Dear Reviewers,

On behalf of myself and my co-authors, I would like to thank you all for your supportive comments and generous suggestions to assist us with improving our manuscript.

Please see our responses typed in italics.

Response to Referee#1:

The main point is moderate revision is needed in which a convincing case is made for the significance of the paper for deglacial & Holocene paleoceanography not only for the Barents Sea Svalbard region, but for the eastern Arctic where AW flows into.

We agree, and the following additional sentence has been added to the introduction: "Since the studied sediment core was retrieved from an oceanographic frontal zone, sensitive to larger-scale changes, we believe that the presented data show the general climatic/oceanographic trends in the eastern Arctic."

Wollenburg did excellent paleoceanographic and paleobiological studies of the last 15 ka, in the Barents Sea region, using forams and other proxies. Her records must be cited and I think plotted against the new records.

We could not find articles by Wollenburg containing paleoceanographical and paleobiological studies of the last 15 ka, in the Barents Sea region, using foraminifera. We have checked her available articles from the Arctic region:

Wollenburg, JE; Kuhnt, W (2000) The response of benthic foraminifers to carbon flux and primary production in the Arctic Ocean., 40(3), 189-231

Wollenburg, JE; Kuhnt, W; Mackensen, A (2001) Changes in Arctic Ocean paleoproductivity and hydrography during the last 145 kyr: the benthic foraminiferal record., 16(1), 65-77

Wollenburg, JE; Knies, J; Mackensen, A (2004) High-resolution palaeoproductivity fluctuations during the past 24 kyr as indicated by benthic foraminifera in the marginal Arctic Ocean., 204(3-4), 209-238

Wollenburg, JE; Mackensen, A; Kuhnt, W (2007) Benthic foraminiferal biodiversity response to a changing Arctic palaeoclimate in the last 24.000 years., 255(3-4), 195-222

The only core discussed by Wollenburg located in the Barents Sea region (2138; Wollenburg et al., 2004) lies at a great distance from our coring site and spans the last 24 ka.

There is no reason given why the O^{18} is not corrected for sea level ice volume of vital effects. But in fact Fig 8 does correct.

Data on Fig. 6 have been corrected for the sea level ice volume. However, there is no reliable vital effect correction created for E.excavatum f.clavata. Ślubowska et al. (2007) noted that the vital effect of E. excavatum is not consistent, but seems to be large and variable as confirmed by several other studies. Poole et al. (1994) and Polyak et al. (2003) recorded negative values, whereas Bauch et al. (2004) observed both positive and negative values. Due to these uncertainties, they followed Knudsen et al. (2004) and adjusted the δ^{18}*O values of E. excavatum to the corrected values of M. barleeanum, resulting in a correction factor of 1.4‰. Rasmussen et al. (2007) used the similar method, while they have corrected the values by correction of +0.7‰. Therefore we have decided not to correct* the values for the vital effect, *particularly that the paleotemperature was not calculated from the* δ^{18}*O.*

The sections of the paper are fairly straightforward and descriptive, and perhaps redundant.

In our view, a detailed description is needed for further discussion. However, minor changes have been made in this section.

What is missing is a critical discussion of why this new core is so important given all the previous studies. For example, warm productive periods during H-events have been proposed – what about these?

Our study concerns the Younger Dryas, which sometimes is seen as the H0. Earlier H-events remain beyond the reach of our sediment core.

Mid depth warming in the Arctic during glacial periods is also proposed due to Halocline changes. Does this deglacial record support this?

Our data from the glacial period concerns subglacial unit of the sediment (no foraminiferal data).

How fast are ocean temperature changes compared to let's say the Greenland ice core records of the YD? Decadal?

The resolution of our sediment core (Ice Proximal Unit) varies from 40 to 100 years. In our opinion, inclusion of such a comparison would be speculative.

How do deglacial ocean changes compare to those Spielhagen and others have shown for the last century in Fram Strait?

Though this question is very interesting, it is beyond the scope of this study as we are unable to compare the range of changes Spielhagen et al. (2011) have shown for the last century, as we didn't calculate the paleotemperatures from stable isotopes signal. Moreover, in our record there is a limited amount of data regarding surface water condition (only few planktic foraminifera specimens were found).

Does sea level rise affect the regional oceanography?

Yes, this problem is discussed in our manuscript in paragraphs: 5.3 Glaciomarine unit I; 5.5 Glaciomarine unit III mainly in relation to near bottom sea currents.

Figure 7 compares IRD to GISP ice core. What about other sediment proxies? What about other papers on the YD from the Barents Sea-Svalbard region? The current paper would be an ideal place to review the paleoceanography of the deglacial Holocene from this region, especially the YD, which is complex and the subject of many papers.

Additional information has been added to the revised version of this manuscript.

Figure 8. What are the key messages to derived from this isotope figure?

The key messages of Fig. 8 are showing that all the records are shifted towards lighter values in the early Holocene however, the record from our core remain mostly depleted. This proves that the records located on the western and northern shelf of Svalbard directly mirror the effect of warmer Atlantic water inflow, while record from Storfjordrenna shows the influence of isotopically lighter Arctic Water from the Barents Sea (Duplessy et al., 2005).

The early-Holocene period is often described as being influenced by an intensified inflow of Atlantic water to the Nordic Seas. Although we have observed in our record signs of warming (e.g. increasing foraminiferal biodiversity), the glacier head still remained in the proximity of the coring site. Therefore, the process of transition from Arctic water domain to the Atlantic water domain occurred later than further to the west.

I have trouble seeing significance in the low IRD measurements in Fig. 9 and the huge *norcrossi* increase without comparable IRD. Perhaps Polyak and Solheim overestimated *norcorssi* as a direct sea ice proxy. Much more sophisticated sea ice proxies have been used, some including other foram species [ie not *norcrossi*]. Moreover there is a large literature on the Neoglacial in these high latitudes, I would expect this Fig 9 to address neoglacial climate and ice activity from the study region. So I think this part of the study on IRD & sea ice is in need of revision or omission, it is simply not that strong an argument.

We agree. Fig. 9 and the related discussion has been removed from the manuscript.

Page 4 Svalbard/Barents Sea Ice Sheet – there must be a slash or hyphen after Svalbard

It has been corrected.

Page 4-5 AW = Atlantic Water, this is convention. ArW = Arctic water is too similar and other terms are used/preferred PW=polar water, surface etc. Also page 6 "Surface water" is used, but it is confusing because it does not designate an origin of the water mass. Plus SW is abbreviated in caption but not here in text.

We disagree. The abbreviation "ArW" is convention too, often used in oceanographic and paleoceanographic literature (e.g. Loeng, 1991; Cottier et al., 2005; Skogseth et al., 2005; Majewski et al., 2009; Jernas et al., 2012; Rasmussen and Thomsen, in press). Arctic water is connected with East Spitsbergen Current and its salinity is between 34.3 and 34.8 (Loeng, 1991)

Polar water (PW) is a mixture of Atlantic and Arctic waters and it is found in the western Barents Sea (Loeng et al., 1991). The salinity of PW is higher and varies between 34.8 and 35.0, while its temperature oscillates between -0.5 and 2.0 (Loeng et al., 1991; Haarpaintner et al., 2001).

Surface water (SW) is abbreviated in the text of water masses (section 2.1.). SW is formed locally and is described as *the upper 50 m; cold and fresher during the autumn and warm and fresher due to ice melting, during the summer (Skogseth et al., 2005).*

Page 6. Brine-enriched [lwer case 'b'], Page 7 Percentages: delete extra "p"

It has been corrected.

Page 10 The lithological description is important but perhaps too long for the main text, can it go in appendix/supplement? Also it is really a geochronological section , not simply litho description.

In our opinion this section is important as a base for further interpretation and discussion. We would prefer to leave it as it is. The title of this section has been changed into "Sedimentological and geochemical parameters".

Page 11 line 10. THE benthic: : : – add "The" , Page 12. Isn't *Buccella frigida* spelled with two "c's" ?

It has been corrected.

Page 12 general. This foram sequences seems really common and important in post glacial deglacial deposits of the N hemisphere. Not just northern Europe. Perhaps point this out with references.

We have increased the number of references: Vilks, 1981 from Scotian and Labrador shelves (Canada); Osterman and Nelson, 1989 from eastern Baffin Island continental shelf (Canada) and Polyak and Mikhailov, 1996 from the southeastern Barents Sea.

Page 15 references to the Agassiz out flow need updating. Rayburn et al. 2012, Cronin et al. 2012 in St Lawrence Valley, Murton & Tarasov & Peltier, in MacKenzie, Spielhagen in the Arctic, etc.

It has been updated. Two recent references by Murton et al., 2010 and Cronin et al., 2012 have been added.

Page 16 line 5 , first part of sentence is incorrect grammar,

It has been corrected.

line 6 glaciomarine spelling,

It has been corrected.

Page 17 line 12 should it be Mid-Holocene ??

It has been corrected.

Page 20 line 13 Rasmussen WHO noted[note which noted], line 20 until today [not until present days], 21 sea-ice hyphenate when used as adjective

It has been corrected.

Page 20 and elsewhere. Will the reader be confused if several geographic terms are used to refer to the study region: ie., Edgøya area – which is not identified in Figure 1 map, Storfjordrenna. Please label all place names and ocean currents and water masses that are mentioned in the text in the figures.

It has been corrected. All of the places described in the text have been label in Figure 1.

Page 35 caption, What about the core NP94-51 located in the inset map?

It has been described in the caption and then discussed in the text.

Page 43 caption. English is awkward, rewrite, “may indicate seasonal sea-ice cover” [delete “the”].

This figure has been removed.

Response to Referee#2

The objectives of the study are not well presented. The introduction is unclear and includes too many details that are not relevant for the study.

We have added some additional information to the introduction: “In this paper we present results from multi-proxy analyses of a sediment core retrieved 100 km east of the mouth of Storfjordrenna. We provide a new age for the retreat of the last Svalbard-Barents Sea Ice Sheet from Storfjordrenna and discuss the interaction of oceanography and deglaciation, as well as the postglacial history of Atlantic Water inflow onto the shelf off southern Svalbard. Since the studied sediment core was retrieved from an oceanographic frontal zone, sensitive to larger-scale changes, we believe that the presented data reflects the general climatic/oceanographic trends in the eastern Arctic.”

The language is fluent, nonetheless it is clear that neither of the authors are native English speakers and expressions as “evanescent delivery of IRD” or the use of “hydrology” where “oceanography” is more appropriate needs to be corrected.

It has been corrected.

The last figure (Fig. 9) also appear not to be relevant and should be removed.

Figure 9 has been removed.

Abstract “. . .the beginning of late Holocene. . .” – when? Please indicate ca. calendar years BP.

The date 3600 yr BP has been added.

Introduction Page 3055, line 10: Which fjords? Be more specific.

It has been corrected, “Svalbard fjords” has been used instead ”fjords”.

Page 3055, lines 18 – 29: Too detailed – include only main point.

We respectfully disagree. As the colonization of the eastern coast of Storfjorden by Mytilus edulis was one of the drivers behind the presented study, it remains an important indicator of Atlantic water inflow to Storfjorden during the middle Holocene. The presented study explains the sea environmental condition of Storfjorden which allowed to develop species, characteristic for temperate fjords.

Page 3056, lines 1 – 11: The development of the knowledge and understanding of water masses in Storfjord seems to be beyond the scope of the current paper. I suggest removing all. Some details may be relevant in chapter 2 on study area.

We do not agree. In our opinion the knowledge and understanding of modern oceanography of Storfjorden is the basis for understanding the paleoceanography of eastern Svalbard.

Page 3056, lines 14 – 16. What time? Be more specific and add more on this. The information is very relevant for the scope of the paper. Refer to Rasmussen et al. (2007) and the recent paper by Rasmussen et al. (2014) (Quaternary Science Reviews 92, 280-291. Online November 2013)

We have added additional information to this paragraph and the relevant reference: Storfjordrenna is a sensitive area (Fig. 1) where two contrasting water masses form an oceanic polar front, separating colder, less saline and isotopically lighter ArW from warmer, high saline and $\delta^{18}O$ *heavier AW. An abrupt cooling (e.g. Younger Dryas, Little Ice Age) and warming (e.g. early Holocene warming) of the European Arctic might be linked to relatively* *small displacements of this front (Sarnthein et al., 2003; Hald et al., 2004; Rasmussen et al., 2014).*

Page 3056, lines 17 – 19. Introduction lacks a coherent part on previous paleo-records from the region and Storfjordrenna. These sentences should be combined with the previous making a proper introduction to previous paleo-records from the region and Storfjordrenna.

The additional references have been added: Two sediment cores taken at the mouth of Storfjordrenna, reveal a continuous inflow of AW to the south western Svalbard shelf since the deglaciation of Svalbard-Barents Ice Sheet (Rasmussen et al,. 2007), while inner Storfjorden basins undergo a shift from being occupied by continental ice to ice proximal condition (Rasmussen and Thomsen, in press). Nevertheless a limited amount of paleoceanographical data is available from this region, thus the reconstruction of Svalbard-Barents Ice Sheet retreat and further development of Storfjordrenna oceanography is often speculative.

Introduction to the deglaciation of the Barents Sea Ice Sheet is also lacking.

The main focus of our manuscript is the paleoceanography of Storfjordrenna after our coring site was deglaciated. However, we discuss the timing of deglaciation of Storfjorden in the section 5.1 Sub-glacial unit (>13,450 cal yr BP).

Page 3056, lines 20 – 24. Unclear where the authors wish to take this?

We agree that this sentence was unclear and we have removed it from the Introduction.

