



Special Issue

**Geohazards in Subduction Zone
Environments and their Implications
for Science and Society**

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Cover

Front: Largest Porites coral boulder in eastern Ishigaki Island, Okinawa, Japan, which was transported and deposited by the 1771 Meiwa tsunami based on the sedimentological observation and radiocarbon dating. This was designated as a national monument in Japan in 2013. Refer to the paper of Goto et al. in this issue. (Photo taken by Kazuhisa Goto)

Back: Northern view of Ontake Volcano summit area, where thickly covered by grey phreatic ash and ballistics. (Photo courtesy: Shun Nakano, GSJ, AIST on Sep.28, 2014). Phreatic eruption occurred at the southern part (upstream area of Jigokudani Valley; white plume area) of Ontake Volcano, central Japan at 11:52 on Sep. 27, 2014. The phreatic eruptions were continued for more than one hour and associated pyroclastic surges were observed. Thick accumulation of phreatic ash (up to 30 cm -1m in thickness) and a lot of ballistics (a few cm to m size) were observed at the summit area. The total discharged mass was about 1 million ton. This is the almost same discharged mass of the previous 1979 eruption. More than 500 climbers and hikers were on the summit area at the time of eruption, because it was noon of Saturday weekend. Totally 57 people, who were within about 1 km from the vent area, were killed mainly by the impact of ballistics. Six people are still missing (as of Nov 14, 2014). 69 people were injured. The number of victims is the worst volcanic disaster in Japan after the World War II. The front crater with a small pond is Ninoike and central crater is Ichinoike. The summit of Ontake Volcano, Kengamine (3,067 m a.s.l.), is seen at the left side of Ichinoike, where many people were dead and injured. (Shinji Takarada, GSJ, AIST)

by Ren Yefei, Wen Ruizhi and Song Yuying

Recent progress of tsunami hazard mitigation in China

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Since the disastrous aftermath of the 2004 Sumatra Tsunami (Indonesia) and the 2011 Tohoku Tsunami (Japan), China has made much effort to mitigate tsunami hazards. We briefly reviewed the progress of cataloguing, modeling, early warning and hazard analysis for tsunamis in China. Compiling a Chinese tsunami catalogue is a challenge at present due to a large number of inconsistent research results. In China, the numerical models widely used in engineering and related studies are developed by other countries, and the development of a domestic model is being funded by the Chinese government. The tsunami early warning system has been set up and used during the recent tsunami events, such as the Chile earthquake on February 27, 2010, and the Tohoku earthquake on March 11, 2011. Probabilistic tsunami hazard analysis (PTHA) in China has been used for the national zonation map. A test case of PTHA at Mirs Bay of South China was demonstrated. The test case supported the general view that a regional tsunami could be a great hazard to the south China coast.

Introduction

Recently, many large infrastructures have emerged along the Chinese coast, necessitating a rigorous tsunami risk assessment, because the Chinese coast cannot be immune to tsunami hazards. Therefore, China began to keep track of the potential tsunami hazards emanating from the Pacific Ocean after the 2004 Sumatra Tsunami. On March 11, 2011, the Japanese Tohoku Earthquake triggered a destructive tsunami that swept over cities and farmlands along the northern part of Japan and threatened coastal areas throughout the Pacific. This event led to a reconsideration of the safety of coastal nuclear power plant (NPP) sites and other infrastructures. There are 13 NPP sites along the coast of the Chinese mainland at present, with 15 nuclear units in operation and 26 units under construction (Chang et al., 2013). After the Japanese Fukushima NPP accident in 2011, which was caused by an earthquake and tsunami, Chinese NPP safety from extreme external events, including events beyond the design basis, such as tsunamis, was reevaluated. In addition, the coastal area is the most economically developed zone in China. Based on 1:100 m digital elevation models (DEM) and national GDP data in 2004,

the statistical analysis shows that 25% of the Chinese GDP is produced along the coastal areas at elevations below 5 meters (Chen et al., 2007).

The lessons from the 2004 Sumatra Tsunami and 2011 Tohoku Tsunami have increased the awareness of tsunami risks in China. In this paper, we briefly review the recent progress of tsunami hazard mitigation in the Chinese mainland, not including Taiwan and Hong Kong. This study focuses on a Chinese historical tsunami event catalogue, a numerical tsunami model, and tsunami early warning system as well as the tsunami hazard analysis methodology.

