Editor Decision: Reconsider after major revisions (15 May 2017) by Erin McClymont

Comments to the Author (pdf): cp-2016-102-comments-to-author.pdf

Comments to the Author:

The authors have replied to both reviewers, and submitted a revised version of the text. The main issues raised by the reviewers and the editor centred on:

1. Age model construction. This is generally improved in the revised submission, but the authors still resist moving the construction of the age model before discussion of the proxies. I agree that it is difficult to identify the correct ordering here, but since there is no discussion of what the productivity records mean before they are tuned (this comes later), the structure of the text is very difficult to follow. If the authors wish to keep the age model after the discussion of the productivity proxies and what they might mean, so that there is some process-based rationale for why you might expect different records to align with other sites and with the monsoon. This is particularly key when one considers that the different proxies don't always show the same patterns, so that a reason why some peaks were tuned and not others needs to be stated. A revised submission needs to either (1) place the age model construction first, before discussion of the productivity signals; (2) explain first what the proxy signals record, to make the link to why tuning could or should be appropriate (see next point)

Answer 1. In revised text we first present additional information how the different seven productivity proxies were responded for primary productivity changes and how centennial events with higher productivity were separated and numbered through studied core. Here we also explained why different variability of productivity proxies may be occurred not everywhere synchronicity. So, the more remarkable peaks in detrended stack of productivity present more reliable NW Pacific centennial productivity events.

Only then, we discussed an age model construction and show why we conclude that NW Pacific centennial productivity events are correlated in time with EA summer monsoon sub interstadials.

2. Productivity proxies and their interpretation. The authors do now include some additional information on how the productivity proxies could and should be used, but this needs to come earlier in the discussion, to justify why these different proxies were used and how they have been interpreted. This is particularly important for the generation of the stack, and what it means. I don't agree with the authors that this is the subject of a different paper: you are using these data to make bold statements about NW Pacific productivity changes, but as Reviewer 2 points out, the selection of which peaks are being used seems to vary through time and be quite arbitrary. It needs justification. This would also address the concerns of point 3 below, where the focus on the NW Pacific would be a better demonstration of the value of the next records, but give detail in how we should interpret them, especially where they may disagree or show variable responses.

Answer 2. We had revised text according these comments and comments of Editor in PDF file" cp-2016-102-comments-to-author. 15.05.17"and answers for them. This PDF file with author answer are applicated.

3. Teleconnections. I still agree with reviewer 1 that you should undertake the cross-correlations for your own, new data, rather than shifting to an analysis of previously published records of monsoon variability. Yes, you have tuned your data to the monsoon data, but what would be most interesting here is to learn whether the productivity in the NW Pacific Ocean could be linked to millennial scale events elsewhere (see also comment by Reviewer 2 that section 5.1 is largely tangential – I agree).

You note that not all of the same proxies show the same patterns: would it not be interesting to detail those relationships, which may evolve through time and give some interesting insights into what controls NW Pacific Ocean circulation and productivity? There must be factors beyond monsoon intensity which affect the regional primary productivity, which could be interesting to learn.

Answer. Follow to reviewer 1, we present cross-correlation of the productivity stack with δ18O of NGRIP record In the revised version.

We strongly revised former section 5.1 and more focus on the different mechanisms which controlled the NW Pacific centennial productivity events during LGM-HE1, B/A and EH periods.

Here is where the SST data could be very useful (Reviewer 1), rather than the repeated assumption throughout the revised text that productive equals warmth (cold oceans can be productive, depending upon the driver).

Answer. We present references for SST data of core 12 KL and other cores and show that events with increased productivity in the NW Pacific had happened during abrupt climate warming.

Reviewer 2 also raises concern about the circular logic of tuning to the monsoon and then describing the synchroneity of the events between the two regions.

Answer. We infer the synchronicity of the NW Pacific centennial events with increased productivity with sub interstadials of EA summer monsoon after projection the radiocarbon datum of both cores with productivity events on the absolute U-Th dated δ^{18}O record of Chinese stalagmites.

The focus on the NW Pacific data and its variability has not been addressed in the revised manuscript, and I continue to be concerned that the main data analysis and discussion in the document is not about the new data which has been presented here. A revised version needs to address this concern by focussing more on the new data and less on the monsoon-Greenland teleconnections.

Answer. We closely follow these comments in revised MS

4. Graphics. These are better in the revised manuscript.

5. Written style. Whilst some of the corrections made have clarified the text, there remain areas of grammatical errors which require careful editing. I have highlighted a number of these on the tracked-changes document, but there is work to be done here.

Non-public comments to the Author:

Dear authors,

I apologies for the delays in replying to your submitted documents. I hope you appreciate that given the complexities of the detailed reviews we received, and the responses that you made, that it was important that full consideration was given as to whether your revision addressed the concerns raised.

Whilst efforts have been made to address many of the comments, I still have concern about the structuring of the current version, particularly in terms of where the discussion of the productivity proxies sits.

I am also very concerned that you continue to focus on the links between EAM (not your data) and Greenland/Antarctica (also not your data) in your discussion. You have presented some very interesting and detailed data for the NW Pacific, yet your discussion focusses instead on the importance and teleconnections of the records which were your tuning targets. I continue to agree with reviewer 2 that it would be better to focus on your new findings from the NW Pacific, perhaps considering what that data might contribute to discussions of teleconnections. You have provided some explanation of what might drive the productivity cycles when you outline the principles of what drives those records, but as I note above there must be other (interesting?) processes beyond the monsoon which can explain productivity variations, especially since your proxies do not always match in their directions and amplitudes. At the moment the significance and richness of your new data is diminished by a discussion focussed on data which is already published and not your own.

Answer. Thank you very much for these comments. We try to fully understand your concerning's and respectively do revision of text.

I have made many comments on your revised submission, and attached it here. Please take the time to read these from start to finish, because you will find some positive statements about text which may simply need to be moved and restructured to address some of the concerns.

If you feel that you are able to address the concerns still noted in my public comments above, and the edits and questions I have made to your manuscript, I would be happy to consider reviewing a revised submission.

Answer. We look carefully all your comments in the former revised manuscript and give answer for them. They very help us to improve structure and text of MS. Thank you a lot again.

Best wishes

Erin McClymont

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 sedimentof core LV63-41-2 (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 age model of the core 41-2 is established by AMS ^{14}C dating using foraminifera shells and by correlating the projections of AMS ^{14}C data of the nearby core SO-201-12KL through correlation of the productivity cyclesproxies and relative paleomagnetic intensity records with those of well dated nearby core SO201-12KL. Our results show a pronounced feature. Resulted sequence of centennial – millennial productivity increases/climate cycles ofwarming events in the NW Pacific had occurred synchronicitysynchronously with the summer East Asian Summer Monsoon (EAM) at

EASM) sub-interstadials during the LGM (4 events), Heinrich Event 1 (HE1) (4 events), Bølling/Allerød (B/A) warming (4 events), and over the EH (4 events). Remarkable similarity of the sequence of the NW Pacific increased productivity events with the EASM sub-interstadials over the LGM-HE1 implies that Siberian High is a strong common driver responded to the variations in productivity and sub-interstadial ~~scale during the LGM (3 cycles), Heinrich Event 1(3 cycles), Bølling/Allerød warming (4 cycles), and over the EH (3 cycles). Our comparison of the centennial millennial variability to the Antarctic EDML (EPICA Dronning Maud Land) ice core suggests a "push" effect of Southern hemisphere temperature gradients on the summer EAM intensifications. Besides~~. The comparison with the $\delta^{18}O$ record from Antarctica suggests that, another mechanism associated with temperature gradient in the Southern Hemisphere may be also responded for the EASM / NW Pacific centennial events over the LGM-HE1. During the B/A warming and resumption of the AMOC, clear synchronicity between the NW Pacific, EASM and Greenland sub-interstadials was mainly controlled by changes in the atmospheric circulation. During the EH 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~~between sun-ocean-climate, likely, control the synchronicity of abrupt climate changes in the NW Pacific and North Atlantic. The sequence of centennial ~~millennial productivity/climate variability in the NW Pacific associated with sub-interstadials/stadials in the EAM from the LGM to EH are~~ events recorded in this study is a persistent regional ~~features, synchronous with the Greenland/NorthAtlantic short term changes. We speculate that such climate synchronicity was also forced by changes in Atlantic meridional overturning circulation coupled with Intertropical Convergence Zone shifting and the northern westerly jets reorganization.~~ feature during the LGM-EH, which may serve as a template in high resolution paleoceanography and sediment stratigraphy in the NW Pacific.

1. Introduction

Model simulations and proxy-based interpretations 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 N 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 teleconnection in the N hemisphere on the decadal time scale (Max et al., 2012). The winter Arctic Oscillation, which resembles the North Atlantic Oscillation, influences directly the surface air temperature and sea level pressure over the region northwards of 35ºN in East Asia; in turn, Siberian High significantly influences on the East Asia 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 (Saenko et al., 2004). 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). The 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 color reflectance studies on western Bering Sea cores Riethdorf et al. (2013) further suggest a close linkage between millennial-scale productivity changes to the Dansgaard-Oeschger variability were registered in the North Greenland Ice Core Project (NGRIP) ice core, which had been interpreted to support 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). While 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. During 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 decoupled.

