Reconstructions of the Southern Oscillation and Pacific Sea Surface Temperature from Dryness/Wetness in China for the Last 500 Years

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ABSTRACT ENSO events significantly influence global surface climate. In order to understand the anomalies of the climate in the historic time, a canonical correlation technique is used to reconstruct the seasonal index of the Southern Oscillation and the seasonal Pacific SST from the dryness and wetness in China for the last 500 years. These estimates calibrate more than 40% of the SO variance during 1913-1973 with more than 20% of the variance verified over an independent period. In the reconstruction of the Pacific SST, the result is also quite good, with about 60% SST variance calibrated in the tropical areas and the estimates were verified qualitatively over 100 years. It shows that the dryness/wetness data in China can reconstruct the past ENSO events in certain extent. Analyzing the results, we found that ENSO events not only has apparent cycles, but also has about a 250-year cycle change. Besides the well known 2 to 7 year periodicities for both SO and SST, SO has 10.6 year period and SST has 25 to 28.5 and 100 year periods which related with the solar activities. From further analysis, low-index events for SO are estimated to be less frequent during the 18th, 19th and early 20th century than before and since. The occurrence of more (less) low-index events for SO corresponds with the cold (warm) period in history, and the dryness (wetness) period in China relates to the cold (warm) East-Pacific and warm (cold) West-Pacific.

The interaction of the atmosphere and ocean in tropical areas shows the close relationship with ENSO phenomena. Their changes have a great impact on the climate over a large part of the globe. The SO comprises a large-scale fluctuation of atmospheric mass between the south-eastern Pacific and western Pacific/Indian Ocean regions. When surface pressure is high in one region, it tends to be low in the other region. Pressure oscillations between these two areas occur in an irregular period in the range of 2-10 years. Variations of the SO are associated with large-scale changes in the tropical Pacific trade winds, sea surface temperature, rainfall and cloudiness.

In order to study the causes of ENSO events and climate changes, it is imperative to reconstruct the index of SO (SOI) and sea surface temperature (SST) in earlier periods and find out historical ENSO events.

Changes in SOI and SST in the North Pacific and their influence on the climate were unknown before instrument weather data were gatherered in the mid 19th century. In order to investigate the events which were related with the low-phase of SOI, Quinn et al (1978) integrated the early instrument records with documental information, and confirmed certain years in which ENSO events had happened. Lough and Fritts (1985) reconstructed the SO back to 1600 using tree-ring data.

In this paper the SOI and the North Pacific SST for the past 500 years are reconstructed based on the significant relationship between the Dryness/Wetness in China and the currently existing instrument records about SOI and SST data.

Dryness/Wetness Data in China

In "Yearly Charts of Dryness/Wetness in China for the last 500 Year Period" there are charts and time series of dry/wet grades for the past 510 years at 120 stations (Fig.1). Dryness/Wetness is assigned by a five-grade index of 1-wet, 2-subwet, 3-normal, 4-subdry and 5-dry. The main features of yearly variations of Dryness/Wetness from May to September in China since 1470 are illustrated. Stations having a grade index for 500 years or longer are mainly distributed over the Yellow River and the middle and lower reaches of the Yangtze River. Based on the grade indices of the "500 Years Charts", continued grade indices time series for 510 years at stations east of 100°E are obtained by interpolating.

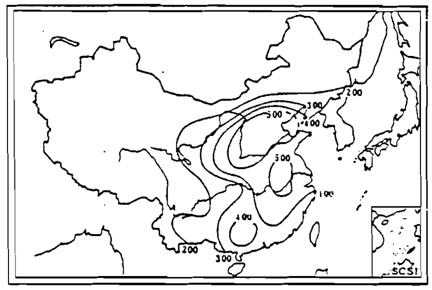

Fig. 1. The number of years in which grades are available.

To describe the main features of the annual variations of Dryness/Wetness, EOF analysis was performed on dry/wet grade index series (1470-1986) at 100 stations east of 100°E in China. The first five eigenvectors with 93% accumulated variance are the basic patterns of Dryness/Wetness, and their coefficients indicate Dryness/Wetness on the large scale.