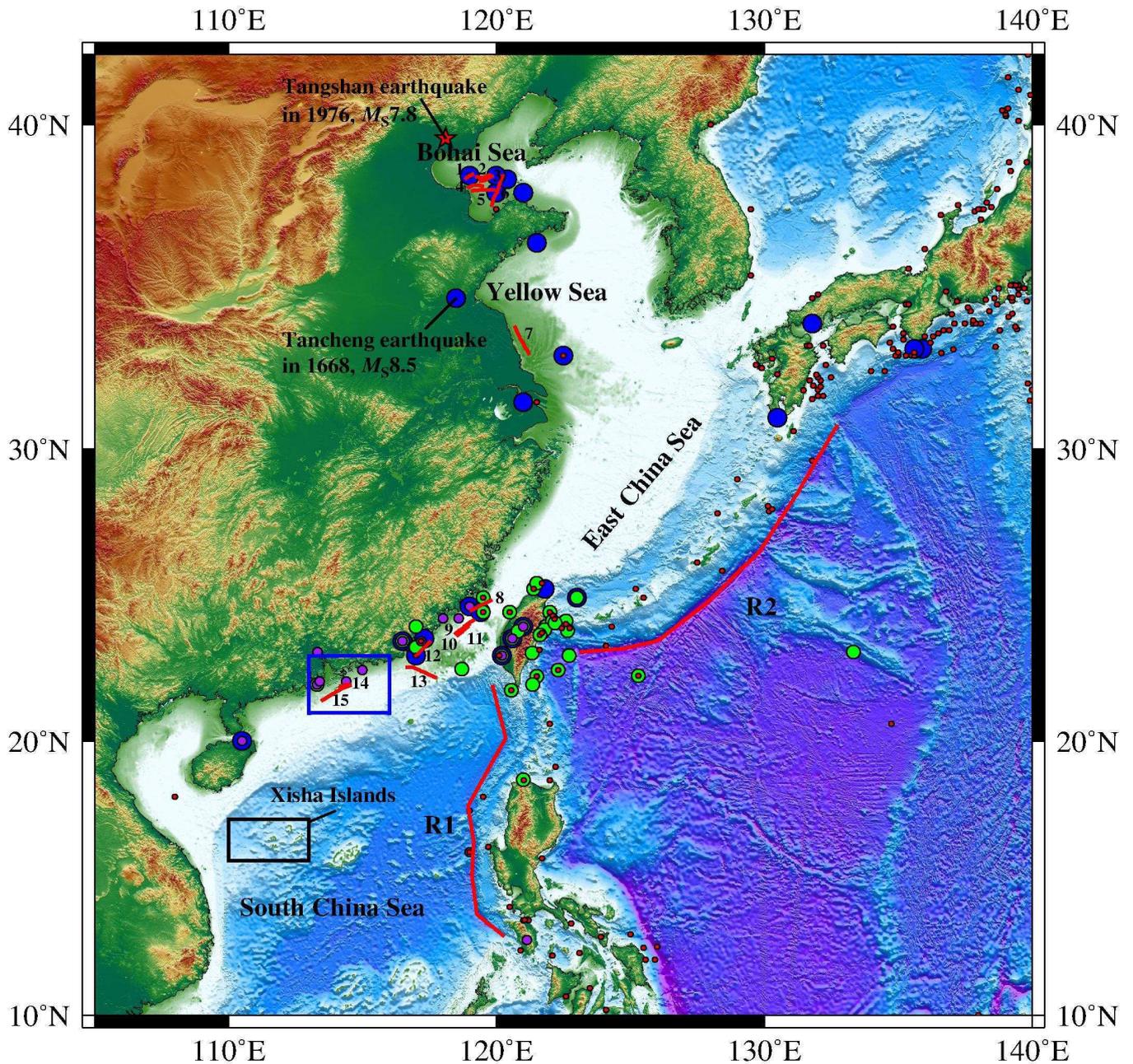
Chinese tsunami research before 2004

China is located at the eastern edge of Asia adjacent to the northwestern segment of the circum-Pacific earthquake belt. From north to south, the seas bordering China are the Bohai Sea, the Yellow Sea, the East China Sea and the South China Sea. In the Bohai and Yellow Seas, the average depth is 18 m and 44 m, with a maximum depth of only 100 m. However, in the East China Sea and the South China Sea, the average depth is 340 m and 1200 m, respectively, as shown in Figure 1.

