

Besançon, the 8th/02/2016

Dear Editors,

We would like to thank the Professor Francus for its constructive comments on our paper untitled: “*Impact of Holocene climate variability on South Greenland lacustrine records and human settlements*”. Please find below a detailed list of changes and replies. We have precisely answered and discussed all the issues raised by the Professor Francus. In a future version of this article, most of these comments will be taken into account.

We hope that these responses will meet to your expectations.

We are looking forward to receiving your comments and decision.

Sincerely yours,

Typhaine GUILLEMOT

Responses to Professor Francus

MAJOR & MODERATE COMMENTS

General

1- Scientific methods are fine, although one may argue that diatoms content – if any, may have biased the grain-size results.

You are right, biogenic silica may have biased the grain-size results. Nevertheless, we don't have measured the biogenic silica or the diatoms content in the sediments of Lake Qallimiut and Lake Little Kangerluluup. However, the microscopic observations of the thin sections realized in the two cores don't revealed higher proportions of diatoms. The coarse silicate fraction seems to be preferentially link to the mineral matter. Moreover, in a closer lake (Lake Igaliku), the Si/Ti ratio are compared to diatoms content and showed "no significant linear relationship between diatoms concentrations and mineral matter, indicating that most of the silica in the sediment is of mineral source" (Massa et al., 2012).

2- Assumptions should be better supported by present day observation, e.g. the processes behind the formation of laminae.

Unfortunately, only one lamina is recorded over the last fifty years when meteorological data are available. In consequence, it is difficult to establish precisely the processes behind the formation of these laminae (snow-melting, storms...). Moreover, this lamina is thin (only 0.5 cm), making it hard to determine the potential seasonality of this event.

3- The occurrence frequency of floods seems to be statistically weak (5 periods of high floods characterized by 10 events only).

Actually, there are five periods of high floods characterized by 37 flood events. However, you are right, it could be statistically weak. This is why we have decided to make a chronological approach in the new version of the discussion. Actually, we do not talk about five distinct periods of flood events but we describe chronologically the presence or absence of flood events and we explain it with the climatic parameters found in the literature.

- 4- **The interpretation relies a lot of comparisons with other records. These comparisons are not convincing because the type of records are different, and their location is not close to the sites investigated here (which is quite important for flood record). Moreover the comparisons are only qualitative. Finally the records are not at the same time resolution.**

Yes, you are right. On the last four millennia, the types of records are located in the North Atlantic and not locally, on South Greenland (excepting the glacier advances). Moreover, they don't have the same resolution. Nevertheless, even if they are different, we cannot deny that our record matches with these parameters, meaning a regional forcing. Actually, we try to obtain the data to make some correlations between our record and the other parameters. The first results show a quite good correlation between Greenlandic flood events and the solar irradiance.

For the last millennium, we already have compared the occurrence of floods with Greenlandic climatic records. To make quantitative comparisons, we try to have all the data to realize correlations between all the records too.

In the text

- 1- **Line 19, page 5402: Are they really global? Many authors argue these changes exist, but are not necessarily synchronous (e.g. Wanner et al, 2008 QSR) except for the LIA that seems to be more synchronous. Many authors define the LIA as cold period between 1250 and 1850 AD (e.g. Miller et al, 2010 QSR and Wanner et al, 2008, QSR).**

Yes, you are right, the rapid climate changes are discussed in many articles. However, we choose to make large intervals for the rapid climate changes, which are supported by many climatic articles (Van Geel et al. 1996; Bond et al. 1997, 2001; Mayewski et al. 1997, 2004; Bianchi and Mc Cave, 1999; Mc Dermott et al. 2001; Sicre et al. 2008; Walker et al. 2012; Martin-Puertas et al. 2012; Magny 2013...)

In addition, we re-phrase the last two sentences of the abstract to point that it still debated and the rapid climate changes recorded may have influenced local to regional Human settlements.

- 2- **Line 20, page 5407: What do you mean “in whole sediment”?**

Actually, we did not realize XRD analyses on the clay fraction but on bulk sediment. We corrected as follow “X-ray diffraction (XRD) analyses were carried out in bulk sediment...”

- 3- **Line 5, page 5408: No treatment for Biogenic silica?**

No, there is no treatment for biogenic silica. See the remark #1 in the section “General” in “MAJOR AND MODERATE COMMENTS”

- 4- **Lines 9-10, page 5410: I suggest to be more cautious here as the error is large.**

Yes, you are right. To be more precise in the chronology of the two lakes, we discuss only about the last 50 years which are well constrained by the age-depth models.

