AN IMPROVEMENT OF STATISTICAL PREDICTION OF TYPHOON TRACKS①

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ABSTRACT

In this paper, a statistical interpretation composite forecast model for typhoon track is set up by using numerical forecast products and several forecast schemes. Tested in 1994 typhoon season, its forecast performance is much better than that of a previous statistical forecast model. The test shows that it is an effective method that sufficiently improves objective forecast of typhoon track using the numerical forecast output products obtained in forecast and adopting several schemes in composition.

Key words: typhoon track, statistical forecast, improvement

I. INTRODUCTION

Some foundation was laid for the objective treatment of typhoon track prediction from the early 1970's to the 1980's when statistical methods were being studied by a number of institutions across the nation. With the evaluation of the forecasting practice and the advancement of research, however, the statistic predictive model developed at that time have been found to have two major insufficient aspects. One is the lack of reproduction in the model of various nonlinear predictors that have essential effects on the track of typhoon, due to ineffective use of existing NWP output; the other is the formulation of monosynoptic-statistic model based on outdated framework which involves no multi-model composition as the means of prediction, and these defects seem all the more obvious with the refinement of numerical forecasts of weather situations and the experimental verification of the advantages of such composition. Then, the replacement of synoptic-statistic model by American National Hurricane Center (NHC) in 1988 (Robert and Sheets, 1990) with composite forecasts by multiple models based fully on NWP output, the so-called NHC (NHC90) (Charles, Neumann and Colion et al., 1991), has offered us a way of thought that is useful for reference in our effort of further improving the statistic interpretation of the track forecasts.

II. STRUCTURE OF PREDICTIVE MODELS

The American NHC73 (Neumann and Lawrence, 1975) played an important part in the objective prediction of hurricane track from mid-1970's to mid-1980's and became one of the models in the same period that had the highest accuracy. In 1983, the NHC83 that is composed of 3 submodels was developed based on NHC73. Through 6 years of trial use from 1983 to 1988, it was proved to be much improved over the NHC73 with respect to the accuracy and stability of the forecast. It then took over the forecast operation from NHC73 in 1983 and has since evolved to be one of the principal models for operational

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guidance (Charles et al, 1991). With the up-date of American medium-term NWP models for weather situations and the increase of forecast level, NHC83 evolved into NHC90 in 1990 by substituting the MOS into PP method for the third submodel.

On the basis of the practice of statistic forecast of typhoon track over the past two decades and more, the NHC experience is drawn with an eye to relevant key national typhoon research project for the "8th five-year" programme, and a predictive composite model developed for statistical interpretation of typhoon track in the region of the East China Sea. There are four major improvements. First, the NWP products are used, the meteorological field of elements and weather situations which act over the time period of the forecast are taken into account and statistical corrections are done for the error by NWP products. Secondly, predictors are composited by use of the values on the levels of 500, 700, 850 hPa and surface for grid and observation points and the factor of a "field" is considered through orthogonal function expansion, which minimizes the deficiency arisen from the use of 500 hPa only and empirical readings by man. Thirdly, for the framework of the model, it is first divided into submodels of climatological persistence, weather statistics, thorough predictions and quasi-prediction, then a comprehensive predictive model is composited. Lastly, the model is highly automated so that the process from data bank, acquisition of real-time data, data treatment, factor combination, model building, forecast, error analysis and output in print, is realized on PC by simple maneuver, thus more adaptive and fitful for the need of real-time operational forecast.

The selected region of the East China Sea is bounded by 17—32°N and 120—130°E, and the samples cover June 15 to October 15 spanning from 1961 to 1990. In this way, a total of 135 cases of typhoon in 561 samples are selected. Due to the current unavailability of 1800 GMT and 0600 GMT times of the NWP products by the European Center for Medium-range Forecast, they have to be rebuilt to match the counterparts in the operational forecast (the time of 1400 GMT is matchable between the two). For this purpose, a total of 131 cases of typhoon in 282 samples for 1800 GMT and 130 cases in 279 samples for 0600 GMT are selected.

Ⅲ. CONSTRUCTION OF PREDICTORS

Before constructing predictors the first thing to take account of is to make sure how clear the synoptic and dynamic significance there is therein and how closely correlated they are with the track of typhoon, for a high value in these aspects is a necessary condition for stable skill in the predictive model.