All 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 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 the 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) that reveal a sequence of centennial-millennial climate/productivity variability over 20 ka to 8 ka. An age model of this core was constructed by AMS ^{14}C dating and by correlating the productivity cycles and relative paleomagnetic intensity (RPI) variability with ones of the well-dated nearby core SO-201-12KL(hereafter, 12KL) (Max et al., 2012, 2014). With our methodologically robust age controls, 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 results have enabled us to investigate further any mechanisms controlling the in-phase relationships of the centennial-

millennial variability in the NW Pacific/EAM with 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).

Model simulations and proxy-based records both have led to contradictory results on the millennial-scale 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; Sarnthein et al., 2006). The in phase relationship has been attributed to rapid atmospheric teleconnections in the Northern Hemisphere on a decadal time scale (Max et al., 2012). The winter Arctic Oscillation (AO), 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 (Sung et al., 2006). The Siberian High (SH), an essential component of northern East Asian atmosphere system, significantly influences the East Asian Winter Monsoon (EAWM) (Wu and Wang, 2002), which in turn affect the environment of NW Pacific. When winter AO is in its positive phase, both winter SH and EAWM are weaker than their normal state and air temperature of the surface- the middle troposphere is higher than normal (Wu and Wang, 2002), which ameliorate the NW Pacific environment. The out-of-phase response, however, was proposed to be driven by a seesaw mechanism, with oceanic readjustments between the weakening of the Atlantic meridional overturning circulation (AMOC) and the strengthening of the Pacific meridional overturning circulation (Okazaki et al., 2010).

Records of $\delta^{18}O$ from the Greenland ice cores revealed the Dansgaard - Oeschger (DO) millennial scale oscillations (interstadials and stadials) during the last glaciation (Dansgaard et al., 1993; Johnsen et al., 1992) and similar millennial scale events have also been identified in a number of terrestrial and marine records in other regions. For example, a synthesis of the last glacial pollen records from the European continent provides evidence that the warmer intervals in Europe correspond to millennial-scale interstadials in Greenland (Fletcher et al., 2010). The sediment cores from the N Pacific and its marginal seas also showed abrupt, millennial scale climate and environment ameliorations, similar to interstadials in Greenland ice cores during the last glaciation. Records of $\delta^{18}O$ of planktic foraminifera (Kennett et al., 2000) and alkenone-derived sea surface temperature (SST) (Seki et al., 2002) from the Northeastern (NE) Pacific also exhibited millennial climate oscillations very similar in magnitude with DO cycles over the last glaciation. INTIMATE stratigraphy studies 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 (during Heinrich Event 1, HE1), GS-2.1b (Last Glacial Maximum, LGM), and GS-2.1c (Björck et al., 1998; Rasmussen et al., 2014). The sequence of abrupt warming and environmental ameliorations similar to DO interstadials in Greenland were also interpreted by using alkenone-derived SST (Harada et al., 2008) and geochemical, diatom and pollen data (Gorbarenko et al., 2004) in sediment cores investigated from the Okhotsk Sea. The Bering Sea was also characterized by climate and environmental oscillations corresponded to DO cycles based on productivity proxies, sediment density, opal content and micropaleontological records (Gorbarenko et al., 2005; Kim et al., 2011; Riethdorf et al., 2013; Schlung et al., 2013).

By comparing the dust content in the North Greenland Ice Core Project (NGRIP) ice core with that of the dust record in a sediment core from the subarctic N Pacific, Serno et al. (2015) demonstrated synchronicity of millennial scale changes in atmospheric circulation between the N Pacific and the Greenland during the last 27 ka (Serno et al., 2015). Previous studies also found the occurrence of increased export of productivity during the period of millennial scale climate and environmental ameliorations, correlated with DO interstadials, in the Okhotsk and Bering Seas (Gorbarenko et al., 2005; Kim et al., 2011; Riethdorf et al., 2013; Seki et al., 2004).

Recent studies on high-resolution and well-dated sediment cores from the subarctic NW Pacific, the Okhotsk Sea, and the western Bering Sea show the variations in SST during the last deglaciation similar to the NE Pacific and to the N Atlantic and Greenland temperature variability (Caissie et al., 2010; Max et al., 2012; Seki et al., 2002). These studies suggest a close linkage to deglacial variations in AMOC associated with rapid atmospheric teleconnection, which were responsible for a quasi-synchronous SST pattern between the N Atlantic and N Pacific during the last deglaciation.

Furthermore, a recent study by Praetorius and Mix (2014), based on multi-decadal-resolution foraminiferal $\delta^{18}O$ records from the Gulf of Alaska, revealed a synchronicity of rapid climate shifts between the N Atlantic/Greenland (NGRIP record) and the NE Pacific between 15.5 and 11 ka. During the Holocene and HE1, inverse relationships between the N Atlantic and the N Pacific are suggested by Praetorius and Mix (2014), while the short-term variability is either not sufficiently resolved or decoupled.

A lack of high resolution records in the NW Pacific prohibits a precise assessment of any possible climatic teleconnection between the N Pacific and N Atlantic.

Besides centennial-millennial oscillations reported during the last glacial periods, centennial precipitation anomalies from LGM to the Holocene have also been reported in cave stalagmite

δ^{18}O records of the East Asian monsoon (Dykoski et al., 2005; Wang et al., 2001, 2005, 2008; Yuan et al., 2004). Furthermore, the timing and pattern of variability during the Early Holocene (EH) regional climate changes are still under debate. In particular, though the EH climate has started from a strong warming in most cases, a Hani peat δ^{18}O record from NE China instead suggest centennial cooling event which is primarily superimposed on a long-term warming trend during the Holocene (Hong et al., 2009).

Here we present high resolution results of productivity proxies, sediment magnetic properties, and lithological composition of a sediment core LV 63-41-2 (hereinafter, 41-2) (off Kamchatka) from the NW Pacific. Our records reveal a sequence of centennial productivity/climate variability from 20 ka to 8 ka. An age model of core 41-2 was constructed using accelerator mass spectrometry (AMS) ^{14}C dating and by correlating the productivity events and relative paleomagnetic intensity (RPI) variability with those of the well-dated nearby core SO-201-12KL (hereinafter, 12KL) (Max et al., 2012, 2014). Using robust age controls, we establish a tight linkage between the centennial events with higher productivity in the NW Pacific and the sub-interstadial strengthened East Asian summer monsoon (EASM) expressed in cave stalagmite δ^{18}O records. These results enable further investigation of any mechanisms in controlling the in phase relationships of the centennial variability in the NW Pacific / EASM and those underlying the Greenland / N Atlantic and Antarctic climate changes during the LGM through EH.

2 Materials and methods

2.1 Coarse fraction measurement

Sediment core 41-2 was recovered in the NW Pacific off Kamchatka peninsula (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. Weight percentage of 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. We made semi-quantity estimations of various components input in sediment CF including terrigenous and volcanogenous particles (tephra), benthic and planktonic foraminifera, diatom frustules, and radiolarians using the microscope and comparative percentage charts for estimating proportions

of sedimentary components (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 only for core interval with insignificant input of tephra.

Sediment core 41-2 (52°34′ N, 160°01′ E; water depth: 1924 m) was recovered from the NW Pacific off Kamchatka Peninsula during the Russian-Chinese Joint Expedition on R/V "Akademik M.A. Lavrentyev" in 2013. The length of the core is 467 cm. In order to establish the age model of core 41-2, we also analyzed paramagnetic magnetization and chlorin content in core 12KL (53°59′ N, 162°23′ E), which has been dated well by Max et al. (2012, 2014).

2.1 Coarse fraction

The weight percentage of coarse fraction (CF; 63-2000 µm) was obtained at 1 cm interval after wet sieving the sediment and calculated as a ratio of CF weight to the total weight of dry bulk sediment.

Terrigenous materials are mainly transported by sea ice in the studied region and therefore the CF and magnetic susceptibility (MS) of sediments (Gorbarenko et al., 2003, 2012; Lisitzin, 2002; Sakamoto et al., 2005), can be used as a proxy for ice rafted debris (IRD). Semi-quantitative estimates of terrigenous and volcanic particles (tephra) in the 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. Semi-quantitative estimates of major components in the sediment CF, including terrigenous and volcanic particles, benthic and planktic foraminifera shells, diatom frustules, and radiolarian skeletons on a twelve-point scale, were made by using a microscope for roughly estimating the proportions of different components in the sediment (Rothwell, 1989).

2.2 Chlorin content measurement

The chlorin content of core 41-2 was measured with 1-cm resolution and with 2-cm resolution in core 12KL through the whole cores using a Shimadzu UV-1650PC spectrophotometer according to the modified method of Harris et al. (1996).

Chlorin content is assumed to reflect changes in primary surface ocean productivity, because continental-derived chlorophyll contributes insignificantly to its composition in deep marine sediment (Harris et al., 1996). The chlorin content in core 41-2 was measured by a Shimadzu UV-1650PC spectrophotometer at 1 cm resolution, and at 2 cm resolution in core 12KL, respectively, using same analytical reagents and pretreatment procedures proposed by Harris et al. (1996).

