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NORTHERN HEMISPHERE SUMMER TELECONNECTIONS INTERANNUAL OSCILLATION AND ITS POSSIBLE RELATION TO ENSO CYCLE

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ABSTRACT: The intense of Northern Hemisphere summer East Asia/Pacific and snow-forced pattern teleconnections have been documented in terms of 43-year summer 500 hPa height data. The analysis results show the phase relationship between these summer teleconnections at quasi-4-year oscillation. The possible relation to ENSO cycle at such time scale has also been deduced.

Key words: Summer teleconnection; interannual oscillation; ENSO cycle

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1 INTRODUCTION

By the end of 1960s, in the analysis of temperature anomaly of Equatorial Pacific and the change of circulation pattern of North-east Pacific westerlies, Bjerknes (1969) named the distant correlation of change in atmospheric circulation as teleconnection. Afterwards, Wallace and Gutzler (1981) calculated the one point correlation of monthly mean sea level pressure and 500 hPa height, and discovered that there exists several types of teleconnection in the change of atmospheric circulation in northern winter. Shukla et al. (1983) illustrated that temperature anomaly in Equatorial Eastern Pacific leads to Pacific North America teleconnection in the northern hemisphere by means of numerical modeling. Hoskins et al. (1981) extended the theory of energy dispersion of Rossby wave to 2-D spherical surface. Wave ray equation was then deduced from barotropic non-divergent equation. The propagation of Rossby wave train along the path of Great Circle of spherical surface originating from the downstream of vorticity source was solved analytically under the assumption of basic flow with constant angular velocity flow. This is the famous theory so-called the Great Circle The theory could partially explain the teleconnection of atmospheric circulation.

However, there was little systematic research on the teleconnection of atmospheric circulation of northern summer. In the study of long-term characteristics of cloud amount and tropospheric circulation in the Pacific region, Nitta (1987) showed that there are Pacific-Japan wave train in the atmospheric circulation during northern summer. In the study of the reason for drought and flood in Eastern China, Huang R H (1988) proposed that the increase in the convective activities in the vicinity of Philippines result in the strengthening of the sub-tropical high over the Jiang-Huai basin of China and the southern part of Japan. Moreover, there is an East Asia-Pacific (EAP) summer teleconnection extending from East Asia to North America. Huang and Sun (1992) further dis-

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Biography: TAN Yan-ke (1971 -), male, native from Wanxian County Sichuan Province, lecturer at Meteorological College, China PLA University of Science and Engineering, now working on Ph.D. at Nanjing Institute of Meteorology, undertaking the study of air-sea-land interaction.

cussed the EAP teleconnection wave train in the summer atmospheric circulation by means of data analysis and numerical experiments, and stated that there is significant interannual variation in EAP. He J H *et al.* (1998) recently discovered snow-forced pattern (SFP) teleconnection in studying the influence of the Eurasian winter snow cover extend anomaly on summer atmospheric circulation. In this article, the relation of inter-annual oscillation between EAP and SFP teleconnection will be discussed. Basing on these, the possible relation with ENSO cycle will be deduced.

2 DATA AND METHOD

2.1 *Data*

Monthly mean of CMA latitude-longitude grid geopotential height data on 500hPa in summer (June, July, August) from 1951 ~ 1993 are employed to calculate the seasonal mean and the data are then normalized. Moreover, sea surface temperature at tropical Pacific in winter from 1951 ~ 1990 prepared by the UK Met. Office are also employed.

2.2 *Multi-channel Singular Spectrum Analysis (MSSA)*

MSSA (Plaut et al., 1994; Wu, 1997) is similar to EEOF in form. This method is effective in reducing the noise signal in the original series, identifying the tendency in climatology or very low frequency component, extracting periodical oscillation component, as well as developing forecast model, etc.

For L time series $x_{k,l}$ ($k=1,2,..,N;\ l=1,2,..,L$) each of length N, a matrix **F** with $L\times M$ rows and N-M+1 columns is constructed by M-order drift. It is then expanded on a set of empirical orthogonal function:

$$f_{i,j,l} = \sum_{k=1}^{L\times M} a_j^{(k)} e_{i,l}^{(k)}$$

where $f_{i,j,l} = x_{i+j-1,l}$, $e_{i,l}$ is space-time empirical orthogonal functions (ST-EOFs), a_j is space-time principle components (ST-PCs), L is channel number, and M is window size.

