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SPECIAL TOPIC ON REGIONAL CLIMATE CHANGE IMPACTS AND ADAPTATION

A Review of Assessment and Adaptation Strategy to Climate Change Impacts on the Coastal Areas in South China

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Abstract

This paper reviews assessment of climate change impacts on economy, society and ecological environment in the coastal areas of South China based on published literatures; it also proposes suitable adaptation strategies and countermeasures. Review shows that climate change has resulted in sea level rise in the coastal areas of South China, increasing the occurrence and intensity of storm surges, aggravating the influence of saltwater intrusion, coastal erosion, urban drainage and flood control, threatening the coastal facility and infrastructures, inundating lowland areas, offsetting mudflat silting, and degrading mangroves and coral reef ecosystem. Therefore, in order to reduce the adverse effects of climate change and to support the sustainable development in the coastal areas of South China, it is critical to improve the monitoring and early warning system, enhance prevention criteria, fortify coastal protection engineering, strengthen salt tide prevention, and reinforce the ecological restoration and protection.

Keywords: climate change; sea level rise; coastal areas; impact assessment; adaptation strategy

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1 Introduction

South China (3°30′–26°24′N, 104°26′–120°05′E) is located at the southern end of Eurasian continent and faces the South China Sea, consisting of Guangdong, Guangxi and Hainan provinces. Along the over 7,000 km coastlines, there are abundant resources, dense population, huge economic output, and countless national strategic facilities in South China, making it one of the most vulnerable areas to climate change in the Chinese coastal areas [*ECSCNARCC*, 2011].

The IPCC Fourth Assessment Report (AR4) [*IPCC*, 2007a] shows that global climate has undergone a significant warming change: observations demonstrate that the global mean temperature has in-

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creased 0.74°C during the past century (1906–2005), and the warming has even accelerated at 0.13° per decade during recent 50 years. Climate warming makes terrestrial ice/glacier melt and seawater thermally expand, resulting in global sea level rise. The global mean sea level has risen at an average rate of 1.8 mm per year since 1961. Climate change and sea level rise have brought out and will continue to bring out a series of adverse effects on environmental evolution and socio-economic development in coastal regions [*IPCC*, 2007b].

Different regions have different warming rates and sea level rise rates [*Fu et al.*, 2003; *Dong et al.*, 2010]. Under the context of global warming, air temperature in South China increases significantly as well with a rate of 0.16°C per decade during the beriod 1961–2010 [*Du et al.*, 2013]. Climate change accelerates regional sea level rise, exacerbates storm surge and coastal erosions, diminishes the function of flooding-prevention engineering and port infrastructures, aggravates the difficulty of coastal urban flooding drainage and preventions, and deteriorates qualities of water resource and coastal ecosystem. Therefore, it is of significance to assess impacts of climate change on the coastal areas in South China, thus putting up suitable adaptation strategies and countermeasures for regional disaster prevention and mitigation, utilization of natural resources, ecology and environment protection, and sustainable development.

2 Climate change impacts on the coastal area in South China

2.1 *Sea level rise*

In the last 30 years, the mean sea level in the South China Sea, within Guangdong, Guangxi and Hainan provinces, has an increase rate of 2.6 mm per year, similar to the national level but higher than the global level (1.8 mm per year), mostly due to the impacts of global warming and coastal land subsidence. In the next 30 years, the sea level in the South China Sea is projected to be one of the fastest increasing areas worldwide, rising 78–130 mm relative to 2010 for the entire area, and 84–149 mm for Guangdong province, 78–116 mm for Guangxi province, and 85–132 mm for Hainan province, respectively [*SOAPRC*, 2011].

2.2 *More and intensified storm surges*

The coastal area in South China is one of severe areas of storm surges in the nation. Sea level rise and enhancing intensity of tropical cyclones [*Du et al.*, 2013] lift up the base water level of storm surges, resulting in higher peak level of storm surges and increasing coastal water depth, and further intensify the wave force of storm surges and aggravate coastal risk. The peak level of storm surges has risen by 0.76 m at Zhanjiang Port in Guangdong province since the 1960s. Percentage of strong tide ($\geqslant$ 2 m above the local mean sea level) was 4.8% in the 1950s, 7.6% in the 1960s, 10.6% in the 1970s, and 11.8% in the 1980s [*Huang et al.*, 2000]. The frequencies of strong storm surges during 1996–2005 were 2.5 times as that of 1949–1995 in the coastal areas of Guangdong [*Chang et al.*, 2008]. If sea level rises by 30 cm, the return period of severe tide disaster ($\geqslant$ 1 m above the local warning level) would shorten 50%–60%. If sea level rises by 1 m, the present constraining water level at the Chiwan tide gauge station in the Pearl River Estuary, which is designed for the highest tide water level of a 100-year return period, will be lower than that of a 10-year return period, and the highest tide water level for a 50-year return period will be higher than the local standard designed for the maximum highest water level [*Huang et al.*, 2000].

