taiwan Strait, the Strait of Malacca, the Sunda Strait, the Strait of Hormuz, the Mandeb Strait, and the Suez Canal. These nodes are further described and analyzed below.

6.2.1 The Taiwan Strait

Geographical features

The Taiwan Strait is located between China's Taiwan Island and the Fujian coast, which belongs primarily to the East China Sea and can be connected to the South China Sea. The strait runs northeast to southwest and is about 370 km long. The northern end of the Taiwan Strait is narrow, but the south is wide. The width of the northern mouth is about 200 km, the width of the southern mouth is about 410 km, and the narrowest part is about 130 km from Baisha Cape on Taiwan Island to Haitan Island of Fujian. The water depth in most of the strait is less than 80 m, and the average water depth is about 60 m. The terrain is relatively flat in the northwest, the slope is larger in the southeast, and the islands and shoal constitute an arc-shaped belt in the middle. Near the southern mouth, the Taiwan Shoal consists of more than 900 submerged dunes that are elliptically distributed; the length from east to west is about 140 km, and from north to south, about 75 km. The water depth is 10–20 m, and the shallowest is 8.6 m. There are jet streams on the Taiwan Shoal, so that the hydrological conditions are complex. The Taichung Shoal is west of Taichung; the length from east to west is about 100 km, the width from north to south is 15–18 km, and the shallowest water depth is 9.6 m. The Penghu Islands reef area is between the Taiwan Shoal and Taichung Shoal; the length from north to south is about 70 km and the width from east to west is about 46 km. This area consists of islands, reefs, and underwater rocks. In the north, the islands and reefs are concentrated and the channels are narrow, but the opposite is true in the south (Baidu Baike 2015a).

Climate

The Taiwan Strait has a subtropical and tropical monsoon climate. In the middle, the average maximum temperature is 28.1 °C, the minimum temperature is 15.9 °C, and the annual precipitation is 800–1500 mm. The annual temperature range is large in the northwest. The annual temperature range and daily variation are small in the southwest. From October to the following March is the northeast monsoon period, with average wind speed of about class 4–5 on the Beaufort Scale, and sometimes higher than class 6. From May to September is the southwest monsoon period, with average wind speed of about class 3 on the Beaufort Scale. From July to September, there are on average 5–6 tropical cyclones per year. In the strait there is less fog than there is close to shore; there are more than 30 fog days per year.

Strategic position

The Taiwan Strait is an important traffic artery connecting the East China Sea, the South China Sea, and the Indian Ocean. It is not only the throat of China's coastal maritime traffic arteries but also an important international waterway in the western Pacific region for trade and transportation among the countries in Northeast Asia and Southeast Asia, with a daily average of a hundred ships passing through the strait. China's north-south trade routes and three foreign trade routes to the south need to pass through the Taiwan Strait. Almost all the routes included in the Maritime Silk Road have to pass through the Taiwan Strait. Therefore, smooth navigation has a very significant influence on the development of our national economy and foreign trade.

6.2.2 The Malacca Strait

Geographical features

The Malacca Strait is located between the Malay Peninsula and Sumatra. The strait borders the Andaman Sea to the west and the South China Sea to the east and runs northwest to southeast. It is about 1080 km long (together with the Singapore Strait at the exit, it is about 1185 km long). The width of the northwestern end of the Malacca Strait is 370 km, and the width of the southeastern end is 37 km. The seabed is relatively flat and has more sediments. Water depth decreases both from north to south and from east to west, and the water depth is usually 25–115 m. At the southeastern gap, there are several small islands, on the edge of some of which are rocks and sand ridges that hinder navigation. The major deep-water channel is located on the east side of the strait; it is about 2.7–3.6 km wide, with a navigable draft of 20 m (Baidu Baike 2015b).

Climate

The Malacca Strait has a tropical rainforest climate with perennial high temperatures and a rainy season. The annual average temperature is above 25 °C, and the average annual precipitation is 2000–2500 mm, even reaching more than 3000 mm at the Malacca port. During most of the year, wind speed is very low, due to which the Malacca Strait is known as the "calm sailing strait." However, there are frequent storms and thunderstorms, especially from April to May and from October to November when ships passing through the strait need to be on guard.

Strategic position

As the communication channel between the Pacific Ocean and the Indian Ocean, the Malacca Strait is an important component of global shipping routes. According to statistics, more than 200 ships every day and more than 80,000 ships every year pass through the Malacca Strait, constituting a quarter of the global maritime trade, and nearly half of all tankers pass through the Malacca Strait. For China, 85% of oil transport is through the Malacca Strait. Moreover, the Malacca Strait is the basic route for import and export trade among China, Europe, and Africa. Therefore, the Malacca Strait can be regarded as a key node of the Maritime Silk Road.

6.2.3 The Sunda Strait

Geographical features

As the communication channel between the Java Sea in the Pacific Ocean and the Indian Ocean, the Sunda Strait is located between Sumatra and Java. The channel is narrow, about 120 km long and 22–110 km wide. The minimum width is 3.3 km, the average water depth is 50–80 m, and the maximum water depth is 1080 m, which is far deeper than the Malacca Strait. The bottom of the channel consists of mud, sand, stone, and shellfish. The channel is ideally suited for large vessels, but it is also vulnerable to destruction and blockades.

Climate

The strait has a tropical rainforest climate with perennial high temperatures and rainy seasons, and active convection. The annual average temperature is about 30 °C and the minimum temperature is 23 °C. The annual precipitation is 1500–1800 mm. From November to the following March is the northwest monsoon period, and from April to October is the southeast monsoon period, when it is sunnier and there is less rainfall. In addition, it is important to note that the strait is located in an active crustal zone with volcanic activity and tsunamis.

Strategic position

The Sunda Strait is one of the most important strategic channels connecting the Pacific Ocean to the Indian Ocean, and it is also the throat of maritime traffic arteries from countries around the northwestern Pacific Ocean to Africa around the Cape of Good Hope to Europe; especially, many large oil tankers going to China also pass through this strait. It is an important trade channel between China and Australia. In addition, the channel is highly suitable for large ships and submarines, so that the US military pays attention to the strait, and it is an important sea lane for the US Navy 7th fleet that plies between the Pacific Ocean and the Indian Ocean (Li 2005).

6.2.4 The Strait of Hormuz

Geographical features

The Strait of Hormuz is located between the Arabian Peninsula and southern Iran and borders the Persian Gulf to the west and the Gulf of Oman to the east. Iran is on the north shore, Oman is on the south shore, and Geshm Island, Hormuz Island, and Hart Island are in the middle. The length of the Strait of Hormuz is about 150 km from east to west, and the width is 56–125 km from south to north. The average water depth is 70 m, the shallowest is 10.5 m, and the deepest is 219 m. The terrain in this strait is complex and shallow in the north, where there are several beaches and coral reefs along the coast, and deep in the south, where there are several bays and small peninsulas along the coast.

Climate

The Strait of Hormuz is located in the subtropical zone and has a tropical desert climate that is hot and dry all year round. The annual average temperature is above 26 °C; in July, it is 31–32 °C, and in January, it is 20–21 °C. In most of the strait, the annual precipitation is only 100–200 mm, and only precipitation in the vicinity of Bushehr can reach 300 mm. In this strait, the average wind speed is low, and wind speed greater than class 6 generally appears only from November to the following March. The frequency of sea fog is very low. However, visibility is low from May to July because of dust (Shi 2014).

Strategic position

The Strait of Hormuz is the only exit from the Persian Gulf to the Indian Ocean. It is the only sea lane from the Persian Gulf oil to Europe, America, and East Asia. It is also one of the busiest oil transportation corridors in the world and has an important economic and strategic position (Li 2011). The Strait of Hormuz must be passed through on the China–Red Sea route of the Maritime Silk Road, so it has great significance for China, West Asia, and Africa to carry out maritime trade. Meanwhile, the strait must also be passed through for China's major oil route—the Middle East routes. About 40% of China's total oil imports pass through this channel (Shi and Li 2013). Therefore, the Strait of Hormuz is one of the most important energy channels for China.

6.2.5 The Bab-el-Mandeb Strait (Mandeb Strait)

Geographical features

The Bab-el-Mandeb Strait (or Mandeb Strait) is located between the southwestern tip of the Arabian Peninsula and the African continent, with coordinates of 43° 20′E and 12° 40′N. This strait connects the Red Sea, the Gulf of Aden, and the Indian Ocean. The Mandeb Strait is about 50 km long, 26–32 km wide, and 30–323 m deep. There are several small islands at the entrance of the strait, of which the largest is named Pilin Island and has an area of about 13 km^2. Pilin Island divides the Mandeb Strait into eastern and western channels. The eastern channel is only 3.2 km wide and about 30 m deep, and it is an important route from the Red Sea to the Indian Ocean. The western channel is about 28.95 km wide and about 333 m deep, but it is difficult to sail as there are several reefs and shoals (Zhang 2014).

Climate

The Mandeb Strait has a tropical desert climate, which is hot all year round. The hot season is from April to October, when the average temperature is about 37 °C and the maximum temperature is above 45 °C. The cool season is from November to the following March, when the average temperature is about 27 °C. Rainfall is scarce, with annual average precipitation of 150–200 mm. Because evaporation is far greater than precipitation, because there are few rivers flowing into the sea, and because water exchange with the Gulf of Aden and the Arabian Sea is blocked, seawater salinity in the strait is above 38, making this strait the world's highest-salinity channel (Li 2010).

Strategic position

Since ancient times, the Mandeb Strait has been a busy commercial road and a strategic link between the Indian Ocean, the Gulf of Aden, and the Red Sea. Zheng He's seventh expedition passed through the Mandeb Strait, proceeding northward to Mecca along the Red Sea. Since the construction of the Suez Canal, the Mandeb Strait has been not only a necessary channel for the shortest route from the Atlantic Ocean to the Indian Ocean but also an important maritime trade channel for Europe, Asia, and Africa, with more than 20,000 vessels passing through the strait each year, making it one of the most important and busiest straits in the world, known as the "world's strategic heart" (Li 2005). For China, this strait is not only an important link between China and Western Europe but also a key channel for China to import crude oil from Saudi Arabia, Yemen, and North Africa.

6.2.6 The Suez Canal

Geographical features

The Suez Canal is an artificial sea-level waterway located in northeastern Egypt. This canal is the dividing line between Asia and Africa and is also the most direct water channel among Asia, Africa, and Europe. The west side of this canal is the low-lying Nile delta, and the east is a higher, uneven and arid area named the Sinai Peninsula. The canal connects the Mediterranean Sea and Red Sea through the Isthmus of Suez. The canal is about 190 km long, 280–345 m wide, and about 22.5 m deep on average, and it has good natural conditions.

Climate

The Suez Canal has a subtropical Mediterranean climate, being hot and dry in summer and mild and rainy in winter. The average temperature is about 12 °C in January and about 26 °C in July. The annual precipitation is 50–200 mm.

Strategic position

The Suez Canal is a famous international waterway connecting the Mediterranean Sea and the Red Sea. It is a gateway for maritime navigation between the North Atlantic Ocean, the Indian Ocean, and the western Pacific Ocean and has important international economic and strategic value. As the shortest route between Western Europe and the Persian Gulf and between Western Europe and the Asia-Pacific region, it is the busiest route in the world, with the vessels of more than 100 countries traversing it every year. Its cargo volume accounts for 20% of the world's total marine trade volume, and nearly 80% of Eurasian maritime cargo. For the Maritime Silk Road, it is an important node in the China–Mediterranean Sea route and has an important strategic position (Li 2005).

6.2.7 The Strait of Gibraltar

Geographical features

The Strait of Gibraltar is located between the southernmost part of Spain and northwestern Africa. It is an important gateway connecting the Mediterranean Sea and the Atlantic Ocean. It is about 90 km long. The shallowest part of this strait is only 13 km wide, and the west is the widest, about 43 km wide; the shallowest depth is 50 m; the deepest is 1181 m, and the average depth is about 375 m (Baidu Baike 2015c).

Climate

The Strait of Gibraltar and the surrounding area have a subtropical Mediterranean climate. In summer, it is controlled by subtropical high temperatures, and it is dry and hot and has scarce rainfall and strong evaporation. In winter, it is controlled by westerlies, with multiple cyclone activity, and is mild and rainy. In spring and autumn, there are several storms. In spring, the strait frequently has fog, and visibility can be very low, which is a great threat to ships.

Strategic status

The Strait of Gibraltar is the only gateway from the Mediterranean Sea to the Atlantic Ocean, and it is also the throat channel for Western Europe. Vessels from the Nordic countries pass through it to the Mediterranean Sea and the Suez Canal, proceeding southward to the Indian Ocean. Ships carrying oil from the Persian Gulf also pass through the Strait of Gibraltar to Western Europe and the Nordic countries. According to statistics, shipping through the strait accounts for 25% of the world's shipping every year, and more than 120,000 vessels pass through it (Li 2005). As the shortest route between China and northwestern Europe, it is also of great significance for the construction of the Maritime Silk Road.

The above analysis shows that several important nodes on the Maritime Silk Road are key points of the world's economy, trade, and energy transportation and are of vital strategic importance to China's sustainable economic development and national defense security. However, these channels are often narrow and have complex geographical conditions and poor hydrological and meteorological conditions, making navigation vulnerable to artificial blockades and natural conditions; hence, we need to analyze and prevent these risks. Toward the deep sea, remote islands and reefs usually play a positive role. As a result, it is necessary to analyze the marine environment and energy characteristics of remote islands and reefs for the construction of the Maritime Silk Road.

6.3 Important Ports

Ports are regarded as special nodes of international logistics; they are important gathering points and hinges for waterway transportation. Thus, ports become the natural nodes connecting inland areas and ocean transportation. The ports along the Maritime Silk Road are the base points and bridges for China and the relevant countries and have an extremely important economic status. It is important to analyze the key points of the Maritime Silk Road, which will be given the functions of consolidated replenishment, ship maintenance and repair, information gathering, ocean monitoring, humanitarian assistance, medical treatment and rescue, maritime rights and interests maintenance, and so on to supply marine construction. In this section, the characteristics of some important ports around the South China Sea and the Indian Ocean are analyzed, including primarily geographical location, climate, cultural background, cargo throughput, and so on (as shown in Tables 6.1 and 6.2), in the hope of providing a scientific reference for remote islands and reefs construction.

6.3.1 Important Ports Around the South China Sea

The ports around the South China Sea are usually natural harbors with favorable natural conditions, and these ports play an important role in the construction of the Maritime Silk Road. In this section, the geographical location, climate, humanistic background, and cargo throughput of the important ports around the South China Sea are presented in Table 6.1.

6.3.2 Important Ports Around the Indian Ocean

In recent years, China has actively participated in the investment and construction of some ports around the Indian Ocean and has provided support for the security of our sea lanes and logistic replenishment for humanitarian assistance overseas. Basic information for some ports related to China's ocean strategy is shown in Table 6.2. International security experts have stated that building strategic points is an important means of realizing the safety of sea lanes and the construction of sea power. Drawing on ancient historical experience, on the basis of the Maritime Silk Road initiative, through interconnection and interworking, infrastructure investment, and the layout of port construction, we focus on making the ports into key points (Zhang 2015). For instance, as the development and upgrading of industries such as smelting and shipbuilding can be realized through the demarcation of industrial parks and investment in infrastructure construction, the modernization of the abovementioned key ports can be strengthened. Furthermore, we may actively participate in port

Table 6.1 Basic information for major ports around the South China Sea

Port	Geographical location (Latitude and longitude, altitude, water depth)	Climate (Temperature, pressure, humidity, wind, precipitation)	Humanistic background (Population, ethnicity, religion, etc.)	Cargo throughput
Cam Ranh Bay (Vietnam)	11° 59′ 53″N, 109° 13′ 10″E. Located on the southern coast of Fuqing Province in Vietnam. The inner harbor is known as Cam Ranh, with an area of 60 km^2, water depth of 1–16 m, and a bay mouth only 1300 m wide; the bay is 20 km long and 6 km wide. The outer harbor is known as Ap Binh Ba, the water depth is less than 30 m, the bay mouth is 3–4 km wide, and the depth outside the mouth is more than 30 m	Has a tropical climate, with high temperatures and rain. The annual average temperature is 24 °C. Annual precipitation is 1500–2000 mm, and the rainy season and dry season are distinct; from May to October is the rainy season; from November to the following April is the dry season	With a population of about 1.1 million (2003), the residents are primarily Jing. Religion is primarily Mahayana	Has the capability of parking aircraft carriers and hundreds of warships
Subic Bay Harbor (The Philippines)	14° 49′ 12″N, 120° 14′″E. Located southwest of Luzon Island in the Philippines, it is an important harbor on the east coast of the South China Sea. The east is known as the Mayaggio Cape, and the west is known as Bini Ke Tikan Cape. The harbor is 14 km long, 8–13 km wide, and 24–50 m deep and has good anchorage	Has a tropical monsoon climate. Hot all year round, but cool from December to the following February, and hottest from March to April. Rainfall is abundant, and annual precipitation is more than 3000 mm. From December to the following April is the dry season, and other times are the rainy season	With a population of 230,000 (2007), the major residents are Tagalog and Ilok. Religion is primarily Catholicism	In the first phase of the project, container berths 280 m long will be completed; the annual throughput can reach up to 300,000 TEUs
Singapore Port (Singapore)	1° 16′N, 103° 50′. Located on the southern coast of Singapore, the west next to the southeastern side of the Malacca Strait, the south next to the northern side of the Singapore Strait. The natural conditions are superior; the waters are spacious, and the water depth is suitable. A ship with a draught of about 13 m can enter the port smoothly	Has a tropical rain forest climate. The annual average temperature is 24–34 °C. The annual precipitation is about 2400 mm. From October to the following March is the rainy season. The tide in the port is diurnal, and the average tidal range is 2.2 m	With a population of about 5.47 million (2014), the major residents are Chinese, Indian, Malay, and Eurasian; the primary religions include Taoism, Buddhism, Islam, Catholicism, and so on	A total of more than 250 routes with connections around the world. In 2006, the cargo throughput was 24.8 million TEUs

(continued)

Table 6.1 (continued)

Port	Geographical location (Latitude and longitude, altitude, water depth)	Climate (Temperature, pressure, humidity, wind, precipitation)	Humanistic background (Population, ethnicity, religion, etc.)	Cargo throughput
Darwin Harbor (Australia)	12° 27′, 130° 50′E. Located on the northwest coast of Australia, the capital of the Northern Territory. There are three major piers, with a length of 734 m and water depth of 9–13 m	Has a tropical climate. Dry season is from May to September; June and July are the coolest months. Rainy season is from December to the following March, when there are often tropical storms and thunderstorms	With a population of about 220,000 (2012), residents are mostly descendants of European immigrants, Aborigines, and Torres Strait Islanders. The primary religions are Anglicanism and Catholicism	The annual cargo throughput reaches up to 3 million tons
Port of Sihanoukville (Cambodia)	10° 38′N, 103° 29′E. Located on the southwest coast of Cambodia, it is the largest port in Cambodia. There are a total of six berths and three anchorages, with water depth of 7.5–13 m. The water depth of the large ships' anchorage can reach up to 18 m	Has a tropical monsoon climate. The annual average temperature is about 29 °C. September to the following February is the cool season, with a monthly average temperature of 24 °C. Annual average precipitation is about 2000 mm. From June to November is the rainy season, while from December to the following May is the dry season. The average tidal range is 0.7 m	With a population of about 240,000 (2007), residents are primarily Khmer	Has the capability for 4 million-ton freighters at the same time, with a cargo throughput of nearly 2 million tons in 2006
Lin Chap Ban (Thailand)	13° 5′N, 100° 53′E. Located on the east bank of Bangkok Bay in the central part of Thailand, southeast of Bangkok. The water depth of the channel berth is maintained at a maximum of 16 m and is at least 14 m at low tide. The city, including the port, is less than 2 m above sea level	Has a tropical monsoon climate. There is a clear hot season, a cool season, and a rainy season each year. The annual average temperature is 27.5 °C. June is the hottest month, and the maximum temperature can reach up to 35 °C. From November to the following January is the cool season; the monthly average temperature is 17–24 °C. Annual precipitation is 1500 mm	Bangkok has a population of about 1197 million people, more than half of whom are of Chinese descent. Every year, a large number of immigrants and foreigners come into Bangkok. The primary religion is Buddhism. Bangkok is also known as the "Buddhist capital"	There are 11 terminals, of which five are container terminals. In 2005, with a throughput of 3,793,802 TEUs, it ranked 20th in the world

Table 6.2 Basic information for major ports around the Indian Ocean

Port	Geographical location (Latitude and longitude, altitude, water depth)	Climate (Temperature, pressure, humidity, wind, precipitation)	Humanistic background (Population, ethnicity, religion, etc.)	Cargo throughput
Port of Sittwe (Myanmar)	20° 8′19″N, 92° 54′ 4″E. Located in the largest city along the Bay of Bengal in Myanmar. On the north side of the Bay of Bengal, west of the Galatan estuary	Has a tropical monsoon climate. From December to the following April is the dry season, whereas the other months are the rainy season. The precipitation is more than 1000 mm from June to August. From December to the following February is a relatively dry and cool season	With a population of about 181,000, the major residents are Rakhine and Burmese; there are also Miao, German, Kami, and others. The primary religion is Buddhism	–
South Port (Sri Lanka)	6° 56′N, 79° 50′E. Located south of Colombo in Sri Lanka, it is a hinge connecting the east-west line of the Maritime Silk Road and an important node on the Maritime Silk Road. The water depth of the harbor is 9–11 m	Has a tropical monsoon climate. The prevailing wind is westerly. The annual average temperature is 22–32 °C. The annual average precipitation is about 2300 mm. The average high tide is 0.7 m, and the low tide is 0.1 m	With a population of about 642,000, the major residents are Sinhalese. Religion is dominated by Buddhism, followed by Islam, Christianity, and Hinduism	There are four berths. The coastline is 1200 m long. The berths were designed with an annual handling capacity of 2.4 million TEUs, and they can accommodate the world's largest container ships. The port is suitable for large and super-large vessels
Gwadar port (Pakistan)	25° 07′ 35″N, 62° 19′21″E. Located in Gwadar city in southwest Baluchistan province in Pakistan. The port is about 460 km east of Karachi, about 120 km west of the Pakistani–Iranian border and next to the northern Arabian Sea, at the mouth of the Strait of Hormuz. The water depth is more than 15 m	Has a tropical desert climate, dry and hot. It is hottest in June; the average temperature is 31–32 °C. It is coolest in January; the average temperature is 18–19 °C. From June to August, there are monsoon showers. The annual precipitation is only about 100 mm	With a population of about 90,000, the major residents are the Baluchistan and Baltan people, whose belief is Islam, and the vast majority follow the Sunni school	The first phase of the project includes three berths for multipurpose wharfs with ro-ro. Designed for annual handling capacity of 100,000 TEUs and 720,000 tons of grocery bulk grain

(continued)

Table 6.2 (continued)

Port	Geographical location (Latitude and longitude, altitude, water depth)	Climate (Temperature, pressure, humidity, wind, precipitation)	Humanistic background (Population, ethnicity, religion, etc.)	Cargo throughput
Chittagong (Bangladesh)	22° 22′N, 91° 48′E. About 8 nautical miles from the mouth of the Canafu River, near the northeast side of the Bay of Bengal. It is the largest harbor in Bangladesh. Berth depth is 6.4–8.5 m	Has a tropical monsoon climate. The annual average temperature is 13–29 °C. The number of days with fog is about 20 per year, and 50 days have thunderstorms. The annual precipitation is 2800 mm. The high tide in spring is 4 m, and the low tide is 0.5 m	With a population of about 1.75 million, the majority of residents are Bengali and Tibetan-Burmese people. The primary religions are Islam, Hinduism, Buddhism, and Christianity	It is a natural harbor. There are 28 quays; berths with 60,000 deadweight tons of crude oil. The annual throughput is 4 million tons
Port of Male (The Maldives)	4° 26′N, 73° 20′E. Located in the central part of the northern coast of Male Island in the Maldives, in the northern Indian Ocean. It is the largest port in the Maldives. It is the capital of the Maldives and also a military and traffic point in the Indian Ocean. The water depth in the east channel is more than 30 m	Has a tropical monsoon climate, with prevailing southwest wind. The annual average temperature is about 28 °C. The annual precipitation is about 2000 mm. The average tidal height is 1.1 m, and the low tide is 0.7 m	With a population of about 150,000 (2014), the major ethnicity is Maldivian; the primary religion is Sunni Islam and is considered the state religion	There are more than 10 carrying ships with the capacity for 75–150 tons of barges. The annual export of fresh fish products is 4000 tons
Port of Mombasa (Kenya)	4° 04′S, 30° 40′E, located on the southeast coast of Mombasa Island in Kenya, in the western Indian Ocean. It is the largest port in Kenya and one of the largest ports in East Africa. There are 21 primary berths in the port area, with a coastline 2343 m long. The maximum water depth is 9.5–13.4 m	Has a savanna climate, with prevailing southeast wind. The annual average temperature is about 24 °C, and the annual precipitation is 1200 mm. The average tidal range is about 1.8 m	With a population of about 700,000, it is Kenya's second-largest city and the capital of the coastal province. The primary residents are Bantus, Arabs, and Indians	There are 21 berths of over 10,000 tons, and navigation is for 24 h. According to incomplete statistics, in Mombasa port, the annual throughput for import and export is about 15–20 million TEUs

(continued)

Table 6.2 (continued)

Port	Geographical location (Latitude and longitude, altitude, water depth)	Climate (Temperature, pressure, humidity, wind, precipitation)	Humanistic background (Population, ethnicity, religion, etc.)	Cargo throughput
Baja Mogo port (Tanzania)	6° 26′S, 38° 54′E. Tanzania's famous port, close to the Zanzibar Strait, near the riverside estuary. The port is an important transit point in the East Africa-Arabia-India trade line. Water depth is 3.6–9.1 m	Has a tropical maritime climate. Damp heat throughout the year; the annual average temperature is 26 °C	With a population of about 30,000 people, the major ethnic groups are Sukuma, Nyamvich, Chaga, and others. The primary religion is Catholicism, Christianity, and Islam	With the completion of the integrated development project of Bajamogo, the annual throughput will reach 20 million TEUs, while the current annual throughput of the port of Dar es Salaam is 800,000 TEUs
Port of Djibouti (Djibouti)	11° 36′N, 43° 8′E. Located on the promontory of southeastern Djibouti in the Gulf of Aden. It is 77 nautical miles north of the Mandeb Strait and 130 nautical miles east of the Gulf of Aden. It is one of the largest modern ports in East Africa. Water depth is 9.7–12.1 m	Has a tropical desert climate; the annual average temperature is above 35 °C, and the maximum temperature can reach up to 46 °C. The average winter temperature is about 25 °C. The annual precipitation is about 150 mm. The maximum tide height is 2.9 m, and the minimum tide height is 0.2 m	With a population of about 810,000, the primary ethnic groups are the Issa and Afar. The major religion is Islam	There are 12 berths; the coastline is 2300 m long; 2500 tons of crude oil can be downloaded per hour. In 1992, the container throughput was about 5.7 million TEUs

management, so that these ports can provide logistic support for ships and security forces and contribute toward the maintenance of safe sea lanes and the control of key waterways.

