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Biogeosciences Discussions

Interactive comment on "Temporal variability of the anthropogenic CO_2storage in the Irminger Sea" *by* F. F. Pérez et al.

F. F. Pérez et al.

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lines 5-6: Please add a reference, a possible weakening of the MOC in the 21st century so far has not been detected in the observations without ambiguity, so you likely refer to one or several model studies.

You are right; this prediction is not free of ambiguity. We left this sentence quite open to such uncertainty, as this is a future projection based on current knowledge were direct measurements play a small role and models take up the lead. The text in the manuscript is as follows:

"... On the other hand, the long-term evolution of the MOC such as the ***possible*** *weakening during the 21st century might be related to a decrease in the density of the Denmark Straight Overflow Water (DSOW) and the Iceland-Scotland Overflow Water*

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Interactive Discussion
Discussion Paper

(ISOW) (Cubasch et al., 2001; IPCC report, 2007; Böning et al., 2006).”

lines 9-10: Reference ’Yashayaev et al. (2008)’ is listed as ’Yashayaev and Dickson’ in the reference section. But probably the authors refer to the different study of Yashayaev et al. (2008) which was published in the same book. This should be clarified, since the reference is used several times.

Done

line 16: Something like ’thickness of up to 2000m’ should be inserted to clarify this sentence. It should be noted that the penetration of convection down to depths of about 2000m is rather an exception and not the rule. Though Lazier et al. (2002) noticed the active convection of the early 1990s reaching down to 2000m, they did not relate this to the North Atlantic Oscillation index.

Done:

“. . . The LSW is formed in winter, when deep convection caused by intense air-sea heat loss results in the formation of homogeneous layers that can exceptionally reach depths of up to 2000 m (Kieke et al., 2006)”

line 19-20: Please, add some more information about the relationship between the strength/phase of the NAO and convection activity in the Labrador Sea, e.g. why a positive NAO-index supports/enhances deep convection. The reader might not be necessarily familiar with these issues. Also, please, add a reference.

Done:

“The convection activity in the Labrador Sea is related to the persistence and phase of the North Atlantic Oscillation (NAO) index. A positive NAO phase causes the intensification of winds and heat loss (surface cooling) in the Labrador Sea, fostering convection processes. During the early 1990’s, the strongly positive NAO index forced an impressive and exceptional convection activity down to more than 2000 m (Dickson et al., 1996; Lazier et al., 2002; Häkkinen et al. 2004; Yashayaev et al., 2007). This

BGD

5, S1991–S1999, 2008

resulted in the formation of the thickest layer of cLSW observed in the past 60 years (Curry et al., 1998).”

line 23: What is "weaker" in comparison to "strong" convection? Please provide numbers, e.g. convection depths.

Done (see above inserted paragraph).

lines 24-25: Azetsu-Scott et al. (2003) and Stramma et al. (2004) focused on that particular product of convection that emerged in the late 1990s. However, the existence of ULSW has already been discussed earlier by Pickart (1992) and Pickart et al. (1996, 1997). They observed uLSW to be formed in the DWBC region of the Labrador Sea.

Thank you. The text now is as follows:

“. . . Nonetheless, weaker convection events (to less than 1000 m depth on average) continued to take place in the central Labrador Sea and formed the less dense uLSW. This water mass had been first detected and described in the western side of the Labrador Sea by Pickart et al. (1997). Alternatively, the uLSW was spotted successively during the second half of the 1990’s (Azetsu-Scott et al., 2003; Stramma et al., 2004).”

line 28: The decadal time series of LSW layer thicknesses have been presented earlier by Kieke et al. (2006).

OK. Corrected.

page 1590

line 1: Please, explain CFC, since this is an abbreviation which should be introduced prior to using it.

Done.

lines 1-5: Figure 4 of Azetsu-Scott et al. (2003) does not really indicate a decline in the

BGD

5, S1991–S1999, 2008

CFC-12 concentrations of cLSW. Changes between the observed annual values from the period 1995-2000 appear to fall within the range of associated uncertainty. Kieke et al. (2007) presented CFC-12 inventories, which certainly declined. But in fact their inventory is a product of layer thickness and CFC-12 concentration, and changes in the layer thickness might be greater than changes in the CFC concentration.

