Dear Dr. Kiefer,

thank you very much for asking us to submit a revised version of our manuscript. Please, find below how we finally addressed your comments as well as the reviewer's comments in this new version of the article. Your comments and the reviewer's comments are written in black, our replies are blue. All line numbers refer to the tracked-changes version of the article.

In addition to suggested changes by the reviewers we rearranged the introduction (section 1) and parts of the discussion in order to improve the logic and the flow of the text. Also, most parts of section 3.2 (which describes the lipid extraction procedure) were replaced by a citation (Meyer et al., 2016).

Yours sincerely,
Vera Meyer

Reply to Editor's comments:

I do notice that you responded to Ref#2's question about the selection of records taken into consideration and their geographical distribution also simply by adding references. I wonder whether this will self-explain your reasoning or whether some formulated explanations wouldn't be more appropriate.

We agree with the reviewer's concern that if the terrestrial records from Alaska are included the marine records from the NE Pacific should be mentioned as well. Therefore, we added references for records from the NE Pacific. In order to clarify that both the NW Pacific and NE Pacific are meant we write "N Pacific".

As a minor editorial point, I would ask you to consider minimising abbreviations in the text, especially local ones, such as BLB and AS.

Full expressions of BLB and AS are given.

Reply to reviewer #1

Dear reviewer,

thank you very much for your detailed and constructive review on our manuscript. Please, find below how we addressed your comments in the revised version. Your comments are given in black, our replies in blue.

Specific comments

Line 166: list the number of samples analyzed and the approximate or average depth and time sampling resolution
Done.

Line 204: How exactly was the standard deviation measured? Is this for this lab or labs in general? Was a standard measured regularly among sample injections, or were the repeat measurements of the samples? What is the pooled standard deviation of samples that were run

multiple times (if any?...and if none, then that is important to report)? Please clarify in the text.
The standard deviation derives from repeated measurements of a standard sediment extract (n=7) which had been treated in the same way as the samples. Repeated measurement for the samples of core 12KL were not possible, because of small amounts.
We mention the standard sediment in line 205.

Line 215: it is critical to report the calibration error, which is much larger than the analytical error. While relative changes in a single record are likely real, the absolute temperature change is difficult to pinpoint because of this large calibration error. Please clarify in the text.
The calibration error (± 5°C) as well as the analytical uncertainty of our measurements is noted in section 3.4. We agree with the reviewer that absolute changes are difficult to pinpoint but that relative changes in the records are real and that the latter make the important information of the data presented in our study. Therefore, whenever absolute estimates of temperature changes appear in the text they are presented with a ~. (e.g. ~7.5°C).

Line 230: does the word "glacial" belong here? it doesn't make sense. Please clarify in the text.
No, the word does not belong here. Deleted. Thanks!

Line 238-239: what parameters were used in this simulation? While the reader can check the references given here, it would be good to briefly summarize the parameters that were used to force the model and the parameters that were changed between the glacial and preindustrial runs (ice volume? sea level? orbital forcing? Greenhouse gases? land cover? etc: : :.) Please clarify in the text. Ice volume, sea level, and land cover are of particular importance for this region, where a large amount of land was exposed during the LGM.
The following paragraph is included:
"External forcing and boundary conditions are imposed according to the protocol of PMIP3 for the LGM (available at http://pmip3.lsce.ipsl.fr/). The respective boundary conditions for the LGM comprise orbital forcing, greenhouse gas concentrations (CO_2=185ppm; N_2O=200ppb; CH_4=350ppb), ocean bathymetry, land surface topography, run-off routes according to PMIP3 ice sheet reconstruction and increased global salinity (+ 1 psu compared to modern value) to account for a sea-level drop of ~116 m. The glacial ocean was generated through an ocean-only phase of 3000 years and coupled phase of 3000 years (LGMW in Zhang et al., 2013). The land cover is calculated interactively in the climate model which has an interactive land surface scheme and vegetation module (Brovkin et al. 2009). The modular land surface scheme JSBACH (Raddatz et al., 2007) with vegetation dynamics (Brovkin et al., 2009) is embedded in the ECHAM5 atmosphere model. The background soil characteristics (which are described in Staerz et al., 2016) are set to the values which are closest to the pre-industrial land points."

Line 253: what does "integrated" mean? is this the model spin up? was this done twice, once for each the LGM and Pre-Industrial runs? Please clarify in the text.
Integration means "simulated years".
In order to clarify we write: "For both, PI and LGM conditions, the climate model was integrated twice for 3000 model years and provides monthly output (Wei et al., 2012; Wei and Lohmann, 2012; Zhang et al., 2013)."

Line 282: Because this record is not in the North Atlantic, it would be best to avoid using terms that are related to North Atlantic climate change (ie. Bolling Allerod) in this results-oriented portion of the paper. When the authors later discuss links with the North Atlantic, these North-Atlantic-based terms can and should be introduced.
We replace Atlantic-related terms by dates. For example: "…until the beginning of the Bølling/Allerød" turns into:"…until 14.6 ka BP."

Line 311: It seems to me that the change from exposed land during the LGM to ocean during the PreIndustrial run over the land bridge would be a source of large changes in modeled SAT. This aspect is important to address, not only how this is handled in the model (is this exposed land in the LGM simulation?), but also how this could affect SAT in the model, and whether that is similar to the real-world effects. I would question whether these anomalies are even meaningful, and would need more explanation of what the changes mean, because of the changes from land to ocean surface.
As already mentioned in the reply to the comment on line 238-239, we add a paragraph describing the model setup in more detail. The effects of the exposed land in the model and the proxy world are addressed in the discussion (lines 505-520). Moreover, we show land boundaries for LGM and PI conditions. This clarifies that these anomalies occur over exposed land in the model.

Line 341: using slashes to indicate opposite effects is confusing. I suggest removing them and adding a phrase at the end of the sentence, like "with the opposite effect occurring with low terrigenous input". See [Robock, 2010] for a humorous take on how confusing it can be to use slashes to express opposites.
Lines 330-340 are rewritten and the slashes have been removed.

Line 346: do the authors mean "in marine areas where brGDGTs are thought…"? Please clarify.
Yes. Sentence is rephrased.

Line 360: what are the uncertainties or standard deviations on these temperature observations? Please clarify.
The calibration error is ±5°C which is noted in section 3.4. In order to remind the reader at this point in the text we add the error to the CBT/MBT' temperature estimates in those lines.

Line 368: cite PMIP?
Done.

Line 390: clarify whether this attribution was by previous studies, or by this study.
By previous studies. Text clarified.

Line 404 and others: Clarify in the text what proxy was used to produce this Sea of Okhotsk SST reconstruction.
The sentence encompassing lines 404 and 405 begins with: Alkenone-based SST… This implies the application of $U^{K'}_{37}$. In order to specify we replaced "Alkenone-based" by "$U^{K'}_{37}$". In all other instances within lines 404-412 we mention the TEX^{L}_{86} proxy, now.

Line 411: 1°C is well within calibration error of these proxies, and is important to mention in the text.
As the reviewer pointed out in his comment on line 215 relative changes in records based on those proxies are likely real and significant but absolute values of those changes are difficult

to pinpoint due to large calibration errors and due to different types of calibrations. However, the important point of the paragraph encompassing lines 400-410 is that at site 12KL the relative SST change is smaller than in the marginal seas when the same proxy and the same regional calibration are applied. Therefore, this regional difference is significant although the 1°C change at site 12KL is well within the calibration error of TEX^{L}_{86} (1.7°C Seki et al., 2014). We do not change the paragraph.

Line 454-458: It seems as if the final two sentences in this paragraph say opposite things. Can this be clarified?
In order to clarify we append an additional paragraph to line 458.

Line 480: How robust or meaningful is this warmer-than-present temperature, given that there were large changes in surface conditions (land to ocean) from the LGM to present? I would expect summer temperatures to be quite warm over land, as dark soils can retain quite a bit of heat, whereas sea water remains much cooler. It is important to address the changing surface conditions in the text.
We include the land boundaries used in the PI and LGM simulations into Figure 4a and 4b (as requested in the reviewer's comment on Figure 4). Based on these modifications we also reorganized and expanded sections 5.2.2 and 5.2.2.1.

Line 531: It might clarify to add the following wording: "potentially explain the mismatch between model and proxy…"
Changed.

Line 540: does the term "in the surrounding seas" refer to the Pacific or the Atlantic? It is unclear, as both are mentioned in this section. Please clarify.
It refers to the surrounding seas of Kamchatka, i.e. the Bering Sea, the subarctic NW Pacific and the Sea of Okhotsk. We put "in the surrounding seas of Kamchatka (Bering Sea, NW Pacific, Sea of Okhotsk)" along this line.

Line 553: in addition to the age model error, the authors must also discuss error in marine reservoir corrections, and it would be helpful show age uncertainties in Fig. 2 time series.
This is an important point, thanks. In section 3.1 we add a short paragraph describing the uncertainties introduced by the AMS dating as well as by the assumptions for reservoir ages.

In line 553, we refer back to this paragraph.

Concerning age uncertainty estimates in Figure 2, we do not include any graphical features, e.g. bars, as those would make the figure look very busy. The information on uncertainty is given in section 3.1.

Line 562: clarify what proxy is used to reconstruct SST in the NW Pacific.
Paragraph rewritten to clarify the content. No proxies are mentioned here.

Line 562-566: this sentence is unclear, please rewrite and clarify.
Lines 558-570 are rewritten.

Line 568: What does AS stand for? Perhaps just spell out the full term.
Thanks, "AS" stands for "Alaskan Stream". We decided to use the full term instead of the abbreviation everywhere in the text (see Editor's comments).

Line 570: why would ocean waters place a "restriction" on atmospheric teleconnections?

Can this be clarified?
This has been elaborated in Meyer et al., 2016 on the basis of two SST records from the Western Bering Sea and the NW Pacific. Lines 558-570 are rewritten

Line 613: I don't understand how the HTM is delayed on Kamchatka relative to other parts of Siberia, as both have the same beginning time (9ka). Can this point either be deleted or made more clear?
Since our paper focusses on the deglaciation and the LGM, the Holocene section was shortened. The lines encompassing the delay of the HTM are removed. For the same reason the pollen record from Kamchatka is removed from Figure 2.

Lines 620-623: these speculative connections with the North Atlantic seem like a stretch and could be explained by other, regional climate forcing mechanisms. Perhaps it would be best to remove these sentences?
These lines are removed.

Lines 638: It is unclear what this sentence means. Please clarify.
The sentence deleted.

Fig. 2: Plot age and proxy uncertainty envelopes for all data from core 12KL. Proxy uncertainty includes analytical uncertainty (relatively small) and calibration uncertainty (quite large, relative to the signal). This is important to report.
Since the calibration error is relatively large it would require a large y-axis for the MAT_{ifs} record. As a result the figure would probably become too large to fit on one page. Since the calibration error as well as analytical uncertainty are reported in section 3.4. nothing is changed.

Fig. 4: show the model LGM land boundaries and the PI land boundaries. Are these annual or summer anomalies? Clarify in the figure caption.
The figure shows boreal summer (JJA) anomalies. This is added to the caption. Furthermore, we include the land boundaries applied to the PI and LGM simulations into Figures 4a and 4b:

Figure 4a) COSMOS-simulation for the JJA SLP-anomaly over Beringia and the N Pacific during the LGM (21 ka) relative to PI. Arrows represent the wind anomaly.

4b) COSMOS-simulation for the SAT-anomaly together with the and wind-anomalies during JJA

Technical corrections:
Line 12: Branched Glycerol…does not need to be capitalized
Done.

Line 44: clarify what "next to" means: rather than? or in addition to?
It is meant in the sense of "in addition to". "Next to" is replaced by "in addition to" (see line 108)

Line 59 (and elsewhere in the text): I think the authors mean 150°W here, and this same typo is made elsewhere (e.g., line 584).
Yes, there is a typo, thanks for pointing out. "150°E" is the correct term. Changed everywhere.

Line 128: clarify what "over the northern shelves of central Beringia" means. Is this a geographic location? Could this be highlighted on a map or described in more clear terms?
This describes the geographic location of the average position of the EAT. In the revised version we write "over the Chukchi Shelf" instead of "shelves of central Beringia". As the Chukchi Shelf is indicated on the map in Figure 1, this should clarify.

Line 270: it might help to add the word "respectively" to the end of the sentence that lists the percentages.
Done.

Line 281: change "with approx." to "at approx."
Done.

Line 293: Add "North" before "American continent"
Done.

Line 303: remove the w in "now"
Done.

Line 311: it might be more clear to say that the SAT anomaly becomes stronger or becomes more pronounces from east to west (because the anomaly is actually decreasing from east to west).
Done.

Line 333: this is an incomplete sentence.
Indeed. Sentence completed.

Line 363: add comma between climate and according
Done.

Line 365: change 'computer' to 'general circulation'
Done.

Line 369: change "ice caps" to "ice sheets"
Done.

Line 371: is CO2atm defined prior to this? If not, then define here.
Done

Line 379: add "summer" between present and conditions.
Done.

Line 412: define what "it" refers to.
Sentence removed.

Line 622: change "were as high as at present" to "were similar to present temperatures" or something to that effect.
Done.

Line 623: remove "a" before "stronger-than-present"

Done.

Reply to reviewer #2

Dear reviewer,

Thank you very much for constructive and detailed review. Please find below how your comments are addressed in the revised version of our manuscript. Your comments are given in black, our replies in blue.

Abstract Line 14: Rather than 'western continental margin off Kamchatka/marginal Northwest Pacific ' suggest 'western continental margin off Kamchatka in the Northwest Pacific'
Changed

1. Introduction Line 30-35: Long, awkward sentence. Suggest reworking for clarity.
Sentence has been rewritten (see lines 103-110).

Line 40: Unsure why this sentence begins with 'Particularly' in context of previous sentence.
During the reorganization of the introduction, the sentence has been removed.

On line 42: Statement that majority of sea surface temperature records from the subarctic NW Pacific and marginal seas mirror N. Atlantic climate oscillations needs to be qualified. I am assuming that this claim pertains to millennial scale N. Atlantic climate oscillations as recorded from ice core d18O? If so, Caissie et al. 2010 reference is for a surface ocean temperature record of multi-millennial scale resolution with very limited chronological control that bears little resemblance in structure to NGRIP d18O outside of a crude transition from apparently full glacial to interglacial conditions between 12-11 ka. Of the 6 records from the 'NW Pacific and marginal seas' presented by Max et al., 2010, while the nearly all the color b* records resemble deglacial NGRIP d18O in structure, only one of the attendant SST records (the NW Pacific core SO201-12-KL that is also the subject of this paper) looks anything like NGRIP d18O at millennial scales. I can't comment on the Meyer et al. reference as it's unpublished.
If correct, this rather sweeping assertion that NW Pacific SST mirrors N. Atlantic climate has fairly important implications vis-a-vis the following suggestion that N Atlantic teleconnections control deglacial temperature development in the N. Pacific. However this assertion seems poorly defended by the references offered in the text at this point and at the very least needs further qualification/elaboration.

We agree that the statement appears not well defended as the reference list is incomplete. Therefore, we added more references, also from the NE Pacific (Barron et al., 2003; Praetorius and Mix, 2014; Praetorius et al., 2015), into the introduction and also into the discussion. Together with the references listed, the current state of the art will be well represented. In doing so, the idea that the atmospheric teleconnections with the N-Atlantic were important for deglacial climate change in the N-Pacific realm, will be much better defended.
Note that during the reorganization of the introduction this paragraph was shortened (see lines 89-100). This was done as it contained too much details which are all repeated in the discussion.

The Meyer et al., submitted is now published (Meyer et al., 2016).

Line 45: In the marine environment you only address records from the broader NW Pacific, but then for terrestrial records you include records from the Alaskan portion of Beringia. Why is there no discussion of the well-dated marine records of climate from the NE Pacific, or alternatively, why are the terrestrial Alaskan records being included in this discussion?
See comment on line 42. We will include references for the SST development in the NE Pacific and refer to the N Pacific as a whole. (see lines 87-90).

2. Regional Setting Line 126: Suggest replacing 'which are' with a comma.
Done.

Line 131: Why is Jet capitalized? Should it be 'westerly jet stream'? Similarly 'Jetstream' in line 134 should also be two lowercase words.
Changed.

Line 140: Add comma after 'ranges'.
Done.

Line 142: Would read better as 'Mean temperatures averaged for the entire Peninsula range from: : :'. Alternatively, place a comma after 'Peninsula'.
Changed.