2.3 Total organic carbon (TOC), calcium carbonate, (CaCO$_3$), and color b* measurements

Total carbon content and inorganic carbon in core 41-2 were measured every 2 cm through the core depth by coulometry using an AN-7529 analyzer (Gorbarenko et al., 1998). TOC content was determined by calculating 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. It has been shown that variability in color b* correlates well with the changes in biogenic opal contents in sediment cores (Nürnberg and Tiedemann, 2004).

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). The 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 and inorganic carbon contents in core 41-2 were measured at every 2 cm throughout the core by Coulometry using an AN-7529 analyzer (Gorbarenko et al., 1998). TOC content was determined by calculating the difference between total carbon and inorganic carbon content. Color b* index (psychometric yellow–blue chromaticness) was measured with 1 cm resolution using a Minolta CM-2002 color reflectance spectrophotometer (Harada, 2006).

2.4 Radiocarbon dating (AMS ^{14}C)

AMS ¹⁴C ages were measured on monospecific samples of the planktic foraminifers *Neogloboquadrina pachyderma* sinistral (*N. pachyderma* sin.) from the 125–250 μm fraction and benthic foraminifera *Epistominella pacifica,* and *Uvigerina parvocostata* from the 250–350 μm fraction of the core. The radiocarbon dating has been 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 reservoir age (900 ± 250 yr) of the NW Pacific surface water (Max et al., 2012) was adopted in this study to calibrate the ¹⁴C ages of our samples into calendar ages for establishing consistent AMS ¹⁴C chronologies of cores 41-2 and 12KL. All reservoir age corrected ¹⁴C data were converted into calendar age by using Calib Rev 6.0 (Stuiver and Reimer, 1993) with the Marine13 calibration curve (Reimer et al., 2013).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 (Max et al., 2014).

AMS ^{14}C-ages were measured in monospecific samples of the planktic foraminifera *Neogloboquadrina pachyderma* sinistral (*N. pachyderma* sin.) from the 125–250 μm fraction, and benthic foraminifera *Epistominella pacifica*, and *Uvigerina parvocostata* from the 250–350μm fraction of the core. The radiocarbon dating was performed by 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 reservoir age (900 ± 250 yr) of the NW Pacific surface water (Max et al., 2012) was adopted in this study to convert the ^{14}C data into calendar ages by using Calib Rev 6.0 (Stuiver and Reimer, 1993) with Marine13 calibration curve (Reimer et al., 2013) to establish consistent AMS ^{14}C chronologies between cores 41-2 and 12KL. 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 measurementsproperties

Magnetic properties were measured with 2.2 cm resolution in the both cores. Volume magnetic susceptibility (MS) of these samples was measured using an AGICO MFK1-FA device. The characteristic remnant magnetization (ChRM) of the 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 by the JR-5A rock generator. 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). 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.

Core 41-2 RPI in response to variations in the Earth's magnetic field presents an independent chronological instrument of marine and continental sediments (Channell et al., 2009), and are widely used for sediment correlation and chronology determination (Kiefer et al., 2001; Riethdorf et al., 2013). The sediment paramagnetic magnetization (PM) was formed in marine sediments in the open NW Pacific by silicate, paramagnetic iron sulphide (FeS), and fine clay minerals, the main part of which was transported from land as an eolian dust through atmospheric circulation by westerly jets (Serno et al., 2015). Therefore, the sediment PM may serve as a proxy for the land aridity and atmosphere circulation pattern changes in response to climate change. The volume MS of sediments was mainly formed by ferromagnetic minerals delivered together with terrigenous materials from adjacent land by sea ice, which is the main transport agent of clastic materials into the NW Pacific and its marginal seas (Gorbarenko et al., 2003; Lisitzin, 2002; Sakamoto et al., 2005).

The sediment magnetic properties were measured at 2.2 cm resolution in cores 41-2 and 12KL. MS of these samples was measured by an AGICO MFK1-FA device. The characteristic

of remanent magnetization (ChRM) of the samples was measured in the same way by studying the stability of natural remanent magnetization (NRM) in an alternative magnetic fields of up to 80-100 mT on the basis of analysis of Zijderveld vector plots, using an AGICO LDA-3Adevice 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 vanishing amplitude (Malakhov et al., 2009). Ahysteretic remanent magnetization (ARM) was generated using an AGICO AMU-1A device and measured using the JR-5A rock-generator. The RPI of the studied core was determined by the normalization of the ChRM after demagnetization at 20 mT by ARM (ChRM/ARM) (Tauxe, 1993). The sediment 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).

~~2.6 XRF measurements~~

2.6 In-situ X‑ray fluorescence core scanning

Previous studies have shown that the non-destructive, high resolution X-ray fluorescence (XRF) measurements of biogenic barium, bromine and silica (Ba-bio, Br-bio, and Si-bio, respectively) by a core scanner or synchrotron radiation are consistent with analytically measured contents of 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 proxy of productivity (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., 2013) and therefore may also be used as a paleoproductivity proxy.

The elemental composition, ~~given in~~ of core 41-2 was measured as peak area (in counts per second~~, cps), was measured with~~ 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 water content and surface roughness of the core ~~(Röhl and Abrams, 2000).~~(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 XRF scanning results for estimating ~~biogenic Ba, Br and Si (~~the productivity proxies such as Ba-bio, Br-bio and Si-bio ~~respectively)~~ contents in our sediment ~~cores, which serve as proxies of productivity.~~core. The content of Ba-bio was estimated by the subtraction of its terrigenous component ~~(Ba-ter)~~ from the total ~~bulk~~ Ba concentration in sediment (Ba-tot). The terrigenous component was, in turn, ~~was~~ calculated from empirical regional $(Ba/Al)_{ter}$ ratios in the sediment core with the lowest Ba-tot contents multiplied on relative Al content:

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

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

The contents of Br-bio and Si-bio were calculated using the same ~~technique~~way.

3. Results

~~AMS radiocarbon data for core 41-2 are presented in Table 1. The variability of suite of productivity proxies (color b* and content of TOC, chlorin, CaCO₃, 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). Increased productivity at the interval ~315-230 cm according to several productivity proxies and available AMS ¹⁴C data could be chronologically assigned to the B/A warming right after the termination of the last glaciation (467-315 cm) (Fig. 2). 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 warm climate condition.~~

In core 41-2 the time resolutions of measured chlorin content and color b*; TOC, CaCO$_3$ content and magnetic parameters (PM, MS and RPI); and Ba-bio, Br-bio, Si-bio concentration over the LGM-YD periods are nearly 30 years, 15 years and 60 years respectively. The resolution is high enough to allow us to detect centennial-millennial scale climate variability in the far NW Pacific. Presented high resolution productivity and magnetic records reveal quasi-synchronously centennial-millennial productivity cycles associated with abrupt environmental variability (Fig. 2) via mechanisms similar to established earlier regularities at the orbital-millennial scale (Broecker, 1994; Ganopolski and Rahmstorf, 2002; Sun et al., 2012). Therefore, in particular we suggest that the sharp increased productivity events demonstrate quickly response of the NW Pacific environment associated with abrupt regional warming and vice versa similar as for interstadials events in the NW Pacific and Okhotsk and Bering Seas. The rises in SST of surface water and environment amelioration in the NW Pacific and Japan, Okhotsk and Bering Seas correlated with interstadials in δ^{18}O records in NGRIP ice core (North Greenland Ice Core Project members, 2004) and Chinese cave stalagmites promote to increase in productivity at the millennial scales (Gorbarenko et al., 2005; Nagashima et al., 2011; Seki et al., 2002, 2004). Although an each used productivity proxy have own specific peculiarities in his response to climate and environmental changes, the used complex of proxies allow us to more definitely determine increased productivity events in the past. In results, presented productivity proxies and sediment paramagnetic magnetization (PM) records show that 6 short increased productivity/warmer events happened during the last glacial and 4 ones during the B/A warming (Fig. 2). During the EH we find 5 short lower productivity/colder events and 3 higher productivity/warmer events. We notice 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 colder event identified at depth 106-109 cm of 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).

The share of tephra in sediment CF show significantly increase in upper part of core since 130 cm (Fig. 2); therefore, below this interval, CF and MS variability was mostly responded to IRD input. The CF and MS records, controlled by tephra share in CF, indicate high IRD input in sediment of lower part of core and strong decrease to top in interval 325-315 cm. MS and CF records also show some increase of IRD at the interval of 230-200 cm related to the YD (Fig. 2).

Available productivity proxies (chlorin, Ca/Ti ratio, color b*) plus magnetic properties RPI and PM for core 12KL were compared with results of core 41-2 versus cores depth (Fig. 3). For simplicity, a suite of productivity proxies for core 41-2 (color b* and chlorin, TOC, CaCO3, Ba-bio, Br-bio and Si-bio content and PM record) was replaced with the calculated stack of productivity proxies. The color b* index and Ca/Ti ratios (analog of $CaCO_3$ 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).

