Clim. Past Discuss.,
https://doi.org/10.5194/cp-2019-29-AC2, 2019

Interactive comment on "Late Pliocene Cordilleran Ice Sheet development with warm Northeast Pacific sea surface temperatures" *by* Maria Luisa Sánchez-Montes et al.

Maria Luisa Sánchez-Montes et al.

m.l.sanchez-montes@durham.ac.uk

Received and published: 22 June 2019

We would like to thank Anonymous Referee 2 for the constructive comments provided to help us improve our manuscript. Please find below our responses to these comments and the manuscript changes.

1-Comment from Referee

Sánchez-Montes et al. present a new comprehensive set of Plio-Pleistocene records from IODP site U1417 in the Gulf of Alaska encompassing SST, IRD, input of terrigenous organic matter and pollen counts. The authors infer dynamics of the Cordilleran

ice sheet over 4-1.7 Ma and discuss conceptual models for potential climatic controls. It is an exciting dataset and a valuable contribution to the debate on regional versus global climatic triggers for glaciation in the Northeast-Pacific realm during the Northern Hemisphere Glaciation. The study also adds new information to the plioVar database. The application of biomarkers, pollen and IRD is robust and state of the art. Nevertheless, the manuscript needs some revision regarding the clarity and logic of several parts in the discussion. The interpretations of the TAR-index partly need a more detailed discussion to clarify the interactions of different factors controlling the TAR (i.e. vegetation cover, petrogenic contributions and aquatic production) and the link to glaciation. At the present stage, particularly section 4.3 on the iNHG and the early Pleistocene is inconclusive with respect to variations in the sources of organic matter and the inferences on glaciation dynamics in the region. Also, the chronology of processes described in section 4.3 is a bit convoluted. In order to clarify and strengthen the interpretations of the TAR-index, the CPI has to be better represented in the manuscript. At the moment it is mentioned a few times in the text but the record is not shown in any figure. I recommend to plot the CPI along with the TAR in figure 2.

2-Author's response

We agree that adding a more detail discussion on the TAR sources and associations with climate would help to deliver a clearer message in our manuscript. We will include details as suggested (see replies on your detailed comments at the end of the document). The authors agree that including the CPI record in Fig. 2 in the manuscript would help in visualising its variations, including arrows where organic matter becomes more/less mature. We will amend Fig. 2 to include the CPI (see Fig. 1 below) and we will present some information on the broad changes in organic matter sources to the GOA (since the data shows a slight increase towards less mature OM as IRD inputs increase). As the reviewer notes (and as we noted in our reply to reviewer 1), there are multiple potential sources to the TAR, including complex onshore petrogenic sources (Yakutat terrain; Childress, 2016), which are not easily disentangled. In the revised manuscript we can comment that we see evidence for less mature organic matter (increase in CPI) contributing as ice-rafting increases and the TAR decreases, suggesting a potential shift in organic matter source as the glaciation develops (also becomes evident by the range of C and N bulk and isotopes at Site U1417 that show a shift during the early Pleistocene in comparison with the Pliocene and NHG, Table 1 below).

3-Author's changes in manuscript

We will amend Fig. 2 to include the CPI (see Fig. 1 below) and we will present some information on the broad changes in organic matter sources to the GOA (since the data shows a slight increase towards less mature OM as IRD inputs increase).

1-Comment from Referee

In section 4.4 the discussion about the climatic controls on glaciation is very hard to follow and needs to be revisited for clarity. The reader gets lost in the detailed descriptions and comparisons of different gradients during the Plio-Pleistocene and today. I recommend to at least shorten these paragraphs or to delete them. Similarly, the extensive discussion of the PDO analogue in cold and warm periods is confusing and could be shortened. Since the Plio-Pleistocene SST gradients are highly dependent to uncertainties in the absolute SST-estimates associated with the application of UK'37, the gradients need to be discussed in context of those uncertainties. In light of uncertainties on absolute values, section 4.4 would be strengthened by setting the focus on the warming trend that is recorded across the entire North Pacific instead of setting it on the SST gradients.

2-Author's response

This was also a concern of Reviewer 1. The authors agree that this section needs to be shortened to avoid complexity.

