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# PREDICTION OF ANNUAL FREQUENCY OF AFFECTING TROPICAL CYCLONE USING THE PRODUCTS OF A HYBRID COUPLED AIR-SEA MODEL

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**ABSTRACT:** Better correlation exists between the activity of tropical cyclones affecting East China and Shanghai and the concurrent signals of SSTA in tropical Pacific. In an attempt to justify this statistic finding, a four-dimensional variational data assimilation system is established to optimize the initial fields of a hybrid air-sea coupled model. The prediction skill of tropical SSTA is improved. Long-term statistical models for predicting annual TC frequency affecting East China area and Shanghai city are developed based on 37-year products of this model and the forecast trials have achieved satisfactory results in 1998 and 1999.

**Key words:** sea surface temperature anomaly; four-dimensional variational data assimilation; affecting tropical cyclone

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## 1 INTRODUCTION

It is shown in observational facts that the East China and the region of Shanghai are two of the areas that are severely affected by tropical cyclones in China. The number of the tropical cyclones affecting the areas varies considerably from year to year, with the highest being 13 and 3 and lowest being 7 and 0, respectively. It is therefore important for the coastal economic development and safeguarding life and property to have good short-term climatological predictions of tropical cyclones that would have the potential to affect these two areas.

The tropical cyclones that affect East China and Shanghai mostly occur in June ~ October. Quite a number of studies have shown that the frequency of the tropical cyclones in the northwest Pacific that are active and affecting is by some degree related with the SSTA in the tropical central and eastern Pacific Ocean[1, 2]. On the other hand, long-term predictions of tropical cyclone frequency are usually statistic ones that identify correlated factors existing in preceding periods. For instance, anomalous signals in the SST in the equatorial Pacific over the preceding winter and spring are useful in assisting the diagnosis of the frequency of tropical cyclones that would affect in the following summer and autumn[3, 4]. Statistic facts of the current paper will show that the affecting tropical cyclones are better correlated with the concurrent anomalies of SST in the equatorial Pacific in the summer and autumn. Therefore, if accurate predictions of SSTA and general circulation of the tropical ocean in summer and autumn are possible, we can have higher accuracy in predicting the frequency of tropical cyclones that would influence the areas mentioned above.

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**Biography:** LI Yong-ping (1961 –), male, native from Jiangsu province, research associate at the Shanghai Typhoon Institute, undertaking the study of marine meteorology.

## 2 OBSERVATIONAL FACTS

Based on the frequency data of the tropical cyclones affecting the East China region from 1951 to 1998 (a total of 48 years), computations are done for their correlation (Fig.1) with the SSTA in the north Pacific in the preceding winter (December & January), spring (March, April & May) and summer (July, August & September).

As shown in the result, the coefficient is generally small for the number of tropical cyclones affecting the area of East China in correlation with the equatorial central and eastern Pacific in