Page 3056, lines 25 – 29. Clear presentation of study, but the introduction should contain information leading up to this and make objectives more clear.

We agree, additional sentences have been added to the introduction.

Page 3057, lines 10 – 13. This belongs to "Introduction", where more details on retreat are necessary making it clear why a new age on the retreat is relevant.

This sentence has been moved to the discussion. Please, see our response to Page 3056, lines 17-19.

Page 3057, lines 16. “(Table 1 after Skogseth et al., 2005)” should be corrected to “(Skogseth et al., 2005; Table 1)”.

It has been corrected.

Page 3058, lines 9 – 11. Reduce the numbers of references.

The number of references has been reduced.

Page 3058, lines 24 – 25. Simply refer to figure 2 without the details.

It has been corrected.

Page 3059, line 29. This reference does not deal with stable isotope measurements of *E. excavatum* f. *clavata* nor stable isotope measurements as a method. Please find relevant references on this and/or discuss accordingly.

The reference has been removed.

Page 3060, lines 9 – 11. “Bivalve. . .” this belongs - with thanks - in Acknowledgement

It has been corrected.

Page 3060, line 16. Why not Marine13? This paper was submitted July 15 2014.

It has been corrected.

Page 3062, lines 2 – 4 a. This is the first place where the boundaries of the lithological units are presented, use and list both core depth in cm and ages in cal yr BP.

It has been corrected.

Page 3062, lines 2 – 4 b. In figure 4 of the lithology the boundaries between the units are sharp. Hence, the use of ""/"ca." is not quite right, and all "" should be deleted throughout this chapter.

It has been corrected.

Page 3062, line 9. Delete “Munsell code”. Page 3062, lines 13 – 14. >63 um AND between 7-10 um? This must be a mistake; please correct.

It has been corrected.

Page 3062, lines 24 – 25. Is there a color change bewteen L3 and L4? If yes, please describe this.

There is no color change between these two units. This information has been added to the text.

Page 3062, lines 26 – 27. Again >63 AND up to 15?

It has been corrected.

Page 3063, line 6. Make it clear this is the relative abundance.

It has been corrected.

Page 3063, lines 7 – 8. “. . .with 25% of agglutinated foraminiferal fauna. . .” – what do the authors mean here? Have the agglutinated foraminifera been included in the calculations of relative abundance or does the calcareous species constitute 100% in the calculations?

Yes, agglutinated foraminifera were included in the calculations.

Page 3063, lines 8 – 9. What is low? Please state the value of this sample.

The number of specimens (13 specimens g^{-1} *of sediment) has been added to text.*

Page 3064, lines 1 – 28. Throughout the description, mention numbers in addition to "high" and "lower".

It has been corrected.

Page 3064, line 1. Which species is the most frequent?

It has been corrected: Zone F1 is dominated by the opportunistic E. excavatum f. clavata and C. reniforme. The latter one dominates over E.excavatum f.clavata between 12,450 cal yr BP and 11,950 cal yr BP.

Page 3064, line 5. Low biodiversity? Please state the value of this sample and what it is compared to.

It has been corrected: Species richness and Shannon-Wiener index show low biodiversity (mean values of 8 and 1.26, respectively).

Page 3064, lines 22 – 25. Which species are the most frequent?

It has been corrected: The percentage of E. excavatum f. clavata increases slightly while C. reniforme decreases. The fluxes of Islandiella spp. and Buccella spp. increase significantly, *and from 2850 cal yr BP Islandiella spp. and E.excavatum f.clavata dominate the foraminiferal assemblage.*

Page 3065, lines 18 – 19. Please make it clear that this is a minimum estimate.

It has been corrected.

Page 3065, lines 19-25. It is emphasized in the introduction that a new age on the deglaciation of BSIS is presented. This new date should be discussed in light of the latest results from the region, please refer to e.g. Andreassen et al (2014) and Rüther et al (2012). REFS: Andreassen, K., Winsborrow, M.C.M., Bjamadottir, L.R., Ruther, D.C., 2014. Ice stream retreat dynamics inferred from an assemblage of landforms in the northern Barents Sea. Quaternary Science Reviews 92, 246-257 (online November 2013). Rüther, D.C., Bjarnadóttir, L.R., Junttila, J., Husum, K., Rasmussen, T.L., Lucchi, R.G., Andreassen, K., 2012. Pattern and timing of the northwestern Barents Sea Ice Sheet deglaciation and indications of episodic Holocene deposition. Boreas 41, 494-512

Appropriate sentence and references have been added to discussion: "Our data stays in agreement with ice stream retreat dynamics presented by Rüther et al. (2012) and refines the recent models of the Barents Sea deglaciation (e.g. Winsborrow et al., 2010; Hormes et al., 2013; Andreassen et al., 2014)."

Page 3066, lines 7 – 9. A reference on this?

It has been corrected. This assumption has been based on the literature after Lucchi et al., 2013 and Witus et al., 2014.

Page 3066, line 11. Indicate the lithological units on the figure with foraminiferal data. It is not possible to assess this statement/correlation easily.

The lithological units have been added to the Figure 5 and Figure 6.

Page 3066, line 12. *A. gallowayi* is not epibenthic, but infaunal? In the Barents Sea, it is often found in areas with coarse sediments and stronger bottom currents together with *C. lobatulus*. NB I cannot find any mentioning on *A. gallowayi* in the cited reference: Hald & Steinsund 1996.

We agree, this sentence has been elaborated.

Page 3066, lines 17-18. This needs to be elaborated.

This sentence has been elaborated. Please, see the response to Page 3066, line 12.

Page 3066, lines 22 – 24. A reference on propagules is needed.

The description of the transport of propagules by sea currents and their subsequent settlement on the seafloor is congruent with a study by Alve and Goldstein (2003), and the reference has been added to the text.

Page 3066, lines 27. What kind of ice? Please discuss and make it clearer.

The term "glacier proximal" has been used instead of "ice proximal".

Page 3067, line 1. No, *Elphidium excavatum* f. *clavata* may also be the most frequent species in other environments than glacier proximal environments, e.g. Saher et al, 2009. In order to make this interpretation it is necessary to refer to studies of the position and distribution of the BSIS at this point.

Saher et al. 2009 showed the distribution (abundance) of E. excavatum f. clavata in the central Barents Sea. Therefore, their conclusions regard relation between abundance of foraminifera and inflowing Atlantic water/polar front position. However, clear correlation between distance from the glacier fronts and opportunistic species (E. excavatum f. clavata and C. reniforme) occurrence in the fjords was described in numerous papers (Steinsund, 1994; Hald and Korsun 1997, 1998; Majewski and Zajączkowski, 2007; Włodarska-Kowalczuk et al., 2013).The species assemblage is found in numerous deglacial records from Svalbard shelf areas (e.g. Ślubowska et al., 2005, 2007; Skirbekk et al., 2010; Rüther et al., 2012)

Page 3067, lines 5 – 6. Which areas are these records coming from? There are additional records that should be included in the comparison.

The areas where the records are coming from have been added to the text.

Page 3067, lines 13 – 16. It must be emphasized in the text what the temporal resolution is, and that there are not that many data points in this interval...

The points showing the resolution of our data (40-100 years) has been added to Figure 7.

Page 3067, lines 16 – 17. A more specific describing is needed.

This sentence has been elaborated.

Page 3067, lines 18 – 19. It is necessary to refer to a study of this mechanism.

Proper reference has been added to the text.

Page 3067, lines 20 – 27. This need to be presented and discussed in much more detail, also refer to Bakke et al 2009 (Nature Geoscience, DOI: 10.1038/NGEO439)

This part of discussion has been complemented.

Page 3068, lines 1 – 3. It is not clear what the authors mean with this? Heavier δ^{18}O values = warmer water? Explain in more detail and be specific.

Additional explanation has been added to this part of discussion

Page 3068, lines 8 – 9. It is necessary to include other type of data/references on the position of BSIS. It cannot be included solely on the foraminiferal content. This interpretation has to be supported by other findings.

We have rearranged this section, now the lithological parameters follow the interpretation based on foraminiferal content.

Page 3068, lines 14 – 19 a. The values of the current study are lighter from xxxxx cal yr BP and not just from 11500 cal yr BP. It must be addressed. Figure 8: Plot all δ^{18}O data from the current study, i.e. begin y-axis at 14.500 cal yr as figures 5-6. Discuss the lighter values in more details in the paper.

It has been improved.

Page 3068, lines 14 – 19 b. Are these values robust? It should be discussed if there are any dissolution effects on the isotope record.

As Storfjorden is known for its brine-enriched water production, we put focused attention on picking the foraminifera for stable isotopes analyses. Chosen tests had no dissolution signs, thus we assume that the isotopes records are robust.

Page 3068, lines 14 – 19 c. Any references confirming Arctic Water are isotopically lighter than AW?

The reference Duplessy et al., 2005 has been added.

Page 3069, line 3. Correct the spelling of “mollusk”.

It has been corrected.

Page 3069, lines 5 – 7. This ratio has not been described or addressed before? That is necessary or this should be left out altogether.

This ratio has been described widely in the revised version of this manuscript.

Page 3069, line 22. Erbs-Hansen et al (2013) is about a paleo-record. The current ecological interpretations must be based on modern analogues/ studies of recent fauna.

The reference has been changed.

Page 3069, lines 19 – 20. Khusid and Polayk (1988) is a study from Arctic Ocean? Argue why it is relevant for this study area. It is recommended to use Saher et al 2009 which is a study of modern foraminifera in the current study area. REF: Saher, M., Kristensen, D.K., Hald, M., Korsun, S., Jorgensen, L.L., 2009. Benthic foraminifera assemblages in the Central Barents Sea: an evaluation of the effect of combining live and total fauna studies in tracking environmental change. Norwegian Journal of Geology 89, 149-161.

We have added reference to two works: Sejrup et al., 2004 and Saher et al., 2009 as the first one describes in more detail the environmental preferences of E.excavatum f.clavata. Moreover, we have rewritten the sentence and skip the reference to Khusid and Polyak (1989) as their study site is located too far away from our coring site.

Page 3069, line 29 **-** page 3070, line 3. It is not quite right to assume. *M. barleanus* cover a wide temperature range. Please refer to for example Hald & Steinsund 1996 (Berichte zur Polarforschung 212, ISSN 01765027) which the authors have used previously in this paper.

We do not agree. Hald and Steinsund (1996) point only that this species follow the troughs of W Barents Sea with soft and organic- rich bottom sediments. These troughs are the main gateway for Atlantic water influx to the Barents Sea.

Page 3070, lines 4 – 5. Explain how/why?

The reference to the paper describing this relationship in the Arctic fjord has been added.

Page 3070, lines 5 – 8. This need to be seen in the light of the unusual light values prior to this time (cf figure 8). What happens here? Could these values influenced by dissolution?

As Storfjorden is fairly known for its brine-enriched water production, we put a lot of attention during analyzing the foraminiferal samples to look for the dissolution effects on foraminiferal tests.

Page 3070, lines 9 – 11. This needs to be discussed in much more detail before this may be suggested. Other paleoceanographic records from the Barents Sea and Svalbard region must be taken into account as well, e.g. Risebrobakken et al, 2010. The Holocene, 20, 609-621.

Additional references regarding the AW inflow to W and NE Svalbard including Kveithola Trough has been included. However, we do not agree that data presented by Risebrobakken et al. (2010) supports our discussion as they focus on the southern Barents Sea influenced by the continental discharge. Moreover, an extra branch of AW adds warm and saline water to WSC in Bjørnøya area (Walczowski and Piechura 2006, 2007).

Page 3070, lines 18 – 21. Before comparing to terrestrial records compare to paleoceanographic records from the region including new work by Groot et al 2014; Berben et al, 2014, then compare to other records as Forwick et al (2010). REFS: Berben, S.M.P., Husum, K., Cabedo-Sanz, P., Belt, S.T., 2014. Holocene subcentennial evolution of Atlantic water inflow and sea ice distribution in the western Barents Sea. Clim. Past 10, 181-198. Groot, D.E., Aagaard-Sørensen, S., Husum, K., 2014. Reconstruction of Atlantic water variability during the Holocene in the western Barents Sea. Clim. Past 10, 51-62.

It has been corrected.

Page 3070, lines 21 – 25. Please summarize and present this with less detail.

It has been corrected.

Page 3070, lines 25 – 29 a. Explain why *M. barleanus* indicate an increased influence of AW + cite a references on its modern ecological preferences.

The additional information has been added.

Page 3070, lines 25 – 29 b. Explain/discuss the apparent contradicting signals of more AW and more IRD

In our opinion in a small extent these two signals are not contradictory since snow accumulation on land and slight glaciers advance depend on humid air transport from the *ocean. Thus slight change in atmospheric frontal zone could cause fluctuation of the glaciers range.*

Page 3071, lines 14 – 15. This must be explained and argued in more detail. Please refer to later comments on figure 5.

This sentence has been rewritten.

Page 3071, lines 16 – 18. This is difficult to understand? On figure 6 it very much looks like the values become slightly heavier (higher values) for the period 3600-1200 cal yr BP indicating minor cooling and/or more salty water masses?

Indeed, the values become slightly heavier for the period 3600-1200 cal yr BP. It has been corrected in the revised version of the manuscript.

Page 3072, lines 1 – 3. Shortly state what happens with the flux shown in figure 4 and refer to figure 4 alone instead of referring not quite rightly to figure.

This sentence has been rewritten.

