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THE OBJE CTIVE ANALOGUE PREDICTION MODEL FOR TROPICAL CYCLONE TRACK WITH COMPREHENSIVE ASSESSMENT OF THE ENVIRONMENT

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ABSTRACT: An objective analogue prediction model for tropical cyclone (TC) track is put forward that comprehensively assesses the environmental field. With the parameters of the tropical cyclone and environmental field at initial and future time, objective analogue criteria are set up in the model. Analogous samples are recognized by comprehensive assessment to historical TC cases for similarity with multivariate criteria,using non-linear analogue indexes especially defined for the purpose. When the historical tracks are coordinateconverted and weighted with reference to analogue indexes,forecast tracks are determined. As shown in model verification and forecast experiments, the model has forecasting skill.

Key words: environmental field; tropical cyclones; analogue forecasts

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1 INTRODUCTION

At the end of the 1960's, Hope and Neuman put forward a HRRAN model[1] that employs the analogue method to forecast the track of TC. Afterwards, its modified scheme and other analogues schemes were available in China[2, 3]. They all set as criteria the initial parameters of TC (time, location and moving direction/speed, etc) when screening historical TC for analogy. Then, historical track in the analogue sample is sought for average to determine the forecast track.

When analogy is sought with these methods, neither the effect of initial environment on the TC motion nor the evolution of the environmental field is considered. It is well known that the environmental steering effect is very important to the movement of TC. Any persistence forecast will be at odds with facts if it is made with only the inertial motion but with the exclusion of dynamic role. The analogy in the initial state does not necessarily lead to analogous development in the future. It accounts for less satisfactory forecast results from these techniques.

In the 1990's, a forecast model named TRANTECH (an analogy technique for tropical weather) was developed. It incorporates numerically predicted results of the TC into the analogue forecast, indirectly using the atmospheric dynamic field for the current time, which is called a "quasi-dynamic reference model". As the current numerical prediction of TC track falls short of what is desired for, especially poor when compared to prediction of weather situations, the model performs less satisfactorily than the reference scheme CLIPER such that it has no forecasting skill until upgrade[4].

With the progress of numerical weather forecast, large-scale weather situation forecasts are valid for as long as 168 hours while short-term 24-72-h forecasts are fairly accurate. It is now possible to presume that the environmental numerical forecasts may be included in the analogue forecast of TC as the criteria of analogy to secure analogous relation well founded in dynamic

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framework. It is favorable for recognition of any analogous points from the present up to the future, thus improving the forecast.

2 DATA AND METHODS

For the historical sample of TC, cases acquiring the intensity of tropical storm or typhoon over the western Pacific at 15°N ~ 30°N, 120°E ~ 145°E are picked. Then, a total of 275 TC have been chosen over the time from 1961 to 1990, adding up to 1205 samples within the area of forecast. The *Yearly Book of Typhoons* is the source from which TC parameters (time, location, central pressure and maximum wind speed) are read for each sample. The reanalysis daily data from NCEP / NCAR are taken as the environmental field while the numerical prediction products from the ECMWF and Beijing Meteorological Center as the forecast field.

It is difficult, with a single, simple criterion, to determine whether a TC is analogous to another, as its motion is resulted from interactions between the internal force and the environmental field. Relatively logical analogy can be recognized only if the TC parameters are used in comprehensive assessments that also include multi-variate criteria consisting of elements of multiple time and various layers of environmental field. Tracks that a TC is likely to take in future will be known by locating a number of historical TCs that bear the most resemblance in the forecast model and drawing conclusions through conversion and weighting integration of relevant tracks.

3 INDEXES OF ANALOGY

When analogous criteria are constructed applying various factors, it is hard to assess them synthetically due to inconsistency in domain of value and dimension. It is then necessary to define an index of analogy, which serves as a unified standard for vast-differentiating criteria to decide the degree of analogy. In addition, it can separate numerous historical samples by analogy so as to highlight the most analogous ones.

