



Climate change and China's coastal zones and seas: Impacts, risks, and adaptation

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ABSTRACT

This article provides an assessment of the changes in marine climate drivers (hazards), associated impacts, risks, and adaptation to the coastal China zones and seas since the mid 20th century. The results show that: ① Marine climate drivers, such as ocean warming, sea level rise, typhoon, storm surges and marine heat waves (MHWs), have increased significantly in strength, frequency and range over the past decades. ② Ocean warming has caused substantial changes in marine phenology, species composition, geographical distribution, and frequent occurrences of ecological disasters such as red tides, green tides, and macro-jellyfish outbreaks, while MHWs have induced degradation in tropical coral reefs and major losses in the marine aquaculture industry in the coastal China seas. ③ Sea level rise threatens the typical habitats of coastal wetlands such as mangrove and estuaries, and exacerbates coastal erosion, seawater intrusion and the impacts of typhoon, storm surges on the coastal flood disasters. ④ Human activities, such as large-scale reclamation, pollutant discharge, and over-fishing, have increased the exposure and vulnerability of China's marine and coastal ecosystems, leading to the low-aging and miniaturization of fishery types, decline of offshore fishery resources, reduction of coastal wetland areas, and degradation of biodiversity and ecosystem stability. ⑤ Under different climate scenarios such as low and high greenhouse gases emission scenario (RCP 2.6 and 8.5), as the warming and sea level rise in the coastal China seas continue, extreme sea level (ESL) events will occur more frequently, e.g., by the end of this century, the current once per century ESL events will become annually or even annually less (RCP 8.5) in many coastal areas, such as at Lvsu and Xiamen tidal gauge stations; and the ESL events could pose serious risks on the coastal areas. Finally, the article further discusses the adaptation measures and related uncertain issues to address climate change in the coastal China zones and seas, and puts forward relevant countermeasures and suggestions in order to reduce its negative impacts on the sustainable development of human community.

1. Introduction

Since the industrial revolution, human activities have discharged a large amount of greenhouse gases (GHGs) such as CO₂, CH₄, and N₂O, into the earth's atmosphere. The oceans, which account for ~71% of the earth's surface area, have absorbed approximately 93% of the extra heat generated due to the greenhouse effect (IPCC, 2014). The global oceans have significantly warmed and global mean sea level (GMSL) has obviously been rising. Since the 1990s, the rate of global ocean warming has doubled; since the 21st century, the rise in GMSL has accelerated, and extreme events, such as strong typhoon (hurricane)-storm surges, extremely high temperature, marine heat waves (MHWs), and heavy rain, have distinctly increased, which pose a serious threat to the health of global marine and coastal ecosystem and the sustainable development of coastal economy and society

(Bindoff et al., 2019; Collinins et al., 2019; IPCC, 2019; Oppenheimer et al., 2019; Cai et al., 2020; Yu et al., 2020). China has more than 18,000 km of continental coastline, ~4.73 × 10⁶ km² marginal seas such as Bohai Sea, Yellow Sea, East China Sea, and South China Sea (SCS) (Feng et al., 1999), wide shallow sea continental shelf, many estuaries, bays and coral reefs, rich and diverse marine life, and many important fisheries and fishery aquaculture areas. The coastal areas, which only account for 14% of China's total land area, comprise more than 42% of the total population and more than 60% of the gross domestic product (GDP) (Cai, 2010). The low-altitude coastal areas vulnerable to sea-level rise and typhoon-storm surges cover an area of 126,000 km². Therefore, the sustainable development of the coastal economy and society faces great challenges from climate change (CC).

In 2017, the Chinese government initiated the compilation of the *Fourth National Assessment Report on Climate Change*, and assessed the

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impacts of CC on the coastal China zones and seas and associated risks and adaptation countermeasures. Based on the analysis of marine climate hazards and the latest published studies worldwide, this paper evaluates the impacts of CC on coastal China zones and seas. Furthermore, it assesses the risks ensued, analyzes and discusses some adaptation measures for and uncertainties in response to CC in the coastal China zones and seas. Also, it puts forward relevant countermeasures and suggestions to provide scientific basis for the response to CC and sustainable development of China's coastal economy and society.

