The Windpower Model of Typhoon on the South China Sea

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Keywords: nonlinear parameter estimation, deviation revising, wind model of typhoon, wind power forecast

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Contents

Abstract

This paper, based on fluid mechanics of tropical cyclones and the fundamental relationship between wind and pressure, considering the balance among centrifugal force, Coriolis force, pressure gradient force and friction force in a quasi-axisymmetrical ideal situation, aims to set up the wind model of typhoon on the South China Sea by means of using the observed data and statistical method. The variables and parameters of mathematical model about typhoon wind are both highly complex and nonlinear, so the common data fitting and linear regression methods are not suitable for the parameter estimation of this model. Here, a method is suggested to estimate these parameters by repeatedly revising from their deviation, the estimated parameter is converted to a new parameter which is the deviation corresponding to an initial estimated parameter. Then the complex nonlinear model will be translated into a comparatively sample model which parameter is linear. This leads to a success in the parameter estimation of the both complex and nonlinear model. As the friction force can change very complicatedly in typhoon's evolution process, it is compared that two different formulation of friction force is separately with constant frictional factor or fluctuant frictional factor according to wind speed. The tests show that the model with fluctuant frictional factor based on the wind speed does a better work, the frictional factor has an obvious effect on the simulation wind. Based on the preliminary information given out by the weather forecast, people can make a detailed wind forecast at home by using the model we set up. This model can help people who live near the coastal areas to understand the destructive capacity of typhoon local winds faster and more easily, then to take a better defense.

Keywords: nonlinear parameter estimation, deviation revising,
wind model of typhoon, wind power forecast

1. Introduction

Typhoon (hurricane) is a severe tropical cyclone occurring on the tropical ocean. Typhoons are often accompanied by strong winds, heavy rains or severe storms and other convective weather. Typhoon can do severe destruction to some unsubstantial buildings, varieties of aerial wire, trees, ships at sea, marine fish cage culture and corps on the seaside etc. What's more, typhoon is seasonal which often happens during summer and autumn. China is one of the few countries which are most affected by the typhoon. As a matter of fact, typhoon has had a deep influence to some coastal cities in our country, for the reason that it has caused millions of dollars' economic losses to agriculture and fishery. The super typhoons "Saomai" (No.0608), for example, landed on Zhejiang province at about 17:25 on August 10th, 2006, with the maximum sustained winds near the center to 17 level (60m/s). And "Saomai" successively crossed many provinces and cities like Zhejiang, Shanghai, Jiangxi, Fijian and Taiwan. "Saomai" brought about $2.5- billion loss in total. Recently Severe Tropical Storm Nock-ten landed on Guangdong and Hainan province resulting in $5- million loss, 32 people missing and 16 deaths. Twelve counties and 126 towns in Hainan were affected, causing direct economic losses of 377 million Yuan. Besides, 59 million Yuan of water conservancy facilities were lost, and 18600 hectares of crops were destroyed.

As a responsible citizen, we have built up the wind model of typhoon on the South China Sea. We hope to help more people who live in littoral to see the damage of typhoon in a faster and easier way by using a simple arithmetic. In that way they can use some protective measures as soon as possible to better respond to typhoon and cut down the loss. As we know, the weather forecast fails to do very meticulous and accurate reports in general. So the fishermen and farmers who live on the sea can't get some accurate information to make preparations, which leads to the loss of property, even life-threatening. To sum up, with this relatively simple method of calculation, people can make a prediction to the further weather on their own according to the data from the weather forecast, and get ready.

2. The principle of the windpower model of typhoon

(1) The fundamental assumption of the model

There are many control parameters of the typhoon model. In order to build up our model expediently, we can do a proper predigestion [1]:

- The wind speed of typhoon model is determined by the four forces. They always keep in a dynamical balance. They are Coriolis force, friction force, pressure-gradient force and centrifugal force.
- The friction force is considered into two situations, a constant or a fluctuant factor depends on wind.(Typhoon is affected by the geostrophic influence and the friction force influence from the earth's surface)
- We take no consideration of random wind, but the main wind direction into account. The precision can be up to 80%.
- The natural environment of ocean and land or the facilities and the building on the surface may impact the speed and motion of wind differently. Here, we just consider the changes depending on the coefficient of friction in the underlying surface. (Choose classic value of them), and ignore other difference.

(2) The related formulas of the model

The distribution of the wind is a heated discussed topic among the domestic and foreign research, forecast, application and service on typhoon. Some scientists have built up typhoon wind distribution functions or models [2-4]. But their works focus on their scientific issues, rather than aims at t building up an applicable wind model for the general public. This paper is based on the summary of previous works. And aiming at the general public, we have built up a typhoon wind model near the ground. Because our model is in allusion to the atmospheric surface layer in which we live. We must take consideration about the complex friction in the underlying surface which was not included in the previous work.

We use "*r*" to denote the distance depart from typhoon center, which can be calculated by the longitude and latitude). It is also the independent variable in our model. The wind vector $\vec{V}$ is the wind speed of the typhoon flow relating to the ground, which we usually name it the wind speed. It includes two components, the tangential wind 'v' and the radial wind 'u'. In fact, the radial wind 'u' is much smaller than the tangential wind 'v'. So we just care about the calculation of the tangential wind 'v', 'v' is the variable which will be computed in the model.

