Reply to Robert F. Spielhagen (Referee #1), interactive discussion (C2747-C2755, 2012) on „*The Holocene thermal maximum in the Nordic Seas: the impact of Greenland Ice Sheet melt and other forcings in a coupled atmosphere-sea ice-ocean model*" by M. Blaschek and H. Renssen:

We thank the reviewer very much for his positive and constructive review, which helps to improve the manuscript and its use for interested readers that are unfamiliar with climate modelling.

1. 5265*12 "down-wind continents" Which are these? Are there several affected?

Reply: These continents are *Europe and Asia, and can be considered separate or together. We will clarify this in the revised manuscript*

2. 5265*15-16 "in the Labrador Sea, causing expanded sea-ice cover and cool surface conditions compared to today" The Labrador Sea is rather cool already today. Do you mean "cooler" or "colder"?

Reply: *Corrected to cooler.*

3. 5265*16-17 "An important part of this spatio-temporal complexity can be explained by the impact of the remnant LIS in North America" This restrictive statement is somewhat surprising since the reader got the impression from lines 11-16 that the LIS is the only factor.

Reply: *In lines 11-16 we refer to a previous modelling study by Renssen et al. (2009) investigating the LIS effect on the HTM, and to Kaufman et al. (2004) and Kaplan and Wolfe (2006), who argue similarly. However, the results of Renssen et al. (2009) have not been compared to marine surface reconstructions as is suggested by the sentence that follows.*

4. 5266*5-7 "It has been suggested that the eastern side has a stronger response to orbital forcing in the early Holocene compared to the western side (Andersen et al., 2004)." The reader will be interested to know the reason for this variability without looking it up in the Andersen et al. Paper.

Reply: *We will add: ...compared to the western side, because of postglacial sea-ice and melt water influence.*

5. 5266*27-28 "although eastern SST reconstructions might be not as well known as previously anticipated" What do you mean here? The reconstructions are published and therefore quite well known!

Reply: *We thank the referee for pointing this out to us. The point is that SST reconstructions give different estimates depending on the proxy used. A lot of factors (environmental conditions, nutrients, habitat depth) are relevant for temperature reconstructions. We agree that the statement was too vague.*

We will rephrase in combination with our response to Referee #2 (#4):

The non-uniform response across the Nordic Seas as reconstructed by Andersen et al. (2004) seems to be a robust feature in palaeo-reconstructions, thus challenging the question of the origin of this zonal difference, despite the fact that eastern SST reconstructions give a broader range of warmer SSTs.

6. 5267*12-13 "It is likely that in the early Holocene the GIS was bigger than at present- day." There is a relative new review on the GIS history which may useful here: Funder et al., The Greenland Ice Sheet During the Past 300,000 Years: A Review. In J. Ehlers, P.L. Gibbard and P.D. Hughes, editors: Developments in Quaternary Science, Vol. 15, Amsterdam, The Netherlands, 2011, pp. 699-713. ISBN: 978-0-444-53447-7.

Reply: *We will rephrase the sentence for clarification: Geological records (as reviewed in Funder et al. , 2011) and modelling studies (Simpson et al., 2009) agree that the GIS was bigger in the early Holocene and may have reached its Holocene minimum at 6 ka BP, followed by a regrowth.*

7. 5267*16-17 "Vinther et al. (2009) suggest changes in the range of 100–300m higher for 9 ka BP compared to today." What do you mean here? Were the changes higher? Or was the site higher? Or what?

Reply: *Vinther et al. (2009) have reconstructed bore hole elevation histories from d18O records. We will rephrase as follows to avoid confusion: „Reconstructed GIS borehole site elevations from Vinther et al. (2009) indicate that these sites were 100-300 m higher for 9k BP compared to today.“*

8. 5267*21-23 "No quantified estimates of this early Holocene melt flux have yet been published, but based on Peltier (2004) we could infer a best guess additional flux of 13 mSv (1 Sv=1e6 m3 s−1) for 9 kaBP." What is this flux additional to? It may be interesting for the reader to have some published estimates of modern fluxes here, just for comparison.

Reply: *We agree that this was not clear. The flux is added on top of the normal runoff, caused by the precipitation surplus. Modern-day estimates of GIS melt flux are provided by Dickson et al. (2007), who give as best estimate a value of 18 mSv. We will add the value and the citation.*

9. 5270*20-22 "We have added this melt water to the top layer of the ocean corresponding to the surface runoff outlets of the Greenland landmass." Where was it added? At one single point? At several points? How were these selected and how was the discharge calculated? Or was the discharge distributed homogeneously around Greenland? This is a crucial point because later (5274*18ff) you discuss regional differences of the impact of this melt water (Nordic Seas vs. Arctic). Most likely sea-ice formation etc. will depend on the distribution of freshwater outlet points.

