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Decadal-scale variability of warm season temperature in Beijing over the past 2650 years

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A continuous record of surface temperature for the past 2650 years was obtained in an earlier study from a Beijing stalagmite based on sedimentary layer counting and thickness measurements. Singular spectrum analysis, multi-taper and wavelet spectral analyses are used in this study to identify decadal-scale signals and their origins in this record. Besides long-term cycles of solar origin identified in earlier studies, this record contains cycles that dominate temperature with periods of 102–70, 66–50, 31, 25–22, 19, 15, 12 and 9 years. The 102–70, 25–22, 12 and 9 year cycles are attributable to solar variation, while the others are likely to be related to low-latitude ocean forcing. These results suggest that century-scale changes in the Beijing summer temperature over the past 2650 years are primarily controlled by solar variation, while ocean-atmospheric interactions play a prominent role in modulating decadal-scale variability.

stalagmite, singular spectrum analysis (SSA), decadal climate cycles, warm season temperature

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Although humankind are thought to have played an important role in the increase in the global surface temperature over the past century, understanding natural climate variability in the past few millennia is critical for evaluating future climate scenarios [1]. Towards this end, climate records with annual resolution and accurate chronology are of particular value to explore climate signals on the century to decadal time scales.

Using instrumental temperature records and Northern Hemisphere temperature proxies to form an age model, variations in the numbers and thickness of annual layers in a stalagmite near Beijing have been shown to have continuously documented the variability of surface temperature of the Beijing warm season for the past 2650 years [2] (Figure 1(a)).

Some of the century-scale cycles in this record have already been reported [2]. Mostly attributed to solar changes, they are likely to be correlated with the North Atlantic ice-rafting cycles, suggesting a solar-coupled connection between the East Asia and North Atlantic climates [3]. The shorter term oscillatory signals in this stalagmite have already been discussed [4,5]. However, because the time span of the record has now been extended, and the thickness dataset calibrated (by removing the non-climatic sedimentary trends), a new analysis is necessary [2].

The aim of this work is to analyze the century to decadal signals in this temperature record using singular spectrum analysis (SSA) and multi-taper (MTA) and wavelet spectral (WSA) analyses. Analysis of the decadal variability is emphasized. The potential origins of these signals, which help our understanding of the factors driving summer temperature in the mid-latitude continents, are also discussed.

1 Data and methods

The 2650 year temperature record analyzed in this study

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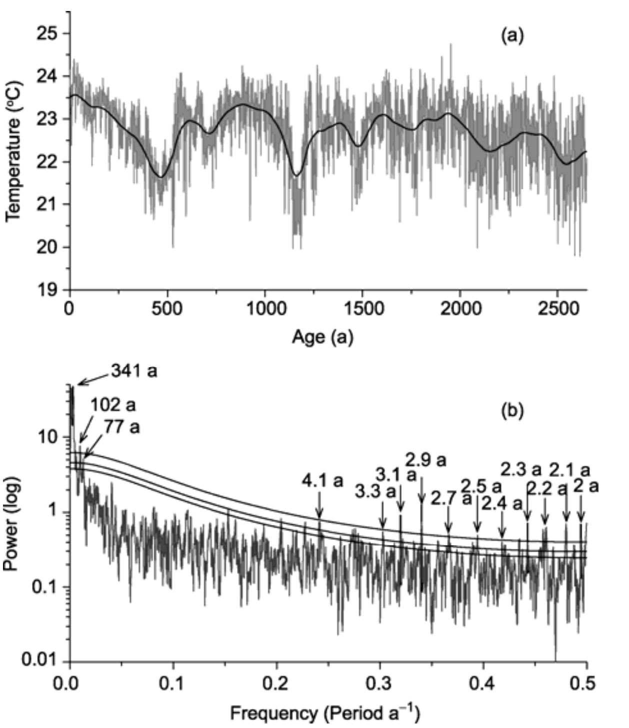

Figure 1 Stalagmite record of warm-season temperatures for the past 2650 years in Beijing with spectral features added. (a) Original warm-season temperature reconstruction (gray line) [2] with the thick line representing non-linear and low frequency trends (the first principle component, PC1). The top of the record corresponds to 1985 AD. (b) Multi-taper spectrum of the warm-season temperature time-series. The three horizontal lines indicate the 99%, 95% and 90% confidence limits, respectively.

was reconstructed from a stalagmite in the Shihua Cave (39°47′N, 115°56′E) near Beijing [2] (Figure 1(a)). The site is located within the East Asian monsoon zone, and the top of the time series corresponds to 1985 AD. Annual layer thicknesses of the stalagmite show a high consistency with the instrumental record of warm season temperature (May, June, July and August in Beijing) [2]. The reconstructed time series is also in good agreement with the other temperature proxies from the Northern Hemisphere, confirming the climate significance. The dataset is available at http://www.ncdc.noaa.gov/paleo/datalist.html.

