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Interactive comment on "The mechanisms of North Atlantic CO_2 uptake in a large Earth System Model ensemble" *by* P. R. Halloran et al.

Anonymous Referee #1

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General comments: Halloran et al investigate the North Atlantic carbon sink and its response to increasing anthropogenic CO2 levels, addressing whether ocean carbon uptake in this region will continue with increasing atmospheric CO2 levels. This is an important question because a decline in ocean uptake of carbon from the atmosphere, as has been hypothesized here and in other regions such as the Southern Ocean, could have important consequences for future changes in climate.

Their analysis draws on an ensemble of runs with a state-of-the-art Earth System Model (ESM). Forced by large CO2 emissions, the ESM ensemble displays uptake of atmospheric CO2 by the ocean on a global scale between 1850 and 2100, with the magnitude decreasing somewhat towards the end of the simulation. In contrast, subpolar North Atlantic uptake peaks in the middle of the 21st century before declining to near zero uptake.

To investigate the causes of this behavior, due to the complex nature of the coupled system and the emergent character of the potential drivers of this CO2 flux variability, Halloran et al use a box model to “emulate” the larger system. Use of simplifying frameworks such as this is becoming increasingly necessary as the ESMs become more intricate, allowing specific processes of interest (in this case temperature, salinity, alkalinity, Atlantic overturning strength and atmospheric CO2) to be considered in isolation.

Temperature and alkalinity changes appear to drive short term CO2 fluxes, while long term changes are driven by atmospheric pCO2, alkalinity and temperature. The mid-century peak and then decline in the subpolar Atlantic (previously theoretically identified by one of the coauthors) results from gyre contrasts in CO2 buffering capacity: Increased uptake occurs in the subtropical gyre under increasing atmospheric CO2, due to high alkalinity. Northward transport of these anthropogenic carbon-enriched waters into the subpolar gyre, where alkalinity is low, exhausts the subpolar gyre’s capacity to hold carbon leading to a weakening (and potential reversal) of subpolar CO2 uptake from the atmosphere.

I think the study is well defined with care taken to ensure the box model emulator represents the ESM ensemble carbon fluxes. I also liked the cleanness of the process and the timescale separations. I recommend that this paper be published after addressing a few minor clarifications that I have detailed below:

Specific comments: I am still slightly confused about which “CO2 flux” is sometimes being discussed. Perhaps the authors would consider adopting the natural/anthropogenic/contemporary terminology in key places such as p14552, line 9 “we will explore subpolar North Atlantic CO2 uptake. . .” to be more specific?

I found the result of the absence of a role of the MOC variability in changes in carbon uptake intriguing (neither short- nor long-timescale filtering had any appreciable effect)

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especially as it has been implicated in recent observed subpolar North Atlantic CO2 uptake reduction (Perez et al 2013) and is central to the hypothesis for the peak and decline in subpolar North Atlantic CO2 fluxes as presented in Figure 9. Is this lack of sensitivity because the MOC in the ESM doesn't vary that much? Or is the importance reduced because only ∼30% (for case 1, Table 2) actually goes from the low latitude to the high latitude box (even less for case 2 where mixing from below appears more important)? I think perhaps plotting the other box model inputs from the ESM, as in Figure 10 would be useful for the reader.

Point 3 on p14557 about numerous idealized simulations suggests running the emulator with different CO2 power-law curves, but these experiments are not presented. Why not instead describe forcing the model with filtered input, which you actually do present?

Technical corrections: 1.) Typo: p14552, line 17 "Revelle" not "Ravelle" 2.) Figure 1 is never actually referred to. 3.) The abbreviation ESPPE is used on p14577, line 7 but not actually defined until p14558, line 4. 4.) Typo: p14560, line 24 "a time series vary around zero". 5.) Parameter names in Table 1 do not match those in Table 2. For example there is no "flux_north" in Table 2 but there is a "piston(Sp)", which I suppose is "subpolar", but this is not clarified. Similarly "a" and "b" in Table 1 are defined as 7/14 and 2/14 respectively, but then "alpha" and "beta" in Table 2 are given different values. 5.) I found the scatter plots (Figures 5b and 11b) with pastel coloring and transparent dots with dark outlines to be very difficult to read, largely because the color on the legend is not reflected on the plot where all the points are overlying. I appreciate that there is a lot of data on here, but the transparency really doesn't help the reader in this respect. These plots also are missing units.

Interactive comment on Biogeosciences Discuss., 11, 14551, 2014.

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