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The influence of the de Vries (~200-year) solar cycle on climate variations: Results from the Central Asian Mountains and their global link

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Abstract

Long-term climatic changes related to solar forcing were examined using millennium-scale palaeoclimatic reconstructions from the Central Asian mountain region, i.e. summer temperature records for the Tien Shan mountains and precipitation records for the Tibetan Plateau. The reconstructions were based on juniper tree-ring width records, i.e. *Juniperus turkestanica* for the Tien Shan and *Sabina przewalskii* for the Tibetan Plateau. The data were processed using spectral and wavelet analysis and filtered in the frequency range related to major solar activity periodicities. The results obtained for various tree-ring chronologies indicate palaeoclimatic oscillations in the range of the de Vries (~210-year) solar cycles through the last millennium.

The quasi-200-year variations revealed in the palaeoclimatic reconstructions correlate well ($R^2=0.58–0.94$) with solar activity variations ($\Delta^{14}C$ variations). The quasi-200-year climatic variations have also been detected in climate-linked processes in Asia, Europe, North and South America, Australia, and the Arctic and Antarctica. The results obtained point to a pronounced influence of solar activity on global climatic processes.

Analysis has shown that climate response to the long-term global solar forcing has a regional character. An appreciable delay in the climate response to the solar signal can occur (up to 150 years). In addition, the sign of the climate response can differ from the solar signal sign. The climate response to long-term solar activity variations (from 10s to 1000s years) manifests itself in different climatic parameters, such as temperature, precipitation and atmospheric and oceanic circulation. The climate response to the de Vries cycle has been found to occur not only during the last millennia but also in earlier epochs, up to hundreds of millions years ago.

Keywords: Climate change; Solar activity; Dendrochronology; de Vries solar cycle; Tien Shan; Tibetan Plateau

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1. Introduction

The ~200-year solar cycle (de Vries cycle) is commonly believed to be one of the most intense solar cycles. Variation of cosmogenic isotopes ^{14}C and ^{10}Be concentration in terrestrial archives carry information about the past periodicity of solar activity. Using $\Delta^{14}C$ variations (radiocarbon concentration) in tree-rings Vasil'ev et al. (1999) and Muscheler et al. (2003) inferred that the ~200-year solar activity cycle (de Vries cycle) is a dominant cycle during the Holocene. The deep solar minima (Maunder, Spörer, Wolf) can be regarded as manifestations of the de Vries cycle during the past few millennia (Eddy, 1976). By examining ^{10}Be concentration in Greenland ice as a proxy for solar activity variations, Wagner et al. (2001) traced the development of this periodicity between 50,000 and 25,000 years ago. Their findings suggest that the de Vries cycle persisted over even longer timescales.

Sonett and Suess (1984) showed the existence of a correlation between the spectra of ^{14}C concentration and the radial growth of tree rings of bristlecone pines from eastern California at ~200-year periodicity. Palaeoclimatic data obtained in recent years further demonstrate the connection between ~200-year solar activity periodicity and other climatic parameters (see, for example, Schimmelmann et al., 2003). The temporal synchrony between the Maunder, Spörer, and Wolf minima and the expansion of Alpine glaciers (Haeberli and Holzhauser, 2003) further point to a climate response to the deep solar minima. A similar conclusion was inferred from analysis of glacier expansion in Alaska (Wiles et al., 2004). However, the climate response to a solar signal can vary from one region to another. Wiles et al. (2004) showed that regional climate responses to the de Vries cycle can markedly differ in phase even at distances of several hundred kilometers. This can result from the nonlinear character of the atmosphere–ocean system response to solar forcing. The possibility of a regional response to de Vries cycles is supported by model simulations which examine the effect of variations in solar irradiance on the atmosphere–ocean system (Waple et al., 2002). Similar conclusions were inferred from analysis of solar forcing of the climate during the Maunder Minimum (Shindell et al., 2001).

It is therefore necessary to carry out analysis of a climate response to the de Vries periodicity for different regions of the Earth and compare the results with the data obtained by simulation. The goal of this paper is to analyze climate variations in Central Asia that may be related to the ~200-year solar cycle.

2. Methods

To reveal the long-term climatic changes that occurred during the last millennium, we used variations in tree ring widths of junipers from two mountain regions of Central Asia: the Tien Shan mountains and the Qinghai-Tibetan Plateau (Fig. 1). The distance between the regions where the dendrochronological data were collected is approximately 2000 km.

We analyzed tree ring growth for two types of junipers: for *Juniperus turkestanica* (variations of summer temperatures) in the high timberline in the Tien Shan mountains and Qilian juniper (*Sabina przewalskii)* (variations of precipitation) on the Qinghai-Tibetan Plateau. We have subjected these data to band-pass filtering in the 180–230 period range, wavelet transformation (Morlet basis) for the range of periods between 100 and 300 years, and spectral analysis to quantify variability that may be related to the de Vries cycle. The palaeoclimatic data are then compared with an estimate of solar activity based on $\Delta^{14}C$ variations to describe the development of the ~200 year solar activity periodicity (de Vries cycle) during the last millennium.

In this paper we do not discuss possible physical mechanisms of the influence of solar activity on atmospheric processes. The interested reader can find information on this subject in our earlier paper concerned with the problems of influence of solar activity on atmospheric processes as applied to the Hale cycle of solar activity (Raspopov et al., 2004, 2005).

