Study on the assessment method of typhoon regional disaster based on the change of cholorophyll-a concentration in seawater

Di Wu[*#], Yu Zhang[*#], Hao Wang[§], Mengxing Huang[*#], Wenlong Feng[*#], Rouru Chen[*#]

[*]State Key Laboratory Marine Resource Utilization in South China Sea, Haikou, 570228, China
[#]College of Information Science and Technology, Hainan University, Haikou, 570228, China
[§]Big Data Lab, Dept. of ICT and Natural Sciences, Norwegian University of Science and Technology, Aalesund, 6009, Norway

Abstract—**Due to global climate change, the frequency and uncertainty of typhoon become more and more prominent. When a typhoon disaster occurs, it's an imminent problem to estimate the disaster zone and help ships to move to safer waters. Existing studies on typhoon disaster are mainly based on the overall wind assessment or the route prediction of the typhoon, with much less attention on the detailed impact in different regions along the route. In this paper, we propose a new estimate method based on the assessment of chlorophyll-a concentration in seawater. We (1) study Landsat-8 satellite images under typhoon weather and normal weather in the same area; (2) calculate chlorophyll-a concentration, based on which we (3) build a typhoon disaster model. The experiment shows that our model can assess the impact of a typhoon in different regions based on the level of chlorophyll-a concentration.**

Keywords—*typhoon disaster assessment; chlorophyll-a; typhoon hazard model*

I. INTRODUCTION

According to the analysis of 92 typhoons in the South China Sea during 1998-2009 by Yang and Tang [1], typhoon is mainly generated by tropical depression above the sea level. When the typhoon is coming, there will be a cold vortex in the upper ocean environment. The ocean thermal structure is not stable because of the cold vortex, so that the cold water below the mixed layer is more likely to be brought to the upper layer of the sea to cause phytoplankton bloom and increase the chlorophyll-a concentration [1][2].

A traditional method to studying typhoon is to use fixed-location buoys, so that the change of the water surface in those spots can be recorded. This method is inefficient, time-consuming, and can monitor only a small area. Along with the development of advanced satellite remote sensing technology, using satellites to monitor and study typhoon disaster is more efficient and effective due to large observation area, time and space synchronization, and continuity, and etc. For example, He and Zhang [3] monitored tropical storm "Sepat" and typhoon "Fitow" about their development route and its landing on Southeast China using the Fengyun-3 satellite Liu et al. [4] used Landsat-8 data, combined with Hainan Island topographic

index and damage potential index to make the impact analysis of typhoon for rubber tree plantations. However, these works mainly focus on the route prediction or the degree of overall impact, lacking the assessment of the impact on different regions along the typhoon route.

In this paper, with satellite data, we propose a new method by studying the chlorophyll-a concentration in seawater which is calculated by chlorophyll-a inversion operation with Landsat-8 sensing data. According to the regular change of chlorophyll-a concentration in the seawater during typhoon weather[5][6], we build a new typhoon disaster model, named *Chlorophyll-a Typhoon Disaster Model (CTDM)*, based on the regression model between growth rate of chlorophyll-a concentration, tropical cyclone intensity and moving speed, by Shao [7]. In particular, CTDM has the following advantages: Firstly, it does not need to directly measure the wind speed on the sea surface instead it assesses the impact of a typhoon by the change of chlorophyll-a concentration in the seawater when the typhoon is coming. Secondly, a more detailed assessment can be performed in different regions, compared to existing methods.

II. BACKGROUND

A. Chlorophyll-a Inversion Model

The principle of chlorophyll-a inversion by the satellite remote sensing technology is through the sensor of satellite to detect the surface of seawater and obtain relevant hydrological information. After reflection and scattering on the sea and spontaneous radiation, the electromagnetic waves emitted by the sensor carry the information on the sea surface temperature, sea surface roughness and the concentration of various substances in seawater back to the sensor. The sensor can measure the energy of different wavelengths of the electromagnetic wave, according to the analysis of the energy, we can deduce a variety of marine physical quantities such as the concentration of chlorophyll-a in the seawater.