2. Global and China's marine CC (MCC)

Observations show that the impacts of global warming (GW) have occurred in continents, oceans, and human society (Cai et al., 2020; IPCC, 2014). Since the 1950s, the GW trend on land and ocean surfaces has become increasingly significant, and the warming rate in the northern hemisphere is more faster than that in the southern

hemisphere. The warming rate in the eastern part of China and its adjacent sea areas exceeds the global average (*very high confidence*^①) (Cai et al., 2018). From 1958 to 2018, China's coastal seas (Bohai Sea, Yellow Sea, East China Sea, and SCS) continuously warmed rapidly, and the sea surface temperature (SST) increased by $\sim 0.98 \pm 0.19^\circ\text{C}$, much than the global ocean average temperature ($0.54 \pm 0.04^\circ\text{C}$). Notably, the Bohai Sea, Yellow Sea, East China Sea, and Taiwan Strait (hereafter referred to as the East China Sea, ECS) witnessed prominent warming, with a rate faster than that of the adjacent East China Sea land and other sea areas (Cai et al., 2017; Yan et al., 2020) (*very high confidence*). During winter and summer, SST in the ECS increases by $1.82 \pm 0.25^\circ\text{C}$ and $0.92 \pm 0.18^\circ\text{C}$, respectively, and the SST in the SCS increases by $1.11 \pm 0.18^\circ\text{C}$ and $0.79 \pm 0.12^\circ\text{C}$, respectively (Fig. 1) (Cai et al., 2017). The SST increment resulted in significant changes in phenology in China's offshore waters, especially in the ESC. Spring comes earlier, and autumn ends later (*robust evidence, high agreement*) (Cai 2010; Cai and Fu, 2018).

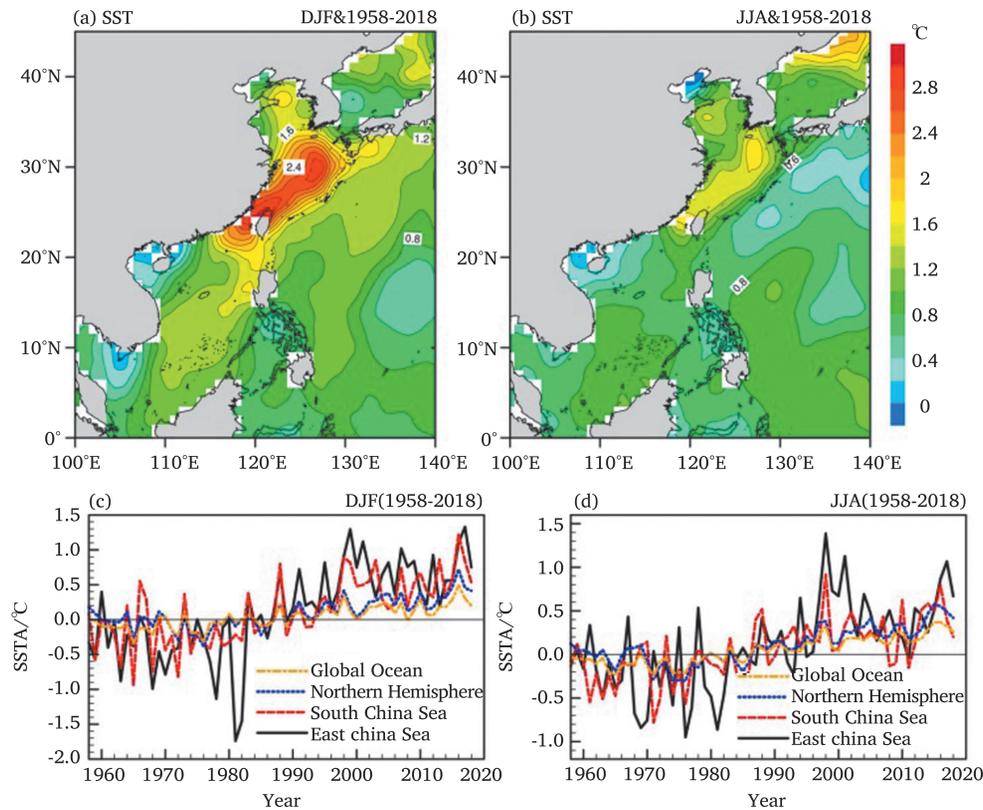


Fig. 1. (a) and (b) Linear rising amplitude ($^\circ\text{C}$). (c) and (d) anomaly time series ($^\circ\text{C}$) of SST in East China Sea (Bohai Sea, Yellow Sea, and East China Sea) and South China Sea in the winter and summer from 1958 to 2018.

