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Biogeosciences Discussions

Interactive comment on "Imminent ocean acidification projected with the NCAR global coupled carbon cycle-climate model" *by* M. Steinacher et al.

Anonymous Referee #1

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In this paper the evolution of ocean aragonite saturation levels over the 21^{st} century is examined for two CO_2 emission scenarios with the help of a coupled climate-carbon model. The authors present results not only at the global scale but also at the regional and seasonal scales. They offer a detailed analysis of the evolution in the Arctic Ocean. The consequences for ecosystems are also adressed. The model results lead to the conclusion that unless future CO_2 levels are drastically controlled a dramatic situation may develop in the oceans.

This work would be worth publishing once the points listed in the specific comments section hereafter are cleared.

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1 Specific comments

- Arctic publication. Three of the authors also co-author a submitted paper focussing on the Arctic Ocean. Though I do trust the authors that no duplicate material is used in the present work it would be good that similarities and differences between the two studies are explicited.

- Carbonate chemistry. There is no description of the method used for the computation of K'_{sp} and of the pressure dependency of chemical constants. Incidentally the appropriate reference for OCMIP routines is not Orr(2008).

  Another issue concerning carbonate chemistry is the way SiO_4 is treated. Silica intervenes in the expression of alkalinity but its role is not essential. Since the model does not include silica it would be better not to consider it (neither in the model-derived nor in the data-based formulations). By mixing the WOA01 SIO_4 climatology with model results the authors introduce more bias in their chemistry than they eliminate. The reasons are twofold. First any tracer distribution that would be coherent with the model hydrodynamics most probably differ from that provided by WOA01 (the correlation and relative standard deviation would be very different from 1). Second, considering that SIO_4 keeps its present-day distribution despite the profound changes that could occur throughout the 21st century is not appropriate. One could argue that the impact of the authors method on the actual values of chemical variables is small but this method is nevertheless not scientifically sound.

- The difference in distributions of $[CO_3^{2-}]$ and Ω_{arag} in the Taylor diagram (Fig. 2) is striking. I suppose this is a consequence of the model performances at reproducing the T and DIC (and may be S) fields. It would be worth investigating the reasons for such a difference. If available such an analysis would prove useful for model evaluation as well as provide indications of confidence levels in the predicted changes. For a better understanding similar plots for DIC, T

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and S should be provided. They would help the reader appreciate the model performances.

- Global evolution of pH and Ω_{arag}. Previous works (Orr et al., 2005,Cao et al., 2007, McNeil and Matear, 2007) conclude in a weaker effect of climate on pH than on Ω_{arag} by 2100 A.D. This is in contrast with the present study in which the impact on both pH and Ω_{arag} is of the same order of magnitude (page 4363, lines 26–28).

  On page 4370 the authors suggest that one possible explanation is that McNeil and Matear (2007) used a prescribed CO_2 concentration scenario rather than a CO_2 emission scenario. This is in contradition with the results of Cao et al. (2007). Indeed Cao et al. (2007) performed experiments with both constrained and prognostic atmospheric CO_2. In both cases the pH relative changes do remain smaller than the relative changes of Ω_{arag} (Table 1 in Cao et al. (2007)).

  I do not see any reason why an emission scenario rather than a concentration scenario would lead to different relative behavior in pH and Ω. The reason for the differences among the above-mentionned studies must lie in the ocean processes. One exploratory path could be to reproduce Fig. 6 from Mcneil and Matear (2007) with the present model results and look for differences.

- Changes in the Arctic (pages 4366 and 4367). The combination of model and data such as performed here implies that the model bias is and would remain linear. Isn't this assertion at odds with the non-linearity of the carbonate chemistry? I would surely not state as the authors do on page 4367 that "... the emerging undersaturation of the surface Arctic Ocean is a **robust** feature and **independent** of these model biases". Since the reasons for the bias are not clearly elucidated there are no reasons to believe that the evolution of the aragonite saturation would be that predicted by the model. The reasons for the model bias could result in non-homogeneous bias to occur with time.

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- Results presentation. A first remark is that the titles of subsubsections 3.3.1 and 3.3.2 contradict that of the parent subsection 3.3. Also subsubsection 3.3.2 is quite important in size and subject. It should deserve to be discussed in a subsection of its own.

  Further some global aspects discussed on page 4363 are again addressed at the end of section 3.3.2. Lines 7–20 on page 4370 should be gathered with lines 22–28 on page 4363.

  Some reorganization of section 3. would improve the readability of the manuscript. The discussion about the Arctic ocean should be separated and material from 3.3.1 and 3.3 should be merged with that in 3.2. I suggest something like this:

  3.1 Comparison of modeled aragonite saturation and CO3 concentration with observation-based estimates

  3.2 Projected global and regional changes

  3.3 Seasonal and interannual variability of Ω_{arag}

  3.4 Changes in the Arctic Ocean and climate feedbacks

2 Minor and technical comments

- Abstract, lines 11–12. I am in favour of reporting pH changes in pH units rather than in hydrogen ion concentration changes. pH units usually carry more meaning for the reader.