4. Age model

An age model of core 41-2 was constructed using all available AMS-^{14}C dating, with more age control points identified by correlating the centennial-millennial events of the productivity proxies, RPI and PM of 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 close located cores. With this conception of age model developments, the centennial-millennial variability of productivity proxies with increased productivity events, relative paleointensity (RPI) of Earth magnetic field and paramagnetic magnetization (PM) identified in cores 41-2 and 12KL have to be closely matched in the both cores over the last glaciation, the B/A warming to the EH (Fig. 3). We noticed that the available for core 12KL the Tiedemann/Max age model 2 (Max et al., 2012, 2014) was based on the AMS-^{14}C data and correlation of color b* index with the NGRIP $\delta^{18}O$ curve (PANGAEA Data Publisher). By adopting an age model of core 41-2,

AMS ^{14}C dating of core 12KL of Max et al. (2012, 2014) were transferred successfully to core 41-2 according to correlation of related increased productivity events and RPI values (Fig. 3). Color b* minimum in core 12KL at depth of 706 cm, which R. Tiedemann/L. Max correlates with minimum in NGRIP δ^{18}O curve at 16.16 ka, is also clearly correlate with color b* minimum of core 41-2 at depth of 348 cm (Fig. 3). All correlated AMS ^{14}C key points are also well-matched between 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 depth 127.5 cm, 156 cm, 298 cm and 306 cm respectively are rather closed to nearby projected ^{14}C datum from core 12 KL (Table 2) and confirm validity of this age projection. But here we prefer to used ^{14}C data of core 12KL because this core have higher sedimentation rate and planktonic foraminifera for these measurements were picked from intervals with highest Ca content that significant decrease a bioturbation effect.

A close time correlation of these NW Pacific productivity increasing/environmental amelioration events with sub-interstadials in summer EAM become apparent after projection of the radiocarbon datum of both cores on the absolute U-Th dated δ^{18}O record of the China caves stalagmites (Wang et al., 2008) over the 20-8 ka (Fig. 3). Such inferred synchronicity of NE Pacific productivity abrupt events and EAM sub-interstadials was used for further fine age model construction by tuning of increased productivity events with related sub-interstadials of δ^{18}O Chinese stalagmites for depth beyond the projected AMS ^{14}C data (Fig. 3; Table 2).

53.1 Productivity events

Down-core variability of all productivity proxies (color b*and contents of TOC, chlorin, $CaCO_3$, Ba-bio, Si-bio, and Br-bio) in core 41-2 is presented Fig. 2. Taking the available AMS ^{14}C data into account (Table 1), the middle part of the core (the interval ~315-230 cm) with increased contents/values of all productivity proxies could be chronologically assigned to the Bølling/Allerød (B/A) warming right after the late last glaciation (467-315 cm) consistently with current investigations. The climate became warmer in the northern extra-tropics during the B/A period, terminating the last glaciation, then it reversed to the cooling during the Younger Dryas (YD) followed by the significant warming throughout the Holocene. This climate sequence had

been well-documented by the $\delta^{18}O$ records of the Greenland ice cores and climate records from the N Atlantic (Bond et al., 2001; Dansgaard et al., 1993; Johnsen et al., 1992; Stuiver et al., 1995), by classical sequence of European pollen zone (Nilsson, 1983) and by well-dated pollen biome records of the southern Siberia (Bezrukova et al., 2010; Tarasov et al., 2009). Above mentioned patterns of climate variability during the LGM–EH in moderate-high latitudes of the Northern Hemisphere is consistent with the N Pacific and its marginal seas, evidenced by the alkenone- derived SST (Barron et al., 2003; Max et al., 2012) and pollen records (Gorbarenko et al., 2003, 2004). The significant increase in productivity during the B/A was likely achieved by additional nutrient input into euphotic layer due to accelerated sea level rise (Siddall et al., 2010) accompanied by the supply of organic matter from the submerged shelf and by prolonged blooming season due to the warming that is a common paleoceanography feature of the N Pacific and its marginal seas (Barron et al., 2003, 2009; Caissie et al., 2010; Galbraith et al., 2007; Gorbarenko, 1996; Gorbarenko et al., 2005; Gorbarenko and Goldberg, 2005; Keigwin, 1998; Keigwin et al., 1992; Max et al., 2012; Seki et al., 2004). A decreased trend of productivity records at the interval of~230-190 cm is likely associated with the YD cooling and the subsequent high productivity trend in the upper 190 cm of the core is presumably related to the Holocene warming (Fig. 2).

In core 41-2, the temporal resolutions of measured color b*, chlorin, TOC, $CaCO_3$ and magnetic parameters (PM, MS, and RPI), and Ba-bio, Br-bio, and Si-bio are nearly 30 years, 15 years, and 60 years respectively. The resolution is high enough to allow us to detect the centennial scale productivity variability in the NW Pacific. However, not all productivity proxies change synchronously (Fig. 2).

Each used productivity proxy has its own specific limitations and peculiarities in response to the environmental and primary productivity changes. For example, although carbonaceous fossils (planktic foraminifera and coccolithophorids) rain from the euphotic layer, exported by primary production, and they provide the main carbonate input into the sediment. While the $CaCO_3$ 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 contents are responsible for the accumulation of siliceous fossils, and siliceous plus carbonaceous fossils with other organic remains, respectively (Berger et al., 1989), they vary in different ways at various

periods in sediments of the NW Pacific and its marginal seas. For example, biogenic opal content in the Okhotsk Sea lags significantly relative to TOC changes during the last deglaciation—the Late Holocene interval (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. Although it was suggested that color b* values correlate well with the changes in biogenic opal content in sediment cores (Nürnberg and Tiedemann, 2004), measured color b* in core 41-2 do not change synchronously with Si-bio content in the entire length of the core (Fig. 2). The presentation of a wide range of productivity records allows us to evaluate the discrepancy among proxies. In addition, the combination of proxies provides a more reliable way for evaluating the productivity changes.

For the statistical assessment of the centennial productivity variability, the stack of productivity proxies is calculated. It is an average of the normalized data of each proxy with equal weight (Fig. 2). Data from the productivity stack were detrended by subtracting long-term periodicity that allow us to determine the sequence of centennial productivity events with higher productivity throughout the studied core and events with lower productivity during the EH based on the seven productivity proxies measured (Fig. 2). Calculated productivity stack has high negative correlation with PM of sediments (r = -0.63). This indicates that centennial events with increased productivity occurred during weakening of dust delivery and deposition in the NW Pacific by atmospheric circulation associated with abrupt climate warming. Such causal linkages between centennial productivity increases and abrupt climate warming in the NW Pacific is also consistent with millennial scale productivity /climate oscillation during the DO interstadials found in the Okhotsk and Bering Seas (Gorbarenko et al., 2005; Kim et al., 2011; Riethdorf et al., 2013; Seki et al., 2004). As a result, the records of different productivity proxies and detrended productivity stack show eight short-term events with higher productivity occurred during the LGM and HE1 and 4 events during the B/A warming. During the EH, productivity records show 4 events of lower and higher productivity, respectively (Fig. 2).

It is noted that a low productivity event at ~9.1 ka (Table 1) is well-correlated with the 9.3 ka cold event recorded in NGRIP (Rasmussen et al., 2014). Moreover, a low productivity event identified at depth of 105-110 cm also correspond to the 8.2 ka cold event, a well-known chronostratigraphic marker in the Early to Middle Holocene boundary (Walker et al., 2012).

3.2. Age model

The RPI, productivity stack and PM of core 41-2 were compared with the RPI, several productivity proxies, and PM records of nearby core 12KL (Fig. 3). The color b* index and Ca (analog of $CaCO_3$ content) of core 12KL were obtained from Max et al. (2012, 2014). The correlation of the centennial productivity events between cores was provided by comparison of productivity stack of core 41-2 with productivity proxies of core 12KL and by comparison of the RPI and PM curves. An age model of core 41-2 was constructed using all available AMS ^{14}C data, with additional age control points identified by correlating the centennial productivity events, RPI and PM of the studied core with those of the well-dated adjacent 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 NW Pacific since the last glacial, especially for closely-located cores. Therefore, the centennial variability of productivity proxies with increased productivity events, RPI of Earth's magnetic field, and PM identified in cores 41-2 and 12KL have to be closely matched in both cores over the last glaciation—B/A warming to the EH (Fig. 3). It was noted that the available age model for core 12KL (the Tiedemann/Max age model) (Max et al., 2012, 2014) was based on the AMS ^{14}C data and correlation of color b* index with the NGRIP $\delta^{18}O$ curve. For adopting this age model to Core 41-2, the AMS ^{14}C data of core 12KL were projected to Core 41-2 according to the correlation of related productivity events, RPI and PM (Fig. 3). The color b* minimum in core 12KL at a depth of 706 cm, which correlates with a minimum in the NGRIP $\delta^{18}O$ record at 16.16 ka, is also clearly correlated with the color b* minimum in core 41-2 at a depth of 348 cm (Fig. 3). All correlated AMS ^{14}C data points are also well-matched with the measured RPI curves of both cores (Fig. 3). Our four AMS ^{14}C data are fairly close to the projected ^{14}C data from core 12KL (Table 3) with age differences within ±0.1 ka, confirming the validity of these key point projections. Here the use of ^{14}C data of core 12KL is preferred, because this core has a higher sedimentation rate, and planktic foraminifera for these measurements were picked-up from intervals with higher Ca peaks, aiming to reduce the effect of bioturbation on the precision of age model.