2.1. Tien Shan data

In the Tien Shan, tree-ring width variations of *J. turkestanica* (ΔR) growing above 2800–2900 m altitude were used for analysis. The trees at these locations can reach ages of 2000 years, and analyses have revealed that variations in juniper tree-ring widths primarily reflect June–July temperatures with no significant influence of precipitation (Mukhamedshin and Sarbaev, 1988; Maksimov and Grebenyuk, 1972; Esper et al., 2003b). Therefore, analysis of long-term juniper ring width variations, when compared with solar activity variations, allow relationships between long-term changes in solar activity and summer temperatures in Central Asia to be investigated. To reliably detect the ~200-year fluctuations in ΔR for *J. turkestanica*, we analyzed long-term ring width records developed for different sites in the Tien Shan mountains by independent research teams: Maksimov and Grebenyuk (1972), Mukhamedshin and Sarbaev (1988), and Esper et al. (2003b). The locations of these three collections are shown in Fig. 1a.

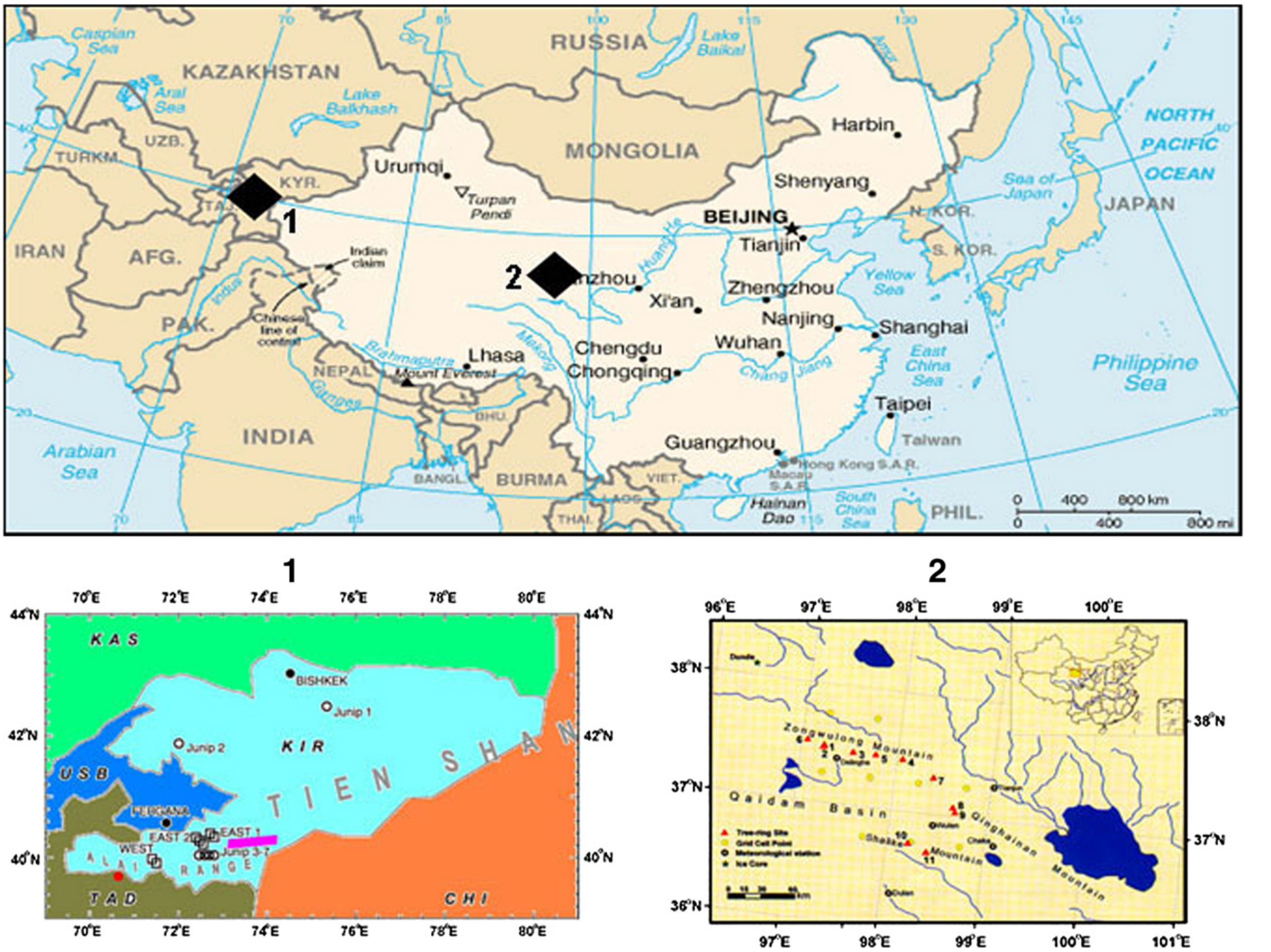

Fig. 1. Location of study areas within Asia, and maps showing location of sampling points A: The Tien Shan mountain region: the triangle marks the site used by Maksimov and Grebenyuk, the thick line marks the site used by Mukhamedshin and Sarbaev, and the rectangle is the site used by Esper et al. (2003b) B: The Tibetan Plateau region: the triangle marks the sites used for collecting juniper tree rings.

The chronology published by Maksimov and Grebenyuk (1972) covers the time interval from 1170 to 1970 AD. It is based on processing data for trees older than 800 years, i.e. the records are much longer than the period of interest. The samples were collected in Tajikistan on the northern slope of the Zeravshan range at an altitude of 3500 m, about 1.0 km from the glacier (39.5°N, 70.7°E).

