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A Study on the Development of Typhoon Track Forecast Model Based on the Past Track Data

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Abstract : *This paper is aimed to develop a mathematical model for making the forecast information of typhoon's movement such as the estimated movement direction and positions after 24 and 48 hours. The proposed model calculates such kind of information of a typhoon by similar past typhoon's track data which are selected with three similarity criteria among the database of typhoons' tracks for past fifty years. We carried out a simulation forecast with No.14 typhoon formed in 1997, and found that the results of the proposed model were reasonable and it would be suitable for a simulation system for training mariners so that they can take suitable actions to evade the typhoons.*

Key words : *Typhoon's forecasting model, Similarity criteria, Avoiding typhoon simulation*

1. Introduction

Typhoons (or Hurricanes) have been the cause of many maritime disasters, and unfortunately there is no single rule that can be used by mariners to ensure safe separation from typhoons at sea. Although, in recent decades, modern technologies make communications more convenient and express, vessels more strong, meteorological information more complete and exact, vessels are still stricken by typhoons frequently and suffered a lot of losses and damages.

The main cause of such disasters is that mariners are lack of not only necessary knowledge for avoiding typhoons at sea, but also relevant training. Therefore, a simulation system is needed to train students and mariners in order that they can take suitable actions to evade typhoon's strike promptly and sufficiently.

Normally when a typhoon happens, mariners take actions under the consideration of information about typhoon such as present position, lowest pressure, maximum wind speed and the estimated movement direction with the positions after 24 and/or 48 hours from meteorological information center. Therefore, in this kind of simulation system, in order to be closer to the actual conditions, the forecast information of existing typhoon's movement should be supplied to the trainees so that they can take right actions to evade the existing typhoon. However, since we have no more information about historical typhoons except the track data, it is thought to be very difficult to get such kind information even if we want to make a simulation system with the past typhoons' data(Hope,1969 ; Hope,1970 ; Goerss,2004).

Therefore, in this paper, we propose a mathematical model for making the forecast information of typhoon's movement such as the estimated movement direction and positions after 24 and 48 hours. The proposed model calculates such kind of information of a typhoon by several past typhoon's track data which are selected with three similarity criteria. In simulation system, an instructor set an initial simulation environment parameter such as typhoon's position, date/month and so on. Then, the mathematical model calculates the forecast information of typhoon's movement with initial set parameters and shows such information to trainees by two dimensional graphics.

2. Forecast mathematical model based on similar tracks of past typhoons

A typhoon track is the result jointly caused by various physical factors that influence typhoon movement, and is forecasted commonly in consideration of those factors and similar tracks in history. Similar track, in this paper, means the past tracks which have similar movement and weather situation.

The proposed model calculates the future movement of a typhoon using the information of similar tracks selected by

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similarity criteria among 1,162 tropical cyclone tracks in the Western North Pacific area for 56 years from 1945 to 2001. All 1,162 tropical cyclone tracks and twelve past typhoons' tracks among them are shown in Fig. 1 and Fig. 2, and the original data of past typhoon track is shown in Table 1.

Table 1 Structure of past typhoon track data

Date : 5-23 AUG 1997 Super Typhoon #14						
ADV	LAT	LON	TIME	WIND (m/s)	PR (hPa)	STAT
1	5.60	168.00	08/05/00Z	15	1006	Tropical depression