For a series of factors used as criterion, historical sample $x_{i,j}$ and sample value of forecast TC $x_{i,0}$ form a relationship of analogy $f_{i,j}(x_{i,j}, x_{i,0})$. $f_{i,j}$ can be a coefficient of analogy, distance or an equivalent function relation for absolute distance, with the subscript i the criteria order and j the sample order for criteria factor. When the maximum $\mathrm{Max}(f)_i$ and minimum $\mathrm{Min}(f)_i$ are determined for the series of the i^{th} criteria factor, divide the range into 10 equal parts:

$$\Delta D_i = [\mathrm{Max}(f)_i - \mathrm{Min}(f)_i]/10$$

With the bound value T_i (to be maximal or minimal depending on $f_{i,j}$) known for the series of criteria factor, the analogy index $SI_{i,j}$ is defined setting ΔD_i as the unit of distance:

$$Df_{i,j} = |f_{i,j} - T_i|$$

With j the sample order, M the total number of samples and j=1, 2, …, M, we have

$$SI_{i,j}=\begin{cases}10, & Df_{i,j}=0\\ 10-k, & (k-1)\dfrac{\Delta D_i}{4}<Df_{i,j}<=k\dfrac{\Delta D_i}{4},\ k=1,2,3,4\\ 6-k, & (k+1)\dfrac{\Delta D_i}{2}<Df_{i,j}<=(k+2)\dfrac{\Delta D_i}{2},\ k=1,2\\ 4-k, & (3k+1)\dfrac{\Delta D_i}{2}<Df_{i,j}<=(3k+4)\dfrac{\Delta D_i}{4},\ k=1,2\\ 1 & 5\Delta D_i\langle Df_{i,j}<=7\Delta D_i\\ 0 & 7\Delta D_i\langle Df_{i,j}<=10\Delta D_i\end{cases} \tag{1}$$

where j = 1, 2, ···, M. j is the series of historical samples and M the total number of the samples.

Fig.1 gives the distribution of analogous index $SI_{i,j}$ with $Df_{i,j}$. As shown in the definition, the index is not proportional to equal intervals of ΔD_i. The consequence is that only a few historical samples with high similarity to forecast samples are assigned with high values of $SI_{i,j}$ while the remaining majority with little resemblance are given low ones. It makes it possible for differences in samples to increase, i.e. to be separated in the extent of analogy, when this discriminating factor is converted to non-linear analogous index of $SI_{i,j}$ series.

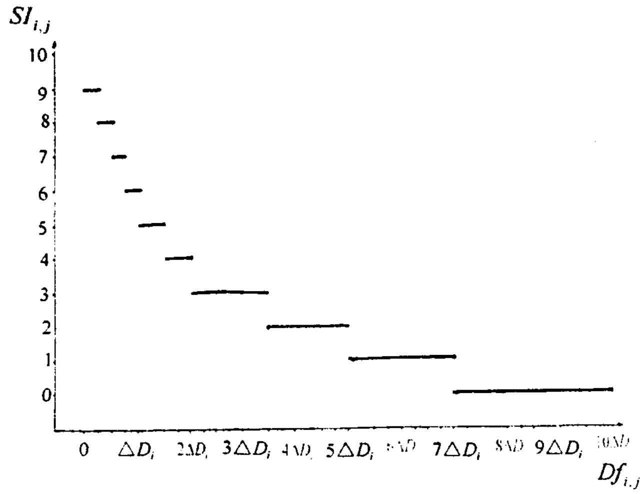

Fig.1 Distribution of analogy index with $Df_{i,j}$.

For comparison, an analogous index $SI'_{i,j}$ distributed over equal intervals of ΔD_i is defined as follows:

$$SI'_{i,j}=\begin{cases}10-k & k\Delta D_i<Df_{i,j}<=(k+1)\Delta D_i,\ k=1,2,\cdots,9\\ 10 & Df_{i,j}=0\end{cases}$$

Fig.2 gives mean frequency distribution (%) for analogous index $SI'_{i,j}$ and $SI_{i,j}$, respectively classified for equal and unequal intervals of ΔD_i, for historical samples in 20 discriminative criteria (see below). Under the condition of equal intervals, the frequency distribution of historical sample $SI'_{i,j}$ is one of quasi-normal mode, with frequency of low $SI'_{i,j}$ value (0 ~ 3) taking up 15%, medium value (4 ~ 7) 60% and high value (8 ~ 10) 26%. In

