Response to Reviewer 2

Title: Updated climatological mean delta fCO2 and net sea–air CO2 flux over the global open ocean regions, by Amanda R. Fay et al.

General comment:

Amanda Fay and CO2-authors revisit the Takahashi et al (2009) climatology using SOCAT version 2022. As there are much more fCO2 data available in SOCAT this is a very good idea to reconstruct such climatology extensively used to constraint atmospheric inversions (a-priori fluxes), methods that reconstruct ocean pCO2 fields (e.g. Rodenbeck et al, 2015) or to validate ocean carbon models (e.g. RECCAP 1 and RECCAP 2 stories). Compared to previous climatology (T-2009), authors found significant differences in the high latitudes (in winter in the SO; in summer in the North Atlantic) and in the south-east Pacific where data were sparse and are still missing in large regions (including in SOCAT-v2024 in progress). The paper is well structured, figures adapted. What is missing is a table (somehow like presented by Takahashi et al 2009, see their table 6) where authors would list: Regions (or biomes), their surface area, the mean DfCO2 and the Flux.

We thank the reviewer for these comments and we have added a table (Table 1) as suggested to provide an overview to the reader of the regional mean values for this updated climatology.

Biome	ΔfCO2 (µatm)	Flux (PgC yr^{-1})	Area (10^6 km^2)
NP Ice	-24.6 (9)	-0.02 (0.02)	4.2
NP SPSS	-11.5 (12)	-0.11 (0.11)	12.8
NP Subtropics	-8.2 (16)	-0.40 (0.53)	47.9
Pacific Equ	35 (2)	0.35 (0.03)	26.4
SP Subtropics	-2.3 (10)	-0.14 (0.31)	52.7
NA Ice	-19.3 (4)	-0.04 (0.01)	4.5
NA SPSS	-36.2 (17)	-0.27 (0.08)	9.7
NA Subtropics	-10.0 (16)	-0.24 (0.26)	23.4
Atlantic Equ	14.7 (3)	0.04 (0.01)	7.4
SA Subtropics	5.6 (14)	0.01 (0.12)	18.1
Indian Subtropics	-4.5 (8)	-0.18 (0.16)	35.9
SO STSS	-22.1 (3)	-0.59 (0.06)	29.6
SO SPSS	-6.0 (6)	-0.21 (0.22)	30.7
SO Ice	-6.8 (14)	-0.08 (0.12)	18.7

Table 1 Mean annual ΔfCO2 and flux in global open ocean biomes (Fay & McKinley 2014). Value in parentheses is one standard deviation over the 12-month climatology. Area of each biome is also included. NP: North Pacific; SP: South Pacific; NA: North Atlantic; SA: South

Atlantic; SO: Southern Ocean. SPSS: Subpolar seasonally stratified; STSS: Subtropical seasonally stratified. Northern hemisphere subtropical regions are reported to match the regions shown in Figure X (combining the STPS and STSS biomes from Fay & McKinley 2014 into one).

The paper is pleasant to read and suitable for publication in ESSD after few corrections. Below are listed specific comments.

Specific comments:

C-01: Line 22: In Key point: add error/uncertainty on the flux -1.79 PgC yr-1

Thank you for this suggestion. The uncertainty is now included: "-1.79 +/- 0.7 PgC yr^{-1}"

C-02: Line 35: In Abstract: add error/uncertainty on the flux -1.79 PgC yr-1

Thank you for this suggestion. The uncertainty is now included: "-1.79 +/- 0.7 PgC yr^{-1}"

C-03: Line 41: "now exceed 415 ppm": As atmospheric CO2 increases rapidly, maybe specify the year for the value 415 ppm. Thank you for this suggestion. We have revised the sentence to indicate the year.

C-04: Line 55: Here maybe specify you list the approaches based on observations (i.e. not models):

"multiple approaches based on atmospheric and/or oceanic observations".

We thank the reviewer for this suggestion. We have revised the text to read: "Over the last several decades, multiple approaches based on atmospheric and oceanic observations have been developed to measure the impact of the ocean on the global.."

