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Quasi ~500-year Cycle Signals in Solar Activity

Lihua Ma[1], Zhiqiang Yin[1] & Yanben Han[1]

[1] National Astronomical Observatories, Chinese Academy of Sciences, Beijing, China

Correspondence: Zhiqiang Yin, National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China. Tel: 86-10-64860253. E-mail: yinzhq@nao.cas.cn

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Abstract

Direct observations of solar activity are available for the past four century, so some proxies reflecting solar activity such as ^{14}C, ^{10}Be and geomagnetic variations are used to reconstruct solar activity in the past. In this present paper, the authors use rectified wavelet power transform and time-averaged wavelet power spectrum to investigate long-term fluctuations of the reconstructed solar activity series. Results show obvious a quasi ~500-year cycle exists in the past solar activity. Three reconstructed solar activity series from ^{14}C variations confirm the periodic signals.

Keywords: solar activity, long-term cycle, wavelet transform

1. Introduction

Solar activity has the profound influence to geodynamics processes, and the Sun directly or indirectly affects some terrestrial phenomena on the Earth. Some studies showed variation of solar activity closely relates to global and regional climate change (Rasmus, 2006; Miyahara et al., 2008; Mendoza & Velasco, 2009; Ogurtsov et al., 2013; Dergachev et al., 2016). After analyzing the solar variation, global and regional sea-surface temperature, Weng (2005) concluded that inter-annual and centennial climate change signals were not purely internal, but also external because of the existence of the solar activity cycle. Kilcik et al. (2008) made use of surface air temperature, pressure and tropospheric absorbing aerosol data as climate parameters and solar flare index data as solar activity indicator, to study effect of solar activity on the surface air temperature of Turkey. With Indian temperature series of more than one-hundred years, Aslam (2014) investigated the influence of solar activity on regional climate. Results indicated that the solar variation may still be contributing to ongoing climate change. The solar activity can influence atmospheric circulation on various time scales, and variations of the atmospheric circulation then impact precipitation process in some area (Ratnam et al., 2014). Ma et al. (2007) investigated the connection between Indian summer monsoon rainfall and solar activity series, and believed that the solar variation affects the Indian rainfall variation to some extent. Taking into account reconstructed precipitation series in Huashan mountain area of China and solar variation series, the influence of solar activity on the Huashan mountain precipitation to some extent was found (Ma et al., 2010).

More and more people attach importance to studies about long-term solar variation (Usoskin & Mursula, 2003; Yin et al., 2007; Ma, 2007, 2009). However direct observations of solar activity in the past four centuries are insufficient to calculate the long-term solar variation. Some proxies including ^{14}C, ^{10}Be and geomagnetic variations can reflect the solar activity. Therefore solar activity in the past can be reconstructed with these proxies. In this work, rectified continuous wavelet transform reveals quasi ~500-year cycle signals existing in the reconstructed solar activity series.

2. Description of the Data

In the Earth atmosphere ^{14}N can be bombarded by the neutrons in the cosmic ray, and converted into natural radioactive element ^{14}C. The life time of newly-produced ^{14}C is very short, and it usually reacts with O_2 to become $^{14}CO2$ among atmosphere environment. Mixing with $^{12}CO_2$, $^{14}CO_2$ participates in exchange cycles in nature. Through measuring the $^{14}C/^{12}C$ ratio in tree-rings, the solar activity in the past can be reconstructed. The ^{14}C concentration is contaminated by the combustion of fossil fuel since the late 19th century and the nuclear tests in the atmosphere later, therefore the ^{14}C change before 1900 is used to estimate sunspot variations. A sunspot number (SN) series from 9455 BC to 1895 AD was reconstructed (Solanki et al., 2004). Furthermore, with a new adjustment-free physical reconstruction of solar activity, ^{14}C data was converted into a long sunspot number series over the last 3000 years (Kovaltsov et al. 2012; Roth & Joos 2013; Licht et al. 2013; Usoskin et al., 2014). The two reconstructed sunspot number series are referred to as SN1 and SN2, and given in Figure 1 with blue color solid-line and green color solid-line, respectively.

Korte and Constable (2005) used a thorough analysis of global samples to present a new series of the palaeomagnetic dipole moment reconstruction for the last 7000 years. With the new geomagnetic data series, Usoskin et al. (2006) revised the earlier sunspot activity reconstruction since 5000 BC and released the sunspot number series cover the period during 5000 BC to 1995 AD. The solar variation series is referred to as SN3 series, and given in Figure 1 with red color solid-line.

