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Earth System Dynamics Discussions

Interactive comment on "Projected changes in the seasonal cycle of the Atlantic meridional heat transport in MPI-ESM" *by* Matthias Fischer et al.

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Reply to reviewer #1

We thank the reviewer for carefully reading the manuscript and for the constructive comments. Below, we reply to all comments (starting with a (*)).

The authors examine the Atlantic meridional heat transport in their model in the present day and in the future and attempt attribute the cause of the changes. The paper is well written and clear. There is a lot of good background and the work is good. Technically, it fits into the scope of ESD as heat transport is very much a climate variable, not just an ocean variable, and it fits into aims and scope (2) Earth System Change. That said, the sister journal Ocean Science would also be a good fit.

(*) Thanks – indeed, we did ponder both journals, but decided for ESD to reach beyond the oceanographic community.

I have two major issues that need addressing. Firstly, the shift in latitude of the seasonal cycle causes some shifts in time. This is not properly treated. I would suggest comparing the seasonal cycles of HISTmean and RCPmean shifted by five degrees to try to quantify this. See further comments below.

(*) Thanks. The figure is an interesting suggestion, yet, the shift in latitude is not so uniform that with its help we could quantify the shift in the seasonal cycle further.

Secondly, One of the main conclusions of the paper is that all changes to the seasonal cycle are explained by changes in the wind. Or at least that is the impression the reader gets. However, comparing Fig 8f with 6d although the wind explains most of what changes close to the equator, it does not have a magnitude large enough to explain what happens north of 30N. What is happening there? If there is a feedback that amplifies the signal or another contributing process this needs to be clearly written in the text, even if at this stage it is a little bit speculative.

(*) We carefully checked whether this notion appears in the abstract and added the following statement to the conclusions: "In the subpolar North Atlantic, we also find that the reduction of the North Atlantic Deep Water formation result in a weakened seasonal cycle with a weakened seasonal amplitude by the end of the 23rd century and thus changes the OHT seasonal cycle in the SPG." Also, see below, in response to your further comments, for additional places, where we changed this notion.

Title: projected for when?

(*) We changed the title to: 'Changes in the seasonal cycle of the Atlantic meridional heat transport in a RCP 8.5 climate projection in MPI-ESM'

Page 1 Line 6: "For the total OHT seasonal cycle," I do not understand what follows this statement. The last part of the abstract needs to be revised so that it is clearer.

(*) We revised the abstract and now mention the reference period: “We investigate changes in the seasonal cycle of the Atlantic Ocean meridional heat transport (OHT) in a climate projection experiment with the Max-Planck Institute Earth System Model (MPI-ESM) performed for the Coupled Model Intercomparison Project phase 5 (CMIP5). Specifically, we compare a RCP8.5 climate change scenario, covering the simulation period from 2005 to 2300, against a historical simulation, covering the simulation period from 1850 to 2005. In RCP8.5, the OHT declines in comparison to the historical simulation in the North Atlantic by 30-50\% by the end of the 23rd century. The decline in the OHT is accompanied by a change in the seasonal cycle of the total OHT and its components. We decompose the OHT into overturning and gyre component. For the OHT seasonal cycle, we find a northward shift of 5 degrees and latitude-dependent shifts between 1 and 6 months that are mainly associated with changes in the meridional velocity field. We find that the changes in the OHT seasonal cycle predominantly result from changes in the wind-driven surface circulation which projects onto the overturning component of the OHT in the tropical and subtropical North Atlantic. This leads in turn to latitude-dependent shifts between 1 and 6 months in the overturning component. In the subpolar North Atlantic, we find in RCP8.5 in comparison to the historical simulation, a reduction of the North Atlantic Deep Water formation and changes in the gyre heat transport result in a strongly weakened seasonal cycle with a weakened amplitude by the end of the 23rd century.”

Page 1 Line 11: What changes in the gyre? Don’t just say that it changes, say how it changes.

(*) We omit this statement in the abstract, since we could – within the constraints – not elaborate enough on the changes in the subpolar gyre (in addition to what is mentioned for the gyre heat transport before).

Page 2 Line 7: I don’t think it is correct to say that the storm track will move northwards in light of the results of Zappa et al (2013).

(*) We agree that the storm track response is more complex than a simple northward shift. We have therefore changed this sentence to read: "The atmospheric circulation patterns are projected to move poleward in concert with the warming of surface temperature, leading to a poleward expansion of the tropical cell and an associated poleward shift of the jet stream (Chang et al., 2012; Hu et al., 2013; IPCC, 2013), while the response of the storm track exhibits a more complex pattern (Zappa et al., 2013)."

