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A STATISTICAL MODEL FOR PREDICTION OF INTENSITY AND FREQUENCY OF TROPICAL CYCLONES MAKING LANDFALL ON CHINA

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Abstract: Based on NCEP/NCAR reanalysis data and Yearbook of China landfalling tropical cyclones (hereafter CLTC) from 1949 to 2008, correlation between CLTC frequency/intensity and 500 hPa height field and sea surface temperature (SST) fields are investigated and employed for TC statistical prediction. A prediction model for yearly and monthly intensity and frequency of CLTC is established with binomial curve fitting by choosing the gridpoints with high correlation coefficients as composite factors. Good performance of the model in experiments shows that the model could be used in routine forecast.

Key words: weather forecast; binomial prediction model; China-landfalling TCs; intensity and frequency

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1 INTRODUCTION

China is one of the countries most affected by tropical cyclones (TCs) with an annual direct economic loss of more than 22 billion yuan[1] during 1982 to 2006. Therefore operational TC forecast methods are in urgent need for better meteorological disaster prevention and mitigation. Previous studies have made valuable contribution to investigating CLTC activities and related atmospheric circulations as well as the relationships between them[2-12]. Proposed prediction models for CLTC[13-17] are plentiful, but few of them are proved to be operationally useful in the prediction of yearly and monthly TC intensity and frequency. Prediction models by polynomial curve fitting can predict maxima and minima better, compared with traditional linear regression equations. Years of practice and experiments show that binomial curve fitting is more favorable for predicting yearly and monthly TC frequency. Hence, based on the analysis on the correlation of CLTC frequency and intensity with preceding winter (from December to February) SST and geopotential height gridded field at 500 hPa, a forecast model based on binomial equation has been established and a verifying process has been completed.

2 DESCRIPTIONS

2.1 *Predictors*

This paper chooses the monthly average SST and monthly average 500 hPa geopotential height as predictors after referring to the National Center for Environmental Prediction (NCEP)/ National Center for Atmosphere Research (NCAR) monthly average SST (5°×5° latitude-longitude grid) of North Pacific (10–50°N, 120°E–85°W) and the monthly average 500 hPa geopotential height field (5°×10° latitude-longitude grid) of the Northern Hemisphere (10–85°N).

2.2 *Prediction objects*

In this paper, the predictants are the monthly and yearly frequency and intensity of CLTC and its maximum intensity (the maximum value of peak wind velocity near the center in sea areas west of 140°E) before landfall. The sample data, or the monthly (from May to December) and yearly datasets of predictants, were established according to the Typhoon (Tropical

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Cyclone) Yearbooks (1949–2008) published by China Meteorological Administration (CMA).

2.3 *Application*

A year-by-year verifying process has been completed by comparing predictions by binominal equation with actual situations. By assuming *Y* as a particular year to be tested between 2001 and 2008, we obtain the coefficient of prediction equation factors through the sample data of prediction objects before the *Y*th year and corresponding data of predictors to construct a prediction equation for the flood season after the *Y*th year. Finally, the validity of this prediction model is evaluated by comparing the prediction with actual situation. In practice, predictants and corresponding predicators in the preceding winter period are used to construct prediction equations for successive flood seasons as described above.

3 ANALYSIS ON CORRELATION OF TC FREQUENCY AND INTENSITY WITH PRECEDING GEOPOTENTIAL HEIGHTS AND SST

3.1 *TC frequency and geopotential height field*

According to experienced forecasters, if there is a strong cold air or a cold wave in Guangdong Province in winter or spring, a strong typhoon can usually be expected in the following summer or autumn. This implies that the circulation system of the atmosphere in the preceding winter period (from December to February) is highly related to TC frequency in successive flood seasons. Liu[12] pointed out that a year with high frequency of Guangdong-landfalling TCs usually witnesses relatively large meridional coverage of 500 hPa geopotential height in Eurasia and middle-to-high latitude areas of Asia in the preceding winter period, and vice versa. Therefore, this paper constructs a prediction equation by identifying the correlation between the monthly average 500 hPa geopotential height field in the preceding winter period and TC frequency.

