

Using the Asymmetrical Typhoon Model to Calculate the Typhoon High Wind Distribution in China Sea and Adjacent Regions

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ABSTRACT: This paper used the asymmetrical typhoon model, combined with tropical cyclone (TC) central pressure and wind speed data of Shanghai Typhoon Institute of China Meteorological Administration and reanalysis data of Japan Meteorological Agency to calculate the 2-hourly wind field of TC which affected China sea and its adjacent regions from 1978 to 2007, got the 50km×50km grid wind speed of TC. And automatic meteorological observing station data was used to compare with the calculating results, the results indicated that calculating wind speed comparatively tallies with the observation wind speed. After that, Poisson-Gumbel joint extreme value model was adopt to calculate the wind speed of N years return period of each grid under the influence of TC, and finally the design wind speed can be provided for the development and safe operation of China offshore wind farm and other ocean engineering.

Keywords: tropical cyclone; asymmetrical typhoon model; Poisson-Gumbel joint extreme value model; ocean engineering

INTRODUCTION

Because of the energy shortage and region limitation of renewable energy development on land, many countries begin to strengthen the exploitation and use of ocean energy, ocean engineering, such as sea oil platform, offshore wind farm, etc., is increasing. China also faces the same question. On the one hand, China's coast is an important economic development zones, but energy shortage constrains the development of these regions, on the other hand, less and less land can be used, therefore, it's development trend to exploit ocean energy and develop offshore wind farm in China offshore.

However, China offshore is a tropical cyclone (TC) activity frequent region, according to statistic, about 12 TC pass China offshore every year, under the influence, ocean and coast projects are often destroyed by the high wind, wave and storm tide which were caused by TC, so the high wind distribution and the extreme wind speed of TC are important parameters for the design and safety of ocean engineering.

With TC approaching land, the original axisymmetric wind field becomes to asymmetric distribution, and the original round symmetric radius becomes to asymmetric radius.

At present, the experience typhoon wind field models are mostly using, such as Jelesnianski^[1], Fujita T^[2] and Myers^[3], etc.,

they proposed the centre symmetry wind field models, and Chen Kongmo^[4], Huang Xiaogang^[5], Yang Zhi-zhong^[6], Li Yan^[7] and Hu Banghui^[8], etc., they modified the symmetric model and proposed the asymmetric models. Through comparing these models, this paper selected asymmetric model, modified by Hu Banghui, et al.^[8], which could be better and easier to calculate the wind speed of offshore TC. Then using this model, the wind speed of TC was calculated, after that, Poisson-Gumbel joint extreme value model was adopt to calculate the wind speed of N (N=100, 50, 30, 20) years return period of each grid under the influence of TC, and finally the design wind speed can be provided for the development and safe operation of China offshore wind farm and other ocean engineering.

1. DATA AND CALCULATION AREA

In this paper, the used data are four parts below:

- 6-hourly TC central pressure and wind speed data from 1978 to 2007, which was provided by Shanghai Typhoon Institute of China Meteorological Administration.
- 6-hourly reanalysis data from 1978 to 2007, and the resolution is 125km × 125km, which was provided by Japan Meteorological Agency.
- Automatic meteorological observing station data, which was provided by China Meteorological Administration.
- Terrain data, its resolution is 25km × 25 km, which was provided by China Meteorological Administration.

In this paper, the calculation area is (15° N - 45° N) and (105° E - 130° E), and the wind speed of TC was calculated, only whose centre is in the calculation area.

2. Methodology and Case Calculation

2.1 Asymmetric Typhoon Model

In this paper, several typhoon models were compared with each other, combining with the asymmetric characters of offshore typhoon, the suitable asymmetric typhoon model was selected, which was modified by Hu Banghui, et al.^[8]. The main equations of this model was described below.

