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DETERMINATION OF PRECIPITATION CYCLE IN BEIJING AREA AND COMPARISON WITH SOLAR ACTIVITY CYCLE

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Abstract. We examine the annual precipitation in Beijing area response to solar activity changes during the period 1749–2001. A hierarchy of changing complex periods of precipitation is carefully detected and related cycles compared with results from SN analysis. Our findings support the suggestion that solar activity influence precipitation, at least in part in Beijing.

Keywords: Annual precipitation, period, sunspot numbers

Abbreviations: SN: Sunspot numbers

1. Introduction

Earth, a habitable planet, is enclosed by solar radiation. Normal radiation of Sun plays a decisive role in maintain the good ecological environment of Earth. It has long been speculated that long-term solar output and solar cycle variations influence Earth's climate. Such linkages have profound discussions from different regions. In 1991 and 1995, Friis-Christensen and Lassen presented findings that showed a high degree of correlation between the length of the sunspot cycle and the global mean temperature on the Earth in the period 1861–1989 and in the past about 1500 years (Friis-Christensen and Lassen 1991; Lassen and Friis-Christensen, 1995). Withbroe et al. proposed that the radiation and corpuscular variation on 11-year period scale influence the temperature change on the Earth, even as influence climate change (Withbroe and Kalkefen, 1994). From analyzing the climatic history of Yucatan Peninsula of Mexico over the past 2600 years, Hodell et al. found that a significant recurrent drought periodicity of 208 years that matched well with a cosmic ray-produced ^{14}C record preserved in tree rings that is believed to reflect variations in solar activity. The results suggest that variable solar activity has been the major player in orchestrating the cyclical history of drought in this region (Hodell et al., 2001).

Although many geophysical phenomena are correlated with solar activity, it has remained unclear how the relatively minor fluctuations whose direct effects occur predominantly in the upper atmosphere, could have important impacts on Earth's surface. Now, a lot of articles have been published that present the question in different lights. Changes in flux of cosmic ray influence on clouds have been proposed (Friis-Christensen and Svensmark, 1997). Another proposed a model that showed how upper stratospheric ozone changes may amplify observed, 11-year solar cycle irradiance changes to affect climate (Shindell et al., 1999). Lean explained that solar UV irradiance variations affecting ozone, which then changes the temperature and wind patterns in the stratosphere, modulating and altering planetary wave energy etc., propagating from the troposphere (Lean, 2000). Tinsley provided another explanation about weather and climate variation with solar activity. He pointed out that the solar wind, a highly conducting and extremely hot gas that blows from the sun outward over the earth, impedes high energy cosmic ray particles, and energizes high energy electrons in the earth's radiation belts that precipitate into the atmosphere and change the global atmospheric electric circuit. It is likely to affect properties of clouds that have consequences for reflectivity to sunlight, and for precipitation rates and latent heat transfer, both of which are capable of affecting global atmospheric temperature and dynamics. And he proposed about half of the global warming over the past century appears to be due to changes in the sun and the solar wind. Yearly and decadal climate changes attributable to the sun are significant compared with climate changes due to other sources (Tinsley and Yu).

Some people thought that it seems difficult to explain the influence of the solar activity on the precipitation, even climate system because of short of completely understanding of how the energy associated with solar variability produces the responses at each step of the process and began to hesitate to the relationship. However, we could not defy that a lot of empirical and statistical observation exist. The Sun is responsible in a dominant way on climate system. Since the Sun is by far the largest supplier of energy to the Earth, any change could affect the energy balance of the Earth, so that at some level it influences our climate. Except solar influence, maybe there are other forcings influencing the precipitation at the same time. If we want to clearly knowledge the climate system feedbacks and internal oscillations, a first step is appreciating the effects of solar activity. It has become increasingly crucial to determine the relative importance of solar variation on climate.

Manifested differently in different geographical regions and depends on longitude, as well as latitude. This has been evident in research of solar activity and climate. Here, we present analyses from the variation of annual precipitation in Beijing area of China and solar activity, and suggest that the precipitation were affected by cycle oscillations in solar activity.

