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Interactive comment on "Freshening of the Labrador Sea as a trigger for Little Ice Age development" *by* Montserrat Alonso-Garcia et al.

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Response to Reviewer#1 on "Freshening of the Labrador Sea as a trigger for Little Ice Age development" by Montserrat Alonso-Garcia et al.

We would like to thank Reviewer#1 for his thorough work reviewing the manuscript and for his insightful comments. We really appreciate the feedback provided by a person with expertise on climate and ocean dynamics since it helped us to improve the manuscript.

In order to provide context to our replies, the referee's comments have been copied below and our replies are preceded by "REPLY". We agree with most of the suggestions to reformulate the text, so below we only included the discussion comments for which we can give an answer.

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The paper by Alonso-Garcia and co-authors presents a high resolution record of ice-rafting in the Labrador Sea during the past millennium that allows assessment of the effect of freshwater discharges on the North Atlantic circulation for the first time. Several periods with relatively high debris concentration are identified in this record, periods that extend both the Medieval Climate Anomaly (MCA) and the Little Ice Age (LIA), with debris origin suggested from SE Greenland and the Arctic region respectively. The authors, in addition, compare this new record with other climate reconstructions from the subpolar North Atlantic, and hence argue, first, that a warm medieval climate might have enhanced iceberg calving along the SE Greenland coast, freshening the subpolar gyre region, and later, that this freshening could have forced a weakening in the subpolar gyre/North Atlantic circulation through reduced Labrador Sea oceanic deep convection, itself leading to reduced northward oceanic heat transport and, eventually, to the cold conditions in the North Atlantic during the LIA.

In my opinion, the result of this paper could be of great interest for the community and, thus, worth publication. I found the paper mostly clear and well written. I have, nonetheless, some concerns about the interpretation of the records (see below) that I would like the authors to address before I can recommend publication. Since it might require important changes in the paper, I suggest major revisions.

The role of the North Atlantic Oscillation (NAO): Throughout the entire manuscript, the authors argue that the NAO could potentially have played a key role in driving the Arctic ice export to the Labrador Sea. This interpretation is based on the Trouet et al. [2009]'s NAO reconstruction, which exhibits a marked shift from persistent positive phases during the MCA to more variable phases in the LIA that agree with the reconstructed increase in the percentage of hematite-stained grains in this study. The robustness of this NAO reconstruction, however, was put into question in Lehner et al. [2012]; and, more importantly, it was updated in Ortega et al. [2015], using a larger amount of proxies and a more robust reconstruction technique. This new reconstruction shows more positive NAO phases for the period ca. 1150–1400 CE, probably associated with the

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strong volcanic activity during these years; it does not show, however, the strong NAO shift any longer.

Additionally, the authors find results of this record in agreement with the modelling study by Moreno-Chamarro et al. [2016]; in this study, in fact, most of the reconstructed changes in upper-ocean temperature and salinity, in sea ice conditions, or in wind field during the LIA, are explained by an abrupt weakening in the SPG alone, without invoking the NAO at all.

I therefore wonder the need to explain results from this study in terms of the NAO, if the connection might actually not be so clear, and if previous study have already found that changes could be driven by the SPG alone – of course, it was a modelling study, and it is said that all models are "wrong", but the study here under review is indeed supporting it so, why not building upon it?. For these reasons, I strongly suggest the authors to rethink the interpretation of their results.

REPLY

The role of the NAO in past ocean circulation and climate changes is still not very well understood by climatologists, and, therefore, the literature shows many articles with contradictory findings, which may lead to confuse interpretations of paleo-data. Ortega et al. (2015) improved the reconstruction of NAO during the last Millennium using a selection of 48 proxy records validated by model simulations. This article indicates that the previously published NAO reconstruction by Trouet et al. (2009), which shows persistent positive values for the MCA, was biased due to using only 2 proxy records and, thereby, all paleoclimate interpretations supported on this persistent positive NAO may be incorrect too.

In our article, we didn't mean to base all the interpretation on NAO reconstructions. Instead, we just wanted to link our conclusions about oceanic-atmospheric changes to other records of atmospheric patterns like the NAO. Our record shows an increase in the supply of Arctic Sea ice (inferred by the increase in HSG) associated with the en-

hanced storminess over Greenland (increase in Na+) inferred by Meeker and Mayewski (2002), which indicates changes in the atmospheric conditions in the Arctic and subarctic region. Therefore, we thought about a change in either AO or NAO conditions, but, as the reviewer said it is not necessary to invoke the NAO to interpret our results. The regional atmospheric changes inferred with the proxies may or may not be linked to NAO since we don't really know what is happening in the Azores High.

