

Besançon, the 8<sup>th</sup>/02/2016

Dear Editors,

We would like to thank the anonymous reviewer 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 anonymous reviewer. 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 Reviewer anonymous #2

### General Comments

- 1- While I think the authors provide a very interesting and technically sound data set, I don't believe that their conclusions are warranted based on the evidence. More specifically, I think the authors are over-interpreting their data in the time domain – that is to say, I don't think the so-called “flooding intervals” can be interpreted at such fine time scales, due to the scarcity of events detected in the cores.**

The flooding intervals are based on a statistical calculation of frequency realized in the K1D software. Because the mean error of the two age-depth models is around 200 yr, flood frequencies are then smoothed over a 250-year moving window. Considering this time resolution and the quite good identification of our sedimentary events, it is possible to work on pluri-centennial time scale.

Thanks to this graphical representation, it is possible to define different clusters of flood events, synchronous to global climatic periods (Middle to Late Holocene transition, Sub-boreal/Sub-Atlantic transition, Medieval Warm Period and Little Ice Age).

We take into account this comment to the next version of this article. Instead of define different flood intervals, we make a chronological description of the Fig. 5 and Fig. 6 (see responses to the Prof. Francus comments). In this new approach, we identify the presence or absence of flood events and we explain these events thanks to the climatic parameters obtained in the literature, at a local scale to a global scale.

- 2- I also don't think the discussion follows logically from the data set. The human settlement and climate-human interaction discussion takes up the largest part of the discussion section, however it is a review of discussions found elsewhere in the literature (and cited by these authors), rather than being a direct outgrowth of the new dataset. Because of this, the discussion feels contrived and does not really add any value to the paper, nor does it add new information to the overall understanding of climate-human interactions on Greenland during the late Holocene.**

The discussion in this article is written on a total of six pages and the part “climate influences on Human settlements” concerns only two pages. So, it doesn't take the largest part of the discussion section.

Yes, you are right, we are based on some articles to write this part, especially on D'Andrea et al. 2011 concerning the impacts of climate changes on Paleo-Eskimos culture. However, it is interesting to note that we record similar results.

We propose new results in this part concerning the Norse settlement. For the first time, an inventory of radiocarbon dates is made on Norse sites, revealing the dynamics of this population in South Greenland. We can see the colonization between AD 950 and AD 1100 (with a rise of the radiocarbon dates), a slight deprise of the landscape between AD 1100 and AD 1200 (with a slight drop of the radiocarbon dates), a recovery between AD 1200 and AD 1300 (with a second rise of radiocarbon dates), and the final abandon of the Norse, beginning in AD 1300 (with the drop of radiocarbon dates until zero). For the first time, we have observed a slight deprise of the landscape by the Norse between AD 1100 and AD 1200, synchronous with numerous flood events and glacial advances recorded by Young et al. 2015 in their new article. This could attest to a slight climate deterioration in South Greenland during the Medieval Warm Period, probably affecting the Norse. So, this is very important to highlight it. In the new version of this paper, we particularly insist on this point.

- 3- I do not think that the paper in this form is suitable for CoP, but I think that the authors should rewrite it and send it to a more specialized sedimentological or paleolimnological journal where the physical and chemical attributes of the flood deposits can be discussed in more detail (I think this is to be the greatest value of the manuscript), and the human settlement discussion can be minimized, if not eliminated entirely.**

It is possible to see in the website of Climate of the Past: “Climate of the Past (CP) is an international scientific journal dedicated to the publication and discussion of research articles, short communications, and review papers on the climate history of the Earth. CP covers all temporal scales of climate change and variability, from geological time through to multidecadal studies of the last century. Studies focusing mainly on present and future climate are not within scope. The main subject areas are the following: - reconstructions of past climate based on instrumental and historical data as well as proxy from marine and terrestrial (including ice) archives; [...]”. In this paper, we identify flood events on South Greenlandic lacustrine sediments during the last four millennia. Flood events give information about temperature and humidity conditions. So, with our data, it is possible to reconstruct past rapid climate changes at a pluri-centennial scale in South Greenland, and potentially, in the North Atlantic. This is in total agreement with the text underlines just above and written in the website of CP. Moreover, there is recently a special issue in CP named “Climate change and human impact in Central and South America over the last 2000 years”. Except for the geographical area and the period, we have exactly the same key words in our article and in our title. For all these reasons, we think that this work is well adapted for CP.

The physical and chemical attributes of the flood deposits is only a part of this paper. The main idea of our article is to highlight that south Greenlandic flood events corresponded to global rapid climate changes, impacting local Human populations.

- 4- While I understand the inclination to bring a human dimension to paleoclimate investigations, particularly in this region where the Norse settlement was so dense and the footprint so large, I do not think this is necessary in all cases – and in this case the archaeological discussion detracts from the sedimentological value of the study.**

Please, see the response #2 above.

In this paper, we bring new data concerning the Norse settlement in South Greenland. However, we slightly change this part to clarify it. Indeed, we especially focus on this Norse period to put in the spotlight our new data.

This part doesn't detract the sedimentological value of the study because they are separated in different sections inside the discussion.

