

## ***Interactive comment on “Pulses of enhanced North Pacific Intermediate Water ventilation from the Okhotsk Sea and Bering Sea during the last deglaciation” by L. Max et al.***

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Response to Anonymous Referee #2 (AC = Author Comment)

The new data presented by Max et al. from the Okhotsk Sea and Bering Sea reveal in a convincing way the emergence of well ventilated North Pacific intermediate waters during HS1 and YD and a weaker ventilation during the Bolling Allerød. Unfortunately, an uncritical assessment of major conclusions drawn from previous studies muddles the discussion of the author's findings. This needs to be revised.

AC: First of all, we would like to thank anonymous referee #2 for comprehensive discussion and helpful comments. The main criticism made by referee #2 concerns an “un-  
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critical assessment of major conclusion drawn from previous studies” regarding deep circulation changes in the North Pacific during the last deglaciation. In general, we feel confident that our data and interpretation of deglacial circulation changes in the northwest Pacific and its marginal seas is robust and corroborate previous studies (as stated by referee #1). We think that the re-interpretation of previous studies done by referee #2 regarding North Pacific deep-water ventilation changes (e.g. Lund et al., 2011) can explain some inconsistencies (deep-water formation versus no deep-water formation) and we will clarify this issue by close examination of discussed datasets from the subarctic Pacific.

Hoping to provide some guidance for the discussion, I am showing here (in the attached pdf file) a rough consistency matrix of intermediate water, deep water and bottom water changes from recent studies.

Contrary to the claims in Lund et al. 2011, the Lund data in fact document increased ventilation during HS1, at least down to 2300m (see figure below), which is entirely consistent with the paleo and model data discussed in Okazaki. So far, the biggest inconsistency among the datasets is between the Jaccard studies and the Rae and Sarnthein 2013 data for North Pacific deepwater formation in the eastern North Pacific (I don't know whether the Rae paper is already out, but it would be worth for the authors to inquire about the paper and the data).

AC: Lund et al., (2011) used radiocarbon measurements of planktonic and benthic foraminiferal shells from a core collected at 2.7 km water depth in the northeast Pacific to estimate deglacial ventilation ages of deep waters. They found that deep water masses in the NE-Pacific increases in age by ~1000 years during the last deglaciation and suggest that a decrease in the ventilation rate, an increase in the surface water reservoir age in the Southern Ocean, or an influx of old carbon from another source could explain this anomaly. In detail, the data of Lund and colleagues show an abrupt rise in deep-water ventilation ages, in particular during H1, between 17 – 14 kyr BP. As also stated by Lund and colleagues mean ages of the deep-water masses are

indistinguishable during the early deglaciation ( $1,360 \pm 270$  years) from modern values ( $1,220 \pm 200$  years) and clearly suggest that deep-water ventilation in the North Pacific has not improved during these intervals (see attached figure). A more recent study from Lund (2013) based on the same sediment core in the NE-Pacific used in Lund et al., (2011) even show a 1000-yr increase in NE-Pacific ventilation ages during H1 (14.5–17.5 kyr BP) and a 500-yr increase during the Younger Dryas (YD) in harmony with our results.

AC: Okazaki et al., (2010) used a combination of proxy data and climate model data to estimate changes in deglacial circulation dynamics in the western North Pacific. By providing a stack of all available ventilation ages integrated over a broad depth range (approx. 1000 – 2700 m water depth) they showed that there is a positive anomaly in ventilation ages during H1 in the NW-Pacific. These results are further corroborated by climate simulation done with LOVECLIM. However, some careful examination of the considered proxy data showed significant depth-related differences between intermediate- (<1350m water depth) to deep-water (>2150m water depth) ventilation ages. Attached you will find a figure with western Pacific ventilation data from Okazaki et al., (2010) but now depth-differentiated (which has not been done by Okazaki and colleagues!) between mid-depth (<1350m water depth) and deeper (>2150m water depth) sediment records with corresponding ventilation ages. The largest difference in ventilation ages of approx. 1000 years between intermediate- to deep-water is found during H1 (see attached figure). Positive ventilation age anomalies during H1 (younger water masses) are restricted to sediment cores shallower than approx. 1350m water depths. Deeper sediment cores (>2150m water depth), also considered in the Okazaki stack, showing no enhanced ventilation but even an opposite trend in ventilation during H1. That is not surprising as rigorous changes in intermediate water formation during H1 has been inferred before by Duplessy et al., (1989); Ahagon et al., (2003) or Ikehara et al., (2006) from shallow sediment cores located near Hokkaido. This datasets are also implemented by Okazaki in his original work in 2010 (see also supplements of Okazaki et al., 2010) However, NPIW ventilation changes inferred from shallow sed-

