

Reviewer 2:

The manuscript by Legrain et al. provides a comprehensive and valuable synthesis of sea-surface temperature changes during the relatively understudied interglacial Marine Isotope Stage 7 (MIS 7). I find this to be an impressive piece of work, which makes a significant contribution to our understanding of climate variability during MIS 7. The study has some limitations that the authors acknowledge, but the main conclusions remain supported by the results. Most of my comments are therefore minor and relate to some points that in my opinion require some clarification.

We thank Reviewer 2 for their positive assessment of the study.

Specific comments:

L.350: “In contrast, the atmospheric CO₂ record shows a higher concentration during MIS 7e (275 ppm) than during MIS 7c (245 ppm), highlighting a partial decoupling between radiative forcing and global surface temperature variations.” Yes, but the highest CO₂ concentrations during MIS 7e only correspond to the overshoot. Mean CO₂ concentrations during MIS 7e are not higher than during MIS 7c but fall within a similar range.

Caption Fig. 7: CO₂ values correspond to maximum concentrations. How is the “climate optimum” defined? Does it correspond to the time of maximum CO₂ or maximum temperature, even if these are not synchronous? Would MIS 7e and MIS 9e align more closely with other interglacials if mean values were considered instead of peak overshoot values?

We agree that the highest CO₂ concentration reported for MIS 7e corresponds to a short-lived overshoot rather than sustained interglacial background levels. Figure 7 explicitly addresses this issue by testing alternative 3-kyr averaging windows for MIS 7e (and MIS 9e), either including or excluding the overshoot (panel A). When the overshoot is included (yellow symbols in panel C), MIS 7e and MIS 9e clearly deviate from the linear GMST–CO₂ relationship defined by the other interglacials. This offset reflects transient decoupling between atmospheric CO₂ and global surface temperature: CO₂ reaches very high values without a proportional increase in GMST. However, when the overshoot is excluded (light-blue symbols), the window-averaged values for MIS 7e fall within a range comparable to MIS 7c and align closely with the regression defined by the other interglacials. This indicates that the decoupling does not characterize the sustained interglacial state, but rather the brief overshoot phase. In other words, the decoupling exists but it is confined to the overshoot interval and not to the whole interglacial. It does not imply a fundamentally different equilibrium relationship between radiative forcing and temperature during MIS 7e, but only during the overshoot, also occurring at the onset of the MIS 9e. We revised the manuscript to clarify that the mentioned radiative decoupling relates to the interval during which the overshoot peak occurs, and to better distinguish between transient peak values and sustained mean interglacial conditions.

Now read in the revised manuscript, lines 462-489:

(...) From a radiative forcing perspective, the greenhouse gas difference between MIS 7e (~275 ppm CO₂, ~700 ppb CH₄) and MIS 7c (~245 ppm CO₂, ~600 ppb CH₄) corresponds to an estimated radiative forcing of ~1 W/m², which would produce a global temperature change of ~0.8°C (Hansen et al., 2011; Past Interglacials Working Group of PAGES, 2016). Given that MIS 7e was cooler than MIS 7c by 0.4°C despite higher GHG concentrations, this implies an anomalous offset of ~1.2°C between the two periods, suggesting a decoupling between radiative forcing and global temperature response. However, it is important to note that the high CO₂ concentrations observed during MIS 7e are confined to its very beginning (approximately 2 kyr), forming a brief overshoot. After this overshoot, CO₂ concentrations no longer exceed those recorded during MIS 7c (Legrain et al., 2024).

