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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.

L. Max et al.

lars.max@awi.de

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Response to Anonymous Referee #1 (AC = Author Comment)

Lars Max and colleagues present new convincing evidence documenting large changes in North Pacific Intermediate Water (NPIW) formation rates across the last glacial termination. The authors follow a multi-proxy approach combining benthic-planktic foraminifera radiocarbon age differences (i.e. ventilation ages) and benthic foraminifera d13C measurements on a series of sedimentary archives retrieved from the (relatively) shallow Bering Sea and Sea of Okhotsk.

Their observations corroborate (and further document) enhanced ventilation at intermediate depths in the North Pacific at times where the Atlantic meridional overturning circulation (AMOC) was severely altered. Furthermore, the rich array of data presented in the manuscript does clearly not support enhanced "deep" water production during HS1 and the YD as previously inferred based on model results. To me, the opposite trend shown by "intermediate" and "deep" d13C records combined with the ventilation ages is particularly convincing. In essence, I support publication of the submitted manuscript provided the authors can address the following comments. The manuscript will undoubtedly contribute to the ongoing debate regarding the evolution of North Pacific subsurface ventilation in the past.

I hope the authors will find my comments helpful and constructive. Please do not hesitate to come back to me (via the editor) if my comments were unclear.

AC: We thank anonymous referee #1 for his critical and helpful comments made to the manuscript.

l. 46 – briefly outline why no deep water is forming today in the North Pacific to better orient the non-specialized reader

AC: We agree and included following phrase: "No deep-water is formed in the modern subarctic Pacific, as surface waters are isolated from the highly nutrient-rich waters below by a steep salinity gradient (permanent halocline), which leads to a robust stratification of the surface ocean in this region (see Page 2 line 45 - 47).

l. 52 – if I'm not mistaken, most of the models see deep convection induced in the NE Pacific under salinity perturbation experiments

AC: Numerous climate models show changes in circulation in the western North Pacific under salinity perturbation experiments (e.g. Mikolajewicz et al., 1997; Schmittner et al., 2007; Okumura et al., 2009; Okazaki et al., 2010; Chikamoto et al., 2012; Menviel et al., 2012). However, we are not aware of any published climate model results showing an onset of deep-convection in the NE-Pacific. Any reference?

l. 67 – please clearly define your definition of the term "ventilation". It has been misused again and again inducing some unnecessary controversy.

AC: We agree and now provide a clear definition what is meant with "ventilation" in the introduction. (see Page 3 line 84 - 87).

l. 69 – ". . . differences in radiocarbon ages between COEVAL planktic and benthic foraminifers"

AC: Done.

l. 88 and throughout the manuscript – d13C does not allow to make inferences about past changes in ventilation. d13C is merely a proxy indicating the extent a water mass has been affected by carbon remineralization, overprinted by air-sea gas exchange kinetics. It is however helpful to trace changes in water mass characteristic (as correctly stated a few lines below – l. 118-122). This is certainly a semantic question, but using a very precise, sensu stricto definition will help dissipate misunderstandings.

AC: We agree and modified the phrase introducing different proxies we used in this study to: "Here we present a detailed view on deglacial northwest Pacific circulation changes by providing new proxy data derived from epibenthic δ13C measurements indicative of differences in past seawater nutrient- and oxygen level in combination with a suite of new ventilation ages to infer changes in ocean circulation from the northwest Pacific and its marginal seas." We also revised all paragraphs in the manuscript dealing with changes in δ13C as tracer for water mass characteristics and replaced "ventilation changes" by "circulation changes" and/or "changes in nutrient- and oxygen level" to avoid any misunderstandings. (see e.g. Page 4 line 112 - 115)

l. 162 – reservoir ages. The authors apply a constant 500-900 yr reservoir correction for Okhotsk and Bering sea planktic foraminifers, respectively. While this correction seems entirely adequate, one could refine this reservoir age correction by comparing the raw 14C ages derived from planktic foraminifers with the age model derived using magnetostratigraphy and benthic d18O stratigraphy (Riethdorf et al., 13). Alternatively, one could use the comparison between the SO201-2-12KL SST and the NGRIP temperature records to derive an independent age model, allowing to (roughly) address changes in surface reservoir ages.