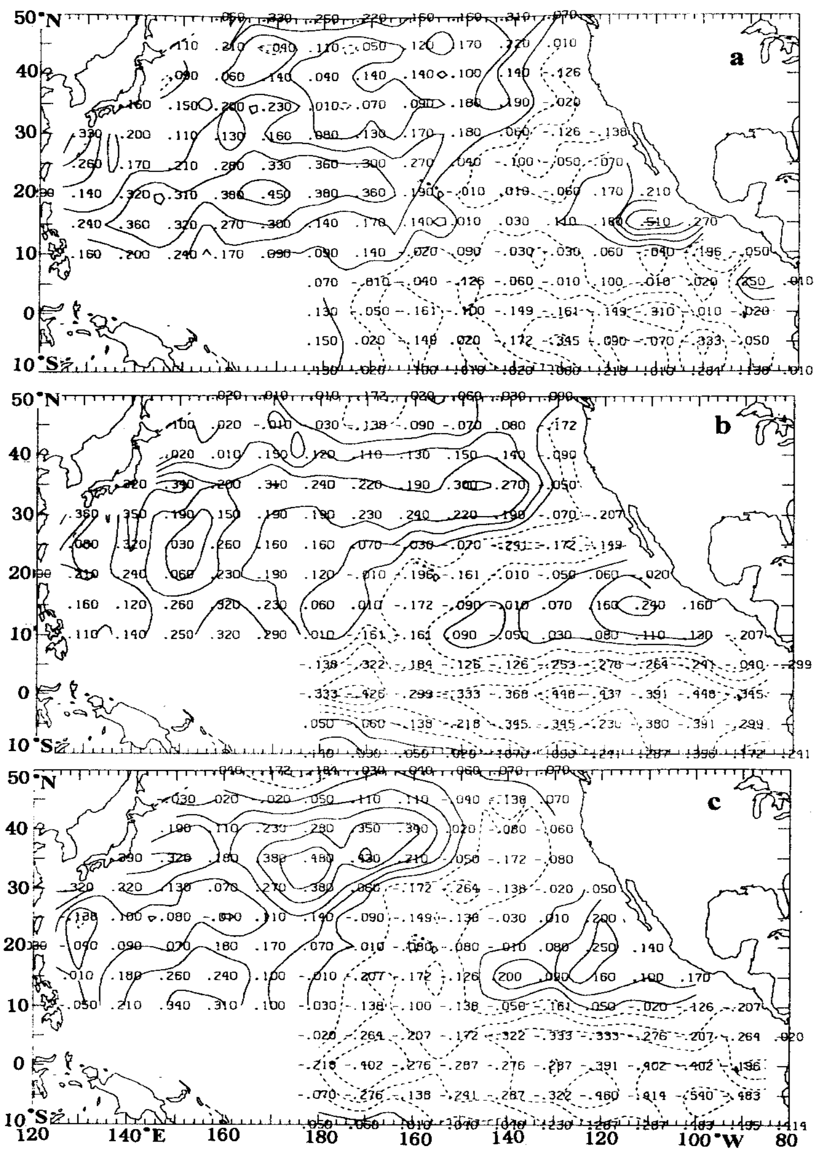


Fig.1 Correlation between the frequency of tropical cyclones affecting East China and SSTA in north Pacific in (a) preceding winter (Dec. ~ Jan.), (b) preceding spring (Mar. ~ May) and (c) summer (Jul. ~ Sept.)

winter with just a few gridpoints being as high as 0.30. In spring, the correlation with this part of the Pacific Ocean is slightly better than in winter, being about 0.42 for some gridpoints. Of the three seasons, the current summer has the best correlation coefficient, with many of the gridpoints inside the region of Nino3 (150°W ~ 90°W, 5°N ~ 5°S) being larger than 0.48 and the maximum being 0.54. It is a sign that the frequency of the tropical cyclones having influence on the areas of interest may be dependent on the conditions of the ocean and atmosphere over the simultaneous period.

## 3 FOUR-DIMENSIONAL ASSIMILATION SYSTEM OF THE HYBRID COUPLED AIR-SEA MODEL

In the hybrid coupled air-sea model[5] adopted in the work, the oceanic component is made up of shallow water equations that are linear and longwave-approximated, a non-linear SST variation equation that is divided up into two layers, a surface layer and a subsurface layer; the atmospheric component is assumed to be at the Gill-type linear constant state, the SST responds to the atmospheric field through heating effects, and whether and how much latent heat is released into the atmosphere depends on the diversity at low-levels of the atmosphere.

Usually, an coupled air-sea model is used to predict the ENSO, in which the initial field is forecast mainly based on the observed historical wind stress fields existing before the initial moment of integration, without considering the SST fields at or before the initial time [5]. As a result, such initial fields neglect information about the SST that could have been available through observation. As shown in Kleeman et al [6], forecasts can be improved significantly when the observed oceanic and atmospheric data are fully made use of in coupled air-sea models, which employ the technique of data assimilation. Using a four-dimensional variational data assimilation technique which is based on the adjoin method[7, 8], our work takes the observed SST as one of the thermodynamic factors and includes them into the initial field of the LEDO model integration in an attempt to increase the model capability of predicting the anomalies of the SST.

The data assimilation technique is an efficient method for incorporating the observations into the model. The advantages of the four-dimensional variational data assimilation technique are its ability to include observations at various time levels into the model with the coordination between observations and model secured.