In view of it, six groups of factors for initial time are constructed using typhoons' initial parameter and environmental field and derived factors and another four groups are built on basis of NWP products by ECMWF and derived factors for 24, 48 and 72 h. These predictors are fully objectively composited on computers in an automatic manner.

(1) Parameters of typhoon initialized field——they include persistence factors of the initial position, intensity, maximum near-center winds, moving speed and direction, β effects and climatologically averaged recurvature point and its variations etc.

(2) 500 hPa geopotential field——they are the geopotential values at 200 grid points and variables over the range of 24 h within a 5°×5° mesh bounded by 20—55°N and 60—180°E at the initial time.

(3) Derived factors at 500 hPa geopotential field and variables——they include various factors derived and their variables that reflect at the initial time all kinds of features

of synoptic systems, trough and ridge circulation, latitudinal position, westward extension point, poleward lateral boundaries of the western Pacific subtropical high as well as its southward advancement.

(4) Surface pressure field and its variations——they are pressure values at the surface grid points and 24-h variables within a 5°×5° mesh bounded by 20—55°N and 105—140°E at the initial time, in addition to derived factors depicting the features of surface pressure systems and variations.

(5) Field of elements for observation stations——they include elements and their variables of geopotential heights (pressure), temperature, dew point, wind direction and velocity, and latitudinal and longitudinal wind components in terms of vectors, and their derived factors, at 34 observation stations (being equivalent of 34 irregular grid points) on four layers of 500, 700, 850 hPa and the surface within the domain bounded by 10—50°N and 80—150°E.

(6) 500 hPa geopotential field and its variables in the simultaneous period of forecast——they are 500 hPa geopotential heights and variations at 24, 48, 72 h after the initial time within the range bounded by 20—55°N and 60—180°E.

(7) Derived factors for 500 hPa geopotential field at the simultaneous period of forecast——they include derived factors (in the same way as in (3)) and their variables for 24, 48 and 72 h after the initial time within the domain of 20—55°N and 60—180°E.

(8) Surface pressure field and its variations in the same period of forecast—they include surface pressure field and variations and pressure gradients at 24, 48, and 72 h after the initial time within the range of 20—55°N and 105—140°E.

(9) Natural orthogonal function expansion for 500 hPa geopotetial field——three regions are defined at the 500 hPa geopotential field, namely, Region 1: 20—40°N, 90—135°E; Region 2: 20—40°N, 120—145°E; Region 3: 30—50°N, 90—120°E. These regions coincide with the interactions between synoptic systems and typhoons, activity of typhoons and subtropical synoptic systems and synoptic regimes in the westerlies, respectively. The geopotential heights are taken up on 5×7 grid points on the 5×5 mesh in all of the regions for expansion of natural orthogonal function. As the characteristic eigenvector is singly correlated with spatial distribution, i. e. it is determined by the characteristics of all series in the geopotential field given, features and properties of the set of designated fields are truly reproduced, characteristic functions are converged rapidly and over 93% of the total variance is accountable with 1—10 components. In light of it, temporal coefficients in the previous 10 characteristic functions for the three regions are chosen to be the predictors.

The same domain and precedure is followed to perform the expansion of natural orthogonal function for the geopetential field at 500 hPa at 24, 48 and 72 h after the initial time, so that the temporal coefficients for Components 1—10 are used as the predictors over the same period the forecast covers.

(10) Typical field of Chebyshev polynomial expansion for 500 hPa geopotential field——the same region and mesh as in (9) are used to expand the geopotential height field of H (φ, λ) following the Chebyshev polynomial of ψ_k (φ) ψ_s (λ) with the number of order truncated at $k=4$, $s=6$. The function ψ_k (ψ) φ_s (λ) is a typical spatial field that is time-independent and its synoptic implication, more clearly with lower order, gives a quite well-defined picture of circulation features. Moreover, the field is shown to have influence on the track of typhoon by the its very correlation with the time-weighted coefficient. The expansion coefficient in the Chebyshev polynomial for the three regions are

used as the predictors.