The wind speed of typhoon is determined by the four forces, namely, Coriolis force, friction force, pressure-gradient force and centrifugal force. They keep in a dynamical balance in the ideal case. So we have:

$$F_{pressure} + F_{centrifugal} + F_{Coriolis} + F_{friction} = 0 \quad (1)$$

They are:

The pressure-gradient force: $F_{pressure} = -\frac{\partial p}{\partial r}$ （2）

The pressure-gradient force is caused by the horizontal pressure difference, it pushes the air particles from high pressure to low pressure. In the situation of our paper, p is the pressure of the location (the observation), r is the distance departs from typhoon center.

The centrifugal force: $F_{centrifugal} = \rho \frac{v^2}{r}$ (3)

Due to the inertia, objects doing circular motions always have a tendency of flying away along tangential direction. The tendency is known as the centrifugal force. The centrifugal force is force that actually doesn't exist, which is a virtual force assumed for helping people to understand and make things convenient. Hereinto, the "v" is the tangential wind in the circle. The "ρ" is the atmosphere density in the area of typhoon.

The Coriolis force: $F_{Coriolis} = \begin{cases} -\rho f u & \text{(Tangential friction)} \\ \rho f v & \text{(Radial friction)} \end{cases}$ (4)

The f is a variable in response to the earth rotation, which depends on the geographic latitude. Here, ω is the earth rotation angular velocity，φ is the latitude. The value of f on the south china sea is about $f = 5\times10^{-5}$。

The Coriolis force is to describe the migration of the linear motion in a rotation system (such as the earth). The Coriolis force comes from the inertial motion.

The friction force: $F_{\text{friction}} = \begin{cases} -\rho k h_v v & \text{(Tangential friction)} \\ -\rho k h_u u & \text{(Radial friction)} \end{cases}$ (5)

The friction force is caused by the friction of the earth's surface. We can simplify the friction force into the product on the coefficient *k*, the wind speed and the wind shear (h_u, h_v).

The friction coefficient *k* can be divided into two situations:

$$k = \begin{cases} k' & \text{(constant)} \\ k''V & \text{(variable)} \end{cases} \qquad (6)$$

To use the balance of four forces and equation (2),(3),(4),(5), we can get the following equations:

$$\begin{cases} \rho \dfrac{v^2}{r} + \rho f v - \dfrac{\partial p}{\partial r} - \rho k h_u u = 0 & \text{(Radial force balance)} \\ -\rho f u - \rho k h_v v = 0 & \text{(Tangential force balance)} \end{cases}$$

To eliminate ρ, they can be neatened further:

$$\begin{cases} \dfrac{v^2}{r} + f v - \dfrac{1}{\rho}\dfrac{\partial p}{\partial r} - k h_u u = 0 & (7) \\ f u = -k h_v v & (8) \end{cases}$$

We use (8) to substitute (7). After predigesting, we have

$$\frac{v^2}{r} + f v - \frac{1}{\rho}\frac{\partial p}{\partial r} + \frac{1}{f} h_u h_v k^2 v = 0$$

Because the influencing factor of friction force is very complex. We consider friction factor *k* as a parameter to be estimated. Without lossing generality, we define $h_u h_v = 1$. So the upper formula can be written into:

$$\frac{v^2}{r} + f v - \frac{1}{\rho}\frac{\partial p}{\partial r} + \frac{1}{f} k^2 v = 0 \qquad (9)$$

Equation (9) is the control equation of typhoon windpower. After getting the friction factor *k* and the pressure-gradient force, we can work out the tangential speed of typhoon wind.

Typhoon is a weather system which is strongly self-systematical. It has a clear configuration and special rule. We can find in plenty of scientific experiments that: the radial distributing of the sea level pressure content the empirical Formula by Fujitais [3].

$$p(r) = p_E - \Delta p[1 + \left(\frac{r}{R}\right)^2]^{-0.5} \quad (10)$$

Here, the p_E is the atmosphere sea level pressure of the typhoon environment (1000hPa in commonly). The Δp is the strength factor of typhoon, it is the pressure difference between environment and typhoon center. The R is an estimated parameter which describes the size and shape of typhoon. The function of $[1 + \left(\frac{r}{R}\right)^2]^{-0.5}$ is to standardize the various shape of typhoons.

Equation (9) and (10) are the fundamental equations in our mathematical model. Hereinto, the size factor R and the friction factor k are the estimated parameters (If the typhoon environmental pressure p_E is not confirmed, it can also be an estimated parameter.)

3. The estimation of parameters

From equation (9) and (10), we can infer that, to get the wind speed in the forecast location, we just need to estimate the size factor *R* and the friction factor *k*. The typhoon environmental pressure p_E can be obtained from the information of weather forecast. With the help of the scientific observation data, we use methods of data fitting to estimate the parameters. As the estimation of parameters in equation (9) and (10) are both complex, the common method of data fitting is not suitable for the parameter estimating. We need more appropriate methods to work it out.