The original series are then reconstructed using the decomposed ST-EOFs and ST-PCs:

$$x_{i,l}^k = \frac{1}{i}\sum_{j=1}^{i} a_{i-j}^k e_{j,l}^k \qquad (1 \le i \le M-1)$$

$$x_{i,l}^k = \frac{1}{M}\sum_{j=1}^{M} a_{i-j}^k e_{j,l}^k \qquad (M \le i \le N-M+1)$$

$$x_{i,l}^k = \frac{1}{N-i+1}\sum_{j=N-M+1}^{N} a_{i-j}^k e_{j,l}^k \qquad (N-M+2 \le i \le N)$$

where x_l^k is the k-th reconstructed component of channel l(RC-k).

Propagating oscillations in the series of field could be extracted by MSSA. Theoretically, a pair of ST-EOFs and ST-PCs should satisfy the following conditions: (1) the value of the two neighboring eigenvalues are similar to each other; (2) the period of the corresponding time series described by the two ST-EOFs should be the same and the ST-EOFs should be orthogonal; (3) the corresponding ST-PCs should be orthogonal. However, observations are usually scattered with limited length in time. Even for (1) it is very hard to fulfill in periodical oscillation. Therefore, in applying this method, the sample error of the eigenvalues are used to distinguish whether the neighboring eigenvalues are the nearly same, whereas the period of the various MSSA reconstructed components on the frequency band are revealed by power spectrum estimation. If two neighboring eigenvalues are similar in the sampling error region, and the corresponding reconstructed components have similar frequencies, then one of periodical oscillation of the original series is regarded as recovered from this pair of neighboring reconstructed components.

To study the periodical oscillation by MSSA, the data are analyzed by respectively assigning the SFP and EAP teleconnection intensity index (I_{SFP} and I_{EAP}) for all years (1951 ~ 1993) as channel 1 and 2, where sample size N=43, channel number L=2. The window size is taken as 14 years, i.e. M=14.

2.3 *Estimation of power spectrum*

For a time series X_t, t=1,2,…,n. Let m be the longest time lack and the lack correlation coefficients $r(t)$, t=0,1,…,m are evaluated. The estimation equation for the power spectrum shall be (Huang J Y, 1990):

$$P(l)=\frac{B_l}{m}\left[r(0)+\sum_{r=1}^{m-1}r(t)\left(1+\cos\frac{pt}{m}\right)\cos\frac{lpr}{m}\right]$$

where $P(l)$ is the power spectrum, l=0,1,…,m and

$$B_l=\begin{cases}1 & (l\neq 0,m)\\ 1/2 & (l=0,m)\end{cases}$$

The power spectrum of the first twelve reconstructed components is evaluated in the analysis of I_{SFP} and I_{EAP} making use of MSSA for 43 years data (1951-1993), i.e. n=43, m=14.

3 SUMMER TELECONNECTION INTENSITY INDEX

On a constant pressure level, the activity of atmospheric teleconnection is basically multi-centered arranging on a spherical Great Circle, and the intensity of the atmospheric teleconnection could be described by the center of these activities. He *et al.* (1998), Tan *et al.* (1999) discovered that snow-forced teleconnection (SFP) could be found in the change of summer atmospheric circulation, and the intensity index was defined as:

$$I_{SFP}=\frac{1}{4}\left[-H^*(160^oE,55^oN)+2H^*(140^oW,70^oN)-H^*(80^oW,65^oN)\right]$$

while the EAP teleconnection intensity index was defined as:

$$I_{EAP}=\frac{1}{5}\left[-H^*(120^oE,25^oN)+H^*(160^oW,45^oN)\right.$$
$$\left.-H^*(170^oW,55^oN)+H^*(120^oW,45^oN)-H^*(100^oW,35^oN)\right]$$

In the above equations, H^* denotes the normalized geopotential height at 500 hPa. The one point teleconnection in northern summer between 500 hPa height and I_{SFP}, I_{EAP} are respectively given in Figs.1a & 1b. The figures show that the atmospheric circulation anomaly is reflected by these two indices. As shown in Fig.1a, there is significant negative correlation between I_{SFP} and the height field above Kamchatka Peninsula and Foxe Bs., whereas the correlation is significantly positive over Alaska. Moreover, these three correlation centers with significant magnitude are basically of wave-like structure arranging on a spherical surface. This implies that in the years of high (low) I_{SFP} index, the height field above Kamchatka Peninsula and Foxe Bs. decreases (increases), while that above Alaska increases (decreases). These show that I_{SFP} is a fairly good indicator in reflecting the summer anomaly of Northeast Asia and North America. It has been shown (Tan, 1999) that