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iment cores (<1350m water depth) as originally proposed by Duplessy et al., (1988), Ahagon et al., (2003) or Ikehara et al., (2006) are in harmony with our results and not indicative for a switch to deep-water formation in the NW-Pacific during H1 (Okazaki et al., 2010).

AC: Unfortunately, the Rae and Sarnthein data is not published, yet. Thus we are not able to consider this data or check inconsistencies between this data and data provided by Jaccard and Galbraith (2013). However, results presented by Jaccard and Galbraith (2013) based on new redox-sensitive trace metal data from a sediment core in the subarctic Pacific “shows also no sign of ventilation during the early deglaciation in any available core from water depths of 2393 m and deeper, while the deepest core to display clear signs of enhanced ventilation during HS1 was raised from 1366 m water depth”. This is also in accordance with our results.

Specific comments, line numbers refer to the printed version - Please specify which depth range is referred to as intermediate water, versus deep and bottom water in the Pacific

AC: We agree and give a definition at the end of the introduction for intermediate water and deep-water to avoid any confusions (see Page 4 line 112 - 115).

- Page 6222, line 19: “antiphase to those of the North Pacific” – this is only one part of the story, because the Rae and Sarnthein data suggest an in-phase relationship for data in the NW Pacific.

AC: Unfortunately, the mentioned data from Rae and Sarnthein are not published, yet. Thus we are not able to implement the data or interpretation in this study. However, we are excited to see new data regarding ventilation changes in the NW-Pacific.

- Page 6223, line 16, “salinity-driven stratification” sounds strange

AC: We changed the term “salinity-driven stratification” to “density-driven stratification” (see Page 2 line 57 - 58).

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- Lines 16-20, there is a little bit a mix-up between feedback (Stommel) and forcing (atmospherically induced changes in Atlantic/Pacific freshwater transport) – please clarify

AC: We agree and revised the paragraph to better distinguish between forcing (changes in Atlantic/Pacific moisture transport) and feedback (physical mechanism of positive feedback between salinity anomalies and ocean circulation known as Stommel feedback (see Page 2 line 58 - 75).

- Line 21 “. . . hence the proposed. . .” – it is a common confusion (see also Jaccard) that the SST changes are an indicator only of the (heat) transport changes. SSTs in the North Pacific are driven by changes in heat transport convergence, mixing and air-sea heat fluxes. Even with an increased heat transport convergence, one can still have a due to enhanced mixing, reduced SW radiation (clouds) and enhanced evaporation. Please rectify this oversimplification.

AC: We agree. The key role in destabilizing the permanent halocline in the North Pacific plays salinity. But a more rigorous transport of subtropical water masses from the tropics to the North Pacific during H1 should have also an impact on SST in the subarctic Pacific. The results from LOVECLIM indeed show an increase of at least 1.5°C in the western North Pacific due to intensified PMOC during H1. Simply, the important role of PMOC in buffering the decrease in poleward global oceanic heat transport (Okazaki et al., 2010) is not seen in proxy-based SST reconstructions provided by Harada et al., 2012 and Max et al., 2012 (the opposite is the case), thus questions the results of the LOVECLIM model simulation. Our results, however, are in harmony with model simulations with MIROC done by Chikamoto and colleagues in 2012. This work used both LOVECLIM and MIROC climate models and made freshwater perturbation experiments in the North Atlantic to investigate its effect on circulation changes in the North Pacific for H1. Interestingly, the models computed quite different results (e.g. LOVECLIM shows an onset of PMOC and warming in the NW-Pacific with deep-water formation versus MIROC shows cooling in the NW-Pacific and changes in circulation are restricted to the upper 20000 m water depth).