High-resolution records of CO₂ concentrations and GMST estimates are now available over MIS 1 (Bauska et al., 2021; Osman et al., 2021), MIS 5 (Hoffman et al., 2017; Landais et al., 2013), MIS 7 (Legrain et al., 2024; this study), MIS 9 and MIS 11 (Clark et al., 2024; Nehrbass-Ahles et al., 2020; Stevenard et al., 2025). When comparing the average maximum CO₂ concentrations period (3 kyr window) with GMST over the same period, it reveals that for MIS 7c, the atmospheric CO₂ concentrations are within the range of expected values considering the GMST over this period and the CO₂–GMST relationship of the past interglacials (Fig. 7). However, both MIS 7e and MIS 9 evidence anomalously high CO₂ concentrations of 31 ±14ppm and 41 ±13ppm (1σ), respectively,

compared to the expected CO₂ concentrations value based on their GMST (Fig. 7b). However, these two interglacials are characterized by the most pronounced overshoots of atmospheric CO₂ concentration of the past 500 ka, which consist in an abrupt increase followed by a similarly abrupt decrease of atmospheric CO₂ concentrations at the end of a Termination (Bereiter et al., 2015; Legrain et al., 2024; Nehrbass-Ahles et al., 2020). Over MIS 7e, atmospheric CO₂ concentrations increase and drop by 30 ppm in 2,000 years, while during MIS 9 concentrations fluctuate by 35 ppm in 4,000 years. In contrast, when considering a 3 kyr window immediately following the CO₂ overshoot, once CO₂ levels have stabilized at typical interglacial equilibrium values, MIS 7e and MIS 9e fall in line with the other interglacials. These results suggest that during the overshoot phase, the global climate does not fully equilibrate with CO₂ concentrations, leading to a transient radiative decoupling. However, once the overshoot has subsided and CO₂ follows a more stable interglacial trajectory, this decoupling disappears. (...)

Finally, based on these new analyses, we decided to remove the final discussion paragraph of this section regarding the hypothesis of the role of sea ice to explain this decoupling.