The chronology published by Mukhamedshin and Sarbaev (1988) covers the time interval from 750 to 1972 AD. It is based on data from trees older than 650 years, with individual samples containing up to 1250 annual growth rings. Unlike the other tree-ring records presented herein, this record is not annually resolved as it is composed of 10-year averages of annual ring width increments. The samples were collected in southern Kirghizia on the northern slope of the Alay range at elevations above 2900 m (39.9°N, 72.5°E). Both the records of Maksimov and Grebenyuk (1972), and Mukhamedshin and Sarbaev (1988) were developed using tree discs rather than core samples.

The third dataset used in this analysis is the RCS (Regional Curve Standardization, Esper et al., 2003a) detrended chronology by Esper et al. (2003b) integrating juniper core samples from several high elevation sites (>2900 m a.s.l.) in the Alay range, southern Kirghizia (39.8°–40.2°N, 71.5°–72.6°E). This record spans the past millennium. The age-trend in this record was removed by using a technique to maximally preserve low-frequency information in the tree ring data. Using RCS or similar techniques, variations are not inherently limited by the lengths of individual tree series — a consideration that is particularly important in datasets that combine shorter tree segments to form a chronology significantly longer than the span covered by individual tree ring measurement series (Cook et al., 1995). However, for all of the Tien Shan datasets, the shortest tree series are more than three times longer than the ~200-year periodicity of interest, suggesting that potential changes of this periodicity could be preserved.

2.2. Qinghai-Tibetan Plateau data

To analyze long-term climatic changes on the Qinghai-Tibetan Plateau, tree-ring width variations of Qilan juniper (*S. przewalskii*) growing in the mountains of arid and semiarid areas in the northwestern part of the plateau were used. The tree ring chronology was developed by cross-dated samples from 11 sites of Qinghai Province (36.7–37.5°N, 97.0–98.7°E) (Fig. 1b). These data were used as a basis for constructing a regional chronology (RC). Shao et al. (2005) found that Qilan juniper growth in the area under study was mainly limited by moisture conditions in May and June and that there is a significantly positive correlation between the RC and the total precipitation from July of a previous year to June of a subsequent year. By using the connection between variations in precipitation and tree ring width, Shao et al. (2005) made a 1437-year reconstruction of July–June

