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Interactive comment on "Anthropogenic carbon distributions in the Atlantic Ocean: data-based estimates from the Arctic to the Antarctic" *by* M. Vázquez-Rodríguez et al.

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Interactive comment on “Anthropogenic carbon distributions in the Atlantic Ocean: data-based estimates from the Arctic to the Antarctic” by M. Vázquez-Rodríguez et al.

Anonymous Referee #2 Received and published: 24 May 2008

The manuscript of Vazquez-Rodriguez et al. compares different methods to reconstruct excess, anthropogenic carbon (Canth) using data from the Atlantic Ocean. The manuscript is timely as several different methods to reconstruct Canth have been published and these methods are increasingly applied. It is important to compare the different methods using the same input data to assess the uncertainties in the recon-

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struction of Canth in a systematic way.

I recommend the publication of the manuscript after the following comments have been taken into account.

A) In general, I believe that more details and figures are needed to provide a comprehensive overview of the agreement/disagreement among reconstructions. 1) I miss a formal statistical comparison among the different Canth data. In the climate and biogeochemical modeling community Taylor diagrams are frequently used to assess the agreement between two different data sets, e.g. observation versus model results. I suggest that the data sets are compared using statistics.

Thank you very much for this suggestion. We have found that the Taylor diagram would have been very useful for comparing the various Cant distributions if it was not because of: a) the fact that there is no reference field or method for Cant b) The dataset is not exactly the same for all methods, since there is no data available for the ΔC* method in the Nordic Seas, and this somewhat weakens the validity of a potential Taylor diagram. Instead, we decided to use the same set of three statistics used in Taylor diagrams and had them arranged in colour matrices displayed in the newly added Fig. 5. The corresponding text on this figure has been added to section 3 in the manuscript. This new figure supports previous results and adds a new perspective to them in a more quantitative way.

Nevertheless, we did take a look at a Taylor diagram we produced (included below) keeping in mind the caveats attached to it in our particular case. This was done using the data from all cruises available, meaning the ΔC* method does not have any estimate in the Nordic Seas. Since there is no observed reference Cant field against which others can be checked, we chose the TTD method as a reference to compare with the rest of carbon-based methods, which are conceptually based on very different principles. In addition, the TTD method is the only one, asides from ΔC*, that has Cant estimates available from the GLODAP data portal for the A16 (1993 –

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Oaces93) cruise, that we had to use to get ΔC* results for this region.

TO VIEW THE FIGURE PLEASE FOLLOW THE LINK:

http://www.iim.csic.es/˜mvazquez/Taylor.jpg

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Taylor diagram comparing the TTD and the carbon-based methods. The red dots represent each of the methods, namely: A=TTD; B=ϕCTž; C=TrOCA; D=CžIPSL ; E=ΔC*. Based on the Law of Cosines, this 2D-plot gathers information on three statistics of the Cant fields: standard deviation (σ; μmolůkg-1), correlation coefficient (R) and root mean square difference (RMSD; μmolůkg-1). The R and RMSD are computed with respect to the TTD. The x and y-axis give the σ values of the TTD and carbon-based methods, respectively. They have the same scale and σ must be read following the dashed black circle sectors, not orthogonally. The reference field (TTD) is always represented along the abscissa. The points representing the carbon-based methods are positioned such that the ratio γ = σC-based / σTTD is the radial distance from the origin, R is the cosine of the azimuthal angle (dotted blue lines) and RMSD (dashed green circle sectors) is the distance to point A=TTD. When the distance to point A is relatively short, good agreement is found between the carbon-based methods and the TTD. In the limit of perfect agreement (which is generally not achievable), RMSD would approach zero, and γ and R would approach unity.

In the broad view, the statistical similarity of the different carbon-based approaches with the TTD is quite remarkable and they are all close to each other. This did not add much to our discussion because the dataset is so large that a good correlation is generally expected.