Method

A technique referred to as canonical analysis is applied to simplify two groups of variables into two minimum groups of new variables. Let x_i ($i=1,2,\cdots,p$) and y_j ($j=1,2,\cdots,q$) denote two sets of variables: dry/wet grades and the SOI. Their anomalies are denoted by ${}_nX_p$ and ${}_nY_q$, where n is the number of years.

Two new sets of variables ${}_nW_r$ and ${}_nQ_r$ are found

$$
\begin{aligned}
{}_nW_r &= {}_nX_p\,{}_pA_r \\
{}_nQ_r &= {}_nY_q\,{}_qB_r
\end{aligned}
\tag{1}
$$

where r is the minimum of p and q. In ${}_nW_r$ and ${}_nQ_r$, each variable is orthogonal to all others, and

$$
\begin{aligned}
{}_rW_n Q_r &= {}_r\Lambda_r \\
\left(\frac{1}{n}\right){}_rW_n W_r &= {}_rI_r \\
\left(\frac{1}{n}\right){}_rQ_n Q_r &= {}_rI_r
\end{aligned}
\tag{2}
$$

If $p>q$, then

$$
{}_n\hat{Q}_r = {}_nW_r\Lambda_r \tag{3}
$$

${}_pA_r$ and ${}_qB_r$ can be obtained by (1) and (2) (Anderson, 1958), then using (1) and (3), we have

$$
{}_n\hat{Y}_r B_r = {}_nX_p A_r \Lambda_r \tag{4}
$$

and multiplying ${}_rB_r$ to both sides of (4), we can get

$$
\begin{aligned}
{}_n\hat{Y}_r &= {}_nX_p A_r \Lambda_r B_r^{-1} = {}_nX_p T_r \\
{}_pT_r &= {}_pA_r \Lambda_r B_r^{-1}
\end{aligned}
\tag{5}
$$

Where ${}_pT_r$ is called transfer function, composed of a set of canonical regressive coefficients, through which ${}_nX_p$ can be transformed to ${}_nY_r$. However, prior to the determination of the transfer function, the significance of canonical correlation coefficients has to be tested. For different time periods, different transfer functions can be obtained. This time period is called the calibration period. The $_nY_q$ estimated by $_nX_p$ should be tested over an independent time period (called the verification period). The performance of the reconstruction model can be tested by correlation coefficient square and the reduction of error.

Reconstruction of SOI and SST

The reconstruction of SOI needs a set of coherent, reliable and long series of SOI in order to assure the necessary data length for calibration and verification. The seasonal value of SOI from 1851 to 1974 was given by Wright (1975). The SO seasonal index defines spring as February to April, summer as May to July, autumn as August to October and winter as November to January, which are known as the SO seasons. This division ensures that the data are independent and not smoothed. The inter-correlation among seasons smaller than with any other kind of division. The data of SST in Northern Pacific are monthly data from January, 1949 to December, 1986 ranging from 120°E to 80°W, 10°S-50°N, totally 286 grid-points.

(1) Results and Analysis of the Estimated SOI

In the SOI reconstruction, as SOI has a relationship with Dryness/Wetness at earlier and later periods, the array of the predictor $_nX_p$ with p=16 consists of the first four time coefficients in the year (N), last year (N-1), the year before last year (N-2) and the next year (N+1). $_nY_q$ with q=4 denotes SOI for the four seasons. The calibration period is from 1913-1973, 1974-1985, and the verification period is from 1852-1912.

According to the reconstructed seasonal index of SO, a series of low-index years were defined by the standard that two consecutive seasonal values must be lower than one standard deviation. Table 1 shows the statistic number of years in which a low-index SO occurred during each of the 11 time periods.

