Review of original submission

Paper Title: Improving the representation of anthropogenic CO_2 emissions in climate models: a new parameterization for the Community Earth System Model (CESM)

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Overview and recommendations:

The paper addresses important questions regarding improving the performance of Earth System Models (ESM) – the important tools to study and understand the complexity of the Earth's climate. Improving these models is a major goal of the science community as they can be a very valuable tool in studying the response of the Earth's system to anthropogenic forcing, providing guidance to policy makers.

In particular, the paper investigates the impact of a new parameterization of CO2 emissions that the authors have recently developed, called the POPEM module (POpulation Parameterization for Earth Models). POPEM presents an important advancement in the way CO2 emissions are modeled, as it accounts dynamically for the changing emissions. Like previous research, POPEM uses population data as proxies for emission. What is unique to this new parameterization, though, is that it models the evolution of the population while previous research has relied on historical data, hence not being dynamical, preventing them from making reliable predictions for the future emissions and the response of the climate system.

Using this new parameterization (POPEM) presents an important advancement and this makes the described research very valuable. However, before going forward one have to evaluate the performance and assess the impact of the new parameterization. Indeed, this is the goal of this paper.

The paper begins by describing what is unique about POPEM.

It then validates the stand-alone performance of POPEM by comparing its predication over a past 63 (and 70) -year period to existing data. The comparison is done globally but also by several regions. This validation is done in two ways: by comparing forecasted to observed population growth rates; and by comparing the forecasted to observed emission rates. The results show that despite the difficulty of predicting non-linear trends in the growth of population and emissions, POPEM preforms quite well. These comparisons give credibility to the POPEM forecasts, hence to its use in forecasting future scenarios.

Next, the paper uses a coupled ESM, the Community ESM (CESM) to evaluate the impact of POPEM. The evaluation focusses on the impact of POPEM on two very important, and difficult to predict, parameters of the Earth's system - the precipitation and the sea surface temperature (SST). The evaluation is done in two ways:

- by comparing the results from a control run (using global CO2 concentration parameters that I believe are homogeneous – this needs clarification) to those from POPEM. This choice of model setups highlights the value of POPEM as it predicts the population (and the emissions) in every grid point, showing the impact and the importance of the spatial variability.
- By comparing both control and POPEM forecasts to actual observations (over a 20-year period for precipitation and 50-year period for SST).

The paper finds that:

- The global predictions for both parameters compare to the observations in a very similar way for the CONTROL and the POPEM simulations. Hence, the more realistic POPEM parameterization "does no harm". This is an important test and conclusion because it is occasionally the case that including more realistic parameterizations might degrade the performance of the forecasts for certain parameters. This is because often the models are "tuned" to predicting some of the parameters, giving the right answer for the wrong reason, and impacting negatively the forecasting of the non-tuned parameters when the more realistic parameterizations are employed.
- More importantly, the paper finds that using POPEM results in regional differences between its forecasts and that of the control run. Comparison to observations seems to suggest the POPEM produces better regional distribution of the precipitation. This is a very important conclusion, in my view. It does not seem to be well highlighted in the paper summary.

Overall, the paper addresses a very important topic. The approach is sound and uses a very good modeling framework. There is a very extensive set of references. The paper is presented in a fluent and precise language.

However, there are several places where the paper could be improved, as detailed below.

Because of all that, I propose the paper be accepted with minor revisions.

Detailed comments and suggestions for modifications

Title: The current title is: "*Improving the representation of anthropogenic CO_2 emissions in climate models: a new parameterization for the Community Earth System Model (CESM)*"

I would suggest a modification to read "*Improving the representation of anthropogenic CO_2 emissions in climate models: **Impact of** a new parameterization for the Community Earth System Model (CESM)"*

The reason is that main goal of the paper is not to describe the new parameterization but to evaluate its performance and impact.

Abstract

- "*The results show that it is indeed advantageous to model CO2 emissions and pollutants directly at model grid points rather than using the forcing approach*". Please, reword as it is not clear (at this point) what is this forcing approach.

