Editor Decision: Reconsider after major revisions (10 Feb 2017) by Dr. Erin McClymont
Comments to the Author:
Both reviewers have commented favourably on the value of the very detailed, multi-proxy and high-resolution study provided in this publication. It is clear that there could be some very valuable new information revealed by the data, but at present the relevance and support for those linkages is masked by a number of factors: (1) a lack of clarity around several components of the age control; (2) a lack of clarity on how the productivity proxies are interpreted, and what processes drive each of these; (3) difficulties in following the discussion where links are made between the East Asian Monsoon, Greenland, and Antarctica.

  I agree with the reviewers, and think that they make a compelling set of arguments for the corrections required for the manuscript text. Due to the density of data being presented here, it is also likely that very detailed graphics will result. But, as the reviewers also pointed out, some of these become overwhelming to negotiate. The authors have replied to the comments provided by the reviewers, in places clarifying their interpretations and/or methods. However, I still found several components of the discussion to be confusing, or not clarified to the extent that was sought by the reviewers. I have outlined below what is required to make a convincing case that a robust set of arguments is put forward in this manuscript, which will require more clarification that the information currently given in the authors replies to the reviewers. As a result, I recommend that the manuscript is reconsidered only after major revisions are made.

1. Age model construction
I agree with both reviewers that there are some serious concerns around the construction of the age model and how it is outlined in the main text. It is difficult to follow exactly what was done, where points were transferred or not, why certain offsets were considered, and how the tuning of productivity cycles was tested. The replies given to the reviewers are not totally convincing: a revised submission needs to very carefully lead the reader through each step, and justify the approach.

Answer. The age model construction of core 41-2 is not straight-forward but step-wisely based on millennial to centennial scales of productivity and climate in the NW Pacific.

First, in core 41-2 with high sedimentation and high resolution sampling we have documented the centennial millennial productivity/climate events in the NW Pacific and only numbered them (without any timing) (Fig. 2).

Second, having orbital scale stratigraphy and one AMS 14 C data of core 41-2 with age of 9.12ka, we applied graphic correlation of productivity/climate events and PRI curve of this core with ones of the well-dated nearby core 12KL. In frame of this correlation we projected AMS 14C data of core 12KL on the depth of core 41-2, while taking into account the RPI variability of both cores as well. Projected AMS 14C data from core 12KL that were measured on the planktic foraminifera and age model 2 of Tiedemann/Max of this core is a valid approach (PANGAEA Data Publisher) as the adjacent locations of two cores.   Other four AMS 14C data of core 41-2 were used only to re-confirm the validity provided by the AMS data projection (Fig. 3) on core 41-2 depth and have not been used explicitly in our age model.

Third, with the initial controls of age model from the two steps described in above, we put established AMS 14C data of both cores on the coeval ages of precisely dated δ18O record of the Hulu cave stalagmites. In results, it was able to see, that centennial millennial productivity/climate events in the NW Pacific cores had occurred in-phased with sub-interstadial of summer EAM system with a convincible structural similarity of the events (Fig. 3). This similarity allows us to construct our age model in more detailed by tuning of the all centennial millennial productivity/climate events in NW Pacific cores with relative dated sub-interstadial of summer EAM. In revised manuscript we have described the construction of our age model step by step. As the construction of our age model is not that straight forward, in the manuscript we thus had to present the section with productivity events and then an age model construction.

There is a discussion of benthic-planktonic offsets and whether they vary through time – the authors reply that above 15 ka this offset was constant in the core from which they transfer their age model. But there are fluctuations shown in the Max et al. (2014) paper which also become pronounced before 15 ka – and this new manuscript includes older samples which might have been affected by these intervals. Furthermore, if there are large changes in productivity (which might reflect changes in mixing and/or carbon export) could these not also have affected these planktonic-benthic offsets? Answer. Very approximately interpolation of the regional deep water ventilation age of Max et al. (2014) show that deep water ventilation was nearly constant before 15 ka (nearly 1400 year) and vary between 1400-2000 year in an interval 15-19 kyr. We had used only younger AMS 14C data of core 41-2 for our age model with accepted BF-PF age difference nearly 1400 year, which age (9.2 ka) marks low productivity/cold event closed to established in the Greenland cold event 9.3 ka. As we responded earlier, we did not use other four radiocarbon data for core 41-2 in our final age model, though they fit quite closely with framework of core 12KL age model.

A revised submission needs to more carefully outline the steps taken to generate the age model and the assumptions which have gone into it. There is confusion about where tuning to Greenland and/or East Asian monsoon records might have occurred: this needs to be clarified. I agree with the reviewers that the construction of the age model would be better placed before discussion the productivity records, because then the text can flow into the timings of the productivity changes not just the overall pattern. This could be achieved if there was an outline of what the different productivity proxies represent and so we might expect that e.g. b* can be used to tune between sites. At the moment, the text talks about the timings of changes and cycles in the productivity data BEFORE the age control has been justified.

2. Productivity proxies and their interpretation

A number of different proxies for productivity are presented. The paper does not review the benefits and limitations of these different proxies, to make a clear statement of how they should be interpreted. This means that, where the reviewer comments that different proxies do different things at different times, it is then difficult to know which record to accept, and when, and why. A link needs to be made at the site first between what these proxies mean, and then how the oscillations are interpreted. The reviewers may have been able to understand the tuning approaches and the descriptions of productivity trends if there was a stronger rationale of the data interpretation. In a revised submission I recommend that the interpretations of the proxies are outlined with more detail so that the reader knows how you are finding a productivity argument (e.g. preservation can affect several of your indicators but is not discussed).

Answer. Usually people present in their results only 1-3 productivity proxies and suggest that they exactly reflect productivity changes without discussion of any their limitations and preferential. We agreed overwhelming with the review comments and therefore added a brief review of productivity proxies being used in this study and also a discussion on their limitations. It is worthy to emphasize in our manuscript as the centennial millennial productivity events are key issues of our study.

A. In Method section, we added brief implication of each used method, especially for the productivity proxies.
B. In Result section, we described briefly limitation and peculiarity of productivity proxies. That is why presentation a wide range of productivity proxies allows us to take into account different aspects transformation of primary produced organic matter into different proxies and their preservation in sediment providing more realistic picture of productivity changes. We provide graphic correlation of all used productivity proxies in order to establish the centennial millennial productivity events in studied core in the Fig. 2. In Fig. 3, we provide the productivity stack instead of used productivity proxies; its variations are consistent with graphic correlation. The stack reduced amount of curves on the figure and understanding of figure become easier.

I am not totally convinced by the use of the 'stack', but that is because without a revised manuscript to see what you did it is not clear to me what this represents. Is this an average of normalised data from several proxies? Is it a weighted mean? And is this even an appropriate way to create a kind of summary of the data, when you note in the text that sometimes the proxies behave in different ways? Given the complexity of the data, did the authors try any form of additional statistical analysis to determine whether there are 'groups' of productivity indicators or patterns?

In a revised submission you will need to very clearly explain what went into the stack, why those parameters were chosen, whether there is susceptibility in the stack to one or two of the records etc.

Answer. It's well-known that the productivity proxies, used in this study, initially are controlled by surface water productivity, but the productivity proxies are also susceptible to controlling factors other than productivity, such as preservation or early diagenesis. In the revised text we added a description that, in order to find out a commonly joint pattern of the multiple productivity proxies, we presented a productivity stack calculated from an average normalized data in range of 0-1 for all used productivity proxies plus reversed paramagnetic magnetization (PM) because this parameter reflects climate changes. We had used an equal weight for all proxies in the stacking calculation as it is the best solution for encompassing all available proxies without any preferential for any particular proxies before the full mechanisms of biological or geochemical processes that have controlled the proxies are fully understood.

3. Teleconnections

Reviewer 1 makes valuable comments about the way that the text links the monsoon and Greenland records and/or with Antarctica. I agree with their comment that a slight restructuring or separating of the sections across lines 243-285 would be valuable, to first set the NW Pacific data into a hemispheric context, and only then discuss links with the south. This doesn't have to be a problem for the figure (as the authors suggest): more than one section of the text can cite the figure.

Answer. Thank you. We revised this piece of text significant and had discussed first set the NW Pacific data into N hemispheric and then into S hemisphere.

I also agree with reviewer 1 that explaining the longer term trends first, in your interpretation, would allow you to move from the long term into the short term variability. The structure might then flow better for the comparisons with wider teleconnections and their timescales.

Answer. Main issue of our ms, as reflected in the title, is centennial-millennial productivity/climate events in the NW Pacific and their teleconnection with sub-interstadials in EAM system and then with Greenland and Antarctic temperature abrupt changes. So, we mainly focused on describing our finding of the time scales.Longer term trend interpretation of our results is of course important but we have placed it as secondary. Sorry, therefore we prefer to save previous order of presentation.

I also agree with reviewer 1 that when making the cross-correlations for teleconnections (see below), what would make a stronger discussion of the significance of your data is a cross-correlation of this new data with the monsoon/Greenland records (whichever is appropriate).

Answer. In this chapter, we try to correlate the N Pacific climate changes with ones on the N Atlantic. Our age model based on AMS 14C data and fine-tuning with well dated δ^{18}O of China stalagmites reflected the on EAM temporal activity which, likely, are the best dated available template for NW Pacific region. Therefore, the age model of our data is a derivative of the EAM chronologies for the first approximation. That is why we used EAM data as a best approach of NW Pacific for cross-correlation with the NGRIP and GISP2 data.

First, find the mechanisms and links with your own data, and then (possibly) make the bigger hemisphere/polar comparisons.

Answer. We briefly show links of NW Pacific abrupt climatic/productivity events with EAM millennial variability in text. Bigger hemisphere/polar comparison was discussed and presented in Fig.5.

4. Graphics

A positive aspect of this publication is the number of detailed new data sets, showing multiple indicators of productivity at high temporal resolution. The reviewers made some suggestions for how to simplify these – the use of a 'stack' in a revised figure 3 was one response by the authors. I agree with the reviewers that the graphics are still complex. One way to try and simplify e.g. figure 3, might be to plot the data sets that you are tuning side-by-side e.g. plot both RPI records together, then both b* together, or whatever the combination might be. Or in fact was it the 'stack' that was used for the tuning.

Answer.On the figure 3 proxy curves are plotted versus their own depth, so we cannot put side-by-side records from different cores together due to different sedimentation rates in these cores. For tuning we use whole bunch of productivity proxies and PM. These records reflect environmental changes more or less definite depend on time period. The obtained stack combines all features of all used records. The main purpose of this stack curve is to simplify our figures and clearly figure out the centennial-millennial productivity events.

The revised figure 4 is more clear.

Figure 5 is a bit strange/messy with simply an addition of the Bond 2001 hematite grains overlying Antarctica.

Answer. We changed the order of curves on the figure 5

I'm not convinced that Figure 6 is needed, unless you include (as one reviewer suggests) the cross-correlation of your own data into this. Discussion of monsoon/Greenland climate phasing is an important question, but to better embed this into your new findings you need to include a component of your data here.

Answer. We presented figure 6 to show different correlation (connection) between NW Pacific and Greenland/N Atlantic in various time intervals. As we mentioned above our age model is based on EAM chronologies as the best available dating template for NWPacific region. Therefore, the age model of our data is partly   converted from the EAM chronologies and that is why we used it for cross-correlation with the NGRIP and GISP2 data.

Or, remove the detailed discussion of the wider teleconnections from the manuscript and focus more strongly on your new data and its relationships to e.g. monsoon, Greenland, Antarctica.
Answer. We are not sure what exactly you meant here, because the teleconnection and relations to monsoon, Greenland, Antarctica are the same issue in our opinion.

