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Climate of the Past Discussions

Interactive comment on "Patterns of millennial variability over the last 500 ka" *by* M. Siddall et al.

Anonymous Referee #2

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General comments

This paper investigates millennial scale variability using a long (500 ky) deuterium excess record from an Antarctic ice core. The goal is to identify periods when millennial variability is present in the record, and to draw connections between the occurrence of millennial variability and global ice volume. Finally, the authors suggest a source for this millennial variability via precession-driven changes in atmospheric circulation.

The idea of looking for clusters of millennial variability in such a long (500 ky) record is interesting and original, and the possibility of establishing a robust connection between millennial variability and ice volume has many important climate implications. My main concerns are about the statistical analyses, how robust they are, and whether, based on the analyses, it is possible to arrive at the conclusions presented by the authors. I believe that if the authors can make a convincing case for their methodology and add a few carefully constructed graphics to clarify their results to readers, this could be a valuable contribution to the study of millennial scale variability.

Specific comments

As I understand it, the authors lead the reader through the following sequence of conclusions by comparing various time series with their analyzed deuterium record. I feel that Figure 1 as it currently stands is not very convincing at any of these steps.

A) There are clusters of millennial-scale variability in the 500 ky deuterium record. > Fig. 1d (running standard deviation of AAprobed)

B) Millennial variability occurs during (1) periods of intermediate ice volume with extensive IRD, and (2) during glacial terminations > comparison of Fig. 1d (running standard deviation of AAprobed) with Fig. 1e (sea level) and Fig. 1f (IRD)

C) Millennial variability does not occur during (1) periods of rapid ice sheet growth and (2) periods of extensive land ice greater than 80m sea level equivalent > Fig. 1e (sea level)

D) There is a relationship between clusters of millennial variability and precession > Fig. 1d (common 21 ky "cycle" in precession and clusters)

E) This relationship changes depending on land ice volume, with the two being in phase when ice volume is intermediate and out of phase when ice volume is small > comparison of Fig. 1d (precession and running standard deviation of AAprobed) and Fig. 1e (sea level).

In the identification of A2-like variability (step A), the authors perform four operations on the deuterium record, as described in section 2. One in particular (step 3) is not standard signal-processing practice, and I feel that quite a lot more explanation is required to justify its use. Also, I feel that statistical significance are necessary when a time series has gone through a series of (really frequency-filtering) manipulations such as this. Roughly in order of importance:

CPD

6, C55–C58, 2010

Interactive Comment

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1. Does a standard signal-processing technique like deconvolution (i.e., regularized spectral ratio of record by A2), cross-correlation (of A2 with the record) or wavelet transforms identify the same periods/clusters of millennial variablity? If so, it seems much simpler to use one of these.

2. If one of these standard techniques deconvolution does not work, or does not identify the same clusters of millennial variability as your analysis, the reasons for this should be clearly explained. I realize the sampling frequency is probably not constant for the entire record, but interpolating seems to be a straightforward solution for this (and probably what the authors did to deal with the problem in the AAdetrended - Aprobed operation of step A?). Else, I think the authors could still make a more convincing case by using only the newer part of the record that is presumably better sampled and better dated.

3. If deconvolution cannot be used and the reasons are established (#2), then the need for a new methodology to identify the millennial variability clusters is clear. In this case, I think the authors need to provide a rigorous demonstration of the viability of their new methodology. The interpretation that "AAprobed shows little variation during periods without millennial variability", and thus "where the standard deviation of AAprobed is high, the record contains millennial signals" makes sense in an intuitive way, but a more objective standard is needed given that the rest of the results rest on this. For example, how does one know that high values of std(AAprobed) are exclusively associated with out-of-phase A2-like variability? How unlikely is it that non-A2-like variability can create periods with comparably high standard deviations (i.e., can you reject this null hypothesis)? Perhaps this could be done by testing synthetic time series including A2-like and "other" variability in combination with carefully designed statistical significance tests. This will also help to establish objective measures for when std(AAprobed) is "high" and when it is "low".

4. Why not use an average of A1-A4 rather than A2 to identify millennial variability? If the results are the same no matter which Antarctic event is used, this seems to be a

reasonable approach.

The rest of the comments refer to steps B-E.

5. Some of the relationship in steps B and C are very difficult to see by visually comparing the sea level and IRD curves to Fig 1d (this applies more to B, since the shaded bars do help a lot with C). To illustrate the problem I'm having, when I look at the current figure, I do see some places where B holds (i.e., millennial variability tends to occur during periods of intermediate ice volume with extensive IRD or during glacial terminations), but quite a few where B seems not to hold. For example, the maximum in std(AAprobed) around 475 ka seems to be associated with intermediate ice volume but no IRD, the one just before 100 ka seems to be associated with neither (no glacial termination and low ice volume), etc. It would just be nice to have a graphic that clearly displays result B so the reader gets an immediate sense of how often it holds and how often it doesn't.

6. I have a similar comment for steps D/E. The out-of-phase relationship does seem to hold for most of the low ice volume periods, except around 400 ka, but not the in-phase relationship. For example, there are extended periods of intermediate ice volume near 375 ka, 225 ka and 175 ka where there is no obvious in-phase relationship between precession and std(AAprobed), or in a few cases, even a $\sim$ pi/2 lag. Again, a graphic that makes it easier for the reader to see at a glance how robust this relationship is would have much more impact.

7. Precession affects how much insolation an entire hemisphere receives in a certain season. Do you have some ideas about how this would influence the zonality of the jet? The link is not clear to me, and some additional discussion would lend some weight to this suggestion.

8. Small detail regarding step C: How do you define periods of rapid ice sheet growth?

Interactive comment on Clim. Past Discuss., 6, 19, 2010.