Note: cited from Cai et al. 2017, updated to 2018 by HadISST^② data.

Under the GW background, the ocean keeps warming from the surface to deep layer, and the seawater expands when heated. Simultaneously, the terrestrial glaciers and ice sheets, which account for $\sim 10\%$ of the earth's surface area, melt continuously due to heat absorption (Oppenheimer et al., 2019). The freshwater coming from melting terrestrial glaciers and ice sheets flows into the ocean, increasing the

volume and mass of the ocean, which in 2006, exceeded the contribution of seawater thermal expansion to the sea-level rise. The sea-level rise is hence accelerated (*high confidence*^①) (Oppenheimer et al., 2019). From 1980 to 2019, the sea-level rise rate in China's coastal areas was 3.4mm/a , which was more than the global average level in the same period, and the regional variation characteristics were significant

^①This paper draws on the uncertainty assessment method in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2010). That is, according to the analysis and judgment of basic evidence and consistency (type, quantity, quality, and consistency of evidence), the uncertainties of key findings are evaluated, and special terms, such as “very low”, “low”, “medium”, “high” and “very high”, are used to express the level of confidence; “virtually certain, 99%–100% probability”, “very likely, 90%–100%”, “likely, 66%–100%”, “about as likely as not, 33%–66%”, “unlikely, 0–33%”, “very unlikely, 0%–10%”, “exceptionally unlikely, 0%–1%”, and other technical terms are used to indicate the level of likelihood. Such terms indicating the level of confidence and likelihood are typed in italics, e.g., *very high confidence* and *very likely*.

^②Hadley Centre Sea Ice and Sea Surface Temperature data set, HadISST.

(Ministry of Natural Resources, MNR, 2020). Also, the increment rate in local sea level in China's coastal areas is far more than the national average in the same period. For example, the relative sea-level rise rates of Lvsi in the vicinity of Yangtze River Estuary and Haikou tide gage station in Hainan Province exceed those of other areas (Fig. 2) (MNR, 2020; Yan et al., 2019). Since the 21st century, the frequency of super typhoons and storm surges affecting China has increased markedly (Qi

et al., 2019). Accordingly, the extreme water level and associated frequency have increased in coastal areas. Statistics show that from 2000 to 2019, there were 40 (super) strong typhoons landing in China, twice as many as that (18) from 1980 to 1999 (this study uses the data statistics of Tropical Cyclone Data Centre of China Meteorological Administration). Besides, the extreme water level along the coast has a noticeable upward trend (*very high confidence*).

