Response to referee 2

The manuscript addresses the question of the Eocene-Oligocene Southern Ocean and its sensitivity to wind stress strengthening and widening/deepening of the Tasmanian Gateway and Drake Passage in setting up an ACC. The paper is very interesting and provides a solid demonstration of the momentum balance at play through an analysis of the zonal momentum balance and its different terms. The results, subject to all possible limitations and caveats, are convincing. However, I found the paper poorly written, very long and repetitive at times. I have the impression the same message and results can be conveyed with perhaps half of the text, improved figures and a more structured discussion/summary.

We are grateful to the referee for their positive and helpful comments. We will address the proposed problems and strengthen our paper by improving its clarity and conciseness. Our response is given below in bold and italic.

Please find below a list of suggestions, questions and corrections.

L56 New and improved estimates could be used here: Koenig et al. (2014) estimated a full depth transport of 141 ± 2.7 Sv and Chidichimo et al. (2014) and Donohue et al. (2016) estimated a full depth transport of 173.3 ± 10.7 Sv.

Response: Thanks for suggesting these recent estimations. We will modify this sentence as "...the strongest ocean current, with a full depth transport of 137 ± 7 Sv (1 Sv=106 m3s-1) at DP (Meredith et al et al., 2011). It is further estimated with a full depth baroclinic transport of 127.7 ± 1.0 Sv (Chidichimo et al., 2014) and full depth total transport of 173.3 ± 10.7 Sv (Donohue et al., 2016).

L115 This is something that you could easily check and should be shown to test the regime change from subtropical gyre dominated to a proto-ACC: please add an analysis of the ocean heat trasport and its eddy contribution.

Response: We will add our analysis of meridional heat transport in the revised manuscript to show the sensitivity heat transport for mid-high latitudes due to the inception of proto-ACC. This will increase the length of our paper. However, we will work to ensure that this does not harm its clarity.

L154-155 Please rephrase, something is odd here.

Response: We will delete "remains unknown".

L240 Why do you use a model with no sea-ice? In understand and appreciate the idealized framework of a regional configuration but I don't see what is gained here by eliminating all possible feedbacks induced by sea-ice. Also, the model of Hutchinson et al, 2018 presumably uses sea-ice (CM2.1), so your surface restoring has that infomration.

Response: Around 38 Ma, the observed global SST was in the range of 25 to 19.5 °C (Bijl et al., 2009; Liu et al.,2009; Houben et al., 2019). The minimum SST of our simulations is around 11°C, which reflects the warm zonal-annual-mean conditions in Hutchinson et al.'s model. These warm surface temperatures remove the possibility of sea-ice in our model, and so we have not included a sea-ice component.

(Bijl, P.K., Schouten, S., Sluijs, A., Reichart, G.J., Zachos, J.C. and Brinkhuis, H., 2009. Early Palaeogene temperature evolution of the southwest Pacific Ocean. Nature, 461(7265), pp.776-779.

Liu, Z., Pagani, M., Zinniker, D., DeConto, R., Huber, M., Brinkhuis, H., Shah, S.R., Leckie, R.M. and Pearson, A., 2009. Global cooling during the Eocene-Oligocene climate transition. science, 323(5918), pp.1187-1190.

Houben, A.J., Bijl, P.K., Sluijs, A., Schouten, S. and Brinkhuis, H., 2019. Late Eocene Southern Ocean cooling and invigoration of circulation preconditioned Antarctica for full-scale glaciation. Geochemistry, Geophysics, Geosystems, 20(5), pp.2214-2234.)

L248 You use a relatively strong SST and SSS restoring of 10 days. How is that affecting your simulations and results when you try to initiate a thermal isolation of the Antarctic?

Response: Due to the strong feedback between SST and surface heat flux, 10 days is a fairly standard restoring time for SST in many applications. In contrast, for salinity there is only a weak feedback between SSS and evaporation/precipitation. As a result, this is quite a short timescale for salinity restoring. Our aim in using 10 days for both temperature and salinity was to ensure a good fit to Hutchinson et al.'s SST and SSS fields.

