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Climate of the Past Discussions

Interactive comment on "Multiproxy evidence of the Neoglacial expansion of Atlantic Water to eastern Svalbard: Does ancient environmental DNA complement sedimentary and microfossil records?" *by* Joanna Pawłowska et al.

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We would like to thank the Referee for constructive review, that will help us to improve the manuscript. Written below are our responses to the Referee's comments. The comments were reproduced and are followed by our responses. Based on the comments, we propose the changes of the manuscript. The revised version of the manuscript will be prepared based on the decision of the Editor.

Anonymous Referee #2 The authors present new study on multicentennial environ-

mental reconstruction of eastern Svalbard region over the last ca. 4000, the so-called Neoglacial. Well established proxies (sedimentary, geochemical and microfossils) along with very novel molecular approach (foraminifera and diatom derived ancient DNA) were studied in marine sediment core in order to deliver the broad database for the paleo-interpretations. The study area was already investigated in number of studies, however here the authors tested new molecular proxy, which seems to well support and improve the interpretations based on standard tools. In my opinion, the study is well worth to be published after some, rather minor improvements, particular of the discussion chapter. Please follow the detailed comments below:

Detailed comments: Referee's comment: Abstract: Perhaps it could be more pronounced why the authors choose Storfjorden for the area of study and what is the specific importance of the region.

Response: We agree with this comment. We have added more information about Storfjorden to the Abstract. The added text is as follows: Storfjorden is one of the most important "brine factory" in the European Arctic, responsible for the deep water production. Moreover, it is a climate-sensitive area, influenced by two contrasting water masses: warm and saline Atlantic Water (AW) and colder and fresher Arctic Water (ArW)

Referee's comment: Introduction: Page 3, line 27. Wouldn't be enough to refer only to the published study of Pawłowska?

Response: The study of Pawłowska et al. (2014) considers only foraminifera. Unfortunately, the results of diatom analysis from sediment cores have not been published yet, therefore, it was necessary to refer to personal communication.

Referee's comment: Study area: Page 4, lines 27-29. The location of the studied sediment core seems to be rather off the Storfjorden, in the trough, thus I wonder if the study area descriptions, including low energy and high SAR environment, are still applying?

Response: The core is located in the central Storfjorden, off the through. The study of Winkelmann and Knies (2005), where the sedimentary environment in Storfjorden was described, covers also central and outer parts of Storfjorden.

Referee's comment: Do you know what is the thickness of AW branch that enters the core location, does it affect the bottom environment directly, do you have modern bottom temperature and salinity data?

Response: The temperature and salinity profile from the coring site has been added to the manuscript. During the August 2014, AW occupied the uppermost 47 m, while the intermediate layer was dominated by TAW. In the near bottom layer, BSW was observed.

Referee's comment: Sampling: With a relatively short sediment core, the aDNA sampling resolution could be higher.

Response: Material for aDNA analysis have been taken before the core was dated, therefore, we have decided to sample the core with fixed 5-cm interval. Indeed, the sampling resolution could have been higher. Unfortunately, we have no more material suitable for aDNA analysis to provide a higher resolution record.

Referee's comment: Fossil foraminifera: It should be mention somewhere what was the resolution of fossil foraminiferal analysis, I assume it was every 1 cm.

Response: Fossil foraminifera were analyzed every 2 cm. The appendix with raw data, including sampling resolution, will be provided as electronic supplementary material.

Referee's comment: Page 6, line 15. Please provide full name of the species as it is mentioned here for the first time.

Response: The full name has been added to the sentence.

Referee's comment: Do you have any possible explanation for the low time resolution between 7890 and 2700 cal BP? Strong bottom currents or possible sediment slide?

Response: The low sediment accumulation rate recorded for the period from 7890 to 2700 yr BP was most likely a result of glacial retreat and consequent low delivery of sedimentary material. SAR recorded in the studied core was consistent with the results obtained by ŁÄĚcka et al. (2015) in Storfjordrenna for this time period. On the other hand, Knies et al. (2017) and Rasmussen and Thomsen (2015) recorded higher accumulation rates in the central and inner Storfjorden. However, their studied cores were located relatively close to the shore, therefore, were more affected by sedimentary material delivery.

Referee's comment: Page 8, lines 33-34 to page 9, line 1. The mentioned three percentage values, what are they refer to, it is not clear from the sentence, consider rewording.

Response: The sentence has been corrected as follows: After $\sim$ 2.7 cal ka BP, there were AW/frontal zone indicator peaks recorded at 2.4 and 1.8 cal ka BP, where the percentages increased to 33%, and 28% of the total abundance.

Referee's comment: Foraminiferal aDNA: The authors focus only on soft walled monothalamea group with regard to molecular record. Do the authors plan to relate the fossil and the molecular records of hard walled foraminifera as well? Perhaps the agglutinated taxa which are also difficult to stay preserved could be investigated molecularly.