2.3 *Severe saltwater intrusion*

Saltwater is a phenomenon that the water in the lower course of a river in an estuary becomes salty when the river freshwater discharge is low in a dry season (typically in winter) and sea water moves upstream, usually worsened by the tide-flowing. Due to sea level rise and climate warming, the tide level increases; together with increase of precipitation temporal variability and decrease of freshwater discharge, the saltwater intrusion in the Pearl River Estuary is worsening. Saltwater has occurred 9 times in winter since 1989 in the Pearl River Estuary, with 10–15 km farther and 15–20 d earlier. Five of them were severe, three in

2003 and one in 2004 and 2005, respectively. In the fall of 2003, the chloride concentration at Dongchong water station in Guangzhou was once over 12,000 mg L^{-1} (the upper limit of chloride concentration in drinking water is 250 mg L^{-1}). The chloride concentration of river water at the Guangchang pump station, which supplies fresh water for Macao and Zhuhai, exceeded the criteria for consecutive 38 days during the period 2005–2006.

The influence of saltwater intrusion has expanded from agriculture to industry, residential life and ecological environment. When the sea level rises by more than 10 cm, saltwater intrusion in dry season will affect Guangzhou, Zhongshan, Zhuhai, Hong Kong, and Macao, etc., further threatening the urban and rural water supply security. When the sea level rises by 10 cm, 30 cm, and 60 cm, the contour line of 250 mg L^{-1} (chloride) will move upstream of 1.1 km, 2.0 km, and 3.1 km respectively at the Hengmen Estuary in the Pearl River if 97% is upstream flow, i.e., 1,430 m^3 s^{-1} at Makou gauge station; it will move upstream 0.9 km, 1.0 km and 1.9 km if 90% is upstream flow, i.e., 1,861 m^3 s^{-1}; and 0.7 km, 0.8 km and 1.7 km respectively if 50% is upstream flow, i.e., 4,879 m^3 s^{-1} [*Kong et al.*, 2010].

2.4 *Exacerbated problems in urban drainage and flood control*

Sea level rise increased the tide level as well, leading to a slight increasing trend of water level in Pearl River Estuary [*Jiang et al.*, 2012], diminishing the function of flooding-prevention engineering and port infrastructures, and exacerbating problems in coastal urban flooding drainage and urban flooding. The elevation standard of sewage outfall in Guangzhou was 1.73 m (Pearl River Datum) in the 1950s, changed to 2.07 m in the 1980s, increased to 2.50 m in the 1990s, and became 2.75 m in the early 21st century. However, the maximum water level was higher than 2.96 m in the 1990s. In actualities, it will cause severe problems in Guangzhou once the water level in the Pearl River exceeds 1.8 m.

The sewage outfall elevations of Shenzhen and Zhuhai are 1.20 m and 1.24 m above their local mean sea levels, respectively. Both are tens of centimeters lower than their local highest tide level, and there are about 12% (Shenzhen) and 11% (Zhuhai) of times when the cities need pumps for sewage/flooding water drainage each year. Water logging frequently occurs in both cities once there are heavy rains during high tide period. If a flood is defined as that when the mean water level in the river is higher than the predefined outfall elevation, the flood will increase from the present 7%–11% to 9%–14% in the Pearl River Delta when sea level rises by 30 cm [*Huang et al.*, 2000; 2003]. When the sea level rises by 50 cm, the 100-year highest tide level (3.47 m) will become a 20-year one (3.49 m) near Guangzhou, and the flooding control infrastructures designed for a 50-year return period will be good for only a 10-year return period [*Yang and Shi*, 1995].