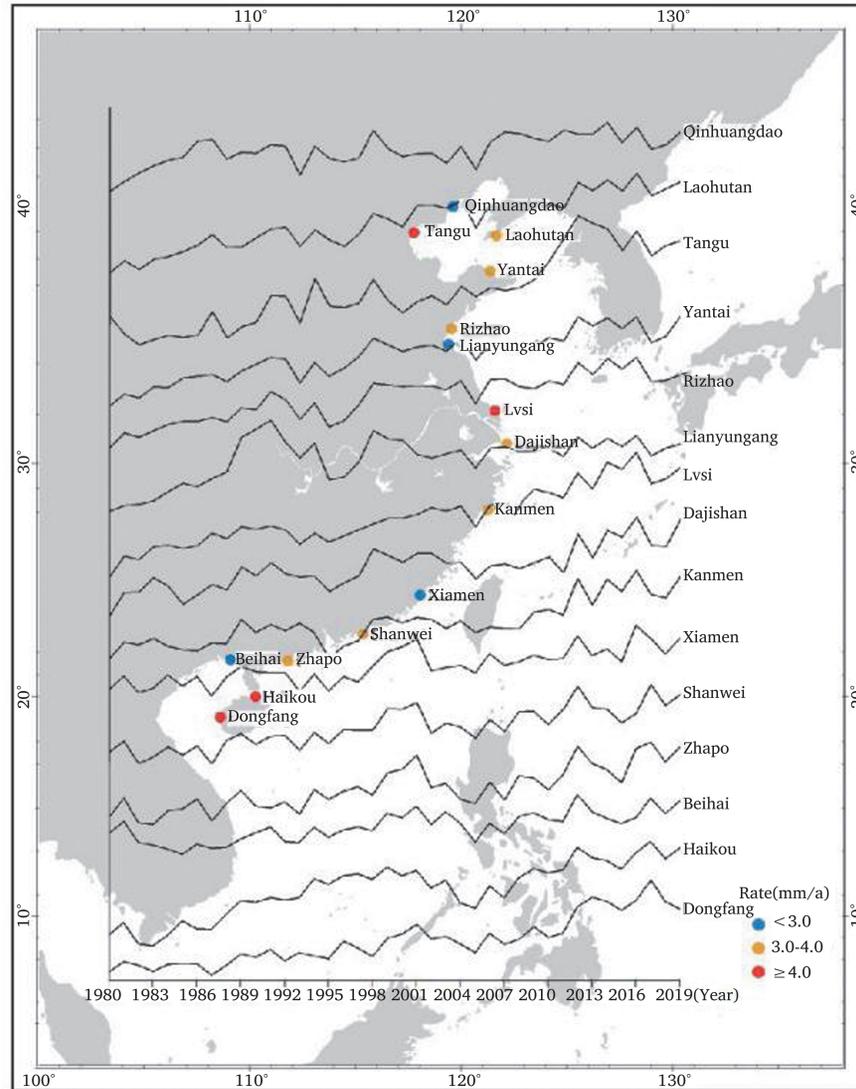


Fig. 2. Sea-level changes at major marine stations along China's coast from 1980 to 2019. Data Sources: cited from Ministry of Natural Resources of China, 2020.

The above analysis shows that under the GW background, the associated climate hazards of global and China's ocean warming, sea-level rise, and typhoon-storms have increased evidently (*very high confidence*).

3. Impact of CC on China's coastal zones and seas

3.1. On marine and coastal ecosystems

Since 1980, China's ocean warming has aggravated the imbalance of nutrient structure, seawater acidification, and the expansion of the low-oxygen zone, especially in the estuary of the Yangtze and Pearl Rivers and adjacent waters. Ocean warming has caused the phenology changes, affecting the biological growth and behavior, marine

species composition and distribution, and the outbreak of marine ecological disasters (*high confidence*) (Cai et al., 2010; Cai and Fu, 2018; Cai et al., 2020). Among them, the phytoplankton community structure has evolved distinctly, and the main dominant group remains the diatom. Because of the sea water temperature rise and the change in nutrient structure, the dinoflagellate/diatom ratio increases continuously, and ecological disasters, such as red tide, green tide, and explosive reproduction of large jellyfish, frequently occur in the ESC.

The outbreak frequency of red tide in the ESC shows an interdecadal increase (*very high confidence*) (Fig. 3), and the changes in red tide species demonstrate the evolution tendency of “diversification, harmfulness, and miniaturization” (Cai, 2010; Cai et al., 2016, Cai et al., 2020). Additionally, due to the combined effects of ocean warm-

ing and human overfishing, China's offshore fishery resources are seriously declining (*very high confidence*) (Li et al., 2009; Lin et al., 2010; Hu et al., 2015). Important marine fishery economic types are younger and smaller than before (*very high confidence*), which are particularly evident in Yangtze River Estuary, Zhoushan, and Bohai Bay Fishing grounds. The average body length of hairtails and small yellow croakers in the ESC decreased by 23% and 32%, respectively, and the breeding population changed from second-instar to first-instar fishes. Some important economic species' resources are nearly exhausted, and it is impossible to form fishing season for traditional economic species, such as small yellow croakers and hairtails (Li et al., 2009; Lin et al., 2010; Hu et al., 2015).

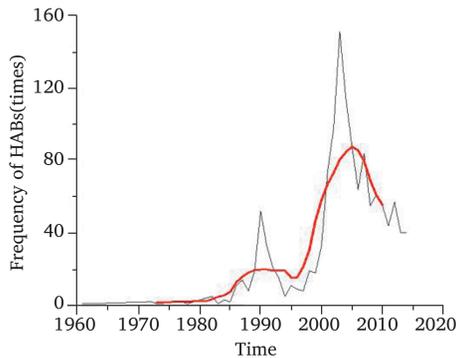


Fig. 3. Frequency of red tide in the East China Sea from 1960 to 2014.

Note: The thin line indicates the occurrence frequency of red tide, and the thick line is the 9-year running mean of that in the ECS (cited from Cai et al., 2016).