The reviewers noted that there is other data on e.g. SST, sea ice, available which could help you to make the links between the mechanisms you outline to change productivity and the potential data which could support these. In your reply to reviewers you say that you will state the relationships: I don't think that this is what the reviewers are asking for. I, like them, would prefer to see you plot the SST and/or sea ice evidence alongside your own.
Answer. SST estimation technique is not well developed for the high latitude oceans. Alkenons concentration strongly vary with time here, therefore estimations of SST are always challenging works here. With the published SST results for core 12Kl presented by Max et al. (2012, Climate of the Past) and Meyer and Max, et al. (2016, Paleoceanography), SST in the first paper (Max et al., 2012) was determined by U^{K}_{37} method and show low SST during YD. SST in the second paper (Meyer, Max et al., 2016) for the same core was determined by TEX86 method and showed that during the YD, the SSTs have significantly decreased and abruptly increased. The patterns have been found difficult to interpret as far.
All climate results for NW Pacific and its marginal Seas, adjoin land and in other regions presented in many papers evident that YD was cold period with increase of sea ice extension and low productivity. With such modelling and data results we are quite confident that the YD must be cooling nearly everywhere in the NW Pacific and East Asia, though SST determinations for the ocean responses during the YD possibly are more complicated due to various effects that are unclear.
As for sea ice evidence. We have shown that the presented MS and CF may be used as IRD proxy. They show that IRD content (sea ice influence index) was high during LGM-HE 1, then significant decrease from 15.3 ka ago and increase during YD. We had presented many proxies reflected environment and productivity changes and find centennial-millennial productivity/climate events in the NW Pacific coeval with EAM sub-interstadials. We believe that it is important.

5. Written style
Both reviewers comment that there are grammatical errors, leading to confusion and/or a lack of clarity in the arguments and presentation of data. I agree with this comment. A thorough and careful reading of the manuscript is required to remove these errors, to ensure that your arguments are being made with improved precision.

Answer. We used the proofreading service from native English speaker.

marked-up manuscript version

Centennial to millennial climate variability in the far northwestern Pacific (off Kamchatka) and its linkage to ~~the~~ East Asian monsoon and North Atlantic from the Last Glacial Maximum to the Early Holocene

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Abstract

High resolution reconstructions based on productivity proxies and magnetic properties measured from sediment core 41-2 (off Kamchatka), reveal prevailing centennial -millennial productivity/climate variability in the northwestern (NW) Pacific from the Last Glacial Maximum (LGM) to the Early Holocene (EH). The ~~core~~ age model ~~of core~~ is established by AMS 14C dating using foraminifer shells ~~from the core~~ and by ~~the~~ correlating the productivity cycles and relative paleomagnetic intensity records with ~~the same cycles and records those~~ of well-dated nearby core, SO-201-12KL. Our results show a pronounced feature of centennial--millennial productivity/climate cycles ~~of~~ in the NW Pacific ~~had~~ occurred ~~synchronicity~~ synchronously with the summer East Asian Monsoon (EAM) at sub-interstadial scale during the LGM (3 cycles), Heinrich Event 1(3 cycles), ~~and~~ Bølling/Allerød warming (4 cycles), and over the EH (3 cycles). ~~Our C~~comparison of the

centennial-millennial NW Pacific productivity/climate cycles with the variability of the Antarctic temperature of the EPICA to the Antarctic EDML (EPICA Dronning Maud Land (EDML) ice core suggests a "push" effect of Southern hemisphere temperature gradients on the intensifications of the summer EAM intensifications. Besides the linkages of NW Pacific high productivity and summer EAM, we observed that five low productivity cycles during EH are nearly synchronous with cooling in Greenland, with weakening of the summer EAM, and with decreases in solar irradiance. We propose that such centennial-millennial productivity/climate variability in the NW Pacific, associated with and sequence of sub-stadial/interstadials in the EAM from the LGM to EH, is are a persistent regional features and is quasi-synchronous , synchronous with the Greenland/North Atlantic short-term changes. We speculate that such climate synchronicity was also forced also by changes in Atlantic meridional overturning circulation, coupled with Intertropical Convergence Zone shifting, and reorganization of the northern westerly jets reorganization.

1. Introduction

Model simulations and proxy-based interpretations have led to contradictory results concerning the millennial environmental variability in the northwestern (NW) Pacific and its underlying mechanisms during the last deglaciation. These model and proxy studies suggested either in-phase relationships of deglacial variability between the North (N) Atlantic and NW Pacific (Caissie et al., 2010; Chikamoto et al., 2012; Kienast and McKay, 2001; Seki et al., 2002) or out-of-phase responses (Gebhardt et al., 2008; Okazaki et al., 2010; Sarnthein et al., 2006). The in-phase relationship has been attributed to rapid atmospheric teleconnections in the N hemisphere on years toa decadal time scales (Max et al., 2012). The winter Arctic Oscillation, which resembles the North Atlantic Oscillation, directly influences the surface air temperature and sea level pressure over the region northwards of 35ºN in East Asia. In turn, the Siberian High significantly influences

the East Asian Winter Monsoon (Wu and Wang, 2002). The out-of-phase response, however, was proposed to be driven by a seesaw mechanism, with oceanic readjustments between the Atlantic meridional overturning circulation (AMOC) and Pacific meridional overturning circulation. Recent studies on high-resolution and precisely-dated sediment cores from the subarctic NW Pacific, the Sea of Okhotsk, and the western Bering Sea show a deglacial sea surface temperature (SST) evolution similar to the northeastern (NE) Pacific and to the N Atlantic and Greenland temperature variability (Max et al., 2012). These studies suggest a close linkage to deglacial variations in AMOC associated with rapid atmospheric teleconnection, which were responsible for a quasi-synchronous SST development between the N Atlantic and N Pacific during the last deglaciation. On the basis of high resolution X-ray fluorescence (XRF) and sediment surface color reflectance studies on western Bering Sea cores, (Riethdorf et al., (2013) further suggest a close linkage between millennial-scale productivity changes to and the Dansgaard–Oeschger variability were registered in the North Greenland Ice Core Project (NGRIP) ice core, which had been interpreted to as supporting the atmospheric coupling mechanism. A study comparing the subarctic N Pacific dust record to dust content in the NGRIP ice core also shows synchronicity of the timing of abrupt millennial changes during the last 27 ka (Serno et al., 2015). Furthermore, Though a recent study by Praetorius and Mix (2014), based on multidecadal-resolution foraminiferal oxygen isotope records from the Gulf of Alaska reveals a synchronicity of rapid climate shifts between the N Atlantic/Greenland (NGRIP core record) and the NE Pacific between 15.5 to 11 ka., inverse relationships between the Atlantic/Pacific dDuring the Holocene and Heinrich Event (HE) 1, inverse relationships between the Atlantic/Pacific are suggested in this paper, while the short-term variability is either not sufficiently resolved or is decoupled.

All of these the instances indicate that a lack of high resolution proxy records in the NW Pacific prohibits precise assessments of any possible climatic teleconnection mechanisms across the basins. Although abrupt centennial-millennial precipitation anomalies over from the Last Glacial

Maximum (LGM) to the Holocene have been reported in cave sediment $\delta^{18}O$ records of the East Asian monsoon (EAM) (Dykoski et al., 2005; Wang et al., 2001, 2005, 2008; Yuan et al., 2004), the timing and the trend of variability of Early Holocene (EH) regional climate changes are still controversial. In particular, though the EH climate has started from a strong warming in most cases, a Hani peat $\delta^{18}O$ record from northeastern China instead suggest cooling events which are primarily superimposed on a Holocene long-term warming trend (Hong et al., 2009).

Here ~~we present~~ the high resolution results of a suite of productivity proxies, magnetic properties, and lithological changes from the NW Pacific sediment core LV 63-41-2 (hereafter, 41-2) (off Kamchatka) are presented and ~~that~~ reveal a sequence of centennial-millennial climate/productivity variability ~~over~~ from 20 ka to 8 ka. An age model of this core was constructed using Accelerator mass spectrometry (AMS) ^{14}C ~~by AMS 14C~~ dating and ~~then fine-tuned~~ by correlating the productivity cycles and relative paleomagnetic intensity (RPI) variability with ~~one~~ those of the well-dated nearby core~~,~~ SO-201-12KL (hereafter, 12KL) (Max et al., 2012, 2014). Using ~~With our~~ methodologically robust age controls, it is possible ~~we are able~~ to infer a tight linkage between the centennial-millennial productivity variability in the NW Pacific and the sub-interstadial summer EAM intensifications expressed in cave sediment $\delta^{18}O$ records. ~~Our~~ These results ~~have~~ enable~~d us to investigate~~ the further investigation of any mechanisms controlling the in-phase relationships of the centennial-millennial variability in the NW Pacific/EAM ~~with~~ and those underlying the Greenland/N Atlantic and Antarctic climate changes during the LGM – HE 1 – Bølling/Allerød (B/A) – Younger Dryas (YD) – EH (~20-8 ka).

2 Materials and methods

2.1 Coarse fraction measurement

Sediment core 41-2 was recovered in the NW Pacific off Kamchatka Ppeninsula (water depth 1924 m; 52°34,' N; 160°00,6' E; core length 467 cm) during the joint Russian-Chinese expedition at R/V "Akademik M.A. Lavrentyev" in 2013. The Wweight percentage of the coarse fraction (CF) >63 μm and <2000 μm, sampled every 1 cm and separated by sieve washing, was calculated as ratios of CF weight to the weight of the dry bulk sediment. Semi-quantitative estimates were made of the amount of various components in the sediment CF, including terrigenous and volcanogenous particles (tephra), benthic and planktonic foraminifera, diatom frustules, and radiolarians, using a microscope to roughly estimate the proportions of different components in the sediment (Rothwell, 1989). The indicators of materials mainly transported to the study region by sea ice, such as CF and MS of sediments (Gorbarenko et al., 2003; Lisitzin, 2002; Sakamoto et al., 2005), are used as an ice rafted debris (IRD) proxy. Semi-quantitative estimates of the amount of terrigenous and volcanic particles in sediment CF allow the determination of core intervals with insignificant amounts of tephra, and therefore intervals with implications for CF and MS as an IRD index. The CF of sediments, indicator of the component of materials mainly transported to the study region by sea ice (Gorbarenko et al., 2003; Lisitzin, 2002; Sakamoto et al., 2005), is used as an ice rafted debris (IRD) proxy here. The tephra material input in the CF was estimated by semi-quantitative component analyses of this fraction with a total of 12 ranged scales. We made estimations of various components including terrigenous and volcanogenous particles, benthic and planktonic foraminifera, diatom frustules, and radiolarians in this study.

2.2 Chlorin content measurement

Chlorin content is assumed to reflect changes in primary surface ocean productivity, because continental-derived chlorophyll does not contribute to the chlorin content in deep marine sediment (Harris et al., 1996). The chlorin content of in core 41-2 was measured on samples taken everyat 1

cm resolution, and at 2 cm resolution in~~on~~ core 12KL ~~every 2 cm~~ through the whole core~~s~~, as in Harris et al. (1996), modified using a Shimadzu UV-1650PC spectrophotometer (Zakharkov et al., 2007). ~~using a Shimadzu UV-1650PC spectrophotometer according to the modified method of Harris et al. (1996).~~

2.3 Total organic carbon (TOC), calcium carbonate, and color b* measurements

Contents of TOC, CaCO$_3$, and biogenic opal in deep sea sediments are usually used as key parameters to assess paleoproductivity (Berger et al., 1989; Narita et al., 2002; Prahl et al., 1989; Seki et al., 2004). Shipboard color b* values correlate well with the changes in biogenic opal content in sediment cores (Nürnberg and Tiedemann, 2004) and are widely used as a paleoproductivity proxy in the NW Pacific and its marginal seas (Gorbarenko et al., 2012; Max et al., 2012; Riethdorf et al., 2013).

