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Interactive comment on "Deriving a sea surface climatology of CO_2 fugacity in support of air–sea gas flux studies" *by* L. M. Goddijn-Murphy et al.

Anonymous Referee #1

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This article describes the creation of a sea surface climatology of fCO2 (fugacity of carbon dioxide surface) for the global oceans for the year 2010. The authors argue that in situ sea surface temperature (SSTdepth) as reported in the SOCAT version 1 data base provides a poor estimate for the subskin temperature (Tym,i), required for accurate calculation of surface water fCO2. This is a worthwhile observation, which merits discussion and thought.

Next a calculation is carried out for fCO2 data from SOCAT version 1 and ARC temperature data for the period (1?) August 1991 to 31 December 2007, when both data sets overlap. The authors correct the individual surface water fCO2 values at SSTdepth (as reported in SOCAT) to individual pCO2 and fCO2 values at the subskin temperature. This calculation is complex and involves an inversion. Next, individual climatological

pCO2 and fCO2 values are calculated for the year 2010 by applying an increase of a 1.5 μatm/year. Next the individual climatological pCO2 and fCO2 values are grouped by month and put on a 1° x 1° grid for the year 2010. Finally the authors proceed to interpolate their fCO2 and pCO2 results by ordinary block Kriging.

Unfortunately the text is complex and technical in places. It is a struggle to work out the exact procedure followed. The calculation procedures seem unnecessarily complex. The interpolation method as applied here creates strange looking maps of surface water fCO2 in the global oceans with high standard deviations. Text on SOCAT procedures distracts from the procedures followed by the authors.

My recommendations are: 1)Simply the calculation procedure by applying the temperature correction directly to fCO2. If pCO2 is needed, use the simplified equation in Landschützer et al. (2013) based on (Körtzinger, 1999), rather than the complex inversion method (equation 10). Avoid using two temperature corrections (equations 12 and 13).

2)If the above is deemed unsuitable, make at least a comparison (error analysis) of the final pCO2 and fCO2 values following the above simplified procedure.

3)To centre the climatology on 2000 or 2005, ideally a mid-point for the available fCO2 data in the period 1991-2007, not 3 years after SOCAT version 1 ends.

4)Check whether the correction of 1.5 μatm/year is appropriate for the later years of the fCO2 data set and for 2008, 2009 and 2010.

5)The maps created by Kriging do not show oceanographic features, such as the Antarctic Circumpolar Current. This suggests that something is not quite right in the application of the Kriging or that the interpolation technique is not suitable. The fact that the Kriging provides an unbiased estimate does not make it a good estimator in areas without any data (as the high Kriging variance shows).

5a.Does the Kriging procedure stop at land barriers? (It should.)

5b.Does the application take into account the reduction in size of a degree of longitude (in kilometres) with latitude?

5c. Have you considered using a dx different from dy? In some ocean regions, fCO2 varies more strongly in e.g. the north-south direction than in the east-west direction (and the other way around) (Jones et al., 2012).

5d.Blank any areas on the fCO2 maps with a large Kriging standard deviation (e.g. >25 μatm), i.e. unconstrained by fCO2 data. SOCAT version 1 has no data in the Arctic Ocean, Hudson Bay, the Black Sea, the Caspian Sea, Davis Strait, the Sea of Okotsk and the Gulf of Mexico. The provision of a variance (or standard deviation) is one of the strengths of the Kriging method. Use it!

Have you tried other methods, such as optimal interpolation or co-Kriging with month of the year as an extra variable? What are the units for the Kriging parameters (Table 2)?

6)Add a comparison to a pCO2 climatology (Takahashi et al., 2009) or a mean mapping product (e.g. Landschützer et al., 2013; Rödenbeck et al., 2013).

7)Rewrite the paper and make it easier to understand. Clarify which period you study. Add units.

8)Change scale of figure 5 (fCO2 climatology) to e.g. 280 μatm – 440 μatm. Enlarge the figure for at least one month.

9)Shorten sections on SOCAT and move them to an Appendix.