In this study, the band ratio method is used to establish the chlorophyll-a inversion model. This model is as follows:

$$ChLa = a * (B\_NIR/B\_RED) + b \qquad (2-1)$$

Where $ChLa$ is the concentration of chlorophyll-a; B_{NIR} and B_{RED} are respectively expressed in the near infrared band and the red band; a and b are the coefficients.

B. The Regression Model

The correlation between typhoon and chlorophyll-a is complicated and influenced by many factors. It is more effective to set up the optimal combination with multiple independent variables to predict and estimate dependent variables than to use one independent variable.

The regression model is built with the change rate of chlorophyll-a concentration and the intensity of typhoon and the speed of typhoon, which comes from the experiment with the data from the South China sea by Shao [7].

$$Rate = \beta_0 + \beta_1 S_1 + \beta_2 S_2 + \varepsilon \qquad (2-2)$$

Where $Rate$ is the change rate of chlorophyll-a concentration; S_1 is the intensity of typhoon; S_2 is the speed of typhoon; β_0, β_1 and β_2 are the regression coefficient and estimated by data; ε is the random error.

C. Fujitais Empirical Formula

A great deal of experiments confirmed that the longitudinal distribution of the atmospheric pressure of typhoon above the sea surface can meet the requirements of Fujitais empirical formula [8]. Fujitais empirical formula is as follows:

$$p_{(r)} = p_E - \Delta p \left[1 + \left(\frac{r}{R}\right)^2\right]^{-0.5} \qquad (2-3)$$

$p_{(r)}$ is the atmospheric pressure of typhoon above the sea surface; p_E is the standard atmospheric pressure (generally 1000hpa); Δp is the intensity factor of typhoon, which also is the pressure difference between the environment and the center of typhoon; R is the scale factor typhoon; $\left[1 + \left(\frac{r}{R}\right)^2\right]^{-0.5}$ is used to standardize typhoon.

D. The Balance Model of Four Forces of Typhoon

Typhoon is a weather system with very strong self-organization, the structure of typhoon is clear and has a specific law. Typhoon in the movement is mainly affected by pressure gradient, centrifugal force, Coriolis force and friction force. The four forces balance in the ideal condition, as follows:

$$F_p + F_c + F_{Co} + F_f = 0 \qquad (2-4)$$

F_p due to the horizontal pressure difference, and it pushes the air particles from the high-pressure area to the low-pressure area, as follows:

$$F_p = \frac{\partial p}{\partial r} \qquad (2-5)$$

P is the atmospheric pressure of the observed place; r is the distance from the observed place to typhoon.

Because of the inertia of an object that makes a circular motion, there is always a tendency for the object to fly along the tangential direction of the circle. This tendency is described as:

$$F_c = \rho \frac{v^2}{r} \qquad (2-6)$$

ρ is the atmosphere density of typhoon area; v is the wind speed of the circumferential tangential direction.

The Coriolis force is a fictitious force used to explain a deflection in the path of a body moving in latitude relative to the earth when observed from the earth. This force is described as:

$$F_{Co} = \begin{cases} -\rho f u, & \text{（Tangential Coriolis Force）} \\ \rho f v, & \text{（Meridional Coriolis Force）} \end{cases} \qquad (2-7)$$

f is a constant determined by the selected region: $f = 2\omega * \sin\varphi$; ω is the angular velocity of the rotation of the earth; φ is the dimension value of the selected area, which is positive in the northern latitude area and negative in the southern latitude area.

The friction force is caused by the rubbing action of the surface of earth, as follows:

$$F_f = \begin{cases} \rho k h_u u, & \text{（Meridional Friction Force）} \\ \rho k h_v v, & \text{（Tangential Friction Force）} \end{cases} \qquad (2-8)$$

k is the friction coefficient; u and v are the speed of wind; h_u and h_v are the factor of wind shear.

