Chin. J. Astron. Astrophys. Vol. 4 (2004), No. 2, 189–197
(*http://www.chjaa.org* or *http://chjaa.bao.ac.cn*)

Chinese Journal of
Astronomy and
Astrophysics

The Effect of Solar Activity on the Annual Precipitation in the Beijing Area *

Juan Zhao[1,2], Yan-Ben Han[2] and Zhi-An Li[1,2]

[1] Department of Astronomy, Beijing Normal University Beijing 100875; zj@bnu.edu.cn
[2] National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012

Received 2003 May 14; accepted 2003 December 2

Abstract Using continuous wavelet transform, we examine the relationship between solar activity and the annual precipitation in the Beijing area. The results indicate that the annual precipitation is closely related to the variation of sunspot numbers, and that solar activity probably plays an important role in influencing the precipitation on land.

Key words: Sun: activity — sunspots — solar-terrestrial relation

1 INTRODUCTION

Scientists from the different fields of astronomy, space physics, climate and weather, and hydrology, have done numerous studies, and obtained many proofs of a correlation between solar activity and disaster climate and weather. Many forms of solar activity, such as flares, solar radiation bursts and solar wind, can cause radiation enhancement and plasma movement. All these affect global climatological changes directly or indirectly (Herman et al. 1978). It has been known for some time that there is a statistical relation between solar activity as expressed, for instance, by the sunspot number, and the precipitation on the land on the Earth's surface. Much scientific effort has been exercised in trying to understand how much influence the Sun exerts on Earth's precipitation. Here, we highlight some of the recent scientific researches on such solar linkages with precipitation. For example, Guo et al. (1992) thought that super floods may more easily occur in the years of maximum solar activity because the increase of energy from the Sun will cause an enhancement in the thermo-mechanical function of the Earth's atmosphere. However, in an activity minimum year super floods are also easier to occur because of the spontaneous magnetostriction effect. Verschuren et al. (2000) presented a decade-scale reconstruction of rainfall and drought series in equatorial east Africa over the past 1100 years. Their analyses indicated that the 'Little Ice Age' (∼AD 1270–1850) was interrupted by three prolonged dry periods, 1390–1420, 1560–1625 and 1760–1840, that these dry periods were all broadly coeval with phases of high solar radiation, while the intervening periods of increased moisture were coeval with phases of low solar radiation. Neff et al. (2001) investigated the

---

* Supported by the National Natural Science Foundation of China.

relationship between solar variability and the monsoon rainfall in Oman between 9 and 6 kyr ago. They found that an excellent correlation between the two datasets suggests that one of the primary controlling factors of centennial- to decadal-scale changes in tropical rainfall and monsoon intensity during this time is the variation in the solar radiation. Kniveton et al. (2001) investigated the relationship between cosmic ray flux in solar minimum and maximum years and the precipitation during the period of 1979–1999 and found a strong statistical correlation between the two datasets over mid to high latitudes. This study also suggested that small changes in solar output can indeed cause significant changes in Earth's climate. Starkel (2002) investigated the change in the frequency of extreme events as an indicator of climatic change in the Holocene. He attributed the above-average rainfall during the Little Ice Age to solar influence.

Comparisons with tree rings (which serve as a proxy for the varying intensity of solar activity) for precipitation have shown a close covariation over thousands of years (Hodell et al. 2001). For example, Pederson et al. (2001) found possible evidence for solar influence from the annual precipitation and other hydro-meteorological reconstructions in Northeastern Mongolia derived from tree rings from 1651 to 1995. Their spectral analysis revealed significant periodicities around 12 years and 20–24 years that are believed to be solar induced.