- 5- **Lines 4-9, page 5412: These values are biased because they depend of the resolution of each sensor and the size of each sub-sample. For instance, the grain-size of the thickest lamina looks to be the coarsest, but that the sample might be entirely composed of coarse material, while a lamina that is 0.1 mm thick might be composed of 20 % of coarse material and 80% of background material. A second example is the density measured by Gamma Ray. The sensor resolution is about 4 cm, hence the measured density is not representative of the lamina itself.**

Yes, you are right, values are biased because of the resolution of each sensor and the size of each sub-sample.

In this paragraph, we have tried to define common features of these laminae. To do that, we first based on the thicker laminae (> 0.5 cm). They represent almost 60 % of the total identified laminae. Then, we have looked thin laminae (< 0.5 cm) and we noticed similar properties.

Moreover, concerning the sediment of Lake Qallimiut, a lot of measured parameters have a resolution well-adapted for the thin laminae presents. For the Lake Little Kangerluluup, all the laminae are enough thick (centimetrics) to solve the resolution problem.

- 6- **Lines 14-16, page 5412: This is a little bit stretch: since these laminations are so thin (and you do not have thin-section for that), you cannot be really sure that all of them are normally graded, and therefore representing the same kind of events.**

Yes, you are right, it is not possible to make a thin-section for each laminae to verify their sedimentary structures and to be sure that all of them are normally graded. However, we have firstly observed the thicker laminae to be certain that the analyzed sediment is typical of the lamina and to determine their common geochemical and physical signatures. Then, we have looked the thinnest laminae. They show similar responses, meaning their similar origin.

We do the same to identify the sedimentary figures: we have made a thin section in the thicker lamina to be sure that the structure observed is characteristic of this event and then, we extrapolate its sedimentary structure on the others laminae because they have the same geochemical and physical signatures.

- 7- **Lines 1-2, page 5414: Same comment than above, i.e. do you think all laminations have a similar structure?**

See the two answers above (#5 and #6)

- 8- **Lines 5-6, page 5414: No idea why these laminations have different colors?**

These laminae show similar carbon organic content and we identify similar organic particles. So their different colors (identify by spectrocoulometric measures) seem to be explained by their different quality of organic matters. However, it needs to be confirming by Rock-Eval analysis.

- 9- **Lines 23-26, page 5414: This is logical and valid interpretation. However, it is not the only possible interpretation. Indeed, delta front failures (due to oversteepening of the delta) have also been reported to produce hyperpycnal flows (e.g. Girardclos 2007). I suspect the signature of these laminae to be similar to the ones due to flood events. I'm not saying this is the case, but this should be mentioned as an option.**

Yes, you are right. We cannot exclude this possibility and we have added this option in the text. However, the adequacy between these events and the climatic records indicates that the delta front failures have minor impacts in the sedimentation.

10- Lines 4-6, page 5415: Maybe it is true, but they have different colors. You should at least have an idea why this is the case.

See the answer #8 just above.

11- Lines 13-14, page 5415: which are +/- 160 and 200 years. It could be nice to at least discuss the temporal accuracy of this analysis.

Yes, you are right. We have adding a small paragraph to discuss the temporal accuracy of the two age-depth models.

12- Line 15, page 5415: I wonder if it is valid to claim that there are 5 periods of high flood frequency in a record where only 10 events are reported. The occurrence (of non occurrence) of such events would dramatically change the results. This is critical because storms are localized events and do reflect the local climate. I think it would be much safer to just saying that floods frequency increased during the last millennium. Due to the local character of flood events, I guess the best way to go is to stack the two records together.

Yes, you are right. Please see the response #3 in “General comments”.

Of course, Lake Qallimiut and Little Kangerluluup flood frequencies are synchronous and we can stack these two records together. However, we think that it is important to show that the two records are correlated before adding a figure with only one signal of flood frequency.

13- Lines 22-25, page 5415: Each curve should be labelled a, b, c...Furthermore, these curves should also be smoothed to the same 250-year window to make them comparable to your dataset. I find these correlations rather difficult to believe. The second coolest event in D’Andrea curve is around 2000 cal BP, a period without any event. Arctic glaciers advances records are from several places that are not necessarily representing the climate on South Greenland. Moreover, one should discuss what these records are meaning, i.e. are they really meaning a cooler, and/or a wetter climate. The North Atlantic ice-rafting events of Bond et al, 2001, is the stack of 4 records from 2 sites in the Atlantic ocean (of shore Ireland and Newfoundland) that used to look at the climate cyclicity during the Holocene, but I have some doubts this is a record of temperature or moisture against which you can compare your record (unless authors come up with good arguments).

