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Ocean Science Discussions

Interactive comment on "The Atlantic's Freshwater Budget under Climate Change in the Community Earth System Model with Strongly Eddying Oceans" *by* André Jüling et al.

Anonymous Referee #2

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The manuscript "The Atlantic's Freshwater Budget under Climate Change in the Community Earth System Model with Strongly Eddying Oceans" by Jüling, Zhang, Castellana, von der Heydt, and Dijkstra provides a detailed analysis of the salt/freshwater budget of the (North) Atlantic and the role of mesoscale eddies in meridional transport and changes thereof under global warming. This is a very thorough study also validating the importance of explicitly resolving mesoscale eddies in global ocean/climate simulations and estimates of the bistability of the AMOC. The analysis and results are well embedder din existing literature and thus are an important contribution to the ongoing discussion on AMOC stability and eddy-resolving ocean simulations.

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I recommend publication of the manuscript after considering the following minor comments.

MINOR COMMENTS (by line):

Title: For most parts of the paper the discussion focusses on the salt/freshwater budget of the North Atlantic and only little analysis and information is provided for the South Atlantic and its import pathways through Drake passage and Agulhas leakage. I thus suggest to add “North” to the title: “The North Atlantic’s Freshwater . . .”

1f Please add specific ocean grid resolution information to the abstract: "We investigate the freshwater and salinity budget of the Atlantic and Arctic oceans in two configurations of the Community Earth System Model (CESM), one with a strongly eddying ocean on a 0.1ËŽ grid and one of coarser, non-eddying resolution (1.0ËŽ) typical of CMIP6 models.“

27 "salt-advection feedback“ should have a reference, e.g. Peltier and Vettoretti (2014)? [add. references provided below]

28f This sentence could use a reference as well, for example Behrens et al. (2013)

33f "17 Sv at 26.5ËŽN“ Is this based on observations, e.g. RAPID, or your model simulations? Please add reference, for RAPID: Smeed et al. (2016) or Smeed et al. (2018), the latter already used in the manuscript at a later point (line 423). Should be cited here as well.

37 "0.8 Sv of relatively fresh Pacific“ reference? For example Woodgate and Aargaard (2005)

39f "Freshwater is also exchanged with the Mediterranean Sea which is strongly evaporative.“ I would rather term this a salinity exchange, because Mediterranean outflow is very salty, i.e. the Atlantic provides "freshwater“, which is in this terminology somewhat awkward.

42 "... and advect salt meridionally when there is a zonal salinity gradient.“ In the same sentence it is said that the gyres are wind-driven. This part sounds like they are driven by a zonal salinity gradient. I suggest to rephrase this part: "... and advect any zonal salinity gradient also in meridional direction.“ In context with the previous sentence, this most importantly means that the salinity differences caused by precipitation patterns in the ITCZ are advected poleward by the gyres. Maybe this should be stressed more.

43 "under greenhouse gas increases“ rather is "under increasing greenhouse gas concentrations“

58-66 very nice, brief explanation of the impact of freshwater import from the south on the salt-advection feedback. However, in principle the AMOC does not import freshwater to the North Atlantic but rather negative salinity anomalies (in models often a virtual salt flux anyways, see line 105). Also, a note on the calculation of F_ovS would be helpful, i.e. the typical reference salinity and whether zonally averaged velocities are used (AMOC streamfunction) or actual transports in 3-D are computedâĂŤis there a standard in place already?

117 How does the difference in vertical ocean grid resolution (42 vs. 60 levels) affect overflows in the North Atlantic? In particular resolution at Denmark Strait has the potential to significantly affect the AMOC.

132 more precise: “Green lines in Figure 1b,c mark the bounding latitudes which . . .”

165 Meaning of this introductory sentence not quite clear. Circulation changes between models must affect much more than just Bering Strait exchange and Mediterranean outflow. Maybe simply drop this sentence? Or move to line 199.

174f please provide depth in meters (not km)!

174 The reference should more clearly point to Figure 3d for the northward extent of AAIW, which by the way seems not to reach 20ËŽNâĂŤmaybe 10ËŽNâĂŤas stated here, and Figure 3j for the low salinity signature of AAIW.

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176 Figure 3i shows a section at 34ËŽS and thus cannot serve as a reference for the addressed bias at 15-30ËŽN.