C-05: Line 83: For Takahashi et al (2009), add also reference to Takahashi et al 2009b (corrigendum). Thank you for pointing out this omission. We have added the requested reference.

C-06: Line 83: I guess you can also refer to Tans et al (1990) who present the first global seasonal map of DpCO2 with the data they had in hand at that time. I think this was the first study that use a "DpCO2 climatology" to constraint a global carbon budget and clearly motivated the next steps (toward a full year ocean pCO2 and flux climatology, Takahashi et al 1997, 2002, 2009…). This also motivated the start of SOCAT first discussed in 2007 (Metzl et al, 2009) and released in 2011.

Thank you for this suggestion and the additional references and context to the history of this field of research and it's motivation. We have added the reference.

C-07: Line 196: You used fCO2, SST, SSS and sea level pressure from SOCAT; for SSS when there is no measurement for a cruise you can recall that you used the SSS from WOA also in SOCAT data files (see Pfeil et al, 2013). Should you indicate somewhere that you select only the Cruises with flags A-B-C-D and data for fCO2 with WOCE flag 2 ?

We have added this information to the SOCAT database discussion (Section 2.1), indicating that we use only SOCAT data with flags A-D and WOCE flag of 2. Added text: "For this analysis we select SOCAT data from cruises with flags A-D and observations with a World Ocean Circulation Experiment (WOCE) flag of 2 (Pfeil et al. 2013)."

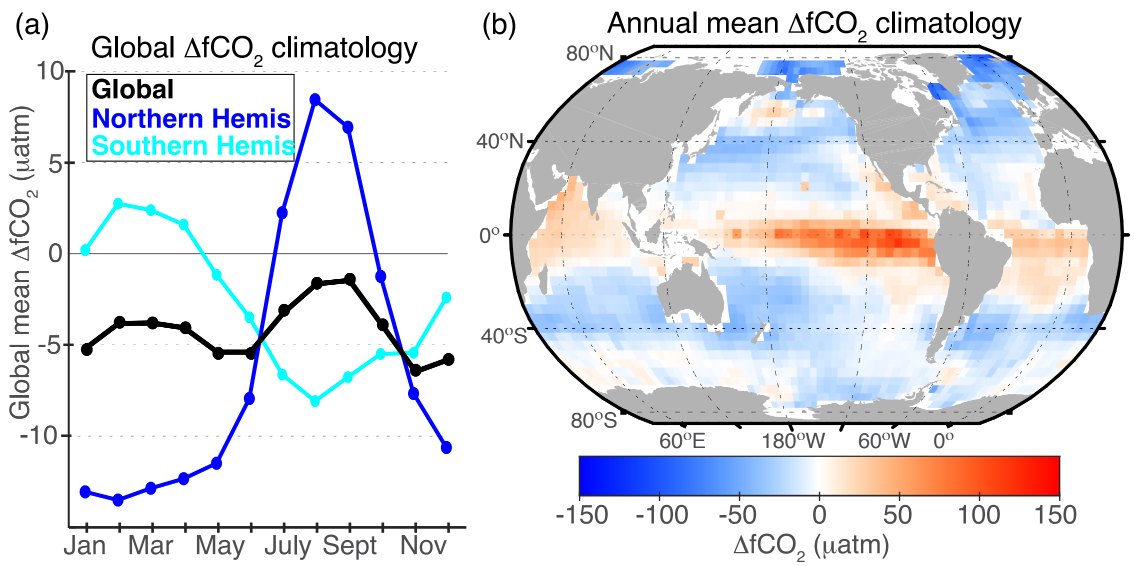
C-08: Line 275: add error/uncertainty on the flux for both the normalization method (-1.85 PgC yr-1) and the current method (-1.79 PgC yr-1). We thank the reviewer for this suggestion however we have not amended the text here. The focus of this comparison is simply the impact of the differing normalization on the resulting ΔfCO_2 climatology. Unfortunately, it's difficult to really gauge the meaning of differences of, for example, 0.5µatm when in terms of ΔfCO2, and that is why we here quote the comparison in terms of flux. We hold off on discussing uncertainty until later in the manuscript. If we were to choose an uncertainty value for each of these global flux numbers stated here, they would be the same (0.7PgC yr^{-1} as discussed in Section 4.2). It could even be suggested that this comparison here could provide some clarity to the uncertainty calculation- specifically the portion that is attributed to the normalization method (0.5 PgC yr^{-1}). The comparison here suggests a much smaller uncertainty due to the correction of available observations to one climatological year than those proposed in previous work (T-2009, Wanninkhof et al. 2013).

