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SINGULAR SPECTRUM ANALYSIS FOR TROPICAL CYCLONE LANDING IN GUANGDONG

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ABSTRACT: Using the method of Singular Spectrum Analysis (SSA), the evolution regularity of tropical cyclones landing in Guangdong are analyzed. The main periods of yearly topical cyclones landing in Guangdong are found at 8 and quasi-3 years, and in the west of Pearl River Mouth are 12 and quasi-2 years to the west of Pearl River Mouth. The northwest Pacific that topical cyclones are generated is divided into 8 areas, and the SeaSurface Temperature (SST) in each area is analyzed using SSA. The main periods of NINO-west are 8 and 3 years, and those of the warm pool are 12 and 2 years, respectively. This may be the physical reason for the generation tropical cyclones landing in Guangdong. By combining the Maximum Entropy Method (MEM) with SSA (SSA-MEM), the yearly variation trend of tropical cyclones landing in Guangdong and the Pearl River Mouth are forceast, and the results are good. The method can be used in operational short-range climate forecast.

Key words: SSA; tropical cyclones; periodic oscillation

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1 INTRODUCTION

Facing the South China Sea to the south and having a long coastline, the Guangdong province is subjected to frequent attacks by western Pacific and South China Sea tropical cyclones, about 40% of the national total of landfalls and potential threats. It seems compellingly necessary to offer scientific and accurate bases for disaster mitigation by analyzing and predicting how the tropical cyclone evolves climatologically. Besides, the development of society and the economy is posing increasing demand on short-term climatic prediction — tendency prospects reports are required to cover not only the whole year but also the route of landfall. The annual variation of tropical cyclones is subjected to joint interactions by many complicated factors with a wide range of climate noise. The SSA is the right technique for series generated out of these limited data. Being a digital signal processing technique, the SSA extracts reliable information as much as possible from limited-length observed series containing noise, for a system about which physical nature is unknown in advance. As no sinusoidal assumption is needed in SSA, the wave signals it identifies agree more with reality, especially for the study of non-linear oscillation of the atmosphere[1-4]. Owing to SSA, significant oscillation signals are extracted from noise-contained systems, which are hidden in the time series $\{\chi_i\}$ (which is the annual number of tropical cyclones making landfall in Guangdong). The oscillation signals are then used to compose a predictors set for extrapolation forecast. In the current work, the SSA is combined with the maximum entropy method (SSA-MEM) to predict the landfall number of tropical cyclones in the province. The result shows that it is helpful in short-term climate prediction.

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Biography: XIE Jiong-guang (1942 -), male. native from Guangdong Province, professor-level senior engineer, undertaking the study of medium-and long-term climate prediction.

2 BASIC PRINCIPLES OF SSA ANALYSIS

2.1 *Temporal EOF and principal temporal components*

In essence, the SSA technique is establishing a phase spatial matrix based on the time lag order of the 1-dimensional temporal series $X_1, X_2, \cdots\cdots, X_N$ as in

$$X = \begin{bmatrix} x_1 & x_2 & \cdots & x_{i+1} & x_{N-M+1} \\ x_2 & x_3 & \cdots & x_{i+2} & x_{N-M+2} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_M & x_{M+1} & \cdots & x_{i+m} & x_N \end{bmatrix} \equiv \begin{bmatrix} X_{10} & X_{11} & \cdots & X_{1,N-M} \\ X_{20} & X_{21} & \cdots & X_{2,N-M} \\ \vdots & \vdots & \vdots & \vdots \\ X_{M0} & X_{M1} & \cdots & X_{M,N-M} \end{bmatrix} \quad (1)$$

in which $i = 0,1,\cdots\cdots, N-M; M = N/2$, X is called the trajectory matrix of the phase space in which the elements are lag correlating with the original 1-dimensional series, and M is called the length of window or number of dimensions imbedded.