Reply: *In our model the runoff points are fixed and correspond to present-day major runoff points from the GIS. The additional melt water is added there. It is not homogeneously distributed around Greenland, but to the fixed runoff locations. We rephrase in combination to our reply to Referee #3*

(#2):

We add the additional melt water to the normally calculated surface runoff (e.g. sum of excess precipitation and snow melt), which is then evenly distributed to 10 major runoff points, as for present-day (c.f. Bakker et al. (2012) for locations of the river outflow points).

10. 5270*10-16 Does the model take into account the strong melt water influx from the LIS at the onset of the 8.2 ka event? Should we (do we) see an effect of this event in the model results? Not every paleoceanographer working in the area will be acquainted with the details of the Renssen et al. (2009) model but all of them know about the 8.2 ka event...

Reply: *No the model does not take the 8.2 melt water pulse into account (c.f. Figure 1), because that would complicate the story even more. Our focus in this manuscript is on the impact of the GIS melt water in comparison to that of the background LIS forcing and other forcings.. We clarify this point in the revised manuscript.*

11. 5272*22 add "in 9kOGMELT" at the end of this sentence to clarify what you are referring to.

Reply: *added.*

12. 5273*4ff You are discussing "gradients" a lot in this paper but you do not use this term correctly. By definition, a gradient is a quotient of two differences, in your case usually dT/dL (where T is temperature and L is degree longitude). Accordingly, a gradient cannot have just a temperature value. In most cases you should replace "gradient" by "difference" in your paper.

Reply: *The referee is correct, it is a gradient between two points and we try to state as often as possible that there is an eastern and an western point or side, which would indicate then the dL. We think it is valid to use the term gradient here and the correct unit description is often abandoned for readability, but we will make sure that when the word gradient is used also the longitude distinction is made for the sake of correctness. Thanks.*

13. 5273*7 I have problems to understand what a "yearly gradient" is.

Reply: *We rephrase: annual gradient*

14. 5273*16-17 "Along with this gradient reduction, a reduction in variability can be noted by smaller standard deviations." The differences in standard deviations do not seem large to me. Are the differences statistically significant so that you can make an argument out of that?

Reply: *You are correct, the differences are small and statistically not significant. However, they could indicate a reduction in variability. We will clarify this as follows: Along with this gradient reduction, a reduced variability can be noted by smaller standard deviations. However, note that these standard deviations are not statistically significant.*

15. 5273*20-24 These comparisons to published proxy data sound a bit like cherry picking. As long as you do not discuss the pros and cons of the different proxies and what they may or may not

reflect, the reader remains puzzled and has no idea as to what may more trustworthy: Proxy data (which?) or model results. I suggest that you elaborate somewhat more on this issue in the paper - it's a crucial thing...

Reply: *We note that there is quite some discussion (e.g. Risebrobakken et al., 2011) on what these proxies show and in response to what forcing (NAC heat transport, insolation,..). In combination with our response to Referee #3 (#10) we expand this paragraph by (underlined):*

There is good agreement between simulated August SST gradients and reconstructed gradients for the diatom-alkenone combination (alkenone SST (east) minus diatom SST (west)). Although this combination might not be as straightforward as using a single-proxy-gradient, reconstructed values are taken to represent summer SSTs. In our model it is not possible to increase summer SSTs to values as high as eastern SSTs reconstructed by diatoms within the setup of these experiments. A lower gradient compares better to our model results. The gradient is strongest in winter.

16. 5274*12-14 "In our simulations we find the impacts of the following forcings on August SSTs: (1) GIS melt near Greenland, (2) LIS melt water in the Labrador Sea, (3) the remnant LIS, (4) the combined effect of LIS and GIS". Point (4) sounds like as if the other effects were acting single. In fact you will always have combined effects! Or do you want to sum up the factors in the different experiments here? Then I must say that this was done already in chapter 2.

Reply: *Yes we agree that it is a narrative element to increase the readability and connect this chapter with the previous. We have changed the text accordingly.*

17. 5274*15 "...mechanisms like (1) reduced vertical heat transfer,..." Do you mean atmospheric or oceanic vertical heat transfer?

Reply: *Added. Oceanic vertical heat transfer.*

18. 5274*24-25 "In the Arctic Ocean, however, surface waters are already quite fresh and stratified, minimizing the effect of additional melt water." The differences in terms of salinity and stratification are certainly depending on the input localities for the melt water. See my comment above.

Reply: *We hope we have clarified this point in the above reply (#9).*

19. 5274*25-26 "As a consequence of cooler and fresher surface waters, sea-ice growth is facilitated here".... Sea ice growth will also be facilitated almost anywhere around Greenland by melt water input because we must assume that winter air temperatures were low enough.