3. Materials and Methods 3.1 Core material and chronology
Although you reference Max et al. (2012) for details of chronology, as it's highly pertinent to this paper it would be nice to have some basic information offered on the core length and the number of radiocarbon dates that constrain accumulation. Similarly, as these results are the subject of another paper, a mention of the mean sedimentation rates in the Holocene and deglacial sections of the core (properly cited) would be useful to the reader.
This information will be included into the paragraph:
"Age control is based on accelerator mass spectrometry (AMS) radiocarbon dating of planktic foraminifera (Neogloboquadrina pachyderma sin; 9 dates in total) as well as on correlations of high-resolution spectrophotometric (color b*) and X-ray fluorescence (XRF) data of different sediment cores from the NW Pacific, the Bering Sea and the Sea of Okhotsk (Max et al., 2012). The correlation allowed to transfer AMS results from core to core, which provided 10 more age control points for site 12KL (Max et al., 2012).
Based on the age model by Max et al. (2012) Holocene, deglacial and glacial sedimentation rates are 39, 79 and 59 cm/ka, respectively, allowing to investigate climate change on multicentennial to millennial timescales (Max et al., 2012). The core has a length of 11.78 m representing the past 20 ka (Dullo et al., 2009; Max et al., 2012).
It was sampled in 10 cm steps providing an average resolution of approximately 200 years between samples (Meyer et al., 2016).

3.2 Lipid Extraction Line 176: No need for a comma after n-hexane.
Section has been shortened by citing Meyer et al (2016) for sample processing as we used the same extracts as these authors.

3.4 Temperature determination

I'm unclear from this how the BIT-index controls for GDGT's from fresh water environments?
The BIT-index is a means to estimate the relative abundance of brGDGT (terrigenous) vs isoprenoid GDGTs (marine) in marine sediments and is used to estimate terrigenous input to the sediments. It does not distinguish between soil or fresh water derived GDGTs. Nothing is done here, since the BIT index is interpreted in section 5.1.

In this and previous (3.3) section, in many locations in the text I'm unclear on what precipitates the use of the abbreviation GDGT as opposed to brGDGT? I would have guessed it was branched versus all Glycerol Dialyl Glycerol Tetraethers, but in some cases (if I'm not mistaken) GDGT appears to be used interchangeably with brGDGT.
Really this comment could extend to entire manuscript.
In section 3 "GDGT" is used for the total GDGT distribution comprising isoprenoid and branched GDGT. "brGDGT" is used when only brGDGT are intended to be addressed. If specific brGDGTs are mentioned (e.g. GDGT III) the "br" is not indicated in order to keep consistency with the common nomenclature in the literature.
In section 4. "GDGT" is exchangeable with "brGDGT", indeed. In the revised version "brGDGT" is used everywhere.

Line 225: pluralize 'sample'. Also no need for 'present'.
Done.

4. Results 4.1 Concentrations and fractional abundance of brGDGT
It would seem to me that Figure 3 (and the discussion of it) should precede Figure 2 in the text.
We agree that there is reason to let Figure 3 precede Figure 2, because in sections 4 and 5 fractional abundances are discussed before the temperature evolution. However, in section 4 and 5 the concentrations of ΣbrGDGT and the BIT-index are discussed prior to the fractional abundances (and the concentrations and BIT-index are shown in Figure 2). This order is required by the logic of section 4.1 where the low BIT index is the reason for a detailed discussion about the sources of brGDGT in core 12KL. The fractional abundances are used to evaluate the sources. In order to keep a consistent organization throughout sections 4 and 5 we decided to introduce the results for concentrations (given in Figure 2) prior to the results for fractional abundances (Figure 3). This requires Figure 2 to precede Figure 3.

4.2 Temperature development over the past 20 ka

Line 277: This is a very narrow definition of the late Holocene (1 ka BP), and it only affords you one data point in the record of 12KL to compare to the dozen or so available for the 2 ka window afforded the glacial (18-20 ka BP). Perhaps consider broadening the definition of 'late Holocene' and when presenting a surface temperature include a standard deviation that encompasses both analytical/calibration error as well as observed variability over that time interval.
Sentence was rephrased without giving age ranges for either the LGM or the Holocene.
We do not add any uncertainties to absolute values in the text but mention the calibration error as well as the analytical uncertainties in section 3 (methods). All absolute values are given as approximations (e.g. ~7.5°C) and this does not necessarily require to present the value together with the uncertainty. Also, the analytical error (0.1°C), or errors imparted by variability over a time interval (0.3°C), are negligible compared to the calibration error (5°C). So, the order of magnitude of the uncertainties would be the same for every value (~5°C).

Therefore, it should be sufficient to mention the calibration and analytical errors once in the method section.

Also, here and every future instance, why is approximately abbreviated?
Done in every instance. Sometimes replaced by ~.

While I don't doubt that the glacial temperatures are statistically 'the same' as those in the late Holocene, this could easily be presented quantitatively.
See comment on line 277.

Line 279: In this and every instance throughout the paper, when giving a temperature, present that value in the context of its uncertainty.
See comment on line 277.

Line 279-282: This pair of sentences is awkward and read poorly. The discussion of the single warm data point at 16 ka reads like a stream of consciousness as opposed to a well-digested scientific observation.
Section is rewritten.

Line 283: If you're going to present ages down to the century scale, you need to include estimates of temporal error that reflect the chronological control of the core.
We include a discussion of age-model uncertainties into section 3.1 where the achievement of age control is described.
"Max et al. (2012) converted radiocarbon ages into calibrated calendar ages using the calibration software Calib Rev 6.0 (Stuiver and Reimer, 1993) with the Intcal09 atmospheric calibration curve (Reimer et al., 2009). A constant reservoir age of 900 years was assumed for the entire time-interval covered by the core (Max et al., 2012). The uncertainty of AMS dating was smaller than ± 100 years (Max et al., 2012). Another source of uncertainty are changes in reservoir ages of the surface ocean, in particular during the last deglaciation (Sarnthein et. al., 2015). However, recent studies suggest that reservoir ages of the Bering Sea and the N-Pacific varied by less than 200 years during the last deglaciation (Lund et al., 2011; Kühn et al., 2014) and are within the range of reservoir ages originally assumed by Max et al. (2012)."

Line 289: What is the average mid-Holocene thermal maximum temperature between 8.0-4.0 ka BP (with errors)? Perhaps present the average temperature in that window, then give the highest temperature reached and the age (again, with errors) that that peak temperature is observed.
Added.

Line 291: How do you determine when the cooling trend is initiated? It would seem that the cooling arguably begins closer to 5 ka, but then again if you're interpreting at this level (and you probably shouldn't) you could argue the cooling stops by 3 ka.
As the term Holocene thermal maximum already implies that temperature is lower in the periods preceding and following the HTM, the last sentence is deleted.

Line 292: This last sentence needs to be quantitative. Also, when calculating variance, remember to use equivalent temporal windows for the Holocene and deglacial and smooth the record to a constant resolution.
Sentence deleted.

5. Discussion
5.1 Sources of brGDGT and implications for CBT/MBT'-derived temperatures
Line 325:
Either here or in the methods section some very basic discussion of how to interpret the BIT-values should be given.
Included into section 3.4.

Line 330: Eminent might not be the right word choice for this sentence. Perhaps 'Marine settings where terrigenous input is low are particularly sensitive to bias from in-situ production, thus non-soil derived brGDGTs potentially have a considerable effect on the temperature: : :'
Changed.

Line 334: Again, would suggest minor reworking. Perhaps 'Ti/Ca-ratios reflect the proportion of terrigenous and marine derived inorganic components of the sediment, and can be used as an estimator of terrigenous input'.
Changed.

Line 336: 'With relatively high values at 15.5 and 12 ka BP, and minima at 14 and 11 ka BP' is an incomplete sentence. Also, again, if presenting chronologies at the centennial scale really need to give errors on those ages.
Sentence completed.

Line 362: 'Mai' should be 'May'.
Changed.

5.2 Temperature evolution over the past 20 ka 5.2.1 The LGM (20-18 ka) – warm summers and the regional context
What definition of LGM are you using? Should give a reference. Clark et al., 2009 is the most widely used citation that I'm aware of and they define global LGM as ending at 19 ka.
We are referring the definition of Mix et al. (2001) according to which the LGM lasted from 18-24 ka BP. This definition is given in the introduction of the revised manuscript (section 1).

Line 371: While you could say there was a 'cooling tendency' from MIS-3 into the LGM, since time moves forward when comparing the LGM to the Holocene it would be better to say 'Generally cooler LGM temperatures are thought to result from: : :'
That is a good point, thank you. Sentence is rearranged.

Line 378: What does 'BLB' stand for?
BLB stands for "Bering Land Bridge". The abbreviation is removed everywhere in the text.

Line 382: No need to hyphenate 'insect-data'. Also suggest rewording to 'Markovo, and ElGygytgyn and Jack London lakes'
Changed.

5.2.2. Controls on MATifs
In this section you identify a possible seasonal bias in alkenone-based SST reconstructions towards warmer temperatures and dismiss them in favor of TEXL86 reconstructions.
You then discuss the results of the TEXL86 reconstruction for site 12KL currently submitted for review. However there is no discussion of the already-published alkenone-based SST record for 12KL of Max et al., (2012), nor is there a presentation of this record alongside the

TEXL86 record from the same site in Figure 2. For the period of overlap, it would appear that at least at this location the alkenone SST's are several degrees colder than the TEXL86 temperature reconstruction. Why would this be?
The alkenone temperature record from site 12KL is excluded from the LGM discussion since it does not reach beyond 16 ka BP (see Max et al., 2012). For the discussion on millennial scale oscillations we did not show the $U^{K'}_{37}$ as it is in line with the TEX^{L}_{86} from core 12KL (Meyer et al., 2016). Since the general trend is the same in both records it appears more reasonable to represent the SST evolution of the NW Pacific by the TEX which spans the entire LGM-Holocene transition.
Differences between $U^{K'}_{37}$ and TEX^{L}_{86} are discussed in Meyer et al., 2016 (in the paper referenced as "Meyer et al., submitted" in the original version of the manuscript) and are attributed to different blooming seasons of coccolithophores and archaea.

Line 390: Need to clarify that you're discussing warm Siberian summers during LGM
Changed.

Line 414: As the paper Meyer et al., (submitted) has yet to pass through peer review, probably best to state that the relatively warm SST's at site 12KL may be explained by stronger-than-present influence of the Alaskan Stream.
Since the Meyer et al (submitted) is now accepted (Meyer et al., 2016), nothing is changed.

5.2.3 The deglaciation (18 ka-10 ka BP)
Define/defend the use of the words 'strong' and 'clear' when describing the resemblance between the N-Atlantic d18O and 12KL MAT. Can you calculate covariance between the normalized/equivalently smoothed NGRIP d18O and 12KL MAT? To my eye they appear quite different: the Y-D is greatly compressed in the Kamchatka MAT record, the trend from the LGM to HS1 in 12KL is completely absent in NGRIP. A climate oscillation in HS1 apparently comparable in magnitude and duration to the regional expression of the Y-D (although a warming as opposed to cooling event) at 16 ka with no analogue in NGRIP is discarded from interpretation. I'm not arguing that there are similarities, but to say it's obvious or 'undoubtable' that the North Atlantic is driving NW Pacific climate via atmospheric teleconnection is a strong claim that needs to be quantitatively defensible. If this can't be done in the context of this paper, perhaps dial the tone of the text down a bit.
Also, as stated earlier in the text, when comparing 12KL to NGRIP at centennial scales chronological uncertainties in 12KL need to be addressed and stated.
Expressions like "clear" and "strong" and "undoubtedly" are deleted
As for age uncertainties, see comment on line 283.

5.2.4 The Holocene
The statement at line 620: "Hence it seems that the atmospheric linkage (with the N Atlantic) that determined climate variability during the deglaciation likely persisted into the Holocene where it acted as an important driver for long-term climate changes as well as abrupt, short-lived climate events." seems poorly defended by the visual similarity between NGRIP d18O and Kamchatka MAT in Figure 2. To my eye the Holocene in the MAT record appears more variable, while the mid-Holocene thermal maximum and neoglacial cooling described for the NW Pacific region are absent in NGRIP. Quantitatively evaluating the covariance between these records would be challenging at best as the current chronology for 12KL is virtually

unconstrained in the Holocene. If this statement remains in the discussion/conclusions, at the very least some discussion of what is meant by 'long-term climate changes' versus 'abrupt, short-lived climatic events'.
The Holocene section is rewritten and shortened. This statement is removed.

6. Summary and Conclusions
Line 624-629: This introduction to the conclusions reads awkwardly.
The introduction of that chapter is rewritten.

Line 631: Perhaps replace 'likely' with 'may' or 'could' as there is no evaluation of statistical certainty of this hypothesis.
Replaced by "may".

Line 645: Again, the use of the word 'obvious' to describe the role of N-Atlantic climate in driving the NW Pacific seems somewhere between bombastic and unfounded. There are some similarities in deglacial climate, there are differences, and as yet these remain poorly quantified in the manuscript.
"Obvious" replaced by "seem to be linked".

Figures

Figure 1: Could some kind of shading be used to more clearly denote Holocene landmasses? With apparently identical solid lines used to denote boundaries of continents, ocean currents, and rivers it's a bit difficult to visually parse.
Holocene landmasses are grey, now. (similar as in Figure 1b)

Figure 2: As this figure includes the TEXL86 SST record from Site 12KL to be published in Meyer et al., submitted, it should probably also include the deglacial alkenone SST record from site 12KL published in Max et al., 2012.
Nothing changed as the alkenone record does not reach into the LGM and as the Meyer et al (submitted) is published by now. (Meyer et al., 2016)

Figure 3: As mentioned in my comments on the results section, I think this figure should be reversed with Figure 2 in its presentation order in the text. Also, instead of giving ages at 4 depths in the core, could a secondary axis with appropriately dilated/ compressed ticks be added for age alongside the depth scale? If this isn't possible, would almost suggest it would be better to present results versus time than versus depth to facilitate comparison to Figure 2.
As discussed above (see comment on the result section), we do not change the order.
We increase the density of the age scale in Figure 3.

Summer-temperature evolution on the Kamchatka Peninsula, Russian Far East, during the past 20,000 years

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Abstract. Little is known about the climate evolution on the Kamchatka Peninsula during the last ~~deglaciation~~ glacial-interglacial transition as existing climate records do not reach beyond 12 ka BP. In this study, a summer-temperature record for the past 20 ka is presented. Branched ~~Glycerol~~ glycerol ~~Dialkyl~~ dialkyl ~~Glycerol~~ glycerol ~~Tetraethers~~tetraethers, terrigenous biomarkers suitable for continental air temperature reconstructions, were analyzed in a sediment core from the western continental margin off Kamchatka in the ~~/~~marginal Northwest Pacific (NW Pacific). The record ~~reveals~~ suggests that summer temperatures on Kamchatka during the Last Glacial Maximum (LGM) equaled modern. We suggest that strong southerly winds associated with a pronounced North Pacific High pressure system over the subarctic NW Pacific accounted for the warm conditions. A comparison with ~~outputs from~~ an Earth System Model reveals discrepancies between model and proxy-based reconstructions for the LGM-temperature and atmospheric circulation in the NW Pacific realm. The deglacial temperature development is characterized by abrupt millennial-scale temperature oscillations. The Bølling/Allerød warm-phase and the Younger Dryas cold-spell are pronounced events, ~~providing evidence for a strong impact~~suggesting a connection to ~~of~~ North-Atlantic climate variability~~on temperature development in southeastern Siberia~~. ~~Summer insolation and teleconnections with the North Atlantic determine the long-term temperature development during the Holocene.~~

Key words: CBT/MBT, summer temperature, Northwest Pacific, deglaciation, atmospheric circulation

1. Introduction

~~The Kamchatka Peninsula is attached to Siberia and protrudes into the North Pacific Ocean separating the Sea of Okhotsk from the Northwest Pacific (NW Pacific) and the Bering Sea (Fig. 1a). The Peninsula is a remote part of western Beringia. "Beringia" extends from the Lena River in Northeast Russia to the lower Mackenzie River in Canada (Fig. 1a, Hopkins et al., 1982). During Pleistocene sea-level low-stands the Bering Land Bridge~~Bering Land Bridge ~~(BLB) linked Eastern and Western Beringia as the Chukchi and Bering Shelves became exposed (Fig. 1a). Kamchatka is one of the least studied areas of Beringia since the available terrestrial climate archives, such as peat sections or lake sediments, do not reach beyond 12 ka BP (e.g. Dirksen et al., 2013, 2015; Nazarova et al., 2013a; Hoff et al. 2015; Klimaschewski et al., 2015; Self et al., 2015; Solovieva et al., 2015) and the climatic~~

conditions during the LGM (i.e. 24-18 ka BP; Mix et al. (2001)) and the deglaciation are poorly understood. However, the climatic history of Kamchatka may provide important insights into the deglacial development of regional atmospheric and oceanic circulation, since the Holocene climate evolution largely responds to those regional forcing mechanisms (Nazarova et al., 2013a; Brooks et al., 2015; Hammarlund et al., 2015; Self et al., 2015) next to global or supra-regional climate drivers, e.g. summer insolation (Savoskul, 1999; Dirksen et al., 2013; Brooks et al., 2015; Self et al., 2015). Particularly, information about atmospheric and oceanic circulation in the Northwest Pacific (NW Pacific) realm is important to confirm outputs from climate models.