Total carbon content and inorganic carbon in core 41-2 were measured every 2 cm throughout the core depth by coulometry using an AN-7529 analyzer (Gorbarenko et al., 1998). TOC content was determined by calculating ~~computing~~ the difference between total carbon and inorganic carbon content. A color b* index (psychometric yellow–blue chromaticness) was measured with 1 cm resolution using a Minolta CM-2002 color reflectance spectrophotometer ~~that generates visible-light reflectance data (400 to 700 nm wavelengths)~~ (Harada, 2006) ~~of the core every 1cm. In this study we used the trend of color b* that well correlates with the changes in biogenic opal contents in sediment cores (Nürnberg and Tiedemann, 2004).~~

2.4 Radiocarbon dating (AMS 14C)

AMS 14C-ages were measured ~~on~~ in monospecific samples of the planktic ~~foraminifers~~ foraminifera *Neogloboquadrina pachyderma* sinistral (*N. pachyderma* sin.) from ~~a~~ the 125–250 μm

fraction, and benthic foraminifera *Epistominella pacifica*, and *Uvigerina parvocostata* from the 250–350μm fraction of the core. The radiocarbon dating ~~has been~~was performed by the Dr. John Southon at the Keck Carbon Cycle AMS Facility (UCIAMS) in the Earth System Science Department of the University of California, USA. The constant ~~same~~ reservoir age (900 ± 250 yr) of the NW Pacific surface water (Max et al., 2012) was adopted in this study to convert ~~calibrate~~ the ^{14}C ages of ~~our~~ the samples into calendar ages, in order to ~~for~~ establish~~ing~~ consistent AMS ^{14}C chronologies of cores 41-2 and 12KL. ~~When using benthic foraminifera for AMS 14C dating on our cores, we take the age difference of 1400 yrs between coexisting benthic and planktic foraminifera ages to make further corrections (Max et al., 2014).~~ All reservoir age corrected ^{14}C data were converted ~~in~~to calendar age by using Calib Rev 6.0 (Stuiver and Reimer, 1993) with the ~~IntCal09 and~~ Marine13~~09~~ calibration curve ~~data sets~~ (Reimer et al., 2009). When using benthic foraminifera for AMS ^{14}C dating on the cores, an age difference of 1400 yrs is taken between coexisting benthic and planktic foraminifera ages (Max et al., 2014).

2.5 Magnetic property measurements

Magnetic propert~~ies~~y ~~analyses of cores 41-2 and 12KL~~ were measured at 2.2 cm resolution in both ~~conducted by taking samples every 2.4 cm throughout the~~ cores. The ~~V~~volume magnetic susceptibility (MS) of these samples was measured using an AGICO MFK1-FA device. The characteristic remnant magnetization (ChRM) of the ~~cube~~ samples was measured in the same way by studying the stability of natural remanent magnetization (NRM) in the alternative magnetic fields of up to 80-100 mT on the basis of analysis of Zijderveld vector plots, using an AGICO LDA-3A device and rock-generator AGICO JR-5a (Zijderveld, 1964). The module and direction of NRM were measured on a JR-5A rock-generator after the stepwise demagnetization of reference samples by alternating magnetic fields with a vanishing amplitude (Malakhov et al., 2009). Ahysteretic remanent magnetization (ARM) was generated using an AGICO AMU-1A device and measured using ~~by~~ the JR-5A rock-generator. The ~~R~~relative paleomagnetic intensity (RPI) of the studied core

sediments was determined by the normalization of the ChRM after demagnetization at 20 mT by ARM (ChRM/ARM) (Tauxe, 1993). The sediment paramagnetic magnetization (PM) was measured for each sample from curves of magnetic hysteresis by a J Meter coercitive spectrometer at Kazan State University, Kazan, Russia (Enkin et al., 2007; Jasonov et al., 1998).

Past relative paleomagnetic intensity (RPI) value changes in response to variability in the Earth's magnetic field present an independent chronological instrument of marine and continental sediments (Channell et al., 2009), and are widely used for sediment correlation and chronology (Kiefer et al., 2001; Riethdorf et al., 2013). PM was formed in marine sediments of silicate, paramagnetic iron sulphide (FeS), and fine clay minerals transported from land as an eolian dust through atmosphere circulation by westerly jets. Therefore, the sediment PM may serve as a proxy of the land aridity and/or atmosphere circulation pattern changes in response to climate changes. MS was mainly formed by ferromagnetic minerals delivered together with terrigenous materials from adjacent land, and is therefore related to IRD. It is the main transport agent of clastic material input into the sediment of the NW Pacific and its marginal seas (Gorbarenko et al., 2003; Lisitzin, 2002; Sakamoto et al., 2005).

2.6 XRF measurements

The Core 41-2 elemental composition of core 41-2, given in peak area (counts per second, cps), were was measured at 0.5 cm resolution using the Itrax XRF core scanner at the First Institute of Oceanography, State Oceanic Administration, China. The Itrax XRF core scanner was set at 20 s count times, 30 kV X-ray voltage, and an X-ray current of 20 mA. Though absolute elemental concentrations are not directly available from the micro-XRF measurements, the count values can be used as estimates of the relative concentrations. The count values may be influenced by the changes in the physical properties of the sediment, such as the surface roughness of the core (Röhl and Abrams, 2000). However, the grain size of the 41-2 core is rather fine and the surface has been

processed to be as flat as possible to minimize any effects from changing physical properties or roughness during the scanning.

In this study, ~~we paid~~ attention was paid to the scanning results for estimating biogenic Ba, Br and Si (Ba-bio, Br-bio and Si-bio respectively) contents in our sediment cores, which serve as proxies of productivity. The content of Ba-bio was estimated through ~~by~~ subtraction of its terrigenous component (Ba-ter) from the total bulk Ba concentration in sediment (Ba-tot). The terrigenous component, in turn, was calculated from empirical regional $(Ba/Al)_{ter}$ ratios in the sediment core with the lowest Ba-tot contents:

Ba-bio = Ba-tot – $(Ba/Al)_{ter}$*Al (~~by~~ Goldberg et al. ~~(~~2005~~)~~).

Br-bio and Si-bio were calculated using the same technique.

Earlier it was shown that the non-destructive, high resolution X-ray Fluorescence (XRF) measurements of Ba-bio, Br-bio, and Si-bio by a core scanner or synchrotron radiation are consistent with analytically measured Ba-bio, TOC, and biogenic opal, respectively, and therefore may be used as paleoproductivity proxies (Goldberg et al., 2005; Nürnberg and Tiedemann, 2004; Riethdorf et al., 2016). Ba-bio is formed during the decay of organic matter in the water column and the uptake of Ba in settling particles (Dymond et al., 1992), and has been previously used as a paleoproxy (Goldberg and Arrhenius, 1958; McManus et al., 1998). Si-bio, related with biogenic opal in deep sea sediments, is usually used as a key parameter to assess paleoproductivity (Berger et al., 1989; Narita et al., 2002; Seki et al., 2004). Br-bio content measured using a core scanner is strongly correlated with TOC variability (Riethdorf et al., 2016) and therefore may also be used as a paleoproductivity proxy.

3. Results

AMS radiocarbon data for core 41-2 are presented in Table 1. ~~The sediment PM and MS, and~~

~~a suite of productivity proxies - TOC, chlorin, CaCO3, Ba-bio, Br-bio, Si-bio contents, and color parameter b* with four AMS 14C data~~ The variability of a suite of productivity proxies (color b* and contents of TOC, chlorin, CaCO$_3$, Ba-bio, Si-bio, and Br-bio), plus magnetic properties (RPI, sediment PM, and MS), are presented for core 41-2 versus depth (Fig. 2). ~~We observed high~~ Increased ~~productivity in the middle part of the core (~~ at the interval ~315-230 cm~~)~~, according to several productivity proxies and available AMS ^{14}C data ~~which~~ could be chronologically assigned to the B/A warming right after the termination of the last glaciation (467-315 cm). The high productivity during the B/A warming is a common feature in the far NW Pacific and its marginal seas (Galbraith et al., 2007; Gorbarenko, 1996; Gorbarenko et al., 2005; Gorbarenko and Goldberg, 2005; Keigwin, 1998; Seki et al., 2004). The interval at ~230-190 cm with a decreased trend of productivity is likely associated with the YD cooling. After this low productivity/cold climate event the high productivity/warm trend in the upper 190 cm of the core is presumably related to the Holocene warming~~warm climate condition~~.

~~Time resolutions for our core 41-2 data over LGM-YD periods are ~30 years for chlorin and color b*, ~60 years for TOC, CaCO3 and magnetic parameters (PM, MS and RPI), and ~15 years for the Ba-bio, Br-bio, Si-bio contents.~~ In core 41-2, the time resolutions of measured color b*, and chlorin, TOC, CaCO$_3$ content and magnetic parameters (PM, MS, and RPI); and Ba-bio, Br-bio, and Si-bio concentrations over the LGM-YD periods are nearly 30 years, 15 years, and 60 years respectively. ~~All t~~The resolutions ~~are~~ is high enough to allow ~~us to~~ the detect~~ion of~~ centennial-millennial scale climate variability in the far NW Pacific. ~~Our high resolution productivity and magnetic records presented here~~ Graphic correlation of the productivity proxies (chlorin, TOC, CaCO$_3$, Ba-bio, Br-bio, Si-bio content, and color b*) and the PM record reveal ~~nearly~~ quasi-synchronous the centennial-millennial cycles likely associated with abrupt ~~productivity/~~environmental variability (Fig. 2) ~~with~~ via mechanisms ~~likely~~ similar to previously established ~~earlier~~ regularities at the orbital-millennial scale ~~(Fig. 2)~~ (Broecker, 1994; Ganopolski

and Rahmstorf, 2002; Sun et al., 2012). Therefore, ~~in particular we~~ it is suggested that the sharp increase~~s~~ ~~shown~~ in ~~our~~ productivity ~~records~~ demonstrate~~s~~ ~~a quick~~ the fast ~~response of the oceanic climate system~~ of the NW Pacific environment associated with ~~to~~ abrupt ~~global~~ regional warming~~.~~, and vice versa, similar to interstadial events in the NW Pacific and the Okhotsk and Bering Seas. The rises in temperature of surface water and environmental amelioration in the NW Pacific, the Okhotsk and Bering Seas, and the Sea of Japan are well correlated with interstadials in $\delta^{18}O$ records in the NGRIP ice core (North Greenland Ice Core Project members, 2004) and in the Chinese cave stalagmites promoting to increase in productivity at the millennial scale (Gorbarenko et al., 2005; Nagashima et al., 2011; Schlung et al., 2013; Seki et al., 2002, 2004).

Each productivity proxy used here has its own specific limitations and peculiarities in its response to environmental and primary productivity changes. For example, although carbonaceous fossils (planktonic foraminifera and coccolithophorids) rain from the euphotic layer derived by primary production, and provide the main carbonate input into the sediment, $CaCO_3$ content in the deep sea sediment is mostly governed by climatically forced variability in the deep water chemistry and carbonate ion concentration (CO_3^{2-}), resulting in different carbonate preservation in the past (Yu et al., 2013). As for the Ba-bio proxy, Jaccard et al. (2010) suggest that in the highly productive areas, barite dissolution has been observed under suboxic conditions, precluding its application as a quantitative proxy to reconstruct past changes in export production. Although it has been suggested that biogenic opal and TOC content, being responsible for the accumulation of siliceous fossils, and siliceous plus carbonaceous fossils, respectively, present basic key proxies for the assessment of productivity changes (Berger et al., 1989), they vary in different ways at various times in sediments of the NW Pacific and its marginal seas. For example, in the Okhotsk Sea biogenic opal content lags significantly relative to TOC changes during the last deglaciation—the Late Holocene (Gorbarenko et al., 1998; Seki et al., 2004). TOC content in the hemipelagic sediment includes the organic carbon

formed by marine primary production, and the terrigenous organic material delivered from land. The input of which depends on the river runoff and sea level changes. Therefore, centennial-millennial changes in different productivity proxies vary not exactly synchronously, depending on organic matter transformation into a different proxy, and its subsequent preservation in the sediments.

The presentation of a wide range of productivity proxies allows different aspects of the transformation of primary produced organic matter into different proxies, and their preservation in sediment, to be considered. This approach provides a more reliable pattern of productivity changes. Beside productivity proxies the PM record is also used, because the sediment PM reflects the changes in the transportation of dust from continents by atmospheric circulation associated with climate change. For the statistical assessment of the centennial-millennial productivity variability, the productivity stack is calculated. It is an average of the normalized data of each proxy, given equal weight (Fig. 3).

