Biogeosciences Discuss.,
https://doi.org/10.5194/bg-2020-254-RC1, 2020

Biogeosciences Discussions

Interactive comment on "Ocean Carbon Uptake Under Aggressive Emission Mitigation" *by* Sean Ridge and Galen McKinley

Anonymous Referee #1

Received and published: 6 August 2020

General Comments

The manuscript by Ridge and Galen analyses the factors behind the decreasing efficiency of oceanic anthropogenic carbon (C_{ant}) uptake in three different ensembles of climate model model runs with the community earth system model, until the end of the current century. The ensembles differ in their forcing of the carbon cycle and range from a scenario with continuing strong emissions, RCP8.5, an intermediate emissions scenario (RCP4.5) and a scenario where the radiative forcing from the emissions remains so low that the 1.5°C target set in the Paris agreements is reached. Of these, the last and most desirable scenario shows the strongest decrease in the efficiency of the ocean to take up C_{ant}. A priori this is to be expected because a decrease in carbon

emissions will lead to a less strong pressure on the ocean to take up more carbon.

It is known that, globally, the efficiency of C_{ant} uptake in the ocean will decrease through several mechanisms. One effect is a purely chemical one, caused by the declining buffering capacity of seawater with increasing $p\mathrm{CO}_2$, together with the temperature effect on carbonate chemistry. A second is what the authors call the "carbon gradient effect", and has to do with the rate of incrase of atmospheric $p\mathrm{CO}_2^a$: The surface ocean pCO_2^o tends to equilibrate with the atmosphere, but at the same time anthropogenic carbon is moved into the interiour of the ocean by diffusion and advection, working against this trend. Any slowing of the $p\mathrm{CO}_2^a$ increase therefore will lead to lessening of the carbon gradient between atmosphere and ocean, reducing the uptake (Raupach et al., 2014).

The manuscripts investigates the relative role of these two processes by fitting a one-dimensional reaction-diffusion model for ocean carbon uptake to the evolution of ocean C_{ant} in the ensemble averages over the historical period. Using the one-dimensional model then one can easily separate the two above-mentioned effects in the scenario runs.

This approach is an elegant way to help understanding how future uptake of carbon in the ocean will evolve and merits publication in Biogeosciences. But I would suggest two larger changes, before the manuscript should be accepted:

The first is that the manuscript could be significantly shortened. One candidate for shortening are the many repetitions of the main results in chapter 3, 4 and ultimately 5. Especially the discussion subchapter 4.1 reads like a lengthy repetition of the main results, rather than a true discussion. The other candidate for shortening is that the manuscript is in several places much too verbose to explain fairly standard calculations and mathematical techniques. I list those in more detail under specific comments.

The second is that the manuscript hardly relates the results obtained with some of the previous literature: especially the earlier studies on carbon and climate feedbacks on

ocean carbon uptake are cited in the introduction, but their results are later not related to again. Feedback analysis of the last CMIP5 model runs have e.g. shown a climate sensitivity of ocean carbon uptake of -8 $\pm$ 3 GtC K^{-1} (e.g. Friedlingstein, 2015). What part of this feedback would be included in which effect in the analysis performed here? While I see that the methodologies in the feedback analysis and the methodology used here may not be easy to concile, it would at least be useful to discuss how they are related, and whether the results are compatible. The authors also state somewhat in passing (lines 348-349) that changes to the ocean circulation do not seem to play a large role in C_{ant} uptake. This should also be discussed somewhat more.

Specific Comments

The nomencalture of anthropogenic carbon is handled quite confusingly, with C_{ant} meaning very different things in different places in the manuscript without proper distinction. In some places, $C_{ant}(z,t)$ is used to descibe the time-and depth-dependent anthropogenic carbon in the 1-d model, in other places, either the depth or time-dependency is left away (e.g. line 142). In equation 7, then again C_{ant} means the surface ocean concentration only. I suppose that is also, what is meant on the left-hand side of equation 8, while on the right hand side the depth- and time-dependent field is meant. In that form, the equation cannot hold in the interior of the ocean. I suggest to clarify what is meant in each instance e.g. by adding additional superscripts, e.g. C_{ant}^{ML} for the mixed-layer C_{ant}.

I think readers are able to understand the linear equation 4 and its consequence equation 5 without the lengthy explanation in lines 114 to 124.

A similar statement holds for the explanation of the impulse response function 7 from lines 179 to 195; this is a fairly standard mathematical technique and does not need to be explained in so much detail.

An important point in the methods chapter is line 220 to 222, where it is stated that the relation between C_{ant}^{ML} and $\delta p CO_2^{ocn}$ contains the effects of changing buffer factor and of changing temperature. Here would be a good place to discuss how the decomposition of effects made here is related to the more traditional feedback analysis that results on the two feedback factors β and γ. I must admit that I wondered why it is necessary to have fitted relation between the two (Appendix B), rather than using standard carbonate chemistry and calculating one from the other, assuming constant alkalinity.

Line 314: "Assuming ocean circulation remains constant" To what extent is that assumption justified?

I do not completely understand, how the fields shown in Figure 4 have been calculated. Is this the zonal average of the 3-d model output minus the expected profile from the 1-dimensional model? How does advection enter this picture?

Section 4.1 contains very little discussion and is in large parts a repetition of results. Then, in the end (lines 468-471), some other results on future C_{ant} uptake are cited, but without giving any connection to what this study has shown. Is there a relation between these results, or is it just inserted here without too much meaning?

Line 410 ff: "We find ...": Is this really a finding, or not rather an assumption that went into the methodology?

Appendix A again explains the impulse response function, even repeats equation 7, and gives details about using it that can be found in many textbooks. I suggest to remove it (including Figures A1 and A2), or shorten it to not more than one paragraph.

Appendix B: The coefficients shown in equation B3 to B7 all have different units, but these are not shown.

Technical Corrections

Lines 297 and 298: should one of the mentioned scenarios be RCP8.5 rather than RCP4.5?

References: Many references give two web addresses for the cited papers, one being the http-form of the doi (I would rather have the doi without the `https://doi.org` in front), and the journal address. Are really both necessary?

References

Friedlingstein P. (2015): Carbon cycle feedbacks and future climate change. Phil. Trans. R. Soc. A 373: 20140421. doi: 10.1098/rsta.2014.0421

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