Reference: Zappa, G., Shaffrey, L. C., Hodges, K. I., Sansom, P. G., Stephenson, D. B., Zappa, G., et al. (2013). A Multimodel Assessment of Future Projections of North Atlantic and European Extratropical Cyclones in the CMIP5 Climate Models*. Dx.Doi.org. http://doi.org/10.1175/JCLI-D-12-00573.1

Page 8 Line 11: "the equator the pole"?

(*) Corrected.

Page 8 Line 19: "can not be fully explained by the northward shift" - which features do you refer to here? The following sentence indicates that it is at the gyre boundaries, but then the sentence after that claims the changes there "result from the northward shift", which leaves the reader confused. The only region that cannot to first order be explained as a northward shift is north of 50N, but as the values are so small there this may not be a robust result.

(*) Reworded to explain that the seasonal cycle at a given place could be changed as a result from an overall northward shift, but this does not fully explain the entire shift.

Page 9 Line 25: You should point out to the reader here that the seasonal cycle is more than three times larger in amplitude in the subtropics than in the subpolar gyre, just in case they do not look at the axis labels.

(*) We included the following sentence in the figure caption: Please note the different vertical axes in c,d and g,h.

Page 10 Section 4.1.3: There are some references here to Fig 8, which I think are

meant to be Fig 9. Otherwise this paper has no references to Figure 9!

(*) Thanks. Corrected to figure 9.

Page 10 Lines 18-25: To my eye, the Figures show that the seasonal cycle of MHT between 30N-40N cannot be explained by the Ekman component. Figure 11 shows that NADW is changed at these latitudes, so could it be that this part is not wind driven but due entirely to the collapse of the AMOC? This is not acknowledged in this part of the text.

(*) We included a sentence: “Note that between 30N and 40N, the Ekman transport change alone cannot explain the changes in the seasonal cycle of the OHT, though these latitudes are strongly influenced by changes in the mean strength of the North Atlantic Deep Water (appendix A).”

Page 11 Line 35: Although it is difficult to separate global warming and AMOC slow down in surface temperature, their footprints in outgoing longwave and absorbed shortwave radiation are very distinct, making attribution possible (Dirfjhout, 2015)

(*) We included a sentense to cite this study: “This yields an overall increase in surface temperature in the North Atlantic sector, which maybe be possible to separate from an AMOC decrease due to their distinctive footprints in outgoing longwave and absorbed shortwave radiation (Drijfhout, 2015).”

Page 12 Conclusion 1: Some of the shift in time is due to the shift in latitude. The way this conclusion is written it could be interpreted to mean that they are separate.

(*) Changed to read: “Accompanied by a 30 to 50% decline of the time-mean OHT, the seasonal cycle of the OHT shifts in time (1 to 6 months, depending on latitude and season) and in space (5 degrees northward) in both the subtropical and subpolar gyre in RCP8.5.”

Page 12 Conclusion 4: Are the changes in the gyre heat transport seasonal cycle also due to wind-driven changes? It doesn’t appear so from Figures 8 and 9. So what is

causing it?

(*) Changes in the gyre component might result from changes in the wind as well, but are likely to be the results of zonally-varying changes in the wild variability. We reworded the conclusion: “Thus, the changes in the total OHT seasonal cycle in the subtropical gyre result mostly from the zonal-mean wind-driven and surface-intensified part of the overturning heat transport, whereas in the subpolar gyre, the changes in the seasonal cycle are dominated by the gyre heat transport.”

Fig 3 caption, last line: "(v)" should be "(b)"?

(*) Corrected.

Fig 6 (e,f): you could add another line from RCPmean, which is the seasonal cycle 5 degrees further North. This would back up your statement on page 8 saying that the approximate shift of the pattern is 5 degrees. Though if these panels (and the equivalent ones in Fig 8) are meant to characterise the subtropical and subpolar gyre, then perhaps an average over a range of latitudes in each gyre would be better? After all, you wouldn’t believe that the model can predict the climate change impact at one specific latitude, but you would be more confident that an average over most of the gyre is representative.

(*) Indeed, we would like to keep the individual lines as a mere illustration for what the seasonal cycle at an individual latitude looks like, since the actual changes are not only latitude dependent but their structure may be very model dependent. For the conclusions, we would therefore like the reader to focus on the overall picture, which is why we did not add another line into the subpanels.

Fig 8 (a-b): What is the point of the vertical profile of the boundary layer only? It would be much more informative to have the winds at say 925hPa with latitude on the y-axis and month on the x-axis as in the other plots in this figure (which would be less confusing as well)

(*) We included this figure with the vertical axis to be comparable to figure 3. We think it is important to be able to relate the discussion of figure 8 to the discussion of figure 3, and therefore use the same setup. The information of latitude vs months can be drawn from the other available figures.

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