~~In results, our productivity and magnetic records show that 6 short warm events happened during the last glacial and 4 warm events during the B/A warming (Fig. 2). During the EH, our records show 5 short cold events and 3 warm events.~~ A graphic correlation of all the applied productivity proxies with the sediment paramagnetic magnetization (PM) record shows that six short increased productivity/warmer events happened during the last glacial, and four occurred during the B/A warming (Fig. 2). During the EH five short lower productivity/colder events and three higher productivity/warmer events were found. ~~We notice~~ It is noted that a colder event at depth 117-122 cm with an age of ~9.12 ka (Table 1) is well-correlated with the 9.3 ka cold event in Greenland ice core records (Rasmussen et al., 2014). Moreover, a cold event identified at depth 106-109 cm ~~of our~~ in core 41-2 also links well with the 8.2 ka cold event in Greenland ice cores, a well-known chronostratigraphic marker in the Early to Middle Holocene boundary (Walker et al., 2012).

~~Our records of the CF percentages, amount of volcanic particles in CF, and MS indicate high~~

IRD values below a 315 cm depth of the core. A significant increase of CF to the top in the upper 220 cm of the core was mostly driven by increased tephra input (Fig. 2). Our MS record also shows higher terrigenous input in the interval of 230-205 cm included in the YD (Fig. 2). A compilation of all our 195 proxies of productivity, PM, and RPI of core 41-2 and a comparison with ones of core 12KL are shown in Fig. 3. The color b* indices and Ca/Ti ratios (analog of CaCO3 content) of core 12KL were extracted from Max et al. (2012, 2014) available on PANGAEA Data Publisher for Earth & Environmental Science (http://dx.doi.org/10.1594/PANGAEA.830222).

The share of tephra in the sediment CF shows relative low values below 130 cm, and significantly increases in the upper part of the core (Fig. 2). Therefore, CF and MS records, controlled by the tephra share in CF, indicate high IRD inputs in the sediment of the lower part of the core, and a strong decrease towards the top in the interval 325–315 cm. MS and CF records also show some increase of IRD input in the interval 230–200 cm, related to the YD (Fig. 2).

The relative paleointensity (RPI), color b* records, and productivity stack of core 41-2 were compared with the RPI, PM, and several productivity proxies of nearby core 12KL versus core depth (Fig. 3). The color b* index and Ca (analog of $CaCO_3$ content) of core 12KL were obtained from Max et al. (2012, 2014) and PANGAEA Data Publisher for Earth and Environmental Science (https://doi.pangaea.de/10.1594/PANGAEA.786201). The centennial-millennial events with increased productivity shown in Fig. 2 were confirmed by the productivity stack changes for core 41-2, and correlate well with productivity events for core 12KL outlined by the productivity proxies and PM record; their correlation is also consistent with RPI variability in both cores.

4. Age model

An age model of core 41-2 was constructed using all available AMS 14C dating, with more age control points identified by correlating the centennial-millennial events of the productivity proxies, RPI and PM of ~~our~~ the studied core with those of the well-dated nearby core 12KL (Max et al., 2012, 2014) (Fig. 3). The age tuning used in this study assumes a synchronous pattern of productivity, RPI and PM variability in the far NW Pacific since the last glacial, especially for closely-located cores. With this conception ~~framework~~ of age model developments, the centennial-millennial variability of productivity proxies with increased productivity events, relative paleointensity (RPI) of Earth's magnetic field, and paramagnetic magnetization (PM) identified in cores 41-2 and 12KL have to be closely matched in both cores over the last glaciation—the B/A warming to the EH (Fig. 3)~~, magnetic parameters earlier identified in core 41-2 are closely matched in the both cores; they show regionally coherent sequences of productivity/environmental cycles (events) from the last glaciation, the B/A warming to the EH (Fig. 3). We noticed~~ It was noted that the available model for core 12KL—the Tiedemann/Max age model (Max et al., 2012, 2014)—was based on the AMS 14C data and correlation of color b* index with the NGRIP δ^{18}O curve (PANGAEA Data Publisher). By adopting this age model of core 41-2, ~~all available~~the AMS ^{14}C dating of core 12KL of Max et al. (2012, 2014) ~~(with one exception for an age dating of 16.53 ka at depth 695 cm) were~~ was successfully transferred ~~successfully~~ to core 41-2 according to the correlation of related increased productivity events and RPI values ~~within related productivity cycles and RPI values correlation~~ (Fig. 3). The color b* minimum in core 12KL at a depth of 706 cm, which Tiedemann and Max (PANGAEA Data Publisher) correlate with a minimum in the NGRIP δ^{18}O curve at 16.16 ka, is also clearly correlated with the color b* minimum of core 41-2 at a depth of 348 cm (Fig. 3). All correlated AMS ^{14}C key points are also well-matched with the measured RPI curves of both cores (Fig. 3). Core 41-2 AMS ^{14}C data of 9.45 ka, 10.6 ka, 14.39 ka, and 14.61 ka at depths of 127.5 cm, 156 cm, 298 cm, and 306 cm, respectively, are fairly close to the nearby projected ^{14}C datum from core 12 KL (Table 2), and confirm the validity of this age projection. Here

the use of the ^{14}C data of core 12KL is preferred, because this core has a higher sedimentation rate, and planktonic foraminifera for these measurements were picked from intervals with the highest Ca content, to significantly decrease a bioturbation effect.

Derived radiocarbon framework of both cores allow us to infer also close correlation of the productivity/environmental cycles identified in the cores with sub-interstadial of absolute U-Th dating δ18O of calcite recorded in the China caves stalagmites over the 20-8 ka BP (Dykoski et al., 2005; Wang et al., 2008) (Fig. 3), which may be used for further tuning of our age model. In results, the key time points of core 41-2 were based on the available AMS 14 C data of core 41-2, depths correlated with core 12KL AMS 14C datum plus correlation of the productivity/environmental cycles with sub-interstadials of the highly resolved, absolutely dated EAM records (Table 2). In the upper part of core we prefer to use correlation with data of core 12KL because of very high sedimentation rate and since they were measured for planktonic foraminifera.

5. Discussion

With the new age controls our productivity proxies and magnetic results of core 41-2, and some of them for core 12KL (Max et al., 2012, 2014) reveal sequence of noticeable centennial-millennial scale events of increased productivity and decreased PM in the far NW Pacific off Kamchatka over the last 21 ka (Fig. 4). As was mentioned these events changes in-phase with sub-interstadials of δ18O calcite of Chinese stalagmites (CsI) associated with stronger summer EAM (Wang et al., 2008) and, to some extent, are linked to Greenland ice core sub-interstadials (GsI) (North Greenland Ice Core Project members, 2004) (Fig. 4). All the linkages suggest the centennial-millennial productivity changes in the far NW Pacific were likely associated with climatic shifts to warmer and/or higher nutrient conditions in surface water synchronously with CsI

of the summer EAM. Our high resolution records show clearly that three centennial-millennial warmer/higher productive (CsI/GsI) events had occurred during the LGM, three CsIs/GsIs during the HE 1, four CsIs/GsIs during the B/A warming, and three CsIs/GsIs during the EH (Fig. 4). Within the constructed age model of core 41-2, different productivity proxies and magnetic results were combined with similar data from core 12KL (Max et al., 2012, 2014). These data reveal a sequence of noticeable centennial-millennial scale productivity cycles in the far NW Pacific, which occurred in-phase with Chinese sub-interstadials (CsI) associated with a stronger summer EAM (Wang et al., 2008) over the period 21–8 ka (Fig. 4). These linkages suggest the centennial-millennial increased productivity events in the far NW Pacific were likely associated with shifts to a warmer climate and/or higher nutrient conditions in surface water synchronously with CsI of the summer EAM. High resolution records presented here show clearly that three centennial-millennial increased productivity/environment amelioration events correlated with CsI had occurred during the LGM, three CsIs during the HE 1, four CsIs during the B/A warming, and three CsIs during the EH (Fig. 4; Table 3). The Ppossible mechanisms responsible for the in-phase relationships or the synchronicity of the centennial-millennial scale events between the NW Pacific productivity and summer EAM are discussed and proposed and discussed below.

5.1. N-S hemispheres climatic linkages of centennial-millennial climate/environment changes over the LGM - HE 1- B/A warming

Identifying any linkages of centennial-millennial climate changes in the Northern Hemisphere between the NW Pacific, EAM, and N Atlantic/Greenland and the climate changes recorded in Antarctic ice core records from the Southern Hemisphere is important to us, to deepen our understanding of the mechanisms responsible for the timing and spatial propagation patterns that resulted from the abrupt variability in the global climate and environmental system. In order to test the linkages, we demonstrate here the correlation among the highly resolved U-Th dated δ18O

records of the composite Hulu and Dongge caves sediments (Dykoski et al., 2005; Wang et al., 2008), the ~20-year averaged resolution δ18O and Ca2+ content records of the GISP2 and NGRIP with 5 point running mean on the annual-layer counted GICC05 age scale (Rasmussen et al., 2014), and the δ18O record of the EPICA Dronning Maud Land (EDML) ice core from Antarctica (EPICA Community Members, 2006) on the methane synchronized timescale with the NGRIP core over the past 25 ka (Fig. 5). The Ca^{2+} content in the Greenland ice cores serves as a proxy for dust content governed by atmosphere circulation changes. It has been suggested that the nearly synchronous ice core δ18O and Ca2+ changes reflect the shifting of Greenland atmospheric dust loading and is closely linked to the atmospheric circulation and climate changes in the high-latitude of N hemisphere. Initially the persistent millennial scale changes shown in the Greenland ice core records were defined as interstadials (GI) and stadial (GS) (Johnsen et al., 1992), but have been refined by INTIMATE event stratigraphy studies which introduced the subdivision of the GI-1 into sub-interstadials GI-1a to GI-1e. Furthermore, the GS-2.1 was subdivided into sub-Stadial GS-2.1a (over the HE 1), GS-2.1b (LGM), and GS-2.1c (Björck et al., 1998; Rasmussen et al., 2014) (Fig. 5). It also has been noted that the some δ18O differences in coeval δ18O values between Summit and NGRIP ice cores over the LGM period, and abrupt millennial scale variations, were likely governed by changes in the N American Ice Sheet volume and N Atlantic sea-ice extent, that result in the changes of meridional gradients in the δ18O of Greenland ice (Seierstad et al., 2014).

On the basis of the high-resolution NGRIP core investigation (less one year) over 15-11 ka, Steffensen et al. (2008) have suggested that at the beginning of the GI, the initial northern shift of the Intertropical Convergence Zone (ITCZ), identified in a sharp decrease of dust within a 1-3 year interval, triggered an abrupt shift of Northern Hemisphere atmospheric circulation. The circulation pattern changes forced a more gradual change (over 50 years) of the Greenland air temperature associated with high latitude atmosphere circulation and westerly jets ways reorganization. Evidence from a loess grain size record in NW Chinese Loess Plateau (Sun et al., 2011), infer the linkage of

the changes in EAM strength and Greenland temperature over the past 60 ka, and suggests a common force driving both changes (Sun et al., 2011). Using a coupled climate model simulation, Sun et al. (2011) investigated the effect of a slow-down of AMOC on the monsoon system and found a stronger winter EAM that supplies more dust to the Loess Plateau with a reduction in summer monsoon precipitation over East Asia. This study indicates that AMOC is a driver of abrupt change in EAM, with the northern westerlies as the transmitting mechanism from the N Atlantic to the Asian monsoon regions. Other evidences of teleconnection between the EAM and N Atlantic on a millennial timescale come from the investigation of the Japan Sea sediments. Nagashima et al. (2011) infer that temporal changes in the provenance of eolian dust in Japan Sea sediments reflect changes in the westerly jet path over East Asia, happened in phase with Dansgaard-Oeschger cycles.