SSA is a nonparametric method that allows non-linear trend filtering, to decompose climate signals by overcoming the problems of finite sample length and noise. It does not do this by fitting an assumed model; rather, it uses a data adaptive base set [6]. It also allows the reconstruction of main climate signals. The method is particularly efficient when combined with other techniques and has been widely used in paleoclimatic studies [7–10]. In this study, MTA [11–13] and WSA [14] are used to explore the spectral features of the relevant SSA components.

2 Results and discussion

Figure 1(b) shows an MTA spectral analysis on the temperature record [2]. There are clear century-scale frequencies at 341 and 102–70 years. Several peaks on the annual-scale are also detected, all of them are over the 95% confidence level. There are clear decadal-scale signals in the original data, but they are mostly below the 95% confidence level, (Figure 1(b)).

Using SSA to remove the influences of noise, non-linear and low frequency trends, the time series was decomposed with a window-length of 80 (M=80), the Burg covariance estimation [13], and Heuristic significant tests [6]. The 80 principle components (PCs) so obtained are plotted as the rank of their relative powers in Figure 2(a). It is clear that the first 10 PCs (PC1-10) contain most of the signals and account for approximately 60% of the total variance. The Kendall test for trends at 95% significance suggests that the first principle component (PC1) contains non-linear and low frequency trends (Figure 1(a)). A reconstruction using PC(1-10) and the PC(2-10) are shown in Figure 2(b) and (c), alongside the original data.

WSA on PC1 shows a strong period centered at a frequency of 340 years (Figure 3(a)). A period between 600 and 800 years is also clear. Thus, mainly century-scale cycles are contained in PC1 representing approximately 36% of the total variance. Their presence is relatively consistent over the past 2650 years.

WSA on PC2 (Figure 3(b)) and a reconstruction using PC(2-10) (Figure 3(c)) show clear signals at a frequency of 11 years. Strong decadal signals are observed within the

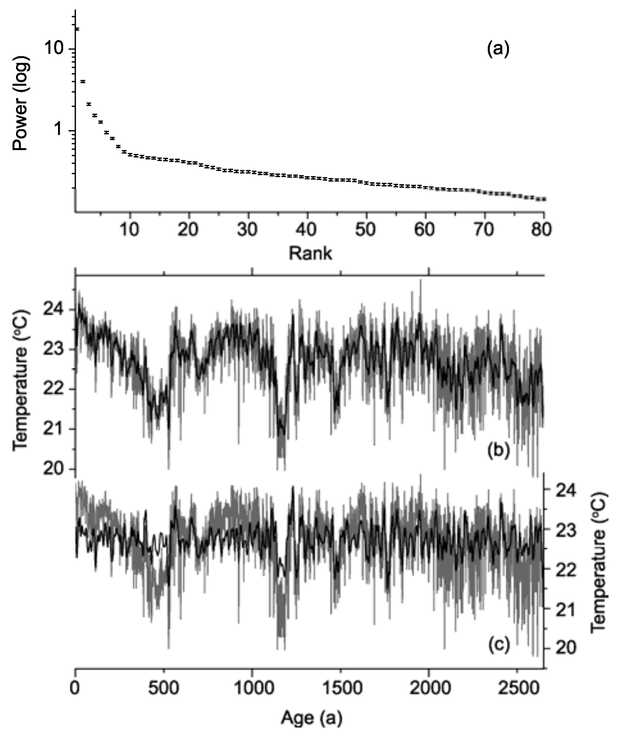

Figure 2 SSA decomposition and reconstructions of the time series. (a) Ranks of powers for the 80 SSA PCs; (b) reconstruction of PCs PC(1–10) (thick line) versus the original data (gray line); (c) reconstruction of PC(2–10) (thick line) versus the original data (gray line).