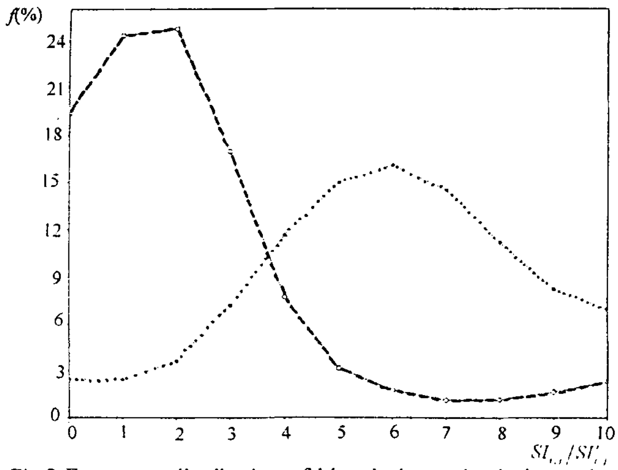

Fig.2 Frequency distribution of historical samples in intervals of different divisions. The dashed line is the equal interval of $SI'_{i,j}$ and the solid line the unequal interval of $SI_{i,j}$.

the case of unequal intervals, however, the frequency of low $SI_{i,j}$ value amounts to 86%, medium value 10% and high value 5%. It is now clear that discriminating factors, which have been non-linear conversion over unequal intervals, decrease the appearance of high-index historical samples from 26% to 5% while increase that of low-index ones from 15% to 86%. As a result, analogous weight is increased for similar samples but decreased for less similar samples, separating samples according to the degree of similarity.

4 CRITERIA FOR ANALOGY

Locating similar tropical cyclones (TC) is a key to criteria for analogy, which requires the ability to reflect the movement and environmental field of TC. The following 20 factors are listed as criteria for analogy, most of which are sets of a number of parameters so that the criteria can hold as much information as possible. Descriptions of the various criteria and parameters are seen below (with the subscript "j" for the series of historical samples and "0" for the forecast samples).

(1) Criterion of time

For a specific time, it has its own climatic background and general circulation background. The criterion is the absolute distance (of number of days) between the date for historical TC samples to appear, $Date_j$, and that for forecast samples, $Date_0$:

$$f_{1,j} = Date_j, \qquad T_1 = Date_0$$

A time analogue index $SI_{1,j}$ is then obtained from the criterion and Eq.(1).

(2) Criterion of TC location

Initial TC location is closely related with environmental background and its own motion in future. The criterion is the spherical distance from the historical location (φ_i, λ_i) to forecast location (φ_0, λ_0):

$$f_{2,j} = R \cdot \arccos\left[\sin\varphi_j \sin\varphi_0 + \cos\varphi_j \cos\varphi_0 \cos(\lambda_j - \lambda_0)\right], \qquad T_2 = Min(f_{2,j})$$

where R is the earth radius and the analogy index $SI_{2,j}$ is determined from the criterion and Eq.(1).

(3) Criterion of central TC pressure

The central pressure describes the intensity of TC and its variation indicates whether TC intensifies or weakens. Any changes in TC's internal force affects the motion. The criterion sets as parameters the central pressure p and its range of variation over 12 and 24 hours:

$$f_{3,j}(0) = P_j \qquad T_3(0) = P_0$$

$$f_{3,j}(t) = P_j - P_j(t), \qquad T_3(t) = P_0 - P_0(t) \qquad (t = 12, 24)$$

From the criterion and Eq.(1), $SI_{3,j}(t)$ is calculated. Then we can have the analogy index for the central TC pressure by the expression of

$$SI_{i,j} = \frac{1}{3}\sum_{t=0}^{24} SI_{3,j}(t) \qquad (t = 0, 12, 24)$$

(4) Criterion of maximum wind near the TC center

Near-center maximum wind is also descriptive of TC intensity. It changes with variations of internal force of TC, which affects the motion. The criterion sets as parameters the maximum wind near the center V_j and its range of variation over 12 and 24 hours:

$$f_{4,j}(0) = V_j \qquad T_4(0) = V_0$$

$$f_{4,j}(t) = V_j - V_j(t), \qquad T_4(t) = V_0 - V_0(t) \qquad (t = 12, 24)$$

From Eq.(1), $SI_{4,j}(k)$ is obtained. Then, the analogy index of maximum wind near the TC center is determined by

$$SI_{4,j} = \frac{1}{3}\sum_{t=0}^{24} SI_{4,j}(t) \qquad (t = 0, 12, 24)$$

(5) Criterion of initial TC velocity

As an inertial action, initial TC velocity directly affects the motion of TC. It takes as parameters mean moving direction θ_j and velocity VV_j between the initial time and the point 12 hours before the present moment:

$$f_{5,j}(1) = \theta_j = \arccos[\sin\varphi_0 \sin\varphi_{-12} + \cos\varphi_0 \cos\varphi_{-12} \cos(\lambda_0 - \lambda_{-12})], T_5(1) = Min(f_{5,j}(1))$$

$$f_{5,j}(2) = VV_j = \frac{R}{12}\theta_j, \qquad T_5(2) = Min[f_{5,j}(2)]$$

From the criterion and Eq.(1), we have $SI_{5,j}(1), SI_{5,j}(2)$

Then, the analogy index for initial TC velocity $SI_{5,j} = \frac{1}{2}\sum_{K=1}^{2} SI_{5,j}(k)$

