Ocean Sci. Discuss.,
https://doi.org/10.5194/os-2020-37-AC1, 2020

Interactive comment on "Variability and stability of anthropogenic CO_2 in Antarctic Bottom Waters observed in the Indian sector of the Southern Ocean, 1978–2018" *by* Léo Mahieu et al.

Léo Mahieu et al.

leo.mahieu@live.fr

Received and published: 5 August 2020

General comments: This manuscript deals with temporal variations of anthropogenic CO2 in bottom waters in the Southern Ocean. The Southern Ocean is said to take up 40% of anthropogenic CO2 absorbed by the ocean. Thus, investigations of temporal variability of anthropogenic CO2 are very important to evaluate ocean's capacity of absorbing atmospheric CO2, information of which is indispensable for the projection of global warming. In terms of oceanic observation, the Southern Ocean is one of the regions, where the number of measurements, especially for chemical and biological properties, is scare. In this point also, it is worth of being published in the journal. The

manuscript is well organized, and is easy to read. The approaches used in the study are not new, but traditional ones. It is not a problem. It would be necessary to adopt an approach, which has been demonstrated to be useful for the detection of small signals of anthropogenic CO2 variations. The authors attempt also to relate the variations to those of AABW formation, although not clearly found. As a whole, it seems that the manuscript is worthy of publication in the journal, but after a moderate revision. A few major comments are stated in the followings, and the minor ones are stated in the specific comments.

Response: we are thankful for the quick answer provided by the reviewer. The concerns of the reviewer have been answered here after and have been valuable help to upgrade the manuscript.

In this paper, temporal variability of anthropogenic CO2 is examined using historical data collected at OISO. The data have been quality controlled by some data synthesis activities such as GLODAP. Nevertheless, I have a question on this point; the data syntheses have been done with a purpose of obtaining data consistency of a basin-scale. By contrast, the authors examine temporal variability of a local scale. In addition, data consistency is usually confirmed by data in deep layers of > 2000 m. This paper deals with data in deep layers. From these points, it is necessary to show that results obtained in the present study is not influenced by the data synthesis. Furthermore, for the recent data, quality control is made independently. Is there any possibility that the Cant stability is caused by the quality control? I recommend the authors to conduct quality-control on OISO data independently.

Response: The reviewer is correct. For most of the ocean basins, data consistency is generally based on data in deep layers (> 1500 or 2000 m). However, because in the Southern Ocean anthropogenic CO2 is also found at depth (> 3000 m), comparison is investigated in "old" deep waters, say around 2000-3000m (LCDW) where Cant (and DIC) should be relatively stable from one year to the next (within error of measurements, 1-3 μmol.kg-1). Following the reviewer's recommendation, we propose to add a figure in Supplement Material (Fig. S1) showing the consistency of our dataset at the two OISO stations where samples were collected down to the bottom, the OISO-ST11 presented in the manuscript and the OISO-ST17 sampled in the Subtropical Zone (30° S-66° E). This figure shows a limited number of measurements that are out of the range of tolerance, but one has to keep in mind that interannual (or multiannual) variations may occur and this calls for great care before applying an adjustment. Since 1987 (when the cruise INDIGO3 was performed), a shift in AT is suggested at high latitudes by the comparisons of INDIGO3 data (unadjusted, following the GLODAPv1 and CARINA recommendations) with other cruises data (adjusted, following the GLODAPv2 recommendations). This comparison shows differences that range between -4 μmol.kg-1 and +10 μmol.kg-1 (Fig. S2). Most of the crossovers that suggest a positive offset for INDIGO3 data (between +6 μmol.kg-1 and +10 μmol.kg-1) are found south of 60°S, suggesting that AT may have decreased in deep waters at high latitudes since 1987. This is why we first decided for no adjustment in the submitted manuscript (as in the GLODAPv1 and CARINA data products, whereas the INDIGO3 data in GLODAPv2 were corrected by -8 μmol.kg-1). However, at the OISO-ST11, AT data from the INDIGO3 cruise are also about 8 μmol.kg-1 higher than the mean value in deep waters (2000-3000m), in good agreement with the other crossovers at high latitudes. In order to reduce the potential bias that could result from either over-adjusting the data (GLODAPv2 recommendation) or not adjusting the data (GLODAPv1 and CARINA recommendations), and because most of the crossovers at mid-latitudes suggest a small positive offset, we propose to apply an intermediate adjustment of -4 μmol.kg-1 in the revised manuscript (the impact on Cant is +2 μmol.kg-1). The uncertainty regarding this adjustment will be discussed in Supplement Material. Fig. 3 (before Fig. 4) presenting the interannual variability of LAABW properties and Table 2 presenting the calculated trends will be adjusted correspondingly. Fig. S2 will be completed by the list of the cruises presented. Figure S1 also shows that the low AT values between late 1998 and 2004 are found both in the Antarctic zone and the Subtropical zone. This is surprising, but there are no reason to believe that the data are biased since CMRs

were used for all OISO cruises, and the instrument and data processing were the same during the first OISO cruise in January/February 1998 (showing AT values close to the mean in Fig. S1) and the following cruises.

In discussion, the authors attempt to relate variations of anthropogenic CO2 in AABW to changes in AABW formation region. It is well discussed, but information of water mass age of AABW is lacking. It is necessary to show that linkages between variations of AABW formation region and observed AABW signals at OISO are appropriate in terms of water mass age. O2 and AOU are used simultaneously. I think, it is enough for one of which, probably AOU.

