ADVANCES IN STATISTICAL METEOROLOGY IN CHINA IN RECENT YEARS

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ABSTRACT

Great advances in statistical meteorology have been made in recent years in China. The main points are as follows: Introducing entropy principle into meteorology, entropy meteorology is founded; Introducing memory function, self-memorization equation of atmospheric motion is derived; The fuzzy reasoning is introduced into meteorology; Using the method of nonlinear dynamics in researches of climatology, some forecasting schemes of phase space are proposed; Chebyshev polynomial is generalized at irregular grids and an iterative scheme for forecast of time series is proposed; The wavelet transform is used in researches in climatology; Logistic discrimination is used in meteorology and quadratic discrimination and stepwise discrimination are investigated; The theory on grey system and the multilevel recursion proposed by Chinese scientists are introduced into meteorological forecast. In addition, complex empirical orthogonal function, singular value decomposition, projection pursuit, principal oscillation patterns and so on are also introduced. All the above methods have played great roles in operational weather forecasts.

Key words: statistics, meteorology, advance

I. INTRODUCTION

The Council of the Chinese Meteorological Society passed a resolution to set up the Committee for Statistical Meteorology in 1990. This is a new stage on statistical meteorology in China. A new scientific term, Statistical Meteorology, is proposed formally since then. Many scientists devote themselves to the researches on the new branch of meteorology. A brief description of the development of statistical meteorology in recent years in China is presented in this paper.

II. APPLICATIONS OF THE METHODS FOR STATISTICAL METEOROLOGY IN OPERATIONAL FORECASTS

Statistical meteorology finds its comprehensive applications and plays a very important role in operational weather forecasts in China.

Numerical model is the main tool in the short-term forecast of weather situation. However, statistical methods are basically used in the forecast of meteorological elements.

One of the effective methods is model output statistics (MOS) using the products of numerical model. This method has been used in the forecast of meteorological elements of Central Meteorological Observatory of China. In addition, it is more important for local meteorological observatories, especially for the observatories where no numerical model can be used. For instances, in the state project for the improvement of operational forecasts of typhoon and heavy rainfall, the statistical interpretation of the products of numerical models is a main tool.

One of the problems in MOS methods is that its forecasting scheme is connected closely with the performance of numerical model. Therefore, the forecasting scheme should change with the change of numerical model. This problem becomes more serious because of the rapid change of the numerical model. Kalman filtering is used in the MOS forecast to match the change of numerical model (Huang and Xie 1993; Liu et al. 1995).

The medium-range weather forecast in Central Meteorological Observatory has a predictability of one week. Beyond this period the forecasting errors get serious and need to be corrected using statistical method. And the forecast of meteorological elements is basically made by using statistical methods.

Great advances have been made in long-range numerical weather prediction. Some models including coupled ocean-atmosphere models and simplified dynamical models are running. These models, however, are still in their initial stage, although they have forecasting skill to certain extent. Therefore, statistical methods are the main tools for operational long-range forecasts.

Various central and local operational expert forecasting systems have been developed in recent years in which a number of statistical methods are used, and the operational forecast becomes more objective and quantitative.

III. ENTROPY METEOROLOGY

The probability distribution of meteorological elements are important contents of statistical meteorology and are very basic. Professor Yao is the pioneer in this area in China. "Climatological Statistics" written by him and Ding published in 1990 (Yao and Ding 1990) is the revised version of his book with the same title published in 1963, in which a lot of new research results were included. Probability of wind in China was investigated by Zhu and Xue (1981). Probability distribution of rainfall in China is given by Zhang and Ding (1991) and climatic extremes are discussed by Dong (1993).

Since Prigogine (Glansdorff and Prigogine 1971) the nonequilibrium theory has found its comprehensive application. The investigations in this field of Chinese scientists such as the application of dissipation structure (Li 1984), forecast of heavy rain (Zhao 1985), model of energy equilibrium (Zhang and Tang 1986), model of entropy climatology (Tang et al. 1989), zero-dimensional stochastic climate model (Yan and Peng 1989), one-dimensional stochastic climate model (Lin et al. 1988) should be mentioned.

The relationship between information entropy and meteorology entropy is discussed by Zhao et al. (1988).

Zhang suggested the word Entropy Meteorology in 1986 and published the book "Entropy Meteorology" in 1992 (Zhang and Ma 1992). Owing to this the research on probability distribution is deepened. Of course entropy meteorology has its comprehensive meaning.