Following the reviewer suggestion we are going to reformulate our interpretation. Instead of referring to NAO, we will refer to changes in the atmospheric conditions in the Polar and Subpolar regions. Besides the findings of Moreno-Chamarro et al. (2016), a recent article about the Great Salinity Anomaly (Ionita et al., 2016) points to a linkage between atmospheric blocking events, Arctic ice export and freshening of the Labrador Sea. These modelling studies support our interpretations about atmospheric changes in the study area and Labrador Sea freshening. The linkage between the subpolar atmospheric conditions and NAO is out of the scope of this paper and, therefore, all the information regarding NAO will be removed. The NAO reconstruction will be also removed from figures 3 and 5.

Minor comments:

Abstract

L32 – What do you mean by "cooling events during the LIA"?

REPLY

We meant the cold episodes that comprised the LIA, because the LIA is not a single event. Within the LIA there are very cold decades and mild decades. This will be rephrased in the new text to clarify it.

4. Results

L191 – Have you tried the new reconstruction of volcanic aerosols in Sigl et al. [2015]? They have a better constrained of the eruption's timing plus distinguishing between

North Hemisphere, Tropical, and South Hemisphere eruptions

REPLY

Even though Sigl et al. (2015) presents a better chronology and more detailed reconstruction the record is very similar to Gao et al. (2008), at least for the major volcanic events. Also during the elaboration of the manuscript, we checked other sources in order to look for more regional eruptions but still there is no clear correlation with any significant eruption and therefore we believe the majority of the grains are transported by ice.

5. Discussion

L244 – Is there a more updated reference than Dickson et al. [2000] that shows this connection?

REPLY

We revised the sentence, and we believe the references (Mysak, 2001; Rigor et al., 2002) may be more suitable for that statement, so we will modify this.

L244 – I have a problem when you treat the Arctic Oscillation (AO) and NAO identically. Although the AO and NAO correlate, especially in winter, they are not identical. In this paragraph AO and NAO are treated as if they were interchangeable

L246 – Then, if such a strong event can occur under a negative NAO phase, why do we need the previous statement? These two sentences contradict each other, and in fact seem to suggest that a strong Arctic freshwater export (also sea ice) can occur under any NAO phase. Is that what you here mean? Does positive correlation here mean that a positive NAO phase leads to more export? Or less, because it is southward, hence negative? This is very confusing. Please, clarify (see above about the NAO role, anyway)

REPLY

Comments to lines 244 and 246: All references to NAO will be removed from the discussion to avoid misunderstandings and to focus on the effects of freshwater export to the subpolar area. The new text will only link our results to changes in the Icelandic Low and/or atmospheric conditions in the Arctic/subarctic regions.

L331 – This is interesting: would the freshwater input from these iceberg be large enough to trigger such a change? Is there a way to get an estimate?

REPLY

I am not a modeller, but I guess it is possible to give estimates of the freshwater transported by icebergs and sea ice based on information from present icebergs and the amount of IRD they transport. However, this calculation may take a lot of time and it may be better suited for a new paper. I would be happy to see a modeller calculating estimates for this, indeed it will be really interesting to see this calculations not only for the LIA but for Heinrich Events or glacial Terminations.

L348 – Could you please summarize the main finding of all these climate reconstructions in some sentences?

REPLY

These references show mineralogical evidence of ice-rafting and compare the ice-rafting frequency with other proxies that indicate the presence of sea ice and low salinity water in the region of Northern Iceland-Denmark Strait. They conclude that ice export from the Arctic is enhanced by the atmospheric conditions very likely related to the Arctic Oscillation.

L371 – I do not understand why this is an hysteris problem. Please, clarify

REPLY

Well, we just observe a lag between SPG weakening and Irminger current slowdown. Maybe the word hysteresis has a different connotation in the reviewer's field of work.

This will be rephrased to avoid misunderstandings.

L373 – This is interesting to point further: usually climate models that simulate past climates do not have enough resolution to characterize this sort of mechanism and, generally, do not put freshwater input from Greenland melting into the ocean. If the mechanism here proposed was actually at play, then the model might be missing a relevant source of freshwater that can potentially drive relevant climate changes, like the LIA. It is worth adding to the Discussion.

REPLY

We agree.

L385 – A more stratified water column also results from the upper-ocean freshening, because this reduces the seawater density, stopping convection. Such freshening can result from an increase of the Arctic freshwater export and from a reduced salt transport by the SPG [Moreno-Chamarro et al., 2016]

REPLY

We agree.