The influence of solar activity on hydrography and meteorology has an obvious local character. It is well known that the water level of Lake Victoria in African (always considered as an indirect index of tropical precipitation) is positively correlated with the 11-year period of sunspot numbers during 1880–1930. This piece of evidence made many people acknowledge that precipitation was closely related to solar activity. After 1930, however, it seems that the correlation ceased to exist. This is evidence that the relationship between solar activity and precipitation is very complicated and varies with time and probably also with geographic position. On the global scale, the correlation between sunspot number and precipitation may be positive, negative, or even zero. The correlation is always different for different areas observed (Zhang et al. 1989). For example, in the middle and lower reaches of Yangtze River, precipitation has been found to increases about 1–2 years before a sunspot minimum year, and to decrease 1–2 years after, whereas in Northern China, there is a tendency in the opposite direction (Zeng 1989). In the whole weather circulation system of the Earth, each local region has its own particular position (Friis-Christensen et al. 1991). Solar activity acts on a land which in its own way translates the effect according to the particular topography and location. That is what makes this study so complicated.

A good understanding of long-term precipitation variability is essential for the management of water resource and land use in the Beijing area, an area situated in a warm temperate and semiarid climate zone. The magnitude of variation of annual precipitation is always considered to reflect the degree of stability of precipitation. In the Beijing area, the variation is very obvious. The annual precipitation is about 500 mm in a normal dry year and below 300 mm in an ultra-dry year. The study of the variation of annual precipitation is significant. Zhao et al. have paid attention to this issue from two aspects, solar activity and El Niño events, and analyzed and examined the data for several years and obtained some results (Zhao et al. 1996, 1999).

In this paper, we will mainly check the variation of annual precipitation in the Beijing area, and compare it with the solar activity.

2 ANALYSIS OF SOLAR ACTIVITY AND ANNUAL PRECIPITATION IN BEIJING AREA

The annual precipitation dataset in the Beijing Area from 1870 to 2002 is obtained from the China Meteorological Administration. The annual relative sunspot numbers for the same period are taken from Solar Geophysical Data (SGD) of National Oceanic and Atmospheric Administration (NOAA) and National Geophysical Data Center (NGDC) of USA.

In the present paper we have chosen the wavelet transform method to analyze the correlation between the annual precipitation in the Beijing area and the sunspots; we choose this method because of its ability of detailing the local characteristics of the signals in both the time and frequency domains.

2.1 Wavelet Analysis of Sunspot Numbers

The periodicity of solar activity has been studied by many authors. Along with the improvement in data analysis method, more attention has been paid to the time variation of some of the periods. Using a wavelet analysis approach, Ochadlicl et al. (1993) found that the resulting estimates of the cycle's period for the nominal 11-year solar cycle were in good agreement with those given by Friis-Christensen and Lassen. Longer periods are also delineated by the wavelet analysis. Vigouroux et al. (1994) analyzed the temporal variation of the cycles using spectrum analysis and wavelet analysis. Fligge (1999) used different indicators, such as sunspot numbers, sunspot areas, and plage area or ^{10}Be records, to trace the cycle length variation back to the 15th century by continuous wavelet transform. All the activity indicators give cycle length records in mutual agreement. Han et al. (2002a, b) used the wavelet method to analyze the sunspot numbers' period from about 25 d to about 200 yr to check the variation of the periods in more details.

Here we make a wavelet analysis of the sunspot numbers, using the Mexican hat wavelet. The relative sunspot numbers have four obvious periods, about 11, 22, 33 and 78 years, and the periods obviously vary in time. Among the four periods, the 11-year period has the strongest amplitude, the 22-year period, the weakest. Both the length and intensity of the periods vary in time. For example, for the well-known 11-year period, its length is sometimes less than 11 years, such as around 1950, sometimes greater than 11 years, such as around 1900. The length actually ranges from 10.01 years to 11.78 years and the mean value is 10.75 years. Variation in the intensity is also obvious. The intensity got weaker around 1900, then got stronger. The 22-year period also varies from 18.81 years to 25.02 years with mean 22.85 years. The 78-year period varies from 76.05 to 79.77 years with mean about 78.31 years.

There also is a period about 33 years (actually ranging from 30.67 to 33.28 years with mean about 31.97 years). This period differs from the other three in that it did not exist before about 1900 but became obvious from 1900 to 1970. After 1970, however, the period gets shorter and shorter to one about 25 years. It will probably merge into the 22-year period.