2.5 *Endangered infrastructures and inundated low-land areas*

Sea level rise enhances the intensity of waves, which increases the probability that waves surge over buildings in port and threatens the safety and working life of coastal infrastructures (such as dock and embankment). Meanwhile, sea level rise increases the coastal water level, reducing the original design criteria of infrastructures and increasing the frequency of flood. For instance, the elevation of a dock, constructed on Dawanshan Island in the Pearl River Estuary in the 1950s, is 1.5 m above local mean sea level; however, the highest tide levels in 6 years during 1984–1993 were higher than 1.5 m. To the 2 km northwest of this dock, there is another pier dock for fishery designed 1.8 m above local mean sea level in the 1960s. But it was inundated by the highest tide level in one third of years by the 1980s [*Huang et al.*, 2000]. Furthermore, the designed highest tide level at several key coastal factories and facilities, such as Daya Bay Nuclear Power Plant, Huangpu Port, Macao International Airport, Huilai Power Plant, have been exceeded by the observed maximum high tides several times at a range of 0.79 m to 2.55 m [*Huang et al.*, 2000; 2003].

Sea level rise will inundate large areas of low-land farmland, salt fields, industry sites, port facilities, villages and even urban areas, forcing population migration and industrial transfer, and impacting the social and economic sustainable development of coastal areas more and more severely. Most areas in the Pearl River Delta are less than 1 m above local sea level, and about 13% of the land area is below local mean sea level [*Dong et al.*, 2010]. If sea level rises by 1 m, 15 counties or cities in the Pearl River Delta will be inundated when a 5-m storm surge occurs. The severe areas are Foshan, Zhongshan, Guangzhou, Zhuhai, and Jiangmen. Particularly, 43% of the land area and 67% of the population in the city of Foshan will be submerged. The flooded GDP of Foshan, Zhongshan and Guangzhou will account for 52.3%, 41.2% and 36.7% of their total GDP, respectively [*Wang et al.*, 2011]. According to the relevant data derived from the Development and Reform Commission of Guangdong province, there were 321 major infrastructure and industrial projects in Guangdong province in the last five years (from * to *), and 260 of them are located in the coastal areas, accounting for 80.9%. Sea level rise will produce more and more adverse impacts on the coastal social and economical development.

2.6 *Offsetting mudflat silting*

Mudflat is important reserved land resource in the coastal areas of South China. There are three major up streams of the Pearl River Estuary, i.e., West, North and East Rivers, bringing up the annual mean sediment by 88.72×10^6 t to the Pearl River Delta, and 80% of which entering the off shore. The rest of the sediments, annually about 18.00×10^6 t, are deposited to form mudflats in the Pearl River Delta [*Cui,* 2004; *Chen et al.*, 2010]. Sea level descending can expose mudflat and increases its areas, and vice versa. Meanwhile, land claims for development greatly exceeds the natural deposition rate, dramatically reducing mudflat area in South China. Mudflat area reduced over 20% in the Pearl River Delta in Guangdong province during 1970–2000, and over 10% in Guangxi province in 2000 versus 1955 [*Chen et al.*, 2010; *Huang et al.*, 2007]. Studies show that the rate of sediment silting is higher than sea level rise in the Pearl River Estuary. Thus, sea level rise will not produce a negative increase of mudflat area, but offset part of the increasing rate of sediment silting and reduce the natural growth of mudflat area. Without sea level rise, mudflat area in Guangdong province would increase 99.8×10^3 hm^2 in 2030. If sea level rises by 0.3 m, mudflat area will reduce 23.3×10^3 hm^2, resulting in a net mudflat area increase by 76.5×10^3 hm^2 [*Huang et al.*, 2000].