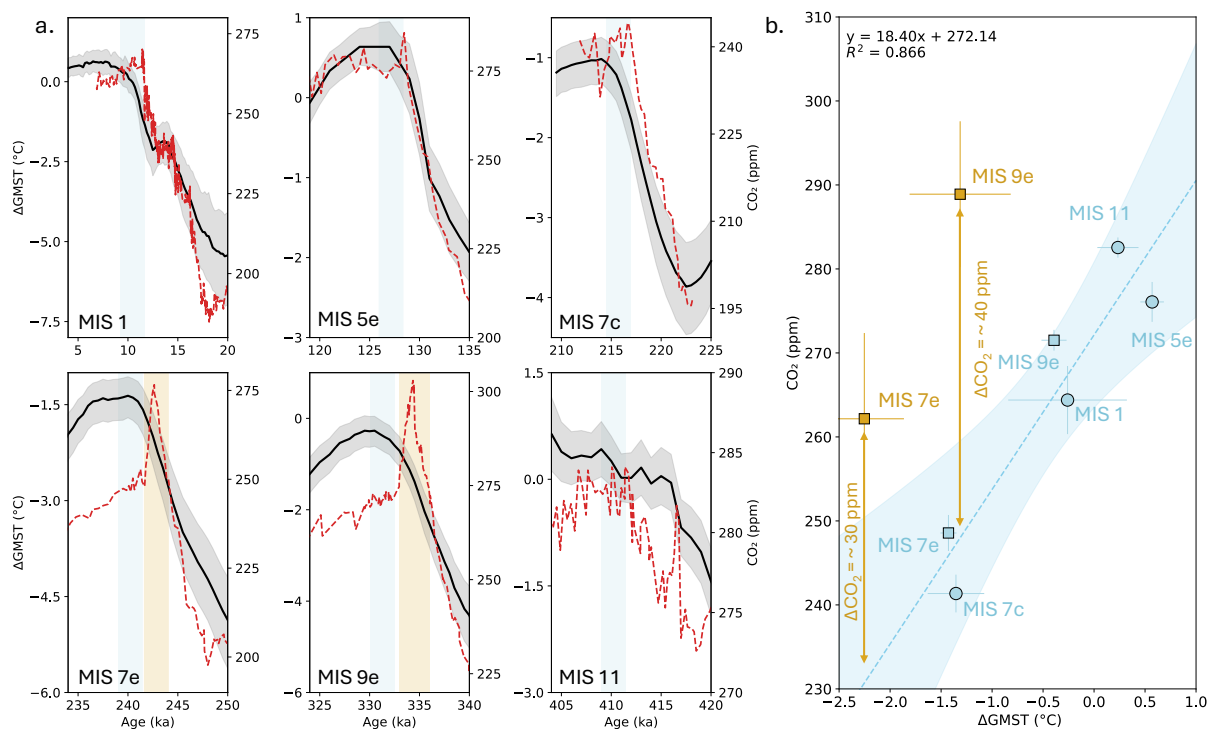


Fig. 7: Relationship between GMST and atmospheric CO₂ across the interglacials of the past 450 ka (a) Global mean surface temperature (GMST; black line with 1 σ grey envelope) and atmospheric CO₂ concentrations (red dashed line) for MIS 1 (Bereiter et al., 2015; Osman et al., 2021), MIS 5e (Bereiter et al., 2015; Clark et al., 2024), MIS 7c and MIS 7e (this study, Legrain et al., 2024), MIS 9e (Nehrbass-Ahles et al., 2020; Stevenard et al., 2025), and MIS 11 (Clark et al., 2024; Nehrbass-Ahles et al., 2020). The timescale used for atmospheric CO₂ records is the AICC2023 chronology (Bouchet et al., 2023). Shaded vertical bands indicate the time windows used to compute the window-averaged values shown in panel (b). For MIS 1, MIS 5e, MIS 7c and MIS 11, light blue bands correspond to the 3kyr time windows following CO₂ concentrations peak. For MIS 9e and MIS 7e, blue/yellow bands denote alternative 3kyr windows including/excluding the CO₂ overshoot. (b) Dots and square represent window-averaged values derived from the intervals shown in panel (a), with horizontal and vertical error bars indicating the standard deviation of GMST and atmospheric CO₂ concentrations within each window. The dashed line shows the best-fit linear regression, with blue shading indicating the 95 % confidence interval of the predicted mean response. Light blue squares and dots represent interglacials values included in the regression. Yellow squares correspond to values calculated including the CO₂ overshoot for MIS 7e and MIS 9e and are excluded from the regression.

L. 421: “In our Δ GMST reconstruction, MIS 7c emerges as the warmest phase of the MIS 7 sequence, with global mean surface temperatures $0.4 \pm 0.4^\circ\text{C}$ warmer than during MIS 7e.” Here, the uncertainty is as large as the inferred temperature difference. While I am not calling this result into question, it should be treated more cautiously. Taken together (i.e. CO₂ values excluding overshoot values and uncertainties in the temperature difference

between MIS 7c and 7e), the evidence for a strong decoupling between radiative forcing and temperature appears weaker than stated.

We agree with the comment of Reviewer 2. We have nuanced the comparison between MIS 7c and MIS 7e in the revised manuscript. Now read, in the revised abstract, lines 26-28:

(...) The warmest phase across MIS 7 occurs during the MIS 7c substage, although the global surface temperature difference compared to MIS 7e is within uncertainty of the reconstruction (around 0.4 ± 0.4 °C warmer). (...)

And in the revised conclusion, lines 696-698:

(...) At the global scale, MIS 7c is the warmest period of the MIS 7 sequence appears comparable to, or slightly warmer than, MIS 7e. (...)

Regarding the second part of the comment, which concerns the decoupling between radiative forcing and temperature, we refer Reviewer 2 to our response to the previous comment.

In my opinion Section 4.3 is less convincing than the rest of the manuscript. This section requires clearer explanations of the methodology and rationale behind using the entire MIS 7 interval, given that phasing with each orbital parameter varies greatly within the stage and that the processes leading to TIII and TIIIa are shown to be different. I strongly recommend adding a supplementary figure showing the global and regional SST stacks alongside orbital forcing. This is necessary to assess whether the reported correlations and lags are representative of both MIS 7e and MIS 7c. The method used to calculate the r-Pearson coefficient to estimate the lag must be more detailed in order to allow reproducibility.