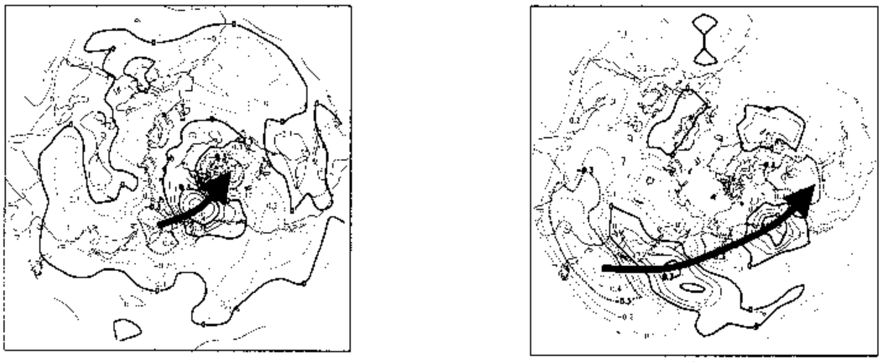

Fig.1 Plot of one-point correlation of I_{SEP} (a) and I_{EAP} (b) with Northern Hemisphere summer 500 hPa. (The thick line with an arrow denotes teleconnection wave-train)

I_{SFP} is closely related to the Eurasian winter snow cover extend anomaly. The tendencies of the inter-annual variation are very similar, and the correlation coefficient for sample data of 21 years is as high as 0.76, with significant level higher than 0.001. This shows that this type of circulation anomaly, SFP, is triggered by the abnormal cooling effect induced by the snow cover anomaly of last winter. The larger (smaller) the snow covering area of the last winter, the higher (lower) the I_{SFP} in the coming summer.

Fig.1b shows a typical EAP summer teleconnection extending from the low latitude of Asia to North America, and elucidates that I_{EAP} is good in describing the summer atmospheric circulation anomaly. EAP summer teleconnection is related to the convective activities at the Eastern Philippines. The higher (lower) the sea surface temperature of Western Tropical Pacific, the stronger (weaker) the convective activities over Philippines, and then the lower (higher) the 500 hPa height, and finally the higher (lower) the I_{EAP}.

4 ANALYSIS OF THE PERIOD OF SUMMER TELECONNECTION INDEX INTENSITY AND ITS PHASE RELATIONSHIP

MSSA is employed in the analysis of 43 years data from 1951 ~ 1993. In the analysis, I_{SFP} and I_{EAP} are respectively assigned as channel 1 and 2 with M=14. Fig.2 shows the values of the first 12

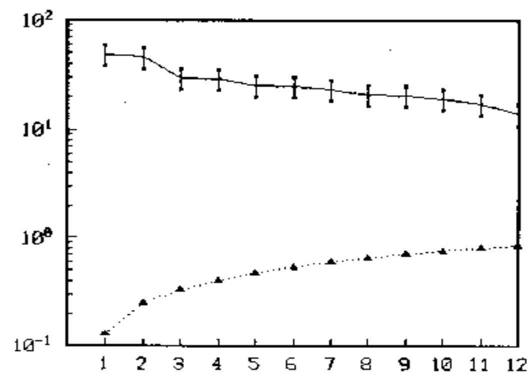

Fig.2 The first 12 eigenvalues, sample errors and accumulated covariance. Long line: eigenvalues; short line: sample errors; arrow line: accumulated covariance

eigenvalues, sample errors and their accumulative covariance in descending order (where the sample error of the eigenvalues is taken as $dl_k = \pm\left[\frac{2}{N-M+1}\right]^{\frac{1}{2}}$, North, 1982). As the eigenvalues are arranged in descending order, when the difference of two neighboring eigenvalues is more than that of the corresponding sample error, the corresponding empirical orthogonal functions are meaningful and these two eigenvalues could be separated. When the difference of two neighboring eigenvalues is less than that of the corresponding sample error, the higher order empirical orthogonal functions shall be meaningless. On the other hand, as the space-time empirical orthogonal functions deduced by two consecutive eigenvalues with similar values are employed in MSSA so as to study the periodical oscillation, therefore, it should be considered separately in determining the significance of the eigenvalues. As shown in Fig.2, the difference between two neighboring eigenvalues is less than that of the sample error as the order is 5 or more, and the 1st and 2nd, the 3rd and 4th eigenvalues could be regards as the same within the range of sample error. The accumulative covariance is more than 40%. Therefore, the first 4 reconstructed components are analyzed so as to reveal the periodical oscillations.

