

Interactive comment on “Inter-annual variability of the carbon dioxide oceanic sink south of Tasmania” by A. V. Borges et al.

A. V. Borges et al.

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Reply to Referee #1

Referee comment : General Comments This study is one of the first to investigate inter-annual variability of air-sea CO_2 fluxes from the Southern Ocean using in situ observations of pCO_2 . The manuscript is very well written and I recommend its publication, provided the following issues are addressed.

Reply : We thank the reviewer for her/his encouraging comments and useful suggestions.

Referee comment : Major Comments (1) There is some confusion throughout the paper regarding the timescales of variability that the authors are

investigating. The title indicates that the major findings relate to inter-annual variability, but there is quite a bit of discussion about higher-frequency variations (seasonal time scale) and low-frequency variations (trends in the time series). Often times, discussions about variability on more than one time scale are grouped into the same paragraph (sometimes the same sentence). I would recommend that the authors work to establish more clearly the timescale of interest to them.

Reply : We clarified the timescales of interest by modifying the text according to the reviewer's comments (hereafter). Our initial aim was to examine the data-set at different time-scales. This was reflected in the structure of results/discussion in different sections that went from high- to low-frequency variations. We now have clearly stated this in text. The paper starts by an analysis of the seasonal cycle (since there are few similar analyses in the Southern Ocean and this is of interest in itself). We go on to analyse inter-annual variability. We use the conclusions of our inter-annual variability to speculate how the system could change on the long-term with projected warming of surface waters.

Referee comment : (2) It seems as though the authors are attempting to explain the inter-annual variations in SST, pCO_2 , and air-sea CO_2 flux by inter-annual variations in the SAM itself, but more could be done to support this idea. Only one time series is shown in the paper (Figure 10), and I think the reader would benefit from seeing the time series of SST, pCO_2 , and air-sea CO_2 flux anomalies (once the seasonal cycle is removed) in the various regions alongside a time series of the SAM index.

Reply : We added a figure showing the SAM index and seasonally detrended SST, wind speed, pCO_2 and air-sea CO_2 fluxes for the 1982-2005 period. No distinct long

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term trend in the SAM index is apparent at this time scale. However, this figure shows a nice anti-correlation of SST and wind speed. This highlighting that inter-annual variability in wind speed (and related mixing) induces the inter-annual variability in SST, and will have an impact on inter-annual variability of pCO_2 in surface waters (through inter-annual variability of inputs of DIC). This figure also shows a general (but not perfect) covariance of wind speed (and SST) and SAM index.

Referee comment : Minor Comments

(1) 3640, line 4 - Mention that this data is being used primarily to investigate interannual variability

Reply : The following sentence has been added to the abstract : “Climatological seasonal cycles of pCO_2 in the CS, the subtropical zone (STZ) and the subAntarctic zone (SAZ) are described and used to determine monthly pCO_2 anomalies. These are used in combination with monthly anomalies of sea surface temperature (SST) to investigate of SST and pCO_2 ”

Referee comment : (2) 3640, line 9 - Seasonality (winter-time input) is mixed into the discussion, which does not necessarily provide an explanation for inter-annual variations.

Reply : Our hypothesis is that the winter-time input of DIC allows to explain the inter-annual variability of pCO_2 .

Referee comment : (3) 3640, line 12 - “the observed trend” is this a discussion of long-term trends in the sink in atmospheric CO_2 , or simply a pattern of inter-annual variability?

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Reply : It is a pattern of inter-annual variability. “trend” was replaced by “pattern”

Referee comment : (4) 3641, line 3 - reference Inoue and Ishii should be in parenthesis

Reply : We agree. This was a modification introduced during the ms production stage by Biogeosciences.

Referee comment : (5) 3643, equation 1 - change subscript pCO_2 sea199i and pCO_2 air199i to pCO_2 seayear and pCO_2 airyear, to account for data for entire time series (1991 - 2003).

Reply : Indeed. Text was changed accordingly.

Referee comment : (6) 3644, line 12 - “using the algorithms of C”, unnecessary text

Reply : We agree. This was a modification introduced during the ms production stage by Biogeosciences

Referee comment : (7) 3644, line 16 - “trends”, word choice clarification, please change to “patterns”

Reply : Indeed. Text was changed accordingly.

Referee comment : (8) 3645, line 12 - “consistent” should read “consistent with”

Reply : Indeed. Text was changed accordingly.