The investigation of deglacial climate change on Kamchatka may also contribute to the understanding of the spatial dimension of atmospheric teleconnections with abrupt climate change in the North Atlantic (N-Atlantic). The majority of sea surface temperature records from the subarctic NW Pacific and the marginal seas mirror the N-Atlantic climate oscillations (e.g. Caissie et al., 2010; Max et al., 2012; Meyer et al., submitted) suggesting supporting climate models which suggest that rapid atmospheric teleconnections with the North Atlantic controlled deglacial temperature development in the N-Pacific realm (e.g. Manabe and Stouffer, 1988; Mikolajewicz et al., 1997; Okumura et al., 2009; Chikamoto et al., 2012Max et al., 2012; Meyer et al., submitted). However, climate records from Siberia and Alaska provide an ambiguous picture concerning the sensitivity of Beringia to climate oscillations in the N Atlantic. Some studies in Siberia and interior Alaska found patterns similar to the N-Atlantic climate variability, including a Bølling/Allerød (B/A)-equivalent warm-phase and a subsequent climatic reversal during the Younger Dryas (YD; Anderson et al., 1990; Andreev et al., 1997; Pisaric et al., 2001; Bigelow and Edwards, 2001; Brubaker et al., 2001; Anderson et al., 2002; Meyer et al., 2010; Anderson and Lozhkin, 2015), while other Alaskan and east Siberian records show progressive warming during the postglacial climate amelioration, without a YD cold spell (Lozhkin et al., 1993, 2001; Anderson et al., 1996, 2002; Lozhkin and Anderson, 1996; Nowaczyk et al., 2002; Anderson et al., 2003; Nolan et al., 2003; Kokorowski et al., 2008a,b; Kurek et al., 2009). As pointed out by Kokorowski et al. (2008a,b) this may attest to regional differences or to uncertainties in chronologies. Therefore, further deglacial climate records with high resolution are necessary. This particularly applies for easternmost Siberia, since most deglacial records are obtained from sites west of 150°N and north of 65°N (Kokorowski et al., 2008a).

In this study, we analyzed branched glycerol dialkyl glycerol tetraethers (brGDGTs), terrigenous biomarkers as recorders of continental temperature (Weijers et al., 2006a, 2007), in a marine sediment core retrieved at the eastern continental margin off Kamchatka/NW Pacific (site SO201-2-12KL, NW Pacific, Fig. 1a, b). We present a continuous, quantitative record of summer temperature on Kamchatka for the past 20 ka. The impact of global

~~climate drivers, N-Atlantic climate change, and regional atmospheric/oceanic circulation is investigated. The record reveals new aspects of LGM atmospheric circulation in the NW Pacific realm, which are compared to an Earth System Model (ESM), and provides new insights into the interplay of global and regional climate drivers in the south-eastern edge of western Beringia since the LGM.~~

During the Last Glacial Maximum (LGM; i.e. 24-18 ka BP; Mix et al., 2001), when sea level regression lead to the exposure of the Bering and Chukchi Shelves, the Bering Land Bridge connected Alaska and eastern Siberia (Fig. 1). The resulting~~a~~ continuous landmass ~~which~~ is commonly known as “Beringia” (defined as the area extending from the Lena River in Northeast Russia to the lower Mackenzie River in Canada; Hopkins et al. (1982)). Beringia’s environmental history since the last glaciation is of particular interest since ~~being~~having been unglaciated during the LGM the landmass formed a glacial refuge for arctic flora and fauna (Abbott und Brochmann, 2002; Nimis et al., 1998; Guthrie, 2001) and allowed plants, animals and humans to migrate between Asia and America (e.g. Mason et al., 2001). Despite several studies investigating the Beringian evolution of temperature, moisture availability and vegetation (e.g. Lozhkin et al., 1993; Anderson et al., 1996; Bigelow and Edwards, 2001; Bigelow and Powers, 2001; Pisaric et al., 2001; Elias, 2001; Ager, 2003; Kienast et al., 2005; Sher et al., 2005; Lozhkin et al., 2007: Kurek et al., 2009; Elias and Crocker, 2008; Kokorowski et al., 2008a, b: Berman et al., 2001; Fritz et al., 2012; Anderson and Lozhkin, 2015) environmental change during the LGM-to-Holocene transition and the respective climatic controls (e.g. rising atmospheric CO_2-levels, insolation and regional atmospheric and oceanic circulation) remain elusive. This is because continuous terrestrial records covering the entire last glacial-interglacial transition are sparse, particularly in western Beringia (i.e. Siberia; e.g. Kokorowski et al., 2008a and references therein; Andreev et al., 2012; Anderson and Lozhkin, 2015). This is a gap of knowledge as independent terrestrial data on temperature and moisture availability are needed to infer LGM-to-Holocene changes in atmospheric circulation in the North Pacific realm (e.g. Mock et al., 1998; Kokorowski et al., 2008a) and to validate climate model outputs.

The sparsity of continuous temperature records in Beringia also limits a comprehensive assessment of the geographic extent of abrupt deglacial climate reversals. There is consensus among sea surface temperature records from the North Pacific (N Pacific) and its marginal seas that the deglaciation was characterized by abrupt warm-cold oscillations (e.g. Barron et al., 2003; Seki et al., 2009; 2014; Caissie et al., 2010; Max et al., 2012; Praetorius and Mix, 2014; Praetorius et al., 2015; Meyer et al., 2016) suggesting teleconnections with the North-Atlantic realm (Manabe and Stouffer, 1988; Mikolajewicz et al., 1997; Okumura et al., 2009; Chikamoto et al., 2012). Yet, it is not fully understood how far this North Atlantic (N Atlantic) connection extended into Beringia. Records are inconsistent suggesting both abrupt warm-cold oscillations (Anderson et al., 1990; Andreev et al., 1997; Pisaric et al., 2001; Bigelow and Edwards, 2001; Bigelow and Powers, 2001; Brubaker et al., 2001; Anderson et al., 2002; Meyer et al., 2010; Anderson and Lozhkin, 2015) and continuous warming (Lozhkin et al., 1993, 2001; Anderson et al., 1996, 2002; Lozhkin and Anderson, 1996; Bigelow and Powers, 2001; Nowaczyk et al., 2002; Ager, 2003; Anderson et al., 2003; Nolan et al., 2003; Kokorowski et al., 2008a,b; Kurek et al., 2009) throughout the deglaciation.

The Kamchatka Peninsula (attached to Siberia, Fig. 1a) is among of the areas in western Beringia where the least is known about environmental conditions during the LGM-to-Holocene transition since terrestrial archives on Kamchatka do not reach beyond 12 ka BP (e.g. Dirksen et al., 2013, 2015; Nazarova et al., 2013; Hoff et al. 2014, 2015; Klimaschewski et al., 2015; Self et al., 2015; Solovieva et al., 2015). Kamchatka is an important location to study deglacial changes in regional atmospheric and oceanic circulation in the Northwest Pacific realm. Protruding into the NW Pacific (NW Pacific: Fig. 1a) the peninsula responds to variations in these regional climate controls in addition to global or supra-regional climate drivers, e.g. summer insolation or teleconnections with the N-Atlantic realm, as has been shown for the Holocene (Savoskul, 1999; Dirksen et al., 2013; Nazarova et al., 2013; Andrén et al., 2015; Brooks et al., 2015; Hammarlund et al., 2015; Self et al., 2015).

In this study, we analyzed branched glycerol dialkyl glycerol tetraethers (brGDGTs), terrigenous biomarkers as recorders of continental air temperature (Weijers et al., 2006a, 2007), in a marine sediment core retrieved at the eastern continental margin off Kamchatka/NW Pacific (site SO201-2-12KL, NW Pacific, Fig. 1a, b). We present a continuous, quantitative record of summer-temperature for the past 20 ka and infer changes in atmospheric circulation. The findings are compared to an Earth System Model (ESM).

2. Regional Setting

The Kamchatka Peninsula is situated south of the Koryak Uplands and seperates the Sea of Okhotsk from the NW Pacific and the Bering Sea (Fig. 1a)~~in Siberia~~. It is characterized by strong variations in relief with lowlands in the coastal areas (Western Lowlands; Eastern Coast) and mountain ranges further inland (Fig. 1b). The mountain ranges, the Sredinny and the Eastern Ranges, encircle the lowlands of the Central Kamchatka Depression (CKD; Fig. 1b). The CKD is the largest watershed of the Peninsula and is drained by the Kamchatka River, the largest river of Kamchatka. The river discharges into the Bering Sea near 56°N (Fig. 1b). The climate is determined by marine influences from the surrounding seas, by the East Asian continent, and by the interplay of the major atmospheric pressure systems over NE-Asia and the North Pacific (N Pacific; e.g. Mock et al., 1998; Glebova et al., 2009). In general the climate is classified as sub-arctic maritime (Dirksen et al., 2013). The winters are characterized by cold and relatively continental conditions since northerly winds prevail over Kamchatka, ~~which are~~ mainly associated with the Aleutian Low over the N Pacific and the Siberian High over the continent (Mock et al., 1998). In summer, Kamchatka experiences warm maritime conditions owing to the East Asian Low over the continent and the North Pacific High (NPH) over the N ~~-~~Pacific (Mock et al., 1998). Furthermore, there are the influences of the East Asian Trough (EAT) which has its average position over the ~~northern shelves of central Beringia~~Chukchi Shelf, as well as the influences of the westerly ~~Jet~~ jetstream and the associated polar front (Mock et al., 1998). Variations in the position and strength of the EAT affect precipitation and temperature over Beringia and can cause climatic contrasts between Siberia and Alaska (Mock et al., 1998 and references therein). With respect to Kamchatka westerly to northwesterly winds associated with the j~~J~~etstream and the EAT form a source of continental air masses from Siberia/East Asia (Mock et al., 1998).

The mountainous terrain with strongly variable relief results in pronounced climatic diversity on the Peninsula (Fig. 1b). The coastal areas, the western Lowlands and the Eastern Coast, are dominated by marine influences. In the coastal areas, summers are cool and wet and winters are relatively mild. Precipitation is high along the coast and in the mountains throughout the year (Kondratyuk, 1974; Dirksen et al., 2013). Being protected from marine influences by the mountain ranges, the CKD has more continental conditions with less precipitation and a larger annual temperature range than in the coastal areas (Ivanov, 2002; Dirksen et al., 2013, Kondratyuk, 1974; Jones and Solomina, 2015). Mean temperatures a~~A~~veraged for the entire Peninsula ~~mean temperatures~~ range from -8 to -26°C in January and from 10 to 15°C in July (Ivanov, 2002).

3. Material and Methods

3.1. Core material and chronology

Within a joint German/Russian research program (KALMAR Leg 2) core SO201-2-12KL (Fig. 1a, b) was recovered with a piston-corer device during cruise R/V SONNE SO201 in 2009 (Dullo et al., 2009). The core material was stored at 4°C prior to sample preparation. Age control is based on accelerator mass spectrometry (AMS) radiocarbon dating of planktic foraminifera (*Neogloboquadrina pachyderma* sin.; 9 dates in total) as well as on correlations of ~~core-to-core correlations of~~ high-resolution spectrophotometric (color b*) and X-ray fluorescence (XRF) data from different sediment cores from the NW Pacific, the Bering Sea and the Sea of Okhotsk (Max et al., 2012). The correlation allowed to transfer AMS results from core to core, which provided

10 additional age control points for site 12KL (Max et al., 2012). Max et al. (2012) converted radiocarbon ages into calibrated calendar ages using the calibration software Calib Rev 6.0 (Stuiver and Reimer, 1993) with the Intcal09 atmospheric calibration curve (Reimer et al., 2009). A constant reservoir age of 900 years was assumed for the entire time-interval covered by the core. The uncertainty of AMS dating was smaller than ±~~+–~~ 100 years (Max et al., 2012). Another important source of uncertainty are changes in reservoir ages of the surface ocean during the last deglaciation (Sarnthein et. al., 2015). However, recent studies suggest that reservoir ages of the Bering Sea and the N Pacific varied by less than 200 years (Lund et al., 2011; Kühn et al., 2014) and are within the range of reservoir ages originally assumed by Max et al. (2012).

Average Holocene, deglacial and glacial sedimentation rates are 39, 79 and 59 cm/ka, respectively, allowing for climate reconstructions on multi-centennial to millennial timescales (Max et al., 2012). For more detailed information about the stratigraphic framework and AMS-^{14}C results, see Max et al. (2012).

3.2. Lipid extraction

For this study we used the same samples as Meyer et al, (2016). These authors sampled the core in 10 cm steps providing an average temporal resolution of approximately 200 years. For GDGT analyses, freeze-dried and homogenized sediment samples (~~approx.~~approximately 5 g) were extracted ~~with dichloromethane : methanol (DCM:MeOH, 9:1 v/v) using accelerated solvent extraction (ASE). Prior to extraction, 10 µg of a C_{46}-GDGT internal standard was added to each sample. The extraction was conducted on a "Dionex ASE 200" device and was performed in three cycles, each of them lasting for five minutes. During the extraction cycles the temperature was maintained at 100°C and the pressure at 1000 psi. After drying with a rotary evaporator, extracts were hydrolyzed with 0.1N potassium hydroxide (KOH) in MeOH:H_2O 9:1 (v/v) to separate carbonic acids from neutral compound classes. After the hydrolyzation, neutral compounds such as hydrocarbons, ketones, alcohols and GDGTs were extracted with *n*-hexane, from the saponified solution. Dissolved in *n*-hexane the neutral compound-classes were separated using silica gel columns. Columns were built with Pasteur pipettes (6 mm diameter) which were filled with deactivated SiO_2 (mesh size 60, filling height 4 cm). After having eluted a less polar fraction with *n*-hexane, a polar fraction, containing the GDGTs, was eluted with DCM:MeOH (1:1 v/v). Dried polar fractions were dissolved in *n*-hexane:isopropanol (99:1, v/v) and were filtered through PTFE syringe filters (4 mm diameter, 0.45 µm pore size). Afterwards, samples were brought to a concentration of 2 µg/µl in order to prepare them for GDGT analysis.~~and processed according to Meyer et al. (2016).

3.3. GDGT analysis

GDGTs were analyzed by High Performance Liquid Chromatography (HPLC) and a single quadrupole mass spectrometer (MS). The systems were coupled via an atmospheric pressure chemical ionization (APCI) interface. The applied method was slightly modified from Hopmans et al. (2000). Analyses were performed on an Agilent 1200 series HPLC system and an Agilent 6120 MSD. Separation of the individual GDGTs was performed on a Prevail Cyano column (Grace, 3 µm, 150 mm x 2.1 mm) which was maintained at 30°C. After sample injection (20 µL) and 5 min isocratic elution with solvent A (hexane) and B (hexane with 5% isopropanol) at a mixing ratio of 80:20, the proportion of B was increased linearly to 36% within 40 min. The eluent flow was 0.2 ml/min. After each sample, the column was cleaned by back-flushing with 100% solvent B (8 min) and re-equilibrated with solvent A (12 min, flow 0.4 ml/min). GDGTs were detected using positive-ion APCI-MS and selective ion monitoring (SIM) of their $(M+H)^+$ ions (Schouten et al., 2007). APCI spray-chamber conditions were set as follows: nebulizer pressure 50 psi, vaporizer temperature 350 °C, N_2 drying gas flow 5 l/min and 350 °C, capillary voltage (ion transfer tube) -4 kV and corona current +5 µA. The MS-detector was set in SIM-mode detecting the following $(M+H)^+$ ions with a dwell time of 67 ms per ion: *m/z* 1292.3 (GDGT 4 + 4´ / crenarcheol + regio-isomer), 1050 (GDGT IIIa), 1048 (GDGT IIIb), 1046 (GDGT IIIc), 1036 (GDGT IIa), 1034 (GDGT IIb), 1032 (GDGT IIc), 1022 (GDGT Ia), 1020 (GDGT Ib), 1018 (GDGT Ic) and 744 (C_{46}-internal standard).

GDGTs were quantified by peak-integration and the obtained response factor from the C_{46} -standard. Concentrations were normalized to the dry weight (dw) of the extracted sediment and to total organic carbon contents (TOC). It has to be noted that the quantification should only be regarded as semi-quantitative because individual relative response factors between the C_{46}-standard and the different brGDGTs could not be determined due to the lack of appropriate standards. Fractional abundances of single brGDGTs were calculated relative to the total abundance of the all nine brGDGTs. The standard deviation was determined from repeated measurements of a lab internal standard sediment and resulted in an uncertainty of 9 % for the concentration of the sum of all nine brGDGT (ΣbrGDGT).

