DETERMINISTIC EARTHQUAKE TSUNAMI HAZARD ANALYSIS IN CHINA

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ABSTRACT :

The method of seismic hazard analysis has been matured in China. And it has made greatly contribute to national infrastructure construction and disaster prevention and mitigation. While the research of tsunami hazard analysis in China is still in the preliminary stage, and there is still not a practical analysis method. In this paper, considering the effects of the slope of coastal seabed and the shape of coastline, based on the technology of mathematic simulation, a deterministic method of earthquake tsunami hazard analysis is proposed. Finally the extent of earthquake tsunami hazard in China coastal areas is evaluated.

KEYWORDS: Earthquake tsunami; Hazard; Deterministic analysis; Method

1. INTRODUCTION

In present, PSHA (Probabilistic seismic hazard analysis) has been widely applied to seismic zonation and the evaluation of ground motions in specific site. The former services to normal seismic design, and the latter services to key or special construction project, such as construction of nuclear power plant (Hu, 1988). It can be said that the method of seismic hazard analysis in China has been matured and it can give the technical supports for urban planning and major engineering project, and give the technical references for some vital policy decisions of government, also then national construction of disaster prevention and mitigation system. Compared to earthquake, the hazard of tsunami should not be neglected. The typical event of 2004 Sumatra tsunami exposed its serious harmfulness. Following the PSHA methodology, how to carry out the works of tsunami hazard analysis in China is still a challenge.

To solve this problem, in this paper a deterministic method of tsunami hazard analysis is discussed. Firstly, potential tsunami source regions of China are delineated, considering historical earthquake data, historical tsunami data and sea depth. Secondly, tsunami sources of these regions are determined, regarded as potential point sources. Thirdly, based on numerical simulation technology, each tsunami source is calculated mathematically. Then the coastal distributions of wave heights are obtained. Finally, these wave heights are normalized. The extent of earthquake tsunami hazard in China coastal areas is evaluated. The method had been used for evaluating the tsunami hazard in east Korea coast and east Russia coast (Kurkin et al., 2004; Ho and Sung, 2001).

The researches of tsunami hazard analysis were started in 1980's in Japan and America. Japan coast was delineated into 8 potential tsunami source regions (Rikitake and Aida, 1988).Based on the characteristic earthquake model, the annual exceeding probability of Japan assaulted by near-field tsunami was given. Annaka and Satake et al. (2007) used the logic-tree method to obtain the tsunami hazard curves (The relationship between wave heights and annual exceeding probabilities) of Japan coast. Some scholars in Korea and Russia used a deterministic method, based on numerical simulation, assessed the hazards that Korea and Russia coast suffer tsunamis generated in Japan west coast (Kurkin and Pelinovskii et al., 2004; Ho and Sung, 2001). Used historical tsunami datum and results of numerical simulation, the tsunami hazards in eastern Mediterranean regions were evaluated (Salamon and Rockwell et al., 2007). The probability of southern California suffered by slide tsunami was predicted, based on Monte Carlo method (Watts, 2004). With the GIS technology application, it has being used for analyzing tsunami hazard and compiling the tsunami hazard maps and flood inundation maps (Florence et al., 2005; Priest, 1995; Priest et al., 1997). Geist and Parsons (2006) reasonably summarized the define and method of probabilistic tsunami hazard analysis. Based on tsunami numerical simulation, using historical tsunami datum and Monte Carlo method separately, the tsunami hazard curves of Acapulco of Mexico and Cascadia of America are given. It indicated that there were two issues on tsunami hazard analysis. One is the difficulty on assigning specific earthquake probabilities of circum-Pacific subduction zones, and another is the limited amplitude range of tsunami measurements.

