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Climate of the Past Discussions

Interactive comment on "Summer-temperature evolution on the Kamchatka Peninsula, Russian Far East, during the past 20,000 years" *by* Vera D. Meyer et al.

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Dear reviewer, thank you very much for your detailed and helpful review on our manuscript. Please, see below how we intend to address your comments and suggestions to revise our manuscript..

Specific comments Line 95: list the number of samples analyzed and the approximate or average depth and time sampling resolution

We will add to line 95: "For this study we used the same samples as Meyer et al, (2016). The core was sampled in 10 cm steps providing an average temporal resolution of approximately 200 years.

Line 133-134: 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. So, the standard deviation is for the sample preparation and measurement processes in our lab. Repeated measurement for the samples of core 12KL were not possible, because of small amounts. We will add the following sentence to line 133-134: "From repeated measurements of a lab-internal standard sediment extract (n=7) the standard deviations for CBT and MBT' were determined as 0.01 and 0.04, respectively."

Line 136: 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. In the results and discussion sections we will refer to the calibration error whenever absolute temperature values are given using xy $\pm$ 5°C.

Line 148: does the word "glacial" belong here? it doesn't make sense. Please clarify in the text.

No, the word does not belong here. It will be deleted. Thanks!

Line 148-149: 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.

We will append the following paragraph to line 156. “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 (CO2=185ppm; N2O=200ppb; CH4=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 $\sim$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 157: 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 will 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 181: 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.

This is a good point, thanks. We will replace the Atlantic-related terms by dates. For example: “. . .until the beginning of the Bølling/Allerød” will turn into:”. . .until 14.6 ka BP.”

Line 204: 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 148-149, we will add a paragraph describing the model setup in more detail. The effects of the exposed land in the model and the proxy world will be addressed in the discussion (see comment on line 330).

Line 227: 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.

We suggest to replace the sentence from line 227 by: “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.”

Line 231: do the authors mean “in marine areas where brGDGTs are thought. . .”? Please clarify.

Yes, we do. In order to clarify we will insert “marine” before “areas”.

Lines 242 and 244: what are the uncertainties or standard deviations on these temperature observations? Please clarify.

Please, see comment on line 136.

Line 251: cite PMIP?

Good idea. We will mention PIMP and cite Braconnot et al. (2012).

Line 267: clarify whether this attribution was by previous studies, or by this study.

In order to clarify we suggest the following modification: “In previous studies the 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).”

Line 280 and others: Clarify in the text what proxy was used to produce this Sea of Okhotsk SST reconstruction.

The sentence encompassing lines 279 and 280 begins with: Alkenone-based SST... This implies the application of UK’37. “UK’37” could be used instead of “Alkenone-based” or can be put in parentheses, in order to specify. In all other instances where we did not mention the SST proxy (lines 285-286) it will be implemented. It is TEXL86 in every case.

Line 285: 1°C is well within calibration error of these proxies, and is important to mention in the text. The calibration error of the calibration applied to the TEXL86 at site 12KL is 1.7°C (Meyer et al., 2016 and references therein). We will write 1 $\pm$1.7°C

Line 325-328: It seems as if the final two sentences in this paragraph say opposite things. Can this be clarified?

In order to clarify we will append an additional paragraph to line 328. The paragraph comprising lines 297-307 will be shifted behind the additional one. The resulting paragraph will be as follows: “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. Therefore, it is unlikely that the increased influence of the NPH over Kamchatka (as inferred from MATifs) was caused by a strengthening of the NPH. So, 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 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; Praetorius and Mix, 2014; Praetorius 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 TEXL86-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 continental low-pressure over western Beringia and the high pressure over the subarctic NW Pacific. As this would intensify the southerly flow over Kamchatka relative to today, this mechanism may supported a westward displacement of the NPH.”