III. CHLOROPHYLL-A TYPHOON MODEL

Generally, the friction coefficient k is estimated by the undermined parameters. And we make $h_u h_v = 1$. Then the equation (2-4) can be changed as follows:

$$\frac{v^2}{r} + fv - \frac{1}{\rho}\frac{\partial p}{\partial r} + \frac{1}{f}k^2 v = 0 \qquad (3-1)$$

We make integration and induction operation between equation (2-3) and equation (3-1), as follows:

$$frv + v^2 + frv^3 \left(\frac{k''}{f}\right)^2 = \frac{\Delta p}{\rho}\frac{a^2-1}{a^3}, \ a = \sqrt{1 + \left(\frac{r}{R}\right)^2} \qquad (3-2)$$

The typhoon parameters are determined by using the measured data and the data fitting method. The scale factor of typhoon and the friction factor are got by this way: the scale factor $R = 21.9$ and the friction factor $k = 3.7 \times 10^{-6}$. The parameters are taken into equation (3-2), then we get the equation about the wind speed of typhoon as follows:

$$v = \frac{1}{2}\left(-fr + \sqrt{(fr)^2 + 4\frac{\Delta p}{\rho}\frac{a^2-1}{a^3}}\right) \qquad (3-3)$$

The equation (2-2) is modified and integrated with the equation (3-3) to obtain the disaster model of wind power in the different and concrete region of typhoon area based on the change rate of the concentration of chlorophyll-a. The chlorophyll-a typhoon model is described as:

$$S_1 = \frac{Rate - \beta_0 - \frac{1}{2}\beta_2\left(-fr + \sqrt{(fr)^2 + 4\frac{\Delta p}{\rho}\frac{a^2-1}{a^3}}\right) - \varepsilon}{\beta_1} \qquad (3-4)$$

IV. THE MODEL IMPLEMENTATION

In order to build our new disaster model, we select and classify the original satellite data, then according to the typhoon path, we find the satellite data of typhoon disaster area.

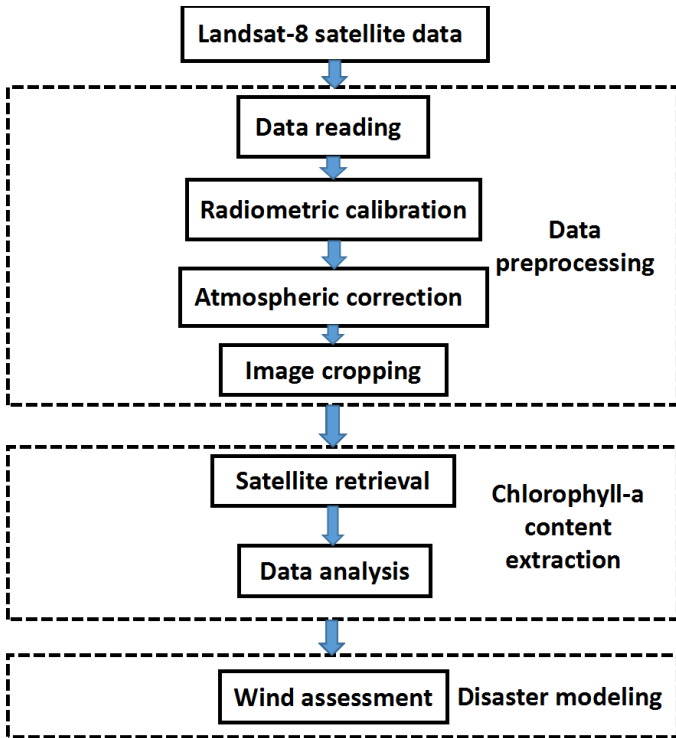Fig. 1 is the framework of the data flow that we used to implement new model.

Landsat-8 satellite data

Data reading

Radiometric calibration

Atmospheric correction

Image cropping

Data preprocessing

Satellite retrieval

Data analysis

Chlorophyll-a content extraction

Wind assessment Disaster modeling

Fig. 1. The framework

In this paper, the value of chlorophyll-a concentration in the seawater of the study area is obtained by satellite data preprocessing and chlorophyll-a inversion, and the related experiments are based on the ENVI (v5.3) software platform by Esri. The correlation coefficient is obtained by the simulation on the Matlab software platform. We combine the correlation coefficient and the inversion result of chlorophyll-a concentration to build the new disaster model, then, the model is applied to evaluate the impact in different regions of typhoon area.

The data flow of the framework makes the experimental process modular, and reduces the repetition rate of the experimental procedure.