3-Author's changes in manuscript

We will implement your comments and edit this section accordingly. In addition, we

have smoothed down to 100 kyr the data sets in Figure 3 in the manuscript following Reviewer 1's advice (see Figure 2 attached).

The text in section 4.4 will be edited (shortened and clarified) to read as follows: "The overall cooling trend during the Neogene, briefly interrupted by the MPWP and intense cooling events such as the M2, is believed to be a dominant pattern in the global climate. This notion is largely based on the global increase in ice volume (e.g. LR04 Benthic ïĄď18O Stack (Lisiecki and Raymo, 2005) and from studies in the North Atlantic SST (i.e. ODP Site 982, Lawrence et al., 2009). In contrast, the contribution of the North Pacific into our understanding of the global climate evolution from the Pliocene to the Pleistocene is limited. Our study at Site U1417 adds valuable regional climate information during the evolution of the Cordilleran Ice Sheet. Unlike the LR04 stack, average Pliocene SST values (4.0 to 2.8 Ma) at Site U1417 are 1 °C colder than the average early Pleistocene values (2.7 to 1.7 Ma) (the Pliocene-Pleistocene SST difference of 1°C has an standard deviation of 0.5°C). In the wider North Pacific, a warming trend from the late Pliocene to early Pleistocene has also been observed at ODP Site 882 in the subarctic Pacific (Martínez-García et al., 2010), at Site 1010 and potentially at Site 1021 (mid-latitude east Pacific) (Fig. 3). Beyond the North Pacific, warmer SST during the early Pleistocene compared to the Pliocene have also been recorded i.e. DSDP Site 593 in the Tasman Sea (McClymont et al., 2016) and Site 1090 (Martínez-García et al., 2010) in the South Atlantic. In contrast, long-term cooling trends mark the early Pleistocene for the mid-latitude west Pacific (Site 1208) and tropical east Pacific (Site 846), more consistent with the development of a cooler and/or more glaciated climate (Fig. 3).

The North Pacific warming occurs despite an atmospheric CO2 drop from 280-450 ppmv to 250-300 ppmv (similar to pre-industrial levels) from 3.2 to 2.8 Ma (Pagani et al., 2010; Seki et al., 2010) and an associated reduction in global radiative forcing (Foster et al., 2017). The early Pleistocene warming signal in the GOA (and the north Pacific more generally) thus implies an important role for local or regional processes.

We have discussed above the potential role played by ocean stratification in the North Pacific, and a possible link to the evolving Cordilleran Ice Sheet in the GOA through evaporation/precipitation feedbacks. The synchrony of these changes with observed tectonic uplift (e.g. Enkelmann et al. 2015) makes it difficult to disentangle the potential climatic and tectonic mechanisms behind ice sheet expansion.

To understand the evolution of the ocean currents governing the North Pacific at the present core sites (Fig. 1) and to find possible explanations of the observed SST distributions during the Pliocene and Pleistocene climate evolution, the modern climate system is used here as an analogue. Modern monthly mean SSTs at ODP 882 SSTs are colder than Sites U1417 and 1021 all year around. During the late Pliocene and early Pleistocene, ODP 882 SSTs are 3-4 °C warmer than in the east (Fig. 3f and g). Modern seasonal climate analogues cannot be used to explain to Pliocene and Pleistocene subarctic SST distribution. However, on longer timescales, the strength of the AL is currently linked to the wider Pacific Ocean circulation by the Pacific Decadal Oscillation (PDO) over periods of 20-30 years (Furtado et al., 2011). The Pliocene-Pleistocene North Pacific SST gradients show similarities with the negative phase of the PDO (-PDO), which is characterized by positive SST anomalies in the central North Pacific surrounded by negative SST anomalies along the North American coast and in the east equatorial Pacific. The -PDO associated route of winds might have increased the precipitation in the Gulf of Alaska and represent a key factor for the fast building of ice in the Alaskan mountains."

1-Comment from Referee

Moreover, the manuscript should be revisited in terms of language and grammar. There are several spelling and grammar mistakes throughout the manuscript (see detailed comments below). This also applies to the supplementary material.

2-Author's response

Thank you.

3-Author's changes in manuscript

We will review the manuscript for typos and amend the ones that you highlight below.

1-Comment from Referee

p. 1, line 24: MPWP should be called Mid-Piacenzian-Warm-Period.