Line 330: 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 included the land boundaries used in the PI and LGM simulations into Figure 4a and 4b (as requested in your comment on Figure 4). Based on these modifications we will also change the paragraph of lines 329-337 as follows: “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 that summer SAT were 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 BLB (Fig. 4b), may also play a role. Given the discrepancies between model and proxy based results for Siberian SAT it seems that the effect of continentality in the COSMOS simulation is weaker than in the proxy world and that other factors are more important. Reduced CO2atm is generally regarded a prominent cause for globally lowered temperatures during the LGM (e.g. Kageyama et al., 2006; Shakun et al., 2012). As a regional factor, cooling over the Arctic Ocean combined with northerly anomalies in the wind patterns over the East Siberian Sea 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 and those are in agreement with summer cooling on the Peninsula (Mock et al., 1998). Given the discrepancies between proxy-based temperature reconstructions for Siberia and the ESM, the thermal gradient between western Beringia and the subarctic NW Pacific seems to differ, too. 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 explain the mismatch between model and proxy based reconstructions of the atmospheric circulation patterns over the NW Pacific.”

Line 344: It might clarify to add the following wording: “potentially explain the mismatch between model and proxy. . .”

You are right, the sentence reads better with your suggestion. We will adapt it (see previous comment).

Line 351: 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 intend to put “in the surrounding seas of Kamchatka (Bering Sea, NW Pacific, Sea of Okhotsk)” along this line.

Line 360: 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. We will implement a short paragraph describing the uncertainties introduced by the AMS dating as well as by the assumptions for reservoir ages in section 3.1.

Paragraph to be added in section 3.1: 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 important issue 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).

As for line 360, we will refer back to this paragraph: "As elaborated in section 3.1 the uncertainty of the age control is a few hundred years. Therefore, uncertainties in the age model are unlikely to explain the temporal offset."

Concerning age uncertainty estimates in Figure 2, we will not include any graphical features, e.g. bars, as those would make the Figure look very busy if we also include error bars for the temperature (as requested in your comment on Figure 2). The reader will be able to read details about the uncertainty in section 3.1 (see comment on line 360).

Line 367: clarify what proxy is used to reconstruct SST in the NW Pacific.

It is TEXL86. We will include this information.

Line 368-369: this sentence is unclear, please rewrite and clarify.

Indeed, this sentence was confusing. We will replace it by the following: "This has recently been described for the SST at this core site in the marginal NW Pacific, which was reconstructed using the TEXL86 proxy (Meyer et al., 2016)."

Line 370: What does AS stand for? Perhaps just spell out the full term.

Thanks, "AS" stands for "Alaskan Stream". The abbreviation will be defined here.

Line 366-373: 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. It was concluded that the Alaskan Stream connected the deglacial SST development of the NW Pacific with the Gulf of Alaska, thereby causing different SST developments in the NW Pacific and the Bering Sea. Details can be found in Meyer et al., 2016 and references therein.

We will reword the sentence to: "the effect of the AS may have also determined temperature evolution on Kamchatka during the early deglaciation, which would explain why the linkage to the North Atlantic did not initiate before 15 ka BP." avoiding the confusing expression "restricting".

Line 405: 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?

Thanks, there is a typo in the parentheses describing the beginning of the HTM in Siberia. This will be corrected. We will write: "As summarized by Brooks et al. (2015), the beginning of the HTM on Kamchatka (approximately 9-8 ka BP; see Brooks et al., 2015 and references therein) on Kamchatka as well as in the sub-Arctic part of eastern Siberia (Nazarova et al., 2013b) is delayed compared to regions further north towards the Arctic Ocean where the HTM initiated at 10 ka BP (Biskaborn et al., 2012 and references therein)."

Lines 407-410: 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?

We will delete the sentences in lines 409-413 as the presence of an 8.2 event on Kamchatka is debatable on the basis of the existing records and it is not apparent in

MATifs. We leave the sentences in line 407 and 408 in as the timing of the HTM in our record fits those studies cited. Therefore, it is reasonable to shortly summarize the main interpretations of the previous work regarding the timing of the HTM. This is summer insolation and teleconnection with Europe. Deleting the teleconnection part would make the summary incomplete.

Lines 428-429: It is unclear what this sentence means. Please clarify.

