Meteorol Atmos Phys 95, 115–121 (2007)
DOI 10.1007/s00703-006-0199-2
Printed in The Netherlands

Meteorology and Atmospheric Physics

The School of Geographic Sciences, Nanjing Normal University, Nanjing, P. R. China

Multi-scale analysis of global temperature changes and trend of a drop in temperature in the next 20 years

Lin Zhen-Shan and **Sun Xian**

With 6 Figures

Received May 2, 2005; revised October 24, 2005; accepted April 6, 2006
Published online: July 31, 2006

Summary

A novel multi-timescale analysis method, Empirical Mode Decomposition (EMD), is used to diagnose the variation of the annual mean temperature data of the global, Northern Hemisphere (NH) and China from 1881 to 2002. The results show that: (1) Temperature can be completely decomposed into four timescales quasi-periodic oscillations including an ENSO-like mode, a 6–8-year signal, a 20-year signal and a 60-year signal, as well as a trend. With each contributing ration of the quasi-periodicity discussed, the trend and the 60-year timescale oscillation of temperature variation are the most prominent. (2) It has been noticed that whether on century-scale or 60-year scales, the global temperature tends to descend in the coming 20 years. (3) On quasi 60-year timescale, temperature abrupt changes in China precede those in the global and NH, which provides a denotation for global climate changes. Signs also show a drop in temperature in China on century scale in the next 20 years. (4) The dominant contribution of CO_2 concentration to global temperature variation is the trend. However, its influence weight on global temperature variation accounts for no more than 40.19%, smaller than those of the natural climate changes on the rest four timescales. Despite the increasing trend in atmospheric CO_2 concentration, the patterns of 20-year and 60-year oscillation of global temperature are all in falling. Therefore, if CO_2 concentration remains constant at present, the CO_2 greenhouse effect will be deficient in counterchecking the natural cooling of global climate in the following 20 years. Even though the CO_2 greenhouse effect on global climate change is unsuspicious, it could have been excessively exaggerated. It is high time to re-consider the trend of global climate changes.

1. Introduction

On interdecadal timescales, whether the global temperature will continue to warm up or to drop in the coming 20 years is not only a hot spot but also a daunting task in global climate change research as shown in many studies (Stott and Ketteborough, 2002; Schneider and Held, 2001; Michael and Jeffrey, 1995).

In recent decades, scientists have paid more attention to the CO_2 greenhouse effects on global climate changes. Some modeling studies (Caldeira and Duffy, 2000; Sarmiento et al, 1998; Manabe and Stouffer, 1993) indicated a relatively significant Southern Ocean sink due to anthropogenic CO_2. Many researches (Houghton et al, 2001; Joos et al, 1999; Sarmiento and Quere, 1996; Manabe and Stouffer, 1994) argued that when CO_2 doubled in the atmosphere, the global mean temperature would increase by about 1.4 to 5.8 °C. That means the global mean temperature will rise as a result of the increase of CO_2 in the atmosphere. But Petit et al (1999) and Stauffer et al (1998) thought that the increasing greenhouse effects would only partly induce the global to warm up as a natural variation process. And the past records have indicated that the increase of CO_2 concentration did not occur before the warming up as shown by some studies

(Fischer et al, 1999; Schlesinger and Ramankutty, 1994). Since it is now obvious that the CO_2 content in the atmosphere does not decrease, will the global temperature go on warming up in the following decades like that in the 20th century? Global climate change is affected not only by anthropogenic activities (the increase of CO_2 concentration in the atmosphere), but also through natural factors in climatic system (driving forces) such as solar activities. The natural driving forces and combined forces generally display multi-timescale oscillations. Thereby, to answer this question, it is primary to ravel whether the climatic period (quasi-period) variation on different timescales or the natural variation trend is affected by the variety of CO_2 concentration in the atmosphere, or which climatic quasi period is most affected by the increase of CO_2 concentration in the atmosphere.