Power spectrum analysis was carried out on the first 12 reconstructed components, the results (Fig.3) show that the 1st and 2nd components attain their maximum values around frequency of 0.28 year-1, while the 3rd and the 4th attains theirs around frequency of 0.1 year-1. Moreover, the peaks of these 4 reconstructed components are isolated from each other. This shows that quasi-4-years oscillation was recovered by the 1st and 2nd reconstructed components, whereas quasi-10-years oscillation was revealed by the 3rd and 4th ones.

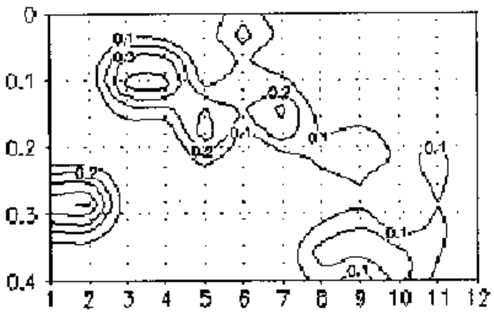

Fig.3 Power spectrum of the first 12 reconstructed components.

The temporal lack correlation coefficients of the first two reconstructed components of I_{SFP} and I_{EAP} were calculated (Tab.1) in order to examine the phase relationship among the oscillations. In table 1, τ designates time lack/lead with unit in year. When the period of the reconstructed component of SFP teleconnection leads (lags) that of the EAP, τ will be positive (negative). Contemporary correlation is denoted When τ=0. For $t \in =[-3,2]$, the correlation coefficients of the first 2 reconstructed components for I_{SFP} and I_{EAP} attain a maximum at t= –1, while they attain a minimum at t =1. In other words, the components of the quasi-4-years oscillation of EAP summer teleconnection

Tab.1 Temporal lag/lead correlation coefficients of the first 2 reconstructed components between I_{SFP} and I_{EAP}.

Lag/lead time τ (year)	–3	–2	–1	0	1	2
Reconstructed component 1	–0.70	–0.44	0.91	0.37	–0.93	0.37
Reconstructed component 2	–0.67	–0.50	0.89	0.14	–0.99	0.26

leads those of SFP by 1 year, approximately one-forth of the period. The quasi-4-years oscillation of this summer teleconnection could be represented as: +EAP → +SFP → -EAP → -SFP → +EAP, and this result is consistent with that given by Tan et al. (1999) in which composition analysis was applied on the band pass filtering data.

For oscillations with a period of about 10 years, EAP leads SFP for 4 years (diagram not shown).

5 POSSIBLE EXISTENCE OF PERIODICAL OSCILLATION BETWEEN SUMMER TELECONNECTION AND ENSO CYCLE.

It is well known that the average period for the oscillations in the ENSO cycle is quasi-4-years, and so is the principle period for the air-sea coupling of the Pacific (He J H et al., 1996). It could easily be found in various members of the land-air system (Chen et al., 1991). When the ENSO cycle is at warm (cold) state, the sea temperature of Equatorial Central and Eastern Pacific increases (decreases), with the sea temperature of the Tropical Western Pacific decreases (increases). These facilitate the weakening (strengthening) of the convective activities of the Eastern Philippines, and then raising (lowering) the 500hPa geopotential height there, and finally resulting in a low (high) I_{EAP} index. Therefore, it could be seen that there is close relation between summer EAP teleconnection and ENSO cycle.