Taking the centre of TC as the origin and considering the friction of the sea surface, the plane polar coordinates equations for the horizontal movement of each point of air in the scale of TC may be written as,

$$\frac{dv_r}{dt} - \frac{v_\theta^2}{r} - fv_\theta = -\frac{\partial P}{\rho \partial r} + F_r \quad (1)$$

$$\frac{dv_\theta}{dt} + \frac{v_r v_\theta}{r} + fv_r = -\frac{\partial P}{\rho \partial \theta} + F_\theta \quad (2)$$

In the equations, F_r and F_θ is the friction separately on the direction of r and θ , and f is coriolis parameter, if it's assumed that the TC was stable and the pressure field was round, the equations, (1) and (2), may be written as,

$$-\frac{v_\theta^2}{r} - fv_\theta = -\frac{\partial P}{\rho \partial r} + F_r \quad (3)$$

$$\frac{v_r v_\theta}{r} + fv_r = F_\theta \quad (4)$$

If it's assumed that the pressure field of TC was expressed by Fujita T formula, the change of pressure and the pressure of any air point may be written as,

$$P = p_\infty - (p_\infty - P_0) \left[1 + 2 \left(\frac{r}{R} \right)^2 \right]^{\frac{1}{2}} \quad (5)$$

$$\frac{\partial P}{\partial r} = \frac{2(p_\infty - P_0)r}{R^2} \left[1 + 2 \left(\frac{r}{R} \right)^2 \right]^{-\frac{3}{2}} \quad (6)$$

Combining with state equation $P = \rho k_c T$ and equation (6), the equation (3) may be changed to,

$$\frac{v_\theta^2}{r} + fv_\theta = \frac{A}{r} - F_r \quad (7)$$

$$A = \frac{2k_c T (P_\infty - P_0) \left[1 + 2 \left(\frac{r}{R} \right)^2 \right]^{-\frac{3}{2}} r^2}{\left\{ P_\infty - (P_\infty - P_0) \left[1 + 2 \left(\frac{r}{R} \right)^2 \right]^{-\frac{1}{2}} \right\} R^2}$$

When the TC moves at the speed of v_s , at any point of TC, the relation between the curvature radius r' of stillness TC and the curvature radius r of moving TC may be written as^[9],

$$\frac{r'}{r} = \frac{v_\theta}{v_\theta + v_s \sin \alpha} \quad (8)$$

$$v_\theta = v'_\theta - v_s \sin \alpha \quad (9)$$

$$v_r = v'_r - v_s \cos \alpha \quad (10)$$

In the equations, v_θ is tangential velocity of moving TC, v'_θ is tangential velocity of stillness TC, v_r is radial velocity of moving TC, v'_r is radial velocity of stillness TC, and the α is the angle between the movement direction of TC and the line connecting any point to the centre of TC, the counter-clockwise is positive.

Using the equations, (4), (7), (8), (9) and (10), the following equations can be got,

$$\frac{v_\theta^2}{r} + \frac{v_\theta v_r \sin \alpha}{r} + f v_\theta = \frac{A}{r} - F_r \quad (11)$$

$$\frac{v_r v_\theta}{r} + \frac{v_r v_\theta \sin \alpha}{r} + f v_r = F_\theta \quad (12)$$

$$v_\theta = v \sin \alpha \quad (13)$$

$$v_r = v \sin \beta \quad (14)$$

$$F_\theta = k v \cos(\varphi + \beta) \quad (15)$$

$$F_r = k v \sin(\varphi + \beta) \quad (16)$$

φ : The angel between the direction of friction and opposite direction of wind vector, in this paper, $\varphi = 38^\circ$.

Putting the equations, (13) ~ (16), into the equations (11) and (12), and eliminating the v , the simple equation may be written as,

$$y^3 + zy + q = 0 \quad (17)$$

$$q = 2 \left[\frac{A - k^2 r^2 \cos^2 \varphi}{3kr \cos \varphi (v_s \sin \alpha + kr \sin \varphi + fr)} \right]^3$$

$$- \frac{A + 2k^2 r^2 \cos^2 \varphi}{3kr \cos \varphi (v_s \sin \alpha + kr \sin \varphi + fr)}$$

$$z = 1 - \frac{1}{3} \left[\frac{A - k^2 r^2 \cos^2 \varphi}{kr \cos \varphi (v_s \sin \alpha + kr \sin \varphi + fr)} \right]^2$$

$$y = \tan \beta + \frac{A - k^2 r^2 \cos^2 \varphi}{3kr \cos \varphi (v_s \sin \alpha + kr \sin \varphi + fr)} \quad (18)$$

