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Climate of the Past Discussions

Interactive comment on "Sensitivity of interglacial Greenland temperature and delta;¹⁸O to orbital and CO₂ forcing: climate simulations and ice core data" *by* V. Masson-Delmotte et al.

Anonymous Referee #2

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This paper provides a very detailed and thorough evaluation of the sensitivity of the Greenland climate to orbital and CO_2 forcing in the context of past warm climates. In order to investigate this the authors interpret ice core data from the NGRIP ice core in central Greenland and simulate a number of orbital configurations and CO_2 forcings (future scenarios) using a general circulation model. In addition, they use climate models with stable water isotopes included in order to make a direct comparison between data and climate model simulation. They find that their model results in a much weaker isotope-temperature relationship compared with the ice core data signal at 126ka and

explain that this can either be reconciled with very large temperature shifts at fixed elevation or a reduction in elevation in central Greenland of 300 to 400 m. To date the only other method that looked at last interglacial Greenland ice sheet elevation reduction from ice cores is the interpretation of the gas content of the GRIP core (Raynaud et al., 1997). This manuscript provides a new way of interpreting what the likely reduction in Greenland elevation might have been by using climate-isotope modelling together with ice core data.

The models also show large shifts in the precipitation seasonality due to increased summer precipitation implying Greenland ice core interglacial data should perhaps be interpreted in terms of summer precipitation weighted temperatures. Although this has been done for several Antarctic modelling studies for the last interglacial, most Greenland last interglacial modelling studies have not included this when comparing their summer warming with data.

The methodology and findings presented here provide new additional possible constraints on Greenland interglacial climate and mark the way for an in depth intercomparison exercise of climate models and data. As such, this manuscript addresses relevant scientific questions within the scope of CP and advances the understanding of the Greenland ice core data using climate-isotope modelling!

Specific Comments:
Since this paper contains both data and modelling it is important that the structure is clear. It would be helpful to highlight more explicitly in the introduction what is different/new in this study compared with previous work. At times I found the order a little difficult to follow.

Below are a few specific and mainly minor points that should also be addressed:

1. What was the duration of the climate snapshot simulations? Please state this.

2. The LMDZiso experiments were run for 5 years, is the atmosphere adequately

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spun-up?

3. With your freshwater flux experiment was the ocean in equilibrium? A brief sentence about this would be beneficial.

4. It would be interesting to run last interglacial simulations with orbit and atmospheric CO_2 changed together and compare with the data although this may be beyond the scope of this paper. If so can you make a brief comment about whether this is likely to make much difference?

5. Within the conclusions it would be worth referring to a number of Greenland ice sheet modelling studies that have looked at the reduction in elevation to see how these compare with your result, e.g. Otto-Bliesner et al. (2006), A. Robinson et al. (2011), Climate of the Past.

6. For traceability it might also be worth including in Table 1 (or a separate additional table) details of the orbital conditions and greenhouse gas concentrations. This could also be put in the appendix instead.

Technical comments:
Below are some suggestions for improving the flow and minor technicalities but the list is not exhaustive. One general comment is that the labels on many of the figures are difficult to read. It is important that these are made as big as possible.

Please check through the manuscript carefully for any inconsistencies. Note that corrections listed here relate to the printer-friendly version of the manuscript.

Abstract
Line 18: Change “A quantitative comparison between ice core data and climate simulations requires to explore the stability of the stable isotope – temperature relationship.” to “A quantitative comparison between ice core data and climate simulations requires stability of the stable isotope – temperature relationship to be explored”

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Line 21: Change “This set of simulations allows to calculate a temporal Greenland isotope-temperature slope...” to “This set of simulations allows calculation of a temporal Greenland isotope-temperature slope...”
Line 26: Please give an example of another mechanism.

Introduction
p1587, line 7: Can you refer to the time-span NGRIP refers to?
p1587, line 10: Time scale(s): insert “s” after scale
p1587, line 11: Insert climate before “abrupt”
p1587, line 11- 15: rephrase with “Ice core data allow us to explore the past magnitudes and rates of change of central Greenland temperature prior to the instrumental record even with uncertainties related to conversion of ice core proxies into past temperatures, the age scale used and the effect of glaciological process on the ice.”
p1588: It might be helpful to number the questions to be addressed in the introduction so that you can easily refer back to this within the rest of the manuscript.
p1588, line 3: Change “This requires to understand the relationship between Greenland surface temperature and snowfall isotopic composition and the various processes that can modify this relationship through time” to “This requires the relationship between Greenland surface temperature and snowfall isotopic composition and the various processes that can modify this relationship through time to be understood”
p1588, line 14: Change “associated to...” to “associated with...”
p1588, line 22: Please be more precise with “sea surface conditions”. Do you mean sea surface temperatures?
p1588, line 24: “This also allows to explore the stability of the isotope-temperature change through time and the mechanisms that can alter this relationship” to “This also allows the stability of the isotope-temperature change through time and the mechanisms that can alter this relationship to be explored”
p1589, last paragraph: Please relate the sections to the questions you address previously for easy flow.