2-Author's response and changes in manuscript

We will change this.

1-Comment from Referee

p. 5, line 19: ". . .provides similar SST estimates in northern high latitudes than previous calibrations." Replace "than" by "to".

2-Author's response and changes in manuscript

We will change this.

1-Comment from Referee

p. 5, lines 17-20. I recommend to mention the standard errors of the calibrations.

2-Author's response and changes in manuscript

We will mention this in p.5 line 18: "which accuracy is constrained by an standard error of ±1.5 °C" and in p.5 line 23: "The standard error of Prahl et al. (1988) (Eq. (4)) is ±1.0 °C".

1-Comment from Referee

p.5, line 23: It would be helpful for non-biomarker experts to indicate what the authors wish to reconstruct using the %C37:4.

2-Author's response and changes in manuscript

We will explain this in p.5 line 24 "The %C37:4 represents fresher and cooler surface water characteristics (Bendle et al., 2005). In the Nordic Seas this has been linked to subpolar and polar water masses (Bendle et al., 2005), whereas elsewhere in the North Atlantic it has been linked to freshwater inputs (e.g. during Heinrich events, by Martrat et al., 2007). In the subarctic Pacific, the %C37:4 proxy has been less well studied, but high %C37:4 is also proposed to reflect cooler and fresher water masses (Harada et al., 2006)."

1-Comment from Referee

p.5, line 29: Sentence uses present tense. Turn to simple past.

2-Author's response and changes in manuscript

We will change this.

1-Comment from Referee

p. 7, line 1: What is the standard deviation of the statistical mean?

2-Author's response and changes in manuscript

We will include this value in the manuscript.

1-Comment from Referee

p. 7, line 5: "Gi1 period (3.6-3.4 Ma) warm period. . .": I suggest to write . . ."Gi1 warm period (3.6-3.4 Ma)" or something similar along this line.

2-Author's response and changes in manuscript

We will change this.

1-Comment from Referee

p. 7 lines 22-24: It is not clear how the high TAR-values relate to limited mountain glaciation as the interpretation of the TAR is missing. The same applies to the %C37:4.

2-Author's response and changes in manuscript

We will explain this including the following sentences in p.5 line 5 "Terrigenous and aquatic organic matter sources increase during the early Pleistocene in comparison with the late Pliocene. High TAR values can be indicative of relative increases in terrigenous organic matter transported to the ocean and/or to relative decreases in aquatic microorganism production. The opposite could explain low TAR values. To disentangle the old organic matter contamination from the fresh signal, we include the CPI index (Bray and Evans, 1961). High CPI values indicate a fresher or relatively newly produced organic matter transported to the ocean. CPI close to 1 indicate mature or old organic matter sources, such as coal or oil deposits, eroded to the ocean. This distinction may be important in the GOA, where the onshore bedrock includes units with high contents of terrigenous organic matter (e.g. the Yakutat Terrain, Childress, 2016; Walinsky et al., 2009)."

1-Comment from Referee

p. 11, lines 1-3: What about petrogenic contributions?

2-Author's response and changes in manuscript

In response to comments from reviewer 1 about organic matter source, and in response to the previous comment, we aim to have given additional detail on the possibility of petrogenic contributions. We will also include this sentence "The CPI values discard mature sources of organic matter to the GOA at this time interval suggesting a contemporary aquatic organic matter contribution."

1-Comment from Referee

p. 11, line 7: Which interval is meant by: "at first"?

2-Author's response and changes in manuscript

We will change this to read "This could indicate that the first IRD in icebergs delivered to the GOA during the late Pliocene and early Pleistocene originated from smaller marine terminating valley glaciers which removed sediment and weathered rock from the landscape rather than eroding bedrock and allowed IRD generation."

1-Comment from Referee

p. 11, line 9: How does the erosion pattern explain the TAR? I don't understand which TAR-variations the authors address.

2-Author's response and changes in manuscript

We have deleted this sentence as the idea is better expressed in the previous sentence (see previous comment).

1-Comment from Referee

p. 11, line 12: Do the authors mean an "alternative or additional explanation" to the interpretations in lines 1-3?

2-Author's response and changes in manuscript

This is now changed to say "Additional" only.

1-Comment from Referee

p. 11, lines 12-15: which changes in the TAR do the authors mean? Do they refer to the iNHG or the period afterwards? Does the CPI record a change in the source?