The sentence will be 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.

We decided to implement the calibration error alone, since the analytical error is so small that it is hardly wider than the line of the plots.

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 will be implemented into the caption. Furthermore, we will include the land boundaries applied to the PI and LGM simulations into Figures 4a and 4b (see supplementary figures to this response letter):

Supplementary Figure 1 (this will replace Figure 4a in the manuscript). 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.

Supplementary Figure 2 (will replace figure 4b in the manuscript). COSMOS-simulation for the SAT-anomaly together with the wind-anomaly during JJA for LGM relative to PI conditions.

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

Yes, thanks. Capital letters will be replaced by lower case letters.

Line 35: clarify what “next to” means: rather than? or in addition to?

It is meant in the sense of “in addition to”. This will be replaced since “next to” seems to be a confusing term.

Line 53 (and elsewhere in the text): I think the authors mean 150°W here, and this same typo is made elsewhere (e.g., line 385).

Yes, there is a typo, thanks for pointing out. “150°E” is the correct term and will be included. The same applies to line 385 and a few more.

Line 74: 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. If this is difficult to understand, we can 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 175: it might help to add the word “respectively” to the end of the sentence that lists the percentages. Will be done.

Line 184: change “with approx.” to “at approx.” Will be done.

Line 194: Add “North” before “American continent” Will be done.

Line 203: remove the w in “now” Yes, thanks.

Line 209: 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).

That is a good point, thanks. We will include “becomes more pronounced from east to west”.

Line 226: this is an incomplete sentence.

Indeed. The sentence will be completed by: ". . .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."

Line 248: add comma between climate and according

Will be implemented.

Line 250: change 'computer' to 'general circulation'

Will be done.

Line 253: change "ice caps" to "ice sheets"

Will be done.

Line 255: is CO2atm defined prior to this? If not, then define here.

You are right, "CO2atm" appears for the first time. We will define it: "atmospheric CO2 (CO2atm)."

Line 261: add "summer" between present and conditions.

Will be done.

Line 412: define what "it" refers to.

"It" refers to the atmospheric linkage, which is mentioned in the previous line. In order to keep the sentence clear, we replaced it by "the linkage"

Line 420: change "were as high as at present" to "were similar to present temperatures" or something to that effect.

We suggest to add "were very similar to present summer temperatures"

Line 421: remove "a" before "stronger-than-present"

Will be done.

References (not listed in the paper): Braconnot, P., Harrison, S. P., Kageyama, M., Bartlein, P. J., Masson-delmotte, V., Abe-ouchi, A., ... Zhao, Y. (2012). Evaluation of climate models using palaeoclimatic data. Nature Climate Change, 2(6), 417–424. http://doi.org/10.1038/nclimate1456 Dullo, W. C., B. Baranov, and C. van den Bogaard (2009), FS Sonne Fahrtbericht/Cruise Report SO201–2. IFM-GEOMAR, Rep. 35, 233 pp, IFM-GEOMAR, Kiel, Germany. Kuehn, H., L. Lembke-Jene, R. Gersonde, O. Esper, F. Lamy, A. Arz, G. Kuhn, and R. Tiedemann (2014), Laminated sediments in the Bering Sea reveal atmospheric teleconnections to Greenland climate on millennial to decadal timescales during the last deglaciation. Clim. Past, 10(6), 2215–2236, doi:10.5194/cp-10-2215-2014. Lund, D. C., A. C. Mix, and J. Southon (2011), Increased ventilation age of the deep northeast Pacific Ocean during the last deglaciation, Nat. Geosci., 4(11), 771–774, doi:10.1038/ngeo1272. Max, L., Riethdorf, J.-R., Tiedemann, R., Smirnova, M., Lembke-Jene, L., Fahl, K., Nürnberg, D., Matul, A. and Mollenhauer, G.: Sea surface temperature variability and sea-ice extent in the subarctic northwest Pacific during the past 15,000 years, Paleoceanography, 27(3), PA3213, doi:10.1029/2012PA002292, 2012. Meyer, V. D., Max, L., Hefter, J., Tiedemann, R. and Mollenhauer, G. Glacial-to-Holocene evolution of sea surface temperature and surface circulation in the subarctic northwest Pacific and the Western Bering Sea. Paleoceanography 31, (2016), doi:10.1002/2015PA002877. Praetorius, S. K., A. C. Mix, M. H. Walczak, M. D. Wolhowe, J. A. Addison and F. G. Prahl (2015), North Pacific deglacial hypoxic events linked to abrupt ocean warming. Nature, 527(7578), 362-366, doi:10.1038/nature15753. Raddatz, T. J., Reick, C. H., Knorr, W., Kattge, J., Roeckner, E., Schnur, R., Schnitzler, K.-G., Wetzel, P., and Jungclaus, J.: Will the tropical land biosphere dominate the climate–carbon cycle feedback during the twenty-first century?, Clim. Dynam., 29, 565–574, 2007. Reimer, P. J., et al. (2009), Intcal09 and Marine09 radiocarbon age calibration curves, 50,000 years cal. BP, Radiocarbon, 51(4), 1111–1150. Sarnthein et al., (2015). Planktic and Benthic 14C Reservoir Ages for Three Ocean Basins, Calibrated by a Suite of 14C Plateaus in the Glacial-to-Deglacial Suigetsu Atmospheric 14C record. Radiocarbon, Vol 57, 1, 2015, p 129–151