Fourier analysis is used as a general tool for examining time series. Although it is valid under general conditions, there are some crucial restrictions of Fourier analysis, i.e., the system must be linear and the data must be periodic or stationary. However, climate dataset is both nonlinear and non-stationary with multi-timescale oscillations. By applying the traditional time-series techniques based on Fourier Transforms, one can get a time-frequency distribution through sliding the window successively along the time axis. Meanwhile, it has to assume the data to be strictly stationary. Furthermore, the window width must be narrow, and the frequency resolution requires longer time series. The wavelet approach is essentially an adjustable window Fourier spectral analysis, and it is of non-adaptive nature. Once the basic wavelet is selected, one will have to use it to analyze all the data. SSA is the Fourier transform of the empirical orthogonal function (EOF), so we have to ensure that each EOF component is stationary. Otherwise, the Fourier spectral analysis will make little sense as for the EOF components. Unfortunately, we cannot guarantee that EOF components derived from a nonlinear and non-stationary dataset are both linear and stationary. Hereby, in order to overcome the difficulty of studying nonlinear and non-stationary time series, a method called the Empirical Mode Decomposition (EMD) was developed in 1998 by Huang et al (1998; 1999) to facilitate the decomposition of climate records in terms of natural oscillatory patterns and trends.

We try to use this method to analyze the maximum weight of CO_2 greenhouse effect on global temperature variation on multi-scales. Based on it, it is possible for us to forecast whether global climate will continue to warm up or to cool down in the next 20 years.

2. EMD method and data

The EMD method is suitable for nonlinear and non-stationary time series. This method naturally decomposes nonlinear oscillatory patterns into a number of characteristic intrinsic mode function (IMF) components. The decomposition is based on the direct extraction of the energy associated with various intrinsic time scales, the most important parameters of the system.

The EMD method can simply use the envelope calculations defined by the local maxima and minima separately. Once the extrema are identified, all the local maxima and minima are connected by a cubic spline interpolation line as the upper and lower envelopes. Their mean is designated as m_1, and the difference between the data and m_1 is the first component, h_1, i.e.,

$$h_1 = x(t) - m_1. \tag{1}$$

However, h_1 is still not a stationary oscillatory pattern, by repeating the above process, with h_1 replace by $x(t)$, m_2 is the mean envelope of h_1,

$$h_2 = h_1 - m_2. \tag{2}$$

By repeating the above process time after time, once the mean of the envelope is close enough to zero, or the sifting process can be stopped by a criterion: standard deviation, SD, a typical value for SD can be set between 0.2–0.3 or less than it, the first IMF results.

$$\mathrm{SD} = \sum_{t=0}^{T} \left[\frac{|(h_{i-1}(t) - h_i(t))|^2}{h_{i-1}^2(t)} \right]. \tag{3}$$

c_1 is the first IMF component from the data. We can substract c_1 from the original timeseries by

$$r_1 = x(t) - c_1. \tag{4}$$

r_1, still containing information of longer period components, is treated as the new data and subjected to the same sifting process as described above. This process can be repeated on all r_i and the result is:

$$r_1 = x(t) - c_1, r_2 = r_1 - c_2, \ldots, r_n = r_{n-1} - c_n, \tag{5}$$

i.e.,

$$x(t) = \sum_{i=1}^{n} c_i + r_n. \tag{6}$$

Thus, we achieve a decomposition of the data into IMFs and a residue, r_n, which can be either the mean trend or a constant.

Although a powerful method, EMD must be used cautiously. One difficulty encountered is the influence of the end points. The envelopes are calculated by a cubic spline, which, however, is notoriously sensitive to end points. It is important to make sure that the end effects do not propagate into the interior solution. Here, this problem is dealt with by extrema extending method as shown in Hao and Huang's study (2001).

The results presented in this paper are based on a 122a (1881–2002) global and NH annual mean temperature dataset provided by Jones (2003; 1999; 1994). Hemispheric and global temperature anomaly time series, which incorporate land and marine data, are continually updated and expanded by P. Jones of the Climatic Research Unit (CRU) with help from colleagues at the CRU and other institutions. The grid-box resolution of the temperature anomalies is $5° \times 5°$. They have areal averaged grid-box temperature anomalies, with weighting according to the area of each $5° \times 5°$ grid box, into hemispheric values; then averaged these two values to create the global-average anomaly. And as well as the same epoch air temperature dataset in China provided by Wang et al (1998) and expanded to 2002. An annual mean temperature series were constructed for ten regions of China: Northeast, North, East, South, Taiwan, South central, Southwest, Northwest, Xinjiang and Tibet on the basis of temperature observations, documentary data, ice core data and tree-ring data. A series of temperature in China was obtained by averaging of the ten regional series in considering area size of the region.

