Modern Applied Science
www.ccsenet.org/journal.html
Vol. 3, No. 2
February 2009

Storm Surge Intensity Grade Classification

Liping Wang, Qingqing Liu & Runyu Han
College of Mathematical Science
Ocean University of China
Qingdao 266071, China
Tel: 86-532-8590-1990 E-mail: wlpjsh@163.com

Jiangen Wang
Department of Computer Science
Guangdong Radio & TV University

This work was supported by Natural Science Foundation of China (No. 40776006) and Innovation Program Item in Postgraduate Education (SDYC08008)

Abstract

In order to accurately describe and predict the intensity of the typhoon storm surge, the paper builds up Poisson—Maximum Entropy Compound Extreme Value Distribution model, and estimates the return period of typhoon storm surge on the basis of observed samples from main storm surge processes in a certain observation station of QingDao from 1963 to 1989. The conclusion verified that the calculating result of new model is similar to other models, but it is relatively stable and can overcome the shortcomings of the traditional methods in the situation of lack of observed material.

Keywords: Poisson—Maximum Entropy Compound Extreme Value Distribution, Typhoon Storm Surge, Intensity, Return period

1. Put forward the question

Typhoon Storm Surge refers to the phenomenon of abnormal rise and fall of surface caused by intense weather system such as tropic cyclone, temperate zone cyclone, the strong wind affecting of cold front and the radical change of air pressure. It is also called Strom Surge or Weather Tsunami. Typhoon storm surge is a huge ocean disaster phenomenon. Accompanying with gale and billow, storm surge can make surface hoik in a short time, ruin seawalls, devour docks and factories, flood farms and buildings and destroy vessels, so that materials can't be moved , people and livestock can't survive ,consequently it results in a great disaster. Once storm surge encounters astronomical tide, because of superposing their high tide, the tide will rise sharply, simultaneously as more intense storm surge and high tide superpose, it must result in greater disaster. From March 3, 2007 to wee hours of March 5.2007, affected by the strong cold air in the north and the cyclone in the Yellow Sea, the strong extratropical storm surge occurred in Bohai Bay. The direct economic loss of marine disasters of LiaoNing, HebBei, and ShanDong Province summed to 4,065 billion. There were 4 tide stations where coastal water level uplift exceeded 100 cm, and the highest was 202cm which occurred in Yangjiaogou tide station in Laizhou Bay; The water levels in Yangjiaogou tide station, Longkou tide station and Yantai tide station were over local alert tide, among these, the water level in Yantai tide station was more 49cm than the local alert tide. In Shandong Province, 7 persons were killed, raft-cultures of more than 6700 hectares were damaged, shrimp ponds and fish ponds of more than 2000 hectares were washed away, breakwater of 10 km collapsed, 1900 vessels were destroyed, all in all, the direct economic loss of marine disaster amounted to 2.1 billion.

With the weather warming and sea-level rising, the storm surge disaster has occurred more frequently in coastal regions of China in recent years (see Figure 1). According to the statistics of the State Oceanic Administration, China annual direct economic losses caused by marine disasters such as the storm surge, storm waves, severe sea ice, sea fog and strong wind at sea rose from more than 2 billion to more than 8 billion, and about 500 people were killed. Of all economic losses, storm surge nearby the coast damaged most severely. Storm surge disaster has become the greatest marine disaster in China.

To further improve the moisture-resistance and disaster reduction of the marine, and reduce the losses caused by disasters, it is necessary to accurately describe the intensity of storm and the size of the disaster and find the way of forecasting, in the hope of helping the authorities deploy the kinds of losses as far as possible. Therefore, the research for the storm surge disaster classification to identify is important and urgent.

At present, the existing classification of the storm surge intensity are the following: 1. Based on the level of the setup of water accompanying with storm surges (Gan, Yuming. 1991.), this standard counts water level uplift of storm surge as the first hazard factor of storm surge. 2. Synthesizing the intensity of water level uplift of the storm surge, we know that storm surge is not an isolated occurrence, which takes effect together with astronomical tide in the coastal areas. Floods, runoff and other factors also play a part in the estuary area. They codetermine the actual water level or water level uplift. This method refers the water level uplift caused by various factors above mentioned as the standard for classification; 3. Based on the highest tide of the storm surge, mainly according to the difference between the local alert tide and forecasting value of the highest tide in the course of typhoon. That is, if the highest tide reaches or surpasses the alert tide, we believe that the storm surge disaster will occur and then release storm surge disaster forecasting; otherwise, we believe no storm surge disaster (Li, Peiwei. 1996.). 4. classifying the intensity of storm surge based on combined tide and waves (Dong, Sheng, Yu, Haijing & Hao, Xiaoli. 2005.) Dongsheng and others promoted compound extreme value with a single variable, considered the occurrence of typhoon, built a compound extreme value distribution model with two-dimensional, and discussed the return period of storm surge according to the water level of storm surge and the significant height of wave; 5. Classifying disaster grade based on the degree of disasters. This method is based on disaster losses such as: the number of death and economic losses, and then establish the disaster grade.