Figure 1 shows the result of the wavelet analysis. It indicates that significant signals are present in the relative sunspot numbers. The upper part of Fig. 1 shows the time variation of the original sunspot number and the lower part shows the result, after the wavelet analysis, of the time variation of the periods between 2 and 100 years. To show more clearly the results, contour lines are drawn: with solid (dotted) lines for positive (negative) values. Energy is indicated by the shading (maximum energy, darkest): the energy of the signal is concentrated at certain frequencies, the strongest concentration is at the center of the circle enclosed by the solid and dotted contour lines.

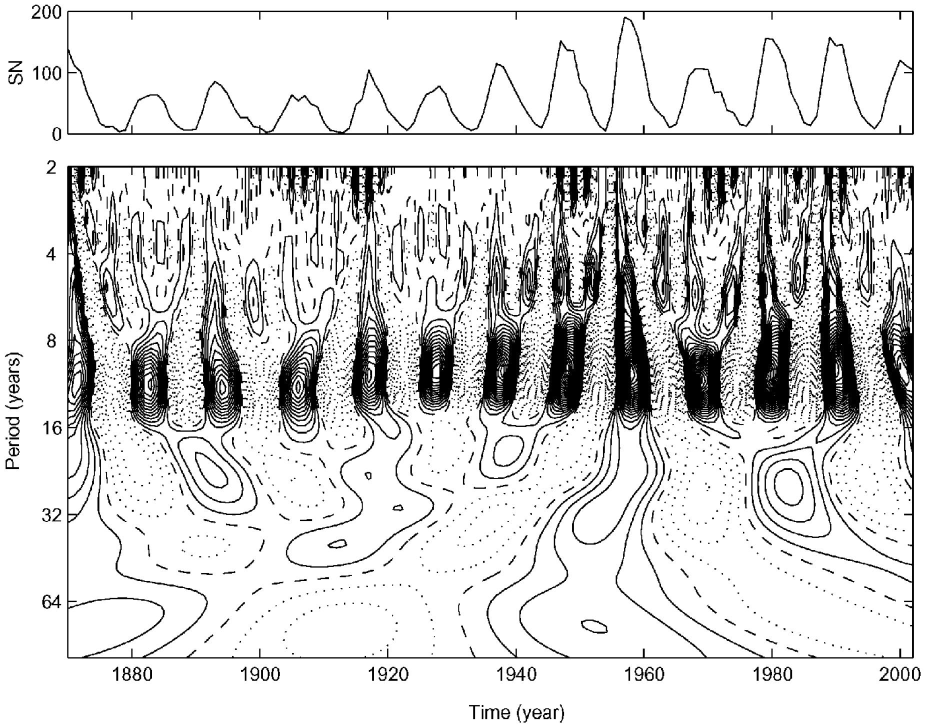

Fig. 1 Wavelet analysis of relative sunspot numbers.

2.2 Wavelet Analysis of the Annual Precipitation in the Beijing Area

We then make a wavelet analysis of the annual precipitation as we did for the sunspot numbers. The corresponding period and energy are calculated by wavelet transform. The results show that there are four main periods, around 11, 22, 33 and 72 years. The lengths of the periods are somewhat uncertain: the periods of the annual precipitation also have an obvious time-varying character, as for the relative sunspot numbers. For example, the 11-year period is sometimes strong and sometimes weak and its length varies from 7.32 to 11.48 years and the mean value is about 9.74 years. The 22-year period varies from 17.34 years to 21.89 years and the mean value is about 20.09 years. As far as climatic change is concerned, the period between 30 and 40 years is not new. The 33-year period, is also a significant period in the precipitation. It ranges from 30.67 to 33.28 years and the mean value is about 32.40 years. The 72-year period varies from 71.87 years to 72.02 years and the mean value is about 72.18 years.

Note that there are also some shorter periods, about 2–7 years, in the annual precipitation besides the decadal periods found from the wavelet analysis.