Solving the equation (17), the results may be written as,

$$y_1 = 2\sqrt[3]{r} \cos \theta, \quad y_2 = 2\sqrt[3]{r} \cos(\theta + 120^\circ),$$

$$y_3 = 2\sqrt[3]{r} \cos(\theta + 240^\circ)$$

$$\text{And, } r = \sqrt{-\left(\frac{z}{3}\right)^2}, \quad \theta = \frac{1}{3} \arccos\left(-\frac{q}{2r}\right)$$

According to the equations (12) and (18), the calculation formulas of inner deflection angle of wind direction and wind speed of moving TC may be written as,

$$\beta = \arctan\left[y - \frac{A - k^2 r^2 \cos^2 \varphi}{3kr \cos \varphi (v_s \sin \alpha + kr \sin \varphi + fr)}\right] \quad (19)$$

$$v = \frac{kr \cos(\varphi + \beta) - v_s \sin \alpha \sin \beta - fr \sin \beta}{\sin \beta \cos \beta} \quad (20)$$

If the maximum wind speed ($V_{\max}$) of TC was known, the radius of maximum wind speed (R) and inner deflection angle of wind direction (β) may be written as,

$$\beta = \arcsin\left(-\frac{b}{2a} \pm \frac{\sqrt{b^2 - 4ac}}{2a}\right) \quad (21)$$

$$R = \frac{A_\alpha - v_s v_\alpha \sin \alpha \sin \beta - v_\alpha^2 \cos^2 \beta}{k v_\alpha \sin(\varphi + \beta) + f v_\alpha \cos \beta} \quad (22)$$

$$a = A_\alpha^2 (k \sin \varphi + f)^2 + k^2 \cos^2 \varphi (A_\alpha - v_\alpha^2)^2$$

$$b = 2k A_\alpha v_\alpha v_s \sin \alpha \cos \varphi (k \sin \varphi + f)$$

$$c = k^2 v_\alpha^2 v_s^2 \sin^2 \alpha \cos^2 \varphi - k^2 \cos^2 \varphi (A_\alpha - v_\alpha^2)^2$$

In this paper, the nonlinear effect of sea surface is considered, the formula of friction coefficient may be written as,

$$k = k_s \left[1 + 7 \frac{r}{R} \exp\left(-\frac{r}{R}\right) \right]$$

And, the reference value of k_s can be given, according to the practical terrain. In this paper, the air temperature upon sea

surface (T) is obtained from Japan reanalysis data.

In this paper, using the asymmetric model, combining with 6-hourly TC central pressure and wind speed data from 1978 to 2007 and 6-hourly reanalysis data from 1978 to 2007, the 2-hourly wind field of TC which affected China sea and adjacent regions from 1978 to 2007 was calculated.

2.2 Poisson-Gumbel Joint Extreme Value Model

In the process of engineering design, a maximum design wind speed needs to be identified for the consideration of safety and economy. Because the extreme value of climatic factors was changing with the years and period of observation, it's unreasonable to use the actual measurement extreme value as the basis. Usually the probability distribution is adopt to describe the climate extreme value, because the probability of extreme value of climatic factors is steady^[10]. So by probability statistic conclusion, maximum wind speed under a certain probability condition can be got.

Because yearly track, intensity and number of TC are random, they make a certain discrete distribution, but maximum wind speed under the impact of TC can make a certain continuous distribution^[11], so the distribution function $G(x)$ of maximum wind speed ξ_n can be calculated, under the condition that the probability distribution of appearance frequency n of TC is P_k .

Assume that the frequency n of TC accord with Poisson distribution, recorded:

$$p_k = e^{-\lambda} \frac{\lambda^k}{k!} \quad (1)$$

And $\lambda = \frac{N}{M}$, N is total number of TC affection, M is total years.