Page 3072, lines 3 – 4. References on the modern distribution and ecological controls of these species must be stated. It is necessary to discuss the interpretations stepwise. *N. labradorica* and *Islandiella* spp. are abundant in areas with a high biological productivity in the upper surface waters. High biological productivity occur near oceanic fronts and/or near ice margins, hence the current foraminiferal fauna indicate that the core site is near an oceanic front or near an ice margin. In the Barents Sea *Islandiella* spp has been found near marginal ice-zones, hence here it is interpreted that the core site is near a marginal ice-zone.

It has been corrected.

In figure 9 Islandiella spp. Is plotted together with IRD, this is not discussed further in the paper as it should. It appears that they only correlate in Late Holocene, hence *Islandiella* spp linked to sea ice using this correlation.

This paragraph has been removed.

Page 3072, lines 6 – 7. A reference on this?

The reference has been added.

Page 3072, lines 13 – 17.The correct reference is Rasmussen et al. (2014). Rasmussen et al (2014) find that "During the last 2000 years conditions have been increasingly unstable although with slightly increasing subsurface temperatures" which is also shown by recent studies by Groot et al (2014) and Berben et al (2014), both Climate of the Past, vol 10. The latter reference also include reconstructions of sea ice using sea ice biomarkers.

It has been corrected.

Figure 5 a: Indicate the unit of the fluxes; I assume it is specimens/g dry sediment/year?

It has been corrected. The description is in the caption - *no.* cm^{-2} ka^{-1}.

Figure 5 b: Some of the ecological tolerances is over simplified and/or not quite right and must be corrected: *C. reniforme* is not opportunistic.

We do not agree with this suggestion, there might be several levels of opportunism. C.reniforme is broadly and commonly described in the literature as an opportunistic species together with E.excavatum f.clavata (e.g. Ivanova, 2009; Korsun et al., 1995). C.reniforme is the second most important species in glacimarine environments (Osterman, 1982; Vilks et al., 1989; Hald et al., 1992; Jennings et al., 2000).

The term “high sea productivity”? – be more specific *N. labradorica* and *M. barleanus* are correctly connected to high biological productivity. This can occur in several settings. This also apply to *Islandiella* spp and *Bucella* spp, so it is not possible to divide them into these two groups of “ocean front” and “ice margin”. They should all be labelled as “high biological productivity”. The interpretation of ocean front vs ice margin must be done using other data and proxies form current study or existing knowledge.

We agree that N.labradorica, M.barleeanum, Islandiella spp. and Buccella spp. are indicators of high biological productivity. However, there is a wide range of available literature dividing those species into two groups: sea ice cover/sea ice margin species (Polyak and Solheim, 1994; Steinsund et al., 1994; Hald and Steinsund, 1996) and frontal zone indicators (Hald and Korsun, 1997; Korsun and Hald, 1998; 2000; Rytter et al., 2002; Jennings et al., 2004; Lloyd 2006; Knudsen et al., 2012; Jernas 2012).

We have updated the revised version of this manuscript of existing knowledge of species ecological preferences.

Figure 6: Data are displayed poorly mixing parameters that does not belong together. Move species richness, diversity and planktonic flux to figure 5. Keep these parameters together with the relevant benthic foraminiferal data and plot stable isotopes separately.

Such change will significantly enlarge Figure 5 and decrease Figure 6. We recommend to ask the editor if it is possible.

NB add the flux of *T. quinqueloba* to the planktonic data. The number may be low, but it may elucidate the influence of TAW.

The flux of T. quinqueloba has been added to Figure 6 and widely described in the text.

Figure 7: show data points of the IRD flux and d18O making the temporal resolution of the current study clear.

The data points have been added to the Figure 7.

Consider to make a plot of δ^{13}C vs δ^{18}O values from the current study evaluating the water masses (cf. Rasmussen, T.L., Thomsen, E., 2009. Stable isotope signals from brines in the Barents Sea: Implications for brine formation during the last glaciation. Geology 37, 903-906).

The scatter plot has been added to the Figure 8.

Figure 9: This comparison of *Islandiella* spp. and IRD are not properly discussed in the paper. As mentioned previously it appears that *Islandiella* spp cannot be linked to sea ice using this correlation.

The figure has been removed.

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Late Weichselian and Holocene paleoceanography of Storfjordrenna, southern Svalbard

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Abstract

Multiproxy analyses (incl. benthic and planktonic foraminifera, δ^{18}O and δ^{13}C records, grain-size distribution, ice-rafted debris, XRF geochemistry and magnetic susceptibility) were performed on a ^{14}C dated marine sediment core from Storfjordrenna, off southern Svalbard. The sediments in the core cover the termination of Bølling-Allerød, the Younger Dryas and the Holocene, and they reflect general changes in the oceanography/climate of the European Arctic after the last glaciation. Grounded ice of the last Svalbard- Barents Sea Ice Sheet retreated from the coring site c. 13,950 cal yr BP. During the transition from the sub-glacial to glaciomarine setting, Arctic Waters dominated the hydrography in Storfjordrenna. However, the waters were not uniformly cold and experienced several warmer spells. A progressive warming and marked change in the nature of hydrology occurred during the early Holocene. Relatively warm and saline Atlantic Water started to dominate the hydrography from approx. 9600 cal yr BP. Even though the climate in eastern Svalbard was milder at that time than at present (smaller glaciers), there were two slight coolings observed in the periods of 9000 - 8000 cal yr BP and 6000 - 5500 cal yr BP. A change of the Storfjordrenna oceanography occurred at the beginning of late Holocene (i.e. 3600 cal yr BP) synchronously with glacier growth on land and enhanced bottom current velocities. Although cooling was observed in the surface water, Atlantic Water remained present in the deeper part of water column of Storfjordrenna.

Usunięto: hydrology

Usunięto: 8

Usunięto: 5

Usunięto: hydrology

1 Introduction

The northward flowing North Atlantic Current (NAC) is the most important source of heat and salt in the Arctic Ocean (Gammelsrod and Rudels, 1983; Aagaard et al., 1987; Schauer et al., 2004; Fig. 1b). The main stream of Atlantic Water (AW) flowing north to Fram Strait as the West Spitsbergen Current (WSC) causes the dramatic reduction of sea ice extent and thickness through the warming of the intermediate water layer in this region of the Arctic Ocean (Quadfasel et al., 1991; Serreze et al., 2003). Paleoceanographic (e.g., Spielhagen et al., 2011; Dylmer et al., 2013) and instrumental (Walczowski and Piechura 2006, 2007; Walczowski et al., 2012) investigations provide evidence of a recent intensification of the flow of AW in the Nordic Seas and the Fram Strait.

The Svalbard archipelago is influenced by two water masses: AW flowing northward from the North Atlantic and Arctic Water (ArW) flowing southwest from the northern Barents Sea (Fig. 1b). An oceanic front arising at the contact of different bodies of water is an excellent area to research contemporary and past environmental changes. Intensification of AW flow and associated climate warming cause decreased sea-ice cover in the Svalbard fjords during winter (Berge et al., 2006), increased sediment accumulation rate (Zajączkowski et al., 2004; Szczuciński et al., 2009) and influences pelage-benthic carbon cycling (Zajączkowski et al., 2010).

Paleoceanographic records indicate that AW was present along the western margin of Svalbard, at least, during the last 12,000 years (e.g. Ślubowska et al., 2007; Werner et al., 2011; Rasmussen et al., 2013); occasionally reaching the Hinlopen Trough and Kvitøya Trough, thus transporting warmer and more saline water to the eastern part of Svalbard from the north (Ślubowska-Woldengen et al., 2007; Ślubowska et al., 2008; Kubischta et al., 2010; Klitgaard Kristensen et al., 2013). Periods of enhanced inflow of AW during the Holocene led to the expansion of marine species being absent or only rarely occurring at present. This includes the mollusc *Mytilus edulis* whose fossil remains are widely distributed in raised beach deposits on the western and northern coasts of Svalbard (e.g. Feyling-Hanssen and Jørstad, 1950; Hjort et al., 1992). *Mytilus edulis* spawn at temperatures above 8 to 10 °C (Thorarinsdóttir and Gunnarson, 2003) and thus is considered to indicate higher surface-water temperature related to stronger AW inflow during the early Holocene (11,000 – 6800 cal yr BP) (Feyling-Hanssen, 1955; Salvigsen et al., 1992; Hansen et al., 2011). Although the progressive development of *Mytilus edulis* is well documented by the periods of warming and inflow of AW to Hinlopen Trough, the presence of this species in Storfjorden (W Edgeøya;

Usunięto: Strait

Usunięto: and

Usunięto: Strait

Fig. 1) is unclear. Hansen et al. (2011) suggested that a small branch of warm AW could have reached eastern Spitsbergen from the south at that time.

In the 1980s and 1990s, Storfjorden was regarded to be exclusively influenced by the East Spitsbergen Current (ESC), carrying the cold and less saline ArW from the Barents Sea (Quadfasel et al., 1988; Piechura et al., 1996). More recent studies suggested that the hydrography in Storfjorden is affected by the production of brine-enriched shelf waters (e.g., Haarpaintner et al., 2001; Rasmussen and Thomsen, 2009), the creation of a coastal polynya (e.g., Skogseth et al., 2005; Geyer et al., 2010) or the overflow of dense waters to the continental shelf (e.g., Fer et al., 2003). However, hydrological data obtained from conductivity-temperature sensors attached to a *Delphinapterus leucas* showed a substantial and topographically steered inflow of AW to Storfjorden through the Storfjordrenna (Lydersen et al., 2002). Recently, Akimova et al. (2011) reviewed typical water masses for Storfjorden, where the AW was located between 50 and 70 meters.

Storfjordrenna is a sensitive boundary area (Fig. 1) where two contrasting water masses form an oceanic polar front, separating colder, less saline and isotopically lighter ArW from warmer, high saline and δ^{18}O heavier AW. An abrupt cooling (e.g. Younger Dryas, Little Ice Age) and warming (e.g. early Holocene warming) of the European Arctic might be linked to relatively small displacements of this front (Sarnthein et al., 2003; Hald et al., 2004; Rasmussen et al., 2014).

Two sediment cores taken at the mouth of Storfjordrenna, reveal a continuous inflow of AW to the south western Svalbard shelf since the deglaciation of Svalbard-Barents Ice Sheet (Rasmussen et al,. 2007), while inner Storfjorden basins undergo a shift from being occupied by continental ice to ice proximal condition (Rasmussen and Thomsen, in press). Nevertheless a limited amount of paleoceanographical data is available from this region, thus the reconstruction of the Svalbard-Barents Ice Sheet retreat and further development of Storfjordrenna oceanography is often speculative.

Usunięto: over the last 20,000 yr

Usunięto: with the presence of surface water from 15,000 to 10,000 ^{14}C yr BP

Usunięto: According to Rasmussen and Thomsen (2009), the isotopic records of δ^{18}O and δ^{13}C in benthic foraminifera tests show low values during cold stadials of the last glaciation, whereas the values from warm periods are higher. Further, the study implies that a light δ^{18}O signal is attributed to brine formation carrying isotopically lighter surface water to the bottom.

In this paper we present results from multi-proxy analyses of a sediment core retrieved 100 km east of the mouth of Storfjordrenna (Fig. 1a). We provide a new age for the retreat of the last Svalbard-Barents Sea Ice Sheet from Storfjordrenna and discuss the interaction of oceanography and deglaciation, as well as the postglacial history of Atlantic Water inflow onto the shelf off southern Svalbard. Since the studied sediment core was retrieved from an oceanographic frontal zone, sensitive to larger-scale changes, we believe that the presented data show the general climatic/oceanographic trends in the eastern Arctic.

2 Study area

Storfjorden is an approx. 190 km long and up to 190 m deep glacial trough located between the landmasses of Spitsbergen to the west, Edgeøya and Barentsøya to the east, and the shallow Storfjordenbanken to the south-east (Fig. 1a). It is not a fjord sensu stricto, as the sounds of Heleysundet and Freemansundet to the north and northeast, respectively, connect the head of Storfjorden to the north western Barents Sea. A sill of 120 m depth crosses the mouth of Storfjorden. The 254 km long Storfjordrenna, a continuation of the trough that extends towards the shelf break, is located beyond this sill. Bottom depth along the trough axis varies between 150 m and 420 m (Pedrosa et al., 2011).

Usunięto: During the late Weichselian Glacial Maximum, Storfjorden and Storfjordrenna were covered by an ice stream draining the Svalbard Barents Sea Ice Sheet (e.g., Ottesen et al., 2005).

2.1 Water masses

The water column of Storfjorden and Storfjordrenna is composed of two main water masses transported with currents from east and south and mixed waters which are formed locally (Table 1. after Skogseth et al., 2005). Warm and saline Atlantic Water (AW) enters Storfjordrenna in a cyclonic manner (Schauer, 1995; Fer et al., 2003), flowing into the trough parallel to its southern margin and flowing towards the trough mouth along its northern slope. The AW occurs between 50 and 70 m in Storfjorden and extends to a depth of 200 m in Storfjordrenna (Akimova et al., 2011). The origin of AW entering Storfjordrenna is an eastward branch of the North Atlantic Current (NAC) following the topography of the Barents Sea Shelf Break. However, approx. 50% of AW flowing northward also penetrate into Bjørnøyrenna (Smedsrud et al., 2013; for location see Fig. 1). The AW in Storfjordrenna is cooler and fresher than in Bjørnøyrenna as an effect of distance and mixing processes (O'Dwyer et al., 2001). AW may occasionally propagate even further east of Svalbard, where it fills the depressions below 180 m (Schauer, 1995). Relatively cold Arctic Water (ArW) is transported to Storfjorden and Storfjordrenna by the East Spitsbergen Current (ESC). The ESC enters the fjord through the tidally influenced sounds of Heleysundet and Freemansundet in the north and northeast (Norges Sjøkartverk, 1988), as well as from the southeast with a coastal current flowing around Edgøya (Loeng, 1991). AW and ArW mix to form Transformed Atlantic Water (TAW), which dominates on the shelf off west Spitsbergen (Svendsen et al., 2002; Table 1). Dense, brine-enriched Shelf Water (BSW) in Storfjorden is produced through high polynya activity and results from intense formation of sea ice (Haarpaintner et al., 2001; Skogseth et al., 2004, 2005). The BSW fills the fjord to the top of the sill (120 m) and initiates a gravity driven overflow (Quadfasel et al., 1988; Schauer, 1995; Schauer and Fahrbach, 1999; Fer et al., 2003, 2004; Skogseth et al., 2005). BSW is characterized by salinity greater than 34.8 and temperature at or slightly above the freezing point (Table 1). Surface Water (SW) in the upper 50 m is cold and fresh during the autumn and warm and fresh due to ice melting during the summer. In winter, the water column in Storfjorden is homogenized due to wind and tidal mixing and is considered to be close to the freezing point (Skogseth et al., 2005).