2.7 *Accelerated coastal erosion*

The total length of erosional coastline in Guangdong province is 736 km, accounting for about 18% of the total national coastline. With sea level rise and the intensified typhoons and storm surges, the coastal erosion has been more and more obvious since the 1950s and intensified since the late 1970s [*Zuo and Li*, 2008]. It was eroded 25 m (0.6 m per year) in the last 40 years (from * to *) along the Maxie Tongguling coastline in Zhanjiang, Guangdong province, 10–25 m during 1938–1978 along the Qing'anwan coastline at the south edge of the Leizhou Peninsula [*Huang et al.*, 2000], and 250 m (10.4 m per year) during 1976–2000 on the Beihai Silver Beach in Guangxi province [*Huang et al.*, 2011]. Along the Chikan village in Leizhou of Guangdong province, the erosion length was 300 m during 2003–2006, with mean and maximum erosion widths of 2 m and 5 m, respectively, and erosion area of 800 m^2. In recent years, coastal erosion was intensified, directly threatening the life and property safety of the local villagers [*SOAPRC*, 2011]. If sea level rises at 1.1 cm per year and the intensity of human activities was similar to that during 1976–2000, the coastal line of Beihai in Guangxi province will be eroded by 225 m in 2020, 674 m in 2060, and 1,136 m in 2110 relative to that in 2000 [*Huang et al.*, 2011]. If sea level rises by 0.3 m, the design elevation for wave protection in the coast areas of Guangdong must increase 0.23–0.27 m, the return period of severe tide disaster will shorten 50%–60%, mean highest tide level will increase 0.34–0.38 m, and wave and storms will aggravate the tidal erosion [*Huang et al.*, 2000]. The tidal erosion caused by a super typhoon was larger than that of all other normal tides and storms during an entire season, and the impacts of some severe erosion caused by a super typhoon can last several years [*Cai et al.*, 2008].

2.8 *Degraded mangrove and coral reef ecosystems*

Mangroves and coral reefs are widely distributed in the coastal areas of South China. Due to climate change and especially human activities, mangroves and coral reefs have been severely disturbed. During the 1950s–1990s, the mangroves in Guangdong, Guangxi and Hainan provinces reduced over 65%. Of the existing mangroves, the majority is secondary forest, and only a small part is virgin/natural forest. There were 37 species of mangroves in Hainan province in 1988; however, less than 27 can be found at present, even some of them are endangered species, such as *Sonneratia hainanensis, Lumnitzera littorea*, and *Heritiera littoralis*. Meanwhile, about 80% of coral reefs in the coastal areas of Hainan has been destroyed since the 1950s. Among the 81 hermatypic coral reefs at Luhuitou Bay in Hainan, 30 of them cannot be found locally. There were 21 genera and 45 species coral reefs in Hezhou Island of Guangxi in 1987, but only 14 genera and 16 species were found in 2001 [*Han et al.*, 2006]. There are different levels of coral bleaching and death in the three provinces of South China [*SOAPRC*, 2009]. In the future, the rising temperature may result in the composition change of the mangrove species. A certain degree of temperature rise is advantageous to the growth and development of mangroves, but extremely high temperature is unfavorable to the sprout of leaf and its photosynthesis [*Ellison*, 1994]. The optimum leaf temperature range of photosynthesis for mangroves is 28–32°C. When the leaf temperature ranges from 38°C to 40°C, the photosynthesis is close to zero [*Clough et al.*, 1982; *Andrews et al.*, 1984]. The pattern of rainfall can affect mangroves by changing the salinity of soil or water [*Lu et al.*, 1995]. When the rate of sea level rise is faster than the deposition rate of substrate of mangroves, the mangrove will be threatened or even die. Fortunately, studies show that the silting rate of sediment in the coastal shoal of Guangdong province is faster than the sea level rise, so sea level rise doesn't have significant impacts on the survival and distribution of the most mangrove species. However, in other areas with less sediment sources and lower silting rate of sediment, sea level rise still has adverse impacts on mangroves. In addition, the increase of inundated frequency and the enhancement of wave intensity can make mangroves degenerate, die and not regenerate naturally [*Zhang*, 2001].

Coral reefs are sensitive to water temperature variations and difficult to survive in the sea water above 30°C. A 2–3°C increase in sea surface temperature will have serious impacts on coral reefs. This is because that a large number of *Symbiotic zooxanthella*, which lives with and provides nutrition for coral reefs, will leave or die as the water temperature rises. The annual mean surface air temperature is projected to increase 1.9–3.4°C in the Pearl River Basin by the end of the 21st century. At that time, many coral reefs will face a serious threat because the sea surface temperature will be at or near their growth temperature threshold [*Yu et al.*, 2004]. Along with the mean air temperature rise, heat events (daily mean sea surface temperature $\geqslant$ 30°C and lasting 10 days) in the Pearl River Estuary, will increase as well, increasing the probability of coral community bleaching and death [*Zheng et al.*, 2008]. Meanwhile, the growth rate of coral reefs is close to sea level rise in the coastal area of South China, so the increasing of sea level will have little effect on coral reefs from this aspect [*Li*, 2011].