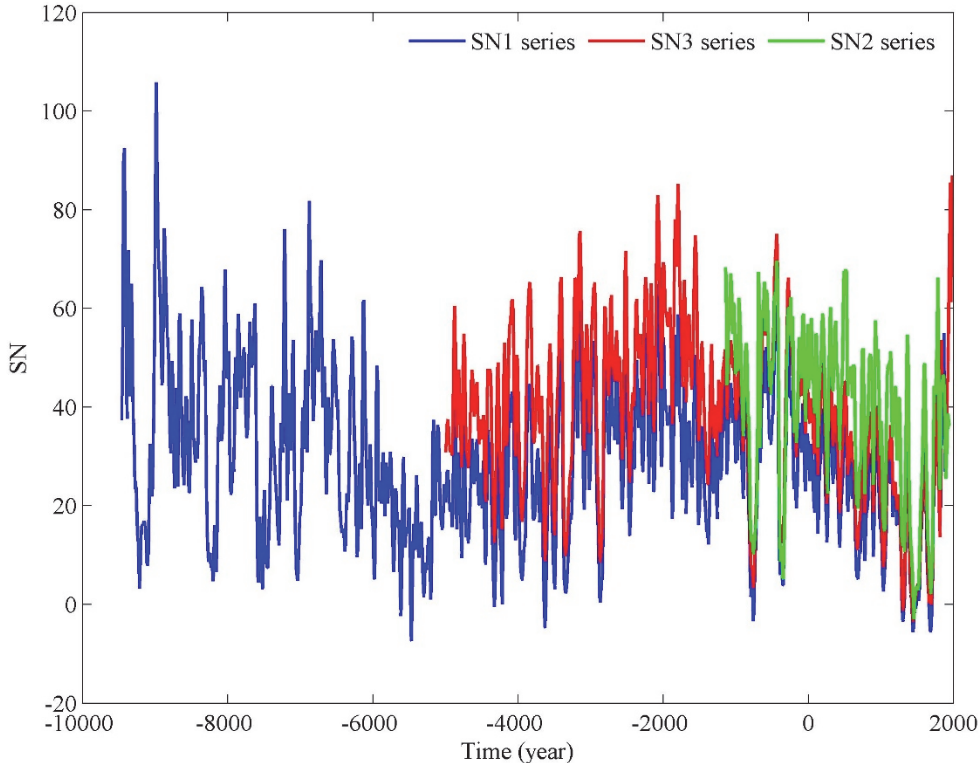

Figure 1. Three reconstructed sunspot number series

3. Wavelet Analysis

With a function of scale and time, wavelet spectrum decomposes a time series into time-frequency space and lays out time variable information of the signal in both time-domain and frequency-domain (Daubechies, 1992; Kumar & Foufoula-Georgiou, 1997; Torrence & Compo, 1998). Actually a physically consistent definition of energy for the wavelet spectrum should be the transform coefficient squared divided by the scale it associates. Therefore, Liu et al. (2007) proposed rectified wavelet spectrum. With the rectified wavelet power spectrum, frequency spectrum structure of the time series with different frequencies is more accurate, and especially suitable for periodic components analysis on long-term time scales.

The rectified wavelet analysis results of above reconstructed solar variation series are shown in Figure 2. In the figure, the subfigures in top row, middle row and bottom row are corresponding to SN1, SN2 and SN3 series, respectively. In every row, the subfigure in left column and right column are corresponding to rectified wavelet power spectrum and time-averaged wavelet power spectrum of every solar variation series. In wavelet power spectrum, red and blue contours indicate high and low wavelet power spectrum values. The regions of greater than 85% confidence level are shown with thick black contours.