In general, a short restoring time scale in the model tends to lead to higher fluxes and acts to damp surface variance in temperature/salinity, as well as eddy kinetic energy. As shown by Zhai & Munday (2014), this also leads to a larger sensitivity to wind stress of the overturning, which is one reason why we have not examined the MOC in this paper. Zhai & Munday do not comment on the sensitivity of the circumpolar transport. However, examination of their figures indicates surface restoring makes the isopycnal slopes less sensitive to wind stress, which implies that the thermal wind transport is as well. In our case, the thermal wind transport is the majority of the zonal flow through TG and DP. Therefore, we can expect that the sensitivity we report is lower than might be achieved in a model that used a pure flux condition on temperature and salinity.

In our revision we will add a short discussion of the surface restoring to the Methods section, as a response to both reviewers. This will include a short version of the above discussion.

(Zhai, X. and D. R. Munday, (2014). Sensitivity of Southern Ocean overturning to wind stress changes: Role of surface restoring time scales, Ocean Modelling, 84, 12-25).

L281 I am not sure about a regional configuration, but a spin-up of 80 years and sensitivity experiments of 60 years seem a little short to me. It would be intersting to see time series of different metrics to show the circulation is stable and how it changes with the deepening of gateways and shifting of winds.

Response: The model was spun-up for 85 years by Sauermilch et al. (2021). After changing to our revised wind stress, we ran our experiments for an additional 60 years to adjust to the wind stress conditions. In terms of circumpolar transport, our simulations are well equilibrated. We will add the following figure of a time series of zonal transports to the Appendix of the revised paper. This shows a good degree of equilibration, according to this metric, for most of our experiments.

L284 Another point related to the model configuration: I am not sure what the actual shape of the zonal wind stress is. Is it a zonal mean and you simply shift it north and south? It is not clear form the text whether zonal wind stress is zonally dependent. Presumably that would matter in terms of alignments with the gateways and relative strength at the DP and TG.

Response: We apologise for the lack of clarity on the form of the wind stress. It is, indeed, a zonally-symmetric wind stress. It has been smoothed slightly, relative to Sauermilch et al. (2021), in order to make adjusting it to the north and south cleaner. We will make this point clearer during revision.

A non-zonally-symmetric wind stress would indeed raise interesting questions regarding the alignment with TG and DP. We will raise this point in our revised discussion, thank you for suggesting this idea.

L360 details of the discretization, also in L634, should go into the supplmentary information (Eq. 4 is already present). Also, Eq. S3 is missing the 1/\rho_0.

Response: Thanks for spotting the missing 1/rho_0. We will add more detail of the algorithm to the Appendices of the revised paper. The revised paper will read, at this point; "Following Masich et al. (2015), the zonally vertically integrated total zonal pressure gradient (or total topographic form stress) is discretised as per Eq (4). We extract the total topographic form stress from the zonally vertically integrated total zonal pressure gradient field. More detail on the calculation of topographic form

stress, and errors associated with the use of partial model cells, can be found in the Appendix section 1 and 2 and method section of Masich et al. (2015).”

L415 Fig.4 is really difficult to read with its present choice of coulours and arrows and should be improved. Consider a specific countour for the SST to highlight the change in temperature along the coast, and different/fewer arrows. Also perhaps less panels

Response: We will remove the arrows and add the suggested contour to improve the clarity of this figure.

L478 Eg. 5 is missing

Response: Thanks for spotting the missing equation, we will adjust the numbers appropriately.

Figure 7 This figure is also difficult to read. Consider adding to the same panel both the normal and doubled wind stress to highlight differences.

Response: Thank you for the idea on how to modify this figure. We will combine the panels as suggested and alter the number of lines so as to improve clarity.

L632 Eq. 5 is missing as well as section 2.5

Response: Thank you for spotting these errors. We will adjust the numbers appropriately.

L665 I really like your results but the Discussion section is difficult to read, repetitive and often not a 'Discussion' but rather a 'Summary'. Please improve your text to ease the read.

Response: Thank you for your positive opinion. We will work to improve the structure and flow of the Discussion. We will remove any repeated material and seek to improve its clarity.