SOME ASPECTS OF OBJECTIVE FORECASTING OF TROPICAL CYCLONE MOTION

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ABSTRACT

As shown in a statistical analysis of the relationship between environmental fields at varied time and tropical cyclone motion, the forecasting ability of the initial environmental field predictors for tropical cyclone motion decreases with the increase of valid time period of forecast; it is higher with these predictors at a future time than at an initial time. The work also indicates that for the tropical cyclone motion over a given period of valid forecast, better predictors appear at times mostly differing from the valid periods; for periods at 48-120 h the environmental predictors at 48-72 h are more capable of forecasting. With statistical interpretation of NWP products, a predictive model for tropical cyclone motion is superior in performance over a statistical forecasting model that employes predictors of the initial field in the basic framework. The concluding remarks can be used as reference in the construction of an objective prediction model for tropical cyclone motion.

Key words: tropical cyclone motion, objective forecast

Ⅰ. INTRODUCTION

Research and application has been going on for years (Anthes, 1987; Wang and Fei, 1987) relative to objective, quantitative statistical predictive model for the motion of tropical cyclones (to be shorten as TC thereafter), but progress in the respect of improvement of forecasting ability and skill has been slow. In spite of efforts made to update and refine the model, the forecasts remain doubts-borne (Neumann and Pelissier, 1981; Jarrel, Brand and Nickhn, 1978). The cause lies in the dependence of the models upon statistical relations between various initialized fields and TC motion.

Substantial non-linear variations take place in both its internal forcings and peripheral environment over the whole cycle of TC movement. The model using predictors of the initialization is incapable of treating the non-linearity of the atmospheric changes, depriving the predicted results of effective use by accumulated forecasting errors of motion over relatively long periods of validity.

Large strides of advance in NWP in recent years has offered right conditions for more development of objective motion prediction for TC. That the atmospheric model of NWP is able to describe the genesis and decaying of disturbances makes it a growing sophisticated tool in routine operation for the forecast of large-scale, quasi-stationary weather regimes in evolution (Bengtsson, 1981; Lorenz, 1981). By constructing such motion predicting model with the technique of statistic interpretation of NWP products, the ability and skill is expected to improve and the valid period of forecast to expand to more than 120 h from the current 60 h.

Ⅱ. DATA AND TECHNIQUE OF ANALYSIS

For a domain bounded by 10—30°N and 120—160°E, a total of 185 cases of TC are selected for the years 1960—1990 that acquire the intensity of or above tropical storm and keep a lifecycle more than 120 h and take normal track of motion, i. e. excluding trajectory of mutual rotation, loopings, quasi-stationary, abrupt changes in direction and speed of motion, etc. There are 450 historical samples in temporal spacings of more than 24 h.

The study shows that the geopotential field at 500 hPa and surface pressure field, especially the former, are efficient, useful predictors used in constructing an objective predictive model for the TC motion because of the representative environmental signature of mid-layer steering effects (Anthes, 1987; Wang et al., 1987). Relavant NWP output stays valid for more than 120 h. In view of it, the current focus is on the influence of changes in the geopotential field at 500 hPa and in 144 derived fields of predictors on the forecast of TC motion. The corresponding synoptic features are within a surface pressure field bounded by 20—55°N and 105—140°E and the region of interest includes the 500 hPa geopotential field at 20—55°N and 60—180°E.

The correlativity of predictors to TC motion denotes how well the former forecasts. When a given environment predictor shows high maximal correlation coefficient relative to TC motion (r_{max}), or has a large total number of predictors with preferred correlation, it is thought to have good forecasting ability for TC motion.

Ⅲ. FORECASTING ABILITY OF INITIAL ENVIRONMENTAL FIELD FOR TC MOTION

Environmental field at initial time, especially that of mid-level steering, can be of great influence on TC motion. The problem now is how long it lasts. With respect to the 24-120 h TC track, a correlation field is computed of initial 500 hPa geopotential field H_0 and the derived predictor P_0 in the surface pressure field. It is apparent by the distribution chart of correlation (figure omitted) that the increase of forecast validity is associated with reduction of correlation maxima values and shrinkage of highly correlated area. The declining situation is much more obvious after 72 h when the correlativity of the initial field to radial TC position λ_t has dropped to below 0. 2, which is largely ineffective for prediction.