3 Adaptation strategy

(1) Improve the monitoring and early warning system and reduce the adverse effects of climate change. It is critical to optimize the monitoring and forecasting system on marine disasters, particularly on storm surge, sea wave, sea fog, red tide, sea level rise, etc., and to improve the emergency scheme and response procedures. Meanwhile, it is also necessary to implement a comprehensive evaluation on the impacts of sea level change on the coastal areas in order to properly understand the regional vulnerability, the scope and degree of the impacts from sea level rise and climate change.

(2) Enhance prevention criteria and fortify coastal protection engineering. It is essential to enhance the design criteria of coastal levee projects, especially in

areas with weak protection capability in the Pearl River Delta. Meanwhile, it is vital to fortify the coastal protection engineering, such as inshore submerged dam, anti-scour dam and submerged dam, for firming beach, protecting dam and preventing coastal erosion. We must establish high standards for flood control, damp proofing wall and levees, optimize the urban sewerage system, and increase the drainage height in subsiding areas of coastal cities. In addition, for huge investing projects on resource and industry development in the coastal areas, we should consider the potential impacts of climate change and sea level rise in the future.

(3) Reinforce the ecological restoration and protection and establish marine ecological barrier. It is significant to reinforce the preservation engineering on marine ecosystem, such as mangroves, coral reefs and sea grass, and to upgrade a series of marine nature reservation areas. Meanwhile, it is necessary to establish coastal ecological barriers by constructing artificial reefs, planting mangroves and coastal shelter forest, etc., for the recovery of biodiversity and the enhancement of the ability to resist marine disasters and climate change.

(4) Strengthen the salt tide prevention and ensure the water resource security. It is the most critical for salt tide forecast to timely monitor the sea level changes and stream flow variations in dry seasons, especially during an astronomical high tide period. It is also decisive for saltwater prevention and mitigation to make full use of the large hydro-engineering and reservoirs in the entire Pearl River Basin by a basin-scale comprehensive planning and unified dispatching of water resources, thus releasing more freshwater to suppress saltwater in a dry season.

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References

Andrews, T. J., B. F. Clough, and G. J. Muller, 1984: Photosynthetic gas exchange properties and carbon isotope ratios of some mangroves in North Queensland. in: *Physiology and Management of Mangroves, Tasks for Vegetation Science*, Teas, H. J. Ed., Kluwer Academic Publishers, 15-23.

Cai, F., X.-Z. Su, J.-H. Liu, et al., 2008: Problems and countermeasures of China's coastal erosion under the background of global climate change. *Advances in Natural Sciences* (in Chinese), **28**(10), 1093-1193.

Chang, J.-X., C.-F. Huang, and X.-L. Liu, 2008: Geographical distribution and risk assessment of typhoon storm surge disasters in coastal regions of Guangdong province in 1949–2005. *Journal of Basic Science and Engineering* (in Chinese), **16**(3), 393-402.

Chen, X.-W., H. Zhao, and H.-R. Xu, 2010: Dynamic change of mudflat wetland resources in the Pearl River estuary based on DEM. *Yellow River* (in Chinese), **32**(9), 10-12.

Clough B. F., T. J. Andrews, and I. R.Cowan, 1982: Physiological process in mangroves. in: *Mangrove Ecosystems in Australia: Structure, Function and Management*, Clough, B. F. Ed., Australia National University Press, 193-210.

Cui, W.-Z., 2004: Study on protection of mudflat wetland in the Pearl River estuary. *Wetland Science* (in Chinese), **2**(1), 26-30.

Dong , S.-C., S. Tao, W.-Z. Yang, et al., 2010: Impacts of climate change on urban agglomerations in coastal region of China. *Advances in Climate Change Research* (in Chinese), **6**(4), 284-289.

Du, Y.-D., A. Hui, H.-L. Duan, et al., 2013: Changes in climate factors and extreme climate events in South China during 1961–2010. *Adv. Clim. Change Res.*, **4**(1), 1-11.

ECSCNARCC (Editorial Committee for Second China's National Assessment Report on Climate Change), 2011: *Second China's National Assessment Report on Climate Change* (in Chinese). Science Press, 710pp.