The CO_2 records presented here is provided by the Carbon Dioxide Information Analysis Center, a compendium of data on global changes, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tennessee, from their Web site at http://www.cdiac.esd.ornl.gov/trends/co2/contents.htm. The CO_2 data from 1881 to 1965 are derived from three ice cores obtained at Law Dome, East Antarctica from 1987 to 1993 (Etheridge et al, 1988, 1996; Morgan et al, 1997). Concentrations of carbon dioxide measured in the air bubbles trapped in the ice are shown in Antarctic ice core from Law Dome near Australia's Casey Station. The CO_2 data from 1966 to 2002 are measured by the South Pole site to be considered indicative of uncontaminated background air.

3. Multi-scale analysis of global and NH temperature variation

Figures 1 and 2 show that the global and NH mean temperature is completely decomposed into four modes (IMF) and a trend (Res) by EMD method. It indicates that both the global and the NH temperature variation contain four quasi-period oscillations on various timescales and a trend of larger timescale in the last century.

Each IMF component denotes the variation on different timescales. There are cases when a phenomenon on certain scale is intermittent,

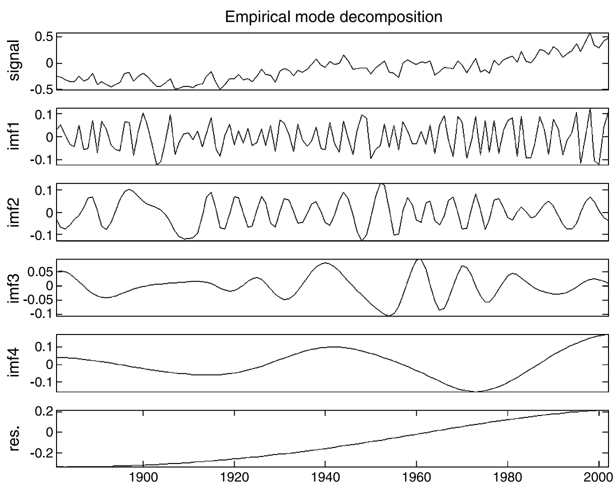

Fig. 1. The global mean temperature is decomposed into four intrinsic mode functions (IMF) and a trend by EMD method. The first IMF is 3–4-year period. The second IMF has 6–8-year period. The third IMF corresponds to 20-year period. The fourth IMF contains 60-year cycles. The Res indicates larger timescale oscillation

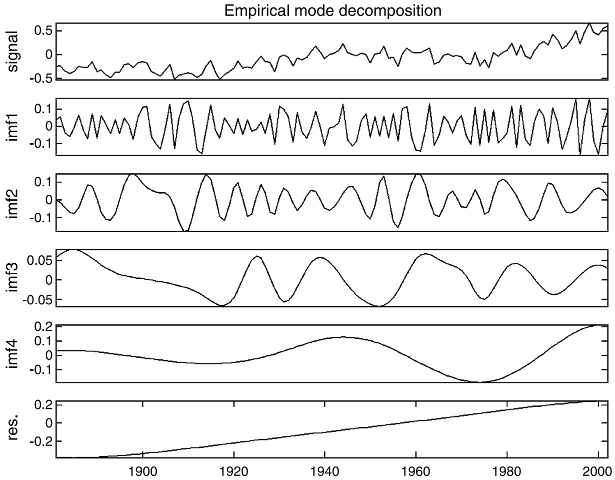

Fig. 2. The northern hemisphere mean temperature is decomposed into four intrinsic mode functions (IMF) and a trend by EMD method. The first IMF has 3–4-year period. The second IMF has 6–8-year period. The third IMF corresponds to 20-year period. The fourth IMF contains 60-year cycles. The Res indicates larger timescale oscillation

IMF component will have pattern confusion, but signals on the same timescale would never occur at the same location in two different IMF components (Huang et al, 1998, 1999). The first IMF has 3–4-year period. The second IMF has 6–8-year period. The third IMF corresponds to 20-year period. The fourth IMF contains 60-year cycles. And the Res indicates a larger-term trend. These IMF components contain not only periodic variation of exterior forces, but also nonlinear feedback effect in climatic system.