We give contours of the wavelet power spectrum of the annual precipitation in the time-period plane in the bottom part of Fig. 2. As in Fig. 1, the top part is the original data of annual precipitation.

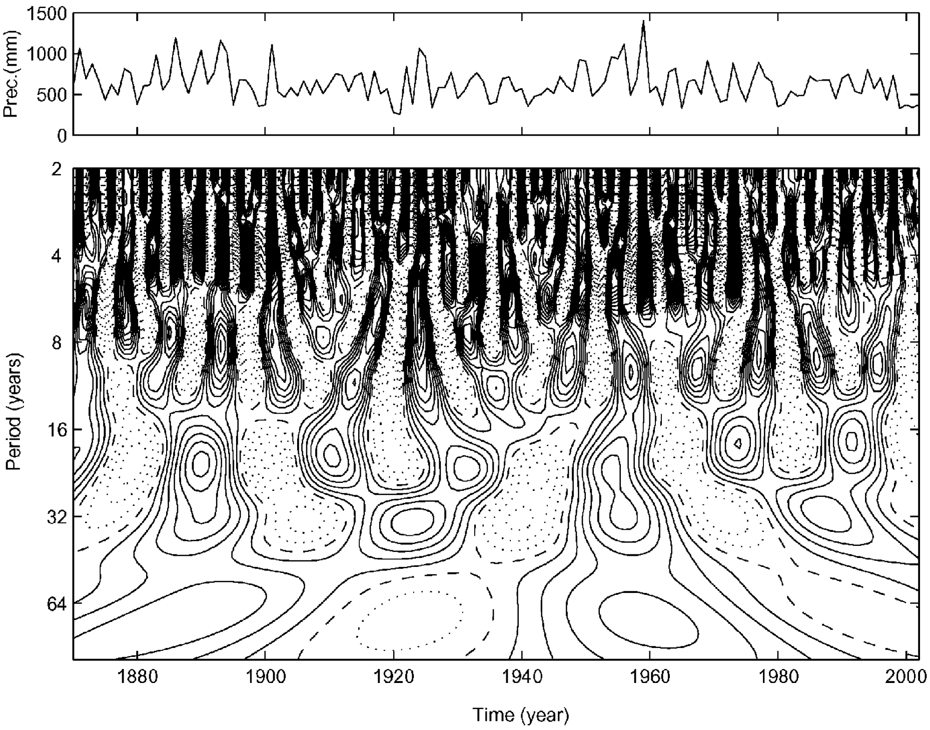

Fig. 2 Wavelet analysis of annual precipitation in the Beijing area.

2.3 Possible Influence of Solar Activity on the Precipitation in the Beijing Area

It should be noted that there is a close association between the two datasets. On the decadal time scale, there are obvious periods about 11, 22, 33 and 72 years in the annual precipitation in the Beijing area. These periods are consistent with the 11-year period, the 22-year magnetic period, the 33-year period and the longer 78-year period of the sunspot numbers. From the wavelet analysis, we could find that the maximum in the 78-year period of sunspot numbers occurred around 1874 and 1952, while the maximum in the 72-year period of annual precipitation occurred around 1887 and 1959. Around 1874, the long period of sunspot numbers is about 13 years ahead of the long period of annual precipitation. Because of the difference between them, however, both periods will come into a maximum around the year 2030. Although there are some differences between the two periods, we consider that there is probably a close connection. The total span of the datasets could have influenced the precision of the long periods, and caused the differences.

Besides the well-researched 11-year and 22-year periods, the 33-year period is also obviously consistent with one of the sunspot activity periods. Brückner(1890) demonstrated that varied climatic phenomena in different regions of the world show phase synchronism in cycles of 33 to 37 years and surmised a connection with solar activity. Clough (1905, 1933) found the period not only in the meteorological variables, but also in the sunspots and especially in the variations in the length of the 11-year sunspot cycle. The 33-year period is a special period of sunspot numbers that sometimes exists and sometimes disappears. Because of its particular character, the period may not come out in an AR spectrum analysis if a special time quantum is chosen.

