

Impact of the temperature-cloud phase relationship on the simulated Arctic warming during the last interglacial by *Nozomi Arima et al.*

Summary:

This manuscript explores how cloud phase representation affects Arctic climate simulations of the Preindustrial and Last Interglacial. The study finds that models allowing more supercooled liquid water simulate stronger warming – particularly in autumn – and reduced sea-ice cover. The manuscript also shows that the inclusion of dynamic vegetation increases warming and reduces LIG sea ice in the Arctic. The paper is mostly well written – it is clear and well structured. I enjoyed reading it. There are, however, several significant issues, some key references are missing, and the use of both present-day and Last Interglacial observations needs improvement.

Major comments

Cloud parameterisations

Overall, the two cloud parametrisations clearly have substantially different impacts on clouds and temperature in the Arctic over the Preindustrial and Historical periods. This should be dealt with much more clearly prior to their use for the lig127k. Results for Historical simulations should be shown against present-day cloud observations, Arctic temperature, and Arctic sea ice. This does not preclude the main point of this manuscript – that lig127k Arctic temperatures and SIA are sensitive to cloud parameterisation – but it should make the presentation and discussion of the meaning of the results much clearer. Prior to the use of the two parametrisations for the LIG, they should be shown against present-day cloud observations, Arctic temperature, and Arctic sea ice. This could be done in a second Appendix, if the authors prefer not to put this in the main text.

Fixed-angle calendar

On the use of a fixed-angle calendar, this paper is largely focused on the correct calculation of energy (and mass) budgets. The re-interpolation from fixed-day to a fixed-angle calendar will lead to incorrect budgets for ice and energy (Sime et al., 2025b). If the authors do include comparison with summer air temperatures in the Arctic, I agree that using fixed-angle JJA averages may be helpful. However, I would like to see a more careful consideration of the impacts of incorrect month lengths on all other averaging – and budgets.

Observations

On observations, the use of the Turney and Jones (2010) dataset is not recommended by the PMIP community because of the weak dating constraints. See various papers from Capron et al. If the authors wish to use summer air temperature data for comparison, please use instead the database of CAPE et al. (2006), later updated by Otto-Bliesner for the IPCC, then Guarino et al. (2020), and Sime et al. (2023). The data reference Guarino, M. V., & Sime, L. (2022) is provided below.

Marine core data

On marine core data, Vermassen et al. (2023) suggest that the Arctic was likely seasonally sea-ice-free during the LIG; however, their Arctic age models are currently characterised by significant uncertainty (Razmjooei et al., 2023). For similar reasons, all but one of the Kageyama et al. (2021) Arctic marine core datapoints are marked as being unreliable with respect to dating. Please address this as suggested below.

Section and Line Comments:

L31-42 The Introduction should be modified to better reflect our current understanding of Arctic sea ice and summer temperatures. Please include that Guarino et al. (2020) pointed out that the Arctic during the Last Interglacial was likely sea-ice-free. (Prior to this, Malmierca Vallet et al. (2018) also noted that the Greenland Last Interglacial ice-core water isotope values were most easily explained by a sea-ice-free summer in the Arctic.) Sime et al. (2023) updated this work, estimating the Arctic-wide summer surface air temperature warming at 127 ka to be 3.7 ± 1.5 K, and that the LIG climatological minimum SIA was most likely 1.3 to 1.5×10^6 km², which is rather close to the definition of a practically summer ice-free Arctic (a maximum sea-ice extent of less than 1×10^6 km²). Read and reference Sime et al. (2025b) *A sea ice free Arctic: Assessment Fast Track abrupt-127k experimental protocol and motivation*.

L42 This is not correct. See Sime et al. (2023) and Sime et al. (2025b). Six models are occasionally practically sea-ice-free in their first 100 years of lig127k forcing.

L44-47 Better to read and reference also Sime et al. (2025b), and make it clearer that albedo feedbacks are crucial, and that the inclusion of advanced ice physics such as explicit melt ponds can lead to a better representation of sea ice in models including CESM2 and HadGEM3 (Guarino et al., 2020; Diamond et al., 2024).

L49-70 I like this section, but find myself also wanting to know what the usual cloud parameterisation schemes used in CMIP6/7 models are. A little background to say which form of parameterisation in cloud scheme A and C are relevant to the CMIP Fast Track community would be very helpful.

Additionally, can you make the relationship between this manuscript and the energy budget findings in Kageyama et al. (2021) clearer? And also relate it to the energy-budget aims of *A sea ice free Arctic: Assessment Fast Track abrupt-127k*.