10) Consider removing figures 7, 8, 9, 10, 11, 12 and most figures in the appendix.

11)Consider carrying out the analysis on SOCAT version 2, rather than version 1.

Hence my overall recommendation: Major revisions.

Below follow more detailed comments.

Throughout the manuscript: Add units in the text, tables, figures and figure captions.

P1897 Line 13. Correct to 'Bakker et al. (2014)'.

P1897 Line 19. Replace 'climatology' by 'data set'. Sabine et al. 2013 do not correct for the gradual surface water fCO2 increase over time. The main output from Sabine et al. are monthly and annual gridded fCO2 data sets.

P1897 Line 26. Correct 'authors'.

P1898 Line 2. Sabine et al. do not 'construct an ocean CO2 flux climatology', as they do not provide fluxes.)

P1898. Line 25. 'monthly composite SST data provided by SOCAT' is confusing. Clarify that you use SOCAT synthesis products and that you grid these data. For example, P1902 Line 11, 14, P1903 Line 13 and P1904 Line 5-6.

Sections 1.2-1.4 P1899. How does the depth for air-sea heat exchange compare to that for air-sea CO2 exchange? What are the depths of Tskin, subskin SST relative to (P1900 Line 2) '5 m depth for SST measurement'? A figure demonstrating the various concepts would help. E.g. P1901 line 20 'base of the mass boundary layer', P1901 Line 24 'base of the thermal boundary layer', P1901 Line 12, Line 16 'diffusive sub layer'.

Section 1.4. Clarify which period you study for SST and fCO2 ((1??) August 1991 to 31 December 2007?). P1902 Line 7: 'from August 1991 to December 2010'. P1904 Line 2-3: '1968 to 2007'. State (more) clearly that you use monthly ARC temperature data for each year on a 1° x 1° grid (P1902 Line 8) and in situ (instant) fCO2 and SSTdepth from SOCAT version 1.

P1902. Line 2-4: 'According to Kettle . . .. is negligible'. If this really is the case, there is no point in making the temperature correction for fCO2 in the remainder of the article.

P1902 Lines 7-12 Clearly define the various temperatures, SSTskin, SSTskin,i, Tym,i

and Tym. It is a struggle to understand the current explanation. Consider a table (Appendix) with all the symbols used in the text and their definition. Clarify the gridding procedure from ARC SSTskin to Tym,i (e.g. Figure 1).

P1902 Line 12 and Line 17. What is the unit for these temperatures?

P1903 Line 7. Remove 'SST data from Bakker et al. (2014)'.

P1904 Line 21 and P1906 Line 13-14. 'Equation (8) was therefore expected to give more accurate pCO2,is estimates' (than equation 1). Takahashi et al. (1993) is the source for both temperature corrections (equation 1 and 8). Takahashi et al. (2009) state the following: 'If Tin situ –Tequ (here SSTdepth and Teq) is less than 2°C, Eq. 2 (here equation 8) yields pCO2 values virtually indistinguishable from the previous ones' (here equation 1). It seems unlikely that the temperature corrections frequently exceed 2°C.

P1905. Line 7. Add 'temperature'. (at equilibrator temperature).

Section 2 P1903-1907. The text on SOCAT procedures (based on Pfeil et al., 2013) distracts from the procedures followed here. Shorten text on SOCAT and move any indispensable text on SOCAT to an appendix. Remove irrelevant comments, e.g. P1906 line 2-6 'they refer to .... isochemical conditions'.

Section 2 P1903-1907. Ideally cite the peer-reviewed publication on SOCAT version 1 (Pfeil et al., 2013), rather than Pfeil and Olsen (2009) published online. Use Pfeil and Olsen (2009), when Pfeil et al. (2013) does not contain specific information. By all means mention Pfeil and Olsen (2009), however, this report is more difficult to locate than the published ESSD article. The routines in Pfeil and Olsen (2009) and Pfeil et al. (2013) are based on Pierrot et al. (2009).