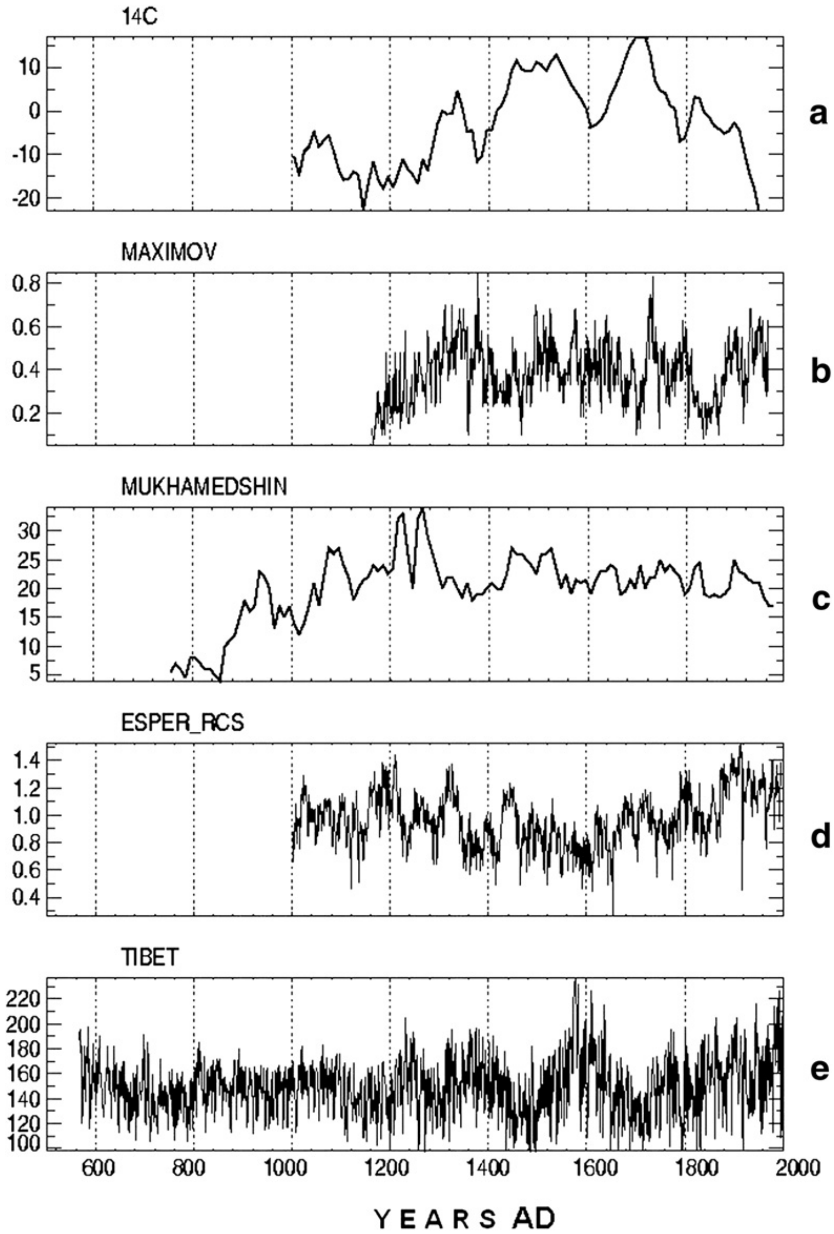

Fig. 2. From top to bottom: (a) variations in 10-year averages of $\Delta^{14}C$ (Stuiver et al., 1998); (b) variations in tree ring widths in the chronology of Maksimov and Grebenyuk; (c) relative variations in tree ring widths in the chronology of Mukhamedshin and Sarbaev (averaged over 10-year intervals); (d) the RCS chronology by Esper et al. (2003b), (e) the precipitation reconstruction record for the Tibetan Plateau by Shao et al. (2005) for the last millenium.

precipitation for the Qinghai-Tibetan Plateau. This reconstruction was used in our work to analyze long-term climatic variations in this region.

2.3. Analysis

In this paper the tree ring data from the Tien Shen and Qinghai-Tibetan Plateau are used to assess the climatic response to possible solar forcing in Central Asia. As an estimate of the past solar activity itself we rely upon data of cosmogenic isotope abundance as preserved in tree rings and ice cores. Galactic cosmic rays entering the Earth's atmosphere generate a number of cosmogenic radionuclides such as carbon isotope ^{14}C and beryllium isotope ^{10}Be. It is convenient to use ^{14}C and ^{10}Be to study the natural processes affecting the isotope concentration, such as time variations of solar activity. As a result of exchange processes in the environment, these radioisotopes fall into the dated natural archives: ^{14}C isotope is present in annual tree rings, and ^{10}Be isotope is found in glaciers and marine sediments. An analysis of the dated natural archives is a unique approach to the investigation of processes on the Earth and near Earth space and the time scales from decades to several thousand years (for ^{14}C) and to hundreds of

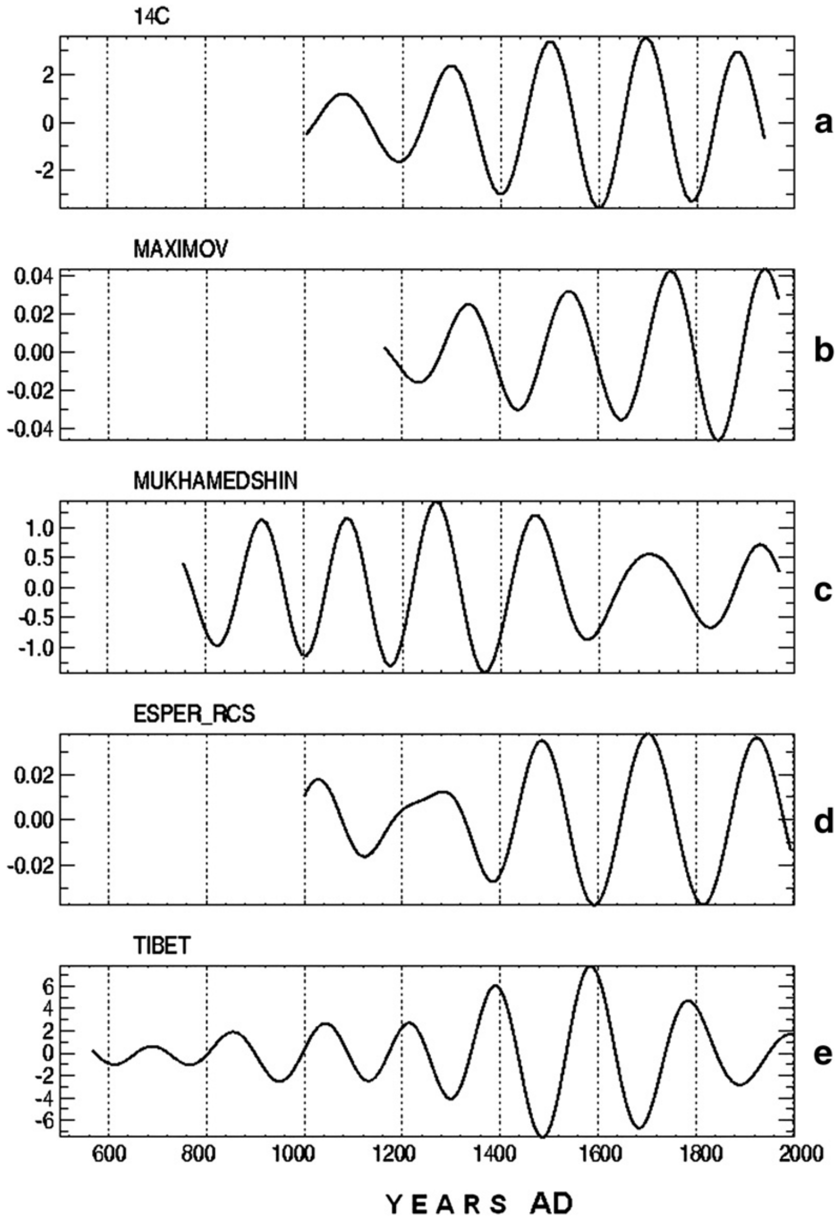

Fig. 3. Results of filtering in the range of periods 180–230 years (from top to bottom): (a) variations in 10-year averages of $\Delta^{14}C$ (Stuiver et al., 1998); (b) variations in tree ring widths in the chronology of Maksimov and Grebenyuk; (c) variations in tree ring widths in the chronology of Mukhamedshin and Sarbaev; (d) the RCS chronology by Esper et al. (2003b), (e) the precipitation reconstruction record for the Tibetan Plateau by Shao et al. (2005).

thousand years (for ^{10}Be). In our study we use data for variations of ^{14}C concentration (Δ^{14}C) detailed in Stuiver et al. (1998) which are based on values measured from tree rings averaged over 10-year periods. This record covers the past millennium — a similar time span as the tree ring data.