3.4. Temperature determination

The Cyclysation of Branched Tetraether index (CBT) and Methylation of Branched Tetraether index (MBT) were introduced as proxies for soil-pH (CBT) and mean annual air temperature (MAT, CBT/MBT) by Weijers et al. (2007). ~~The CBT index was~~ We calculated the CBT index after Weijers et al. (2007). For calculating the MBT-index we used a modified version~~ of the original index~~, the MBT' which excludes GDGTs IIIb and IIIc, and was introduced by Peterse et al. (2012). From repeated measurements of a lab-internal standard sediment extract (n=7) the standard deviation for CBT and MBT' were determined as 0.01 and 0.04, respectively. CBT and MBT'-values were converted into temperature using the global-soil dataset calibration by Peterse et al. (2012). The residual standard mean error of this calibration is 5°C (Peterse et al., 2012). The standard deviation of CBT and MBT' translates into an uncertainty of max. 0.1°C.

Although terrestrial soils are supposed to be the main source of br~~anched~~ GDGTs (Weijers et al., 2007) brGDGT can also be produced in-situ in marine water systems (Peterse et al., 2009; Zhu et al., 2011; Zell et al., 2014) as well as in fresh water environments (Tierney, 2010; Zell et al., 2013; De Jonge et al., 2014; Dong et al., 2015). As in-situ production can bias temperature reconstructions, particularly in marine settings where the input of terrigenous GDGTs is low (Weijers et al., 2006b; Peterse et al., 2009, 2014; De Jonge et al., 2014), the contribution of terrigenous brGDGTs to the marine sediments needs to be estimated prior to any paleoclimatic interpretation of CBT/MBT'-derived temperatures. A common means to estimate the relative input of marine and terrestrial GDGTs is the BIT-index (~~Branched~~ branched and isoprenoid tetraether index) which quantifies the relative contribution of the marine-derived Crenarchaeol and terrigenous brGDGTs (Hopmans et al., 2004). The higher the BIT-value the more abundant the brGDGT relative to the Crenarchaeol and the higher the terrigenous input. BIT-values were adopted from Meyer et al. (~~submitted~~2016) who worked on the same samples used in this ~~present~~ study.

3.5. Climate simulations with the Earth System Model COSMOS

In order to compare inferences for atmospheric circulation during the summer months to ~~computer~~ General Circulation ~~model~~ Model outputs, model simulations for the ~~glacial~~ climate were performed with the Earth System model COSMOS for pre-industrial (Wei et al., 2012) and ~~glacial~~ LGM conditions (Zhang et al., 2013). The model configuration includes the atmosphere component ECHAM5 at T31 resolution (~3.75°) with 19 vertical layers (Roeckner et al., 2006), complemented by a land-surface scheme including dynamical vegetation (Brovkin et al., 2009). The ocean component MPI-OM, including the dynamics of sea ice formulated using viscous-plastic rheology, has an average horizontal resolution of 3°x1.8° with 40 uneven vertical layers (Marsland et al, 2003). The performance of this climate model was evaluated for the Holocene (Wei and Lohmann, 2012; Lohmann et al., 2013), the last millennium (Jungclaus et al., 2006), glacial millennial-scale variability (Gong et al., 2013; Weber et al., 2014; Zhang et al., 2014), and warm climates in the Miocene (Knorr and Lohmann, 2014) and Pliocene (Stepanek and Lohmann, 2012).

External forcing and boundary conditions are imposed according to the protocol of PMIP3 for the LGM (available at http://pmip3.lsce.ipsl.fr/). The respective boundary conditions for the LGM comprise orbital forcing, greenhouse gas concentrations (CO_2=185ppm; N_2O=200ppb; CH_4=350ppb), ocean bathymetry, land surface topography, run-off routes according to PMIP3 ice sheet reconstruction and increased global salinity (+ 1 psu compared to modern value) to account for a seal level drop of ~116 m. The glacial ocean was generated through an ocean-only phase of 3000 years and coupled phase of 3000 years (LGMW in Zhang et al., 2013). The land cover is calculated interactively in the climate model which has an interactive land surface scheme and vegetation module (Brovkin et al.2009). The modular land surface scheme JSBACH (Raddatz et al., 2007) with vegetation dynamics (Brovkin et al., 2009) is embedded in the ECHAM5 atmosphere model. The background soil characteristics (which are described in Staerz et al., 2016) are set to the values which are closest to the pre-indu~~r~~stial land points.

For both, PI and LGM conditions, the climate model was integrated twice for 3000 model years and provides monthly output (Wei et al., 2012; Wei and Lohmann, 2012; Zhang et al., 2013). ~~The climate model was integrated for 3000 model years and provides monthly output~~. Here, anomalies in sea-level pressure (SLP), wind directions (1000 hPa level) and surface air temperature (SAT) between the LGM and pre-industrial conditions were analyzed for the boreal summer season - June, July and August (JJA). We focus on the summer season as in high latitudes brGDGTs seem to reflect summer temperature instead of the annual mean (Rueda et al., 2009, Shannahan et al., 2013; Peterse et al., 2014). All produced f~~F~~igures show climatological mean characteristics averaged over a period of 100 years at the end of each simulation.

4. Results

4.1. Concentrations and fractional abundances of brGDGTs

The summed concentration of all nine brGDGTs (ΣbrGDGT) is shown in Figure. 2a. The concentration of ΣbrGDGTs vary between 40 and 160 ng/g dw throughout the record. Ranging between 60-80 ng/g dw, they are lowest during the LGM and the late Holocene. During the deglaciation and the early Holocene (17-8 ka BP) lowest values are ~~approx.~~approximately 80 ng/g dw, except for two peaks at 15-16 ka BP and 12-13 ka BP, respectively, where concentrations reach ~160 ng/g dw (Fig. 2a).

The fractional abundance of all nine brGDGTs, calculated relative to the ΣbrGDGT, is shown in Figure. 3. All samples are characterized by a similar pattern. The composition of the brGDGT assemblage is dominated by brGDGTs without cyclopentyl moieties which together account for 60-80% of the total brGDGT-assemblage (GDGT Ia, IIa, IIIa; Fig. 3). brGDGTs with a higher degree of methylation are more abundant than lesser methylated ones. In 88 out of 92 samples GDGT IIIa is the most prominent brGDGT accounting for 22-37% of the total brGDGT distribution. It is closely followed by GDGT IIa with 16-29% and GDGT Ia which accounts for 14-23% of the total brGDGT ~~distribution~~assemblage. As for brGDGTs containing cyclopentyl moieties, GDGT IIb is most abundant accounting for 9-16% of the total brGDGT assemblage. GDGT IIc, Ib, Ic, IIIb and IIIc are less abundant reaching 2-6%, 3-7%, 1-3%, 2-4%, and 1-2%, respectively. (Fig. 3).

4.2. Temperature development over the past 20 ka

The CBT/MBT'-derived temperatures are plotted in Fig. 2b. Glacial (20-18 ka BP) and late Holocene (1-3 ka BP) temperatures are the ~~same~~similar~~equal~~ (~7.5°C). ~~During the late Holocene (approx. 1 ka BP), the reconstructed temperature is 7.5°C. Interestingly, glacial temperatures (between 20-18 ka) are the same~~ (Fig. 2b). The deglaciation is characterized by abrupt temperature variations. A~~A~~t 18 ka, temperature drops by ~~about~~ ~1.5°C~~. At 16 ka temperature jumps back to the glacial level. As this increase is based on one single data point, it cannot be excluded that this warming is an artifact resulting from an outlier. Deeming the data point an outlier, temperature increases progressively~~ and remains relatively cold until ~~the onset of the Bølling/Allerød at approx.~~approximately 14.6 ka BP, where it abruptly jumps back to the glacial and Holocene level of ~7.5°C (Fig. 2e). Between ~14.6 and ~13 ka, temperature progressively decreases ~~about~~ ~1-0.5°C. ~~During the Younger Dryas (YD)~~ T~~t~~emperature abruptly decreases by ~~about~~ ~2°C ~~(~~at ~~approx.~~approximately 13 ka BP~~)~~ and remains cold until 12 ka BP (Fig. 2b). ~~At With approx.approximately 4.5°C the YDthis interval is the coldest episode during the Glacial-Holocene transition.~~ The cold spell is followed by a sharp temperature increase of ~~approx.~~ ~3°C at the onset of the Preboreal (PB)/early Holocene (Fig. 2b). After the abrupt temperature increase into the PB temperature progressively increases culminating in a Mid-Holocene Thermal Maximum (HTM) between ~8 and~~-~~ ~4-5 ka BP where temperatures ranges between ~7.5-8°C (Fig. 2b)~~. With ~8°C being reached between 6 and 4 ka BP, the mid-Holocene is the warmest episode since the Last Glacial Maximum (LGM)~~. ~~At approximately 4 ka BP a cooling trend initiates and temperature decreases by about ~0.5°C (Fig. 2b). Compared to the deglacial temperature variations the Holocene variability is relatively small~~.

4.3. LGM-climate simulation with COSMOS

4.3.1. Sea-level pressure and wind patterns

Model-simulations for SLP (JJA) are shown Fig. 4a. The LGM-simulation is characterized by strong positive anomalies in sea-level pressure (SLP) over the North American Continent (Fig. 4a). Positive SLP-anomalies also occur over the Arctic Ocean. Negative SLP anomalies occur south of 50°N and are centered over the NW Pacific and East Asia, but are also observed in a few grid-cells over the central and NE Pacific and over the Sea of Okhotsk. In the Bering Sea, the northern N-Pacific (north of 50°N) and Beringia SLP does not change significantly relative to present.

The positive SLP-anomalies over North America are associated with pronounced anticyclonic anomalies in the wind directions, which expand to the Chukchi-Sea and to the formerly exposed ~~BLB~~Bering Land Bridge (Fig. 4a). Over western Beringia as well as the adjacent Arctic Ocean small northerly anomalies are present. Between 100°E and 110°E pronounced anticyclonic anomalies are present over Russia. Over Kamchatka and the adjacent East Siberian Coast small northerly anomalies occur. The western Bering Sea is characterized by easterly anomalies. Over the NW Pacific anomalies are small and show no~~w~~ general pattern. In the NE Pacific relatively strong westerly to southwesterly anomalies are present.

4.3.2. Surface air temperature

Model simulations for SAT (JJA) are shown in Fig. 4b. The model predicts widespread negative surface air temperature (SAT)-anomalies over Beringia, East Asia, North America, the Arctic Ocean and the entire N ~~-~~Pacific (Fig. 4b). However, in small parts of the formerly exposed ~~BLB~~Bering Land Bridge slightly warmer-than-present conditions ~~are simulated~~occur. On the arctic shelf there is a small band where temperature ~~may equal~~is similar to the PI-conditions ~~as~~ (the SAT anomaly falls in the window of -1 to +1°C)~~, occurs~~. The temperature anomalies are strongest over North America where they reach -17°C. Over western Beringia the SAT anomaly ~~increases~~ becomes more pronounced from east to west with SAT ranging between -1 and -5 over East Siberia and between -5 and -9 further west. Over the N ~~-~~Pacific SAT anomalies are smaller than over western Beringia and range between -1 and -5°C. SAT anomalies are smallest in the Bering Sea and along the eastern coast of Kamchatka. Over the Peninsula itself, the majority of grid-cells indicate a negative anomaly (-3 to -5°C). In the northern part and over the adjacent Bering Sea the SAT anomalies are very small within the window of -1 to +1°C (Fig. 4b).

5. Discussion

5.1. Sources of brGDGT and implications for CBT/MBT'-derived temperatures

Considering that brGDGT are thought to be synthesized by terrestrial bacteria which thrive in peats and soils (e. g. Weijers et al., 2006b) it is most likely that the major origin of brGDGT in the marine sediments of the Bering Sea/NW Pacific would be the Kamchatka Peninsula. However, BIT-values from core 12KL range between 0.08 and 0.2 (Meyer et al., ~~submitted~~2016) throughout the entire record, indicating that marine derived GDGT dominate the total GDGT composition and that terrigenous input is low (Fig. 2c). Marine settings where terrigenous input is low are particularly sensitive to bias from in-situ production (e.g. Weijers et al., 2006b; Peterse et al., 2009; Zhu et al., 2011), thus non-soil derived brGDGTs potentially have a considerable effect on the temperature~~Since a bias from in-situ production is particularly eminent in marine settings where terrigenous input is low (e.g. Weijers et al., 2006b; Peterse et al., 2009; Zhu et al., 2011), non-soil derived brGDGTs potentially have a considerable effect on the temperature~~ reconstruction at site 12KL. However, the concentrations of ΣbrGDGT show ~~strong~~ similarities with the trend of Titanium/Calcium ratios (Ti/Ca-ratios, Fig. 2d) from core 12KL (XRF-data from Max et al. (2012)). ~~Reflecting the proportion of terrigenous and marine derived inorganic components of the sediment, Ti/Ca-ratios can be used as an estimator of terrigenous input.~~ Ti/Ca-ratios reflect the proportion of terrigenous and marine derived inorganic components of the sediment, and can be used as an estimator of terrigenous input. With relatively high values at 15.5 and 12 ka BP, and minima at 14 and 11 ka BP Ti/Ca indicates relatively high contributions of terrigenous material relative to marine components at 15.5 and 12 ka BP and relatively low terrigenous contributions at 14 and 11 ka BP. A similar pattern is visible in ΣbrGDGT-concentrations as these increase during intervals of enhanced terrigenous input (high Ti/Ca-values) and decrease when terrigenous input is relatively low (low Ti/Ca values, see Fig. 2b, d). This suggests that brGDGTs are terrigenous.~~As intervals of relatively high/low terrigenous input (as suggested by Ti/Ca) coincide with relatively high/low ΣbrGDGT-concentrations brGDGTs seem to be terrigenous (Fig. 2b, d)~~. Moreover, the distribution of the brGDGTs the samples from site 12KL resemble the brGDGT composition described for soils world-wide (Weijers et al., 2007; Blaga et al., 2010) as GDGT Ia, IIa and IIIa dominate over brGDGTs with cyclopentyl moieties (e.g. Ib, IIb) accounting for 60-80% of the total brGDGT assemblage (Fig. 3). By contrast, in marine areas where brGDGTs are thought to be produced in-situ, the brGDGT compositions were dominated by brGDGTs containing cyclopentyl moieties (Peterse et al., 2009; Zell et al., 2014). Thus, brGDGT seem to be soil-derived and a bias from in-situ production is unlikely. We also exclude changes in the source of brGDGTs through time because the relative abundance of the brGDGTs is similar in all samples indicating that the source of brGDGTs remained constant throughout the past 20 ka (Fig. 3). We consider the catchment of the Kamchatka River (CKD and inner flanks of the mountains) and the Eastern Coast as the likely sources of brGDGTs deposited in the marine sediments at the core site since the Kamchatka River and several small rivers draining the Eastern Coast discharge into the western Bering Sea. Flowing southward along Kamchatka, the East Kamchatka Current would carry the load of the Kamchatka River to site 12KL (Fig. 1b)

Although the CBT/MBT-paleothermometre has been suggested to generally record mean annual air temperatures (Weijers et al., 2007) it is assumed to be biased to the summer months/ice-free season in high latitudes (Rueda et al., 2009, Shannahan et al., 2013; Peterse et al., 2014). According to Klyuchi climate station (for location see Fig. 1b), mean annual air temperatures in the northern CKD are ~~approx.~~ -0.5°C (http://en.climate-data.org/location/284590/). The CBT/MBT'-derived temperatures for the core-top/late Holocene (7.5~~°C~~ ± 5°C; Fig. 2) exceed the annual mean by ~~approx.~~ ~8°C and are similar to mean air temperatures from the ice-free season (~~Mai~~May-October) at Klyuchi (9°C). Therefore, they are interpreted as summer temperature and will be referred to as "Mean Air Temperature of the ice-free season" (MAT_{ifs}) henceforth.