The subject of research on entropy meteorology is the global atmosphere, which is the same as in dynamical meteorology. However, the analysis of single air minute mass is emphasized in dynamical meteorology and the ensemble of some kind is considered in entropy meteorology. For instance, a lot of air minute masses with different temperatures, a large number of hail pellets, a large number of rainfall processes and so on are the research subjects of entropy meteorology. There are two fundamental conceptions, distribution function and entropy, in entropy meteorology. The distribution function in entropy meteorology is a generalized conception. Probability distribution is its special case and drop size spectrum of cloud and rainfall is also its special case. Entropy in entropy meteorology is also a generalized conception. The ideas of entropy in physics and information theory are also included in entropy meteorology.

About 30 distribution functions in entropy meteorology have been found. They are smoothing and continuous, and almost do not change as a function of time. They can be represented by analystic formula with few parameters. For instance, temperature and pressure obey the uniform distribution, specific humidity, potential energy and velocity obey a negative exponential distribution, total energy and potential temperature obey Γ distribution. Zhang found that these distribution functions are highly stationary.

More than 10 traditional probability distribution functions may be derived by using the maximum entropy principle.

IV. SELF-MEMORIZATION EQUATION IN ATMOSPHERIC MOTION

In view of the fact that atmospheric motion is an irreversible process, Cao (1993) suggested the self-memorization equation in atmospheric motion by introducing a memory function which can recall observational data in the past. The first term in the right hand of the equation called self-memory term represents the memory for the past and the second term called external effect term denotes the contribution of all the points in space.

Self-memorization equation is derived from thermodynamical equation of atmosphere, hence it has solid physical foundation. In addition it has good practical foundation because it involves the experience of forecasters, who condsider both the historical evolution of synoptic process and the horizontal distribution of meteorological fields. Cao pointed out that the self-memorization equation is the generalized form of equation of traditional numerical model. He also stated that some existing difference equations in numerical models can be derived from the self-memorization equation by giving special values to the memory function. Multi-time numerical models can be unified into a framework of self-memorization equation. If stochastic method in solving the memorization function is taken, the self-memorization equation will be transformed to a sort of dynamic-stochastic prediction model. The mean generating function proposed by Cao and Wei (1991) is the pure statistical solution of self-memorization equation.

V. NONLINEAR DYNAMICS

Since the study on the deterministic nonperiodic flow by Lorenz (1963) was published, great advances have been made in the chaos theory and its apllication. Besides theoretical study on the atmospheric motion based on low-order spectral model, the investigation on processing historical data from the view point of nonlinear dynamics has developed widely. The computation of fractional dimension, the study on the predictability and the dynamical model retrieved from the historical data are the main topics in nonlinear dynamics. According to the authors, however, the forecasting based on chaotic theory is also an important area. There is little study in this area abroad since Farmer et al. (1987). Lin (1993) firstly made researches in this field in China. He proposed some forecasting models in phase space and suggested to use group method of data handling (GMDH) technique in forecasting.

Zhou has made some researches in this area and proposed four schemes of forecast based on the theory on chaos. They are schemes of vector similarity in phase space, of variability of phase orbit, of spacial transform and of module (Zhou 1993). A brief description for the forecasting scheme of vector similarity in phase space is as follows.

Introducing a time lag τ, a phase space $R_m(t_i)$ is reconstructed from a univariate time series $X(t_i)$. In this case forecasting problem is transformed into finding the position of phase point at moment t_{i+1}, provided the positions of phase points before moment t_i are known. Evaluate the distances between phase point $X_m(t_i)$ and all other points in phase space. A phase point $X_m(t_b)$ whose distance from point $X_m(t_i)$ is minimal can be found. The distance between $X_m(t_i)$ and $X_m(t_b)$ is named by L_i. At next moment $X_m(t_i)$ reaches $X_m(t_{i+1})$ and $X_m(t_b)$ does $X_m(t_{b+1})$. The distance between $X_m(t_{i+1})$ and $X_m(t_{b+1})$ is L_{i+1}. Assuming $L_i = L_{i+1}$, we get a quadratic equation and obtain two predicted values for $X(t_{i+1})$. In phase space a phase point corresponds to a vector from origional point to that point. Thus phase points $X_m(t_i)$, $X_m(t_{i+1})$, $X_m(t_b)$ and $X_m(t_{b+1})$ correspond to vectors $\mathbf{V}_m(t_i)$, $\mathbf{V}_m(t_{i+1})$, $\mathbf{V}_m(t_b)$ and $\mathbf{V}_m(t_{b+1})$ respectively. The angle between $\mathbf{V}_m(t_i)$ and $\mathbf{V}_m(t_b)$ is θ_i and the angle between $\mathbf{V}_m(t_{i+1})$ and $\mathbf{V}_m(t_{b+1})$ is θ_{i+1}. Assuming $\theta_i = \theta_{i+1}$ we get another quadratic equation and find another two predicted values for $X(t_{i+1})$. Given some criteria the reasonable predicted value can be found.