3 Material and methods

Multi-proxy analyses of the gravity core JM09-020-GC provided the basis for this study. The core was retrieved with R/V Jan Mayen (University of Tromsø – The Arctic University of Norway, UiT) in November 2009 from the Storfjordrenna (76°31489’ N, 19°69957’ E), from a bottom depth of 253 m (Fig. 1a). The coring site was located in an area above the continuous presence of BSW and was selected after an echo-acoustic investigation in order to identify the greatest possible area of flat bottom with minimum disturbance of sediments. Conductivity-temperature-depth (CTD) measurements were performed prior to coring (Fig. 2a) and in summer 2013 (Fig. 2b).

Usunięto: November 5th, 2009;

Usunięto: August 13th, 2013;

Prior to sediment core opening, the magnetic susceptibility (MS) was measured using a loop sensor installed on a GEOTEK Multi Sensor Core Logger at the Department of Geology, UiT. Core sections were stored in the laboratory for one day before measurements thereby allowing the sediments to adjust to room temperature and to avoid measurement errors related to temperature changes (Weber et al., 1997). X-radiographs and digital images were taken from half of the core to define sedimentary and biogenic structures. Sediment colour was defined according to the Munsell Soil Color Charts (Munsell Products, 2009). Qualitative element-geochemical measurements were performed with an Avaatech X-ray fluorescence (XRF) core scanner using the following settings: 10 kV; 1000 µA; 10 sec. measuring time; no filter. Both core halves were subsequently cut into 1-cm slices and transported to the Institute of Oceanology, Polish Academy of Sciences in Sopot for further analyses.

Sediment samples for foraminiferal analyses were freeze-dried, weighed, and wet sieved using sieves with mesh-sizes of 500 µm and 100 µm. Residues were dried, weighted again and then split on a dry micro-splitter. Where possible, at least 300 specimens of foraminifera were counted in every 5 cm of sediment. Species identification under a binocular microscope (Nikon SMZ1500) was supported using classification of Loeblich and Tappan (1987), with few exceptions. Percentages of the 8 indicator species were applied. The number of species per sample and Shannon-Wiener Index were calculated in the program Primer 6. The benthic foraminiferal abundance and ice-rafted debris (IRD; grains >500 µm) were counted under a stereo-microscope and expressed as flux values (no. of specimens/grains cm^{-2} ka^{-1}) using the bulk sediment density and sediment accumulation rate.

Stable oxygen and carbon isotope compositions of tests of the infaunal foraminifer species *Elphidium excavatum* f. *clavata* were determined at the Department of Geological Sciences, University of Florida (Florida, USA). All values are calibrated to the PeeDee Belemnite (PDB) scale and corrected for ice volume changes. In our study we discuss the δ^{18}O and δ^{13}C record as a relative measure for changes in the water mass characteristics (temperature-salinity) and/or the supply of meltwater/freshwater to the area. Therefore, we haven't corrected the values for vital effect.

Usunięto: neither

Usunięto: nor the ice volume changes (Erbs-Hansen et al., 2013).

Grain size (<2 mm) analyses were performed every 1 cm using a Malvern Mastersizer 2000 laser particle analyser and presented as volume percent. To examine relative variability in the near-bottom currents the mean grain size distribution of the <63 µm fraction was calculated, to avoid effect of ice-rafted coarse fraction. Mean grain size was calculated in the program GRADISTAT 8.0 by the geometric method of moments (Blott and Pye, 2001).

3.1 Age control

The chronology for this study is based on high-precision AMS ^{14}C measurements of fragments from nine calcareous bivalve shells. Measurements were performed in the Poznań Radiocarbon Laboratory, which is equipped with the 1.5 SDH-Pelletron Model "Compact Carbon AMS" (Czernik and Goslar, 2001; Goslar et al., 2004). The surface layer of shells was scraped off to avoid contamination with younger carbonate encrustation. The AMS ^{14}C dates were converted into calibrated ages using the calibration program CALIB 6.1 (Stuiver and Reimer, 1993; Stuiver et al., 2005) and the Marine13 calibration curve (Reimer et al., 2013). The difference ΔR in reservoir age correction of the model ocean and region of Svalbard was reported by Mangerud et al. (2006) to be 105±24 or 111±35; we used the first value; calibrated ages are presented in Table 2. It should be noted that the reservoir age is based on few data points from western Spitsbergen, and the age may be different for the eastern coast. However, no data are available from the latter region.

Usunięto: Bivalve taxonomy was confirmed by Dr. Maria Włodarska-Kowalczuk of the Institute of Oceanology, Polish Academy of Sciences.

Usunięto: 09

Usunięto: 09

4 Results

4.1 Modern hydrology

In November 2009 the surface water at the coring site (upper ~27 m) had already cooled down (1.24 °C; Fig. 2a). However, its salinity was still low (34.24 °C). Transformed AW was observed in the layer between 60 and 160 m. The lowermost part of water column shows gradual cooling reaching a minimum temperature of 0.76 °C near the bottom. The lack of BSW at the bottom indicates gradual water mixing during summer and fall. In August 2013, the surface waters had slightly lower salinity, but the temperature was ~5 °C higher than in November 2009 (Fig. 2b). TAW occupied the same depths as in 2009. However, an almost 50 m thick layer of BSW was present close to the seafloor.

4.2 Age model

The ^{14}C ages and calibrated ages are reported in Table 2. The calibration gives an age distribution, not a single value, so the 2-sigma range presented and Fig. 3 shows age probability distribution curves. Ages of samples generally increase with sediment depth except in the case of one sample: St 20A 39, which provided an older age than the sample below. That shell was most likely re-deposited and was thus not used for the age model. However, because all the samples used for dating were shell fragments, it must be taken into account that it is possible that more samples could be subjected to re-deposition, but on the basis of the available data this is not possible to confirm. The age model is based on assuming linear sediment accumulation rates between data points. The highest probability peaks from calibrated age ranges were used as input values for the model. For the lowermost and uppermost parts of the core, we adopted sediment accumulation rates for the neighbouring parts. It is common to observe the loss of the sediment surface layer during coring with heavy gravity cores. In the case of core JM09-020-GC it is likely that at least the top 40 cm of sediments were lost during coring. This conclusion is supported by analysis of a box corer collected prior to coring (Łącka et al., in prep.). The extrapolated age model for the sediment surface is, therefore, 1200 cal yr BP.

4.3 Sedimentological and geochemical parameters

Usunięto: Lithology

The core JM09-020-GC is 426 cm long and consists of four lithological units L1 (bottom of the core to 370 cm; >13,450 cal yr BP), L2 (370 cm to 272 cm; ~13,450 cal yr BP to ~11,500 cal yr BP), L3 (272 cm to 113 cm; ~11,500 cal yr BP to ~3600 cal yr BP) and L4 (113 cm to core top; ~3600 cal yr BP to ~ 1200 cal yr BP). The lithological log was created based on the X-radiographs, grain-size analysis data and foraminiferal flux (Fig. 4). Grains >2 mm are referred to as "clasts" and are marked in the lithological logs as individual features.

Usunięto: 0

Usunięto: 0

Unit L1 consists of compacted massive dark grey (5Y 4/1) sandy mud with various amounts of clasts. Bioturbation and foraminifera were generally absent. However, one shell fragment was found at approx. 395 cm.

Usunięto: (bottom of the core to ~370 cm)

Usunięto: Munsell code

Unit L2 contains massive dark grey (5Y 4/1) sandy mud with some coarser material and generally lower amounts of clasts than unit L1. The mean grain size (<63 µm) ranged from 7-10 µm. The highest IRD flux and Fe/Ca ratio for the entire core occur in this unit. The mass accumulation rate (MAR) is 0.043 g cm^{-2} yr^{-1}. The first signs of bioturbation occur in this unit and the flux of foraminifera increases rapidly up to ~5700 individuals cm^{-2} ka^{-1} (Fig. 4).

Usunięto: (~370 cm to ~272 cm)

Usunięto: >

Usunięto: 4

Usunięto: 60

The unit L3 is composed of massive dark olive grey mud (5Y 3/2) and is characterized by decreasing MAR values (0.019 g cm^{-2} yr^{-1} to 0.002 g cm^{-2} yr^{-1}), moderate sand content and clearly increasing mean grain size (<63 µm). IRD flux is low and the Fe/Ca ratio decreases gradually until c. 9200 cal yr BP and then remains low (between 3 and 4; Fig. 4) Continuous bioturbation and variable foraminiferal fluxes, with maxima in the intervals 9000-8000 cal yr BP and 6000-5500 cal yr BP, are observed.

Usunięto: (~272 cm to ~113 cm)

Usunięto: >

The uppermost unit L4 is mostly composed of the same material as the underlying unit- massive dark olive grey mud (5Y 3/2). However, the sand content is occasionally higher. MAR increases to 0.024 g cm^{-2} yr^{-1}. The mean grain size (<63 µm) through this interval is even higher than in L3 and reaches up to 15 µm and Fe/Ca ratio is increasing. The bioturbation continues, numerous shell fragments are presented and foraminifera flux reaches high values throughout the entire unit.

Usunięto: (113 cm to core top)

Usunięto: >

4.4 Foraminiferal fauna

A total of 54 calcareous and 6 agglutinated species were identified. The foraminiferal assemblages were dominated by calcareous fauna. Agglutinated species occurred only in 14 sediment samples, and their abundance did not exceeded 4%. The only exception is the sample dated to c. 11,350 cal yr BP (262.5 cm depth) with 25% of agglutinated foraminiferal

Usunięto: 0

fauna. However, in this sample the total foraminifera abundance was low (13 specimens g^{-1} sediment). In general, species richness, number of agglutinated foraminifera, as well as rare and fragile species, increase towards the top of the core. Benthic foraminiferal fauna is dominated by *Elphidium excavatum* f. *clavata*, *Cassidulina reniforme*, *Nonionellina labradorica*, *Melonis barleeanum*, *Islandiella* spp. (*Islandiella norcrossi*/*Islandiella helenae*) and *Cibicides lobatulus*. Percentages of *E. excavatum* f. *clavata* show an inverse relationship to *C. reniforme* with the almost constant dominance of the latter species in the periods: ~12,450 cal yr BP to ~12,000 cal yr BP and ~ 9600 cal yr BP to ~2800 cal yr BP (Fig. 5). Planktonic foraminifera are represented by three species, *Neogloboquadrina pachyderma* (sinistral), *Neogloboquadrina pachyderma* (dextral) and *Turborotalita quinqueloba*. However, the two later species are very rare. In general, the abundance of planktonic fauna is low in the older parts of the core and slightly increases approx. 10,000 cal yr BP reaching maximum values c. 2000 cal yr BP (Fig. 6).

Usunięto: 0

Based on the most significant changes in the foraminiferal species abundances, species diversity and δ^{18}O and δ^{13}C in *E. excavatum* f. *clavata* tests the core was divided into the four foraminiferal zones F1-F4: ~13,450 cal yr BP to 11,500 cal yr BP (F1); 11,500 cal yr BP to 9200 cal yr BP (F2); 9200 cal yr BP to 3600 cal yr BP (F3); 3600 cal yr BP to 1200 cal yr BP (F4) (Fig. 5, Fig. 6). Zones correspond to lithological division: the age of unit F4 is the same as L4, units F3 and F2 correspond to L3 and unit F1 is linked to unit L2. In unit L4 foraminifera are rare to absent.

Usunięto: 0

Zone F1 is dominated by the opportunistic *E. excavatum* f. *clavata* and *C. reniforme*. The latter one dominates over *E.excavatum* f.*clavata* between 12,250 cal yr BP and 11,950 cal yr BP. High percentages of *C. lobatulus* (up to 57%) and *Astrononion gallowayi* (up to 2.5%) occur occasionally. Planktonic foraminifera flux was low at the beginning of this section (mean value of 9 specimens cm^{-2} ka^{-1}) and completely disappeared for almost 1500 years from approx. 11,500 cal yr BP (Fig. 6). Species richness as well as Shannon-Wiener index show, compared to the upper part of the core, low biodiversity (mean values of 8 and 1.26, respectively). Furthermore, maxima of δ^{18}O and δ^{13}C occur in this interval.

In zone F2 the contribution of *E. excavatum* f. *clavata* and *C. reniforme* is slightly lower, and *N. labradorica* becomes the most abundant species (Fig. 5). There is also an increase in *Islandiella* spp. percentage. Planktonic foraminifera appeared again c. 10,000 cal yr BP. Biodiversity significantly increased and δ^{18}O reached its minimum value of 2.61 ‰ vs VPDB approx. 10,000 cal yr BP.