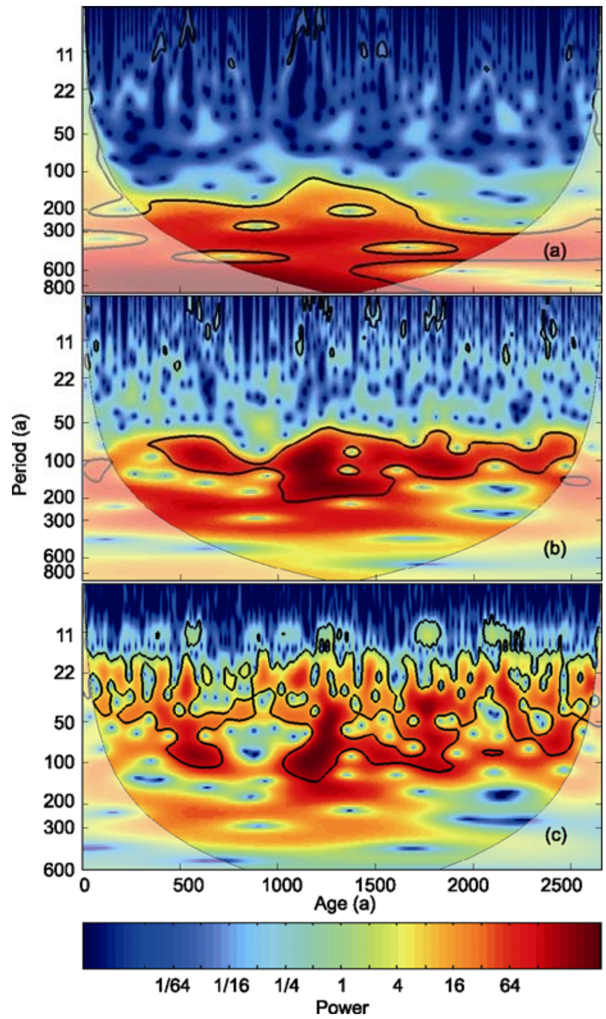

Figure 3 Continuous wavelet analysis [14] of (a) PC1, PC2 (b) and the reconstruction using PC(2–10) (c). The thick black contour designates the 5% significance level against red noise and the cone of influence (COI) where edge effects might distort the picture is shown as a lighter shade.

frequency band between 100 and 15 years. With the exception of the clear signals ranging between 100 and 70 years, discrimination of other cycles is difficult (Figure 3(c)). This indicates the presence of several quasi-oscillatory components that intervene at the decadal-scale.

For a detailed examination of these decadal-scale signals, MTA analyses were performed on a reconstruction using PC (2–10). Explicit peaks at frequencies of 15, 12 and 9 years were resolved (Figure 4), as well as a series of peaks ranging between 100 and 17 years (all over the 99% confidence level). Apart from the peaks ranging between the 100 and 75 year bands, and a peak at 25 years, other individual peaks were hard to distinguish. However, an *F*-test [15] at 95% significance on the harmonic peaks with respect to the background noise reveals several more prominent frequencies shown by the reshaped peaks in the MTA spectrum (Figure 4). They are located between 66 and 50 years, around 31 years, and between 20 and 17 years.

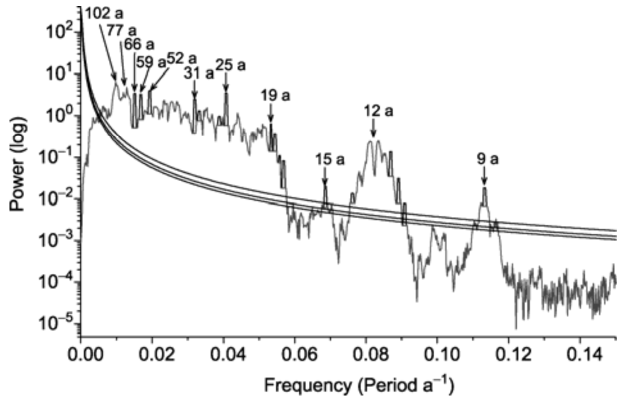

Figure 4 MTA spectrum of the SSA reconstruction using PC (2–10). The three horizontal lines from the top to the bottom indicate the 99%, 95% and 90% confidence limits, respectively.

Examination of individual PCs using WSA reveal a strong quasi-period of 100–70 years in PC2, (Figure 3(b)), a quasi-period of 65–50 years in PC3 and PC4, 30 years in PC5, 25-years in both PC6 and PC7, 22 years in PC8 and PC9, and a cycle of 11 years in PC10. A clear signal centered at a frequency of 9 years is also present in PCs 7–9. Most of these quasi-cycles are present near-continuously over the past 2650 years.

In summary, there are two main century scale periods, one at 600–800 years and, another at 340 years. These long-term periods were previously identified by simple power spectral analysis [2] and were caused by solar variations [16]. Their constant presence over the past 2650 years (Figure 3) indicates that the long-term temperature changes in Beijing have been predominantly driven by solar variations.