2-Author's response and changes in manuscript

We have made this clearer by adding a time reference in the sentence: "An additional explanation for the changing TAR during the early Pleistocene is that tectonic uplift of the Chugach/St Elias area from 2.7 Ma (Enkelmann et al., 2015) led to orogenic precipitation and a change in erosional pathways (Enkelmann et al., 2015)." Then this sentence link to the CPI values mentioned in the next sentence over the same time period.

1-Comment from Referee

p.11, lines 16-17: when exactly is this change in the CPI recorded? How is the switch in the source "away from the more mature coal bedrock" connected to the Surveyor Channel? Does it mark a switch to the channel or a switch away from the channel?

2-Author's response and changes in manuscript

Site U1417, which is located in the surveyor Channel, contains organic matter with a different provenance: terrigenous from different sources (vegetation and different land sediments or aquatic (i.e. phytoplankton). We will make this change more concrete by adding in line 15: "An increase in CPI variability to concentrations up to 2 and 3 during the early Pleistocene (starting from 2.7 Ma) supports the change of source of organic matter away from the more mature coal bedrock into more immature terrestrial organic matter (plant waxes). However, this comes at a time of increasing IRD, which adds a new source of terrigenous sediment to Site 1417. The shift in CPI values at 2.7 Ma agrees with the shift towards the erosion of sediments sourced from metamorphic and plutonic sources, described in Enkelmann et al. (2015) delivered to Site U1417."

1-Comment from Referee

p. 11, lines 20-21: I recommend to add a standard deviation to the average values.

2-Author's response and changes in manuscript

We will change this.

1-Comment from Referee

p. 13, line 9: decree or degree?

2-Author's response and changes in manuscript

We have now erased this sentence as part of the shortening of section 4.4 requested.

1-Comment from Referee

p. 13, line 10: "aren't" should be "are not".

2-Author's response and changes in manuscript

We have now erased this sentence as part of the shortening of section 4.4 requested.

1-Comment from Referee

p.13, lines 11-13: the reference to the figures seems to be mixed up here. C is indicated as summer in the text while in figure 1 panel C is references as winter.

2-Author's response and changes in manuscript

We have now erased this sentence as part of the shortening of section 4.4 requested.

1-Comment from Referee

p.14, lines 21-22: how do the vegetation reconstructions from this study fit the results deduced from the El'Gygytgyn pollen record?

2-Author's response and changes in manuscript

We have deleted this reference during the shortening of section 4.4 requested.

1-Comment from Referee

p.14, line 32, "the data is the first climatic data": replace "is" by "are".

2-Author's response and changes in manuscript

We have now erased this sentence as part of the shortening of section 4.4 requested.

1-Comment from Referee

Figure 1: The sites can be larger and I also suggest to add the study site U1417 to panel A.

2-Author's response and changes in manuscript

We will change this.

1-Comment from Referee

Figure 2 and 3: I recommend to increase the size of these figures. They show a lot of data and the small size makes them look quite busy. It is sometimes hard to read the small annotations. I suggest to increase the font size and also the lengths of the x-axes. Some graphs overlap each other as the y-axes are very closely spaced. The distances between the y-axes should be increased a bit. The x-axes would be easier to read if minor ticks were shown. In Figure 3 the line thickness of the x-axis should be increased and I suggest to add data points to the single graphs, as done in Figure 2.

2-Author's response and changes in manuscript

We will change this.

References cited in our reply:

Addison, J., A., Finney, B. P., Dean, W. E., Davies, M. H., Mix, A. C., Stoner, J. S. and Jaeger, J. M., 2012, Productivity and sedimentary d15N variability for the last 17,000 years along the northern Gulf of Alaska continental slope, Paleoceanography, Vol 27, PA 1206.

Childress, L. B., 2016, The Active Margin Carbon Cycle: Influences of Climate and Tectonics in Variable Spatial and Temporal Records, PhD thesis Northwestern University, Evanson, Illinois.

Interactive comment on Clim. Past Discuss., https://doi.org/10.5194/cp-2019-29, 2019.