Zone F3 is characterized by the minimum mass accumulation rates of sediment and consequently, low temporal resolution. *C. reniforme* dominates over *E. excavatum* f. *clavata* throughout. *M. barleeanum* has its maximum abundance in this zone, and *N. labradorica* is abundant in the lower parts of this zone, decreasing at approx. 7000 cal yr BP. *Islandiella* spp. increases upcore. Planktonic foraminifera occur in the entire zone, and the fluxes are higher than those of previous units (Fig. 6). Biodiversity remains high in this zone, and δ^{18}O and δ^{13}C remain generally stable, however marked peaks occurred at approx. 6800 cal yr BP, 6500 cal yr BP and 5700 cal yr BP, respectively.

A consistently high foraminiferal flux of up to ~4900 no. of specimens cm^{-2} ka^{-1} characterises zone F4. The fluxes of *Islandiella* spp. and *Buccella* spp. increase significantly and from 2850 cal yr BP *Islandiella* spp. dominated the assemblage with *E.excavatum* f.*clavata*. Additionally, the fluxes of *C. lobatulus* and *A. gallowayi* increase. However, their abundances are lower than those of zone F2. A maximum abundance of planktonic foraminifera occurs in this unit. Foraminifera biodiversity continues to increase towards the core top (up to 2.33; Fig. 6). δ^{18}O and δ^{13}C increase slightly, however, with numerous fluctuations.

Usunięto: . The percentage of *E. excavatum* f. *clavata* increases slightly while *C. reniforme* decreases.

5 Discussion

Based on the most pronounced changes in sedimentological and foraminiferal data as well as comparison to previous studies from adjacent areas, we have distinguished 5 units in the studied core: a sub-glacial unit (>13,450 cal yr BP), glacier-proximal unit (13,450 cal yr BP to 11,500 cal yr BP), glaciomarine unit I (11,500 cal yr BP to 9200 cal yr BP), glaciomarine unit II (9200 cal yr BP to 3600 cal yr BP) and glaciomarine unit III (3600 to 1200 cal yr BP).

Usunięto: 0

Usunięto: 0

5.1 Sub-glacial unit (>13,450 cal yr BP)

Usunięto: 0

The lowermost unit L1 (Fig. 4) was significantly coarser, compacted and devoid of foraminifera, which indicates its likely of sub-glacial origin. During the late Weichselian Glacial Maximum, Storfjorden and Storfjordrenna were covered by an ice stream draining the Svalbard-Barents Ice Sheet (SBIS; e.g., Ottesen et al.,2005). The SBIS deglaciation occurred as a response to sea-level rise and increased mean annual temperature (Siegert and Dowdeswell, 2002). Rasmussen et al. (2007) noted that the outer part of Storfjordrenna (389 m depth; Fig. 1a) was deglaciated before 19,700 cal yr BP. The bivalve shell fragment from

Usunięto: , i.e., it was deposited beneath an icestream draining parts of the last Svalbard-Barents Ice Sheet (SBIS) through Storfjorden

Usunięto: 16,310 ^{14}C yr BP (18911-19591 cal yr BP)

395.5 cm in our core suggests that the centre part of Storfjordrenna was ice-free before ~13,950 cal yr BP. This indicates that the ~100 km long retreat of the grounding line from the shelf break to the central part of Storfjordrenna occurred in approx. 5700 years. The deglaciation of the inner Storfjorden basin occurred c.11,700 cal yr BP (Rasmussen and Thomsen, 2014), while the coasts of east Storfjorden islands, Barentsøya and Edgeøya, which are located over 100 km north from the coring site, occurred some 500 years later, i.e., 11,200 cal yr BP (recalibrated after Landvik et al., 1995). Siegert and Dowdeswell (2002) noted that, during the Bølling-Allerød warming (c. 14,700-12,700 cal yr BP), some of the deeper bathymetric troughs (e.g., Bjørnøyrenna) had deglaciated first, forming large embayments of ice around them. Probably, Storfjordrenna was one of such embayments at that time. Our data is in agreement with ice stream retreat dynamics presented by Rüther et al. (2012) and refines the recent models of the Barents Sea deglaciation (e.g. Winsborrow et al., 2010; Hormes et al., 2013; Andreassen et al., 2014).

5.2 Glacier-proximal unit (13,450 cal yr BP to 11,500 cal yr BP)

The transition from a subglacial to the glaciomarine setting is observed as a distinct change in sediment colour, several peaks of IRD, decreased amount of clasts and the appearance of foraminifera. The sediment accumulation rate (0.043 g cm^{-2} yr^{-1}) was in the same order of magnitude as modern proximal and central parts of west Spitsbergen fjords (see Szczuciński et al., 2009 for review). Textural and compositional analyses of L2 recorded bimodal grain-size distribution and low abundance of microfossils, suggesting that deposition during the deglaciation occurred from suspension settling from sediment-laden plumes and ice rafting (Lucchi et al., 2013; Witus et al., 2014). This unit in our core is limited to ~60 cm and is characterized by a lack of bioturbation in its lower part.

The high flux of IRD supported by the high Fe/Ca ratio and depleted δ^{18}O values correlates well with the abundance of *C. lobatulus* and *A. gallowayi* (Fig. 4 and Fig. 5), two species connected with high energy environments (Østby and Nagy, 1982) indicating that the coring site was likely located proximal to one or several ice fronts during the time of deposition of this unit.

During an early phase of the deglaciation of Storfjorden, the East Spitsbergen Current was still not active, because the ice sheet grounded between Svalbardbanken and Storfjordbanken blocked the passage between eastern and western Svalbard (Rasmussen et al., 2007; Hormes et al., 2013). Thus, the first foraminiferal propagules (juvenile forms) were

Usunięto: 8

Usunięto: 4

Usunięto: 2600

Usunięto: 0

Usunięto: 4

Usunięto: in unit L2 correlates well with

Usunięto: g

Usunięto: which are two epibenthic species that often attach to hard substrate e.g., lithic clasts or bivalve shells (e.g., Hald and Steinsund, 1996) and may indicate stronger near-bottom currents (Østby and Nagy, 1982). As the coring site

Usunięto: L2 and the mean grain size (>63 µm) is low (Fig. 4), it is likely that the presence of these epibenthic species reflects abundance of hard substrate (IRD) rather than regional oceanography.

transported by sea currents (Alve and Goldstein, 2003) from the south and west and settled on the seafloor that was exposed after the retreat of grounded ice. The proximal glaciomarine environment affected foraminiferal assemblages and resulted in low species richness, biodiversity and low foraminiferal abundance. Consequently, foraminifera assemblages became dominated by fauna typical for the glacier proximal settings: *E. excavatum* f. *clavata*, *C. reniforme* and *Islandiella* spp. (e.g., Vilks, 1981; Osterman and Nelson, 1989; Polyak and Mikhailov, 1996; Hald and Korsun, 1997). Dominance of *E. excavatum* f. *clavata* confirms the proximity to the ice sheet, decreased salinity and high water turbidity (e.g., Steinsund, 1994; Korsun and Hald, 1998; Włodarska-Kowalczuk et al., 2013).

The upper part of unit L2 (c. 12,800-11,500 cal yr BP) spans the Younger Dryas (YD) stadial. Records of marine sediments from Nordic and Barents Sea (e.g., Rasmussen et al., 2007; Ślubowska-Woldengen et al., 2007, 2008; Zamelczyk et al., 2012; Groot et al., 2014), as well as δ^{18}O records from Greenland ice cores (e.g., Dansgaard et al., 1993; Grootes et al., 1993; Mayewski et al., 1993; Alley, 2000) show that the YD was characterised by a rapid and short-term temperature decrease. This event was likely driven by weakened North Atlantic Meridional Overturning Circulation, a result of the Lake Agassiz outburst (e.g., Gildor and Tziperman, 2001; Jennings et al., 2006; Murton et al., 2010; Cronin et al., 2012) or interaction between the sea ice and thermohaline water circulation (Broecker, 2006), which led to a reduction of AW transport to the north and a dominance of fresher Arctic Water. Our data shows that heavier δ^{18}O recorded e.g., 12,720 cal yr BP and 12,100 cal yr BP, correlate with reduced to absent IRD fluxes, while the peaks of lighter δ^{18}O, e.g., 12,450 cal yr BP, 12,150 cal yr BP and 11,780 cal yr BP, occurred synchronously with significant enhanced IRD fluxes (Fig. 7). Absence of IRD, occasionally for several decades, might reflect temporarily polar conditions (Dowdeswell et al., 1998; Gilbert, 2000) characterized by the formation of perennial pack ice in Storfjorden locking icebergs proximal to their calving fronts and preventing their movement over the coring site (Forwick and Vorren, 2009). On the other hand, warmer periods resulted in massive iceberg rafting and delivery of IRD to Storfjordrenna, thus reflecting more sub-polar conditions. Hydrological variability during Younger Dryas was previously noted in some circum-North Atlantic deep-water records (Bakke et al., 2009; Elmore and Wright, 2011 and references therein; Pearce et al., 2013). Moreover, oxygen stable isotopes record from an ice-core GISP2 shows some warmer spells during that time (Stuiver et al., 1995), which coincides with higher ice-rafting in Storfjordrenna (Fig. 7). Bakke et al. (2009) noted that the earlier part of YD was colder and more stable, whereas later part of this period was characterized by alternations between sea-

Usunięto: ice

Usunięto: Hald et al., 2004;

Usunięto: ; Korsun and Hald 1998, 2000

Usunięto: ounger Dryas

Usunięto: 66

Usunięto: 06

Usunięto: 0

Usunięto: 09

Usunięto: 760

Usunięto: polar

Usunięto: caused by the

ice cover and influx of warmer, salty North Atlantic waters. Our record shows that during the late YD δ^{18}O were slightly shifted towards lighter values. Temporal resolution of our record do not allow for more detailed comparison with available data, nevertheless it clearly indicate that the Younger Dryas was not uniformly cold and that at least some warmer spells occurred on eastern Svalbard.

Usunięto: Our data indicate that

We also conclude that the data on δ^{18}O presented in Fig. 7 reflects temperature variations at the coring site according to the isotopically lighter ArW paleotemperature model (Duplessy et al., 2005). Another explanation of the heavier δ^{18}O periods during the YD could be intermittent inflow of warmer AW. However, this is unlikely to cause the synchronous disappearance of IRD.

5.3 Glaciomarine unit I (early Holocene; 11,500 cal yr BP to 9200 cal yr BP)

During the early Holocene foraminiferal fauna, although low in abundance, was dominated by species related to the glaciomarine environment (*E. excavatum* and *C. reniforme*; Fig. 5). Increasing species richness and biodiversity of foraminifera point to amelioration of environmental conditions and a progressive increase in the distance to the glacier front (Korsun and Hald, 2000; Włodarska-Kowalczuk et al., 2013). Decrease of the Fe/Ca ratio is suggested to reflect increased marine productivity and reduced supply of terrigenous material (Croudace et al., 2006). The mean grain size (>63 µm; Fig. 4) indicates weaker bottom currents at the beginning of the early Holocene and stronger bottom currents at the end of this period, which might have been related to the ongoing isostatic uplift of the land masses of Svalbard, as well as sea level rise (e.g., Forman et al., 2004).

Significant fluctuations of the δ^{18}O and δ^{13}C and increasing abundance of *N. labradorica* and *Islandiella* spp. suggest that Storfjordrenna was under the influence of various water masses at this time (Fig. 6). Comparison of our δ^{18}O record with records from the Storfjorden shelf (400 m depth; Rasmussen et al., 2007; Fig. 1a) and the northern shelf of Svalbard (400 m depth; Ślubowska et al., 2005; Fig. 1b) show that all the records are shifted towards lighter values in the early Holocene (Fig. 8a) with the record from our core being the most depleted (from c. 13,000 cal yr BP). We suggest that the records located on the western and northern shelf of Svalbard directly mirror the effect of warmer Atlantic water inflow, while record from Storfjordrenna is under influence of isotopically lighter Arctic Water from the Barents Sea (Duplessy et al., 2005). The shift from the Arctic water domain to the Atlantic water domain during the end of the early Holocene is also visible on a scatter plot of δ^{13}C against δ^{18}O (Fig. 8b). The results grouped to the left indicate Arctic water domination, while the results grouped to the right shows Atlantic water domination.

According to Kaufman et al. (2004), the early Holocene is characterized by higher summer solar insolation at 60°N (10% higher than today), leading to a reduction in sea-ice cover (Sarnthein et al., 2003). As ice cover decreased, more solar energy was stored in summer and then re-radiated during the winter (e.g., Gildor and Tziperman, 2001). This process accelerated the ice sheet melting and finally, its retreat towards the fjord heads (Forwick & Vorren, 2009; Jessen et al., 2010; Baeten et al., 2010). Our data suggest that the iceberg calving to Storfjordrenna was significantly reduced or even disappeared approx. 10,800 cal yr BP. However, supply of turbid meltwater from land to the study area still resulted in relatively high sediment accumulation rate.

According to Risebrobakken et al., (2011) and Groot et al., (2014) the presence of Arctic water suppressed the warming signal in the western Barents Sea. This is in agreement with our data on planktonic foraminifera reappearing at the termination of the early Holocene (c. 9600 cal yr BP; Fig.6). During this period *N. pachyderma* (sin.) dominated, however some peaks of *N. pachyderma* (dex.) and *T. quinqueloba* were noted. The two latter species are regarded as subpolar species (Bé and Tolderlund, 1971), although *T. quinqueloba* could be also related to oceanic frontal conditions separating Atlantic and Arctic water (Johannessen et al., 1994; Matthiessen et al., 2001). The peaks of *T. quinqueloba* around 9600 cal yr BP were noted previously in western Barents Sea margin (e.g. Hald et al., 2007; Risebrobakken et al., 2010).