C-09: Line 358: Low values of ΔfCO2 in the North Atlantic region also driven by biological activity in Spring-Summer ? (as you mentioned line 445)

We thank the reviewer for this comment. As they point out, we do discuss this spring bloom impact later in the manuscript, in the regional section. Here we are focusing on the annual mean global climatology- looking at broad patterns that emerge on the annual time scale. For that reason, we have opted to keep the text as is here.

C-10: Line 361: Is the near-global mean climatology seasonal curve (figure 2a) useful to discuss ? Would it be better to separate NH and SH (two curves) ?

Thank you for this suggestion. We acknowledge that the mean global curve is indeed not that interesting at first glance, but allowed an interesting look at the bimodal nature and the mean dfCO2 value. We have experimented with your suggestion of a North and South Hemisphere curve and have updated Figure 2 in the manuscript (recreated here).

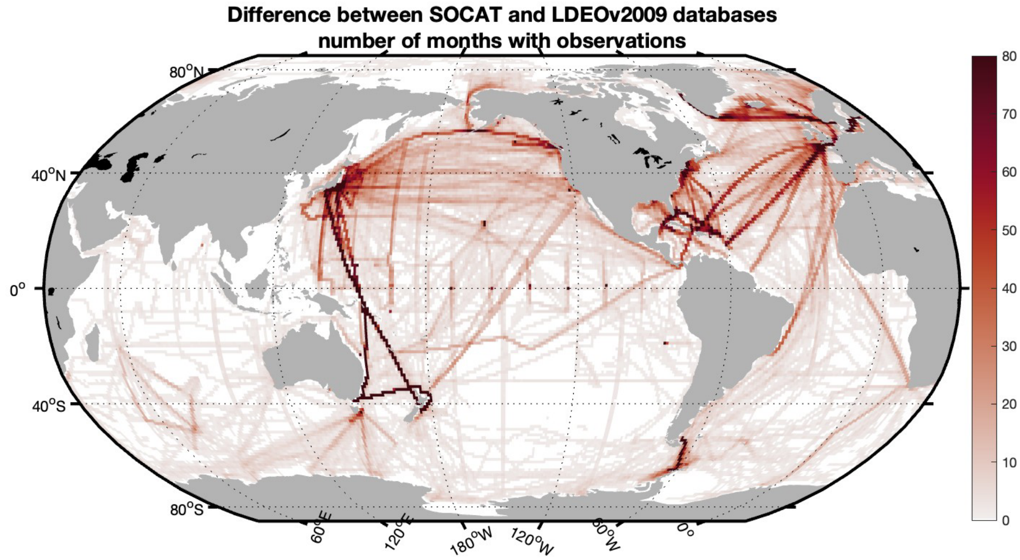


C-11: Line 552: Chen et al: correct: Chen and Tsunogai (1998). For the large fluxes in the Indian sector and Arabian sea maybe refer to Sabine et al (2000) and/or Sarma et al (2023) ? Thank you for this suggestion. We have added a reference to Sabine et al. who also discuss the upwelling in this region and high flux values.

C-12: Line 560-564: The carbon source in the Southern Ocean during austral winter (Atlantic and Indian sector south of 45S) is likely linked to deep mixing and/or upwelling (import of high DIC in surface layers). We thank the reviewer for this comment and have added additional text to the paragraph: "Another possibility is that the austral winter carbon source is linked to deep mixing and/or upwelling water which would bring an import of high DIC to the surface layers."