Temperature signals at the decadal-scale are mainly contained within PCs 2–10, and account for 25% of the total variance. Clear periods of 100–70, 66–50, 31, 25–22, 19, 15, 12 and 9 years were detected (Figures 3 and 4). The cycle at 100–70 years mainly resides in PC2, which accounts for 8.2% of the total variance. This is probably attributable to the *Gleissberg cycle* of solar variations, frequency ranging between 100 and 70 years [17–20], centered about 88 years. The 25–22, 12 and 9 year cycles are also associated with solar cycles [21,22]. These indicate that solar variation was also one of the drivers for the decadal-scale variability of warm season temperature in Beijing over the past 2650 years.

However, the cycles at 65–50, 31 and 15 years do not seem to be directly associated with solar changes. The signals at 65–50 years were reported from the records of the Pacific Decadal Oscillation (PDO) [23–26], while periods at 30–35 years were observed for the ENSO oscillation and typhoon cycle [27–31]. The cycle at 15 years has not been reported frequently, but was identified in typhoon records [29], suggesting again a tropical oceanic origin.

We do not attempt to analyze the physical processes linking these low-latitude ocean signals with the temperature changes in the monsoon region. However, the presence of such climate signals in the Beijing temperature record clearly indicates the impacts of ocean-atmosphere interactions in modulating the decadal variability of summer temperature in the mid-latitudes. This interpretation is supported by modern observations [32–36], consistently showing the influences of tropical SST on the East Asian monsoon climate.

Our results show the clear impacts of both solar variations and ocean-atmosphere interactions on the warm season temperature changes in Beijing over the past 2650 years. Because both solar and ocean changes are not strictly oscillatory, but quasi-oscillatory [37], the integration of these two kinds of signal over time leads to a complex picture of decadal scale the temperature changes.

3 Conclusions

Based on SSA, MTA and WSA techniques, we have analyzed the 2650-year stalagmite record of the warm season temperature in Beijing. The results show clear quasi-cycles of 600–800 years and 340 years. These signals are mostly attributable to solar variation, and hence, suggest that century-scale changes in the warm season temperature in Beijing are primarily linked to solar activities.

At the decadal-scale, clear quasi-periods at the 100–70, 65–50, 31, 25–22, 15, 12 and ~9-year frequencies were found. Some of these signals are clearly linked with the solar forcing while the others are related to the tropical oceans. These indicate that, besides the obvious solar impacts, ocean-atmosphere interactions have played an important role in driving the decadal scale temperature changes in Beijing over the past 2650 years. The integration of these two kinds of signals over time led to a complex picture of decadal-scale temperature changes.