Assuming $L_i = L_{i+1}$ means that the distance between two neibouring phase points is constant, i.e. the phase orbit is parallel during a short period. In order to represent the divergence and convergence of a phase orbit, we can introduce the change rate of distance between phase points and get forecasting model of variability of phase orbit.

The forecasting schemes mentioned above have been used in the forecast of intensity of the Southern Oscillation, Beijing rainfall and the distribution of rainfall over Northern China.

VI. EMPIRICAL ORTHOGONAL FUNCTION

Empirical orthogonal function (EOF) relates closely with principal component analysis (PCA), factor analysis (FA), eigen vector analysis (EVA), canonical correlation analysis (CCA), singular value decomposition (SVD) and principal oscillation pattern (POP). They are all commonly used methods in numerical experiments, MOS, synoptic and climatology.

EOF is commonly used in extracting spatial mode and regionalization of climate (Gong

1991).

It should be studied what the condition for stability is if the spatial pattern is statiorary. Ding and Jiang (1993) discussed the influence of correlation structure of meteorological field on the stability and showed that the more the field unifies. the more stationary the spatial pattern is. Based on the stability the forecast of spatial distribution of meteorological elements may be carried out.

The transient waves can be monitored from the evolution of the field of meteorological elements by using complex EOF. The quasi-biennial oscillation of precipitation in China is discussed by Huang (1988) with CEOF. He indicated that this quasi-periodic oscillation is more evident in North China and mid and low reaches of Changjiang River and it propagates northeastward. The relationship between seasonal evolution of sea surface temperature in the Pacific Ocean and summer rainfall over mid and low reaches of Changjiang River and the south of it is discussed by Tang (1993). Rotated EOF (REOF) is the extension of EOF. The harmonic oscillation of rain day is detected by Huang (1991) with REOF. The precipitation in January and July in the east part of China is analysed by Lu (1989).

Canonical Correlation (CC) is usually used to study the interaction between two meteorological fields. It is the extension of EOF to monitor the relationship between two fields and can be used to forecasting. The forecasting of precipitation during rainy season over Middle and Lower Reaches of Changjiang River is investigated by Shi et al. (1984) with CC. The correlation between sea surface temperature over North Pacific and geoptential height at 500 hPa is discussed by Jiang and Hu (1993) and the forecast is also made.

Singular value decomposition is the new extension of both EOF and canonical correlation analysis. By using it the coordination effect of tropical Pacific and Indian Ocean is investigated by Sun (1992).

Corresponding analysis is also the extension of EOF. With this method Li and Huang (1985) indicated that the monthly variation of subtropical high over North Pacific is similar to that of sea surface temperature in the tropics. Principal oscillation pattern (Zhang et al. 1993) and projection pursuit (Shi et al. 1993) are also introduced into China.

VII. CHEBYSHEV EXPANSION

Previous Chebyshev expansion can be used only at rectangular grids. It is generalized into the case of irregular grids by Zhou. Then the generalized Chebyshev polynomial is used in the forecast of distribution of meteorological elements (Zhou 1990).

Zhou (1994) proposed an iterative scheme of time series based on Chebyshev expansion. This is a nonlinear method and also a nonparametric method in which the stationary assumption is not necessary. Its accuracy of practical forecast is close to that of fitting. A little computation is needed when we reject and renew data.

VIII. GREY SYSTEM AND FUZZY FORECAST

Grey model is a kind of method fitting series in term of differential equation after generating processing of oringinal data. Our knowledge of climatical system on it evolution, mechanism and interaction among its subsystems is too limited to study it in term of dynamical and/or statistical method. As a matter of fact, our knowledge of climatical system is almost got from time series of climatological data. Such series represents the interaction of various components of climatical system. Therefore, climatical system is a typical grey system, part of information of which has been known and other part has not been known. Deng's theory on grey system (Deng 1985) provides a potential tool for diagnosis and forecast of climatical system. It is quickly applied to medium and long-range weather forecast by meteorologists. A review on the grey system and its application is given by Cao and Wei (1988).

Fuzzy set theory was applied in meteorology by Chen (1979) in the first instance. Fuzziness is a representative of fuzzy phenomena in the world and uncertainty in dividing subjects which exists in many meteorological elements. Fuzzy mathematics has been used in scoring of weather forecast, verification of climatical modelling, medium and long-range forecast, expert system, analysis of meteorological disasters, objective analysis and measurement of meteorological service (Cao and Chen 1988).