These agreements support the suggestion that there is probably a direct solar activity influence on the annual precipitation in the Beijing area, that the periods of precipitation arise from solar activity. At least, solar activity possibly accounts for a portion of the influence.

Variations of solar activity reaching the Earth are thought to influence precipitation, but it is still hard to understand how the periodic variation of solar activity influences the variation of the precipitation on land, and the extent of this influence on timescales of millennia to decades still remains unclear. It is significant that further investigations and detailed studies on the physical mechanism of solar activity can probably improve the medium-term and long-term prediction of annual precipitation in the area. Solar activity prediction is being paid more attentions and the prediction methods are being improved (Wang et al. 2002).

3 CORRELATIONS AND STATISTICAL ANALYSIS

3.1 Correlation Analysis

For further investigations of the correlated character between the two datasets, we take moving averages of them after detrending the 11-, 21- and 33-year components. Considering the length of the datasets, we do not make moving averages over degrees above 70. The result is shown in Table 1. At the same time, we display the two datasets after taking moving averages of degrees 11, 21 and 33, respectively, in Figure 3. In the table, SN(0) and Prec.(0) are the original series of sunspot numbers and precipitation, respectively, and SN(11) etc. are the series of moving averages of degree 11 etc. Column 2 is the maximum correlation coefficient and column 3 is the time delay corresponding to the maximum correlation. To assess the significance, we append the values of the correlation coefficient at 95% and 99% confidence levels.

In fact, moving average is a special kind of low-pass filter and taking moving average weakens the independence of the dataset. The degree of freedom will be decreased by that of the moving average. The larger the latter, the smaller the signal remaining in the dataset, and *vice verse.*

Therefore, the correlation coefficient between two datasets after moving average will increase. To check this point, we use the Monte Carlo simulation test of correlation significance levels of Zhou et al. (1999). First, we make a table of threshold values of correlation coefficients using the Monte Carlo simulation tests. Next, we use the same method to compute the threshold values of correlation coefficients after the moving average, after adding the difference to the moving average part. Thus, we obtain the threshold values of the correlation coefficient both before and after moving average. In Fig. 4 we illustrate the threshold value curves of the 99% significance level for three moving average degrees, 3, 5 and 7. From a comparison, the correlation coefficients would increase under the same degree of freedom after moving average. The threshold correlation coefficients increase with increasing degree of the moving average. In this way we obtain the 95% and 99% correlation coefficients shown columns 4 and 5 of Table 1.

Table 1 Cross Correlation between SN and Annual Precipitation in the Beijing Area

	Correlation coefficients	Time delay (unit: year)	Significance level	
			95%	99%
SN (0) & Prec. (0)	–0.225	–17	0.171	0.223
SN (11) & Prec. (11)	0.600	0	0.461	0.573
SN (21) & Prec. (21)	0.882	5	0.622	0.738
SN (33) & Prec. (33)	0.889	7	0.741	0.837

From Table 1 we find that the observed correlation coefficient between original SN and precipitation series is over the 95% significance level, nearly equal to the 99% significance level. After taking moving averages of degree 11, the correlation coefficients greatly increase to 0.6 and far exceed the 95% threshold, and even exceed the 99% threshold, and the two series have the same phase. From Fig. 3a, we can see that there is relative irregularity between the two original datasets and that some regularity emerges after taking moving averages of degree 11. The two datasets after taking moving averages of degree 21 vary in similar manner (see Fig. 3b). They both have a broad maximum from 1940 to 1970. They present an obvious positive correlation and the correlation coefficient reaches 0.882, over above the 99% significance level, and there is a time delay of 5 years: the 21-year moving average series of the annual precipitation is 5 years behind that of the sunspot number. For the 33-year moving average series, there is again a strong positive correlation, with a coefficient of 0.889, above the 99% significance level.