Table 1. The Reconstructed Low-Index of SO

Time Period	Low-Index Year	No. event
1472-1499	1472 1473 1484 1488 1493 1499	6/28
1500-1549	1500 1509 1514 1515 1521 1524 1526 1528 1529 1533 1539 1545	12/50
1550-1599	1560 1561 1563 1568 1581 1585 1586 1590 1595 1596	10/50
1600-1649	1600 1609 1610 1615 1616 1617 1626 1634 1637 1638	10/50
1650-1699	1650 1660 1661 1667 1671 1672 1679 1682 1689 1690 1698	11/50
1700-1749	1704 1707 1721 1722 1729 1740	6/50
1750-1799	1758 1759 1763 1782 1783 1792	6/50
1800-1849	1803 1812 1817 1825 1833 1836 1838	7/50
1850-1899	1857 1875 1876 1877 1884 1899	6/50
1900-1949	1900 1905 1907 1918 1919 1928 1930 1941	8/50
1950-1985	1951 1953 1957 1959 1965 1967 1968 1972 1979 1982	10/36

It can be seen that there were fewer low-index SOs in the 18th and 19th century, 6 to 7 times on the average in each 50 years. In the 16th, 17th and 20th centuries, however, the low-index SOs were more frequent than usual, an average of 10 to 12 times each 50 years. It can be seen that there are several stages, shown in Fig.2

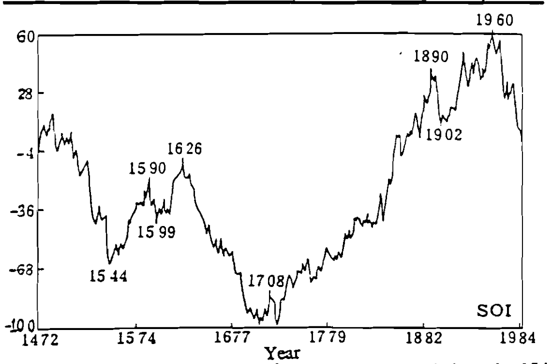

Fig.2 The Accumulation Curve of the Anomaly SOI reconstructed since the 15th Century.

There are three significant stages: 1472-1708, 1709-1960 and 1961-now. As the descendent stage of the curve indicates that the low-index SOs were frequent during that period, conversely, the ascendent stage of the curve means the less frequent occurrence of low-index SOs. Thus it can be inferred from the above that low-index SOs occurred frequently during 1472-1708 and 1961-now, but rarely during 1709-1960. In addition large scale climatic abnormality has frequently happened since 1961, so we are just in the stage of frequent occurrences of low-index SOs.

According to China's climate data for a long period, Zhu Kezhen (1972) defined three historical cold periods, 1470-1520, 1600-1720 (coldest) and 1840-1890. Between these cold periods, there are two warm periods, 1550-1600 and 1720-1830. In comparing these cold and warm periods with Table 5, the first and second cold period correspond with periods 1472-1544 and 1626-1708, which show the frequent occurrence of the low-index, and the two warm periods in Table 5 correspond with 1545-1590 and 1709-1890, which show the rareness of occurrence of the low-index. Thus, it can be concluded that the years of low-index SOs usually occur in a cold climate period.

(2) The Reconstruction of SST

Similar to that of SOI, EOF analysis on the abnormality of SST from 1949-1985 was first performed, and the first five time coefficients of Dryness/Wetness in the year N-1, N, N+1 with the 93% accumulated variance as the predictors $_{n}X_{p}(p=15)$, the first 11 coefficients of SST as the predictand $_{n}Y_{q}(q=11)$ representing 80% of the variance of SST. The reconstructed time coefficients were multiplied by the correspondent eigenvectors to retrieve the anomaly of SST.

Although calibration variance can measure the estimates, it does not obviously verify the results in different areas just by the calibration variance of the coefficients. Estimates of SST were compared with the instrument SOI data. Since the high SST in the eastern tropical Pacific often accompany the low-index SO, another way to verify the reconstruction is to further test the reconstructed SST by actual SOI. Surprisingly, the contrast of SOI and SST is quite compatible, especially during the 1851-1948 independent reconstruction period. This graph indirectly shows that the estimates of SST, especially in the eastern tropical Pacific are reliable.

ENSO events

ENSO events were found from the reconstructed SOI and the eastern tropical Pacific SST. Compared to Quinn's results, 60% of the reconstructed ENSO events occurred in the same year, 18% occurred within plus/minus one year, 12% occurred within plus/minus two years, and 10% were on more than two years difference, also, the El Nino years, which were unknown before the 16th century, are estimated in this work.