A close temporal correlation of these NW Pacific increased productivity events with sub-interstadials in the EASM becomes apparent after projection of the radiocarbon data of both cores on absolute U-Th dated $\delta^{18}O$ record of Chinese cave stalagmites (Wang et al., 2008) during 20–8 ka (Fig. 3). Such inferred synchronicity of abrupt NW Pacific productivity events and EASM sub-interstadials was used for further tuning of age model. This was achieved by fine-tuning of the increased productivity events with related sub-interstadials of $\delta^{18}O$ Chinese stalagmites at a depth beyond the projected AMS ^{14}C data (Fig. 3; Table 3).

The sequence of centennial events of increased productivity seems to be occurred in phase with decreasing of PM in both cores (Fig. 3), indicating a weakening of eolian dust transportation by atmospheric circulation in the study area due likely to climate warming, analogous with millennial scale forcing of dust transportation into the NW Pacific (Serno et al., 2015). Within.

Discussion

With the constructed age model of core 41-2 different kinds of productivity proxies and magnetic results combined with some of them for AMS ^{14}C dated core 12KL (Max et al., 2012, 2014) reveal sequence of noticeable centennial-millennial scale productivity cycles in the far NW Pacific occurred in-phase with Chinese sub-interstadials (CsI) associated with stronger summer EAM (Wang et al., 2008) over the 21-8 ka (Fig. 4). These linkages suggest the centennial-millennial increase productivity events in the far NW Pacific were likely associated with shifts to warmer climate and/or higher nutrient conditions in surface water synchronously with CsI of the summer EAM. Presented high resolution records show clearly that three centennial-millennial increase productivity/environment amelioration events correlated with (CsI) had occurred during the LGM, three CsIs during the HE1, four CsIs during the B/A warming, and three CsIs during the EH (Fig. 4) (Table 3). The possible 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 below.

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

Identifying any the constructed age model of core 41-2, different productivity proxies and magnetic records, combined with similar data from core 12KL (Max et al., 2012, 2014) reveal a sequence of noticeable centennial events of increased productivity in the NW Pacific which occurred in phase with Chinese sub-interstadials (CsI) associated with stronger EASM or weaker EAWM (Wang et al., 2008) and changes in atmospheric circulation during 21–8 ka (Figs. 3 and 4).

These linkages suggest that centennial increased productivity events in the NW Pacific were likely associated with shifts of a warmer regional climate and/or higher nutrient availability in surface water, synchronous with CsI of the EASM. According to Wang et al. (2001), the

interstadials of EASM are broadly correlated with regional climate warming. High resolution records presented here show clearly that four centennial-scale events of increased productivity/environmental amelioration correlated with CsI during the LGM, four events during HE1, four events during the B/A warming, and four events during the EH (Fig. 4; Table 2).

4. Discussion

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 responsible for the Southern Hemisphere is important to us, to deepen 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 δ^{18}O records of the composite Hulu and Dongge caves sediments (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 5 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 results 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 transferring in the high latitudes of the N Hemisphere by atmosphere governed by climate and atmosphere 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 Greenland atmospheric dust loading which is closely linked with the atmospheric circulation and climate changes in the high-latitude of N Hemisphere, where EAM plays 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 stadial (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-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).

Established in the studied off Kamchatka cores the NW Pacific centennial–millennial productivity/environment cycles with stack of productivity and color b* on the base of its chronology (Table 2) were put on the N-S hemispheres climate variability over the LGM-HE1-B/A (Fig. 5). In addition to established in the NW Pacific studied cores the six centennial-millennial productivity/environment cycles over the LGM-HE1, we suggest that coeval with CsIs an additional three abrupt events likely took place in the NW Pacific over the interval of 25-20 ka (Fig. 5). Therefore, we found the three EAM/NW Pacific sub-interstadials which occurred within GS-2.1a (namely CsI GS2.1-1, CsI GS2.1-2 and CsI GS2.1-3), four CsIs within GS-2.1b (CsI GS2.1-4 to CsI GS2.1-7), and two within GS-2.1c (CsI GS2.1-8 and CsI GS2.1-9) (Fig. 5).

It also has been noted that the some $\delta^{18}O$ differences in coeval $\delta^{18}O$ values between Summit and NGRIP ice cores over the LGM-HE1 period, were likely governed by changes in the N American Ice Sheet volume and N Atlantic sea-ice extent, that results in the changes of meridional gradients in the Greenland ice $\delta^{18}O$ (Seierstad et al., 2014). Probably, such $\delta^{18}O$ differences in the Summit – NGRIP $\delta^{18}O$ values may explain that correlation of the EAM/NW Pacific sub-interstadials with Greenland sub-interstadials recorded in $\delta^{18}O$ and Ca^{2+} of the GISP2 and of the NGRIP over the HE1 (GS-2.1a) was less pronounce then ones during LGM. 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. Such 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.,

2012), 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., 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 into the NW Pacific. This study indicates that AMOC is a driver of abrupt change in EAM system, 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 δ^{18}O 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. In results of EAM investigations (Wang et al., 2001) have suggested that between 11,000 and 30,000 yr BP the Chinese interstadials (CI) recorded in δ^{18}O 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 23.6-24.3ka was synchronous with abrupt climate cooling and increases in dust content in the Greenland ice cores NGRIP and GISP2, coeval to HE2 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 CI-2 coeval with sub-interstadial CsI GS2.1-9

associated with summer EAM intensification (Fig. 5). Over the LGM-HE1 period, the most of sub-interstadials in the N hemisphere had occurred during abrupt Antarctica temperature decrease as well (Fig. 5).

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 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 of responses of EAM and Greenland interstadials and sub-interstadials, because the migration of the WPWP may have responded more slowly than the atmospheric changes. All the above interpretations are mostly consistent with variability between the EAM and Antarctica temperature (Fig. 5), when cooling in Antarctica promote to increase summer EAM. The $\delta^{18}O$ record of Chinese EAM changes were more gradual then in the $\delta^{18}O$ of Greenland ice cores, and the amplitude changes of the EAM are more similar to the Antarctic air temperature changes (Fig. 5).

During B/A warming when Antarctic temperature was decreased, four EAM sub-interstadials (CsI GI1-a – CsI GI1-e) coeval with established NW Pacific centennial-millennial productivity/environment cycles have varied in phase with Greenland sub-interstadials (Björck et al., 1998) as well (Fig. 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 three of them within the

B/A. 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, EAM and N Atlantic.

Inferred a tight in-phase linkages between the NW Pacific centennial-millennial productivity/environment cycles and the summer EAM intensity sub-interstadials over GS-2.1-GI-1 (Figs. 4 and 5) allow 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.

5.2 The EH

During EH the presented records demonstrate a series of abrupt increase/decrease 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 $\delta^{18}O$ records of Dongge and Hulu caves (Dykoski et al., 2005; Wang et al., 2008) and Greenland ice core (North Greenland Ice Core Project members, 2004) (Figs. 4, 5; Table 3). Visual comparison with the EAM and Greenland ice cores records show synchronicity (positive correlation) of the 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). The dated pollen reconstructed the vegetation /climate variability of the southeastern Siberia (Lake Baikal region) (Bezrukova et al., 2011) demonstrated nearly the same type of the centennial-millennial climate variability that confirms their common patterns of changes 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) 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 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 also occurred coherent with the periodicities of solar activity and production of the cosmogenic nuclides ^{14}C and ^{10}Be. 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 climate and environments (Hu et al., 2003). Nearly synchronicity in the changes of the centennial-millennial productivity and magnetic proxies obtained in the two studied cores with the δ^{18}O records of Chinese cave speleotherm, the Greenland ice cores, and with the nuclide ^{14}C production during the EH (Figs. 4, 5) imply that variability of the NW Pacific climate and environmental condition has been tightly related with EAM and N Atlantic/Greenland climate changes by atmospheric coupling mechanisms over the studied period of 20-8 ka. In summary, our presented results indicates a tight linkage and coherent, persistent pattern of the centennial-millennial scale climate changes in the N Hemisphere over the LGM-EH which may be serve as template in high resolution paleoceanography and sediment stratigraphy of the moderate-high latitudes.

The uncertainties in the chronologies of the Greenland and EAM records is very small (< 2 %) thus suggest statistic estimation of their correlation during the last 25 ka. Cross correlation (CC) of the EAM intensity and Greenland climate variability calculated by correlation of δ^{18}O 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 more significant synchronization (correlation ranging from -0.6 to -0.9) during period of 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. But both CC during these periods demonstrate occurrence of weak synchronization/or absence of significant correlation (within ranging at ±0.25) (Fig. 6). Significant synchronization was indicated also by CC between EAM-NGRIP during the Middle-Late Holocene. More discrepancies in both CC were observed over 19.5-16.5 ka, that may be explained by errors in ages measurements and/or by different atmospheric teleconnection between the EAM and the GISP2/NGRIP cores due to its differ locations in the Greenland. So 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., 2012).