Response: The relation between the molecular and fossil record has been already studied (see Pawłowska et al., 2014; Geobiology) and it was not our intention to duplicate these results. In our study, we decided to focus on monothalamous foraminifera, as they are the dominant component of aDNA record and may provide the most valuable environmental information.

Referee's comment: Discussion: Overall, I would like to suggest including 'chronological' headlines into the discussion chapter e.g. 'Interval prior to 2.7 ka BP' , 'Episodes of enhanced AW inflow' et. al. to make it easier for the reader to follow.

Response: We agree with this comment, headlines have been added to the Discussion

Referee's comment: Page 10, lines 25-31. It would be highly recommended to provide summary figure that would visualize the correlation between your results and the cited studies.

Response: The data showing temperature and isotopic records from GISP2 core (Cuffey and Clow, 1997; Alley, 2000) and Storfjordrenna (ŁÄĚcka et al., 2015), as well as temperature records of Sarnthein et al., (2003), have been added to the Figure 3.

Referee's comment: Page 11, line 4-7. Can the strong currents provide also unfavorable conditions for benthic foraminifera and explain generally very low fauna abundance? Or this is related exclusively with heavy sea ice cover? Is there any detectable response from current velocity indicators like C. lobatulus?

Response: The percentage of C. lobatulus remained relatively stable during the Neoglacial, except for the peak $\sim$ 0.4 cal ca BP and minor peaks at $\sim$ 2.3 and $\sim$ 1.5 cal ka BP. Therefore, we were not able to make any unequivocal conclusions. Moreover, the low number of samples in the interval prior to $\sim$ 2.7 cal ka BP is not sufficient to warrant the lengthy discussion and does not allow to make any general conclusions. Therefore, we decided to shorten the part of the Discussion considering this time interval.

Referee's comment: Line 2-5. Might be that IRD and higher mean grain size can also source from extensive transport of shore sea ice?

Response: Indeed, the sea-ice rafting may be an important source of ice-rafted debris. However, the sampling station was located relatively distant from the shore, therefore, the terrestrial impact was rather minor.

Referee's comment: Page 12, line 6-8. Is it possible to detect the past occurrence of dense brines transport to the bottom in the foraminiferal isotopic signatures measured by the authors?

Response: The 18O and 13C values prior to $\sim$ 2.7 cal ka BP were relatively stable. However, for this period isotopes were measured in 3 sediment layers, which may affect the result. Therefore, we have added to the mentioned above paragraph conclusion that the potential influence of brines on foraminiferal abundance has to be confirmed by other studies.

Referee's comment: Line 24-25. Yet, no clear response from C. lobatulus.

Response: Indeed, as mentioned above, the percentage of C. lobatulus was rather stable during the Neoglacial. Our observations are consistent with the record of ŁÄĚcka et al. (2015) from Storfjordrenna. They observed an increase in the mean grain size (> 63 μm) during the late Holocene (i.e., after 3.6 cal ka BP), which was not followed by the increase in C. lobatulus abundance.

Referee's comment: Page 13, line 12-14. Here, the authors explain brines as a source of water mixing and nutrient supply, with a positive effect of foraminiferal fauna, whereas for the interval prior to 2.7 cal ka BP, brine formation is presented as a hazardous factor, which seems to be a bit confusing.

Response: As mentioned above, the low number of samples in the interval prior to 2.7 cal ka BP precluded making any general conclusion. The Discussion considering the influence of sea-ice on foraminifera during that interval has been modified. Now the text is as follows: The ST_1.5 foraminiferal assemblage was dominated by glacier-proximal fauna (primarily C. reniforme) and indicators of frontal zones (primarily M. barleeanum; Fig. 5). The presence of C. reniforme and M. barleeanus is linked to cooled and salty AW (e.g., Hald and Steinsund, 1996; Jernas et al., 2013). Moreover, these species are also associated with the presence of phytodetritus, which may be related to the delivery of fresh organic matter observed in frontal zones and/or near the sea-ice edge (Jennings et al., 2004). Relatively light δ13C (Fig. 4), followed by the maximum percentage of sea-ice species Thalassiosira antarctica (cf Ikävalko, 2004; Fig. 8) may indicate primary production associated with the presence of sea-ice and/or

periodic inflow of ArW The typical response of a foraminiferal community to high trophic resources is an increase in diversity and standing stock (Wollenburg and Kuhnt, 2000). According to our data, the foraminiferal community showed no clear signs of increased productivity, as the abundance and flux of foraminifera were low prior to $\sim$ 2.7 cal ka BP (Fig. 4). Similarly, Rasmussen and Thomsen (2015) noted a decrease in concentration of benthic foraminifera in Storfjorden at that time, which was attributed to the more extensive seasonal sea-ice cover. Also, Knies et al. (2017) suggested a variable sea-ice cover extent and a fluctuating sea-ice margin in Storfjorden prior to $\sim$ 2.8 cal ka BP. In contrast, our data may suggest the presence of high-energy environment during the interval prior to $\sim$ 2.7 cal ka BP, what may be the major factor limiting the development of the foraminiferal community. However, low sampling resolution during that period precluded making any general conclusion and the latter assumption should be confirmed by further studies.

