Do bidecadal oscillations exist in the global temperature record?

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MODELS predict[1-3] that increasing atmospheric concentrations of greenhouse gases will result in an increase in the global mean temperature over the next few decades and beyond. It is therefore important to be able to distinguish a warming trend from natural variability in the time series of global temperatures. Recently, Ghil and Vautard[4] applied singular spectrum analysis to a record of global surface air temperatures, and identified a secular warming trend and a small number of oscillatory modes. The oscillations had interdecadal periods of 21 and 16 years (attributed to changes in the extratropical ocean circulation), and interannual periods of 6 and 5 years (attributed to the El Niño/Southern Oscillation). Here we re-analyse the data by considering various lengths of the temperature record, and we apply singular spectrum analysis to five other temperature records (two global, three hemispheric). Our results offer no support for the presence of bidecadal oscillations in the global surface temperature records.

Because of the importance of the problem, considerable efforts have been made to extract information about trends, periodicities, natural variability and noise from the records[5-8]. Ghil and Vautard (GV hereafter)[4] applied singular spectrum analysis (SSA) to one of the available records. This approach[9,10], which is fully non-parametric, considers M lagged copies of a centred time series $X(t)$ sampled at equal intervals τ, $X_i = X(t_0 + i\tau)$, $i = 1, N$, and estimates the eigenvalues λ_k and eigenvectors ρ_k of their covariance matrix $\mathbf{C}$ (here $1 \leq k \leq M$). They (GV) call the eigenvectors empirical orthogonal functions (EOFs) and the coefficients a_k involved in the expansion of each lagged copy, principal components (PCs). EOFs are of interest when among k eigenvalues there exist a number of distinct ones whose magnitude is appreciable, whereas the rest are close to zero. In such cases this would be a strong indication of 'deterministic' parts in the subspace of eigenmodes with the rest of the modes acting as noise. Thus, this method can be used to separate signal from noise. In an earlier study Vautard and Ghil[11] observed that pairs of high-variance eigenvalues $\lambda_k = \lambda_{k+1}$ are associated with oscillatory phenomena (both the corresponding EOFs and PCs are in quadrature with each other).

In their analysis, GV extracted the following oscillatory modes: an oscillation having a period of nearly 20 years (EOFs 3 and 4), an oscillation of 6 years (EOFs 11 and 12) and an oscillation of 5 years (EOFs 6 and 7). The five- and six-year periodicities are attributed to the well-documented El Niño/Southern Oscillation (ENSO). Speculation concerning the 20-year oscillation centres on possible changes in ocean circulation. From these results, GV proceed to reconstruct the global climate record and to investigate the issue of detecting a greenhouse warming signal in the record. They conclude that, as a consequence of the bidecadal oscillation, the warming signal will not be detectable for at least one or two more decades.

Our interest in this important method of analysing the data is the effect of the record length on the results. We thus considered the UK global surface air temperature record of Jones *et al.*[12] and repeated SSA for various record lengths. This record was provided by the Oak Ridge National Laboratory, and it covers the period 1861-1990. Shown in Fig. 1 are the eigenvalues of the lag-covariance matrix $\mathbf{C}$ against order for the entire record ($N = 130$), for the record from 1881-1990 ($N = 110$) and for the record from 1901-1990 ($N = 90$). For all the following analyses, we used $M = 30$. As did GV, we found no significant changes to any of the results when M was varied between 25 and 50. For any length we observe that the first two eigenvalues (λ_1 and λ_2) considerably exceed the rest, explaining 35-65% of the variance. The second two eigenvalues (λ_3 and λ_4) are quite close to the noise floor, and account for only 7-11% of the variance. It is interesting to note that our Fig. 1 does not exactly reproduce GV's corresponding figure based on the same but somewhat larger record (1854-1988, $N = 135$). The reason for the slight mismatch will become clear below.

Shown in Fig. 2 are the corresponding leading eigenvectors (EOFs 1-4) for the different length records. We observe that the estimation of EOFs 1 and 2 is robust; it varies only slightly with record length. EOFs 1 and 2 correspond to the trend in the temperature record. In contrast, however, the estimation of EOFs 3 and 4 is not robust. If the entire record ($N = 130$) is considered, EOFs 3 and 4 are an oscillatory pair in quadrature with each other and have a period of ~20 years, but for $N = 110$ and $N = 90$ this is not the case. Instead, we begin to see an oscillatory pair having a period between five and six years. We note that for $N = 110$ and $N = 90$, no higher EOFs (not shown) indicate the 20-year oscillation. The result is not surprising, as the eigenvalues corresponding to EOFs 3 and 4 are clearly very near the noise floor.