Comparisons of the correlation character of original datasets and moving average series show that the annual precipitation in the Beijing area and the sunspot number have an important connection on 11-year, 22-year and 33-year periods. Evident positive correlations have been found.

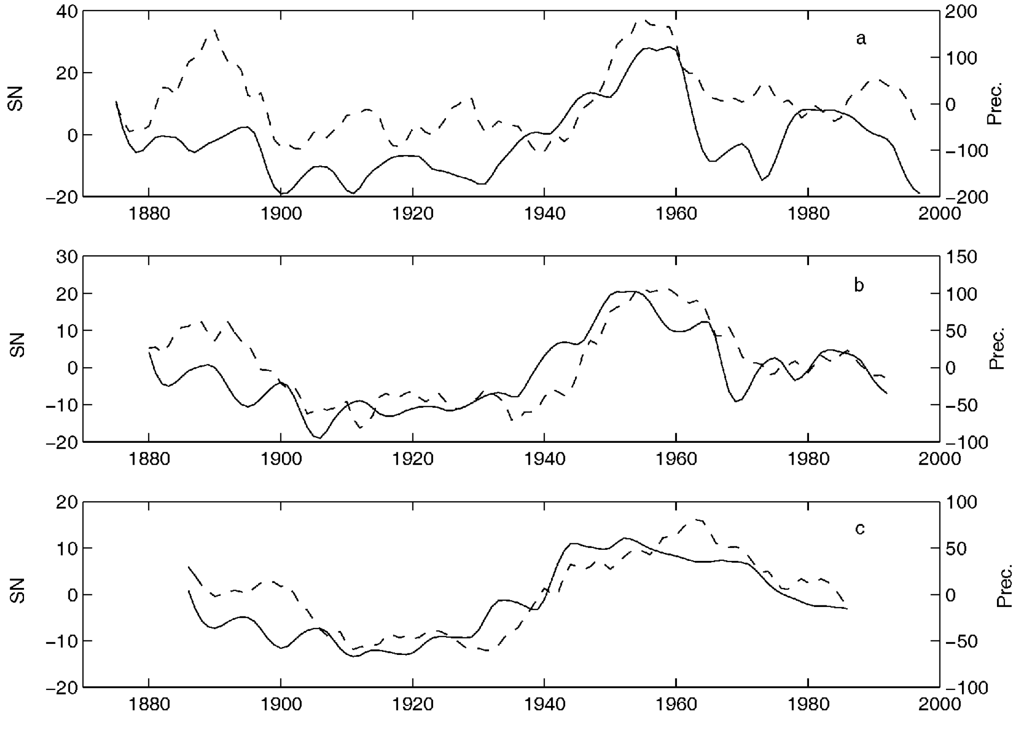

Fig. 3 Moving average series of sunspot number (solid line, scale on left) and the annual precipitation in the Beijing area (dashed line, scale on right). (a), (b) and (c) are the two series after taking moving averages of degree 11, 21 and 33, respectively.

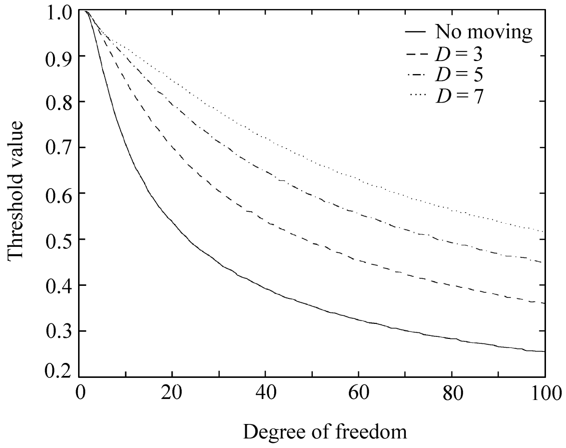

Fig. 4 Curve of threshold correlation coefficient on 99% significance level (D means the degree of moving average).

3.2 Statistical Analysis

The consistent periods between the two datasets illustrate that there is a close correlation between the variations in the precipitation change in the Beijing area and in solar activity. There are 12 cycles of the 11-year period of solar activity during the 133 years. The variation of solar activity may causes a significant part of the changes in the annual precipitation. We have done a statistical investigation as follows.