The Great Tangshan Earthquake (epicenter is shown in Figure 1) on July 28, 1978, raised concerns about the exposure to natural hazards along the Chinese coast. In 1982, it was commonly suggested that the Chinese coast would be little affected by a tsunami (Li, 1982), and this advice was regarded by the China Seismological Bureau (CSB), which is now the China Earthquake Administration (CEA). In fact, from 1904 to 1968 approximately 350 earthquakes with magnitudes greater than 7.0 occurred in the northwest Pacific Ocean; 33 of these earthquakes, approximately 10% of the total number, occurred off the Chinese coast, but only two of them generated tsunamis with low wave amplitudes (Zhou and Adams, 1986; 1988; Wang et al., 2005).

In 1986, a book named Earthquake Countermeasure was published. One of the chapters of this book reconsiders the tsunami disaster countermeasures that should be used in China (Guo, 1986). In the same year, Zhou and Adams (1986) investigated the historical events of Chinese tsunamigenic earthquakes and suggested that the historical data could provide a basis for the development of Chinese tsunami hazard zonation maps considering the geological and geophysical characteristics of three prominent seismic zones for China.

Zhou and Adams (1986) paper could be the first in which Chinese researchers showed their opinions in an international journal. Later, a preliminary tsunami risk analysis was performed for the coast of China, stating that the ratio of risk among the East Taiwan Coast, Continental Shelf and Bohai Sea was approximately 16:4:1, and the



Local sources

- | | | |
|----------------|----------------|----------------|
| 1 Sha'nan No.3 | 6 Penglai No.1 | 11 Xiamen No.3 |
| 2 Bohai No.1 | 7 Subei | 12 Nan'ao |
| 3 Bohai No.2 | 8 Quanzhou | 13 Taiwan |
| 4 Huangbei | 9 Xiamen No.1 | 14 Zhu-Ao |
| 5 Huanghekou | 10 Xiamen No.2 | 15 Dan'gan |

Regional sources

- R1 Manila Trench
- R2 Ryukyu Trench

Tsunami catalogues

- This study
- Lau et al. (2010)
- Mak and Chan (2007)
- NGDC/WDS (2013)



Figure 1. Locations of historical tsunamigenic earthquakes in China derived from several catalogues. The trans-oceanic events are out of this range. The blue circles represent the events from the catalogue developed by this study based on the historical earthquake catalogues (CSB, 1995; 1999) from 23 BC to AD 1990. The green circles represent the events from Lau et al. (2010). The purple circles are from Mak and Chan (2007). The red circles are from the NOAA worldwide database without the inland events (NGDC/WDS, 2013). The potential local tsunami sources are indexed by No. 1-15, and the regional ones are listed by R1 and R2. The epicenter of Great Tangshan Earthquake on July 28, 1978 is also plotted in this figure which first raised concerns about the exposure to natural hazards along the Chinese coast. Blue box bounds the area shown in Figure 3 and black box indicates the locations of the Xisha Islands where evidence of deposits from a possible tsunami was found by Sun et al. (2013). The Bathymetry data are derived from SRTM30 PLUS given by Beker et al. (2009).

tsunami hazard zonation of China with three levels was then suggested (Zhou and Adams, 1988). At the end of 1990, the State Oceanic Administration of China (SOA) launched a research program for collecting historical tsunami data, developing teletsunami and local tsunami propagation models. Both models were then applied to the tsunami hazard assessment in five early NPP sites: Dayawan, Qinshan, Sanmen, Lianyungang and Hui'an (Yu et al., 2001).

The knowledge of tsunami hazards at that time was not completely recognized, and the research was only limited to meet the construction of certain NPP sites. Most of the opinions at that time stated that there was an extremely low probability of the recurrence frequency for tsunamigenic earthquakes near the Chinese coast. On December 26, 2004, the tsunami event in the Indian Ocean became known to the public, leading to a new round of tsunami research and hazard mitigation in China.

Chinese tsunami catalogue

Historical tsunami catalogues have been compiled for many regions in the world, highlighting the occurrence and geographical extent of several large tsunamis. These catalogues may also support an elementary statistical analysis of the recurrence intervals of tsunamis of different magnitudes. Throughout Chinese history over approximately the past 3,000 years, tsunami events and runup data could be found in the literature. To identify a tsunami event, a catalogue needs to collect the information on the location, date and time, event magnitude, maximum water height, total number of deaths and injuries, and total damage. However, many written records seem to be inconsistent and fragmented. As a result, different studies developed tsunami catalogues based on the different data sources and obtained different results. Lu (1984) compiled the historical documents with descriptions of marine disasters, including approximately 227 possible tsunami events, covering the years from 47 BC to AD 1978. However, Chau (2008) believed that this catalogue had been overlooked or ignored by previous authors, and the total number of tsunami associated with definite earthquake events was only four, the number of tsunami induced by meteorological impact was only one, and the remaining 222 events were of unknown origin. Mak and Chan (2007) documented the historical tsunamis of South China, and only two events had been identified as credible reports of tsunamis, and certain events that were previously considered as tsunamis, including a few with many reported casualties, were found to be unsubstantial. Based on 15 previously published regional databases incorporating more than 100 sources for the northeastern region of the South China Sea, Lau et al. (2010) built a database identifying 58 recorded tsunami events between AD 1076 and 2009.