Reply: *In our model this region, southern tip of Greenland is quite sensitive and gives a noticeable response to increased freshwater, whereas other regions that are also affected respond less to more freshwater.*

20. 5275*10-25 For the interested reader a comparison of actual modern overturning values

(from oceanographic data) will be extremely helpful here to understand the significance of the reductions you discuss here. Furthermore, there is ample evidence for a strong Atlantic Water advection to the Arctic at ca. 11-8 ka (e.g., Rasmussen et al., 2007; Risebrobakken et al., 2011). Isn't that contradictory to the model results which seem to indicate a reduction in the AMOC? Discuss!

Reply: *We agree that this point should be clarified. In combination with our reply to Referee #2 (#15) we have added AMOC values and references for present-day.*

You are correct, the conclusions from Risebrobakken et al. (2011) say that proxies beneath the SML (Seasonally Mixed Layer) represent northward heat advection, thus the mechanisms that cause this higher or evenly high compared to present-day advection are unknown. In our model a stronger advection is not present in any of the used simulations, therefore we cannot argue in favour or against it. Nevertheless our study focuses on surface reconstructions and we mention foraminifera and radiolarians because they are reconstructed in the same core. There is evidence that the overall AMOC was weaker in the early Holocene, whereas convection in the Nordic Seas remained at its present-day (as in our model) or even higher level (as can be argued for more heat advection (Risebrobakken et al., 2011)). Convection in the Labrador Sea was suppressed and shows a reduction, please note the differences between Table 1 Nordic Seas convection and North Atlantic convection. We will add a sentence pointing this out and arguing that this might be a reason for mismatch as the higher heat advection is not evident in our simulations.

21. 5275*21 Look up in a map where 30 S is!

Reply: *The oceanic heat transport is transported from the tropics and this parameter is commonly used in climate modelling studies as a benchmark for Atlantic oceanic heat transport.*

22. 5275*29 "NAC" has not been introduced before.

Reply: *added.*

23. 5276*1-8 Is the effect of brine rejection (i.e., salinity and density increase of subsurface waters) from sea-ice formation taken into account in the model? This may be important for the salinity...

Reply: *Yes. Our sea-ice component is part of our ocean model CLIO and sea-ice production and melt are implemented as positive and negative salt fluxes.*

24. 5276*3-4 Is the main deep convection site in the Nordic Seas really south of Svalbard? In the Barents Sea????

Reply: *You are correct South of Svalbard is maybe to loosely said. Correct is south west of Svalbard.*

25. 5277*4-14 Each of these three sentences is too long, sounds weird, and is difficult to understand. Make short sentences here and explain your thoughts in a logical line of arguments.

Reply: *We rephrase:*

Simulated SSTs for the East (Fig. 4a) and West (Fig. 4b) decrease over time, whereas in Fig. 4c the difference is mostly constant over the Holocene, except for the early and late Holocene.

The east-west gradient is clearly steeper in OGGIS than in OGMELTICE, because of the strong impact of GIS melt water. As soon as the GIS melt vanishes, the gradient in OGGIS returns to the same level as the other experiments. In order to simulate a more gradual decrease, as in proxy reconstructions (Andersen et al., 2004), GIS melt water could have been longer active. We speculate that a period of longer GIS melt and/or increase of sea-ice cover over the western side seems possible.

26. 5277*11 "...another yet unknown forcing..." Oooops, here comes the joker? What could be such a "yet unknown forcing"? Discuss it or leave it out!

Reply: *Please notice changes due to previous and this comment (#25). The forcings are mentioned: period of longer GIS melt and/or increase of sea-ice cover*

27. 5277*19ff Figure 5 shows ages of the HTM while in the text you discuss delays with reference to 9 ka. This is confusing!

Reply: *The maps show „absolute" times, but in order to discuss the impacts of forcings we speak of delays. Figure 5 will be changed into anomalies (delays) compared to simulation OG.*

28. 5277*26-28 The first part of this sentence is confusing. What ranges "by 500 to 2500 yr"?

Reply: *We rephrase: The Eastern Nordic Seas are delayed by 2000 yrs, whereas the delay on the western side ranges between 500 and 2500 yrs,...*

29. 5278*9-10 What is "more continuously"? Can you augment the word "continuously"?

Reply: *We rephrase: ...decreases less abrupt than ...*

30. 5278*11-12 Here with "trend" a similar terminology problem comes up as with "gradient". A trend is from A to B and thus cannot be just a temperature value.

Reply: *We will add: per 9000yrs*

31. 5278*13-14 "Slightly better are SST trends from Calvo et al. (2002)" Who is to decide which trend is better or worse? And what is a "good" trend?