Fig. 1 gives the temporal distribution of environmental field predictor H_0 and P_0 with respect to maximal correlative coefficient r_{max} and of total number of predictors n with $|r| \geqslant 0.35$ relative to valid forecast length. The r_{max} consistently drops as the valid period grows and that of λ_t reduces more than that of φ_t does while n follows a much steeper curve of reduction with the increase of forecast validity. It is suggestive that there exists a sharp fall in the number of environmental predictors that have high correlation with TC motion, resulting in much reduced ability of forecasting.

It is concluded that it is initial inertia of TC that dominates the motion and with the growth of valid period the inertia keeps weakening to cause corresponding drop in the correlation of the initial environmental field to the TC motion. In periods after 72 h, the initial inertia becomes so weak that the initial field of environment is no longer capable of predicting TC motion.

Ⅳ. FORECASTING ABILITY OF FUTURE ENVIRONMENTAL FIELD FOR TC MOTION

The fact that the environmental predictors at initial time decrease in terms of forecasting ability for TC motion with the increase of valid period is the fundamental cause for poor performance of previous models for longer periods of time. In the application of

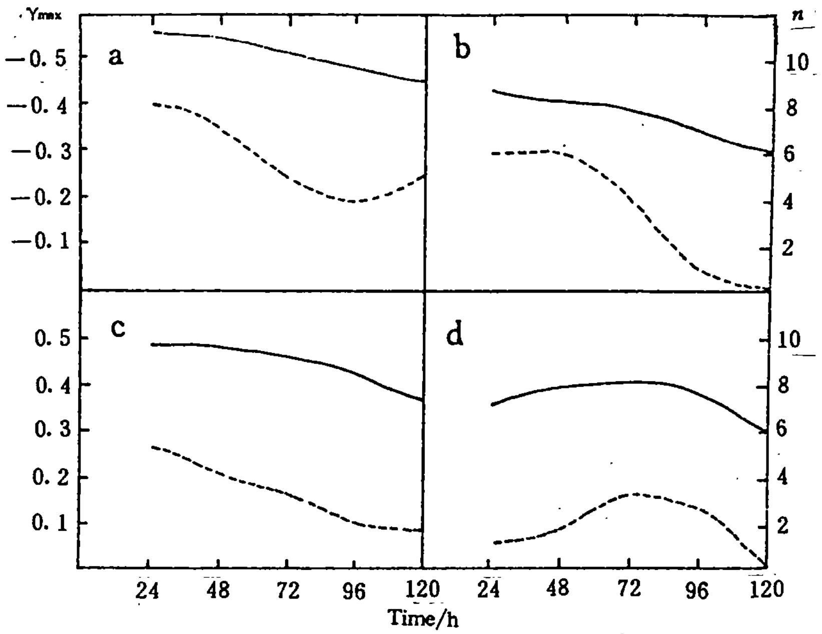

Fig. 1. Distribution of validity of environmental field at initial time with respect to TC motion. The horizontal ordinate is the valid period of forecast, the vertical ones are respectively the maximal correlation coefficient γ_{max} (Left) and the predictor total n that have $|r|\geqslant 0.35$ (Right). The solid line stands for γ_{max} and the dashed line for n. (a) $H_0\sim\varphi_t$, (b) $H_0\sim\lambda_t$, (c) $P_0\sim\varphi_t$, (d) $P_0\sim\lambda_t$.

NWP products in statistical interpretation forecast for TC motion, predictors of future environment field are introduced. But are they advantageous over initial predictors? With this question, a correlation field is computed between the field and TC motion. By future time, it is defined as that after the initial time and real field of environment at that particular time is used in computation instead of output of NWP.

Comparing the correlation fields at initial and future time, it is seen that for short periods of validity, the future field of environment is correlated with φ_t the way largely the same as the initial field; the maxima and high-value area of correlation are significantly better than the initial field of correlation and the longer the valid period of forecast, the more obvious the effects. On the other hand, for each of the forecast periods at 24—120 h the future environmental predictor is better correlated with λ_t than in the case of initial time and the effects get better with the increase of periods of validity. The result is also obtainable with Figs. 2 and 3.

It is now understood that the environmental field at a future time (being the same as or close to that for the forecast validity period) becomes the dominant factor in steering the motion of TC when the inertial effects disappear or weaken for the initial time, resulting in higher correlation with the track than the initial field. It can then be argued that predictors of future environment field are better forecasting tools than those of initial one, especially so for longer periods of validity.

V. FORECASTING ABILITY OF MULTIPLE ENVIRONMENTAL FIELD PREDICTORS FOR TC MOTION

The application of NWP products in statistic interpretation forecast of TC motion is usually done by using future environmental predictors in constructing a predictive model if they cover the same valid period of forecast, or, TC motion. Whenever the NWP product is available, these predictors are useful as forecasting information for all time within the period from the initial time to the time simultaneous with the forecast validity. Among the information for the multiple time, does the environmental field predictor have the best forecasting ability as it covers the same period as the validity? It didn't seem to have occurred to the meteorologist.

