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Comments on: "The magnitudes of millennial- and orbital-scale climatic change in eastern North America during the Late Quaternary" by Shuman et al. [Quaternary Science Reviews 24 (2005) 2194–2206]

1. Introduction

There is a considerable body of research that documents millennial-to-centennial climate variability (e.g. Mayewski et al., 2004). Within this context, Shuman et al. (2005; hereafter S05) analysed 15 pollen diagrams, obtained from the NAPD (www.ngdc.noaa.gov/paleo), to "…quantify and map the magnitude of climatic change in terms of fossil pollen changes across a range of timescales in order to study the extent and character of climatic changes that caused significant ecological impacts." (S05, pp. 2194–2195). They never actually perform a study of climatic change, restricting themselves only to the pollen changes, which they claim "… represent the magnitude of climatic change…" (S05, p. 2195).

In their introduction, they set two goals. First, they "… demonstrate that the fossil-pollen data can capture rapid climate changes.", a conclusion already demonstrated by Gajewski (1983, 1987; see also, 1993), among others, in addition to the more recent studies they cited. Given this conclusion, they "… examine the magnitudes and spatial patterns of paleovegetation changes across all of Eastern North America.", using data exhaustively analysed in numerous studies, for example, Williams et al. (2004; among others, also references therein) and the methodology used by Jacobsen et al. (1987). Their results are similar to those of Jacobsen et al. (1987), not surprisingly. This method uses the computation of the dissimilarity between samples of a pollen diagram, which is estimated using the squared chord distance (SCD), to quantify times of more rapid change. Although changes in pollen assemblages can be estimated by the SCD, vegetation and climate change must be inferred. They conclude that (1) "During the Holocene, millennial-scale climate changes appear, by our analysis to have been small and ecologically less significant than orbitally forced changes" (S05, p. 2203) and (2) "The primary mode of Holocene climate change is the long-term progressive changes … across 3000–5000 year intervals." (S05, p. 2203).

We would argue that their conclusions are due to the methodology they used and not because the pollen record cannot or does not record millennial-scale climate variability. Further, we would argue that these higher-frequency variations are as important in affecting the dynamics of the North American vegetation as Milankovitch climate variations or migrational vegetation changes. That is, studies that purport to show synchronous millennial-scale climate variations across North America based on the analysis of pollen diagrams, such as Viau et al. (2002, 2006) are truly providing information about millennial-scale climate changes and are not simply indicating "slow trends [that] progressively accumulate enough change to justify differentiating pollen assemblages every 1000–3000 years" (S05, p. 2203). Our comments fall into two broad categories: (a) general comments about the approach that they used and (b) technical comments on their methodology.

2. General comments

S05 begin their study by noting that vegetation records are dominated by long-term changes, whereas the oxygen isotope record from Greenland shows little change in mean conditions change during the past 8000 years, and that shorter-term (i.e. centennial to millennial-scale) changes are therefore of comparable magnitude. This is not entirely the case. In the first place, they are comparing different objects. The Greenland record is one point, and, although some of the variables measured in the ice cores may be representative of large spatial scales, even global, it is nevertheless recording effects on top of one point on the Greenland ice cap. Based on its location, there are simply limits within which it can vary. The pollen analytical results that they cite, however, are maps that are recording continental–scale phenomena. Mapped pollen records show long-term trends, however the conclusion that "long-term trends dominate" (S05, p. 2194) does not follow. This would have to be the case for mapped patterns, but it is not the case for any individual site, which would be a more appropriate comparison. So it is not surprising the records S05 are comparing appear different. Of course, as the ice sheet disappeared, and the vegetation migrated onto the newly available land, and this will dominate the "signal" they are interpreting in their maps. Combined with the fact that (a) pollen records are the result of many factors that influence vegetation patterns and (b) most pollen records have been analysed at low temporal and taxonomic resolution (Gajewski, 1993;

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Finkelstein et al., 2006), it is not surprising that it becomes difficult to compare pollen and ice core records. However, when individual sites are investigated at sufficient resolution, variability of many scales is noted (Gajewski, 1987).

A second problem with this study is that they did not really address the question they posed. They set as their goal "... to quantify and map the magnitude of climatic change in terms of fossil pollen changes ..."(S05, p. 2194), however, their study only analyses pollen change. Although they argue that centennial to millennial-scale climate changes can be inferred from pollen changes, and this is the case (e.g. Gajewski, 1987, 1993), it does not follow that maps of the SCD are actually documenting climate changes, since the methodology, as they have applied in this study is too crude to deal with the question.