OK. The text has been slightly modify to allow for this subtleness:

"...These time series show that the strong formation processes of cLSW in the early 1990's are actually the exceptional events. The observations point to a slight chlorofluorocarbon-12 (CFC12) concentration decline (within the analytical uncertainty range, though) towards the end of the decade in the cLSW body (Azetsu-Scott et al., 2003), following a strong CFC12 concentration increase that occurred in the early 1990s. This CFC12 decrease was also observed during the early 2000's in the Labrador and Irminger Seas (Kieke et al., 2007). The fluctuations of convection in the NASPG can modify the expected oceanic C_{ant} uptake rates in a likewise and parallel manner to CFCs."

line 7: 'seven' should be changed to 'six'

Done.

line 15: Please, mention the data source for the non-OVIDE sections.

Done.

line 16: Please, mention whether the cruise from 1991 also did include CRM data for CT measurements.

Done (it does not include CRM data).

lines 20-22: Tanhua et al. (2005) recommended to apply one single and constant off-set to all available TTO-NAS sections, and they provided an explanation. I would suggest to mention this here. Otherwise, the reader cannot easily infer, why your

BGD

5, S1991–S1999, 2008

Interactive Comment

approach, which is simply following the approach of Tanhua et al. (2005), seems to be appropriate. What precisely is 'approximately -3.0 μmol/kg'?

To our knowledge, there is no other approach than the one described in Tanhua et al., 2005. The sentence now is as follows:

"For the TTO-NAS, Tanhua et al. (2005) performed a cross-over analysis with an overlapping more recent cruise. Based on a comparison with modern Certified Reference Material-referenced data, they suggest a correction for TTO-NAS C_T measurements of -3.0 μmol·kg^{-1}, which has been applied to our dataset."

page 1591

line 1: It should be clearly stated whether figure 1b indicates one particular density field from one particular section or an averaged density distribution (Done. Fig. 1b has a text box now specifying that the displayed density field corresponds to the OVIDE 2004 cruise). In 1991, for example, the 27.68-isopycnal outcropped in the Irminger Sea. It would also be much helpful if the chosen isopycnals would be included in the respective subplots of figure 2 (DONE). Since the Vázques-Rodríguez et al. manuscript is not yet available, more details are necessary to understand the methodological approach. For example, what is the particular improvement in comparison to existent methods? The reader might not be too familiar at all with the method 'how to derive C_ant'. Furthermore, what is the rationale for assuming that choosing a subsurface layer at 100-200 m should avoid seasonal variability of surface properties? Like the Labrador Sea, also the Irminger Sea is assumed to be affected by oceanic convection, though at shallower levels. Therefore, also the chosen subsurface level might still be pertained to seasonal effects (Please refer to Appendix 1 for details on the $.\varphi C_T^o$ method, where all these issues have been clearly addressed).

lines 9-15: The error analysis could benefit from adding more details or any reference to the applied method.

BGD

5, S1991–S1999, 2008

Done (please, refer to Appendix 1).

line 17: Please, introduce the abbreviations O2_eq and O2_meas.

Done.

lines 17-21: This long sentence should be cut into smaller pieces.

Done.

line 20: Please add 'section' after 'TTO-NAS'. The authors discuss the stratification, but the density field is not included in figure 2.

Now they are included in Figure 2.

line 23-line 1, page 1592: The sentence starting with 'It must be reminded...' should be linked better to the sentences given before, so the implications becomes more clear.

Done.

page 1592:

line 3-4: Please, add reference Pickart et al. (2003).

Done.

line 6: Kieke et al. (2006) did not show data for 1991 from the Labrador Sea, but Azetsu-Scott et al. (2003) did, but the latter did not analyze time series of layer thickness. Please, verify this statement.

Figure 12 from Kieke et al, 2006 (included below) does show data spanning from 1948 to 2003. Specific reference to this figure is now made in the manuscript. Although there is no specific data point for 1991 (the closest seems to be 1990), the increasing layer thickness trend between 1990 and 1993 is undeniable and has one of the steepest rates of increase over the considered time range.

