

Interactive comment on “Deciphering the spatio-temporal complexity of climate change of the last deglaciation: a model analysis” by D. M. Roche et al.

D. M. Roche et al.

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We thank O. E. Timm for his detailed comments on our manuscript. We answer in details below.

Our response is in **bold**. When we simply followed the reviewer’s suggestion, we stated it as **DONE**.

Individual comments:

Abstract: p.2594,line 5: write: [...] focused on the understanding of the complex sequence [...]

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DONE

p.2594 l. 11: write: [...] we do not include freshwater forcing [...]

DONE

p.2594 l. 14: write: [...] forcing, and the locations wheres those [...]

DONE

1 Introduction:

p.2594, l.23-25: add references (e.g. Hays et al., Science, 194, 1976; EPICA, Nature, 429, 2004; Huybers, Nature, 434, 2005)

We included the reference to Hays et al., 1976, but the other two suggested references seems not appropriate in the context of 100,000 years pacing of ice volume. EPICA links to the Antarctic climate and Huybers is a simple model of the ice ages, as many before (Milankovitch, Calder, Imbrie & Imbrie, Berger, Paillard etc.). We prefer to add Waelbroeck et al., QSR, 2002 as a more directly related citation with respect to ice volume changes in the Quaternary.

p.2594-2595, l. 25-/ l.2): please restructure statement (Milankovitch did not have the information from the paleo records at that time). suggested:

"Milutin Milankovitch was one of the first to propose that low-frequency variability of the orbital parameters, which modifies the energy received at the top of the atmosphere, could be the cause for glaciations on Earth."

DONE

p.2595 l. 6 : write: [...] (LGM) ice sheets covered [. .]

DONE

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p.2595 l. 14: [...] deglaciation have arisen [...]

DONE

p.2595 l.17-19 suggested: [...] there is still some debate on how changes relate to each other at different geographical locations on Earth (Stott et al, Science, 2007; Huybers and Denton, Nature Geoscience, 2008; Timmermann et al, Paleoceanography, 2009; Denton et al., Science, 2010). Though such [...]

DONE

p.2595 l. 23-24: write; [...] within the physical processes contained [...]

DONE

2.1 Model description:

p. 2596, l. 15-17: mention that CLIO uses rotated grid.

DONE

2.2 Deglacial forcing:

p.2597, l.4 : "Our goal" instead of "Our purpose"?

DONE

p.2597 l.17-l.21: please specify what type of temporal interpolation was used between the 1000yr reconstruction snapshots in ICE-5gV1.2, or what is the update interval time for the ice-sheet forcing? **DONE**

p.2597, l.28 additional reference to Friedrich, T., A. Timmermann, L. Menviel, O. Elison

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Timm, A. Mouchet, and D.M. Roche, The mechanism behind internally generated centennial to-millennial scale climate variability in an earth system model of intermediate complexity, *Geosci. Model Dev.*, 3(2), 377-389, doi:10.5194/gmd-3-377-2010, 2010.

The line referred to by the reviewer is on the Bering strait. The Friedrich et al. Paper does not discuss these aspects. We thus decided to leave the citation out.

p.2598, l. 21: write "North Atlantic"

DONE

p.2598, l.26-28: please rewrite sentence. Unclear what is the message.

Sentence cited has been removed, as it did not bring much additional information.

3 Analysis Method

p.2599 formula and text l. 19: please use σ^2 as symbol for the variance. This is the standard convention in many statistical textbooks (σ refers to standard deviation).

DONE

p.2599 significance test: the p-value of 1.962 is for two-sided test? If only tested for temperature increase, then significance is for a one-sided test (2.5%).

No, the test is indeed a two sided test as we test whether the anomaly – positive or negative – is different from the mean. The text has been modified accordingly to clarify this.

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Note: the significance is usually expressed for the probability of rejecting the null hypothesis when means are equal, i.e. $100\% - 95\% = 5\%$ significance level.

DONE

4.1 Results Annual mean

p.2600, l.6-16: Note that seasonal response and/or seasonal feedback can result in a precession signal in the annual mean.

The precessional signal for the time window considered (21 – 19 ka B.P.) is opposite to the observed response in the model. Furthermore, the response obtained is very much in-phase in the northern and southern hemisphere which directly points to a response to obliquity forcing. The text has been clarified in the revised version as such: "The fact that the early significant warmings observed in the model are obliquity driven is further reinforced by the in-phase changes of the northern and southern hemispheres."

p. 2601, l. 10: write: [...] between 30oN and 30oS. [...]

DONE

p.2601, l. 22: "series" instead of "serie"

DONE

p.2601, l. 23: [...] by those two [...]

DONE

4.2 Seasonal means

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p.2602, l.5-7 : this section is introduced as a 'confirmation' of the annual mean results, but it is a more detailed view on the complex season/regional timing of deglacial warming, since DJF and JJA behave quite differently.

The text has been modified accordingly

p.2602,l.15: "northern North"

DONE

l.23: write: [...] linked to shrinking sea-ice extend in winter.

DONE

4.3 Precipitation evolution

p. 2603 l.1: write: tropical regions, the main [...]