EPICA community members (2006) show that methane synchronization of the EDML and the NGRIP δ18O records reveal one-to-one alignment of each Antarctic warming with a corresponding stadial in Greenland ice cores, implying a mechanism of bipolar seesaw on these time scales. Changes in the heat and freshwater flux were connected to the AMOC and a stronger AMOC leads to increased transport of heat from the Southern Ocean heat reservoir. EAM studies (Wang et al., 2001) have suggested that between 11,000 and 30,000 yr BP the Chinese interstadials (CI) recorded in δ18O calcite of cave stalagmites had happened apparently synchronously with the GIs and therefore CIs were likely related to Antarctica cold events also. For example, smoothed warmer condition in the Antarctic at 23.6-24.2 ka was synchronous with abrupt climate cooling and increases in dust content in the Greenland ice cores NGRIP and GISP2, coeval to HE 2 of the N Atlantic and in-phase with summer EAM weakening (GS/CS-3.1) (Fig. 5). Subsequent Antarctica cooling since 23.4 ka was accompanied by Greenland warming with two sharp interstadials GI-2.2 and GI-2.1 with nomenclature of Rasmussen et al. (2014) and China interstadial CI2 coeval with summer EAM intensification – sub-interstadial CsI-2.9 (Fig. 5).

The uncertainties in the chronologies of the Greenland and Antarctica temperature and EAM

records is very small (<2 %) thus suggest their tight relationship during the last 25ka (Fig. 5). Cross correlation of the EAM intensity and Greenland climate variability calculated by correlation of δ18O values between the calcite of Chinese stalagmites responsible for EAM variability (Wang et al., 2008) and NGRIP and GISP 2 ice cores responsible for the Greenland climate (Rasmussen et al., 2014) by moving windows at 1000, 2000 and 3000 years show their significant synchronization (positive correlation) during period of 16.5-9.0 ka BP (Fig. 6). The cross correlation of the EAM and the Greenland NGRIP ice core during earlier (25-16.5 ka ago) and later (9-1 ka ago) periods demonstrates absence of significant correlation (within ranging at ±0.25), or occurrence of weak synchronization (positive correlation) (Fig. 6). The statistics imply that the seesaw mechanism between the EAM/NW Pacific and the Greenland/N Atlantic during 25-1 ka is not effective, however being in line with empiric results of the EAM and the Greenland teleconnection by shifting of the westerly jet path (Nagashima et al., 2011; Sun et al., 2011).

It also has been suggested that a monsoon intensity index including the EAM was controlled not only by Northern Hemisphere temperature ('pull' on the monsoon, which is more intense during boreal warm periods), but also by the pole-to-equator temperature gradient in the Southern Hemisphere ('push' on the monsoon which is more intense during cold periods) that leads to enhanced boreal summer monsoon intensity and its northward propagation (Rohling et al., 2009; Rossignol-Strick, 1985; Xue et al., 2004). Since the summer EAM transports heat and moisture from the West Pacific Warm Pool (WPWP) across the equator and to higher northern latitudes (Wang et al., 2001), the temperature gradient in the Southern Hemisphere "pushes" the summer EAM intensity by means of its influence on the latitudinal/longitudinal migrations or expansion/contraction of the WPWP. This also explains the different form of responses of EAM and Greenland interstadials and sub-interstadials, because the migration of the WPWP may have responded much more slowly than the atmosphere. All the above interpretations are consistent with observed here, that the variability in the δ18O record of Chinese EAM changes was more gradual

then in the δ18O of Greenland ice cores, and the amplitude changes of the EAM are more similar to the Antarctic air temperature changes (Fig. 5).

With the same subdivision as in Greenland records, the EAM sub-interstadials (CsI)/NW Pacific centennial-millennial productivity/environment cycles were put on the N-S hemispheres climate variability with three CsIs identified from the interval of 25-20 ka (Fig. 5). Moreover, we found three EAM/NW Pacific sub-interstadials within GS-2.1a (namely CsI 2.1, CsI 2.2 and CsI 2.3), four CsIs in GS-2.1b (CsI 2.4 to CsI 2.7), and two in GS-2.1c (CsI 2.8 and CsI 2.9) (Fig. 5). During B/A warming when Antarctic temperature was decreased, four EAM sub-interstadials (CsI 1a-CsI 1e) have varied in-phase with Greenland sub-interstadials (Björck et al., 1998).

Our results derived from two studied cores indicate tight in-phase linkages between the far NW Pacific centennial-millennial productivity/environment cycles and the summer EAM intensity sub-interstadials variability (Fig. 4) over GS-2.1-GI-1. These evidence leads us to suggest that the centennial-millennial changes in the NW Pacific and EAM have been forced by similar/or may be less pronounced mechanisms as for interstadials by the shifting of the ITCZ with reorganization of the N Hemisphere atmospheric circulation and the northern westerly jets. Though the responses of the EAM sub-interstadials are more smoothly compared with Greenland ones (Fig. 5), the most of them had occurred synchronicity with ones of the Greenland NGRIP ice core and out of phase with ones of the Antarctica record (Fig. 5). Thus we infer that revealed for studied cores centennial-millennial productivity/environment cycles over 20-8 ka ago are persistent peculiarities of the productivity/environment variability of the NW Pacific couples with EAM sub-interstadials changes which may be used as template in the regional high resolution paleoceanography and sediment stratigraphy. Four productivity/environment events in the far NW Pacific during the B/A warming had occurred in-phase with the EAM and Greenland temperature sub-interstadials (Figs. 4 and 5). Recent high-resolution investigations on Bering Sea sediment cores from the "Bering Green Belt" (Kuehn et al., 2014) have documented four well-dated laminated sediment layers during the

~~B/A warming-beginning of Holocene, with one from them for the Preboreal. The synchronicity of Bering Sea laminated sediment layers with the Greenland sub-interstadial during B/A warming provides one more piece of evidence supporting the close atmospheric teleconnection between the N Pacific, the EAM, and the N Atlantic.~~

The identification of any linkages between centennial-millennial climate changes in the Northern Hemisphere (NW Pacific, EAM, and N Atlantic/Greenland) and the climate changes recorded in Antarctic ice cores representative of the Southern Hemisphere is important for deepening understanding of the mechanisms responsible for the timing and spatial propagation patterns that resulted from abrupt variability in the global climate and environmental system. In order to test these linkages, the centennial-millennial productivity/climate events in the NW Pacific outlined by the productivity stack are correlated with a variety of other records. These are: the highly resolved U-Th dated δ^{18}O records of the composite Hulu and Dongge stalagmites (Dykoski et al., 2005; Wang et al., 2008); the ~20-year averaged resolution δ^{18}O and Ca^{2+} content records of the GISP2 and NGRIP, with a five-point running mean on the annual-layer counted GICC05 age scale (Rasmussen et al., 2014); the δ^{18}O record of the EPICA Dronning Maud Land (EDML) ice core from Antarctica (EPICA Community Members, 2006) on the methane synchronized timescale with the NGRIP core; and the Siberian climate calculated from pollen records of the Lake Baikal region (Bezrukova et al., 2011) over the past 25 ka (Fig. 5). The Ca^{2+} content in the Greenland ice cores serves as a proxy for dust mobilization on the land, and for transfer in the high latitudes of the N Hemisphere by an atmosphere governed by climate and atmospheric circulation changes (Sun et al., 2012). It has been suggested that the nearly synchronous ice core δ^{18}O, and Ca^{2+} millennial-scale changes reflect the shifting of the Greenland atmospheric dust loading, which is closely linked with the atmospheric circulation and climate changes in the high latitudes of the N Hemisphere, where the EAM plays an important role (Ruth et al., 2007). Initially, the persistent millennial-scale changes shown in the Greenland ice core records were defined as interstadials (GI) and stadials (GS)

(Johnsen et al., 1992), but have been refined by INTIMATE stratigraphy studies which introduced the subdivision of the GI-1 into sub-interstadials GI-1a to GI-1e. Furthermore, the GS-2.1 was subdivided into sub-stadials GS-2.1a (over the HE 1), GS-2.1b (LGM), and GS-2.1c (Björck et al., 1998; Rasmussen et al., 2014) (Fig. 5).

During the construction of the age model, a strong correlation was established between the centennial-millennial productivity/environment events in the NW Pacific cores, and the sub-interstadials of the summer EAM over the LGM-HE 1-B/A (Fig. 5), suggesting a strong, causal teleconnection. This suggests that, in addition to the six centennial-millennial productivity/environment cycles over the LGM-HE 1 established in the NW Pacific cores, another three abrupt events likely took place in the NW Pacific coeval with CsIs outlined by the $\delta^{18}O$ of Chinese stalagmites over the interval 25–20 ka (Fig. 5). Therefore, it was found that three EAM/NW Pacific sub-interstadials occurred within GS-2.1a (namely CsI-GS2.1-1, CsI-GS2.1-2, and CsI-GS2.1-3), four CsIs occurred within GS-2.1b (CsI-GS2.1-4 to CsI-GS2.1-7), and two occurred within GS-2.1c (CsI-GS2.1-8 and CsI-GS2.1-9) (Fig. 5).

It also has been noted that there are some $\delta^{18}O$ differences between coeval $\delta^{18}O$ values in the Summit and NGRIP ice cores over the LGM-HE 1 period, which were likely governed by changes in the N American Ice Sheet volume and N Atlantic sea-ice extent, resulting in changes of the meridional gradients in the $\delta^{18}O$ of Greenland ice (Seierstad et al., 2014). Such differences in the Summit/NGRIP $\delta^{18}O$ values may explain why the correlation of the EAM/NW Pacific sub-interstadials with the Greenland sub-interstadials recorded in the $\delta^{18}O$ and Ca^{2+} records of the GISP2 and NGRIP cores was more clear during LGM, and less pronounced over the HE 1 (GS-2.1a) (Fig. 5).

On the basis of the high-resolution NGRIP core investigation (less than one year) over 15–11 ka, Steffensen et al. (2008) have suggested that at the beginning of the GI, the initial northern shift

of the Intertropical Convergence Zone (ITCZ), identified from a sharp decrease of dust within a 1–3 year interval, triggered an abrupt shift in Northern Hemisphere atmospheric circulation. Such circulation pattern changes forced a more gradual change (over 50 years) of the Greenland air temperature, associated with the reorganization of high latitude atmospheric circulation and westerly jets. Evidence from a loess grain size record in the NW Chinese Loess Plateau (Sun et al., 2012), implies a link between the changes in EAM strength and the Greenland air temperatures over the past 60 ka, and suggests that a common force was driving both changes (Sun et al., 2012). Using a coupled climate model simulation Sun et al. (2011) investigated the effect of a slow-down of AMOC on the monsoon system, and found that a stronger winter EAM, accompanied with a reduction in summer monsoon precipitation over East Asia, supplies more dust to the Chinese Loess Plateau and likely also to the NW Pacific. This study indicates that the AMOC is a driver of abrupt change in the EAM system, with the northern westerlies as the transmitting mechanism from the N Atlantic to the Asian monsoon regions. Other evidence of teleconnections between the EAM and N Atlantic on a millennial timescale come from the investigation of sediment cores from the Sea of Japan. Nagashima et al. (2011) infer that temporal changes in the provenance of eolian dust in sediments from the Sea of Japan reflect changes in the westerly jet path over East Asia, which happened in-phase with the Dansgaard-Oeschger cycles.

EPICA community members (2006) show that methane synchronization of the EDML and the NGRIP $\delta^{18}O$ records reveal one-to-one alignment of each Antarctic warming with a corresponding stadial in the Greenland ice cores, implying a bipolar seesaw mechanism on these time scales. Changes in the heat and freshwater flux were connected to the AMOC, and a stronger AMOC leads to the increased transport of heat from the Southern Ocean heat reservoir. As a result of EAM investigations Wang et al. (2001) have suggested that between 11,000 and 30,000 yr BP the Chinese interstadials (CI) recorded in $\delta^{18}O$ calcite of cave stalagmites had happened apparently

synchronously with the GIs. Therefore, CIs were also likely related to Antarctic cold events. In confirmation, smoothed warmer conditions in the Antarctic at 23.6–24.3 ka were synchronous with abrupt climate cooling and increases in dust content in the Greenland ice cores NGRIP and GISP2, coeval to HE 2 of the N Atlantic, and in-phase with the weakening of the summer EAM (GS/CS-3.1) (Fig. 5). The Antarctic cooling since 23.4 ka was accompanied by warming in Greenland, with two sharp interstadials GI-2.2 and GI-2.1 (Rasmussen et al., 2014) and China interstadial CI-2 coeval with sub-interstadial CsI-GS2.1-9 associated with summer EAM intensification (Fig. 5). Over the LGM period, most of the sub-interstadials in the NW Pacific/summer EAM had occurred during abrupt Antarctic temperature decreases, while during HE 1 sub-interstadial linkages between the N and S hemispheres are less evident (Fig. 5).