Yes, you are right. Once we have all the data we will smooth all the curves to the same 250-year window. Then, we will make quantitative comparisons to better support our results. To assure the visibility of this figure, we have labelled and classified each curves according to their geographical proximity (from local to regional, to global signals).

We have revised the organisation of the discussion. First of all, we discuss about the sedimentary events and their possible origins (climatic and/or anthropogenic) in a section #5.1. Then, in the section #5.2, we focus on the last millennium, when flood events are compared to Greenlandic parameters, previously defined. In this part, we separate different periods of time to explain precisely the origin of flood events (the type of climate, the presence of agropastoral practices influencing the sedimentary responses... see the response #3 in “General comments”). We do the same work in the section #5.3, with a larger time-scale (during the late Holocene) and larger spatial-scale (using regional to global climatic parameters). Finally, in the section #5.4, we explain the potential influences of these climate changes (identified thanks to flood events) on local to regional Human

settlements.

During 2000 cal BP, we do not have recorded any flood event maybe because this is a cold and dry period (no glaciers advances and low ice-rafted debris).

The representation of the Arctic glaciers advances contains the advances of South Greenlandic glaciers. In the figure we highlight and complete it with new data concerning South Greenlandic glaciers advances (Balascio et al. 2015). Actually, the South Greenlandic glaciers represent directly the local climate. Moreover, we can noticed that a glacial advance in South Greenland is also visible in Iceland and in Baffin Island.

Yes, you are right, we provide two paragraphs in the new version where all the climatic parameters found in literature are defined.

14- Lines 2-3, page 5416: Please explain this part of sentence “associated to increased summer ice and snow-melting episodes”.

Flood events occur during different kinds of climate periods, especially during a hot and wet climate. Here, flood events preferentially occurred during global cold and wet periods. Cold and wet periods allow creating an important stock of snow. During these global cold and wet climatic periods, some days of warmer conditions make it possible snow-melting episodes, provoking flood events.

15-Line 3, page 5416: If it is colder, then there is no intense rainfall because precipitation is snow. I find this not compatible. Maybe authors are correct but they should spend more time to demonstrate this is correct, maybe with some present day instrumental data.

Please see the response just above (#14).

As we said before (#2 in general comment), it is not possible to compare with present day instrumental data because only one flood event occurs during this period and the sediment accumulation rate is too small to provide information about the seasonality of this event.

16-Lines 4-9, page 5416: This is quite contradictory. Authors claim that the flood events are occurring during cold and wet episodes, but here one needs warm or even “hot spells” to create the floods. The cited reference is valid for a watershed that is linked to the GrIS, which is not the case for the site investigated in this study.

Please see the three responses above (#13, #14, #15).

We understand that the cited reference is valid for a watershed linked to the GrIS. However, we can imagine that locally, with a sufficient stock of snow, few days of warmer temperatures could create episodes of important snow-melting, provoking flood events. Obviously, in the Lakes Qallimiut and Little Kangerluluup catchments, it is not possible to create a rupture of a glacier ice dam because there are not link to the GrIS.

17-Line 11, page 5416: This is quite strangely expressed. When saying there is a solar forcing, one would expect that it is positively linked to solar irradiance. Maybe re-phrase this sentence.

Yes, we re-phrase this sentence. Actually, we highlight that flood events are preferentially driven by solar forcing. They occur preferentially during solar minima. This means that solar minima could be also considered as wet periods. This is already observed and discussed in Simonneau et al. 203 (The Holocene).

18- Lines 15-25, page 5416: I find these correlations not convincing at all. These are very different kind of records from the Northern Hemisphere. They are highly hypothetical and if authors want to keep these interpretations in the text they should come up with stronger evidences or explanations.

Please see the responses above (#4 in general comments and #13, #14, #15 just above).

19- Line 15, page 5417: This is odd to mention a solar minimum here if you want to show this is happening during a warm period.

Yes, you are right. However, there is also a solar minimum during this global warm period. This shows, as I said two responses above (#17), that solar minima not especially correspond to cold periods but potentially to wet periods too. Furthermore, we show all the flood events associated to this forcing in the same way during the last four millennia.

20- Lines 18-19, page 5417: Thickness should be normalized because the two lacustrine systems do not react the same way.

Yes, you are right but we don't compare the Lakes Qallimiut and Little Kangerluluup flood deposits thickness between them. We just highlight that the thicker lamina of Lake Little Kangerluluup is present during the Norse settlement. As we already know that there is some anthropogenic pressure around this lake during the Middle-Ages, the thickness of this deposit could be influenced by the agropastoral activities (because of the soil destabilization for example).