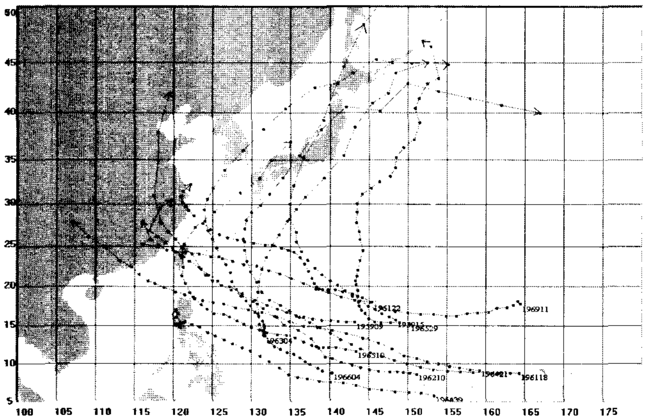

Fig. 1 Examples of past typhoon track

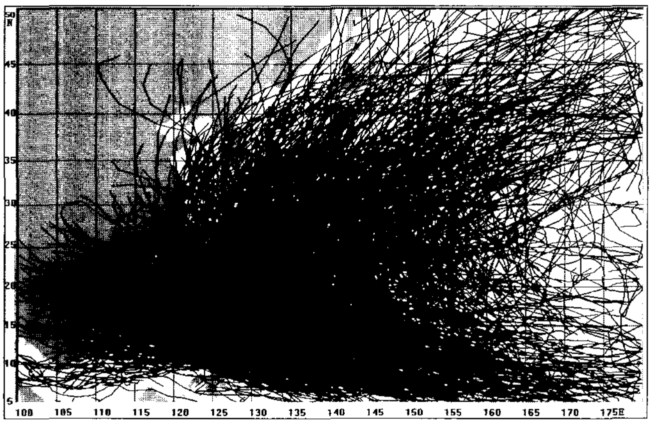

Fig. 2 All tropical cyclone tracks from 1945 to 2001

2.1 Database of past track data

We build the database of all tropical cyclone tracks by the tools of Microsoft Access which provides an inexpensive yet powerful database solution for small-scale projects. There are only two tables : one is "Summary" with 9 fields (YearNo, Name, FromMonth, FromDate, ToMonth, ToDate, MaxWind, MinPressure and Category), and another is "TrackData" with 9 fields (No, ADV, LAT, LON, TIME, WIND, PR, STAT, and YearNo). The relation of these two tables is indicated by the field "YearNo" owned in common. "YearNo" means the information of the year and the number of the sample typhoon. The structures of database and the contents of two tables are shown in Fig. 3 and Fig. 4.

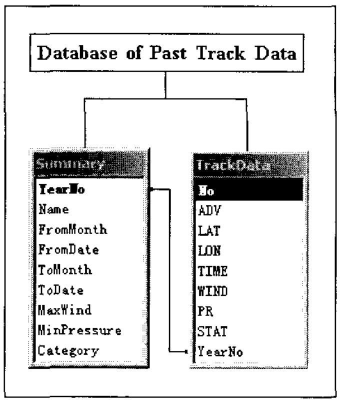

Fig. 3 Structure of the database

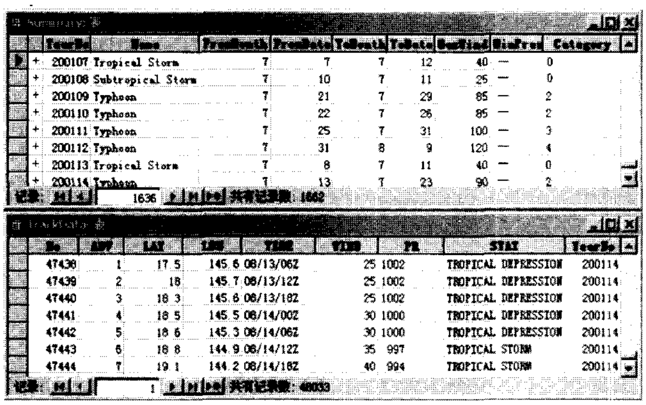

Fig. 4 Tables of the database

2.2 Similarity criteria

Typhoon track forecast by using similar course and similar weather situation in history is a common method based on experience. Therefore, the future movement of existing typhoon could be forecasted by information of similar tracks selected among all past typhoons' tracks.

In this paper, we define three similarity criteria for selecting similar tracks detailed as follows(Wang, 1987).