(1) The method of estimating parameters

Define: $a = \sqrt{1+(\frac{r}{R})^2}$ （11）

Eq. (10) can be transformed into

$$p = p_E - \frac{\Delta p}{a} \quad (12)$$

or $$p = p_c + \frac{\Delta p}{a}(a-1) \quad (13)$$

Here $\Delta p = p_E - p_c$

From eq. (10), here is the pressure-gradient force

$$\frac{1}{\rho}\frac{\partial p}{\partial r} = \frac{\Delta p}{\rho}\frac{r}{R^2}\Big/\left(1+(\frac{r}{R})^2\right)^{1.5} \quad (14)$$

Use eq. (14) to substitute eq. (9), acquire

$$\frac{v^2}{r} + fv - \frac{\Delta p}{\rho}\frac{r}{R^2}\Big/\left(1+(\frac{r}{R})^2\right)^{1.5} + \frac{1}{f}k^2 v = 0$$

$$v^2 + frv - \frac{\Delta p}{\rho}(\frac{r}{R})^2\Big/\left(1+(\frac{r}{R})^2\right)^{1.5} + \frac{r}{f}k^2 v = 0$$

$$v^2 + \left(1+(\frac{k}{f})^2\right)frv = \frac{\Delta p}{\rho}\frac{a^2-1}{a^3} \quad (15)$$

Define: $\tilde{f} = f\left(1+(\frac{k}{f})^2\right)$ （16）

Then, we make a substitution of the variable. The eq. (15) can be translated into

$$v^2 + \tilde{f}rv = \frac{\Delta p}{\rho}\frac{a^2-1}{a^3} \quad (17)$$

Use eq. (13) to expunge Δp

$$v^2 + \tilde{f}rv = \frac{p-p_c}{\rho}\frac{a+1}{a^2} \quad (18)$$

When the wind speed and the pressure of the forecast location are both obtained, we can divide the parameter estimation into two steps, one is to get parameter *R*, and the other is to get parameter *k*.

a. The estimation of the nonlinear parameter "*R*"-size factor

In eq. (12), we only need to evaluate the size factor "*R*", barring friction factor "*k*". Therewithal, with the observation of the pressure, we can use data fitting to estimate the size factor "*R*".

Because the variable "*r*" and parameter "*R*" in the eq. (12) are nonlinear, the method of common data fitting can't be used to estimate the parameters. Therefore, we suggest a revising method of parameter deviation estimation to evaluate the nonlinear parameters as follows.

First, we can figure out R_o, the initial value of "*R*".

From eq. (12), we have

$$a = \frac{p_E - p_c}{p_E - p}, \quad R_0 = r/\sqrt{a^2-1} \quad (19)$$

Taking p_E=1000hPa into account, we use eq. (19) to average the initial R_o after calculating the size factor R from the data of pressure observation.

Second, we figure out Δ*R*, the parameter deviation of *R*, with the way of data fitting.

Although we can calculate the strength factor $\Delta p = p_E - p_c$ basically with the use of the information from the weather forecast. Actually, the environment pressure p_E maybe a little bit different from the average 1000hPa, which will impact the precision of the strength factor. Consequently, we also take p_E as a parameter to estimate.

When we do the function fitting of eq. (12) or eq. (13), we need to transform them aptly because of theirs complexity,

From (13)：

$$\ln(p - p_c) = \ln(p_E - p_c) + \ln\frac{a-1}{a}$$

We use Taylor expansion approximation to linearize the above equation. The right items of the equation are expanded respectively comparing the initial value p_{Eo} and initial value R_o, and the first order of the expansion formula is only reserved. The above equation can be translated into:

$$\ln(p - p_c) = \ln(p_{Eo} - p_c) + \ln\frac{a_0 - 1}{a_0} + \frac{\Delta p_E}{p_E - p_c} + \frac{\Delta a}{a_0(a_0 - 1)}$$

Here, Δp_E is the parameter deviation of the environmental pressure p_E. And Δa is the parameter deviation of the variable a. According to the connection between Δa and ΔR, the above formula can be written into:

$$\ln(\frac{p - p_c}{p_{Eo} - p_c}\frac{a_0}{a_0 - 1}) = \frac{\Delta p_E}{p_{Eo} - p_c} - \frac{a_0 + 1}{a_0^{\ 2}}\frac{\Delta R}{R} \qquad (20)$$

Define: $z = \ln(\frac{p - p_c}{p_{Eo} - p_c}\frac{a_0}{a_0 - 1})$; $x = \frac{1}{p_{Eo} - p_c}$; $y = \frac{a_0 + 1}{a_0^{\ 2} R_0}$

Eq. (20) can be transformed into:

$$z = x\Delta p_E - y\Delta R \qquad (21)$$

In this way, the variable "r" and the parameters "R，p_E" described by eq. (12), which are both complex and nonlinear models, can be transformed into a simple linear model described by eq. (21). Then we can use data fitting to estimate the parameters.

Define function:

$$g(\Delta p_E, \Delta R) = \sum_{n=1}^{N} (z_n - x_n \Delta p_E + y_n \Delta R)^2 \tag{22}$$

Here, n=1,…, N, the N is the total of the observations.