Usunięto: oceanic

Increasing foraminiferal biodiversity in Storfjordrenna (Fig. 6), as well as the occurrence of the thermophilous mollusc *Mytilus edulis* on western Edgeøya (Salvigsen et al., 1992) suggest that the inflow of AW crossed Storfjordrenna and continued northward to the inner fjord by 9600 cal yr BP.

Usunięto: k

Usunięto: 5

Usunięto: Decrease of the Fe/Ca ratio is suggested to reflect increased productivity in the sea and reduced supply of terrigenous material (Croudace et al., 2006).

5.4 Glaciomarine unit II (mid-Holocene; 9200 cal yr BP to 3600 cal yr BP)

The mid-Holocene was characterized by relative stable environmental conditions, low sediment accumulation rates (0.002 g $cm^{-2}yr^{-1}$) and slight delivery of IRD (Fig. 4), reflecting very limited ice rafting and reduced supply of fine-grained material to Storfjordrenna. Low sedimentation rates and the low Fe/Ca ratio reflect reduced glacial conditions on Svalbard during the mid-Holocene (Elverhøi et al., 1995; Svendsen and Mangerud, 1997). In contrast, Hald et al. (2004) noted that in the record from Van Mijenfjorden, an enhanced tidewater

Usunięto: evanescent

Usunięto: matte

Usunięto: from our records are assumed to reflect glaciation occurred during this period; it was thus argued that IRD is a more reliable indicator of glaciation than sedimentation rates. However, ice rafting in Storfjordrenna was generally low.

Shifts between the dominant species *C. reniforme* and *E. excavatum* f. *clavata* (Fig. 5) reflect environmental/hydrological changes (Hald and Korsun, 1997). The decrease of *E. excavatum* f. *clavata* (percentage and flux), which prefers colder bottom waters (Sejrup et al., 2004; Saher et al., 2009) and increase of *C. reniforme* points to the constant inflow of less modified AW and reduction in sedimentation (e.g., Schröder-Adams et al., 1990; Bergsten, 1994; Jennings and Helgadóttir, 1994; Hald and Steinsund, 1996; Hald and Korsun, 1997). Furthermore, the relative abundance of *M. barleeanum* (Fig. 5) indicates that environmental conditions in Storfjordrenna were similar to contemporary Norwegian fjords that are dominated by AW with a temperature of 6 - 8 °C and salinities of 34 - 35 (Husum and Hald, 2004). High total foraminiferal flux at the beginning of this period, as well as high foraminiferal species richness and biodiversity clearly point to AW conditions at the bottom (Hald and Korsun, 1997; Majewski and Zajączkowski, 2007; Włodarska-Kowalczuk et al., 2013). These conclusions are also supported by the heavier δ^{18}O, showing AW dominance and significant reduction in the amount of freshwater and ArW in Storfjordrenna (Fig. 8). The continuous presence of *Mytilus edulis* during the entire mid-Holocene points to the reduced inflow of the East Spitsbergen Current on account of the AW inflow (Feyling-Hansen, 1955; Forman, 1990; Salvigsen et al., 1992. The pathway and range of AW inflow to the western and north-eastern Svalbard during mid-Holocene were well described by Ślubowska-Woldengen et al. (2008) and Groot et al. (2014). Together with our results it is suggested that one of the main ways of AW inflow to the eastern Svalbard may have occurred trough Storfjordrenna.

Even though sediment accumulation rates were low, and grain size, as well as geochemical proxies, remain relatively constant during the mid-Holocene, the foraminiferal flux (including planktonic foraminifera) increased in two periods: of 9000 - 8000 cal yr BP and 6000 - 5500 cal yr BP, respectively (Fig. 4 and 6). In both cases the increase in IRD and *I. norcrossi* fluxes was followed by a slight depletion in δ^{18}O and heavier δ^{13}C suggesting minor cooling and likely seasonal sea-ice formation leading to beach sediment transport by shore ice. Our observations support earlier studies of the overall mid-Holocene shifts towards colder environment (Skirbekk et al., 2010; Rasmussen et al., 2012; Berben et al., 2014; Groot et al., 2014) and fluctuations in the glacial activity in the Svalbard region (e.g., Forwick and Vorren, 2007, 2009; Beaten et al., 2010; Ojala et al., 2014). Our data shows an increased supply of

Usunięto: Erbs-Hansen et al., 2013

Przeniesione (wstawienie) [1]

Usunięto: and *M. barleeanum*

Usunięto: points to the reduction in sea ice cover and the limited significance of Transformed Atlantic Water (Khusid and Polyak, 1989). Furthermore, the increase of

Przeniesione w górę [1]: *C. reniforme* and *M. barleeanum* points to the constant inflow of less modified AW and reduction in sedimentation (e.g., Schröder-Adams et al., 1990; Bergsten, 1994; Jennings and Helgadóttir, 1994; Hald and Steinsund, 1996; Hald and Korsun, 1997).

Usunięto: The

Usunięto: throughoutis suggested that the main way of AW inflow to the eastern Svalbard may have occurred through Storfjordrenna.

Usunięto: (Fig. 9)

Usunięto: Sarnthein et al., 2003;

Usunięto: Skirbekk et al., 2010

Usunięto: ; Rasmussen et al., 2012

Usunięto: In particular Forwick et al. (2010) suggested that the Tunabreen glacier in Tempelfjorden area advanced between 6000 and 4000 cal yr BP, Baeten et al. (2010) noted higher glacial activity in Billefjorden approx. 5470 cal yr BP and Ojala et al. (2014) pointed to glacier re-advance or surge in Isvika (Nordaustlandet) c. 5600 cal yr BP.

IRD fraction to Storfjordrenna sediment followed by variation of δ^{18}O, however, high flux of *M. barleeanum* associated with Atlantic-derived waters (Steinsund, 1994; Jennings et al., 2004; Fig. 5) indicates AW condition in southern Storfjorden throughout the whole mid-Holocene. The similar ameliorated condition with consistent AW inflow prevailed over the mid-Holocene also in the Kveithola Trough south of Storfjordrenna (Berben et al., 2014; Groot et al., 2014). To a small extent these two signals (AW inflow and higher IRD flux) are not necessarily in contradiction, since snow accumulation on land and inconsiderable glaciers advance depend on humid air transport from the ocean. Thus slight change in the atmospheric frontal zone over Svalbard could cause fluctuation of the glaciers range.

Usunięto: (Fig. 5)

5.5 Glaciomarine unit III (late Holocene; 3600 cal yr BP to 1200 cal yr BP)

The late Holocene is characterized by a gradual increase in sediment accumulation rates followed by numerous sharp peaks of sand content and minor peaks of IRD flux, as well as increased Fe/Ca ratio, indicating ice growth on land (compare with e.g. Svendsen and Mangerud, 1997; Hald et al., 2004; Forwick and Vorren, 2009; Kempf et al., 2013), slightly enhanced iceberg calving and/or ice rafting over the core site. The IRD record shows few irregular small peaks in the late Holocene (Fig. 7), which, according to Hass (2002), could be correlated with enhanced sea currents increasing the drift of the icebergs. Forwick et al. (2010) suggested several glacier front fluctuations during the past two millennia in Sassenfjorden and Tempelfjorden (W Spitsbergen), hence we suppose increased iceberg calving occurred at Storfjordrenna during this time. However, increased IRD flux can also reflect deposition related to enhanced shore ice rafting. The latter explanation is in agreement with heavier δ^{18}O record (Fig. 6) indicating a minor cooling.

Usunięto: the high percentage of *Islandiella* spp. during the late Holocene (Fig. 5) as well as with the lighter

Usunięto: periodic water freshening as the result of meltwater delivery and/or ArW intrusions from the Barents Sea.

The mean grain size (<63µm) increases in late Holocene (Fig. 4) and may indicate stronger bottom current velocities and winnowing of fine grained sediments. Andruleit et al. (2006) observed similar increased erosive activity of bottom currents during late Holocene on the SW Svalbard shelf. This sudden increase in current velocities may be connected with (1) postglacial reorganization of oceanographic conditions, (2) relative lowering of the sea level during the postglacial isostatic rebound and/or (3) more intensive sea-ice formation enhancing formation of BSW, forming seasonal near-bottom dense water mass flowing over the coring site (Andruleit et al., 1996). Nevertheless, this process is still not fully understood.

The sharp increase in the foraminiferal flux (Fig. 4) pointing to the increased nutrient advection/upwelling and biological productivity at the coring site during the late Holocene was probably caused by variable hydrological conditions and most likely strong gradients leading to the formation of hydrological fronts. Our data shows increased fluxes of opportunistic species *E. excavatum* and *C. reniforme* as well as *N. labradorica* and *Islandiella* spp. *N. labradorica* and *Islandiella* spp. are abundant in areas with a high biological productivity in the upper surface waters (e.g. Hald and Steinsund, 1996; Korsun and Hald, 2000; Knudsen et al., 2012). Abundant, though variable *M. barleeanum*, documented in organic-rich mud within troughs of the Barents Sea (Hald and Steinsund, 1996) and in temperate fjords of Norway (Husum and Hald, 2004) points to high productivity in the euphotic zone leading to enhanced export of organic material/nutrients to the sea floor. Our data also shows high *N. pachyderma* flux throughout this unit, reflecting a significant increase of euphotic productivity at the coring site. However, low percentage of dextral specimens and *T.quinqueloba* point to low sea-surface temperatures (Fig. 6). This is in agreement with Rasmussen et al. (2014), who noted that after c. 3700 cal yr BP, Atlantic Water was only sporadically present at the surface. Cooling at the sea surface reflects the general trend in the Northern Hemisphere related to orbital forcing and reduction of summer insolation at high latitudes over the late Holocene (Wanner et al., 2008).

The last evidence of AW inflow to Edgøya area based on *M. edulis* is dated to 5000 cal yr BP (Hjort et al., 1995). After that time *M. edulis* remained absent until present days. However, its disappearance can rather be related to the freshening of surface water (Berge at al., 2006) and sea ice forcing as opposed to the extinction of AW in Storfjorden over the late Holocene (Rasmussen et al., 2007).

6 Conclusions

Multi-proxy analyses of one sediment core provide new information about the environmental development of the central part of Storfjordrenna off southern Svalbard since the late Bølling-Allerød. The main conclusions of our study are:

- Central Storfjordrenna was deglaciated before ~13,950 cal yr BP. The new data may help refine the future models of Svalbard-Barents Ice Sheet deglaciation.

- Between c. 13,450 to 11,500 cal yr BP, Storfjordrenna remained under the influence of Arctic Water masses with periodical sea-ice cover limiting the drift of icebergs. Nevertheless, at least three peaks of temperature increase during Younger Dryas stadial (12,800-11,500 cal

Usunięto: increased nutrient advection/upwelling and biological productivity at the coring site during the late Holocene (see Foraminifera flux in Fig. 4).

Usunięto: frontal-zone preferring

Usunięto: sea-ice related

Usunięto: points to high productivity within the euphotic zone leading to enhanced export of organic material/nutrients to the sea floor. This species has been documented in organic-rich mud within troughs of the Barents Sea (Hald and Steinsund, 1996),

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yr BP) presumably led to seasonal disappearance of sea ice and significantly enhanced IRD flux indicating more sub-polar conditions.

- Atlantic Water started to flow onto the shelves off Svalbard and into Storfjorden during the early Holocene leading to a progressive warming and significant glacial melting. From c. 9600 cal yr BP, the Atlantic Water dominated the water column in Storfjordrenna.

Usunięto: 5

- Environmental conditions off eastern Svalbard remained relatively stable from 9200-3600 cal yr BP with glaciers smaller than those of today. However, some small-scale cooling events (9000 - 8000 cal yr BP and 6000 - 5500 cal yr BP) indicate minor fluctuations in climate/oceanography of Storfjordrenna.

Usunięto: hydrology

- A surface-water cooling and freshening occurred in Storfjordrenna during the late Holocene, synchronously with glacier growth and cooling on land. Even though, AW was still present in the deeper part of Storfjordrenna. The late Holocene in Storfjordrenna has been characterized also by increased bottom currents velocities however the driving mechanism is not fully understood.

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Table 1

Water mass characteristics in Storfjorden and Storfjordrenna (Skogseth et al., 2005, modified). The two main water masses are in bold.

Watermass names	Watermass characteristics	
	Temperature (°C)	Salinity
Atlantic Water (AW)	**>3.0**	**>34.95**
Arctic Water (ArW)	**<0.0**	**34.3-34.8**
Brine-enriched Shelf Water (BSW)	<-1.5	>34.8
Surface Water (SW)	>0.0	<34.4
Transformed Atlantic Water (TAW)	>0.0	>34.8

Table 2

AMS ^{14}C dates and calibrated ages.