L404 – Is it possible to talk about “closely coupled” with the temporal resolution of the record presented here?

REPLY

For marine paleoproxies I think we can say they have a similar timing and therefore they are closely coupled.

L406 – There are already new reconstructions of volcanic eruptions and solar variability. Crowley [2000] is an out-of-date version, even for the CMIP5

REPLY

Instead of the volcanic+solar activity from Crowley (2000), the Global volcanic forcing

from Sigl et al. (Sigl et al., 2015) has been included in figure 5.

L409 – Maybe for other cold events in the Holocene, solar irradiance did indeed play a big role. For the LIA cooling, newest works suggest a dominant role of the volcanic forcing instead [e.g. Atwood et al. 2016]

REPLY

We will include this in the discussion

L438 – Here again the authors argue about the role of the NAO, having cited two lines before the work of Moreno-Chamarro et al. [2016], who actually found no role of the NAO in the LIA onset

REPLY

The NAO discussion has been removed

L443 – "first strong minimum of solar irradiance associated with the LIA (Wolf, _1300 yr AD)" The actual timing of the LIA defers very much in the literature, but it is usually given around AD 1450–1550. AD 1300 is actually rather soon for the LIA

REPLY

Well, that is why we wrote "associated with" and not "within the LIA". Anyway, we can rephrase this as "prior to the LIA".

L450–452 – This statement strongly needs a citation. If it is not the result of previous studies but a theory here proposed, then it should be rephrased to make clear that it is so, also suggesting some physical mechanism to support it

REPLY

Yes, this is our hypothesis. Based on the available data and our results we suggest a freshening of the Labrador Sea started well before the LIA started and could have been one of the factors triggering the LIA as suggested by the modelling study of Moreno-

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Chamarro et al. (2016). However, we are not suggesting this is the only driver of the LIA, but very likely a weak subpolar gyre enhanced the effect caused by other forcings, such as volcanic and solar irradiance.

References

Gao, C., Robock, A., Ammann, C., 2008. Volcanic forcing of climate over the past 1500 years: An improved ice core-based index for climate models. J. Geophys. Res. 113, D23111. Ionita, M., Scholz, P., Lohmann, G., Dima, M., Prange, M., 2016. Linkages between atmospheric blocking, sea ice export through Fram Strait and the Atlantic Meridional Overturning Circulation. Scientific Reports 6, 32881. Meeker, L.D., Mayewski, P.A., 2002. A 1400-year high-resolution record of atmospheric circulation over the North Atlantic and Asia. The Holocene 12, 257-266. Moreno-Chamarro, E., Zanchettin, D., Lohmann, K., Jungclaus, J.H., 2016. An abrupt weakening of the subpolar gyre as trigger of Little Ice Age-type episodes. Clim. Dyn., 1-18. Mysak, L.A., 2001. Patterns of Arctic Circulation. Science 293, 1269-1270. Ortega, P., Lehner, F., Swingedouw, D., Masson-Delmotte, V., Raible, C.C., Casado, M., Yiou, P., 2015. A model-tested North Atlantic Oscillation reconstruction for the past millennium. Nature 523, 71-74. Rigor, I.G., Wallace, J.M., Colony, R.L., 2002. Response of Sea Ice to the Arctic Oscillation. J. Clim. 15, 2648-2663. Sigl, M., Winstrup, M., McConnell, J.R., Welten, K.C., Plunkett, G., Ludlow, F., Buntgen, U., Caffee, M., Chellman, N., Dahl-Jensen, D., Fischer, H., Kipfstuhl, S., Kostick, C., Maselli, O.J., Mekhaldi, F., Mulvaney, R., Muscheler, R., Pasteris, D.R., Pilcher, J.R., Salzer, M., Schupbach, S., Steffensen, J.P., Vinther, B.M., Woodruff, T.E., 2015. Timing and climate forcing of volcanic eruptions for the past 2,500 years. Nature 523, 543-549. Trouet, V., Esper, J., Graham, N.E., Baker, A., Scourse, J.D., Frank, D.C., 2009. Persistent Positive North Atlantic Oscillation Mode Dominated the Medieval Climate Anomaly. Science 324, 78-80.

