

## ***Interactive comment on “North Atlantic deep water formation and AMOC in CMIP5 models” by Céline Heuzé***

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**This manuscript examines North Atlantic deep water formation and its association with AMOC in 23 CMIP5 climate models. Much variability is found in the location, timing and strength of deep water formation. For example, only 9 out of the 23 models show deep water formation in the Labrador Sea, and not out in the Subpolar Gyre. Even so, the conclusion is that the CMIP5 models have improved compared to the CMIP3 models.**

The author thanks Peter R. Gent for agreeing to review this manuscript. A response to each of his comments is provided below with the following structure:

- The reviewer's comment is repeated, with **bold** font;

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- The author's response is given in plain font;
- The corresponding changes to the manuscript are indicated in *italics*.

The role of the reviewers has been acknowledged at the end of the manuscript: *“The author would like to thank [ . . . ], as well as P.R. Gent and an anonymous reviewer, whose suggestions notably improved the quality of this manuscript.”*

**Figure 2 compares the mean mixed-layer depth versus density bias at two depths in the Subpolar Gyre and the GIN Seas, and no obvious relation is found. I think the MLD would be more related to the vertical density gradient, rather than the density itself. Too deep a MLD is probably related to too small a vertical density gradient in the deep ocean below about 1500m. Models that convect to the ocean bottom probably have very weak density gradients throughout the whole column.**

The author agrees with the reviewer. In fact, the stratification was one of the first processes tested for this study, but owing to the lack of across model correlation was not mentioned in the manuscript. This as an error; that has been rectified in the revised version. Since there is no across model relationship, and since the reviewer also suggested to add extra scatter plots for the salinity (see below), the author decided to not add a new figure with the scatter plots of stratification vs MLD to avoid making the manuscript too repetitive. Instead, following a suggestion from Reviewer 2, *the correlation between the MLD and the vertical density gradient for each model has been added to table 2*. These results are discussed in a new paragraph added to section 4.1:

*“Fourteen models out of 23 show a significant, logical relationship between the vertical density gradient and deep convection in the subpolar gyre, and thirteen in the GIN seas, but only nine in both regions (Table 2, grey cells). This relationship MLD - stratification does not correlate with the model MLD biases. For example, CCSM4 and CESM1-CAM have similar deep convection depth and area in the subpolar gyre (Fig. 1e and f), but only CCSM4 has a significant correlation between MLD and vertical*

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*density gradient.*"

**The mean temperature bias at the same locations is shown in Fig 3. I would like to see the mean salinity bias as well, because salinity is more important in setting the density when the temperature is this low.**

The reviewer is right that salinity is most important to set the density. *Figures 2 and 3 have been modified as follows in order to show the salinity biases:*

- Fig. 2 now shows the density, temperature and salinity biases in the subpolar gyre;
- Fig. 3 is the same as Fig. 2 but for the GIN seas.

*Section 5.1 has been rewritten accordingly (discussing SG first, for all parameters, and then GIN), and the following comments on the salinity biases have also been added:*

*"As was to be expected in a region where salinity dominates the density signal, the salinity biases resemble the density biases (Fig. 2e,f). As such, no relationship is found between the salinity and the MLD in the subpolar gyre.*

[...]

*A similar result is found for salinity biases in the GIN seas (Fig. 3e,f). There is no significant cross-model relationship between MLD and salinity biases, and the most extreme biases are encountered for similar MLD. FGOALS-g2, the saltiest, and CNRM-CM5, the freshest, both have a mean MLD of approximately 1000 m (Fig. 3e).*

[...]

*In fact, most models have a warm and salty bias in both seas (Figs. 2 and 3), but those compensate in density."*

**I would also like to see finer temporal resolution in Fig 4, as I'm unsure whether the warming is causing the MLD errors, or whether the MLD errors are causing the warming.**

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The author agrees with the reviewer. As the manuscript already states, a higher temporal resolution is needed to perform a proper causality study. Unfortunately, such output has not been archived for the ocean realm in CMIP5 models, hence monthly means are the best that can be used. As a result, no change has been made to the manuscript to address this point.

**The lag of 2 years between Subpolar Gyre convection and AMOC strength in Fig 5, and the fact that the Fram Strait heat flux is proportional to AMOC in Fig 6 have been documented before; please add some references.**

*References to Delworth et al. (1993), Menary et al. (2012), Lohmann et al. (2014) and Ba et al. (2014) have been added to section 5.2.*

**Probably the most useful comment for modelling groups is that they need to get the winter sea ice extent correct in order to get deep water formation in the right location. Are there any other helpful insights that the author can make to help the modelling groups?**

Reviewer 2 advanced the hypothesis that the different vertical mixing parameterisations used by the different models may be linked to the representation of polar mixed layers. Of particular interest was whether the new Fox-Kemper (2011) parameterisation would be associated with better mixed layers. No such result was found, but the following comments have been added to the manuscript:

*"Moreover, there is no apparent relationship between stratification, MLD, and the vertical mixing parameterisation. In particular, the parameterisation designed by Fox-Kemper et al. (2011) to improve the mixed layer representation (present in the models marked with a black bullet point, Table 2) do not perform consistently better than those with other parameterisations. This lack of relationship between MLD biases and vertical mixing parameterisation was already found by Huang et al. (2014) for the summer MLD."*

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**Minor Comments: Page 5, line 1; constrained.**

The typo has been corrected.

**Page 9, line 27: says 3 maxima, but only 2 lags are given on line 28.**

The typo has been corrected.

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