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2) The discussion on vertical and horizontal gradients and how they differ should be improved. This is of relevance for both ocean inversion studies and for ocean model validation. One possibility may be to show averaged vertical profiles for different regions, e.g. those used in recent ocean inversion studies, and the top ˜1500 m. Another way to highlight agreement and disagreement among the reconstructions might be to present the difference in the distribution between an individual reconstruction and the average of all reconstructions in a figure similar to figure 1.

The new Fig. 4 includes the averaged Cant vertical profiles in the regions highlighted in Fig. 1b that are analyzed more in-detail throughout the manuscript, particularly through the length of subsections 3.1.x. They have provided more information on average penetration depths and local distributions, which adding to new Fig. 3 showing regional average Cant against pCFC12 has much improved the description and examination of results.

3) How do the surface values of Canth compare among reconstructions? It is suggested to complement figure 3 by an additional panel showing the Canth concentration for the surface ocean together with the Canth concentration in equilibrium with the atmospheric CO2 concentration.

We did this graph (shown below) but decided not to include it given the fact that surface Cant estimates from the various methods are not too reliable because they are subject to strong influence from biological and thermohaline variability. Also, calculating a theoretical surface saturation concentration for Cant is subject to many uncertainties, and this left the interpretation of the graph to be somewhat awkward. It must be noticed that the manuscript specifically avoids taking surface estimates for inventory calculations (point b) on first paragraph in section 3.2): “…b) No in situ surface Cant estimates were used at all so as to avoid the seasonal biogeochemical variability from surface layer data. Instead, values from the bottom limit of the winter mixed-layer were extended to 0 meter, so that Cant from surface waters is still being considered in inventory calculations (Lo Monaco et al., 2005b)…”

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TO VIEW THE FIGURE PLEASE FOLLOW THE LINK:

http://www.iim.csic.es/˜mvazquez/surface_Cant.JPG

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These are the average Cant estimates (μmolůkg-1) of the uppermost sampling levels selected in the present work calculated every 5ž intervals over the latitudinal extension of the cruises in Fig. 1a. The error bars stand for the standard error of the mean (śsigma/sqrt(N)). The shaded area from 33ž S to 55ž S indicates the region over which 300 m was used as the uppermost sampling level used, based on a WML bottom limit criteria. Elsewhere, this limit was set to 100 m depth. The theoretical saturation concentration of Cant for surface waters in equilibrium with the atmosphere at the moment of the cruise is plotted as a reference. The Cant_sat values were calculated considering the total alkalinity, the molar fraction of atmospheric CO2 in 1994 and the effects of salinity and temperature on solubility. The fact that the plotted Cant values are not exactly surface, but subsurface concentrations, partly explains the generalised undersaturation observed over the whole latitude range. The estimates here plotted tend to separate more from saturation towards the Polar and the Equatorial divergence regions. In the case of the high latitudes the ice-cap hindrance of the air-sea gas exchanges can be partly responsible for the deviation from surface saturation. In the Equatorial region the parting from the line of Cant saturation of all Cant estimates is mainly attributed to the upwelling of old waters (Fig. 1b), far from the state of equilibrium with the fast-growing high-CO2 present atmosphere.

Lo Monaco, C., C. Goyet, N. Metzl, A. Poisson, F. Touratier, Distribution and inventory of anthropogenic CO2 in the Southern Ocean: Comparison of three data-based methods, Journal of Geophysical Research, VOL. 110, C09S02, doi:10.1029/2004JC002571, 2005b.

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B) The role of seasonal and interannual variability in Canth reconstructions is not discussed. Perhaps a few words could be given on the uncertainty introduced by variability.

All the considered methods assume that the natural carbon cycle is at a steady state (end of second paragraph in section 2): “…They all make a steady-state assumption in terms of seasonal and interannual variability of the natural carbon cycle…”. Given this fact, we thought that including in the manuscript a discussion like the one here below about seasonal and interannual variability would deviate from focus.