The data adopted here are annual mean temperature, while the biennial cycle and other smaller scale are omitted. Nevertheless, quasi-periods of 3–4-year, 6–8-year and 18–22-year emerge prominently. Though they do not contain the quasi-11a period relative to sun radiation, IMF2 component of the global and NH temperature presents a quasi 11-year oscillation before 1900 and after 1980. The quasi 60-year oscillation is consistent with an earlier study (Schlesinger and Ramankutty, 1994).

Table 1. Variance explained by IMF1–IMF4 and Res components of the NH, global and China mean temperature (%)

	IMF1	IMF2	IMF3	IMF4	Res
NH	10.58	8.90	2.50	15.31	62.71
Global	17.55	11.34	6.77	24.15	40.19
China	19.85	11.09	8.59	28.50	31.97

By calculating the variance explained of IMF1–IMF4 and Res components (Table 1), we find that the variance contribution of the trend in the global is the largest (40.19%), followed by the quasi 60-year low-frequency oscillation IMF4 (24.15%). As for temperature in NH, the variance contribution of the trend is the most significant (62.71%), followed by the quasi 60-year low frequency oscillation IMF4 (15.31%).

In Figs. 1 and 2, IMF3 with quasi 20-year periodicity oscillation and IMF4 with quasi 60-year periodicity oscillation in global and NH temperature have been decreasing since the year 2000. Hence, we consider that global temperature will witness a drop on 20–60-year timescales in the following 20 years.

To have a profound understanding of the future global temperature variation, the Res and IMF4 of global and NH temperature, whose variance explained amount to 64.34 and 78.02%, respectively, are used to reconstruct mean temperature on century scale (Fig. 3).

From Fig. 3, we see clearly that global and NH temperature will drop on century scale in the next 20 years.

Now that the trend of global and NH temperature has arrived at the peak and their IMF4 have been cooling since this century, we tend to conclude that global temperature shows a falling tendency on 20–60-year timescales in the next 20 years.

It is now apparent that CO_2 content in the atmosphere will not decrease in the next 20–60 years. And global climate change is affected not

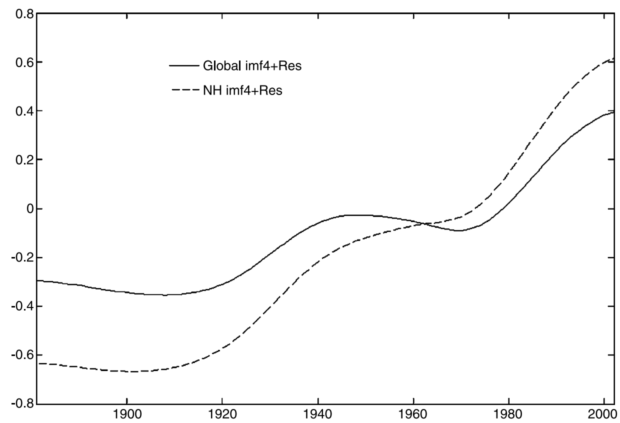

Fig. 3. Reconstructed mode by using IMF4 (60-year timescale) and Res (century timescale) components for mean temperature in global (real line) and NH (dashed) from 1881 to 2002

only through increasing CO_2 concentration in the atmosphere, but also via climatic driving forces. Thereby, to diagnose the trend of global climate changes accurately, it is primary to understand how much is the influenced weight of the CO_2 greenhouse effects on the global temperature variation.

4. Multi-scales analysis of atmospheric CO_2 concentration variation in the last century

Now we will answer the two important questions put forward above: how much is the influencing weight of CO_2 greenhouse effect in the atmosphere that leads to global temperature variation? Whether the climate periodical (quasi-period) variation on various timescales or the natural variation trend is affected by the variation of CO_2 concentration in the atmosphere?

In Fig. 4, the time series of CO_2 concentration in the atmosphere from 1881 to 2002 is separated into two modes and a trend that indicates an increase over time by EMD method.