Assume that wind speed under the influence of TC accord with Gumbel distribution, recorded:

$$G(x) = \exp\{-\exp[-\alpha(x-\delta)]\} \quad (2)$$

Then, get the distribution function of Poisson-Gumbel joint extreme value distribution:

$$F(x) = \sum_0^k p_k [G(x)]^k = \exp\{-\lambda[1-G(x)]\} = P \quad (3)$$

$$\text{So,} \quad G(x) = 1 + \frac{1}{\lambda} \ln P \quad (4)$$

$$\exp\{-\exp[-\alpha(x-\delta)]\} = 1 + \frac{1}{\lambda} \ln P \quad (5)$$

Through twice logarithm, got

$$\alpha(x-\delta) = -\ln\left[-\ln\left(1 + \frac{1}{\lambda} \ln P\right)\right] \quad (6)$$

Then the wind speed extreme value of probability P is:

$$V_P = \delta + \frac{-\ln[-\ln(1 + \frac{1}{\lambda} \ln P)]}{\alpha} = \delta + \frac{-\ln[-\ln(1 + \frac{1}{\lambda} \ln(1 - \frac{1}{T}))]}{\alpha} \quad (7)$$

$\alpha = 1.28255/\sigma$, $\delta = \bar{x} - 0.57722/\alpha$, $\bar{x}$ is the average of sample series, σ is the standard deviation of sample series.

2.3 Case Calculation of Asymmetric Model

In this paper, the typhoon 0709 was selected to calculate the wind speed, in order to checking the calculating result of asymmetric typhoon model. Table I shows that the calculating wind speed comparatively tallies with the observation wind speed, that indicates that the result of the asymmetric typhoon model is reasonable.

The Fig.1, the corresponding figure of Table I, shows the wind speed distribution of model value. This figure shows that the wind field is asymmetric, and this tallies with the asymmetric character of TC approaching the mainland, and also tallies with the asymmetric character of shear wind and the character of the half-moon maximum wind speed at the right of TC.^[12]

Then, in this paper, the typhoon 9615 was calculated, using the asymmetric model. And the calculating result compared with the result of close isobar

model. Li Y. et al.^[7] calculated the wind speed using the close isobar model.

Table I : The model value (V-mod) and observation value (V-obs) of typhoon 0709. Unit: m/s; Time: UTC 2007091812

Lat	Lon	V-mod	V-obs
26.20	119.68	19.7	17.0
25.63	119.51	25.7	30.6
26.60	119.94	14.3	12.8
26.30	119.90	16.4	17.9
25.88	116.14	10.7	10.1
26.30	119.70	16.9	17.4
26.96	120.32	11.9	8.6
25.97	119.50	22.5	22.3

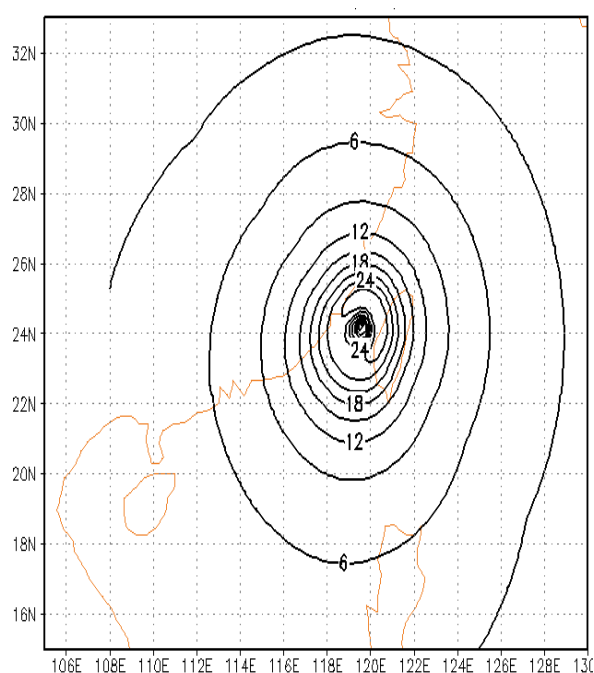


Fig.1: The corresponding figure of Table I , shows the wind speed distribution of model value.