First of all, an order function is defined in the process of the four-dimensional variational data assimilation so that the "distance" (deviation) between the model predictions and observations are measured. Here it is expressed as

$$f = \int_{t_0}^{t_1} \left(x(t) - x^0(t)\right)^T w \left(x(t) - x^0(t)\right) \mathrm{d}t$$

Specifically, $x(t)$ is the model-predicted value at the time $t$, $x^0(t)$ is the observed value at the time $t$, $T$ stands for the transposed computation, and $w$ is the matrix of weighted coefficients, which is in theory the matrix of covariance of errors for individual variables observed. Through such an order function, the "distance" between the model predictions and observations are derived. The aim of assimilation is to minimize the order function by locating an initial field fittest for the model, i.e. to draw the model predictions closer to the observations.

By split steps, the assimilation can be decomposed into:

(1) integrating the prediction model to produce outputs $x(t)$ of forecast for different initial

time $t$;

(2) substituting model forecasts $x(t)$ at different time and observed data $x^0(t)$ to the order function for determining the function value while substituting the difference between $x(t)$ and $x^0(t)$ to the conjugate model in the prediction models, which is integrated oppositely to obtain corrections to the model initial fields;

(3) modifying the model initial field based on which a fresh initial field begin.

Steps (1), (2) and (3) are repeated until the order function reaches its minimum (i.e. the discrepancy between the model forecasts and the observations are the minimum).

(4) integrating the prediction model with the initial field that has been assimilated for outputs.

By using the assimilation described above, the observed SST data at different time can be assimilated into the model so that the prediction is as close to the observation as possible over the period it is recorded, securing more accurate prediction in the time to follow.

The adjoin model in this work is constructed directly through the forward model by observing the principle of conjugate codes [9].

## 4 RESULTS OF NUMERICAL PREDICTIONS

Fig.2 gives the accuracy of retrospect forecast of monthly SSTA in the area of Nino3 using a model that has been processed with the assimilation system over a period of 36 years (1962 ~ 1997).

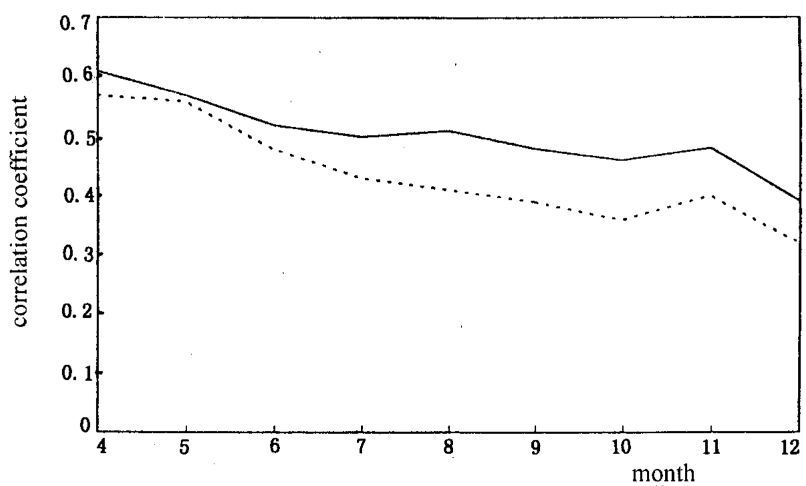


Fig.2 Correlation coefficients between the model output and the observations. —— : results with initial field treated with variational data assimilation; - - -: results with initial field not treated with it

Meeting the needs in operational forecasting, the initial forecast time of the model is set in every March. Consequently, the time window for the assimilation then covers 12 months from April to March in the next year and so does the valid period of the forecast. As shown in Fig.2, the SSTA in the area of Nino3 that has been assimilated is well correlated with the observation over the 12-month period, being about 0.50 in summer and autumn. In general, the forecast of the SSTA in Nino3 is more accurate when it has been through the assimilation treatment than the one that has not.