In Table 2, the variance explained of the trend of CO_2 is 99.52%. And the variance explained

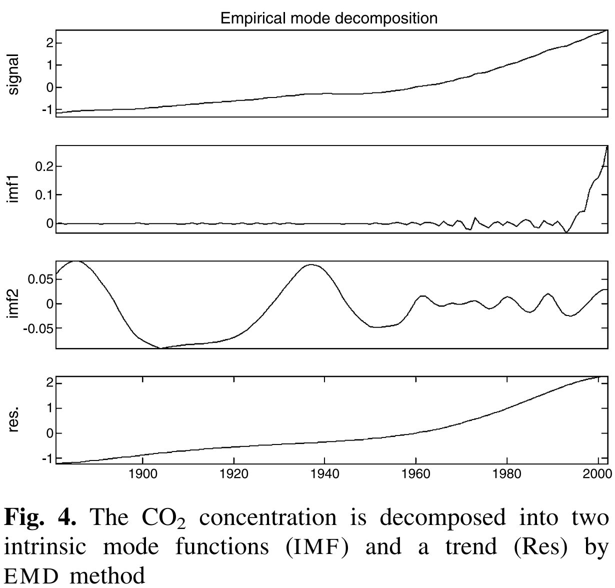

Fig. 4. The CO_2 concentration is decomposed into two intrinsic mode functions (IMF) and a trend (Res) by EMD method

Table 2. Variance explained by IMF1–IMF2 and Res components of concentration of CO_2 (%)

	IMF1	IMF2	Res
CO_2 concentrate	0.26	0.22	99.52

of IMF1 and IMF2 are 0.26% and 0.22%, respectively. We have calculated the correlation coefficients between IMFs of CO_2 and the IMFs of the global, and found that they are very small. The IMFs components of CO_2 are all dissimilar to IMFs of the global temperature. Since their variance explained only account for a mere 0.48%, we presume the IMFs of CO_2 are just some noise. Therefore, the greenhouse effect of CO_2 in the atmosphere on global temperature variation is mainly the century scale trend. And CO_2 concentration in the atmosphere has little effect on periodical variation on the rest of the timescale.

Here we stress two points: (1) the variance explained of the trend of global temperature is only 40.19%, while that of the trend of CO_2 concentration in the atmosphere tops to 99.52%; (2) Accordingly, the contribution of CO_2 concentration to global temperature variation is no more than 40.19%, or in other words, 59.81% of the weight of global temperature variation is caused by non-greenhouse effect.

Despite the increasing trend of atmospheric CO_2 concentration, the components IMF2, IMF3 and IMF4 of global temperature changes are all in falling. Thus, if CO_2 concentration remains constant at present, the effect of greenhouse warming is deficient in counterchecking the natural cooling of global climate change in the coming 20 years. Consequently, we believe global climate changes will be in a trend of falling in the following 20 years.

5. Multi-scales analysis of China temperature variation

The mean temperature in China is decomposed into four IMFs and a Res (trend) by EMD method (Fig. 5). It illuminates the temperature variation in China is consistent with the global and NH in the aspects that they all have four quasi-period oscillations on various timescales and a trend of larger time scale in the last century, and that the variance explained of each component is similar (see Table 1).

However, temperature variation in China is quite different from that in the global and NH since its trend has been falling in recent years.

The reconstructed curve of IMF4 with a quasi 60-year period oscillation and Res, a larger scale

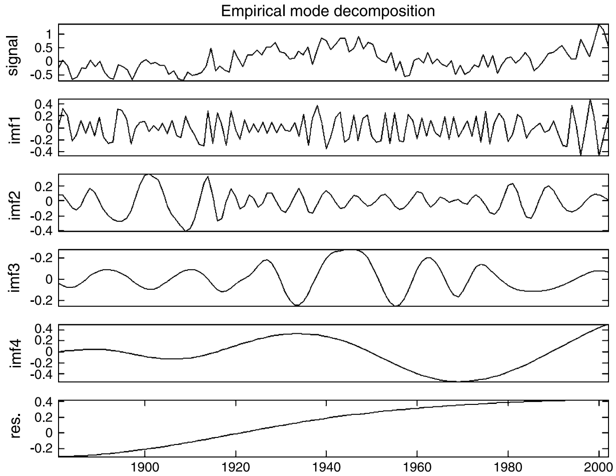

Fig. 5. The China annual mean temperature is decomposed into four intrinsic mode functions (IMF) and a trend by EMD method. The first IMF has 3–4-year period. The second IMF has 6–8-year period. The third IMF corresponds to 20-year period. The fourth IMF contains 60-year cycles. The Res indicates larger timescale oscillation