C-13: Line 567: "Uncertainties are higher in the Southern Ocean region due to the limited number of observations, particularly in winter". Could you specify "uncertainties": fCO2 reconstruction, fluxes, both ? Compared to T-2009, is there are more data in winter in SOCAT in the SO that would reduce these uncertainties ? We thank the reviewer for this comment. We have opted to rephrase this sentence because it is not appropriate to say "uncertainties are higher" if we aren't calculating regional uncertainties. Our point with this statement was simply that because there are fewer observations in this dynamic area, it requires more interpolation from the method in order to create the monthly climatological map. Thus, we would say we have less confidence in this region due to the known lack of available observations, especially in certain seasons.

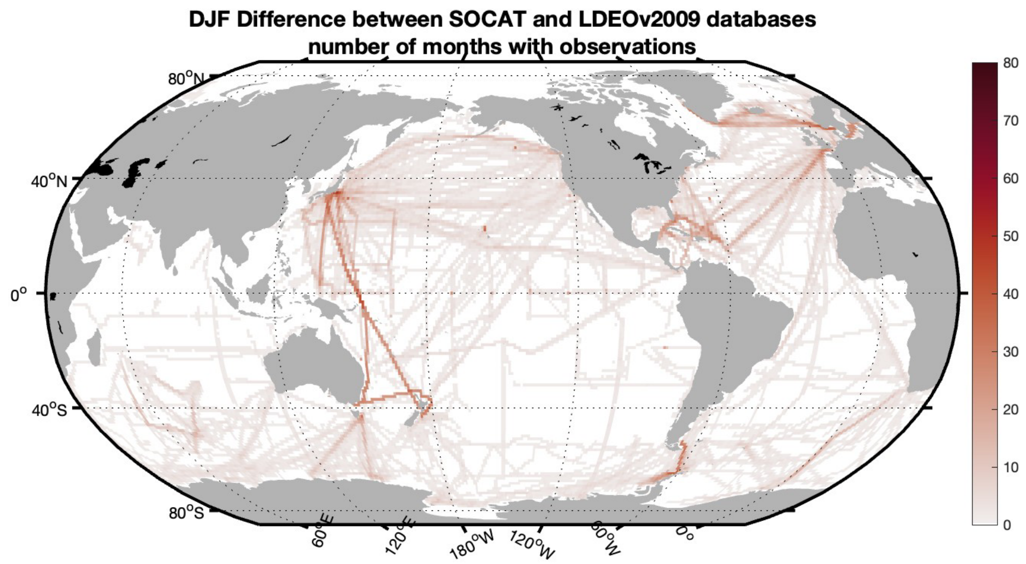
To answer your specific question about comparing seasonal data availability to the database used in T-2009, there is indeed much more winter data in SOCAT than there was in the LDEO database that fed into the previous version of this climatology (see figure below). Another view of this can be seen by comparing Figure 1 showing SOCAT to the the LDEOv2019 database (supplementary Figure 1b)- you can see few areas of the Southern Ocean (outside of the drake passage) that have more than 2 different months sampled for the entire time period in the LDEO version.



Map showing number of additional months per gridcell for data in SOCATv2022 as compared to the LDEO dataset that was used in T-2009. Specifically, that dataset ended with year 2007 and SOCATv2022 includes observations through 2021.

C-14: Line 611: For the comparison of data used in T-2009 and this study, could you show a map where data are in SOCAT-v2022 but not in T-2009. The supp mat (figure S1) shows the LDEOv2019, but might be useful to show the original LDEO when comparing fluxes with T-2009. I guess this is from Takahashi, Sutherland, and Kozyr (2009)

We thank the reviewer for this suggestion. We can understand how a map directly comparing the difference in available observations would help with interpretation of Figure 7 and Supplementary Figure 8b. Here I have plotted maps showing the difference in the number of months with observations, by gridcell, between the two datasets for two seasons: DJF and JJA. The map above shows the difference for all 12 months of the year as a comparison. We have opted to add these figures in the Supplementary rather than the main text.