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p1589, line 7: Remove semi colon and start a new sentence.
P1590, line2: What are the first ice core sites? Please give an example.
p1590, line 21: Please give some examples/references for information on air temperature at the ice sheet surface classically derived from stable isotopes.
p1590, line 26: Insert "of δ^{18}O" before per °C
p1590, line 27: Change probably to likely.

Greenland Holocene climate and ice sheet elevation
p1591, line 4-5: Change "Recently, (Vinther et al., 2009) conducted a synthesis of the Greenland ice core Holocene stable isotope information has recently been conducted." to "Recently, Vinther et al. (2009) conducted a synthesis of the Greenland ice core Holocene stable isotope data."
p1591, line16: For clarity, it would be good to give a definition of what you mean by fixed elevation. You mention this previously in the introduction so perhaps put it there.
p1591, line 20: Insert higher before elevation.
p1592, line 5: Move respectively to the end of the sentence.
p1592, line 6: Please reference the GICC05 age scale.
p1592, line 14-16: Change "The NorthGRIP record does not allow to explore this aspect for the last interglacial because it does not span the whole length of this period NorthGRIP-community-members, 2004)" to "The NorthGRIP record does not allow this aspect for the last interglacial to be explored because it does not span the whole length of this time period (NorthGRIP-community-members, 2004)"
p1592, line 22: Remove the degree symbol before Wm^{-2} and the same for line 23.
p1593, line 3: You have not defined SST previously. Either define this when you first mention it (p1592, line 17) then use the acronym subsequently for all occasions or refer to it in full on all occasions.
p1593, line 9: Remove "also"

Climate modelling

p1593, line 16: Change intensively to extensively
p1593, line19: Insert commas before LMDZ and after the Hourdin reference
p1594, line 2: What are the large biases? Are they temperature?
p1594: How many model years were the orbital forcing experiments run for?
p1594, line 6: It would be useful to quantify the cold bias for central Greenland
p1594, line 8: Add an "s" to description
p1594, line 15: Change contrasted to contrasting
p1594, line 18: Change "We particularly focus on the most contrasted situations (126 ka and 115 ka) in some of the analyses" to "In particular, our analysis focuses on the most contrasting simulations: 126 and 115ka."
p1594, line 20: Change "(Sime et al., 2008)" to "Sime et al. (2008)"
p1594, line 27: I assume the topography is fixed at present day. Please clarify.
p1595: Please explain the context of mentioning the model response in monsoon areas.
p1595, line 3 – 9: Move this to the beginning of this section so that it flows more easily. i.e. model description, previous use etc followed by the experiments you are conducting in the paper.

Impact of orbital forcing on IPSL simulated central Greenland climate

p1595, line 21 - 25: This sentence is difficult to follow, please rephrase more clearly. Also insert relative to pre-industrial after 126ka, line 22.
p1595, line 26: Move respectively to the end of the sentence.
p1596, line 9: Add an "s" to temperature
p1596, line11: Please give a reference for ^{10}Be method
p1596, line 21: Insert "that" before derived
p1596, line 21: Remove "will"
p1596, line 24: Please state the amount of Greenland melt flux you are using and whether the ocean is in equilibrium.

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Differences between increased CO_2 and orbitally forced IPSL climate responses
p1597, line 9: Insert after anomalies (relative to pre-industrial)
p1597, line 10: Remove b after Fig.3a and remove "s" after budgets
p1597, line 13: At end of sentence put "(Fig. 3b)"
p1597, line 13-15: This is not shown in Figure 3. Please give more clarification. Also the first paragraph begins comparing 126ka with increased CO_2 and then reintroduces this in the next paragraph (beginning line 16). It would be good to reorganise this for ease of flow!
p1597, line 19: Change present day to pre-industrial
p1597, line 21: Change present day to pre-industrial
p1597, line 23: Change to (relative to the pre-industrial simulation)
p1598, line 22: Remove Fig. b from Fig.3a and b since you are talking about the 126ka simulation only.
p1598, line 13: Insert "c" after Fig. 3
P1598, line 14-15: Remove "to be" so it reads "...reaching 8°C, compared to the ..."
P1598, line 20: Change "The different climate responses to orbital (126 ka) and $2\times CO_2$ forcing also have a signature on patterns of evaporation changes" to "The different climate responses to orbital (126 ka) and $2\times CO_2$ forcing are also shown in the global pattern of evaporation changes"
p1598, line 21: Add the label to Fig.3 (i.e. Fig3e)
p1598, line 21-22: State which seasons this contrast in evaporative pattern is occurring
p1598, line 24: Change "expect" to "hypothesize"