The researches of tsunami hazard analysis in China were started in 1988, while Zhou Qinghai published a paper named "Tsunami Risk Analysis for China" in *Natural Hazards* (Zhou and Adams, 1988). In this paper, China tsunami historical datum were utilized. Combined with the geology and earthquake characteristics of China's continental shelf, the relative ratio of tsunami hazard in China coastal areas was given. It suggested that the ratio of Eastern Taiwan Coast, Continental Shelf and Bo Hai Bay is 16:4:1. And the zoning map of tsunami hazard along China coast was given. Although the results were ambiguous, it has taken an important step in the tsunami research in China. Then it had come to a standstill period. After 2004 Sumatra tsunami, it become a hot spot again. Limited to utilize historical data, geology and geophysical characteristics of continental shelf, the possibilities of China coast suffered by tsunami were given (Wen and Ren, 2007; Yang, 2005; Yang and Wei, 2005). In 2007, Liu Yingchun, doctor of SCSIO (South China Sea Institute of Oceanology, Chinese Academy of Sciences), used the method of numerical simulation, analyzed probabilistic tsunami hazard of China southeast costal areas (Liu and Santos et al., 2007). The exceeding probabilities of southeast five major cities, which are Shantou, Xiamen, Xianggang, Aomen, Tainan is proposed, suffered by tsunami whose amplitudes are 1-2m and above 2m separately. These results are more substantive and make China tsunami research come to a higher level. In addition, Ren Yefei and Wen ruizhi, scholars of IEM (Institute of Engineering Mechanics, China Earthquake Administration), following the similarity to the seismic hazard analysis method, gave the definition of probabilistic tsunami hazard analysis, and suggested the method in this work (Ren, 2007). It can provide theoretical basis and technical reference for doing further research of tsunami hazard analysis in China.

2. DELINEATING POTENTIAL TSUNAMI SOURCE REGIONS ALONG CHINA COAST

There are no occurring conditions of tsunami generation in Bohai Sea and Yellow Sea (Gao and Min, 1994), but East Sea and South Sea exist ones (Yang and Wei, 2005; Wei and Chen, 2005). Tsunami mostly generate by earthquake. So when potential tsunami source regions along China coast are delineated, the regions where earthquake break out infrequently are not considered. Just Korean peninsula coast, Japan coast, Ryukyu Islands coast, Taiwan coast and Philippine coast are considered.

Plate tectonics, seabed geological conditions, paleoseismological evidences, historical earthquake datum, historical tsunami datum, sea depth, and so on, are the main basis of delineating potential tsunami source regions. To be different with potential seismic source regions, the earthquake must be adequate enough to have historical tsunami in potential tsunami source regions, generally which magnitude is above 6.5. In addition, the water depth of potential tsunami source region must be deep enough so as to satisfy the condition of tsunami generation, which is generally considered above 200m. Due to lack of detailed data, only historical earthquake datum, historical tsunami datum and sea depth are considering in this paper.

1470 significant earthquake events, supplied by NTL (Novosibirsk Tsunami Laboratory, Russia), occurred in the areas between 0°N to 45°N and 105°E to 150°E, from 2150 B.C to 2002 A.D, are selected, as shown in Figure 1. 471 historical tsunami events, supplied by NGDC (National Geophysical Data Center, USA), occurred in the areas between 0°N to 45°N and 105°E to 150°E, from 173 A.D to 2007 A.D, are selected, as shown in Figure 2. By using global bathymetric data supplied by NGDC, the isobaths of China coast are drawn. 200m sea depth is selected as one of necessary conditions of tsunami generations, as shown in Figure 3. Based on these datum, China potential tsunami source regions are reasonably delineated, as shown in Figure 4.