To place our results from central Asia in a broader context we also include comparisons and discussions with data from trees that grew in Chile ~50,000 years ago (Roig et al., 2001), varve data from the southern USA (W. Dean, unpublished data, personal communication), estimates of solar activity for the past 8000 years based on Δ^{14}C in tree rings (Stuiver and Becker, 1993; Vasil'ev et al., 1999), glacial fluctuations over the past 1000 years in Alaska (Wiles et al., 2004) and ^{10}Be concentrations from a Greenland ice core for the period from 50,000–25,000 years ago (Wagner et al., 2001).

3. Results

The Δ^{14}C record, the three Δ*R* chronologies for the Tien Shan mountains, and precipitation reconstruction for the Qiaghai-Tibetan Plateau are shown in Fig. 2. Solar minima are indicated by peaks in ^{14}C concentration (Fig. 2a); the Maunder minimum refers to the period of highest ^{14}C concentration around 1700 AD, with the Spörer and Wolf minima occurring around 1500 AD and 1300 AD, respectively. The earliest ^{14}C peak, ~1050 AD, reflects the Oort minimum, and the two smaller peaks after 1800 AD reflect the Dalton and Damon minima.

All five of these records were subjected to band-pass filtering in the range of periods 180–230 years and wavelet transformation (Morlet basis) for the range of periods between 100 and 300 years. The result of the band-pass filtering is shown in Fig. 3. The band-pass filtered records of *J. turkestanica* tree rings (which in essence represent variations in summer temperatures in Western Central Asia) (Fig. 3b–d), and also the band-pass filtered record of the precipitation reconstruction based on the Qilian juniper chronology for the Tibetan Plateau (Fig. 3e) and of the Δ^{14}C curve (Fig. 3a), all exhibit pronounced ~200-year oscillations.

The waveforms evident in the band-pass filtered (summer temperatures, precipitation, and Δ^{14}C) have similar periodicities, however, they are not in phase (Table 1). This shift can be due to the reservoir effect in the ^{14}C deposition in tree rings. Additionally, local climatic conditions (proximity to glaciers, etc.) of the two different regions covered (Tien Shan mountains and the Qinghai-Tibetan Plateau), the varying responses of temperature and precipitation sensitive trees to differing environmental forcing, and ocean–atmosphere lags to the forcing can affect the phase relation between the curves (see Discussion).

If we account for the phase shift, the curves shown in Fig. 3 demonstrate high correlation coefficients in the 180–230-year period range (Table 1). For the Δ^{14}C curve and chronology of Maksimov and Grebenyuk, this coefficient reaches 0.94 when a lag of 150 years is applied. High correlation coefficients are another indicator (in addition to the spectrum dynamics) suggesting that there is a relationship between solar activity and climatic processes.

The result of wavelet transformation is shown in Fig. 4. It is evident that a decrease in the period of quasi-200-hundred-year variations during the last millennium is observed in both the Δ^{14}C (Fig. 4a) and dendrochronological (*J. turkestanica*) data (Fig. 4b–d). Within the range of the periodicities shown (100–300 years), all three of the temperature proxies (Fig. 4b–d) display a weakening of the signal at ~1700 AD, thought likely to be a consequence of the low solar activity around this time. The Esper et al. (2003b) record displays minima between 1000–1100 AD centered around the 150-year periodicity, and ~1300 AD centered around the 200-year periodicity (Fig. 4d). However, in the Esper et al. record there is no clear evidence for a minimum that is centered around 1500 AD that can be linked with low solar activity at around this time. The dynamic spectrum of precipitation variations on the Tibetan Plateau also exhibits ~200-year oscillations (Fig. 4e), yet these are not as pronounced in the wavelet decomposition as the temperature related proxies (Fig. 4b–d). Furthermore, because of a considerable increase in the precipitation from about 1800 AD, the decrease in the oscillation period to the end of the millennium is less pronounced in this record.

4. Discussion and the 200-year cycle globally

The dynamic spectra of changes in solar activity and climatic processes estimated from millennium-long tree-ring records for Central Asia are similar, pointing to

Table 1
Correlation coefficient between band-pass filtered Δ^{14}C record (Stuiver, 1980) and band-pass filtered chronology presented in Fig. 3

Δ^{14}C correlation with	Correlation coefficient	Δ*t* (years)
Summer temperature (Maksimov and Grebenyuk, 1972)	0.94	−150
Summer temperature (Mukhamedshin and Sarbaev, 1988)	0.58	−10
Summer temperature (Esper et al., 2003b)	0.73	0
Precipitation on the Tibetan plateau (Shao et al., 2005)	0.84	−100

potential relationships. The above results, based upon temperature and precipitation sensitive tree-ring data from the central Asian mountain regions show significant variability at wavelengths around 200 years. We link the variability at these periodicities with the de Vries solar cycle.