191 add “modelled” in “. . . this is the salinity of modelled North Atlantic . . .”

227 I assume brine rejection is counted as negative freshwater flux into the ocean; add parentheses: “. . . sea ice melt (and brine rejection) . . . defined as positive (negative) freshwater fluxes . . .”

244, 284ff and Appendix B: It is not quite clear to me whether your method of computing eddy transports accounts for eddy induced velocities from the GM parameterization, which I believe is used in the LOW model run. While it is quite obvious that the velocity field of LOW is much smoother than the one in HIGH (as you point out for Figures 5d and 5e), the unresolved eddy fluxes should partly be compensated by the eddy mixing scheme (GM as noted only later in line 289), which would provide eddy induced velocities. These should be included in the eddy transport discussed with Figure 7. In this respect, the comment on line 280f should be moved upward and included in the introduction to section 3.3. [I was a bit impatient when reading this page and would have preferred to read the discussion of lines 280ff earlier. However, when reading this page again, I now think the structure is OK only that a small comment in line 259 would help, such as “In the following we take a closer look at these two differences.”

248 Providing the year 2100 value of the linear trend seems a good way to limit the effect of internal variability in illustrating the changes under RCP scenario. However, it would be helpful to also note the correlation and significance of the linear trends in the text (or a table?) as a goodness-of-fit affirmation.

257 The obvious difference between the green CTRL lines (F_eddy) of HIGH and LOW runs should be pointed out first before discussing the deviations in trends, i.e. that LOW does not “exhibit the negative transport trend” at the SPG-STG boundary.

272 here or earlier: reference Yang et al. for shift in ocean gyres [see full reference

below]

275 It could be noted in addition to the present discussion that the differences between LOW and HIGH are not only due to resolving eddies but also due to a generally better representation of boundary currents (azonal flow system) in HIGH, which I assume is the case.

280f this statement should be made earlier (see comments on line 244 and App.B).

343 It would be helpful if you indicate the bar color you are referring to. For the 32% vs 18% increase I assume you mean the total, i.e. red bars. This is a very nice, detailed analysis. And I also like Figure 9 very much but it is somehow difficult to keep track of the bars (colors) each sentience refers to. Adding hints for the color would help to link text and figure.

345 If sea ice is one of the few bigger differences between HIGH and LOW worth noting, then please add this flux to Figure 9! A "(not shown)" is not very satisfying here.

363 I cannot see the advantage of presenting the spin up timeseries for this discussion. (see more comments on Figure 10)

391 one reference to Jüling et al 2020 is sufficient in this line. Also, this citation lacks a journal and DOI in the reference list. Is the paper accepted/published already?

Tables

Table 1 In addition to the start year of the RCP run, please provide the length of the CTRL run (spinup?). Otherwise it looks like the high-resolution model was only spun up for 200 years, which would be very short to study the AMOC. Did these runs branch off of any longer CESM spinup?

Table 2 I recommend to use sign + for transports into the Atlantic-Arctic basin. (I would think the Mediterranean provides a net (virtual) salt inflow to the system, i.e. +1.2 and -0.032.)

Figures

Figure 1: please use fewer colors for all plots to enhances visibility of actual differences.

Figure 5: the offset applied to the linear trend lines is not necessary, I think. Just use tone down the color a little bit, then it can be placed right in top of the smoothed timeseries without information loss.

Figure 7: thick and thin lines of CTRL and RCP are barely distinguishable. Please increase the difference in thickness or use dashed lines for RCP.

Figure 10: I depreciate the change in timescale. I think this gives a wrong impression on the trend under RCP w.r.t. the equilibration process. Also, I cannot grasp the purpose of showing the spinup period at all. Why do you not focus on the last 100 years in both cases? Further, I suggest to add labels for the regimes defined by the sign on the y-axis, e.g. on the righthand side y-axis.

Appendix B: Does the velocity v in your calculations for the LOW model include eddy induced velocity components from an eddy parameterization such as GM? I think this should be included for a fair comparison between LOW and HIGH. The salinity distribution will inherently include the effect of such parameterization but does v?

511: Why annual mean? Since you have mean(vS) from model output you can compute the eddy transport also on monthly basis and thus eliminate the effect of seasonal variability from you calculation.

Additional References

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