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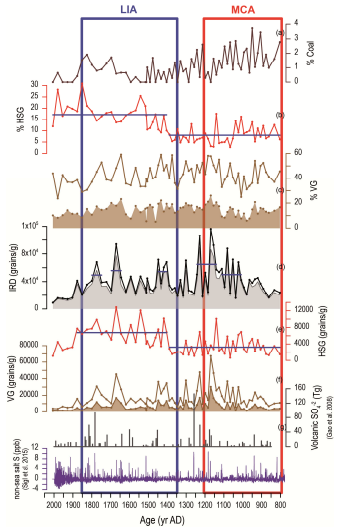

Figure 2. Ice-rafted debris (IRD) records from site GS06-144-03. a) Coal grains relative abundance; b) Hematite stained grains (HSG) relative abundance; c) total volcanic glass (VG) relative abundance (brown line) and white VG relative abundance (shaded area); d) total IRD concentration in each sediment sample (black line), and IRD concentration not including the white volcanic glass (shaded area); e) concentration of HSG; f) concentration of total VG (brown line) and white VG (shaded area); g) Northern Hemisphere sulphate aerosol injection by volcanic eruptions (after Gao et al. (2008), revised in 2012) and non-sea salt Sulfur from NEEM Greenland ice core (Sigl et al., 2015). Blue horizontal lines indicate mean values for the intervals they encompass. The approximate standard duration of the Little Ice Age (LIA) and Medieval Warm Period (MWP) has been shaded in blue and red respectively.

This figure is just to show the reviewer that even though the resolution is higher in Sigl et al. (2005) the main events occur at the same timing and there is no consistent linkage between higher concentrations of volcanic fragments and volcanic events. The final figure will include only Sigl et al. (2005) volcanic reconstruction.

Fig. 1. Revised version of figure 2

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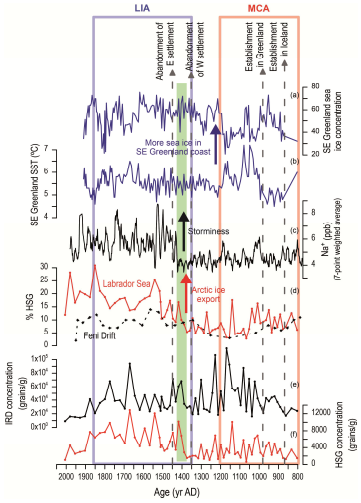

Figure 3. LIA shift at ~1400 yr AD (green vertical bar) in several records compared to site GS06-144-03 IRD records. a) SE Greenland April sea ice concentration (Miettinen et al., 2015); b) SE Greenland April se surface temperature (Miettinen et al., 2015); c) Na+ record from GISP2 (Meeker and Mayewski, 2002); d) HSG record from Eirik Drift (red line)and from Feni Drift in the NE Atlantic (black dashed line, Bond et al., 2001); e) total IRD concentration; f) HSG concentration. The main events in Norse colonisation and abandonment of settlements are depicted on the top of the figure, according to Ogilvie et al. (2000).

This is the new figure 3, where the NAO references have been removed

Fig. 2. Revised version of figure 3

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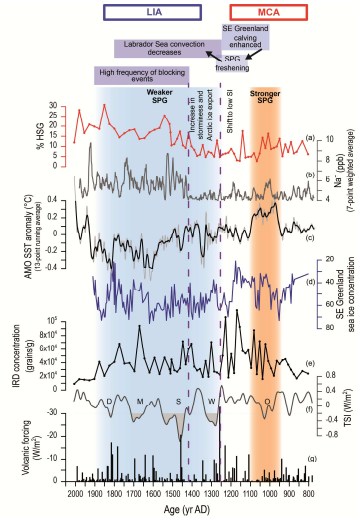

Figure 5. Sequence of events during the transition from the MCA to LIA and correlation to the potential forcings. a) Hematite stained grains (HSG) relative abundance at site GS06-144-03; b) Na+ record from GISP2 (Meeker and Mayewski, 2002); c) Atlantic Multidecadal Oscillation (AMO) SST anomaly (Mann et al., 2009); d) SE Greenland April sea ice concentration (Miettinen et al., 2015); e) total IRD concentration at site GS06-144-03; f) Reconstruction of total solar irradiance based on 10Be isotopes from ice cores (Steinhilber et al., 2009); f) Radiative forcing based on volcanic eruption reconstructions (Sigl et al., 2015). During the interval shaded in red SPG circulation was stronger, according to the interpretations of this work, whereas during the interval shaded in blue SPG circulation was weak. The letters in the solar irradiance record indicate the minima of solar irradiance named Oort (O), Wolf (W), Spörer (S), Maunder (M) and Dalton (D).

This is the new figure 5, where the NAO references have been removed.

Fig. 3. Revised version of figure 5