2.2.1 Occurrence time similarity criterion

Since the climate characteristic of atmosphere circulation varies with a time through the year and effects the typhoon's movement, the occurrence time of a typhoon is very important factor when we determine it's similar tracks.

If a typhoon formed, this criterion checks the occurrence time of all historical typhoons and defines as similar tracks which were formed within a period of 30 days, 15 days before and after the typhoon's occurrence time. This period may be longer in the season when the typhoon has a rare occurrence.

2.2.2 Geographical region similarity criterion

If the regions of typhoons are different, factors effecting typhoon movement are still different even if they are of occurrence time similarity. So, it is necessary to provide that similar typhoons are of geographical region similarity.

If a typhoon formed, this criterion calculates the distance from the typhoon's position to the tracks of all historical typhoons and defines as geographical region similar tracks which were apart less than 150 n miles. Fig.5 shows that the historical typhoons 1, 2, 3 and 4 are of geographical region similarity to the typhoon 0 and, the sample 5 is not.

$$D \leq 150 \text{ n miles} \quad (1)$$

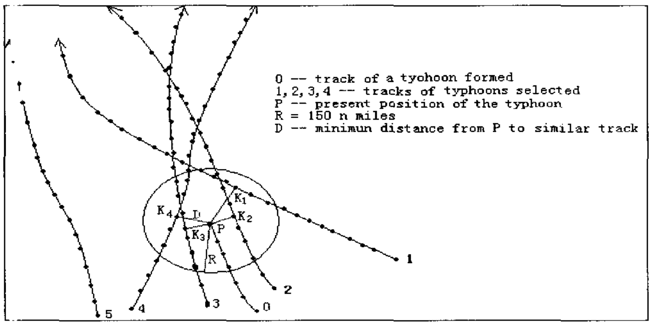

Fig. 5 Geographical region similarity of typhoons

2.2.3 Direction and speed similarity criterion

Typhoons with similar moving direction and speed reflect the similar comprehensive interactive effect of basic atmosphere circulation and typhoon's internal force. Moving direction and speed are very sensitive to forecast result even it may lead to forecast failure. This criterion calculates the differences of moving direction and speed between a typhoon formed and the tracks of all historical typhoons, and defines as a direction and speed similar track which has the difference as belows.

$$\text{direction difference} \quad \triangle\theta = |\theta-\theta_0| \leq 22.5° \quad (2)$$

$$\text{speed difference} \quad \triangle\upsilon = |\upsilon-\upsilon_0| \leq \upsilon_0/2 \quad (3)$$

Where θ and υ are the moving direction and speed of a typhoon formed, and θ_0 and υ_0 are those of the tracks of all historical typhoons, respectively.

2.3. Track Forecast Model

The proposed model calculates the estimated forecast position of a typhoon formed by two factors, which are the inertial factor of the typhoon and the average position's differences of similar tracks selected by three similarity criteria above-mentioned from the database of all past track data.

In this model, the inertial factor means an effect of initial typhoon's characteristics. Since the inertial factor is considered only within 36 hours and reduced with time at the rate of 1/6 every 6 hours during the simulation, it is no longer considered after 36 hours, and the forecast result is completely determined by the every 6-hours average position of similar tracks selected. The Fig.6 shows this process simply.

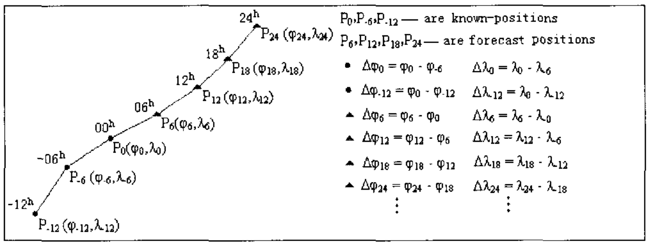

Fig. 6 Sketch of forecast process

In Fig.5, the P indicates the position of a typhoon No. 0 and the K_j (j=1,⋯,4) are the positions on each similar tracks minimum distance to P. This model calculates the average values of every 6-hour latitude differences ($\triangle\phi_{ij}$) and longitude differences($\triangle\lambda_{ij}$) of selected similar tracks at the positions K_j as follows(Chen, 1979):