P1905 Line 23: Correct the statement: 'Pw is set to zero'. Pw is not set to zero. Pw is absent from the equation.

P1906. Line 9-10. On '(TCO2 and Talk ....may vary)'. Consider removing this, as it

distracts. Alternatively explain TCO2, Talk.

P1906. 2nd equation. What is the unit for T ? Degrees Celsius?

Section 3 P1907 Line 15-16. Remind the reader of the objective of this section.

P1908 Line 18. Correct. Tym,i (equation 13) is not 'a climatological temperature'. P1902 Lines 7-12 suggests that Tym,i is the monthly SSTskin at grid points for each year interpolated to the SOCAT measurements plus 0.14K.

P1910 Line 1, P1915 Line 15. Avoid the term: 'missing SOCAT values', when referring to absent measurement salinity, pressure or similar. You might say that certain ancillary parameters are absent in SOCAT.

P1910 Line 1. Correct the statement: 'We dealt with missing SOCAT variables, following Pfeil and Olsen (2009) etc... Pfeil and Olsen (2009) do not 'use SST when Teq is invalid'. The procedures that you follow are very different from those in SOCAT.

P1911. Line 6-10. Add units for 4, 20, 60, 5x5 sized blocks.

P1915. Line 18. SOCAT used NCEP Pressure and WOA salinity (Table 4 in Pfeil et al.). Not sure if these classify as earth observation (EO). Clarify EO, if you use it.

P1919. Line 19. Correct '(Bakker et al., 2014)'.

P1918. Line 2. Change to 'SOCAT-based fCO2 (and pCO2) predictions' or similar.

P1919. Acknowledgements. SOCAT has revised its data policy with more text to be added to the acknowledgments (www.socat.info).

Tables Table 1. Add entry on data source and period covered by data source. What is meant with 'pCO2 ($\sim$fCO2)' in column 2?

Table 2. Add units for radius, dx, dy. Clarify meaning of min and max.

Table 3. Add units for all parameters. On the footnote: Clarify that not all data in SOCAT meet SOP criteria (Pfeil et al., 2013). Data sets with flags of C and D (59% in version

1; Bakker et al., 2014) do not meet SOP criteria. (N.B. In case of a flag of D the data may meet SOP criteria, but the metadata are incomplete.)

Figure 1: Add a unit for temperature on the x-axis and for average 'dT = -0.09'. Replace 'all available years' by e.g. 'August 1991 to December 2007'. What is the impact of the difference in timing between monthly satellite subskin SST and instant (daily) in situ SST from SOCAT version 1.5? Clarify (or refer to relevant text) how you compare 'monthly gridded data of subskin SST' to 'in situ SST from SOCAT'.

Figure 2. Add a unit for temperature on the y-axis. Replace 'all available years' by e.g. 'August 1991 to December 2007'.

Figure 3. Replace 'all available data from 1 August 1991 to 31 December 2007' by e.g. 'for the months of January from 1992 to 2007'.

Figure 4. What are the units on the axes (distance, semi-variance)? Increase the font size. Is the distance the same in the east-west direction as in the north-south direction?

Figure 5. Add units for min, max, radius, block size. Reduce the range for the colour scale. Blank areas with a standard deviation (Figure 6) exceeding a certain limit as 'unconstrained' or similar.

Figure 5 versus Figure A8. The fCO2 in Hudson Bay for July changes from $\sim$580 μatm (version1) to $\sim$220 μatm (version 2). This highlights that areas with a large standard deviation should be blanked and/or that the method should stop at land barriers.

Figure A1 versus A9. Why has the standard deviation for November increased from version 1 to 2?

References: Jones et al. (2012) GBC 26 GB2042. doi:10.1029/2010GB004017 Landschützer et al. (2013) BG 10:7793-7815. Pierrot et al. (2009) DSRII 56(8-10):512-522 Rödenbeck et al. (2013) Ocean Science 9: 193-216, doi:10.5194/os-9-193-2013. Takahashi et al., 1993 Takahashi et al., 2009

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