According to the above classification, we find that the methods which calculate the return tide and storm surge of many years are all based on Pearson Ⅲ model, Gumbel model and so on. But as the numerical model used is apriority, so its own accuracy is not good. On the basis of these models, the early warning to storm surge disaster will be inevitably different from the real situation.

In view of the above, this paper gives a compound extreme value distribution consisting of Poisson distribution and the maximum entropy distribution. Through statistically calculating return period of storm surge based on the samples of maximum wave height in an observation post from 1987 to 1963, and comparing to the results got from other methods, we can see that the result from this paper is similar to others, but more stable under the condition of short observed time. At the same time, this method can solve the problems existing in other methods, and because of the nature of maximum entropy function, it can overcome the shortcomings of the other traditional models. Then comparing with the existing materials of marine disasters, this paper puts forward the standard of classifying the intensity grade of the storm surge hazard, and refers it as the criterion of the disaster degree of the future storm surge. This model will be very valuable for the socio-economic risk assessment of storm surge.

2. Theory of Poisson—Maximum Entropy Compound Extreme Value Distribution

Theorem: Let ξ,η be random vectors. Their distribution function are $G(x)$, $Q(x)$ respectively. Let ξ_i be the i-th observed value of ξ and n be a random variable which is independent of ξ, η and nonnegative integer. The distribution function of n is

$$P\{n=k\}=p_k,\ \ k=0,1,\cdots,\ \ \sum p_k=1\,. \tag{1}$$

Define random vector ζ

$$\zeta=\begin{cases}\eta, when\ \mathrm{n}=0,\\ \underset{1\le i\le n}{Max}\{\xi_i\}, when\ \mathrm{n}\ge 1,\end{cases} \tag{2}$$

And then the distribution function of ζ is

$$F(x)=\sum_{k=0}^{\infty}p_k[G(x)]^k-p_0[1-Q(x)] \tag{3}$$

The proof is as follows:

$$
\begin{aligned}
F(x) &= P\{\zeta < x\} = P\{\zeta < x, n = 0\} + \sum_{k=1}^{\infty} P\{\zeta < x, n = k\} \\
&= P\{\zeta < x|_{n=0}\}P\{n = 0\} + \sum_{k=1}^{\infty} P\{\zeta < x|_{n=k}\}P\{n = k\} \\
&= P\{\eta < x\}p_0 + \sum_{k=1}^{\infty} P\{\underset{1\le i\le n}{Max}\{\xi_i\} < x\}p_k \\
&= p_0 Q(x) + \sum_{k=1}^{\infty} p_k[G(x)]^k \\
&= \sum_{k=0}^{\infty} p_k[G(x)]^k + p_0[1 - Q(x)]
\end{aligned}
$$

Therefore theorem is proved.

Let

$$F_0(x) = \sum_{k=0}^{\infty} p_k[G(x)]^k \tag{4}$$

Then we can see $F_0(x)$ is not only compound extreme distribution consisted of the distribution n and the distribution of ξ mentioned above, but also decided entirely by ξ and η.

In actual application, the primary problem is solving Equation (5) when $R(0 < R < 1)$ is given

$$F(x) = R \tag{5}$$

Let $P = 1 - R$ (P is design frequency)

$$T = \frac{1}{P} = \frac{1}{1-R} \tag{6}$$

(T is called return period). If x_R agrees with equation(5), (that is $F(x_R) = R$), then x_R is the return value of T years. If n agrees with Poisson distribution

$$p_k = \frac{\lambda^k}{k!}e^{-\lambda}, \quad k = 0, 1, \cdots, \quad T = \frac{1}{P} = \frac{1}{1-R}$$

Then

$$F_0(x) = e^{-\lambda[1-G(x)]} \tag{7}$$

$$G(x) = 1 + \frac{1}{\lambda}\ln R \tag{8}$$

In formula (8) $G(x)$ can be any type of univariate continuous distribution.

3. Application

First of all, we compare the results of Gumbel distribution and the maximum entropy distribution fitting extremum wave height with the histogram respectively (Figure 2).We can see from the comparison, that the difference between Gumbel distribution and the histogram is larger when the extremum wave height is greater, while the maximum entropy distribution is better no matter when the extremum wave height is greater or smaller. Obviously, the maximum entropy is more applicable.