$$\left.\begin{aligned} \overline{\Delta\varphi_i} &= \frac{1}{N}\sum_{j=1}^{N}\Delta\varphi_{ij} \\ \overline{\Delta\lambda_i} &= \frac{1}{N}\sum_{j=1}^{N}\Delta\lambda_{ij} \end{aligned}\right\} \quad (4)$$

Where, N is total number of selected similar tracks, and i(=6,12,⋯,72) and j(=1,⋯,N) are the forecast time and the sequential number of similar tracks respectively.

Then, taking into consideration that the weight of inertial function reduces with time within 36 hours(Chen, 1980), the model seeks the every 6-hour latitude differences($\triangle\phi_i$) and longitude differences($\triangle\lambda_i$) of a typhoon formed as follows:

$$\left.\begin{aligned} &\begin{cases} \Delta\lambda_i = \dfrac{36-i}{36}\Delta\lambda_0 + \dfrac{i}{36}\overline{\Delta\lambda_i} \\ \Delta\varphi_i = \dfrac{36-i}{36}\Delta\varphi_0 + \dfrac{i}{36}\overline{\Delta\varphi_i} \end{cases} \quad i < 36 \\ &\begin{cases} \Delta\lambda_i = \overline{\Delta\lambda_i} \\ \Delta\varphi_i = \overline{\Delta\varphi_i} \end{cases} \quad i \geq 36 \end{aligned}\right\} \quad (5)$$

Finally, we can obtain the forecast positions of a typhoon at every 6-hour interval as follows:

$$\begin{cases}\varphi_6 = \varphi_0 + \Delta\varphi_6 \\ \lambda_6 = \lambda_0 + \Delta\lambda_6\end{cases} \begin{cases}\varphi_{12} = \varphi_6 + \Delta\varphi_{12} \\ \lambda_{12} = \lambda_6 + \Delta\lambda_{12}\end{cases} \cdots \begin{cases}\varphi_{72} = \varphi_{66} + \Delta\varphi_{72} \\ \lambda_{72} = \lambda_{66} + \Delta\lambda_{72}\end{cases} \quad (6)$$

If there are no similar tracks of a typhoon formed, the model calculates its forecast positions by an extrapolation method using quadratic polynomial with the past three positions.

3. Realization of the mathematical model

3.1 The Flow Chart

The initial conditions such as the occurrence time and the three points of a typhoon's initial positions are set by a instructor, then the model calculates the initial moving direction and speed of the typhoon and finds it's similar tracks with three similarity criteria among all past typhoons' tracks. Finally, the model outputs the forecast positions of the typhoon by eq.(4)~(5) when there are some similar tracks or by the extrapolation method when there is no similar track. This forecast procedure is realized by programming using Visual Basic 6.0, and its flow chart is shown in Fig.7.