2. Data

The 253-year-long records of annual precipitation in Beijing area of China are obtained from China Meteorological Administration (CMA) in the period 1749–2001. The inter-annual variation is very big and the mean value is about 616 mm. Relative sunspot numbers is an index of the activity of the entire visible disk of the Sun and is a proxy of solar activity. The relative sunspot numbers that span the interval 1749–2001 with yearly resolution are obtained from Solar Geophysical Data (SGD) of National Oceanic and Atmospheric Administration (NOAA), National Geophysical Data Center (NGDC) of USA.

AR spectral analysis of the annual precipitation in Beijing area revealed some obvious decadal-scale periods, such as about 11-year, and short periods about 2–7-year (Figure 1). Four periods, about 11-, 22-, 33-year and a long period on decadal time scale obviously dominate the spectrum. This situation is likely to be similar to the well-known solar activity.

Corroborating this inference is the coherency between precipitation and SN. The Cross Spectral Density using Welch's averaged periodogram shows the correlated information between these two datasets in frequency domain and to reflect common period components (Figure 2). A lot of periodicities coincide with each other. The power spectrum reveals three obvious peaks around 11-, 22-year and a long period existing in two datasets over the past 253 years. Thus, the spectral similarity implied that solar variation was an important trigger of precipitation changes in Beijing.

Correlation analysis of precipitation and SN further elucidate the relationship. We could get the threshold values of correlation coefficients about 0.123 and 0.162 at 95% and 99% confidence levels using Monte Carlo technique. The sun-precipitation correlation coefficient (about 0.194) for the interval 1749–2001 is above the 99% significance level. Correlation analysis confirms the linkage between the precipitation and SN.

A lot of results of study demonstrate that precipitation is sensitive to extremely weak oscillations in the Sun's energy output, not just on the decadal scale that have been investigated here, but also on short-time and on the centennial to millennial time scales documented in other papers.

3. Wavelet Analysis

Although AR spectrum analysis is an adequate tool for detecting and quantifying constant periodic fluctuations and reflects the total intensity of a

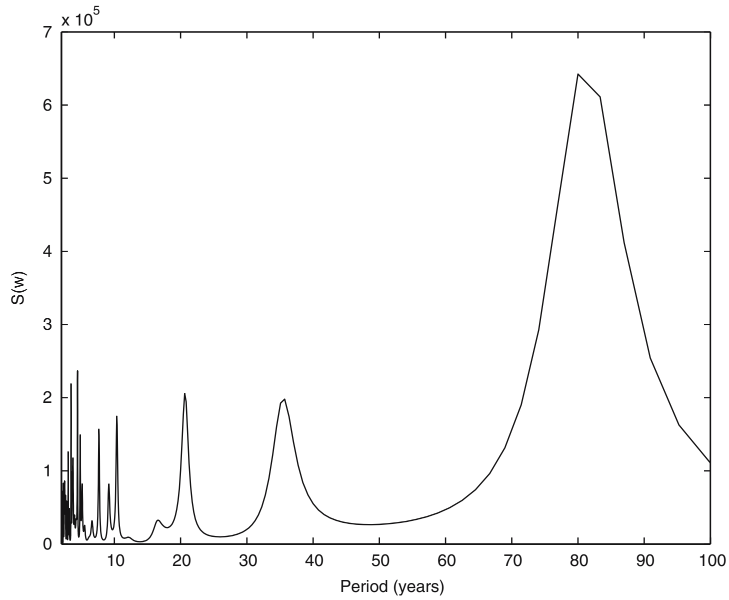

Figure 1. AR spectrum analysis of annual precipitation in Beijing area.

certain period in time series, it cannot completely provide information about the local character and temporal variation of the time series. However, the wavelet analysis has the ability to express the local character of signals in time domain and frequency domain and reflect the time evolutions of the frequency distribution.

Non-stationary signals include multiple components from high frequency to low frequency and noise. The wavelet analysis could overcome the weakness that the resolution is fixed in Fourier transform. It could depict the signal's profile and even express the details. In order to better detect the information in time series, we could get a relative narrow time window for better resolution of high frequency and get a relative wide time window for complete information of low frequency. Wavelet transform provides an adjustable time–frequency window that could become narrow automatically to get a high time resolution for high frequency and become wide automatically to get a high frequency resolution for low frequency. That time resolution is variable with frequency is the advantage of the wavelet analysis. Wavelet analysis offers an alternative to Fourier analysis based on time series, especially when spectral features are time dependent. By decomposing a time series into time–frequency space, we are able to determine both the dominant modes and how they vary with time.