From these results, we raise the question of whether a minimum N is required for delineation of the bidecadal oscillations. To answer this question, we repeat the analysis using records that are shortened from the end (most recent years), rather than from the beginning (earlier years) as was done above. Results are shown in Fig. 3. We now find that, along with the estimation of EOFs 1 and 2 (not shown), the estimation of EOFs 3 and 4 is robust with bidecadal oscillations present for all data lengths considered. Thus the comparison of Figs 2 and 3 reveals that it is not the length of the record, but the inclusion of data points before roughly 1881 that makes the difference. Include the earliest years in the analysis and you will detect a bidecadal oscillation, but exclude them and it disappears.

Other global surface air temperature records tell a similar story. Estimates of EOFs 3 and 4 from SSA on the USA global data set[13], on the IPCC global time series[14] and on the USSR data set[15] are shown in Fig. 4. The USA record extends from 1880 to 1987 ($N = 108$). The IPCC record extends from 1961 to 1990 ($N = 130$; the 1990 value of the IPCC data was supplied by D. E. Parker). The USSR data set represents annual mean surface air temperatures in the Northern Hemisphere, and it covers the period 1891-1987 ($N = 97$). Estimates of EOFs 1 and 2 from all data sets (not shown) are close to those estimated from the UK data set. In both the USA and the USSR sets,

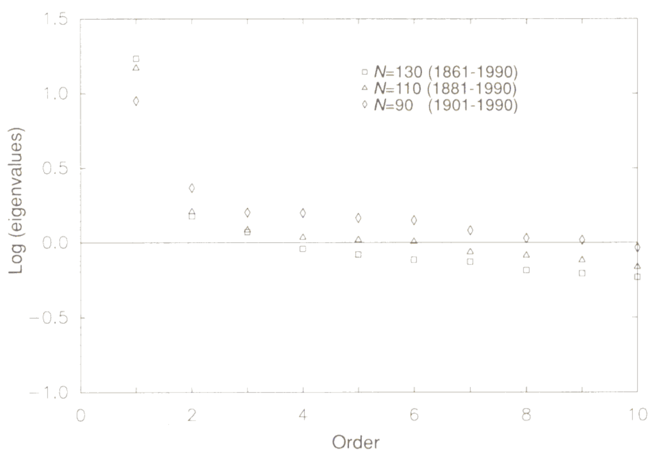

FIG. 1 The estimated eigenvalues, λ_k, of the lag-covariance matrix $\mathbf{C}$ ($M = 30$) calculated for various lengths of the global surface temperature record[12]. Only the first two eigenvalues extend above the noise floor.