21- Lines 1-2, page 5418: Or it can also be explained by the geomorphology of the lake.

Yes, you are right, the geomorphology of the lake can influenced the flood events too. However, we don't think that it can change during the period of time studied.

22- Lines 3-12, page 5418: So what is the pertinence of this paragraph if the records cannot tell anything about the recent decades?

We think that it is important to tell that the sedimentation of Lake Qallimiut and Little Kangerluluup is mainly driven by climate changes because, in the last decades, when the anthropogenic pressure is higher, we do not record any impact due to agropastoral activities. Maybe this paragraph is not well placed, we can put it in the section #5.4 when we discuss about the interactions Climate changes/Human settlements.

23- Lines 26-29, page 5419: Again, prior to use these records in the discussion, one needs to better explain what these records means.

Yes, you are right, we write a paragraph to explain what each record means (please see the response #13 just above).

24- Line 24, page 5420: To keep this conclusion here, you need to provide better arguments (see my comments above).

Please see the responses above (#4 in general comments and #13, #14, #15 just above).

25- Lines 8-9, page 5421: Well, here I'm not convinced at all, present day monitoring and a better understanding of the lacustrine and watershed systems is needed. Moreover, I suggest to look into the present day teleconnections to see if the sites are indeed correlated to location of the records with whom a comparison is made.

Recently, there is no local monitoring concerning flood events. There is only one reference already cited in a watershed connected to the GrIS (see the answer #16 just above). Moreover, it is not possible to compare the flood events recorded in Lakes Qallimiut and Little Kangerluluup to meteorological data as we already said (answers #15 and #2 in general comments).

26- Lines 9-10, page 5421: This is indirect evidence, I'm quite sure historians or archaeologists will have a different view on this.

Yes, you are right, we have to re-phrase and moderate this conclusion. However, the climate impacts on Human settlements are now well admitted by historians and archaeologists (Mc Govern, 2000; Edwards et al. 2007; Antunes et al. 2014) because they limit the accessibility to food, especially in the Arctic zone.

In the figures

1- Table 1: Why not providing the ^{13}C information provided by the labs?

We do not think it is necessary because all the radiocarbon dates are made from terrestrial remains. However, we can add this information in the Table 1, if you and the other reviewers judge it necessary.

2- Figure 2: It would be nice showing the ^{226}Ra values to provide an estimation of the non-supported activities. I wonder why only one sample was measured below the Cs peak: one sample is not enough to make sure that the background noise is reached.

We don't illustrate the ^{226}Ra because it is stable in both lakes (~100 bq/k in the sediment of Lake Qallimiut and ~150 bq/k in Lake Little Kangerluluup). However, we can show these values in the section "Supplementary data" if you and the other reviewers judge it necessary.

Other samples were measured below the Cs peak (six in total). However, we do not show them because at this depth, the non-supported Pb reached a threshold closed to zero.

MINOR COMMENTS

In the text

- 1- **Title: Impact of climate variability is likely, but not demonstrated. I would be more cautious in the title.**
We propose another version of the title like:
“Late Holocene lake flood records and human settlements in South Greenland”
- 2- **Line 3, page 5402: try to avoid repetition.**
Yes, we correct it.
- 3- **Line 12, page 5402: Replace « events » by occurrence.**
Yes, we correct it.
- 4- **Line 16, page 5402: I’m not sure it is pertinent to use the abbreviation RCC for this. It is not used that often and it makes the text less easy to read.**
Yes, we correct it if you think that it makes the text easier to read.
- 5- **Line 5, page 5403: Delete « and their influence on past Human societies ».**
Yes, we correct it.
- 6- **Line 8, page 5403: Add « a portion of ».**
Yes, we correct it.
- 7- **Line 13, page 5403: I suggest using « GrIS » instead of « GIS », because the latter also mean Geographic Information System and is very often used.**
Yes, we correct it.
- 8- **Line 25, page 5403: Use from instead of « on ».**
Yes, we correct it.
- 9- **Line 27, page 5403 and in line 7, page 5404: GrIS.**
Yes, we correct it.
- 10- **Line 1, page 5404: This study aims at reconstructing the global climatic variations in high resolution.**
Yes, we correct it.
- 11- **Line 2, page 5404: through.**
Yes, we correct it.
- 12- **Lines 13-14, page 5404: with mean annual temperatures of 0.9°C, yearly precipitations of 907 mm.**
Yes, we correct it.
- 13- **Lines 20-21, page 5404: Two main tributaries feed the lake on the north-west and the east shores respectively, while a single outlet flows directly.**

Yes, we correct it.