DONE

l.3 [...] in annual precipitation.

DONE

l.3-11: Is this the correct interpretation:

The test for differences in precipitation is a two-sided test. The significance level is now 5% for a two-sided test (i.e. you tested if $\text{abs}(t) > 1.962\hat{\sigma}$?

Yes it is. We are indeed performing a two-sided test. This aspect is now noted in the text in the section on temperatures, and applies also to the paragraph quoted here.

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I.11: define acronym ITCZ here: "Intertropical Convergence Zone (ITCZ)"

DONE

I.12: suggested writing: "The annual mean precipitation shows a significant decrease in a zonal belt in the southern equatorial regions during 20 and 16 kyrs BP."

DONE

I.14: write [...] of the ITCZ in response [...]

DONE

p.2604,I.10 : "northern Africa"

DONE

I.10-12: suggested citations: (1) deMenocal et al., Quat. Sci. Rev. , 2000; (2) Tjallingii et al., Nature Geosc., 2008; (3) Timm et al., J. Clim., 2010

DONE

4.4 Impact of interannual variability

p.2604 I. 14- p.2605 I.9: The text is okay, but maybe the authors could refer back to Section 3, the equation for the t-statistic. One could emphasize that two factors are defined by the climate system itself (the differences in means, and the internal variability), whereas one has the 'freedom' to adjust the sample size. The authors had to find a trade-off between the power of the test and the timing accuracy of the first significant change. Robustness was tested by changing the sample size.

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We now refer to the Welsch's test equation in the text as suggested.

p.2605, l. 13: write: " In the northern tropical regions over the Pacific and southwestern North America [...]"

DONE

5 Discussion

p.2606, l. 10: suggested writing: "To reproduce the effects of millennial-scale climate variability, the modeling study would require the use [...]"

DONE

p.2606, l.16-l.22: The discussion of the use of ensemble simulations for detecting the timing of first changes: If the temporal samples could be replaced by ensemble samples, how large should the ensemble size be? 25, 100, 300 members?

The greatest advantage might be that one could test the changes at every year, instead of a window of 25,50,100,300 years. Therefore, the timing accuracy would be better.

We would need the same number of ensembles that we have of years in our averaging window, that is on the order of 100. We have modified the text accordingly with this suggestion.

p. 2606, following l.23: One should discuss also how the choice of the significance level affects the outcome of the test. More conservative significance levels reduce the type-one-error (rejecting the null-hypothesis [means are equal] when they are equal). On the other side, with a larger tvalue one might risk to miss an early small change (type-two error: accepting the null hypothesis [means are equal] even though

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the samples have different means. Fig. 6 appears to me that type-2 error is likely encountered in the t-test at 5% significance.)

We have tested (but not shown) the effect of using 15, 10 or 5% in the analysis and the outcome is very similar. The advantage of 5% is to yield a clearer picture for the precipitation analysis, though we agree that the type-2 error is likely to be increased.

p.2607, l. 1-17: The implications from the model analysis for the proxies should be extended by at least two more questions of interest: (1) Even if proxies were perfect records of past climate variability without dating uncertainty, there is a statistical limitation in the accuracy of determining the first deglaciation signal in single proxies.

We assume that the referee refers to the fact that even with perfect proxies, the first start of the deglaciation signal will fall within the noise of the system, and since the signal is only detected as it is outside this noise level, there is an uncertainty in the detection of the precise timing of this signal. That is true. However, to the extent of detecting the first warming in the deglaciation, the uncertainty added is probably well under the dating uncertainties already present in the data. In other words, this is part of an overall uncertainty that we cannot really assess independantly.

(2) the model results could provide guidelines which geographical regions could provide proxies with the best signal-to-noise ratio for identifying externally driven climate signals, and how wide the sampling window should be.

That is true. But we need first to do it in different climate models in order to be sure that the anomaly seen in one model is robust and can be extended. This is work in progress within the ORMEN project.

Figures:

Fig.2: Caption: [...] anomaly to the 0-21 kyrs BP mean [...]

The figure depicts the anomaly to 0-30 ka BP, not 0-21 ka BP. It is apparent in that the values at 21 ka BP are not zero. We thus kept the caption as it was.

Please describe more precisely the winter/summer season (mid-month values for Jan/ Jun?

Values are for the summer (winter) season, calculated as the 2nd quarter of year after the spring equinox. This is now stated explicitly in the figure caption.

Fig.4: [...] from a 100-yr sample at 5% significance. Color scale is the date in kyrs BP. Black denotes [...]

DONE

Fig. 5: write "color scale"

DONE

Fig. 6: Optional: This really illustrates great the difficulties with objective statistical testing: If you could indicate the mean and standard deviations in the PDFs, this would be appreciated. Furthermore, is there a way to mark the 95% confidence range equivalent to the t-test in the red PDF? Then, one could use this illustration to refer to in the discussion of the statistical test procedure (i.e. Type-1 error and type-2 error).

We have redone the figure accordingly to the suggestion. The mean and standard deviations are now marked in the new figure 6.

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Fig. 7-Fig.9: write "Color scale"

DONE

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