Author's response to referee comment on egusphere-2024-2768

We thank Anonymous referee #2 for this second round of thoughtful comments and suggestions. We have addressed all points raised in the review as detailed in our point-by-point response below. Please note additional remarks independent from the referee comments, placed at the end of this document.

The referee comment is shown in italic grey font while our reply including the relevant changes made in the manuscript are shown in black font. Line numbers refer to the location in the version of the manuscript that the referee reviewed (i.e., before the hereby edits, version without track-changes).

Report #1, Submitted on 28 Jul 2025, Anonymous referee #2

I have previously reviewed Bourgeois et al., which conducted an extensive literature review to define 15 marine ecosystem impact metrics and 4 levels of thresholds (which they call "mitigation limits") corresponding to each metric, and then used CMIP6 ESMs and two additional ESMICs to evaluate the probability of each metric staying/exceeding each threshold under different mitigation scenario. I am overall satisfied with and appreciate the amount of efforts that the authors made to address my earlier comments, and see much improvement in the quality of the revised manuscript.

Thank you for this positive feedback.

I have one more suggestion to make, though, to further improve the clarify of the abstract/intro/methods of the manuscript, as I find these sections are quite difficult for the readers to follow unless the readers jump to the Results (e.g., Table 1) first. Examples are Lines 26-29, Line 67, Lines 85-88, sentences hard to understand even for myself as a second-time reader of this manuscript.

We rephrased and split sentences at the lines mentioned to improve the readability (see further down for detailed changes).

As mentioned above, the manuscript defines: 15 marine ecosystem relevant impact metrics 4 levels of thresholds exceeding which the marine ecosystem may be at risk (first of all, I think it is more appropriate to call these thresholds "mitigation targets" or just "thresholds" than "mitigation limits", the latter of which sounds more related to factors that limit a mitigation strategy reaches its targets.)

The choice of using "threshold", "mitigation target", or "mitigation limit" has been a topic of discussion within our team in the early step of writing the manuscript. We initially used the term "mitigation target".
Without context, a target is a value that is desirable to reach while a limit is a value to avoid or stay within. The latter is more in line with what we aim to express. The term "target" is rather used for commitments related to climate and energy policy, such as nationally

determined contributions, and carbon neutrality under the UNFCCC[1] framework. As for the term “threshold”, it means semantically that exceeding a certain limit would trigger an event (e.g., abrupt change, tipping point). This is not necessarily the case in our study where our limits are express a gradual increase in severity of impacts induced by a wide range of long-term ocean changes due to climate change, including (but not limited to) tipping points and abrupt changes. However, we see the referee’s point that mitigation limit “sounds more related to factors that limit a mitigation strategy reaches its targets”. Thus, we suggest keeping the use of the term “limit” but agree on removing the word “mitigation”. Considering the multiple occurrence of the expression “mitigation limit”, we do not list below the locations where the word “mitigation” has been removed and we refer the reviewer to the track-changes version of the manuscript.

*The manuscript also evaluates model simulations under 3 emission scenarios: SSP1-2.6, SSP-3.4 and SSP5-8.5. Finally, the manuscript computes the probability (>80% vs. 50-80%) of each metric exceeding a certain threshold. There are together 15*4*3 = 180 probability (and when that will happen) to compute, and each can be phrased as a science question, such as: “Under the highest emission scenario considered, by year 2100, how likely is it for global mean sea level to rise 0.4 m compared to 1850-1900, and when will that happen?”. I suggest that authors throw out questions like this as early as possible in the manuscript (no later than Intro), then state that in order to answer this type of questions we need to define XX, YY, ZZ, and need data to compute xx, yy, zz.*

We agree that stating explicitly scientific questions in the introduction section improves the clarity of the manuscript. We followed the referee’s suggestion (see further down for detailed changes, edits on lines 66–72).

Also clearly define that the targets level 1-4 are from more ambitious (challenging to reach) to more relaxed.

This aspect is already defined in lines 84-87 (second sentence of the methods section), but we have now replicated the referee’s wording at the end the introduction (see further down for detailed changes, edits on lines 66–72).

Break long sentences into shorter ones where it is possible. I hope (and believe) this will help improve the readability of the manuscript.

As mentioned above, we rephrased and split sentences not only at the lines mentioned earlier but also in other instances where appropriate to improve the readability (see further down for detailed changes).

[1] United Nations Framework Convention on Climate Change

Lines 26–28 (rewording)

Before

“Using this comprehensive model database, we estimate when and at which warming level 4 mitigation limits for 15 different impact metrics are exceeded along with an assessment of uncertainties. We find that under the high-emissions scenario, the two highest limits are exceeded with high probability for…”

After

“Using this comprehensive model database, we estimate the timing and warming level at which 15 different impact metrics exceed 4 limits, along with an assessment of the associated uncertainties. We find that under the high-emissions scenario, the strongest severity of impacts is expected with high probability for…”

Line 66–72 (addition of introductory scientific question and sentences splitting)

Before

“In this study, we define a set of 15 impact metrics associated to 4 mitigation limits following the approach of Steinacher et al. (2013). We aim at determining the probability of staying within a given mitigation limit based on scenario simulations from state-of-the-art Earth system models from the latest Coupled Model Intercomparison Project (CMIP6), and two perturbed parameter ensembles from Earth system models of intermediate complexity (EMICs). EMICs are an important modelling tool in climate sciences because of their relatively low computational cost compared to ESMs, which makes them suitable to create large ensembles for uncertainty quantification (e.g., Steinacher et al., 2013; Steinacher and Joos, 2016), and for simulations over long time scales (several 1000 years, e.g., Battaglia and Joos, 2018; Plattner et al., 2008).”