In addition, it has been particularly noted that participation in the construction and operation of Gwadar port has special significance for the safety of our energy transport. After completion of the project, oil in the Middle East can be transported via Gwadar port to Xinjiang province through an oil pipeline, reducing the traditional route of more than 12,000 km via the Arabian Sea and the Malacca Strait to 2395 km. It is easy to see the significance of constructing this key point (Wang 2015).

6.4 Prospects

The construction of the 21st Century Maritime Silk Road is a gradual process. After Zheng He began his voyages in the early Ming Dynasty, rulers instigated a ban on maritime trade, resulting in a lack of understanding of the ocean. This lack of survey information regarding important routes, channels, and ports urgently needs to be resolved to serve the construction of the Maritime Silk Road. More than 70% of the earth's surface is ocean, 80% of the world's countries are coastal states, and more than two-thirds of the entire world population lives in the coastal zone (Suerci 2014). In the context of steady expansion of foreign trade, the United Nations Convention on the Law of the Sea should be used to steadily advance the common development of China and the coastal countries around the Maritime Silk Road, in order to realize the goal of neighborliness and to promote the common prosperity and progress of human society.

To better serve the construction of the Maritime Silk Road, we make a preliminary assumption in understanding the characteristics of the important routes, channels, and ports of the Maritime Silk Road. (1) Build a stereoscopic observation and monitoring platform. Build a four-dimensional network with observations based on space, air, land, and sea platforms to enhance real-time monitoring capabilities. With this observation and monitoring platform, we can widely collect and analyze marine data to provide support for basic research and marine development and construction. (2) Perform statistical analysis of marine climate characteristics (Zheng et al. 2014a, b; Zheng and Li 2015), including the climate background and historical weather systems (especially disaster weather systems). Experience is very important in meteorological and hydrological service. However, when entering unfamiliar waters, forecasters and sailors have little experience. As a result, a systematic and meticulous statistical analysis of climate characteristics is urgently needed. (3) Forecast and predict the marine environment (Zheng and Zhou 2011; Zheng et al. 2014c, 2015). Marine environmental forecasting and prediction include regional, route, and port forecasting and prediction. Forecasting and prediction elements include weather, visibility, wind, waves, current, temperature, salinity, and so on. Time series include short-term forecasting and mid- to long-term prediction. In particular, disaster weather forecasting and real-time early warning systems are necessary. (4) Plan routes for different seasons. According to the characteristics of disasters in different seasons, geographical features, cost, and other factors, developing optimal routes for different seasons is necessary. (5) Assess risk. This includes important routes, ocean engineering, and so on. (6) Construct the Marine Information Integrated Application System. Combining the primary information on routes, nodes, and ports, geographical data (islands, water depth, coastline, topography, etc.), marine meteorology (winds, clouds, visibility, barometric pressure, precipitation, fog, etc.), marine hydrology (seawater temperature, salinity, waves, currents, tides, etc.), electromagnetic environment, ocean observation and monitoring platform, humanistic background, risk assessment, and other important information, in accordance with a three-dimensional grid time series to store the data, we propose to construct the Marine Information Integrated Application System, which has the capability to conveniently query and assist decision-making and the functions of four-dimensional visualization and real-time updates.

References

Baidu Baike (2015a) Taiwan Strait. http://baike.baidu.com/subview/15923/7116831.htm?fromtitle=%40%23Protect%40%23
Baidu Baike (2015b) Strait of Malacca. http://baike.baidu.com/view/15939.htm?func=retitle
Baidu Baike (2015c) Strait of Gibraltar. http://baike.baidu.com/view/15949.htm
Li B (2005) The channel of international strategy. Central Party School of the Communist Party of China
Li J (2010) Global strategic channel survey. Decision Inf 11:73–76
Li J (2011) Global strategy for the channel. Party Gov Forum 3:55
Shi CL, Li XY (2013) The impact of the security of the Strait of Hormuz on China's imported oil supply and shipping. China Soft Sci 7:1–15
Shi JW (2014) Strait of Hormuz. Risk Analysis Council of China Association for Disaster Prevention
Suerci (2014). Asia ocean strategy. People's Publishing House, Beijing
Wang R (2015) Pakistan's Gwadar has ability to operate. Port Econ 4:53
Zhang J (2015) The construction of sea channel security and China's strategic pivot and talk about the safety of the Marine Silk Road construction in the 21st century. J Int Secur Stud 2:100–118
Zhang MS (2014) Important sea lanes in the Arab world. Jianghuai Tribune 1:76–81
Zheng CW, Li CY (2015) Important role of ocean in the development of modern society. Ocean Dev Manage 32(9):4–12
Zheng CW, Zhou L (2011) Seasonal variation of wave and wave energy in Xisha and Nansha sea area. Adv Mar Sci 29(4):419–426
Zheng CW, Pan J, Huang G (2014a) Forecasting of the China Sea ditching probability using WW3 wave model. J Beijing Univ Aeronaut Astronaut 40(3):314–320
Zheng CW, Shao LT, Li G et al (2014b) Analysis of influence on the security of sea skimming caused by a typhoon wave. J Harbin Eng Univ 35(3):301–306
Zheng CW, You XB, Pan J et al (2014c) Feasibility analysis on the wind energy and wave energy resources exploitation in Fishing Islands and Scarborough Shoal. Mar Forecasts 31(1):49–57
Zheng CW, Gao ZS, Zhang Y et al (2015) Strategic of the 21st century Maritime Silk Road: Extreme wind speed and extreme wave height. Ocean Dev Manage 32(11):4–8

Chapter 7
Maritime Silk Road from the Perspective of International Law

The Maritime Silk Road, which began in China, connects Asia, Africa, and Europe through commercial trade. Historically, the Maritime Silk Road, with its core goals of equality and mutual benefit, cooperation, and win-win scenarios, has promoted the exchange and development of politics, economy, and culture between the East and West. In September and October 2013, during a state visit to Central Asian countries and the Association of Southeast Asian Nations (ASEAN), Chinese President Xi Jinping made a speech in which he proposed building the Silk Road Economic Belt and the 21st Century Maritime Silk Road (Xinhua net 2014). The marine environment has a significant impact on ocean construction, the maintenance of maritime rights and interests, and so on (Zheng and Li 2015a, b; Zheng et al. 2015a). To serve the construction of the Maritime Silk Road, Zheng et al. (2014a, b, 2015b, c, d), Zheng and Li (2015c) systematically presented information on the marine environment, important routes and port features, geographical features, climatic profiles, marine resources, and the utilization status of the Maritime Silk Road.

To make a better contribution to the construction of the Maritime Silk Road, legal escort is essential (Wan et al. 2015). Legal escort is helpful to protect the rights, interests, and enthusiasm of countries and regions that participate in the construction of the Maritime Silk Road. This chapter discusses the legitimacy and rationality of development and construction in the South China Sea and the Maritime Silk Road according to the United Nations Charter, the United Nations Convention on the Law of the Sea, the Declaration on the Code of Conduct on the South China Sea, and the China–ASEAN Agreements in the hope of providing a reference for the legal protection of the Maritime Silk Road.

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7.1 Time Characteristics of the Maritime Silk Road

7.1.1 Peaceful Development Road

The ancient Maritime Silk Road has been a peaceful channel of economic and cultural exchange for 2000 years. As an early ocean power, China has never used its strong overall national power to plunder and conquer the countries along the Maritime Silk Road. Infiltrated with deep historical and cultural foundations, the Maritime Silk Road adheres to the spirit of openness and inclusiveness. Unlike existing international political and economic unions, the Maritime Silk Road aims for complete openness, equality, and mutual trust, without limits as to countries and political systems. The purpose of the Maritime Silk Road is to create win-win situations and common prosperity, not to control the economic lifeline of other countries. The Maritime Silk Road provides a huge inclusive platform for cooperation and development, which combines the development and common prosperity of China and the countries along the route. In a word, the Maritime Silk Road is a peaceful development road.

7.1.2 Road for Development of Cooperation and Win-Win

With the development of economic globalization and regional economic integration, global economic growth, trade, and investment are undergoing a profound adjustment. Economic restructuring and upgrading has become a key means for countries to shake off economic sluggishness and achieve economic growth. The traditional pattern of economic growth, trade, and investment patterns cannot meet the current developmental needs. Only by enhancing economic cooperation and integrating existing resources can countries can achieve rapid economic growth. The Maritime Silk Road initiative provides a platform of complementary advantages for the countries along the route. At the same time, the Maritime Silk Road initiative does not aim to control the economic lifeline of other countries or to change the political systems of other countries. The great tolerance, openness, and diversity of the Maritime Silk Road are conducive to the cooperation of countries along the route.

7.2 International Law Relating to the Maritime Silk Road

7.2.1 Charter of the United Nations

After World War II, the World Anti-Fascist League established the United Nations and discussed and formulated the Charter of the United Nations on the basis of summing up the lessons of war and promoting the restoration of post-war order. “Promoting international cooperation" is one of the three basic purposes of the United Nations found in the Charter of the United Nations. This aim is compatible with China's mutually beneficial foreign policy of cooperation and common development. At the same time, it is the legal basis and purpose for the Maritime Silk Road initiative.

7.2.2 United Nations Convention on the Law of the Sea

Marine rights and interests are a natural extension of national territory. After World War II, peace and development became the major trend worldwide. Competition between states for territory is not in conformity with this international trend. Countries have gradually turned their sights to the oceans to expand their respective maritime rights and interests. Joint development and utilization of marine resources and maintenance of regional maritime security and stability have increasingly become the focus of global competition and focus. The promulgation of the United Nations Convention on the Law of the Sea was in the context of the intensification of such trends. China has a long coastline and a large number of reefs, which cover an area of more than 3 million km^2. The formulation and setting of marine strategy is of great strategic significance to national security and economic and social development. At the same time, as a member of the United Nations Convention on the Law of the Sea, China enjoys a wide range of maritime rights and interests in accordance with the convention and the general principles of international law.

7.2.3 Declaration on the Conduct of Parties in the South China Sea

In November 2002, the Foreign Ministers of China and ASEAN countries signed the Declaration on the Conduct of Parties in the South China Sea (the Declaration of the South China Sea), which affirmed the commitment of China and ASEAN countries to strengthen a neighborly partnership of mutual trust and to jointly safeguard peace and stability in the South China Sea. The declaration stressed that parties should resolve disputes in the South China Sea through friendly and peaceful consultations and negotiations. The declaration is the first political document signed by China and ASEAN countries on the South China Sea issue, which is of great significance for safeguarding China's sovereign rights and interests, protecting the peace and stability of the South China Sea, and enhancing mutual trust between China and ASEAN countries. After signing the declaration, China and ASEAN countries followed the purposes and principles of the declaration and actively explored and communicated about the declaration in earnest. After several years of peaceful consultation and concerted efforts, in June 2013, the declaration parties reached an agreement on the promotion and implementation of the declaration and signed the Code of Conduct for the South China Sea.

7.2.4 China–ASEAN Agreements

As strategic partners for China–ASEAN, mutual exchange and mutual trust are strategic all around. As a major participant in the Maritime Silk Road, ASEAN comprises several countries and regions along the Maritime Silk Road. Since 1997, China and ASEAN countries have signed a series of agreements, such as the Joint Declaration on China–ASEAN Strategic Partnership for Peace and Prosperity in 2003 and the Joint Statement on China and ASEAN Leaders on Sustainable Development in 2010. These will be the legal basis of the Maritime Silk Road.

7.2.5 Other Treaties and Agreements Between China and the Countries Along the Maritime Silk Road

International treaties and agreements help to determine the rights and obligations of the parties through peaceful negotiations. As the world's second-largest economy and the largest developing country, China has reached several treaties and agreements with the countries and alliances along the Maritime Silk Road. India signed a dual taxation avoidance agreement and bank cooperation memorandum of understanding between the two countries in 1994. China and Bangladesh signed an agreement for the encouragement and protection of investments with each other in 1996. China and Saudi Arabia signed a memorandum of understanding between the Ministry of Commerce of the People's Republic of China and the Ministry of Commerce and Industry of the Kingdom of Saudi Arabia on trade relief cooperation in 2010. China, Kuwait, and Bahrain signed an agreement on the promotion and protection of investment, the Agreement on the Avoidance of Double Taxation and the Prevention of Fiscal Tax Evasion, the Framework Agreement on the Economy, Trade and Technical Cooperation, and so on. China and the South African customs union signed the China and Botswana investment promotion and protection agreement, the Agreement on the Avoidance of Double Taxation and the Prevention of Fiscal Evasion with China and Botswana, the Agreement on Bilateral Investment Protection between China and Namibia, the Agreement on the Promotion and Protection of China and South Africa, the Agreement on Trade and Economic Cooperation between China and the EU, and the China–EU Cooperation Forum signed by China and the EU.

7.3 Advantages of Using Legal Mechanisms Along the Maritime Silk Road

7.3.1 Co-construct and Maintain Sea Lanes to Ensure Maritime Safety and Facilitate Investment

Port construction is the key to the Maritime Silk Road and is important in bringing about interconnection. How to overcome differences between legal systems is a major obstacle of overseas port construction and interoperability. Cooperation from the countries along the Maritime Silk Road in constructing and jointly safeguarding sea lanes, protecting the safety of maritime transport, and facilitating investment will benefit this interconnection. Therefore, an important topic during the APEC meeting in Beijing was how to strengthen regional interconnection.

7.3.2 Cooperation in the Development and Protection of Marine Resources and Environment to Achieve Win-Win

Since the industrial revolution, with science and technology taking off, the consumption of and demand for resources have obviously increased. Several countries have been forced to investigate marine energy. To ensure the peace and security of the world and to realize the interests of all countries, the sustainable development of marine resources has become a consensus. The protection of the marine ecological environment in maritime shipping and other resource development activities is also a common requirement of relevant international conventions and national laws. Most of the countries along the Maritime Silk Road are parties to the relevant conventions and should fulfill their obligations under international law to protect the marine environment.

7.3.3 Jointly Safeguard Maritime Security and Peace and Achieve International Maritime Legal Order

Security and order are fundamental values pursued by international law. Therefore, we need to adhere to the principle of peaceful coexistence of international law through diplomatic channels, political dialogue, and economic and business cooperation to establish good neighborly relations with the countries along the Maritime Silk Road. The Maritime Silk Road reflects China beyond sea disputes and local interests, focusing on international maritime cooperation and development. In addition, the joint maintenance of maritime security and order also includes the maintenance of sea lane safety, fighting against maritime crime, and so on. In addition to the United Nations Convention on the Law of the Sea and the Convention for the Suppression of Unlawful Acts against the Safety of Maritime Navigation, the Declaration on the Conduct of Parties in the South China Sea and the China–ASEAN Agreement clearly require all parties to be concerned about maintaining maritime security.

7.4 Perfect the Legal Mechanism of the Maritime Silk Road

After World War II, the world economy developed rapidly, and economic globalization became the developmental trend. Under the theme of peace and development, global political, economic, and cultural exchanges are becoming increasingly close. Solutions by force have been excluded from international dispute settlements. Diplomatic channels may intensify the contradiction because of differences in national comprehensive strength. This international context leads to the judicial settlement of international disputes, namely settlement according to established rules, or by a neutral third party to resolve international disputes. Professor Robert Kieu concluded that "international relations are being legalized" (Men 2002). According to incomplete statistics, there are about 100 international judicial institutions and 20 permanent international judicial institutions, and more than 10 permanent institutions have been set up in the last 10 years (Wang 2010).

7.4.1 Peaceful Settlement of Territorial Sovereignty Disputes

Under the theme of world peace and development, the traditional resolution of territorial sovereignty disputes using threats or force is no longer suited to the requirements of modern international relations. There are three primary methods to settle territorial sovereignty disputes: negotiation and consultation, good offices and mediation, and investigation and mediation. To effectively expand the diplomatic space and to carry out international economic and trade cooperation, the Maritime Silk Road provides a new platform of mutual trust and mutual assistance for the countries along the route.

7.4.2 Improving the Co-active Dispute Settlement Mechanism

As previously described, settling international disputes through diplomatic channels remains the current major mode, and the odds of dispute settlement via arbitration or international court decisions are not high. We should see that the legalization of international relations is a development trend. We should go along with the historical tide and actively improve the co-active dispute settlement mechanism. Therefore, the authors believe that first, we cannot ignore the consistent level of peaceful foreign policy. The rise of peace is not only one of China's basic national policies but also its commitment to the world as a world power. We should adhere to the way of peaceful negotiations through diplomatic channels to settle international disputes. Second, the treaties and agreements concluded by China may be seen as an application of a dispute settlement mechanism, especially for countries along the Maritime Silk Road. Third, it is necessary to promote the establishment of a dispute settlement mechanism and a permanent body for the settlement of disputes between countries along the Maritime Silk Road. It is of great significance to promote regional economic and trade development and enhance mutual trust and cooperation among countries along the Maritime Silk Road. Therefore, the Maritime Silk Road is also a new initiative for the improvement and development of international relations.

7.4.3 Improving Co-active Settlement Mechanisms for Justice Domination Collisions

In the context of modern international law, there are three specific methods for international dispute settlement by judicial means as follows: the adoption of international court decisions, international arbitration, and specific judicial channels under other bilateral or multilateral treaties. Regardless of the approach chosen, the primary issue that cannot be avoided is jurisdictional and justice domination collisions. At present, there are two types of jurisdiction of the United Nations International Court of Justice: litigation jurisdiction and advisory jurisdiction. Litigation jurisdiction is divided into voluntary jurisdiction, agreement jurisdiction, and arbitrary compulsory jurisdiction. Countries in conflict, when selecting judicial channels for dispute settlement, will inevitably compete for jurisdiction or refer the conflict to the judiciary that they consider to be beneficial.

The Maritime Silk Road is built to eliminate conflicts and achieve harmony. It is a matter of course to resolve conflicts between countries. The judicial approach is not only advantageous in avoiding the diplomatic imbalance between countries due to differences in national strength but also propitious to full consultation and mediation under the intervention of third parties. However, how to settle justice domination collisions caused by conflicts of jurisdiction is important. We think that first, we should respect the parties' autonomous choice; that is, the parties may voluntarily choose the court of jurisdiction. Second, the principle of "inconvenient tribunal" should be invoked; that is, even if the court in that country has the power to accept the case, if it is connected to the party concerned, the court cannot accept the case, and if national courts can make good use of the principle of self-limitation, they will be better able to avoid or resolve conflicts of jurisdiction (Li and Zou 2015). Finally, interests can be balanced through consultation to resolve jurisdictional issues. This is in accordance with Clause 59 of the United Nations Convention on the Law of the Sea that "such conflicts shall be settled on an equitable basis, taking into account all relevant circumstances, taking into account the importance of the interests to the parties concerned and to the international community as a whole."

7.4.4 Deepening Interconnection and Promoting Regional Economic and Trade Cooperation

Interconnection is a concept put forward by China in the Master Plan on ASEAN Connectivity for dealing with the relationship between China and ASEAN countries. Through the ASEAN–China Free Trade Area (CAFTA) negotiation and the Maritime Silk Road initiative, interconnection has been a hot spot in the field of regional economic and trade cooperation development. As one of the core tenets of the Maritime Silk Road initiative, interconnection touches on many areas, including fund allocation, interregional standards, and differences in economic and cultural development. The effective development of interconnection will reach a win-win result, which will help to promote mutual trust and cooperation between China and the countries along the Maritime Silk Road. As interconnection began in the field of infrastructure construction, throughout its history, the concept of interconnection has not been clearly defined and lacks any formal plan. How to establish interconnection has become the finishing touch. In this regard, the authors believe that interconnection can be established from the following aspects: First, establish special funds for accessing, upgrading, and maintaining a country's shared information network, and information sharing between China and countries along the Maritime Silk Road. Second, enhance mutual trust and build consensus to coordinate the imbalances caused by nonuniform standards, and imbalances in economic and cultural development, by signing interoperability of bilateral and multilateral agreements, in which a co-active dispute settlement mechanism must be explicit, so that disputes can be settled effectively and rapidly. Third, establish a regional combined institution that consists of each national transport sector, customs departments, and inspection and quarantine departments, so that the institution has the capability to organize regional interconnection, especially the construction of transport infrastructure, which supervises the implementation and resolution of emergencies (Li 2015).

7.4.5 Perfecting Legal Mechanisms for the Safety of Navigation Channels in the South China Sea

The inexpensiveness and convenience of maritime transport determine its important position in the economic and social development of coastal countries. As the key to the Maritime Silk Road and development sought from the sea, the safety of the South China Sea waterway is critical for promoting the initiative of the Maritime Silk Road. The Maritime Silk Road has formed the initial legal mechanism for protecting the safety of the South China Sea waterway with post-war development in the countries around the South China Sea. With the increasingly complicated international situation, especially with piracy being more rampant today, methods to effectively protect the safety of the South China Sea waterway urgently need to be reviewed, along with improving existing legal mechanisms. First, strengthen the binding ability of the legal mechanism. Interest is the eternal theme of international exchanges. In retaining the active participation of the subjects of international law in international affairs and expanding areas of cooperation, international law is often ineffective in compulsory performance. Therefore, to ensure the safety of the South China Sea waterway and the shipping facilities of the countries along the Maritime Silk Road, with the prerequisite of guaranteeing conduct for the South China Sea under the premise of respecting sovereignty and freedom of expression, it is necessary to negotiate for all parties of the South China Sea to co-sign an agreement or protocol with compulsory execution and binding force by way of mutual consent. Second, enhance mutual trust and understanding and strengthen the effective implementation of legal cooperation. The creation of a new, coercive code of conduct is only the construction of a system; the key to safeguarding the safety of the South China Sea channel lies with the South China Sea parties to enhance mutual trust and common effective measures to ensure the common principles of promotion and implementation. The countries around the South China Sea should further improve the legal mechanism of cooperation within the establishment of waterway safety, a meteorological and marine hydrological data-sharing mechanism, the establishment of unified regional cooperation, and the implementation of a dispute settlement mechanism.

7.5 Prospects

At present, in the face of the increasingly grim international situation, China's development has been greatly oppressed. The great strategic vision of the Maritime Silk Road aims to promote national stability and development along the Maritime Silk Road and to achieve a win-win situation through constructing regional security and confidence by regional organizations. This is not only consistent with the appeals for stability and development by the countries along the Maritime Silk Road but also effectively promotes regional economic and trade development. How to face and properly handle relationships with the countries along the Maritime Silk Road in order to resolve the contradictions between the parties is the practice of the Maritime Silk Road—the great initiative to deal with the primary problem. Since traditional diplomatic solutions to international disputes cannot be fully adapted to the rapid development of international relations, under the trend of the legalization of international relations, strengthening mechanisms of regional legal collaboration through judicial means to settle disputes among the countries along the Maritime Silk Road is in line with the current theme of peace and development, which will be helpful in avoiding international conflicts and friction and promoting world peace and development.

References

Li JX (2015) The lessons of the legal system to secure the South China Sea for “the 21st century Maritime Silk Road”. Pac J 23(5):68–77
Li RD, Zou LG (2015) A study on the legal mechanism for the co-construction of the new Maritime Silk Road by China and ASEAN. Chin J Marit Law 26(1):8–13
Men HH (2002) Power and interdependence. Peking University Press, Beijing
Wan JJ, Zheng CW, Cheng XJ et al (2015) Strategic of the 21st century Maritime Silk Road: legal escort. Ocean Dev Manage 32(12):4–9
Wang LB (2010) The judicial tendency of international dispute settlement. J Xinjiang Univ (Philos, Humanit Soc Sci) 38(1):34–37
Xinhua net (2014) Xi Jinping put forward the strategic concept: one belt and one road to open the dream space. http://news.xinhuanet.com/fortune/2014-08/11/c_1112013039.htm
Zheng CW, Li CY (2015a) Development of the islands and reefs in the South China Sea: wind climate and wave climate analysis. Period Ocean Univ China 45(9):1–6
Zheng CW, Li CY (2015b) Development of the islands and reefs in the South China Sea: wind power and wave power generation. Period Ocean Univ China 45(9):7–14
Zheng CW, Li CY (2015c) Important role of ocean in the development of modern society. Ocean Dev Manage 32(9):4–12
Zheng CW, Pan J, Huang G (2014a) Forecasting of the China Sea ditching probability using WW3 wave model. J Beijing Univ Aeronaut Astronaut 40(3):314–320
Zheng CW, Shao LT, Li G et al (2014b) Analysis of influence on the security of sea skimming caused by a typhoon wave. J Harbin Eng Univ 35(3):301–306
Zheng CW, Chen X, Li CY (2015a) Observation analysis of wave climate in Korean Peninsula waters. Period Ocean Univ China 45(9):21–27
Zheng CW, Pan J, Sun W et al (2015b) Strategic of the ocean environment of the 21st century Maritime Silk Road. Ocean Dev Manage 32(7):4–9
Zheng CW, Li XQ, Gao ZS et al (2015c) Strategic of the 21st century Maritime Silk Road: wind climate analysis. Ocean Dev Manage 32(8):4–11
Zheng CW, Fu M, Rui ZF et al (2015d) Strategic of the 21st century Maritime Silk Road: wave climate analysis. Ocean Dev Manage 32(10):1–7

Chapter 8
Construction of a Comprehensive Application Platform for the Maritime Silk Road

Due to the lack of systematic basic theoretical support, there is no professional application system for the Maritime Silk Road either at home or abroad, which is urgently required by ocean navigation, remote islands and reefs construction, ocean engineering design, resource development, disaster prevention and mitigation, and so on. Since 2015, Zheng Chong-wei's team has presented research on the management and plan for 21st Century Maritime Silk Road for the first time at home and abroad, with 12 scientific and technical papers published in the *Journal of Xiamen University*, *Ocean Development and Management*, and *Acta Scientiarum Naturalium Universitatis Pekinensis*. This series of research systematically and finely analyzes the characteristics of the marine environment (wind climate, wave climate, rough sea occurrence, gale occurrence, extreme wind speed, extreme wave height, ocean currents, etc.) based on ocean big data, as well as important routes and port characteristics, geographical features, climate features, legal escort, and so on.

Based on our previous research, this chapter proposes to construct a professional application system for the Maritime Silk Road. We first analyze the importance and urgency of the construction of a comprehensive application platform for the Maritime Silk Road. We then propose to construct professional and comprehensive big data for the Maritime Silk Road, covering the marine environment, resources, humanities, geography, economy, and legal cases to provide scientific data regarding the Maritime Silk Road for researchers at home and abroad. With marine power generation, marine resource utilization, marine environmental forecasting, legal protection and support of ocean navigation and escort, ocean engineering design, disaster prevention and mitigation, and remote islands and reefs construction as the top-level design target, based on the Maritime Silk Road big data combined with our previous results, we systematically and meticulously analyze the marine environment, marine energy, and remote islands and reefs construction. Then, data visualization and human-computer interactions are realized (Zheng et al. 2016a, b, c, d, e, f, 2017; Zheng and Li 2016). Finally, a comprehensive application platform for the Maritime Silk Road is established, which is close to a practical, convenient querying and theoretical system, which will implement the national strategy and effectively strengthen

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the Belt and Road academic research and theoretical support, as well as provide a scientific basis for efficient decision-making to enhance China's marine construction capability, sea power maintenance capability, and the ability to control the situation in the South China Sea. It will also enhance our commitment to maritime search and rescue, disaster prevention and mitigation, and other international responsibilities and obligations and thus contribute to the progress of human society. The construction of a professional and comprehensive application system for the Maritime Silk Road is of great urgency.