The response of precipitation variations to solar forcing must *a priori* have a more complicated and ambiguous character as compared with the temperature response. This is due to the fact that the precipitation intensity depends on changes in the atmospheric circulation and physical and chemical condition of the atmosphere. On the whole, in

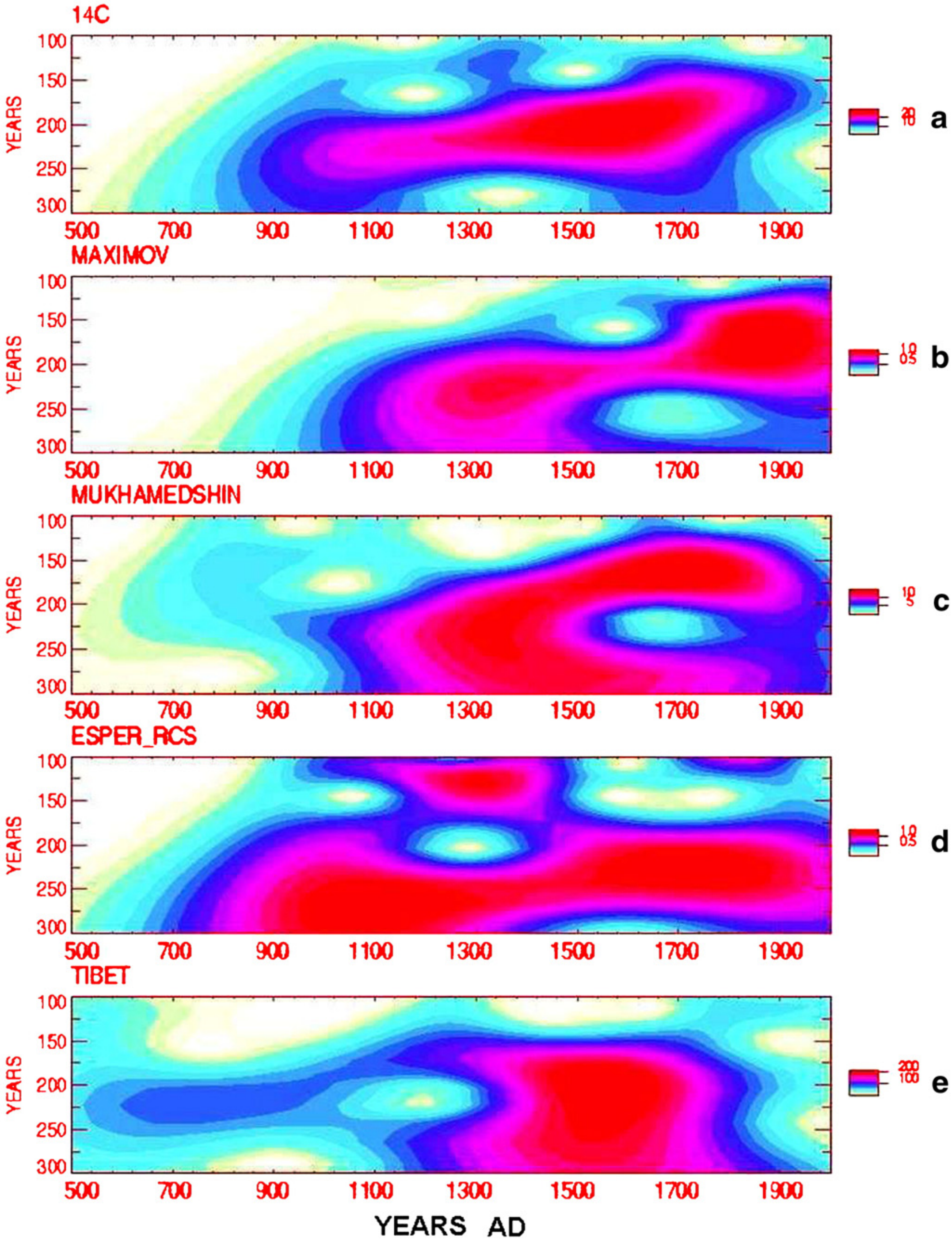

Fig. 4. Results of wavelet transformation (Morlet basis) of the data given in Fig. 2 in the range of periods 100–300 years: (from top to bottom) (a) variations in 10-year averages of $\Delta^{14}C$ (Stuiver et al., 1998); (b) variations in tree ring widths in the chronology of Maksimov and Grebenyuk; (c) variations in tree ring widths in the chronology of Mukhamedshin and Sarbaev; (d) the RCS chronology by Esper et al. (2003b), (e) the precipitation reconstruction record for the Tibetan Plateau by Shao et al. (2005).

spite of the diversity of the factors affecting precipitation formation in the atmosphere, the effect of the ~200-year solar activity variation on the climate on the Tibetan Plateau is very pronounced.

It is evident from the temperature proxy data presented (Figs. 2b–d and 4b–d) that all the chronologies related to the 200-year variations considered in this paper have a high coefficient of correlation with $\Delta^{14}C$ variations, i.e. from 0.58 to 0.94 (Table 1). The coefficient of correlation between the precipitation intensity proxy on the Tibetan Plateau (Figs. 2e and 4e) and the de Vries cycle is also high and equals 0.84 (Table 1). However, when the estimates of the phase shift between the $\Delta^{14}C$ variations and the chronologies are examined, attention is immediately focused on a large phase shift of 150 years for the temperature record of Maximov and Grebenyuk (Figs. 2b and 4b) and a phase shift of 100 years for the precipitation record from Tibet (Figs. 2e and 4e).