Kieke, D., et al., Changes in the CFC inventories and formation rates of Upper Labrador

BGD

5, S1991–S1999, 2008

Sea Water, 1997–2001, J. Phys. Oceanogr., 36, 64–86, 2006.

line 9: Yashayaev et al. (2008) already observed the temperature minimum one year earlier in 1996, but this cannot be resolved in the data set which is investigated by the present authors.

We agree. A mention to this fact is now given in the text.

lines 9-10: This sentence is unclear since the authors list average DSOW temperatures of +/- 1.72 degC in 1997 (Table 2). Please, also add the year of FOUREX cruise. The missing DSOW signature in 1997 seems to be an artifact resulting from using bottle data. Analyzing CTD data yields a pronounced DSOW layer with temperatures well below 2_C. Thus, the explanation for the "missing DSOW signature" given by the authors a few lines later seems not to be appropriate.

Done (this issue was already answered in the general comments section).

lines 14-16: Please, also note that Yashayaev and Dickson (2008, ASOF book) describe the spreading of a salinity maximum in the NEADW which has its origin near the overflow regions.

OK. Done.

lines 16-17: Kieke et al. (2006) have limited their analysis to the years 2003 and earlier, but the paper by Rhein et al. (2007, GRL) supports this view for the period 2003-2005.

OK. The reference has been updated.

lines 23-24: Please, clarify sentence.

Done:

". . . In 1981, there is a manifest stratification between the nearly oxygen-saturated subsurface waters and the older NEADW that is clearly identified from the AOU profiles. The relative AOU minimum at the bottom of the western part in the Irminger Basin

BGD

5, S1991–S1999, 2008

indicates the marked presence of DSOW."

line 24: 'West' should be changed to 'west'. What is precisely meant with 'west of the Irminger Basin' when the authors discuss a section from the Irminger Basin? It should be something like 'in the western part ...'.

Done. See sentence given right above.

line 29: Please, mention where deep convection does occur. Do the authors refer to the Irminger Sea?

Yes:

"During the first deep convection events in the Irminger Sea in the early 1990's there was a significant and parallel increase in the C_{ant} and oxygen loads in the upper 1500 m."

page 1593

line 3: Reference should be changed to Rhein et al. (2002, JPO) and/or Lazier et al. (2002, DSR-1).

Done.

line 9: Please, introduce the abbreviation CGFZ (OK. The acronym is also given in Fig. 1 caption). It is not necessarily the case that LSW and NEADW flow in opposite directions. L'Herminier et al. (2007) provided one snapshot. Another one from the same year was presented by Schott et al. (1999, GRL). These authors reported on a blocking event observed summer 1997, when the location of the North Atlantic Current above the CGFZ was responsible for eastward flow of LSW and blocking of westward flow of NEADW.

The "snapshot" provided in Lherminier et al., 2007 corresponds with the general circulation pattern in the North Atlantic shown in Schott et al., 2004 and in Yashayaev et al., 2008. In addition, the work by Bower et al., 2008 explains how the blocking of ISOW in

BGD

5, S1991–S1999, 2008

the CGFZ caused by the excursions of the NAC northwards have a 6% occurrence in time over a 13 year period in a time series of surface geostrophy observations.

The reference to Lherminier et al. work has been replaced by Yashayaev et al. 2008, and the work by Lherminier et al. is mentioned only to refer to the particular situation in 1997 (intense LSW transport).

Schott, F. A., R. Zantopp, L. Stramma, M. Dengler, J. Fischer, and M. Wibaux, Circulation and Deep-Water Export at theWestern Exit of the Subpolar North Atlantic, Journal of Physical Oceanography, 34, 817-843, 2004.

Bower, A.S. and von Appen W., Interanual variability in the pathways of the North Atlantic Currrent over the Mid-Atlantic ridge and the impacto f topography, *J. Phys. Oceanog..*, 30, 104-120, DOI: 10.1175/2007JPO3686.1, (2008).

Interactive comment on Biogeosciences Discuss., 5, 1587, 2008.