

Referee1

Review of: Irreversible ocean thermal expansion under negative CO₂ emissions D. Ehlert and K. Zickfeld **Overall evaluation:**

The manuscript investigates the reversibility of thermal sea-level-rise under idealized climate scenarios where CO₂ concentration increases exponentially, for 140 years and then are symmetrically return to pre-industrial concentration. Consistent with previous studies the manuscript finds that sea-level-fall lags the reduction in atmospheric CO₂ concentration and global temperature. The study shows that this behaviour is robust to the parameterization scheme used to close meridional overturning circulation.

Overall the manuscript is a solid contribution to the understanding the dynamics of the Earth system under reversibility scenarios, and fills a gap in the literature by exploring a major uncertainty left by previous studies. I recommend that the paper undergo minor revisions.

Response: We want to thank the reviewer for a helpful and detailed review.

General Comments:

The study is clearly intended as a sensitivity study and is generally presented in that way. However, it should be noted in the manuscript (the discussion would be a good place) that the scenarios used are highly idealized and deeply unrealistic. I accept the 1%-up 1%-down scenarios have been used extensively in the study of reversibility of climate change but the shape of these scenarios is implausible. Going from 11ppm increase in CO₂ to an 11ppm decrease in CO₂ concentration in a single year is technologically absurd. CO₂ concentration pathways shaped like bell-curves, would make much more sense for these kind of idealized reversibility studies.

The shape of the CO₂ pathway is particularly important for exploring the reversibility of sea-level-rise as the longer radiative forcing exceeds the radiative response the higher thermal sea-level rise will be and the longer it will take to dissipate the ocean heat to back to space.

To be clear I do not wish the authors to re-do their study with new CO₂ pathways, the study as-is is a satisfactory contribution to literature, I simply wish for the effect of the shape of the scenarios to be noted and discussed.

Response: Thank you for pointing out this gap in the discussion. We agree and have included a discussion of it in the manuscript.

Specific Comments:

Page 2 line 6 - 7: This is not quite true, the scenarios used in the cited papers follow unrealistic emissions pathways (1%-up 1%-down). The actual technological feasibility of large-scale atmospheric CO₂ removal is unknown and will likely extend over many lifetimes.

Response: This is not true for the Tokarska and Zickfeld, 2015 paper, where emission reduction rate were restricted to a maximum decline of 4% per year relative to year 2000.

Page 3 line 18 - 19: Should note that the version of the climate model you use does not have ice sheets. If I recall correctly other versions of the model do have ice sheets.

Response: Thank you for pointing out this negligence.

Figure 2: Why does the X-axis of b - d stop at 1oC?

Response: To enable readability of temperature differences in the deep ocean between model versions. The surface ocean temperatures can be inferred from global mean surface air temperature time series.

Figure 6 & 7: Is having both panels necessary? Panel a & b appear to be identical except for the zero of the Y-axis.

Response: We prefer keeping both panels, as the b panels are essential they show the stronger intensification/overshoot of some of the low mixing cases relative to the high mixing cases. However, only showing the change relative to year 0 might be misleading. We chose to combine Figure 6 and 7 into one figure.

Page 14 line 31: The quantity is usually called ‘radiative response’, not ‘radiative damping’. Damping is an odd way to conceptualize the restoration of planetary energy balance.

Response: We choose to use the same wording as in Zickfeld et.al. 2017 to clarify to readers that the same underlying theoretical idea is used.

Page 15 lines 32 - 35: This seems slightly confused. The ocean models are intentionally made too diffusive to close meridional overturning circulation (e.g. Munk & Wunsch, 1998) because the processes that control MOC closure occur at too small a scale to capture with most ocean models (Marshall & Speer, 2012). The lines as written seem to imply we should just turn down the diffusivity in our ocean models.

Response: Thank you for pointing out this potential misunderstanding. We rephrased the sentences to make this point more clear.

Typos, style and grammar:

The equations are unnumbered.

Response: We included numbering for the equations.

Variables in-text should be italicized.

Response: They have been italicized now.

Page 1 line 8: The abbreviation ‘TSLR’ is only used once.

Response: It is being used three times (incl. The time the abbreviation is included). We prefer to keep the abbreviation in the abstract as we think it improves the abstract's readability.

Page 1 line 9: Change “thousand” to ‘a thousand’

Response: Has been included.

Page 1 line 22 - 24: The sentence should be re-written for clarity.

Response: The sentence has been re-phrased to improve clarity.

Page 1 line 24: delete ‘though’

Response: Has been deleted.

Page 1 line 25: Change ‘applied’ to ‘tested’, and ‘that do’ after ‘scenarios’

Response: Changed accordingly.

Page 2 line 11: ‘they’ is ambiguous.

Response: The sentence has been adjusted to improve clarity.

Page 2 line 30: “The thereby induced increase” reads wrong, please re-write for clarity.

Response: The sentences has been rephrased.

Page 3 line 32: Spelling error in ‘McWilliams’.

Response: It has been changed.

Page 5 line 20: Using a two character symbol for radiative forcing is confusing (it implies you are multiplying two quantities together). Maybe use RF for radiative forcing or just F .

Response: RF has been replaced with RF in the text and equations.

Figure 1: Maybe use dashed and dotted lines to separate the various gray vertical lines.

Response: The line styles have been changed.

Figure 2 caption: change ‘continuous line’ to ‘solid line’. All the lines are continuous in the mathematical sense of the word.

Response: Thank you for pointing to this error. It has been changed accordingly.

Page 9 line 5: Use times symbol (\times in latex) in place of ‘*’

Response: It has been replaced.

References:

Marshall, J. and K. Speer, 2012: Closure of the meridional overturning circulation through southern ocean upwelling. *Nature Geoscience*, 5 (3), 171 - 180.

Munk, W. and C. Wunsch, 1998: Abyssal recipes ii: energetics of tidal and wind mixing. *Deep Sea Research Part I: Oceanographic Research Papers*, 45 (12), 1977 - 2010.