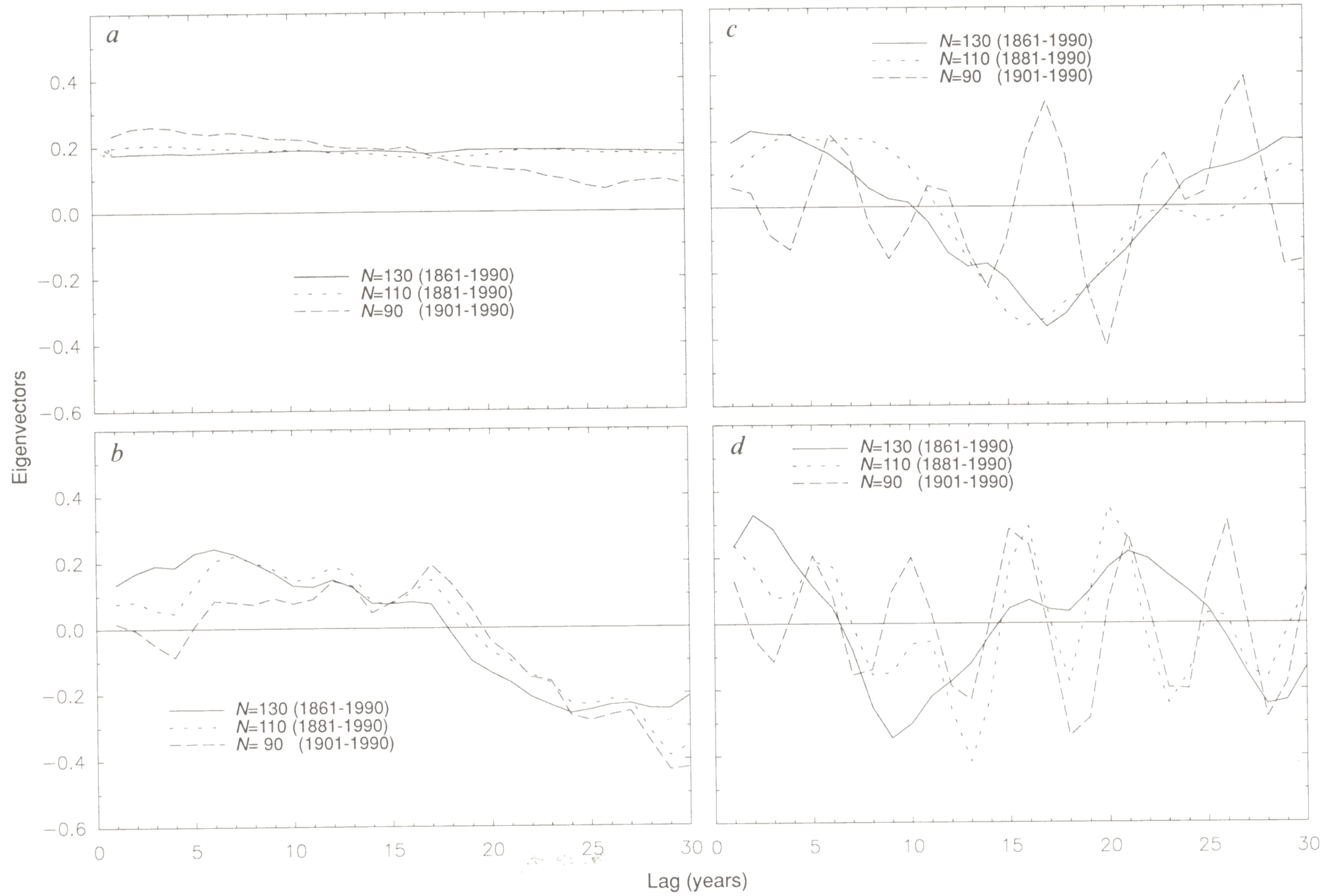

FIG. 2 *a*, The first eigenvector (EOF 1) of the lag-covariance matrix **C** ($M=30$) computed for various lengths of the record[12]. All records end with the year 1990. *b*, As in (*a*), but for EOF 2; *c*, as in (*a*) but for EOF 3, *d*, as in (*a*) but for EOF 4. Here EOFs 3 and 4 are a pair in quadrature and having a period of ~20 years only for $N=130$ (1861–1990). EOFs 1 and 2 correspond to the trend and are virtually unchanged for different record lengths.

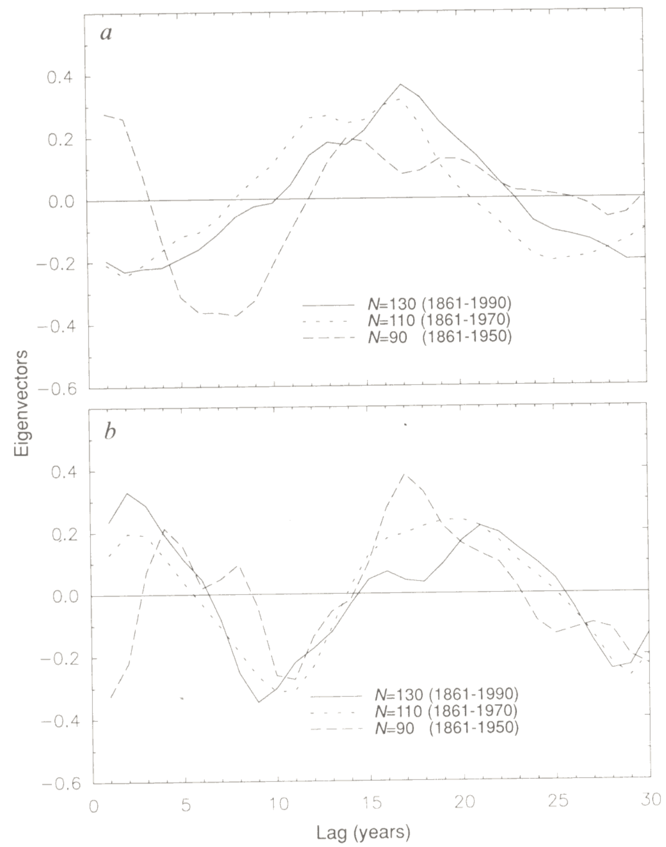

FIG. 3 *a*, EOF 3 estimated from the lag-covariance matrix **C** ($M=30$) using various lengths of the record[12]. Now all records begin with the year 1861. *b*, As in (*a*) but for EOF 4. Here EOFs 3 and 4 are an oscillatory pair in quadrature and with a period of ~20 years for all record lengths.