A more direct way to determine the magnitude of millennial-scale climate change is to reconstruct the climate itself. As an example, we reconstructed mean July temperature for all 15 sites used by Shuman et al. (2005) to illustrate the climate variability in the region. We used an 89-type pollen sum and interpolated the data at 100-year intervals. The mean July temperature was estimated for all of these data points using the method of modern analogues (MAT) and we then computed the mean of all of the time series. We present one curve representing the mean conditions for the study area, as a way to make the comparison to the Greenland or North Atlantic results more reasonable (Fig. 1).

Notice that even if the original data do not have this temporal resolution, this should not affect the outcome of averaging all records. Linear interpolation between data points is comparable to simply drawing a line between the points. That is, the peaks and troughs remain in the same position and interpolating simply allows us to compute the mean value for a series of points. The autocorrelation induced in the series would be a problem if we were computing statistical significance, which we are not. This analysis should reveal information on the magnitude of temperature changes within this network of sites.

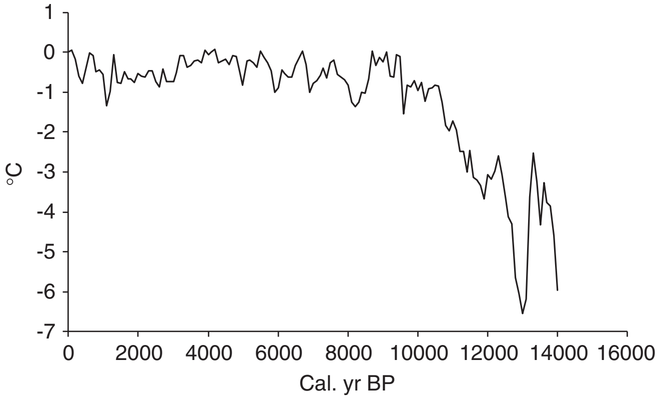

Fig. 1. Mean July temperature anomalies reconstructed from 15 pollen sites used by Shuman et al. (2005).

Next, note also that we used the one best analogue, as opposed to the average of several of the top analogues, as is sometimes done (Jackson and Williams, 2004). Use of only the best analogue is conceptually superior, as it is the modern pollen assemblage that is most similar with the fossil spectrum within a region. On the other hand, the rationale for averaging over several best analogues is that this accounts for known random variation in pollen assemblages (Jackson and Williams, 2004). However, when the past climates are estimated from the average of several analogues, this average may be based on "good analogues" from a wide geographical area (Anderson et al., 1989), greatly reducing variability that would be reconstructed using the fossil data. For, example, the best analogues for a fossil assemblage from the boreal region of western Canada or Alaska can be found in northern Quebec as well as in western Canada, although the climate and vegetation differs among these regions. Taking an average of these analogues would give a climate from central Canada, and if this is done for many samples, this would tend to "smooth" the resultant climate reconstruction. By using only the best analogue and an expanded pollen sum, it is possible to reconstruct small but significant vegetation and climate changes representative of within-biome variability, if we assume that non-analogues are not a contributing factor and that vegetation changes are occurring within the biomes themselves. This is one way to better geographically constrain the best analogues used in pollen reconstructions; there are other ways as well.

The magnitude of change in the temperature reconstruction based on the 15 sites is approximately ±0.6 °C during the period between 14,000 and 8100 years BP and ±0.3 °C after 8000 years BP, during the mid-to-late Holocene. This range of variability is consistent with other high-resolution paleoclimate records of the northern Hemisphere that have been sampled on annual to millennial scales (e.g., Mann et al., 1999; Esper et al., 2002; Moberg et al., 2005). Although the network is small (i.e. 15 sites), the mean July temperature curve also shows millennial-scale variations in temperature. Further, when we compare the Holocene portion of this curve with the GISP2 Ice Core oxygen isotope record (Grootes et al., 1993), we can see that the variability is comparable (Fig. 2).

Although S05 interpret the changes seen in mapped pollen patterns as simply reflecting accumulated changes in the SCD in response to slow variations in pollen caused by Milankovitch-scale solar variations, this ignores the fact that abrupt changes are synchronous among the different regions and between different proxies. For example, Viau et al. (2006) show the close similarity between pollen-based and several other proxy-climate records of the Holocene, and Gajewski et al. (2006) illustrate a synchronicity in pollen transitions between Europe and North America.