14- Line 13, page 5405: directly drained.

Yes, we correct it.

15- Line 16, page 5405: similar to.

Yes, we correct it.

16- Line 18, page 5405: only one river.

Yes, we correct it.

17- Line 3, page 5406: nomadic.

Yes, we correct it.

18- Line 11, page 5406: and still are present today (Gullov 1983, 2004). Thanks to recent global warming.

Yes, we correct it.

19- Line 20, page 5406: Two cores were retrieved during the summer 2011 in the deepest part of each lake basin (26 m for Lake Qallimiut and 6.4 m for lake Little Kangerluluup), using a UWITEC gravity corer: QAL-2011 (118 cm long) and LKG-2011 (109.5 cm long).

Yes, we correct it.

20- Line 7, page 5407: with a millimetre resolution.

Yes, we will correct it.

21- Line 23, page 5407: was placed.

Yes, we correct it.

22- Line 24, page 5407: was realized.

Yes, we correct it.

23- Line 2, page 5408: This is quite contradictory: a 0.5 cm thick slice implies a regular sampling while “based on X-ray to provide homogeneous samples” implies irregular sampling.

Yes, we re-phrase it.

24- Line 4, page 5408: delete “therefore”.

Yes, we correct it.

25- Line 18, page 5408: Vario MAX

Yes, we correct it.

26- Line 5, page 5409: radiocarbon dates perform on terrestrial plant macrofossils.

Yes, we correct it.

27- Line 20, page 5409: It is not clear in Fig.2 where such event has been removed from the age model.

We put some cross in the vertical axe to highlight the flood events.

- 28- Line 16, page 5410: mm/yr.**
Yes, we correct it.
- 29- Line 21, page 5411: This is not really visible in Fig. 3A. The grain-size distribution plot does not show that. To convince the reader, maybe should you add the curve of the mode on top of this plot?**
We replace the grain-size distribution plot to the curve of the mode.
If we add it in addition to the grain-size distribution plot, the figure could be less visible.
- 30- Line 21, page 5411: delete “a maximum of”.**
Yes, we correct it.
- 31- Line 24, page 5411: Do you mean in the white laminae or in the background sediment? Try to be more specific. Reading next page I understand it is the background sediment.**
Yes, you are right, we re-phrase it.
- 32- Line 11, page 5412: thickest.**
Yes, we correct it.
- 33- Lines 4-5, page 5413: density is around 1.1 g/cm³, Ti content reach values of 6000 peak area; TOC mean value is c.a. 10% and TOC/TN ration around 14.**
Yes, we correct it.
- 34- Line 8, page 5413: a darker and coarser part.**
Yes, we correct it.
- 35- Line 9, page 5413: Again, these modes are not visible in Fig.4 and should be displayed somehow.**
Yes, you are right, we do it.
- 36- Line 11, page 5413: 1.2 g/cm³**
Yes, we correct it.
- 37- Line 25, page 5413: thicker.**
Yes, we correct it.
- 38- Line 9, page 5414: a rise of the particle grain-size.**
Yes, we correct it.
- 39- Line 12, page 5414: high TOC/TN ratio, a mineralogical composition of granite, both resulting from the reworking of detrital inputs from the catchment area and a predominance of rAP and LCF particles.**
Yes, we correct it.
- 40- Line 11, page 5415: 250-year.**
Yes, we correct it.
- 41- Lines 17-21, page 5415: Maybe indicated these phases on Fig. 5.**
Yes, we can do it to better visibility.

42- Line 7, page 5417: LIA defined as the period between AD 1300 and AD 1900 in the abstract. Authors should be more consistent.

Yes, we correct it.

43- Line 13, page 5419: Please try avoiding repetition of the same word on the same sentence.

Yes, we correct it.

44- Line 4, page 5420: Only one occurrence, there is no need for an abbreviation.

Yes, we correct it.

45- Line 11, page 5420: the rapid climate changes.

Yes, we correct it.

46- Lines 19-20, page 5420: The way it is written, we may think that 37 flood events have been recorded in each sequence, which is not the case.

Yes, we re-phrase this sentence.

In the figures

1- Table 1b : calibrated

Yes, you are right, we correct it.

2- Figure 1c: dots

Yes, you are right, we correct it.

3- Figure 3: This might be a little larger. Picture is not very clear.

Yes, we correct it.

4- Figure 4: Same comment than Fig.3.

Yes, we correct it.

5- Figure 5: Put your record on top (or bottom) of the figure and then divide the figure in a, b, c...for clarity.

Yes, we correct it.

6- Figure 6: Please identify each curve with a, b, c...

Yes, we correct it.