Following the same domain and method, the 500 hPa geopotential field at 24, 48 and 72 h after the initial time is put through the Chebyshev polynomial expansion before abstracting corresponding temporal coefficients as the predictors for the same period the forecast covers.

Ⅳ. STATISTIC CORRECTON OF NWP PRODUCTS

For day-to-day June-October NWP products of ECMWF at 24, 48 and 72 h and objective analysis data at simultaneous time for 1991—1993, numerical output of 500 hPa height and surface pressure are reduced with the method of univariate regression on a monthly basis. The reduction is for 200 values of geopotential height at 200 grid points within a domain bounded by 20—55°N and 60—180°E, and for 64 values of surface pressure within a domain bounded by 20—55°N and 105—140°E. When the values predicted are $H(\varphi,\lambda,t)$ and $P(\varphi,\lambda,t)$, respectively, in the NWP products, the following correction equations are obtained following the method of univariate regression:

$$\hat{H}(\varphi,\lambda,t) = a_0 + aH(\varphi,\lambda,t) \qquad \begin{bmatrix} \varphi = 20, & 25,\cdots, & 55 \\ \lambda = 60, & 65,\cdots, & 180 \\ t = 24, & 48,\cdots, & 72 \end{bmatrix}$$

$$\hat{P}(\varphi,\lambda,t) = b_0 + bP(\varphi,\lambda,t) \qquad \begin{bmatrix} \varphi = 20, & 25,\cdots, & 55 \\ \lambda = 105, & 110,\cdots, & 140 \\ t = 24, & 48,\cdots, & 72 \end{bmatrix}.$$

$\hat{H}(\varphi,\lambda,t)$ and $\hat{P}(\varphi,\lambda,t)$ are the reduced values of NWP products for the 500 hPa height and surface pressure where derived factors are estimated from $\hat{H}$ and $\hat{P}$ to be the predictors in the predictive model induced.

Ⅴ. SET-UP OF COMPOSITE PREDICTIVE MODEL

In order to have a comprehensive assessment of the effects of climatological persistence, variations of the environmental field at initial and future time on the track of typhoon, four groups of submodel are first set up using four different predictors; the predicted results by these submodels are then composited to arrive at predictive conclusions.

(1) Climate persistence model (CP). Taking as predictors the initial parameters and derived factors of typhoon, the model has 12 latitudinal and longitudinal predictive equations for 12—72 h each at 1800 and 0600 GMT.

(2) Weather-climatic model (WS). Taking as predictors the environmental field parameters and derived factors at the initial time, the model has 12 latitudinal and longitudinal predictive equations for 12—72 h each at 1800 and 0600 GMT.

(3) Perfect prediction model (PP). Taking as predictors the environmental parameters and derived factors at the same time as followed by the track of typhoon, the model has 12 predictive latitudinal and longitudinal equations for 12—72 h each at 1800 and 0600 GMT.

(4) Quasi-perfect prediction model (QPP). Taking as predictors the environmental parameters and derived factors at the initial time and the time in simultaneity with ty-

phoon, the model has 12 latitudinal and longitudinal equations for 12—72 h each at 1800 and 0600 GMT.

In applying PP and QPP models, the predictors constructed for a future time with reduced NWP products are replaced by predictors at the simultaneous time. Due to limitation of space, the regressive coefficients and predictors in a total of 96 predictive equations at various periods for 1800 and 0600 GMT are removed from the above four predictive models.

For the results predicted by these models, composition is done with the method of total regression to combine into a predictive model.

$$\varphi_t = a_{0t} + a_{1t}\varphi_{CPt} + a_{2t}\varphi_{WSt} + a_{3t}\varphi_{PPt} + a_{4t}\varphi_{QPPt}$$
$$\lambda_t = b_{0t} + b_{1t}\lambda_{CPt} + b_{2t}\lambda_{WSt} + b_{3t}\lambda_{PPt} + b_{4t}\lambda_{QPPt}$$
$$(t = 12,24,36,48,60,72)$$

Taking as example the 1800 GMT predictive model for the region of East China Sea, Table 1 gives the weight taken up by the predicted results by PP and QPP models in the composite forecast.

Table 1. The weight of PP and QPP forecast model in composite forecast model in East China Sea.