These two catalogues focused on the South China Sea. In the present study, we attempt to develop a tsunami catalogue characterizing the whole Chinese coast. As we know, tsunamis are mainly triggered by large earthquakes, and a simple way to find the historical tsunami events is to search statements about the inundation phenomenon in currently recognized earthquake catalogues. We took a closer look into the Chinese Historical Strong Earthquake Catalogue from 23 BC to AD 1911 and the Chinese Modern Earthquake Catalogue from 1912 to 1990 (CSB, 1995; 1999). We have identified 25 events as the tsunamigenic earthquakes during approximately the past 2000 years along the Chinese coast, as shown in Figure 1. However, some of the events are still arguable, such as the Tancheng earthquake in 1668, which had an epicenter located inland (Figure

1), but some studies stated that this giant earthquake caused a tsunami that affected the Korean Peninsula (Li et al, 2003). Note that four events generated in Japan also affected the Chinese coast. These are the Meio Earthquake in 1498, Hoei Earthquake in 1707, Ansei-Nankai Earthquake in 1854, and Ryukyu Earthquake in 1923. Many Chinese historical documents recorded the phenomena of rising tide at different locations for each event. However, the flood and inundation associated with injuries and deaths were recorded only in the Ansei-Nankai Earthquake. In general, tsunamis generated in Japan have little effect on the Chinese coast.

Figure 1 shows the event locations of the three above mentioned catalogues. The events from the NOAA tsunami database, which is a list of historical tsunami events and runup locations throughout the world that range in date from 2000 BC to the present, are also shown in Figure 1 (NGDC/WDS, 2013). Until now, there has been no evaluation of the different tsunami catalogues in China. Figure 1 clearly shows that there is still not a consistent list of events along the Chinese coast due to the different literature and identification rules. The compilation of a Chinese tsunami catalogue is still a great challenge.

Furthermore, paleo-tsunami research, which is the investigation of geological deposits, is another way to identify past tsunami events. For a major tsunami that causes extensive inundation and reaches multiple kilometers inland, a unique geological deposit would be produced. The identification of paleo-tsunami deposits in China was performed in recent years. Shi et al. (2012) surveyed 55 coastal sites on the Chinese coast to look for evidence of tsunami-generated geological deposits. Unfortunately, no visual evidence was found. Considering the tectonic setting, the study concluded that "the sea-overflow" described in Chinese ancient books could be not considered as tsunami events (Shi et al., 2012). However, Sun et al. (2013) recently reported preliminary research results from the Xisha Islands (location is shown in Figure 1) in the South China Sea, investigating a large tsunami that may have occurred around AD 1024. Sand layers in lake sediment cores and the geochemical characteristics indicate a sudden deposition event around AD 1024, which is temporally consistent with the written record of a disastrous event, characterized by high waves in AD 1076. This study presents evidence of deposits from a possible tsunami in this area and calls for awareness of the potential risk of tsunamis in the South China Sea.

Paleo-tsunami information could help to expand the time span of the tsunami catalogue. Studies on historical documents and tsunami deposits are the two key ways to understand much more about the magnitude and return period of great events in the past. Results from these two topics will help to improve the later studies such as PTHA. Therefore, we suggest a complete tsunami catalogue should be authoritatively published, and many more field surveys on the identification of tsunami geological deposits should be performed along the whole Chinese coast.

Tsunami modeling and its application

The National Marine Environmental Forecasting Center (NMEFC) of SOA is an early institution in China to develop numerical models for simulating the process of tsunami generation and propagation in the 1980s with reference to the TUNAMI (Tohoku University's Numerical Analysis Model for Investigation of near and far field tsunamis) code (Yu et al., 2001; Imamura et al., 1988). The Chinese Tsunami Model (CTM) was established and has run since

2005, just after the 2004 Sumatra Tsunami. For this model, the geometrical displacement of the seafloor is assumed to be the same as the initial tsunami wave field, and the formula of fault dislocation in elastic anisotropic half-space is deployed (Mansinha and Smylie, 1971). The finite difference method is used to solve linear and non-linear shallow-water equations, and the leap-frog scheme is used to improve the model's high-speed computation. After 2009, this model was updated to a parallel version based on the OPENMP (Open Multi-Processing) system and was used to estimate the probable maximum tsunami waves for several NPP sites. Recently, several researchers from universities and institutions have become interested in studies on tsunami simulation that emphasize the fundamental physical theory (Zhu et al., 2006).