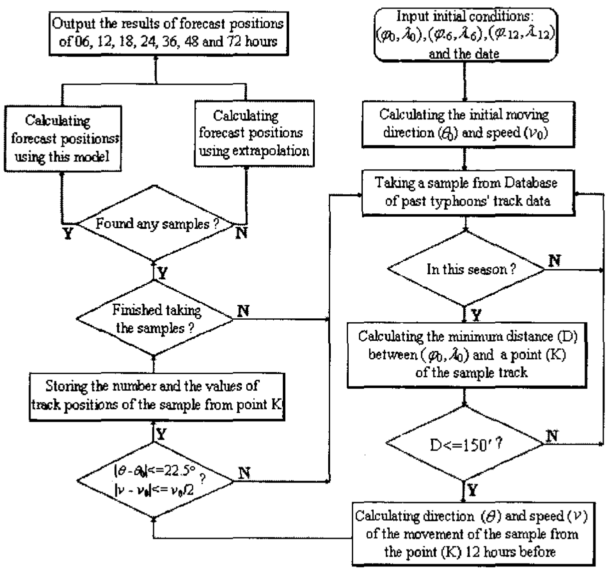

Fig. 7 Flow Chart of the model

3.2 Error radius of 24- and 48 hours forecast positions

Mariners receive typhoon's information through the weather facsimile at sea such as the present typhoon's location, lowest pressure, maximum wind force, its forecast position with error circle and so on. In order to make the simulation more actual, the present and forecast positions of a typhoon should be shown to trainees with its error circle.

We may consider that forecast error circle is caused by forecast direction error and forecast distance error, so that it could be calculated from these two errors by eq.(7).

$$R_i = \sqrt{\left(\frac{\beta\cdot\pi}{180}D_i\right)^2 + (\rho\cdot D_i)^2} = D_i\sqrt{\left(\frac{\beta\cdot\pi}{180}\right)^2 + (\rho)^2} \quad (7)$$

where with Fig.8, i is the forecast time(24 or 48 hours) and β and ρ are the forecast direction error and the rate of forecast distance error respectively. Here, β is the angle between $\overline{P_{00}F}$ and $\overline{P_{00}P}$, and ρ is the rate of $\triangle D$(the length difference between $\overline{P_{00}F}$ and $\overline{P_{00}P}$) and D(the distance between a present position and forecast position). We found the statistical values of those errors through 141 typhoons' tracks as shown in the following Table 2.

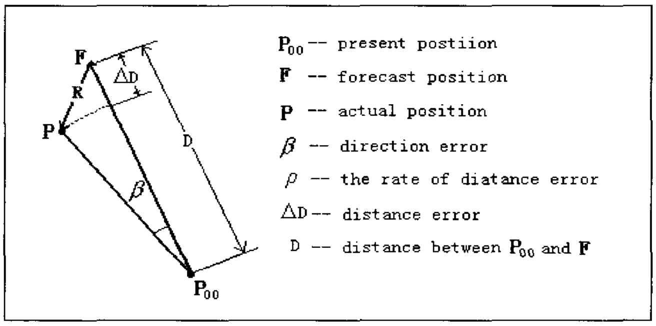

Fig. 8 Calculating error radius of forecast area

Table 2 Statical forecast errors

	24 hours	48 hours
β	14.3 deg.	17.5 deg.
ρ	0.236	0.273

3.3 Experiment of the Model

We applied No.14 typhoon formed on 14th August of 1997 to this forecast model, and evaluated its performance by comparing eight forecast positions with the corresponding actual ones from the time of 1200 on 14th August. Fig.9 shows both the forecast and actual positions for two days, and those data at the time interval six hours is shown in Table 3. Fig.10 is a example screen which is shown to trainees and it includes the present and forecast positions of the typhoon with the forecast error circle.