8.1 Urgent Need for a Comprehensive Application Platform for the Maritime Silk Road

The impact of the oceans on modern social and economic activities is becoming increasingly significant. At the same time, marine problems also lead to the development of technology. Modern marine countries are concerned about the construction of marine data. China's marine data construction and data sharing services are lagging behind, a situation that needs to be resolved by marine workers (Hou 1999). International organizations [such as the International Oceanographic Data and Information Exchange (IODE), the International Maritime Organization (IMO), the World Meteorological Organization (WMO), the United Nations Environment Program (UNEP), the International Council of ICSU (ICSU), the United States National Oceanic and Atmospheric Administration (NOAA), the United States National Aeronautics and Space Administration (NASA), and the European Centre for Medium-Range Weather Forecasts (ECMWF)] have successively adopted guidance and input on national policies to strengthen the collection of marine scientific data, management and service work, and the timely sharing of all or part of the data. However, from the effect of data access and application download, the general applicants are affected by the authority to obtain a relatively simple information There is not high time and space resolution, and the time span is short and so on, where poor data comparability exists and the overall application value is not high. In 1996, the National Marine Data and Information Service completed the National Marine Information Service System. Subsequently, Nanjing University established the Jiangsu Island Resources and Environment Information System, which has information on the hydrology and meteorology, seawater chemistry, marine life, geology, and geomorphology of 16 islands in the north branch of the Yangtze River and the waters near Lianyungang. During 1996–2005, the National High-Technology Project (863) presided over the establishment of the Shanghai Demonstration Zone and six other regional marine environmental monitoring and information service demonstration systems. In 2003, the First Institute of Oceanography of the State Oceanic Administration established the Qingdao Marine Science Data Sharing Service Center of the State Fund Committee. Then, the Ministry of Science and Technology initiated the construction of a marine scientific data sharing center and established the Beihai, Donghai, Nanhai, and Polar regions as Marine Science Data Sharing Sub-Centers. In 2006, the National Marine Data and Information Service completed the Coastal Island Basic Database System and digitized and integrated the archives formed by the comprehensive survey of the coastal resources implemented nationwide in the 20th century. In 2007, the National Marine Data and Information Service was responsible for the construction of the 908 "Digital Ocean" information infrastructure framework. The project is a national marine data-sharing project for unified design, standards, interface, and function with existing grassroots business systems.

On the whole, most of the existing platforms are scattered, with a special function of the database where the visitor has authorized restrictions, and there are very few platforms for the Maritime Silk Road. The Maritime Silk Road is a forward-looking initiative designed by the 18th CPC National Congress of China according to the international situation. In addition, the existing platforms are mostly around China's coastal zone and islands, where most of the data are primarily about the China seas with few data about the deep sea. Therefore, data regarding the Maritime Silk Road are scarce, which does not help the construction of a comprehensive application platform for the Maritime Silk Road. Such a platform has practical value for ocean navigation, remote islands and reefs construction, ocean engineering design, resource development, disaster prevention and mitigation, and so on and urgently needs to be complemented by a specialized design.

8.2 Function of the Comprehensive Application Platform for the Maritime Silk Road

In 2015, Zheng et al. presented research on the management and plan for the 21st Century Maritime Silk Road for the first time at home and abroad, with 12 scientific and technical papers published in the *Journal of Xiamen University*, *Ocean Development and Management*, and *Acta Scientiarum Naturalium Universitatis Pekinensis*. This series of research first analyzed the importance of the Maritime Silk Road in various fields such as economy, culture, and politics. Then, it systematically and finely analyzed the marine environment (wind climate, wave climate, rough sea occurrence, gale occurrence, extreme wind speed, extreme wave height, ocean currents, etc.) based on ocean big data, as well as marine energy, important routes and port characteristics, geographical features, climate feature, and legal escort (Zheng et al. 2015a, b, c, d, 2016b, c, d; Zheng and Li 2015a; Wan et al. 2015; Chen et al. 2016). Based on our previous research, we proposed to construct professional and comprehensive big data for the Maritime Silk Road, covering the marine environment, resources, humanities, geography, economy, and legal cases, to provide scientific data regarding the Maritime Silk Road for researchers at home and abroad.

With marine power generation, marine resource utilization, marine environmental forecasting, legal protection and support of ocean navigation and escort, ocean engineering design, disaster prevention and mitigation, and remote islands and reefs construction as the top-level design target, we systematically and meticulously analyzed the marine environment, marine energy, and remote islands and reefs construction based on the Maritime Silk Road big data. Then, we extracted useful information such as geographical information, climate characteristics of the marine environment, marine resource distribution and development status, potential analysis, short- and long-term prediction of the marine environment and resources, marine chemical elements, marine life, route information, port information, humanities and religious information, legal support, and risk assessment. Then, data visualization and human-computer interaction were realized. Finally, a comprehensive application platform for the Maritime Silk Road, which is a practical, convenient theoretical system, was provided as a scientific basis for decision-making regarding the Maritime Silk Road initiative.

The platform's short-term forecasting and long-term prediction of marine resources and the marine environment come from various ocean mode real-time hindcast data, such as the internationally popular current model HYCOM, the classical current models SBPOM, WAVEWATCH-III, SWAN, and WRF, and the tidal calculation model TMD. Climate analysis of the marine environment is usually based on ocean and meteorological data for the last 30 years, which are updated quarterly. The legal support function uses a text model to show the "International Law of the Sea Joint Pledge" and other sea-related laws, the legal framework system in the South China Sea–northern Indian Ocean region and coastal countries, and legal documents and legal agreements between China and other countries. Through professional legal analysis and case analysis, we can provide favorable supporting information for legal issues and methods regarding economic, social, cultural, and other activities.

In addition, the comprehensive application platform uses an open concept, where users can submit the required data or functions according to their own needs. Because the integrated application platform can provide historical and future marine environmental data, users can utilize their own data in conjunction with platform-provided data to aid in ocean navigation, escort, ocean engineering design, disaster prevention and mitigation, remote islands and reefs construction, maritime search and rescue, and salvage and other operations.

8.3 Big Data of the Maritime Silk Road

The marine researches are the key basic for the marine development and construction, which has a urgent demand for marine data. The application and sharing of scientific data has become a measure of national science and technology and an important indicator of comprehensive national strength. In particular, marine data has the characteristics of strong spatial and temporal correlation, long time series, large variety, and diverse formats, so the requirements for the production and management of ocean big data are correspondingly high. Both developed and developing countries are actively engaged in marine scientific data construction and sharing.

Centered on geopolitical interests, the entity will be in accordance with the identity of the visitors to authorize their use of data.

Currently, there are several major international ocean data institutions: the National Oceanic and Atmospheric Administration (NOAA), the National Center for Atmospheric Research (NCAR), the National Centers for Environmental Prediction (NCEP), the National Data Buoy Center (NDBC), and the European Centre for Medium-Range Weather Forecasts (ECMWF). Europe and the United States have an obvious advantage in basic marine research. Most people think that a powerful naval force is a symbol of maritime power. However, a maritime power is in fact a country that has strong comprehensive national strength in the development of the oceans, the use of the oceans, marine protection, and the ability to control the ocean. How can we quantitatively measure whether a country has become a maritime power? We believe that the construction of maritime power is not easy; it must be concentrated in marine infrastructure with great effort. When one country establishes a series of international authorities and widely recognized marine data institutions, that will be a symbol of maritime power.

At present, most studies at home are aimed at one certain factor. The function of an ocean data management system is singular, and ocean data management is not systematic. Although some marine data-sharing platforms have been established to meet local business requirements, they are dispersed in different regions or different business sectors, where poor correlation between services and functions, large differences in data expression, a low degree of integration, and cross-domain coordination difficulties exist, and the data require obtaining authorization based on the user's identity and the download. The policy-making of the Maritime Silk Road requires multidisciplinary, multicategorical, long time series, multitemporal, and spatial resolution of the ocean data. The current data format is not uniform and has inconsistent quality control standards. As a result, extensive preprocessing work is needed before the application, which seriously affects the efficiency of marine development.

We propose to build comprehensive Maritime Silk Road big data, covering the marine environment, marine resources, humanities, geography, economy, and law cases, to provide scientific data regarding the Maritime Silk Road for researchers at home and abroad and thus to contribute to disaster prevention and mitigation, marine development, environmental protection, and national security. Based on the hindcast data of WW3, SWAN, HYCOM, and so on, combined with land-based, sea-based, space-based, and sky-based observation data, we can obtain big data for the Maritime Silk Road on the marine environment and marine energy with a long time series (not less than 30 years), high spatial-temporal resolution and high precision, which can also enhance the ability of real-time monitoring of the ocean at the same time. Marine environmental factors include meteorological elements (temperature, pressure, humidity, winds, clouds, visibility, precipitation, fog, etc.), ocean hydrological elements (temperature, salt, density, waves, ocean currents), chemical elements (pH, nutrients, turbidity, etc.), and geographical data (islands, water depth, coastline, seabed topography, etc.). The analysis of marine environmental factors should include the spatial-temporal distribution, long term variation, periods, abrupt phenomenon, relationship with important astronomical and earth factors, etc. Marine resources include primarily wind energy, wave energy, tidal energy, temperature-difference energy, marine life, and a variety of mineral resources. The analysis of marine resource factors should include the spatial-temporal distribution, available rate, stability, richness, total storage, effective storage, technological storage, long term variation, etc. In addition, the marine environment and marine resources should also include the short term forecasting and long term prediction of the factors, to service for the daily operation and long term plan of ocean development. We will also organize the human and religious information regarding the Maritime Silk Road (population, ethnicity, religious beliefs, history, culture, etc.), the current system, economic status, geographical information (islands, water depth, coastline, seabed topography, etc.), port information (cargo throughput, berthing capacity, etc.), legal cases, and so on.

Using both traditional and cloud computing technology, the abovementioned elements will be fully digitalized and holographically stored in accordance with the three-dimensional grid and time series. Quality control of the data will also be performed to construct the Maritime Silk Road big data. The data will be updated once a month, or immediately in case of critical circumstances. Users will be able to directly search the multidimensional features of the marine objective reality and history of dynamic images. The integrated application platform will gradually realize the standardized organization and management, and then gradually realize the data sharing and exchange function to accurately and efficiently provide multiple types of dynamic resources and environmental information services, and thus provide scientific and technological support and decision-making support for the Maritime Silk Road.

8.4 Short-Term Forecasting System of the Maritime Silk Road

In addition to the short-term forecasting of the traditional marine environment (such as winds, waves, ocean currents, and temperature), attention is also needed on the short-term forecasting of marine energy resources (such as wave energy, offshore wind energy, tidal energy, etc.) to provide a reference for the operational application of seawater desalination, wave power generation, offshore wind power generation, tidal power generation, and so on. Consider wave energy as an example; we took the lead in building a short-term numerical forecasting structure for wave energy resources by selecting the China seas as an experimental region (Zheng 2014). The forecasting factors included the wave power density (WPD), "wave energy rose", daily total storage of wave energy, daily effective storage of wave energy, and total storage and effective storage of wave energy. We also found that not only forecasting the WPD, the energy storage, is necessary; it is also necessary to systematically forecast the primary incoming direction of energy, the stability of energy, and the contribution of sea conditions to wave energy (Zheng et al. 2016e) to provide more accurate, practical forecasts for wave energy development. In the future, this short-term numerical forecasting structure can be widely used to serve wave energy development in global oceans, especially along the Maritime Silk Road. This structure can also provide a reference for the short-term forecasting of offshore wind energy, ocean current energy, and other new marine energy resources.

With the rapid development of marine construction, more and more aircraft (such as helicopters, carrier-based aircraft, unmanned aerial vehicles, and other aircraft) are widely used in disaster prevention and reduction, humanitarian relief, maritime search and rescue, mineral exploration, and so on. To achieve better results, low-altitude flight is often needed. However, just as a coin has two sides, low-altitude flight usually seriously threatens the safety of the aircraft (Zheng et al. 2014a, b, c). In 2004, a helicopter from the United States Coast Guard crashed after encountering bad sea conditions when carrying out a rescue mission. In 2012, a helicopter from Taiwan crashed due to an encounter with bad sea conditions when carrying out a rescue mission. There are several issues here. As a result, it is necessary to forecast the ditching probability of sea-skimming. In 2014, we took the lead in the short-term numerical forecasting of the ditching probability of sea-skimming, which can provide a quantitative scientific basis for the route planning of helicopter rescues and the sea-skimming flight of missiles and other aircraft in bad sea conditions (Zheng and Li 2015b).

Regarding the range of short-term forecasts, besides the traditional regional forecasts of the Maritime Silk Road, it is also necessary to pay attention to route forecasts and the forecasts of key points along the Maritime Silk Road.

8.5 Climate Characteristics and the Mid- to Long-Term Prediction of the Marine Environment and Resources

Short-term forecasts can well serve an operation for 3–7 days. However, when it comes to mid- to long-term plans (such as annual or semi-annual plans), short-term forecasts cannot provide any reference. In the marine environment, for example, our navigators are usually familiar with the marine environment of China seas, whereas they have less experience in ocean navigation. As a result, mid- to long-term prediction of the marine environment is necessary to provide a reference for ocean navigation, maritime missions in unfamiliar waters, and so on. Zheng and Li (2016) pointed out that there are usually three methods of mid- to long-term prediction of the marine environment: (1) use the relationship between the marine environment and important factors (Madden-Julian Oscillation, Niño3 index, etc.) combined with the climatic trend of the elements of the marine environment; (2) use the fifth phase of the Coupled Model Intercomparison Project (CMIP5) to drive an ocean model; (3) use the Hilbert-Huang, Least Squares Support Vector Machine (LSSVM), artificial neural network, etc., to predict the factors of marine environment.

Regarding the prediction elements, besides the traditional focus on the marine environment (winds, waves, currents, ditching probability, etc.), it is also necessary to pay attention to marine energy (wave energy, offshore wind energy, current energy, etc.). Prediction of the marine environment needs to be systematic and comprehensive. Considering the mid- to long-term prediction of wind as an example, in addition to the prediction of the traditional factors (such as wind speed and direction), it is also necessary to pay attention to the prediction of the wind scale (especially gale occurrence), extreme wind speed, wind direction, strong wind direction, abrupt wind speeds, etc. Marine energy prediction also needs to be systematic and comprehensive. Taking the prediction of wind energy as an example, prediction factors should systematically include wind power density, wind energy level occurrence, exploitable rate of wind energy, stability of wind energy, the incoming direction of wind energy, and so on.

Regarding climate statistics, in addition to paying attention to the traditional elements, it is also necessary to statistically analyze climate characteristics according to the actual demand, especially for port construction, anti-wave construction, and runway construction on islands and reefs. Considering the climatic characteristics of wind as an example, traditional climatological statistics include prevailing wind speed and wind direction, wind scale, and wind direction (usually expressed by a radar chart). In addition, a wind rose is needed. A traditional radar chart cannot express wind direction and wind speed at the same time, and it especially cannot show strong wind direction. A wind rose can show wind direction, wind speed, and strong wind direction at the same time (Zheng and Li 2015c), which can provide a good reference for decision-making regarding runway construction on islands and reefs. In other words, climate characteristic statistics should be available for the actual demand of a variety of platforms and equipment.

In addition, the organic integration of climate characteristics, short-term forecasts, and mid- to long-term prediction is needed. In the case of wave power generation, the climate characteristics of wave energy can provide a scientific basis for wave power plant location. Short-term forecasts of wave energy can provide a reference for the operational application of a wave power plant. Mid- to long-term predictions can be used for the mid- to long-term planning of wave energy development (Zheng et al. 2014a, b, c). The organic combination of the three can make a more reasonable assessment of resource distribution characteristics, exploitation value, development potential, and so on, thus helping to ease the resource and environmental crises, remote islands and reefs construction, and so on.

8.6 Construction of Remote Islands and Reefs

Remote islands and reefs are an important support for humans toward the deep sea. At present, the world's maritime powers are particularly focused on remote islands and reefs construction. In the United States, for example, the Hawaiian Islands, located in the central North Pacific, are an important relay station for the United States in the

Pacific Ocean. Another example, Diego Garcia, located in the center of the Indian Ocean, is a key support for the United States in the Indian Ocean. However, so far, our research on the remote islands and reefs construction is relatively scarce, and this is urgently necessary for the construction of the Maritime Silk Road. Remote islands and reefs usually have the following functions: consolidated replenishment, ship maintenance and repair, information gathering, ocean monitoring and observation, humanitarian assistance, medical treatment and rescue, maritime rights and interests maintenance, and so on. Remote islands and reefs with stable and efficient function will effectively enhance our ocean-going capability and our ability to control the ocean, thus contributing to the construction of the Maritime Silk Road.

Remote islands and reefs construction includes not only sea reclamation but also infrastructure facilities, equipment construction, and so on. Remote islands and reefs construction has been a worldwide problem for a long time. Shortages of power and freshwater have seriously troubled the viability and sustainable development capacity of remote islands and reefs. In today's era of high electrification, some equipment cannot run or is even paralyzed without electricity. Mankind cannot survive without freshwater.

The common practice is to use shipped diesel fuel for power generation, which has the following two obvious disadvantages: (1) bad sea conditions will affect the ship supply and (2) diesel generators cause pollution, which will damage the fragile ecology of islands and reefs. Once the ecology of islands and reefs is damaged, it is difficult to repair. Rational development and utilization of marine energy (wave power generation, offshore wind power, wind and wave combined power generation, photovoltaic power generation, etc.) of the waters surrounding remote islands and reefs according to local conditions will help reefs achieve power self-sufficiency. After power problem-solving, the desalination problem can then be solved. Self-sufficiency in freshwater and electricity will significantly enhance the viability and sustainable development capability of remote islands and reefs, thus contributing to the construction of the Maritime Silk Road. However, all these tasks must be based on a complete understanding of marine resources. Consequently, an understanding of the climate, short-term forecasting, and long-term prediction of marine energy resources in the waters surrounding remote islands and reefs is urgently needed.

In addition, the remote islands and reefs construction usually involves runway construction. In runway design, the primary concern is strong winds and their direction. A wind rose can be used to fully exhibit strong wind speed and strong wind direction (Zheng and Li 2015c). In the process of taking off and landing, the biggest threat to an airplane is crosswinds. Crosswinds can easily cause airplanes to slide off the runway, a phenomenon that is more obvious on island reefs and aircraft carriers. Obviously, the marine environment and meteorological environment should be fully considered in remote islands and reefs construction.

Currently, we have made a series of achievements in marine environment analysis, as well as demonstrating the feasibility of wave and wind power generation of a series of important remote islands and reefs (Zheng and Li 2015c, 2016; Zheng et al. 2014a, b; Zheng et al. 2016a, b, c, d, e, f). These results can provide technical support for the remote islands and reefs construction and can also be widely used on the Maritime Silk Road.

8.7 Geographical Information, Religion, Legal Escort

The Maritime Silk Road marks a new chapter in China's great sailing era. Ocean sailing requires an understanding of route characteristics, including geographical information (such as islands, water depth, coastline, and submarine topography) and port information (cargo throughput, parking capacity, etc.). The Maritime Silk Road includes not only the South China Sea but also the northern Indian Ocean. In the process of foreign communication, it is necessary to fully investigate human societal information (population, nationalities, etc.) and the religious beliefs of the countries and regions along the Maritime Silk Road in order to avoid friction from communication problems and thus greatly improve the efficiency of the construction of the Maritime Silk Road.

The Maritime Silk Road is meant to achieve a win-win situation, thus contributing to the common prosperity, progress, and peaceful development of human society. This is consistent with the interests and needs of the countries and regions along the Maritime Silk Road and also benefits the stability and development of these countries and regions. How to face and properly handle the relationships between the countries along the Maritime Silk Road and how to resolve conflicts between the parties are primary problems under the practice of the Maritime Silk Road initiative. It is helpful to protect the rights and interests of the countries and regions that participate in the construction of the Maritime Silk Road by making assumptions based on various types of disputes in advance and based on the principle of fairness and justice to resolve the problems. At the same time, it is also conducive to ensuring the enthusiasm of the countries and regions to participate in the construction of the Maritime Silk Road.

8.8 Prospects

The Belt and Road initiative, the Asian Infrastructure Investment Bank (AIIB), African aid, assistance in the multinational evacuation in Yemen, escorting in the Gulf of Aden, and so on highlight our consistent theme of peace and development. The Maritime Silk Road, forging a link between the South China Sea and the northern Indian Ocean, opens a new chapter of cooperation and win-win, equality, and mutual assistance. However, challenges and opportunities often coexist. Understanding the marine environment is a prerequisite for the safe and efficient construction of the Maritime Silk Road. The efficient, rational, and orderly development and utilization of marine resources will be an effective way for us to deal with the resource and environmental crises and will also be a highlight in the construction of the Maritime Silk

Road. Remote islands and reefs are an important support in the development of the deep sea. However, the scarcity of ocean data seriously restricts ocean development.

Since 2015, our team has launched a series of studies on the marine environment of the 21st Century Maritime Silk Road in *Ocean Development and Management*, *Journal of Xiamen University*, and *Acta Scientiarum Naturalium Universitatis Pekinensis*. First, we analyzed the significance of the Maritime Silk Road initiative in various fields such as economy, culture, and politics. We then systematically and meticulously analyzed the marine environment of the Maritime Silk Road, as well as the characteristics of the important routes, channels, and ports, geographical features, climate profiles, marine resources and utilization status, legal escort, and so on in the hope of providing a scientific basis for decision-making regarding ocean navigation, ocean engineering design, marine energy resource development, and disaster prevention and reduction. In addition, we also carried out scientific research on a series of important remote islands and reefs such as Gwadar port in the hope of building it into China's overseas demonstration project, thus to contribute to the construction of the Silk Road on sea and land. Based on the achievements of this scientific research, we proposed to further deepen the research on the Maritime Silk Road to build a comprehensive application platform, which will be a practical and convenient theoretical system. The scientific achievements will be transformed into practical application products to contribute to the "Sea Dream" and the common prosperity and progress of human society.

The comprehensive application platform for the Maritime Silk Road will provide information on the climate, geography, society, law, marine environment, and marine resources of the South China Sea and the northern Indian Ocean and the countries and regions along the Maritime Silk Road. The system will be a platform for data and methods of sharing that can serve local sea-related professional enterprises, individuals, and research institutions. The system will realize the standardization, visualization, and modularization of data and reserve multiple modules. During its operation, the system will add modules according to actual needs, such as special tasks, legal escort, medical treatment, and rescue and humanitarian relief. As a result, this comprehensive application platform will provide comprehensive scientific and technological support for diversified tasks, thus meeting the demands of national decision-making.

References

Chen X, Zheng CW, Li XQ et al (2016) Strategic of the 21st century Maritime Silk Road: ocean current. Ocean Dev Manag 33(4):3–7

Hou WF (1999) Tentative ideas on the development of Digital Ocean in China. Mar Sci Bull 18(6):1–10

Wan JJ, Zheng CW, Cheng XJ et al (2015) Strategic of the 21st century Maritime Silk Road: legal escort. Ocean Dev Manag 32(12):4–9

Zheng CW (2014) Wave energy density forecast in China Seas by WW3 wave model: a study based on two cold air events. J Subtrop Resour Environ 9(2):18–25

Zheng CW, Li CY (2015a) Important role of ocean in the development of modern society. Ocean Dev Manag 32(9):4–12
Zheng CW, Li CY (2015b) Development of the islands and reefs in the South China Sea: wind climate and wave climate analysis. Periodical of Ocean Univ China 45(9):1–6
Zheng CW, Li CY (2015c) Development of the islands and reefs in the South China Sea: wind power and wave power generation. Periodical of Ocean Univ China 45(9):7–14
Zheng CW, Li CY (2016) Review on the global ocean wave energy resource. Mar Forecasts 33(3):76–88
Zheng CW, Shao LT, Li G et al (2014a) Analysis of influence on the security of sea skimming caused by a typhoon wave. J Harbin Eng Univ 35(3):301–306
Zheng CW, Pan J, Huang G (2014b) Forecasting of the China Sea ditching probability using WW3 wave model. J Beijing Univ Aeronaut Astronautics 40(3):314–320
Zheng CW, You XB, Pan J et al (2014c) Feasibility analysis on the wind energy and wave energy resources exploitation in Fishing Islands and Scarborough Shoal. Mar Forecasts 31(1):49–57
Zheng CW, Pan J, Sun W et al (2015a) Strategic of the ocean environment of the 21st century Maritime Silk Road. Ocean Dev Manag 32(7):4–9
Zheng CW, Li XQ, Gao ZS et al (2015b) Strategic of the 21st century Maritime Silk Road: wind climate analysis. Ocean Dev Manag 32(8):4–11
Zheng CW, Fu M, Rui ZF et al (2015c) Strategic of the 21st century Maritime Silk Road: wave climate analysis. Ocean Dev Manag 32(10):1–7
Zheng CW, Gao ZS, Zhang Y et al (2015d) Strategic of the 21st century Maritime Silk Road: extreme wind speed and extreme wave height. Ocean Dev Manag 32(11):4–8
Zheng CW, Li Chong-yin, Yan Y et al (2016a) Analysis of wind energy resource in the Pakistan's Gwadar Port. J Xiamen Univ (Nat Sci Edition) 55(2):210–215
Zheng CW, Gao ZS, Gao CZ (2016b) Strategic of the 21st century Maritime Silk Road: construction of strategic points. Ocean Power Forum
Zheng CW, Sun W, Li X et al (2016c) Strategic of the 21st century Maritime Silk Road: important route, crucial node and port feature. Ocean Dev Manag 33(1):4–13
Zheng CW, Li X, Chen X et al (2016d) Strategic of the 21st century Maritime Silk Road: geography and climate characteristic. Ocean Dev Manag 33(2):3–10
Zheng CW, Li X, Chen X et al (2016e) Strategic of the 21st century Maritime Silk Road: marine resources and development status. Ocean Dev Manag 33(3):3–8
Zheng CW, Li CY, Chen X, Pan J (2016f) Numerical forecasting experiment of the wave energy resource in the China Sea, Adv Meteorol Article ID 5692431:12 p. http://dx.doi.org/10.1155/2016/5692431
Zheng CW, Gao Y, Chen X (2017) Climatic long term trend and prediction of the wind energy resource in the Gwadar Port. Acta Scientiarum Naturalium Universitatis Pekinensis 53(4):617–626

Erratum to: 21st Century Maritime Silk Road: A Peaceful Way Forward

Erratum to:
C. Zheng et al., *21st Century Maritime Silk Road: A Peaceful Way Forward*, Springer Oceanography,
https://doi.org/10.1007/978-981-10-7977-1

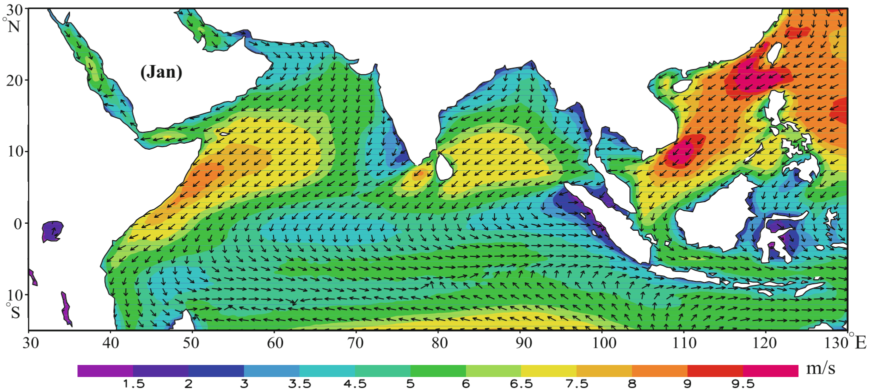
In the original version of the book, the affiliations of authors Ziniu Xiao, Wen Zhou, and Xuan Chen have to be amended in Copyright page. The erratum book has been updated with the changes.