5.3 NW Pacific productivity trends over the LGM-HE 1

Beside of the centennial–millennial productivity/environmental cycles, we find common NW Pacific productivity trends over the LGM and HE1 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/HE1 on nearly the 17.8 ka (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 HE1, 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 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 through time (Fig. 4). Severe environmental condition in the central Asia inferred from vegetation reconstruction (Bezrukova et al., 2011) (Fig. 5) promote to increase in winter sea ice covering consistently with high IRD accumulation in studied region inferred from CF and MS records (Fig. 4) that hamper productivity. It is in

concord 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 15.3 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 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 therefore nutrient supply into 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 HE1 (Max et al., 2014) based on the δ^{13}C foraminifera data from the intermediate water and radiocarbon-derived ventilation ages. However, rather constant CaCO$_3$ values in both cores (water depth 1924-2145 m) during LGM-HE1 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 HE1 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; 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 and rise of diatom production since ~15.3 ka indicated by most productivity proxies and Si-bio and color b* records with

culmination at sub-interstadial GI1-e of B/A warming was, likely, induced by decrease of sea ice influence and its spring melting favoring for weakening of surface stratification (Figs. 4 and 2). The timing of 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 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 kyr BP) due to the later diminish of sea-ice cover and later breakdown of spring/early summer surface water stratification (Gorbarenko et al., 2014).

4.1 Productivity patterns during the LGM-HE 1

Besides the centennial productivity/environmental events, similar NW Pacific productivity patterns are found in cores 41-2 and 12KL during the LGM and HE1 with some differences in different productivity proxies. During the LGM, most proxies demonstrate a minimum primary productivity in the NW Pacific without definite trends (Fig. 4). Severe environmental conditions in central Asia inferred from pollen data (Bezrukova et al., 2010) (Fig. 5) seem to be promoted an increase in winter sea ice formation and sea ice cover in NW Pacific, consistent with high IRD accumulation inferred from CF and MS records (Fig. 4), that might have inhibited productivity in the study area. It is also consistent with the minimum 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, the TOC and chlorin contents associated with the production of calcareous phytoplankton (mostly coccolithophores) show a significant increase concurrently to the diminished AMOC (McManus et al., 2004). The diminished AMOC resulted in a major cooling of the Northern Hemisphere and, most likely, reduced water evaporation in the N Atlantic and therefore Atlantic-Pacific moisture transport. This condition facilitates an overall

increase in surface water salinity, and decrease in surface stratification in the N Pacific, promoting an intensified ventilation of the intermediate water. The observed trends of productivity proxies are in concord with strong intensification of the intermediate-depth water ventilation in the N Pacific during HE1 (Max et al., 2014). However, fairly constant $CaCO_3$ values in both cores (water depth 1924–2145 m) during the LGM-HE1 do not indicate that the water ventilation penetrated to deep water in the N Pacific over that time interval, because carbonate concentration in the sediment is strongly constrained by the ventilation of bathed water (Yu et al., 2013). The productivity proxies such as Si-bio and color b*, associated with siliceous phytoplankton production (mostly diatoms), do not show significant trends during HE1 up to ~15.3 ka. The enhanced coverage of sea ice, shown by CF and MS records (Fig. 4), until 15.3 ka in the studied area probably lead to the overwhelmed production of diatom, due to the subsequent large spring–early summer surface water stratification. Both CF and MS records may represent IRD changes over the LGM-YD because the input of volcanic materials estimated in CF was insignificant during 21-12 ka compared to that of the Holocene (Fig. 4).

A sharp increase in the NW Pacific primary production, and a rise in the diatom production since ~15.3 ka indicated by most productivity proxies and Si-bio and color b* records with a peak at sub-interstadial GI1-e of B/A warming (Fig. 4), was likely induced by a decreased effect of sea ice and its spring melting, favoring a weakening of surface stratification. The timing of the decrease in the sea ice cover since ~15.3 ka is consistent with the regional surface water warming (Max et al., 2012). Such a pattern in productivity changes in the N Pacific and the Bering Sea during the glacial/interglacial transitions has been reported in previous studies (Caissie et al., 2010; Galbraith et al., 2007; Gebhardt et al., 2008; Gorbarenko, 1996; Keigwin, 1998) and was likely a persistent feature of the N Pacific and its realm, forced by the resumption of the AMOC at the B/A warming.

4.2 Centennial variations in productivity during the LGM-HE1-B/A

The identification of potential linkages between centennial climate changes in the Northern Hemisphere (NW Pacific, EASM, and N Atlantic/Greenland) and the climate changes recorded in the Antarctic ice cores is important for deepening our understanding of the mechanisms responsible for the timing and spatial propagation patterns that resulted from abrupt variability in global climate and environmental system. In order to test these linkages, the centennial productivity/climate events in the NW Pacific outlined by the productivity stack are compared with records from the Northern Hemisphere ($\delta^{18}O$ and Ca^{2+} of NGRIP, $\delta^{18}O$ of EASM, N

Atlantic IRD, Siberian climate) and from the Southern Hemisphere (Fig.5). It has been suggested that the nearly synchronous ice core $\delta^{18}O$ 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 Northern Hemisphere, where the EASM plays an important role (Ruth et al., 2007).

Similarity of glacial millennial-scale climate variability recorded in Chinese cave stalagmites and Greenland ice cores (Sun et al., 2012; Wang et al., 2001) implies a plausible influence of high-latitude climate of the Northern Hemisphere on the EASM by atmospheric circulation changes. Several main elements of atmospheric circulation, including the Intertropical Convergence Zone (ITCZ), northern westerly jet, AO and the SH, were previously considered as potential mechanisms linking abrupt climate changes in the N Atlantic and East Asia (Jin et al., 2007; Nagashima et al., 2011; Sung et al., 2006; Timmermann et al., 2007).

Apparent similarity of centennial climate and environment variability between the NW Pacific productivity events, EASM and Greenland records (Fig. 5) allow us to suggest that mechanisms responsible for their teleconnection were the same as on millennial scales. Remarkable similarity of sequence of the NW Pacific productivity events with the sub-interstadials of EASM records during the LGM-HE1 (Fig. 5) implies a strong common driver responded to their variations. Wu and Wang (2002) concluded that SH has provided direct and significant influence on the EAWM, particularly by sea level pressure and northerly wind along the East Asian Coast. Simultaneously, the SH strongly influences on the sea ice formation in the NW Pacific and marginal seas by the similar mechanisms like the wind intensity controlled by pressure gradient and winter air temperature at the sea level (Kimura and Wakatsuchi, 1999). Records of CF and MS, related with IRD accumulation, show that studied area off Kamchatka was undergone to the influence of sea ice during the LGM-HE1 (Fig. 4). Enhancement of SH, associated with abrupt climate cooling, led to an increase in terrigenous material delivery by sea ice from the coast and to a decrease in primary productivity by shrinking of productive season between events with increased productivity.

Correlation of the centennial changes in the NW Pacific productivity events / CsIs with Greenland sub interstadials during the LGM-HE1 was mainly observed but less clear, due to the discrepancy in constructed age models / or to whatever differences in atmospheric teleconnections (Fig. 5). There are some $\delta^{18}O$ differences between coeval $\delta^{18}O$ values in the Summit and NGRIP ice cores during the LGM-HE1, which were likely controlled by changes in the N American Ice Sheet volume and N Atlantic sea-ice coverage, resulting in the meridional discrepancy in the $\delta^{18}O$ of Greenland ice (Seierstad et al., 2014).

EPICA community members (2006) showed that methane synchronization of the EDML and the $\delta^{18}O$ of NGRIP reveal one-to-one alignment of each Antarctic warming with a corresponding stadial in the Greenland ice cores, implying a bipolar seesaw mechanism on millennial time scales. Since it was shown that Chinese and Greenland interstadials have occurred synchronously (Wang et al., 2001), therefore, Chinese interstadials (CIs) were also, likely, related to the Antarctic cold events. For example, warmer conditions at the Antarctic during 23.6–24.3 ka (coeval with Chinese sub-stadial CsS-GS3-1) were synchronous with abrupt climate cooling and an increase in dust content in the Greenland ice cores NGRIP, coeval with HE2 of the N Atlantic, and in phase with the weakening of the EASM (GS/CS-3.1) (Fig.5). The Antarctic cooling after 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 EASM interstadial CI-2 (Wang et al., 2001) (Fig. 5).

It has also been suggested that an index of monsoon intensity was controlled not only by the 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 EASM transports heat and moisture from the West Pacific Warm Pool (WPWP) to higher latitudes (Wang et al., 2001), the temperature gradient in the Southern Hemisphere "pushes" the northward propagation of EASM via the latitudinal/longitudinal migrations or expansion/contraction of the WPWP (Rohling et al., 2009; Xue et al., 2004). This also explains the difference in responses to the EASM and Greenland interstadials and sub-interstadials, because the migration of the WPWP may have occurred more slowly than the atmospheric circulation changes (Rohling et al., 2009; Xue et al., 2004). The changes in the $\delta^{18}O$ records of Chinese stalagmites were more gradual than in the $\delta^{18}O$ records of Greenland ice cores, and were more similar to the changes of Antarctic air temperature (Fig. 5). So, it is possible that forcing from low latitudes "push effect" on the EASM was additional mechanism in centennial productivity changes in the NW Pacific due to surface water amelioration. Although time resolution of the Antarctic $\delta^{18}O$ curve was not as high as ones from the Greenland and the EASM, records demonstrated in Figure 5 do not exclude one-to-one alignment of each Antarctic centennial cooling with related EASM sub-interstadial / NW Pacific productivity events.

We suggest that, in addition to the eight centennial productivity/environmental events during the LGM-HE1 established in the studied cores from the NW Pacific, other three abrupt

productivity/climate events likely took place in the NW Pacific, synchronous with CsIs outlined by the $\delta^{18}O$ records of Chinese stalagmites and the Greenland during the interval of 25–20 ka (namely CsI-GS2.1-11, CsI-GS2.1-10, and CsI-GS2.1-9) (Fig. 5).

