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Climate of the Past Discussions

Interactive comment on "The onset of Neoglaciation in Iceland and the 4.2 ka event" *by* Áslaug Geirsdóttir et al.

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Dear Referee

We would like to thank the reviewer for the constructive comments and suggestions that help clarify some issues in this manuscript and improve it. Below we address all of this reviewer's comments and concerns to the best of our ability. Corresponding revisions will be made to the manuscript.

Comment 1 - Individual scientific questions/issues ("specific comments") It seemed to me that it was not completely obvious why these six proxies were chosen. Can you please specify the processes of the selection of proxies. Three of them (BSi, d13C, d15N) reflect bioproductivity and summer temperature, and other three (TOC, MS, C/N)

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– erosion activity during the cold period. It is curious that TOC refers to the cold period.

Response: As pointed out by the reviewer, this paper applies the same proxies selected and used by Geirsdóttir et al. (2013). In our 2013 paper, we do explain and describe the selection rationale and interpretation of individual proxies in detail. We feel here that by referring to that paper, we can exclude similar discussions in this paper. However, we have now made corresponding revision to the manuscript where we have added a brief discussion of the reasoning for using these proxies and their interpretation. For a detailed explanation, we direct the reader to the 2013 paper. To specifically address the reviewer's question about TOC, we suggest that TOC in the sediment is a product of both production and transport terms (among other factors). The production term is increased during warm periods due to increased plant growth, but transport is minimized as organic material in the catchment accumulates (and remains sequestered) in soils. During cold periods, even though the production term is minimized, the transport of previously accumulated organic matter from eroding soils contributes a large influx of OC to the lake sediment. This more than compensates for any decrease in productivity due to shorter growing seasons and leads to a net increase of sediment TOC during cold periods.

Comment 2 - The authors argue that the TOC increases due to soil erosion occurring during the cold, dry and windy seasons (Geirsdóttir et al., 2009b). However, the logic might be different: more organic material is transported in the lakes due to more intensive precipitation and snow melt. I would suggest to expand a little this part and explain the mechanisms.

Response: Please see the response to comment 1 for an explanation of the mechanisms that lead to increased TOC during cold periods. The soils of Iceland lack cohesion and are susceptible to erosion, both through eolian processes and overland flow (Arnalds, 2004). Of these processes, wind transport of soils is widespread and significant in Iceland, as displayed by characteristic 'rofabard' features (Arnalds, 2000). Because of this wind transport of soils, Iceland is a significant source of dust on a

global scale (Arnalds et al. 2016). A comparison of modern winter wind speed and lake sediment shows good correspondence during the instrumental record in northwest Iceland (Geirsdóttir et al., 2009). We do not discount that soil erosion happens due to overland flow, but conclude that wind is the dominant driver. This part of the manuscript has been expanded as suggested.

Arnalds, O., 2004: Volcanic soils of Iceland. Catena 56:3–20.

Arnalds O., 2000. The Icelandic “Rofabard” soil erosion features. Earth Surf Process Landforms 25:17–28.

Arnalds et al., 2016. The Icelandic volcanic aeolian environment: Processes and impacts – A review. Aeolian Research 20,176-195.

Comment 3 - A few interesting questions remained outside the scope of the paper, although they might be interesting for the reader. It would be helpful to compare the reconstruction provided in this paper with those based on pollen analyses. Are they coherent?

Response: As pointed out by the reviewer, a comparison between the reconstructions provided in this paper with those based on pollen analyses is beyond the scope of this paper. However, we agree that it would only strengthen our results to point out the coherency between published pollen records from Iceland and our results. Most, if not all, pollen studies in Iceland do show similar changes occurring between 4.5 and 4.0 ka (e.g. Hallsdóttir, 1995). The most recent pollen study by Eddudóttir et al. (2016, 2017) conforms to the temperature decline seen in our lake records. More specifically, the authors show retreating woodland from 6000 to 4000 cal yr BP and further development from woodland to dwarf shrub heath around and after the Hekla 4 eruption when Betula nana and Empetrum nigrum pollen reappear in their record, suggesting a continued decrease in summer temperature. These authors also point out that the vegetation (and pollen) are susceptible to tephra fallout and abrasion, - the pollen records are not fully independent from the temperature forcing after both H4 and

H3. We have added a sentence emphasizing this in the current manuscript.

Hallsdóttir, M., 1995. On the pre-settlement history of Icelandic vegetation. Búvísindi Icel. Agr.Sci. 9, 1995: 17-29.

Eddudóttir et al., 2016. Climate change and human impact in a sensitive ecosystem: the Holocene environment of the Northwest Icelandic highland margin. Boreas 45:715-728.

Eddudóttir et al. 2017. Effects of the Hekla 4 tephra on vegetation in Northwest Iceland. Veget Hist Archaeobot.

Comment 4 - The dates of moraines are not mentioned. Do they agree with the sediment records?

