Reviewer 3

General comments

Summary

The article's main question is how the climate system reacts to different CO2 concentration pathways to a fixed global surface warming by 2100. Having RCP4.5 as a standard scenario, the authors set up two new different CO2 pathways to 1.5K warming, the "stabilization" and "overshoot" scenarios, with the goal of reflecting two extremes of hypothetical short-term and long-term climate policy. Conducting their simulations with the GFDL-ESM2M earth system model, the authors document the global climate response in the 21st century in what respects AMOC intensity and steric sea level rise and give the climate state by 2100 of surface temperature, sea level rise and sea ice concentration. The experiment main conclusions for overshoot pathway relative to stabilization pathway by 2100, are: (i) overshoot achieves the same global average temperature target with greater cumulative carbon emissions, but, leads to stronger ocean acidification (not quantified), higher global mean steric sea level rise and lower AMOC volume transport; (ii) overshoot forcing causes the ocean surface to be cooler over the subpolar NAtlantic and some regions of the SO with associated expansion of sea ice, suggesting a negative radiative feedback; (iii) geographic patterns of sea level rise are sensitive to the selected pathway, with overshoot forcing producing up to 10 cm of additional sea level rise in some cities of the east coast of NAmerica

We thank the reviewer for a supportive, insightful and thorough review, which helped us to improve the manuscript. We respond to each point in blue text interwoven with the reviewer comments below. All major additions to the manuscript are also highlighted in blue text.

Overall evaluation

This paper addresses a very relevant scientific question with huge societal implications. Authors carry a numerical experiment with a well-tested state of the art Earth System Model, and their results are supported by suitable simulations setup and appropriated analysis methods. The document is well structured, and its language is fluent and precise. The credit given to related work is very well balanced and authors contribution is clearly indicated. The principal study findings are clearly stated and flow natural from the presented results.

Specific comments

Abstract

The abstract gives a correct summarized perspective of the different components of the paper and it can be understood without reading the remainder document. I just have a few considerations:

- Because the research is based on a single model experiment, the GFDL-ESM2M model, it should be, in my opinion, explicitly declared (line 3)

The model is now specified in the abstract.

- Due to its importance for marine ecosystems, I would like to see the "ocean acidification" Included in the list of other climatic metrics that show important differences in response to different CO2 concentration pathways (lines 10-11)

We have added ocean acidification to this list.

- rephrase lines 12-13, to make clear that the overshoot relative to the stabilization simulations gives a higher global steric sea level rise and a reduced AMOC volume transport.

Clarified.

1. Introduction

- pg 2, line 2: to be more precise, "negative emissions" designation should also include "on-site capture of CO2"

We have added reference to on-site capture.

- pg 2, lines 18-23: the use of RCP4.5 and RCP8.5 scenarios in the simulations, justifies, in my opinion, to quote a summary reference(s) on these scenarios (e.g. Moss et al., 2010; van Vuuren et al., 2011)

These references have been added.

- pg 2, line 24: before paper's outline, I think that will be more appropriate to give here the justification for setting up the "stabilization" and "overshoot" pathways, than later in page 3 lines 23-25 ("Our goal in setting up the two new pathways (i.e. 'stabilization' and 'overshoot') was : : :")

We have reorganized this text as suggested.

2 Methods

Some of the comments intend to improve the results traceability

- pg 3, line 6 – What were the criterions for choosing the number of elements in each ensemble? Why five?

We added the following text to the Methods: Five ensemble members provide a means of averaging out internal variability in order to more clearly separate the differences in the simulations arising from the CO_2 forcing at reasonable computational expense.

- pg 3, line 8 – "very tiny perturbation" : : : "similar to the approach by Wittenberg et al. (2014)". Could you please be more specific? How "tiny" is this perturbation and how "similar" is to Wittenberg et al. approach?

For each ensemble member $i = 1,2 \ldots, 5$, we added: $dT = 0.0001°C * i$ to a single ocean grid cell in the Weddell Sea at 5-m depth. This information has been added to the Methods.

- pg 3, line 11 – "the final year of the simulation"; do you mean 2100? The simulations period was not yet clearly stated in the text.

Yes, 2100, as clarified in the revised text.

- pg 3, line 14 – "limiting atmospheric CO2 growth rates to approximately 0.25 ppm year^{1}"; please mention the period for which this growth rate is valid. (2070-2100)

The following details were added to the Methods:

This warming target was achieved by setting atmospheric CO_2 growth rates to be approximately 0.65 ppm year^{-1} from 2020 to 2060, and then having these growth rates decline to nearly zero by the end of the century. Under these slow growth rates, atmospheric CO_2

concentrations never exceed 435 ppm before 2100 (Figure 1a).