- 5- In summary, I think these data will make a fine scientific contribution, just not to CoP in the manner they are presented in this manuscript.**

Thank you. Please see response #3.

### Specific comments

- 1- You often refer to “global” climatic variations and “global” glacier advances, but the evidence for synchrony in glacier behaviour and climate during this time certainly indicates they are not global. I suspect you mean “regional”, but even there, it is controversial whether there were synchronous climate changes during centennial-scale intervals of the Neoglacial. The spatial teleconnections are such that we don't expect the entire Arctic to cool in concert during abrupt events. If your discussion is to argue for synchrony regionally, you will need to include the datasets that you think demonstrate this synchrony. Also, please note that there are “synchronous” climate changes that are not necessarily the same in sign, due to spatial patterns of climate variability associated with climate transitions. Thus, you will not find warm temperatures during the Medieval Climate Anomaly everywhere and you will not find cold temperatures associated with the LIA everywhere.**

The expression “global glacier advances” is a mistake, we talk actually about “North Atlantic glacier advances”. It is changed now.

Please see the response #1 in general comments. We clarify the discussion with a new organization. We don't point flood periods but we make a chronological approach. In a first part, we focus on the last millennium to identify the climatic conditions responsible of flood events thanks to local climate records. Then, in a second part, we do the same work but during a larger time scale (on the last four millennia), using regional to global climatic data.

We are conscious about the different kind of impacts occurring during the same climatic event at various spatial scales. However, in this case, we identified past climate changes in South Greenland which apparently work with North Atlantic climatic parameters, underlying a global climatic signal recorded in Lakes Qallimiut and Little Kangerluluup sediments.

**2- You refer to the lakes in this study as proglacial, but I don't see glaciers in the catchments.**

Yes, you are right. They aren't glaciers in the two catchments. When we said that these two lakes are proglacials, we would say that they have a proglacial origin. It is now corrected in the text.

**3- In the flood frequencies discussion you have identified 5 periods with increased flood frequency. This is not reasonable. Looking at the record of flood events, I think you can convince me that the period from 2000 to 1200 yr BP had no flooding events, the period from 1200 to present had many, and the period from 4 to 2ka had some. To cut the record down into finer temporal units than this is not possible. The most striking aspect of the flood data is the LACK of floods between 2ka and 1.2ka. This is very interesting, and seems to be a robust feature of your records. You might want to consider why the interval 2-1.2ka might be different in S Greenland than the millennia preceding and following this interval.**

For the characterisation of the five flood periods, please see the responses #1 in general comments and #1 just above.

Concerning the period between 2 ka BP and 1.2 ka BP without flood events, you are right, we haven't discussed about it. In the new version, we take it into account to complete our argumentation. Dry conditions (no glacial advances and low ice-rafter debris) could explain it.

**4- Figure 5. You don't need the TSI record on here. You also don't need to discuss solar forcing and volcanic forcing unless you have some explanations for how these forcings would lead to changes in flooding frequency. Unless you can explain this mechanistically, I think you should primarily report this as a record of flooding and have only a small discussion about the potential links to larger scale climate changes (again, at the millennial scale, rather than centennial)- this is all very speculative and tenuous in the way it is written right now.**

We observe similar variations of the flood frequencies and the solar irradiance, indicating global climatic mechanisms. We have supported it by statistical analyses in the new version. However, you are right, we have to propose some explanations for how these forcings work in our future text.

The time resolution of the two age-depth models allows us to study these variations at the pluri-centennial scale.

- 5- The associations that you cite in the text between the different climate records plotted on Figure 5 are not clear at all. I do not look at those records together and see synchrony. Therefore, the basin premise of your conclusion, that the floods occur at times when other records all show a clear picture of change that is well understood, is faulty.**

We currently try to obtain the data of the climatic parameters what we use in the paper. Once we have it, we will make statistical tests to highlight the correlation between the different climatic records. Moreover, the chronological approach in the discussion clarifies our interpretations.

Yes, you are right, we have to re-write the conclusion to moderate our interpretations.

- 6- You mention the average age-model error is 200 year. How is this determined?**

We have made the two age-depth models with the software R<sup>©</sup> and the CLAM package. At different depths and according to a chosen sampling step, this procedure gives us the minimal and the maximal age. It also calculates the best age considering the error of each date and the kind of interpolation. So, it is possible, thanks to a subtraction between the maximal and the minimal ages, to obtain the age-model error at each depth. Then, we have just realized a mean between all the age-model errors calculated. To have more details about the age-model error all along the two cores, please look at the Table 1 and 2.

- 7- The discussion in section 5.2 is so speculative that it is not really of much value for the paper. Here you are trying to build a case for how cold conditions could lead to increased flooding. This is great, and you should build that case, but I think you'll need a more thorough discussion of this. Also, this discussion is based on the 5 units of increased flooding, which I think is too fine temporally to discuss.**

We have re-write the discussion in the new version of the article. Please see the responses #1 in general comments and the responses # 1 in specific comments.

