

Comments on “Model constraints on the anthropogenic carbon budget of the Arctic Ocean”

by Terhaar et al., submitted to Biogeosciences, doi: 10.5194/bg-2018-283

In this study the authors examine the anthropogenic CO₂ budget of the Arctic Ocean and how this inventory depends on model resolution. In that purpose they take advantage of the NEMO-v3.2 OGCM coupled to the biogeochemical model PISCES-v1. They perform experiments with three different horizontal resolution of the OGCM, namely 2°, 0.5°, and 0.25°. Inventories of anthropogenic carbon in the Arctic appear to increase with increasing resolution (from 2.0 to 2.6 Pg C). The role of air-sea fluxes and lateral transport in building these inventories is examined. In this model lateral transport accounts for 75% of the Arctic Ocean anthropogenic CO₂ inventory. A comparative study of the outputs of other modeling studies (CMIP5) allow concluding that models with larger lateral transport appear to better fit data-based estimates of the anthropogenic carbon in the Arctic Ocean. This partitioning does not depend on the model resolution. Resolution appears important in shaping the tracer distribution and improving data-model agreement.

The paper is well written and very well structured. However I have several concerns about the method and the way data-model comparison is performed. Before the method is thoroughly assessed this paper is not fit for publication.

Major comments

1. I have serious concerns about the applied method for estimating the C_{ant} . Conclusions about the impact of model resolution might not be robust due to shortcoming in the method.

C_{ant} is rightly defined as the difference between the simulated historical and control ocean dissolved carbon contents. However, there is only one control experiment performed (page 5), that for ORCA05. As far as I understand the C_{ant} for ORCA2 and ORCA025 is evaluated as the difference between the respective 1958 → 2012 experiments and the ORCA05 control for the same period. Therefore I strongly suspect that the differences in CFC and C_{ant} among the different models may be explained by model drift.

In order to lift that concern the following actions should be taken:

- a. Perform control experiments over the period 1958 → 2012 for each model resolution.
- b. While it is defensible to reduce the computation length with the high resolution model (ORCA025) there is no such need for ORCA2, which runs even faster than ORCA05. The authors should also present results of historical and control experiments performed with ORCA2. The perturbation experiments should also be repeated with ORCA2.

The results of these additional experiments should then be compared to those presented in the present paper. This would provide a means of validating their method and assessing potential drifts

2. The experiments which are presented here are global. What would be the global figures for anthropogenic CO₂ uptake in the 5 cases? How do these figures compare to other

assessments? Answering this request would allow evaluating whether the OGCMs as a whole would need serious refinements or should the effort concentrate on less-well resolved areas such as the Arctic Ocean.

3. The other main concern deals with the correction of data-based reconstructions of C_{ant} (Abstract, Sections 4.2 and 4.5, Fig. 9). The authors assume that reconstructed deep values of C_{ant} should be corrected downwards since observed CFC-12 concentrations at those depths are negligible. Doing so means overlooking the important fact that CFCs started to be emitted in the atmosphere much later than CO_2 . Data-based estimates relying on the TTD method take into account the different tracer histories in the atmosphere. Clearly, the TTD method has limitations. The end-product displays rather large uncertainties. However, there are no sound arguments for setting the C_{ant} in the deep Arctic to zero.
4. Modeled CFC-12 inventories in the Arctic (Fig. 5 and page 12, lines 24 and 25) appear to be much lower than the observed ones, even with ORCA25. Would it be possible to provide total (integrated over depth and distance) inventories along the AOS94 and Beringia 2005 expedition pathways and compare the 3 model results to the data inventories? The low CFC inventory provides an indication that low C_{ant} would be expected too.
5. In addition, a description of how CFC-12 is modeled is lacking.

Minor comments

- Abstract, line 10: C_{ant} is not defined yet.
- Page 3, line 2: a reference to the figure displaying the map of the Arctic should be made here; the reader does not necessarily know about the area characteristics. In this sense Fig. 2 should become Fig. 1.
- Page 3, line 2: “The bathymetry of the Arctic Ocean differs from that of the in other other oceans...”
- Page 3, line 25: is ‘laminar’ right?
- Page 4, line 2: table 3 does not come into order.
- Page 4, lines 11 and 12: “NEMO uses partial steps so that the model better matches the observed topography. Thus the depth of the deepest cell can be smaller than the original grid cell.” Could you develop or reformulate? It is hard to understand what it is meant here.
- Page 4, line 22: there is no mention of the Si:P and Fe:P ratios.
- Page 4, line 29: does sediment mobilization only intervene in the Fe cycle? Or does it also affect the other nutrients?
- Page 4, line 30: “... following the lead of Moore et al. (2004).”
- Page 5, line 33: “... simulations made in with the same circulation model...”
- Pages 5 and 6: the many occurrences of ‘ $x\text{CO}_2$ ’ should be changed into ‘ CO_2 ’.
- Page 6, equation (1): what are the units of $p\text{CO}_2$ and T?

- Page 6, line 25: “given that it is based on results from ORCA05.”
- Page 6, line 28: reference to Table 4 should appear here.
- Page 10, line 24: “apparent in ORCA025-~~6~~.”
- Page 12, line 22: “that ~~that~~ excess simulated CFC-12 between 1000 and 2000 m...”
- Tables do not come into order. Table 3 should become Table 1, Table 1 → 2, and Table 2 → 3.
- Table 1: the ‘b’ subscript does not appear anywhere in the table
- Table 2, caption: “Fitted parameters for the perturbation approach ~~for the tracers~~ starting in 1765 (P1765) and in 1870 (P1870).”
- Table 4: what do exactly represent the lines “Total transport” and “Summed lateral flux”?
- Table 4, caption: “Simulated values are calculated for the same time period as observations.”
- Fig. 1 and Fig. 2 should be inverted
- Fig. 10, caption:
 - The first sentence “Profiles of Ω_A ~~after the early industrial period period simulated only in ORCA05 (1870–1957), after intializing the other models in 1958.~~” is confusing. I suggest to remove most of it; it is not needed.
 - “Results are shown for ORCA05 in 1960 (black solid) as well as **for** ORCA2 (green dot-dash), ORCA05 (red dashes), and ORCA025 (blue dots) in 2012.”.