To solve $\Delta p_E, \Delta R$ when the $g(\Delta p_E, \Delta R)$ is extremal. At the extremum of $g(\Delta p_E, \Delta R)$, the derivative equal zero. We have：

$$\begin{cases} \sum_{n=1}^{N} (z_n x_n - x_n x_n \Delta p_E + y_n x_n \Delta R) = 0 \\ \sum_{n=1}^{N} (z_n y_n - x_n y_n \Delta p_E + y_n y_n \Delta R) = 0 \end{cases} \tag{23}$$

$$\begin{cases} \sum_{n=1}^{N} (z_n x_n) - \sum_{n=1}^{N} (x_n x_n) \Delta p_E + \sum_{n=1}^{N} (y_n x_n) \Delta R = 0 \\ \sum_{n=1}^{N} (z_n y_n) - \sum_{n=1}^{N} (x_n y_n) \Delta p_E + \sum_{n=1}^{N} (y_n y_n) \Delta R = 0 \end{cases}$$

$$\begin{cases} \Delta p_E = \dfrac{\sum_{n=1}^{N} (x_n y_n) \sum_{n=1}^{N} (z_n y_n) - \sum_{n=1}^{N} (y_n y_n) \sum_{n=1}^{N} (z_n x_n)}{\sum_{n=1}^{N} (x_n y_n) \sum_{n=1}^{N} (x_n y_n) - \sum_{n=1}^{N} (x_n x_n) \sum_{n=1}^{N} (y_n y_n)} \\ \Delta R = \dfrac{\sum_{n=1}^{N} (x_n x_n) \sum_{n=1}^{N} (z_n y_n) - \sum_{n=1}^{N} (x_n y_n) \sum_{n=1}^{N} (z_n x_n)}{\sum_{n=1}^{N} (x_n y_n) \sum_{n=1}^{N} (x_n y_n) - \sum_{n=1}^{N} (x_n x_n) \sum_{n=1}^{N} (y_n y_n)} \end{cases}$$

Whereupon，from $p_E = p_{Eo} + \Delta p_E$， $R = R_0 + \Delta R$ we can get the pressure of environment p_E and the size factor R.

Using the new value of p_E and R after the parameter deviation revising to perform an iteration for improving the accuracy of estimated parameters, until the desired accuracy is reached.

b. The estimation of parameters "*k*"-friction factor

From equation (17),we have

$$v^2 + frv + frv(\frac{k}{f})^2 = \frac{\Delta p}{\rho} \frac{a^2 - 1}{a^3}$$

Define: $z = \frac{\Delta p}{\rho}\frac{a^2-1}{a^3} - (v^2 + frv)$

(a) When the friction factor k is a constant, because $\Delta f = (\frac{k}{f})^2$, $\Delta f' = (\frac{k'}{f})^2$ also is a constant, we use least square method to evaluate $\Delta f'$. Then the parameter k' can be calculated.

Define: $y' = frv$

Eq. (15) can be written into

$$z' = y'\Delta f' \tag{24}$$

Define function:

$$g(\Delta f') = \sum_{n=1}^{N}(z_n - y'_n\Delta f')^2 \tag{25}$$

Here, n=1,…,N, N is the total of the observations.

To solve $\Delta f'$ when the $g(\Delta f')$ is extremal. At the extremum of $g(\Delta f')$, the derivative equal zero. We have:

$$\sum_{n=1}^{N}(z_n y'_n - y'_n y'_n \Delta f') = 0$$

$$\sum_{n=1}^{N}(z_n y'_n) = \Delta f' \sum_{n=1}^{N}(y'_n y'_n)$$

$$\Delta f' = \sum_{n=1}^{N}(z_n y'_n) / \sum_{n=1}^{N} y'_n y'_n)$$

$$\tilde{f} = f(1 + \Delta f')$$

In the situation, the eq. (17) can be cleared up into:

$$v^2 + \tilde{f} r v = \frac{p - p_c}{\rho}\frac{a+1}{a^2} = c \tag{26}$$

When the friction coefficient is a constant, $\tilde{f}$ is irrelevant to v. The above equation is a unitary quadratic equation. We can calculate it, keep the true solution and eliminate the virtual solutions. Then, we can get the following wind speed:

$$v = \frac{1}{2}\left(-\tilde{f}r + \sqrt{(\tilde{f}r)^2 + 4c}\right) \tag{27}$$

(b) When the friction factor k is a fluctuant factor depended on wind:

From equation (6), we have:

$$\Delta f = (\frac{k'' v}{f})^2 = v^2 (\frac{k''}{f})^2 = v^2 \Delta f''$$

Define: $y'' = frv^3$

Also have: $z = y'' \Delta f''$

We use least square method to calculate $\Delta f''$. Then, to calculate k''.

$$\tilde{f} = f(1+\Delta f) = f(1 + v^2 \Delta f'')$$

When the friction coefficient is a fluctuant factor depended on wind. The equation (18) is written into:

$$v^2 + frv + frv^3 \Delta f'' = \frac{p - p_c}{\rho} \frac{a+1}{a^2} = c \tag{28}$$

The equation above is a cubic equation. We choose Newton iteration method to obtain the true solution.