5.2. Temperature evolution over the past 20 ka

5.2.1. The LGM (until~~till~~ ~~20-~~18 ka) ~~– warm summers and the regional context~~

The finding that LGM summers were as warm as during ~~the~~the~~and~~ Holocene ~~MAT_{ifs} are equal~~ contrasts with the general understanding of the glacial climate, according to which the extratropics were significantly colder than today, as documented by several proxy-based temperature reconstructions ~~(e.g. MARGO compilation, Kageyama et al., 2006; Waelbroeck et al., 2009)~~ and ~~computer~~ general circulation model simulations (e.g. MARGO compilation or~~f~~ PIMP, and others; see Kutzbach et al., 1998; Kageyama et al., 2001; Kageyama et al., 2006; Kim et al., 2008; Braconnot et al., 2012; Alder and Hostetler, 2015~~)~~). Generally cooler LGM temperatures are thought to result from ~~The general cooling tendency is thought to result from~~ low summer insolation, reduced carbon-dioxide concentrations in the atmosphere and extensive continental ice ~~caps~~ sheets (Berger and Loutre 1991; Monnin et al., 2001; Kageyama et al., 2006, Shakun et al., 2012). Therefore, one may expect that the Kamchatka Peninsula would experience a glacial-interglacial warming trend. As MAT_{ifs} deviates from the trends in atmospheric CO_2 (CO_{2atm}) and insolation (Fig. 2b, e, f) regional climate drivers may have overprinted the effects of CO_{2atm} and summer insolation. Interestingly, several studies investigating climate in Beringia based on pollen and beetle-assemblages indicate that in NE Siberia and the formerly exposed ~~BLB~~Bering Land Bridge (catchments of the Lena, Kolyma and Indigirka Rivers, Ayon Island, Anadyr Lowlands, Lake El'Gygytgen, Seward Peninsula, Fig. 4c) summers during the LGM were as warm as at present or were even warmer (Fig. 4c; Elias et al., 1996, 1997; Elias, 2001; Alfimov and Berman, 2001; Kienast, 2002; Kienast et al., 2005; Sher et al., 2005; Berman et al., 2011). Only a few pollen and insect ~~-~~data from Markovo, ~~Lakes~~ Jack London and Lake El'Gygytgyn Lakes

(Fig. 1a), point to colder-than-present summer conditions (Fig. 4c; Lozhkin et al., 1993; Alfimov and Bermann, 2001; Lozhkin et al., 2007; Pitul'ko et al., 2007). The fairly large number of sites indicating warm summers in Siberia suggests that a thermal anomaly was widespread over western/central Beringia (Fig. 4c) and extended to Kamchatka. The thermal anomaly did probably not extend to eastern Beringia as insect-data as well as pollen consistently point to summer cooling of up to 4°C (Fig. 4c; e.g. Mathews and Telka, 1997; Elias, 2001; Kurek et al., 2009).

5.2.2. Regional c~~C~~ontrols on MAT_{ifs}

In previous studies t~~T~~he warm Siberian summers during the LGM were attributed to increased continentality, which would arise from the exposure of the extensive Siberian and Chukchi shelves at times of lowered sea-level (Fig. 1a; e.g. Guthrie, 2001; Kienast et al., 2005; Berman et al., 2011). The greater northward extent of the Beringian landmass (~~approx.~~approximately +800 km relative to today) would have minimized maritime influences from the cold Siberian and Chukchi Seas (Guthrie, 2001; Alfimov and Berman, 2001; Kienast et al., 2005; Sher et al., 2005; Berman et al., 2011). Increased seasonal contrasts resulting in warmer summers and colder winters would have been the result (e.g. Guthrie, 2001; Kienast et al., 2005). Winter cooling in Siberia (relative to modern) is indicated by ice-wedge data (Meyer et al., 2002) from Bykovski Peninsula (Fig. 1a). Also, the presence of stronger-than-present sea-ice cover in the Bering Sea (Caissie et al., 2010; Smirnova et al., 2015) points to cold winters in Siberia and Kamchatka during the LGM. However, for Kamchatka it is unlikely that the thermal anomaly and an increased seasonal contrast were a direct result from lowered sea-level as the bathymetry around the Peninsula is relatively steep and the exposed shelf area was very small. (Fig. 1a, b). Thus, other climate drivers were likely responsible for the relatively warm summer conditions. Potential mechanisms are changes in oceanic or atmospheric circulation.

Intriguingly, $U^{K'}_{37}$~~alkenone~~-based SST reconstructions from the Sea of Okhotsk indicate that glacial SST were slightly warmer than today or equal to modern conditions (Seki et al., 2004, 2009; Harada et al., 2004, 2012; Fig. 4c). However, these records are considered to be biased by seasonal variations in the alkenone production rather than to reflect real temperature anomalies (Seki et al., 2004, 2009; Harada et al., 2004, 2012). This seems to be supported by a few TEX^{L}_{86}-based SST reconstruction from the Sea of Okhotsk suggesting that LGM SST were ~~approx.~~ ~5°C colder than at present (Seki et al. 2009; 2014). In this light, a climatic relation between alkenone-based SST and MAT_{ifs} seems very unlikely. Interestingly, LGM-SST in the subarctic NW Pacific (site 12KL, TEX^{L}_{86}) were only ~1°C lower than at present (Fig. 2 h), a relatively small temperature difference compared to other SST records from the NW Pacific and its marginal seas (all obtained from TEX^{L}_{86}) which suggest a cooling of ~4-5°C (e.g. Seki et al., 2009; 2014; Meyer et al., submitted2016). The relatively warm SST at site 12KL were explained by a stronger-than-present influence of the Alaskan Stream in the marginal NW Pacific (Meyer et al., submitted2016). Such warm SST may have supported the establishment of warm conditions on Kamchatka. However, it is unlikely, that the temperature development on Kamchatka was fully controlled by oceanic influences since this would probably have caused a reduction of LGM MAT_{ifs} relative to present similar temperature reduction as in the SST record of site 12KL.

If oceanic circulation alone is unlikely to have caused the warm temperatures on Kamchatka, atmospheric circulation may have exerted an important a strong control on glacial summer temperatures in the region. In terms of atmospheric circulation the summer climate of the Kamchatka is largely determined by the strength and position of the North Pacific High (NPH) over the N Pacific (Mock et al., 1998). As the southerly flow at the southwestern edge of the NPH brings warm and moist air masses to Kamchatka summers on the Peninsula become warmer when the NPH and the associated warm southerly flow increase in strength (Mock et al., 1998). This modern analogue suggests that the LGM-NPH over the subarctic NW was stronger than today and the resulting warming effect may have balanced the cooling effects of CO_{2atm} and insolation. This atmospheric pattern could be explained by an increased thermal gradient between western/central Beringia and the N Pacific Ocean. While warm summers were widespread in western Beringia, the majority of sea surface temperature (SST) records from the open N Pacific and the Bering Sea indicate colder conditions during the LGM (Fig. 4A; deVernal and Pedersen, 1997; Seki et al., 2009, 2014; Kiefer and Kienast, 2005; Harada et al., 2004; 2012; Maier et al., 2015; Meyer et al., submitted). Under the assumption that alkenone-based reconstructions of LGM SST in the Sea of Okhotsk are biased, also the Sea of Okhotsk may have been 4-5°C colder than at present as suggested by TEX^{L}_{86}-based SST reconstruction (Seki et al. 2009; 2014). An increased thermal gradient between the subarctic N Pacific and western Beringia would translate into an increased pressure gradient between the low-pressure over western Beringia and the high pressure over the subarctic NW Pacific, and in response the southerly flow over the Kamchatka would have intensified relative to today. (Fig. 4c).

5.2.2.1. Comparison to the COSMOS-simulations

These inferences contrast with results from the climate simulations with COSMOS. For JJA the model predicts a decrease in SLP over the NW-Pacific suggesting that the southerly flow at the western edge of the NPH was reduced rather than strengthened (Fig. 4a). The weakening of the southerly flow is also discernable in the anomaly of the major wind-patterns over the NW Pacific (Fig. 4a) as a small northerly anomaly occurs north of Kamchatka, over the Peninsula itself and along the Asian coast (Fig. 4a). The weakening of the NPH is agreement with several other General Circulation Model (GCM) ~~outputs~~, which consistently predict a reduction in SLP over the N-Pacific (Kutzbach and Wright, 1985; Bartlein et al., 1998; Dong and Valdes, 1998; Vetteoretti et al., 2000; Yanase and Abe-Ouchi, 2007; Alder and Hostetler, 2015). ~~According to the climate synopsis by Mock et al (1998) a northerly anomaly would have caused summer cooling on Kamchatka.~~ It has been suggested that a pronounced positive SLP-anomaly and a persistent anticyclone over the American continent resulted in reduced SLP over the Western North Pacific (Yanase and Abe Ouchi, 2010). The positive SLP-anomaly and the strong anticyclonic tendencies are clearly present in the COSMOS simulation of SLP and wind-patterns (Fig. 4a) and were also simulated by several other GCMs (e.g. Yanase and Abe-Ouchi, 2007; 2010; Alder and Hostetler, 2015). Its development was attributed to the presence of extensive ice sheets on the American continent (Yanase and Abe-Ouchi, 2010), which would have caused severe cooling of the overlying atmosphere. Considering the consistency of different GCMs, the anticyclonic anomalies over North America as well as resulting cyclonic anomalies over the N-Pacific seem to be a robust feature of the glacial atmospheric circulation. ~~As this contrast with the inferences made from the MAT_{ifs} record, one may speculate that the effect of the ice-caps on the NPH mainly influenced the NE Pacific and that a strengthened anticyclone (as suggested in sec. 5.2.2) was restricted to the subarctic NW Pacific. In other words, the NPH may have shifted westward in response to the presence of a strong anticyclonic anomaly over the LIS.~~ Therefore, it is unlikely that the increased influence of the NPH over Kamchatka (as inferred from MAT_{ifs}) was caused by a general strengthening of the NPH. We hypothesize that the NPH may have weakened in response to strong anticyclonic anomalies over the LIS but at the same time shifted westward relative to today. Since the NPH is centered over the NE Pacific under present-day conditions a westward shift would automatically increase the strength of the southerly flow over the NW Pacific. This may explain why the influence of the NPH became stronger over the NW Pacific despite a general weakening of the anticyclone.

Interestingly, the general patterns of temperature change over Beringia and the N Pacific Ocean (as inferred from the proxy compilation, Fig. 4c) suggests that the LGM thermal gradient between western/central Beringia and the N-Pacific Ocean was increased relative to today (Fig. 4c). While warm summers were widespread in western Beringia (Alfimov and Berman, 2001; Kienast, 2002; Kienast et al., 2005; Sher et al., 2005; Berman et al., 2011), the majority of SST records from the open N Pacific and the Bering Sea indicate colder conditions during the LGM (Fig. 4c; deVernal and Pedersen, 1997; Seki et al., 2009, 2014; Kiefer and Kienast, 2005; Harada et al., 2004;

2012; Maier et al., 2015; Meyer et al., 2016). Under the assumption that alkenone-based reconstructions of LGM SST in the Sea of Okhotsk (Seki et al., 2004, 2009; Harada et al., 2004, 2012) are biased, also the Sea of Okhotsk may have been significantly colder than at present as suggested by TEX$^{L}_{86}$-based SST reconstruction (reduced by ~4-5°C Seki et al. 2009; 2014). An increased thermal gradient between the subarctic N Pacific and western Beringia would translate into an increased pressure gradient between land and ocean which would intensify the southerly flow over the Kamchatka relative to today. Combined with a weakening of the NPH over the NE Pacific (due to American ice sheets) this mechanism may have been a potential cause for the westward shift of the NPH.

The COSMOS simulation also contrasts with the temperature patterns in western Beringia suggested by proxy-based climate reconstructions (see. Sec. 5.1) as summers were simulated to be colder than at present on Kamchatka and in large parts of Siberia (Fig. 4b). As for Siberia warm summer conditions were explained by increased continentality as a result of the exposed Siberian, Bering and Chukchi Shelfs during the LGM (refernces). However, Iin small parts of the formerly exposed BLB and the arctic shelves temperatures level or exceed PI-conditions (Fig. 4b) in the COSMOS simulation. This would be in agreement with tThe exposure of the Siberian Shelf and the BLBmay also have an effect. However, in the model these anomalies are restricted to a relatively small area and are not comparable with the widespread warming tendencies over Siberia, which are visible in the proxy-compilation (Fig. 4b, c). Considering that that these positive anomalies are in the area of influence of the dominant anticyclonic anomalies over North America and the associated easterly to southeasterly winds over south Alaska and the BLB (Fig. 4b), it is more likely that the modeled positive anomalies in SAT over the BLB are associated with the changes in atmospheric circulation, rather than with continentality. As for the model-proxy discrepancies regarding Siberian SAT one may speculate that the effect of land-mass exposure on temperature is underestimated in the model. These positive anomalies in the model are probably associated with the dominant anticyclonic flow over North America and the associated easterly to southeasterly winds over south Alaska and the BLB (Fig. 4b). The exposure of the Siberian Shelf may also have an effect. However, these anomalies are restricted to a relatively small area and are not comparable with the widespread warming tendencies over Siberia, which are visible in the proxy-compilation (Fig. 4b, c). Given the discrepancies between proxy-based temperature reconstructions for Siberia and computer-model simulationsthe ESM, the thermal gradient between western Beringia and the subarctic NW Pacific may also differ. In the model simulation the thermal contrast between land and ocean tends to become smaller since the negative temperature anomaly over western Beringia for the most part is more pronounced than over the subarctic N-Pacific (Fig. 4b). This contrasts with the proxy compilation according to which the thermal gradient was increased relative to present (Fig. 4c). As the model predicts a

~~reduction of the thermal gradient the preconditions for the increased landward air-flow are not given. In contrast a reduced thermal gradient would support a northerly anomaly, which is in accordance with the simulated wind-patterns over Kamchatka (Fig. 4a). Hence, the discrepancies between proxies and model outputs concerning glacial summer temperature over western Beringia potentially entail~~ explain ~~the mismatch~~ between model and ~~proxy based reconstructions of~~ ~~regarding the atmospheric circulation patterns over the NW Pacific.~~

The distribution of temperature anomalies in the COSMOS simulation shows a different pattern than the proxy compilation (Fig. 4b and c). The model predicts a widespread cooling over Siberia and Kamchatka where the majority of proxy data suggests warmer or equal temperatures relative to present. Relatively warm summers in western and central Beringia (as inferred from the proxy data) have been explained by increased continentality due to the exposure of the Siberian, Bering and Chukchi Shelfs during the LGM (Guthrie, 2001; Kienast et al., 2005; Berman et al., 2011). In the model the impact of continentality may be comparable to the proxy world over the eastern Siberian and the northern Chukchi Shelf since SAT anomalies are between -1 and +1°C (Fig. 4b) implying summer SAT similar to PI conditions. Also, positive anomalies over parts of the Bering and Chukchi Shelf are likely associated with the shelf exposure (Fig. 4b). However, for the latter, easterly to southeasterly wind anomalies over south Alaska and the Bering Land Bridge (Fig. 4b), may also play a role. Given the discrepancies between model and proxies for SAT in the Siberian interior it seems that the effect of continentality in the COSMOS simulation is weaker than in the proxy world and that other factors are more influential. Reduced CO_{2atm} is a prominent cause for lowered temperature during the LGM (e.g. Kageyama et al., 2006; Shakun et al., 2012). Furthermore, cooling over the Arctic Ocean combined with northerly anomalies in the wind patterns over the East Siberian Sea (Fig. 4b) may have enhanced the advection of cold arctic air masses to Siberia, a mechanism supporting SAT decrease in Siberia (Mock et al., 1998). Similarly, northerly anomalies are also present over Kamchakta which are in accordance with summer cooling on the Peninsula (Fig. 4a).

Given the discrepancies between proxy-based temperature reconstructions for Siberia and the ESM, the thermal gradient between western Beringia and the subarctic NW Pacific may also differ. In the model simulation the thermal contrast between land and ocean tends to become smaller since the negative temperature anomaly over western Beringia for the most part is more pronounced than over the subarctic N-Pacific (Fig. 4b). This contrasts with the proxy compilation according to which the thermal gradient may have been increased relative to present (Fig. 4c). As the model predicts a reduction of the thermal gradient the preconditions for the increased landward air-flow are not given. In contrast a reduced thermal gradient would support a northerly anomaly, which is in accordance with the simulated wind-patterns over Kamchatka (Fig. 4a). Hence, the discrepancies between proxies and model-outputs concerning glacial summer temperature over western Beringia potentially explain the mismatch between model and proxy based reconstructions of the atmospheric circulation patterns over the NW Pacific.