(6) Criterion of initial 500-hPa height field

Weather situation is a summary of interactions between TC and various systems, which is closely related to TC motion. The analogy index for initial 500-hPa geopotential height s_j, which is defined below, is taken as parameter.

Over a domain of 10°N ~ 50°N, 90°E ~ 150°E, 21×25 gridpoints of initial 500-hPa geopotential values are taken over a mesh with resolution of 2.5°×2.5° for calculation of zonal analogy coefficient $s_{z,j}$, meridional analogy index $s_{m,j}$ and geopotential height analogy coefficient sh_j:

$$s_{j,k}=\left(\sum_{l=1}^{25}H_{j,k,l}\cdot H_{0,k,l}\right)\bigg/\sqrt{\left(\sum_{l=1}^{25}H^2{}_{j,k,l}\sum_{l=1}^{25}H^2{}_{0,k,l}\right)}$$

$$s_{j,l}=\left(\sum_{k=1}^{21}H_{j,k,l}\cdot H_{0,k,l}\right)\bigg/\sqrt{\left(\sum_{k=1}^{21}H^2{}_{j,k,l}\sum_{k=1}^{21}H^2{}_{0,k,l}\right)}$$

$$s_{z,j}=\frac{1}{21}\sum_{k=1}^{21}s_{j,k},\qquad s_{m,j}=\frac{1}{25}\sum_{l=1}^{25}s_{j,l}$$

$$f_{6,j}=sh_j=s_{z,j}\cdot s_{m,j},\qquad T_6=Max\left[f_{6,j}\right]$$

From the criterion and Eq.(1), the analogy index $SI_{6,j}$ for the initial 500-hPa geopotential height is estimated.

(7) Criterion of future 500-hPa geopotential height

It is obvious that future weather situations are a more important criterion than the initial ones, for it links directly with future motion of TC. By taking the region and gridpoints the same as (6) and applying numerical predictions, $\hat{H}_{0,k,l}(t)$, at 24, 48 and 72 hours and records at the next 24, 48 and 72 hours in historical samples, $H_{j,k,l}(t)$, for the level of 500 hPa, analogy coefficient $\hat{sh}_j(t)$ is calculated using the same technique. It is then used together with Eq.(1) as a criterion to estimate the analogy index $SI_{7,j}(t)$ for the coming 24, 48 and 72 hours. Correspondingly, the analogy index for future geopotential field is $SI_{7,j}=\frac{1}{3}\sum_{t=24}^{72}SI_{7,j}(t)$, where t = 24, 48, 72.

(8) Criterion of distance for 500-hPa geopotential height

The geopotential height value for a given spatial point describes its nature. The analogy in distance of geopotential field reflects that in thermal background of any two TC. For calculation of their Eular distance, the region and gridpoints, which are the same as in (6), are taken, together with parameters of 500-hPa initial field and 24-, 48- and 72- hour forecast fields, to calculate the Eular distance:

$$f_{8,j}(t)=\sqrt{\sum_{k=1}^{21}\sum_{l=1}^{25}\left(H_{j,k,l}(t)-\hat{H}_{0,k,l}(t)\right)^2},T_8(t)=Min\left[f_{8,j}(t)\right]\ (t=0,\ 24,\ 48,\ 72)$$

From the criterion and Eq.(1), we can have $SI_{8,j}(t)$. Then, the analogy index for distance in the 500-hPa geopotential field, $SI_{8,j}=\frac{1}{4}\sum_{t=o}^{72}SI_{8,j}(t)$ is obtained.