Most engineers and scientists in the Chinese mainland prefer to use popular international models for engineering applications and scientific studies related to tsunami hazards. For instance, Pan et al. (2009) used the COMCOT (Cornell Multi-grid Coupled Tsunami Model) to simulate scenario tsunamis in the South China Sea and showed that there would be an approximate 0.3-0.5 m tsunami wave height along the coastline where the water depth is 20 m in the case of an M8.0 earthquake, and above 3 m in the case of an M9.0 earthquake. Wen et al. (2008) also used the COMCOT to simulate the tsunami propagation generated by a scenario M8.5 earthquake near the Okinawa Trough and showed that the maximum initial tsunami wave height was estimated to be 4.3 m. It would take approximately 4 hours for a tsunami wave to propagate from the source to the coast of Zhejiang Province in this case, with a maximum height of approximately 2.0 m, and 8 hours to reach to the shoreline of Shanghai. Using the TUNAMI-N2-NUS model, Dao et al. (2008) studied various tsunami scenarios in the South China Sea, and the maximum tsunami wave height reached 8 m in the coastal area of Guangdong Province for the worst-case scenario. Yu et al. (2011a) used the GeoClaw model to simulate the propagation process and characteristics of the 2010 Chile Tsunami around China coastal areas and quantitatively analyzed the impact of this tsunami on Chinese coast.

In general, engineers and scientists in China apply commonly used numerical tsunami models to accomplish their engineering or research tasks. However, we hope a domestic model will be developed in the future supported by more funds from the Chinese government.

Chinese tsunami early warning system

In 1994, when tsunami waves were observed by tide gauges around Hainan Island in China, the development of a Chinese tsunami warning service system was proposed (Ye et al., 1994). After the 2004 Sumatra earthquake, Wen et al. (2006) suggested the integration of the Chinese seismic monitoring network and the tsunami simulation model to build the tsunami early warning system in China. Liu et al. (2009) proposed a procedure to establish a tsunami early warning system for the South China Sea region focusing on the characteristics of tsunamis generated from earthquakes along the Manila subduction zone. In 2010, the Regional South China Tsunami System (RSCTS) was established by the Earthquake Administration of Guangdong Province, which is in charge of backing up the data of the Chinese seismic monitoring network. The seismic monitoring data can be easily integrated into RSCTS, and this system is mainly responsible for tsunami warning for the coast of the Guangdong and Hainan Provinces (Chen and Ye, 2010).

The China Tsunami Early Warning Center (CTEWC) was established in 2013 and is the only national agency responsible for producing and issuing tsunami warnings. Based on the earthquake information provided by the Chinese Earthquake Networks Centre (CENC) and the tsunami information provided by the Pacific Tsunami Warning Center (PTWC), CTEWC has the ability to evaluate the maximum wave height in the Chinese coastal area using a CTM model and to release tsunami warning information to the public in 20 minutes after the earthquake occurs. CTEWC releases the tsunami early warning to their local agencies first; then the agencies release it to local people who may be affected by the coming tsunami waves. Meanwhile, the warning information would be pasted on the CTEWC's webpage where anyone can access it. The Chinese Tsunami Travel Time Model (CTTTM) can also provide an estimation of the wave arrival time after a tsunami event. This model was implemented in 2005 by CTEWC, covering the entire Chinese sea with the 2' resolution bathymetry data.

The color-coded warning class is used in China based on tsunami heights and the seriousness of the potential hazard. Tsunami warnings are classified into four classes: I, II, III and IV, with red, orange, yellow and blue color codes, corresponding to the tide height ranges of approximately > 3.0 m, 2.0-3.0 m, 1.0-2.0 m and less than 1.0 m, respectively. Half an hour after the occurrence of the Chile earthquake on February 27, 2010, CTEWC released a blue warning and predicted that the tsunami could have a height of approximately 0.2 m and would not cause damage along the Chinese coast. The wave heights retrieved from tide gauges along Chinese coast are shown in Figure 2 and imply an agreement with the predicted height (Yu et al., 2011b). Three hours after the start of the Tohoku earthquake on March 11, 2011, CTEWC issued a blue tsunami warning and predicted that the leading wave would arrive at Shanghai in 10 hours with a maximum height of 0.5 m. The recorded maximum wave height near a tide station of Zhoushan Island close to Shanghai was approximately 0.55 m (NGDC/WDS, 2013). In addition, CTEWC also issued a safety warning for some moderate and small tsunamis, such as the Chile tsunami on April 1, 2014. The warning information showed that the tsunami wave would not reach the coastline of China. Correspondingly, there is not any record from tide gauges along the Chinese coast.

