

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

Matthias Fischer et al.

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Reply to reviewer #2

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

General Comment In this manuscript the authors analyse how the seasonal cycle of the ocean heat transport in the Atlantic is affected by future climate change conditions, and the mechanisms responsible for these changes. The meridional ocean heat transport is known to be a key variable to understand the climate of the North Atlantic region. Thus, this analysis addresses convincingly a relevant scientific topic, by providing a mechanistic understanding of the potential future changes in the region.

C1

Overall, I found the manuscript to be compelling and worthy of publication in Earth System Dynamics. The paper is well written and clear although there are some lingering points that need to be addressed.

I thus recommend acceptance pending a few revisions. Printer-friendly version My major concern relates to the way that some of the results are presented. Many of the figures show equivalent panels for the historical and the RCP simulations. And these are often discussed in terms of the differences. However, I find that the changes usually discussed are not so evident when one looks at the plots. For example, the temporal shifts commented in lines 27-28 of page are hardly discernible in Fig 8e-f. As I see it, it would be more illustrative for the reader to present the figures differently. Instead of the separate patterns for the historical and the RCP simulations, it is more helpful to show one of the two (e.g. the panel of the historical run, which represents a baseline configuration) and then additionally a panel on the differences (historical-RCP), like in Fig. 3c. The main advantage is that this will show directly the actual changes that you discuss later on.

(*) Thank you for this thoughtful comment. Prior to submission of the manuscript, we did test various ways of illustrating the results. The difference plots are an obvious candidate. Yet, for shifts in the seasonal cycle that occur on one or both axes, the differences plots are unfortunately not as clear as one would hope. After careful consideration (at that time and now again after your comment), we still decided to show the fields; which also makes clear that sometimes the differences happen to be small.

Another indirect benefit of showing the plots on the differences is that they allow including some statistical tests on the significance of the differences. These tests are actually key to identify which of the reported changes from the historical period to the climate change projections are actually significant, and which ones are probably due to climate noise. I strongly recommend the authors to include such tests on their plots.

(*) We agree. Yet, given the length of time series, and the focus on the physics, we

C2

decided to leave out a statistical analysis, whose assumptions would in the given case influence the result considerably. Following your comment, we did change the notion in the entire manuscript, focusing on the changes and their possible physical reasons.

Please, find a list of other specific comments below:

#1 [Page 1, lines 1-2]: As it is written, the authors seem to suggest that the changes in OHT's seasonal cycle appear in response to the overall OHT strength reduction. This is not exactly true. As I see it, both (the OHT strength weakening and the changes in its seasonal cycle) are simultaneously responding to the strong GHG forcing in the future projections.

(*) Thanks. We reworded the sentence to read: "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)."

#2 [Page 2, line 1]: Please, substitute "expected" by "predicted".

(*) Replaced by 'projected', since we anticipate to build on the present study with a multi-year prediction study.

#3 [Page 2, line 15]: It could be one cause or another, or both causes. So I suggest changing "or" to "and/or".

(*) Changed as suggested.

#4 [Page 2, line 34]: More than "to the ocean" in general they refer to "to internal ocean dynamics".

(*) Changed as suggested.

#5 [Page 3, line 10]: "Long-term variability" is too generic and depends on the length of the timeseries considered. The important thing to specify here is that they show decadal trends (which are an indicator of, at least, decadal variability in the overturning

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circulation and related OHT).

(*) Replaced 'long-term' with 'interannual', as the time series are just over a decade long.

#6 [Page 3, line 21]: I presume that you refer to the "meridional" overturning. Please, clarify in the text.

(*) Changed to 'meridional overturning circulation'.

#7 [Page 4, line 11]: Please, specify how this further increase is (Linear? Exponential?)

(*) Corrected to 'stabilized'.

#8 [Page 4, line 30; and other similar entries]: "zonal-mean zonal wind" is a bit confusing. I suggest "zonally-averaged zonal wind".

(*) While maybe sounding a bit cumbersome at first, "zonal-mean zonal wind" is a commonly used term in atmospheric dynamics. Examples are e.g.Ã

Barriopedro, D., & Calvo, N. (2014). On the Relationship between ENSO, Stratospheric Sudden Warmings, and Blocking. *Journal of Climate*, 27(12), 4704–4720. <http://doi.org/10.1175/JCLI-D-13-00770.1>

Birner, T., & Williams, P. D. (2008). Sudden stratospheric warmings as noise-induced transitions. *Journal of the Atmospheric Sciences*, 65(10), 3337–3343. <http://doi.org/10.1175/2008JAS2770.1>

#9 [Page 5, lines 2-4]: This sentence needs rephrasing. It is not to the NAO itself but to the zonal-wind pattern characteristic of a positive NAO that the shift in Fig 3b resembles. However, to support this claim, it would be good to include in Figure 3 an additional panel (Fig 3d?) showing simply the correlations between the NAO index and the zonally-averaged zonal winds. This result, to be confirmed, suggests also that the NAO is becoming more positive in the RCP runs. Have you checked if this is true?

C4

(*) Yes, the NAO is becoming more positive in the RCP simulation. However, correlating the changes in the wind pattern to the NAO is rather complicated due to the changes in the NAO pattern itself between pre-industrial control and RCP scenarios. Ning & Bradley (2016) find that the centers of the NAO loading patterns change considerably in the strong RCP scenarios, and the NAO pattern to project onto it therefore a "moving target". We have therefore rephrased the sentence to include this notion: "As a consequence, the westerlies between 30N and 60N are shifted poleward in RCP8.5 by about 5 degrees (Fig.3b,c). This shift resembles the wind pattern observed during a positive NAO anomaly (as defined from pre-industrial control, while the loading pattern may change considerably with climate change (Ning & Bradley, 2016)), which is associated with an acceleration of the westerlies over large areas of the SPG (Fig.3b,c), along with a deceleration of the westerlies between 30N - 40N and a slight intensification of the trade winds south of 30N."