3. Comments on the methodology

S05 compute the squared chord distance between pollen samples as a measure of pollen changes. There are 2 issues

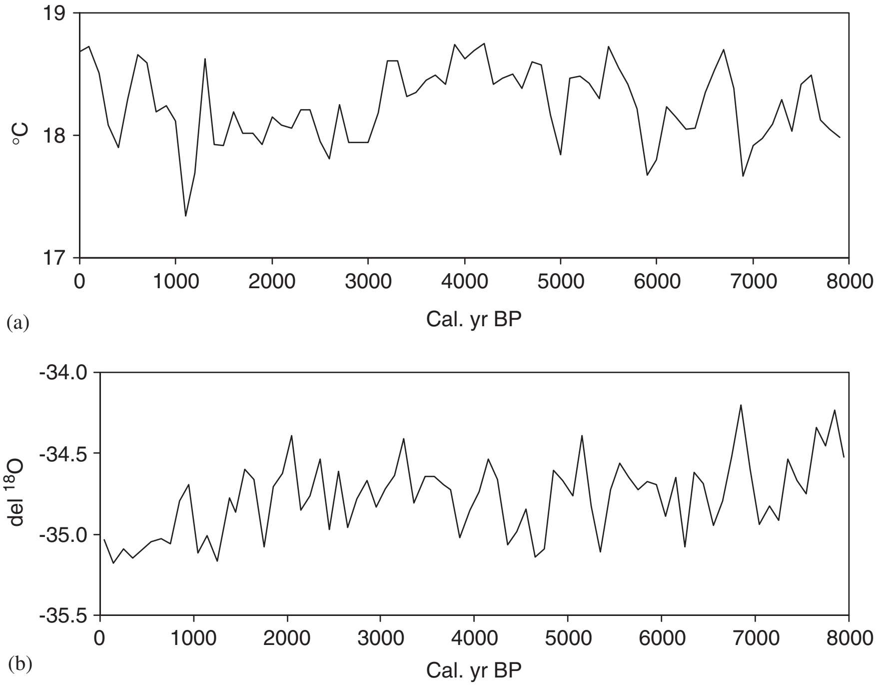

Fig. 2. (a) Mean July temperature anomalies reconstructed from 15 pollen sites used by Shuman et al. (2005). This is the same data as in Fig. 1, but only the Holocene portion is depicted. (b) Oxygen isotope ratio from GISP2 ice core (Grootes et al., 1993). Data from www.ngdc.noaa.gov/paleo.

that would affect their interpretation. First, they assume that an SCD threshold of 0.15 defines the difference between biomes, based on a study by Overpeck et al. (1985). This is a simplification. Jackson and Williams (2004) review the literature on the modern analogue method and point out that many empirical values have been proposed, based on the particular data and vegetation classification used. The threshold value is a function of the pollen assemblages and the desired resolution of the comparison. Although the definition of analogue and non-analogue is necessary, there is no particular theoretical or generally applicable reason to choose any value over another. The value depends on the definition of vegetation type; a broader vegetation classification would arrive at a higher value. Further, the SCD value that defines a non-analogue situation is a function of the pollen sum. Sawada et al. (2004) showed under a randomization scheme that by increasing the pollen sum, the SCD values and threshold value increase (e.g. for 89 types = 0.23). Finally, as S05 note, the value of 0.15 reflects differences between biomes. Within-biome changes, in fact precisely the kind that would be expected during millennial-scale climate changes (Gajewski, 1987; Bernabo and Webb, 1977), would not be detected by using this threshold.

A second issue is the number of taxa they used to compute the SCD. They use only 24 taxa in their computations. Using fewer taxa is a strategy that enables continental-scale paleoclimate mapping to be done, a strategy put to good use by the authors over 30 years of paleoenvironmental study. However, a larger pollen sum makes possible more precise distinctions and comparisons between pollen assemblages.

Another problem is the interpolation scheme used by S05. Interpolating at 500-year intervals may cause aliasing or under-sampling of the millennial-scale variations, thereby smoothing over peaks and troughs. This interpolation scheme would therefore reveal only regional “time-progressive “changes in SCD values and ignore much of the higher-frequency variability, if the critical threshold of 0.15 is assumed to be statistically significant.

4. Conclusions

In summary, Shuman et al. (2005) are attempting to ask a significant question: to what extent can millennial to century-scale climate variations be analysed using pollen diagrams. However, we feel that they have significantly underestimated the extent to which these variations are important and affecting the vegetation of North America. This is due in large part to the methodology they are using; readers can see Gajewski (1987, 1993), Gajewski (1988); Gajewski et al. (2006) or Viau et al. (2002, 2006) for alternative methods using pollen databases to approach this question. In fact, an increasing number of studies are revealing that vegetation does respond rapidly to climate variations; these studies are finding comparable times of transition in different regions. This would not be occurring if there is not an immediate forcing of these changes by millennial-scale climate variability. Whether or not there are leads, lags, or even magnitude differences between the different Holocene records remains a major research concern. Research is needed to enhance the temporal and taxonomic resolution of pollen analyses to better understand centennial- to millennial-scale bands of climate variability during the past 8000 years using these data.

Acknowledgments

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