L115 The meaning of the comment on which parameterisation is more accurate is very unclear. The two parametrisations clearly have substantially different impacts on clouds and temperature in the Arctic over the Preindustrial and Historical periods. This should be dealt with much more clearly. Prior to the use of the two parametrisations for the LIG, they should be shown against present-day cloud observations, Arctic temperature, and Arctic sea ice.

L175-182 Because the Earth moves fastest near perihelion (when Earth is closest to the sun) and slowest near aphelion (when Earth is farthest from the sun), the use of a fixed-angle calendar causes problems in the calculation of energy budgets (e.g. Otto-Bliesner et al., 2017; Bartlein and Shafer, 2019). This is because the use of a fixed-angle calendar results in months and seasons of unequal day lengths. Given that this paper is largely focused on the correct calculation of energy (and mass) budgets, the re-interpolation from fixed-day to a fixed-angle calendar will lead to incorrect budgets for ice and energy (Sime et al., 2025b). The authors are correct that switching to a fixed-angle calendar can be helpful for comparing seasonal observations across different time periods. However, in the analysis that follows this is not done (see also below). I can see that there are ‘monthly’ comparisons used for the lig127k output. I’d like to see a more careful consideration of the impacts of incorrect month lengths in this ‘monthly’ averaging (that it is not possible to compare months in a truly meaningful way between the PI and lig127k), and ideally instead the use of fixed-length output averaging – perhaps centred on their season/date of interest. For example, using the 15 days either side of

the solstice or equinox, rather than ‘September’ or ‘March’ averages. This prevents the temporal stretching and compression which introduces artefacts into energy budgets that are otherwise associated with re-interpolating to a fixed-angle calendar. It would also be helpful for the authors to confirm that they produce any annual averages without angle-based interpolation – i.e. that these are standard (correct) CMIP fixed-length type averages.

L212, and below Such large temperature differences between the A and C simulations imply that there should be a preference for one or the other parameterisation on the basis of its match to present-day observations. For example, one can say whether 2.8 °C warmer in November in the PI/present-day is an improvement or not.

Figure 6, and other places If removing the attempt to compare ‘months’, the month (or 30-day period) with the minimum SIC/SIA is otherwise used in most of the papers below – rather than ‘September’.

5.2 The use of the Turney and Jones (2010) dataset is not recommended by PMIP because of the weak dating constraints used (see various papers from Capron et al.). If the authors wish to use summer air temperature data for comparison, please use instead the database of CAPE et al. (2006), later updated by Otto-Bliesner for the IPCC, then Guarino et al. (2020), and Sime et al. (2023). The data reference Guarino, M. V., & Sime, L. (2022) is provided below.

Marine core data Vermassen et al. (2023) suggest that the Arctic was likely seasonally sea-ice-free during the LIG; however, their Arctic age models are currently characterised by significant uncertainty (Razmjooei et al., 2023). For similar reasons, all but one of the Kageyama et al. (2021) Arctic marine core datapoints are marked as being unreliable with respect to dating. For this reason, it is good practice to either (i) not show the Kageyama et al. (2021) datapoints which cannot be reliably dated to the Last Interglacial, or (ii) mark them as ‘date unknown’ (e.g. see Figure 3 in Sime et al., 2023, and the figures in Kageyama et al., 2021). To show them as dated to the Last Interglacial is misleading.

Section 5.4, and other places A main feedback on clouds in the Arctic is the release of heat in autumn that is stored in the Arctic mixed layer (upper ocean). Less sea ice in summer → more heat absorbed and stored in the mixed layer → released to the atmosphere in autumn, with slower freeze-up and cloud feedbacks. This process is not currently adequately covered in 5.4 or the rest of the paper. The process and its consequences need consideration.

~L379 referencing etc Do refer to the energy budget work done in the various Guarino (2020), Diamond (2021/4), Kageyama (2021), and Sime (2025b) papers here too, and rewrite as necessary.

L386 and thereafter Strangely phrased here. Perhaps start with the obvious – that the differences between cloud parameterisation A and C have an impact in a particular temperature range. This therefore means that impacts will clearly be different between the Southern Ocean and the Arctic.

L401 Again, odd claim that you can’t tell whether a 3 °C warmer Arctic in November (and other temperature and cloud changes) in the PI/present-day is better or not. Best to rewrite these sections once this is clearer to the authors.

L. Sime

Data reference:

Guarino, M. V., & Sime, L. (2022). Last Interglacial summer air temperature observations for the Arctic (Version 1.0) [Data set]. NERC EDS UK Polar Data Centre. <https://doi.org/10.5285/9AB58D27-596A-472C-A13E-2DCD68612082>

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