5.2.3. The deglaciation (18 ka-10 ka BP)

The deglacial ~~short-term~~millenneial-scale variability ~~strongly~~ resembles the climate development in the N-Atlantic as MAT_{ifs} follows the deglacial oscillations recorded in the NGRIP-$\delta^{18}O$ (Fig. 2b, i), particularly after ~15 ka BP. MAT_{ifs} ~~clearly~~ mirrors the Bølling/Allerød (B/A)-interstadial, the Younger Dryas (YD)-cold reversal and the subsequent temperature increase into the Preboreal (PB; Fig. 2b, i). This similarity ~~suggests a strong coupling with climate change in the N-Atlantic realm and hence variations in the AMOC-strength. The pronounced response~~ to N-Atlantic climate change is in line with ~~the temperature development in the surrounding seas where~~ the majority of ~~climate~~SST-records from the surrounding seas ~~shows a Greenland-like pattern~~ (Ternois et al., 2000; Seki et al., 2004; Max et al., 2012; Caissie et al., 2010; Praetorius and Mix, 2014; Praetorius et al., 2015; Meyer et al., ~~submitted~~2016). This in-phase variability between Greenland and N Pacific records is assumed to result from atmospheric teleconnections between the N-Atlantic and the N-Pacific Oceans (e.g. Manabe and Stouffer, 1988; Mikolajewicz et al., 1997; Vellinga and Wood, 2002; Okumura et al., 2009; Chikamoto et al., 2012; Max et al., 2012; Kuehn et al., 2014; Praetorius and Mix, 2014). While ~~the effects of an~~ atmospheric coupling with the N-Atlantic ~~are undoubtedly~~seem to have affected Kamchatka ~~present~~ between ~15 and ~10 ka BP ~~their relevance~~such connection is questionable during Heinrich Stadial 1 (HS1). The cold-spell between ~18 ka BP and ~14.6 ka BP ~~as evident~~ in the MAT_{ifs} record may coincide with the HS1 in the N-Atlantic but initiates 2 ka earlier than in NGRIP-$\delta^{18}O$. ~~Considering that also SST records from the Western Bering Sea indicate that the~~show a ~~Heinrich-equivalent cold-spell commenc~~inged ~~at approx. 16.5 ka BP (site 114KL, Meyer et al., submitted~~2016)~~,~~ Therefore, the event in MAT_{ifs} is probably not associated with climate change in the N-Atlantic (Fig. 2b, g). This temporal offset cannot be explained by age-model uncertainties in core 12KL since these are in the range of a few hundred years ~~error (1σ) of the calibrated radiocarbon ages is smaller than 100 yrs~~ (Max et al., 2012). If the cooling was not associated with climate change in the N-Atlantic, it could perhaps represents a local event on Kamchatka, and potentially western Beringia, marking the abrupt end of the warm LGM-conditions. Since, to the knowledge of the authors, such an event is not reported in the terrestrial realm of western Beringia, it is difficult to identify the driving processes. One may speculate that the southerly flow abruptly weakened over Kamchatka.

~~A clear similarity~~ Similarity ~~between MAT_{ifs} and NGRIP-$\delta^{18}O$ establishes at approx.~~approximately ~~15 ka BP.~~ While SST in the Western Bering Sea was likely coupled to the N Atlantic already prior to 15 ka BP, SST in the

NE Pacific (Praetorius and Mix, 2014) and marginal NW Pacific became linked at ~15.5 ka BP (Praetorius and Mix, 2014; Meyer et al., 2016). In the NE Pacific this was explained by a southward shift of the westerly Jet over America (Praetorius and Mix, 2014). In the marginal NW Pacific ~~This has recently been described for the SST in the marginal NW Pacific (Meyer et al., submitted) reconstructed for the same core site as investigated in the present study~~ (~~site 12KL, Fig. 2h). This record implies that the climate of the Kamchatka Peninsula until 15 ka BP was tied to the climate change in the NW Pacific rather than to climate change in the Western Bering Sea (Fig. 2b, g, h, i). For SST~~ T~~this pattern was explained by~~ accumulation of Alaskan Stream ~~(AS)~~ waters ~~in the NW Pacific, which~~ likely overprinted the effect of the atmospheric teleconnection by linking the western and the eastern basins of the N Pacific (Meyer et al., ~~submitted~~2016). Hence, the effect of the Alaskan Stream may have also determined temperature evolution on Kamchatka during the early deglaciation, which would explain why the linkage to the North Atlantic ~~did not~~ initiated around~~before~~ 15 ka BP~~restricting the teleconnection to the period after 15 ka BP~~.

~~The clear and constant impact of N-Atlantic climate change between 15 and approx. 10 ka BP on Kamchatka is in agreement with palynological data from the Kankaren Range/Northeast Siberia (Fig. 1a) where abrupt climatic changes corresponding to the B/A and the YD are reported (Anderson and Lozhkin, 2015). Abrupt warming at the onset of the B/A is also evident in a high resolution record from Lake Elikchan 4 (Lozhkin and Anderson, 1996; Kokorowski et al., 2008b) and may indicate a linkage to N-Atlantic climate change.~~ The presence of a YD cold reversal on Kamchatka is in agreement with palynological data from Lakes Dolgoe, Smorodynovoye, Ulkhan Chabyda and Lake El'Gygytgyn (Fig. 1a; Pisaric et al., 2001; Anderson et al., 2002, Kokorowski et al., 2008a) suggesting that the N-Atlantic climate signal was transmitted to these sites (Kokorowski et al., 2008a). ~~However~~By contrast, a climatic reversal equivalent to the YD is often absent in records from northeast Siberia ~~(east of 140°N and north of 65°N; Fig. 1a; e.g.~~ Lake Jack London, Lake Elikchan 4; Lake El'Gygytgyn and Wrangel Island~~;~~ (Fig. 1a; Lozhkin et al., 1993, 2001, 2007; Lozhkin and Anderson, 1996; Nowaczyk et al., 2002; Nolan et al., 2003, Kokorowski et al., 2008a,b; Andeev et al., 2012)~~, as compiled by Kokorowski et al. (2008a)~~. ~~By contrast, palynological data from Siberia (e.g. from Lakes Dolgoe, Smorodynovoye and Ulkhan Chabyda, (Fig. 1a) indicates that a YD climatic reversal was present west of 140°N (Pisaric et al., 2001; Anderson et al., 2002, Kokorowski et al., 2008a).~~ Compiling deglacial records from Beringia Kokorowski et al. (2008a) identified an east-west gradient across western Beringia with a YD-like climatic reversal being present west of 140°E but absent in records east of 140°E. This east-west gradient was explained by a westward shift of the East Asian Trough (EAT; ~~normally~~ today situated over the ~~central Beringian coast~~Chukchi Shelves; Mock et al., 1998) which caused cooling west of 140°~~N~~ E by enhancing cold northerly winds, and together with an anticyclone over the Beaufort

Sea brought warming through stronger easterlies into the region east of 140°~~N~~ E (Kokorowski et al., 2008a). The presence of a YD-cold reversal on Kamchatka implies that the southeastern edge of Siberia was probably not affected by the shifting EAT. Several general circulation models investigating the nature of teleconnections between the N-Atlantic and N-Pacific realms suggest that the westerly Jet played an important role by acting as heat-conveyor between the N-Atlantic and the N-Pacific-Oceans (e.g. Manabe and Stouffer, 1988; Okumura et al., 2009). Considering the modern average position of the westerly Jet (between 30 and 60°N) Kamchatka likely received the YD-cold reversal through the westerlies. Together with a shift of the EAT,~~the suggested by~~ (Kokorowski et al. ~~(~~2008a), ~~northward decreasing influences of the westerly Jet and the Pacific Ocean north~~this may explain north-south differences in northeast Siberia.

5.2.4. The Holocene

Although not quite pronounced in magnitude, the long-term MAT_{ifs} evolution during the Holocene is characterized by a mid-Holocene Thermal Maximum (HTM) between ~8 and ~4-5 ka BP ~~which is followed by neoglacial cooling~~ (Fig. 2b). Since core 12 KL a relatively poor density of age control points during the Holocene (Fig. 2b) the timing of Holocene climate change has to be interpreted with appropriate caution. Nevertheless, ~~tThis long-term development~~the timing of the HTM is in ~~good~~ agreement with existing climate records from central and southern Kamchatka ~~(Fig. 2j)~~ where diatom and pollen-based records indicate warm and wet conditions between 8 and 5.2 ka BP, which are associated with the HTM (Dirksen et al., 2013; Hoff et al., 2015; Brooks et al., 2015). ~~A climate deterioration after the HTM, at ~4-5 ka BP, According to MAT_{ifs} the climate deterioration after the HTM started at approx. 4 ka BP. This timing is consistent withindicated by diatom-based climate reconstructions as well as chironomid-based temperatures from central and south Kamchatka (Dirksen et al., 2013; Hoff et al., 2014) and with re-advancing mountain glaciers (Savoskul et al., 1999, Barr and Solomina, 2014).~~ As already discussed in previous studies this long-term temperature development is thought to respond to changes in mean summer insolation (Brooks et al., 2015 and references therein). ~~(Fig. 2b, e, j)~~. ~~As summarized by Brooks et al. (2015), the timing of the HTM (approx. 9-4 ka BP) on Kamchatka as well as in southern parts of eastern Siberia is delayed compared to northern parts of Chukotka and Siberia where the HTM initiated at 9-8 ka BP (Biskaborn et al., 2012 and references therein; Nazarova et al., 2013b; Anderson and Lozhkin, 2015). Since a similar delay of the HTM has been found in northern Europe (Seppä et al., 2009), Brooks et al. (2015) concluded that the climate on Kamchatka was connected with the N-Atlantic realm by an atmospheric coupling. Furthermore, the fact that Andrén et al. (2015) detected an 8.2 cooling-event in pollen-based climate records from Kamchatka also points to a linkage with N-Atlantic climate.~~

Hence, it seems that the atmospheric linkage that determined climate variability during the deglaciation likely persisted into the Holocene where it acted as an important driver for long-term climate changes as well as for abrupt, short-lived climatic events.

6. Summary and Conclusion

Based on the CBT/MBT'-paleothermometre a continuous LGM-to-late Holocene record of summer-temperature in Kamchatka is presented. The temperature evolution and the driving mechanisms were investigated. The record allows inferences for the glacial atmospheric circulation patterns (i) and to describe how regional climate drivers (such as oceanic and atmospheric circulation) as well as global and supra-regional drivers (including CO_{2atm}, summer insolation and N-Atlantic climate variability) influenced the climate change on Kamchatka (ii). The findings can be summarized as follows:

LGM-summers temperatures were as high as at present the samewere as warm as at present. The warm summers likely may result from a change in the regional atmospheric circulation including a stronger-than-present southerly winds over Kamchatka as a result of a stronger-than-present anticyclone over the subarctic NW Pacific. The temperature reconstruction as well as the inferences for atmospheric circulation contrasts with model simulations, which predict widespread cooling over Siberia and Kamchatka, and a weakening of the NPH over the NW Pacific together with a reduction of southerly winds over Kamchatka. These discrepancies underline the need of further investigations of the LGM-climate in the NW Pacific realm using environmental indicators and model simulationsGCMs.

During the LGM the warming effect of the altered regional atmospheric circulation likely balanced the cooling effects of lowered CO_{2atm} and summer insolation.

Abrupt millennial-scale fluctuations characterize the deglacial temperature development and represent the most prominent temperature changes in summer temperature during the past 20 ka. A first abrupt cooling-event at 18 ka BP marks the end of the warm LGM conditions and is likely caused by regional climate change, the origin of which cannot be identified, yet. From around 15 ka onwards the temperature variations are obviouslyseem to be linked to climate change in the N-Atlantic, presumably via rapid atmospheric teleconnections, as the B/A-interstadial and the YD cold reversal are clearly present. Regional differencesDiscrepancies with northeast Siberian records regarding the presence of a YD-cold reversal in Siberia are possibly related to the position of the westerly Jet. During the Holocene the atmospheric linkage

~~with the N-Atlantic remained active and together with summer insolation is a primary driver for the long-term temperature development.~~

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Figure captions

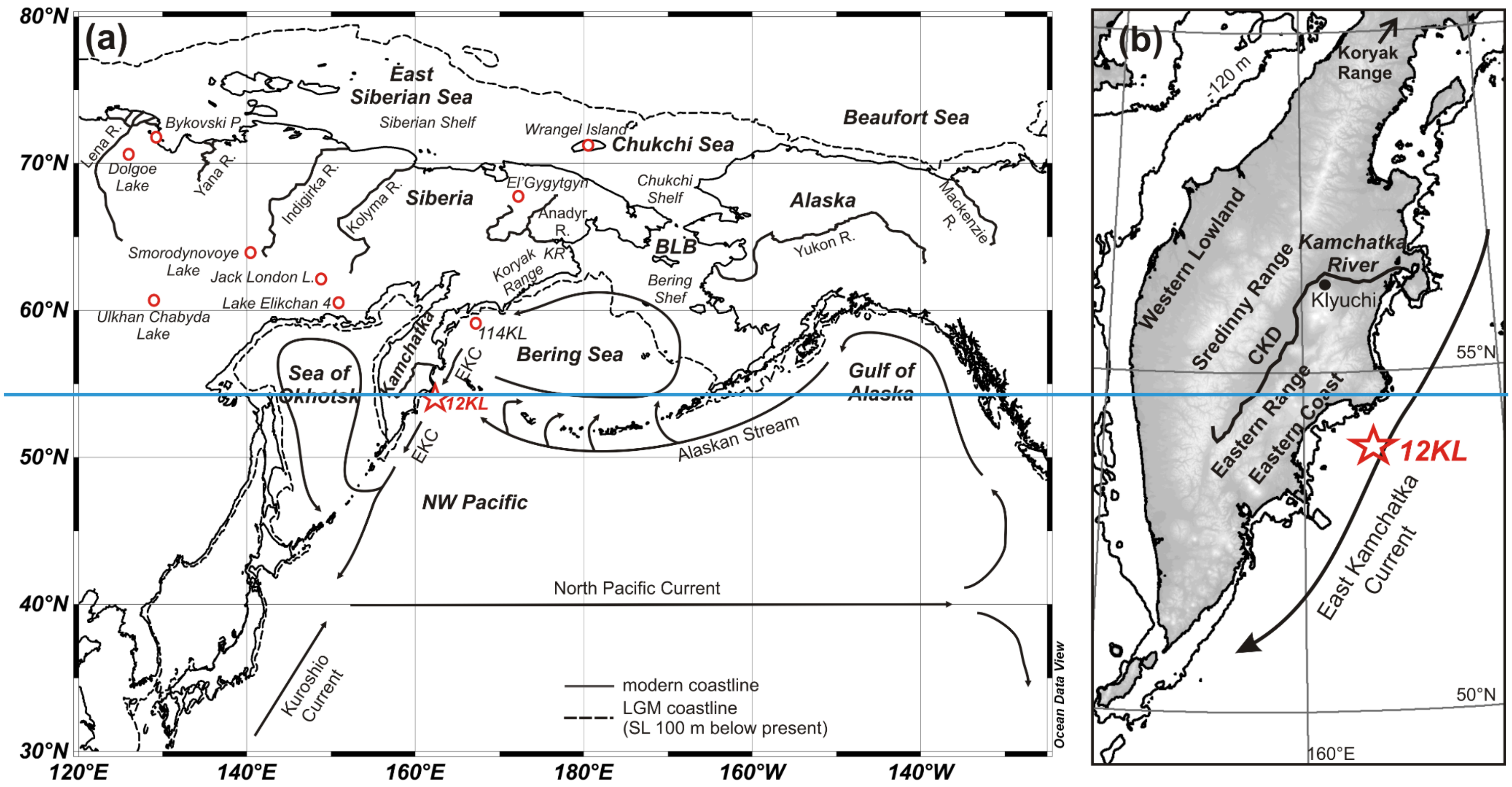
Figure 1. (a~~A~~) Overview of Beringia and the N Pacific. Site SO201-2-12KL is marked by a red star. Circles represent sites mentioned in the text. Black arrows indicate the surface circulation patterns of the N Pacific (e.g. Stabeno and Reed, 1994). BLB = Bering Land Bridge, KR = Kankaren Range, R = River, EKC = East Kamchatka Current. P = Peninsula. L= Lake (~~B~~b) Map of the Kamchatka Peninsula and its major orographic units. CKD = Central Kamchatka Depression.

Figure 2. a) Concentrations of ΣbrGDGT of core 12KL. b) CBT/MBT' derived MAT_{ifs} from Kamchatka (this study). Black pins represent the age control points from core 12KL (based on radiocarbon dating of planktonic

foraminifera, Max et al., 2012). c) BIT-index values of core 12KL (Meyer et al., ~~submitted~~2016). d) Titanium/Calcium ratios (Ti/Ca, XRF-scan core 12KL, Max et al., 2012). e) Mean July insolation at 65°N (Berger and Loutre, 1991). f) Atmospheric CO_2 concentration (EPICA dome C, Monnin et al., 2001; Parrenin et al., 2013). g) SST development in the marginal NW Pacific (site 12KL, Meyer et al., submitted). h) SST evolution in the western Bering Sea (site 114KL, Meyer et al., ~~submitted~~2016). i) NGRIP-$\delta^{18}O$ (NGRIP, 2004) represents climate change in the N Atlantic. ~~j) Pollen-based temperature reconstructions from the CKD (after Dierksen et al., 2013).~~ Grey-shaded bars mark the HS1 and YD stadials.

Figure 3. Fractional abundances of all nine brGDGT in core 12KL, given in percentage relative to the amount of ΣbrGDGTs.