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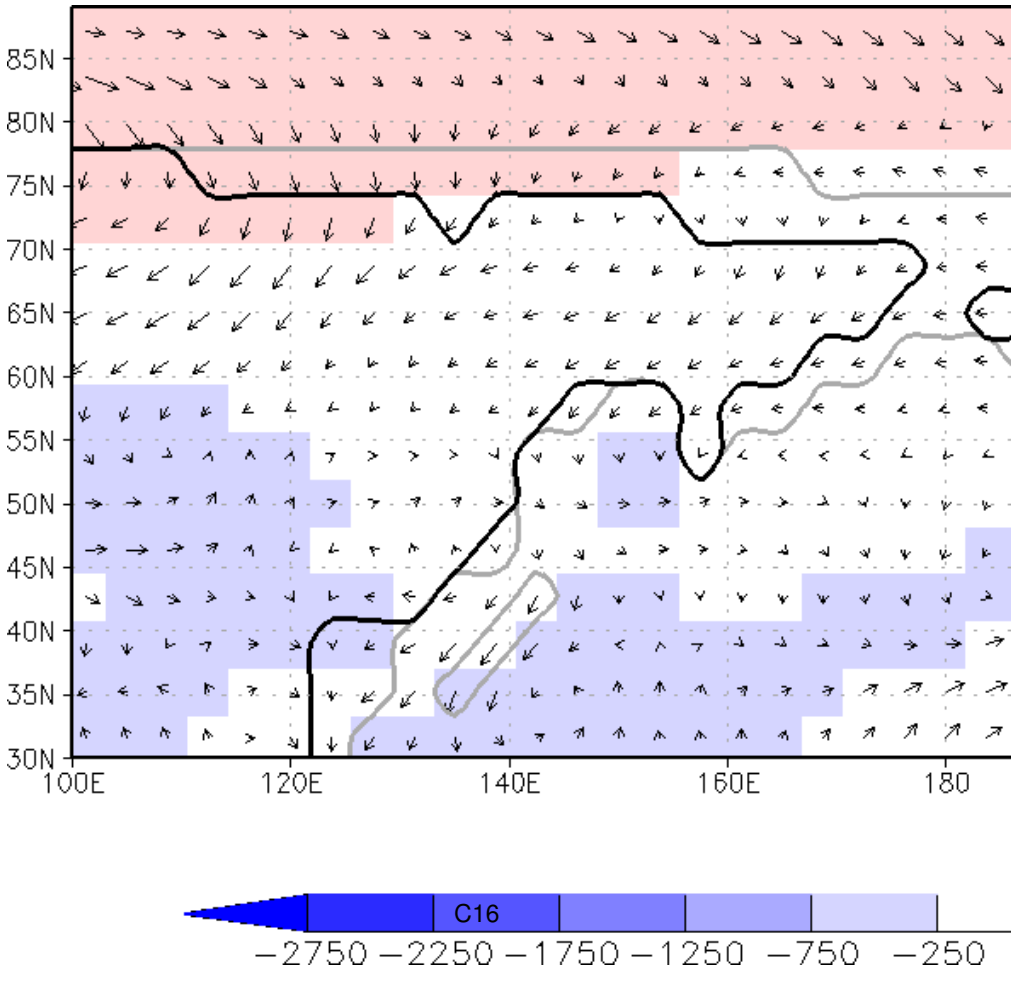