Define: $g(v) = v^2 + frv + frv^3 \Delta f'' - c$

$$g'(v) = 2v + fr + 3frv^2 \Delta f''$$

The iteration deviation is: $\Delta v = -g(v) / g'(v)$

Equation (28) is a cubic equation. There is no doubt that it has one true solution and two virtual solutions. The right choose of the initial value is the guarantee of acquiring the true solution. Because the cubic item of equation (28) is small in physics. The true solution is near the positive solution as the cubic item is taken out to become a quadratic equation. Forasmuch, the true solution of the quadratic equation is near its true solution, and they are in a monotonic interval. The iterative initial can choose:

$$v_0 = \frac{1}{2}\left(-fr + \sqrt{(fr)^2 + 4c}\right)$$

When the iteration reach 3-5 times, we consider it is constringed. At that time, v is the wind speed which we want to know.

(2) The results of the data fitting

We choose a group of observation (typhoon Molave, No.6 2009), as the tables showing. Table 1 is about the observing location and wind speed. Table 2 is about the position and pressure of typhoon center. Here we use Beijing time.

Table 1: Observing Location 22.60N，115.56E
Unit: Pressure-hPa， wind speed-m/s

Time (BJ)	pressure	Speed
0907181300	997.9	6.0
0907181330	996.8	9.0
0907181400	996.4	10.7
0907181430	995.8	10.5
0907181500	995.2	11.5
0907181530	994.2	12.4
0907181600	993.3	12.5
0907181630	993.0	13.9
0907181700	993.0	16.3
0907181730	992.7	15.5
0907181800	992.0	14.3
0907181830	991.4	16.3
0907181900	990.3	17.2
0907181930	989.2	19.4
0907182000	987.5	21.8
0907182030	986.5	22.8
0907182100	984.0	26.2
0907182130	980.7	31.8
0907182200	982.0	31.6
0907182230	986.2	22.5
0907182300	989.3	17.7
0907182330	991.5	17.1
0907190000	992.3	19.3
0907190030	993.9	16.5
0907190100	994.6	16.0
0907190130	995.2	16.4
0907190200	995.3	15.5
0907190230	996.2	13.1
0907190300	997.1	13.1
0907190330	997.6	15.3
0907190400	998.0	12.9
0907190430	998.8	12.3
0907190500	999.4	11.1

Table 2: Location, Pressure in typhoon center

Time (BJ)	Latitude	Longitude	Pressure
0907181300	21.7	117.4	970
0907181400	21.7	117.2	970
0907181500	21.8	117.1	970
0907181600	21.9	116.9	970
0907181700	22.0	116.7	970
0907181800	22.1	116.5	970
0907181900	22.2	116.2	970
0907182000	22.2	116.0	965
0907182100	22.2	115.7	965
0907182200	22.3	115.5	965
0907182300	22.4	115.1	965
0907190000	22.5	114.8	965
0907190100	22.5	114.5	970
0907190200	22.6	114.4	975
0907190300	22.7	114.2	975
0907190400	22.7	114.0	975
0907190500	22.7	113.7	980

The value of parameters is estimated as the follow:

a. Friction Coefficient is constant

The estimated parameter		
Pe (hPa)	*R* (km)	*k*
999.8	21.9	6.0E-05

b. Friction Coefficient depend on wind speed

The estimated parameter		
Pe (hPa)	*R* (km)	*k*″
999.8	21.9	3.69E-06

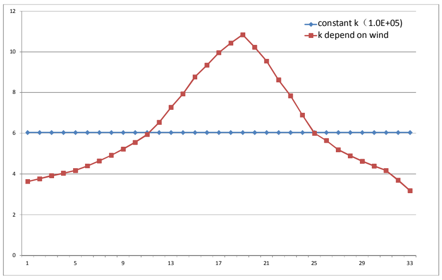


Figure.1 The friction coefficient (unit: 1.0E+05)

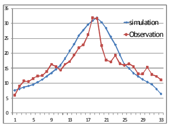
The red line is the value of variable k which depends on the wind speed, the blue are the value of constant *k*. All appearance, when the friction factor *k* depends on wind speed, the changes are more obvious.

(3) Parameters Verifying

a. Friction Coefficient is constant

Figure 2a shows the wind speed contrast between the simulation and observation. The blue points are simulation, the red points are observation.

Figure 2b shows the pressure contrast between the simulation and observation. The blue points are simulation, the red points are observation.



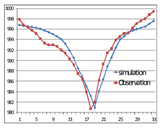


Figure 2a: the wind speed Figure 2b: pressure

From the figures, we can see the fitted value of the model match the observation.

b. Friction Coefficient depend on wind speed

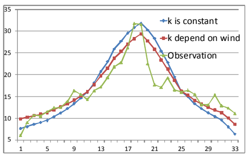


Figure 3: The wind speed

The figure 3 shows the contrast between the constant *k*, variable *k* and the observation. The green points are the observation, the red points are the variable *k*, and the blue points are the constant *k*. We can find that the simulation of variable *k* is closed to the observation except for the max points. And we can see the obvious difference between two situations. That means the friction is obviously producing effect on the results.

Figure 4 compares the simulation to the observation in fit error of speed of the two kinds of "*k*". The blue one represents the constant "*k"*, and the red one represents the variable "*k*".