Figure 4. Comparison of proxy- and model-based inferences regarding glacial anomalies in temperature and atmospheric circulation over the N Pacific and Beringia relative to present. (A) COSMOS-simulation for the JJA SLP-anomaly over Beringia and the N Pacific during the LGM (21 ka) relative to PI. Arrows represent the wind anomaly. Note that the model predicts a northerly anomaly over Kamchatka. (B) COSMOS-simulation for the SAT~~-anomaly together with the~~ and wind-anomaliesy during JJA. (C) Compilation of proxy based anomalies of summer air temperature in Beringia and of summer/autumn SST reconstructions in the N Pacific for the LGM. Sites and corresponding references are given in the appendix, Table A1. Doted arrows sketch the general summer anticyclone over the N Pacific, the NPH. Based on MAT_{ifs}, the NPH and associated southerly winds over the subarctic NW Pacific were stronger than at present (represented by solid arrow).


(a)
East Siberian Sea
Siberian Shelf
Beaufort Sea
Bykovski P.
Lena R.
Dolgoe Lake
Yana R.
Indigirka R.
Kolyma R.
Siberia
Wrangel Island
Chukchi Sea
Chukchi Shelf
El'Gygytgyn
Anadyr R.
Alaska
Mackenzie R.
Yukon R.
BLB
Bering Shef
Koryak Range
KR
Smorodynovoye Lake
Jack London L.
Lake Elikchan 4
Ulkhan Chabyda Lake
114KL
Bering Sea
Sea of Okhotsk
Kamchatka
EKC
12KL
Gulf of Alaska
Alaskan Stream
NW Pacific
North Pacific Current
Kuroshio Current
modern coastline
LGM coastline
(SL 100 m below present)
Ocean Data View
80°N
70°N
60°N
50°N
40°N
30°N
120°E
140°E
160°E
180°E
160°W
140°W
(b)
120 m
Koryak Range
Western Lowland
Sredinny Range
Kamchatka River
Klyuchi
CKD
Eastern Range
Eastern Coast
12KL
East Kamchatka Current
55°N
50°N
160°E

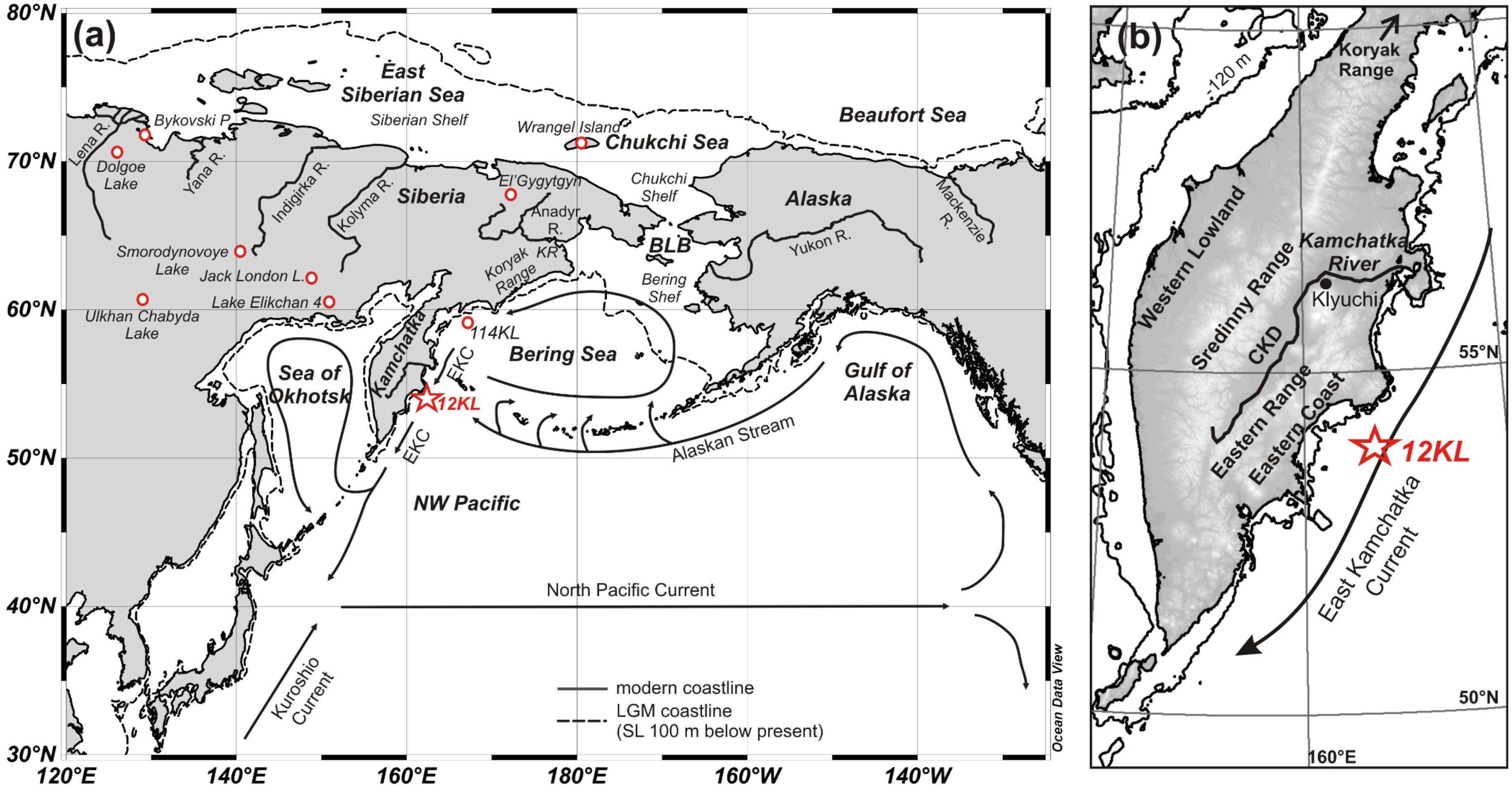
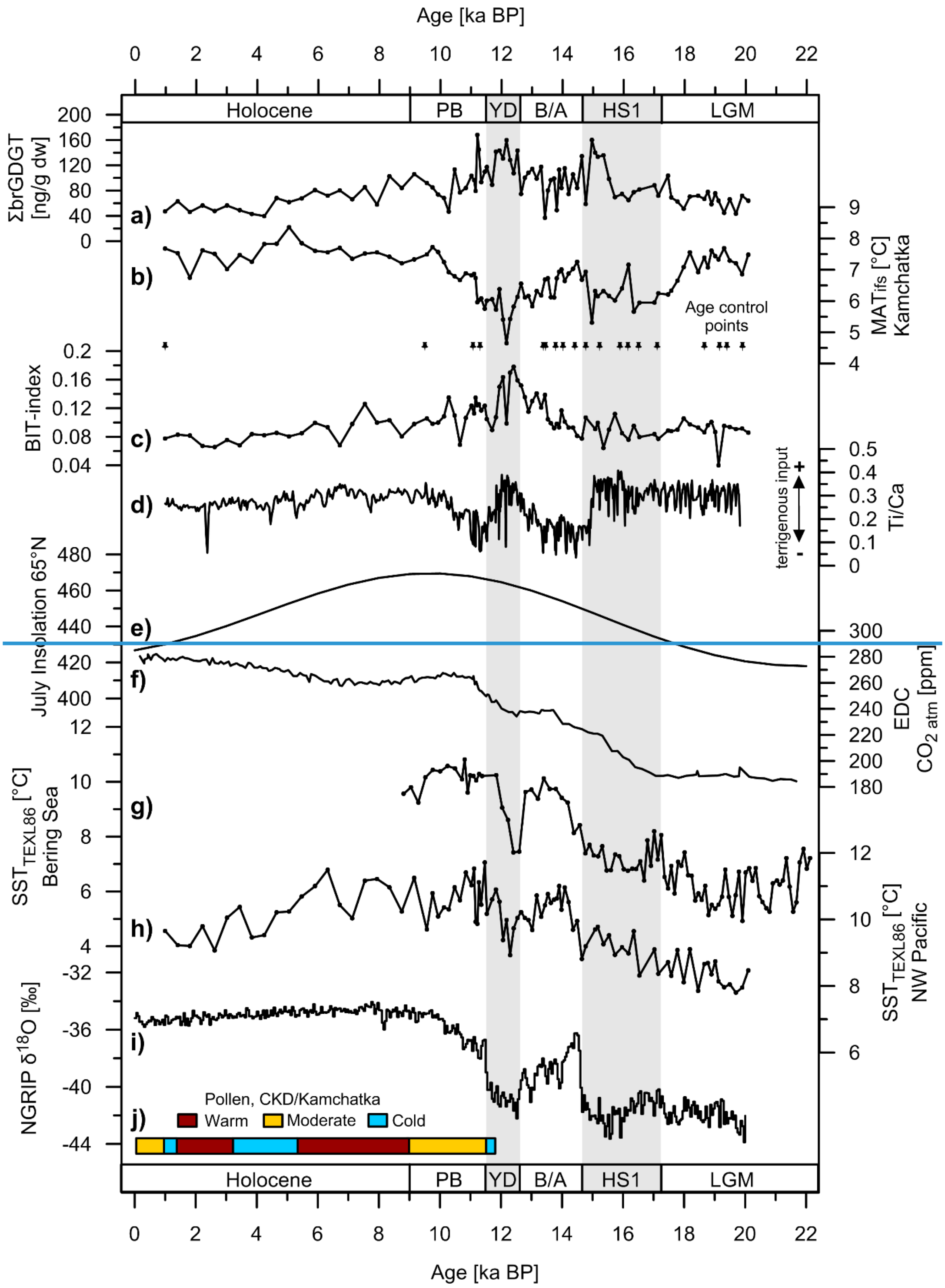
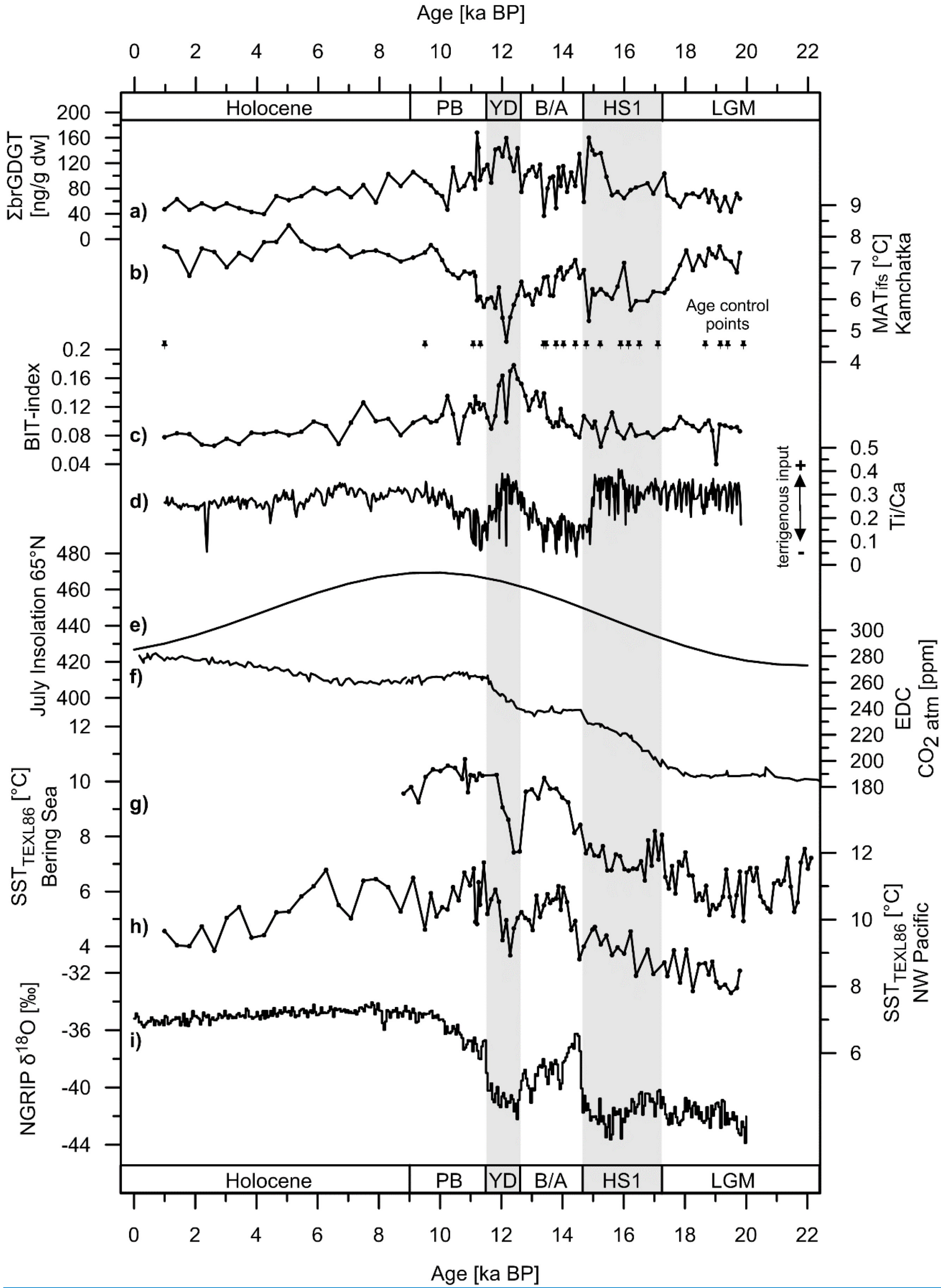

(a)
East Siberian Sea
Siberian Shelf
Bykovski P.
Lena R.
Dolgoe Lake
Yana R.
Indigirka R.
Kolyma R.
Siberia
Wrangel Island
Chukchi Sea
Beaufort Sea
El'Gygytgyn
Anadyr R.
Chukchi Shelf
Alaska
Mackenzie R.
Yukon R.
BLB
Bering Shef
Smorodynovoye Lake
Jack London L.
Lake Elikchan 4
Koryak Range
KR
Ulkhan Chabyda Lake
114KL
Bering Sea
Sea of Okhotsk
Kamchatka
EKC
12KL
Gulf of Alaska
Alaskan Stream
NW Pacific
North Pacific Current
Kuroshio Current
modern coastline
LGM coastline (SL 100 m below present)
Ocean Data View
80°N
70°N
60°N
50°N
40°N
30°N
120°E
140°E
160°E
180°E
160°W
140°W
(b)
-120 m
Koryak Range
Western Lowland
Sredinny Range
Kamchatka River
Klyuchi
CKD
Eastern Range
Eastern Coast
12KL
East Kamchatka Current
55°N
50°N
160°E

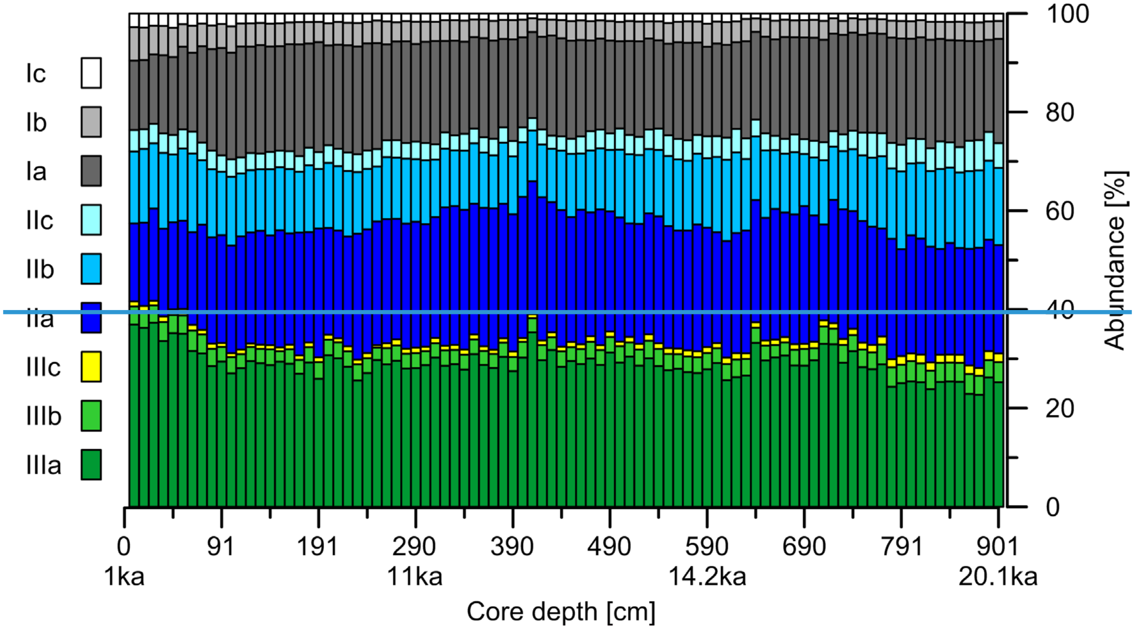
Fig. 1


Age [ka BP]
Holocene
PB
YD
B/A
HS1
LGM
ΣbrGDGT [ng/g dw]
a)
b)
MATifs [°C] Kamchatka
Age control points
BIT-index
c)
d)
terrigenous input
Ti/Ca
July Insolation 65°N
e)
f)
EDC CO2 atm [ppm]
SST TEXL86 [°C] Bering Sea
g)
h)
SST TEXL86 [°C] NW Pacific
NGRIP δ18O [‰]
i)
j)
Pollen, CKD/Kamchatka
Warm
Moderate
Cold