V. EXPERIMENTS AND METHODS

A. Data

The experimental data is from NASA Landsat-8 satellite. The data is in TIFF format, including 11 bands information, image files, the file of quality evaluation and the metadata of TXT format. The quality evaluation file mainly includes the information of shooting time, solar elevation, latitude and longitude of the satellite data and so on. Landsat-8 data can be used to study in different fields by different band combinations. Therefore, the Landsat-8 data can be used to calculate the inversion of chlorophyll-a concentration in seawater. By means of radiometric calibration and atmospheric correction for Landsat-8 satellite data, the effects of atmospheric interference, systematic noise, the posture of sensor and so on can be removed.

In this experiment, we selected two satellite images have the same central dimension (N15.9^{o}; E111.9^{o}) at different times. Fig. 2 is the satellite image of the normal weather on August 31, 2015. Fig. 3 is the satellite image when the typhoon "Mujigae" came on October 2, 2015.
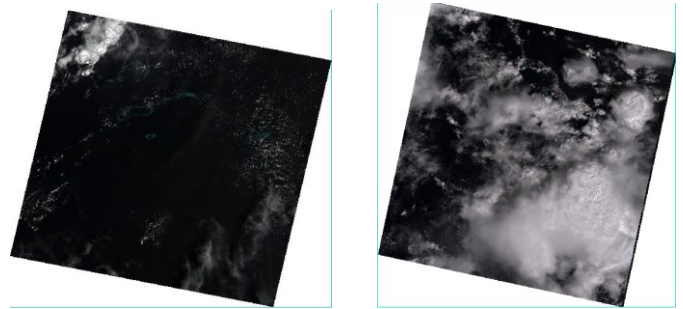

Fig. 2. The image of normal weather   Fig. 3. The image of "Mujigae"

The information on "Mujigae" is obtained by the South China Sea typhoon network (http://typhoon.hainan.gov.cn/).

B. Study Area

According to existing research, a typhoon will cause a large area of precipitation. The precipitation over the land of the coast will make the phytoplankton and the soluble organic matter into the coastal seawater, which will cause the increase of chlorophyll-a concentration in the coastal seawater [9]. At the same time, with the increase of population and the development of industry and agriculture in recent years, the eutrophication of coastal seawater has been aggravated [10]. The above interference factors will affect the experimental results. Therefore in this study, we chose the study area near the Xisha Island because of less interference factors. The Fig. 4 is the detailed assessment area selected according to the route of typhoon "Mujigae".

In Fig. 4, the central latitude of the study area is N15.9^{o} and the central longitude of the research area is E111.9^{o}. We selected point A(N16.572^{o}; E112.154^{o}), point B(N16.570^{o}; E112.162^{o}), point C(N16.449^{o}; E112.612^{o}), point D(N16.395^{o}; E113.903^{o}) and point E(N16.387^{o}; E112.915^{o}) as the sample points in the study area.

In Fig. 4, the time of the satellite image in the study area is Beijing time on October 2, 2015 at 11 a.m. At the same time, the position of typhoon "Mujigae" is shown as the small circle. The central latitude is N16.713^{o} and the central longitude is E119.3^{o} in the small circle. With the continuous movement of typhoon "Mujigae", we obtained the nearest position of typhoon "Mujigea" to the study area through the path of typhoon, as the bigger circle (the central latitude is N19.003^{o} and the central longitude is E114.201^{o}) in Fig. 4. The time of the bigger circle is Beijing time on October 3, 2015 at 4 p.m.

C. Experimental Environment and Method

On ENVI (v5.3) software platform, we obtained the level of chlorophyll-a concentration in the seawater by satellite inversion. Fig. 5 is the curve of spectrum of seawater before the atmospheric correction. Fig. 6 is the curve of spectrum of seawater after the atmospheric correction. By comparing Fig. 5

and Fig. 6, it can be concluded that satellite images can reflect the real situation of the solar radiation after the atmospheric correction.

The visualization, programming and the numerical calculation of the experiment are done in Matlab. The correlation coefficient of the new typhoon disaster model is obtained after a binary linear regression analysis.

The steps of the experimental method are as follows:

- To obtain the typhoon grate "s" of sample points: sa, sb, sc, sd, se.