The Fig.2 shows the wind speed distribution of close isobar model, and the Fig.3 shows the wind speed distribution of asymmetric model which was selected in this paper. By comparing, the structure and the result are similar. But asymmetric model used in this paper is easier to calculate than

the close isobar model, this also is one reason why this paper selected the asymmetric model which modified by Hu B, H. et al.^[8].

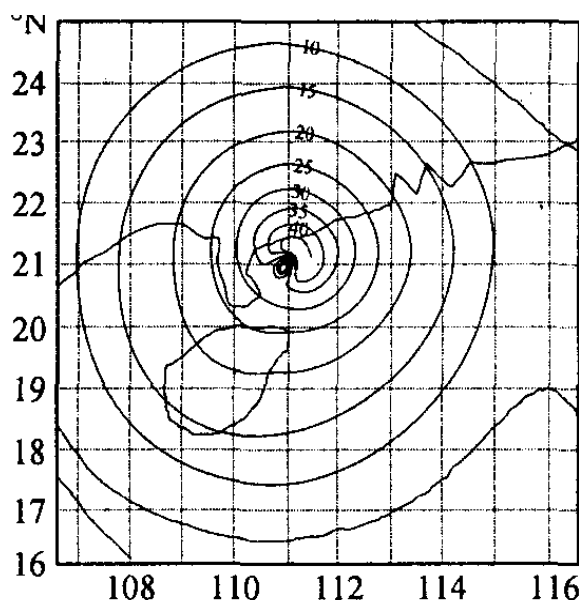


Fig.2: The figure shows the wind speed distribution of close isobar model value. (Cite: Li Y. et al.^[7]. 2003. Calculations for Sea Level Pressure Field and Wind Field Caused by Typhoon.)

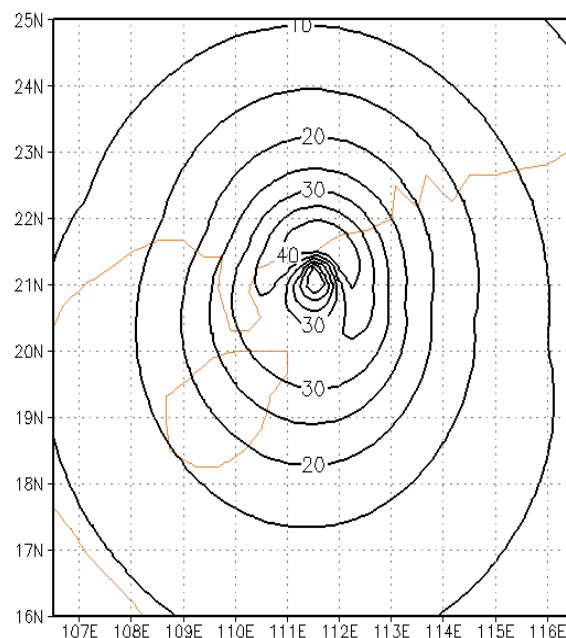


Fig.3: The figure shows the wind speed distribution of asymmetric model value.

3. RESULT

In this paper, the asymmetric typhoon model was used to calculate the 2-hourly wind field of each TC which impacted China offshore from 1978 to 2007, and the maximum wind speed of each grid point in terms of 50km×50km was obtained in China offshore. Poisson-Gumbel joint distribution needs that the sample values are independent from each other in the series, and in order to assure the maximum wind speed of each grid point is independent from each other, only a maximum value was selected for each grid point after the wind field of each TC process was calculated.