Recently, in China, typical coastal ecosystems, such as mangroves, coral reefs, and estuaries, have shown conspicuous climate vulnerability (*high confidence*) (Cai, 2010; Cai et al., 2016; Yan et al., 2019). The mangrove ecosystem faces the grave threat from rapid sea-level rise and increases in strong typhoons (Yan et al., 2019). The coastal coral reefs along the China's mainland and Hainan Island almost disappeared by 80%, and the hard coral coverage rate of atolls and islands in the SCS dropped from 60% to 20% (*medium evidence, high agreement*) (Hughes et al., 2013). Due to sea-level rise and human activities, such as land reclamation, China's coastal wetland areas have decreased sharply. The habitat degradation is severe, and biodiversity has declined; overfishing, large-scale engineering construction, and habitat degradation also lead to the loss of resilience and integrity of biological communities in important estuaries, such as the Yangtze River estuary. Therefore, the combined effects of marine climate-related hazards such as sea level rise, ocean warming, and human activities will increase the exposure and vulnerability of marine and coastal ecosystems, and decrease the ecosystem's stability (*high confidence*).

Under different climate scenarios (from low to high GHG emissions, RCP 2.6, 4.5, and 8.5), the global and China's oceans will be greatly further warming (*medium evidence, high agreement*). By the end of the 21st century, the warming range of the ECS and SCS will exceed 3.24 °C and 2.92 °C (RCP 8.5), respectively. They will become a region with the most remarkable warming in the global ocean warming (Tan et al., 2020). Acidification, anoxia, and nutrient imbalance in China's offshore waters will be aggravated, and coastal China level will further rise (*medium evidence, high agreement*) (Kulp et al., 2019; Wang et al., 2018; Chen et al., 2013; Xu and Cai, 2021), and the intensity, frequency and range of MCC hazards will further increase. This trend will result in more significant changes in the composition and geographical distribution of marine species, and even greater changes in the distribution pattern of marine living resources. For example, species continue to move northward, the outbreak of ecologi-

cal disasters, such as harmful red tide, green tide and large jellyfish is expected to increase, and coastal wetlands in estuaries, mangroves and warm-water coral reefs will be at risk of inundation or extinction (RCP 8.5) (Cai et al., 2020). The centers of major fishery resources, such as small yellow croakers and anchovy, in the ESC, will further move northward (Chen et al., 2013; Liu et al., 2018), and the important cold water species fishery resources, such as sand lance and Pacific cod, in the Yellow and Bohai Seas will further decline or even be depleted (Hong et al., 2020). Besides, the health condition of fishery ecosystems in the Yangtze and Yellow River estuaries will significantly decrease. It is projected that MHWs will occur more frequently by the end of the 21st century, and more than 90% of coral reefs in tropical waters may disappear (*medium evidence, high agreement*) (Bindoff et al., 2019; Cai et al., 2020).

3.2. On coastal economy and society

The coastal sea-level rise has intensified the impacts of salt tide intrusion in the estuary area, coastal erosion, and seawater intrusion in the coastal areas of China (*very high confidence*). Since the 1990s, ~22% of China's coastlines (coastlines of mainland, Taiwan Island, and Hainan Island) have retreated toward the land, and the lost land area has reached 224.48 km², among which the coastline of the Yellow River Delta has retreated obviously (Wu et al., 2014; Xu et al., 2018). In the past 30 years, the length of the eroded mangrove coast in Fangchenggang City of Guangxi Zhuang Autonomous Region has reached 4 km, and the maximum erosion distance is 122 m. From 2011 to 2015, the seawater intrusion distance in Hebei and Shandong Provinces and other plain areas bordering the Bohai Sea was 10 to 43 km, and the soil salinization was severe. Since 1990, the number of salt tide invasions in the Pearl River Estuary remains unchanged significantly, the duration tends to be longer; from January to March 2017, the maximum upstream distance of the salt tide in the Pearl River Estuary exceeded 50 km, which affected the water intake of the Nanzhen Waterworks in Zhongshan, Guangdong Province for 30 days (Li et al., 2019).

The sea-level rise at China's coasts also raises the basic water level of storm surges, which can easily cause serious flood disasters (*high confidence*) in coastal areas, particularly during the period of astronomical tides and heavy precipitation. In October 1999, when Typhoon "Dan" hit Xiamen City, Fujian Province, it coincided with a high astronomical tide, the largest surge increase and heavy precipitation. Under the combined effects of strong onshore winds, heavy precipitation, huge waves, high astronomical tides, and rapid currents, the 1160 m long embankment in Xiamen City was damaged, and the coastal blocks were flooded. More than 700 people were killed or injured (Yang et al., 2001; Xu et al., 2021). In October 2013, the strong Typhoon "Fitow" hit Fujian Province and Zhejiang Province, resulting in 12.16 million people being affected by the disaster and economic losses of ~63.14 billion RMB (*China Meteorological Disaster Yearbook 2014*). Seventy percent of the Yuyao City, Zhejiang Province, was flooded and waterlogged for several days, with 830,000 people affected by the disaster (Wang et al., 2014).

