Answer to reviewer 1 of Mathiot et al. (2026)

We thank the referee for their additional review. Below, you will find a point-by-point response, with the reviewer's comments in blue, our answers in black, and the changes made to the manuscript in purple.

Minor comments:

C1: l. 56: adjust brackets for citation: "As described in (Mathiot and Jourdain, 2023, hereafter MJ2023)"

R1: Done. '(Mathiot and Jourdain, 2023, hereafter MJ2023)' has been changed to 'Mathiot and Jourdain, (2023, hereafter MJ2023)'.

C2: grounding line: introduced as GL in additional text in 4.1
However, in the rest of the text it is used as two words. Consider adjusting either section 4.1 or the rest of the document

R2: Done. We have removed the acronym GL in the text.

C3: l.309 After 70 years, REV exhibits locations thinner

R3: Done.

C4: l. 353 remove comma and space after "In contrast"

R4: Done.

C5: 6 Conclusions (capital C)

R5: Done.

Answer to reviewer 2 of Mathiot et al. (2026)

We sincerely thank the referee for their additional feedbacks. Below, you will find a point-by-point response, with the reviewer's comments in blue, our answers in black, and the changes made to the manuscript in purple.

GENERAL COMMENTS

C2: The abstract should explicitly acknowledge the fixed ice-front assumption as an important limitation of the reported ocean reversibility. This assumption is central to the interpretation and scope of the result, particularly in the sentence, "The ocean conditions reverse over a few years when the atmospheric perturbation ceases." Please qualify this statement accordingly. In addition, "over a few years" appears inconsistent with the main text, where the recovery timescale is described as approximately 40 years. Please check and revise the abstract so that both the timescale and this key model limitation are reported consistently.

R2: We agree that the fixed ice-front assumption should be explicitly acknowledged in the abstract, as it is an important limitation when interpreting our findings. We have also corrected the recovery timescale to 40 years to ensure consistency with the main text. The sentence has been revised to:

'*With the assumption of fixed ice-shelf front positions, our simulations reveal that Antarctic continental shelf waters rapidly warm, leading to a regime shift with increased ice shelf melt rates, significant ice shelf thinning, and retreat of ice sheet grounding lines. The ocean conditions reverse within 40 years when the atmospheric perturbation ceases, while the ice sheet's response is much slower.*'

C3: L21-24 Jacobs et al. (1992). I appreciate that the discussion of Jacobs et al. (1992) was added in response to my previous comment. However, I do not think that this is the most appropriate place for it. This paragraph introduces the two proposed tipping points, whereas the classification of Jacobs et al. describes different basal-melt mechanisms associated with different water masses. Its insertion here interrupts the flow of the paragraph and may blur the distinction between tipping behaviour and melt processes. Please reconsider both the placement and integration of this material. Please also take care to integrate newly added text smoothly into the surrounding context and the overall structure of the manuscript.

R3: We agree that the discussion of the melt modes should not be included in the paragraph introducing the two proposed tipping points in Antarctica. We have therefore moved the sentences defining the melt modes to the beginning of the following paragraph, which discusses the ocean tipping point. This placement provides the physical context for the cold and warm ocean states before discussing the studies investigating their reversibility. The text has been modified as follows:

The cold and warm ocean states mentioned above are associated with different melt regimes, as identified by \citet{jacobs92}: melting by high-salinity shelf water formed during winter

freezing (Mode~1) and melting by warm Circumpolar Deep Water intrusions (Mode~2). \citet{jacobs92} also identified a third mode of melting in shallow areas, driven by tidal pumping and seasonal warming of coastal currents. \citet{hellmer17} found that the cold-to-warm ocean transition of the Filchner-Ronne cavity under future scenarios was irreversible ...

C4: L33-37 'Given the computational cost …'. The Introduction presents the lack of slowly varying perturbation experiments, multiple reversals, and systematic hysteresis analyses in previous ocean studies in a way that suggests that the present study is intended to overcome this limitation. However, the present study does not overcome it, as it applies a single abrupt perturbation followed by a single reversal. The authors also acknowledge later in the manuscript that their framework cannot identify thresholds or systematically explore hysteresis. The current flow of the Introduction is therefore somewhat misleading and should be revised.

R4: We agree that the original wording could implicitly suggest that the present study aims to systematically map hysteresis and identify transition thresholds, whereas this is beyond the scope of our study. We have therefore revised these sentences to clarify that this limitation also applies to the present study:

'Given the computational cost of the ocean models used in these studies and the large number of degrees of freedom of the atmospheric forcing, systematic experiments with slowly varying perturbations and multiple reversals, as performed in ice-sheet modelling studies \citep[e.g.,][]{garbe20,rosier21}, remain computationally challenging for ocean models. Consequently, a systematic analysis of hysteresis and reversibility for the ocean remains lacking, including in the present study.'

We have also clarified the scope of the present study in the final paragraph of the Introduction:

'In this study, we therefore focus on the reversibility of the ocean--ice-sheet response to the large scale perturbation used in MJ2023, rather than systematically mapping hysteresis or identifying transition thresholds.'