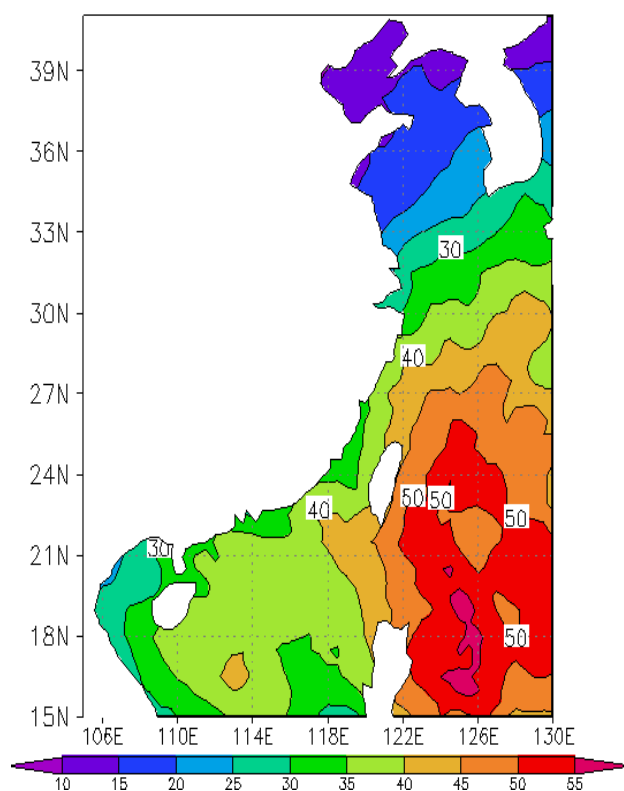


Fig.4a: Maximum 10 minutes average wind speed of 20 years return period

Finally, under the influence of TC, the maximum wind speed time series of 50km×50km-grid in China sea and its adjacent regions was calculated from 1978 to 2007. Then the Poisson-Gumbel joint extreme value model was adopted to calculate the maximum wind speed time series, and the results of the N (N=100, 50, 30, 20) years return period was got. The 1 second, 2

second, 1 minute, 2 minutes, 10 minutes and 1 hour time average maximum wind speed are generally required in ocean engineering. In this paper, only the figures of maximum 10 minutes average wind speed of 50 years return period distribution were given (see Fig.4).

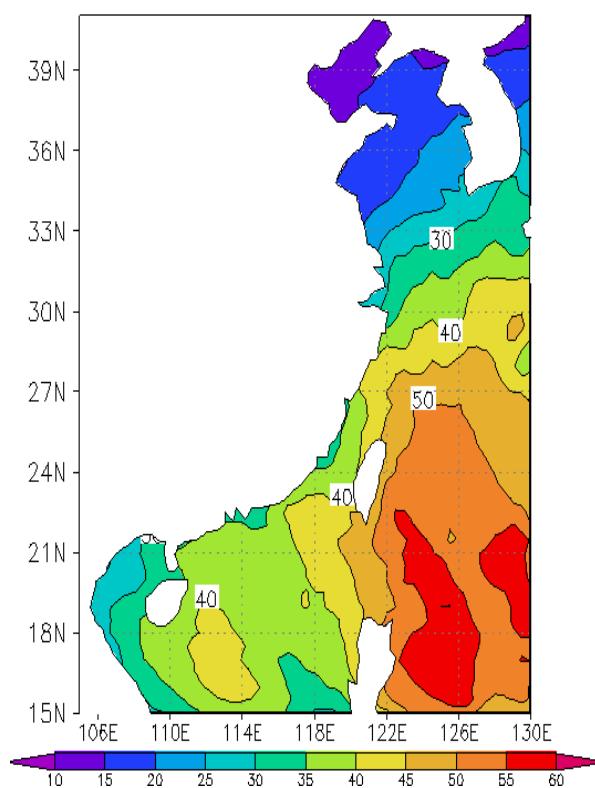


Fig.4b: Maximum 10 minutes average wind speed of 30 years return period

The Fig.4c shows the maximum 10 minutes average wind speed of 50 years return period (V_{50}), in this figure, the maximum wind speed is degressive from south to north in China Yellow Sea and East China Sea, in Yellow Sea, V_{50} is between 20m/s and 30m/s, and in East China Sea, V_{50} is between 35m/s to 50m/s; in Bohai Sea and the north of Yellow Sea, the reliability of calculated maximum wind speed of N years return period is lower because the frequency of TC is less, so the detailed analysis was not given. In Beibu Gulf, the north of South China Sea and the east of Bashi Channel, the maximum wind speed is

progressive increase from west to east, and V_{50} ranges from 30m/s to 60m/s.