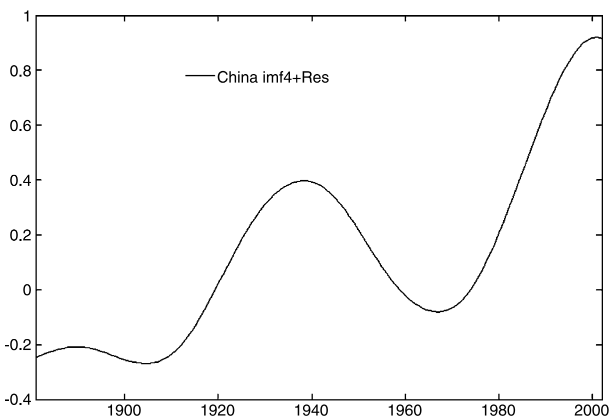

Fig. 6. Reconstructed mode by using IMF4 (60-year timescale) and Res (century timescale) components for China mean temperature from 1881 to 2002

trend (its variance explained amounting to 60.47%), both are components of temperature in China (Fig. 6). It appears to agree with the above conclusion: temperature in China has been falling on century scale in the next 20 years.

Comparing Fig. 6 with Fig. 3, it is possible for us to forecast the trend of global or NH temperature variation according to the trend in China where the temperature variation reveals a leading phase of approximately 5–10 years ahead. So temperature variation in China has a leading significance in the forecast of global temperature changes.

6. Discussions

EMD method can decompose climate dataset into various timescale oscillations and each IMF component indicates temperature variation on different timescales. The trend and the quasi-60-year oscillation are the most prominent in temperature variation in the global, NH and China. In the meantime, temperature variation in China precedes that in the global and NH, so it provides a denotation for global climate changes. Noticeably, the interdecadal oscillations of temperature in China which was at its peak in 2001 have been falling recently. It thus indicates that whether on century scale or on the periods of quasi 60-year oscillations, the global climate will be cooling down in the next 20 years.

It should be noted that we did not forecast it on the timescale of month or year. On the month or year timescale, the influencing factors in climate change are both numerous and inconstant. Therefore, climate change is of multi-frequencies or frequency conversion. But on 60-year to century timescale, the influencing factors in climate change are relatively stable. So, we consider global temperature will be in falling on 60-year timescale in the coming 20 years.

And again, our primary conclusion, i.e., that atmospheric CO_2 concentration is not a key determinant of periodic variation of the global temperature. The global climate warming is not solely affected by the CO_2 greenhouse effect. The best example is temperature obviously cooling however atmospheric CO_2 concentration is ascending from 1940s to 1970s. Although the CO_2 greenhouse effect on global climate changes is unsuspicious, it could have been excessively exaggerated. It is high time to re-consider the global climate changes. We consider that CO_2 greenhouse effect impact on the trend of global temperature, simultaneity we expect to find the effect on climate change on different timescales by analysis the solar activity, earth movement (nutation, rift and volcano activity) and the others greenhouse gases using EMD method.

Acknowledgements

This research is supported by NSF of China (40371108) and National "211" Key Project of China: The Environmental Evolution and Ecological Construction on Multi-spatio-temporal Scales.

References

Caldeira K, Duffy BP (2000) The role of the southern ocean in uptake and storage of anthropogeic carbon dioxide. Science 287: 620–622

Etheridge DM, Pearman GI, Silva FD (1988) Atmospheric trace-gas variations as revealed by air trapped in an ice core from Law Dome, Antarctica. Ann Glaciol 10: 28–33

Etheridge DM, Steele LP, Langenfelds RL et al (1996) Natural and anthropogenic changes in atmospheric CO_2 over the last 1000 years from air in Antarctic ice and firn. J Geophys Res 101: 4115–4128

Fischer H, Wahlen M, Smith J et al (1999) Ice core records of atmospheric CO_2 around the last three glacial terminations. Science 283: 1712–1714

Hao JP, Huang DJ (2001) Mirror extending and circular spline functions for Empirical Mode Decomposition method. J Zhejiang Univ (Sci) 2: 247–252