Sample No	*Depth [cm]*	*Lab No.*	*Raw AMS ^{14}C BP*	*Calibrated years BP ± 2σ*	*Cal yr BP used in age model*	*Dated material*
St 20A 5/6	5	Poz-46955	1835 ± 30 BP	1200 – 1365	1285	*Cilliatocardium cilliatum*
St 20A 39	38.5	Poz-46957	2755 ± 30 BP	2245 – 2470	Not used	*Astarte crenata*
St 20 78/79	78	Poz-46958	2735 ± 30 BP	2177 – 2429	2320	*Astarte crenata*
St 20 110	109.5	Poz-46959	3450 ± 30 BP	3079 – 3323	3220	*Astarte crenata*
St 20 142	141.5	Poz-46961	6580 ± 40 BP	6850 – 7133	6970	*Astarte crenata*
St 20A 152	151.5	Poz-46962	7790 ± 40 BP	8018 – 8277	8160	*Astarte crenata*
St 20 157	156.5	Poz-46963	8610 ± 50 BP	8989 – 9288	9120	*Bathyarca glacialis*
St 20 251/252/253	252	Poz-46964	10,200 ± 60 BP	10,895 – 11,223	11,230	*Thracia sp*
St 20 396	395.5	Poz-46965	12,570 ± 60 BP	13,780 – 14,114	13,950	Bivalvia shell

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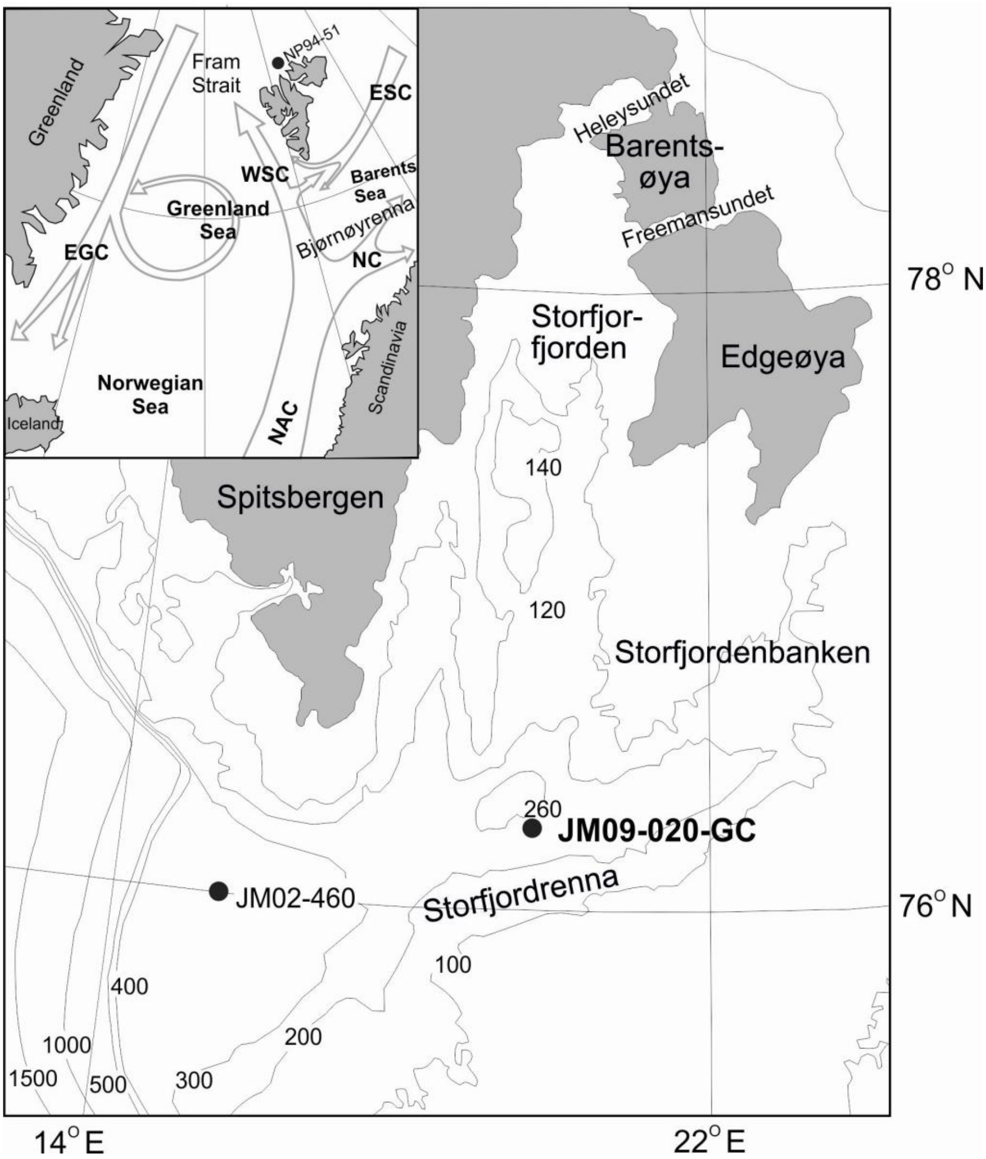

Fig. 1. Location map (a) showing the core site from this study (JM09-020-GC) and core site of JM02-460 (Rasmussen et al., 2007). The inlet map (b) shows the modern surface oceanic circulation in Nordic Seas and location of a core NP94-51 (Ślubowska et al., 2005). Abbreviations: NAC- Norwegian-Atlantic Current; WSC- West Spitsbergen Current; ESC- East Spitsbergen Current; EGC- East Greenland Current; NC- Norwegian Current. The cores JM02-460 and NP94-51 are discussed in the text.

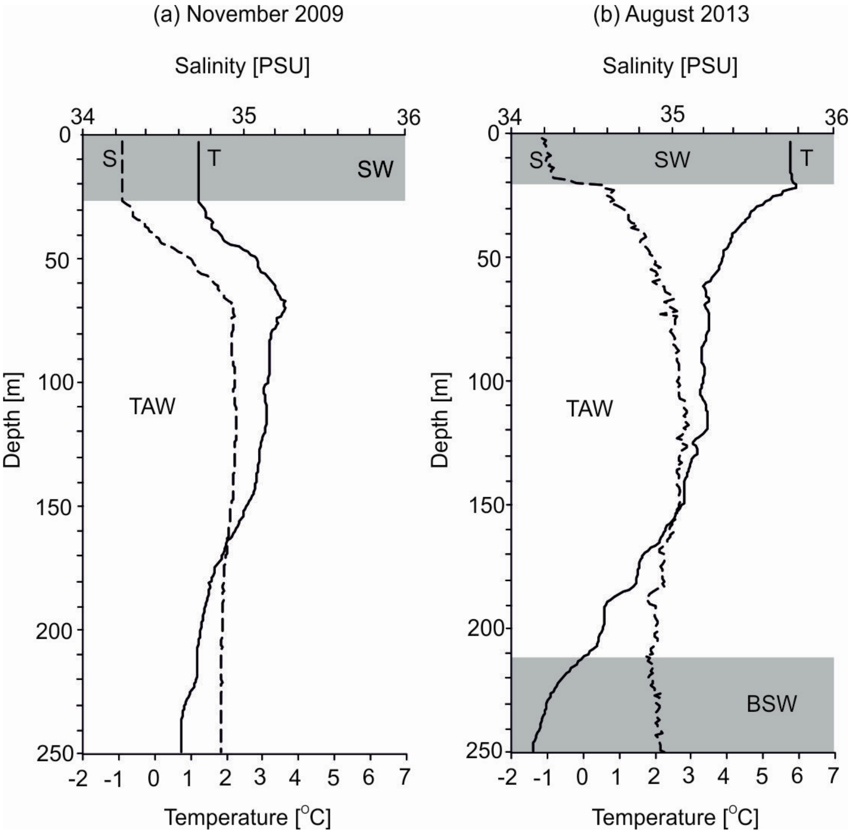

Fig. 2. Temperature and salinity versus depth, measured in November 5th 2009 (a) and in August 13th 2013 (b) at the site of core JM09-020GC. SW - Surface Water, TAW - Transformed Atlantic Water, BSW - Brine-enriched Shelf Water.

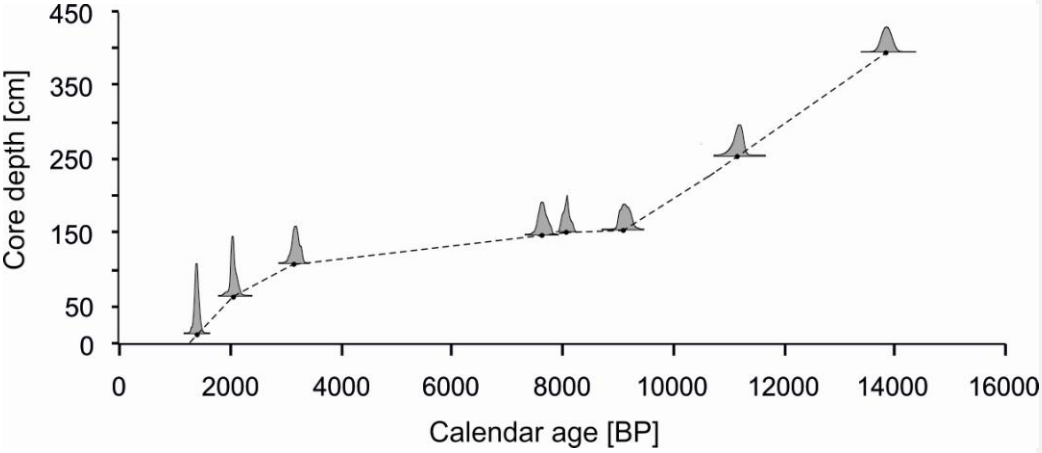

Fig. 3. Age-depth relationship for JM09-020-GC based on 8 AMS ^{14}C calibrated ages with 2-sigma age probability distribution curves. The chronology is established by linear interpolation between the calibrated ages.

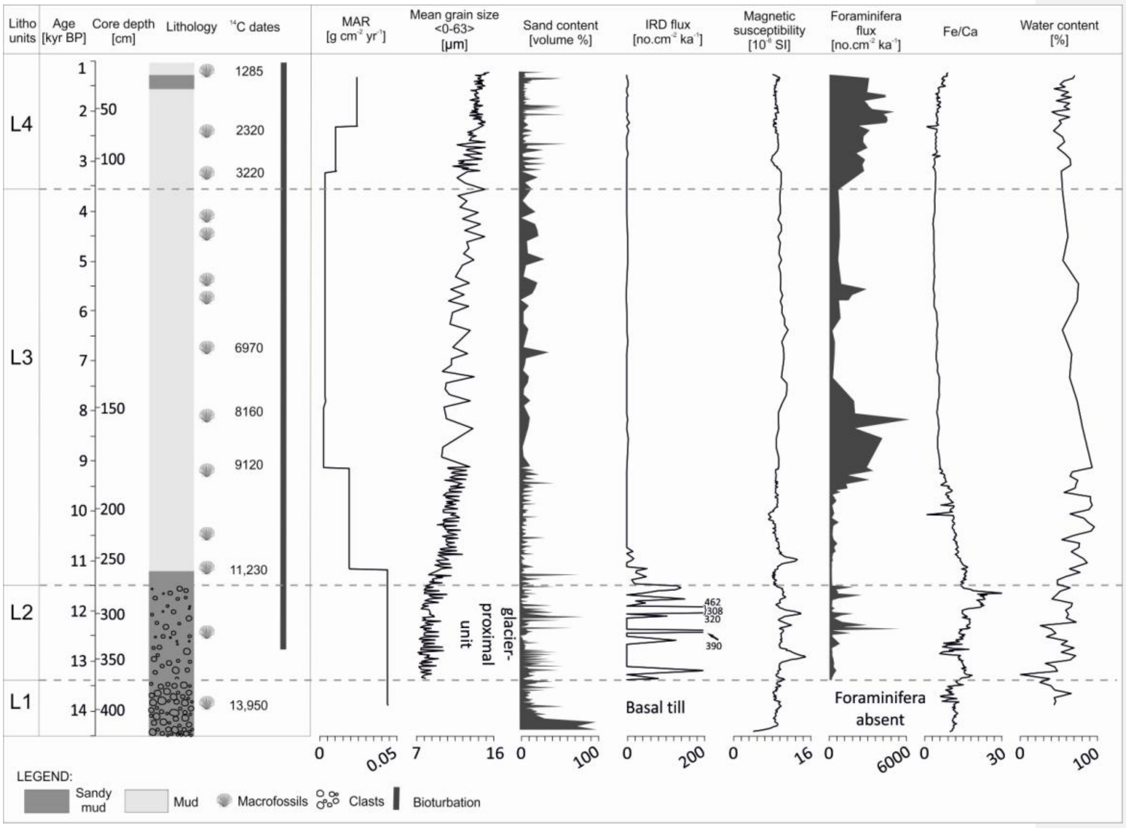

Fig. 4. Lithological log of core JM09-020GC. Lithology, ^{14}C dates, occurrence of bioturbation, mass-accumulation rates, mean grain size in the range of 0-63 µm, sand content, ice-rafted debris flux, magnetic susceptibility, foraminifera flux as well as Fe/Ca ratio and water content. The results are presented with lithostratigraphic units (L1-L4), versus calendar years (cal kyr BP) and core depth (cm).