Since the 21st century, MHWs in the global ocean and China's offshore have increased (*very high confidence*) (Li et al., 2018); from 2016 to 2018, the SST and temperature in China's coastal areas culminated to the highest recorded values (*high confidence*) (Li et al., 2018; Tan et al., 2018), which caused great economic losses (*high confidence*) in the coastal areas. From July to August in 2018 alone, the MHWs affected 950,000 mu (1 ha = 15 mu) of sea cucumber culture in Liaoning coastal areas, causing an economic loss of 6.87 billion RMB. The annual total loss due to various marine disasters in China is as high as 10 billion RMB (the average annual direct economic loss is ~12 billion RMB), among which the total loss in 2005 was ~33.2 billion RMB (Fig. 4) (Qi et al., 2019). It is expected that the frequent MHWs in the future will probably bring greater threats to the maricul-

ture industry.

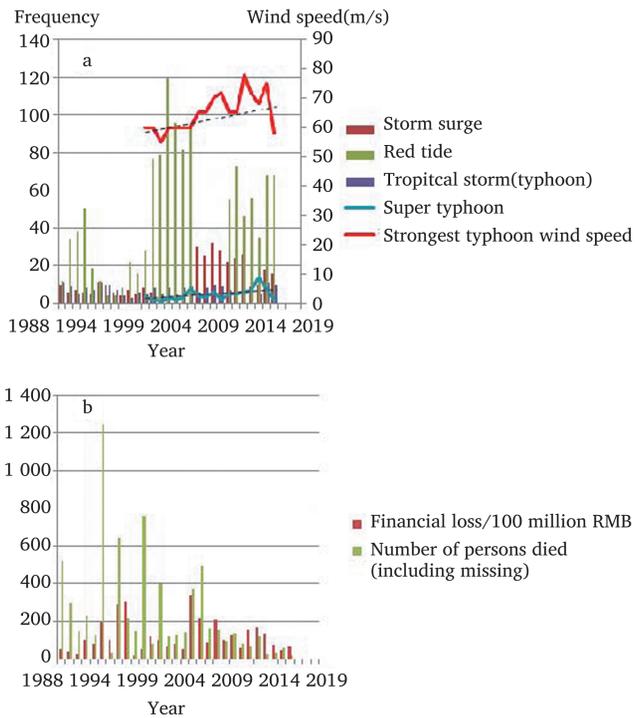


Fig. 4. Frequency of tropical storms (or typhoons), storm surges, and red tides affecting China's coastal areas from 1989 to 2017, and total loss of marine disasters.

Data Sources: cited from Qi et al.2019.

Studies have shown that the intensity of strong tropical cyclones (strong hurricanes and typhoons) has increased recently under the GW background and become frequent, posing a major disaster risk to many regions worldwide (Kossin et al., 2020). There are several (super) strong typhoons landing in the China's mainland, with stronger intensity and polar extension (*high confidence*) (Chen et al., 2018; Kossin et al., 2014; Mei et al., 2016). Under different climate scenarios (RCP 2.6, 4.5, and 8.5), the global climate is expected to be warming, and the sea level will continuously increase in the future. There will be much more stronger typhoons with stronger intensity. The locations where typhoons reach the maximum intensity or their landing place move northward (*medium evidence, high agreement*). There may be more and stronger typhoons landing in China, which would move northward. This situation may lead to more frequent exposure of coastal areas in northern China to strong typhoons and storm surges, and may further threaten the safety of infrastructures, such as nuclear power plants, coastal airports, port projects, flood control and drainage projects, and oil platforms, in coastal areas of China. The projection shows that the sea level worldwide and China's coastal areas will rise significantly in the future, and the return period of extreme water levels in many coastal areas will be shortened notably. By 2050, ~150 to 250 million people in the global coastal areas will live below the coastal high tide line. By 2100, the extreme water levels at the Lvisi tide gage station in the vicinity of Yangtze River Estuary and Xiamen tide gage station in Fujian Province that historically occurred once per century are projected to become the ESL events that occur once every few years and less than once every year, respectively (RCP 8.5) (Xu et al., 2021), which indicates that the extreme water-level change in the future is *very likely* to pose a more overwhelming threat to coastal areas and causes grave disaster risks.