Reply: *Apologies for this unnecessary judgement. We rephrase: SST trends from Calvo et al. (2002) with 2-3 K/9ka compare better to 1-2 K/9ka for the model.*

32. 5278*15-16 "Marine sites from Kaufman et al. (2004) in the Nordic Seas give SST trends between 2.5 and 6.6 K, mostly being diatoms" This a weird sentence. What are the diatoms? The temperature? The sites? The SSTs? Or what? I can guess what you mean but this should be intelligible also for people who have less time to read this article...

Reply: *We agree that is unclear. We rephrase: Marine sites from Kaufman et al. (2004) in the Nordic Seas give SST trends between 2.5 and 6.6 K/9ka, based mostly on diatom proxies and also*

Coccoliths (1 core).

33. 5278*19-20 "...but leave some similarities." This is rather vague. What do you mean? The comparison of timing in models and proxy records is very interesting and should be discussed properly.

Reply: *We agree again and propose the following revision (underlined):*

Despite this weak consistency in absolute temperatures, the proxies give gradients that vary more (between ~2 K for present-day and ~6–8 K for the early Holocene (Calvo et al., 2002; Andersen et al., 2004) compared to the model gradient (2.5–4.5 for present-day and ~ 5 K for the early Holocene). The cause for this mismatch can be easily attributed to the lack of climate models in simulating strong variability connected to being too stable to show outliers and the proxy reconstructions that give preference to event-like variability within a problem of temporal resolution. Both methods of reconstructing past climates have their advantages. When comparing our results to proxy-based reconstructions, we point to the results closer to our model results, without completely rejecting contradictory results.

34. 5278*25 "whereas the North Iceland shelf is between 9 and 6 ka BP" I do not understand. What happened to the shelf between 9 and 6 ka?

Reply: *The sentence points out the timing difference between the North and South of Iceland. Meant are periods of the HTM. We will clarify this in the revised text.*

35. 5278*26 What is a "spatial timing gradient"? I have problems to imagine...

Reply: *This might refer to the loosely used word gradient, as we speak of a temporal and spatial gradient together. Better: spatial timing-difference. We changed the text accordingly.*

36. 5278*27-28 "the Norwegian site" Which site? This was not mentioned before.

Reply: *Rephrased: ...however for the Eastern side the ...*

37. 5278*28 "the timing delay is ~1 kaBP." Is that really what you mean? "1 ka BP" means 1000 years before present.

Reply: *corrected to: the timing delay is ~1 ka.*

38. 5279*10-12 You should mention what the reference is for the differences in temperature and overturning that you are mentioning.

Reply: *We rephrase: August SSTs are up to 3 K lower near the Denmark Strait, overturning is reduced by 2–3 Sv and winter sea-ice margin expands south of Denmark Strait in a simulation with 13 mSv GIS melt compared to an orbital and greenhouse gas forced simulation.*

39. 5279*14-15 "Although absolute model temperatures do not compare well with exact core locations" No wonder! Temperatures and core locations are apples and oranges...

Reply: *We rephrase: Although absolute model temperatures do not compare well with absolute reconstructed temperatures at core locations.*

40. 5279*20-22 Be specific: It is better reproduced than what?

Reply: *We rephrase: The spatial distribution of the timing of the HTM in the Nordic Seas is better reproduced in a simulation with GIS melt compared to a simulation without.*

41. 5279*25-5280*7 This is all new to the reader. In my mind, conclusions should not come up with issues that have not been discussed properly in the chapters before. They should give the essentials from the discussion, not some brandnew ideas.

Reply: *We agree that this part of the manuscript could be improved and that we have to separate the conclusions from the results and the discussion and implications of the paper. We propose to restructure this part with the following new paragraph:*

4. We find in our experiments that GIS melt plays an active role in the Nordic Seas environment and GIS evolution therefore has to be considered in the evolution of the early Holocene climate and future melting scenarios.

In the context of future climate change this study underlines the importance of GIS melt water and its active role in the climate system. Compared to today, in the early Holocene the annual and summer insolation forcing at 65N (i.e. in S Greenland) was 2.4 and 42 Wm^{-2}, respectively (Berger and Loutre, 1991). This value of 2.4 Wm^{-2} is close to the lower range of the annual radiative forcing of proposed future anthropogenic emission scenarios, that varies between 3 and 8.5 Wm^{-2} (Meinshausen et al., 2011). Therefore it is not surprising that recently Rignot et al. (2011) reported an acceleration of GIS melt rates that could soon outrange those of the early Holocene, and thereby stressing the importance of GIS melt for Nordic Seas future climate evolution.

New References:

Bakker, P.; Van Meerbeeck, C. J. & Renssen, H., Sensitivity of the North Atlantic climate to Greenland Ice Sheet melting during the Last Interglacial, *Climate of the Past,* 2012, 8, 995-1009