

Authors Response Reviewer 1 - The Macquarie Island [LoFlo2G] high-precision continuous atmospheric carbon dioxide record

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We would like to thank the reviewer for their comments. Below we have provided a response to each comment along with any subsequent changes to the manuscript. The original review is in italics and our responses are in normal font.

The article by Stavert et al is submitted to Atmospheric Measurement Techniques (AMT). It describes retrieved CO₂ measurements with a LoFlo2 instrument from Macquarie Island, a site in the Southern Ocean and the importance of this unique dataset.

The paper gives a detailed description about the site at Macquarie Island, measurement collection routines and limitations, the instrument setup, calibration and uncertainty analysis, definition of the baseline record as well as a general climatology of the dataset.

Main comments:

- 1. It's probably too late now, but I would suggest that this is not so much a "technique" paper as a "data" paper, and ESSD(D) might have been a better target journal.*

As noted by the reviewer this paper does present a large volume of information in relation to the Macquarie Island dataset and as such, could be considered a "data paper". However, we feel that the description of the LoFlo instrument along with the novel baseline assessment method and the method development work conducted to define the data uncertainty estimate are significant "technique" developments and of interest to the AMT readership. Although previous reports and manuals related to the LoFlo have been published, this is the only description available in peer-reviewed literature.

- 2. I would highlight the importance of these measurements even more in the introduction, and the potential 'gaps' these measurements could fill with references about studies that focused on the importance of Southern Ocean CO₂ measurements and their application.*

The introduction has been changed to include the below.

“However, better quantification is limited by the temporal and spatial availability of observations (both ocean CO₂ and atmospheric CO₂) across the Southern Ocean region.

For ocean pCO₂, techniques exist to extrapolate and map temporally and spatially sparse measurements but these approaches are limited. Recent work (Ritter et al., 2017) found that while often agreeing on the sign of broad scale decadal trends these methods fail to agree on the magnitude, mean values, interannual variability and regional distribution. Atmospheric CO₂ measurements can be used to estimate ocean fluxes through an inversion methodology, with the potential advantage that they sample the impact of fluxes over a wider region than would be achieved with oceanic pCO₂ measurements. However, most atmospheric measurements from this region are flask samples and previous work (Law et al., 2008) has shown that the Southern Ocean flux trends calculated by inversions are sensitive to atmospheric CO₂ data quality. Lenton et al. (2013) also noted that when observational data were sparse, CO₂ inversion results were highly sensitive to data quality and the number of regions used in the inversion. As such the addition of a new in situ data record, like that outlined in this paper, should significantly improve future attempts to quantify the Southern Ocean CO₂ sink.”

3. *If it is not too time consuming a paragraph about general error propagation (with reference) and adding the difference between those and your measurement uncertainty method would be useful. More emphasis on the filtering techniques would lean the paper back towards AMT appropriate.*

The introduction of the uncertainty section has been altered significantly to encompass this suggestion, see new text below.

“Measurement uncertainty is typically composed of multiple elements and evaluated using a combination of a statistical analysis of replicate measurements (Type A) or based on an alternate source of information (Type B) (Klausen et al., 2016). The individual Type A and Type B components are then combined, usually in quadrature, to determine the overall measurement uncertainty. An example of this model can be found in Andrews et al. (2014) who evaluate in detail the uncertainty associated with tall tower GHG measurements.

It is particularly important to characterise the measurement uncertainty of the MQA record given the small atmospheric signals at mid-high latitudes in the Southern Hemisphere. An earlier study documents the significant impact of measurement errors and biases of LoFlo, conventional NDIR and flask measurements on CO₂ growth rate estimation at Cape Grim, another key Southern Hemisphere site (Francey et al., 2010). Here, following the approach discussed earlier, we aim to quantify the measurement uncertainty of the MQA CO₂ observations by examining each of five possible sources of error. We will examine how these errors contribute to the uncertainty of hourly and minutely mean values and combine them to determine estimates of the overall measurement uncertainty.”

For clarity we have also changed the section heading from “Error propagation” to “Uncertainty analysis”.