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AC: We revised this paragraph (see comments above).

- Page 6224, line 9 replace “likely source” by “possible source”

AC: We agree and changed the term “likely source” to “possible source” (see Page 3 line 92).

- Page 6227, please discuss the issue of a constant reservoir age, given the fact that much older intermediate waters are brought up to the surface of the North Pacific during HS1 and YD. Would this probably change the age model? If yes, in which direction?

AC: We are not aware of a paper presenting the “fact” that much older intermediate water are brought up to the surface of the North Pacific during H1 and YD. In our study we propose that old North Pacific deep-water is much more isolated during H1 and YD (given by the gradient in  $\delta^{13}C$  and ventilation ages between intermediate and deep-water presented in this paper). Several studies propose similar, young well-ventilated NPIW during H1 and YD (e.g. Duplessy et al., 1989). However, in theory upwelling of old carbon would alter the age model. An invasion of old carbon from deep-water could alter the reservoir age (higher reservoir age).

AC: We included the following text in the manuscript to acknowledge the issue of constant reservoir ages: “There is increasing evidence that surface reservoir ages could have varied over the course of the last 20 kyr, due to global thermohaline reorganizations as well as changes in upper-ocean stratification. In the northeast Pacific, surface ocean reservoir ages have been reported to be close to  $730 \pm 200$  years and varied by less than 200 years during the last deglaciation (Lund et al., 2011). A recent study based on plateau tuning shows that northwest Pacific reservoir ages varied by a few hundred years during the last glacial termination (Sarnthein et al., 2013). Since available  $^{14}C$  datings are by far not dense enough to identify the age-calibrated  $^{14}C$ -plateaus in sediment cores presented here, we were not able to assess the variability of paleo-reservoir ages. However, the reservoir age corrections used in this study are well within the range of calculated reservoir age changes reported from plateau tuning

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during the last deglaciation but the use of constant reservoir ages inevitably leads to an uncertainty of a few hundred years in the calculated age models.” (see Page 6 line 186 - 198)

- Line 23, If the Rae and Sarnthein data are already available I would also include them, if not, never mind

AC: Please see comments above.

- Page 6229, line 16 “intensified” ventilation of intermediate waters” – specify depth range

AC: We agree and gave a definition at the end of the introduction for intermediate water and deep-water to avoid any confusions (see Page 4 line 112 - 115).

- Page 6230, line 9 replace “was” by “were”

AC: Done.

- Page 6230, line 25 “Minor ventilation changes” – although claimed by Lund, their data (see figure below) suggest actually the opposite. A decrease of projection ages at depths of >2000m of 1500 years during HS1 can not be regarded as a small change and is consistent with the conclusions of Okazaki.

AC: We follow the interpretation of Lund et al. (2011), which claims that there is no sign of improved ventilation (deep-water formation) during H1 in the NE-Pacific (see also follow-up paper by Lund 2013).

- Page 6231, line 13, definition of “deep water,. . .” should be moved to the introduction

AC: Done (see comments above).

- Page 6231, line 27, Looking at the data in Lund, I would say that there was enhanced HS1 NPIW/deep water formation down to 2700m (see figure below), maybe even further down to 3600m (see Figure 3c of Lund et al. 2011)

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AC: We kindly refer to a follow-up paper by Lund published in Earth and Planetary Science Letters in 2013, which clearly suggests a decline in ventilation ages during H1 and YD in the deep NE-Pacific. This is broadly consistent with our results.

- Page 6232, line 8 “contradict the model-derived hypothesis” - double check the exact depth horizons discussed in Okazaki versus Galbraith. I am not sure that there is a contradiction (see table above).

AC: We agree. The data presented by Galbraith and colleagues comes from a sediment core collected in the deep North Pacific from approximately 3200 m water depth (ODP882). We modified this paragraph and added previous studies that evidently show no change in deep-water ventilation deeper than 1366 m water depth during H1 (e.g. Jaccard and Galbraith 2013), which clearly contradict the model-derived hypothesis of Okazaki et al., (2010) (see Page 10 line 326 - 331).

