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Reply

Response to "Comments on: 'The magnitude of millennial- and orbital-scale climatic change in eastern North America during the Late-Quaternary' by Shuman et al."

1. Introduction

We are puzzled by some of the comments of Viau and Gajewski (hereafter "V&G") about our study of "The magnitudes of millennial- and orbital-scale climatic change in eastern North American during the Late Quaternary". We find important points of agreement. We agree with V&G in recognizing that many paleoclimatic records demonstrate the existence of millennial and sub-millennial climate variability. Indeed, our paper (Shuman et al., 2005, hereafter "S05") began: "Recently developed datasets with high temporal resolution have drawn attention to paleoclimatic variations on millennial-to-centennial time scales (Bond et al., 1993, 1997, 2001; Dansgaard et al., 1993; O'Brien et al., 1995)." (S05, p. 2194). Likewise, with respect to the ecological responses to such short-term climate variability, V&G state "within-biome changes… would be expected during millennial-scale climate changes" (V&G, p. 8). We also showed that although changes in fossil pollen data measured across 3000-yr intervals "often exceeded the maximum difference expected from samples collected within the same biome", the changes across "individual millennia were smaller [than the difference among samples from the same biome today]" (SO5, p. 2194).

We differ with V&G, however, in our contention that despite the presence of millennial-scale variability, orbitally driven climate changes throughout the Holocene nonetheless dominate the vegetation changes recorded by pollen data. We also disagree with V&G that our attempt to demonstrate this observation using an analysis of pollen data alone is flawed. We show here that our contentions about the dominance of orbitally driven climatic variation during the past 16,000 years holds whether viewed through the medium of climate reconstructions based on the pollen data (as proposed by V&G) or directly through the pollen data. Several points raised by V&G require discussion.

(1) Studies "*based on the analysis of pollen diagrams, such as* Viau et al. (2002, 2006) *are truly providing information about millennial-scale climate change*" (V&G, p. 3). This may be so, but orbital time scale variations still dominate the record, as may be seen in Fig. 2 of Viau et al. (2006), their reconstruction of mean July temperature for North America for the past 14,000 years based on fossil-pollen data. We agree with their characterization of this reconstruction as having an overall amplitude of about 4 °C, superimposed on which are "millennial-scale temperature variations with a magnitude on the order of ±0.2 °C". (Viau et al., 2006, p. 4). We therefore disagree that millennial-scale climate variation is the *dominant* source of vegetation change in North American during the Holocene. We emphasize that large long-term trends exist, and note that short-term variation is small compared to multiple uncertainties in the reconstruction technique.

(2) S05 "*only analyzes pollen change*" (V&G, p. 4). V&G emphasize (incorrectly) that we "restrict[ed] [our]selves only to the pollen changes" (V&G, p. 1–2) and to "15 pollen diagrams" (V&G, p. 1). S05 included an analysis of isotopic data and showed consistent patterns in both pollen and isotope data. We also mapped data from over 600 pollen records. Our approach relied on the same pollen dataset and statistical techniques as V&G, Viau et al. (2006), and Gajewski et al. (2006). We show here that our analysis of the raw pollen data is robust.

(3) *Vegetation migration "onto newly available land…will dominate the 'signal'"* (V&G, p. 4). Many studies disagree and, indeed, such an assumption would invalidate the climate reconstructions of V&G, Viau et al. (2006) and Gajewski et al. (2006). Indeed, migration into newly deglaciated areas would also fail to explain large vegetation changes in areas distant from the ice sheet.

(4) The method of S05 "*is too crude to deal with the question*" (V&G, p. 4). V&G state that pollen-based climate reconstructions, which rely on measurements of dissimilarity between pollen samples, capture centennial- to millennial-scale climate change. However, they contend that analysis of the dissimilarity measures alone (without the noisy calibration to climatic values) cannot obtain the same results. We disagree and think that the dissimilarity data, at least, provide a useful check on histograms of uncalibrated radiocarbon ages used as a measure of climate change by Viau et al. (2002) and Gajewski et al. (2006). Below we follow their suggestion that we repeat our analysis by first reconstructing climate from the pollen data, and show that our results are unchanged.

(5) "*Mean July temperature… shows millennial-scale variation*" of about 0.3–0.6 °C (V&G, p. 6). We note that

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such variations are small in the context of uncertainties in the reconstructions. We also demonstrate that vegetation responded to any short-term variations in mean July temperature in the context of much larger long-term changes in both winter temperatures and moisture. Summer temperatures show the least variation of several key climate variables during the Holocene.