- Abstract, lines 15–16. I do not understand the sentence “Aragonite undersaturation in Arctic surface waters is projected to **occur locally soon** and to become more widespread as atmospheric CO2 continues to grow.”

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- Use of adjective "alkaline" (p. 4354, line 23 and p. 4356, line 17): in the everyday language the word alkaline is often used as a synonymous for base. I would recommend not to use this word in the present context mainly because it may confuse the reader and let her believe the authors refer to an alkalinity change rather than to a pH modification but also because of the fact that not all bases are alkali.
- p. 4356, line 9. Wouldn't fertility be more appropriate than fertilization?
- p. 4356, line 10. "... life stage**s**".
- p. 4357, line 8. "... biogenic production and dissolution of $CaCO_3$ **are** mainly controlled..."
- p. 4357, line 22. It is often written, as the authors do, that "*coccolithophores are a major contributor to the open-ocean carbonate pump*", but what is the actual percentage of the rain attributable to coccolithophores?
- p. 4359, line 15. Is the too extensive ice cover in NP and NA a cause or a consequence of the model shortcoming? As formulated the sentence implies the first!
- p. 4361, 1st paragraph. Couldn't this paragraph be reformulated in a more concise way?
- p. 4361, line 23. What is it meant by "*this specific section*"?
- p. 4361, lines 23–24. A more proper formulation would be "*..., the Artic Ocean is defined to be waters north of 65^{o}N, except ...*" (the basin index of CSM1.4 model is of no interest for the reader).

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- p. 4362, lines 14–15. There is an incoherency in the formulation: "**Surface** [CO_3^{2-}] is approximately proportional to the difference Alk–DIC. **Consequently**, the nutrient and carbon rich water of the North Pacific **thermocline** ... ".
- p. 4364, line 19. The years given here do not correspond to the values in Fig. 6.
- p. 4364, lines 22–23. "..., high latitude surface waters **poleward of about 50**^{o} are projected to be undersaturated **under** the A2 scenario".
- p. 4365, line 20. decades, not deceades.
- p. 4366, line 25. "... the model-only projection also show**s** ..."
- p. 4369, line 7. "**Considering** all fluxes, (Alk-DIC) ..."
- p. 4374, line 2. "**Our model predicts that water** with a saturation ..."
- p. 4374, line 4. "... and **will be** gone ..."
- p. 4374. Lines 14 to 19 should be reformulated. The meaning of the sentence referring to the time series station is not clear.
- Figure 4. Wouldn't it be possible to organize this figure so that pannels (a) to (d) would be wider? This would facilitate the reading.
- Figure 5. Could be suppressed.
- Figure 6. Pannel (b) of Fig. 6 is not really discussed in the text. I would suggest that pannel (a) be also drawn for scenario B1 in replacement of Fig. 5 and pannel (b) of Fig. 6.
- Figure 6. An explanation of the meaning of the dotted lines is missing in the caption.

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- Figure 7. The global average is dominated by the Pacific Ocean. I would suggest that four pannels be drawn : Atlantic, Pacific, Arctic and Southern Ocean.
- Figure 7. The caption says "... annual mean aragonite supersaturation ΔCO_3^{2-}"; shouldn't it be "... annual mean ΔCO_3^{2-}". Why not produce time-depth diagrams of Ω which is mostly discussed in the text rather than ΔCO_3^{2-}?
- Figure 8, caption line 6. " ... decrease to 25% and 70% **with respect to** the preindustrial values by 2100."
- Figure 12. Wouldn't it be possible to re-organize the figure into 2 rows (and 3 columns) rather than 3 for better readability?

Cao, L., Caldeira, K., and Jain, A. K.: Effects of carbon dioxide and climate change on ocean acidification and carbonate mineral saturation, Geophys. Res. Lett., 34, L05607, doi:10.1029/2006GL028605, 2007.

McNeil, B.I., and Matear, R.J.: Climate Change Feedbacks on Oceanic pH. Tellus, 59B, 191-198, 2007.

Orr, J. C., Fabry, V. J., Aumont, O., Bopp, L., Doney, S. C., Feely, R. A., Gnanadesikan, A., Gruber, N., Ishida, A., Joos, F., Key, R. M., Lindsay, K., Maier-Reimer, E., Matear, R., Monfray, P., Mouchet, A., Najjar, R. G., Plattner, G.-K., Rodgers, K. B., Sabine, C. L., Sarmiento, J. L., Schlitzer, R., Slater, R. D., Totterdell, I. J., Weirig, M. F., Yamanaka, Y., and Yool, A.: Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms, Nature, 437, 6818211;686, 2005.

Interactive comment on Biogeosciences Discuss., 5, 4353, 2008.