The field of correlation between the TC motion φ_t, λ_t in each period of valid forecast of 24—120 h and predictors of the environmental field before each corresponding time has been computed. One point that is restressed is that the environmental predictor for each time is emanated from the observed rather than NWP-predicted field.

Fig. 2 gives the temporal distribution of correlation between the TC motion at 24—120 h valid forecast periods and 500 hPa geopotential field H_t at each time within the period from the initial to the forecast. For φ_t, r_{max} drops as time t increases at 24—48 h, but rises first and then falls at 72—120 h, both peaking at 48 hours after the initial time. For short (long) periods of validity, the n curve is peaked at 24 h (48—72 h). For λ_t, r_{max} and n both rise with t in short periods of validity, acquiring peak value within forecast

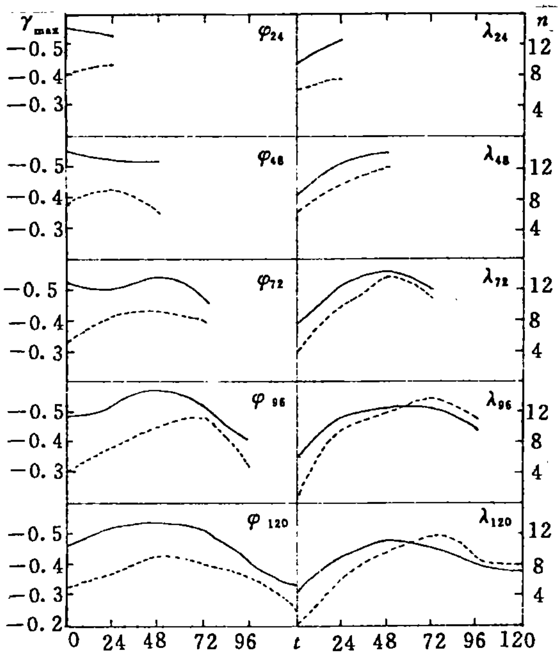

Fig. 2. Temporal distribution of correlation 500 hPa geopotential field and TC motion at multiple time. The denotation is the same as Fig. 1 except for the length of time from the initial time expressed by the horizontal ordinate.

periods; the peak of r_{max} appears at 48 h for longer periods and that of n at 48—72 h.

As the tendency of variations of r_{max} and n curves differ with the period, it is assumed here that a predictor of the environment field at a given time t is considered to have high forecasting ability for TC motion if it is associated with the peak of a curve of either r_{max} or n. It can be argued that the 500 hPa geopotential predictors having higher forecasting ability appear at 0—24 h after initial time for φ_t and at 24—48 h for λ_t over short periods of time; the appearence is at 48—72 h over long periods of time.

Fig. 3 gives the distribution of correlation between the TC motion at 24—120 h of forecast periods and derived predictor P_t at t between the initial time and the forecast period. It is seen in the figure that with regard to φ_t the r_{max} drops as t and n peak at 24 h after the initial time over periods 24—72 h, but all have maxima at 48 h over periods 96—120 h; with regard to λ_t the former (latter) witnesses the peak at 48—72 (24—48) h after the initial time over periods 72—120 h.

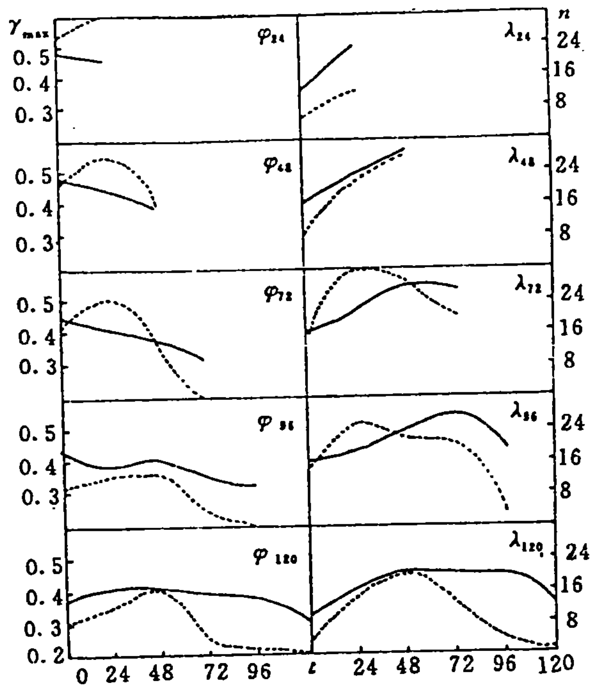

Fig. 3. Same as Fig. 1 except for derived predictor of surface pressure field at multiple time.