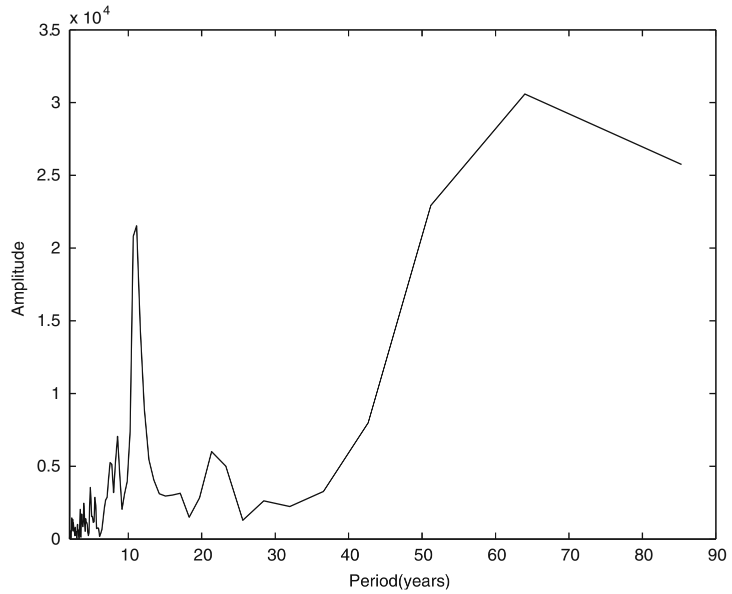

Figure 2. Cross Spectral Density estimate between the annual precipitation in Beijing area and SN.

3.1. Wavelet analysis method

Here we choose the Mexican hat wavelet as mother wavelet (Figure 3b). The Mexican hat wavelet is second derivative of the Gaussian. Its probability density function is $\Psi(x) = \frac{2}{\sqrt{3}}\pi^{-1/4}\left(1 - x^2\right)e^{-x^2/2}$.

Mexican hat has the fine scale structure. This is because the Mexican hat is a real valued analyzing wavelet and captures both the positive and negative oscillations of the time series as separate peaks in wavelet power (Torrence and Compo, 1998).

3.2. Wavelet power spectrum

3.2.1. *Wavelet analysis of annual precipitation*

We now apply continuous wavelet transform to the investigation of annual precipitation. Since having the time series of $N = 253$ observations, we extend with zeros to next higher power of 2, in order to prevent wraparound from the end of the time series to the beginning and speed up the FFT used to do the wavelet transform. The software is based on routines that originally came from Torrence and were properly modified (Torrence and Compo, 1998). The wavelet power spectrum is defined as the absolute value squared of the wavelet transform, $|W_n(s)|^2$. The normalized wavelet power spectrum,

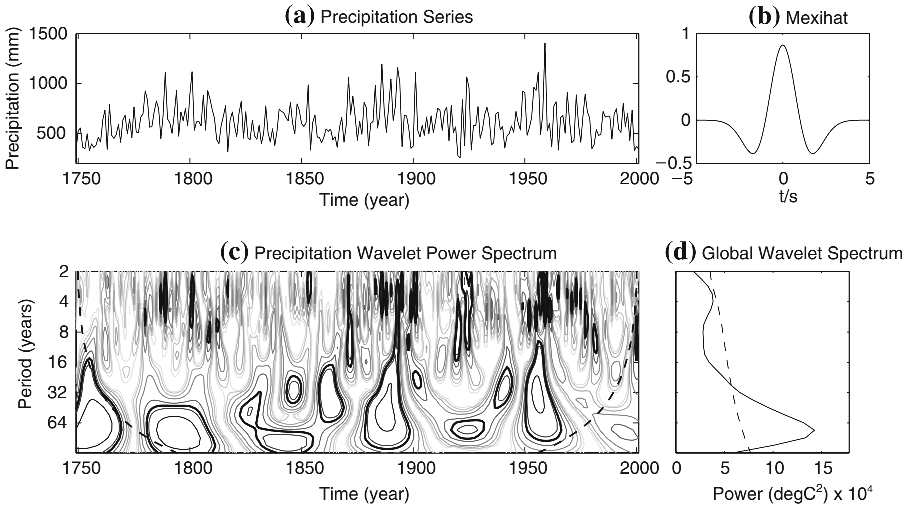

Figure 3. Wavelet analysis of annual precipitation in Beijing area (a) the original time series; (b) mother wavelet; (c) local wavelet power spectrum (dashed line indicates the cone of influence and the darkest solid contour is the 90% significance level); (d) global wavelet power spectrum (dashed line is 90% significance level).