IX. DISCRIMINATING ANALYSIS

Ordinary discriminating analysis and stepwise discriminating analysis have been used in China in many years. Quadratic discrimination was investingated by Shi and Cheng (1986). All these methods are limited by normal distribution of variables. Logistic discrimination is less limited for the distribution of variables and could be used in the case that continuous variables and discrete variables exist simultaneously. Logistic discrimination is introduced into China by Lu and Chen (1992), and quadratic Logistic discrimination (Lu and Chen 1986) and stepwise Ligistic discrimination (Lu et al. 1995) is studied by him.

X. DYNAMIC DATA PROCESSING AND MULTILEVEL RECURSION

Stationary time series analysis is a classical statistical method which is also named autoregression. The method, however, can be used only in the case that the series is stationary. This requirement is hardly met in meteorological series. On the other hand, the coefficients in regression equation based on the above method are unchanged. And this is not suitable for evolution of meteorological phenomena. Mathematicans made many improvements in order to overcome the shortcomings. A new method named multilevel recursion for forecast of dynamical system is suggested by Han (1983). The formula for evaluating the changing coefficients are derived based on the temporal change of coefficients in regression equation. Good results in meteorological forecast are got (Wu and Yao 1989) and some improvements are made (Li and Wang 1990). A review is given by Xiang et al. (1991) for dynamic and stationary data processing.

In addtion to classical methods of time series analysis used, many kinds of new methods have been introduced including periodic rank, time series method based on mean generating function proposed by Cao and Wei (1991) and artificial nervous network which is used by Cai et al. (1994) to monitor the artificial precipitation enhancement.

XI. WAVELET TRANSFORM AND WALSH FUNCTION

Wavelet is a new function series and is convenient for describing time series with non-smoothing, multiscale and strong locality. It projects the data on the axes formed by muturally orthogonal or closely orthogonal wavelet basis and can be considered as new development of Fourier transform. Liu et al. (1995) studied the temperature change over the Northern Hemisphere and abrupt climatic change in different hierarchies by using it. The periods of runoff over Changjiang and Huanghe Valley were studied by Dai and Chou (1994). Many kinds of wavelet filterings are suggested by Lin et al. (1995) to diagnose global climate, temperature and drought/flood.

Walsh function is a function to describe pulses, and can remedy the defect of Fourier function in describing meteorological series. It has been used in the long term forecast of rainstorm flood (Ma 1984) and the analysis and prediction of precipitation field (Wang 1989).

XII. NONLINEAR REGRESSION ANALYSIS

Regression analysis is a commonly used classical statistical method in meteorology and it makes prediction using previous predictors. Complicated and changing interaction between meteorological elements is hardly dealt with it. Extreme meteorological series usually affects the results in monitoring the regularity of series. Robust regression is a method to remedy the defect (Yu and Zhao 1987; Shi and Wang 1992). The regression based on minimazing of forecast error is another method to improve classical regression (Huang and Wang 1990). The assumption on normality is not necessary for Logistic regression (Zhu and Wang 1990). Period analysis with stepwise regression is useful to select significant period (Wei et al. 1983; 1989). To make forecast using nonlinear regression is a new trend in recent years, and long-term forecast (Feng and Yang 1989) and MOS (Huang and Fu 1993) are investigated. Economic metric model intorduced by Lu and Chen (1992) is useful in monitoring the relationship between predictors and predictands and that between a number of predictands.

Many new methods for selecting predictors were introduced. For example, rotating coordination (Gong et al. 1990) and symmetry gap (Zhou et al. 1992) are used to select predictors.

Self-adapting Kalman filter was used in dynamical and statistical forecast, such as forecasts of typhoon track, which involves the change of regression coefficients (Liu et al. 1995; Jin and Zhou 1986).

XIII. CONCLUSIONS

The characteristics in development on statistical meteorology in China in recent years are as follows:

(1) The development is closely associated with the practical operational forecast. A lot of statistical methods have played a great role in operational forecasts.

(2) New ideas and methods, such as entropy meteorology, self-memorization equation, forecasting models in phase space, iterative scheme for time series and so on are

proposed.

(3) Introducing new techniques rapidly. Some new mathematical results at home and abroad such as fuzzy mathematics, grey system and multilevel recursion were introduced into statistical meteorology rapidly.

Although great advances in statistical meteorology have been made in China in recent years, there are still some problems to be solved. For example, a basic framework of statistical meteorology has not been built up owing to the restriction of the level of the displine and its development stage. This needs to be studied further.

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