- By the chlorophyll-a inversion operation, to calculate the chlorophyll-a concentration "CHL-a": CHL-aA, CHL-aB, CHL-aC, CHL-aD, CHL-aE.

- The relevant parameters of the sample points are brought into the equation (3-4) the new disaster model to obtain the calculated value "S" of the wind power of typhoon: SA, SB, SC, SD, SE.

- We made the curve of the typhoon grate "s", the curve of the chlorophyll-a concentration "CHL-a" and the curve of the wind power value "S" respectively. According to the comparison of the different tendencies of the above three curves, we determined if it is possible to assess the typhoon disaster in advance by studying the chlorophyll-a concentration of different sample points in seawater when the typhoon is coming.
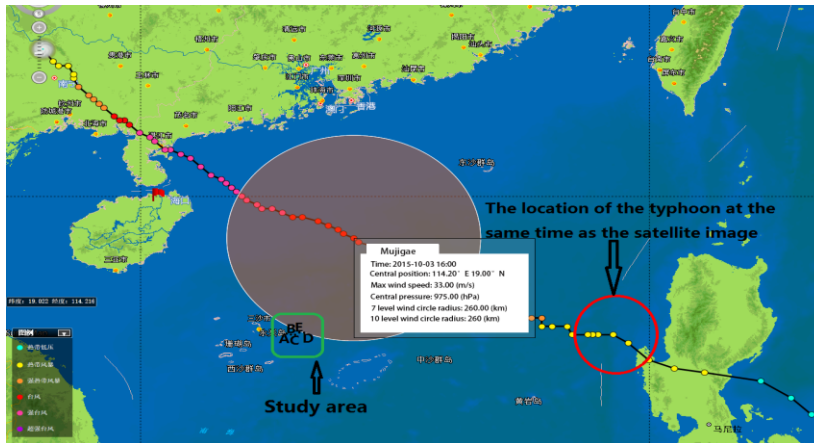
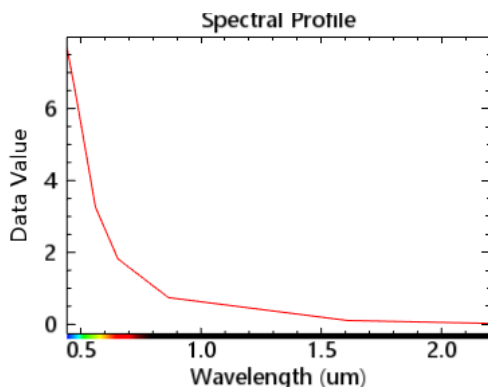Fig. 4. The moving path of typhoon "Mujigae"

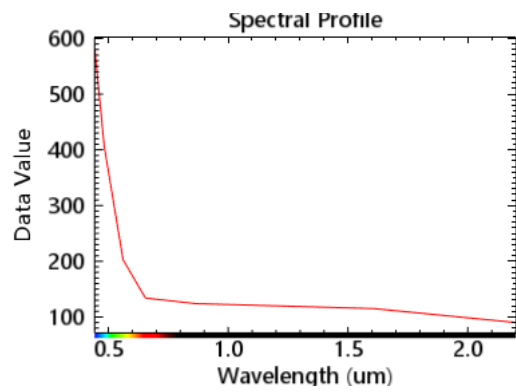Fig. 5. The curve of spectrum of seawater before the atmospheric correction