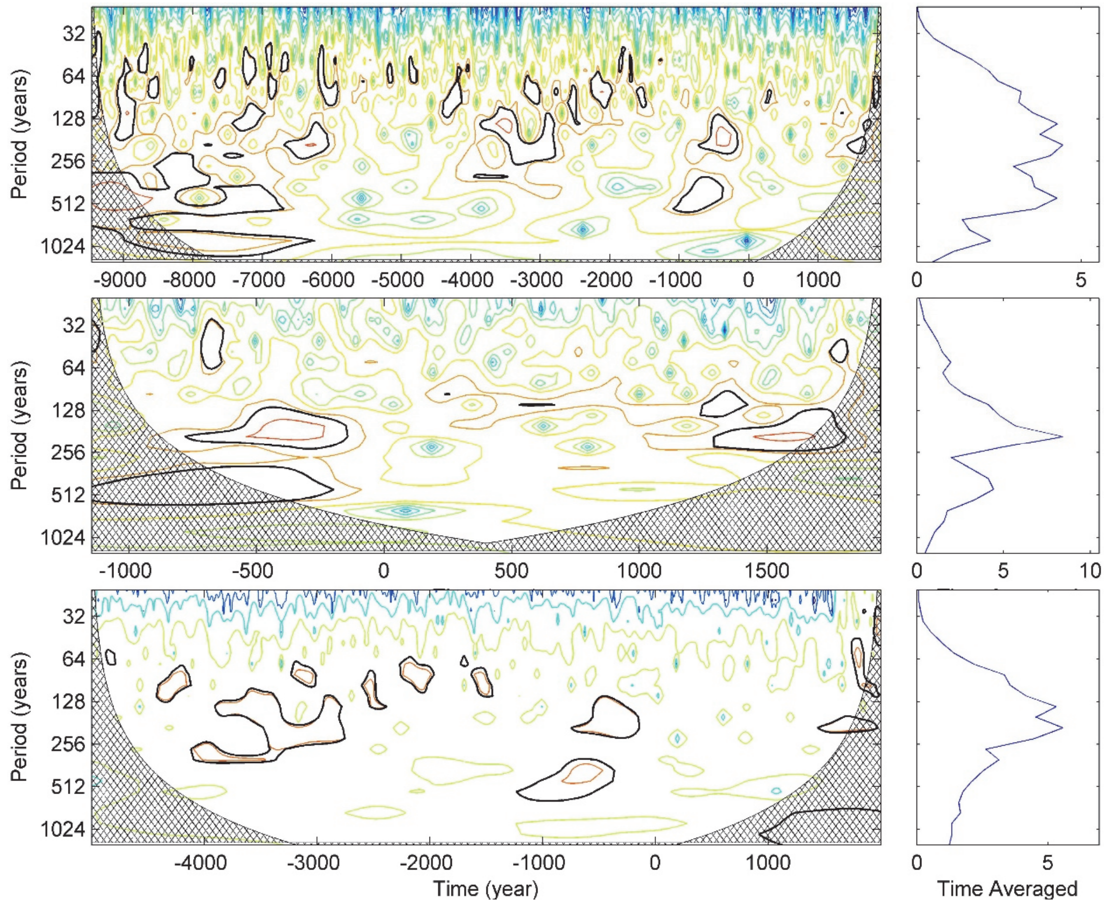

Figure 2. Rectified wavelet power spectra and time-averaged wavelet power spectra of SN1 (top row), SN2 (middle row) and SN3 (bottom row)

From the rectified wavelet spectrum of SN1 series, ~80-, ~200-, ~500-, ~1000-year cycle can be found. As for ~500-year cycle, detailed spectrum structure is investigated. During 9000 BC - 6600 BC and 1000 BC - 200 BC, the quasi ~500-year cycle is remarkable, with the 85% significance contours. We also clear found the solar cycle signals from the wavelet spectrum of SN2 and SN3 series. Obviously, the signals are not affected by other fluctuation signals. Meanwhile the quasi-periodic signals have obvious time-variable characteristics. That is to say, its periodic- length and amplitude both change with time. Especially, the quasi ~500-year period is remarkably found in the time-averaged wavelet spectrum shapes of SN1 and SN2 series.

4. Conclusion

In this work, the reconstructed sunspot number series in the past are analyzed to research for quasi ~500-year cycle signals. Results of the rectified wavelet analysis show the obvious time-variable characteristics exist in the solar variation. Periodic amplitude of this cycle changes with time and it is not a cycle in the strict periodic sense but rather cyclicity with a varying time scale. The quasi ~500-year cycle may be a periodic signal in the solar activity, and attention should be paid to it when the long-term fluctuation in the solar variation is studied.