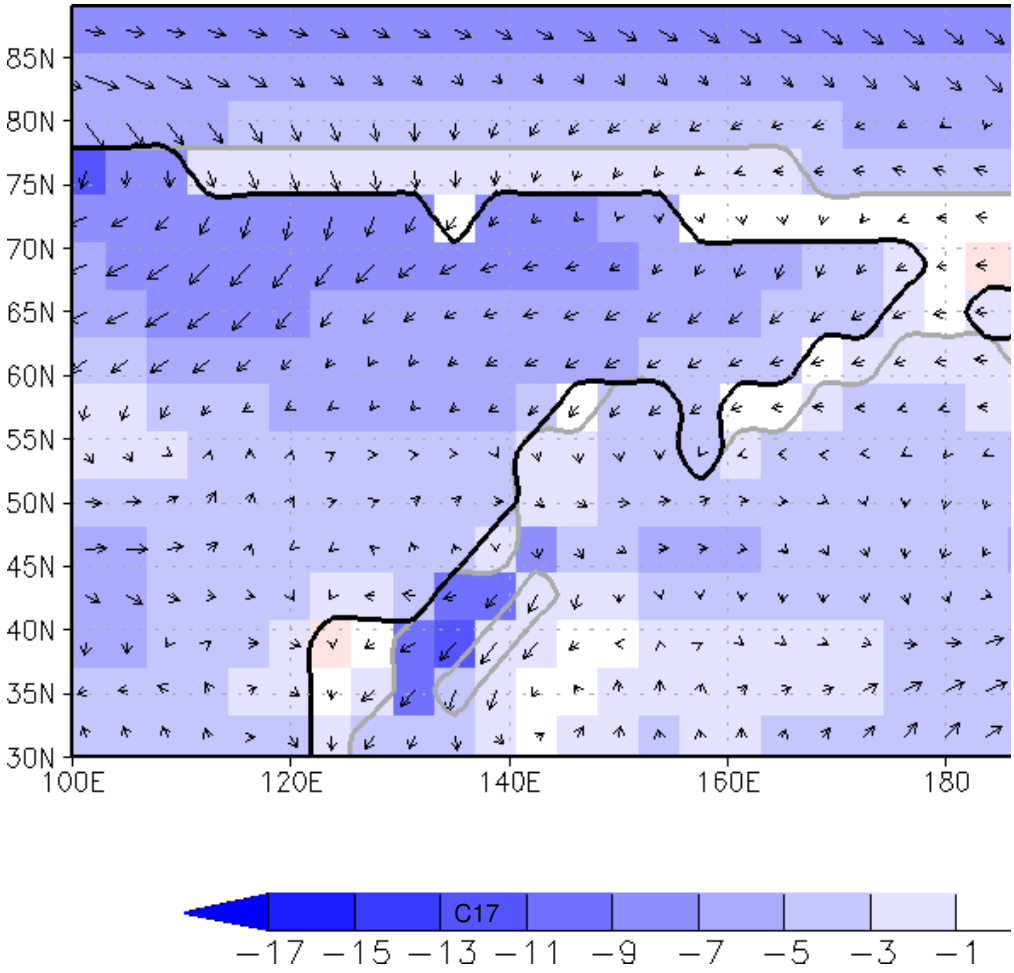
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