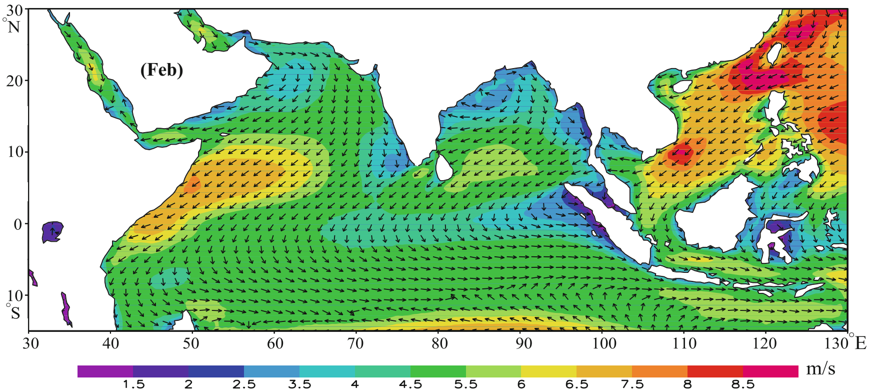
The updated online version of this book can be found at
https://doi.org/10.1007/978-981-10-7977-1

C. Zheng et al., *21st Century Maritime Silk Road: A Peaceful Way Forward*,
Springer Oceanography, https://doi.org/10.1007/978-981-10-7977-1_9

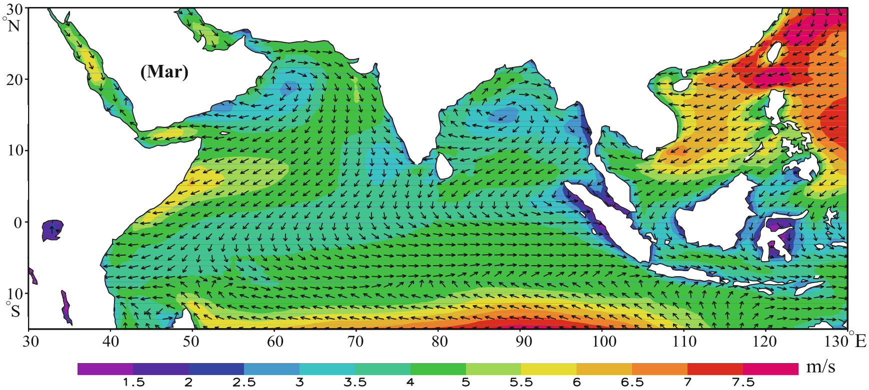
Appendix

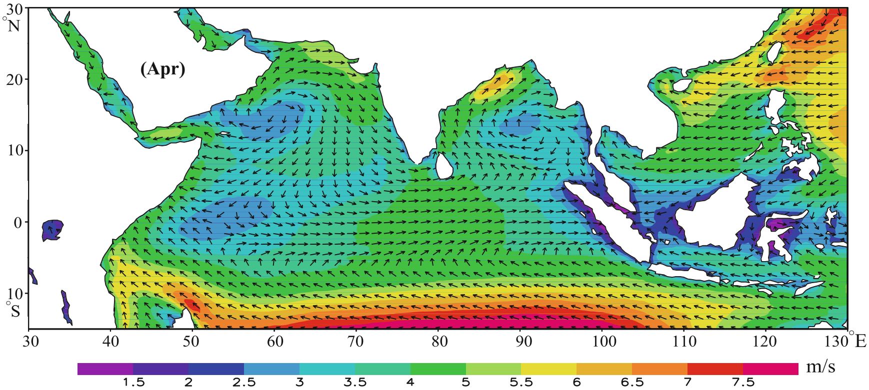
(1) **Sea Surface Wind field in each month of the Maritime Silk Road**





C. Zheng et al., *21st Century Maritime Silk Road: A Peaceful Way Forward*,
Springer Oceanography, https://doi.org/10.1007/978-981-10-7977-1


(Mar)
30°N
20
10
0
10°S
30
40
50
60
70
80
90
100
110
120
130°E
m/s
1.5
2
2.5
3
3.5
4
5
5.5
6
6.5
7
7.5


(Apr)
30°N
20
10
0
10°S
30
40
50
60
70
80
90
100
110
120
130°E
m/s
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2
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3.5
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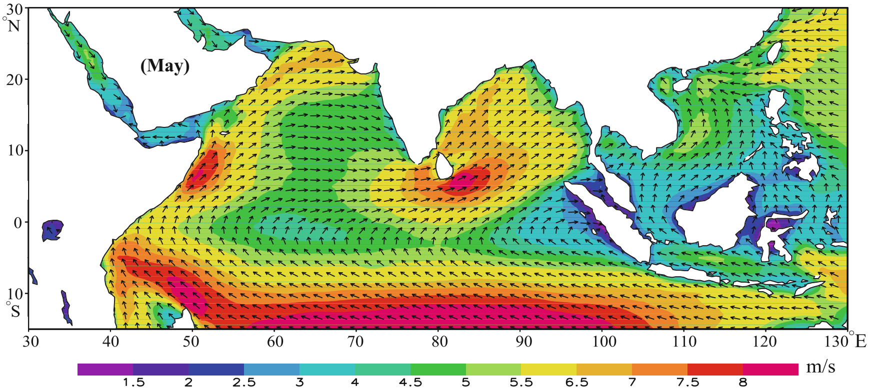
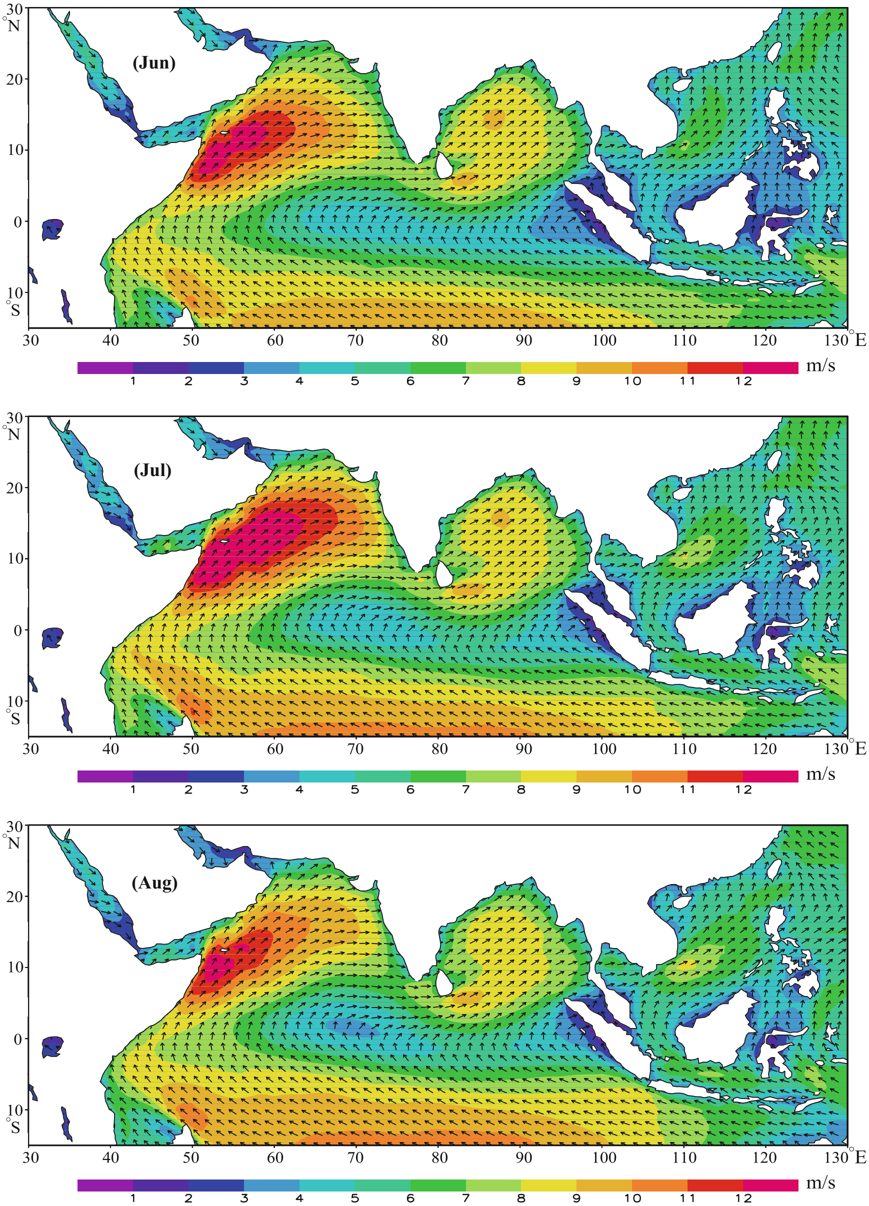
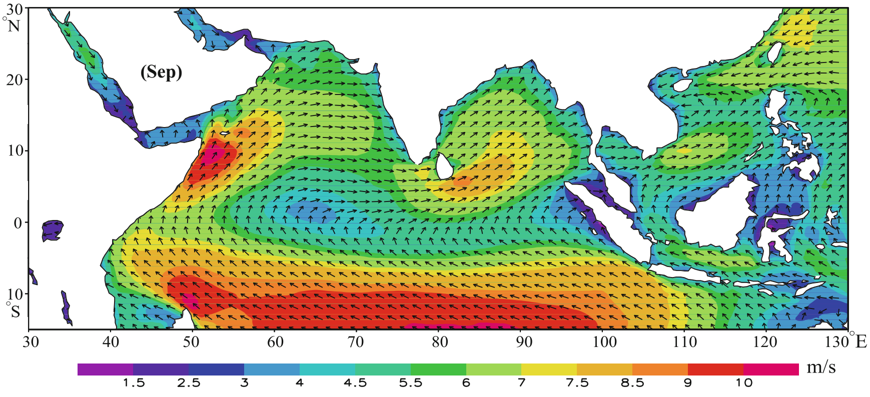
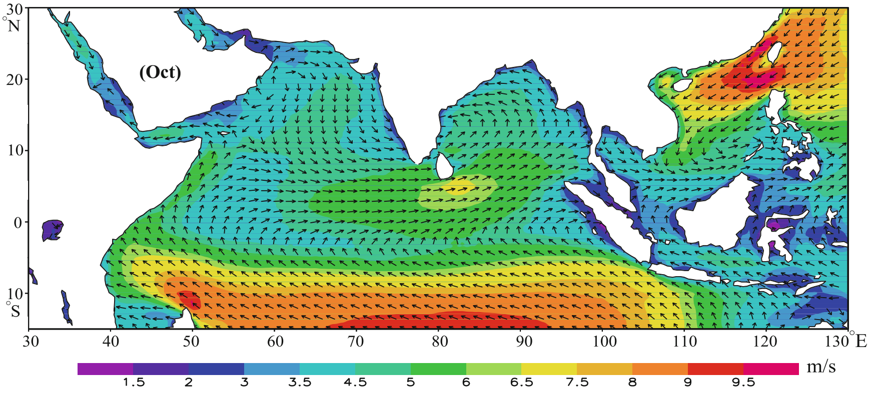
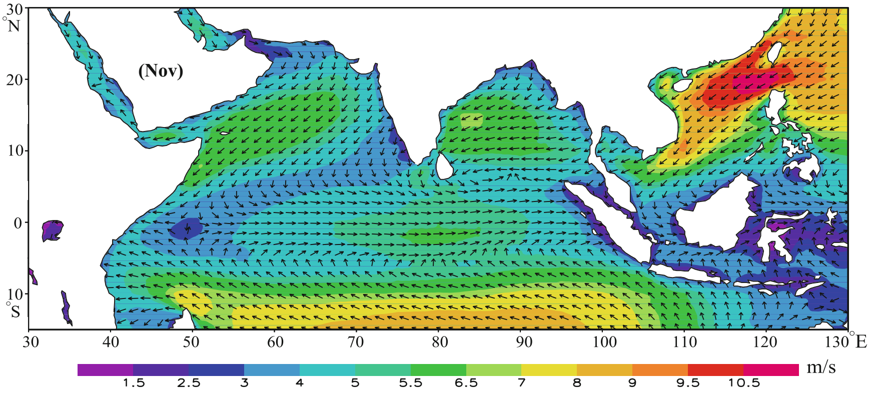
6
6.5
7
7.5

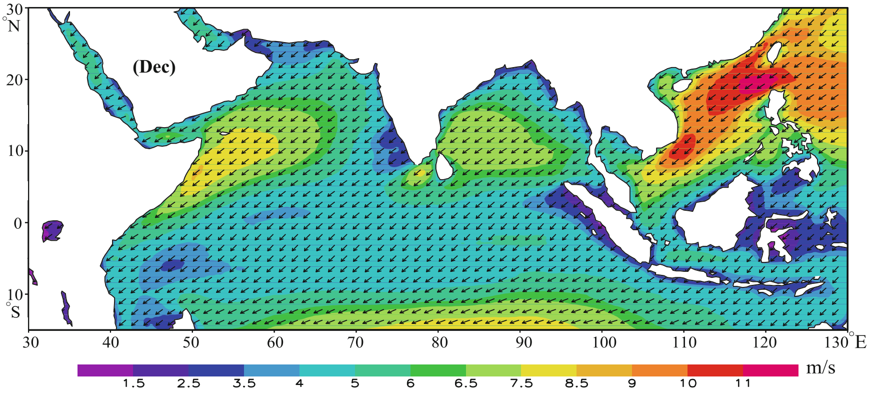

(May)
30°N
20
10
0
10°S
30
40
50
60
70
80
90
100
110
120
130°E
m/s
1.5
2
2.5
3
4
4.5
5
5.5
6.5
7
7.5
8

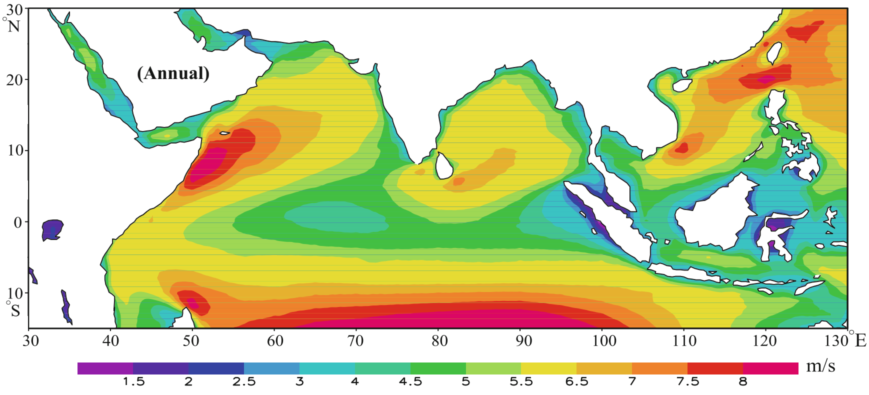

(Jun)
(Jul)
(Aug)
30°N
20
10
0
10°S
30
40
50
60
70
80
90
100
110
120
130°E
m/s
1
2
3
4
5
6
7
8
9
10
11
12


(Sep)
30 °N
20
10
0
10 °S
30 40 50 60 70 80 90 100 110 120 130 °E
1.5 2.5 3 4 4.5 5.5 6 7 7.5 8.5 9 10
m/s

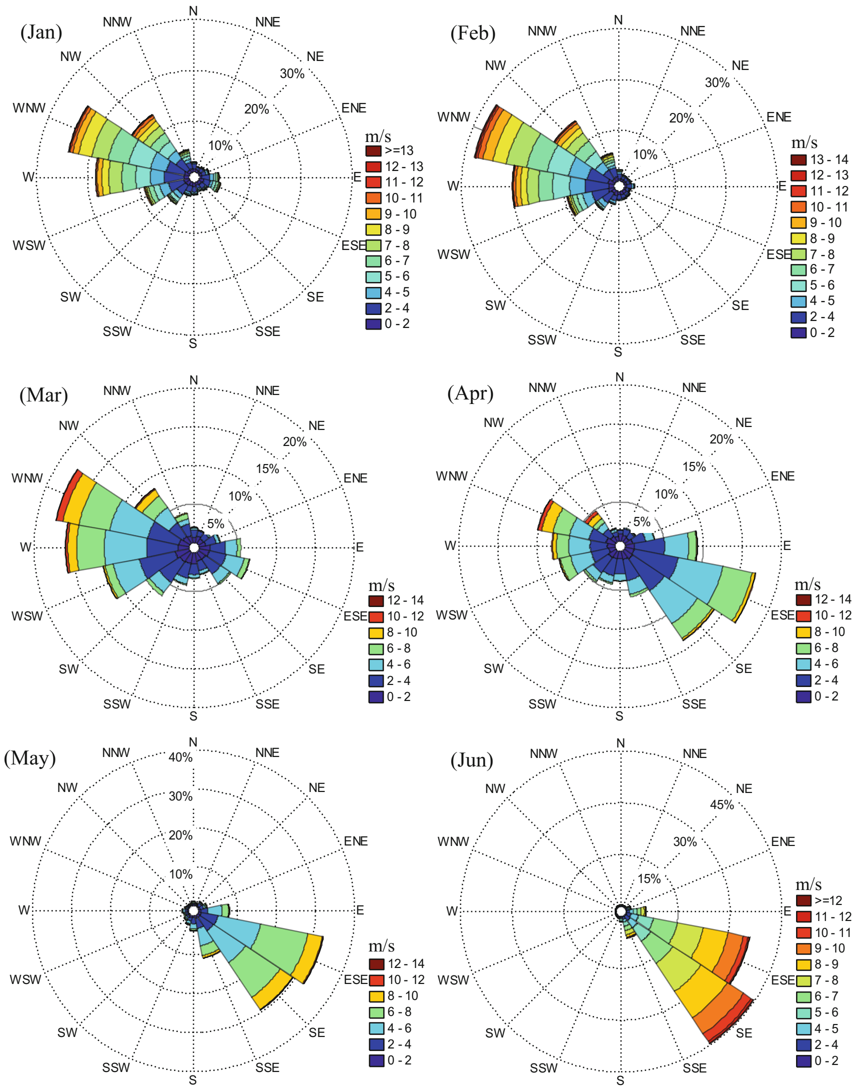

(Oct)
30 °N
20
10
0
10 °S
30 40 50 60 70 80 90 100 110 120 130 °E
1.5 2 3 3.5 4.5 5 6 6.5 7.5 8 9 9.5
m/s

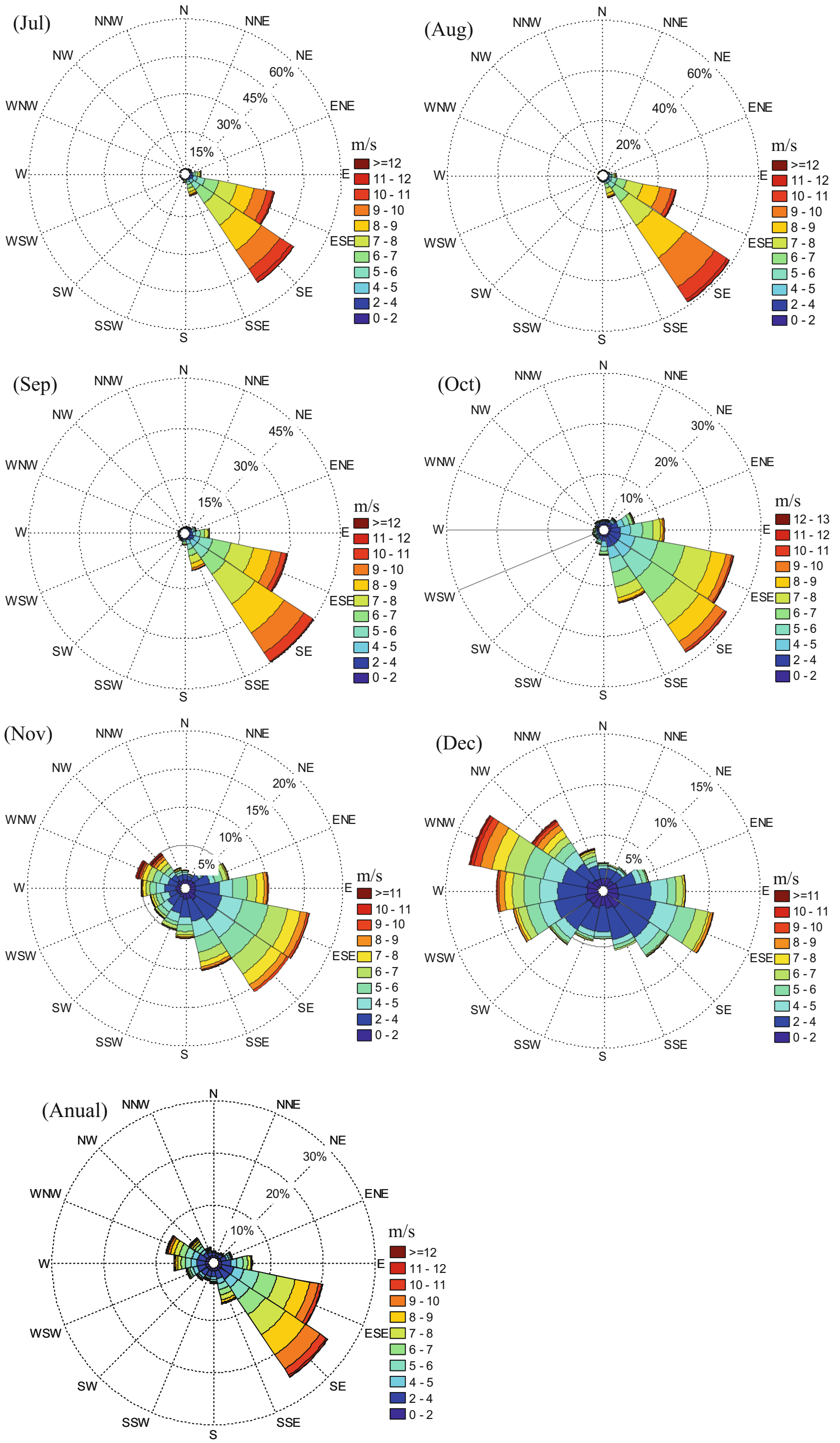

(Nov)
30 °N
20
10
0
10 °S
30 40 50 60 70 80 90 100 110 120 130 °E
1.5 2.5 3 4 5 5.5 6.5 7 8 9 9.5 10.5
m/s


(Dec)
30°N
20
10
0
10°S
30
40
50
60
70
80
90
100
110
120
130°E
1.5
2.5
3.5
4
5
6
6.5
7.5
8.5
9
10
11
m/s

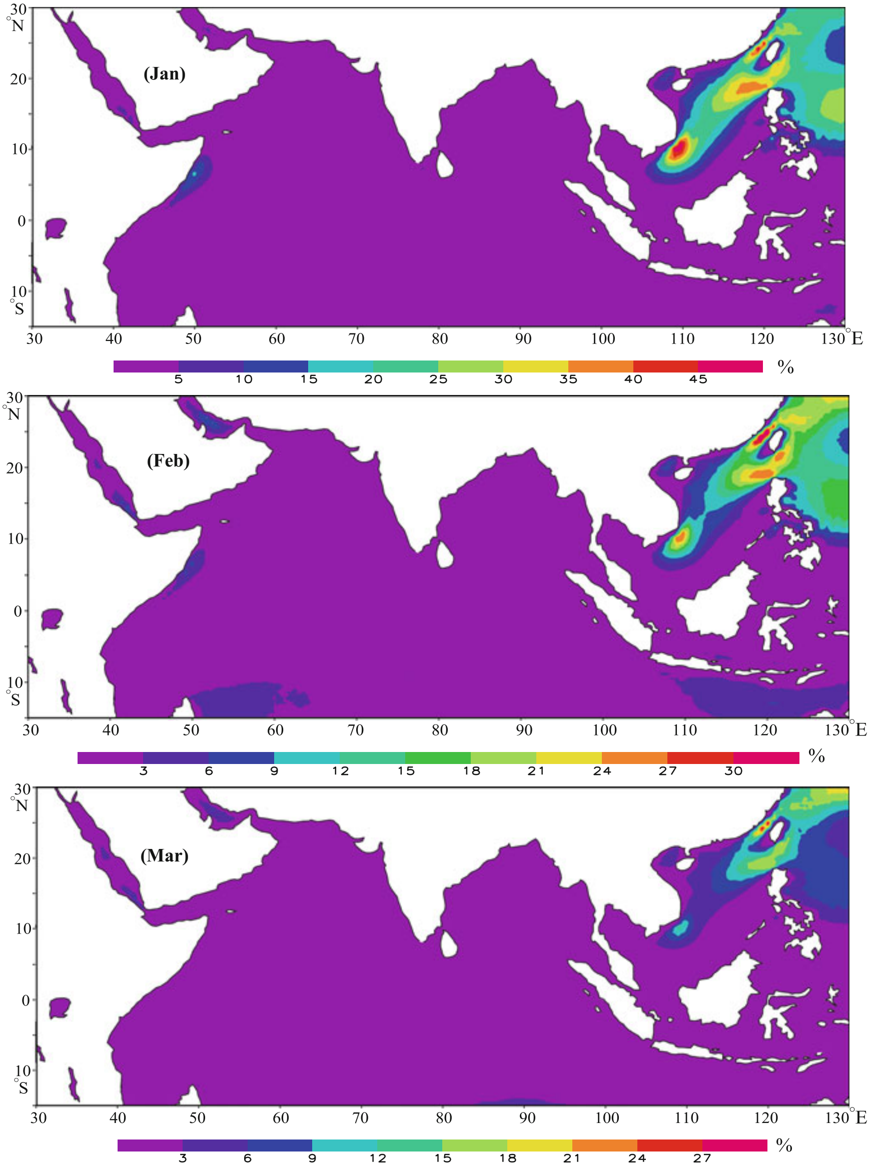

(Annual)
30°N
20
10
0
10°S
30
40
50
60
70
80
90
100
110
120
130°E
1.5
2
2.5
3
4
4.5
5
5.5
6.5
7
7.5
8
m/s

