Marine hazards from 2000 to 2016 in Zhejiang province of the subtropical region, South China

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Abstract. Coastal and offshore regions are regarded as the key zones exposed to marine disasters. Zhejiang province, located on the verge of the East China Sea, is one of the provinces mostly affected by marine disasters that have brought serious economic losses and casualties. The data of marine disasters in Zhejiang province, which occurred during the period from 2000 to 2016, were selected and analyzed. The results indicate that (1) storm surge, wave, and red tide are the main kinds of marine hazards in the coastal region of Zhejiang province. (2) a total of 1,099 marine disasters occurred in the coastal region of Zhejiang province during 2000—2016, and resulted in about 275 deaths or missing with 18.544 billion yuan of direct economic losses. In addition, marine disasters are mainly distributed in Zhoushan City, Ningbo City, Taizhou City, and Wenzhou City of Zhejiang province.

1. Introduction
The eastern part of China is adjacent to the Bohai Sea, the Yellow Sea, the East China Sea, and the South China Sea. Rapid development of marine economy, rapid growth of population, and the continuous expansion of urbanization in the coastal zone lead to the frequent occurrence of marine hazards, which are drawing great attention [1]. Marine disasters mainly refer to the events that endanger society, economy, environment and life and property seriously caused by abnormal or drastic changes in the marine natural environment, including storm surge, wave, tsunami, red tide, coastal erosion, sea level change and seawater intrusion. These disasters mainly happen in China's coastal regions, including Liaoning, Hebei, Shandong, Jiangsu, Zhejiang, Fujian, Guangdong, and Hainan. Previous studies have indicated that marine disasters tend to produce different damages to varying degrees [2].

Zhejiang province, a large marine province with a total area of 260,000 km², is located in the south part of the Yangtze River Delta and along the East China Sea. It has experienced fast marine economic development, of which the total output value of marine economy has been increasing year by year [3]. By 2016, the total output value of marine economy in Zhejiang province reached 379 billion yuan [4-5]. However, Zhejiang province is also facing the most severe marine hazards every year, especially in recent years.

2. Data source
The data of marine hazards were mainly derived from Zhejiang’s Natural Resources and Environment Statistical Yearbook (2000—2017), China’s Marine Disasters Bulletin (http://www.soa.gov.cn/), Zhejiang’s Marine Disasters Bulletin, and Marine Environment Bulletin (http://www.zjoaf.gov.cn/).
3. Marine hazards in the coastal region of Zhejiang province

According to statistical data, a total of 1099 marine disasters occurred in Zhejiang province, and the direct economic loss reaches 18.544 billion yuan during 2000—2016. In 2004, the number of marine disasters and casualties were the largest. Moreover, the direct economic loss was the highest in 2012, reaching 42.67 billion yuan (Figure 1). On the other hand, four coastal regions were suffered the most serious marine disasters in Zhejiang province, that is, Zhoushan City, Ningbo City, Taizhou City, and Wenzhou City, causing irreparable economic losses (Figure 2).

![Figure 1. Occurrences of marine disasters and losses in Zhejiang province during 2000—2016](image)

Figure 1. Occurrences of marine disasters and losses in Zhejiang province during 2000—2016

In recent years, Zhejiang province witnesses marine hazards every year. Based on the bulletin of marine disasters in China and marine environment in Zhejiang province, there are three major types of marine hazards, namely, storm surge, wave, and red tide, which have caused many casualties and direct economic losses (Table 1).

![Figure 2. Spatial distribution of marine disasters in Zhejiang province](image)

Figure 2. Spatial distribution of marine disasters in Zhejiang province

| Type of marine hazards | Frequency | Casualty (people) | Direct economic losses (million Yuan) |
|------------------------|-----------|-------------------|---------------------------------------|
| Storm surge            | 34        | 58                | 18027.0                               |
| Wave                   | 699       | 374               | 76634.68                              |
| Red tide               | 428       | —                 | —                                     |

3.1. Storm surge hazard

The storm surge mainly refers to the phenomenon of local sea surface oscillation or non-periodic abnormal increase (decrease) due to the strong wind and sudden change of air pressure associated with the passage of storms, such as tropical cyclones, extra-tropical cyclones, and sea squall lines [6]. It is divided into two categories: temperate storm surge and tropical storm surge. Zhejiang’s storm surge disaster is depends on typhoon storm surge. The occurrence of storm surge has obviously changed monthly, and the disasters mainly occur in summer and autumn, namely from July to October [7].
According to statistical data from 2000 to 2016, storm surges in Zhejiang province occurred 34 times, and the direct economic loss amounted to 18.027 billion yuan. People who died or missed are more in 2004 and 2006, with the number of 22 and 32, respectively. But direct economic losses caused by this hazard reached a peak of 42.57 billion yuan in 2012. It was primarily depended on "Sea anemone", "Sura", and "Bravan" that resulted in the loss of aquaculture. This loss was the most serious in 2003, and the lowest was 0.01 billion yuan in 2010.

3.2. Wave hazard
Wave hazard is a phenomenon of sea surface fluctuation caused by wind that causes damages to marine engineering, facilities and production activities [8], mainly making up of wind waves and surges. Further, wave hazard is resulted in by tropical cyclones and cold air in Zhejiang province. The typhoon wave caused by tropical cyclone is the main reason for the direct economic loss, and the disastrous wave caused by cold air brings to casualties [7]. The average days of disastrous waves in Zhejiang province and adjacent sea areas were about 51 days, and the total loss achieved 467,346,800 yuan during 2000—2016. In 2011, there were 44 days of disastrous waves in the sea area of Zhejiang province. Moreover, the wave disaster caused damage to 6 ships, and 14 people died (including missing). The direct economic loss was 398.78 million yuan, which was the most serious in the past 16 years.

3.3. Red tide hazard
Red tide is an ecological abnormal phenomenon of discoloration of water body caused by the explosive proliferation or aggregation of some microalgae, protozoa or bacteria in a certain environment [9]. Zhejiang province belongs to subtropical climate, so the annual peak period of red tide is from May to July [8]. Red tide has become a serious global marine disaster, and it has increased in frequency and distribution worldwide [10]. From 2000 to 2016, red tides in Zhejiang province occurred 428 times, with a total area of 93,930.5 km². Red tides occurred 38 times in the coastal region of Zhejiang province in 2004, with a total area of over 16,000 km², which were the highest from 2000 to 2016.

4. Conclusion
Based on the above statistical data, marine disasters occurred frequently in Zhejiang province, causing severe marine economic losses and casualties during 2000—2016. And also, it can be seen that (1) wave disasters causing human losses are the main kind of marine disasters among marine disasters; (2) storm surge disasters take up a large part of direct economic losses; and (3) red tide causes relatively less casualties and economic losses.

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