For the time series $\{x_i\}(i = 0,1,\cdots\cdots, N)$, a maximum time lag M is given so that the Toeplitz matrix can be determined which is made up of auto-covariance and auto-correlation function for individual expressions of $\tau = 0,1,2,,\cdots\cdots, M$

$$Tx = \begin{bmatrix} C(0) & C(1) & \bullet & \cdots & \cdots & C(M-1) \\ C(1) & C(0) & C(1) & \cdots & \cdots & C(M-2) \\ \bullet & C(1) & C(0) & \cdots & \cdots & \bullet \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \bullet & \bullet & \bullet & \cdots & C(0) & C(1) \\ C(M-1) & C(M-2) & \bullet & \cdots & C(1) & C(0) \end{bmatrix} \quad (2)$$

Eq.(2) is equivalent to the covariance in Eq.(1), i.e. Eq.(2) is sought for characteristic values and vectors, which is equivalent to applying EOF expansion of Eq.(1). The SSA is expanded to

$$X_{i+j} = X_{ji} = \sum_{k=1}^{M} a_i^k E_j^k \quad (3)$$

A time series is consisted of M components for each of the characteristic vectors E^K, which reflects the time dependence of the X series. The E^K is called the time EOF (T – EOF). For the project of the K^{th} principal component, which is defined as the state vector of Eq.(1), on the K^{th} T-EOF

$$a_i^K = X_i^T E^k = \sum X_{i+j} E_j^k \qquad (0 \le i \le N\text{-}M) \quad (4)$$

As Eq.(1) has $N - M + 1$ state vectors, the length will be $N - M + 1$ for the principal components. a_i^K is the principal temporal component (T - PC), the weight of the temporal pattern which is expressed by E^K over the time section of $X_{i+1}, X_{i+2}, \cdots\cdots, X_{I+M}$ in the original series.

2.2 *Spectral nature of SSA*

In the analysis of time series, periodic changes are often used to describe how things evolve with time. According to the harmonic principle, the time series for any one element can be formed by superimposing oscillations of various frequencies. By studying and comparing the amount of variance contribution by waves of various frequencies, we know the principal frequencies or periods. The method based on frequency or temporal series is called the spectral

analysis. One of the important implications of SSA is that the sum of contribution by individual decomposed T – PC power spectral contribution equals the power spectrum in the original series

$$P_x(f)=\frac{1}{M}\sum_{K=1}^{M}P_k(f) \tag{5}$$

2.3 *Reconstruction and forecast models*

With E^K and α^K computed, we are now able to select sets for E^K and α^K we are interested in to reconstruct the original series and attempt at prediction. The reconstruction is conducted with the expression of

$$\begin{aligned} y_i &= \frac{1}{M}\sum_{j=1k\in A}^{M}\sum \alpha_i^k E_j^k && M\le i\le N-M+1 \\ y_i &= \frac{1}{i}\sum_{j=1k\in A}^{i}\sum \alpha_{i-j}^k E_j^k && 1\le i\le M-1 \\ y_i &= \frac{1}{N-i+1}\sum_{j=i-N+M}^{M}\sum_{k\in A} \alpha_{i-j}^k E_j^k && N-M+2\le i\le M \end{aligned} \tag{6}$$

where A is a subset of interest regarding to characteristic components.

3 DATA FOR COMPUTATION

The sea surface temperature is taken from the global gridpoints of WMO, which have intervals of 5°×5° and cover a period of 48 years from 1949 to 1996. For tropical cyclones making landfall or serious impacts on the Guangdong province, it must be the one that makes landfall on coastal Guangdong or moves within 1 latitude off the coast and it is defined to take a western route if it the landfall takes place west of the Pearl River Mouth. The threshold is used to calculate the yearly number of tropical cyclones and those taking the western route over the years 1951 – 1996. The dataset is provided by the medium- and- long- term forecast division of the Guangzhou Central Meteorological Observatory.