Fig. 6. The curve of spectrum of seawater after the atmospheric correction

VI. RESULTTS AND DISCUSSION

A. Chlorophyll-a Concentration

Fig. 7 is the distribution histogram of chlorophyll-a concentration in the study area. According to the distribution histogram, we can find the concentration of chlorophyll-a is mainly concentrated in 0-9 (μ g/L) and is in a reasonable range [11].
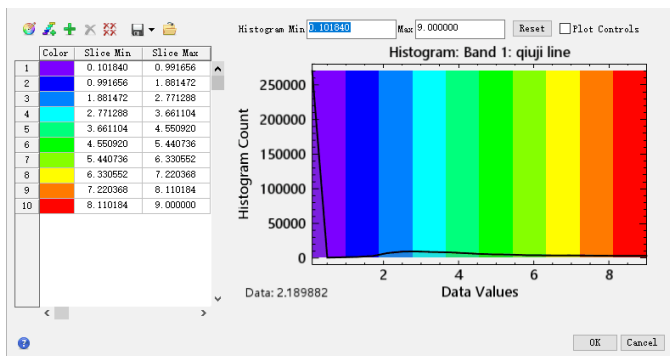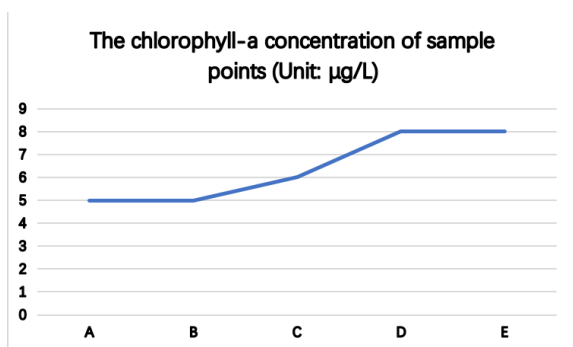
Fig. 7. The distribution histogram of chlorophyll-a concentration

At the same time, we obtain the value of the sample points A, B, C, D, and E. As shown in the Fig. 8, the value of point A is 5(μ g/L), the value of point B is 5(μ g/L), the value of point C is 6(μ g/L), the value of point D is 8(μ g/L) and the value of point E is 8(μ g/L).

B. The Wind Speed of Typhoon

The correlation coefficient of the new typhoon disaster model is obtained after the binary linear regression analysis in Matlab. We brought the correlation coefficient and the change rate of chlorophyll-a concentration in the sample points into the new typhoon disaster model, then we got the calculated value "S" of the wind power of typhoon. As shown in the Fig. 9, the value of SA is 33.714(m/s), the value of SB is 33.715(m/s), the value of SC is 33.766(m/s), the value of SD is 33.796(m/s) and the value of SE is 33.795(m/s). And the values of the wind power of the typhoon are conformed to the national standards for tropical cyclones in China, as shown in the TableⅠ.

C. The Discussion Between Chlorophyll-a Concentration And The Wind Power Value

Fig. 10 shows the distribution of chlorophyll-a concentration of the normal weather on August 31, 2015 in seawater of the study area. Through Fig. 10, we can see the concentration of chlorophyll-a distributed evenly in the normal weather condition, and the main concentration is concentrated on about 4(μ g/L).

Fig. 11 shows the distribution of chlorophyll-a concentration, when typhoon "Mujigae" was coming on October 2, 2015.

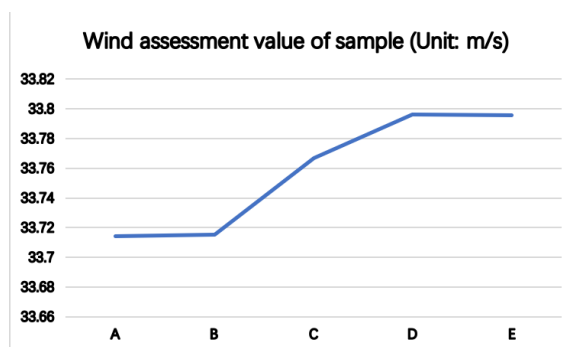Fig. 8. The chlorophyll-a concentration of sample points

Fig. 9. The wind assessment value of sample points

TABLE I.　　NATIONAL STANDARDS FOR TROPICAL CYCLONES IN CHINA

National Standards for Tropical Cyclones in China		
Grade of Tropical Cyclones	The maximum average wind speed near the center of the bottom ($m \cdot s^{-1}$)	The maximum wind near the center of the bottom(level)
Tropical depression	10.8~17.1	6~7
Tropical storm	17.2~24.4	8~9
Severe tropical storm	24.5~32.6	10~11
Typhoon	32.7~41.4	12~13
Severe typhoon	41.5~50.9	14~15
Super typhoon	≥ 51.0	16 or above

The white part of the image is the cloud brought by typhoon "Mujigae". In Fig. 11, we can see the concentration of chlorophyll-a in the seawater of the study area has a irregular distribution when typhoon "Mujigae" was approaching. The chlorophyll-a concentration in seawater of the study area is in 0.11-9.99(μ g/L), and the highest chlorophyll-a concentration is 9.99(μ g/L). The place of the highest concentration is near the area of the blast ring of typhoon "Mujigae". The concentration of chlorophyll-a in the rest area is different according to the wind power of typhoon "Mujigae".

