



Spatial-temporal changes of coastal and marine disasters risks and impacts in Mainland China



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ABSTRACT

China is amongst the countries most severely affected by coastal and marine disasters. In this study, the annual variation and geographic distribution of the direct economic losses and fatalities caused by rapid-onset coastal and marine disasters in China have been analysed. This was based on a collection of historical documents and official records. The five main hazards include storm surges, rough seas, sea ice, red tides and green tides. The results show that: (1) Storm surges caused the most economic losses (92% of the total); (2) At national scale, direct economic losses induced by coastal and marine disasters fluctuated with no clear trend; the number of fatalities per year declined, and in relative terms both economic losses and fatalities decreased dramatically throughout time; (3) Substantial heterogeneity exists across the 11 provincial-level administrative regions in terms of the spatial pattern and temporal trends of coastal and marine hazards, exposure, vulnerability and observed impacts. Guangzhou, Fujian, Zhejiang and Hainan provinces experienced the highest direct economic losses and fatalities due to repeated typhoon-induced storm surges. The decline in adverse impacts caused by hazards is due to substantial progress in coastal and marine disaster prevention and migration in China, largely thanks to institutional measures, plus adaptation and mitigation actions at both national and regional levels. Coastal China still faces growing risks due to socio-economic development, climate change, as well as subsidence and new emerging marine disasters (e.g. green tides). Further management needs to promote integrated solutions across socio-economic development, disaster risk reduction and environmental conservation in coastal regions. This should happen at national and international levels as disasters can affect neighboring countries, and their marine environments and socio-ecological systems. Lessons may be learnt from countries experiencing similar problems over the long-term.

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1. Introduction

Coastal and marine disasters are caused by natural hazards, usually anomalies or extreme changes in the marine environment. They often result in serious damage to the environment, society,

economy, and livelihoods at sea or in coastal zones. According to EM-DAT,¹ several of the most devastating natural disasters in the 21st century have been coastal and marine disasters. The 2004 Indian Ocean tsunami led to 230,000 deaths in 14 countries; hurricane Katrina in 2005 caused total property damage of nearly US\$

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¹ A global disaster database which contains core data on the occurrence and effects of over 18,000 large disasters from 1900 to the present day. <http://www.emdat.be/database>.

Abbreviation

CMDFDC	Chinese Maritime Disasters Four Decades Compilation
CPI	Consumer Price Index
ETSS	Extra-tropical-induced storm surge
GDP	Gross domestic product
IPCC	Intergovernmental Panel on Climate Change
MDB	Maritime Disaster Bulletin
MEQB	Marine Environment Quality Bulletin
NBS	National Bureau of Statistics of China
NMEFC	National Marine Environmental & Forecasting Center of China
SOA	State Oceanic Administration of China
SST	Sea surface temperature
PSMSL	Permanent Service for Mean Sea Level
TC	Tropical cyclone
TSS	Typhoon-induced storm surge

108 billion (in 2005 prices) in the United States; the 2011 Tōhoku earthquake in Japan led to a series of cascading effects including triggering powerful tsunami waves, massive economic damage, as well as severe nuclear accidents and social instability (Guha-Sapir et al., 2015). All these disasters had global ramifications, such as disruptions in global trade and adverse impacts in the marine environment. Coastal zones are often characterised by high densities of population and economic activities, and are vulnerable to natural disasters and climate change (Kron, 2013; McGranahan et al., 2007; Neumann et al., 2015). As the current trend of urbanisation continues worldwide, it is expected that economic and population growth in coastal areas will continue to grow at a faster rate than inland (Seto, 2011; Small and Nicholls, 2003; Vafeidis et al., 2008). Climate change will likely further exacerbate those presently exposed, and this is likely to continue, jeopardising the long-term sustainability of coastal regions (Hallegatte et al., 2013; Hanson et al., 2011; Hinkel et al., 2014; Neumann et al., 2015). Without effective adaptation measures or policies to withstand or reduce risk resulting from extreme events, damage from natural disasters will continue to increase around the world's coasts.