In the past, the calculation of return period was based on distribution function such as Pearson III, Gumbel distribution function. So it inevitably was apriori and also had some subjective factors as a result of a variety of other reasons. In this paper, the maximum entropy function manages to avoid the problems above. The maximum entropy theory is following:

Theory of maximum entropy: Let X is continuous random variable. $H(X)$ (natural unit) is the information entropy of X and is defined as

$$H(X) = -\int_{-\infty}^{+\infty} f(x)\ln f(x)dx$$

In this formula, $f(x)$ is the probability density function of X. From information theory, we know $H(X)$ is the disordered measure of X, that is people measure X with ignorance. Accordingly, Jaynes put forward the theory of maximum entropy .In 1975, Ulry and Thomas applied the maximum entropy theory to the spectroscopy analysis of wave, and in his article he narrated: we use a designed probability density function to describe the given information, but to maintain the greatest ignorance for the unknown information. Consequently this function must possess the maximum entropy.

When $G(x)$ is the distribution function of the maximum entropy, formula (8) becomes

$$\int_0^x f(t)dt = 1 + \frac{1}{\lambda}\ln R \tag{9}$$

In formula (9)

$$f(x) = \begin{cases} \alpha x^r e^{-\beta x^{\zeta}}, x \geq 0 \\ 0, x < 0 \end{cases} \tag{10}$$

Then:

$$\int_0^x \alpha t^{\gamma} e^{-\beta t^{\xi}} dt = 1 + \frac{1}{\lambda}\ln R \tag{11}$$

In formula (11), α , β , γ , ξ can be got from the following equations:

$$\left.\begin{aligned} &\frac{\Gamma^2(\frac{\gamma+2}{\zeta})}{\Gamma(\frac{\gamma+1}{\zeta})\Gamma(\frac{\gamma+3}{\zeta})} = \frac{A_1^2}{A_2} \\ &\frac{\Gamma(\frac{\gamma+2}{\zeta})\Gamma(\frac{\gamma+4}{\zeta})}{\Gamma^2(\frac{\gamma+3}{\zeta})} = \frac{A_1 A_3}{A_2^2} \\ &\beta = \left(\Gamma(\frac{\gamma+2}{\zeta})/[A_1\Gamma(\frac{\gamma+1}{\zeta})]\right)^{\zeta} \\ &\alpha = \frac{\zeta\beta^{\frac{\gamma+1}{\zeta}}}{\Gamma(\frac{\gamma+1}{\zeta})} \end{aligned}\right\} \tag{12}$$

A_m can be estimated from the following formula, in the actual applicaton.

$$\widetilde{A}_m = \frac{1}{n}\sum_{i=1}^{n} x_i^m \quad m = 1,2,\cdots,n \tag{13}$$

Under the condition of the storm surge disaster occurred, this paper sums up the past researches on return period and early-warning method of storm surge, then gives a series of $R(0 < R < 1)$ value .we can get x_R from formula(6) and formula(11). x_R is the return value of T years.

In the formula (11), λ is the annual average of the times of typhoon affecting this sea region, that is,

$$\lambda = \frac{the\quad total\quad times\quad of\quad typhoon\quad affecting\quad sea\quad region}{the\quad total\quad years} = \frac{82}{26} = 3.1538$$

Formula(11) has four parameters α , β , γ , μ , and from formula (12)and formula(13) ,we can see these parameters only relate to the original state ,so this method can fit the observed samples more acutely and perfectly. In addition, this function has simple form and has parameters which can be calculated from the observed samples easily, thereby it is more applicable.

In order to test the quality of Possion-the maximum entropy compound extreme value distribution, we take the course of the typhoon hazard occurring in Qingdao since 1963 for example. We use a designed return period to calculate the extreme wave height of storm surge and compare with Possion-Gumbel compound extreme value distribution (Table 1). The table shows that, when the samples observed is less, the results of Possion-maximum entropy compound extreme value distribution model are still very stable.

For 26 years' (1963~1989) samples of main extremum wave height in a observation station of QingDao ,we give the grade classification (Table 2) of storm surge disasters intensity, according to the formula (11) that is the size of the return period of extremum wave height of Poisson-maximum entropy compound extreme value model.

We have selected the samples from some storm surge disasters in QingDao to calculate the return period and the results are in Table 3.From the following table, we can see that the calculation of the intensity grade of the storm surge is basically consistent with the actual situation. It should be noted that due to other factors, the calculation of typhoon No. 9216 has great difference with the actual situation (the result is serious disaster while the actual situation is very serious disaster and is the return situation of a hundred years).