By comparing Fig. 10 and Fig. 11, we can draw several conclusions as follows:

- When a typhoon comes, it will cause the change of chlorophyll-a concentration in the seawater.

- The concentration of chlorophyll-a in seawater is related to the wind power of a typhoon.

- Stronger wind means, higher chlorophyll-a concentration in the same area.

We compare the chlorophyll-a concentration with the wind power of typhoon "Mujigae" of the sample points in Fig. 12, and obtain the relationship between them. The Fig. 13 is the typhoon level of the sample points.

By comparing Fig. 12 and Fig. 13, we can see that the variation tendencies of chlorophyll-a, the wind power and the wind level of the sample points are the same.

Through the above experiments, it can be concluded that when typhoon comes, the change of the content of chlorophyll-a in seawater can be used to evaluate the typhoon's wind force in the region. The content of chlorophyll-a in different regions of the seawater indicates that the wind force is different in different regions. When the content of chlorophyll-a in seawater is higher, the wind force is stronger. The experimental results above, confirmed that our new typhoon disaster model (3-4) is feasible and effective for the prediction of typhoon disaster. The model also provides a new way to study the regional disaster of typhoon. According to the chlorophyll-a concentration in the seawater of the typhoon, the ship can choose the path with slower wind to reduce the loss caused by the typhoon disaster.
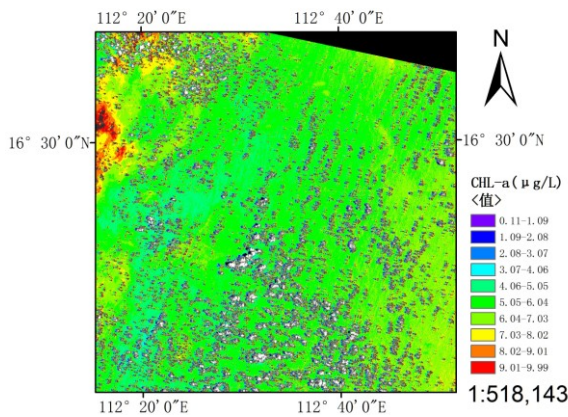

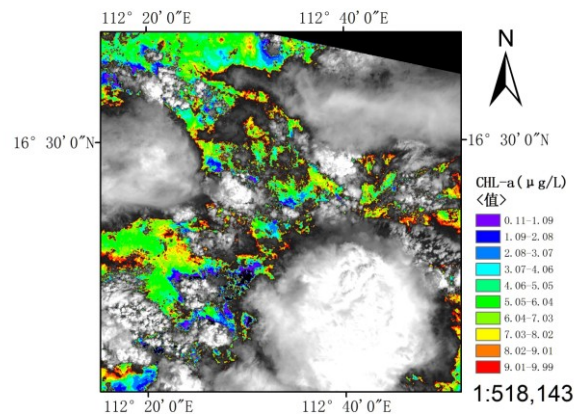Fig.10. The distribution in the normal weather

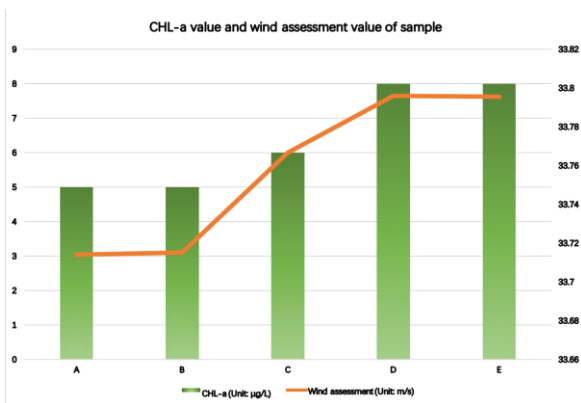Fig. 11. The distribution in typhoon "Mujigae"