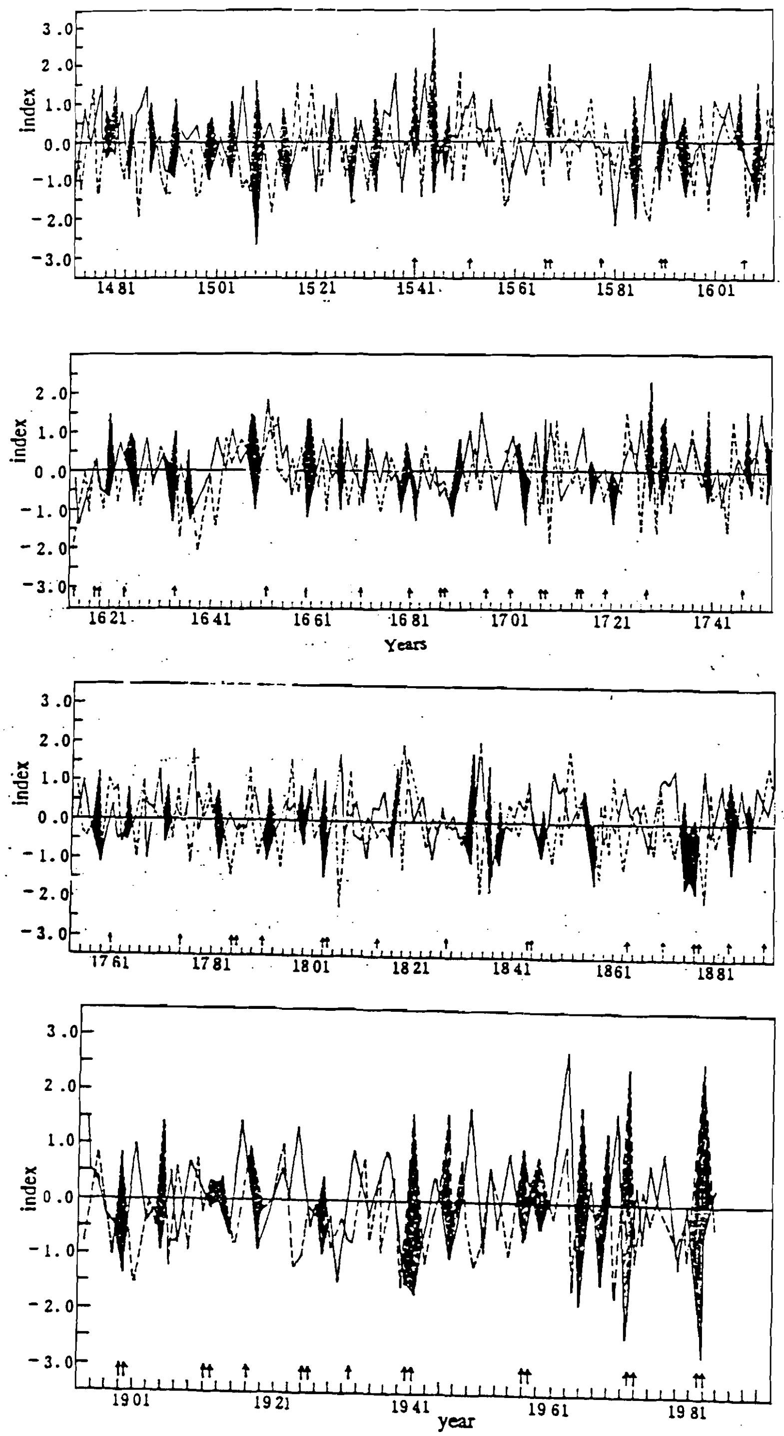

Fig. 3 Reconstructed Anomaly of SOI (solid line) and East Tropical Pacific SST (dashed line, unit*0.4℃) (arrow represents El Nino year declared by Quinn, 1978)

Discussion

Global climate change is an unneglegible issue. It is impossible to predict future climate change without knowing the past. It seems plausible to reconstruct ENSO in certain extent by using the close relation between climate in China and abnormal tropical climate. Further accurate reconstruction will depend on studying the coupled interaction between tropical and middle latitude as well as atmosphere and ocean.

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