which do not include any values before the 1880s, the 20-year oscillatory pair is not apparent (if anything, EOFs 3 and 4 indicate a five- to six-year oscillatory pair). The results from the IPCC record are similar to the results obtained from the UK set: the 20-year oscillation is not robust. It exists when the whole record is considered, but it is absent when somewhat smaller periods excluding early values, such as the period 1891–1990 ($N=100$) shown in Fig. 4, are considered. As the USSR set is for the Northern Hemisphere, we also repeated the analysis for the northern hemispheric values of the USA and UK records that were available to us. Both data sets are in agreement: each reveals a five- to six-year periodicity associated with ENSO and no bidecadal oscillation when data before 1880 are not included. In addition, we note that no bidecadal oscillation is found in any of the higher EOFs.

In the past, other investigators have come across a peak at 21–23 years but none of them refers to a global surface air temperature record. For example, there is a pronounced peak at 23 years in the maximum entropy spectrum of a 300-year

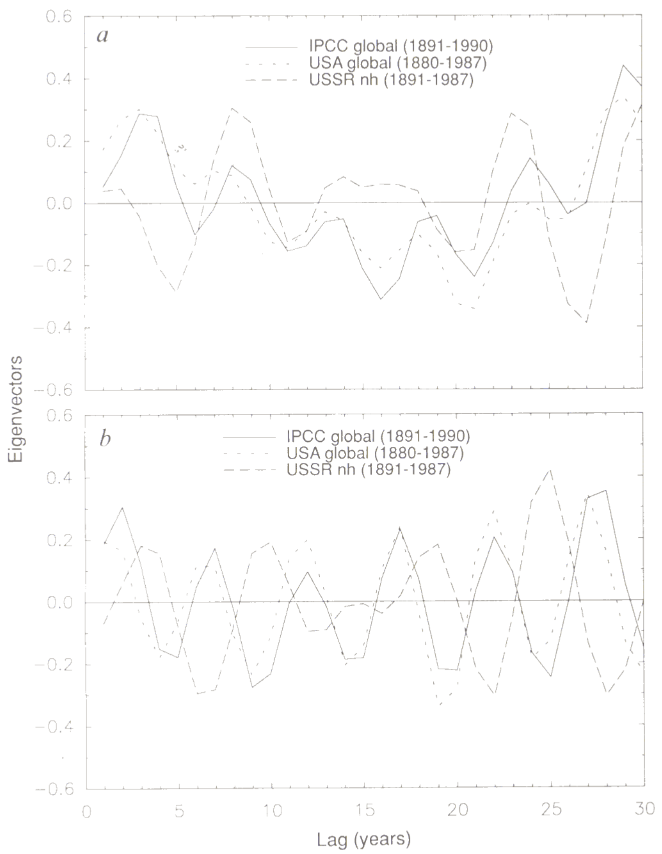

FIG. 4 *a*, EOF 3 and *b*, EOF 4 estimated from the lag-covariance matrix **C** ($M=30$) for the USA global temperature record[13] (1880–1987), the IPCC record[14] (1891–1990) and for the USSR data set[15] (1891–1987; nh, Northern Hemisphere). Note the absence of bidecadal oscillations.

temperature record[16] and a 21.8-year peak is contained in the Fourier transform of global marine air temperature data[17] covering the period 1856–1986. The 23-year peak refers to just a small area in central England, and the 21.8-year peak refers to marine data only. Although both important, their statistical significance with respect to their connection to global surface air temperature records is not straightforward and was never established.

We therefore conclude that it is only the values from before the 1880s that cause the SSA to delineate bidecadal oscillations in global surface air records. A record of length $N=100$ years starting at 1861 would show bidecadal oscillations, but a record of equal length ending today would not. The great dependence of the results of GV on the data before 1880, together with the poor quality and density of the data during this period (a fact that GV recognized) and possibly the fact that SSA is designed for stationary data (which the temperature records most surely are not) make the existence of bidecadal oscillations in the global surface temperature records, at best, questionable.

The idea that low-frequency variations in the climate system can be traced to the thermal inertia of the ocean is not questioned. Certainly ENSO is an example. But without a physical model of the mechanisms involved, supported by other evidence from the data, the bidecadal oscillation cannot be considered significant at this time. □

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