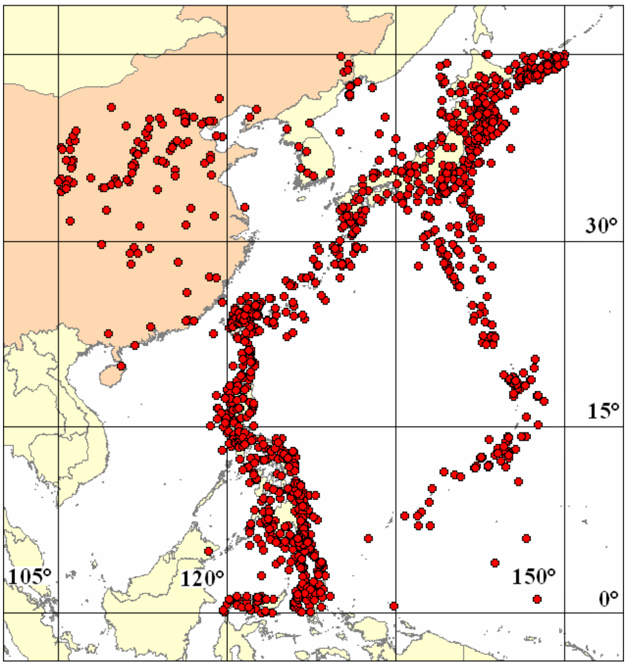

Figure 1 Distribution of historical earthquake events along China coast

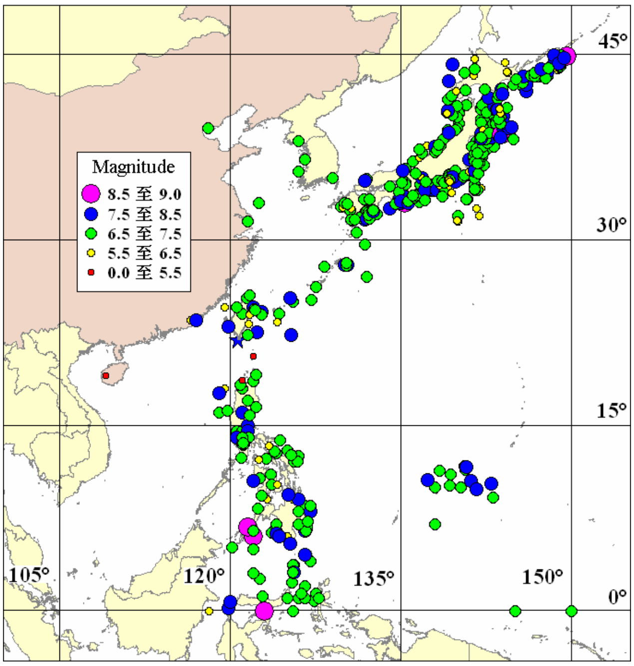

Figure 2 Distribution of historical tsunami events along China coast

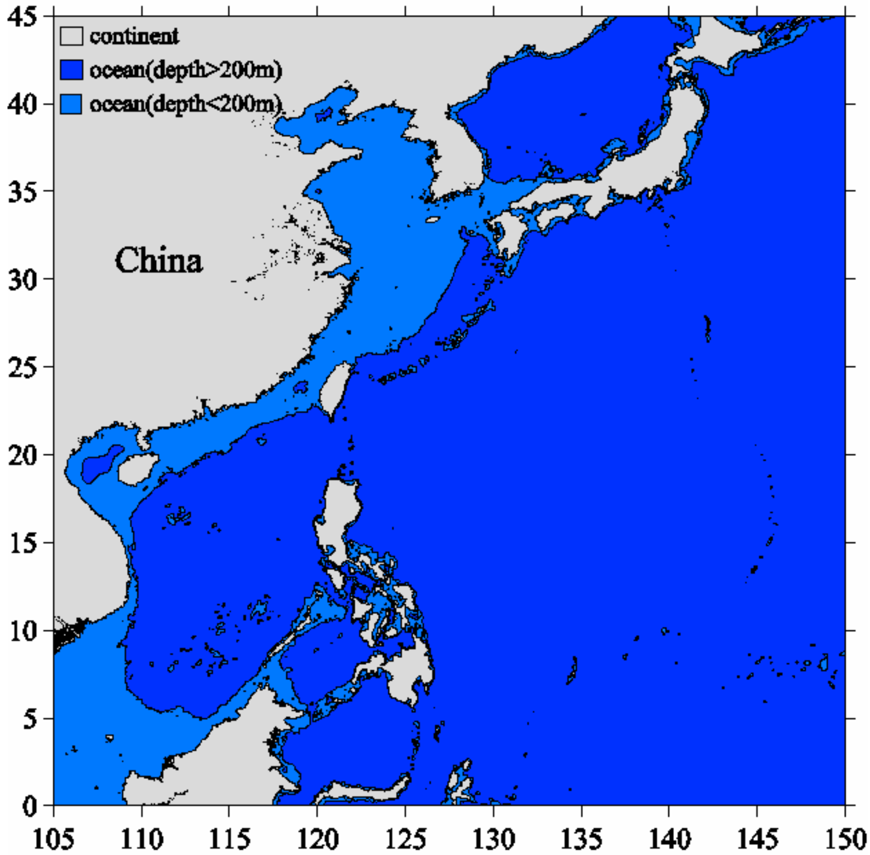

Figure 3 Isobaths of China coast
(200m sea depth is selected as one of required conditions of tsunami generations)

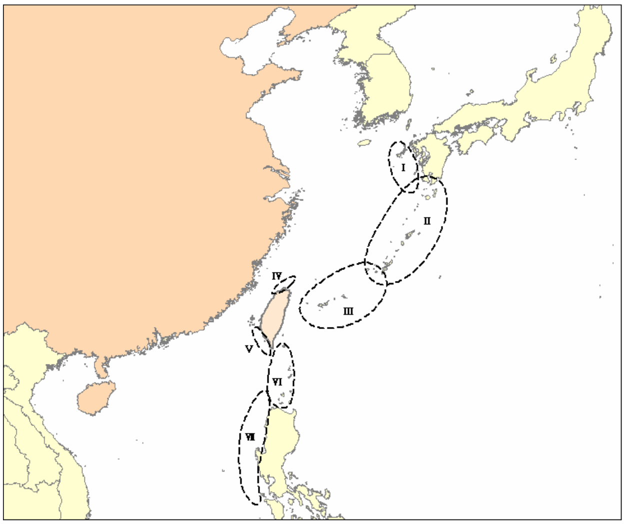

Figure 4 Potential tsunami source regions along China coast

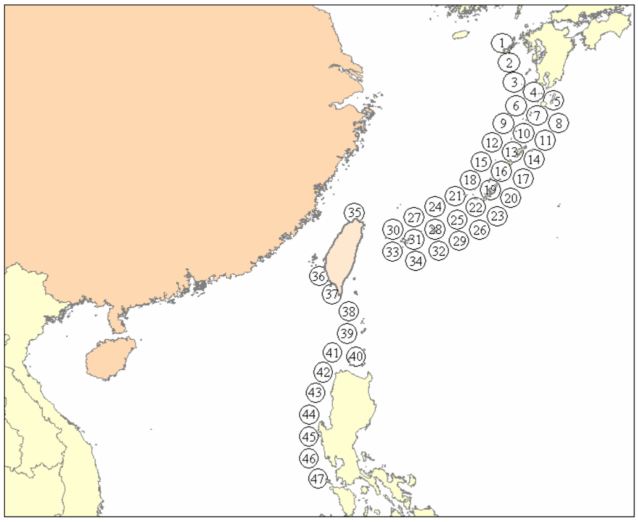

Figure 5 Distribution of potential tsunami sources along China coast

3. DETERMINING POTENTIAL TSUNAMI SOURCES

For all potential sources, potential point sources are set as the initial tsunami displacement fields in the processes of tsunami simulation. As Figure 5 shown, 47 point sources, whose radiuses are 50km, are given. The shape of the source is set as a cone shape which is 5m high, as figure 6 shown. It should be noticed that initial displacement field of tsunami numerical simulation is calculated by the theory of fault dislocation in an elastic half-space, but point source is deployed here due to lack of active fault fundamental information. Because in this paper tsunami wave heights are normalized first, it does not lead to erroneous assessment results so it is used for elevating tsunami hazard along China coast.