Houghton JT et al (2001) Climate change 2001: The scientific basis. Cambridge University Press, pp 1–94

Huang NE, Shen Z, Long SR et al (1998) The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis. Proc R Soc Land A 454: 899–955

Huang NE, Shen Z, Long SR (1999) A new view of nonlinear water waves: the Hilbert spectrum. Ann Rev Fluid Mech 31: 417–457

Jones PD (1994) Hemispheric surface air temperature variations: A reanalysis and an update to 1993. J Climate 7: 1794–1802

Jones PD, Moberg A (2003) Hemispheric and large-scale surface air temperature variations: An extensive revision and an update to 2001. J Climate 16: 206–223

Jones PD, New M, Parker DE et al (1999) Surface air temperature and its variations over the last 150 years. Rev Geophys 37: 173–199

Joos F, Plattner G-K, Stocker TF et al (1999) Global warming and marine carbon cycle feedbacks on future atmospheric CO_2. Science 284: 464–467

Manabe S, Stouffer RJ (1993) Century-scale effects of increased atmospheric CO_2 on the ocean-atmosphere system. Nature 364: 215–218

Manabe S, Stouffer RJ (1994) Multiple-century response of a coupled ocean-atmosphere model to an increase of atmospheric carbon dioxide. J Climate 7: 5–23

Michael ME, Jeffrey P (1995) Global interdecadal and century-scale climate oscillations during the past five centuries. Nature 378: 266–270

Morgan VI, Wookey CW, Li J et al (1997) Site information and initial results from deep ice drilling on Law Dome. J Glaciol 43: 3–10

Petit JR, Jouzel J, Raynaud D et al (1999) Climate and atmosphere history of the past 420.000 years from the Vostok ice core, Antarctica. Nature 399: 429–436

Sarmiento JL, Quere CL (1996) Oceanic carbon dioxide uptake in a model of century-scale global warming. Science 274: 1346–1350

Sarmiento JL, Hughes TMC, Stouffer RJ et al (1998) Simulated response of the ocean carbon to anthropogenic climate warming. Nature 393: 245–249

Schlesinger ME, Ramankutty N (1994) An oscillation in the global climate system of period 65–70 years. Nature 367: 723–726

Schneider T, Held MI (2001) Discriminants of twentieth-century changes in earth surface temperatures. J Climate 14: 249–254

Siegenthaler U, Sarmiento JL (1993) Atmosphere carbon dioxide and the ocean. Nature 365: 119–125

Stauffer B, Blunier T, Dällenbach A et al (1998) Atmosphere CO_2 concentration and millennial-scale climate change during the last glacial period. Nature 392: 429–436

Stott PA, Kettleborough JA (2002) Origins and estimates of uncertainty in predictions of twenty-first century temperature rise. Nature 416: 723–726

Wang SW, Ye JL, Gong YD et al (1998) Construction of mean annual temperature series for the last one hundred years in China. Quart J Appl Meteor 19(4): 392–401

Corresponding author's address: Lin Zhen-Shan, The School of Geographic Sciences, Nanjing Normal University, Nanjing 210097, P.R. China (E-mail: linzhenshan@njnu.edu.cn)

Verleger: Springer-Verlag GmbH, Sachsenplatz 4–6, 1201 Wien, Austria. – Herausgeber: Prof. Dr. Reinhold Steinacker, Institut für Meteorologie und Geophysik, Universität Wien, Althanstraße 14, 1090 Wien, Austria. – Redaktion: Althanstraße 14, 1090 Wien, Austria. – Satz und Umbruch: Thomson Press (India) Ltd., Chennai. – Druck und Bindung: Krips bv, Kaapweg 6, 7944 HV Meppel, The Netherlands – Verlagsort: Wien. – Herstellungsort: Meppel – Printed in The Netherlands.

Offenlegung gem. § 25 Abs. 1 bis 3 Mediengesetz: Unternehmensgegenstand: Verlag von wissenschaftlichen Büchern und Zeitschriften. An der Springer-Verlag GmbH ist beteiligt: Springer Austria GmbH, Sachsenplatz 4–6, 1201 Wien, Austria, zu 99,8%. Geschäftsführer: Dr. Sven Fund, Sachsenplatz 4–6, 1201 Wien, Austria.