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Interactive comment on "Decadal-scale progression of Dansgaard-Oeschger warming events" *by* Tobias Erhardt et al.

Anonymous Referee #1

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Review of Erhardt et al: Decadal-scale progression of Dansgaard-Oeschger warming events

Erhardt et al. present high-resolution Ca and Na records from the Greenland NGRIP and NEEM ice cores, and combine these with NGRIP annual layer thickness (an estimate of past accumulation) and d18O data. The study evaluates the phasing of the various records during abrupt climate events of the Dansgaard-Oeschger cycle, and finds a clear sequence of events consistent with some previous work. Accumulation rate changes lead, followed by Ca, d18O and finally Na. Taken at face value, this sequence would argue for event initialization at lower latitudes, with the sea ice response associated with DO events coming last.

These records are of great value to the scientific community, and the analysis is mean-

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Discussion paper

ingful and appears to be rigorously done (request for minor clarification below). This paper is clearly a great contribution to the literature, and I have only some minor suggestions that may improve the clarity and interpretation.

(1) The current manuscript only describes the relative phasing of the onset, midpoint and endpoint of each transition. What is missing is an analysis of the duration of each of the transitions, to put the lead/lag values into perspective. For example, if the transition were to take 100 years, then a 10-yr lead indicates that the climatic components reflected by these records co-evolved; if the transition were to take 5 years only then the same 10-yr lead suggests a decoupling, with the shift in one component (say the jet) completed before the others respond.

I request the authors add one panel to Figures 3 and 4 each that gives the transition duration.

Many of us are visually oriented. Would it be possible to show the D-O average transition in Ca, Na, lambda and d18O together in one plot like is done in Fig. 2 for Ca? Either the data or just the fits (if the data are too messy). This would really give a nice visual representation of how the "average" transition occurs.

(2) The paper only analyzes the glacial-to-interglacial (or D-O warming) transitions, and not the interglacial-to-glacial (or D-O cooling) transitions. Have you tried analyzing the latter? I would be very interested to see the phasing for these transitions also. I imagine it is more challenging given the smaller and less abrupt nature of these transitions – but I think it would be valuable nevertheless.

(3) How precise is the depth registration of the various CFA components relative to one another? And relative to the layer thickness and d18O records? I can imagine there may be cm-scale offsets, which could become important given the extremely small time phasings that the authors interpret. Please address this briefly.

(4) Appendix A was not completely clear to me, and I think it should be elaborated on

in some more detail for the lay reader. Do I understand correctly that the function that is being fit to the data is the ramp function plus an AR(1) noise function, and that the parameters of both are varied in the Monte Carlo sampler?

The language of prior and posterior distributions suggests this is a Bayesian approach – please confirm.

How is the goodness of fit evaluated, and what criterion is used in the MC sampler to accept or reject individual solutions?

It would help greatly if you could add a figure showing how several individual iterations of the fitting process look like.

(5) I am confused by the statements below Fig 4 (Starting on P9 L18). If both Ca and lambda lead Na by ∼10 years, how come these two are not necessarily synchronous? This is very counter-intuitive; all records are evaluated on the same depth scale, so why wouldn't they be? I think the relative phasing of all these records is the central result of this paper, so it would be important to establish a robust sequence of events. What would be needed to establish synchroneity of Ca and lambda? Would you need to run the analysis again relative to the Ca transition instead of relative to the Na transition? If not too much work, that may be worth doing, given the importance for the interpretation.

I could imagine a 4x4 matrix for NGRIP with the lead/lag of each of the records evaluated relative to the others, and a 2x2 matrix of the same for NEEM.

(6) All age axes have a "BP" label. Do you use BP 1950 or b2k? This is a contentious point in the ice core community (Wolff, 2007), but BP 1950 is the best choice in my view based on precedent in the literature and convention of the radiometric dating communities. At least specify which is used.

Line-by-line comments:

P1 L17-19: The phrase "DO event" is unfortunately ambiguous, with some people equating them to the abrupt warming phases, and others to the interstadials. To avoid this, consider "... millennial-scale abrupt climate change, called the Dansgaard-Oeschger cycle (REFS). During abrupt DO warming, ..."

L22: I assume your are still talking about DO warming here? Please specify that the changes described are for the warming phase.

P2 L6: Consider replacing Henry et al. with the recent review by (Lynch-Stieglitz, 2017), to avoid arbitrarily picking one study out of dozens that demonstrate the link to AMOC.

P2 L23: "Some of ...". I think you can safely say "All of" (or "most of " to be conservative). I am not aware of any model simulation or theory that does not involve sea ice as either the trigger or amplifier. You simply cannot get that much warming that quickly without sea ice.

P3 L20: "exact co-registration". How exact? Please specify relative and absolute depth registration of various CFA components.

P3 L23: Do you use the actual single layer annual counts, or the 20yr averages that are publicly available?

P3 L27: All data ARE shown... (the word "data" is plural not singular)

Figure 1+3: Please consider plotting the age axis in reverse (so time goes from left to right). This is what much of the paleoclimate literature is moving towards. That is also what Figure 2 uses.

P5 L30-31: So are your interpreting the changes in terms of the source strength only? Or does transport to the site dominate? Some would argue for the latter.

P5 L33: Do you actually fit an exponential, or do you fit a linear to the log(Ca) time series?

P6L16: "decreases" should be "increases" here, right? (it goes from 2 to 7yr, so increase?)

Figure 2: please add units to the y-axis labels. Also, how come the fit is so smooth / rounded? Isn't the fit a linear ramp? Is this because you average over many solutions?

P9 L5: Buizert et al. 2015 should be cited as WAIS Divide Project Members 2015.

P10 L23-24: Add a reference for this claim.

P10 L24: "lack of covariance" seems like strange phrase here. The records you are talking about are correlated with $r > 0.95$ probably.

P10 L32: "events" is confusing here. Are you talking about individual synoptic / precip events? or DO events, better specify more clearly.

P11 L15: This idea was suggested by (Seager and Battisti, 2007) and (Wunsch, 2006)

P11 L16: I had expected a larger discussion about wet vs. dry deposition. Could the coincidence of lambda and Ca changes be explained that way to some degree?

P11 L18: effect should be affect

P11 L34: This further supportS. . .

P12 L13: "reduction of the sea ice cover that ultimately coincided with the Greenland warming AND WAS PRESUMABLE A MAJOR DRIVER THEREOF"

Again, I think it's hard (impossible?) to get such a large Greenland temp response without a change in sea ice cover.

P18 L25: What is the rationale for taking the log of lambda instead of just lambda itself?

P19: specify what all the symbols mean in your maths.

References:

Lynch-Stieglitz, J., 2017. The Atlantic Meridional Overturning Circulation and Abrupt Climate Change. Annual Review of Marine Science 9, 83-104.

Seager, R., Battisti, D.S., 2007. Challenges to our understanding of the general circulation: abrupt climate change. Global Circulation of the Atmosphere, 331-371.

Wolff, E.W., 2007. When is the “present”? Quat. Sci. Rev. 26, 3023-3024.

Wunsch, C., 2006. Abrupt climate change: An alternative view. Quat. Res. 65, 191-203.

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