(9) Criterion of initial 500-hPa flow field

500-hPa flow field reflects mid-layer interactions between TC flows and environmental flows, which affect future movement of TC. By taking the same region and gridpoints as in (6), we calculate the analogy indexes Su_j for zonal flow and Sv_j for meridional flow, and analogy coefficient of flow field Sw_j:

$$Su_{j,k}=\left(\sum_{l=1}^{25}u_{j,k,l}\cdot u_{0,k,l}\right)\Big/\sqrt{\sum_{l=1}^{25}u_{j,k,l}^2\cdot\sum_{l=1}^{25}u_{0,k,l}^2}$$

$$Sv_{j,k}=\left(\sum_{l=1}^{25}v_{j,k,l}\cdot v_{0,k,l}\right)\Big/\sqrt{\sum_{l=1}^{25}v_{j,k,l}^2\cdot\sum_{l=1}^{25}v_{0,k,l}^2}$$

$$Su_j=\frac{1}{21}\sum_{k=1}^{21}Su_{j,k},\ Sv_j=\frac{1}{21}\sum_{k=1}^{21}Sv_{j,k},$$

$$f_{9,j}=Sw_j=Su_j\cdot Sv_j,\ T_9=Max\left[f_{9,j}\right]$$

From the criterion and Eq.(1), the analogy index $SI_{9,j}$ can be estimated for the initial 500-hPa flow field.

(10) Criterion of future 500-hPa flow field

By taking the same region and gridpoints as in (9), we use the same method to calculate the analogy index $SI_{10,j}(t)$ for flow fields in the next 24, 48 and 72 hours. Then, the future analogy index for 500-hPa flow field $SI_{10,j}=\frac{1}{3}\sum_{t=24}^{72}SI_{10,j}(t)$ is determined (t = 24, 48, 72)

(11) Criterion of 500-hPa flow field distance

We use the same method to calculate the Eular distance of u and v fields for the initial time and in the next 24, 48 and 72 hours for the same region and gridpoints which are the same as in (9):

$$Du_j(t)=\sqrt{\sum_{k=1}^{21}\sum_{l=1}^{25}\left(u_{j,k,l}(t)-u_{0,k,l}(t)\right)^2},\quad Dv_j(t)=\sqrt{\sum_{k=1}^{21}\sum_{l=1}^{25}\left(v_{j,k,l}(t)-v_{0,k,l}(t)\right)^2}$$

$$f_{11,j}(t)=Du_j(t)\cdot Dv_j(t),\ T_{11}=Min\left[f_{11,j}(t)\right],\qquad t=0,24,48,72$$

From the criterion and Eq.(1), $SI_{14,j}(t)$ can be separately calculated. Then, the 500-hPa flow field distance is obtained:

$$SI_{11,j} = \frac{1}{4}\sum_{t=0}^{72} SI_{11,j}(t) \qquad t = 0, 24, 48, 72$$

(12) ~ (17) Criteria of flow fields at 850 hPa and 200 hPa

The 850- and 200- hPa flow fields are closely associated with the inflow and outflow fields of TC, respectively. Taking the region and gridpoints same as (12) and starting from these fields at the initial and future time, the same method is used to estimate analogy indexes $SI_{12,j}$, $SI_{13,j}$, $SI_{14,j}$, $SI_{15,j}$, $SI_{16,j}$ and $SI_{17,j}$ for the fields and distance at the initial and future time.

(18) Criterion of initial steering flow field

Interactions between TC and environmental field pose significant influence on TC motion and steering air currents contribute much to it. By a popular observational result, air flows at 700 hPa or 500 hPa are considered the most relevant steering current[5] while mean layer current has more consistent and stable relation when viewed as steering current[6].

With a 9×9 square mesh with resolution of 2.5°×2.5° that centers around a TC at 10 latitudes, steering analogy coefficients are calculated using mean flows of $\bar{u}, \bar{v}$ over layers of 500 hPa, 700 hPa and 850 hPa as the steering fields:

$$S\bar{u}_j = \left(\sum_{k=1}^{9}\sum_{l=1}^{9} \bar{u}_{j,k,l} \cdot \bar{u}_{0,k,l}\right) \Big/ \sqrt{\sum_{k=1}^{9}\sum_{l=1}^{9} \bar{u}_{j,k,l}^2 \sum_{k=1}^{9}\sum_{l=1}^{9} \bar{u}_{0,k,l}^2}$$

$$S\bar{v}_j = \left(\sum_{k=1}^{9}\sum_{l=1}^{9} \bar{v}_{j,k,l} \cdot \bar{v}_{0,k,l}\right) \Big/ \sqrt{\sum_{k=1}^{9}\sum_{l=1}^{9} \bar{v}_{j,k,l}^2 \sum_{k=1}^{9}\sum_{l=1}^{9} \bar{v}_{0,k,l}^2}$$

$$f_{18,j} = S\bar{w}_j = \bar{S}u_j \cdot \bar{S}v_j, \qquad T_{18} = Max\left[f_{18,j}\right]$$

From the criterion and Eq.(1), the analogy index $SI_{18,j}$ can be estimated for initial steering.

