Response to referees
"Controls on the spatial distribution of oceanic $\delta^{13}C_{DIC}$" by P. B. Holden et al.

We are grateful for the constructive critisisms and suggestions of both referees. We will incorporate all of the suggested revisions in the re-submitted manuscript. Our responses are in red below with actions in bold.

Anonymous Referee #1

General comments

This study describes and evaluates an ensemble of simulations with the GENIE earth system model aimed at simulating the carbon cycle on timescales of thousands of years (glacial-interglacial cycles). It first evaluates the ensemble results during the pre-industrial period, and then studies the main processes governing the uncertainty in the distribution of DIC and d13C in the ocean both during the pre-industrial period and the recent industrial era.

The model simulates well the carbon cycle variables and the method demonstrates that different processes drive the uncertainty of the penetration of DIC and d13C in the ocean, which is important when compared to data.

This is a well presented and useful study, both to describe and evaluate the ensemble which will be used in the future, and to analyse the different processes governing the DIC and d13C penetration in the ocean. This last point could nonetheless be studied in slightly more details, to better explain why different processes explain most of the variance for DIC and d13C.

Specific comments

1. The study of the different main processes which explain the uncertainty in the DIC and d13C distribution in the ocean is very interesting, but the reasons why it is so should be discussed in more details.
We agree. **The revised manuscript will expand this discussion.**

2. Results during the pre-industrial: The variables are only given for the Atlantic (Figure 4), why not the Pacific as well? It would be good to have the results plotted for both basins and the comparison with data discussed.
The revised manuscript will include plots and discussion of the Pacific basin data.

3. As DIC is an important variable of the carbon cycle and discussed later in the manuscript, its distribution in the ocean should also be plotted, either in Figure 4, 5 or an additional figure. Alkalinity could also be plotted and its distribution discussed.
The revised manuscript will add plots and discussions for both DIC and alkalinity.

4. Figure 5: the observations for d13C should be plotted either on Figure 5 or another figure, it is not convenient to compare the results with other papers. Is there a reason not to include and discuss more recent data such as the GLODAP d13C data as well?
The revised manuscript will include plots and discussion of more recent d13C data.

Technical corrections

5. P.11857 (section 5.3), line 18: something is missing before "important here"

6. P. 11867 (section 8), line18: “Suess” instead of “Seuss”

7. References: there are a few errors at the beginning of the references: - Antonov et al., 2006: remove “Salinity” after “edited by:” - Bondeau et al., 2007: doi is written twice - Eby et al., 2012: doi is written twice, “and EMIC” should be “an EMIC”

8. Figures: The labels of the color bars on Figure 4 are too small, they should be bigger. They could also be made slightly bigger in Figures 3, 6 and 7. The x and y labels are also generally too small (Figures 3, 4, 5, 6 and 7), and sometimes missing. Although in some cases they are obvious, it can still be useful and in some cases they are necessary, such as in the latitude-depth plots. Finally, concerning the units, instead of mol/kg it would be easier to have micromol/kg and the units (permil) should be better specified in Figures 6 and 7.
We will make these corrections and improvements to the figures in the revised manuscript.

Anonymous Referee #2

This paper takes an interesting approach to mapping out the controls on the ocean carbon cycle. Rather than trying to produce a well-tuned model, and then test its sensitivity to environmental change, the sensitivity of the model to its tunable parameters is varied across a huge range that is simultaneously meant to represent environmental sensitivities. This approach has the drawback that many of the solutions are likely to be unreasonable, but the strength that it is less reliant on arbitrary tuning. (I say less, rather than completely unreliant, since both the choice of parameters to vary and their ranges remain arbitrary.)

I think this is a useful contribution, and worthy of publication. My comments are aimed at improving the paper.