Fig.12. The relationship between CHL-a value and wind power
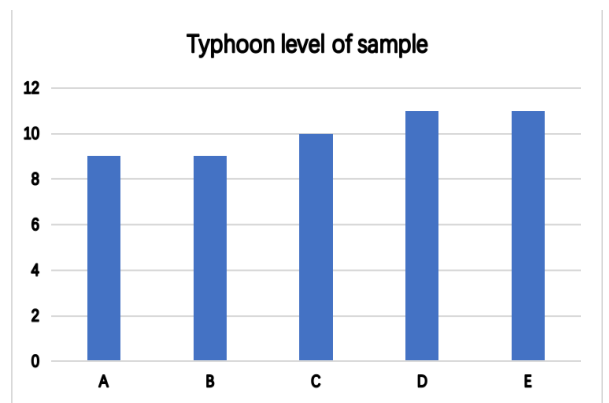

Fig.13. Typhoon level of sample points

VII. CONCLUSION

The study in this paper presents a new typhoon disaster model, forming a theoretical basis for the exploration of utilizing the variation of chlorophyll-a in seawater in the assessment of typhoon disaster. It provides a new way of thinking for further studies of the use of hydrological information in the typhoon weather for the assessment of regional disaster. At the same time, it can also help the ship to avoid the loss of life and property during the typhoon weather.

However, there are still some limitations in this study, which could be improved in next steps:

- The research data based on the data of NASA Landsat-8 satellite, which can be disturbed by the clouds in the typhoon weather. It is suggested that microwave remote sensing satellite data can be used, for example, the satellite data of GF-3, which has been launched in China. At the same time, it can also measure the concentration of chlorophyll-a in seawater by means of water buoy or coastal radar microwave detection. Through the fusion of multi-source data, the measurement accuracy of chlorophyll-a concentration in seawater can be improved.

- Our experiment only considered part of the South China Sea, and further validation of the model should be done in other regions.

REFERENCES

[1] Yang Xiao-xia, Tang Dan-ling, Location of sea surface temperature cooling induced by typhoon in South China Sea. Journal of Tropical Oceanography,2010, 29(4):26-31.

[2] Zhou L, Tan Y, Huang L, et al. Phytoplankton growth and microzooplankton grazing in the continental shelf area of northeastern South China Sea after Typhoon Fengshen. Continental Shelf Research, 2011, 31(16):1663-1671.

[3] He Jieying, Zhang Shengwei. Introduction of MWHTS onboard FY-3C Satellite and Typhoon Detecting. Remote Sensing Science, 2015(2):17-24.

[4] Liu S, Zhang J, Cai D, et al. Application of Landsat 8 in monitoring of rubber plantation typhoon disaster. Journal of Natural Disasters, 2016.

[5] Liu X, Wang M, Shi W. A study of a Hurricane Katrina-induced phytoplankton bloom using satellite observations and model simulations. Journal of Geophysical Research Oceans, 2009, 114(C3):819-834.

[6] Lin, I.‐I. Typhoon‐induced phytoplankton blooms and primary productivity increase in the western North Pacific subtropical ocean. Journal of Geophysical Research Oceans, 2012, 117(117):3039.

[7] Shao Jinchao. The impact of tropical cyclone translation speed and intensity on phytoplankon chlorophyll-a concentration in the northern South China Sea. Guangdong Ocean University, 2015.

[8] Wang Yunfeng, Lu Qiang, Wang Bin, Comparative Analysis of Four Initialization Schemes in Typhoon Numerical Simulation. Meteorological Science And Technology. 2011

[9] Davergne T. Offshore and nearshore chlorophyll increases induced by typhoon winds and subsequent terrestrial rainwater runoff. Marine Ecology Progress, 2007, 333(1):61-74.

[10] Li Zhao, Song Shuqun, Li caiwen. Distribution of chlorophyll a and its correlation with the formation of hypoxia in the Changjiang River Estuary and its adjacent waters. Marine Sciences, 2016, 40(2):1-10.

[11] Luan Hong. Based on Landsat8 the suspended sediment concentration and chlorophyll a concentration of the Pearl River Estuary remote sensing inversion and time and spatial change. Guangdong Ocean University, 2016.