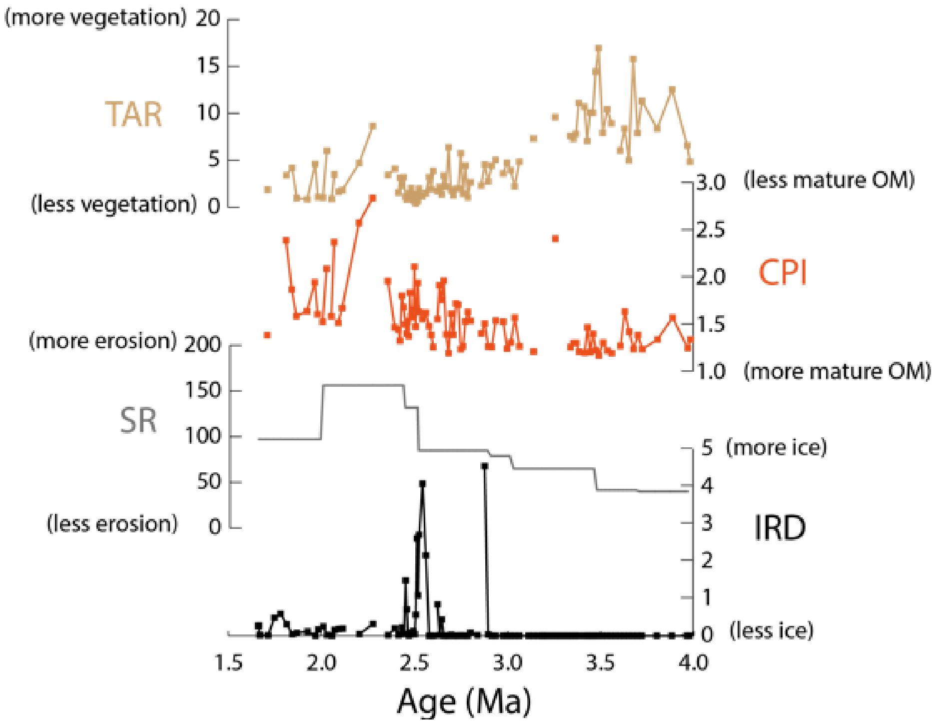

Fig. 1. Figure 1 TAR, CPI, SR and IRD at Site U1417. Missing data points are either a result of samples analysed for SSTs at the early stages of the project which were not subsequently analysed for n-alkanes.

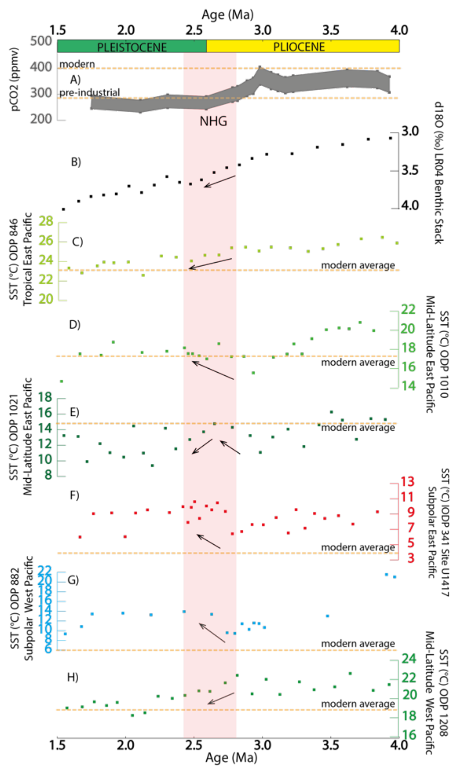

Fig. 2. Figure 2: ∼100 Kyr smoothed North Pacific sites (adapted from Fig. 3 in original manuscript).

	EW0408–85JC	Site U1417		
		Pliocene	NHG	Early Pleistocene
N/C	0.035 to 0.12	0.06 to0.26	0.05 to 0.23	0.04 to0.13
$\delta^{13}C$ (‰)	-26.5 to -22	-26.0 to -21.8	-25.9 to -23	-25.35 to -23.9

Fig. 3. Table 1: N/C vs δ13C (‰) at Site U1417 vs range of data at EW0408–85JC (Addison et al., 2012). Data from the Pliocene (4 to 3 Ma), NHG (2.9 to 2.4 Ma) and the early Pleistocene (2.3-1.7 Ma).