Correlation analyses and experiments based on the decade data led to significantly correlated areas where gridpoints of the preceding winter monthly average 500 hPa geopotential height field in different months coexist with corresponding successive occurrence of TCs. The correlation coefficients are high (by 0.05 significance test), while the scope of correlated areas is large.

The correlation is shown in the 500 hPa monthly average geopotential height field in Decembers and the CLTC frequency in Augusts the following years. Figure 1 shows the correlation coefficient distribution obtained by analyzing the data for 1995 to 2004. Three areas of high correlation include a positively correlated area in the North Atlantic Ocean and the other two negatively correlated areas near Greenland Sea and Sea of Japan, respectively. Therefore CLTC frequency and intensity in the successive flood season can be predicted by analyzing data on the gridpoints of the preceding winter monthly average 500 hPa geopotential heights within the correlated area.

3.2 *TC activities and ENSO*

As Li [18] and Chen et al.[19] indicated in their researches, TC frequency is relatively low in El Nino years and relatively high in anti-El Niño years. Wu[20] also argued that the frequency of typhoon making landfall in Guangdong and Guangxi is relatively low in El Niño years and relatively high in anti-El Nino years. Inspired by this finding, this paper attempts to predict TC frequency by constructing prediction equations with data of preceding winter SST gridpoints.

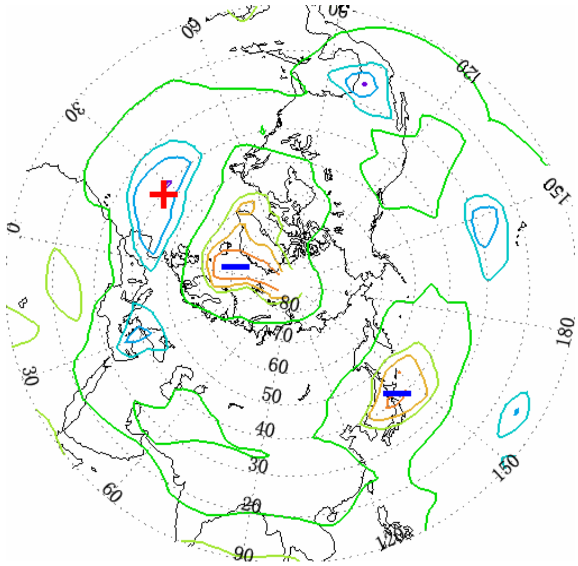

Figure 1. Correlation between the monthly-averaged 500 hPa heights in Decembers and the yearly frequency of typhoons making landfall on China during 1995–2004.

Correlation analyses and experiments on the decade basis have identified areas of high correlation where gridpoints of the preceding monthly average SST field in different months coexist with corresponding successive TC frequencies.

The correlation coefficients between the monthly average SST in Decembers and the TC frequency over the South China Sea in subsequent years are examined. The coefficient during 1995–2004 (not included in this paper) identifies negative high correlation within the region (28–30°N, 148–152°E) and positive high correlation over the region (38–42°N, 173–168°W) and around the equatorial region (135–125°W) respectively. With the data of preceding winter monthly average SST gridpoints within regions of high correlation, the yearly frequency of South China Sea TCs can be predicted.

4 BINOMIAL PREDICTION MODEL FOR TC INTENSITY

Linear prediction models, such as variance analysis, multiple linear regression, and stepwise regression, were widely used in TC activities forecast in the 1970s and 1980s. In the late 1990s, non-linear prediction models became more popular, which can effectively reflect the correlation between the predictants and predictors. In the following sections, TC intensity simulation through binomial curve fitting will be described.

4.1 *Establishment of combined factors*

This method firstly calculates the correlation coefficient between the monthly average 500 hPa geopotential height (or SST) field of a particular month and highest CLTC intensity. Then choose 6 to 12 gridpoints, whose correlation coefficient has passed the 0.05 significance test, set every three of them as a combined factor, and calculate the correlation coefficients between the combined factors and the predictants.

