Controls on Early Cretaceous South Atlantic Ocean circulation and carbon burial - a climate model-proxy synthesis

Response to Reviewer #2

We thank reviewer #2 for their positive evaluation of our work and for providing very helpful suggestions for further improvement. Below we provide a point-by-point reply to all comments raised. Reviewer comments are in black, our response is in red font.

In their manuscript *Controls on Early Cretaceous South Atlantic Ocean circulation and carbon burial – a climate model-proxy synthesis'* by S. Steinig et al. used an ensemble of 36 coupled ocean-atmosphere simulations to evaluate South Atlantic Ocean circulation during the early Cretaceous. They setup the simulations in order to account for the uncertainty in basin configuration, regional seaways (Drake passage and Walvis ridge) and pCO2. To do so they account for all possible combination of forcing. They then carefully analyzed the contribution of each factor on oceanographic changes in the Southern Atlantic basin. In the last part of the paper, they integrate simulated scenarios with eNd data and sedimentological information to discuss evolution of Southern Ocean oceanography during the Barremian-Aptian.They notably highlight that paleogeography changes, happening at higher temporal resolution than those commonly investigated with paleo-climate modeling might have very strong impact locally, which would be reflected in the proxy.

I find the methodology very interesting. Those ensemble simulations, that are now accessible with classic ESM/GCM thanks to improved model performance seems to be one of the steps forward for deep time paleo-climate modeling, though they are not often used yet. The choice of boundary conditions and forcing are well justified in the text and relevant with regard to existing literature. The manuscript is overall super easy to read, and I appreciate the care that have been given to figures. I really enjoyed reading this paper and find remarkable that I am almost left with nothing to say. So congrats!

Thank you for the thorough summary and the positive feedback regarding the study design.

I only have minor comments:

- Authors analyze the dynamics of Southern Atlantic as isolated from the global circulation. I wonder whether the boundary conditions they implemented have also an impact of global circulation and whether global changes could affect the regional signal. For example, do the water masses transported through Drake Passage and entering the Southern Atlantic always have the same characteristics? Or does changes in source water characteristics might also impact the paleoceanography of the Southern Atlantic basin?

This has also been recommended by reviewer #1 and we agree with the usefulness of a description of the mean state and sensitivity of the global ocean circulation. In our simulations, we do find an important influence of the Drake Passage depth on the large-scale ocean circulation and the associated meridional heat transport. For this, we extended the simulations of three ensemble members with three different Drake Passage depths for a further 1500-2000 model years each to analyse changes in the global equilibrium circulation. Please see the new Supplementary Fig. 3 and description of the main results in our response to reviewer #1.

Figure 1 – 2 : It could be useful to have the location of basins indicated on the maps as well so it's easier to visualize. While it's not essential for understanding what the authors are writing it would help reader not always familiar with local geology structures to better understand.

We will add basin labels to Figure 1 to have a common reference for all basin and gateway names used throughout the study.

Figure 1 : Color distinction between sites 249 and 693 is not strong enough.

Agreed. The colour contrast between both sites will be increased.

Figure 2 : would be good to have a plot showing global time series for the sensitivity as well.

Yes, we will add this plot (Supplementary Fig. 1 in this document) to the Supplementary Material of the revised manuscript and present the results in Section 2.3. This plot now also includes the three extended spin-up integrations to test for deep ocean equilibrium mentioned above. It shows that the existing ensemble members are already near equilibrium – even in the deep ocean – as the temperature drift over the additional 1500-2000 model years of all extended simulations is below 0.3 °C at all levels.

Figure 4c-d : This one is a very minor suggestion but changing the color scale for c) and d) to a scale that have various shade of the same color (like white – light blue to dark blue for example) would help better emphasize where temperature/salinity are highly variable and where variability is small.

We agree that this would help to highlight areas of small/high variability and will update the colour scales accordingly.

L.185 – Note that the maxima in salinity and temperature are not strictly located at the same depth: one looks to be in the subsurface while the other is at the surface in the figure. Also *"the southern South Atlantic and the Angola Basin both show pronounced"* – do the authors mean Cape-Argentine basin instead of southern Atlantic ? Because this would make more sense in the sentence?

Yes, we will change this to "Cape-Argentine Basin" and remove the reference to a subsurface temperature maximum. The part will now read:
"As a result of the salinity-driven intermediate water formation, the Cape-Argentine and the Angola basins both show a pronounced subsurface maximum in salinity at depths between 200-600 m (Fig. 4b)."

L. 197-198 – authors should also refer to figure 5c in this sentence.

This figure reference will be added as suggested.

L.275 – *"somewhat surprising result is that the doubling of atmospheric CO2 does not only increase evaporation over the ocean but also reduces local precipitation, contradicting a simple dry gets drier, wet gets wetter paradigm."* This sounds that it is a general response while looking at figure S6 at first order region of E-P > (<) 0 have increased (decreased) E-P with CO2 doubling no matter if this is driven more by changes in precipitation or evaporation. I suggest that the authors reformulate this sentence.