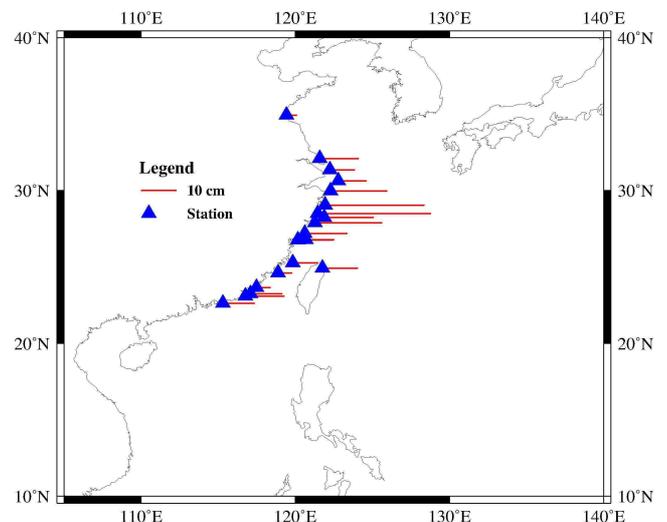


Figure 2. Observed tsunami wave heights along the Chinese coast for the 2010 Chile Earthquake (Yu et al., 2011b)

CTEWC, which is now attached to NMEFC, is collaborating with the U.S. Pacific Marine Environmental Laboratory (PMEL) to build a real-time tsunami forecasting system in the South China Sea. To monitor potential tsunami waves generated by a submarine earthquake in the Manila Trench and to provide early warning for the southern China coast, SOA deployed two buoys in the South China Sea that can monitor tsunami waves within 15-30 min if the tsunami is generated by an earthquake in the Manila Trench, and the real-time buoy data could also be accessed (Zhao et al., 2013).

The Chinese seismic monitoring network consists of many seismic stations, and SOA manages more than 100 marine gauges, most of which collect and transmit real-time data. Recent advanced numerical modeling technologies are being integrated with both earthquake and tsunami monitoring networks to create a more effective tsunami early warning system. Automatic collection of earthquake information data could be processed. We believe that the tsunami warning bulletin could also be automatically generated in the future based on predefined templates.

Probabilistic Tsunami Hazard Analysis (PTHA) in China and a test case

Deterministic Tsunami Hazard Analysis (DTHA) is a simple way to qualitatively assess the tsunami hazard for a site of interest and has been widely used in China (e.g., Zhou and Adams, 1988; Yang and Wei, 2005; Wen et al., 2008; Ren et al., 2010). However, the preferred method for evaluating the tsunami hazard in China is starting to shift from DTHA to Probabilistic Tsunami Hazard Analysis (PTHA). Liu et al. (2007) performed a PTHA for the southern China coast affected by the potential sources in the Manila Trench. The results show that the probability that a tsunami wave with a height over 2.0 m will hit

coastal areas in Hong Kong and Macau is approximately 10%, and the cities in Taiwan are less vulnerable than those on the mainland coast. The authors of this paper are devoted to pushing the PTHA forward in China under the funding supported by the National Natural Science Foundation of China (NSFC). We have proposed a Chinese PTHA method by following the regular seismic hazard analysis methods in China and gave a detailed description of the framework (Wen et al., 2011).

PTHA is derived from Probabilistic Seismic Hazard Analysis (PSHA). If we assume a Poisson time process, the probability that a tsunami with amplitude H greater than a given height h (i.e., $H \geq h$) occurs per year at a coastal site is given by the function:

$$P(H \geq h) = 1 - \prod_{n=1}^N (1 - P_n(H \geq h)) \quad (1)$$

where P_n represents that the probability of amplitude $H \geq h$ when the tsunami is generated by the n^{th} source. The following is a trial case applied at the site in Mirs Bay (114.77°E, 22.59°N) near Guangzhou and Hong Kong, as shown in Figure 3.