Response: Our record on the onset of Neoglaciation is mostly based on lake sediments and glacier modeling from large ice caps, and not moraines, - and the discussion on the 4.2 ka event is mainly based on records indicating temperature decline or perturbations. Langjökull's efficient delivery of glacial sediments into Hvítárvatn dominates sediment accumulation in the lake, so any perturbations to the lake system, such as large fluctuations of the ice cap margin, result in changed sediment delivery. Lake sediment records also benefit from secure dating techniques, particularly when varved. Studies of glacial fluctuations during the mid- to late Holocene are relatively few in Iceland and identified moraines have been difficult to date accurately. Furthermore, these moraines have so far been outboard of small, surging mountain glaciers, which do not fully respond to climate changes. Stötter et al (1999) reported glacier advances in North Iceland ca. 5.4 ka, 4.7 ka and 3.4-3.5 ka and Kirkbride and Dugmore (2006) identified groups of moraines in the highlands of Iceland dated to ca. 5.7-5.2 ka, 3.8-3.2 ka. Both these records support our conclusion in the current paper that Neoglaciation in Iceland commenced between 5.5 and 5.0 ka.

Stötter, J., Wastl, M., Caseldine, C., Haaberle, T., 1999. Holocene palaeoclimatic re-

constructions in Northern Iceland: approaches and results. Quaternary Science Reviews 18, 457–474.

Kirkbride, M.P., Dugmore, A.J., 2006. Responses of mountain lee caps in central Iceland to Holocene climate change. Quaternary Science Reviews 25, 1692–1707.

Comment 5 - The modern warming is not manifested in the records (see fig. 5c). What is going on nowadays in this region? I think a few words on the current climate trends (including seasonality) in the region are necessary.

Response: We feel that discussing modern climate trends is beyond the scope of this paper. As the title states, this paper focuses on the inception of Neoglaciation and the 4.2 ka event.

Comment 6 - The Medieval Climatic Anomaly is not mentioned and discussed here. What is your opinion on this? All lake records indicate a strong decline in temperature _1.5 ka. Can you suggest an explanation for the absence of the MCA in this region unlike some other areas in the North Atlantic?

Response: As pointed out previously, the scope of this paper is the onset of Neoglaciation and the relation to the 4.2 ka event. We have previously published several papers on the last 2 ka (e.g., Geirsdóttir et al., 2009; Larsen et al., 2011; Miller et al., 2012; Harning et al., 2016), which reflect both the strong decline in temperature after 1.5 ka as well as the Medieval Climate Anomaly (MCA) and the Little Ice Age. Those papers clearly show that the MCA is not absent in our records especially when compared to the last 1.5 ka. But if we are to compare to the last 8 ka, the smaller magnitude changes of the MCA-LIA anomalies become obscured in the large-scale changes of the first-order Holocene temperature decline.

Geirsdóttir Á, Miller GH, Thordarson T, Ólafsdóttir KB. 2009b. A 2000 year record of climate variations reconstructed from Haukadalsvatn, West Iceland. J Paleolimnol 41:95–115.

Larsen DJ, Miller GH, Geirsdóttir Á, Thordarson T. 2011. A 3000-year varved record of glacier activity and climate change from the proglacial lake Hvítárvatn, Iceland. Quat Sci Rev 30:2715–2731.

Miller GH, Geirsdóttir Á, Zhong Y, Larsen DJ, Otto-Bliesner BL, Holland MM, Bailey D a., Refsnider K a., Lehman SJ, Southon JR, Anderson C, Björnsson H, Thordarson T. 2012. Abrupt onset of the Little Ice Age triggered by volcanism and sustained by sea-ice/ocean feedbacks. Geophys Res Lett 39:L02708

Harning, D.J., Geirsdóttir, Á., Miller, G.H., Anderson, L.,2016a. Episodic expansion of Drangaj€, VestfirâĂžir, Iceland over the last 3 ka culminating in its maximum dimension during the Little Ice Age. Quat. Sci. Rev. 152, 118-131.

Comment 7 - I am not sure why the authors limit themselves by the Neoglacial time having the complete Holocene records? I would suggest to reconsider the title. They state that the 4.2 ka event is undistinguishable in the period 4.0 - 4.5 ka, so why it should be the focus and mentioned even in the title?

Response: This paper is being submitted to a special issue of CoP that is focusing on the 4.2 ka event. Although we do agree that our complete Holocene record deserves a special paper, we would like to see such a paper discuss evenly all the different perturbations that have taken place during the last 10 ka – such a paper would be more suited as a review paper and needs to be much longer with different focus than the one for this special issue.

A primary conclusion of this paper focuses on the prominent step towards cooling at 4.5-4.0 ka being statistically indistinguishable from the 4.2 ka event and coincident with Hekla 4, one of the largest explosive eruptions of the Holocene in Iceland. We state that we do see abrupt temperature decline between 4.5 and 4.0 ka, a period that also includes the timing of the Hekla 4 eruption. However, because of the uncertainties in the 14C dates we cannot say whether that temperature decline is due to the volcanic eruption or preceded the eruption, and connected to the more widespread changes

associated with the 4.2 ka event.

Comment 7 - Technical corrections âĂźËŸa 10 line 4 The current ELA pattern reflects reflect the patterns and temperature and precipitation across Iceland – please edit

Response: Thank you – this typo has been corrected

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