4. *A few sections in the results could be simplified (e.g. the discussion of using minutely S.D. to filter out local influences). A careful reading to condense some of the text would be useful.*

Agreed. Sec 5.1 and 5.2 have been modified to try and simplify the text. Other smaller changes have been made to remove unnecessary detail.

5. *In terms of the uncertainties (e.g. Type 4) have you tested using the interquartile range (or the 25th and 75th percentile) as the measure of uncertainty instead of the 1 sigma, and also maybe to weight the fitting based on the uncertainty? This is more a comment and I am not suggesting to re-calculate everything but it would be interesting (maybe in some future measurement uncertainty quantification work) to see how much those changes would affect the results.*

Using the interquartile range rather than the standard deviation as an estimate of the spread and hence the uncertainty in our measurements is indeed an interesting suggestion. However a preliminary investigation did not find a significant difference between uncertainties calculated using the interquartile range and the standard deviation. We have not looked at weighting the fit and thank the reviewer for the suggestion but considering the size of the within hour variability we do not expect that this will have a large effect on the resulting fit.

General comments

A number of abbreviations are not defined the first time they are mentioned (e.g. MQA in abstract and throughout the text, CSIRO in the introduction, WMO). Also you jump from writing the full term to abbreviations often, it would be better to have some consistency, either use the full term of the abbreviation.

We have altered the manuscript so that abbreviations are defined the first time they are mentioned and are used more consistently. For MQA, we now introduce this later in the manuscript, specifically noting that this is the station site code for Macquarie Island within the Global Atmosphere Watch regional network. For this reason we mostly restrict our usage of MQA to those parts of the text that relate to the CO₂ records at Macquarie Island, while using ‘Macquarie Island’ in full when discussing the island more generally.

Page 2 line 12 However, efforts... → is there some additional reference for this sentence/statement?

This sentence has been altered and an additional paragraph, see below, included in the introduction.

“However, better quantification is limited by the temporal and spatial availability of observations (both ocean CO₂ and atmospheric CO₂) across the Southern Ocean region.

For ocean pCO₂, techniques exist to extrapolate and map temporally and spatially sparse measurements but these approaches are limited. Recent work (Ritter et al., 2017) found that while often agreeing on the sign of broad scale decadal trends these methods fail to agree on the magnitude, mean values, interannual variability and regional distribution. Atmospheric CO₂ measurements can be used to estimate ocean fluxes through an inversion methodology, with the potential advantage that they sample the impact of fluxes over a wider region than would be achieved with oceanic pCO₂ measurements. However, most atmospheric measurements from this region are flask samples and previous work (Law et al., 2008) has shown that the Southern Ocean flux trends calculated by inversions are sensitive to atmospheric CO₂ data quality. Lenton et al. (2013) also noted that when observational data were sparse, CO₂ inversion results were highly sensitive to data quality and the number of regions used in the inversion. As such the addition of a new in situ data record, like that outlined in this paper, should significantly improve future attempts to quantify the Southern Ocean CO₂ sink.”

Page 2 line 16 subantarctic zone and polar front zone → are there any studies that explore how this affects the measurements?

As this is the first time this data record has been released there are no studies which explore the effects of its location relative to the subantarctic and polar front zone. As far as the authors know there are also no papers examining this relationship for the co-located flask record. However, as the reviewer notes this is an interesting topic which we hope to explore in future work.

Technical Comments

Page 2 line 7 → The Southern Ocean abbreviation (SO) is unnecessary, it is only used in the introduction.

As suggested, we have removed this abbreviation.

Page 3 line 5-6 north-south and south east → consistency, do you need a dash or not?
We have made these consistent (using a dash in each case).

Page 13 line 1 'the figure' → specify again which figure
The figure number (6b) has been added

Page 14 line 15 criterion . → remove the space before the dot
The space has been removed.

Page 14 line 16 Standard deviation (SD) → you used the standard deviation before in the text so define the abbreviation before.

The abbreviation has been moved earlier in the text and used from that point on.

Page 16 line 11 Thoning et al. → missing year

This has been added

Figure 3, could the right axis (standard deviation) be coloured to blue? Do the flask samples come with some uncertainty that could be added to the plot?

The suggested changes have been made and the figure caption updated.

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