Following the convention set out in the previous text, it is known that the derived predictor of surface pressure field P having high forecasting ability for TC motion φ_t appears at 0—24 (48) h over periods 24—72 (96—120) h; in the respect of forecasting λ_t, the more capable P_t appears at 24—48 (24—72) h after the initial time over periods 24—72 (96—120) h.

The analyses above indicate that the predictors of the environmental field, though having high forecasting ability, are concurrent with valid forecast periods, i. e. being in simultaneous period with TC motion only on few occasions ($\lambda_{24}-\lambda_{48}$); they don't appear over the valid periods in most cases. Generally, the preferred occurrence of the predictor is mostly at 0—24 (48—72) h after the initial time for periods 24—48 (72—120) h.

For a period of longer validity, the environmental field predictor weakens 72 h after the initial time in terms of forecasting ability may well be associated with two possible trends of motion of TC. At 48—72 h after initial time, most TC is at or close to averaged climatological point of recurvature when the environmental field determines two opposite future tendencies of either moving northwest or turning towards northeast. It accounts for high correlation with TC motion at 72—120 h, i. e. having high forecasting ability. At 72 h after the initial time, however, most TCs have moved out of the climatological point where the environmental field afterwards is only related to either tendency in TC motion—some of the predictors in the sample are monotonously related with the northwest movement while the other with the northeast one, resulting in reduction of general level of correlativity and forecasting ability.

Ⅵ. FORECASTING ABILITY OF TECHNIQUE OF STATISTICAL INTERPRETATION OF NWP PRODUCTS FOR TC MOTION

Two predictive models, one based on predictors of the environmental field at initial time (ST, statistical) and the other on those at future time (PP, perfect), following the technique of stepwise regression analysis and using samples in identical length and predictors of the same categories, are set up. Comparison of the regression parameters of the two models reveal that the multiple correlation coefficient is always higher in the PP model than in the ST model over each of all valid forecast periods 24 through 120 h and the residual root-mean-square error is always smaller in PP than in ST model, and the longer the valid period, the more obvious the difference. For φ_t, R is increased by 0. 01 —0. 07 and S is decreased by 0. 04—0. 59 as the PP is compared with the ST model; for λ_t, R is up by 0. 01—0. 09 and S is down by 0. 07—1. 54 in the same comparison.

Forecasting verifications are performed of the two models using 129 independent samples from 34 TC in 1991-1993 and the result is presented in Table 1. Within all valid forecast periods of 24—120 h, the PP model is superior over the ST model concerning the error in range, moving direction and speed and the longer the validity, the more obvious the difference is between them. It is argued that the predictive model employing statistical interpretations of NWP products is more advantageous in terms of forecasting TC motion as compared with the one which is dependent of predictors at the initial time and the difference is getting larger with the length of valid periods.

Table 1. Results of verification of predictive models.

Predictive model		ST					PP				
Valid period(h)		24	48	72	96	120	24	48	72	96	120
	Range(km)	189	392	653	891	1061	171	345	580	757	889
Errors	Direction(d.)	14	17	24	22	19	13	15	22	19	16
	Speed(km/h)	0. 42	0. 81	1. 13	1. 52	1. 85	0. 35	0. 69	0. 91	1. 21	1. 47

Ⅶ. CONCLUDING REMARKS

a. Due to primary reliance on inertial effects, the predictors of environmental field at initial time are of good forecasting ability only over 48 h or shorter periods, decaying sharply as the length of validity increases.

b. It is the environmental filed at future time that dominates the TC motion, which has much better predictors than the initial field as regard to the TC motion forecast. The forecast is much more improved with longer periods of validity.

c. For TC track over a given period of validity, the predictors of environmental field have varied ability of forecasting for different time. In most cases, predictors with high ability appear at times differing from TC motion. For short (long) periods of validity, high forecasting ability is found in those 0—24 (48—72) h after the initial time.

d. A predictive model is much more capable of forecasting TC motion that uses the technique of statistical interpretation of NWP products than a statistical forecast model that applies the predictors of environmental field at initial time. The improvement becomes more obvious with the increase of valid period of forecast.

e. The remarks concluded above can be relied on in constructing an objective predictive model for TC motion.

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