The ring of subduction zones around the Pacific Ocean is responsible for most tsunami sources for China. The distant sources were not considered in this paper because they have minor effect on China. For example, tsunami sources in Chile and Japan, where the tsunamis were generated by great earthquakes in 2010 and 2011, had almost no effect on the Chinese coast, as mentioned earlier. The potential regional tsunami sources for China are typically along the Korean Peninsula, the Sea of Japan, and the Ryukyu Islands as well as along Taiwan and the Philippines. For this evaluated site, only three potential tsunami sources are considered: the Manila Trench, which is a regional source, and the Zhu-Ao Fault and the Dangan

Fault, which are the local sources. All of the related parameters of these sources are listed in Table 1.

First, the seismic activities should be evaluated for these three sources. For the Manila Trench, constant b (slope of Gutenberg–Richter relationship of frequency vs. magnitude) was determined as $b=0.89$ or 0.98 for different fault segments given by Liu et al. (2007), as shown in Table 1. For the other potential tsunami sources, we used $b=0.73$, which was given by Chan and Zhao (1996). Then the numerical model COMCOT was applied to evaluate the wave heights at the given site in each computational tsunami case with various earthquake magnitudes.

From the simulated results, we find that the tsunami hazard for this site is dominated by the Manila Trench; both local sources contribute a small amount due to their small values of upper bound magnitude M_u and fault sizes. Tsunami waves generated by the Manila Trench region can reach this site with little loss in energy. We did not consider another regional potential tsunami source, the Ryukyu Islands, for this site. We believe that tsunami waves from this region could be blocked by Taiwan

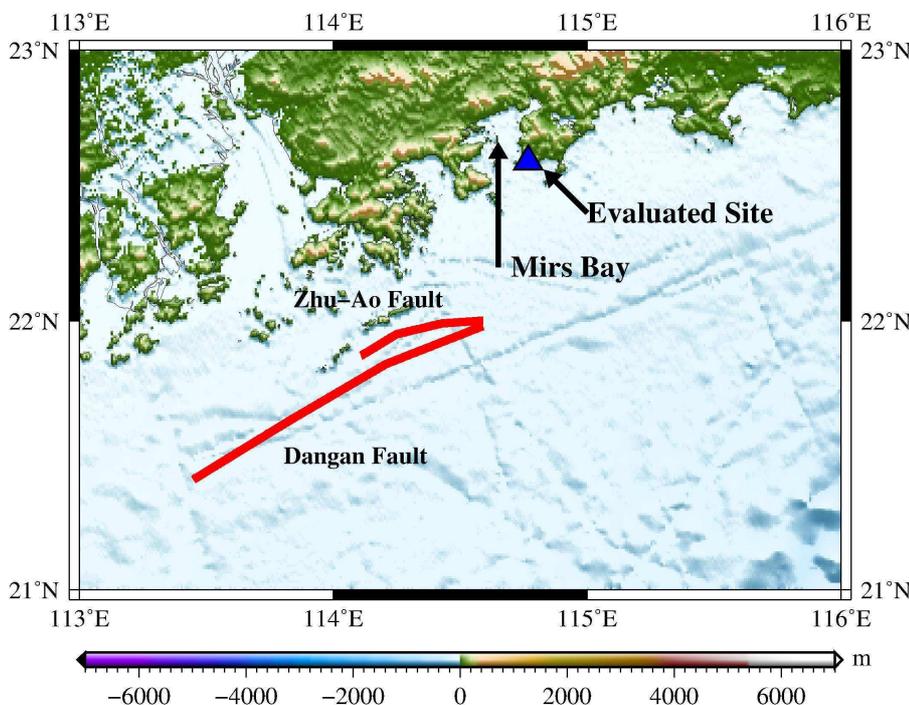


Figure 3. Geographical locations of the PTHA-evaluated site with two local potential sources, Zhu-Ao Fault and Dangan Fault, which are No. 14 and No. 15 in Figure 1. A regional source, the Manila Trench, is shown in Figure 1 as a blue box. A large-scale map of the area is also shown in Figure 1 as a blue box.

