

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

**Anonymous Referee #1**

Received and published: 19 August 2016

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,

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to the cold conditions in the North Atlantic during the LIA.

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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.

Interactive comment

**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 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

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supporting it so, why not building upon it?. For these reasons, I strongly suggest the authors to rethink the interpretation of their results.

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Minor comments:

Abstract

L20 – Add comma before “modifying”

L24 – Is the core's exact geographical information, depth and complete name really needed in an Abstract? I would suggest a better use for the few Abstract words we usually have

L25 – “IRD . . . shows”

L25 – “higher” than? This happens several time throughout the manuscript. I suggest “relatively high”, for example, since a reference level is not defined to separate high concentrations from not so high

L30 – Acronym HSG is not used in the Abstract

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

L36 – “internal feedbacks” is here a bit vague. I do not exactly see what feedbacks we should think of

L37 – “Atlantic meridional overturning circulation”: I would say North Atlantic circulation, without further distinction

L38 – Add comma before “inducing”

L39 – Please, rephrase “volcanic input”

L38–40 – The fact that a cold North Atlantic climate during the LIA might have pre-conditioned it to be more sensitive to external forcing is not a direct result from this study, but a theory – which I do not see and agree with. It should be removed from the Abstract anyway

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## 1. Introduction

L59, and later on in the text several times too – One should be careful with such a statement. In general, the demise of the Norse Greenland settlements is seen as the result of a bad adaptation to environmental, socioeconomic, and cultural changes occurring at that time. I suggest reading Dugmore et al. [2012], for instance. This sentence, therefore, needs to be softened

L71 – “be the drives of” vs. drive

L76–78 – These results are based on a modelling study and could, therefore, be strongly model-dependent. I would suggest something like: “Freshwater input to this region can potentially reduced oceanic deep convection, slowing down the Atlantic circulation and its related heat transport [e.g., Born et al., 2010; Moreno-Chamarro et al., 2015]”. A few notes:

- deep convection and deep water formation in the end refer to the same thing
- oceanic deep convection, in contrast to atmospheric deep convection. It is worth mentioning it at least once at the beginning of the text
- Atlantic circulation better than Atlantic meridional overturning circulation. The former comprises the AMOC, the SPG, etc., which all contributing to the oceanic heat transport
- In Moreno-Chamarro et al. [2016] is was also shown this – but only affecting the SPG

L92–93 – Moreno-Chamarro et al. [2015] clearly showed the exact mechanism that drives such an impact. Worth adding the reference. The word “may” might thus be replace by “can”

## 2. Geological and oceanographic setting

L127 – Add comma after Labrador Sea

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L128 – Please, rephrase “usually”. In fact, the East Greenland Current transports about 90% of the total sea ice that goes out of the Arctic. It is hence more than usually

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### 3. Materials and Methods

L170 – Add comma before which

### 4. Results

L181–191 – Here “higher” without giving any reference is used several times

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

### 5. Discussion

L243 onward – Here, the NAO discussion begins

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

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)

L262 – “and hence” I do not see the causal connection. Since it is an interpretation

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of the proxy, shouldn't it be instead something like "... Icelandic Low in a way that the increase in ..."

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L305 – Add comma after "conditions"

L307 – "higher"

L320 – Please, rephrase "volcanic-solar downturns"

L327 – "sin" should also be italics, right?

L329 onward – Please, add the letter of the time series you refer after each "Fig. 4". This Figure contains a lot of information and it is difficult to find what you mean from the name and without any further help

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?

L335–339 – From the text, it is not clear whether this climate proxies support your conclusions. Please rephrase and clarify

L339 – "Denmark Strait data". Which one?

L345 – Rephrase "moreover" ("In agreement with this"?)

L345 – "climate proxies". Proxy per se does not mean much

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

L349 – Rephrase "remarkable" (anomalously?)

L358 – This is also found in Moreno-Chamarro et al. [2016] in the context of the last millennium

L359 – Actually, what matters then is that the freshwater input is in the Labrador Sea or in the Nordic Seas. The source may be irrelevant (SE Greenland or higher latitudes),

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as long as it affects deep water formation. Please, rephrase

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L364 – “Labrador Current”, “Irminger Current”, etc., like in Labrador Sea, Irminger Sea, etc.

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

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.

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]

L387 – “SPG”

L389–391 – Under negative NAO, the Icelandic Low is actually not so deep with a weakened winter circulation over the North Atlantic. Hence, it is more wavy and prone to atmospheric blocking situations

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

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

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]

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L418 – “internal and external forcings” should be external forcings and internal climate variability

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L424 – Please, rephrase “low volcanic forcing”

L431 – “which weakens the North Atlantic circulation” including AMOC, SPG, etc.

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

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

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

L457 – Please, add comma before “even though”

L462 – Please, add comma before “triggering”

L467 – See above about Norse Greenland settlements

## 6. Conclusions

L472 – “shows” “higher”

L485 – Remove comma after “MCA”

L488 – Change AMOC for North Atlantic circulation – a weak SPG also transports less heat

L489 – The arrival of less warm waters is essentially the reduced heat transport to the Labrador Region (and SE Greenland) from the previous sentence

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## Interactive comment

L491 – Please, rephrase “which and promoted”

L491 – “Cooling and freshening . . .” is again not clear whether it is a theory. In any way, it is not the result of this paper and should not go in the Conclusions

L496 – It is not a result of this paper how atmospheric blocking events boosted further cooling across Europe and Nordic Seas. It should hence not go in the Conclusions

L497 – “solar-volcanic-induced”

L498 – Again, the Norse issue

L504 – This sentence needs a citation

Here, I strongly encourage the authors to combine Discussion and Conclusions into one single section

Figure 5:

L771 – “correlation”. Let’s keep this word for statistical uses. Better, maybe, connection?

References

Atwood, A. R., Wu, E., Frierson, D. M. W., Battisti, D. S., & Sachs, J. P. (2016). Quantifying Climate Forcings and Feedbacks over the Last Millennium in the CMIP5–PMIP3 Models\*. *Journal of Climate*, 29(3), 1161-1178.

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Lehner, F., Raible, C. C., & Stocker, T. F. (2012). Testing the robustness of a precipitation proxy-based North Atlantic Oscillation reconstruction. *Quaternary Science Reviews*, 45, 85-94.

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Interactive comment on *Clim. Past Discuss.*, doi:10.5194/cp-2016-80, 2016.

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