During the B/A warming and resumption of the AMOC, four sub-interstadials (CsI-GI1-a to CsI-GI1-e) were clearly and simultaneously observed in the Greenland ice cores $\delta^{18}O$ (Björck et al., 1998) and dust records and EASM sub-interstadials synchronously with centennial productivity / environment events of the NW Pacific (Fig. 5). It is consistent with enhancement of the "pull effect" on the intensified EASM and therefore amelioration of the NW Pacific during boreal warm period, which implies a dominant control of Northern Hemisphere climate processes on the atmospheric circulation in high latitudes (Rohling et al., 2009). Related significant coeval changes in the atmosphere circulation with periodicity *ca* 0.4 ka exert strong influence on the climate and environment in ocean and continent of the Northern Hemisphere during the B/A (Bezrukova et al., 2010).

4.3 Centennial variations in productivity during the EH

During the EH the records presented here show an alternation of the four NW Pacific centennial events with lower and four ones with higher productivity, namely as CsS-EH-1 -CsS-EH-4 and CsI-EH-1 - CsI-EH-4, respectively (Figs. 4 and 5; Table 2). The low productivity events (CsS-EH-1 and CsS-EH-2) are likely correlated with Greenland cold events at 8.2 ka and 9.3 ka, respectively (Rasmussen et al., 2014). Also, the NW Pacific low productivity events (CsS-EH-1, CsS-EH-2 and CsS-EH-3) occurred synchronously with the EASM decrease and whatever climate cooling recorded in $\delta^{18}O$ of the Dongge cave stalagmite D4 (Dykoski et al., 2005) (Fig. 5). Therefore it may be suggested that during the EH the NW Pacific events with higher / lower productivity had occurred coeval with climate warming / cooling as well. The pollen-based reconstruction of the variability of the vegetation / climate from a well-dated core from south Siberia (Lake Baikal region) (Bezrukova et al., 2010) demonstrated nearly the same pattern of centennial variability during the EH (Fig. 5). Well-dated, high resolution lithological and geochemical results from the Yanchi playa (NE China) also clearly showed a sequence of three sharp cooling events at 8.2 ka, 9.9–10.1 ka, and 11.0–11.2 ka (Yu et al., 2006), quasi-synchronous with the NW Pacific productivity / climate events CsS-EH-1, CsS-EH-3 and CsS-EH-4. Yu et al. (2006) explained this correlation through linkages between the tropical Pacific and N Atlantic.

An alternation of the NW Pacific events with lower / higher productivity during the EH demonstrates a perfect correlation with periodicities of solar activity and the production of the

cosmogenic nuclides ^{14}C and ^{10}Be (Reimer et al., 2004) (Fig. 5). The production rates of these cosmogenic nuclides and residual atmospheric $\Delta^{14}C$ record are negatively correlated with total solar irradiance due to the strength of magnetic fields embedded into the solar wind (Hu et al., 2003). Small variations in solar irradiance could be responsible for pronounced changes in northern high-latitude climate and environments (Bond et al., 2001; Hu et al., 2003). The NW Pacific events of higher productivity occurred during increased solar irradiance and climate warming, indicating that variability of the solar irradiance was a potential driver of the climate and environmental changes in the NW Pacific during the EH. The low productivity / cold climate CsS-EH-2 event in records of atmospheric $\Delta^{14}C$ and the Greenland $\delta^{18}O$ ice core was marked by sharp cooling at its onset and termination with some warming during the transition (Fig. 5). The CsS-EH-4 event shows a similar pattern in records of productivity stack and $\delta^{18}O$ of the Greenland and Dongge cave D4, indicating fine structure of these cold events.

The influence of variations in solar output on hydrography of surface ocean in the subpolar N Atlantic during the Holocene was reported by Bond et al. (2001). The variability of subpolar N Atlantic ice drifting, recorded as the percentage of hematite-stained grains (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 Northern Hemisphere during the EH (Fig. 5).

The high resolution records of an alternation of the NW Pacific events with lower / higher productivity related with climate cooling / warming, demonstrating that centennial scale climate events during the EH were similar between the N Atlantic and NW Pacific, possibly because of the close linkages of sun-ocean-climate, consistent with earlier conclusions (Bond et al., 2001; Hong et al., 2009; Hu et al., 2003).

4.4 Cross-correlation of the N Atlantic-NW Pacific climate variability

Since whether N Atlantic-NW Pacific climate and hydrological in-phase or out-of-phase linkages are still under debate, empirical data obtained from sediment cores off Kamchatka offer the provision for clarifying this issue at high resolution. Here we provide comparison of the productivity stack of core 41-2, responsible for NW Pacific environmental variability, and $\delta^{18}O$ records of the NGRIP ice core, responsible for the Greenland / N Atlantic climate changes (Rasmussen et al., 2014). Cross correlation of these records using moving windows at 2000 years shows more significant synchronization (from -0.6 to - 0.9) from 15.8 ka up to 10.8 ka confirming strong atmospheric teleconnections between the NW Pacific and the N Atlantic during this period (Fig. 6). Cross correlation during early (19 ka - 15.8 ka) and later periods (10.8

ka - 9 ka) indicates weak NW Pacific - N Atlantic linkages, but do not support the out-of-phased hypothesis.

6. Conclusion

This study presents high resolution records of a suite of productivity proxies (TOC, $CaCO_3$, chlorin, color b*, Ba-bio, Br-bio, Si-bio), sediment lithological (CF) and magnetic properties (PM, MS and RPI) from a sediment core 41-2 taken from the NW Pacific (East Kamchatka slope). Presented results reveal a sequence of 13 centennial-millennial scale regional productivity increased/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 ^{14}C dating, with more age control points identified by correlating the centennial-millennial events of the productivity proxies, RPI and PM of studied 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 were transferred successfully to core 41-2. Based on projected radiocarbon datum of both cores on the $\delta^{18}O$ record of the Chinese caves stalagmites (Wang et al., 2008) the close time correlation of NW Pacific productivity events with sub-interstadials in summer EAM over the 20-8 ka was used for further fine age model construction. In results, established three NW Pacific abrupt productivity increase events are tightly linked to CsIs during the LGM (20-17.8 ka), three during HE1 (17.8-14.7 ka), and four during B/A warming and three over the EH.

Presented reconstruction suggests that the NW Pacific centennial-millennial productivity increase/summer EAM intensified events are positively correlate with Greenland warming, indicating a tight atmospheric teleconnection between the N Pacific and the N Atlantic, most likely by ITCZ shifting and reorganization of the northern westerlies and 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 to $\delta^{18}O$ records of the EDML ice core and of the Chinese

stalagmites on the centennial-millennial time scale over glacial and deglaciation suggests a Southern Hemisphere "push" effect on the boreal summer EAM propagation.

During the LGM our results indicate productivity minima that are consistent with previous observations in the NW Pacific, severe vegetation/climate condition in the central Asia (Bezrukova et al., 2011) and therefore strong regional sea ice covering are consistent with the hypothesis that proposes a strong stratification prevented nutrients supply for supporting productivity in surface waters (Gebhardt et al., 2008). The productivity proxies associated with calcareous phytoplankton productions show increased trends since 17.8 to 15.3 ka. These trends share the same structure and the rate of changes of 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 and Atlantic-Pacific moisture transport, which 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 supply into the euphotic layer. Especially noticed is that a sharp increase of NW Pacific primary production since nearly 15.3 ka was indicated by nearly all productivity proxies accompanied by some climate warming and decrease in sea ice covering. Subsequent 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 of diatom production.

The synchronicity in changes of the NW Pacific centennial-millennial productivity events with the δ^{18}O of Chinese stalagmites calcite, Greenland ice cores and with the nuclide ^{14}C production during the EH (Figs. 4 and 5) imply that variability of the NW Pacific climate is tightly linked to summer EAM and N Atlantic/Greenland climate changes. The linkage is likely driven effectively by atmospheric coupling mechanisms forced by solar irradiance variability. Regardless what specific driving mechanisms are responsible for the linkage, the centennial-millennial and sub-stadial/interstadial productivity variability in the NW Pacific 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, synchronous with the Greenland/N Atlantic short-term changes.

5. Conclusions

This study presents high resolution records of productivity proxies (TOC, $CaCO_3$, chlorin, color b*, Ba-bio, Br-bio and Si-bio), sediment lithological, and magnetic properties from sediment cores, 41-2 and 12KL, taken from the NW Pacific. Results presented here reveal 16 centennial regional productivity events during the LGM-EH (20–8 ka) in the NW Pacific. Four NW Pacific abrupt productivity increased events are linked to CsIs during the LGM (20–17.8 ka), four ones during HE 1 (17.8–14.7 ka) and four ones during the B/A. An alternative occurrence of four centennial events with lower and higher productivity was established during the EH.

On the basis of age models of cores 41-2 and 12KL, we suggest that NW Pacific centennial events of increased productivity occur synchronously with sub-interstadials of the EASM. These NW Pacific events and EASM sub-interstadials are positively correlated with Greenland abrupt warming, indicating an atmospheric teleconnection between the NW Pacific and the N Atlantic during the LGM-HE 1-B/A.