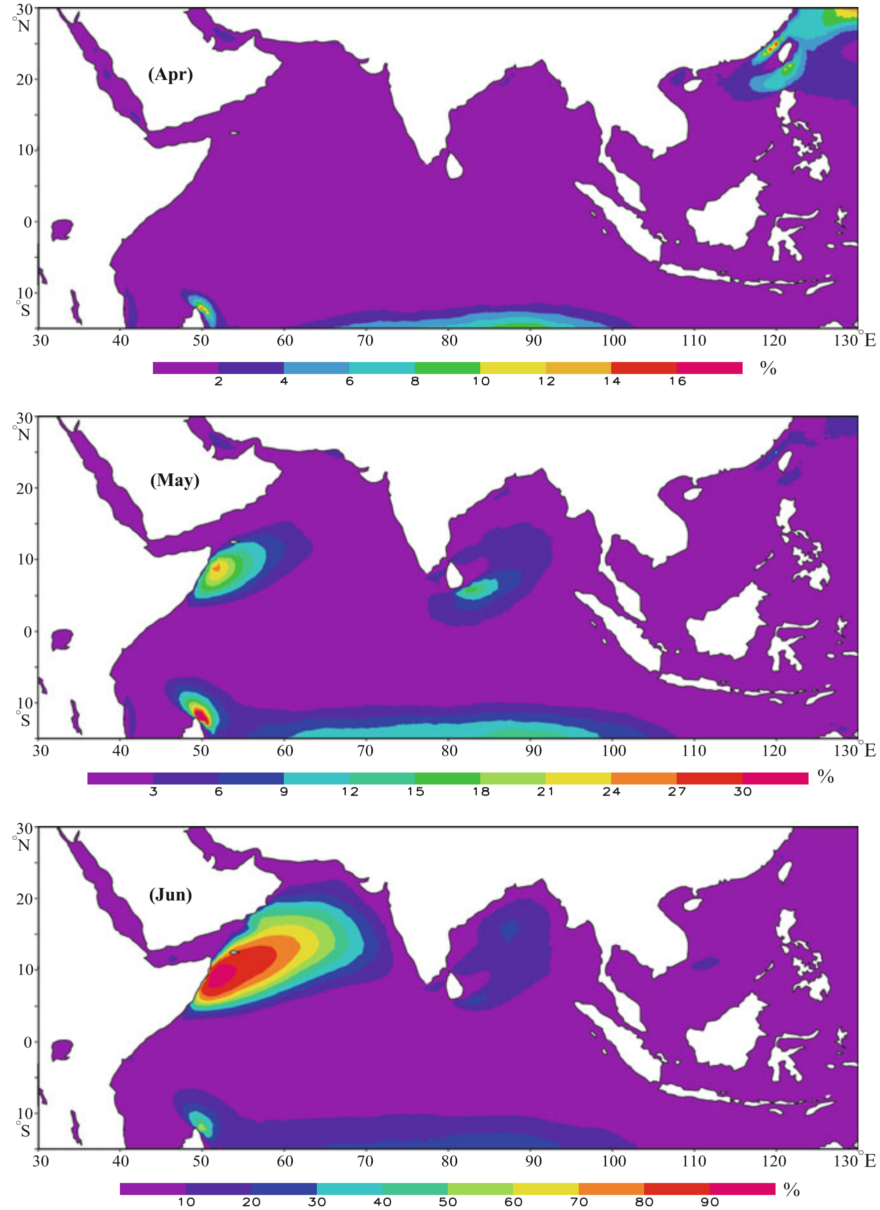
(2) Wind Rose of Diego Garcia (Co-occurrence of Wind Speed and Wind Direction)

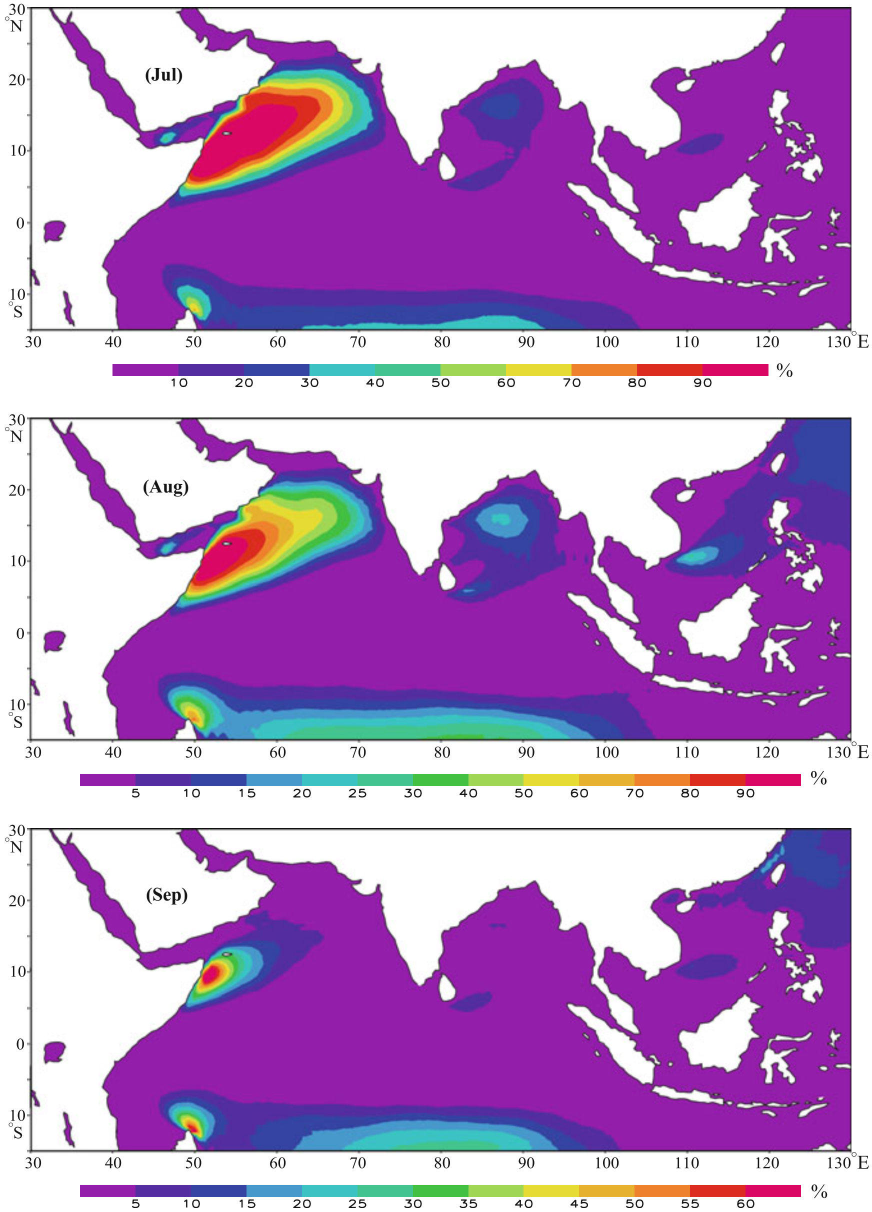


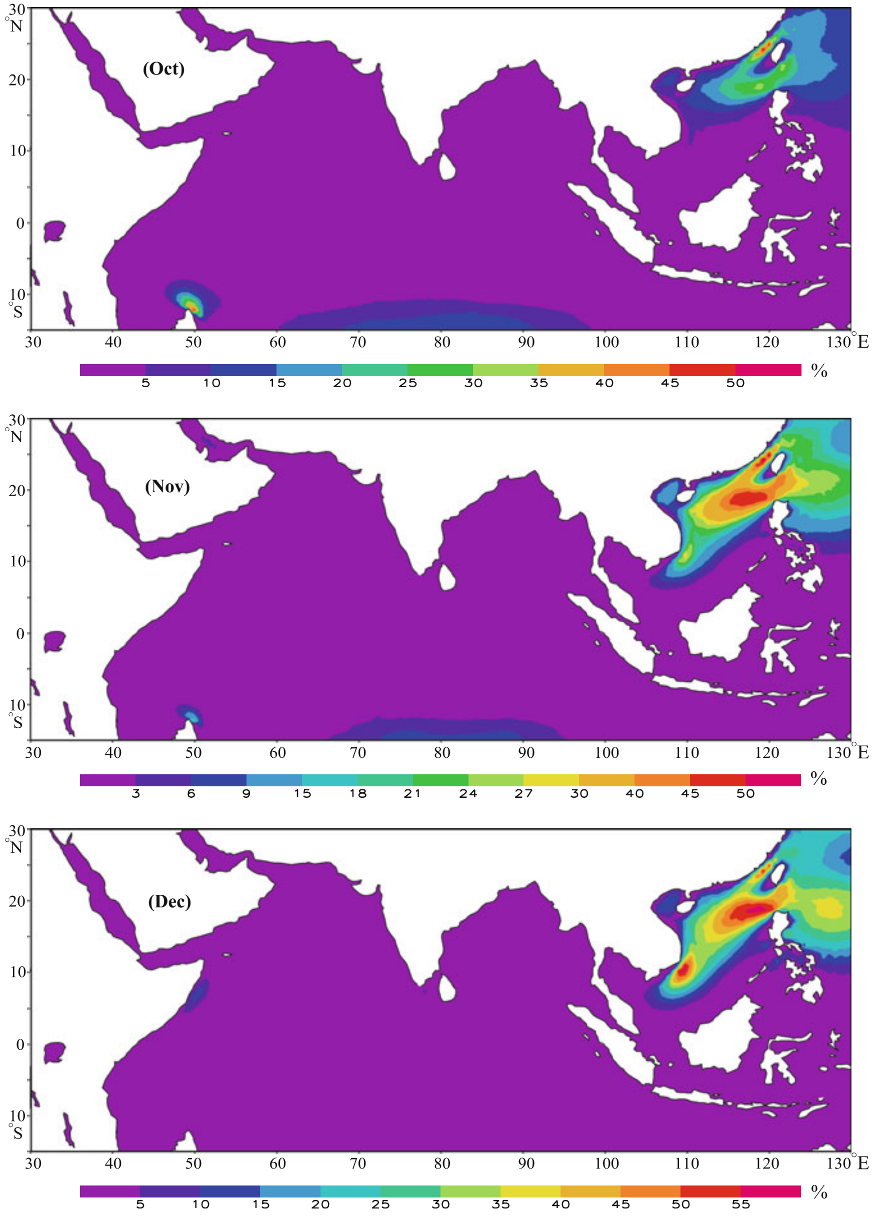

(Jul)
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
15%
30%
45%
60%
m/s
>=12
11 - 12
10 - 11
9 - 10
8 - 9
7 - 8
6 - 7
5 - 6
4 - 5
2 - 4
0 - 2
(Aug)
20%
40%
60%
m/s
>=12
11 - 12
10 - 11
9 - 10
8 - 9
7 - 8
6 - 7
5 - 6
4 - 5
2 - 4
0 - 2
(Sep)
15%
30%
45%
m/s
>=12
11 - 12
10 - 11
9 - 10
8 - 9
7 - 8
6 - 7
5 - 6
4 - 5
2 - 4
0 - 2
(Oct)
10%
20%
30%
m/s
12 - 13
11 - 12
10 - 11
9 - 10
8 - 9
7 - 8
6 - 7
5 - 6
4 - 5
2 - 4
0 - 2
(Nov)
5%
10%
15%
20%
m/s
>=11
10 - 11
9 - 10
8 - 9
7 - 8
6 - 7
5 - 6
4 - 5
2 - 4
0 - 2
(Dec)
5%
10%
15%
m/s
>=11
10 - 11
9 - 10
8 - 9
7 - 8
6 - 7
5 - 6
4 - 5
2 - 4
0 - 2
(Anual)
10%
20%
30%
m/s
>=12
11 - 12
10 - 11
9 - 10
8 - 9
7 - 8
6 - 7
5 - 6
4 - 5
2 - 4
0 - 2

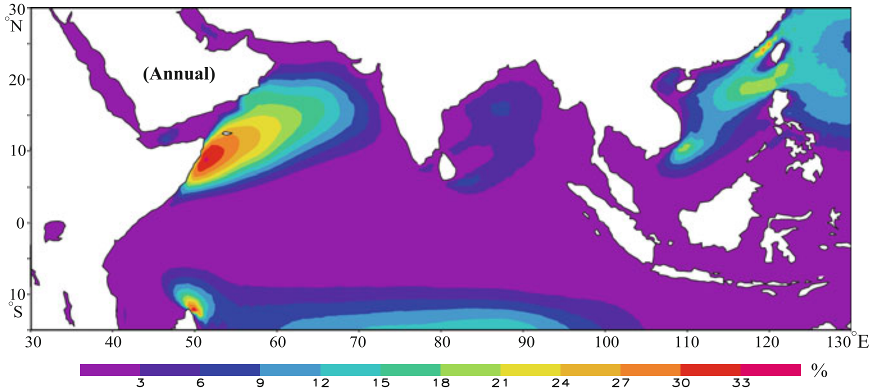
(3) **Gale Occurrence** (Occurrence of Average Wind Speed Greater Than Class 6)




(Apr)
(May)
(Jun)
30 °N
20
10
0
10 °S
30 40 50 60 70 80 90 100 110 120 130 °E
2 4 6 8 10 12 14 16 %
3 6 9 12 15 18 21 24 27 30 %
10 20 30 40 50 60 70 80 90 %

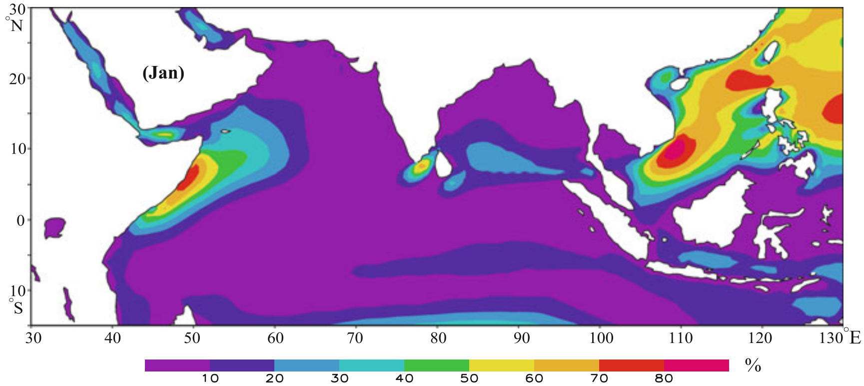

(Jul)
30 °N
20
10
0
10 °S
30 40 50 60 70 80 90 100 110 120 130 °E
10 20 30 40 50 60 70 80 90 %
(Aug)
30 °N
20
10
0
10 °S
30 40 50 60 70 80 90 100 110 120 130 °E
5 10 15 20 25 30 40 50 60 70 80 90 %
(Sep)
30 °N
20
10
0
10 °S
30 40 50 60 70 80 90 100 110 120 130 °E
5 10 15 20 25 30 35 40 45 50 55 60 %

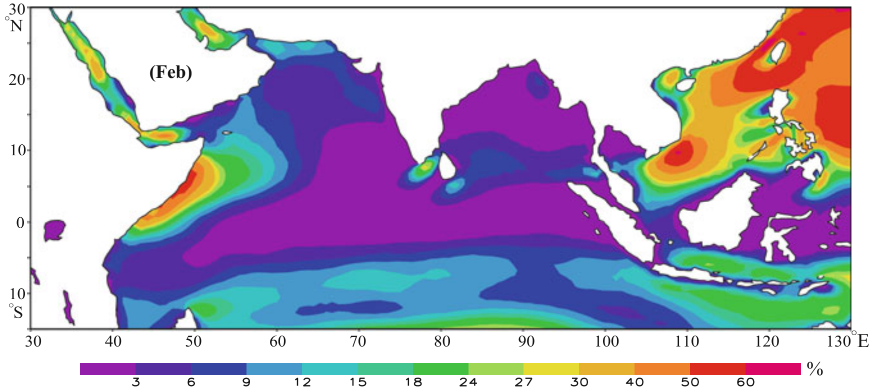

(Oct)
30°N
20
10
0
10°S
30
40
50
60
70
80
90
100
110
120
130°E
5 10 15 20 25 30 35 40 45 50
%
(Nov)
3 6 9 15 18 21 24 27 30 40 45 50
%
(Dec)
5 10 15 20 25 30 35 40 45 50 55
%

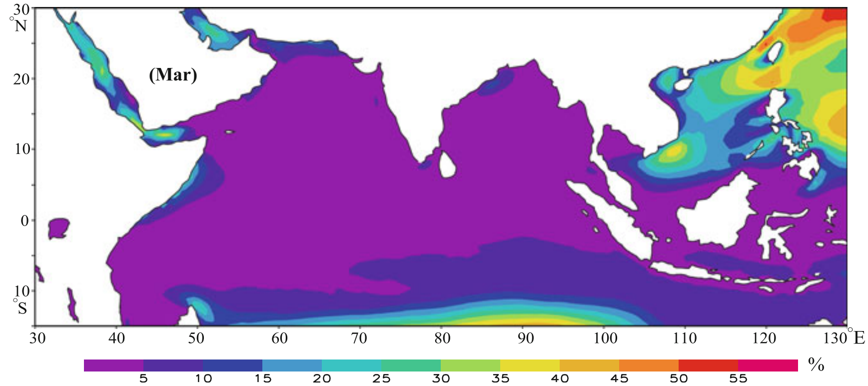


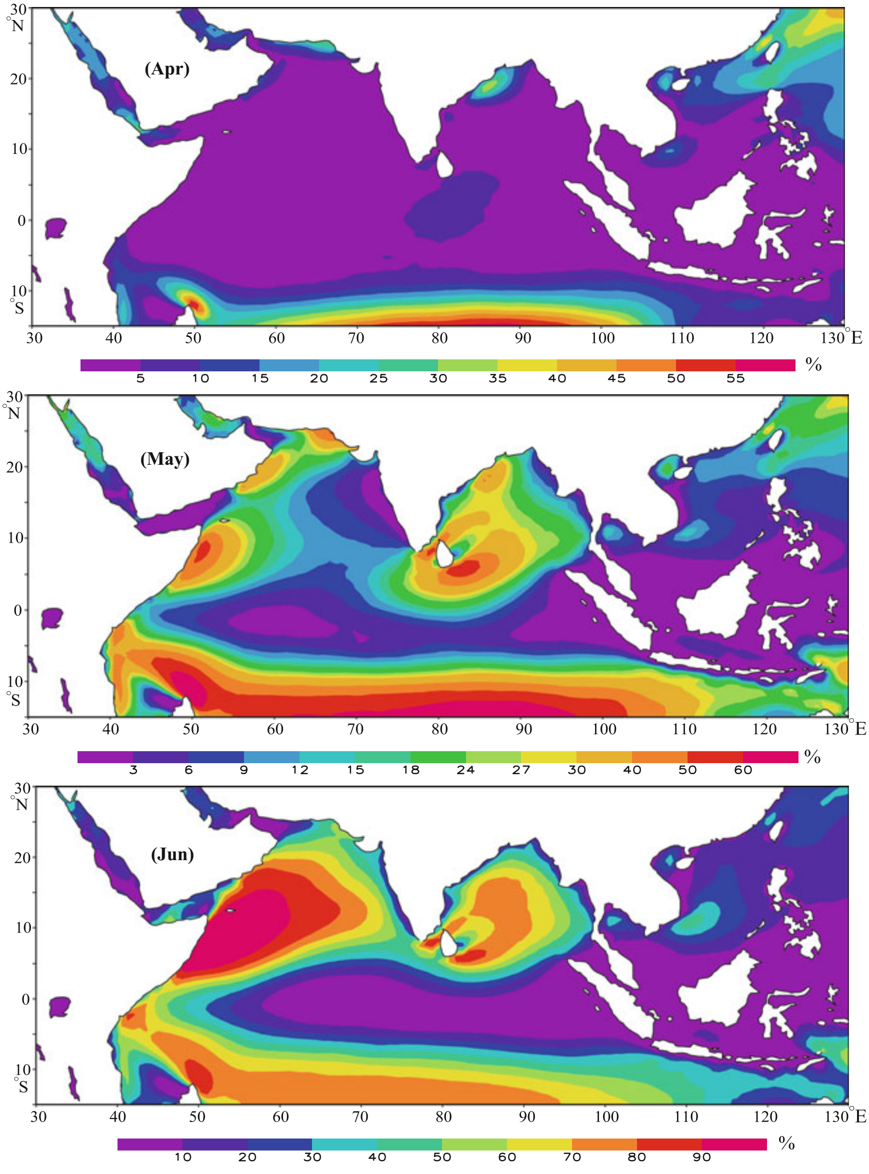
30°N
20
10
0
10°S
30
40
50
60
70
80
90
100
110
120
130°E
(Annual)
3
6
9
12
15
18
21
24
27
30
33
%

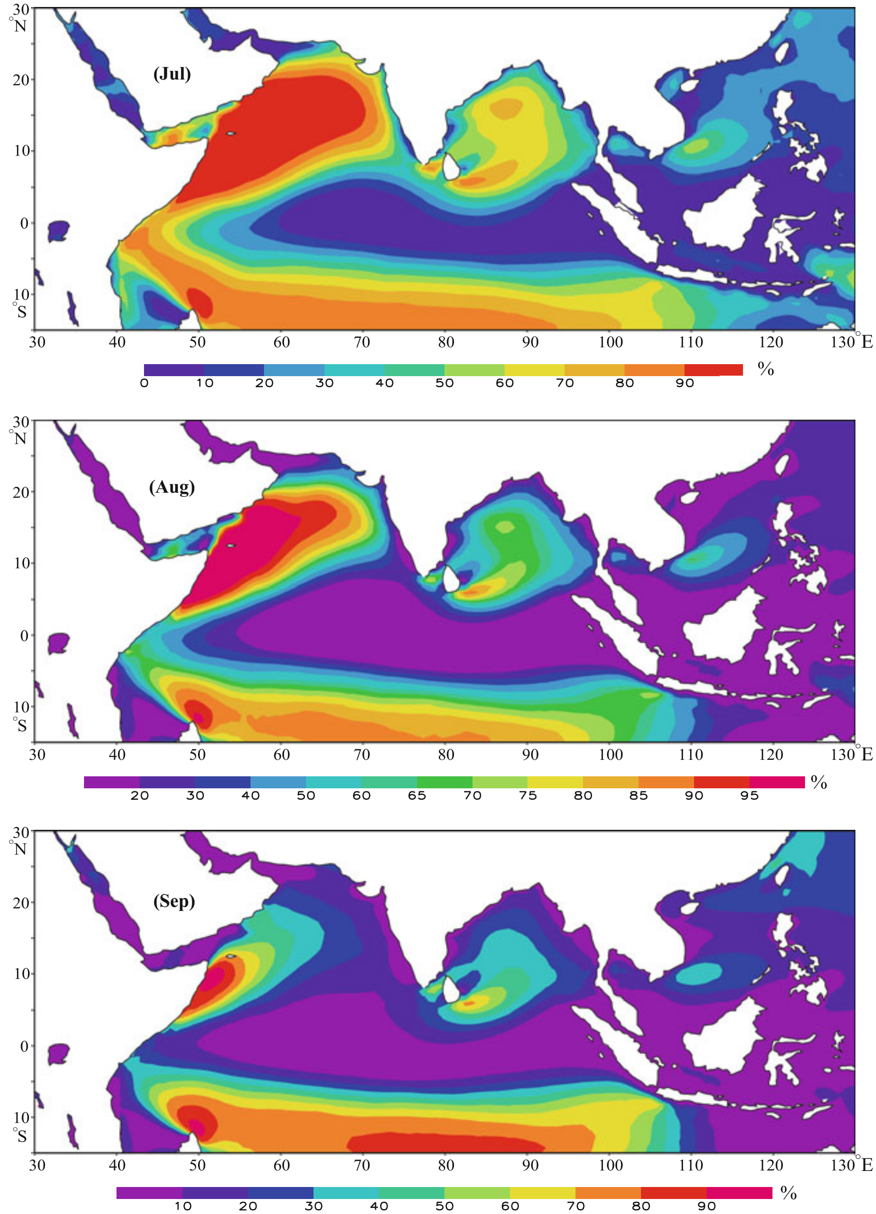
(4) **Gale Occurrence** (Occurrence of Gust Wind Speed Greater Than Class 6)