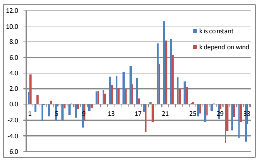


Figure 4: Fit Error of Speed

When the "*k*" depends on wind speed, the fit error is obviously smaller than the constant "*k*". So when "*k*" is variable, the mathematical model is much better.

The Root Mean Square Error of estimation speed (unit: m/s) is like the below table. When the "*k*" is variable, the root mean square error of the estimation is much smaller than the constant "*k*". And also much smaller than the typhoon wind speed itself, so the parameter estimation is good.

Root Mean Square Error	
constant k	variable k
3.8	2.7

According to all above, we chose the variable "*k*" to issue our mathematical model of typhoon wind.

4. Building of the typhoon model

From the above, when the "k" is variable with wind speed, the average root mean square error is smaller than the other. That means the precision is much higher on the condition that the variable "k" is used. Thereby, we choose the variable "k" to build up our model. We can conclude the wind speed of typhoon as follows:

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

In this equation, the typhoon size factor R=21.9 and friction factor k'' =3.7E-06 are the estimated value of the parameters from above.

This is a cubic equation about "v". It is worthy of consideration how to get the true solution. The Shengjin's Formulas, etc, were used to solve a cubic equation. But, these formulas is very troublesome to do, in special, it is difficult to determine which root is the true solution.

The Newton iteration method is adopted to solve the equation above. (It can reach the iterative convergence after 3 cycles). As the last part's description, in order to get the true solution in the end, the initial value of 'v' should be chosen as:

$$v_0 = \frac{1}{2}\left(-fr + \sqrt{(fr)^2 + 4\frac{\Delta p}{\rho}\frac{a^2-1}{a^3}}\right)$$

After estimating the parameters, we just need to know the distance between the forecast location and the typhoon center, the wind speed can be calculated. A calculation flow chart of our model is given as the Figure 5.

In the computation flow of our model, it is involved to forecast typhoon position. Here, we will use some preliminary information from the weather reports (including the current position of typhoon, the intensity and the moving speed) to calculate the position of typhoon at any time we want.

As long as the parameters are estimated and the scheme of the mathematical model is designed, the Matlab is used to program our model, and build an application system easy to operate. Users just need to input some fundamental information about typhoon, and the wind speed of typhoon can be gotten in a fast way.

Figure 6a and 6b is the input interface and output interface of our typhoon model program by Matlab. Users just need to get the information expediently from the internet and the media like television or radio. Then open Matlab, type "TyphoonModel" in the command window and input the information in the input interface. Then, we can get the output of the wind speed of the place we want. The output interface is shown in a direct way by the chart.

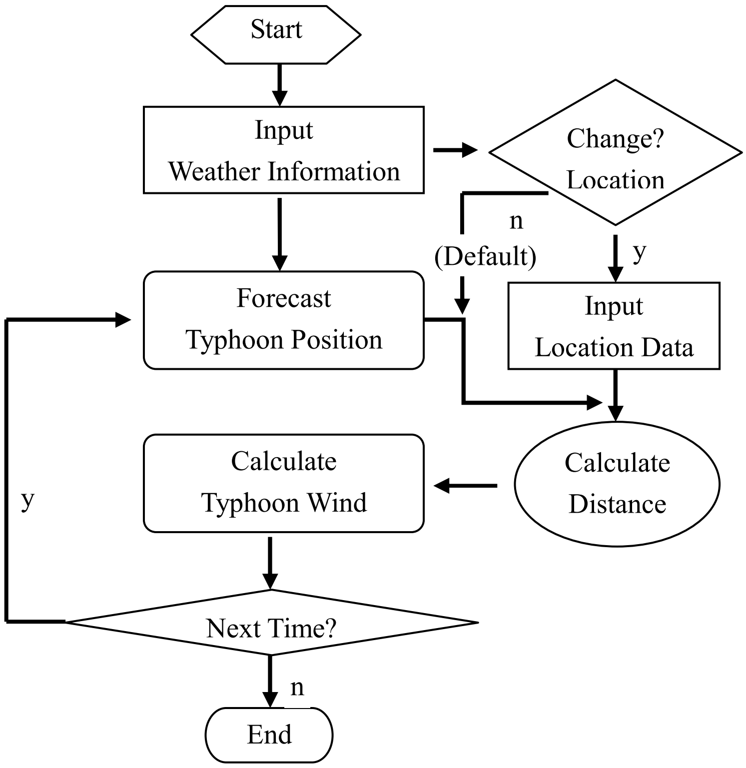
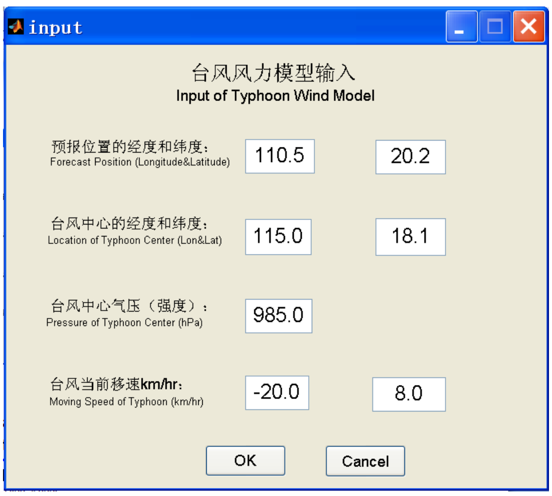