To sum up, in the context of GW, the marine climate hazards (intensity, frequency, and range), such as global and China ocean warming, sea-level rise, typhoon-storm surges, and MHWs, have increased

significantly (*very high confidence*). Also, the exposure and vulnerability of marine and coastal ecosystems have increased (*high confidence*). Moreover, human activities, such as large-scale reclamation, pollutant discharge, and overfishing, have aggravated the impacts of marine climate hazards and increased the vulnerability of ecosystems (*very high confidence*). With the continuous GW and sea-level rise in the future, the sustainable development of China's marine and coastal ecosystems and coastal economy and society is *very likely* to face more serious CC risks.

4. Adaptation measures and uncertainty

4.1. Adaptation measures

Based on assessment of CC impacts and risks on the coastal China zones and seas, if only the current adaptive capacity is maintained, by 2050, five coastal cities in China (Guangzhou City, Shenzhen City, Tianjin City, Zhanjiang City, and Xiamen City) will be among the 20 coastal cities with the most losses in the world based on their average annual economic losses due to coastal floods (Hallegatte et al., 2013). Also, due to the coastal sea-level rise, most of the low-altitude areas along the Yangtze River estuary, such as Shanghai City, will be below the coastal high tide line (*medium evidence, high agreement*). Therefore, it is urgent to take more adequate adaptation measures (*high confidence*).

4.1.1. Strengthen the capabilities of ecological protection of coastal zones and seas and enhance the climate resilience of marine and coastalecosystems

“Land and sea coordination” must be strictly implemented to restrict the scale of reclamation, pollutant discharge, and overfishing, reduce the eutrophication of coastal waters and the frequency of ecological disasters, and boost the health of marine ecosystems. Also, the coordination enhances the capabilities of marine conservation areas and related protection and introduces dynamic conservation areas and fishing time according to the changes in marine and coastal phenology. Furthermore, according to “Nature based Solutions, NbS” and the principle of “natural restoration first, supplemented/supported by human intervention”, it is necessary to restore typical damaged marine and coastal ecosystems, such as damaged warm-water coral reefs and mangroves, and enhance their resilience to adapt to CC.

4.1.2. Promote the sharing of observation and investigation data and strengthen the planning and assessment of coastal climate disaster risk

Given the complexity of the impacts and risks of CC on marine and coastal areas, it is vital to improve observation data sharing, such as hydrology and tide stations, in coastal areas, strengthen the capabilities of climate models for coastal disaster risks and the predictability the impacts and risks of sea-level rise. In the development planning of coastal areas and the construction of major projects, it is important to strengthen the assessment of major climate disaster risks and improve the design standards of coastal projects and major coastal projects. Also, it is essential to improve the capability of early warning systems for extreme weather disasters in coastal areas, and strengthen the adaptation measures in coastal areas, such as damp coastal proof and flood control and drainage projects. Furthermore, it is necessary to increase the monitoring of runoff and sea-level change in the estuary area, and adopt the basin water resources control measure of “reduce (supplement) the flow at the peak (trough) of runoff, use the flow of fresh water to suppress the invasion of salt water” to ensure water safety in the upper reaches of the estuary area and alleviate the impact of sea-level rise.

4.1.3. Improve public awareness of participating in marine protection and fully mobilize society to address CC

We should actively publicize and improve public awareness of marine territory and awareness of actively participating in the protec-

tion of marine ecosystems in China. Also, a climate disaster insurance system in line with China's national conditions should be constructed, climate disaster risk prevention funds should be established, and rare super-large climate disasters in China should be handled. Furthermore, commercial catastrophe insurance should be actively promoted, and regional catastrophe insurance should be implemented according to the actual situation in different regions to fully meet the needs of differentiated regional protection. Additionally, a catastrophe response strategy of “hanging together when one of us is in trouble” should be developed, and the economic and social resilience of coastal areas should be improved comprehensively to address the catastrophe.