4. Conclusion

This paper builds up a model of Possion-maximum entropy compound extreme value distribution and then applys it to the classification of typhoon surge intensity .From the above argument, we can see:

(1) The model of Possion-maximum entropy compound extreme value distribution is based on the theory of maximum entropy and the concrete form of maximum entropy probability function entirely determined by parameters not artificial factors, so this model can overcome the shortcomings of other traditional methods and more accurately reflect the relation between extremum wave height and disasters.

(2) This paper statically analyses the extremum wave height in the course of main storm surge in QingDao area since 1963.From the example， despite the short observed time, the result is still stable. So this model is more applicable in coastland where samples are relatively shorter than other areas.

(3) In order to further improve the assessment model and the accuracy of assessing disasters. It is necessary to deeply and quantitatively analyse and research the relation between disaster and other random factors affecting disasters such as the regional economic situation, the conditions of disaster prevention and disaster resist, and the land feature and landform of disaster areas.

References

Dong, Sheng, Yu, Haijing & Hao, Xiaoli. (2005). Typhoon surge intensity grade classification based on combination of wave height and tide level. *Periodical of Ocean University of China*. 2005. Vol. 35, No.1, 152-156.

Gan,Yuming. (1991). The identity and judgment of storm surge. In Disaster preventing association of China(Eds). *Exploring the disaster reduction and development of the coastland*. Earthquake Press. pp. 322-327.

Li,Peiwei. (1996). Exploring the forecast of storm surge in QingDao area. *Marine Forecasts*. 1996. Vol. 13, No. 1, 53-57.

State Oceanic Administration.Oceanic disaster communiqué of China in 2007. [Online] Available: http://www.soa.gov.cn/hyjww/index.htm.

Zhang, Lizhen & Xu, Delun. A new maximum entropy probability function about nonlinear displacement of sea wave surface.

Table 1.

Calculation	Time of material (start-stop time)	Number of material	Extreme value wave height(m)				
			10	30	50	100	200
Poisson–Gumbel	1963~1989	82	3.38	4.53	5.05	5.75	6.44
Poisson–maximum entropy	1963~1989	82	3.29	4.45	4.97	5.67	6.34
	1963~1976	47	3.52	4.67	5.18	5.88	6.58
	1976~1989	35	3.22	4.37	4.89	5.59	6.28

Table 2. storm surge intensity grade

Grade	1	2	3	4
Disaster intensity	weak	a little strong	strong	very strong
Return period(year)	0~10	10~30	30~50	50~200

Table 3. the disaster situation of storm surge in QingDao area

Typhoon number	Significant wave height	Return period	Calculating storm surge intensity
8509	5.5	80	Very strong
9005	1.8	10	weak
9216	5.0	50	strong*
9414	2.2	10	weak
9415	4.4	30	A little strong

Figure 1 Times of the storm surge disaster occurring in China for 26 years (1989~2006)

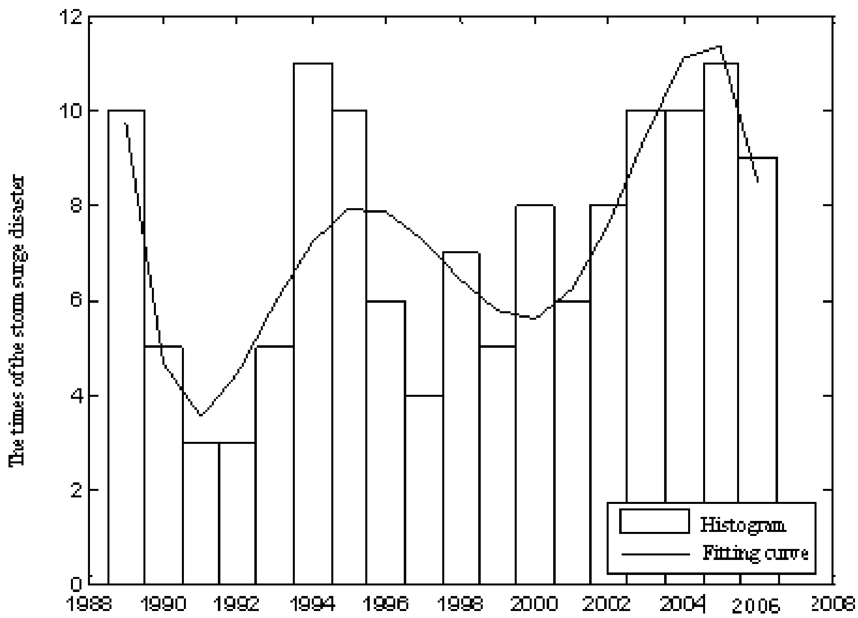

Figure 2 Histogram of extremum wave height distribution