4 ANALYSIS OF CALCULATIONS OF TROPICAL CYCLONES MAKING LANDFALLS IN GUANGDONG

4.1 *Analysis of the annual tendency of tropical cyclone landfall on Guangdong*

Running an SSA study with the data above, we know that the sum of interpretive variance is more than 95% for the former seven characteristic values, in which T-EOF 1 (Fig.1) is the mean of the series. The figure also shows that there is phase orthogonal between T-EOF 2 and T-EOF 3, T-EOF 4 and T-EOF 5, and T-EOF 6 and T-EOF 7, with two series described by corresponding temporal and spatial EOF being quasi-periodic — quasi-3-year with T-EOF 2 and T-EOF 3, quasi-8-year and quasi-3-year with T-EOF 4 and T-EOF 5, and quasi-8-year with T-EOF 6 and T-EOF 7. Fig.2 gives the sum of power spectrum derived from the maximum entropy method (MEM) for the seven T-PCs in SSA. Fig.3 gives the entropy spectra obtained from MEM for the original series. From Fig.2 and Fig.3, we know that the series is of quasi-8- and quasi-3- year oscillation. As shown in [5, 6], a 3-year oscillatory period exists in the rainfall for the second raining season of Guangdong. It is revealing for the analysis of the trends of drought and floods evolution in the raining season.

4.2 *Analysis of tendency of landfall west of Pearl River Mouth*

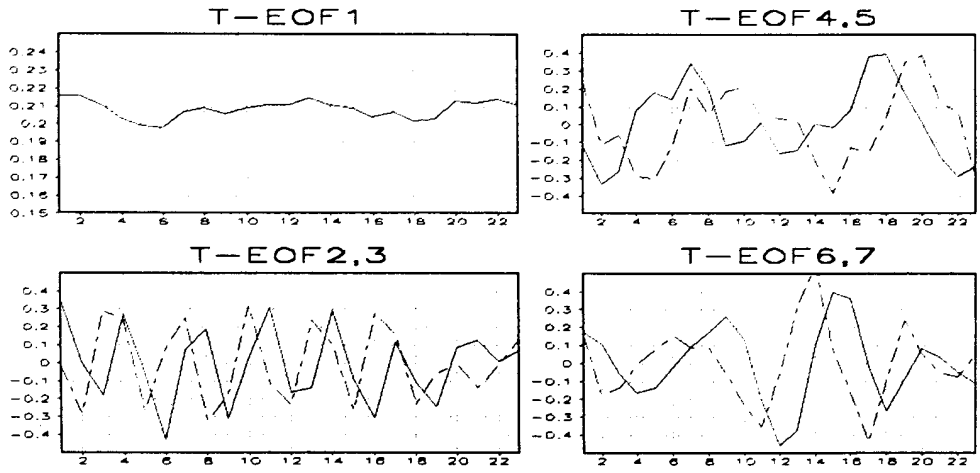

Fig.1 Distribution of the first seven characteristic vectors by SSA for tropical cyclone landfalls in Guangdong.

For western-route tropical cyclones, the SSA study shows that the sum of interpretive variance for the former nine characteristic values is more than 95%. Fig.4 gives the sum of MEM results for the nine *T*-PCs. The figure shows that the western route tropical cyclone is marked with 12-year and biennial oscillations. It is interesting to find that the oscillations are also found in some principal components like *T*-PC 1 and *T*-PC 2. It is then clear that the annual landfall tendency is associated with the western route tendency, which will be studied in more detail.