The phase shift between $\Delta^{14}C$ and climatic parameters could be caused by different factors. First, it could be due to the reservoir effect in production and incorporation of ^{14}C in terrestrial archives. According to Stuiver and Braziunas (1998), the delay between solar activity changes and corresponding response of the radiocarbon concentration in the 11-year solar cycle is about 2 years. This means that the time difference between the moment of solar activity variation and, hence, the moment of ^{14}C production and completion of the exchange cycle in the atmosphere–ocean system and sedimentation of ^{14}C in terrestrial archives can amount to several years. The phase shift between solar forcing and ^{14}C response increases with increasing solar cycle length, as shown by Dergachev and Stupneva (1975): the maximum correlation between changes in the solar activity and radiocarbon concentration for the solar activity periods of hundreds of years occurs at a phase shift of about 20 years. These factors could explain the phase shift seen in the summer temperature records of Mukhamedshin and Sarbaev (10 years) (Table 1). However, the phase shift caused by the reservoir effect in $\Delta^{14}C$ (20 years) is insufficient to explain the phase shift for the temperature record of Maksimov and Grebenyuk (150 years) and the precipitation record from Tibet (100 years) (Table 1).

Variations in ^{14}C production have been shown to induce larger phase shifts between $\Delta^{14}C$ and climate proxies. Stuiver (1980) reconstructed from the radiocarbon data ($\Delta^{14}C$) the atmospheric ^{14}C-production rate changes due to solar oscillatory modes such as the Maunder minimum and compared them with the climatic data inferred from measurements of the ^{18}O concentration in ice cores from the Camp Century and Devon Island stations. The maximum correlation coefficient was found to occur at a phase shift of 50–70 years between changes in the radiocarbon production rate and climatic data. These larger phase shifts are still however insufficient to explain those identified for the summer temperature record of Maksimov and Grebenyuk or the precipitation record from Tibet. This suggests that local climate conditions may be responsible for these longer phase shifts.

Consideration of the study site supports the argument for local climatic influence. The juniper trees described by Maksimov and Grebenyuk grew at 3500 m altitude in the immediate vicinity of the glacier, i.e. only 100 m lower from the glacier and at a distance of not more than 1 km from its edge. The trees used to reconstruct the temperature records of Mukhamedshin and Sarbaev and Esper et al. were collected at the heights ~500 m lower than the samples for Maksimov and Grebenyuk, i.e. at larger distances from the edges of glaciers. The proximity to a glacier could appreciably change the microclimatic conditions in general and also as a function of the glacier dynamics (advance and retreat), and thus increase the phase shift between the global solar signal and the climatic response at the particular site of the juniper growth.

Unfortunately, no studies of the response of the glacier dynamics in Tien Shan to the forcing of the 200-year solar cyclicity have been carried out. However, studies on a similar glacier have been carried out in Alaska (Wiles et al., 2004). Wiles et al. demonstrated glacial moraine formation in Alaska linked to the Maunder minimum (1640–1710 AD) and identified leads and lags of up to 150–160 years for the Beer and Ultramarine glaciers. Thus, the time differences in the completion of advances of glaciers located in one region and separated only by several tens or several hundreds of kilometers can amount to tens of years and reach 150–160 years. The data from Alaska suggest the large lag in the climatic signal behind the solar forcing in the summer temperature record of Maximov and Grebenyuk (150 years) could be a result of the close proximity of the trees to the glacier edge. The large lag seen in the precipitation record from the Tibetan Plateau relative to solar activity variations is attributable to specific features of atmospheric circulation in this region. However, this problem needs further investigation.

Since the revealed ~200-year climatic signal is likely associated with the global solar forcing, it can be expected that development of the ~200-year climatic periodicity can be detected in different regions of the Earth. The available palaeoclimatic data confirm the existence of this periodicity in Europe, North and South

America, Asia, Tasmania, Antarctica and Arctic, and sediments in the seas and oceans (Sonett and Suess, 1984; Peterson et al., 1991; Anderson, 1992, 1993; Cook et al., 1996; Zolitschka, 1996; Dean, 1997; Cini Castagnoli et al., 1998; Qin et al., 1999; Hong et al., 2000; Hodell et al., 2001; Nyberg et al., 2001; Yang et al., 2002; Fleitman et al., 2003; Haeberli and Holzhauser, 2003; Hu et al., 2003; Schimmelmann et al., 2003; Soon and Yaskell, 2003; Wiles et al., 2004; Wang et al., 2005).

Spatial non-uniformity in the temperature response to solar forcing has been modeled at a global scale by Waple et al. (2002). As can be seen from Fig. 5, the same solar irradiance variations lead to both positive and negative temperature responses in different regions. Moreover, there are border regions (e.g. the North Atlantic and the north of Scandinavia), where the response to long-term solar signal variations can be absent or change sign over time.

The Tien Shan and Tibetan Plateau are in areas predicted to show a pronounced positive response to solar forcing (Fig. 5). This agrees with the pronounced manifestation of the ~200-year climatic signal found in the tree ring data (Fig. 4b–e). The crosses on the map mark the regions where ~200-year climatic variations were observed in other proxy records.