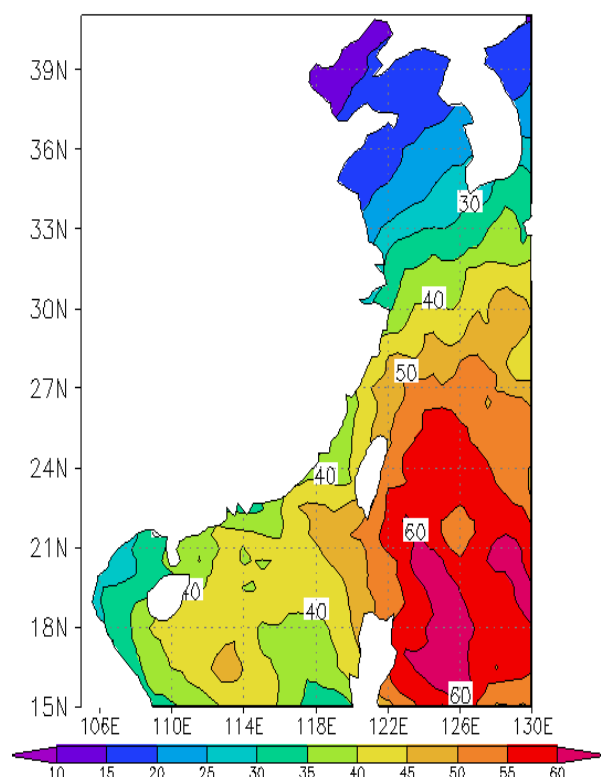


Fig.4c: Maximum 10 minutes average wind speed of 50 years return period

China offshore area is the major development and construction region for near-shore engineering, such as offshore wind farm, port engineering, etc., so it's especially important to study the influence of TC. In Jiangsu offshore area, V_{50} ranges from 20m/s to 30m/s, and in Hangzhou Gulf and Yangtze River estuary, V_{50} ranges from 30m/s to 35m/s; in the central-southern offshore area of Zhejiang and the northern offshore area of Fujian, the high wind caused by TC is strongest, V_{50} ranges from 40m/s to 45m/s. Because the TC was blocked and weakened by Taiwan Island, in the central-southern offshore area of Fujian, the influence degree of TC is less than its north and south adjacent sea area, and V_{50} ranges from 35m/s to 40m/s. In the north of South China Sea, the eastern offshore area of Guangdong, Shangchuan Island offshore area, and the eastern and the southern

offshore area of Hainan, the influence degree of TC is larger than other offshore areas, V_{50} is larger than 40m/s. Because the Leizhou Peninsula and Hainan Island weaken TC, V_{50} is less than 35m/s in Beibu Gulf.

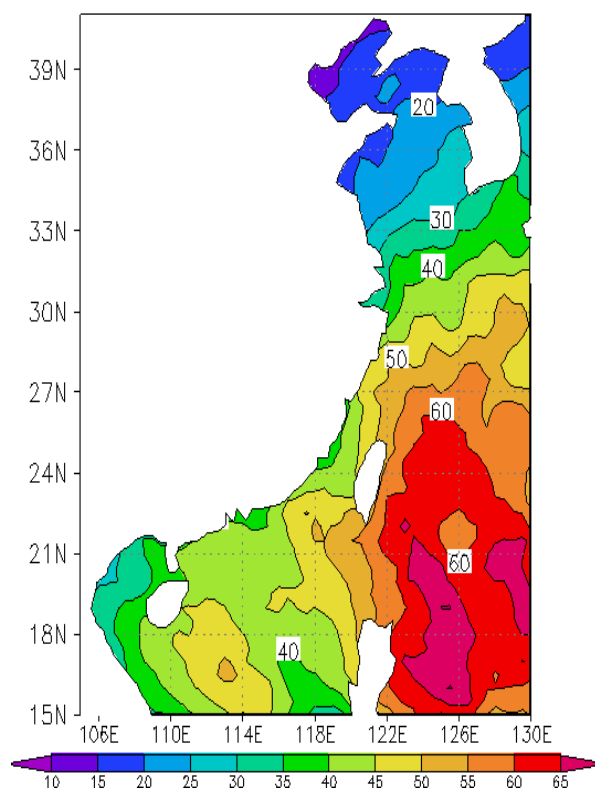


Fig.4d: Maximum 10 minutes average wind speed of 100 years return period

The wind speed distribution of other figures of Fig.4 is consistent with Fig.4c, only the values are different. For example, the maximum 10 minutes average wind speed of 100 years return period ranges from 45m/s to 50m/s in the eastern offshore area of Guangdong and the offshore area from the south of Zhejiang to the north of Fujian.