Figure 5: The flow chart



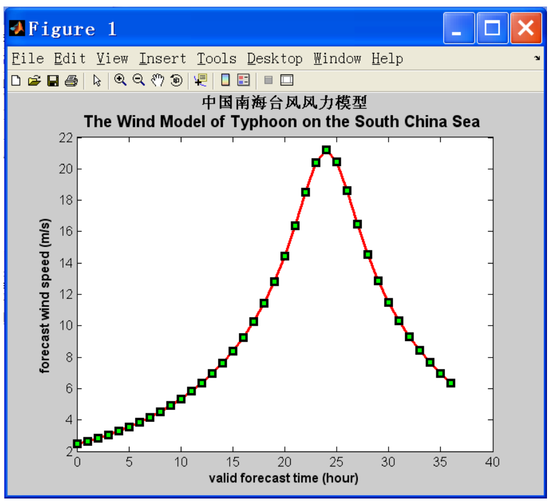


Figure 6a: Input Interface

Figure 6b: Output Interface

5. Application Example

(1) Case one: Typhoon "Nock-ten"

On the night of July 28th,2011, someone wanted to know how strong the typhoon will be at Qiongzhou Strait the next day and if the ship will be out of service.

The information of typhoon can be found on internet that the typhoon is located on 18.1N,115.0E at 20110728 16:00 16:00 BJ time, the center pressure is 985hP, and its movement is 20km/h, WNW.

From the above weather forecast, we can't get the detailed wind forecast of July 29th 2011. But using the typhoon model, we can forecast the wind speed of Qiongzhou Strait.

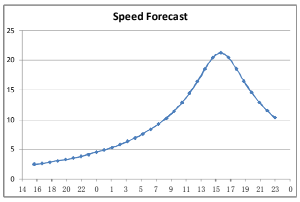


Figure 7: The forecast of typhoon wind

Figure 7 shows the wind forecast from the night of July 28th to the next day at Qiongzhou Strait (20.2N, 110.5E) by using our model. From the figure we can see that the wind speed at Qiongzhou Strait will be over 15 m/s from 12 a.m. to 8 p.m. of July the 29th. Because of the laws, the ship must stay in the harbor. So if that man wanted to cross the Qiongzhou Strait on 29th, July by ship, he must sail before noon or he would not be allowed to go.

The forecast by the model is close to accuracy.

(2) Case two: Typhoon “Nanmadol ”

On the night of August 29th ,2011, someone was worried about that his relatives who were traveling in Xiamen would meet the typhoon “Nanmadol ”. So he wanted to know if Xiamen would suffer from the strong wind the next day so that he could warn his relatives.

The information of typhoon found on the internet shows the typhoon is located on 23.5N,119.7E at 20110829 16:00 time, the center pressure is 982hP, and its movement is 10km/h, NW.

From the weather report above, Xiamen’s wind speed on August the 30th can’t be receive in detail. Using the typhoon model we set up, we can forecast the wind speed of a detail place in Xiamen.

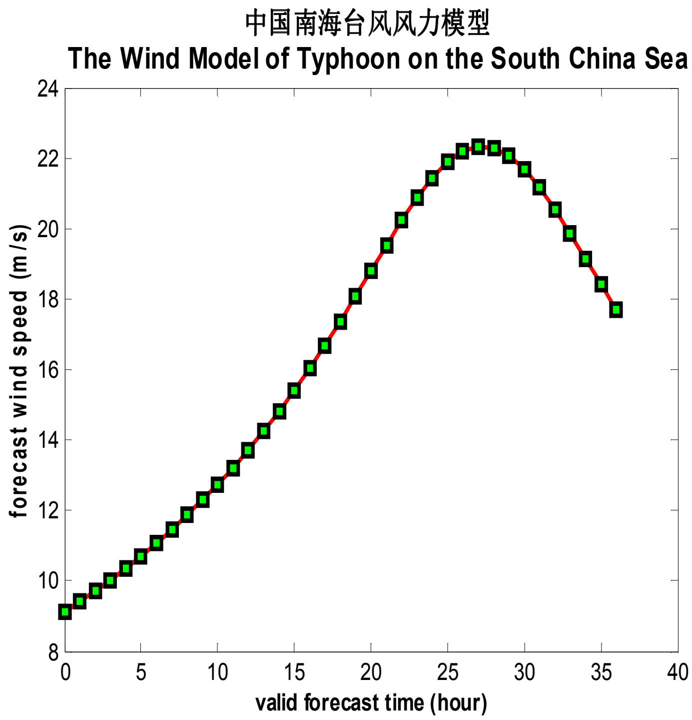


Figure 8: The forecast of typhoon wind

Figure 8 shows the forecast by the model of typhoon. We set up of the wind speed in Xiamen (24.43N, 118.06 E) from the time of the night on August the 29th to August the 30th. Looking at this figure, we can also find that from 2 p.m. to zero a.m. on August the 30th, the wind speed in Xiamen will be over 20m/s. So it’s not suitable to play on the coast.