1) We make a statistical analysis on the changes in the annual precipitation changes of the Beijing area, departures from the mean of period 1870–2002 around the sunspot minimum year. Note that, about 1–2 years before the sunspot minimum year, the Beijing area was always arid, but in the minimum year and for about 1–2 years after, the precipitation always increased. Solar activity may have influence on the annual precipitation.

2) There were 32 El Niño events from 1870 to 2002. We divide these 32 events according to the annual precipitation relative to its mean. Note that the annual precipitation is above average for 22 (or 69%) of the 32 El Niño years, and is below the average for only 10 (or 31%) of the El Niño years. In about 75% of the El Niño years, the summer rain belt (June–August) in China is located in the reaches of the Yangtze River and the Huai River, Northern China was always arid in these years. Our statistical results show that the Beijing area was arid generally. This result is consistent with the result of Chen (1991). From the statistical results, we can see that for the special year, which is both an El Niño year and a sunspot extreme year or its following year, the annual precipitation was obviously less than a normal year.

Our result strongly supports the view that the variability of solar activity can effect the annual precipitation in the Beijing area, although the physical mechanism of such influence remains still unclear. Further studies in the future may help us to understand the mechanism that links solar activity with annual precipitation.

Acknowledgements We would like to gratefully thank the referee for his constructive and detailed instruction. We thank Prof. Zhou Yonghong for his kind discussion. This work was supported by the National Natural Science Foundation of China (Grant No.19973011, 10373017).

References

Brückner E., 1890, Geographische Abhandlungen, 14, 325

Chen J. Y., 1991, Analysis for drought and waterlogging and long-term prediction in China, Beijing: Agriculture Press

Clough H. W., 1905, Astrophysics Journal, 22, 42

Clough H. W., 1933, Monthly Weather Review, 60, 99

Fligge M., Solanki S. K., Beer J., 1999, A&A, 346, 313

Friis-Christensen E., Lassen K., 1991, Science, 256, 698

Guo Z. J., Qin B. Y., 1992, Journal of Natural Disasters, 1(3), 101

Han Y. B., Han Y. G., 2002a, Chinese Science Bulletin, 47(7), 609

Han Y. B., Han Y. G., 2002b, Chinese Science Bulletin, 47(23), 1969

Herman J. R., Goldberg R. A., 1978, Sun, Weather and Climate, Washington: NASA

Hodell D. A., Brenner M., Curtis J. H. et al., 2001, Science, 292, 1367

Kniveton D. R., Todd M. C., 2001, Geophysical Research Letters, 28, 1527

Neff U., Burns S. J., Mangini A. et al., 2001, Nature, 411, 290

Ochadlick A. R. Jr., Kritikos H. N., Giegengack R., 1993, Geophys. Res. Lett., 20(14), 1471

Pederson N., Jacoby G. C., D'Arrigo R. D. et al., 2001, Journal of Climate, 14, 872

Starkel L., 2002, Quaternary International, 91, 25

Wang J. L., Gong J. C., Liu S. Q. et al., 2002, Chin. J. Astron. Astrophys., 2(6), 557

Verschuren D., Laird K. R., Cumming B. F., 2000, Nature, 403, 410

Vigouroux A., Delache Ph., 1994, Solar Phys., 152, 267

Zeng Z. Q., 1989, Solar-Terrestrial Relationship, Beijing: Seismological Press, 197

Zhang Y. D., Li W. B., 1989, Sunspot Numbers, Beijing: Overseas Chinese Press, 139

Zhao J., Li Z. A., 1996, Fujian Astronomy, 2(3&4), 35

Zhao J., Li Z. A., Han Y. B., 1999, Journal of the Beijing Normal University (Natural Science), 35(1), 75

Zhou Y. H., Zheng D. W., 1999, Acta Geodaetica et Cartographica Sinica, 28(4), 313