To explain the prediction principles and operation, the geopotential height field of November, 2007 will be considered as a factor to predict the highest CLTC intensity in August, 2008. According to the statistics, the correlation coefficients between the geopotential heights of the six gridpoints (No.505, No.506, No.507, No.548, No.549 and No.550) in the monthly average 500 hPa geopotential height field in November and the predictants are –0.487, –0.472, –0.402, –0.516, –0.459 and –0.513 respectively. Setting every three girdpoints as a combined factor, we have

$$X_A = X_{505} + X_{506} + X_{507,} \qquad (1)$$

$$X_B = X_{548} + X_{549} + X_{550.} \qquad (2)$$

The correlation coefficients between X_A, X_B and the predictant Y are

$$R_A = -0.469,$$

and

$$R_B = -0.512,$$

respectively.

Both of the combined factors' correlation coefficients are higher than 0.45.

4.2 *Establishment of regression weights equation by combined factors*

The two combined factors are X_A and X_B, with correlation coefficients R_A and R_B, respectively. Let the sum of absolute values be E, we have $E=|R_A|+|R_B|=0.981$.

The regression weights coefficients are calculated as:

$$A = R_A / E = -0.4781,\ B = R_B / E = -0.5219.$$

$$Y_1 = AX_A + BX_B \qquad (3)$$

From the above regression equation, we get two combined factors. The correlation coefficient between Y_1 and the predictant Y is: R_{Y1}=0.516

4.3 *Establishment of binomial equation*

By substituting the data of geopotential height field gridpoints into the Eq. (1)–(3), we will have equivalent Y_1 and predictant Y. Orthogonal polynomial is feasible here. Let $X = Y_1$, then

$$Y_t = a_0 + a_1 X_t + a_2 X_t^2 + \ldots\ldots + a_k X_t^{\ k} \qquad (4)$$

In the equation, Y_t is the predictant (i.e. the highest TC intensity), X_t is the composite predictor of geopotential height field gridpoints.

By applying the normal equations, we are able to get the coefficients a_0, a_1, a_2,……, a_k for Eq. (4). Considering historical data of Y_t obtained from Eq. (3) as a predictor, and substituting them into the reduced Eq. (4), we will get a second-order equation, i.e. the binomial equation,

$$Y = 24\ 339.550\ 370\ 87 + 187.422\ 2422X + 0.361\ 386\ 6X^2 \qquad (5)$$

In Eq. (5), the correlation coefficient between Y and X is R_{Y2}=0.5556. When compared with R_{Y1} = 0.516 in Eq. (3), the value is increased. This is consistent with the catastrophe theory of non-linear prediction.

4.4 *Prediction result of binomial equation*

The geopotential heights of six gridpoints (No.139, No.140, No.141, No.175, No.176, No.177) of the monthly average 500 hPa geopotential height field in February are X_{139}, X_{140}, X_{141}, X_{175}, X_{176}, and X_{177}, respectively. By substituting the six potential heights into Eqs. (1) and (2) and then the result into Eq. (3), we get X =257.870203283469. Then, substitute X =257.870203283469 into Eq. (5), and get the predictor Y = 40.078 m/s (the highest CLTC intensity in August, 2008). The normal average value of highest CLTC intensity in August is 47.847 m/s (the actual highest intensity in August, 2008 is 40 m/s).

5 PREDICTIONS AND TESTS ON CLTC INTENSITY FROM 2001 TO 2008

This model takes gridpoints data of the 500 hPa height field and SST field as predictors, while actual situation of the previous month as a predictant, in order to calculate the correlation coefficients and construct equation coefficients for the prediction of the intensity, frequency (yearly and monthly) and peak intensity of CLTC. Verifying processes showed that, overall percentages of prediction accuracy of 8 years is 73.9% for SST (of November and February), and 71.3% for 500 hPa geopotential height field (of November and February). The use of 500 hPa height field in February leads to more accurate predictions than that of other months.

The verifying process of the intensity prediction method showed that if the ratio between the predicted intensity and actual intensity is equal to or less than 1, the prediction is regarded as correct. The TC level partition method in the experiment takes reference from the *National Standard Chart for Tropical Cyclones Level Partitioning*[21] published in 2006. The tropical cyclone can be divided into TD (tropical depression), TS (tropical storm), STS (strong tropical storm) and TY (typhoon). In this paper，TY (typhoon), STY (strong typhoon) and Super TY (super typhoon) are unified as TY(typhoon).

The process proved that the monthly (June–October) and yearly predictions of CLTC intensity are more precise by using SST and height fields of November in the preceding year and February in the present year.