(19) Criterion of future steering field

With the same region and mesh as in (18) and employing the same method, the analogy index for future steering field $SI_{19,j}$ can be estimated.

(20) Criterion of steering flow field distance

With the same region and mesh as in (18), the analogy index $SI_{20,j}$ can be estimated for steering flow field distance, using mean flow over 500 hPa ~ 850 hPa layers for the initial time and the next 24, 48 and 72 hours.

5 FORECAST MODELS

(1) Preliminary screening of historical samples

For the historical samples selected in analogy forecast to be as close to each other as possible in time, climate and atmospheric circulation background, only samples satisfying the following condition will be taken in:

$$\left|Date_j - Date_0\right| <= 20$$

$$\sqrt{(\varphi_j-\varphi_0)^2+(\lambda_j-\lambda_0)\cos^2\left(\frac{\varphi_j-\varphi_0}{2}\right)}<=3$$

(2) Estimation of comprehensive analogy indexes

For M historical TC samples selected by the standard of (1), the above criteria are applied to determine each of the analogy indexes of $SI_{i,j}$. As it is possible that some simultaneous environmental field factors may be linearly related, it is decided that linear correlation coefficients among analogy index series are first calculated for all analogy criteria and then one of the two analogy criteria is deleted when significant correlation occurs with the confidence being 0.05. For this case, there are 20 analogy criteria after the deletion. As a result, the comprehensive analogy index is expressed by

$$SI_j=\sum_{i=1}^{20}SI_{i,j} \qquad \begin{pmatrix} i=1,2,3\ldots 20 \\ j=1,2,3\ldots M \end{pmatrix}$$

(3) Analogy forecast

By realigning historical sample series according to the SI_j values, we have made these values in the new series $\{N_j$ decrease monotonously. When present SI_j value in N samples meet the condition of

$$SI_1-SI_k<=10 \qquad (k=1,2,3\ldots N)$$

previous N samples are analogous.

When the track of analogous samples ($\varphi_{k,t}, \lambda_{k,t}$) comes most closest to the location of forecast samples $\varphi_{k,0}, \lambda_{k,0}$, we can have the forecast track for analogous TC samples at t after conversion of coordinates:

$$\hat{\varphi}_{k,t}=\varphi_{k,t}+(\varphi_{k,0}-\varphi_0) \qquad (k=1,2,\ldots,N)$$

$$\hat{\lambda}_{k,t}=\lambda_{k,t}+(\lambda_{k,0}-\lambda_0) \qquad (t=6,12,\ldots,T)$$

in which the subscript k is the order of analogous samples, subscript t is the time, which is taken a point every 6 hours and T is the eventual valid duration of forecast:

$$\hat{\varphi}_t=\sum_{k=1}^{N}SI_k\hat{\varphi}_{k,t}\Big/\sum_{k=1}^{N}SI_k \qquad (k=1,2,\cdots,N \qquad t=6,12,\cdots,T)$$

$$\hat{\lambda}_t=\sum_{k=1}^{N}SI_k\hat{\lambda}_{k,t}\Big/\sum_{k=1}^{N}SI_k \qquad (k=1,2,\cdots,N \qquad t=6,12,\cdots,T)$$

6 MODEL VERIFICATION AND FORECAST EXPERIMENT

With 51 TC in 183 independent samples for July ~ September in 1991 ~ 1996, we conducted verification of the current model (SAN). The forecast errors are presented in Tab.1. It also gives comparison between the analogy forecast and HUR forecast.

As shown in the result, the SAN model improves much over the HUR mode, especially over time periods between 72 and 120 hours, with error decreasing by 37 ~ 170 km in distance and 3 ~ 8 degrees in direction of movement.