Globally, China is one of the world's fastest growing coastal nations (Liu and Diamond, 2005). With the advantages of resources and economic development, coastal regions have become the most developed and populated areas in China (see Section 3.2). The coastal area of Mainland China is comprised of 11 provincial-level administrative regions (including one autonomous region: Guangxi, two municipalities: Shanghai and Tianjin, and eight provinces from north to south: Liaoning, Hebei, Shandong, Jiangsu, Zhejiang, Fujian, Guangdong, Hainan), which encompasses a wide latitudinal range from Liaodong Bay (at 41° N) to the South China Sea (at 4° N) (Fig. 1). Approximately 2% of China's land area is located in the low elevation coastal zone (the contiguous area along the coast that is less than 10 m above sea level) (Liu et al., 2015; McGranahan et al., 2007). These areas are affected by monsoon weather and extreme meteorological events, and are thus at risk of coastal and marine disasters. In recent decades, most regions in coastal China have experienced more frequent coastal and marine natural hazards, such as storm surges, marine ecological disasters and other meteorological/hydrological events (Feng and Tsimplis, 2014; He et al., 2015; Shi et al., 2015). These coastal and marine disasters threaten lives and livelihoods, properties, water resources and ecosystems. Additionally, rapid urbanisation leading to an

increase in population density, combined with the fast growth of the coastal economy and associated assets in China's coastal zones, makes coastal regions increasingly sensitive to natural disasters and climate change.

Various studies have focused on the intensity, frequency and trends of coastal and marine disasters (e.g. Adam et al., 2016), but most investigated either a single hazard or a country as a whole (e.g. Fischer et al., 2015; Shi et al., 2015; Yap et al., 2015). China's coastal region encompasses a wide latitudinal range with a high variability in climate, socio-economic and ecological conditions. Multi-hazard analysis at sub-national scale is necessary to fully understand the heterogeneity and dynamics of coastal and marine disaster risk and impacts across China. As yet, no such studies are known to the authors. Given China's fast economic growth, especially the recently expedited maritime activities (Zhao et al., 2014), it is crucial to determine (1) how coastal and marine disasters vary across Chinese coastal regions; (2) how these disasters have altered under changing climatic conditions; and (3) what policies, engineering or adaptation have been undertaken to reduce the potential risks of marine hazards and their associated impacts.

The aim of this study is to investigate the spatial-temporal changes of coastal and marine disasters and subsequent risks and impacts across Mainland coastal China at national and provincial level. This will be achieved through the following three objectives:

- To collate a state-of-art coastal and marine database noting the different types and occurrences of disasters;
- To analyse the spatial-temporal pattern of coastal and marine disaster risks, including hazard, exposure and vulnerability, and impacts at both national and provincial scales;
- To understand the observed trends from perspectives of policies, adaptation and regional differences.

The rest of the article is structured as follows. Section 2 describes the data and methods used. Section 3 presents the spatial-temporal patterns found in the data in terms of hazard (3.1), exposure (3.2), vulnerability (3.3) and physical impacts, economic losses and fatalities at both national and provincial scales (3.4). Section 4 explains the observed spatial-temporal patterns through the evolution of institutional arrangements, adaptation and mitigation actions and regional variations. Conclusions and recommendations are discussed in Section 5.

2. Data and method

To analyse coastal and marine disasters, official government statistics data were collected from three sources (Table S1). These were:

- Chinese Marine Disasters Four Decades Compilation (CMDFDC);
- Marine Environment Quality Bulletin (MEQB);
- Marine Disaster Bulletin (MDB).

CMDFDC was published by the National Marine Environmental & Forecasting Center of China (NMEFC) in 1991 (Yang et al., 1991). The remaining sources were issued by the State Oceanic Administration of China (SOA) (SOA, 1989–2014; SOA, 1998–2014). SOA has issued a series of bulletins annually to the public since 1989 to provide official statistical information about the development of the marine economy, marine environment and maritime disasters. This information is collected by marine administrative departments at various levels and provides first-hand information on how coastal and marine disasters affect the coastal economy and society.

In this paper, to assist the analysis, several other datasets were used alongside the disaster databases mentioned above. These

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