Yes, the sentence indeed intended to highlight that the northern Angola Basin behaves differently than the zonal mean, as it switches from a precipitation to an evaporation-dominated region between the 600 ppm and 1200 ppm simulations. We will split this sentence into two to make this contrast clearer. The part will now read:
"*A somewhat surprising result is that the doubling of atmospheric CO2 does not only increase evaporation over the ocean but also reduces local precipitation over the most northern grid points of the Angola Basin, resulting in a switch from a previously precipitation to now evaporation-dominated*

region in response to a CO_2 doubling. This is different compared to the dry gets drier, wet gets wetter pattern simulated for most of the ocean surface (Supplementary Fig. S6)."

L337 - *Anagola Basin* --> Angola Basin ?

Yes, this will be changed.

L385 - Walvis Ridge Overflow Water – can you plot that on you maps/cross section to improve readability?

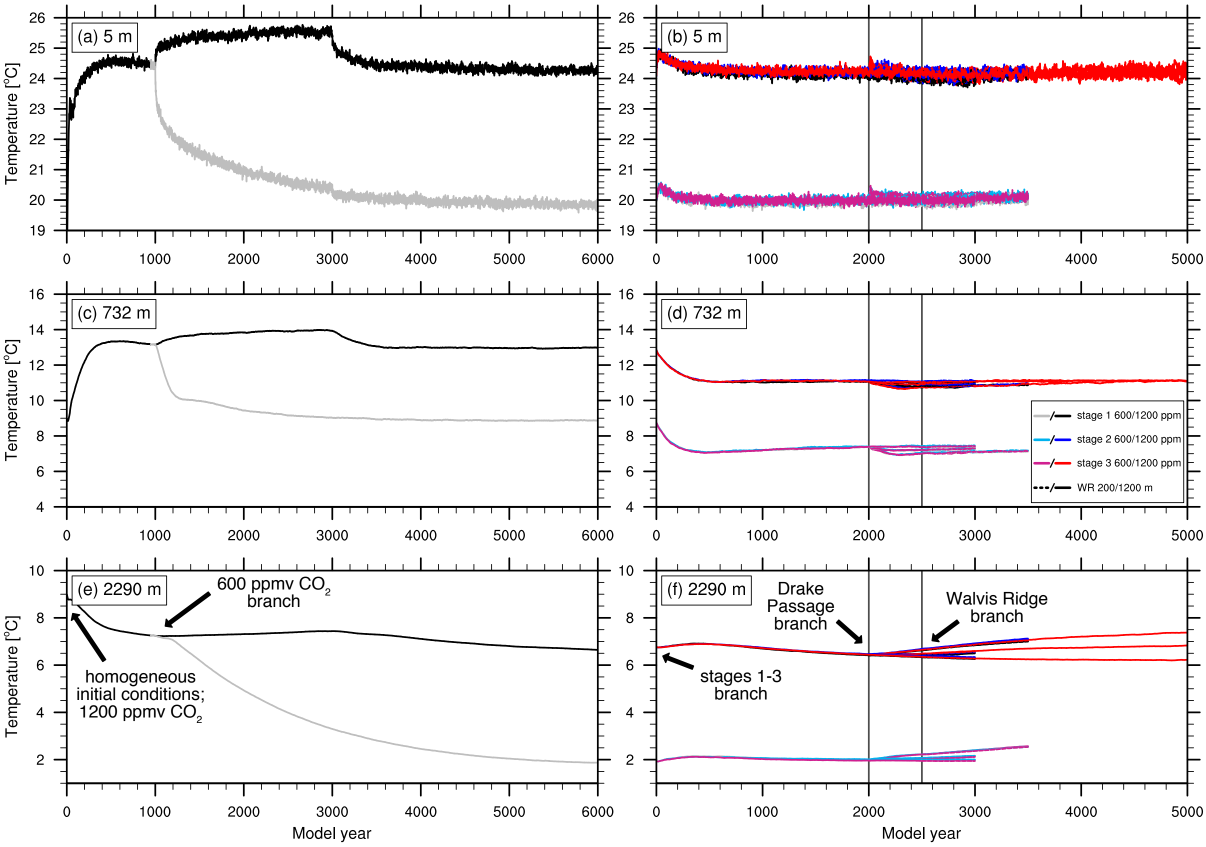
The label and an arrow will be added to the sections shown in Fig. 9.

Figure S1 : to a horizontal grid of 0.5◦ x 0.5◦ horizontal grid --> to a horizontal grid of 0.5◦ x 0.5◦ . Please also specified that this is the case for Perez-Diaz & Eagles, 2017 but that KCM plots are at model resolution.

The sentence will be changed to:
"Only the minimum and maximum reported water depths are shown for each stage. KCM bathymetries are shown on the native model grid, while the reconstructions have been re-gridded to a 0.5° x 0.5° horizontal grid.

Figure S6 vs Figure 10. Please chose between P-E or E+P notation.

We will remove this inconsistency by changing Supplementary Fig. S6 to show E-P fluxes as well.



Supplementary Figure 1: Time series of globally averaged annual mean ocean temperatures in °C at 5 m, 732 m and 2290 m water depth.