Tab.1 Verifications of forecast models

Valid dur./ hr	24		48		72		96		120	
Fcst model	SAN	HUR	SAN	HUR	SAN	HUR	SAN	HUR	SAN	HUR
Dist. err./km	156	160	352	395	587	624	746	891	823	993
Dir.err. /deg.	13	14	16	18	20	23	19	23	16	24

A total of 122 forecast experiments were performed applying the model in 37 cases of TC in 1997 ~ 2000, with the result compared with that of the Cliper (CLP) scheme (Tab.2).

Tab.2 Results of forecast model experiments

Valid dur./ hr	24		48		72		96		120	
Fcst model	SAN	CLP	SAN	CLP	SAN	CLP	SAN	CLP	SAN	CLP
Dist. err./km	166	164	367	378	605	623	816	884	894	989
Dir.err. /deg.	13	12	17	17	21	23	20	25	18	24

As shown in the forecast experiments, the two models have comparable magnitudes of error over short duration of valid forecast from 24 to 48 hours while the SAN model is 18 ~ 95 km smaller in the error of distance and 2 ~ 6 degrees smaller in the error of moving direction, than the CLP scheme. As the Cliper scheme is the standard in assessing the skill of forecast models, the SAN is then considered to be of forecasting skill, especially higher for long valid periods (72 ~ 120 hrs).

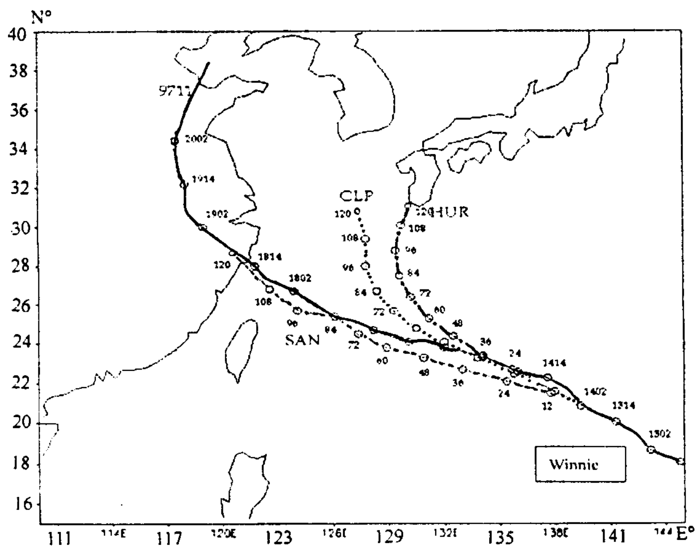

Fig.3 Model predictions of Typhoon Winnie (No.9711). The solid line stands for the track of Winnie, the dashed line for the prediction by SAN, the dotted line for CLP and the dotted and dashed line for HUR. The numerals are for the time of day.

Winnie (No.9711) was one of the typhoons that had caused huge economic losses in Zhejiang Province. Generated in northwestern Pacific, it made landfall on the coast of central Zhejiang. At 0200 (L.T.) August 14, 1997, the typhoon (see Fig.3) was at 20.6°N, 140.2°E. The SAN model was successful in predicting that it would move on land in the central part of the Zhejiang Province in about 120 hours while the HUR and CLP models both pointed to a direction change over waters east of 125°E.

7 CONCLUDING REMARKS

a. An objective analogy TC track forecast model, which gives comprehensive assessment of environmental field, is used to assess effects of interactions between TC and the environment on its motion, taking into account all possible factors. Multiple objective criteria are incorporated to make it easier to recognize best-analogous TC. It is of course possible for the incorporation to decrease particular roles by some of the criteria.

b. The analogy indexes as defined in this model are able to integrate different criteria under a consistent framework. Its non-linear distribution increases the weight of analogous samples but decreases that of those that are not analogous. It is favorable for historical samples to separate according to the degree of analogy and to screen for best-analogous samples.

c. The current model uses output of numerical weather forecasts as analogous condition of future environmental field, in addition to consideration of analogy between initial and future environmental fields. In this way, the analogy is made more reasonable due to its dynamical foundation. The forecast output from the model is, however, unavoidably affected by errors of numerical prediction.

d. As analogy criteria directly affect the result of the model, factors having influence on TC motion should be selected in the screening for analogy criteria. As some concurrent environmental factors may be linearly correlated, efforts should be made to eliminate analogy criteria of linear correlation when analogy indexes are being integrated.

e. As shown in model verification and forecast experiments, the current model is of forecasting capability and skill in TC motion prediction, especially so for periods of longer valid time.

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