Referee's comment: Line 29-31. Was the strong bottom current activity reflected also in the changes in grain size fraction?

Response: Indeed, there were slight peaks in the 0-63 μm that coincided with the increase in C. lobatulus. The relevant information has been added to the Discussion.

Referee's comment: Page 15, line 25. The authors mentioned LIA but what about the other prominent climatic events that occurred during the last 2 ka. Can the results be related to them as well, if not, can the authors discuss the possible reason for the lack of larger scale climatic signals, e.g. perhaps local variability. The discussion could improve from a bit broader overview of other Svalbard records, that also underly the AW inflow.

Response: We have followed the Reviewer's suggestion and added a paragraph considering other records from the Nordic Seas. The added text is as follows: Our record revealed two-phase Neoglacial, with a major shift in environmental conditions at $\sim$ 2.7 cal ka BP. According to the ST_1.5 record, the Neoglacial in Storfjorden was not a

constantly cold period, but comprised alternate, short-term cooling and warming periods, associated with variability in sea-ice coverage and productivity. There is various evidence of a shift in environmental conditions in the Nordic Seas region in mid-Neoglacial. Alkenone record from the Norwegian Sea revealed a significant drop of sea surface temperature at 2.7 cal ka BP (Calvo et al., 2002). Risebrobakken et al. (2010) recorded a change in oceanographic conditions in the SW Barents Sea ca. 2.5 cal ka BP, followed by the episodes of reduced surface and subsurface salinity after 2.5 cal ka BP, what was attributed to the expansion of coastal waters and the occurrence of more sea-ice. Moreover, our evidence of the presence of AW in Storfjorden during the Neoglacial supported previous suggestions that AW inflow during the late Holocene was strong enough to reach also the eastern coasts of Svalbard (e.g., ŁÄĚcka et al., 2015). Moreover, Sarnthein et al. (2003) postulated pulses of AW inflow to the western Barents Sea shelf at 2.2 and 1.6 cal ka BP. According to Perner et al. (2015), the Neoglacial delivery of chilled AW to the Nordic Seas culminated between 2.3 and 1.4 cal ka BP. Also, Rasmussen et al. (2014a) and Jernas et al (2013) recorded slightly warmer and less glacial conditions during the last 2 ka on the western Spitsbergen shelf.

Referee's comment: General comment, can the authors observe a relation of the reconstructed higher bottom current activities and the diversity of fragile, soft organic-walled monothalamids?

Response: The most intensive bottom currents were likely to occur during the interval prior to 2.7 cal ka BP. Unfortunately, the aDNA was analyzed only in one sample during this time interval, therefore, we cannot make any general conclusions. Moreover, the knowledge about monothalamids ecology and environmental tolerance is still scarce and incomplete and no bottom currents indicators have been identified in this group so far.

Referee's comment: Figures: Fig. 3. Could you perhaps mark the sampling points on the graphs. It seems as for the interval 4 ka BP to 2.7 ka BP there are very few

sampling points, thus there is almost no detectable variability in the data. Would it be reasonable to consider sediment turbation and homogenization of the signals in such a small thickness of sediment? The dash lines indicating intervals are very useful, you could probably apply them also to figure 4 and 5 and 7 so it is easier to compare the data.

Response: Sampling points and dashed lines have been added to the graphs, according to the Reviewer's suggestion. Our sedimentary record indicated more vigorous bottom currents and consequent winnowing of fine sediment. Therefore, the homogenization of signal may be related to selective removal of mineral and organic particles, rather than turbation.

Referee's comment: Fig. 4. I would suggest to change scale down to 30% in order to have better over view for the potential variability, except C. reniforme.

Response: There are two taxa that exceeded 30% of foraminiferal assemblage – C. reniforme and E. excavatum. We have decided to use the scale reaching up to 50% to clearly show the differences between the percentages of certain taxa and to highlight the dominance of species such as C. reniforme or M. barleeanum. Therefore, we would prefer to keep the scale in its current form.

Referee's comment: Fig. 5. The age scale is bit too compacted, please consider stretching it.

Response: We have prepared the figure according to the Reviewers comment, however, stretching the scale resulted also in the increase in the distance between the data bars and, in consequence, graph became less clear and the trends were less visible. Therefore, we would prefer to keep the scale in its current form.

Referee's comment: Fig. 6. 'Clade I' was not mentioned in the result chapter, does it stand for 'environmental clade' (page 9, line 21)?

Response: Clade I does not stand for the environmental clade. Allogromiids belonging

to Clade I were noted only in one sample, where they made 0.88% of allogromiid sequences. The information about the occurrence of Clade I have been added to the Results section.

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