Evidence for climatic and solar variations related to the de Vries cycle has been found to occur not only during the time intervals of the last millennia and the Holocene, but also during earlier epochs. A 192-year periodicity was revealed in the varves lacustrine sediments of Lake Lissan, Dead Sea Rift for the time interval 26.2–17.7 ka (Prasad et al., 2004). In Southern Chile, a 200-year periodicity was registered in variations of ring widths of subfossil 50,000-year old *Fitzroya cupressoides* (Roig et al., 2001). In addition, Wagner et al. (2001) demonstrated the presence of intense variations on time scales equivalent to the de Vries cycle in ^{10}Be concentrations associated with solar activity in Greenland ice for the time interval from 50,000 to 25,000 years ago.

Unique palaeoclimatic data pointing to the ~200-year variability were obtained by W. Dean (personal communication) in analysis of the sediments from the Upper Permian (250 million years) Castile Formation in the Delaware Basin in the west Texas and New Mexico, USA. Fig. 6 shows a smoothed (moving averaged) 800-year record of calcite–anhydrite varve thickness in Halite I Member of Permian Castle Formation, measured in the core from Winkler County, Texas, USA. In the opinion of the authors the ~200-year variations clearly

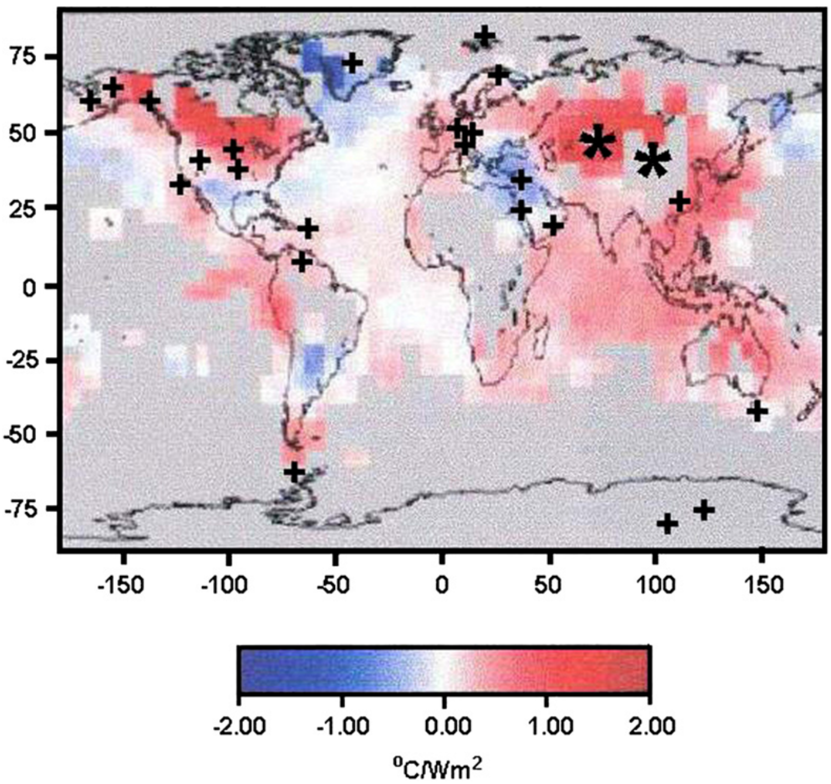

Fig. 5. The map demonstrating results of simulation of the temperature response of the atmosphere-ocean system to the effect of long-term (>40 year) variations in solar irradiance (modified from Waple et al., 2002). The asterisks show the location of the regions in Central Asia the palaeoclimatic data for which are analyzed in this paper. The crosses mark the sites where quasi-200-hundred-year climatic variations were revealed.

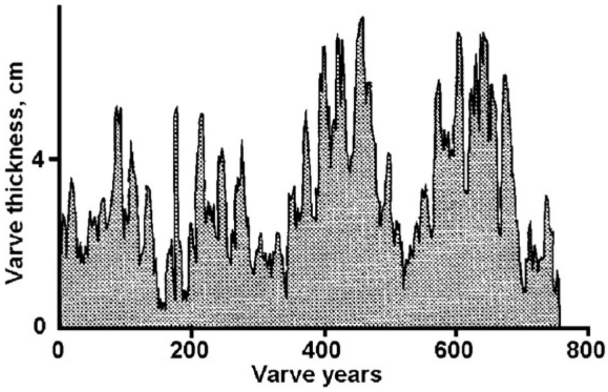

Fig. 6. Smoothed (moving averaged) 800-year record of calcite–anhydrite varve thickness in the Permian Castle Formation (250 Ma) measured in the core from Winkler County, Texas, USA (unpublished, with permission by W.E. Dean).

seen in the graph are associated with solar forcing. Therefore, it is likely that 250 million years ago the de Vries cycle was also one of the most intense solar activity periodicities that affected climatic processes.

5. Conclusions

Analysis of long-term dendrochronological data for two Central Asia mountain regions (the Tien Shan and Qinghai-Tibetan Plateau) obtained by four independent research teams has demonstrated the presence of ~200-year climatic variations. These variations show a high correlation ($R=0.58$–0.94) with a similar solar periodicity (de Vries period) inferred from the radiocarbon concentration that is modulated by temporal variations in solar activity.

Review of published palaeoclimatic data shows that the ~200-year climatic variations are evident in the oceans and different regions of the Earth (Europe, North and South America, Asia, etc.). Analysis of the results obtained in simulation of the effect of long-term variations in solar irradiance has shown that, because of an essentially nonlinear character of the processes in the atmosphere–ocean system, the climate response to external long-term solar forcing, including the 200-year variation, differs in different regions of the Earth and can manifest itself in various climatic parameters.

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