General comments

- I find it a bit confusing that the paper initially states its motivation to study the glacial-interglacial change, but the conclusions are not presented in a way that bears on the glacial-interglacial change. I would suggest that the authors focus this paper just on the pre-industrial and industrial time periods, even if their ultimate motivation is to explore the glacial in future.
We agree that the relevance of the analysis to glacial-interglacial dynamics is not clear in the present version, however, the degree to which processes can be constrained (the level of uncertainty in input parameters and model structural error) is dependent on the problem and timescales of interest, therefore the context of large-amplitude climate variability is fundamental to the experimental design of the study. **This will be clarified in the revised manuscript.**

- The list of ’Parameters’ in 3.1 includes items that are not parameters under investigation. For example, CO2 solubility, Carbonate compensation, and Sea ice cover were not directly changed; they change as a result of other parameter changes. I find this confusing. I think it would be better to discuss only the actual parameter changes here, with a proper description of the parameters. For example, what exactly is the air-sea gas exchange parameter? Furthermore, the results are strongly dependent on the chosen range. Yet, little or no explanation is given for the choice of range for each parameter. I think the ensemble would

be much more useful if both the high and low values were justified, and an attempt made to select the ranges for different parameters based on the same logic.
We will reorganise this section to only discuss the varied parameters. We will then supplemement this discussion with a brief summary of how uncertainties in other processes are captured. We will discuss the parameterisations, especially those whose interpretation is less clear, and will justify our choices of ranges. These ranges were chosen with care and have, in general, been influenced by previous tuning exercises.

- I think it would be best to reserve use of the word 'uncertainty' for parameters that are uncertain in the modern world. Many of the ranges here are meant to span Quaternary climate variability, and as such, are significantly larger than modern uncertainties. Maybe it would be better to use a term like 'sensitivity range', rather than 'uncertainty', when discussing these.
We agree that it is essential to clearly identify the multiple different sources of potentially different appropriate values for input parameters in a study such as this, principally structural, measurement and parametric errors. **We will clarify these sources, and our terminology, more precisely in the revised manuscript**. We note that although many of the parameter ranges are wider than the uncertainty in observations, the rationale for varying them more widely is to allow for model structural errors, for instance associated with the low modeled resolution, the application of globally constant parameters, or with the form of the parameterisations.

- Finally, I feel that the paper comes very close to offering some valuable mechanistic insight on carbon uptake, by identifying the contrast between d13C EOF 1 and d13C EOF2 / DIC EOF 1. But it seems to stop short of carrying this on to provide deeper insight, in terms of what this means for physical mechanisms. For example, do the temperature-dependence of fractionation and the long equilibration timescale for isotopes dominate d13C, whereas the thermocline ventilation rates dominate the transfer of DIC into the interior?
We agree this would be very useful. **The revised manuscript will expand this discussion.**

Other specific comments
- p 11846, line 4: I am personally not a fan of the moniker EMIC, since it seems imprecise, and is actually applied to quite a heterogenous mix of models. I would prefer to see this phrased as something like 'an Earth system model of low resolution with a non-dynamical energy balance atmosphere'. However, this is just an opinion.
- p 11846, starting line 18: "The motivation. . ." is a run-on sentence. Please rephrase.
- p 11854, lines 1-3: The importance of the input parameter range is key, as nicely explained here, and should be highlighted elsewhere in the paper, including the introduction and conclusion. This has a large bearing on the interpretation of the emulator coefficients.
- In my experience, the terms PC and EOF are often conflated, which can lead to confusion. Perhaps the best way to describe their use here would be to include an equation of the SVD, explicitly stating which matrix/elements you refer to with each term.
- The Ridgwell and Death, 2012 reference is missing.
- It would be great to plot the d13C observations directly on the model output figures, as done by Tagliabue and Bopp (2008).
- p11866, line 5: This error seems too large - should it be +/- 0.014? the reviewer is correct, this should read +/- 0.014
- p11868, line 6: 'unsurprisingly'? Is it unsurprising that air-sea gas exchange does not contribute to uncertainy in the ocean carbon sink?
- Many of the figure labels are too small, and not legible. It would also be nice to include the emulator coefficitent names on figures 6 and 7, perhaps as a labeled axis beneath the colour

scale? At least, it would be helpful to draw vertical lines on the coefficient plots in order to separate the atmosphere, ocean, land and marine biogeochemistry parameters.

The revised manuscript will address these corrections. We will improve the description of SVD, including the equation and a description of terms. We agree this would be very useful.