C5: L 189 "sea ice is no longer formed". This statement appears inconsistent with Fig. 5, which suggests that sea-ice production is strongly reduced rather than completely absent. Please revise the wording to describe the change more accurately, preferably quantitatively.

R5: We agree that this formulation was an oversimplification. We have added quantitative results and revised the sentence as follows:

'The ocean responses to the strong atmospheric perturbation are also very similar in the ocean--ice-shelf coupled simulations and in the standalone experiments analysed in MJ2023: at the Antarctic scale, September sea-ice area decreases by 97\%, from 16.2 million km^2 in REF to 0.5 million km^2 in PERT, while September sea-ice production decreases by 99.8\%, from 52 to only 0.1 Gt\,day^{-1}, resulting in a collapse of dense-water formation.'

C6: L229 “Since calving is proportional to ice-shelf thickness and velocity …”. This statement appears to be closely related to the fixed ice-front treatment and the representation of pseudo-collapsed areas. In particular, the simulated recovery of iceberg calving may depend strongly on retaining a 1 m-thick ice shelf rather than allowing actual front retreat or collapse. Please clarify that this relationship reflects the model formulation and discuss briefly how the fixed-front and minimum-thickness assumptions may affect the inferred recovery timescale of iceberg calving.

R6: We agree that this point needs to be clarified. Furthermore, the same limitation applies to the response of calving in PERT. To integrate this clarification smoothly into the manuscript, we added a few sentences on iceberg melt and calving in REF and PERT as follows:

‘Another difference with MJ2023 is that the iceberg calving flux is now computed interactively and depends on ice-shelf thickness and velocity. In REF, the mean iceberg calving flux, estimated from the mean iceberg melt over the period, is 1,125~Gt\,a^{-1} over 2009--2018 (Fig.~\ref{ts:ocean}c). This iceberg calving flux, provided by Elmer/Ice, is consistent with the observational estimate of ice front flux by \citet{rignot13} (1,325~Gt\,a^{-1}). Following the onset of the perturbation, the integrated iceberg melt initially increases sharply to 3,620~Gt\,a^{-1} in PERT, but subsequently decreases and stabilizes at a lower value of 535~Gt\,a^{-1} (years 46--55). This response reflects the adjustment of the iceberg calving flux to the ice-sheet response to the perturbation: ice-shelf thinning caused by enhanced basal melting reduces the iceberg calving flux in our model formulation, while the associated increase in ice-shelf velocity is not sufficient to compensate for this effect.’

We then slightly modified the section discussing the ocean reversibility as follows:

‘The reversibility of iceberg melt is closely linked to the timescale required for iceberg calving to recover from the perturbation. In our model formulation, and under the fixed ice-front approximation, the iceberg calving flux is equal to the ice front flux, consequently its recovery follows the timescale of the ice sheet rather than that of the ocean. Returning to the REF iceberg melt state therefore takes more than 70 years (Fig.~\ref{ts:ocean}c), but the deficit remains limited and does not seem to affect the ocean reversibility.’

Finally, we added the following points to the discussion of structural limitations in the general discussion section:

‘With a prognostic iceberg calving law, the net response would depend on multiple processes, such as ice-shelf thinning, flow acceleration, deformation and damage, and the evolution of the ice front \citep{wilner23}. The iceberg calving response simulated in PERT and REV, including the recovery timescale of more than 70-year, should therefore be regarded as characteristic of our model formulation rather than as a robust estimate of the physical response or recovery timescale of iceberg calving.’

Figures:

C7: All horizontal maps lack latitude and longitude information. Please add latitude–longitude labels or grid lines to improve geographical orientation.

R7: We added latitude–longitude grid lines to all horizontal map figures, except for Fig. 8. For Fig. 8, the grid spacing would need to be adjusted individually for each subplot, and adding latitude–longitude labels to all panels would substantially reduce the readability of the figure. We therefore retained the current layout for this figure.

Overall comments:

C8: A number of minor typographical and grammatical errors remain throughout the manuscript. Please ensure that the revised manuscript is carefully proofread by the co-authors before resubmission. Examples include "Experience name" in Table 1, which should be "Experiment name"; missing or incorrect subject–verb agreement, such as "the grounding line do not return"; typographical errors such as "extented" and "shallower then"; and incorrectly formatted citation parentheses and section references.

R8: We thank the reviewer for pointing out the remaining typographical and grammatical errors. We have carefully proofread the entire revised manuscript, with particular attention to grammar, spelling, citation and cross-reference formatting, and consistency in terminology and LaTeX formatting. We corrected the issues identified by the reviewer. We also corrected additional errors identified, including subject–verb agreement, missing articles, typographical errors, citation parentheses, section and figure references, unit formatting, and the consistent hyphenation of compound terms such as "ice-sheet", "ice-shelf", "grounding-line", and "present-day" where appropriate.