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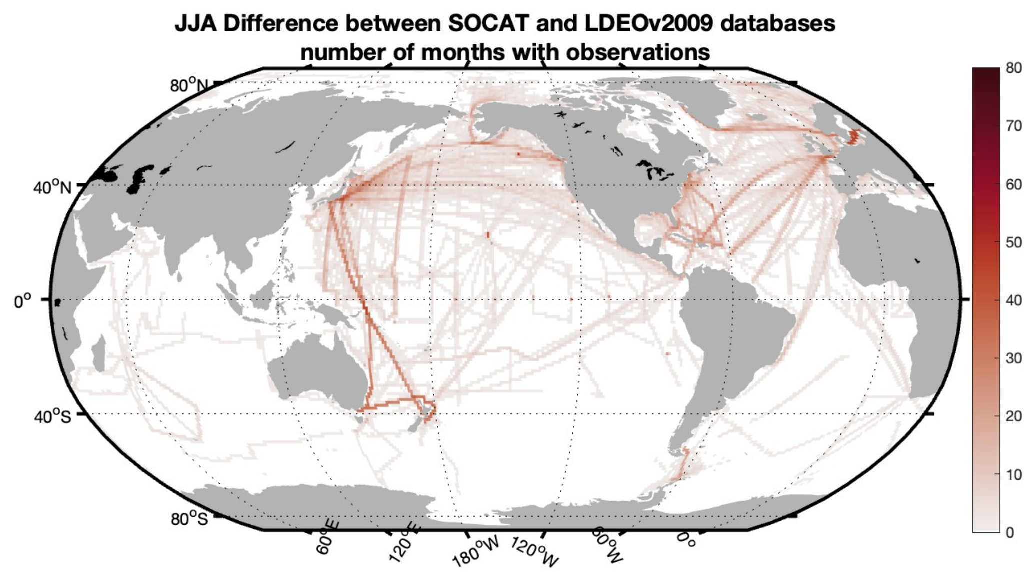

Map showing number of additional months per gridcell for data in SOCATv2022 as compared to the LDEO dataset that was used in T-2009 for 2 seasons: December, January, and February (DJF) and June, July, and August (JJA). LDEOv2009 dataset includes observations through 2007 and SOCATv2022 includes observations through 2021.

C-15: Line 741: "less data in socat since 2017". Maybe refer to the Bakker et al (2023) ? We thank the reviewer for this comment and suggestion. We were aware of the figure showing this trend but had not seen this citation. We have included the reference.

;;;;;;;;;;; In Figures:

C-16: Figure 7: maybe change the range -50 to 50 µatm to better highlight the differences ? We thank the reviewer for this comment and have considered this option in previous versions of the figure. We elected to use this colorbar range as it matches up with a similar figure in T-2009 (their Figure 11) where they show the differences between that version and the previous version of the climatology. In order to make comparisons with regard to how much change occurred with this update, we opted to maintain a similar colorbar range.

C-17: Figure 8: maybe indicate in the caption that white area in the SO in JJA is because of ICE extend ? We thank the reviewer for this comment and have added a statement in the caption of this figure.

;;;;;;;;;;;; In references:

C-18: Line 771: Antonov et al : not cited in the MS We thank the reviewer for catching this extra citation. We have removed it from the reference list.

C-19: Line 834: De Vries et al (2023) now published

We have updated the reference.

C-20: Line 1026: Takahashi et al 2009 (check list of authors)

We thank the reviewer for catching this error. We have updated the reference.

;;;;;;;;;;; In Supplementary Material:

C-21: Table 1: add unit for number listed in this table (µatm/yr)

We thank the reviewer for this comment. We have updated the Table caption.

;;;;;;;;; Reference added in this review not listed in the paper

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