Ellison, J. C., 1994: Climate change and sea level rise impacts on mangrove ecosystem. in: *Impacts of Climate Change on Ecosystems and Species: Marine and Coastal Ecosystems*, Pernetta, J. Ed., IUCN, 11-30.

Fu, C.-B., W.-J. Dong, G. Wen, et al., 2003: Regional response and adaptation to global change. *Acta Meteorologica Sinica* (in Chinese), **61**(2), 245-249.

Han, J.-Y., X.-P. Huang, P. Shi, et al., 2006: Degradation trends, causes and protection measures of the coastal wetland in southern China. *Chinese Science Bulletin* (in Chinese), **51**, S102-S107.

Huang, H., J.-H. Chen, and Z.-N. Hu, 2007: Analysis on the characteristics of changeable intertidal zones along Guangxi coast in the late of 50 years. *Marine Sciences* (in Chinese), **31**(1), 37-42.

Huang, H., Z.-J. Dai, and K. Sheng, 2011: Coastal erosion and associated response to the sea level rise of Yintan, Beihai, Guangxi. *Journal of Oceanography in Taiwan Strait* (in Chinese), **30**(2), 275-279.

Huang, Z.-G., X.-D. Xie, J.-C. Fan, et al., 2000: *Guangdong Sea Level Changes as Well as Their Effects and Countermeasures* (in Chinese). Guangdong Science and Technology Press, 263pp.

Huang, Z.-G., W.-Q. Zhang, Q.-L. Chen, et al., 2003: Impacts of sea level rise on design parameters of coastal engineering in Guangdong province. *Scientia Geographica Sinica* (in Chinese), **23**(10), 39-41.

IPCC, 2007a: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Solomon, S. D. et al. Eds., Cambridge University Press, 996pp.

IPCC, 2007b: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Parry, M. L. et al. Eds., Cambridge University Press, 976pp.

Jiang, C.-J., Q.-S. Yang, Z.-J. Dai, et al., 2012: Spatial and temporal characteristics of water level change and its causes in the Pearl River Delta in recent decades. *Acta Oceanologica Sinica* (in Chinese), **34**(1), 46-56.

Kong, L., X.-H. Chen, J. Du, et al., 2010: Impact of sea-level rise on saltwater intrusion based on mathematical model. *Journal of Natural Resources* (in Chinese), **25**(7), 1097-1104.

Li, N., 2011: Climate warming swallows coral reef? *Science and Technology Review* (in Chinese), **29**(7), 9.

Lu, C.-Y., P. Lin, Y. Ye, et al., 1995: Review on impact of global climate change on mangrove ecosystems and research countermeasure. *Advance in Earth Sciences* (in Chinese), **10**(4), 341-347.

SOAPRC (State Oceanic Administration People's Republic of China), 2009: Report on the marine environment quality in China in 2008 (in Chinese).

SOAPRC (State Oceanic Administration People's Republic of China), 2011: Report on the state of sea level in China in 2010 (in Chinese).

Wang, K.-F.-S., Z.-E Yin, and J. Yin, 2011: Analysis on typhoon-induced storm surge vulnerability of China's coastal areas on rising sea level background. *Journal of Tropical Oceanography* (in Chinese), **30**(6), 31-36.

Yang, G.-S., and Y.-F. Shi, 1995: Possible impacts of sea level rise on major projects and urban development in the coastal areas in China. *Scientia Geographica Sinica* (in Chinese), **50**(4), 302-309.

Yu, K.-F., M.-X. Jiang, Z.-Q. Jiang, et al., 2004: Latest forty two years sea surface temperature change of Weizhou lsland and its influence on coral reef ecosystem. *Journal of Applied Ecology* (in Chinese), **15**(3), 506-510.

Zhang. Q.-M., 2001: Status tropical biological coastal of China: Implications on ecosystem restoration and reconstruction. *Oceanologia Et Limnologia Sinica* (in Chinese), **32**(4), 454-464.

Zheng, Z.-Y., C.-L. Tang, S. Deng, et al., 2008: The potential threat of global warming on the growth of coral reef communities in the Pearl River Estuary. in: *The Fourth Session of the Guangdong, Hong Kong and Macao Symposium on Sustainable Development* (in Chinese), 354-357.

Zuo, S.-H., and B. Li, 2008: Marine disasters characteristics and its prevention measures in China over past 20 years. *Meteorology and Disaster Reduction Research* (in Chinese), **31**(4), 28-33.