- Pages 6232 and following, avoid using the word “shallow meridional overturning” which is reserved in the physical oceanographic literature for the subtropical cells. Why not just call “intermediate-depth overturning cell”?

AC: We agree and replaced shallow meridional overturning” to “intermediate-depth overturning” in the whole manuscript to avoid any conflict with physical oceanographic terminology.

- Page 6232, line 27-28, again double-check with the consistence table.

AC: In your attached table the maximum of better ventilation from this study is given by 1500 m water depth. This is not consistent with data presented in this study, Deepest intermediate-depth core LV29-114-3 is located in approx. 1750 m water depth. Please see abstract for defined intermediate-depth interval.

Page 6233, line 11, the Okazaki model overturning only goes down to 2500m (their figure 2B)

AC: This is not the case as also stated in the abstract as follows: “The global effects

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of this reorganization of poleward heat flow in the North Atlantic extended to Antarctica and the North Pacific. Here we present evidence from North Pacific paleo surface proxy data, a compilation of marine radiocarbon age ventilation records, and global climate model simulations to suggest that during the early stages of the Last Glacial Termination, deep water extending to a depth of ~2500 to 3000 meters was formed in the North Pacific.” (Okazaki et al., 2010)

-Page 6233, lines 20-25 “rendering this scenario unlikely” – this is an oversimplified view of the heat budgets in the North Pacific (unfortunately also shared by reviewer 1), see my comment above and revise. There can be increased heat transport along with the surface cooling, if e.g. enhanced mixing or heat fluxes cause an extra heat loss.

AC: We modified the sentence and stated that the role of PMOC in buffering the decrease in poleward global oceanic heat transport (Okazaki et al., 2010) is not seen in proxy-based SST reconstructions provided by Harada et al., 2012 and Max et al., 2012 (the opposite is the case), thus questions the results of the LOVECLIM model simulation (see Page11-12 line 430 - 450).

AC: We hope that we disentangled the issue regarding deglacial deep-water ventilation by thorough discussion point-by-point on available data in literature and new data presented in this study. However, we are not able to argue for- or against any studies/data/interpretations (Rae and Sarinthein ???), which are not published, yet.

Interactive comment on Clim. Past Discuss., 9, 6221, 2013.

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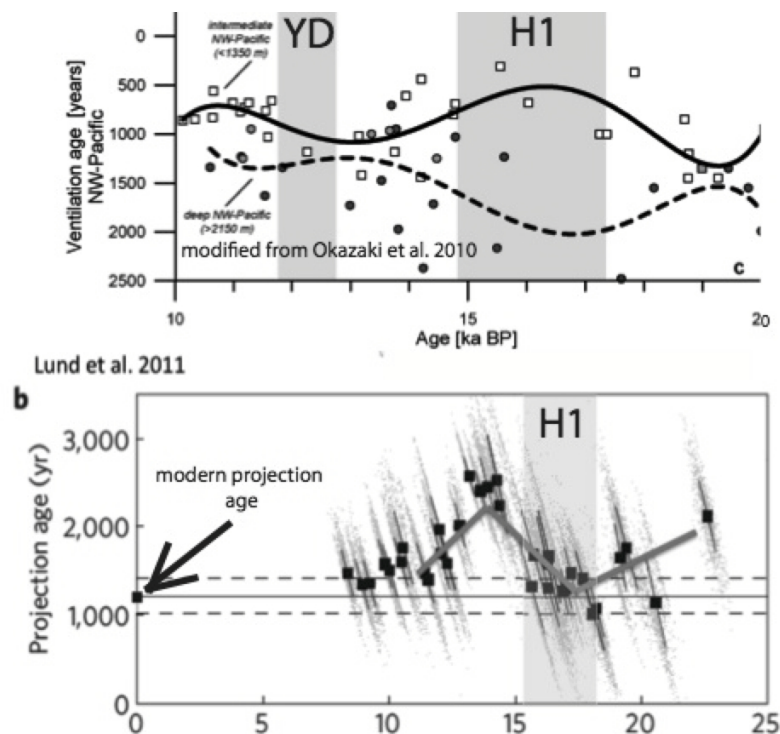


Fig. 1. Deglacial ventilation ages in the North Pacific

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