Reference: Ning, L., & Bradley, R. S. (2016). NAO and PNA influences on winter temperature and precipitation over the eastern United States in CMIP5 GCMs. *Climate Dynamics*, 46(3-4), 1257–1276. <http://doi.org/10.1007/s00382-015-2643-9>

#10 [Page 5, lines 8-9]: You first say that there is "only a weak increase" in the gyre strength, and afterwards that this is "suggesting that changes in the deep circulation are important". Please, rephrase, as both things seem somehow contradictory.

(*) Reworded to bring out clearer that the flat bottom Sverdrup transport is only weakly increasing, hence not explaining the entire increase: "In particular, the flat-bottom Sverdrup transport in the subpolar gyre indicates only a weak increase of about 0.5 Sv in the gyre strength from HISTmean to RCPmean (not shown), suggesting that changes in the deep circulation might also be important (Grecthbach 1991)."

#11 [Page 6, lines 10-11]: Please, change to "The decomposition of . . . is well established by considering. . ."

(*) Changed as suggested.

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#12

(*) #12 was missing in the reviewer comment. Please let us know in case this was more than a formatting problem.

#13 [Page 7, line 13]: Please, change "shifted to the surface" to "becomes shallower" or "shoals".

(*) Changed to "is reduced in strength and becomes shallower".

#14 [Page 7, line 16]: Please, rewrite as "The AMOC in density. . . indicates a similar shoaling of the AMOC cell. . ."

(*) Changed as suggested.

#15 [Page 7, lines 17-18]: To guide the reader, I suggest to specify which are the levels involved in the wind-driven surface cell (~ upper 100m). Also, as opposed to this Ekman-driven cell, it would be good to mention that the deep cell mostly reflects the thermohaline circulation (as discussed in Kuhlbrodt et al 2007).

(*) Changed as suggested.

#16 [Page 8, line 11]: "from the Equator to the Pole".

(*) Corrected.

#17 [Page 8, line 15]: I suggest ending the sentence with "to thus highlight the seasonally varying changes."

(*) Thanks. Changed as suggested.

#18 [Page 8, lines 18-19]: It is not obvious to me how a northward shift can explain a temporal-shift.

(*) 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.

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#19 [Page 9, line 19]: Remove "during summer" to avoid repetition (as it appears also in the same sentence in line18).

(*) Removed as suggested.

#20 [Page 9, line 23 and Fig. 8g,h]: At first sight, the figure seems to suggest that the changes in the subpolar gyre are comparable to those in the subtropical gyre. Some readers might not notice that, indeed, the vertical axes are not the same in both panels. I suggest either to use the same scale in both cases, either to add something in the text like "please, notice that the vertical axes differ".

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

#21 [Page 9, lines 32-33]: The sentence is confusing. Please, rephrase.

(*) Reworded to: "Overall, the seasonal cycle of the Ekman heat transport changes depending on latitude, closely following the changes in the seasonal cycle of the surface wind."

#22 [Page 10, line 2]: Please, change to "similar than for".

(*) Corrected.

#23 [Page 10, line 3]: The first bracket for Fig. 8a,b is missing.

(*) Corrected.

#24 [Page 10, lines 3, 4, 9, 12]: I presume that you refer to Fig. 9 instead of Fig. 8.

(*) Thanks. Corrected.

#25 [Page 10, line 10]: "determines changes" with respect to what?

(*) Reworded to reflect that changes in the amplitude of the seasonal cycle of the overturning component result in changes in the amplitude of the seasonal cycle of the total OHT.

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#26 [Page 10, line 13 and other similar entries]: Please avoid the use of "significant" as this adjective is commonly used for statistical analyses (which have not been considered here). I propose alternatives like "notable" or "remarkable".

(*) Replaced here and elsewhere.

#27 [Page 10, line 25]: "Intermediate circulation" is not a term commonly used. I suggest upper mid-ocean circulation, or simply upper ocean circulation.

(*) Changed to "upper ocean".

#28 [Page 10, lines 30-32]: I don't follow. The two points made seem the same to me. Do you mean that the effect of the overturning dominates the intra-seasonal changes in the OHT, and also explains the differences in the OHT seasonal cycle from historical to RCP conditions? Please, clarify.

(*) We removed the first part of the sentence.

#29 [Page 10, line 33]: Please, change to "wind-driven via changes in the Ekman heat transport, which is mostly. . ."

(*) Changes as suggested.

#30 [Page 11, line 2]: "as well as with changes"

(*) Corrected.

#31 [Page 11, line 10]: "remains under discussion"

(*) Corrected.

#32 [Page 11, line 12]: "show a poleward expansion"

(*) Changed as suggested.

#33 [Page 11, line 18]: "and therefore in the associated"

(*) Changed as suggested.

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#34 [Page 12, line 5-6]: "Based on our analysis. . . we conclude for the Atlantic Ocean meridional heat transport that:"

(*) Changed as suggested.

#35 [Page 12, line 22]: "vertical integral" of what?

(*) Added: ". . .of the temperature and meridional velocity fields"

#36 [Page 13, line 1]: "with $_2$ being"

(*) Corrected.

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