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Climate of the Past Discussions

Interactive comment on "Millennial-to-centennial patterns and trends in the hydroclimate of North America over the past 2000 years" *by* Bryan N. Shuman et al.

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The reviewer provides several insightful points that we will use to improve the manuscript. As context, we would summarize our findings as evidence that long-term (millennial) hydroclimate trends affected North America during the Common Era, but that these trends were potentially small compared to both interannual variation and Holocene-length trends. The records and attendant spatial patterns are noisy because the signals of these trends and other centennial variations are small compared to the sensitivity of many archives used to study Holocene-scale variations. The points relate to three themes raised by the reviewer:

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Discussion paper

Regions and regional patterns: We agree that the spatial patterns do not consistently express strong spatial coherence. We, therefore, propose revisions to the text that explain the basis for the a priori regional assignments as well as additional discussion of the limitations of our dataset, which could produce noisy patterns (see also response to comment by S. St. George).

The regions were identified before our analysis as described by in a PAGES workshop report by McKay (2014, p. 100): "Based on the dominant airmasses, ecology, and the availability of proxy data throughout the continent, the group developed initial spatial targets for subcontinental... reconstructions." However, the distribution of data led to further divisions of the mid-continent and southern plains as well as the northeast and southeast US to ensure that geographically disparate locations were not averaged together; these decisions were guided by previously-published modern climatological pattern analyses (Mock, 1996) before analysis of the paleoclimate trends.

We propose to revise our text to more clearly explain the basis for the regions in section 2.1.1. We propose to insert the text along the lines of the following after the first sentence of section 2.1.1.:

"The nine regions were determined before we compiled the data considered here (McKay, 2014), and were based on the level 1 ecoregions of North America (Commission for Environmental Cooperation Working Group, 1997) and major patterns of covariance within modern climate data (Mock, 1996). Where spatial outliers existed separate from the main cluster of data within a region (e.g., data from Florida versus the northeast U.S.; northern versus southern Great Plains), we split our initial regions to ensure suitable representation of the data in our analysis. We used these designations to ask whether distinct trends were recognizable among commonly recognized regions and whether any trends have parallels to patterns of climate variation observed at finer time scales, such as north-south anti-phased moisture variability along the western margin of North America (Cayan, 1996; Wise and Dannenberg, 2014)."

In this way, we saw the analysis as related to modern climate patterns, although not as explicitly as raised by the reviewer. We propose to expand the Discussion section 4.1 to address potential parallels to historic patterns of variability within the noisy spatial patterns reconstructed by our analysis.

We understand the questions about the PCAs for each region, but would clarify that the analyses served to help us examine intra-regional coherency as well as inter-regional correlation. Figure 2 shows both the temporal and spatial dimensions of patterns regardless of our regional designations, whereas Figure 5 attempts to assess how much variance is shared (based on PCs) among records within each region. Therefore, in section 2.2.3, we proposed to add:

"The PCA-by-region analysis was conducted to evaluate the strength of any signals within each region, rather than simply calculating mean trends, and to assess potential correlations or shared signals across geographically distinct regions. The EOF analysis evaluates the latter from the perspective of the whole dataset."

Trends in the calibrated datasets: The reviewer raises an excellent point about the power of the calibrated datasets. We included Figure 7 as a means to demonstrate that the primary signal in these data is the dominant wetting trend. Unfortunately, these records are spatially clustered (primarily from the northeast U.S.) and may not be representative of the whole. Previous and forthcoming work has shown that no distinct differences exist between the pollen-inferred precipitation changes and P-E changes estimated from lake volume changes (Marlon et al., 2016; Marsicek et al., 2013). We propose to add these points to the text where suitable.

Criteria for data inclusion and overall goals: We had intended this manuscript to focus on the patterns observed in archives that are used to study Holocene-scale climate variations, and thus provide a bridge between the excellent work with dendroclimate records and studies of the whole interglacial. Therefore, we focused on archives that act as low-pass filters on paleoclimate changes. We agree that many different archives

from tree rings to lake sediments may retain low-frequency signals or that such signals could derive from the characteristics of high-frequency events, and that the inclusion of some annually layered records appears to create an inconsistent application of criteria regarding what data were examined.

We should clarify, however, that our primary goal was to determine the signals captured by the types of records used to study the Holocene. We admit that we did not make this aim clear, but propose changing our title to emphasize this aspect of the study (see also our response to Review #2). This goal inherently led us to include ice cores, especially because they represent nearly direct measurements of past precipitation. Tree ring records have been the dominant source of past hydroclimate information over the Common Era, and in many ways, our analysis was intended not as a critique of that excellent work, but rather as a complement intended to ask: what patterns of change are recorded by "everything else"?

Specific comments:

P. 3 Line 16 – We agree that we need to standardize the wording for clarity about hydroclimate versus hydrologic changes, and replace the word "calibrate" in this particular line with "interpreted to represent a specific climate variable."

P. 5 Line 25 – We will provide a sentence clarifying the application of SSA to missing values.

P. 6 Line 14 – As noted above, we propose to clarify about the regions. PCA was not applied where only one or two sites exist. Only the regions shown in Fig. 5 with >10 records were analyzed. We will add text to explain this point.

P. 6 Line 18 – "Interferences" was a typo and should be "inferences".

P. 7, Line 2 – We will rephrase to ensure that the references to the clusters in Figure 2 are clear. The suggestion to refer to them by color seems like it may be useful.

P. 7, Line 5 – We can see the trend that the reviewer mentions and will try to describe

it. However, the primary feature identified as a deviation for the mean in the EOF is the Medieval Anomaly. The EOF contrasts the early portion of these records with the Medieval Period, but we agree that a background trend also exists because the records never return fully to their previous values and instead the scores hover around the mean since ca 1600 CE. As noted, the trend here may be more evident if we standardize the axes in the figure.

P.10, Line 14 – This point is quite useful and we will add several sentences here that address a) relevant modern or historic patterns and b) other local factors (such as elevation) that may have contributed.

P. 11-12, Section 4.3 – In re-reading the text, we agree with the reviewer that this section is an ideal place to insert some more explicit comparison to modern patterns and to discuss the millennial-scale differences observed in each region (and how those differences may related to important processes or climate dynamics). We focused on the Pacific Northwest versus the Southwest because, here, in these two regions, we found the strongest case for a parallel to modern patterns caused by shifts in the position of the jet stream. However, coherent patterns elsewhere, especially in Central America and the northeast U.S. deserve further discussion. We can build upon work within these areas by previous studies of this interval (e.g., Hodell et al., 2005; Marlon et al., 2016). Likewise the PCAs and EOFs detect important differences between millennia in the mid-continent where we can draw on several decades of paleohydrologic work (e.g., Fritz et al., 2000) and analyses of historic droughts and floods (e.g., Schubert et al., 2004).

Table 1 – Where possible, we will obtain additional information about the age control of the various records.

Figure 1 – We can improve upon the figure design for clarity. The regional PCAs were excluded, as mentioned above, for regions with few records.

Figure 2 – The suggestions are good ones and will try to implement them.

Figure 4 – We can add histograms of values to go with each map.

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