Model	φ_{12}	φ_{24}	φ_{36}	φ_{48}	φ_{60}	φ_{72}	λ_{12}	λ_{24}	λ_{36}	λ_{48}	λ_{60}	λ_{72}
PP and QPP	0.346	0.095	0.451	0.758	0.606	0.712	0.885	0.895	0.893	0.577	0.783	0.712

It is seen in Table 1 that for the forecast of φ, the inertial winds takes up a dominant role in the motion of typhoon in periods of or less than 36 h, specifically by showing large weight for non-NWP application models (CP and WS) and small weight for NWP application models (PP and QPP). Beginning from Hour 48, the percentage is increasing dramatically from 0.5 to 0.7 on the part of NWP application models; for the forecast of λ, the weight of such models all exceed 0.57 with the maximum at 0.89, indicating a great improvement in the performance of forecast by the composite model that applies NWP products.

VI. VERIFICATION OF INDEPENDENT SAMPLES AND OPERATIONAL FORECAST TEST

To verify the performance of the composite forecast, a total of 85 independent samples are verified for 18 typhoons in 1991—1993 in the region of East China Sea and 31 real-time operational forecasts are conducted for Typhoons Tim, Doug, Fred, Gladys and Seth from 15 June to 15 October, 1994, for the same region. The results of the verification and test are shown in Table 2.

It is seen in Table 2 that the averaged 24-and 48-h distance error is far less than the standards for examination (200 and 400 km, respectively) as set out in the national key project for the "8th five-year" development plan.

Table 2. The test of composite forecast model.

Item	Error	24 h	48 h	72 h
Verified by indnt. samples	D. er. (km)	165	326	580
	DIR er. (d.)	12	13	19
	V. er. (km/h)	0.32	0.64	0.85
real-time opt'l fcst test	D. er. (km)	179	313	571
	DIR er. (d.)	13	12	18
	V. er. (km/h)	0.37	0.61	0.89

For the purpose of comparison in terms of the forecast performance with the "Statistic Scheme '79" as issued in the broadcasts of objective analysis across the nation of which the Zhejiang Province is a participant, errors in prediction by the two models covering simultaneous periods of time with typhoon are computed. There are in the computation 16 simultaneous periods of time all together for Typhoons Tim, Doug, Fred, Gladys and Seth because of the difference in the coverage of the models. The results are listed in Table 3.

Table 3. The prediction error comparison between two models (unit: km).

Model	24 h	48 h
Stat. scheme '79	189. 1	391. 5
Comp. fcst mode	167. 0	285. 8

It is seen in Table 3 that the composite forecast model is significantly advantageous over the Statistic Scheme '79, being more remarkably so for the 48-h period.

In addition, in order to make comparisons with the subjective, objective and official forecasts from late 1980's to early 1990's, Table 4 gives the averaged distance error at 24 and 48 h for 1985—1993.

Table 4. The comparison of the average distance errors (unit: km).

Valid period	Ntr'l Met. Ctr.	SH ctr'l obsv	FJ prov. obsv	GZ ctr'l obsv	BJ anal.	SH stat. dyn.	FJ suc. reg.	GZ anal. wtd	H.K.	Guam	JPN	PHL
24 h	206.6	194.9	195.0	187.7	183.6	162.5	170.5	186.5	192.0	201.8	204.3	213.3
48 h	418.7	420.7	423.0	386.1	387.3	401.6	409.4	410.4	380.1	405.0	336.0	

* SH=Shanhai, FJ=Fujian, GZ=Guangzhou, BJ=Beijing, JPN=Japan, PHL=the Philippines

Irrationality does arise from differences in the region, particular case, and times in the execution of forecast by various methods listed above, but the condition of error that exists in these methods is largely shown. By comparison between Tables 2, 3 and 4, it is quite telling that the composite model is much skillful.

Ⅶ. CONCLUSIONS

Though the past twenty years have witnessed the statistic forecast of typhoon track, application of statistic interpretation and composite forecast model in the routine operations is infrequent. Judging from what has been tested in this work, it is suggested that sufficient use of NWP-interpreted products available at the time of forecasting and comprehensive composition of multiple models is one of the feasible ways to further improve the accuracy and stability of statistic track forecasts.

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