- 8- In section 5.3 you bring up the important point that farming practices by the Norse may impact the flood record. Is this true? Can it be evaluated in any way? If this is the case, then this is quite problematic for ascribing the floods after 1200 yr BP to a change in climate, rather than a change in land use initiated by the Norse.**

The maximum of flood events is recorded during the Medieval Warm Period when we know that the Norse are present and developed agropastoral activities in South Greenland. It is the first time in our record that we have identified flood events during a global warm (and not particularly wet or dry) period. Similar climatic conditions are observed during the Roman Warm Period and no flood events are recorded. Moreover this period is also characterized by no human and no agropastoral activities in South Greenland. Thus, we can explain that the Norse agropastoral activities have perturbed the soil stability during the Medieval Warm Period and amplified the sedimentary responses of flood events in the two studied catchments. In the catchment of Lake Little Kangerluluup especially, there are numerous agropastoral Norse sites, highlighting important local agropastoral practices.

However, it is not possible to estimate the different effects of climate changes and human practices on the sedimentation. So, evaluating the anthropogenic impact of farming practices in the flood events is not possible here, considering only the sediment archives.

Outside the Norse settlement (AD 986- ca. AD 1450) and the last century, there is no agropastoral practices in South Greenland and more generally, there are no important anthropogenic impacts in this region. Thus, it is possible to only have a climatic record in the sediment outside of these two periods of Human impacts. This is why South Greenland is particularly well-adapted zone to study the interactions between climate/Human and environment.

- 9- It is not quite so clear that climate change was the main trigger for the abandonment of Greenland by the Norse. The archaeological literature has wide ranging discussions concerning the role of trade networks and social interactions, and pressure from the Thule culture. Also, a new paper by Young et al in Science Advances in Dec 2015 challenges the idea that there even were cold conditions during the end of Norse occupation that were any different from the temperatures when they arrived. Thus, it isn't a simple story that climate changes of the LIA led to the demise of the Norse in Greenland. I'll reiterate here that I think you can leave this discussion of the human settlements out of the paper anyway.**

Yes, you are right, many factors interfere when a population leave a region. We complete this part of the discussion to list them. However, it is well-accepted that climate variations are one of the factors responsible of the population movements, especially in the Arctic. Indeed, this is a very sensitive region to climate changes and the smaller changes could impact the accessibility to food.

Many climatic records show that the Norse colonization occurs during a global warm period (the Medieval Warm Period), allowing their access into the fjords by ships. Near the Lakes Qallimiut and Little Kngerluluup, at Igaliku, we have a temperature record showing a short warmer period between AD 950 and AD 1050, synchronous with the Norse colonization (Millet et al. 2014). This climatic parameter also reveals the beginning of the Little Ice Age at AD 1300, synchronous with the reduction of Norse agropastoral activities.

Young et al. 2015 show glacial advances at AD 1130 in West Greenland at ca. 600 km from the two lakes studied. The climatic conditions are different than these recorded in the south. Indeed, the climatic conditions are colder with important glacial advances, involving a Norse settlement less important with fewer sites than the eastern settlement located in south Greenland. However, synchronously with these glacial advances, we record numerous flood events, meaning a regional cold and wet climate. At this date, we revealed a slight abandon by the Norse, identified by a drop of radiocarbon dates measured in Norse archaeological sites. All these parameters are in favour with a slight climatic deterioration during the Medieval Warm Period in Greenland, probably affecting the Norse. This also means that this period is climatically heterogeneous, highlighted by Guiot et al. 2010 in Europe.

We bring new information about the Norse occupation (please see the response #2 in general comments). Of course, this section needs to be re-write and shorten to highlight our contribution.

### **CoP guidelines**

#### **3- Are substantial conclusions reached? The paper reaches conclusions, but I do not think they are justified based on the data presented.**

With the new version of the discussion and the statistical comparisons between the climatic records (see responses #1 in general comments, responses #1 and #7 in specific comments), our conclusions are now better explain and demonstrated.

#### **4- Are the scientific methods and assumptions valid and clearly outlined? Yes, for the most part. However, it is unclear how they chose the intervals of increased flood frequency – this is very subjective.**

The representation of the five flooding periods is not subjective because it is based on a statistical calculation on the K1D software (see responses #1 to general comments). To clarify our purpose, we make a chronological approach in the new version (see responses #1 in general comment and responses #1 in specific comments).

**5- Are the results sufficient to support the interpretations and conclusions? No.**

With the new version of the discussion (see responses #1 in general comments, responses #1 and #7 in specific comments), the results are highlighting and better support our interpretations and conclusions.

**10-Is the overall presentation well structured and clear? Yes, however, the discussion is largely based on literature review, rather than being a direct outgrowth of the data presented.**

You are right, we have now highlighted our exclusive results and reduce our literature review in this part.

**11-Is the language fluent and precise? Yes, minor grammatical problems, but it reads well.**

This article was read by an English native speaker. Professor Francus have already made some minor grammatical corrections to enhance it.

**12- Should any parts of the paper (text, formulae, figure, tables) be clarified, reduced, combined, or eliminated? Yes, see my review.**

We have modified the discussion section and the Figure 5 and 6. Please see responses #1 in general comments and responses #1 and #7 in specific comments.