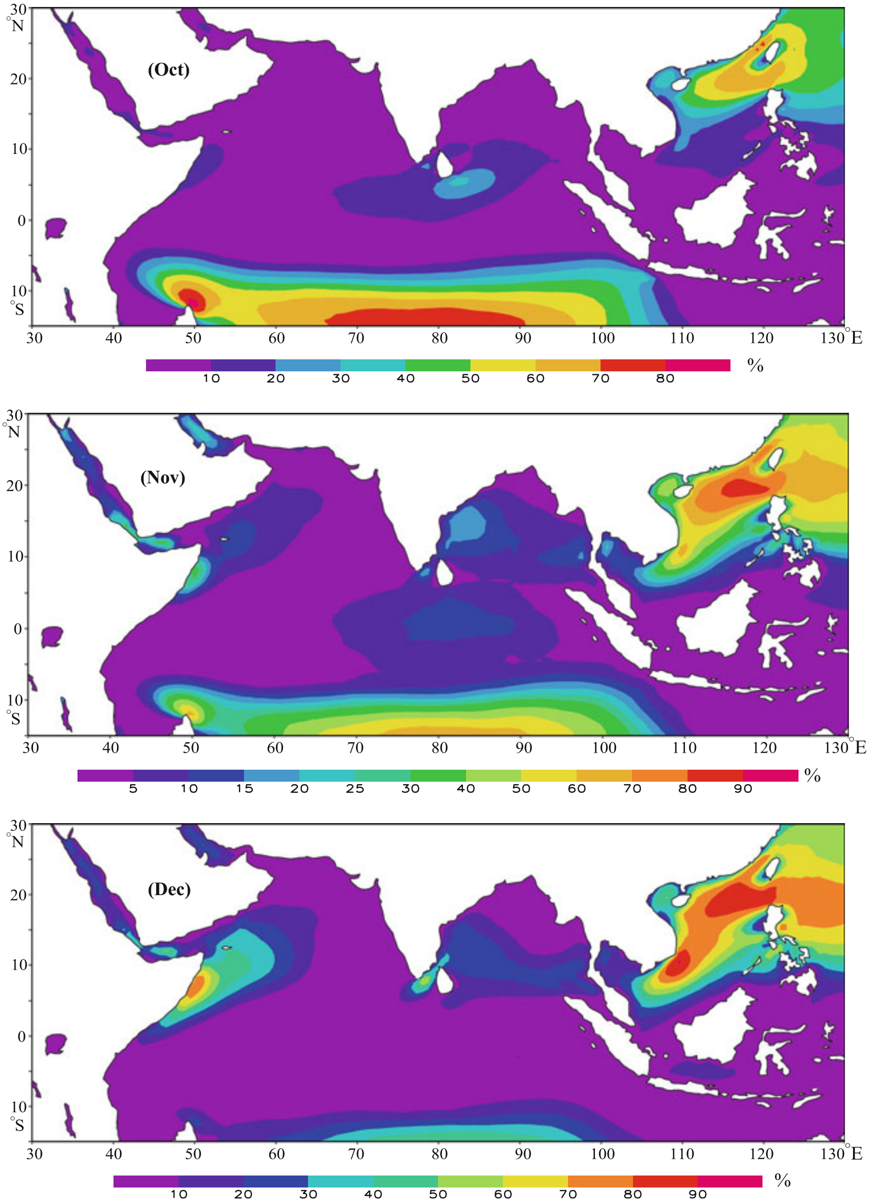


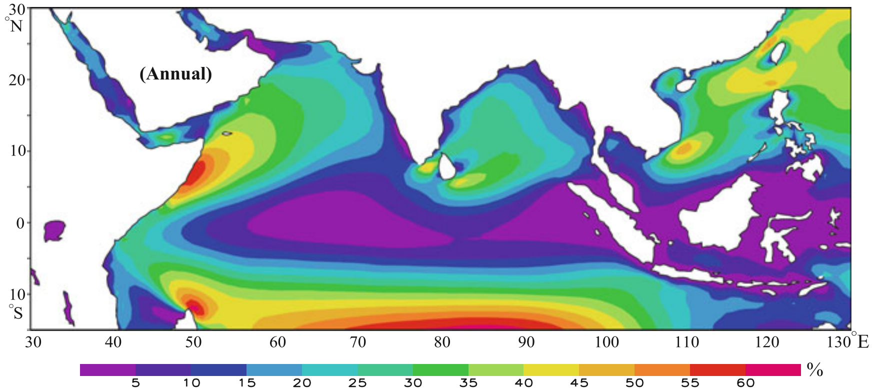




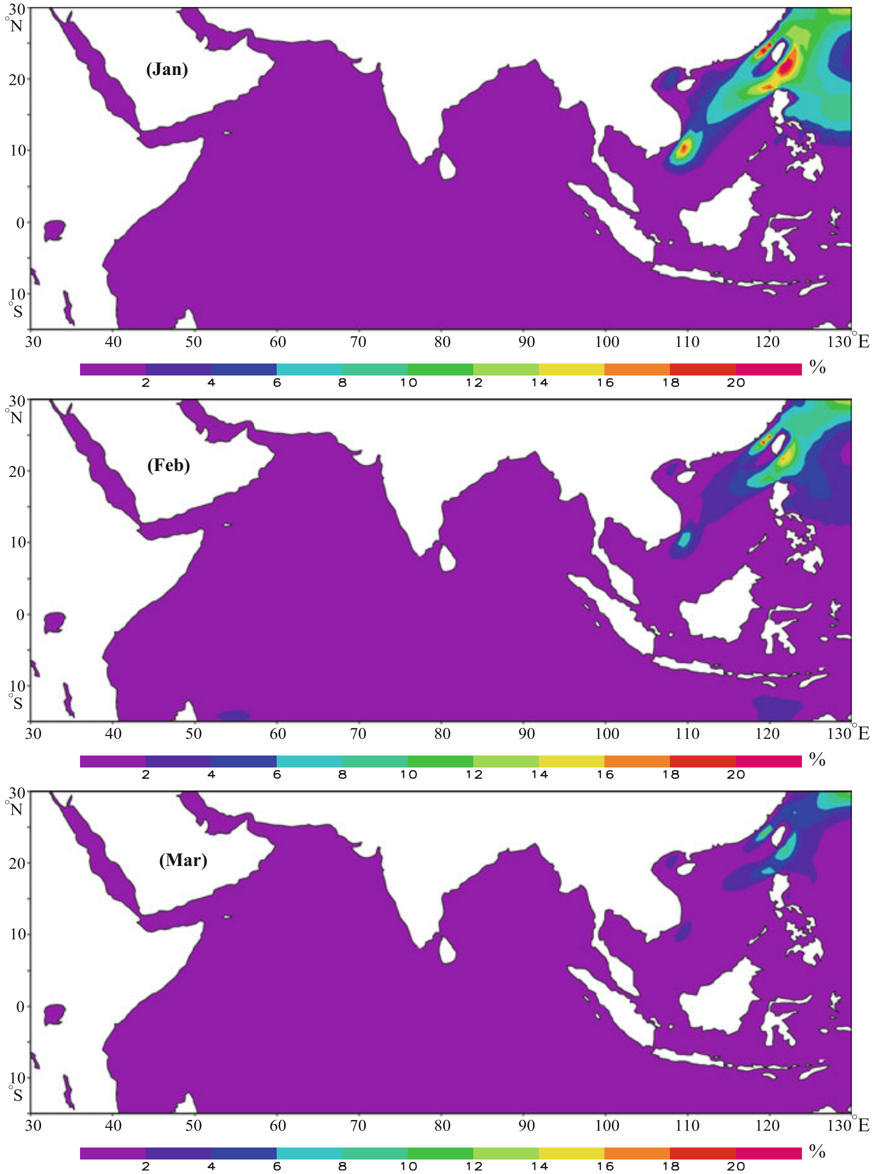

(Apr)
30°N
20
10
0
10°S
30 40 50 60 70 80 90 100 110 120 130°E
5 10 15 20 25 30 35 40 45 50 55 %
(May)
30°N
20
10
0
10°S
30 40 50 60 70 80 90 100 110 120 130°E
3 6 9 12 15 18 24 27 30 40 50 60 %
(Jun)
30°N
20
10
0
10°S
30 40 50 60 70 80 90 100 110 120 130°E
10 20 30 40 50 60 70 80 90 %

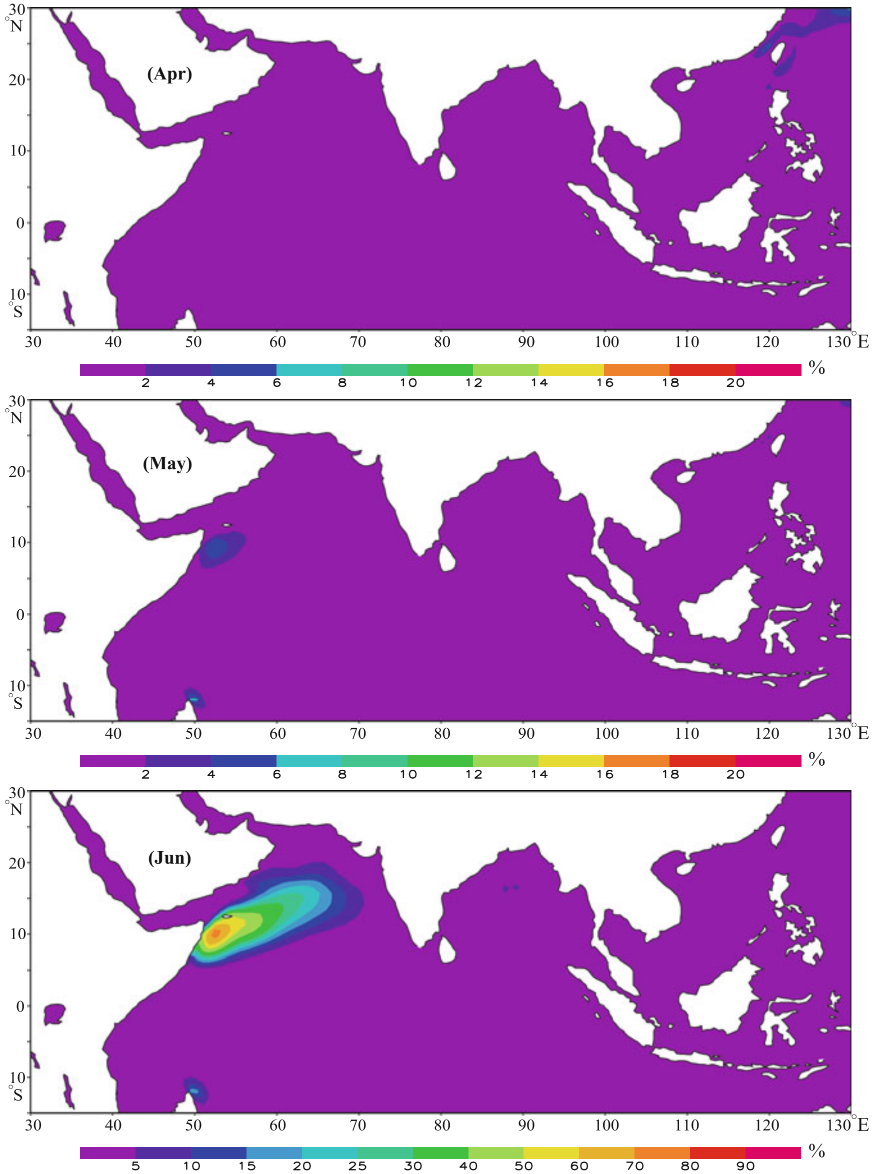

(Jul)
30°N
20
10
0
10°S
30 40 50 60 70 80 90 100 110 120 130°E
0 10 20 30 40 50 60 70 80 90 %
(Aug)
20 30 40 50 60 65 70 75 80 85 90 95 %
(Sep)
10 20 30 40 50 60 70 80 90 %

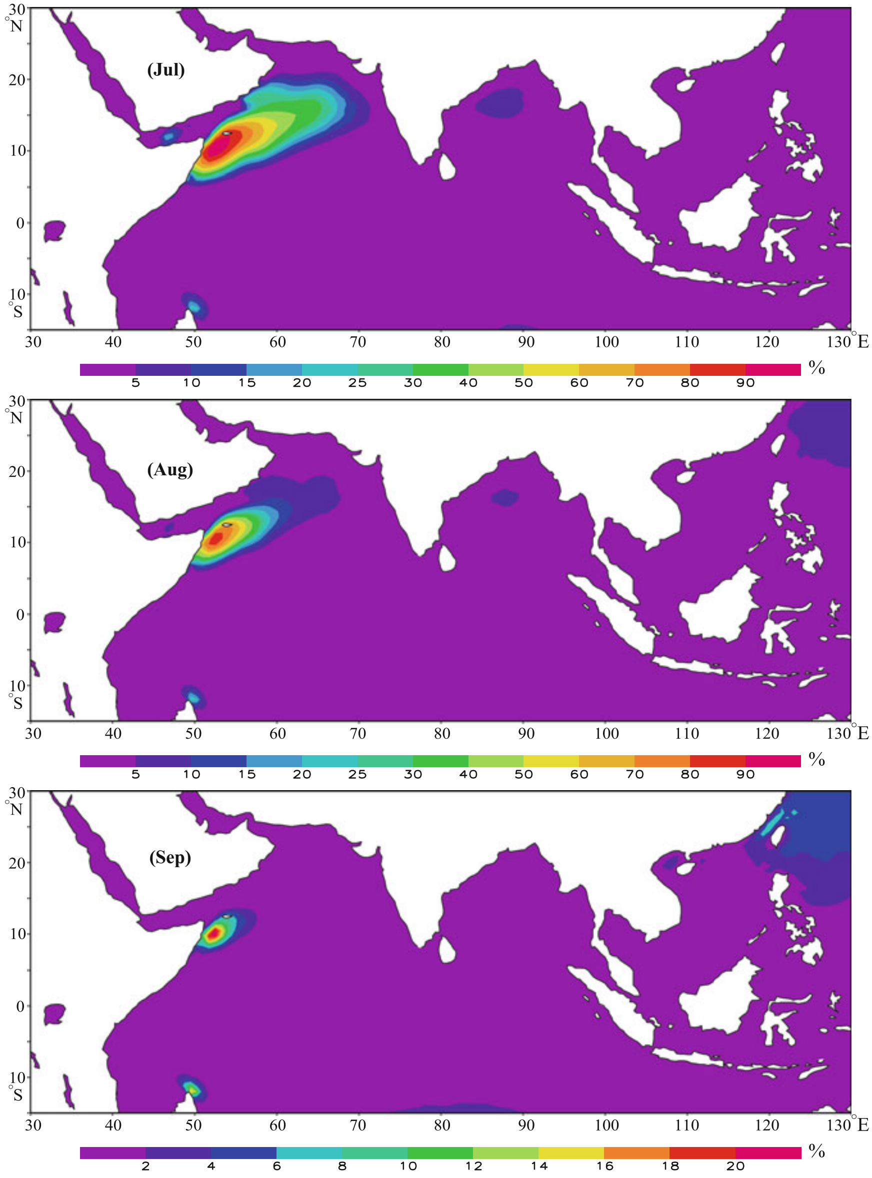

(Oct)
(Nov)
(Dec)
30 °N
20
10
0
10 °S
30 40 50 60 70 80 90 100 110 120 130 °E
10 20 30 40 50 60 70 80 %
5 10 15 20 25 30 40 50 60 70 80 90 %
10 20 30 40 50 60 70 80 90 %

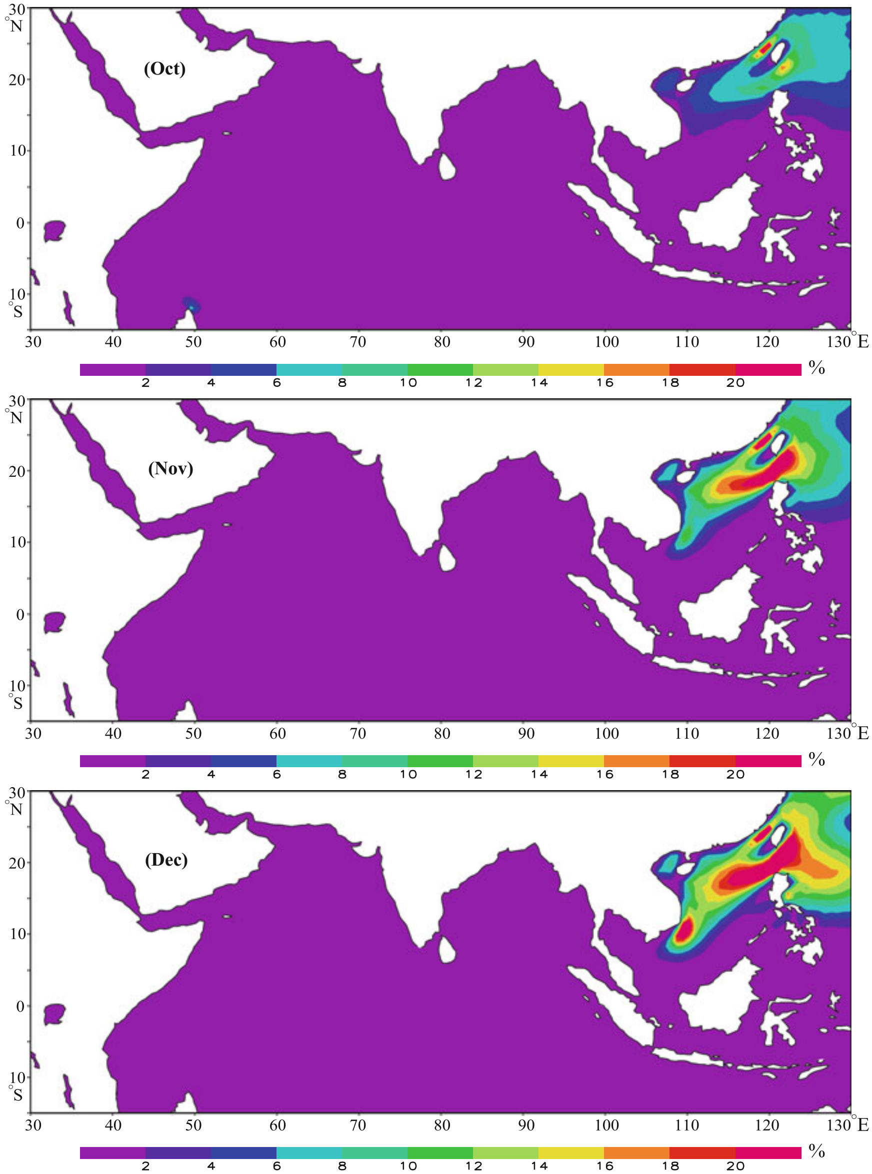

(Annual)
30°N
20
10
0
10°S
30
40
50
60
70
80
90
100
110
120
130°E
5
10
15
20
25
30
35
40
45
50
55
60
%

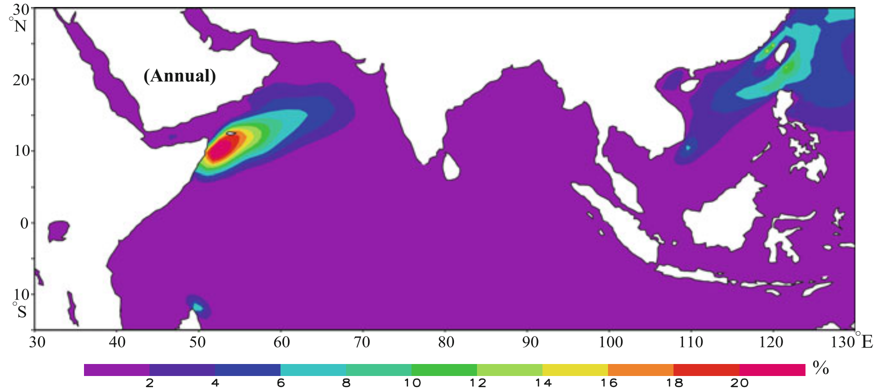
(5) **Gale Occurrence** (Occurrence of Gust Wind Speed Greater Than Class 8)




(Apr)
(May)
(Jun)
30°N
20
10
0
10°S
30
40
50
60
70
80
90
100
110
120
130°E
%
2
4
6
8
10
12
14
16
18
20
5
10
15
20
25
30
40
50
60
70
80
90

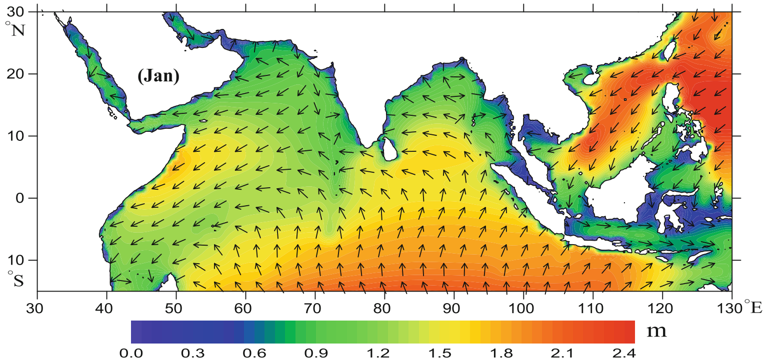

(Jul)
30°N
20
10
0
10°S
30 40 50 60 70 80 90 100 110 120 130°E
5 10 15 20 25 30 40 50 60 70 80 90
%
(Aug)
30°N
20
10
0
10°S
30 40 50 60 70 80 90 100 110 120 130°E
5 10 15 20 25 30 40 50 60 70 80 90
%
(Sep)
30°N
20
10
0
10°S
30 40 50 60 70 80 90 100 110 120 130°E
2 4 6 8 10 12 14 16 18 20
%

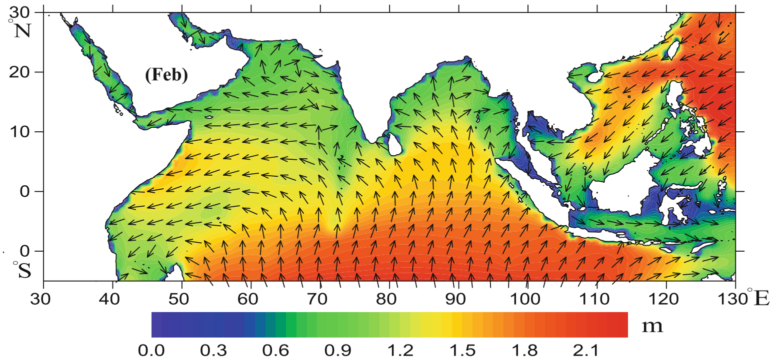

(Oct)
(Nov)
(Dec)
30 °N
20
10
0
10 °S
30 40 50 60 70 80 90 100 110 120 130 °E
2 4 6 8 10 12 14 16 18 20
%

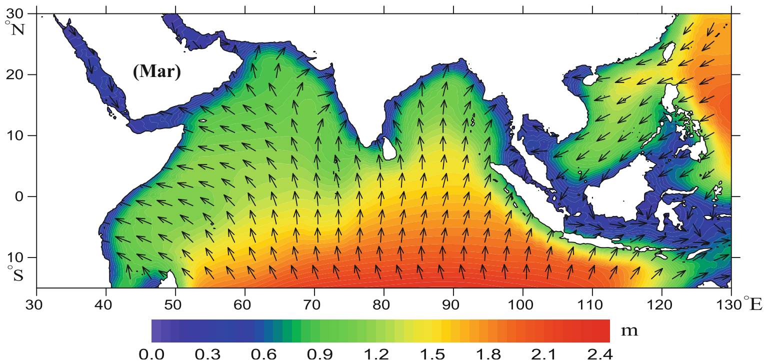


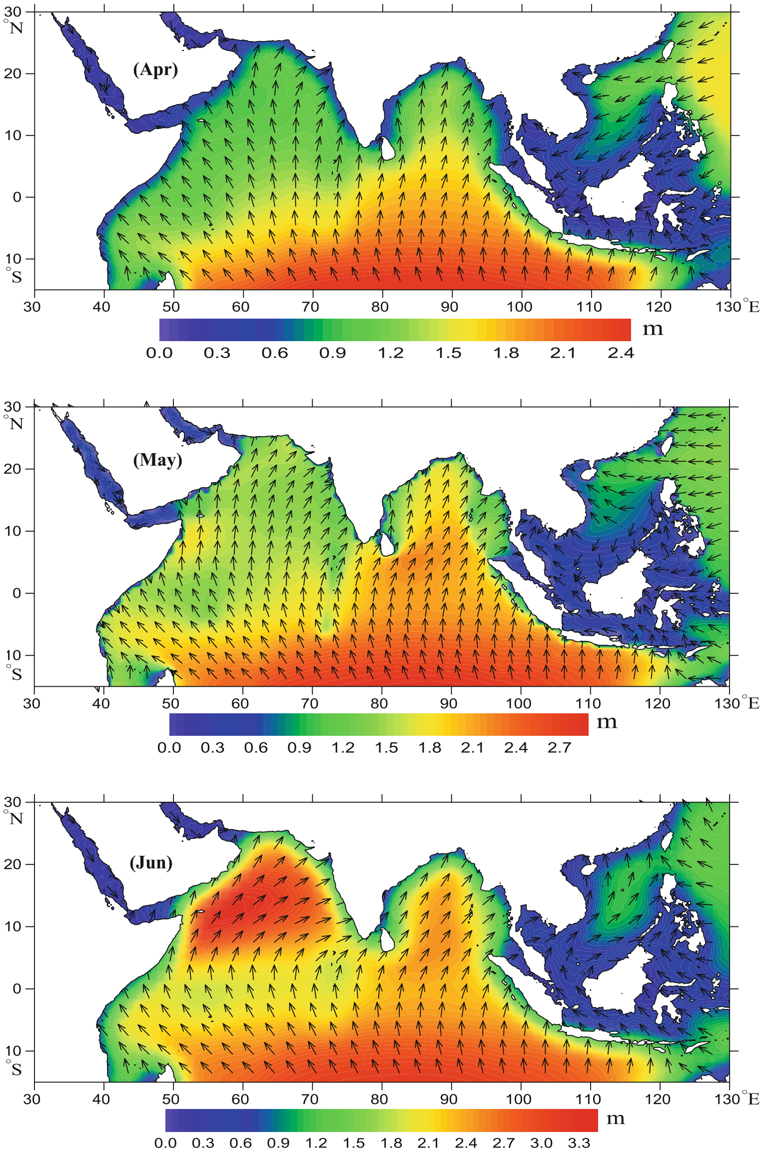
(Annual)
30°N
20
10
0
10°S
30
40
50
60
70
80
90
100
110
120
130°E
2
4
6
8
10
12
14
16
18
20
%

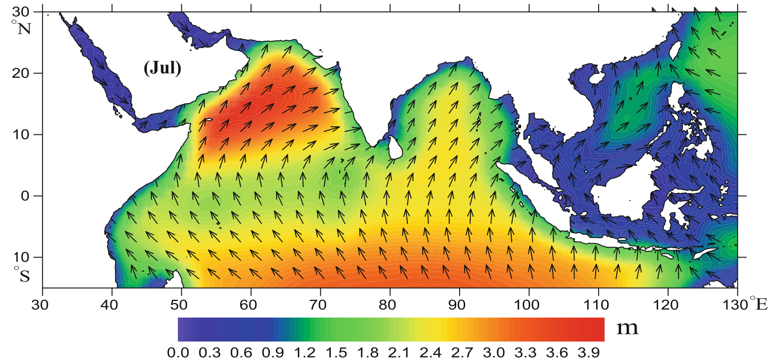
(6) Wave Field in each month of the Maritime Silk Road

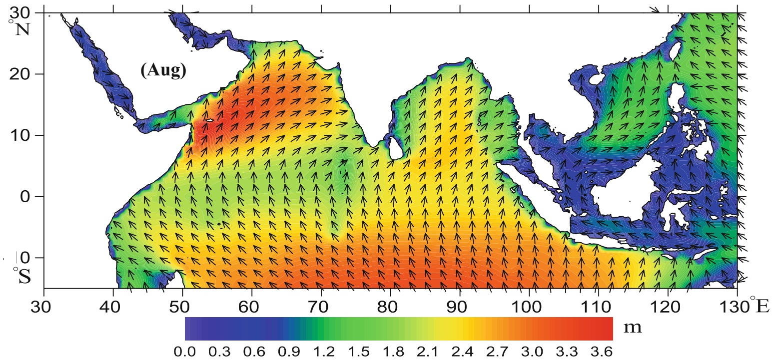


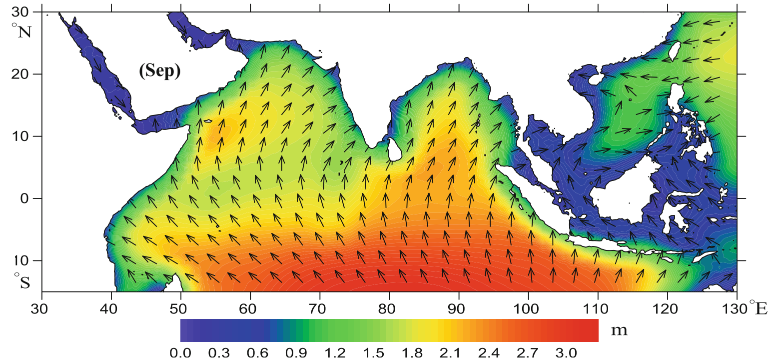


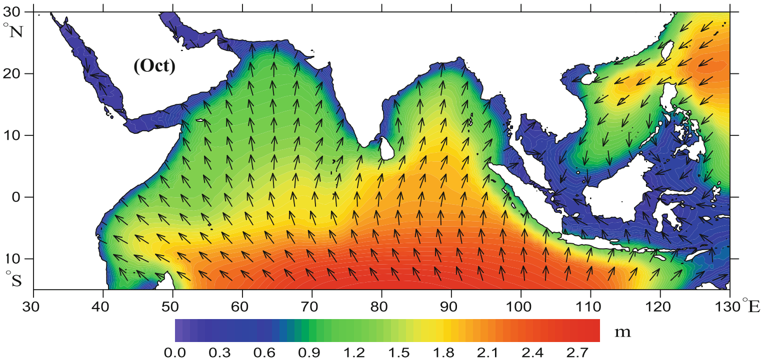



(Apr)
30°N
20
10
0
10°S
30 40 50 60 70 80 90 100 110 120 130°E
m
0.0 0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4
(May)
0.0 0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4 2.7
(Jun)
0.0 0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4 2.7 3.0 3.3

