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Earth System Dynamics Discussions

Interactive comment on "Southern Ocean as a constrain to reduce uncertainty in future ocean carbon sinks" *by* A. Kessler and J. Tjiputra

Anonymous Referee #2

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The authors present an analysis of the suite of CMIP5 models that performed the fully-interactive (CO2 emission-driven) simulation under the RCP8.5 scenario. The authors analyse possible drivers of the inter-model differences in the present-day Southern Ocean uptake and show how the described biases persist in the future projections. They find very interesting differences between two groups of models based on the seasonal cycle of pCO2 and show how these differences are driven by overestimation of NPP or SST, suggesting a predominance of the biological carbon pump for one group and of the solubility carbon pump for the other.

I think this study will make a valuable contribution to our ability to interpret and improve model CO2 uptake predictions and I recommend publication after a number of moderate-to-minor issues have been addressed.

My main concern is on the use of a positive inter-model correlation between present-day and future behaviour of models as an indicator of the Southern Ocean as a constrain to reduce future uncertainty. Here's what I don't get: all models are wrong (G1/G2 too strong/little CO2 uptake) and for those that are less wrong (G2) it is for the wrong reason (opposite seasonal cycle). The link between present and future behaviour is not evidence of models becoming right in the future. It does not give more credibility to the projected sustained growth of CO2 uptake in the SO because this growth is still a result based on present-day biases (the authors show that these biases persist in the future). The sustained CO2 uptake growth in the SO is the reason for which this region is selected for the analysis (and because of the significance of the correlation).

Said so, I am still convinced that the SO indeed is a constrain to improve future projections but I am not sure the inter-model correlation is evidence of it. Perhaps a more explicit explanation on the meaning of this correlation could help.

The use of 45 S as a limit for the Southern Ocean is likely to cut out in some places, depending on the model, part of the region of high CO2 uptake associated with the winter deepening of the mixed layer and the formation of subantarctic mode water (e.g. Sallee et al., 2012). I wonder how sensitive are results on this limit and whether a more dynamic limit based, for example, on outcrop surfaces of isopycnals for SAMW or using Ekman divergence as a separation between Antarctic and subantarctic zones could change results in any way. Have the authors carried out any complementary analysis on this issue? Another choice for the SO limit could shed some light on the negative (although not significant) correlation for the mid-latitude SO. As it is now, this region includes part of the subtropical gyre and part of the deep winter mixer layer area forced by the westerlies. These are likely to evolve in opposite ways in the future with a strengthening of the westerlies due to the increase in the meridional temperature gradient, as stated by the authors at page 2659 (lines 8-13). Stronger winds could enhance intermediate water formation but also SAMW formation which is split between the two regions in the current separation. If further analysis is not possible I suggest at least an expanded discussion on this aspect.

Also, likely less important but still interesting is the uptake of CO2 due to the overestimated open sea convection in the SO. Most CMIP5 models form AABW through unrealistic extended open sea convection in the subpolar SO (Heuze et al., 2013). This is mostly because of still too-coarse resolution and thus the difficulty to resolve the complex formation processes occurring on the continental shelf. Convection regime is however, very variable across models and so it is its response to climate change, with a general reduction of convection area and duration but with large variability of the timing across models (deLavergne et al., 2014). The impact of the reduction and shutdown of convective area on the uptake of anthropogenic carbon can be important, specially when considered in terms of its contribution to the total SO CO2 uptake trend (Bernardello et al., 2014). The authors mention the importance of deep winter mixing in polar regions as an efficient way to transport anthropogenic carbon from surface to depth (page 2659, Lines 6-8). In light of the above I wonder if perhaps considering mixed layer depth, in addition to SST and NPP, could give new insights on the processes involved in determining the inter-model differences in CO2 uptake.

Minor issues:

It's not explained why only fully-interactive simulations are considered. The same processes responsible for the seasonal pCO2 cycle biases described should be active also in simulations with prescribed atmospheric CO2. If so, maybe more models would be available. Is there a motivation behind this choice?

Put in Figure 6 panel titles also G1 and G2 to facilitate the comprehension of the Figure.

Page 2655, Lines 19-22: The numbers given here for the highest uptake estimates do not seem to coincide with the values in Figure 1. For example, NorESM1-ME in the plot does not go below 2.4 Pg C/yr so the average uptake for the period 2001-2010 should be higher than that.

References:

Sallée, J.-B., R. J. Matear, S. R. Rintoul, and A. Lenton (2012), Localized subduction of anthropogenic carbon dioxide in the Southern Hemisphere oceans, Nat. Geosci., 5(8), 579–584, doi:10.1038/NGEO1523

Heuzé, C., Heywood, K. J., Stevens, D. P. & Ridley, J. K. Southern Ocean bottom water characteristics in CMIP5 models. Geophys. Res. Lett. 40, 1409–1414 (2013).

de Lavergne, C., J. Palter, E. Galbraith, R. Bernardello, and I. Marinov (2014), Cessation of deep convection in the open Southern Ocean under anthropogenic climate change, Nat. Clim. Change, 4, 278–282, doi:10.1038/nclimate2132.

Bernardello, R., I. Marinov, J. B. Palter, E. D. Galbraith, and J. L. Sarmiento (2014), Impact of Weddell Sea deep convection on natural and anthropogenic carbon in a climate model, Geophys. Res. Lett., 41, doi:10.1002/2014GL061313.

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