After

“In this study, we define a set of 15 impact metrics associated with 4 limits following the approach of Steinacher et al. (2013) to answer questions of the type:

- Under a high-emissions scenario, how likely is it for global mean steric sea level to rise by 0.4 m compared to 1850–1900?
- When and at which warming level will that happen?

To answer this type of questions, we (1) define a set of large-scale metrics that indicate a threat for ocean ecosystems and/or human systems due to climate change, (2) attribute limits to each metric, from ambitious (challenging to stay within) to more relaxed, which translates into an increase in expected severity of impacts, and (3) explore projections of these metrics in scenario simulations. We use scenario simulations from two types of models: (1) nine state-of-the-art Earth system models from the latest Coupled Model Intercomparison Project (CMIP6), and (2) two perturbed parameter ensembles from Earth system models of intermediate complexity (EMICs). EMICs are an important modelling tool in climate sciences due to their relatively low computational cost compared to ESMs. This advantage makes them suitable for generating large ensembles to quantify uncertainty (Steinacher et al., 2013; Steinacher and Joos, 2016), and for conducting long simulations, spanning several thousand years (e.g., Battaglia and Joos, 2018; Plattner et al., 2008)."

Line 84–87 (sentence splitting)

Before

"Mitigation limits are ordered according to the expected severity of impacts when exceeding the limit, that is, exceeding mitigation limit 4 for a given metric is expected to result in more severe impacts than exceeding mitigation limit 1, and correspondingly, staying under limit 1 is more ambitious because a higher emission reduction would be needed to stay below this limit."

After

"Limits are ranked according to the expected severity of impacts upon exceeding them: exceeding limit 4 for a given metric is expected to result in more severe impacts than exceeding limit 1. Thus, staying below limit 1 is more ambitious because a higher emission reduction would be required to achieve this goal."

Lines 125–128 (sentence splitting)

Before

"Given the lack of strong observational constraints on a global marine heatwave exceedance metric, we distribute uniformly the mitigation limit values of MHW_{fix} over the year as 90, 180, 270, 360 days (the latter representing an almost permanent heatwave) while we distribute the limits of MHW_{shift} over the range of projected values under the scenarios used in this study with 4, 6, 8, and 10 days."

After

"Given the lack of strong observational constraints on global marine heatwaves, we distribute the limit values of MHW_{fix} uniformly over the year as 90, 180, 270, 360 days (the latter representing an almost permanent heatwave). We distribute the limits of MHW_{shift} over the range of projected values under the scenarios used in this study with 4, 6, 8, and 10 days."

Lines 136–138 (rephrased)

Before

"Hinkel et al. (2014) find that under no adaptation, 0.25-1.23 m of global sea-level rise (i.e., 0.1 to 0.5 m of SSL rise assuming a constant steric to sea level rise ratio) in 2100 would expose 0.2-4.6 % of the global population to flooding annually."

After

"Hinkel et al. (2014) find that under no adaptation, 0.25–1.23 m of global sea-level rise in 2100 (i.e., 0.1–0.5 m of SSL rise assuming a constant steric fraction) would expose 0.2–4.6 % of the global population to flooding annually."

<u>Additional typographic and small edits independent from the referee comments</u>

- Affiliation for NORCE researchers updated following a change of legal name (NORCE Research)
- Use of dashes for ranges of values, instead of hyphens (lines 114, 118, 125, 137–138, 141, and 152–153, 198, 221, 222, 266, 349, 373, 414–415, 496 and in Table 1)
- Medium and high probability were sometimes inaccurately referred in the text as "50–80 %" and ">80 %", respectively. "50–79 %" and "≥ 80 %" are now used consistently when referring to medium and high probability (edits in lines 349, 358, 369, 391, 414, 496). These edits do not change the results nor the figures.
- Addition of the sentences below to enrich the interpretation of ESM-EMIC comparison at line 441:
  "Another explanation could be how EMIC ensembles are constrained. For UVic, global mean profiles of ocean tracers have been used as observational constraints. The latter averages large regional variations that compensate each other resulting in similar global mean. Such globally averaged constraints might inefficiently reduce uncertainty for ice-dominated polar regions, especially since we did not constrain sea-ice area. Large variations in sea-ice cover could influence air-sea gas exchange and, as a result, Arctic Ocean $\Omega_a<1$."
- Add missing spaces before "%" or after "≥" symbols (lines 161, 349, 350, 354-360, 371, 391, 414, 476, 496, 508, 589).
- Use of consecutive figure numbering in the appendix from "Figure A1" to "Figure A7" as required by the editorial board.
- Acknowledgments of the reviewers and the associate editor are added.