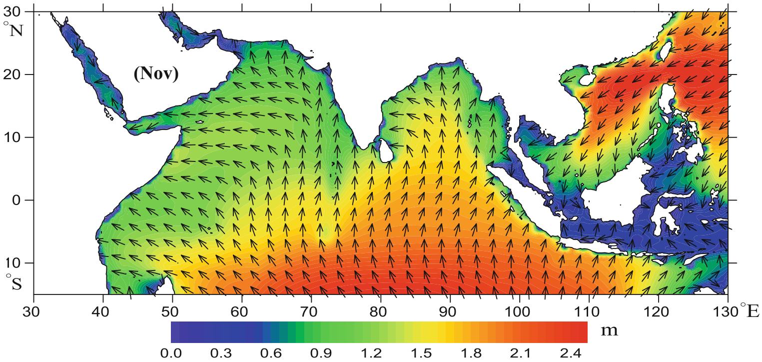

(Jul)
30 °N
20
10
0
10 °S
30 40 50 60 70 80 90 100 110 120 130 °E
m
0.0 0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4 2.7 3.0 3.3 3.6 3.9


(Aug)
30 °N
20
10
0
10 °S
30 40 50 60 70 80 90 100 110 120 130 °E
m
0.0 0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4 2.7 3.0 3.3 3.6

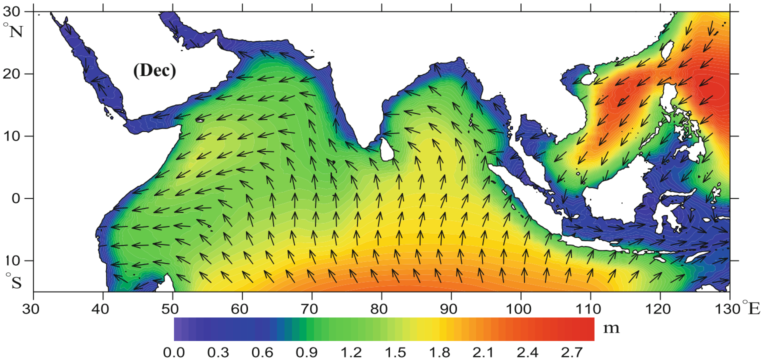

(Sep)
30 °N
20
10
0
10 °S
30 40 50 60 70 80 90 100 110 120 130 °E
m
0.0 0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4 2.7 3.0



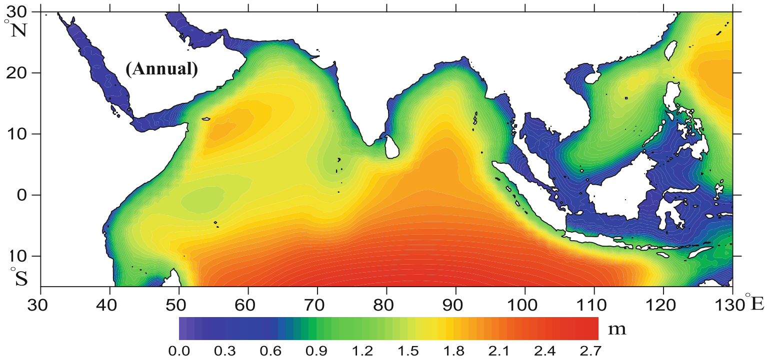
(Oct)
30 °N
20
10
0
10 °S
30
40
50
60
70
80
90
100
110
120
130 °E
m
0.0 0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4 2.7



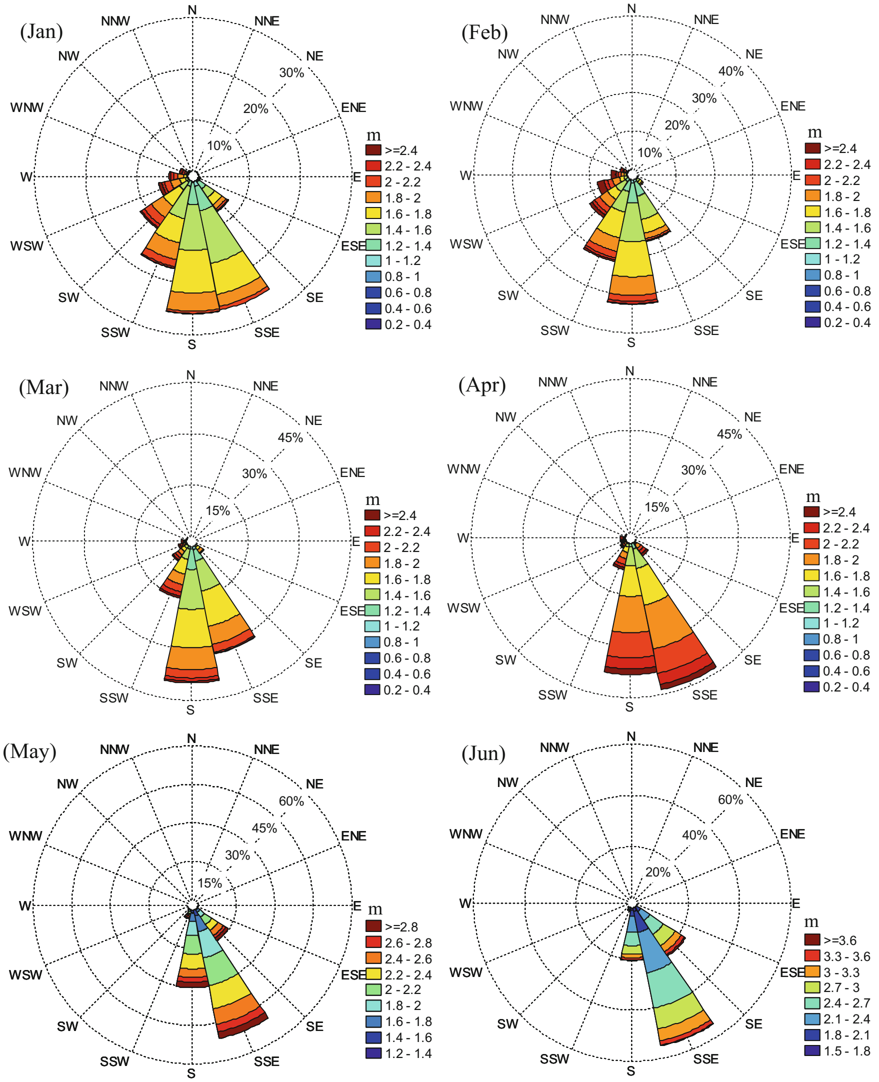
(Nov)
30 °N
20
10
0
10 °S
30
40
50
60
70
80
90
100
110
120
130 °E
m
0.0 0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4

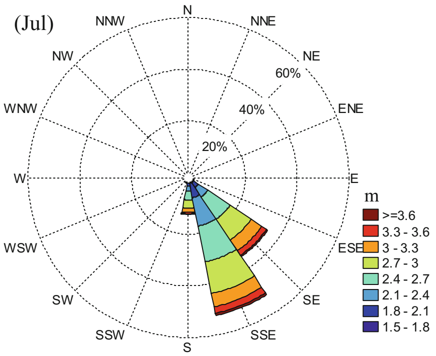


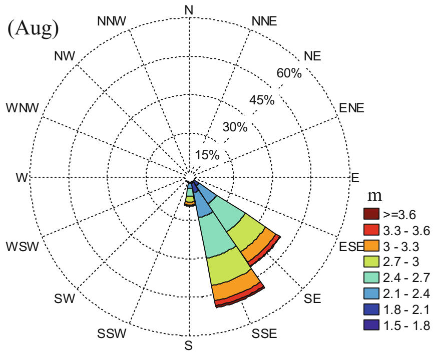
(Dec)
30 °N
20
10
0
10 °S
30
40
50
60
70
80
90
100
110
120
130 °E
m
0.0 0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4 2.7

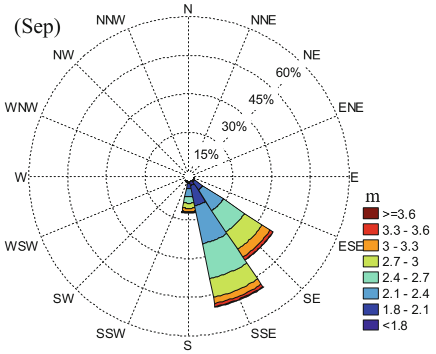

(Annual)
30
°N
20
10
0
10
°S
30
40
50
60
70
80
90
100
110
120
130
°E
m
0.0
0.3
0.6
0.9
1.2
1.5
1.8
2.1
2.4
2.7

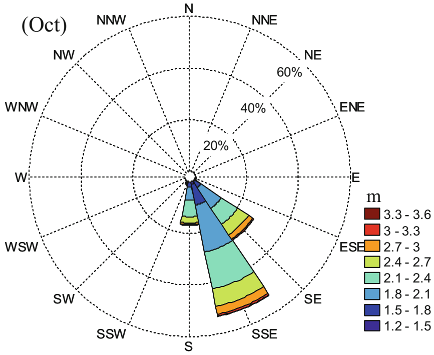
(7) Wave Rose of Diego Garcia (Co-occurrence of Wave Height and Wave Direction)

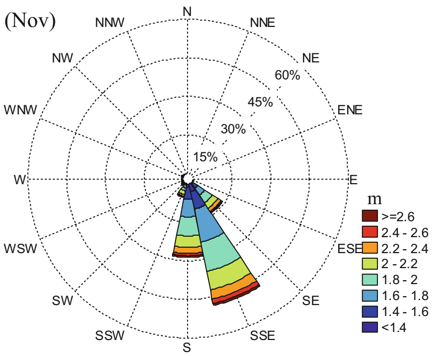


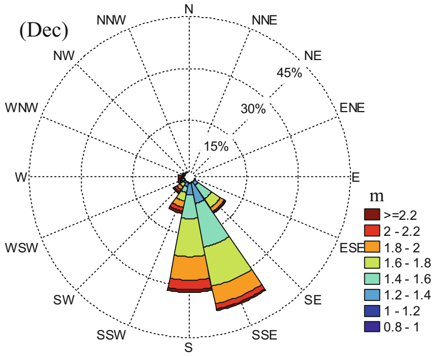

(Jul)
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
20%
40%
60%
m
>=3.6
3.3 - 3.6
3 - 3.3
2.7 - 3
2.4 - 2.7
2.1 - 2.4
1.8 - 2.1
1.5 - 1.8

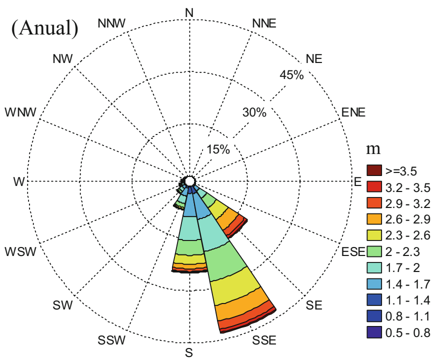

(Aug)
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
15%
30%
45%
60%
m
>=3.6
3.3 - 3.6
3 - 3.3
2.7 - 3
2.4 - 2.7
2.1 - 2.4
1.8 - 2.1
1.5 - 1.8


(Sep)
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
15%
30%
45%
60%
m
>=3.6
3.3 - 3.6
3 - 3.3
2.7 - 3
2.4 - 2.7
2.1 - 2.4
1.8 - 2.1
<1.8

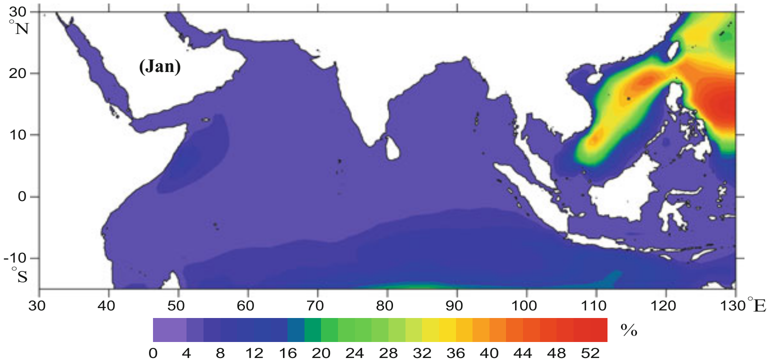

(Oct)
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
20%
40%
60%
m
3.3 - 3.6
3 - 3.3
2.7 - 3
2.4 - 2.7
2.1 - 2.4
1.8 - 2.1
1.5 - 1.8
1.2 - 1.5

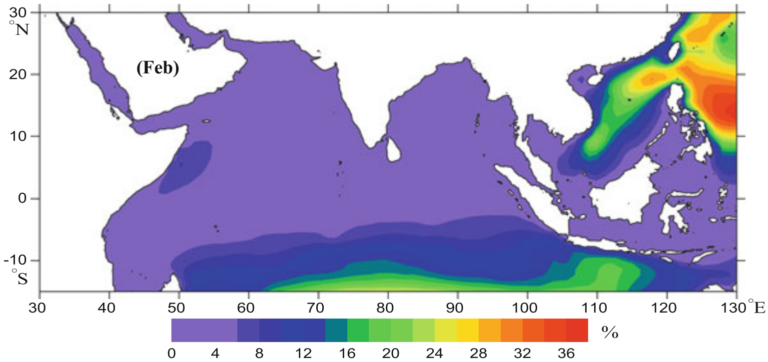

(Nov)
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
15%
30%
45%
60%
m
>=2.6
2.4 - 2.6
2.2 - 2.4
2 - 2.2
1.8 - 2
1.6 - 1.8
1.4 - 1.6
<1.4

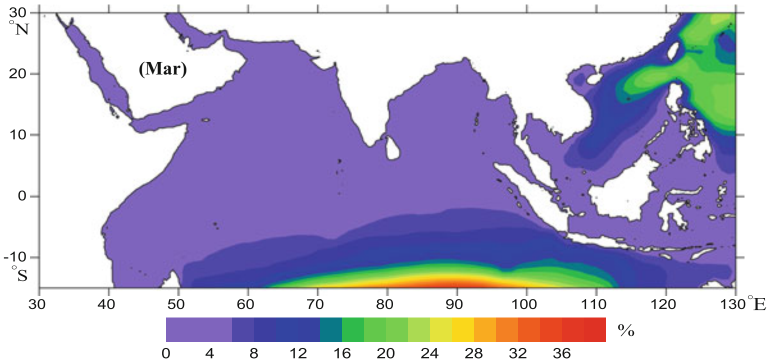

(Dec)
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
15%
30%
45%
m
>=2.2
2 - 2.2
1.8 - 2
1.6 - 1.8
1.4 - 1.6
1.2 - 1.4
1 - 1.2
0.8 - 1

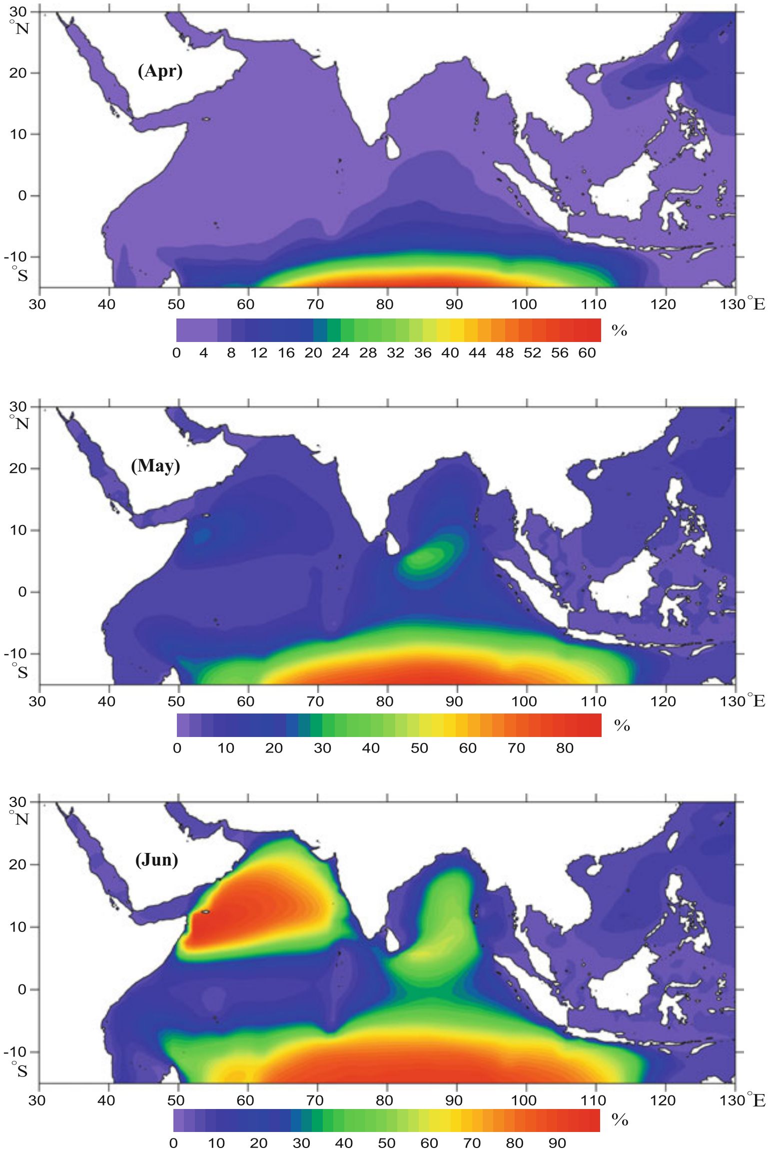

(Anual)
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
15%
30%
45%
m
>=3.5
3.2 - 3.5
2.9 - 3.2
2.6 - 2.9
2.3 - 2.6
2 - 2.3
1.7 - 2
1.4 - 1.7
1.1 - 1.4
0.8 - 1.1
0.5 - 0.8

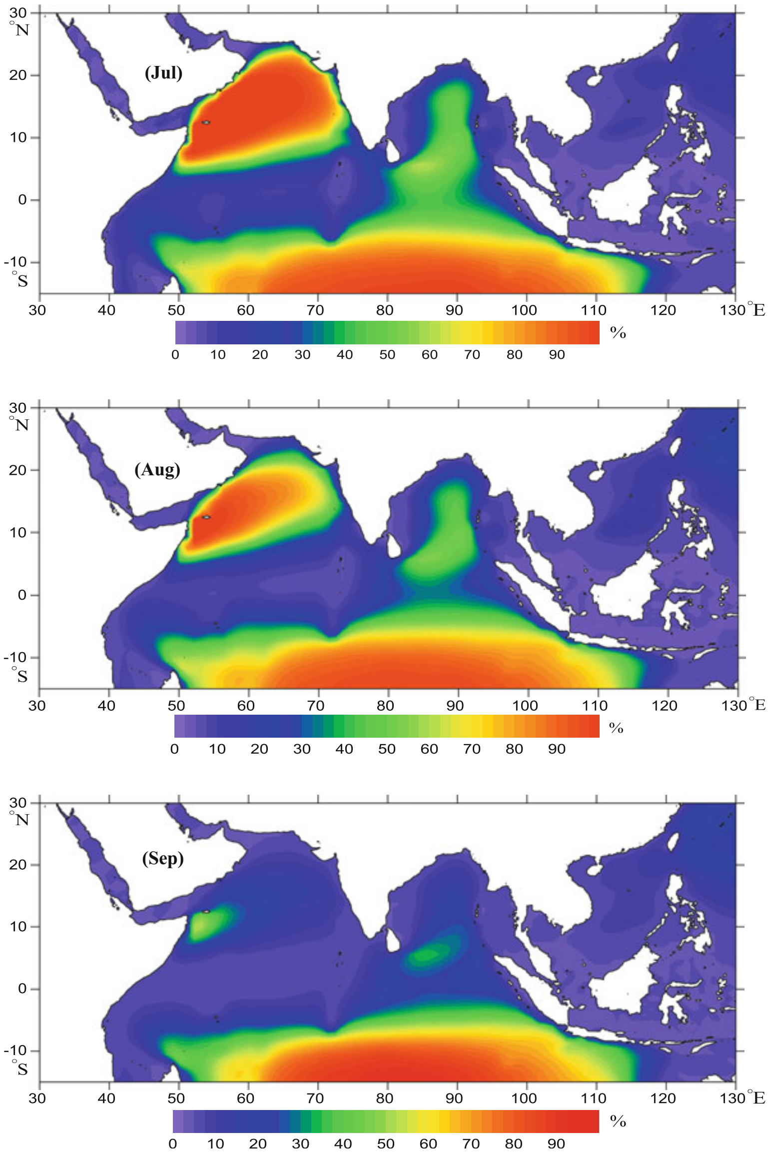
(8) Rough Sea Occurrence (Occurrence of SWH Greater Than 2.5 m)

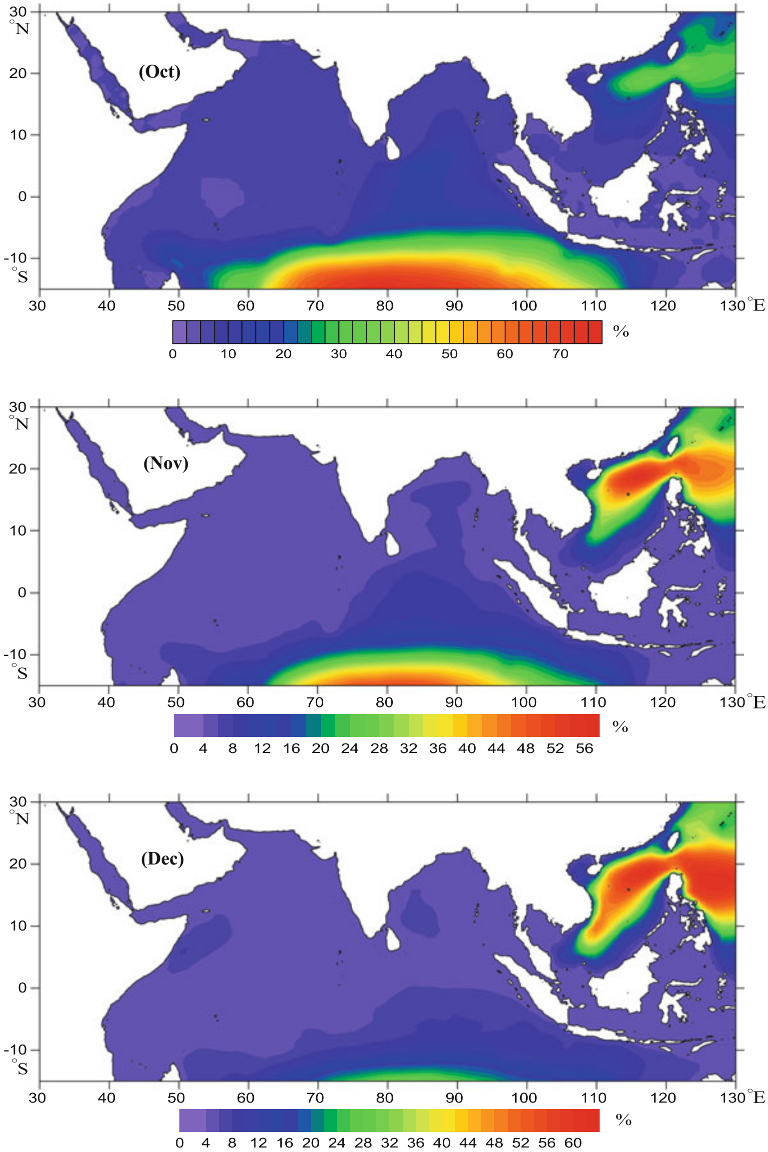


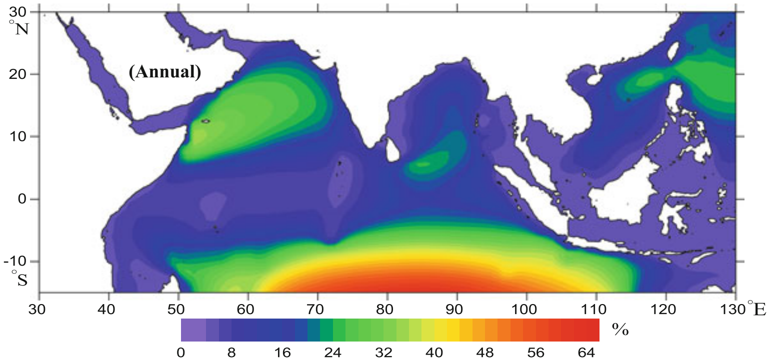





(Apr)
30 °N
20
10
0
-10 °S
30 40 50 60 70 80 90 100 110 120 130 °E
%
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60
(May)
30 °N
20
10
0
-10 °S
30 40 50 60 70 80 90 100 110 120 130 °E
%
0 10 20 30 40 50 60 70 80
(Jun)
30 °N
20
10
0
-10 °S
30 40 50 60 70 80 90 100 110 120 130 °E
%
0 10 20 30 40 50 60 70 80 90

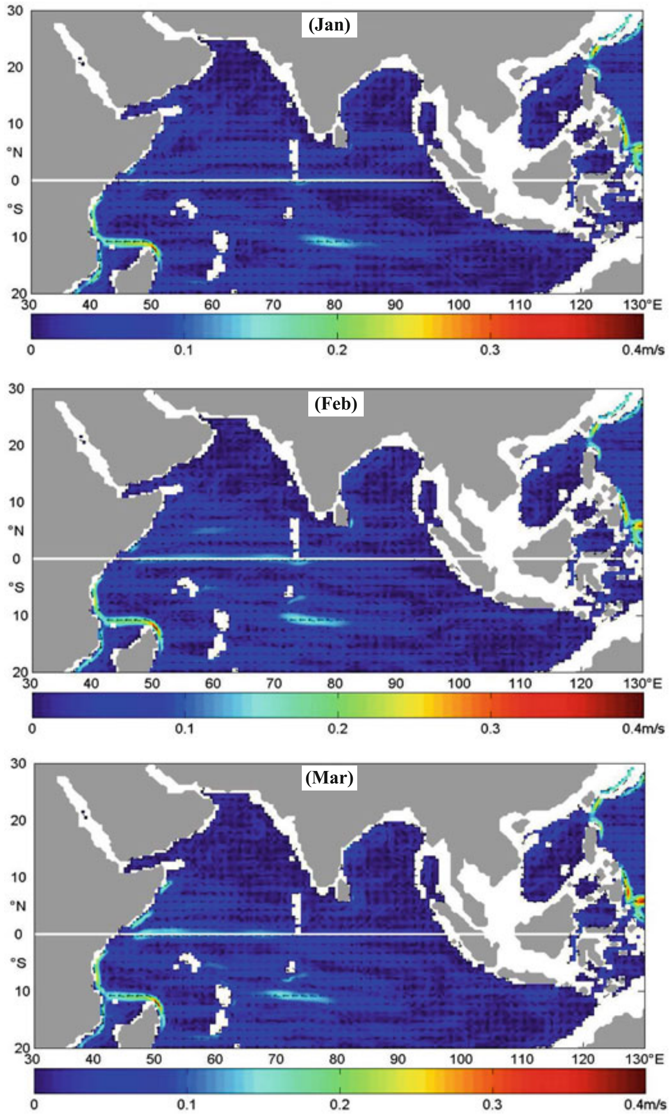

(Jul)
(Aug)
(Sep)
30 °N
20
10
0
-10 °S
30
40
50
60
70
80
90
100
110
120
130 °E
%
0
10
20
30
40
50
60
70
80
90