Response: we are sorry that there is no measurement related to water mass age in the available data (I.e. no CFCs measured during OISO cruises), other than O2 which is too sensitive to biological activity to be used as a water mass age tracer. We agree that the mention of both O2 and AOU is unnecessary. This is a point also noticed by Reviewer 2. Because we are most discussing the O2 concentration in the manuscript, we suggest to only present O2 in Figure 3.

Specific comments:

Line 18: “from about +7 μmol kg-1”, increase from what?

Response: We guess that what confused the two referees is the positive sign. We will delete the positive sign and rephrase as follows: ‘from the average concentration of 7 μmol.kg-1 calculated for the period 1978-1987 to the averaged concentration of 13 μmol.kg-1 in the period 2010-2018.’

Line 20: “CT”, this is the first appearance in the abstract. Write it in full.

Response: this will be added.

Line 23: “ðİIJČ, S”, they are the first appearance in the abstract. Write them in full.

Response: this will be added.

Lines 90-91: “station 430”, depth?

Response: the depth (4710 m) will be added.

Line 91: “405 km and 465 km”, away from where?

Response: These are the distance away from the OISO-ST11 sampling site. This will be rephrased as “located near the OISO-ST11 sampling site (405 km and 465 km away from it, respectively)”

Line 109: “the PET sector”, is it usually used? I do not understand where it is.

Response: A short sentence will be added to the text, as well as the references mentioned here after to clarify the use of this name. The PET, Princess Elizabeth Though, is also referred as the Balleny Though in Orsi et al. (1999), even if more currently mentioned as PET. It corresponds to the ocean section separating the Kerguelen Plateau from the Antarctic continent. Its deepest point is 3750 m, deep enough to allow AABWs to flow between the Australian Antarctic Basin and the Enderby Basin (Heywood et al., 1999). The work of Heywood et al. (1999; Fig. 1) revealed that in the northern part of the PET the AABW flow from west to east, while in the southern part the flow is from east to west.

Line 150: “AT”, Probably this is the first appearance. Spell out here.

Response: this will be added.

Line 160: “ðİIJČ and S”, spell out here. ′

Response: this will be added.

Lines 163-165: according the description, it seems that the figures are not accuracy but repeatability.

Response: The referee is correct. The accuracy is given by the analysis of CRMs. This will be corrected.

Line 236: “January”, which year. In this paper, all the data are analyzed assuming that seasonal variations in deep waters are negligible (lines 154-156). It is not appropriate to refer to months.

Response: the authors agree with the reviewer. This will be adjusted by mentioning the early and late 1998 sampling.

Line 276: “underlying”, do you mean a water mass below AABW?

Response: this is a mistake, we meant overlying the AABW (referring to LCDW). This will be corrected by using ‘LCDW’ instead.

Interactive comment on Ocean Sci. Discuss., https://doi.org/10.5194/os-2020-37, 2020.

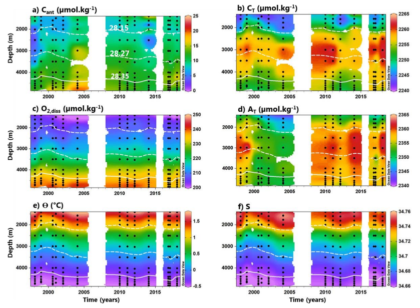

Figure 2. Hovmöller section of (a) Cant via TrOCA, (b) CT, (c) O2, (d) AT, (e) θ and (f) S based on the OISO data presented in Table 1. Data points are represented by the black dots. The white isolines represent the water masses separation by γn (from the bottom: LAABW, UAABW and LCDW). Figure produced with ODV (Schlitzer et al., 2019).

Fig. 1. Figure 2. Hovmoller section

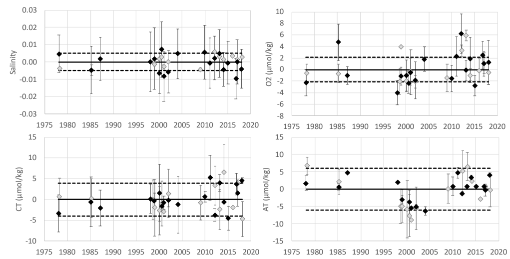

Figure S1. Mean differences observed in deep waters (O_2 minimum) between the measurements obtained during one cruise and the mean value calculated over the full period at the two sites where samples were collected down to the bottom: the OISO-ST11 in the Antarctic Zone (56.5° S-63° E, station investigated in this study, in black) and the OISO station 17 in the Subtropical Zone (30° S-66° E, in gray). The dashed lines indicate the limits for considering an adjustment (as defined in the CARINA and GLODAP syntheses). The data plotted here are adjusted as recommended in the GLODAPv2 synthesis, except for A_T in 1987 (INDIGO3 cruise) that was adjusted by -4 µmol.kg^{-1}.

Fig. 2. Figure S1. Quality control of the bottom OISO measurements

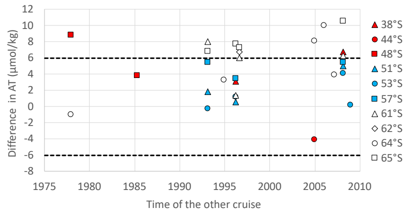

Figure S2. Difference in A_T found in deep waters at crossovers with the INDIGO3 cruise (INDIGO3 - the other cruise). Data are adjusted as recommended in the GLODAPv2 synthesis except for the INDIGO3 cruise for which A_T was not adjusted.

Fig. 3. Figure S2. Crossovers of the INDIGO3 AT measurements