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Biogeosciences Discussions

Interactive comment on "An upgraded carbon-based method to estimate the anthropogenic fraction of dissolved CO_2 in the Atlantic Ocean" *by* M. Vázquez-Rodríguez et al.

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The present review does not add any new critics to those in the open comment from C. Sabine, which were timely addressed and have not generated any further discussion threads. The advancements presented in the manuscript are indeed significant and not difficult to identify. The main advancements are properly introduced in section 1, especially in the last paragraph (lines 7-13 on page 4530). Briefly, these are:

1. The subsurface layer (100–200 m) is taken as the only reference for characterising the properties of the water masses at their respective formation times. The variability of the conservative properties of greatest importance in Cant estimation (θ, S, NO, PO)

is at least one order of magnitude smaller than in the surface layer. In addition, the thermohaline variability of the surface layer encloses and represents all water masses outcropped in the Atlantic Ocean. The use of data from the subsurface layer reduces the sparseness of data available for parameterizations given the high amount of data for subsurface waters at any season compared to the scarce surface wintertime data.

2. The air-sea disequilibrium (ΔCdis) is parameterized at the subsurface layer first using a short-cut method to estimate Cant. Since the average age of the water masses in the 100–200m depth domain, and most importantly in outcropping regions, is under 25 years, the use of the short-cut method to estimate Cant in this particular case is justified and appropriate (not as for application to full isopycnals conformed by older waters) (Matear et al., 2003).

3. The AT° and ΔCdis parameterizations obtained from subsurface data using conservative tracers are applied directly to calculate Cant in the water column for waters above the 5 °C isotherm and via an OMP approach for waters with θ <5 °C. This approach especially improves the estimates in cold deep waters that are subject to strong and complex mixing processes and represent an enormous volume of the global ocean (86%, approx.). One important aspect of the obtained final equations is that, unlike for the ΔC* method, CFC data are not necessary to make Cant predictions, since none of the AT° or ΔCdis parameterizations are CFC-reliant. The AT° parameterization here obtained has an associated uncertainty two times lower than the classical ΔC* method, while the uncertainties for ΔCdis vary between 4 and 7μmol kg$-$1 (average 5.6 μmol kg$-$1). The overall uncertainty in Cant determination for the ÏŢCT° method is 5.2 μmol kg$-$1, compared to the 7.9 μmol kg$-$1 of the ΔC* reported in recent applications of the latter (Lee et al., 2003). This apparently minor reduction in the estimation uncertainty is quite remarkable taking into account that the analytical uncertainties in AT and CT are around 3 μmol kg$-$1. Most importantly, consistent ΔC* biases found in the high Atlantic latitudes (Southern Ocean and Nordic Seas) have been largely corrected.

4. The decrease of preindustrial AT° due to CaCO3 dissolution changes stemming from

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ocean acidification, as projected from models (Heinze, 2004), and the effect of rising sea surface temperatures on the parameterized AT° were corrected in our calculations. These two last corrections are minor and would be very difficult to quantify directly through measurements. However, they should still be considered if a maximum 4 μmol kg$-$1 bias (rather than error!) (2 μmol kg$-$1 on average) in Cant estimates wants to be avoided.

5. The approximation of the spatiotemporal variability of ΔCdis ($\Delta\Delta$Cdis) in the Atlantic Ocean is made in terms of Cant and ΔCdis itself.

The "real" purpose of the manuscript is stated clearly in the title, the abstract and the introductory section: we present an upgraded process-oriented biogeochemical approach based on carbon system measurements to estimate Cant (what's commonly known in the marine carbon science community as a "back-calculation" technique). Presenting a re-evaluation of the Atlantic Cant inventories is the logical thing to do so as to test how the upgraded method performs. The latter springs from the main goal (it is not "it"), and it is certainly an important application of Cant estimation techniques and a useful calculation to make. Since anthropogenic CO2 cannot be measured directly, the natural step to take to evaluate results is to compare them at different scales with previous estimates, and explain the differences from the assumptions and the methodology involved in each calculation method.

Updating Cant inventories as Lee et al. 2003 did using the ΔC*, for example, is beyond the scope of the manuscript. Rather, presenting this upgraded ÏŢCT° method places some caveats on such studies that re-evaluate the Cant inventory applying the classical ΔC*. The ÏŢCT° method gives an alternative to get rid of them, at least the most important ones (Southern Ocean and Nordic Seas results). In any case, the evolution of back-calculation methods is necessary although there might be "nothing new" about this philosophy. Doing things better is the way science has always kept moving forward. The better the processes involved in Cant uptake by the ocean are comprehended and parameterized (as our understanding and quality of data improve), the better the Cant

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estimates get.

An important strength of the upgraded method is that it resolves the Southern Ocean biases in the results of the ΔC^* approach. To date, no other back-calculation technique could reconcile its results with more recent Cant approaches, like the CFC-based TTD or the easy-to-apply TrOCA, and even then, discrepancies still exist (Vázquez-Rodríguez et al., 2009). The back-calculation methods have the advantage over the TTD or the TrOCA of incorporating methodological upgrades more easily because each term in the equations accounts for each of the processes affecting CT.

Modelling stochastic processes where fluid dynamics, mixing and massive interaction of chemical species combine together (such as in meteorological or ocean models) means that complexity and non-linearity need to be faced and dealt with. In models of natural phenomena like these, there is a close compromise between performance and complexity levels as more equations and terms keep on adding. The elegance and simplicity of results is highly valued and longed for by the scientific community, but unluckily a generalisation that is "elegantly precise" (like the classical physics laws) is rarely achieved in these cases. In my opinion, opposing a method based on its complexity is a very poor argument and somewhat unfair. The co-authors were all looking forward to more constructive, detailed critics of the manuscript that could turn out in effective improvements of the method, for which there is always room. The presented review is unproductive in these terms.

One of the strengths of the ÏŢCT$^\circ$ method calculation procedure is that it focuses on how surface properties are transmitted into the ocean interior. It does not rely on using single sets of isopycnal surfaces throughout entire ocean basins like in the ΔC^* approach or, like the TrOCA approach, applies a unique "globally" valid equation. The presented kind of upgrade yields better approximations to the problem both at local and basin-wide scales. All of the existing Cant estimation methods can be applied "safely" as their results converge to some extent on the grand scale. However, there will be advantages and inconveniences (ease of application, regional biasing of results...)

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that will ultimately make the choice of a particular method more appropriate than other, depending on the research objectives.

On the other side, the application of the ÏŢCT° method to the Pacific and Indian Oceans is an ongoing research, given the great potential of the method. The work is on an advanced stage and currently in progress. The global applicability of a method was never a requirement for any of the existing Cant calculation approaches when they were first published. The ΔC^* itself was applied to the three major ocean basins in different steps and, interestingly, their results for the Southern Ocean differ depending on which ocean basin the method is applied (there is no "continuity" in the concentration fields of Cant).

Since the publication in the Biogeosciences journal of the Cant intercomparison paper early this year (Vázquez-Rodríguez et al., 2009) many carbon scientists have asked for a paper that thoroughly described the ÏŢCT° method and included the equations and coefficients so as to be able to apply it in different Atlantic regions. The Vázquez-Rodríguez et al. (2009) paper gives only a very brief outline of the main features of the method, as you mention. It does not provide the details, equations or a focused discussion on the ÏŢCT° method, which we do in the present manuscript. This is just an added reason for the need to publish this manuscript, from which many chemical oceanographers and modellers will profit directly.

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Please also note the Supplement to this comment.

Interactive comment on Biogeosciences Discuss., 6, 4527, 2009.