5. Discussion

Pollen record reflects the dynamics of vertical vegetation zones and temperature change. Using a high-resolution pollen record from a maar annually laminated lake in East Asia, Xu et al. (2014) revealed quasi ~500-year periodic cold-warm fluctuations over the past 5350 years. To investigate the possible influence of the quasi ~500-year signals of solar activity on the pollen record, we calculate scale-averaged wavelet power from 320- to 640-year of solar activity and pollen record series and plot it in Figure 3. Here the first principal component of principal components analysis (PCA F1) loadings of the pollen record series was de-trended using polynomial fit. The residuals are regards as the pollen variation.

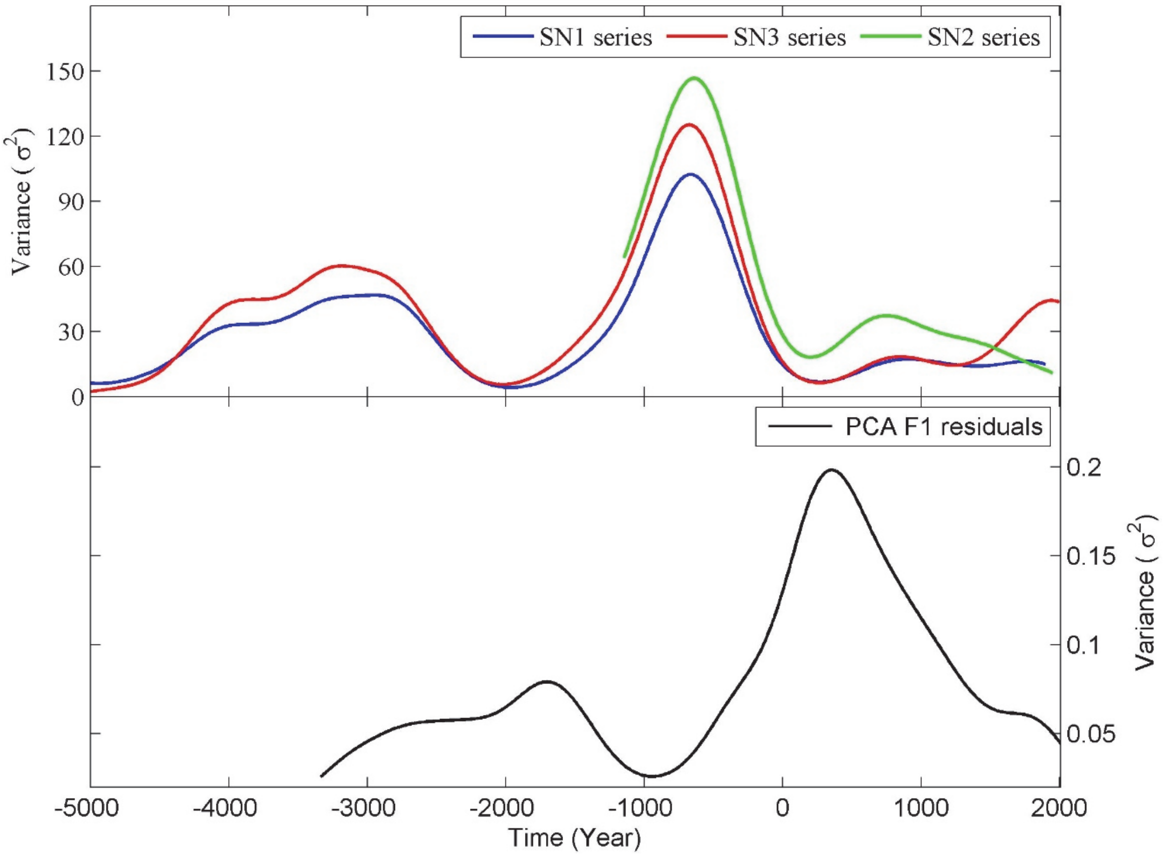

Figure 3. Scale-averaged wavelet power of quasi ~500-year cycle in solar activity and the pollen variation. Wavelet scales of the cycle are from 320- to 640-year

It is obviously that solar activity influences pollen variation in East Asia on quasi ~500-year cycle, with a time advance of nearly 1000 years. Considering that the solar impact on the climate change is a long topic with intense debates for complex interactions among interacting series of spheres or layers in the Earth (Zhao & Feng, 2015), the detailed analysis of possible physical mechanism between solar activity and the pollen variation will be included in an extended article in future.

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