We also discuss a few additional minor points raised by V&G, including several methodological points, such as the specific dissimilarity threshold and the number of analog samples used in the modern analog technique (MAT), which have no direct bearing on the results presented by S05. S05 did not use the MAT because S05 only used the raw dissimilarities in the pollen data that underlie MAT-based climate reconstructions. In contrast, the results of V&G are highly sensitive to methodological uncertainties associated with the MAT and with the generation of temperature reconstructions based on multiple records.

2. Background

Our paper sought to place millennial and sub-millennial climate changes in the context of long-term climatic trends forced by major changes in climatic boundary conditions. Comparisons of climatic variations on different scales and linkages across scales must be evaluated to better understand how Late Quaternary climate dynamics and the biotic responses to them actually worked. Note, for example, that if solar forcing or other factors are important at short-time scales, the effects of these phenomena would still be modulated by changes in perihelion and obliquity (orbital change), in albedo (ice sheet changes), or in atmospheric composition (CO_2 concentration changes). We found that some short-term changes (i.e., at the beginning and end of the Younger Dryas chronozone, YDC) were large relative to long-term trends, but that other short-term changes (i.e., those occurring throughout the Holocene) were small as compared to ongoing long-term trends. We hope that our analysis will contribute to debate about the Late Quaternary evolution of climate (1) by demonstrating the need to integrate across temporal scales to appropriately diagnose key climate dynamics, and (2) by showing the relative ecological significance of the wide range of climatic changes that have been identified.

Our goals were to evaluate the relative magnitudes of long-term and short-term changes, and to answer a few fundamental questions: Were short-term and long-term variations equally important? Did long-term change persist into the Holocene? Were short-term changes in the Lateglacial as significant as long-term trends? To this end, we did not need to introduce intermediate uncertainty into our analysis by first reconstructing climate (and measuring the uncertainty of these reconstructions). We relied instead on a direct measure of change in pollen data.

3. Methodological concerns

We believe (and suspect that V&G do as well) that fossil-pollen data adequately register past climatic changes—despite concerns about migration lags and other biotic processes. We relied on the depth of literature showing the close tracking of climate by pollen data (i.e., Gajewski, 1987; Prentice et al., 1991; Birks and Ammann, 2000; Tinner and Lotter, 2001; Williams et al., 2002; Shuman et al., 2004) and thus assumed that large changes in vegetation reflect large changes in climate. Indeed, many studies have verified the assumption as a reasonable basis for reconstructions such as those shown in V&G, or Viau et al. (2006). We also did not rely on pollen data alone because we included analysis of isotopic data from the northeastern United States, which further confirm the close tracking of climate by pollen data.

To confirm the results and thus the methods of S05, we follow the suggestion of V&G and, in this response, infer precipitation and temperature values from pollen data at the sites in the northeastern United States and adjacent Canada analyzed by S05. S05 used this set of sites to demonstrate that the method for measuring the relative magnitude of vegetation/climate change at different temporal scales can capture short-term events. As noted by S05, these sites "contain records sensitive to climatic changes in the North Atlantic region, such as those that occurred at the beginning and end of the Younger Dryas chronozone (approximately 12,900–11,600 cal yr BP)… [and] have the resolution (>five samples per millennium) to adequately capture >500-yr "events" (S05, p. 2195). The network of sites also constitutes a region that our mapping of vegetation change at a continental scale (Williams et al., 2004) shows behaved coherently over time.

Climatic values were inferred using squared-chord distances (SCDs) to choose the best analog from the Whitmore et al. (2005) modern pollen dataset. SCDs were calculated based on the same sum of taxa as used by S05 to calculate SCDs as a measure of climatic/vegetation change at each site over time. For comparability with V&G, we use only the best analog (all had a SCD <0.3) rather than an average of top analogs. We contest the idea that the "use of only the best analogue is conceptually superior [to averaging the top analogs]" (p. 5) but to make our case, we apply V&G's method here.

Like S05, pollen data were first interpolated to 250-yr intervals. After reconstructing conditions at each site, we then generated a regional-average value for each climatic variable (mean January and July temperatures; mean annual precipitation rate) for each 250-yr interval. By measuring the absolute difference in the value of each variable across 500 and 5000-yr intervals, we checked the conclusions drawn by S05 regarding the relative magnitude of change across different time scales. To evaluate all three variables simultaneously, we used squared standardized Euclidean distances (SSEDs; Overpeck et al., 1985) to