$|W_n(s)|^2/\sigma^2$, for the precipitation series is explained in Figure 3c. The wavelet power was normalized by the variance of the time series to give a measure of the power relative to white noise (Torrence and Compo, 1998; Torrence and Webster, 1999).

Wavelet analysis results of annual precipitation display considerable frequency variation (Figure 3). The time and frequency character of the signal are combined very well through the wavelet analysis. The series in Figure 3a is in its natural units, *mm*, and time is expressed in years. The amplitudes of the wavelet power spectrum in terms of an arbitrary grayscale contour map are shown in Figure 3c. Darker high values are strong energetic contributions to power spectrum, while lighter lower values are weak energetic contributions. The periods analyzed are between 2 and 128 years. The statistical significance tests are used to give a quantitative measure of changes in precipitation variation. The regions enclosed by the darkest black contour indicate that these areas are greater than 90% confidence level. The dashed line indicates the Cone of Influence (COI) that means the region below which suffers from edge effects due to the finite-length of signal (Torrence and Compo, 1998).

The wavelet analysis of the precipitation easily shows that the magnitude of some periods has obvious time-varying character and reveals that there are some dominant periods, which are not directly visible from the original time series. About 4-year period included 2–7 year short-time periods that we did not discussed in the paper is very clear. The ridge around the 11 years activity period is also strong and highly significant as indicated by the 90% confidence level. The cycle is not continuous but it presents some gaps. In addition, we can see some hints of 22- and 33-year oscillation. At even lower frequency, 72-year, is one of the mainly periods in the spectrum. However, these periods do not exist during all time series. It is obvious form Figure 3 that some cycles are stronger than others.

The wavelet transform also gives information on changes in frequency that may occur. For example, the oscillations indicate that high 11-year activity occurred obviously during 1749–1840, 1860–1930, and 1950-present, while 1840–1860 and 1930–1950 were relatively calm. Its magnitude varies from 7.5 years to 11.5 years. It is interesting to note the presence of a non-persistent region around a period of 20–40-years starting from 1840 to 1910 and from 1935 to 1965. Such features, the frequency content changes with time, could not be revealed by means of the conventional Fourier analysis.

3.2.2. *Wavelet analysis of sunspot numbers*

Multiscale periodic analysis of solar activity based on the wavelet approach has been successfully used for many different applications. Using a wavelet analysis approach, Ochadlick et al. found that the resulting estimates of the cycle's period for the nominal 11-year solar cycle are in good agreement with those given by Friis-Christensen and Lassen. More recently, different authors analyzed solar activity using wavelet analysis to investigate more accurately new subtle periodicities and their evolutions (Ochadlick et al., 1993; Vigouroux et al., 1994; Fligge et al., 1999; Han and Han, 2002a, b). Many previous studies based on Fourier spectral analysis and wavelet analysis of solar activity reveal that a high energy content corresponds to the Schawbe ($\sim$11 years) and a lower energy long-term modulation corresponds to the Gleissberg cycles ($\sim$100 years) (Sello, 2000). In order to compare with precipitation, we perform the same procedure of processing the SN series.

It is now much clearer from Figure 4c that there was a dominant period involved in SN and located around 11-year during all parts of the time series and the complex evolution of the cycle, both for scales and amplitudes, is well evident. As can be seen, SN has two obvious periods, about 11- and 78-year respectively. In the two periods, the amplitude of about 11-year is the strongest, and next is about 78-year. There also are some hints about the period about 22-year, but the energy is very weak. The magnitude and intensity of period of SN have obvious time-varying character. For example, for the well-known 11-year period, its magnitude is obviously less than 11-year around 1,775 but greater than 11-year around 1,840. The variation of intensity is also obvious along with time variation. The intensity becomes weaker obviously in 1800–1830 and becomes stronger after that.