Referee comment : (9) 3646, line 1 - word choice, “trends” should be changed to “patterns”

Reply : Indeed. Text was changed accordingly.

Referee comment : (10) 3646, line 4 - word choice, “trends” should be changed to “patterns”

Reply : Indeed. Text was changed accordingly.

Referee comment : (11) 3646, line 21 - “an increase in the SAM” should read “a change in the SAM”

Reply : Indeed. Text was changed accordingly.

Referee comment : (12) 3646, line 23 - “The increased SAM” should read “An increase in the SAM”

Reply : Indeed. Text was changed accordingly.

Referee comment : (13) 3647, line 2 - Add here that these in situ data support this theory (do they?), and draw the readers attention to a figure showing SST time series and SAM time series (as mentioned in major comment #2)

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Reply : Additional text and figure were added.

Referee comment : (14) 3647, lines 21-23 - This sentence is unclear, as the SAM itself has a relatively weak seasonal cycle. Perhaps it should be written, “These regions respond to the SAM differently in different seasons ”?

Reply : Sentence was rephrased as follows : “Inter-annual variability in physical forcing related to SAM could also explain different slopes between $pCO_2@14C$ anomalies and SST anomalies observed during spring-summer and fall-winter periods (Fig. 5, 10).”

Referee comment : (15) 3649, line 7 - Begin this paragraph with a clearer explanation of your methodology. As I understand it: “We lengthen the oceanic pCO_2 time series to include the years 1982 to 2005 using the Reynolds SST data and our previously established relationships between observed SST and pCO_2 from 1991-2003.”

Reply : Sentence was rephrased as follows : “In order to examine the relationship of SST anomalies to inter-annual variations of air-sea CO_2 fluxes, we lengthen the oceanic pCO_2 time series to include the years 1982 to 2005 using SST time-series and our previously established relationships between observed SST and $pCO_2@14C$ from 1991-2003.”

Referee comment : (16) 3649, line 9 - If you include a figure containing time series of the SST and pCO_2 anomalies, here would be a good place to add the newly acquired data to the time series (using a different color for easy identification). Then this sentence could be easily combined with the next sentence and put at the end of the paragraph to read “The pCO_2 and SST anomalies were

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added to the climatological cycles in Figs 2,3,4 and to the anomaly time series in Figure XX.”

Reply : Our in-situ data are not directly comparable to the SST climatology due to mesoscale variability that is not picked up by the Reynolds climatology.

Referee comment : (17) 3650, line 18 - word choice, “trends” should be changed to “patterns”

Reply : Indeed. Text was changed accordingly.

Referee comment : (18) 3650, line 20 - “The small annual F anomalies in 1985 ...”, This statement is confusing, as in the previous paragraph (line 7) it is stated “In particular, the annual F anomalies in 1985 ... are larger compared to other years”. Please clarify this inconsistency.

Reply : Indeed. Text was changed accordingly.

Referee comment : (19) 3650, line 25 - Again, if there were a figure containing air-sea CO_2 flux and SAM time series, it could be used to provide evidence in support of this last sentence.

Reply : Figure was added

Referee comment : (20) 3650, last two lines - should be changed to “Examining the relationship between anomalies in CO_2 flux and SST on inter-annual time scales provides insights of biogeochemical responses to projected long-

term trends in SST and stratification of the Southern Ocean ...”

Reply : Indeed. Text was changed accordingly.

Referee comment : (21) 3652, lines 3-7 and lines 21-23 - Please clarify whether you are discussing interannual variability or seasonal variability here (see Minor Comment #14).

Reply : In order to clarify sentence was rephrased as follows : “Our data-based inter-annual variability analysis does indicate that a decrease of vertical input of DIC during winter due to positive SST anomalies could lead to an increase of the sink for atmospheric CO_2 .”

Referee comment : (22) 3652, line 25 - word choice, “trend” should read “pattern”

Reply : Indeed. Text was changed accordingly.

Referee comment : (23) 3653, line 1 - word choice, “trend” should read “pattern”

Reply : Indeed. Text was changed accordingly.

Referee comment : (24) Figures 2, 3, and 4 should be combined into one figure. They are always referenced together in the text, and it would make for ease of comparison.

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Reply : We agree that Figures are cited together, however, the layout of Biogeosciences is of column-wide figures. Hence, for the figures to be readable in the final format (if the paper is accepted) we prefer to keep Figures 2, 3 and 4 separated.

Interactive comment on Biogeosciences Discuss., 4, 3639, 2007.

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