It has also been suggested that a monsoon intensity index including the EAM was controlled not only by Northern Hemisphere temperature ("pull" on the monsoon, which is more intense during boreal warm periods), but also by the pole-to-equator temperature gradient in the Southern Hemisphere ("push" on the monsoon, which is more intense during the boreal cold periods) that leads to enhanced boreal summer monsoon intensity and its northward propagation (Rohling et al., 2009; Rossignol-Strick, 1985; Xue et al., 2004). Since the summer EAM transports heat and moisture from the West Pacific Warm Pool (WPWP) across the equator and to higher northern latitudes (Wang et al., 2001), the temperature gradient in the Southern Hemisphere "pushes" the summer EAM intensity by means of its influence on the latitudinal/longitudinal migrations or expansion/contraction of the WPWP. This also explains the difference in responses of the EAM and Greenland interstadials and sub-interstadials, because the migration of the WPWP may have occurred more slowly than the atmospheric changes. The changes in the $\delta^{18}O$ of Chinese cave stalagmites were more gradual then in the $\delta^{18}O$ of Greenland ice cores, and were more similar to the Antarctic air temperature changes (Fig. 5).

During B/A warming when Antarctic temperatures decreased, four EAM sub-interstadials (CsI-GI1-a to CsI-GI1-e), coeval with established NW Pacific centennial-millennial productivity/environment cycles, also varied in-phase with Greenland sub-interstadials (Björck et al., 1998) (Fig. 5). Recent high resolution investigations of Bering Sea sediment cores from the "Bering Green Belt" (Kuehn et al., 2014) have documented four well-dated laminated sediment layers during the B/A warming-beginning of the Holocene, with three of them within the B/A. The synchronicity of the Bering Sea laminated sediment layers with the Greenland sub-interstadial during B/A warming provides one more piece of evidence supporting the close atmospheric teleconnection between the N Pacific, EAM, and N Atlantic.

The strongly in-phase linkages between the NW Pacific centennial-millennial productivity/environment cycles, and the sub-interstadials of summer EAM intensity over GS-2.1–GI-1 (Figs. 4 and 5) suggest that these abrupt changes in the NW Pacific and EAM have been forced by similar, or less pronounced, mechanisms to interstadials, such as the shifting of the ITCZ with the reorganization of atmospheric circulation and the northern westerly jets. In-phase teleconnection of the NWP/EAM sub-interstadials with those in Greenland was also observed during LGM-B/A warming. This was weaker during HE 1, which is probably related to differences in δ^{18} O between the GISP 2 and NRGIP.

5.2 NW Pacific productivity trends over the LGM- HE 1

5.2 The EH

During the EH the records presented here show a series of abrupt increasing/decreasing productivity events in the NW Pacific, correlated with sub-interstadials (CsI-EH-1, CsI-EH-2, CsI-EH-3)/sub-stadials (CsS-EH-1, CsS-EH-2, CsS-EH-3, CsS-EH-4, CsS-EH-5) of the δ^{18}O

records of the Dongge and Hulu caves (Dykoski et al., 2005; Wang et al., 2008) and Greenland ice cores (North Greenland Ice Core Project members, 2004) (Figs. 4 and 5; Table 3). A visual comparison with the EAM and Greenland ice core records show synchronicity (positive correlation) of the increased productivity centennial events in the NW Pacific with the abrupt warmer climate cycles in Greenland and the summer EAM intensity events, and vice versa over the EH as well (Figs. 4 and 5). The dated pollen reconstructed the vegetation/climate variability of south Siberia (Lake Baikal region) (Bezrukova et al., 2011) demonstrated nearly the same type of centennial-millennial climate variability—confirming their common patterns of change in the N Hemisphere (N Atlantic, NW Pacific, EAM) over the EH (Fig. 5). Well-dated, high resolution lithological and geochemical results from the Yanchi playa (NE China) also clearly show a separation of three sharp cooling events at 8.2 ka, 9.9–10.1 ka, and 11.0–11.2 ka, synchronous with the cooling shown in the Greenland ice core records (Yu et al., 2006). Yu et al. (2006) explain this correlation through linkages of the tropical Pacific and the N Atlantic. Moreover, high resolution geochemical and lithological analyses of the Arolik Lake sediments (southwestern Alaska) provide evidence that centennial-scale climate shifts during the Holocene were similar in the sub-polar regions of the N Atlantic and N Pacific (Hu et al., 2003).

These regional climate shifts also occurred concurrently with the periodicities of solar activity and the production of the cosmogenic nuclides ^{14}C and [10]Be. The production rates of these cosmogenic nuclides are negatively correlated with total solar irradiance due to the strength of magnetic fields embedded into the solar wind. Small variations in solar irradiance could be responsible for pronounced changes in northern high-latitude climate and environments (Hu et al., 2003). The variability of sub-polar N Atlantic ice drifting, recorded in the percentage of hematite-stained grains in the sediment core (Bond et al., 2001), though having lower time resolution and dating precision compared with production of the cosmogenic nuclides, is consistent

with other centennial climate changes in the N Hemisphere during EH within a timing precision of 200 years.

Quasi-synchronicity of the changes in the centennial-millennial productivity and magnetic proxies obtained in the two studied cores, with the sub-interstadials in $\delta^{18}O$ records of Chinese cave speleothem, the Greenland ice cores, and with the nuclide ^{14}C production during the EH (Figs. 4, 5), imply that the variability of the NW Pacific climate and environmental conditions has been strongly related to the EAM and N Atlantic/Greenland climate changes through atmospheric coupling mechanisms over the studied period of 20–8 ka. In summary, the NW Pacific results presented here indicate a tight linkage and coherent, persistent pattern of centennial-millennial scale climate changes in the N Hemisphere over the LGM-EH, which may serve as a template in high resolution paleoceanography and sediment stratigraphy of the moderate-high latitudes of the N Pacific.

Since whether N Atlantic-N Pacific climate and hydrological linkages are in-phase or out-of-phase teleconnections is still debated, empirical data obtained from sediment cores off Kamchatka allow the provision of an additional test for clarifying this problem at a high resolution. Previously, it was stated that the N Pacific centennial-millennial productivity/climate changes are strongly associated with the EAM system variability, which may serve as key records for the N Pacific due to being the most reliable chronology of the East Asia-N Pacific region. $\delta^{18}O$ records of the GISP2 and NGRIP on the GICC05 age scale (Rasmussen et al., 2014) may serve as key records for the N Atlantic. The uncertainty in the chronologies of the Greenland and EAM records is very small (<2%) thus suggesting statistical estimation of their correlation during the last 25 ka.

Cross correlation (CC) between $\delta^{18}O$ values of Chinese stalagmites (Wang et al., 2008)—responsible for EAM/N Pacific variability—and NGRIP and GISP2 ice cores (Rasmussen et al., 2014)—responsible for the Greenland/N Atlantic changes—using moving windows at 1000, 2000, and 3000 years shows their more significant synchronization (from -0.6 to -0.9) during the

period 16.5–8.5 ka (Fig. 6). During earlier (25–16.5 ka) and later (8.5–1 ka) periods there are differences in CC between the EAM-NGRIP and the EAM-GISP2. However, both CC during these periods show the occurrence of weak synchronization and/or the absence of significant correlation (within a range of ±0.25) (Fig. 6). Significant synchronization was also indicated by CC between EAM-NGRIP during the Middle–Late Holocene. More discrepancies in both CCs were observed over 19.5–16.5 ka, which may be explained by errors in age measurements and/or by differences in atmospheric teleconnection between the EAM and the GISP2/NGRIP cores due to their different locations in Greenland. The statistics imply that the seesaw mechanism between the EAM/NW Pacific and the Greenland/N Atlantic during 25–1 ka is not effective. However, they are in line with empirical data of the EAM/N Pacific and the Greenland/N Atlantic teleconnection by shifting of the westerly jet path (Nagashima et al., 2011; Sun et al., 2012).

Beside of the centennial–millennial productivity/environmental cycles, we find common NW Pacific productivity trends over the LGM and Heinrich E 1 with some differences in other types of productivity proxies. According to the sharp increase of Antarctica temperature, dust content in the Greenland ice cores and significant decrease in the summer EAM we put boundary of LGM/HE 1 on nearly the 17.8 ka ago (Fig. 5). This age is a little earlier to that being placed at ~17.5 ka which is a timing for the beginning of catastrophic iceberg discharges in the HE 1, but nearly coincides with the abrupt increase of the 231Pa/230Th ratio in the N Atlantic core OCE326-GGC5, which marks the beginning of the collapse of AMOC (McManus et al., 2004).

During the LGM most productivity proxies demonstrate minimum primary production in the far NW Pacific without definite trends although the Si-bio of core 41-2 and color b* of core 12KL show even small negative trend versus time (Fig. 4). Severe environmental condition in the central Asia inferred from vegetation reconstruction (Bezrukova et al., 2011) (Fig. 5) promote to increase in cold season sea ice covering and high IRD accumulation in studied region (Fig. 4) that hamper

productivity. It is consistent with early established minimum of productivity in the NW Pacific due to strong stratification prevented nutrients supply for supporting productivity in surface waters (Gebhardt et al., 2008).

Since 17.8 up to 15.5 ka, the core 41-2 productivity proxies such as Ba-bio, Br-bio, TOC and chlorin, associated with production of calcareous phytoplankton (mostly coccolithophores), show significant increased trends simultaneous to gradual Antarctic warming accompanied by strongly diminished of AMOC (McManus et al., 2004). The patterns are consistent with the see-saw N-S hemispheres mechanism (Broecker, 1998). The diminished AMOC resulted in a major cooling of the N Atlantic surface water and, most likely, reduced water evaporation in the N Atlantic and therefore Atlantic-Pacific moisture transport. This condition facilitates a reduction of precipitation and hence an overall increase of surface water salinity and decrease of surface stratification in the N Pacific. Moreover, this condition promotes an intensification of the intermediate water ventilation in the N Pacific and also nutrient supply into euphotic layer. The observed trends of our productivity proxies are in concord with strong intensification of the intermediate depth water ventilation in the N Pacific during HE 1 (Max et al., 2014) based on the δ13C foraminifera data from the intermediate water and radiocarbon-derived ventilation ages. However, rather constant CaCO3 values in both cores (water depth 1924-2145 m) during LGM-HE 1 do not indicate the changes of the water ventilation at these depths in the N Pacific over that time span because carbonate concentration in the sediment strongly defined by the ventilation (Yu et al., 2014). While the productivity proxies Si-bio and color b*, associated with siliceous phytoplankton production (mostly diatoms), do not show significant trends since HE 1 to ~15.5 ka. The strong sea ice effect indicated by our CF and MS records (Figs. 2; 4) was more significant in our studied area and likely overwhelm the productions of diatom algae for coccolithophores due to a large spring-early summer surface water stratification during seasonal sea ice melting.

A sharp increase of NW Pacific primary production since ~15.5 ka was indicated by most

our productivity proxies which culminated by strong productivity peak of sub-interstadial GI-1e at beginning of the B/A warming (Fig. 4). Synchronous decrease of sea ice influence in the studied region since ~15.5 ka marked by dropping in the CF and MS was favor for decrease of surface stratification the rise of diatom production as indicated by the sharp increases of Si-bio and color b* (Figs. 4 and 2). The timing of decrease in the sea ice cover since ~15.5 ka is consistent with the surface ocean warming (Max et al., 2012) and also consistent with the central Asia vegetation/environment amelioration inferred by Bezrukova et al. (2011) by pollen reconstructions (Fig. 5). Such pattern of the productivity changes in the N Pacific and the Bering Sea during glacial/interglacial transition was observed in other cores (Caissie et al., 2010; Galbraith et al., 2007; Gebhardt et al., 2008; Keigwin, 1998) and was, likely, a persistent feature for the N Pacific and its realm forced by resumption of the AMOC at the B/A beginning coeval with the cooling in the Antarctica (Fig. 5). In the Okhotsk Sea, being strongly intruded in the NE Asia continent, the beginning of the diatom production and accumulation of the diatomaceous sediments had occurred only since the Middle Holocene (5-6 ka BP) due to the later diminish of sea-ice cover and later breakdown of spring/early summer surface water stratification compared with ones of the far NW Pacific (Gorbarenko et al., 2014).