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1 IPCC. Climate Change 2007: The Physical Science Basis. Cambridge: Cambridge University Press, 2007. 1008
2 Tan M, Liu T S, Hou J Z, et al. Cyclic rapid warming on centennial-scale revealed by a 2650-year stalagmite record of warm season temperature. Geophys Res Lett, 2003, 30: 1617–1620
3 Tan M, Hou J Z, Liu T S. Sun-coupled climate connection between eastern Asia and northern Atlantic. Geophys Res Lett, 2004, 31, doi:10.1029/2003GL019085
4 Qin X G, Tan M, Liu T S, et al. Spectral analysis of a 1000-year stalagmite lamina-thickness record from Shihua Cavern, Beijing, China, and its climatic significance. Holocene, 1999, 9: 689–694
5 Qin X G, Tan M, Liu D S, et al. Characteristics of annual laminae gray level variations in a stalagmite from Shihua Cave, Beijing and its climatic significance (II). Sci China Ser D-Earth Sci, 2000, 43: 521–533
6 Vautard R, Ghil M. Singular spectrum analysis in nonlinear dynamics, with applications to paleoclimatic time-Series. Physica D, 1989, 35: 395–424
7 Schlesinger M E, Ramankutty N. An oscillation in the global climate system of period 65–70 years. Nature, 1994, 367: 723–726
8 Plaut G, Ghil M, Vautard R. Interannual and interdecadal variability in 335 years of central England temperatures. Science, 1995, 268: 710–713
9 Huang L, Shao X, Liang E, et al. Characteristics of millennial treering width variations of Qilian juniper in Shalike Mountain, Qinghai (in Chinese). Geogr Res, 2004, 23: 365–373
10 Shanahan T M, Overpeck J T, Anchukaitis K J, et al. Atlantic forcing of persistent drought in west Africa. Science, 2009, 324: 377–380
11 Thomson D J. Spectrum estimation and harmonic-analysis. P Ieee, 1982, 70: 1055–1096
12 Percival D B, Walden A T. Spectral Analysis for Physical Applications: Multitaper and Conventional Univeriate Techniques. Cambridge: Cambridge University Press, 1993. 580
13 Penland C, Ghil M, Weickmann K M. Adaptive filtering and maximum entropy spectra with application to changes in atmospheric angular momentum. J Geophys Res, 1991, 96: 22659–22671
14 Grinsted A, Moore J, Jevrejeva S. Application of the cross wavelet transform and wavelet coherence to geophysical time series. Nonlinear Proc Geoph, 2004, 11: 561–566
15 Lomax R. Statistical Concepts: A Second Course. 3rd ed. Mahwah: Lawrence Erlbaum Associates, 2007. 10
16 Lean J, Wang Y, Sheeley Jr N. The effect of increasing solar activity on the Sun's total and open magnetic flux during multiple cycles: Implications for solar forcing of climate. Geophys Res Lett, 2002, 29, doi: 10.1029/2002GL015880
17 Gilliland R L. Solar, volcanic, and CO_2 forcing of recent climatic changes. Clim Change, 1982, 4: 111–131
18 Sonett C, Finney S, Berger A. The spectrum of radiocarbon [and discussion]. Philos T R Soc A, 1990, 330: 413–426
19 Braun H, Christl M, Rahmstorf S, et al. Possible solar origin of the 1470-year glacial climate cycle demonstrated in a coupled model. Nature, 2005, 438: 208–211
20 Berner K S, Koç N, Godtliebsen F. High frequency climate variability of the Norwegian Atlantic Current during the early Holocene period and a possible connection to the Gleissberg cycle. Holocene, 2010, 20: 245–255
21 Friis-Christensen E, Lassen K. Length of the solar cycle: An indicator of solar activity closely associated with climate. Science, 1991, 254: 698–700
22 Labitzke K, Loon H, Shine K. Associations between the 11-Year solar cycle, the quasi-biennial oscillation and the atmosphere: A summary of recent work (and discussion). Philos T R Soc A, 1990, 330: 577–589
23 Mantua N, Hare S. The Pacific decadal oscillation. J Oceanogr, 2002, 58: 35–44
24 Mantua N, Hare S, Zhang Y, et al. A Pacific interdecadal climate oscillation with impacts on salmon production. Am Meteorol Soc, 1997, 78: 1069–1079
25 Newman M, Compo G, Alexander M. ENSO-forced variability of the Pacific decadal oscillation. J Clim, 2003, 16: 3853–3857
26 Biondi F, Gershunov A, Cayan D. North Pacific decadal climate variability since 1661. J Clim, 2001, 14: 5–10
27 Allan R. ENSO and climate variability in the past 150 years. In: Diaz H, Markgraf V, eds. El Niño and the Southern Oscillation. Cambridge: Cambridge University Press, 2000. 3–56
28 Shieh S, Wang S. A stastical analysis of typhoons affecting Taiwan in1897–1996. In: Chang C, Wu G, Jou B, et al., eds. East Asia and Western Pacific Meteorology and Climate. Singapore: World Scientific Publishing Company, 2002. 211–218
29 Yue Q, Dong X, Ma K, et al. Climatic characteristics of northwestern Pacific typhoon activity and Chinese coastal landfall typhoon rain and gale (in Chinese). J Nanjing Univ, 2000, 36: 741–749
30 Yu K F, Zhao J X, Qin S, et al. Reconstruction of storm/tsunami records over the last 4000 years using transported coral blocks and lagoon sediments in the southern South China Sea. Quat Int, 2009, 195: 128–137

31 Chan J, Shi J. Frequency of typhoon landfall over Guangdong Province of China during the period 1470–1931. Int J Climatol, 2000, 20: 183–190
32 Charles C, Hunter D, Fairbanks R. Interaction between the ENSO and the Asian monsoon in a coral record of tropical climate. Science, 1997, 277: 925–928
33 Shen S, Lau K. Biennial oscillation associated with the East Asian summer monsoon and tropical sea surface temperatures. J Meteorol Soc Jpn, 1995, 73: 105–124
34 Wu R, Wang B. A contrast of the East Asian summer monsoon-ENSO relationship between 1962–1977 and 1978–1993. J Clim, 2002, 15: 3266–3279
35 Chang C, Zhang Y, Li T. Interannual and interdecadal variations of the East Asian summer monsoon and tropical Pacific SSTs. Part I: Roles of the subtropical ridge. J Clim, 2000, 13: 4310–4325
36 Huang R, Sun F. Impacts of the tropical western Pacific on the East Asian summer monsoon. J Meteorol Soc Jpn, 1992, 70: 243–256
37 Delworth T L, Greatbatch R J. Multidecadal thermohaline circulation ariability driven by atmospheric surface flux forcing. J Clim, 2000, 13: 1481–1495