Figure 2 demonstrates the comparison of prediction and actual situations. Tables 1 and 2 list the accuracy rates of forecasting.

Table 1. Precision of the yearly prediction of the CLTC intensity (Unit: %).

Predictors	Yearly average	2001	2002	2003	2004	2005	2006	2007	2008
Height field in February	72.9	50	66.7	83.3	83.3	83.3	83.3	50	83.3
SST field in November	75	83.3	33.3	66.7	66.7	83.3	83.3	83.3	100

Table 2. Precision of the monthly prediction of the CLTC intensity (Unit: %).

Predictors	Monthly average	June	July	August	September	October	Annual
Height field in February	72.5	62.5	87.5	87.5	75	50	75
SST field in November	72.5	62.5	100	62.5	75	62.5	87.5

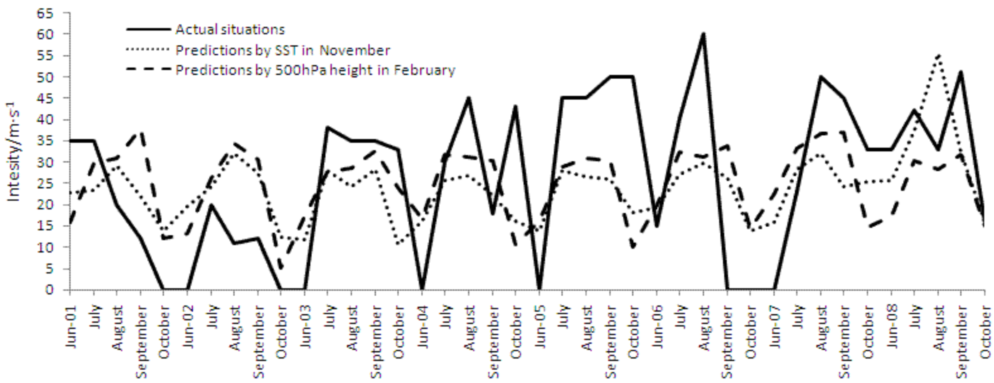

Figure 2. Comparison of the monthly predictions of CLTC intensity by SST and 500 hPa geopotential height.

According to Figure 2, the predictions of CLTC intensity changing trends based on the two predictors agree with the actual situations. If two predictors predict the TC intensity as tropical depression (TD), and one predicts the maximum wind velocity as less than 15 m/s, we can conclude that there will be no landfalling TC in the near future. If both of the two predictors predict the TC intensity as strong tropical storm (STS), and one predicts the maximum wind velocity as more than 25 m/s, we can conclude that there will be a landfalling TC in the near future with a possible intensity of or above TY.

Table 1 presents the average accuracy rates of prediction from June to October in each of the years. For example, in 2001 the accuracy rate equals to the frequency of correct predictions from June to October divided by the total number of predictions. According to Table 1, the accuracy rates are above 50% (except for that of November in 2002, 33.3%).

Table 2 is the monthly and yearly average accuracy rates of TC intensity prediction from 2001 to 2008. The annual accuracy rate equals to the frequency of correct predictions of the strongest CLTC in the next year divided by the total number of predictions. According to Table 2, the July, September and yearly predictions accuracy rates of the TC intensity are the highest. The accuracy rates are all above 75%, among which, with the November SST as the predictor, the accuracy rate of TC intensity in July is the highest (100%).

6 CONCLUSIONS

A statistical model for prediction of intensity and frequency of tropical cyclones making landfall on China is proposed in this study. Preliminary verification is performed. The following major conclusions are drawn.

(1) It is appropriate to physically construct a binomial prediction equation with the regression weighting, statistically derived from analyzing SST, height field and monthly and yearly CLTC frequency.

(2) The binomial prediction equation based on the 500 hPa height and SST performs well in predicting June-to-October and yearly CLTC intensity and frequency. By using SST (of November and February) as the predictor, a 8 year-averaged accuracy rate of prediction is 73.9%, higher than that predicted with the 500 hPa height field (71.3%).

(3) In this statistical model, various factors could be selected according to the different lead time of prediction to make objective prediction of the frequency of TC on various time scales

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