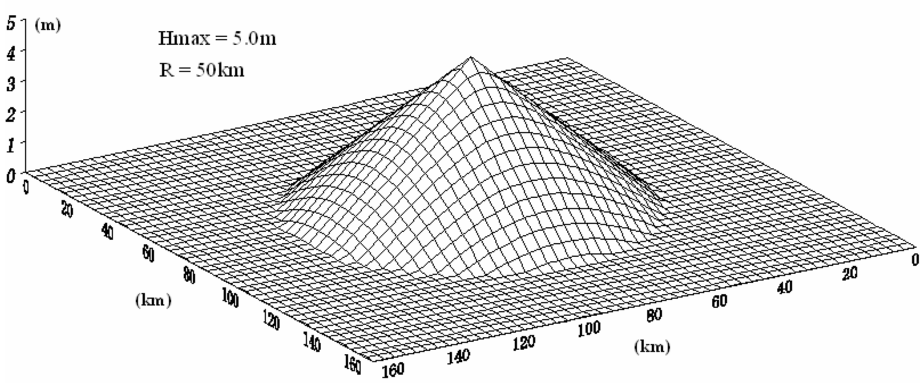

Figure 6 Shape of each potential tsunami source

4. MATHEMATIC CALCULATION

After initial displacement fields being determined, the propagation of each tsunami source is simulated. Near-field tsunami numerical mode is utilized (Wai and Chau et al., 2005; Ren, 2007; Wen and Ren et al., 2007). The governing equation, nonlinear shallow water equations, is solved by finite difference method.

$$\frac{\partial \eta}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0 \tag{4.1}$$

$$\frac{\partial M}{\partial t} + \frac{\partial}{\partial x}\left(\frac{M^2}{D}\right) + \frac{\partial}{\partial y}\left(\frac{MN}{D}\right) + gD\frac{\partial \eta}{\partial x} + \tau_x D = 0 \tag{4.2}$$

$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial x}\left(\frac{MN}{D}\right) + \frac{\partial}{\partial y}\left(\frac{N^2}{D}\right) + gD\frac{\partial \eta}{\partial y} + \tau_y D = 0 \tag{4.3}$$

Where, η is the water surface vertical displacement; $D = h+\eta$ is the total water depth; g is the acceleration of gravity; $M = u(h+\eta)$ and $N = v(h+\eta)$ are the x-direction and y-direction discharges, where u and v are the x-direction and y-direction averaged particle velocities; τ_x and τ_y are the x-direction and y-direction bottom frictions, they can expressed by

$$\tau_x = \frac{gn^2}{D^{10/3}} M\sqrt{M^2+N^2}\ ,\quad \tau_y = \frac{gn^2}{D^{10/3}} N\sqrt{M^2+N^2} \tag{4.4}$$

Figure 7 shows the tsunami heights along China coast resulted from mathematical simulating the propagation of No.18 potential tsunami source. The maximum value is 2.67m appeared near the area of 30°N. This can not indicate the higher risk of tsunami in this area. Maybe it derives from short distance between this area and No.18 tsunami source. Only after synthetically simulating all potential sources and comprehensively analyzing all results, can judgment on the degree of tsunami hazard along China coast be implemented. Figure 8 shows all tsunami heights along China coast resulted from mathematical simulating the propagation of all 47 potential tsunami sources.