4. CONCLUSION

- In this paper, several typhoon models were compared with each other, and according to the asymmetric character of offshore TC, the asymmetric typhoon model was selected, and analysis

showed this model was easy to be calculated and understood, and the character of wind field calculated by the model accords with the asymmetric character of offshore TC.

- For the influence of TC is random, the Poisson-Gumbel joint extreme value model was adopt to calculate the maximum wind speed of N (N=100, 50, 30, 20) years return period.
- The distribution of maximum wind speed of N (N=100, 50, 30, 20) years return period is progressive increase from north to south in East China Sea and Yellow Sea, and it's progressive increase from west to east in Beibu Gulf, the north of South China Sea and the east of Bashi Channel.
- In the offshore area, the high wind caused by TC is strongest in the central-southern offshore area of Zhejiang and the northern offshore area of Fujian, secondly it's in the eastern offshore area of Guangdong and the eastern offshore area of Hainan, the maximum wind speed in the offshore area of central-south of Fujian, centre of Guangdong and west of Guangdong is less than the eastern offshore area of Guangdong, and the maximum wind speed is least in the north of Hangzhou Gulf and Beibu Gulf.

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REFERENCES

- [1]Jelesnianski C P. 1965. Numerical computation of storm surges Induced by a Tropical Storm impinging on a Continental Shelf. *Mon. Wea. Rev.*. Vol 93. No 16. pp343-358. Japan.
- [2]Fujita T. 1952. Pressure distribution in typhoon. *Geophy Mag.* Vol 23. pp437 - 452. Japan.
- [3]Myers V A. 1957. Maximum Hurricane Winds. *Bull. Amer. Metero. Sco.*. Vol 38. No 4. pp227. America.
- [4]Chen, K, M. 1994. A Computation Method For Typhoon Wind Field. *Tropical Oceanology.* Vol 13. No 2. pp41- 48. China.
- [5]Huang, X, G, Fei, J, F, Zhang, G, S, and Lu, H, C. 2004. Construction of Wind Speed in Typhoon on Ocean Surface. *Journal of Tropical Meteorology.* Vol 20. No 2. pp129 - 136. China.
- [6]Yang, Z, Z, Sha, W, Y, Zhu, S, X, and Li, Y. 2005. A New Nonsymmetrical Model of the Sea Surface Pressure and Wind Fields about Typhoon. *Marine Science Bulletin.* Vol 24. No 1. pp62 - 68. China.
- [7]Li, Y, Yang, Z, Z, Sha, W, Y, and Zhu, S, X. 2003. Calculations for Sea Level Pressure Field and Wind Field Caused by Typhoon. *Marine Forecas.* Vol 20. No 1. pp6 -13. China.
- [8]Hu, B, H, Tan, Y, K, and Hu, X, M. 1999. Distribution of Wind Speed of Tropical Cyclones over the Sea. *Chinese Journal of Atmospheric Sciences.* Vol 23. No 3. pp316—322. China.
- [9]Willson, B, J. 1957. Hurricane wave statistic for the Gulf of Mexico. *Proc, 6th Conf. on Coast Eng.* pp78. America.
- [10]Ma, K, Y, Ding, Y, G, and Tu, Q, P. 1993. Climatic statistic principle and method. China Meteorological Press. pp518. China.
- [11]Yan, J, Y, Chen, Q, G, and Zhang, X, Z. 1993. The Climate of Chian Offshore. Science Press. pp600. China.
- [12]Chen, L, S, Ding, Y, H. 1979. An Introduction to Typhoon in the West Pacific. Science Press. pp16-17. China.