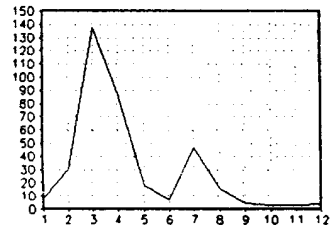

Fig.2 Sum of power spectrum for the seven *T*-PC obtained with SSA-MEM in the SSA analysis of TC

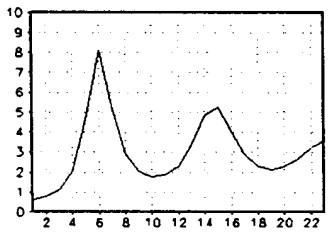

Fig.3 Entropy spectrum of original series (of annual number of TC) obtained with SSA-MEM

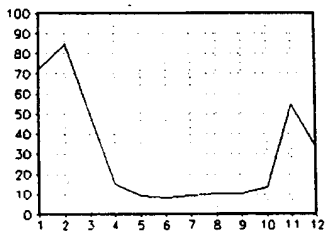

Fig.4 Same as Fig.2 but for the nine *T*-PC and the western-route TC

5 ANALYSIS OF COMPUTATIONS OF RELATIONSHIP BETWEEN 8 NORTHWESTERN PACIFIC ZONES AND TROPICAL CYCLONES

It is well known that the formation of tropical cyclone is very sensitive to the SST over the underlying surface, particularly to the northwestern Pacific SST. As what [7] points out, wind field converges (diverges) and cyclonic (anti-cyclonic) vorticity forms in the lower layers over areas of warm SST anomalies, being dynamically favorable for a tropical disturbance evolving to a tropical cyclone. Besides, increased low-level wind convergence in warm SSTA areas takes in more moisture, enhancing precipitation and latent heat release and causing surface pressure to drop more and wind field convergence to strengthen more, potentially allowing for more cyclonegenesis over the areas. For landfalls in the Guangdong province, it is then reasonable to

locate the physical basis of periodic tropical cyclone oscillations in the variation of SST. In this way, physical foundation can be set up for the patterns governing the variation of tropical cyclones making landfalls in Guangdong.

For this purpose, the whole northwestern Pacific region is divided into eight water zones of westerly drift for 40°N – 45°N, 160°E – 160°W, Gulf current for 35°N – 50°N, 135°W – 125°W, Kuroshio for 25°N – 35°N, 130°E – 145°E, Nino 4 for 5°S – 5°N, 180° – 150°W, Nino 3 for 5°S – 5°N, 145°W – 90°W, Nino 1+2 for 10°S – 0°, 85°W – 80°W, Warm Pool for 10°N – 15°N, 125°E – 135°W, and waters west of Nino for 10°N – 15°N, 145°E – 180°W. With SST mean over 5 – 10 months sought for each of the eight water zones, the SSA is then applied and the results are presented Tab.1.

Tab.1 Results of SSA analysis for each of the water zones

Zones	W.drift	Gulf	Kurioshio	NINO 4	NINO 3	NINO 1+2	Warm Pool	West off NINO
1 period	5.6	8.3		7.1	3.8	4.2	12.5	8.3
2 periods	3.1		3.3	5.0			3.6	5.0
3 periods	2.0	2.0		3.6	2.0	2.0	2.3	3.3

Fig.1 shows that quasi-2 and quasi-3- year periods are generally found in the SST in northwestern Pacific waters and quasi-8.3 and quasi-3.3-year periods are consistent with the quasi-8 and quasi-3- year periods of tropical cyclone landfalls in Guangdong and the quasi-12, quasi-3 and quasi-2- year oscillations of SST in the Warm Pool go in phase with the periodic oscillations of the western route of tropical cyclones. It is seen from the variation curves of the annual landfall number for the province and the SSTA for the area west off Nino (figure omitted), they are roughly in positive correlation. It is seen from the variation curves of the number of the western route tropical cyclones and the SSTA for the warm pool area (figure omitted), they are roughly in negative correlation. It is then known from the study above that the interannual oscillation of tropical cyclones landfalls in Guangdong originates from the oscillatory variation of the northwestern Pacific SST. To understand how the latter evolves, one needs to study from a broader prospective.