Estimating the effects of seasonal variations in terms like oxygen or CT is a thorny issue as their compensating effects on Cant mainly through biological activity would be difficult to quantify empirically and would require subannual sampling in certain regions of the oceans in order to better constrain the natural variability in the system and to robustly estimate the intrusion of anthropogenic CO2 (Levine et al., 2008). In any event, the seasonal variability of these terms has its largest significance on the uppermost ocean layers. This study has used the Cant estimates in the bottom region of the winter mixed layers and extended them up to the surface to avoid such variability.

The interannual variability of water mass formation (WMF) rates and their physical-chemical conditions is largely affected by the North Atlantic Oscillation (NAO) phase changes (Kieke et al., 2007; Pérez et al., 2008). These shifts alter the air-sea CO2 fugacity gradient (ΔfCO2) (Schuster et al., 2007), which in turn makes the ΔCdis term change. The carbon-based methods assume a steady-state behaviour of the ΔfCO2 and general circulation, and formulate their parameterizations based on the data available at the time the methods are developed thus implying that parameterizations of preformed properties and/or the ΔCdis term are subject to some uncertainty. In the case of the TTD method, the interannual variability of WMF rates induced by NAO phase changes affects most importantly the assumption of constant mixing to advection ratio (∆/Г=1) in water mass outcrop regions.

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According to Steinfeldt et al., 2008 this ratio should tend towards values ∼0.5 in strong convection areas, where Cant uptake is largest. In regions far from surface and high-convection areas this effect would be barely inconsequential in the TTD approach, but it would still contribute to the overall ś5 μmolůkg-1 average uncertainty of the Cant reconstruction methods. In sum, the interannual variability affecting Cant estimates can be understood as the noisy signal that no current Cant reconstruction method can strive to model.

Kieke, D., M. Rhein, L. Stramma, W.M. Smethie, J.L. Bullister, D.A. LeBel, Changes in the pool of Labrador Sea Water in the subpolar North Atlantic, Geophysical Research Letters, vol. 34, L06605, doi:10.1029/2006GL028959, 2007.

Levine, N. M., S. C. Doney, R. Wanninkhof, K. Lindsay, and I. Y. Fung (2008), Impact of ocean carbon system variability on the detection of temporal increases in anthropogenic CO_2, J. Geophys. Res., 113, C03019, doi:10.1029/2007JC004153.

Pérez, F.F., M. Vázquez-Rodríguez, E. Louarn, X.A. Padín, H. Mercier and A.F. ríos, Temporal variability of the anthropogenic CO_2 storage in the Irminger Sea. Biogeosciences, in press, 2008.

Schuster, U., and A. J. Watson, A variable and decreasing sink for atmospheric CO_2 in the North Atlantic, J. Geophys. Res., 112, C11006, doi:10.1029/2006JC003941, 2007.

Steinfeldt, R., Rhein M., Bullister J.L. and Tanhua T., Inventory changes in anthropogenic carbon from 1997-2003 in the Atlantic Ocean between 20žS and 65žN. Global Biogeochemical Cycles, submitted, 2008.

C) Further comments 1) line 12 to 23 on page 1426 belong to the method section and should be moved. Done. It has moved to the first paragraph in section 2 (Methods). 2) line 15, p 1426: provide equation to describe how the temporal adjustment has been. Rather than an equation, it is a ratio, and it is now explained in the same paragraph that moved to the beginning of section 2:

“…The selected cruises correspond to different years and thus Cant results had to be referred to the common year 1994 (GLODAP canonical year) to eliminate biases introduced by the effect of increasing atmospheric fCO2. This was done using data from time series of CO2 molar fractions (xCO2) and calculating from here the ratio of Cant saturation concentrations for the year of the cruise and the preindustrial era. The correction typically varied between 1-7 μmolůkg-1 of Cant depending on the sampling year, the potential temperature and salinity of the samples.”.

Interactive comment on Biogeosciences Discuss., 5, 1421, 2008.

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