Analysis of radiative feedbacks
p1599, line 1: Remove brackets and change to "Following Braconnot et al. (2007)..."
p1599, line 3: You define top of atmosphere here as TOA although it is not subsequently used. Please define this on the first occurrence of top of atmosphere (p1597,

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line 10-11) and use TOA subsequently.
p1599, line 13: Change “Figure 5a allows to better characterise...” to “Figure 5a characterises the ...”
p1599, line 18, The “n” in your definition of net shortwave radiation is missing.
P1600, line 23, 24 and 26: Change $\triangle$albedo to $\triangle$ALB so that it is consistent with the Appendix. It might be worth relating to the equation numbers in the appendix where necessary.
p1600, line 21: Replace “in a warmer Arctic” with “for a warmer Arctic”
p1600, line 25: Change to “Figure 5b and c show a comparison of the the seasonal cycle and magnitude of feedbacks for the 126ka and 2xCO_2 simulations respectively. As previously shown, these simulations reach similar magnitudes for summer temperature change over Greenland.”
p1600, line 29-31: Please rephrase as it is difficult to follow.

Atmospheric modelling of water stable isotopes
p1601, line 24: Define LGM.
p1601, line 24: Change “already” to “previously”
p1601, line 26: Expand to “modern spatial isotope-temperature relationship obtained from Greenland ice core sites (included references)”
p1602, line 29: Include “by other atmospheric models that include water stable isotopes”
p1602, line 6: Change sentence in brackets to: (6ka and 126ka orbital forcing and increased greenhouse concentrations)

LMDZiso isotope-temperature relationships
p1602, line 11: Expand to “Consistent with the coupled IPSL model simulations discussed in Sect.3, annual mean temperature changes for central Greenland remain very small for the simulations corresponding to changes in orbital configurations...”

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P1602: Change Fig.6 to Fig.7 and Fig.7 to Fig.6 Since you talk about Fig.7 before Fig.6!
p1602, line 26: Be careful with the phrase “significantly larger” since this often refers to a statistical level of confidence.
p1603, line 18: You referred to t he deepest part of the ice core representing 122ka previously (p 1593, line 1). Please keep this consistent!
p1603, line 18: Change Eemian to last interglacial as you have used this previously
p1604, line 8: Change “The water tagging simulation allows to show...” to “the water tagging simulation shows that...”
p1605, line 15: Replace “so it it” with “it is”
p1605, line 18: Remove “in the two models” at the end of the sentence.
p1605, line20: Do you mean Fig. A1 instead of S1?
p1605, line 28: Remove “from these sections...”
p1605, line 31: Insert “being” before smaller
p1606, line 5: It might be good to include an example of an investigation that could be carried out to understand the reason for inter-model differences.

Implications of IPSL/LMDZiso results for central Greenland ice sheet elevation during the last interglacial
p1606, line 10: Modify to “glacial (Capron et al., 2010a) and Holocene (Vinther et al., 2009) climates”
p1607, line 6: Change Fig.7 to Fig. 6 in accordance with previous comment above
p1607, line 7, Change “request” to “require”
p1607, line10: After feedbacks insert “at the regional scale”

Conclusions and perspectives
p1608, line 2: Remove “first”
p1608, line 6: Modify brackets to “published runs (e.g. Otto-Bliesner et al., 2006;

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Groger et al., 2007)"
p1608, line 7: You mention the evidence that is present for sea-ice retreat in the last interglacial but do not link this to the results you found in your modelling. Please insert an extra sentence with your result!
P1608, line 21: Change "...reducing the magnitude of 126ka ..." to "...decreasing the magnitude of 126ka..."

Tables and Figures:
Table 1
Please define AMIP in the legend.
Please define atmospheric composition i.e. CO_2 concentration (see comment above)

Figure 1
Please increase the NGRIP ΔT scale with labels to at least +10. In order to do this the sea-level panel will need to be shifted upwards.

In the legend change "following (Masson-Delmotte et al., 2005b)" to "following Masson-Delmotte et al. (2005b)".

Figure 2
Please increase the font size of the axes labels for a and b
Please insert a minus before the 2 in Wm^2 on line 8 of the legend.

Figure 3
Shift the figure for (b) left to fit within box.
Increase font size of colour bar labels and label them
Line 4: Modify to "...anomalies are displayed as a function of month number..."

Figure 4
Insert reference for the climatological data displayed.

Figure 5
Lines 3-4: Put orbital context colour descriptions in order from 6 to 126ka.
(c) and (d) panels need to be switched around in figure.

Figure 6
Increase font size of figure legend, perhaps move outside of figure?
Line 1: Change d180 to δ^{18}O

Figure A1
Fig. A1c. Please label the x and y axes.

Line 2: Change mm day to mm/day.
Line 5: Only (a) and (b) show zonal mean anomalies.

Interactive comment on Clim. Past Discuss., 7, 1585, 2011.