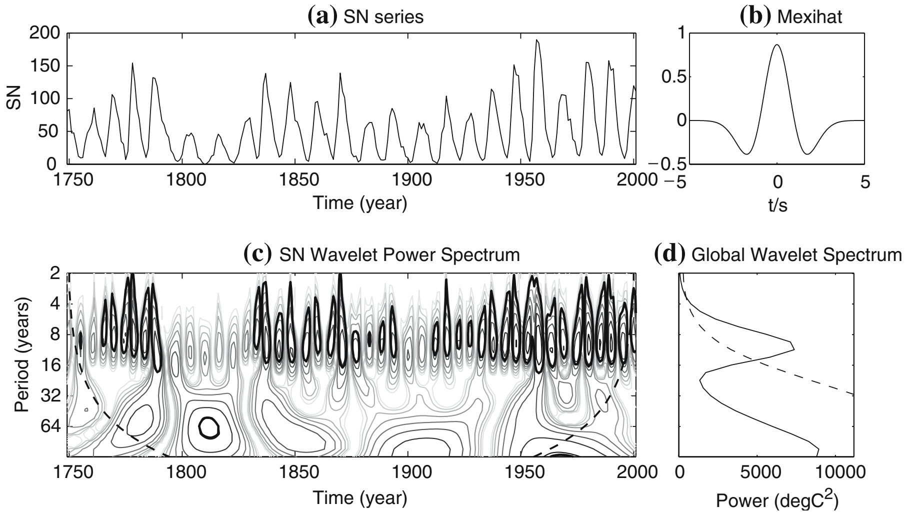

Figure 4. Wavelet analysis of SN (a) the original time series; (b) mother wavelet; (c) local wavelet power spectrum (dashed line indicates the cone of influence and the darkest solid contour is the 90% significance level); (d) global wavelet power spectrum (dashed line is 90% significance level).

3.3. Global wavelet power spectrum

The global wavelet spectrum, which is similar to a smoothed Fourier power spectrum, is given by using the full time range average. It is an averaged power spectrum for all the scales and frequencies. Global wavelet power spectrums of precipitation and SN were presented in Figure 3d and 4d. The dashed line represents the 90% confidence level. As expected, the examination of the global wavelet power spectrum reveals a very prominent peak around the 11-year period of SN. Figure 3d confirms the existence of a period around 4-year. Because the 11-year period of precipitation is not continuous in all time, through full time range average, it is not clear. The two global wavelet power spectrums in Figure 3d and 4d show a significant feature that a long period greater than 70 years exists.

4. Conclusion and Discussion

The comparisons we have outlined imply that solar cycle variability may therefore play a significant role in annual precipitation in Beijing area, even though the extent of its influence on the precipitation is not clear. In agreement with time series of all the investigated direct indicators, precipitation and SN, the ridge around the 11 years activity period is very strong and is highly significant as indicated by the 90% confidence level. There also are some other periods, such as 20–40 years and a long period, about 70–80 year existing in the two series. Conceivably, these may be related to solar activity induced variations, affecting the annual precipitation. Hence, it implies that these oscillations of annual precipitation are likely driven, at least in part, by solar variability.

The general correspondence of prominent precipitation changes in Beijing to variations in solar activity implies a solar influence on area-scale precipitation oscillations during the past 253 years, although the suggested correlation is here limited to a pure qualitative viewpoint. A lot of drought and precipitation series in different areas are correlated with variations of solar irradiance or solar activity proxy records. At present, we still cannot understand how the periodicity variation of solar activity influences variation of precipitation on land. How much the climate system is influenced by solar variability has long been a subject of controversy, due largely to the strictly empirical and statistical nature of the evidences. The climate system is a complicated inter-connected system. Probably there are non-linear actions could amplify or diminish the solar forcing (Rind, 2002). No satisfactory explanation could be derived from classical physical and no physical mechanism for sun-weather effects is generally accepted at the present time. Weather the Sun acts as the controller of precipitation in Beijing on time scales will probably be continued investigation for many years. However, it is significant that further and detailed investigation on physical mechanism of solar activity probably could improve medium-term and long-term prediction of annual precipitation in Beijing area.

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