- pg 3, line 20-22 – from the observation of figures 1c and the supplementary S1 (large dots), I got somewhat different values for the three scenarios: 1.92K, 1.45K and 1.52K respectively RCP4.5, stabilization and overshoot. Did I miss something?

The numbers given in the text were annual means taken in 2100. The figures show 5-year running means. We have made an additional note about this subtlety on page 3, line 24:

"Here, we give the ensemble mean temperature in 2100, since this is the year that the CO_2 forcing is approximately equal in the stabilization and overshoot simulations. The ensemble averages over the years 2096-2100, which are reflected in the final year of the smoothed time series in Figure 1c, are slightly different (1.95 ± 0.05K in RCP4.5; 1.48 ± 0.09K in stabilization; and 1.56 ± 0.09K in overshoot)."

- pg 3, line 30 – "run of GFDL-ESM2M under 1% CO2 increase"; rate is missing (1% per year).

Fixed, thank you.

3 Global average properties

- pg 6, line 23 – suggestion: add "(TCR)" just to indicate that there is a definition behind the words "transient climate response"

Added.

- pg 7, line 5 – ": : : year 2086, respectively"; refer Figure 1

Added.

- pg 7, line 9 – instead of "(Figure 1c)"; refer (Figure 1a,c).

Added

- pg 7, line 24 – "AMOC reaches its lowest point in 2075 (13.6 Sv)"; it is not possible to check this value in figure 1d! It is somewhat confusing to discuss annual values in the text and to observe 10-year running average values in the figures!

We apologize for this confusion. We have replaced the annual means in the text with the 10-year means centered at 2075, which is 14.6 Sv and can be visually matched with Figure 1d.

4 Regional patterns tied to the ocean circulation perturbation

- pg 10, line 10 – "stabilization pathway by 2100."; refer (Figure 1e).

Added.

- Figure 5, caption – please clarify "vertically-averaged sea ice concentration"

We agree that "vertically-averaged" sea ice concentration is confusing, and therefore changed this graphic in the final version. There are 5 vertical layers of sea ice. The concentration over all five layers sums to one if the grid cell is covered in sea ice for the whole year over all five vertical layers. Therefore, the revised figure shows the sum of the concentrations over the five levels and the change in that sum between the preindustrial and the final five year average of the

ensemble mean.

- pg 13, lines 1-2 –refer Figure 6a,b for Boston and St. John's, and Figure 6d,e for Charleston and Miami

Added.

- pg 13, lines 5-6 –observing Figure 4 "on the other side of Atlantic", I would be a little bit more precise and replace "southern Europe" by "southern Iberian Peninsula" and "while Northern Europe : : :" by "while further north the western European coast : : :"

We have made the suggested changes.

- pg 13, line 7 – in this line, only mention Figure 4 and refer Figure 6f at the end of the paragraph.

Done.

- pg 13 - for the analysis of the sea level change results, presented in figure 6, it would be useful to have an estimation of the internal variability (ensemble spread)

We have revised the figure to include ensemble standard deviations.

5 Conclusions

A few questions for your consideration:

- Why it is omitted in your document the simulations results for the distribution of salinity by 2100? The relevance of this oceanic parameter for the AMOC dynamics and for the local steric sea level term, doesn't justify its inclusion in the discussion of the presented results?

We have added a brief discussion of the salinity change in the subpolar North Atlantic, as this is the region most relevant for AMOC dynamics. The halosteric term typically makes a very small contribution to global sea level [*Griffies et al.*, 2014; *Palter et al.*, 2014].

- From the model output, is it possible to quantify ocean acidification and elaborate a little more on the evolution of this oceanic parameter under the selected scenarios?

Yes, we have added a panel to Figure 1 and some additional text to make this result more quantitative.

- It should be brought to the discussion in this final section, the limitations/weaknesses of the used model that can affect the quality/representability of the obtained results (e.g. no representation of interactive ice sheets or glaciers; transient climate response (TCR); ACC position; salinity anomaly over the subtropical Atlantic (Jackson et al., 2014); AMOC depth (Kostov et al.,2014). You have already made some comments at the end of section 2 (pg6, lines 15-19) that can be revisited in the context of this discussion.

We have inserted a few sentences on page 15 (line 17-20) to contextualize this model among other CMIP5 models with respect to the key points emphasized in the conclusions.

Technical corrections

- pg 1, line 11 – insert the (AMOC) acronym and remove the full designation in line 13
- pg 2, line 33 – Anderson et al. 2004 is missing in the references list

- pg 3, line 16 – “reaching a peak of 537 ppm”; observing Figure 1a this value looks like a typing error (probably, should be 573 ppm)
- pg 6, equation 3 – dz is missing in the integration

All corrected. We appreciate your attention to these details.