Based on the Reviewer 2 and Reviewer 3 comments, we decided to remove the correlation analysis performed in the section 4.3 in the new version of the manuscript.

L. 510: MIS 7e does occur during declining obliquity as do other interglacials, but its phasing relative to the obliquity maximum differs from most other interglacials. As noted by the Past Interglacials Working Group of PAGES (2016): “The minimum in $\delta^{18}O$ also always occurs within or just later than a quarter of an obliquity cycle after the obliquity maximum, with the notable exception of MIS 7c and 7e.”

We thank Reviewer 2 for pointing this out. We have now detailed and nuanced this part of the discussion. Now read, in the new version of the manuscript, lines 547-556:

(...) While MIS 7e occurred during a declining phase of obliquity, consistent with most late Quaternary interglacials, its phasing relative to the obliquity cycle shows a deviation from the canonical pattern. In most cases, peak warmth (or minimum $\delta^{18}O$) occurs within a quarter obliquity cycle following the obliquity maximum (Laskar et al., 2004; Past Interglacials Working Group of PAGES, 2016). MIS 7e appears somewhat later within the declining phase, closer to the subsequent obliquity minimum, but remains broadly aligned with the general pacing of interglacials. In contrast, MIS 7c is distinctly unusual: it is the only interglacial of the past 800 ka that coincides with, or occurs slightly before to, an obliquity maximum, which itself represents the highest obliquity value of the past 2 million years (Laskar et al., 2004; Past Interglacials Working Group of PAGES, 2016). (...)

L. 520: “Regarding external orbital forcing, these analyses reveal a strong correlation with eccentricity (average r-pearson of 0.62), consistent with MIS 7 position within the 100-ka world.” The way this sentence is written implies that eccentricity is the main driver of the 100 ky cycle, which is inconsistent with the current debate. Eccentricity produces only weak insolation changes, so direct orbital forcing related to eccentricity of glacial-interglacial variability thought to be negligible and to influence glacial cycles mainly through modulation of precession (Raymo et al. 1997, Imbrie et al. 1984, Lisiecki, 2010). The physical significance of SST correlation with eccentricity, especially over a period of than one eccentricity cycle as in the case of MIS 7, may be discussed more cautiously.

Based on the Reviewer 2 and Reviewer 3 comments, we decided to remove the correlation analysis performed in the section 4.3 in the new version of the manuscript.

L. 536: “A conceptual modelling approach identified both precession and obliquity as crucial to constrain the timing of glacial terminations over the past 800 ka (Parrenin and Paillard, 2012).” Additional key references should be cited in this section, such as Huybers (Science 2006, Nature 2011), Huybers and Wunsch (Nature 2004) and Bajo et al. (Science 2020) for the role of obliquity in driving the glacial-interglacial cycles in the 100-ky and 41-ky worlds and for the timing of termination relative to obliquity and precession forcing in the 100-ky world.

We thank Reviewer 2 for their suggestions of additional references. Now read, in the modified manuscript, lines 588-590:

(...) Conceptual modelling approaches and radiometric dating of glacial terminations identified both precession and obliquity as crucial to constrain the timing of glacial terminations over the past 800 ka (e.g. Bajo et al., 2020; Huybers and Wunsch, 2005; Parrenin and Paillard, 2012). (...)

Typos:

L.145: “Gray and Evans (2019)”

Thanks for pointing this out, we modified the text accordingly.

L.179: “benthic $\delta^{18}\text{O}$ record”

Thanks for pointing this out, we modified the text accordingly.

L. 198: “ ΔGSST ”

Thanks for pointing this out, we modified the text accordingly.

L. 564: “MIS 7c”

Thanks for pointing this out, we modified the text accordingly.

L. 565: “during the Holocene”

Thanks for pointing this out, we modified the text accordingly.