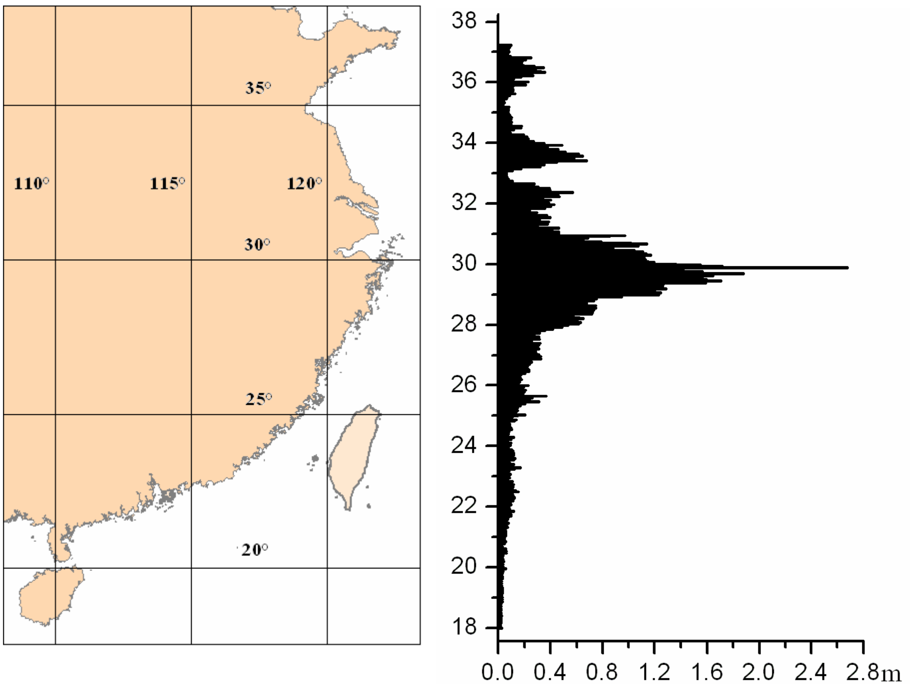

Figure 7 Tsunami heights along China coast by simulating No.18 potential tsunami source

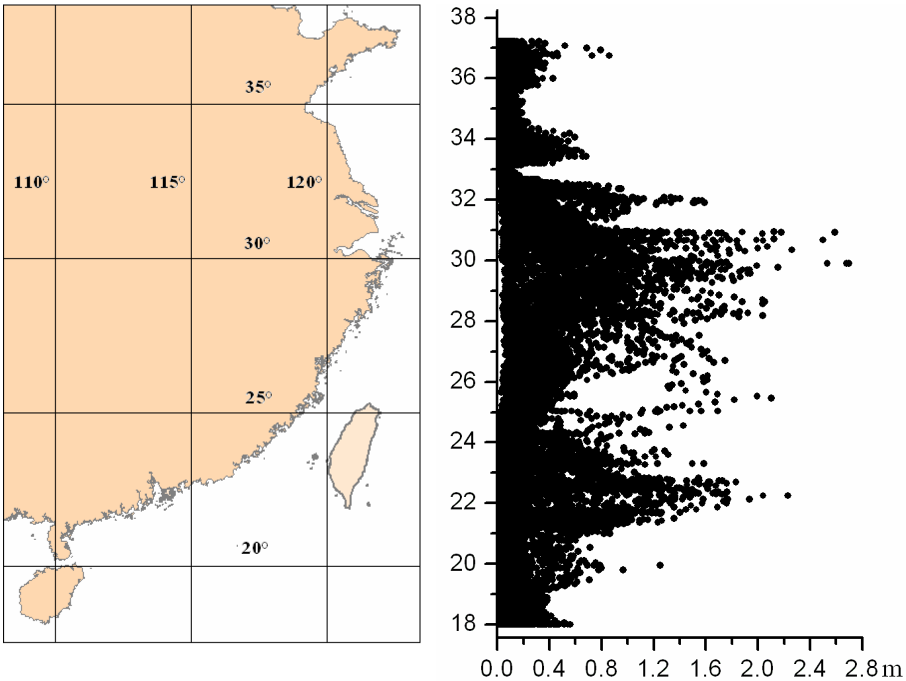

Figure 8 Tsunami heights along China coast by simulating all 47 potential tsunami sources

5. NORMALIZING TSUNAMI WAVE HEIGHTS

All tsunami wave heights are normalized. In other words, in each group of wave heights from one simulation process, select maximum one as a cardinal, then every one is delineated by this cardinal. As a result, a series of ratios which are less than 1 are obtained. Figure 9 shows a plenty of values resulted from normalizing all tsunami wave heights.