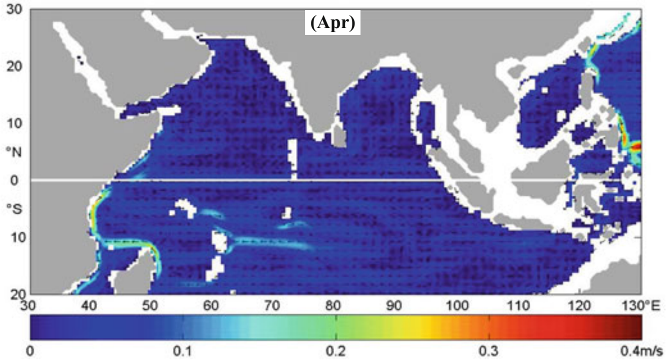

(Oct)
30 °N
20
10
0
-10 °S
30 40 50 60 70 80 90 100 110 120 130 °E
%
0 10 20 30 40 50 60 70
(Nov)
30 °N
20
10
0
-10 °S
30 40 50 60 70 80 90 100 110 120 130 °E
%
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56
(Dec)
30 °N
20
10
0
-10 °S
30 40 50 60 70 80 90 100 110 120 130 °E
%
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60

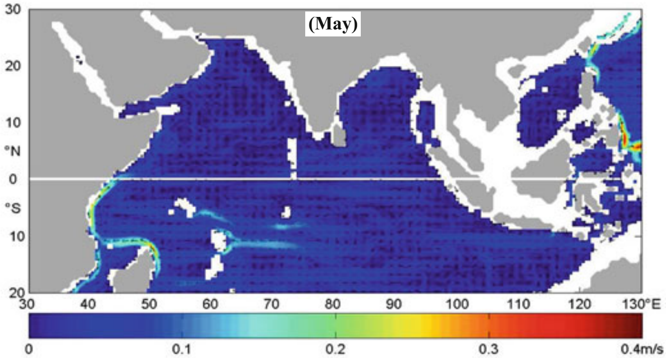


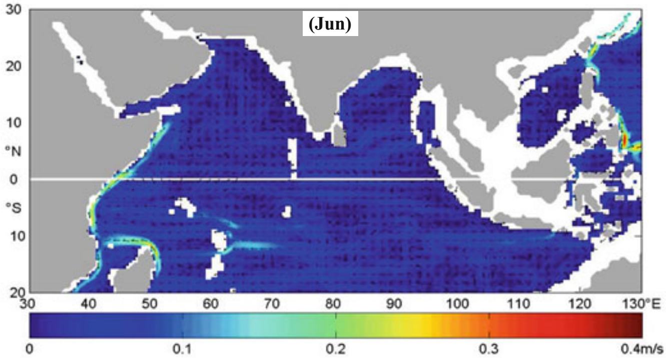
(Annual)
30 °N
20
10
0
-10 °S
30
40
50
60
70
80
90
100
110
120
130 °E
%
0
8
16
24
32
40
48
56
64

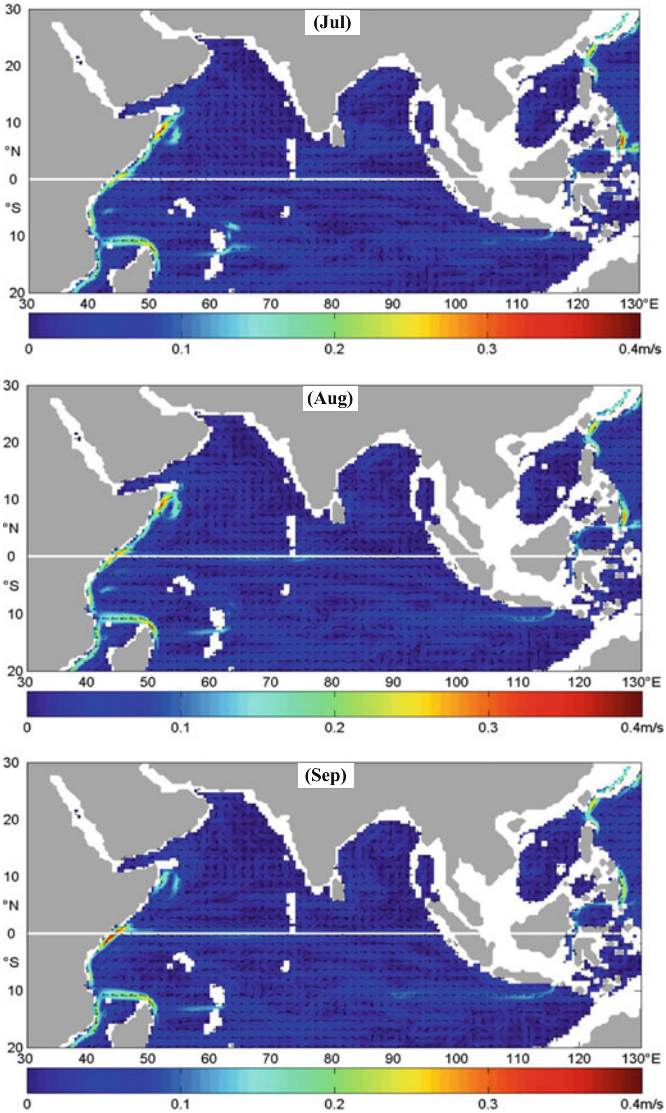
(9) Ocean Current (Averaging from 5 to 1000 m of the Under Water)

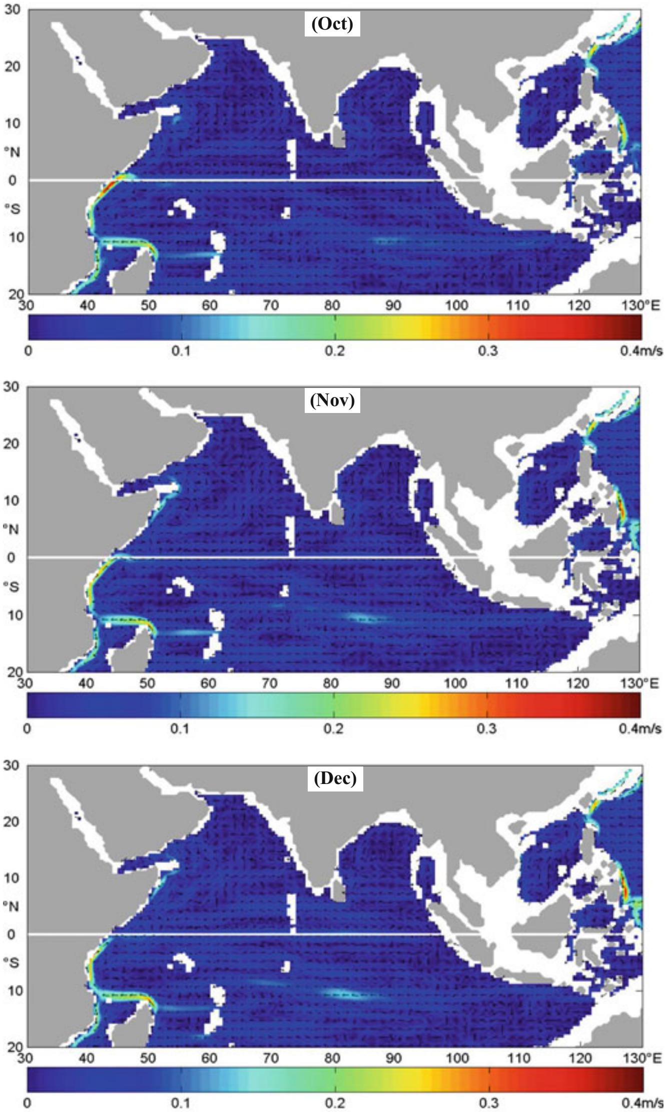



(Apr)
30
20
10
°N
0
°S
10
20
30
40
50
60
70
80
90
100
110
120
130°E
0
0.1
0.2
0.3
0.4m/s

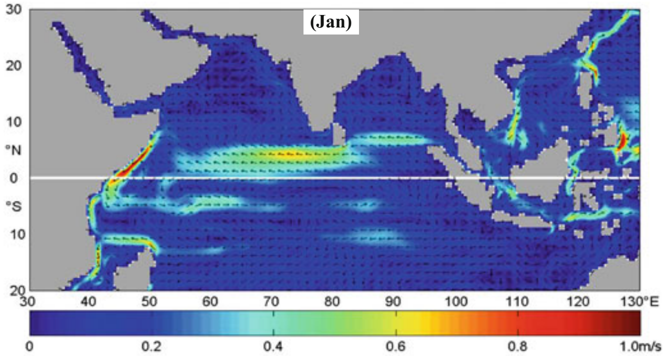

(May)
30
20
10
°N
0
°S
10
20
30
40
50
60
70
80
90
100
110
120
130°E
0
0.1
0.2
0.3
0.4m/s

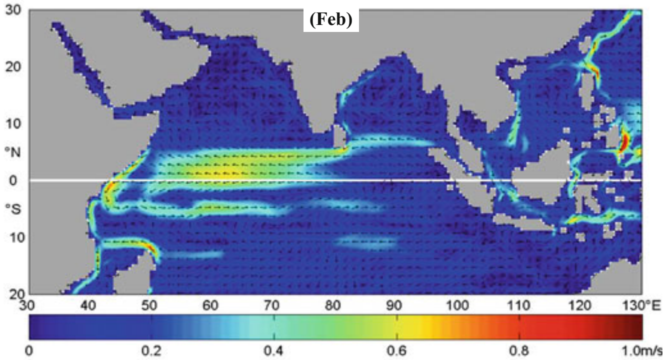

(Jun)
30
20
10
°N
0
°S
10
20
30
40
50
60
70
80
90
100
110
120
130°E
0
0.1
0.2
0.3
0.4m/s

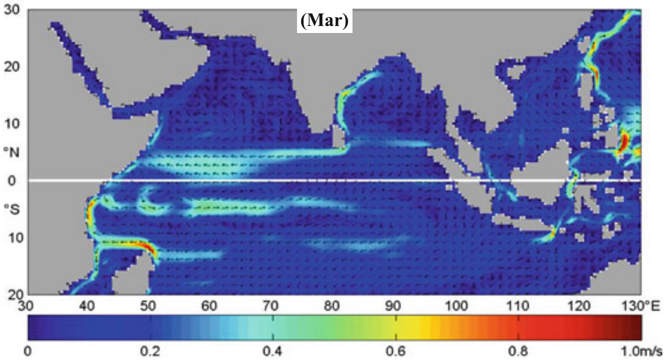

(Jul)
(Aug)
(Sep)
30
20
10
°N
0
°S
10
20
30 40 50 60 70 80 90 100 110 120 130°E
0 0.1 0.2 0.3 0.4m/s

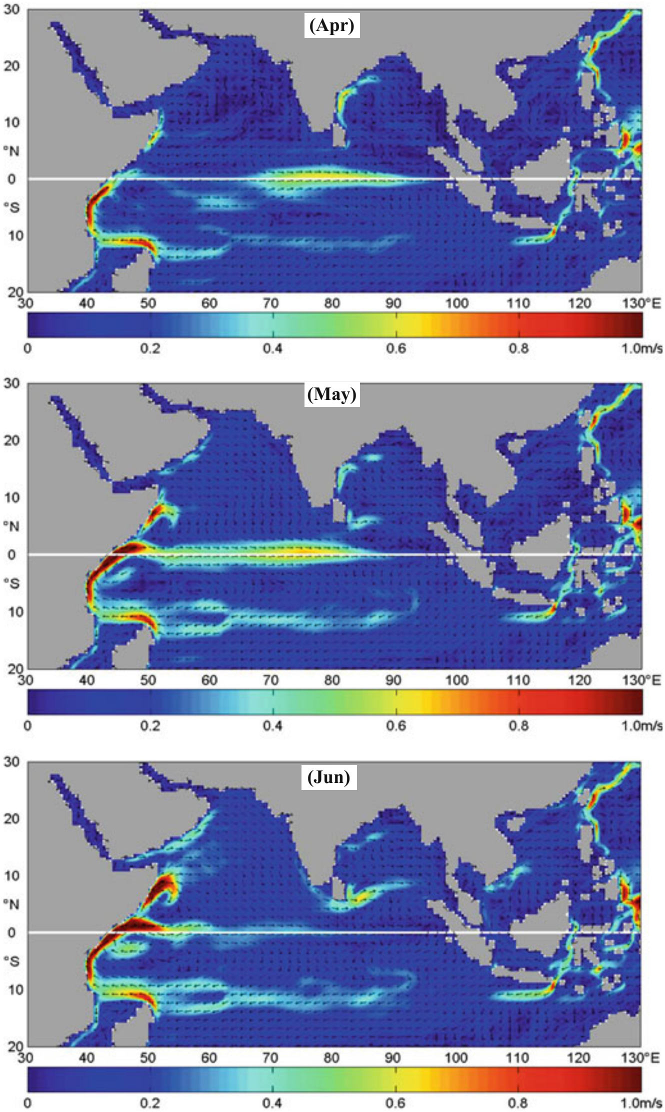

(Oct)
(Nov)
(Dec)
30
20
10
°N
0
°S
10
20
30 40 50 60 70 80 90 100 110 120 130°E
0 0.1 0.2 0.3 0.4m/s

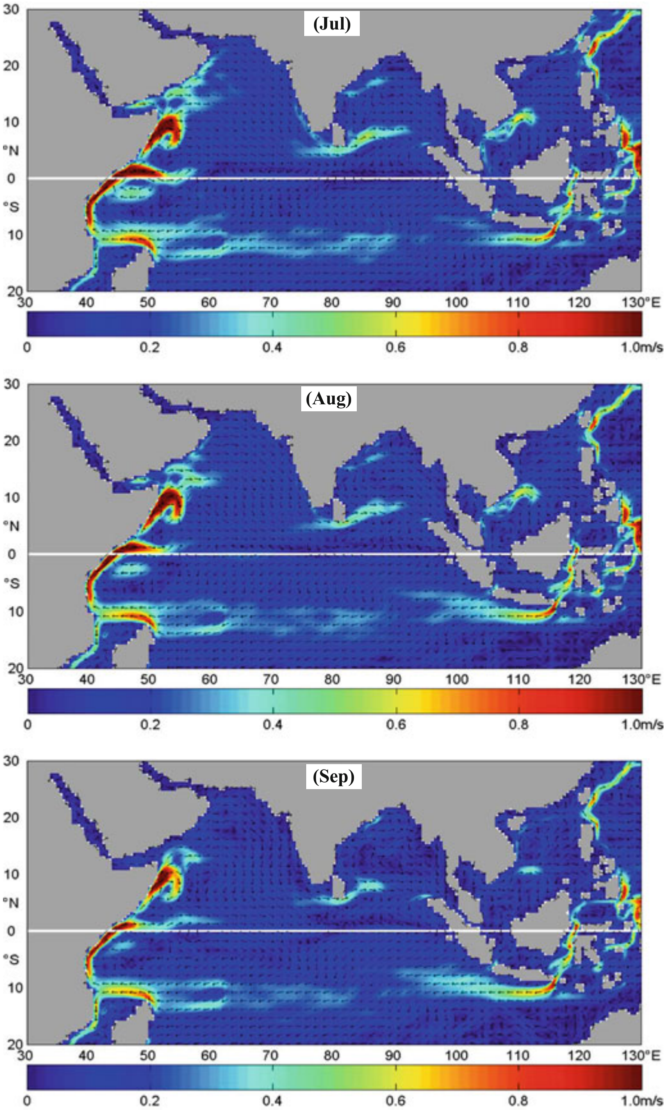
(10) **Upper Ocean Current (5 m of the Under Water)**

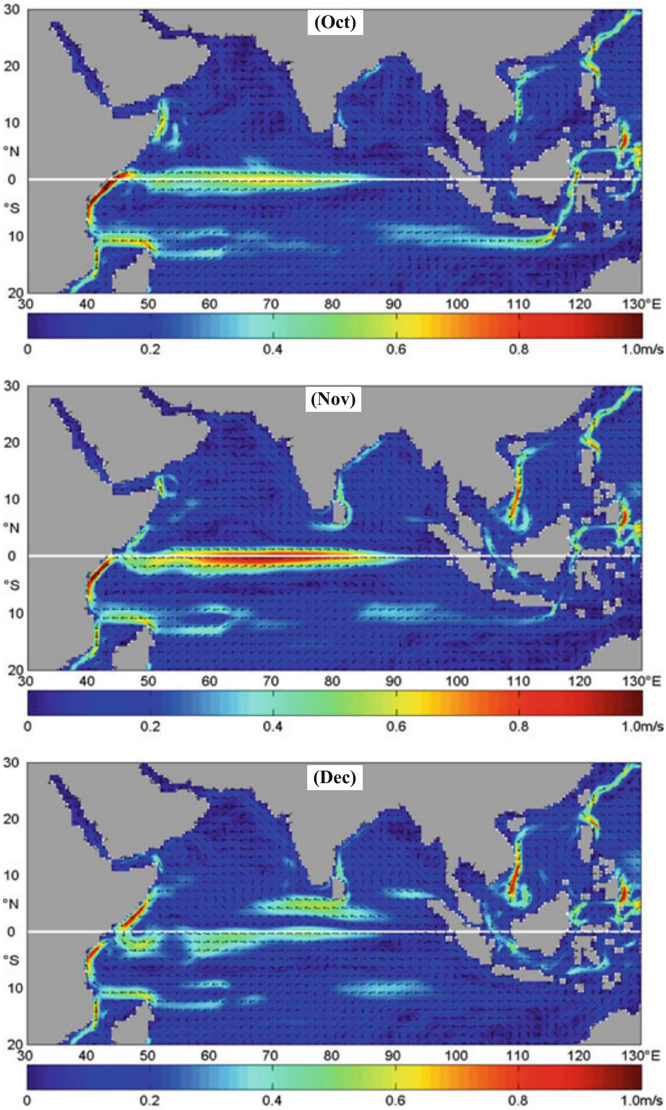




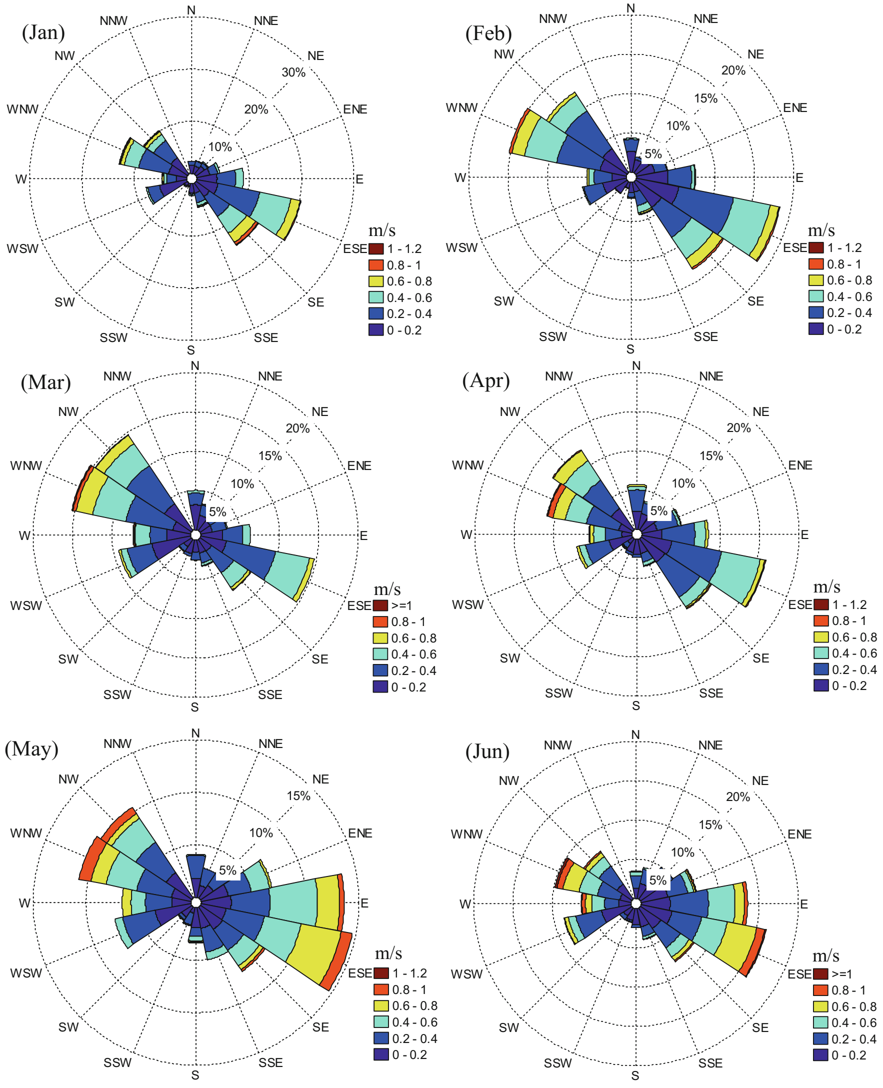


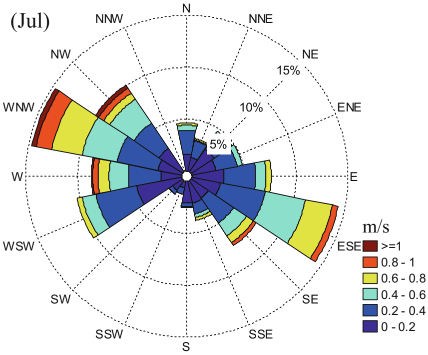

(Apr)
(May)
(Jun)
30
20
10
°N
0
°S
10
20
30 40 50 60 70 80 90 100 110 120 130°E
0 0.2 0.4 0.6 0.8 1.0m/s

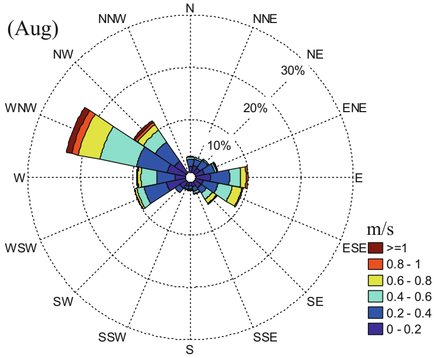

(Jul)
(Aug)
(Sep)
30
20
10
°N
0
°S
10
20
30 40 50 60 70 80 90 100 110 120 130°E
0 0.2 0.4 0.6 0.8 1.0m/s

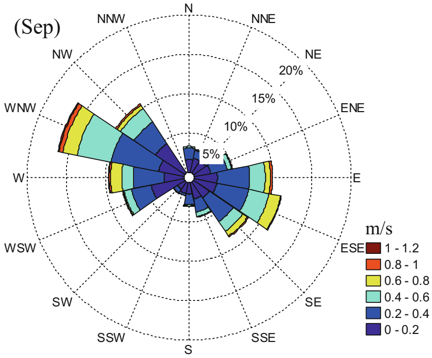

(Oct)
(Nov)
(Dec)
30
20
10
°N
0
°S
10
20
30 40 50 60 70 80 90 100 110 120 130°E
0 0.2 0.4 0.6 0.8 1.0m/s

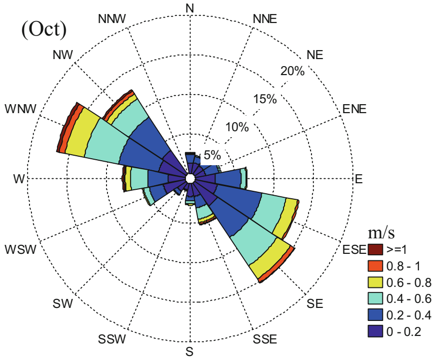
(11) Current Rose of Eluanbi Station (South of Taiwan Island)

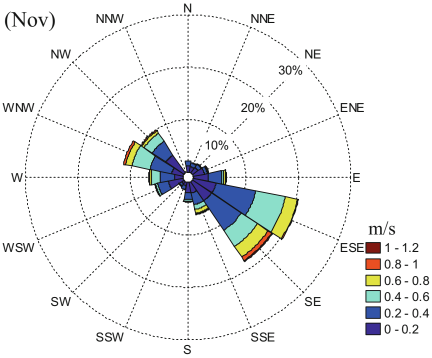


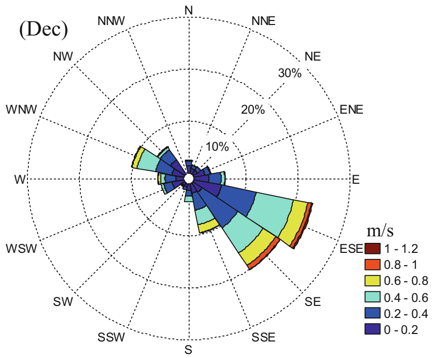

(Jul)
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
5%
10%
15%
m/s
>=1
0.8 - 1
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0 - 0.2

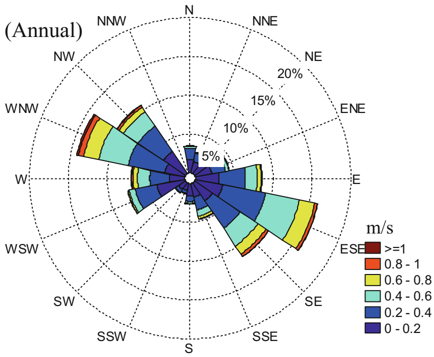

(Aug)
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
10%
20%
30%
m/s
>=1
0.8 - 1
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0 - 0.2


(Sep)
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
5%
10%
15%
20%
m/s
1 - 1.2
0.8 - 1
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0 - 0.2


(Oct)
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
5%
10%
15%
20%
m/s
>=1
0.8 - 1
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0 - 0.2


(Nov)
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
10%
20%
30%
m/s
1 - 1.2
0.8 - 1
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0 - 0.2


(Dec)
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
10%
20%
30%
m/s
1 - 1.2
0.8 - 1
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0 - 0.2


(Annual)
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
5%
10%
15%
20%
m/s
>=1
0.8 - 1
0.6 - 0.8
0.4 - 0.6
0.2 - 0.4
0 - 0.2