5.3 The EH

5.3 NW Pacific productivity trends over the LGM-HE 1

Besides the centennial-millennial productivity/environmental cycles, common NW Pacific productivity trends are found over the LGM and HE 1 with some differences in other types of productivity proxies. According to the sharp increase in Antarctic temperature, dust content in the Greenland ice cores, and significant decrease in the summer EAM, a boundary of LGM/HE 1 was defined at around 17.8 ka (Fig. 5). This is a little earlier than ~17.5 ka, which marks the beginning of catastrophic iceberg discharges in the HE 1, but nearly coincides with the abrupt increase of the

^{231}Pa/^{230}Th ratio in the N Atlantic core OCE326-GGC5, which marks the beginning of the collapse of AMOC (McManus et al., 2004).

During the LGM, most of the productivity proxies demonstrate minimum primary production in the far NW Pacific without definite trends, although the color b* of core 12KL shows a small negative trend (Fig. 4). Severe environmental conditions in central Asia, inferred from vegetation reconstruction (Bezrukova et al., 2011) (Fig. 5), promoted an increase in winter sea ice covering consistent with high IRD accumulation in the studied region, inferred from CF and MS records (Fig. 4), that hamper productivity. It is in concord with the established minimum of productivity in the NW Pacific due to strong stratification preventing the supply of nutrients required to support productivity in surface waters (Gebhardt et al., 2008).

From 17.8 to 15.3 ka, some productivity proxies of core 41-2—namely TOC and chlorin associated with the production of calcareous phytoplankton (mostly coccolithophores)—show significantly increased trends simultaneously to gradual Antarctic warming, accompanied by a strongly diminishing AMOC (McManus et al., 2004). The diminished AMOC resulted in a major cooling of the N Atlantic surface water and, most likely, reduced water evaporation in the N Atlantic and therefore Atlantic-Pacific moisture transport. This condition facilitates a reduction of precipitation and hence an overall increase of surface water salinity, and decrease of surface stratification in the N Pacific. This condition promotes an intensification of the intermediate water ventilation in the N Pacific, and therefore the nutrient supply into the euphotic layer. The observed trends of productivity proxies are in concord with strong intensification of the intermediate-depth water ventilation in the N Pacific during HE 1 (Max et al., 2014), based on the δ^{13}C foraminifera data from the intermediate water and radiocarbon-derived ventilation ages. However, fairly constant CaCO$_3$ values in both cores (water depth 1924–2145 m) during LGM-HE 1 do not indicate that the water ventilation penetrated to deep water in the N Pacific over that time span, because carbonate concentration in the sediment is strongly defined by the ventilation of bathed water (Yu et al., 2014).

While the productivity proxies Si-bio and color b*, associated with siliceous phytoplankton production (mostly diatoms), do not show significant trends during HE 1 up to ~15.3 ka, the strong sea ice effect with high IRD input up to 15.3 ka, shown by CF and MS records, (Figs. 2 and 4) was significant in the studied area and probably overwhelmed the production of diatom algae for coccolithophores, due to a large spring–early summer surface water stratification during seasonal sea ice melting.

A sharp increase in NW Pacific primary production, and a rise in diatom production since ~15.3 ka, indicated by most productivity proxies and Si-bio and color b* records with a culmination at sub-interstadial GI1-e of B/A warming, was likely induced by a decrease in sea ice influence and its spring melting, favoring a weakening of surface stratification (Figs. 4 and 2). The timing of the decrease in the sea ice cover since ~15.3 ka is consistent with the surface water warming (Max et al., 2012), and with the central Asian vegetation/environment amelioration inferred by Bezrukova et al. (2011) from pollen reconstructions (Fig. 5). Such a pattern of productivity changes in the N Pacific and the Bering Sea during glacial/interglacial transitions has been observed in other cores (Caissie et al., 2010; Galbraith et al., 2007; Gebhardt et al., 2008; Keigwin, 1998) and was likely a persistent feature for the N Pacific and its realm, forced by the resumption of the AMOC at the B/A warming coeval with the cooling in Antarctica (Fig. 5). In the Okhotsk Sea, the beginning of the diatom production and accumulation of the diatomaceous sediments had begun only in the Middle Holocene (5–6 kyr BP) due to the later reduction of sea-ice cover, and later breakdown of spring/early summer surface water stratification (Gorbarenko et al., 2014).

During EH our records demonstrate a series of abrupt cold Chinese sub-stadials (CsS) and warm CsIs that are well-correlated with variability shown in Dongge and Hulu caves δ18O records (Dykoski et al., 2005; Wang et al., 2008), and δ18O records of Greenland ice cores: CsS1 (~8.2ka), CsS2 (~9.2ka), CsI1, CsS3 (~10.2ka), CsI2, CsS4 (~10.9ka), CsS4' (~11.1ka), and CsI3 (Fig. 4). These sub-stadials and sub-interstadial were also put on the N-S hemisphere climate variability

patterns (Fig. 5). Visual comparison with the EAM and Greenland ice cores records show synchronicity (positive correlation) of the warmer climate/increased productivity events in the NW Pacific with the Greenland abrupt warmer climate cycles and summer EAM intensity events and vice versa over the EH as well (Figs. 4 and 5). Pollen reconstructed dated variability of the climate/environment conditions of the southeastern Siberia (Lake Kotokel, Lake Baikal region) (Bezrukova et al., 2011) demonstrated nearly the same type of the centennial-millennial climate variability patterns that shows positive climate linkages with climate in the North Hemisphere (N Atlantic, NW Pacific, EAM) over the EH (Fig. 5). Well-dated high resolution lithological and geochemical results from the Yanchi playa (NE China) clearly show a separation of three sharp cooling events at 8.2 ka, 9.9-10.1ka, and 11.0-11.2 ka, synchronous with the cooling shown in the Greenland ice core records (Yu et al., 2006). Yu et al. (2006) explain that correlation by linkages of the tropical Pacific and the N Atlantic. Moreover, high resolution geochemical and lithological analyses of the Arolik Lake sediments (southwestern Alaska) provide evidence that centennial-scale climate shifts during the Holocene were similar between the subpolar regions of the N Atlantic and N Pacific (Hu et al., 2003).

These regional climate shifts had occurred coherent with the periodicities of solar activity and production of the cosmogenic nuclides 14C and 10Be. The production rates of these cosmogenic nuclides are negatively correlated with total solar irradiance through the strength of magnetic fields embedded into solar winds speed. Small variations in solar irradiance could be responsible for pronounced changes in northern high-latitude environments (Hu et al., 2003). Our records of the centennial-millennial warmer climate/ increased productivity cycles in the far NW Pacific are simultaneous with the sharp variability in the EAM and the Greenland temperature over the EH and in phase, within the uncertainty of our age controls, with the decreased production of nuclide 14C and therefore with increased solar input and vice versa (Fig. 5). Nearly synchronicity in the changes of the centennial-millennial productivity and magnetic proxies obtained in the two studied cores

6. Conclusion

This study presents high resolution records of a suite of productivity proxies (TOC, CaCO3, chlorin, color b*, Ba-bio, Br-bio, Si-bio), ~~and content of~~ sediment lithological (CF), and magnetic properties (MS, PM and RPI) from ~~a~~ sediment core 41-2, taken from the NW Pacific (East Kamchatka slope). ~~Our r~~Results presented here reveal ~~indicate~~ a sequence of 13 centennial-millennial scale regional productivity increase~~d~~ /environment amelioration events over the LGM-EH (20–8 ka) in the far NW Pacific.

The age model of core 41-2 was constructed by using available AMS 14C dating, with more age control points identified by correlating the centennial-millennial productivity events ~~of the productivity proxies~~, RPI and PM of ~~our~~ the core with those of the well-dated nearby core 12KL (Max et al., 2012, 2014). Thus, all available AMS ^{14}C dating of core 12KL ~~(with one exception for an age dating of 16.53 ka at depth 695 cm)~~ ~~were transferred~~ was projected successfully to core 41-2. Based on putting all radiocarbon data of both cores on the δ^{18}O record of the Chinese cave stalagmites (Wang et al., 2008), the close time correlation of NW Pacific productivity events with sub-interstadials in the summer EAM over the period 20–8 ka was inferred and used for further fine age model construction. Three NW Pacific abrupt productivity increase events are strongly linked to

CsIs during the LGM (20–17.8 ka); three during HE 1 (17.8–14.7 ka), four during B/A warming, and three over the EH.

~~Derived radiocarbon framework of both cores allow us to infer also close correlation of the productivity /environmental cycles identified in these cores with sub-interstadial of absolute U-Th dating δ18O of calcite recorded in the China caves stalagmites over the 20-8 ka BP (Dykoski et al., 2005; Wang et al., 2008), which were used for further fine age model construction. Therefore our records from studied cores show synchronicity of NW Pacific centennial-millennial higher productivity/environment amelioration events with EAM sub-interstadials during 20-8 ka. Three NW Pacific abrupt productivity increase events are tightly linked to CsIs during the LGM (20-17.8 ka), three during HE 1 (17.8-14.7 ka), and four during B/A warming and three over the EH.~~

~~Our new~~ The reconstruction in this paper suggests that the NW Pacific centennial-millennial productivity increase ~~/~~ and the summer EAM ~~intensified~~ intensification events are positively correlated with Greenland abrupt warmings, indicating a ~~tight~~ strong atmospheric teleconnection between the N Pacific and the N Atlantic, most likely by ITCZ shifting and reorganization of the northern westerlies. ~~and~~This echoes the ~~similar~~ mechanism proposed in previous studies for the N hemisphere interstadials and stadials (Caissie et al., 2010; Kienast and McKay, 2001; Max et al., 2012; Riethdorf et al., 2013). Especially highlighted here is that our comparison of the NW Pacific centennial-millennial productivity events/EAM sub-interstadial with ~~to~~ $\delta^{18}O$ records of the EDML ice core ~~and of the Chinese stalagmites on the centennial-millennial time scale~~ over glaciation~~l~~ and deglaciation suggests a Southern Hemisphere "push" effect on the boreal summer EAM propagation.

~~The involvement of Southern Hemisphere "push" effects offers better interpretation on what have been responsible for the differences in the observed rate of changes of the EAM and Greenland interstadials and sub-interstadials and a much slower reorganization of the WPWP location or expansion/contraction with their impacts on atmosphere circulation are possibly attributed to the~~

~~differences too.~~

During the LGM ~~our~~ the results indicate productivity minima that are consistent with previous observations in the NW Pacific~~,~~ and severe vegetation/climate condition in the central Asia (Bezrukova et al., 2011)~~. and t~~Therefore, strong regional sea ice covering ~~are~~ is consistent with the hypothesis that ~~proposes~~ a strong stratification prevented ~~nutrients~~ the supply of nutrients required for supporting productivity in surface waters (Gebhardt et al., 2008). The productivity proxies associated with calcareous phytoplankton productions show ~~significant~~ increased trends ~~since~~ from 17.8 to 15.5 ka. These trends share the same structure ~~and the~~ rate of changes ~~of~~ with the gradual Antarctic warming accompanied by significantly diminished AMOC (McManus et al., 2004). The cooling of the N Atlantic surface water reduced water evaporation in the N Atlantic, as well as ~~and~~ Atlantic–Pacific moisture transport.~~, which~~This, in turn, facilitates the increased surface water salinity and decreases surface stratification in the N Pacific. The weakening stratification further intensifies the intermediate water ventilation in the N Pacific and ~~nutrients~~ the supply of nutrients into the euphotic layer. It is ~~E~~especially not~~iced is~~ed that a sharp increase of NW Pacific primary production since ~~nearly~~ around 15.~~5~~3 ka was indicated by nearly all productivity proxies, accompanied by some climate warming and decrease in sea ice cover~~ing~~. Subsequent~~ly,~~ a strong productivity spike of sub-interstadial GI-1e at beginning of the B/A warming is associated with a resumption of the AMOC and the further decrease of sea ice influence, accompanied by rise in~~of~~ diatom production.

