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Biogeosciences Discussions

Interactive comment on "Impacts of physical data assimilation on the Global Ocean Carbonate System" *by* L. Visinelli et al.

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Reply to Reviewer 2

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We thank the referee for the careful reading. Following his suggestions, we have modified our previous experimental set-up in the following way:

- We have better described the initialization methods for the model and tested different combination of spin-up procedures. Differently from the previous simulation, the model is now initialized with a 25-years spinup for the physics component only of the OBGCM.
- We used GLODAP initial conditions for the alkalinity.
- We added the $CaCO_3$ cycle and the shell formation/dissolution process in the biogeochemical component.

We have addressed the concerns reported below.

1 Specific comments

1. **All of the other efforts of which I am aware in which physical data assimila-**

tion has taken place alongside a biogeophysical model have experienced severe problems with spurious upwelling. A particularly good example of this problem, which used a similar model and assimilation scheme to your experiments, is shown in While *et al* (). This paper should be referenced in your work and shows upwelling of nutrients in the boundary currents which then diffuse into the gyres. I think it is likely that your runs have something similar occurring; indeed evidence can be found in your plots 8b and 8c where TSREAN has more DIC in the gyres than CTRL, particularly in the Pacific. As this is one of the key problems when assimilating physical data with biology you need to investigate the issue within your runs and comment upon it within the paper.

We are aware of the problem with spurious upwelling, which might be affecting our results as well. We followed the referee's suggestion and we discussed the problem also by referring to the paper suggested. The presence of the TSREAN upwelling in the region considered can be inferred from the plot in Fig. 1. Here, we plot the vertical velocity averaged over whole period of the run and over the region 120E÷160E, 20N÷50N, as reported also in Ref. (). From this figure it is clear that the assimilation of the physical data induces a vertical velocity whose absolute value is much higher than in the CTRL. Above 3000m the higher vertical velocities might be the cause of excessive upwelling of nutrients and DIC which are indeed overestimated in TSREAN.

In Subsection 5.1, we added the sentence "Results for the pCO2 worsen also in the middle of the north Atlantic gyre. This behavior might be related to a well-known problem occurring when performing data assimilation, which can give rise to a spurious upwelling especially in the boundary currents (While et al., 2010). The excessive upwelling is likely due to the fact that the assimilation tends to bring the model toward a state characterized by sharper gradients and that

Vertical_velocities_Kuroshio.pdf

Fig. 1. Averaged vertical velocity in the region for CTRL (blue) and TSREAN (red).

the coarse resolution used here cannot maintain. While et al. (2010) suggested that a consequence of the spurious upwelling is the advection of subsurface material to the surface where it is then diffused around the subtropical gyres.". In addition, in the Discussion Section we added the sentence "Because of data assimilation, there might be a problem with spurious upwelling especially in the Kuroshio western boundary current and in the upwelling regions of the eastern equatorial Pacific and Indian Ocean (While et al., 2010). There is evidence that this problem occurs in particular in the Pacific and Indian Oceans, as shown by the increase of both the absolute average and the error of the pCO2 in these regions.".

2. **a) Your description of the data assimilation system (section 2.3) is inadequate and lacking in important details. In particular, please address the following: The description of the EOF analysis is confusing. It is not clear weather the EOFs just describe correlations between different variables or include vertical correlations. Also you need to state how many EOFs you use and the percentage variance they explain.**

   In Section 2.3, we have added the following description of the EOFs, through which both vertical correlations and cross-correlation between temperature and salinity are modeled: "Thanks to the structure of the background error covariance matrix, vertical corrections are spread over both temperature and salinity by bivariate Empirical Orthogonal Functions (EOFs). This implies that, when only one of the two physical quantities is assimilated, vertical corrections apply to the other as well."

   For the percentage variance, we added the sentence "For the assimilation, we use ten EOF modes for each vertical profile, for which the explained variance averaged over the global oceanic region is 98.9%."

3. **b) If they are not included in the EOFs, then please provide details of the vertical correlations.**

   Vertical correlations are given by the EOFs. For clarity to the reader, we stated this in Section 2.3.

4. **c) Please provide more details of the inflation factor applied to the observation errors. A quantitive statement about the size of the inflation needs to be given, as well as details of the spatial variability – a figure may be useful here. d) The statement "rejects observations with a too large departure" is vague and not scientifically rigorous. Please provide a quantitative description of the quality control criteria.**

   We have discussed the rejection method at the end of Section 2.3, as "In more details, observations are rejected if the square of the misfits between the data and the model outcome is greater than the sum of the quadratic errors of the observation and of the background, times a user-defined constant of the order of ten."

5. **I am not convinced by the methodology used to compare model pCO$_2$ to the SOCAT data. As your model and SOCAT climatologies are of substantially different periods (1993-2010 and 1968-2007 respectively) therefore simply differencing them is scientifically dubious. A far better approach would be the compare the model and data directly and calculate the mean and standard deviations of the differences.**

   We have refined our computation by using the SOCAT monthly data over the period 1993-2010 in Ref. (). We have computed the absolute error and the RMSE between the monthly average of our model and the SOCAT dataset.

6. **In section 3 you describe calculating the RMS of the difference between observations and run TSREAN. Your description implies that you take the difference between the observations and the analysis; i.e. you compare against the observations after they have been assimilated. These observations are not independent of the assimilation and should not be used to assess skill. What you should give in the paper are the statistics of the ob-**

servations minus background; i.e. the statistics of the innovations. These sorts of statistics are commonly used in assessing the skill of assimilation systems While not as good as using genuinely independent data, using the innovation statistics is far more robust than using the observations minus analysis.

In the first version of the paper that we submitted, when performing the analysis we have already take into account the “observation minus background” (difference between the data and the model state before the correction) rather than the “observation minus analysis” (difference between the data and the model state after the correction), the latter being never used in our analysis. We stated this more clearly in the new version of the paper, in Sec. 2.6 when discussing the metrics.

7. **Your equations (4) imply: DpCO$_2$ = exp(θ DT) and DpCO$_2$ = DS (here I have used D for Delta); thus I cannot see how you get the expressions in equations (5).**

   We believe that Eq.4 is correct, since $d(\ln x) = dx/x$, from which our equations derive.

8. **Your argument between lines 20 and 25 on page 5414 seems to rely on the idea that alkalinity is not affected by physical transport, particularly vertical transport. However, this is not true and alkalinity is advected and mixed just like all other properties of seawater.**

   The reasoning behind our argument on Sec.4 relies on the fact that the better reconstruction of the temperature of the water column provided by the data assimilation is the reason why we do not see a spurious increase of ALK and water evaporation in the region. Although transport terms affect alkalinity, we do not observe a substantial difference between the two vertical velocities at BATS over the first 1000m, see Fig. 2. For this reason, we believe that the change in evap-

oration is the main cause for the difference of the trend in surface alkalinity at BATS between CTRL and TSREAN.

Fig. 2. Averaged vertical velocity at BATS for CTRL (blue) and TSREAN (red).

2 Technical corrections

We have addressed the various technical corrections requested in the new version of the paper.

References

J. While, K. Haines, and G. Smith, *A nutrient increment method for reducing bias in global biogeochemical models*, JGR; 115, C10036 (2010).

Bakker, D. C. E. *et al*, *An update to the Surface Ocean CO2 Atlas (SOCAT version 2)*, Earth System Science Data Discussions **6**, 465–512 (2013).