Age [ka BP]
0 2 4 6 8 10 12 14 16 18 20 22
Holocene
PB
YD
B/A
HS1
LGM
ΣbrGDGT [ng/g dw]
200 160 120 80 40 0
a)
b)
MATifs [°C] Kamchatka
9 8 7 6 5 4
Age control points
BIT-index
0.2 0.16 0.12 0.08 0.04
c)
d)
terrigenous input
+
-
Ti/Ca
0.5 0.4 0.3 0.2 0.1 0
July Insolation 65°N
480 460 440 420 400
e)
f)
EDC CO2 atm [ppm]
300 280 260 240 220 200 180
SST TEXL86 [°C] Bering Sea
12 10 8 6 4
g)
h)
SST TEXL86 [°C] NW Pacific
12 10 8 6
NGRIP δ18O [‰]
-32 -36 -40 -44
i)
Holocene
PB
YD
B/A
HS1
LGM
0 2 4 6 8 10 12 14 16 18 20 22
Age [ka BP]

Fig. 2


Ic
Ib
Ia
IIc
IIb
IIa
IIIc
IIIb
IIIa
100
80
60
40
20
0
Abundance [%]
0
91
191
290
390
490
590
690
791
901
1ka
11ka
14.2ka
20.1ka
Core depth [cm]

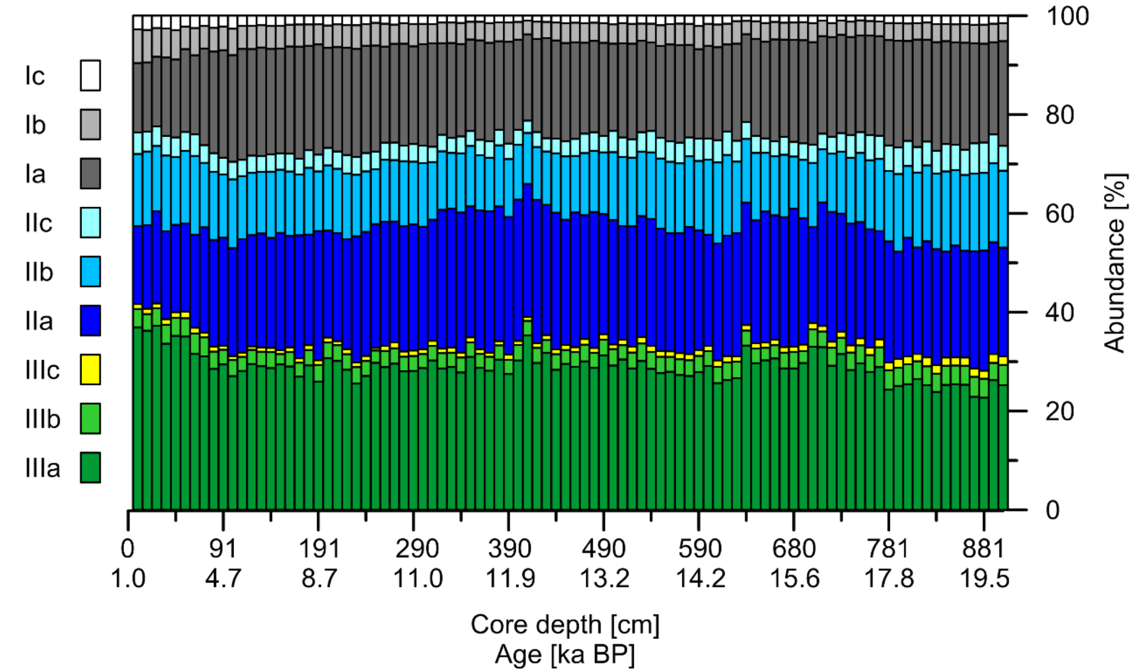
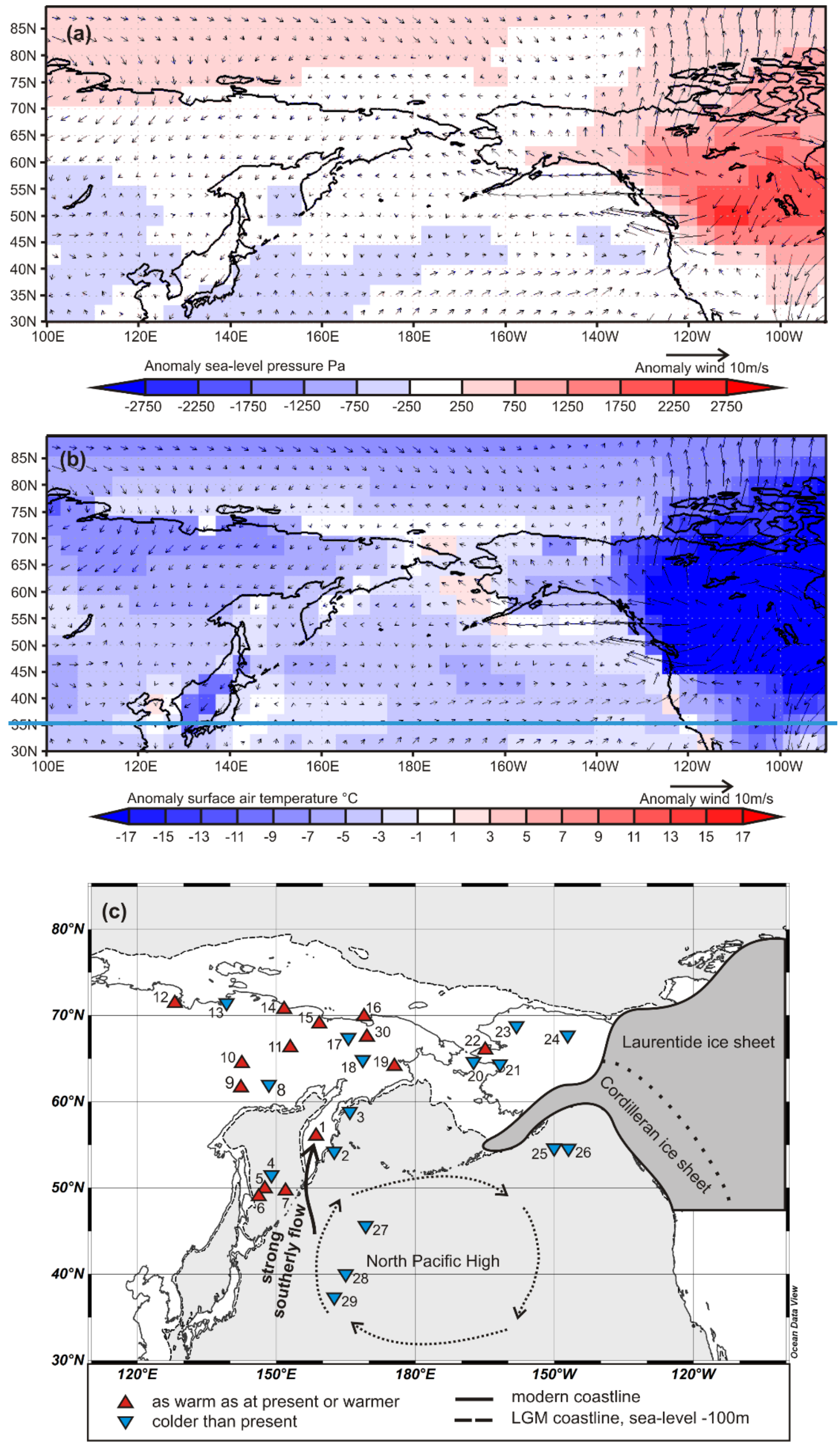

Ic
Ib
Ia
IIc
IIb
IIa
IIIc
IIIb
IIIa
100
80
60
40
20
0
Abundance [%]
0
91
191
290
390
490
590
680
781
881
1.0
4.7
8.7
11.0
11.9
13.2
14.2
15.6
17.8
19.5
Core depth [cm]
Age [ka BP]

Fig. 3


(a)
85N
80N
75N
70N
65N
60N
55N
50N
45N
40N
35N
30N
100E
120E
140E
160E
180E
160W
140W
120W
100W
Anomaly sea-level pressure Pa
Anomaly wind 10m/s
-2750 -2250 -1750 -1250 -750 -250 250 750 1250 1750 2250 2750
(b)
Anomaly surface air temperature °C
Anomaly wind 10m/s
-17 -15 -13 -11 -9 -7 -5 -3 -1 1 3 5 7 9 11 13 15 17
(c)
80°N
70°N
60°N
50°N
40°N
30°N
120°E
150°E
180°E
150°W
120°W
Laurentide ice sheet
Cordilleran ice sheet
North Pacific High
strong southerly flow
Ocean Data View
as warm as at present or warmer
colder than present
modern coastline
LGM coastline, sea-level -100m

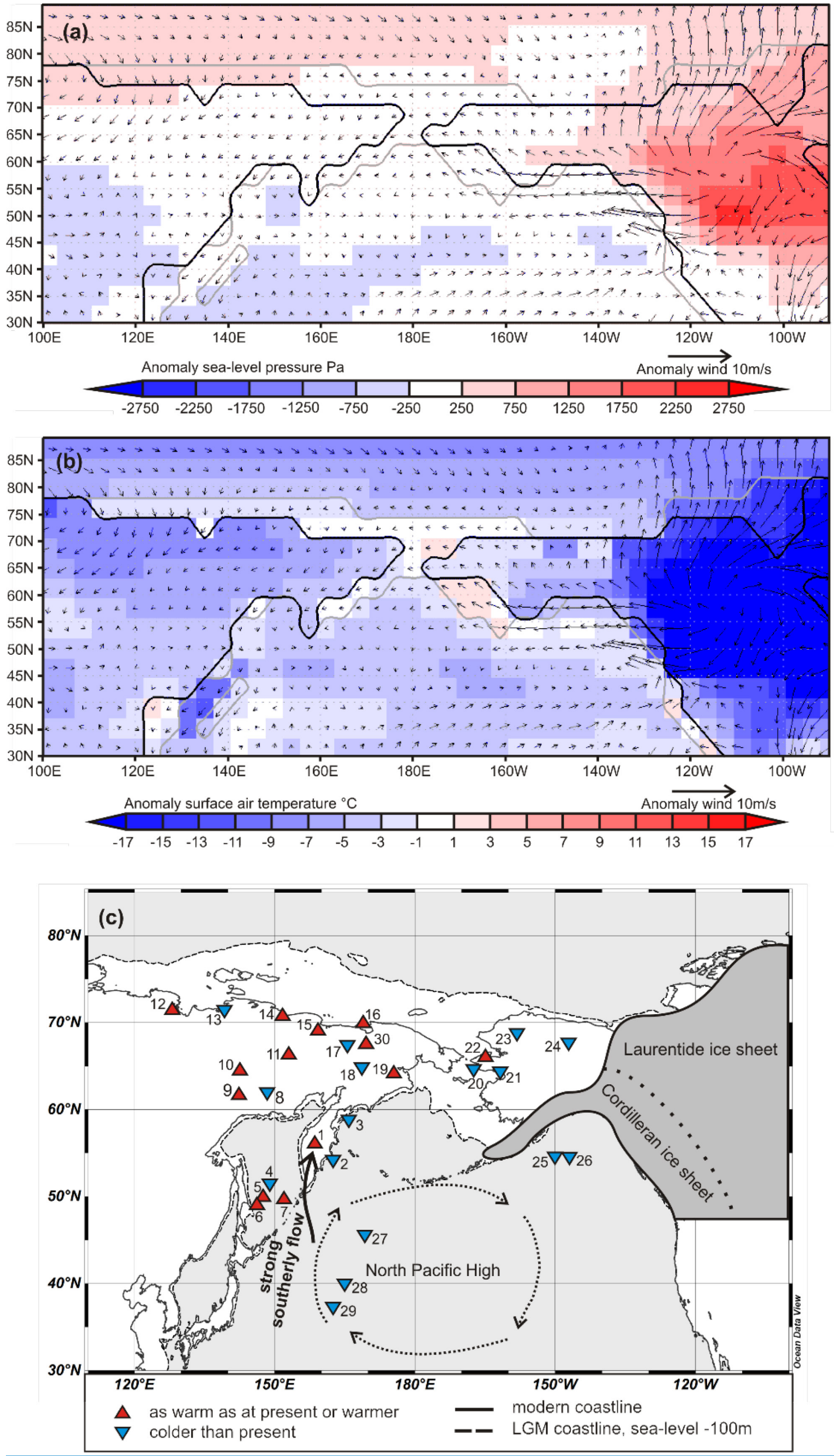

(a)
Anomaly sea-level pressure Pa
Anomaly wind 10m/s
-2750 -2250 -1750 -1250 -750 -250 250 750 1250 1750 2250 2750
(b)
Anomaly surface air temperature °C
Anomaly wind 10m/s
-17 -15 -13 -11 -9 -7 -5 -3 -1 1 3 5 7 9 11 13 15 17
(c)
Laurentide ice sheet
Cordilleran ice sheet
North Pacific High
strong southerly flow
as warm as at present or warmer
colder than present
modern coastline
LGM coastline, sea-level -100m
Ocean Data View

Fig. 4

Appendix A

Table A1. Sites and references for the data compiled in Fig. 4c. BLB: Bering Land Bridge.

No.	Site	Region	Proxy	Reference
1	SO201-2-12KL	NW Pacific/Kamchatka	CBT/MBT'	This study
2	SO201-2-12KL	NW Pacific	TEX^{L}_{86}	Meyer et al., submitted2016
3	SO201-2-114KL	Western Bering Sea	TEX^{L}_{86}	Meyer et al., submitted2016
4	MR0604-PC7	Sea of Okhotsk	$U^{K'}_{37}$	Seki et al., 2009, 2014
5	XP98-PC2	Sea of Okhotsk	$U^{K'}_{37}$	Seki et al., 2004
6	XP98-PC4	Sea of Okhotsk	$U^{K'}_{37}$	Seki et al., 2004
7	MR00K03-PC04	Sea of Okhotsk	$U^{K'}_{37}$	Harada et al., 2004, 2012
8	unknown	Sosednee Lake/Siberia	pollen	Lozhkin et al., 1993
9	unknown	Oymyakon Depression/Siberia	beetle	Berman et al. (2011)
10	unknown	Middle stream of Indigirka River/Siberia	beetle	Berman et al. (2011)
11	unknown	Lower and middle reaches Kolyma River/Siberia	beetle	Berman et al. (2011)
12	Mkh	Bykovski Peninsula/Siberia	pollen/beetle	Kienast et al. (2005); Sher et al. (2005)
13	YA02-Tums1	Yana lowlands/Siberia	pollen	Pitul'ko et al. (2007)

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14	unknown	Indigirka Lowland/Siberia	beetle	Alfimov and Berman, (2001); Kieselev (1981)
15	unknown	Kolyma Lowland/Siberia	beetle	Alfimov and Berman, (2001); Kieselev (1981)
16	unknown	Ayon Island/Siberia	beetle	Alfimov and Berman, (2001); Kieselev (1981)
17	PG1351	Lake El'Gygytgyn	pollen	Lozhkin et al. (2007)
18	unknown	Markovo/Siberia	beetle	Alfimov and Berman, (2001); Kieselev (1981)
19	unknown	Anadyr River middle stream /Siberia	beetle	Berman et al. (2011);
20	Bering Shelf 78-15	Shelf off Seward Peninsula/BLB	beetle	Elias et al. (1996, 1997); Elias (2001)
21	Zagoskin Lake	western Alaska	chironomids	Kurek et al. (2009)
22	Bering Land Bridge Park	Seward Peninsula/Alaska	beetle	Elias et al. (2001)
23	Burial Lake	St. Michael Island /BLB, Alaska	chironomids	Kurek et al. (2009)
24	Bluefish	Bluefish Basin/Alaska	beetle	Mathews and Telka, (1997); Elias et al. (2001)
25	SO202-27-6	Gulf of Alaska	$U^{K'}_{37}$	Maier et al. (2015)

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26	PAR87A-10	Gulf of Alaska	dinocysts	deVernal and Pedersen (1997)
27	MR97-02 St. 8s	NW Pacific	$U^{K'}_{37}$	Harada et al. (2004, 2012)
28	MR98-05 St. 5	NW Pacific	$U^{K'}_{37}$	Harada et al. (2004, 2012)
29	MR98-05 St. 6	NW Pacific	$U^{K'}_{37}$	Harada et al. (2004, 2012)
30	unknown	Chaun Depression/Siberia	beetle	Berman et al. (2011)