4.1.4. Develop comprehensive strategy in actively responding to CC, ecological civilization construction, and disaster prevention and mitigation

For densely populated and economically developed coastal areas, the following are strongly suggested: active avoidance, strengthening protection and effective disaster reduction, design specification improvement for coastal engineering protection, and strengthening the construction of engineering protection facilities, such as coastal dams; for sparsely populated areas, further measures that are strongly recommended include: employing relocation, evacuation and other adaptation measures, and reduction in the construction of engineering revetment facilities to facilitate the adaptation of coastal ecosystem. Also, while strengthening the supervision and management of reclamation, the coastal wetland habitat and marine environment should also be protected, ecological shoreline restoration and comprehensive improvement should be performed, and the construction of marine ecological civilization should be promoted. Furthermore, while strengthening the construction of embankment protection projects in reclamation areas, the monitoring of land subsidence and elevation changes of embankment facilities should be strengthened, exploitation of groundwater and land subsidence in coastal areas should be controlled, and the impact of sea-level rise should be reduced. Also, a dynamic management systems of comprehensive economic and social risks in coastal areas should be built to reduce the comprehensive risks arising from CC and ensure the stability and sustainable development of the coastal economy and society.

4.2. Discussion on uncertainties

Recently, several actions have been implemented in China's coastal areas to address CC. Also, various adaptation measures have been adopted, such as setting up nature reserves, fishing season, and ecological red line systems in the coastal zones and seas, which help in coping with the impacts of extreme climate disasters. However, great uncertainties exist in the occurrences and impacts of future ocean warming, sea-level rise, and extreme weather disasters in future, which result in the corresponding difficulties and risks in decision-making. For example, although decisions can still be made on the following adaptation countermeasures, many challenges (*very high confidence*) still exist, as presented below.

(1) Timely adjusting relevant decisions and adaptation measures by fully considering the risk tolerance and uncertainty of stakeholders. Decisions and adaptation measures with higher risk tolerance may adopt a smaller uncertainty range (i. e., the possible variation range of potential impact and intensity of disaster risk). In contrast, those with lower risk tolerance must consider a larger uncertainty range (*high confidence*).

(2) By considering the costs fully, benefits and trade-offs of adaptation, countermeasures, such as land-use planning, infrastructure investment, strengthening seaward coastal engineering protection, or taking the initiative to relocate and evacuate landward can be implemented to deal with the impacts of sea-level rise and extreme events (*high confidence*).

(3) Presently, many measures based on ocean mitigation or treatment, such as ocean alkalization and fertilization and other measures

to reduce acidification, may increase the adverse ecological risks, or result in the return of the previously removed biological carbon to the atmosphere after some time. However, the carbon storage protection of the coastal “blue carbon” can only offset ~2% of the current GHG emissions, indicating a limited alleviation effect (*high confidence*) (Bindoff et al., 2019).

5. Conclusion

Based on the academic literatures published since the *Third National Assessment Report on Climate Change* issued by the Chinese government in 2015, as well as authoritative climate change assessment reports at home and abroad (IPCC, 2014, 2019), this paper adopts the uncertainty treatment method of the *Fifth Assessment Report* of the IPCC (2010), analyzes and evaluates the changes in major marine climate hazards worldwide (China inclusive) since the middle of the 20th century. Furthermore, the impacts and risks associated with climate change are assessed for the coastal China zones and seas, and the adaptation options are discussed. The main conclusions are as follows:

(1) In the context of GW, the marine climate hazards in the global ocean and coastal China zones and seas have significantly increased (*very high confidence*).

(2) CC has caused obvious anomalies in China's marine and coastal ecosystems. The climate exposure and vulnerability of marine and coastal ecosystems are increasing (*high confidence*), including changes in marine species' composition and geographical distribution, degradation of ecosystems, frequent occurrence of ecological disasters, severe decline in fishing resources, and worsening of coastal erosion and seawater intrusion. Simultaneously, CC has seriously affected the sustainable development of the economy and society in coastal areas and brought serious risks (*high confidence*).

(3) Human activities, such as large-scale reclamation, pollutant discharge, and overfishing, have increased the vulnerability of marine and coastal ecosystems and aggravate the impacts and risks of CC (*high confidence*).

(4) In the different climatic scenarios, especially in the scenario of high GHG emission (RCP 8.5), China's marine and coastal areas are projected *very likely* to face more serious and comprehensive CC risks. Thus, it is important to adopt more adequate adaptation measures to mitigate the impacts and risks of future CC (*high confidence*). However, the economic society in coastal areas still face several challenges (*high confidence*) in policies, mechanisms, and actions, which requires further research and practices to improve the adaptation and mitigation in addressing CC.

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