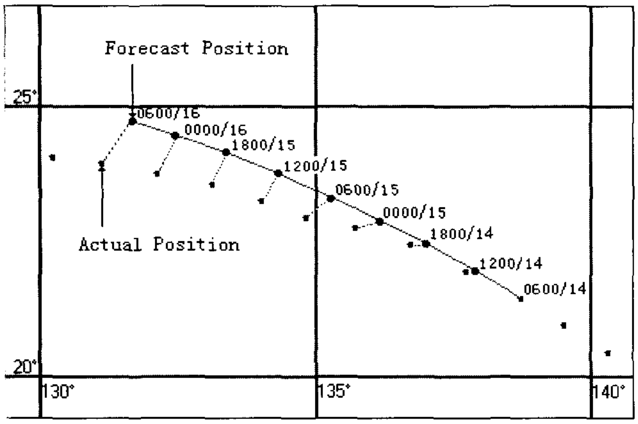

Fig. 9 Result of simulated forecast on No.14 typhoon in 1997

Table 3 Comparison between forecast and actual values

Interval	Time	Actual Values		Forecast Values		Radius of Forecast Error
00	0600/14	φ	λ	φ	λ	R_i(n miles)
06	1200/14	22.00	137.70	22.00	137.89	22.26
12	1800/14	22.50	136.70	22.49	137.02	45.46
18	0000/15	22.80	135.70	22.95	136.14	68.25
24	**0600/15**	**23.00**	**134.80**	**23.36**	**135.25**	**90.65**
30	1200/15	23.30	134.00	23.78	134.31	114.30
36	1800/15	23.60	133.10	24.18	133.36	137.81
42	0000/16	23.80	132.10	24.48	132.46	158.94
48	**0600/16**	**24.00**	**131.10**	**24.75**	**131.64**	**178.44**

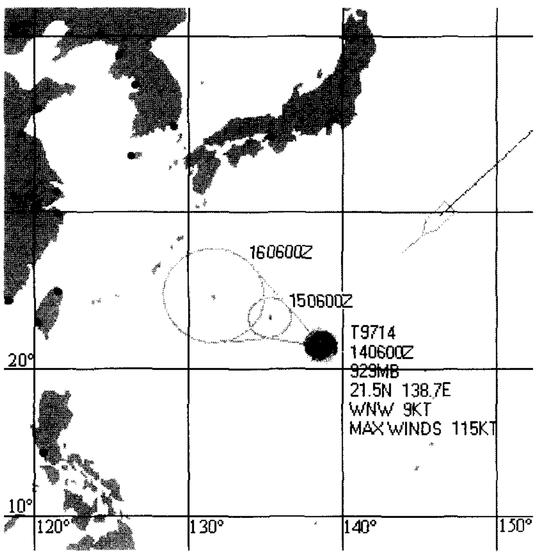

Fig. 10 An example screen during forecast simulation

Obviously, the accuracy of this kind forecast result is depended on the quantity and the quality of the tracks of selected typhoons. Since there are many past tracks to be selected in low latitude area and in midsummer season, the performance of this forecast model is fair and acceptable. Conversely, in transitional season and higher latitude area, and in other area with many samples but large degree of tracks dispersion, the result is poor. Moreover, for typhoons with low-probability movement (such as stagnating, spinning and twisting) and with a sudden change of moving speed, this model is lack of capability to forecast them.

4. Conclusion

In this paper, we built a database of past typhoon tracks, defined three criteria for determining similar tracks, and then proposed a mathematical model for forecasting a typhoon's movement with the forecast error circle. We carried out a simulation forecast with No.14 typhoon formed in 1997, and found that the results of the proposed model were reasonable and it would be suitable for a simulation system for training mariners so that they can take suitable actions to evade the typhoons.

In future, we will develope a model for calculating meteorological information such as wind force and direction at any location around the center of typhoon, so that mariners could be evaluate their avoiding actions with the view point of sea-keeping performance at sea.

REFERENCES

[1] Chen Lianshou and Ding Yihui(1979), "General review of typhoon in West Pacific", Meteorological Publisher, China.

[2] Chen Lianshou and Shu Jiaxin(1980), "A review of typhoon research and operational prediction in China", Symposium on Typhoons, Shanghai, China.

[3] Goerss, C. R. Sampson, and J. Gross(2004), "A history of Western North Pacific tropical cyclone track forecast skill", Wea. Forecasting 2004.

[4] Hope, J. R. and C. J. Neumann(1969), "An operational technique for relating existing tropical cyclone to past track", the sixth AMS Conference on Hurricanes, Miami, USA.

[5] Hope, J. R. and C. J. Neumann(1970), "An operational technique for relating the movement of existing tropical cyclones to past track", *Mon. Wea. Rev.*, 98(12).

[6] Wang Zhilie and Fei Liang(1987), "Typhoon Forecast Manual", Meteorological Publisher, China.

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