Remarkable similarity of the sequence of productivity events recorded in the NW Pacific with the EASM sub-interstadials during the LGM-HE1 implies that SH is a strong driver responded to their variation. The comparison between our stacked productivity with the $\delta^{18}O$ of the EPICA, NGRIP and EASM suggest that another mechanism associated with temperature gradient in the Southern Hemisphere ("pushes effect") may be responded to the EASM sub-interstadials and subsequent variability in productivity events in the NW Pacific on centennial time scale during the LGM-HE1.

During the B/A warming and resumption of the AMOC, synchronicity between the productivity events, EASM sub-interstadials, and the $\delta^{18}O$ and dust records in the NGRIP is consistent with enhancement of the "pull effect" on the monsoon's intensity, which implies a dominant control of atmospheric processes on the productivity and climate of the NW Pacific.

During the EH, the high resolution records of an alternation of productivity events with lower / higher productivity related with climate cooling / warming, reveal that centennial climate events were similar between the subpolar regions of the N Atlantic and NW Pacific, and were controlled by mechanisms of sun-ocean-climate linkages.

In summary, the NW Pacific results presented here indicate a tight linkage and coherent pattern of centennial - millennial scale climate changes during the LGM-EH, which may serve as a template in high resolution paleoceanography and sediment stratigraphy of the moderate-high latitudes in the NW Pacific.

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Figure captures

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 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, 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 (cooling) events according to most productivity proxies and decreases in PM.

Fig. 2. Records (from bottom to top) of the original and detrended productivity stacks, PM, color b*, TOC, chlorin, CaCO$_3$, Ba-bio, Si-bio, and Br-bio versus depth. Preliminary boundaries of the B/A warming, YD cooling, and Holocene are shown according to general variability of productivity in the NW Pacific, Sea of Okhotsk, and Bering Sea (Galbraith et al., 2007; Gorbarenko, 1996; Gorbarenko and Goldberg, 2005; Keigwin, 1998; Seki et al., 2004). AMS ^{14}C data (calendar ka) were shown at the base. Blue bars indicate cold periods / lower productivity events. Orange bars indicate warm periods / high producitivity events.

~~Fig. 3. Correlation of the increased productivity event cycles in the cores 41-2 (low panel) with ones of 12KL (middle panel) versus depth with sub-interstadials of the $\delta^{18}O$ calcite of Chinese stalagmites (Wang et al., 2008) (upper panel). Productivity cycles for cores 41-2 based on stack of productivity proxies and PM records (Fig. 2) and 12KL (Ca, chlorin, color b* and PM records) were correlated according to sychronously 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 shown at the base. According to correlation of the productivity cycles and curves of RPI, the red lines related with key time points of core 12KL (middle panel) and the green lines with 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). Color b* and Ca content, AMS ^{14}C 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. Yellow (blue) bars depict the centennial-millenial increased productivity/environmental ameloiration (cooling) events according to most productivity proxies and decreases in PM.~~

Fig. 3. Age model of core 41-2. Low panel: (a) RPI, PM and productivity stack of core 41-2 versus depth. (b) Middle panel: RPI, color b*, chlorin, Ca and PM of core 12KL versus depth. (c) Upper panel: $\delta^{18}O$ calcite of Chinese cave stalagmites (Dykoski et al., 2005; Wang et al., 2008) over the last 20 ka. The correlation of productivity events between core 41-2 and 12KL was established according to correlation of productivity stack of core 41-2 with productivity proxies of core 12KL and the RPI records of both cores. AMS ^{14}C data of core 12KL (red lines) were projected to the core 41-2 according to correlated productivity events. A close correlation of the productivity events with sub-interstadials in the EASM becomes apparent after projection of the radiocarbon data on the age scale of EASM. Green lines correlate EASM sub-interstadials with productivity events. Orange and blue bars are as in Fig. 2.

~~Fig. 4. High resolution variability of the productivity and lithologic proxies in NW Pacific (off Kamchatka) over the 21-8 ka period. CF percentages, MS, paramagnetic magnetization and color~~

b*, chlorin, CaCO₃, TOC 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 increase in most productivity proxies are clearly associated with the abrupt summer EAM intensification revealed in Chinese cave stalagmites called as sub-interstadial and less pronounced with short-term events in the Greenland ice cores δ¹⁸O records. Linear trends shown 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. 4. High resolution variability of the productivity and lithologic proxies in the NW Pacific during 21–8 ka. Volcanic particles, CF, MS, PM, color b*, chlorin, CaCO₃/Ca, and TOC determined in cores 41-2 (blue lines) and 12KL (red lines) are shown from bottom to top. Δ18O records of EASM (Wang et al., 2008) and NGRIP (North Greenland Ice Core Project members, 2004) are shown at the top of the figure. Linear trends are shown for productivity and lithologic proxies during 20-17.8, 17.8-15.3, and 15.3-14.7 ka periods. Red dashed line marks the boundary in productivity and lithologic trends during HE1 at 15.3 kyr. Orange and blue bars are as in Fig. 2.

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 δ¹⁸O calcite of Chinese cave stalagmites (Dykoski et al., 2005; Wang et al., 2008) characterized EAM activity; the residual atmospheric Δ¹⁴C record of around 2000-year moving average (Reimer et al., 2004) indicated solar irradiance variability; oxygen isotope EDML records after methane synchronization with North Greenland ice core (EPICA Community Members, 2006); the petrologic tracer of drift ice in N Atlantic (Bond et al., 2001); the δ¹⁸O and Ca²⁺ records in the Greenland NGRIP and GISP 2 ice core indicated air temperature and dust variability on GICC05 age scale (Rasmussen et al., 2014), pollen reconstructed Southern Siberia environment changes (Lake Kotokel, Lake Baikal region) (Bezrukova et al.,

2011); productivity stack for core 41-2. 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 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. 5. Compilations of Northern and Southern Hemisphere climate records, solar activity, NW Pacific productivity events, and vegetation records from the southern Siberia during the last 25 ka. From bottom to top: absolutely dated δ^{18}O calcite of Chinese cave stalagmites (Dykoski et al., 2005; Wang et al., 2008); the residual atmospheric Δ^{14}C record of around 2000-year moving average (Reimer et al., 2004); δ^{18}O EDML records after methane synchronization with the N Greenland ice core (EPICA Community Members, 2006); the petrologic tracer of drift ice in the N Atlantic (Bond et al., 2001); the δ^{18}O and Ca^{2+} records in the Greenland NGRIP ice core indicated air temperature and dust variability on GICC05 age scale (Rasmussen et al., 2014), pollen reconstructed Southern Siberia environment changes (Lake Baikal region) (Bezrukova et al., 2010) and productivity stack for core 41-2. Orange and blue bars are as in Fig. 2. Centennial events with increased productivity are associated with sub-interstadial of the EASM and with increasing input of solar irradiance during the LGM-B/A and EH short-term warmings, respectively. The correlation between short-term increased Greenland temperature (NGRIP ice core) and a decreased Antarctic temperature is less pronounced but seems to be marked as well.

Fig. 6. Cross correlation of the EAM and Greenland climate variability calculated by correlation of δ^{18}O values of the calcite of Chinese stalagmites (Wang et al., 2008) with ones of the NGRIP (lower panel) and GISP-2 (upper panel) ice cores (Rasmussen et al., 2014) by 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 moving window 3000 years is negative during period of 16.5-8.5 ka and insignificant or weakly negative during earlier and later periods of 25-16.5 ka and of 8.5-0 ka confirmed the EAM and the Greenland synchronicity.

Fig. 6. Cross correlation (CC) of the NW Pacific productivity stack and δ^{18}O records of the NGRIP (Rasmussen et al., 2014), using moving windows at 2000 years. Yellow bars depict the

CC within range ±0.25. Vertical black lines distinguish an interval from 10.8 to 15.8 ka with significant CC (from -0.6 to -0.9) from less significant CC during earlier and later intervals indicating the synchronicity climate changes between the N Atlantic and NW Pacific.

Table 1. AMS ^{14}C data in monospecies planktic foraminifera *N. pachyderma* sin. and benthic foraminifera *Epistominella pacifica* and *Uvigerina parvocostata* of core 41-2. All measured AMS ^{14}C data were calibrated by Calib 6.0 (Stuiver and Reimer, 1993) with Marine13 calibration curve (Reimer et al., 2013) with a surface water reservoir ages of 900 years (Max et al., 2014). In case of using benthic foraminifera for dating, we accept difference in paired benthic-planktic foraminifera ages equals to 1,400 years, based on unpublished data and total regional results of Max et al. (2014). All radiocarbon ages were converted into calibrated 1-sigma calendar age.

Table 2. Centennial events with increased / decreased productivity during 25-8 ka in core 41-2 and the average ages according to the correlations between productivity events and the EASM sub-interstadials and sub-stadials (CsI/CsS).

Table 3. The age controlling points of core 41-2 is derived from available AMS ^{14}C data of core 41-2, projection AMS 14C age of core 12KL, and tie points through correlation between increased productivity events and EASM CsIs (Wang et al., 2008). One AMS ^{14}C datum of core 12KL at depth of 706 cm was accepted according to the Tiedemann/Max age model 2 (Max et al., 2012, 2014).