The relation between summer SFP teleconnection could be found in Fig.4. In the figure, there is significant positive correlation between I_{SFP} and the sea surface temperature during the winter of Equatorial Central and Eastern Pacific, while there is significant negative correlation between I_{SFP} and the sea surface temperature in the winter of Tropical Western Pacific. Moreover, this type of correlation has the same distribution of sea temperature anomaly during the mature phase of ENSO cycle. This implies that positive (negative) SFP summer teleconnection facilitates the break out of

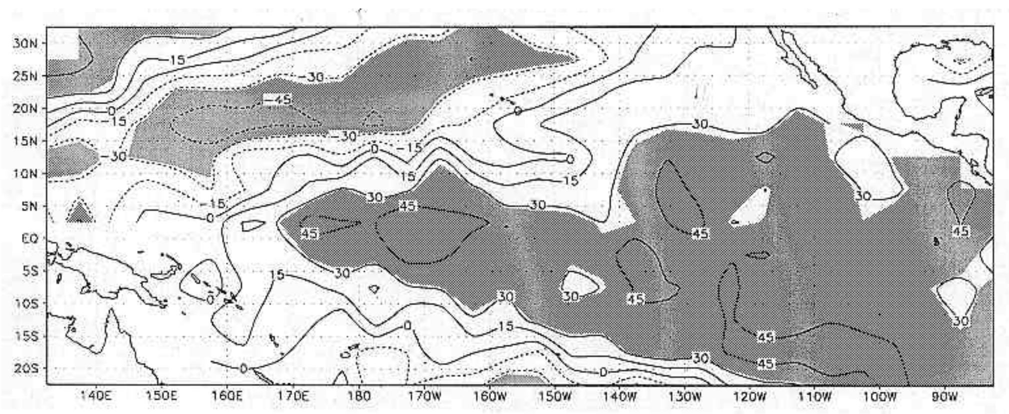

Fig.4 Plot of one-point correlation of I_{SEP} with tropical Pacific SSTA in the winter of the year with the shown coefficients (×100). (Contour intervals of 15 and shaded areas in excess of 0.05 significance)

El Niño (La Niña).

Until now, according to the quasi-4-years oscillation relation between I_{SFP} and I_{EAP}, the relation between I_{SFP} and Eurasian snow cover and the relation of Tropical Pacific sea temperature between I_{SFP} and I_{EAP}, we could deduce that there is possibly a periodical oscillation existing among ENSO, summer teleconnection, and Eurasian snow cover at the time scale of quasi-4-years. As the Eurasian snow cover area becomes larger, the induced effect of the cooling anomaly and the advection effect of the westerlies shall lead to the formation of positive SFP summer teleconnection in mid-high latitude summer. Positive summer teleconnection, or change in summer atmospheric circulation, also facilitates the break out of El Niño. In fact, there were 11 El Niño years from 1951 to 1993, with 6 of them (1951, 1965, 1968, 1972, 1982, 1986) occurring at the peak strength of the I_{SFP} quasi-4-years periodical oscillation. However, owing to the effect of other periodical components (e.g. QBO, annual cycle, etc.) in tropical air-sea coupling systems on the fundamental period (quasi-4-years periodical components) of the ENSO cycle, El Niño may occur at some other time leading or lacking the quasi-4-years period. After the break out of El Niño, the SSTA value of the Tropical Western Pacific is below average, and this weakens the convective activities of the Eastern Philippines in the coming summer, and thus facilitating the formation of a negative EAP teleconnection. EAP teleconnection affects the atmospheric circulation of the Northern Hemisphere probably in the way of reducing the Eurasian snow cover in winter. Reduction of Eurasian snow cover area will then facilitate the formation of the negative SFP wave train in the next summer and the break out of La Niña, and hence changing the distribution of the sea temperature of the Tropical Pacific in such a way to facilitate the formation of the positive EAP teleconnection wave train in the coming year. As the cycle goes on, a quasi-4-years cycle among summer teleconnection, ENSO and Eurasian snow cover is formed. The quasi-4-years cycle elucidates the fact that the atmosphere was influenced in turn by the heating source at tropical low latitude and the cooling source at high latitude with a phase difference of approximately 1 year, and that it interacts with the atmospheric currents to form a cycle.

This model could facilitate us in understanding the possible interaction among the three sub-systems, the atmosphere, the water and the cryosphere, of the climatological system in the time scale of years. This also provides a new information for short-term climatological study and forecast. Nevertheless, this is an elementary model and l more problems left for further investigations.

6 CONCLUSIONS

a. I_{SFP} and I_{EAP} are quite good in reflecting the atmospheric anomaly of northern summer;

b. There exists quasi-4-years and quasi-10-years cycle in the times series of I_{SFP} and $I_{EAP;}$

c. In the quasi-4-years oscillation, I_{EAP} leads I_{SFP} approximately 1 year. Their inter-relationship with ENSO and Eurasian snow cover shows that there very probably exits a quasi-4-years oscillation among the summer teleconnection, ENSO and Eurasian snow cover.

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