Introduction:

- The reader would benefit from a more detailed description of the existing approaches to modeling CO2 emissions. What I gather from the paper is the following: there are two basic approaches that models use to account for CO2 forcing:
    a) using globally homogenous forcing;
    b) using non-homogenous, grid-point specific forcing. This one can be applied in several ways:
        1. using Representative Concentration Pathways (RCPs) that "*are not fully-integrated socioeconomic parameterizations, but rather estimates for describing plausible trajectories of human climate change drivers …. They provide simplified accounts of human activities and processes, including population density and economic development, from non-coupled Integrated Assessment Models (IAMs;)*" Question: are these parameters location-specific? This is what I am understanding.
        2. the proposed here POPEM model being integrated into a fully coupled model. This is similar to RCPs but: uses a coupled model; uses a dynamic model for the prediction of population and emissions.
    c) Is my understanding correct???
    d) If so, I would suggest two possible modifications:
        1. Use some wording or structure as what I've described above
        2. Space-permitting, create either a small table or a flow diagram that shows these different levels of sophistication
- P. 2, lines 25-30 – It says: "*Given the highly non-linear character of the processes involved, it is not unreasonable to assume that location is significant, and the spatial and time distribution of these emissions may affect global climate*" – a bit unclear. Might be better to say "*, it is not unreasonable to assume that specifying (or accounting for) geographical variability is significant*"
- P. 3, lines 2-4: "*The aim of this paper is to show that this grid point scale modeling of anthropogenic CO2 emissions (and other pollutants) represents an improvement, and that two important variables, namely global precipitation distribution and surface temperature, are not negatively affected by this more-detailed approach*." While this is true I believe this is a rather weak statement regarding the benefits of using POPEM-type parameterization of emissions forecasting. I believe the authors are in a position to make a stronger statement,

namely: including the POPEM dynamical forecasting approach that accounts for the spatial and temporal variability of the emission sources, leads to better representation of the geographical variability of the precipitation.

- Space-permitting, I would suggest that the **Introduction** ends with a short description of the outline for the following presentation. Something like: " *the following sections outline: the unique features of POPEM; the validation of the POPEM stand-alone performance; the framework for evaluating the impact of POPEM – incorporation into CESM and framework for testing; the comparison between a control run and a POPEM-specific one: evaluating the differences between the two; evaluating how each compares to observations; discussions; summary and conclusions;*" This would give the reader a clear structure of the paper to follow and will make it easier to highlight the contributions of the paper.

Section 2.2

- currently there are sections 2.2 and 2.2.1 but not 2.2.2 or more. It seems that there is no need for 2.2.1. If there is no 2.2.2. I would suggest the following: "2.*2 POPEM specifics and validation*", followed by "*2.2.1 POPEM parameterization model overview: Unique features*" and "*2.2.2 POPEM trend verification*". Of course, this is just a suggestion.
- P. 6, lines 8-9 – " *Our control case used global CO2 concentration parameters (standard procedure in ESMs), while the POPEM case used geographically-distributed CO2 emissions data"* - is the control using homogeneous CO2 concentrations ? I am pretty sure this is the case but it might be better to say it this way.

Section 3.1

- P.7, line 23 – it appears that figures 6C, 6D, 8C and 8D are referenced before figures 4 and 5 (and the figure 8 is referenced before Fig.7). This should not be the case. The figures should be referenced in order. However, it seems that this is because the current order of the discussions here might need to be modified. Below is what I mean.
    a) Maybe the order should be:
        1. Test for "no harm" – figures 6C-6D and 8C-8D show that.
        2. Compare the CONTROL to the POPEM simulations to see where exactly they differ.
        3. Compare both the CONTROL and the POPEM CESM simulations to the observations, looking at regional distributions. The comparison in steps 2 and 3 brings up the impact of the POPEM geographically-aware CO2 emissions on the geographical distribution of the precipitation, highlighting the positive impact POPEM has (especially in step3).
    b) Steps 2 and 3 could be switched – depending on what the authors think.
    c) I want to point out that the proposed change in the order of the presentation is just a suggestion for the authors to consider.
- P.8, lines 2-3: "*It is clear from the figure that POPEM does alter the spatial pattern of precipitation and exerts a definite effect on the climate pattern, as the module reduces the otherwise exaggerated ITCZ precipitation in the Southern Hemisphere (South East Asia and Australia)*." Do you have a reference that it was exaggerated?? If so, then this is a very strong point that needs to be emphasized. Also, do you mean Fig. 4 or Fig. 5? Please, specify.

- P. 8, lines 7-8: "*There are also important differences in precipitation in the 30N-30S band. Here POPEM reduces model bias, especially in the Southern Hemisphere and on the Tibetan Plateau.*" How do we know that the model bias is reduced?
- P. 8, line 9-10: "*On the other hand, POPEM departs from the control simulation in the*
- *10 Asia-Pacific region between 10N-10S*." Is that good or bad? How do we know?
- *P*. 8, line 31 – "(*Q1 and Q3 remain between ± 0.4 mm/day*)." Please, define Q1 and Q3.