6 ANALYSIS OF RECONSTRUCTED AND FORECAST RESULTS

For the seven *T*-PCs obtained with the SSA, the Burg algorithm for maximum entropy is used to recur the regression coefficients of auto-regression models for the optimum number of order in each of the *T*-PC series and their subsets are used in extension forecasts. Eq.(7) gives the auto-regression model for *T*-PC 7 (omitting the others).

$$\hat{x}_t = 0.4647\, x_{t-1} - 0.5006\, x_{t-2} - 0.3216\, x_{t-3} \tag{7}$$

in which $\hat{x}_t$ is the forecast value and x_t is the observed anomaly.

With Eq.(6), the reconstruction equation, the annual number of tropical cyclones making landfall in Guangdong is determined following the seven *T*-PCs by forecast and the seven *T*-EOFs by the SSA computation. Fig.5 gives both the observations (the solid circles) and forecasts (the hollow circles) and the 1996, 1997 and 1998 are the years when forecasts are made. Fig.6 gives the reconstructed tropical cyclones taking the western route as determined by SSA-MEM and 3-year forecasts. It is clear from Fig.5 and Fig.6 that most of the tendency for reconstructed fittings are well forecast except for a small number of years. The 3-year forecast also agrees well with the reality. Tab.2 compares the results by several forecasting techniques for 1997 – 1999. It

is clear then that the SSA can provide useful guides in the prediction of the annual number of tropical cyclones making landfall in Guangdong or taking the western route.

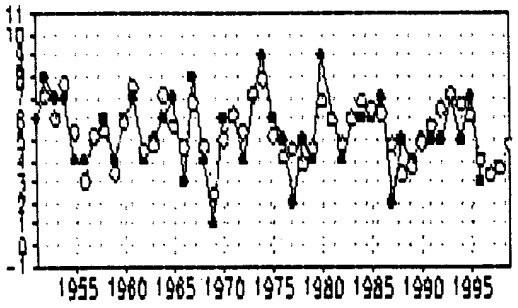

Fig.5 Reconstructed and predicted number of tropical cyclones for 1951 – 1999. The solid circles stand for observations and hollow circles for forecasts.

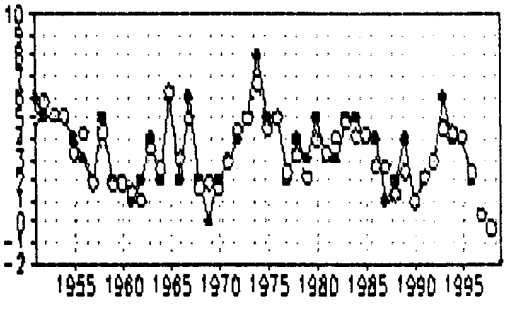

Fig.6 Same as Fig.5 but for tropical cyclones taking the western route.

Tab.2 Comparisons of annual number forecasts of tropical cyclone landfalls in Guangdong from 1997 to 1999

technique	SSA-MEM	Generalized function	Greyness prediction	Harmonic wave analysis	Max. Entropy auto-regressoin	Observation
1997	3.4	5.5	3.5	5.0	5.2	2
1998	3.5	6.3	3.0	5.2	5.3	4
1999	4.8	3.5	2.5	5.7	5.6	7

7 CONCLUDING REMARKS

a. As shown in the SSA results of tropical cyclone landfalls in Guangdong, there are quasi-8 and quasi-3 – year oscillations; there are quasi-12 and quasi-2 – year oscillations in the annual number of western-route tropical cyclones on a yearly basis.

b. Positive correlation is found between the region west off Nino and landfall number for the province and negative correlation is found between the Warm Pool and number of tropical cyclones taking the western route. It shows that the periodic evolution of landfalls is very closely related with the variation of northwestern Pacific SST.

c. The SSA-MEM gives satisfactory fittings of tendency forecast and 3-year predictions of tropical cyclones affecting the province and can be used in short-term operational climate prediction with some degree of reliability.

d. The annual tendency of landfall in Guangdong is associated with where the tropical cyclone lands.

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