6. Achievements

(1) In our paper, based on the physics rule of atmospheric, the dynamical balance among four forces, including centrifugal force, Coriolis force, pressure gradient force and friction force. We have built up the wind model of typhoon on the South China Sea can make a detailed wind forecast of Specific locations of interested with the fundamental information which can be searched form the weather forecast.

(2) The variables and parameters in our mathematical model about typhoon wind are both highly complex and nonlinear. Therefore, the common data fitting and linear regression methods are not suitable for the parameter estimation of our model. Here, an iteration scheme of deviation revision has been raised to estimate parameter of model with complex and nonlinear parameter. We call it "the revising method of parameter deviation estimation". In this scheme, the estimated parameters are converted to a new parameter which is the deviation corresponding to an initial estimated parameter. And this iterative estimation of the parameter deviation is substituted for nonlinear parameter estimation. Then the complex nonlinear model will be translated into a comparatively sample model of which the parameters are linear. We succeed in creating a new method to estimate the parameters which are both complex and nonlinear.

(3) The Friction force is the only one needed to be pending in the four forces. It is divided into two situations. One is a constant frictional factor and the other is a fluctuant frictional factor according to wind speed. The analysis shows that the frictional factor has an obvious effect on the simulation wind. And the tests show that when the friction coefficient is dependent on wind, the fitted value of the model match with the observation is better than constant coefficient. So we choose the variable k to build up our model.

(4) In this paper, the wind model of typhoon, a cubic equation about the variable "v" is first recommended in our paper. We use the Newton iteration method to solve the cubic equation. The result confirmed that the initial value "v_0" can be obtained from the positive solution of the quadratic equation after the friction is taken out.

7. Summary

(1) Main Conclusion

a. The wind model about the typhoon on the South China Sea is set up.

b. A method was suggested and applied to estimate nonlinear parameters. Based on the scientific observation data, the applicable parameter is obtained.

c. The application system is programmed by Matlab. The typhoon wind model is convenient and easy to operate.

d. The wind model has been tested by real case performing. The wind forecast skill of the model is enough to satisfy the living needs of most people, and it can be put into widespread use.

(2) Future Improvement

The model takes no consideration of the environmental flow. It will impact the estimation to a certain extent. In most situations, the movement of typhoon is consistent with steering flow. Typhoon's steering flow means that typhoon in the lower troposphere where the average high and low levels of environmental flow. Although we can use typhoon moving speed to estimate the steering flow, yet it's difficult to further separate layers of environmental flow (as typhoon wind speed near the surface).Meanwhile, for the actual typhoon, it is also difficult to separate the typhoon vortex wind from environmental flow. This is the reason why we take no consideration of the environmental flow, which needs to be further improved.

Here comes the simple analysis which didn't take the errors of the model caused by the environmental flow into account temporarily.

a. If the wind speed of typhoon is 20km/h, according to the rules that the environmental flow near ground is less than the steering flow, we can inform that the error which is caused by a lack of the environmental flow is lower than 5m/s.

b. As we know, the wind speed of severe typhoon can be more than 50m/s. consequently, compared to the wind speed, the error of 5m/s plays a less important part in the estimations of severe typhoon. However, it will bring a larger relative error to the wind speed of weak typhoon. But people always pay more attention to whether there is severe typhoon or not.

c. For the typhoon whose environmental flow is bigger, we can estimate that if it is on the right hand of its forward direction, the real speed is 5m/s more than the estimation. If it is on the left hand, the real speed is 5m/s less than the estimation. The left and right winds of typhoon are asymmetry, and the asymmetry speed can be up to 10m/s. It is necessary to pay attention to the practical application of the model.

(3) Rationalization proposal

a. The meteorological, hydrological departments and the Marine Department ought to strengthen the duty and monitor the forecast of flood control. Closely monitor the typhoon dynamics and make a prediction of not only the moving track of typhoons, the changes of intensity and the coverage but also the waves, rainfall and flood caused by typhoons in time. Departments at all levels are supposed to hold a meeting to discuss betimes according to the forecast. It's important to analyze the position and then nail down the key of defense. Ultimately, the weather bureau should investigate and carry out some precautions.

b. Local government should put the precautions into effect as soon as possible on the basis of the reserve plan. Strengthen monitoring and patrol along some places in danger like reconstructions, prone areas of geologic disasters. After finding out the risk, the government ought to forewarn duly and transfer of people who are in hazardous areas. Meanwhile, informing the public of the typhoon movement through media such as broadcast, television, newspaper, short messages and internet in time is also essential.

c. In peacetime, the relevant departments are expected to gain ground the consciousness of typhoon's precautions and tell the public how to protect against typhoon through various media or distributing pamphlets in order to improve the ability of defense. Or we can gain ground the wind model of typhoon to help them to see the damage of typhoon in a faster and easier way.

d. The public ought to enhance awareness of self protection and have a correct understanding of typhoon In advance. What's more, we need to pay more attention to the typhoon movement in daily life and get ready for them. When we are faced with typhoon, we should pay attention to the latest information given by the observatory. Before the coming of typhoon, we should prepare electric torches, radiograms, food, water and commonly used drugs in case.

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