Table 1. Seismic parameters of three potential tsunami sources for the PTHA evaluated site in this study

Source Name	Node Coordinates	Length (km)	Width (km)	Average Depth (km)	Strike (°)	Dip (°)	Rake (°)	Slip (m)	Upper M (M_u)	b
Manila Trench	(119.85, 21.97), (120.35, 20.10)	210	82	20	350	14	110	2.94	8.2	0.89
	(120.35, 20.10), (118.93, 17.67)	310	109	20	29	20	110	5.3	8.6	0.98
	(118.93, 17.67), (119.15, 16.40)	135	66	20	3	20	90	1.89	7.9	0.98
	(119.15, 16.40), (119.08, 15.20)	140	66	20	351	20	90	1.89	7.9	0.98
	(119.08, 15.20), (119.27, 13.73)	166	71	20	353	30	50	2.19	8.0	0.98
	(119.27, 13.73), (120.28, 12.92)	142	66	20	308	30	50	1.89	7.9	0.98
Zhu-Ao Fault	(114.11, 21.87), (114.25, 21.95) (114.43, 21.99), (114.59, 22.00)	52	50	20	74	60	90	1.00	7.5	0.73
Dangan Fault	(113.45, 21.41), (113.83, 21.63) (114.21, 21.84), (114.59, 21.98)	135	50	20	63	60	90	1.00	7.5	0.73

Island and cannot impose a tremendous tsunami hazard to this site.

Figure 4 shows the calculated exceeding probability curves at the site in Mirs Bay for 1 year, 50 years and 100 years. Because the upper bound magnitude, M_u , is only 8.6 for the Manila Trench and 7.5 for the local sources (see Table 1), the maximum wave height only reaches 2.3 m, which leads to a convergence for the exceeding probability curves for 50 years and 100 years at 2.3 m, as shown in Figure 4. Our results are similar to the analysis result given by Liu et al. (2007), who only considered the regional source of the Manila Trench, for which, in the next century, the probability that a wave with a height of over 2.0 m will hit the near-coast ocean of Hong Kong and Macau was approximately 10%.

We have already launched a project funded by NSFC to compile the national tsunami zonation map. The test case above only shows

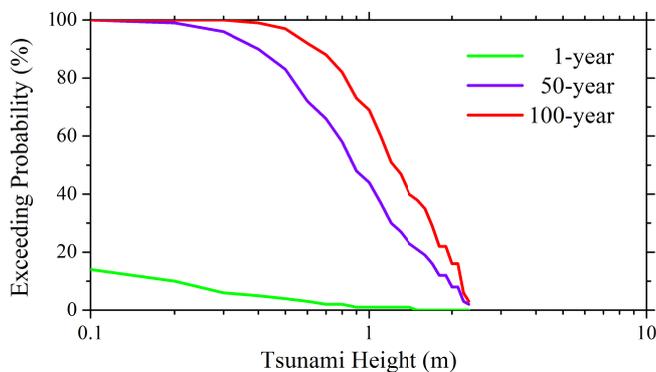


Figure 4. Exceeding probability curve for 1 year, 50 years and 100 years at the site evaluated by PTHA in this study.

the beginning of the use of PTHA in China, and more tsunami sources will be included in PTHA for other sites along the Chinese coast. Furthermore, PTHA with the identification of all possible uncertainties in tsunami source parameters will be considered in the following step. As discussed in Geist and Parsons (2006), the uncertainties associated with PTHA calculations must be included in the processes of generation, propagation and runup.

Conclusions

We introduce the recent progress of tsunami hazard mitigation, including the compilation of a Chinese tsunami catalogue, the development of a tsunami model, the construction of a tsunami early

warning system and the validation of a tsunami hazard analysis methodology in China. Following are several conclusions and remarks:

- 1 There is still not an approved tsunami catalogue for the Chinese coast. Increased funding has led to an increase in people's awareness of tsunami hazards in China that may have previously been underestimated. There is a need to reevaluate all of the related ancient literatures to improve the completeness of the tsunami catalogue so that the recurrence intervals of tsunamis can be estimated accurately. Information from paleo-tsunami studies could help to expand the time span of the tsunami catalogue. Therefore, many more field surveys on the identification of tsunami geological deposit should be performed. Meanwhile, numerical inundation modeling could be used to validate the findings in those paleo-tsunami surveys.
- 2 Several popular numerical models for tsunami simulation have been commonly used in China. However, with a high-performance computation technique, a pre-computed database of simulated heights and arrival times could be developed for a large number of tsunami scenarios, which has been accepted as an effective way to issue timely tsunami warning information. In addition, raising the awareness of tsunami hazards for people who live in the coastal areas and disseminating the knowledge of tsunami early warning systems and evacuation guidance are suggested.
- 3 The calculation of the PTHA test case at the site of southern China coast shows relatively acceptable results. We stress that this test case is an initial step towards a nationwide tsunami hazard assessment. The uncertainty analysis for PTHA should be considered in future work. The final goal of PTHA is to provide a national zonation map of tsunami inundation.

Establishing a national tsunami hazard program in China to mitigate the impact of tsunamis through hazard assessment, early warning, and other means should be the main goal in the future, and collaboration between corporations and international programs is also important.

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