The synchronicity in changes of the NW Pacific centennial-millennial productivity events with the sub-interstadials in δ18O of Chinese stalagmites calcite, Greenland ice cores and with the nuclide 14C production during the EH (Figs. 4~~;~~ and 5) imply that variability of the NW Pacific climate is ~~tightly~~ strongly linked to summer EAM and N Atlantic/Greenland climate changes. The linkage is likely driven effectively by atmospheric coupling mechanisms forced by variations in solar irradiance ~~variability~~. Regardless what specific driving mechanisms are responsible for the

linkage teleconnection, strong causal linkages of the centennial-millennial productivity/climate and sub-stadial/interstadial productivity variability in the NW Pacific with sub-interstadials of summer and the linkage to EAM from the LGM to EH reported here is a persistent feature of the high resolution far NW Pacific paleoceanography and sediment stratigraphy, and is almost synchronous with the Greenland/N Atlantic short-term changes.

Acknowledgements

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Table 1. AMS ^{14}C data on monospecies planktonic foraminifera *N. pachyderma* sin. and benthic foraminifera *Epistominella pacifica* and *Uvigerina parvocastata* of core 41-2. All measured ^{14}C age data were corrected by NW Pacific surface water reservoir ages of 900 years (Max et al., 2012). In case of using benthic foraminifera for dating we accept difference in coeval benthic-planktic foraminifera ages equals to 1400 years for depth water 19001940 m, based on the unpublished datum and total regional results of Max et al. (2014). All radiocarbon ages were converted into calibrated 1-sigma calendar age using the calibration program CALIB REV 7.0.1 (Stuiver and Reimer, 1993) with the Marine13 calibration curve (Reimer et al., 2013).

#	Lab. code	core depth cm	foraminifera species	14C-age year	Err.1 sigma year	calendar age, years	calendar age, ka
1	YAUT-021713	120	*E. pacifica*	10078	47	9121	9.121
2	YAUT-021714	127.5	*E. pacifica*	10340	42	9445	9.445

3	UCIAMS-148095	298	*N. pachyd.*	13160	50	~~14393~~	14.393
4	UCIAMS-148096	156	*Uv. parvoc.*	11135	45	~~10600~~	10.60
5	UCIAMS-148098	306	*Uv. parvoc.*	14185	35	~~16,016~~	14.616

Table 2. Centennial-millennial productivity increase/environment amelioration events over 25-8 ka ago plus abrupt productivity drop/cooling Events during Early Holocene in the NW Pacific core 41-2 which had occurred in-phase with Chinese sub interstadials (CsI) of the summer EAM intensification and Chinese sub stadials (CsS) of winter EAM activation.

Events	Core interval, cm	Averaged cal. age, ka
CsS-EH-1	106-110	8.2
CsS-EH-2	117-123	9.2
CsI-EH-1	125-132	9.8
CsS-EH-3	138-143	10.2
CsI-EH-2	148-153	10.7
CsS-EH-4	155-159	10.95
CsS-EH-4'	162-167	11.15
CsI-EH-3	168-181	11.4
CsI-GI1-a	233-243	13.05
CsI-GI1-c1	248-262	13.5
CsI-GI1-c3	268-278	13.8
CsI-GI1-e	291-312	14.45
CsI-GS2.1-1	335-340	15.45
CsI-GS2.1-2	355-362	16.55
CsI-GS2.1-3	375-383	17.56
CsI-GS2.1-4	388-395	18.1
CsI-GS2.1-5	400-410	18.85
CsI-GS2.1-6	431-447	19.8

Table 3~~2~~.The key time points of core 41-2 based on the available AMS ^{14}C data of core

41-2, ~~depths correlated with~~ projection of AMS ^{14}C data of core 12KL on the core 41-2 depth according to correlation of related increased productivity events and RPI records plus ~~depth~~ correlation of the productivity ~~cycles~~ events with related sub-interstadials of the highly resolved, absolutely dated E Asia monsoon ~~related CsIs~~ (Wang et al., 2008) beyond the projected ^{14}C data. AMS ^{14}C datum of core 12KL and age at depth of 706 cm was accepted according to the Tiedemann/Max age model 2 (Max et al., 2012, 2014).

Depth	AMS 14C core 41-2	~~AMS 14C data (ka)/~~ Key time points of core 12KL	correlation with ages of China subInterstadial ~~correlation with~~	Accepted key time points ~~calendar age~~
cm	~~(cal. kyr BP)~~ Cal. age, ka	~~depth of core 12KL. cm~~ ka/ depth (cm)	Age, ka/CsI ~~ages of China sub-Interstadial~~	Cal. age, ka
120	9.12			9.12
127.5	9.45			
126		9.51/210		9.51
156	10.6			
159		11.08/295		11.08
167		11.31/340		11.31
239			13.0/CsI-GI1-a	13.0
251		13.42~~38~~/508		13.42~~38~~
273		13.79/550		13.79
298	14.39			
303		14.42/611		14.42
306	14.61			

337		15.42/CsI-GS2.1-1	15.42
~~347~~ 348	15.9(15.55)/695		16.16
	16.16/706		
357		16.51/CsI-GS2.1-2	16.51
~~382~~ 379		17.56/CsI-GS2.1-3	17.56
393		18.12/CsI-GS2.1-4	18.12
402	18.6/821		18.6
~~405~~		~~18.8~~	~~18.8~~
431	19.54/876		
~~438~~		~~19.8~~	~~19.8~~

Figures

Fig. 1. Bathymetry, surface water currents and location of the cores 41-2 (star) and 12KL (cross) (Max et al., 2012) in the North Pacific. Surface currents as in ~~(~~Favorite et al., (1976) with modifications. EKC – East Kamchatka Current, WKC – West Kamchatka Current.

Fig. 2. Records (from bottom to top) of the ~~weight percentages of the CF,~~ share of volcanic grains in the sediment fraction ~~more~~ ≥150 μm, weight percentages of the CF, magnetic susceptibility (MS), paramagnetic magnetization (PM), color b*; TOC, Chlorin, $CaCO_3$, Ba-bio, Si-bio (opal) and Br-bio content versus core 41-2 depth. Preliminary boundaries of B/A warming, YD cooling and Holocene are shown according to total reguliarities of productivity variability in the NW Pacific, the Sea of Okhotsk and Bering Sea (Galbraith et al., 2007; Gorbarenko, 1996; Gorbarenko and

Goldberg, 2005; Keigwin, 1998; Seki et al., 2004) and AMS ^{14}C data (calendar ka) shown at the base. Yellow (blue) bars depict the centennial-millenial increased productivity/environmental ~~ameloiration~~amelioration (cooling) events according to most productivity proxies and decreases in PM. ~~Blue bars depict the centennial-millennial decreased productivity/environmental cooling events during EH.~~

Fig. 3. Correlation of the increased productivity event cycles in the cores 41-2 (low panel) ~~and~~with those in 12KL (middle panel) versus depth with sub-interstadials of the $\delta^{18}O$ calcite of Chinese stalagmites (~~Dykoski et al., 2005;~~Wang et al., 2008) (upper panel) ~~and key time points of core 41-2 shown by red lines~~. Productivity cycles for cores 41-2 are based on the stack ~~suite~~ of productivity proxies and PM records (Fig. 2) and 12KL (Ca, chlorin, ~~and~~ color b* and PM records) were correlated according to sychronous~~ly~~ changes in productivity proxies, paramagnetic magnetization, magnetic relative paleomagnetic intensity (RPI) and ^{14}C AMS data of ~~the~~ both cores. AMS ^{14}C data of core 41-2 is shown at the base. According to the correlation of the productivity cycles and curves of RPI, the red lines are related to key time points ~~with 14C AMS data~~ of core 12KL (middle panel) and the green lines with the relative Chinese sub-interstadials of the $\delta^{18}O$ calcite of Chinese stalagmites (Wang et al., 2008) (upper panel) were projected into corresponded depths of core 41-2 (bottom panel). Yellow (blue) bars depict the centennial-millenial increased productivity/environmental ameloiration (cooling) events according to most productivity proxies and decreases in PM. ~~Color b* and Ca content, AMS 14C data of core 12KL and its depth-age correlation with the Greenland NGRIP ice core were introduced from site http://dx.doi.org/10.1594/PANGAEA.830222. Blue lines correlate the productivity cycles of cores 41-2 and 12KL with relative Chinese sub-interstadials of the δ18O calcite of Chinese stalagmites (Dykoski et al., 2005; Wang et al., 2008) during LGM- EH in consistence with their age models.~~

Fig. 4. High resolution variability of the productivity and lithologic proxies in the NW Pacific (off Kamchatka) over the 21-8 ka ~~ago~~ period. CF percentages, MS, paramagnetic magnetization and color b*, chlorin , $CaCO_3$, TOC~~, Br-bio, Ba-bio and Si-bio (analog of biogenic opal)~~ content determined in cores 41-2 (blue lines) and 12KL (red lines) are shown from bottom to top. The NW Pacific centennial-millennial productivity cycles characterized by an increase in most productivity proxies are clearly associated with the abrupt summer EAM intensification revealed in the Chinese cave stalagmites, ~~called~~ defined as sub-~~I~~-interstadial, and less pronounced with short-~~-~~term events in the Greenland ice cores $\delta^{18}O$ records. Linear ~~lines~~ trends are show~~n~~ ~~trends of the siliceous and carbonaceous related~~ for the productivity indices over LGM and HE 1. Yellow (blue) bars depict the centennial-millenial increased productivity/environmental ameloiration (cooling) events according to most productivity proxies and decreases in PM.

Fig. 5. Compilation on N-S hemisphere milestone climate records, solar activity, NW Pacific productivity cycles and Southern Siberia environment during the last 25 ka. From bottom to top: absolutely dated $\delta^{18}O$ calcite of Chinese cave stalagmites (Dykoski et al., 2005; Wang et al., 2008) characterized EAM activity; the residual atmospheric $\Delta^{14}C$ record of around 2000-year moving average (Reimer et al., 2004) indicated solar irradiance variability; oxygen isotope EDML records after methane synchronization with the North Greenland ice core (EPICA Community Members, 2006); the petrologic tracer of drift ice in the N Atlantic (Bond et al., 2001); the $\delta^{18}O$ and Ca^{2+} records in the Greenland NGRIP and GISP 2 ice core indicated air temperature and dust variability on GICC05 age scale (Rasmussen et al., 2014), ~~and~~ pollen reconstructed Southern Siberia environment changes (Lake Kotokel, Lake Baikal region) (Bezrukova et al., 2011); and productivity stack for core 41-2. ~~The vertical yellow bands trace the centennial-millennial NW Pacific productivity cycles with increased productivity, blue bars GS/CS-3.1 (HE 2) and Early Holocene short term coolings.~~ Yellow (blue) bars depict the centennial-millenial increased

productivity/environmental ameloiration (cooling) events. NW Pacific centennial-millennial productivity cycles are accompanied by interstadial and sub-interstadial intensification of the summer EAM over 25-8 ka, ago and increase of solar irradiance during B/A and EH short term warmings. Their correlation with short term increased Greenland temperature (NGRIP ice core) and a decreased Antarctic temperature are less pronounced but seem to be marked as well.

Fig. 6. Cross correlation of the EAM and Greenland climate variability calculated by correlation of $\delta^{18}O$ values of the calcite of Chinese stalagmites (Wang et al., 2008) with ones those of the NGRIP (lower panel) and with ones of the GISP 2 (upper panel) ice cores (Rasmussen et al., 2014) by using moving windows at 1000 years (purple lines), 2000 years (red lines) and 3000 years (green lines) over the last 25 ka. Yellow bars show areas with insignificant cross correlation ranging between +0.25 and -0.25. Cross correlation between the EAM and Greenland by using a moving window 3000 years is negative during the period of 16.5-8.59.0 ka, and insignificant or weakly negative during earlier and later periods of 25-16.5 ka and of 9.08.5-0 ka BP confirmed the EAM and the Greenland synchronicity.