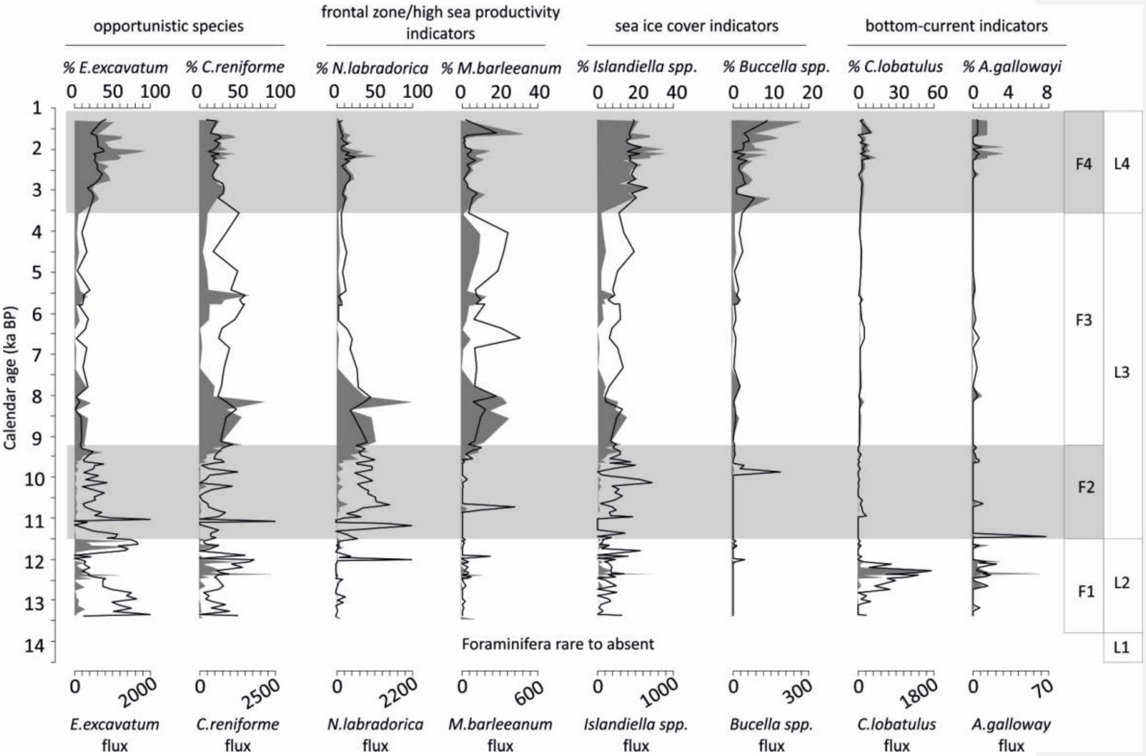

Fig. 5. Percentage distributions (upper scale; black line) and fluxes (no. cm^{-2} ka^{-1}; bottom scale; grey shading) of the most dominant benthic foraminiferal species plotted versus thousands of calendar years with indicated foraminiferal zonation (zones F1-F4) and lithostratigraphic units (L1-L4). Foraminiferal taxa are grouped based on their ecological tolerances described in the text.

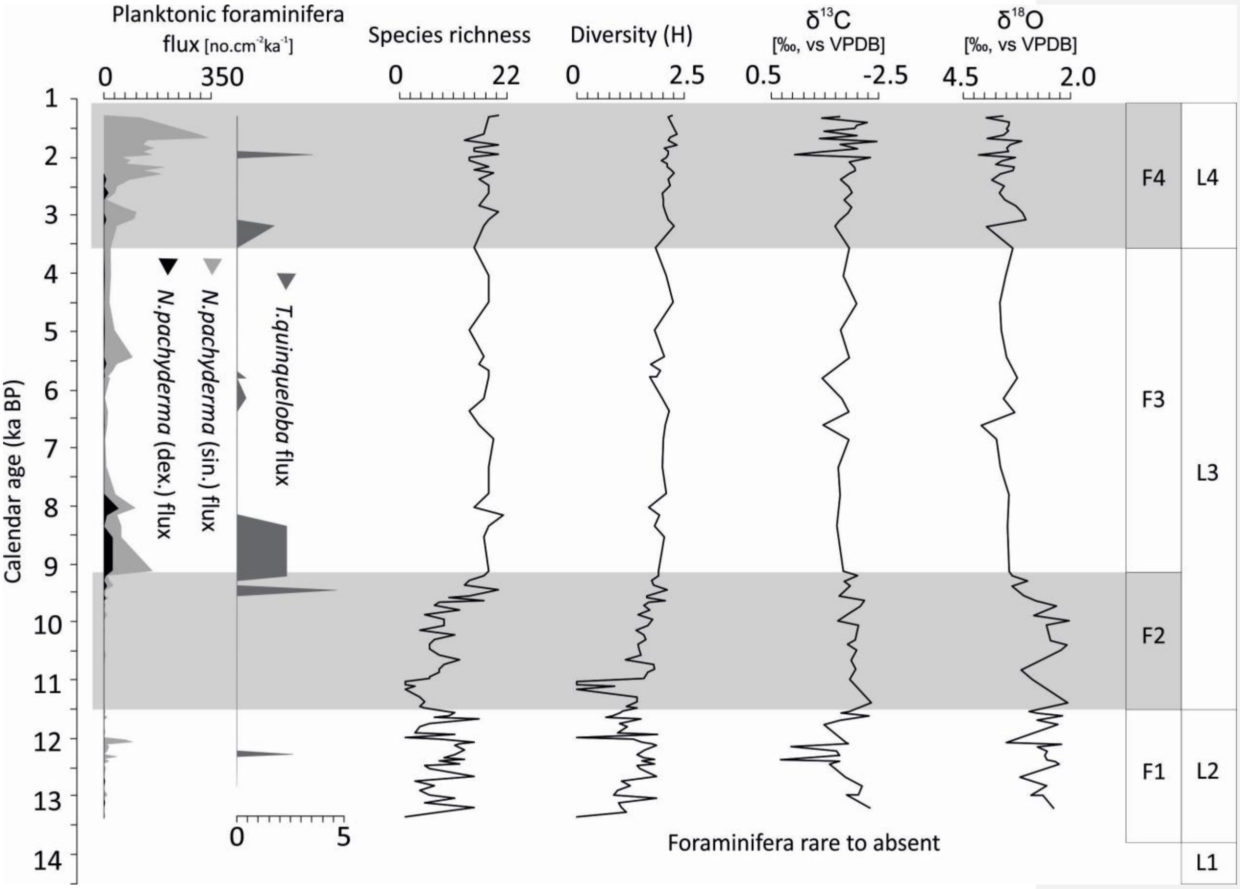

Fig. 6. Fluxes of planktonic foraminifera (no.cm^{-2}ka^{-1}), diversity parameters (species richness and Shannon - Wiener index) and stable oxygen and carbon isotope data (δ^{18}O and δ^{13}C) plotted versus thousands of calendar years. The foraminiferal zonation (zones F1-F4) and lithostratigraphic units (L1-L4) are indicated.

Usunięto: Diversity parameters (species richness and Shannon - Wiener index), stable oxygen and carbon isotope data (δ^{18}O and δ^{13}C), and flux of planktonic foraminifera (*Neogloboquadrina* spp.; over 90% of the planktonic foraminifera assemblage) plotted versus thousands of calendar years. The foraminiferal zonation (zones F1-F4) is indicated.

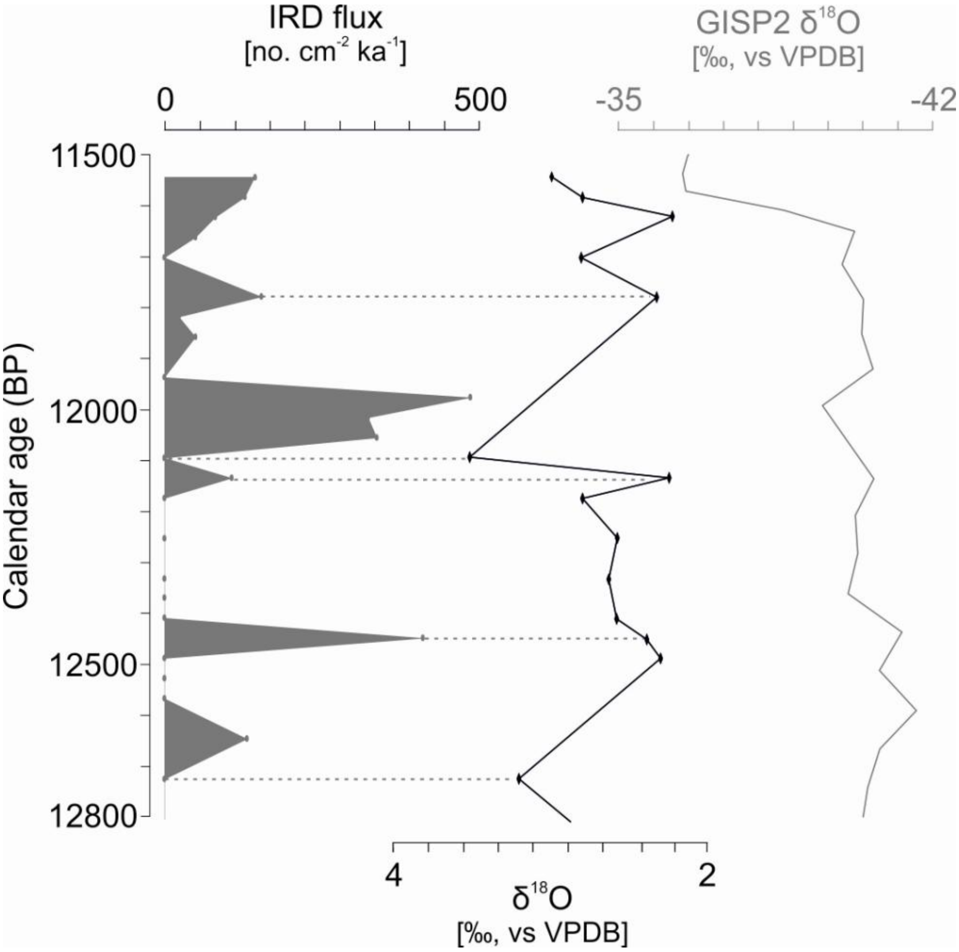

Fig. 7 IRD flux (upper scale, grey shading) and oxygen stable isotopes records (bottom scale, black line) compared with oxygen stable isotopes records from ice core GISP2 from Greenland during the Younger Dryas period (12,800 cal yr BP to 11,500 cal yr BP).

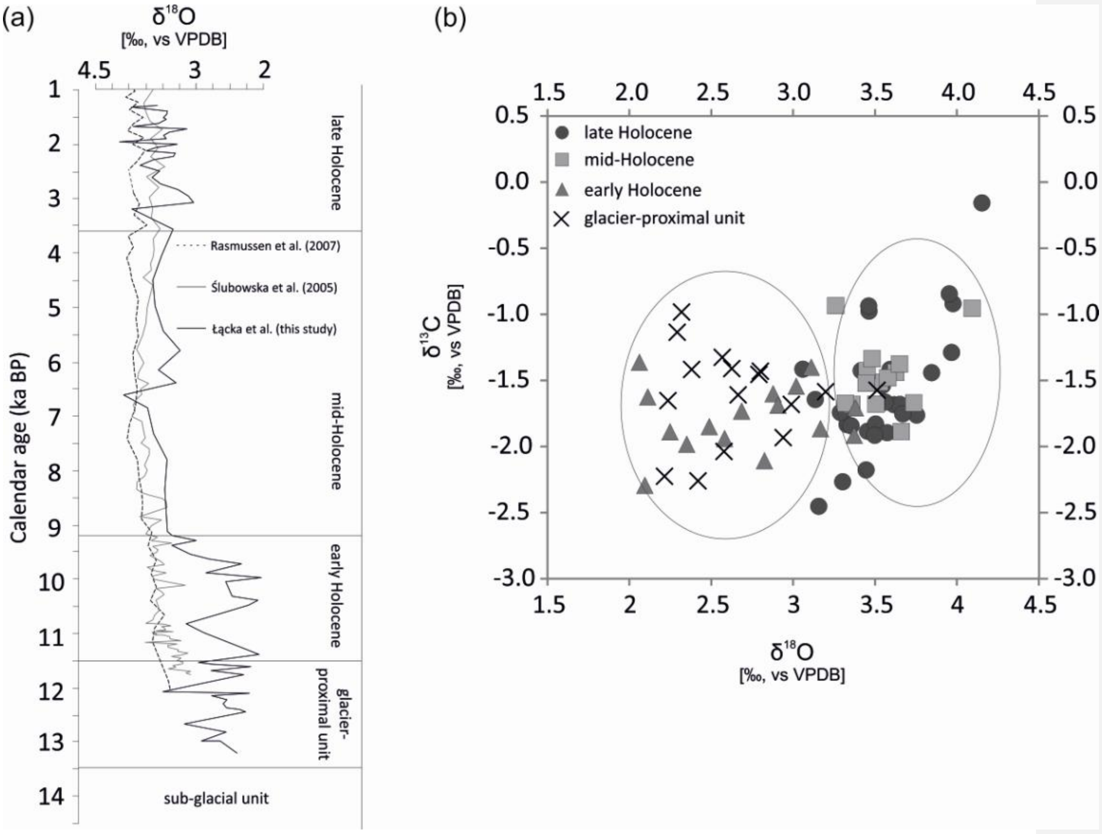

Fig. 8 (a) The comparison of $\delta^{18}O$ records (corrected for ice volume changes) between Łącka et al. (this study; black solid line) and Ślubowska et al. (2005; grey solid line) and Rasmussen et al. (2007; black dashed line) plotted versus thousands of calendar years. The $\delta^{18}O$ records after Łącka et al. (this study) were measured on *E.excavatum* f. *clavata* and the two latter ones (Ślubowska et al., 2005 and Rasmussen et al., 2007) were measured on *M.barleeanum*. (b) Scatter plot showing $\delta^{13}C$ versus $\delta^{18}O$ values from core JM09-020-GC (this study).

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Fig. 9 Fluxes of IRD (bottom scale; grey shading) and *Islandiella norcrossi* (upper scale; black line) plotted versus thousands of calendar years. Both parameters may indicate the seasonal sea-ice cover (Polyak and Solheim, 1994; Hald and Steinsund, 1996) and that this has been particularly high during the past ca. 3600 years.