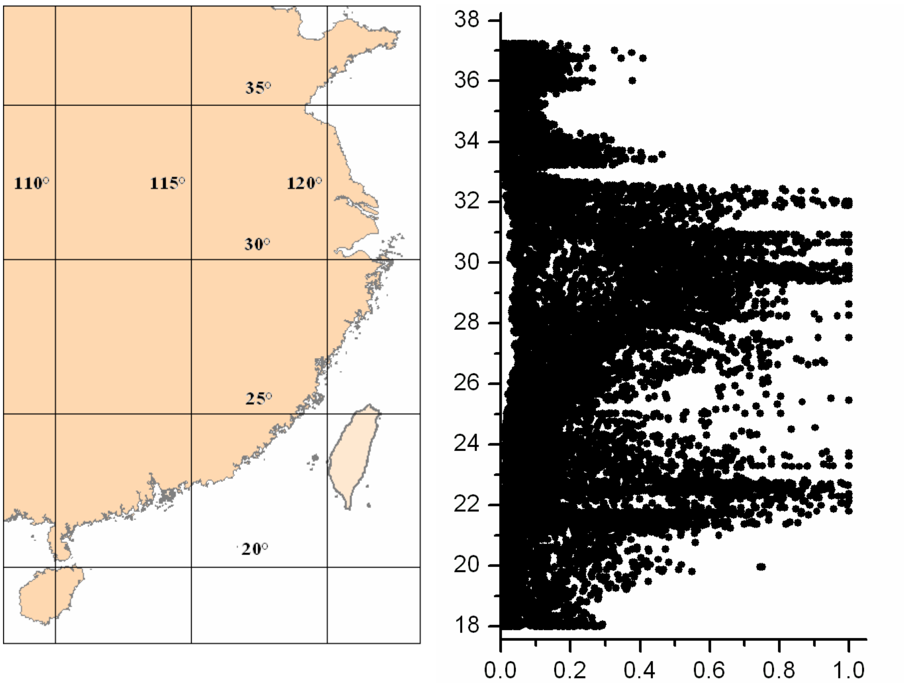

Figure 9 Values resulted from normalizing all tsunami wave heights

6. CONCLUSIONS

The tsunami wave height is related with the size of magnitude, the type of fault, the strike angle of fault, the distance of tsunami propagation, the slope of coastal seabed and the shape of coastline, and so on. Here we use conical tsunami sources in order to eliminate the impact from the size of magnitude,the type of fault and the strike angle of fault. Then normalize all wave heights in order to eliminate the impact from the distance of tsunami propagation. Therefore, in this paper, differences among the degrees of tsunami hazard along China coast are induced by the differences of the slope of coastal seabed and the shape of coastline along China coast. Finally, the consequence can be a reference on analyzing probabilistic tsunami hazard along China coast.

From Figure 9, we can conclude that
(1) The degree of tsunami hazard in Bohai Bay is considerably low, because it is semi-enclosed so that tsunami waves are resisted, also because it has no conditions of tsunami generation.
(2) Judging from the concentration of the point whose value is near 1, from Yellow Sea to Hainan Island, the degrees of tsunami hazard, in three areas of the entrance of the Yangtze River, Qiantang River, and Pearl River, are higher than other areas. East China Sea area is the highest, followed by South China Sea area, lowest in Yellow Sea area.

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