AC: The work of Riethdorf and colleagues are based on the same cores (except core SO178-13-6) used in this study and thus the age models are identical. The original stratigraphic framework was published by Max et al., 2012 for the last deglaciation (<20 ka BP) is based on high-resolution core-logging data combined with in total 37 AMS 14C ages. Core SO178-13-6 was implemented in the original stratigraphic framework presented in Max et al., 2012 by using the same approach here (high resolution X-ray fluorescence data combined with 14C ages) for correlation. However, Riethdorf et al., 2013 used the low-resolution magnetostratigraphy and d180 benthic isotope data to establish the age models for older sediment sections (>20 ka BP). To improve the stratigraphy by correlating the SST data from core SO201-2-12KL one-by-one to NGRIP would be great. But the much lower resolution of SST data from core SO201-2-12KL impede such a tight correlation to significantly improve the stratigraphy or even calculate reservoir ages.

AC: However, possible deglacial changes in reservoir ages in the North Pacific are a serious concern and we now stated this issue in the text: "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±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 14C datings are by far not dense enough to identify the age-calibrated 14C-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 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)

l. 195 & Fig. 3 – please clearly indicate the different depths stations on the water-column profiles depicted in Fig. 3.

AC: We modified Figure 3 and now indicate different depth stations with symbols (squares) on the water column profiles.

l. 203 – where are these poorly ventilated water masses originating?

AC: The poorly ventilated water masses originating from the North Pacific (Pacific Deep Water). We modified the sentence as follows: "Low δ13CDIC values of ca. - 0.6 ‰ mark the depth interval of sediment core SO201-2-85KL and are related to the inflow of old and nutrient-rich Pacific Deep Water originating from the North Pacific (Luchin et al., 1999)." (see Page 7-8 line 236 - 238)

l. 243 – ". . . these water massES. . ."

AC: Done

l. 255 – Galbraith et al., 07 as well as deVries and Primeau, 10 suggested quite significant changes in ventilation in the deep subarctic North Pacific across the last glacial termination. Well, I wouldn't define them as "minor", but maybe this is a question of appreciation.

AC: We agree. To avoid any confusion we modified the sentence as follows: "It is also consistent with studies indicating that the deep North Pacific was more isolated from the atmosphere during HS-1 (Lund et al., 2011; Jaccard and Galbraith, 2013; Lund, 2013) and thus did not contribute to the rise in atmospheric CO2 during this interval (Galbraith et al., 2007)." (see Page 10 line 326 - 331).

l. 272-273 – maybe introduce the defining concept separating “intermediate” from “deep” water masses much earlier in the manuscript.

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).

l. 278 – can the temporal evolution of the 13C gradient be shown in Fig. 5?

AC: Good point! We modified Figure 5 and added the d13C gradient between intermediate and deep-water.

l. 310 – what is meant by “thermodynamic”? air-sea gas exchange?

AC: Exactly. Air-sea gas exchange is temperature dependent and SST changes lead to changes in d13C (1°C $\approx$ 0.1 permille). However, we modified this sentence to make it clearer. (Page 11 line 344 - 345).

l. 325 – this is also consistent with proxy data (Crusius et al., 04; Jaccard and Galbraith, 12)

AC: We partly agree. The work of Crusius and colleagues showed that decreased oxygen in B/A intermediate water can be explained (at least to some extent) in productivity changes. There are no statements about Heinrich 1 or the Younger Dryas. However, we included the work of Jaccard and Galbraith, 12 as they showed changes in oceanic oxygen content through the last deglaciation in harmony with our results (Page 11 line 356 - 360).

l. 333-336 – not all the models show a warming during HS1 under enhanced PMOC. To my understanding this is largely model-dependent. In Okumura et al., 09, the AMOC shutdown during HS1 intensifies the Aleutian Low, which in turn induces a cooling tendency in the western North Pacific. So, in essence, I'm not sure whether an absence of warming in the SST proxy records is an absolute criterion to dismiss deep ventilation. But I agree that the cold SSTs during both HS1 and the YD as inferred in Max et al., 12 and Harada et al., 12 are at odds with the LOVECLIM simulations presented in Okazaki

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et al., 10 and Menviel et al., 12, which were used as prime arguments to drive deep convection in the North Pacific.

AC: We totally 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).

AC: We revised the whole paragraph to better distinguish between forcing and mechanisms to avoid any confusion to the reader (see Page 11-12 line 366 – 378).

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