## 5 STATISTIC FORECAST OF AFFECTING TROPICAL CYCLONES WITH MODEL OUTPUT

Setting as candidate factors the SSTA in the Nino3 region and equatorial central and eastern Pacific (155°E ~ 180°, 5°N ~ 5°S) and the divergence in the lower atmospheric levels as output by the model on a monthly basis May through October, a set of prediction models are prescribed using the stepwise regression method to predict tropical cyclones that may influence the regions of East China and Shanghai. The factors and coefficients are listed in Tab.1.

Tab. 1 Predictors and coefficients of the predictive equation for the annual frequency of tropical cyclones affecting the East China area and Shanghai

| | $B_0$ | $TE_7$ | $TW_8$ | $TW_9$ | $DIV_9$ | R |
|---|---|---|---|---|---|---|
| $TC_{East\ China}$ | 4.933 | –0.105 | | –3.259 | –8.443 | 0.59 |
| $TC_{East\ China\ S.}$ | 4.84 | –0.14 | | –3.278 | –7.808 | 0.59 |
| $TC_{East\ China\ N.}$ | –1.01 | | –5.112 | | | 0.39 |
| $TC_{Shanghai}$ | 1.159 | –0.13 | | –2.143 | | 0.45 |

In Tab.1, $TE_i$ and $TW_i$ are the SSTA respectively in the Nino3 region and equatorial central Pacific in the *ith* month, $DIV_i$ is the divergence in the lower levels of the atmosphere in this part of the Pacific Ocean in the *ith* month while *R* is the complex correlation coefficient. The historical fitting rates computed with the regression equation described above in terms of the frequency of the tropical cyclones affecting the regions are presented in Fig.3.

Tab.2 gives the operational forecasts for 1998 and predictions for 1999 in unit of storms. It shows that the current method is generally successful in making annual prediction of the frequency of the tropical cyclones that affect the regions over the past two years. Specifically, the statistic evaluation does not extend beyond October 15 for the prediction of 1999. It must be noted that the

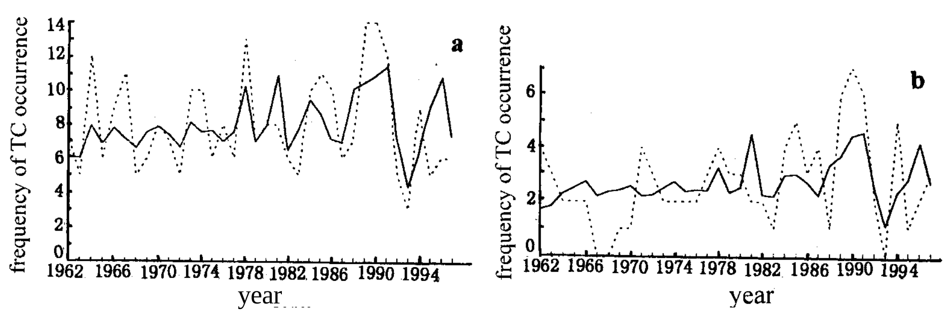


Fig.3 Historical fitting rates for the frequency of affecting tropical cyclones in (a) East China and (b) Shanghai; solid line: observation; dashed line: fitting.

frequency of affecting tropical cyclones from June to October generally stands for that for the whole year as far as the East China and Shanghai region are concerned.

Tab. 2 Trial forecasts for 1998 and predictions for 1999 in the annual frequency of tropical cyclones affecting East China and Shanghai

| Region | Trial forecast 1998 | Observations 1999 | Predictions 1999 | Climatic mean |
|---|---|---|---|---|
| East China | 6.7 | 5 | 10.1 | 7.8 |
| Southern East China | 6.6 | 5 | 10.0 | 7.7 |
| Northern East China | 2.1 | 1 | 2.7 | 2.3 |
| Shanghai | 2.4 | 3 | 4.1 | 2.7 |

## 6 CONCLUDING REMARKS

a. The four-dimensional data assimilation of a hybrid coupled air-sea model, which is developed on the basis of an adjoin model, can be effectively used to optimize the initial field during model integration and to increase the accuracy with which the model predicts the ENSO.

b. The model outputs are of statistic interpretation for the prediction of annual frequency of the tropical cyclones that would influence the East China and Shanghai regions.

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