Review of "Harmonization of global surface ocean pCO2 mapped products and their flux calculations; an improved estimate of the ocean carbon sink" by Andrea Fassbender

Fay and coauthors aim to improve the global net air-sea CO2 flux estimate and ease model-data comparisons by making a diversity of pCO2 data products (n=6) with methodological differences more consistent and releasing the results as a new data product: SeaFlux. Their approach involves relying on a climatological pCO2 data product to spatially extrapolate estimates from other pCO2 data products with more limited ocean coverage. After extrapolating all pCO2 data products to the same ocean mask, the authors calculate the net air-sea flux using three wind speed products, while accounting for gas exchange coefficient sensitivities to the individual wind speed products. The authors find that the flux estimate discrepancies between these products can be reduced most by simply using a consistent ocean domain for the pCO2 data products.

The paper is clearly written, the findings are important, and the data product will simplify model-data comparisons. However, a justification for the extrapolation approach is not provided, and a few simple analyses are required to verify that the approach is "a step forward from" existing methods. Reviewers 1 and 2 have already outlined several concerns; therefore, I will keep this brief and focus on specific suggestions and technical corrections for the authors to address.

We would like to thank Andrea Fassbender for the thoughtful comments and suggestions. In the following we will respond (in italics) to each of her specific comments.

Specific Comments

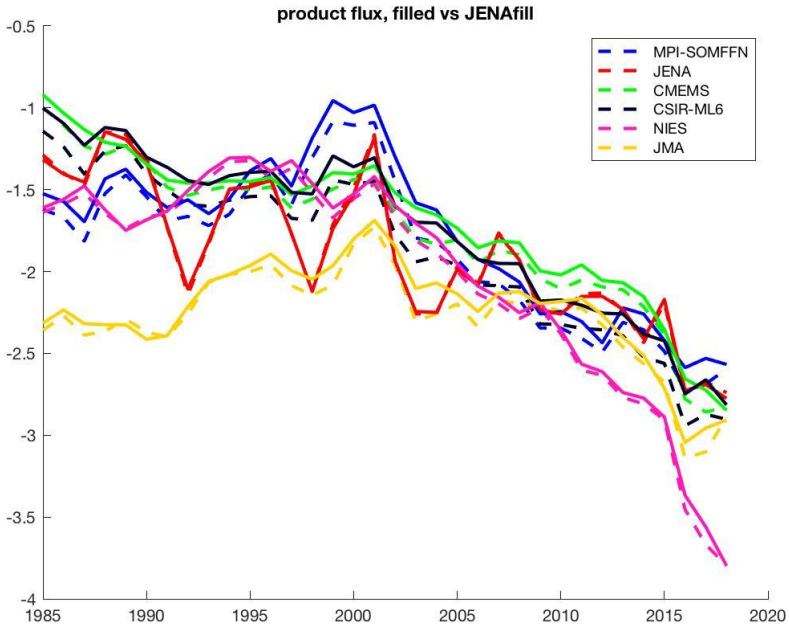
R3: My primary concern is with the pCO2 scaling approach. It is not clear why the MPI-ULB-SOMFFN climatology was used for gap filling rather than the time evolving JENA-MLS data product. As noted by Reviewer 2, the authors could test their scaling method by using JENA-MLS as the reference data product to see if they achieve similar results.

Response: Thank you for this question. We will respond, as we did with Reviewer 2, that we are aware of at least 4 of the products working towards the goal of full spatial coverage. But until those are released and available we have to work with what we have.

We thank the reviewer for their suggestion of using the Jena-MLS product as an independent estimate of the missing regions. While this does seem like a plausible option from the full-coverage map shown, the Jena-MLS product is stated to be an "open-ocean" product. The creator of the Jena-MLS product (Christian Rodenbeck) specifically cautioned us against using the product as a coastal estimate, specifically stating that CarboScope (aka Jena-MLS product) is an open-ocean product. Additionally, the Jena-MLS product is released in its native resolution as a 4x5 degree map and we have downscaled it to 1x1 degree for this ensemble work.

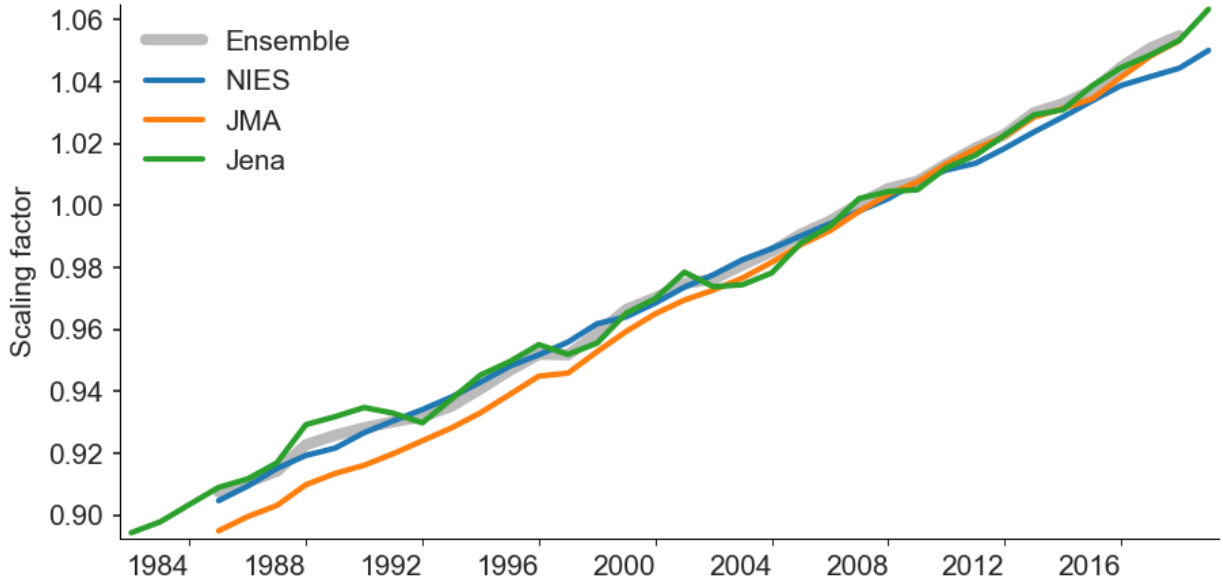
Therefore, it is not produced in a sufficiently fine-scale resolution to capture coastal and continental shelf processes. The MPI-ULB-SOMFFN climatology is produced at 0.25 degree spatial scale at the coastal margins (up to 400km off land) and therefore provides an improved representation of these regions.

For completeness, we did calculate the resulting flux with the Jena-MLS product pCO2 used to fill in missing gridcells in the remaining products and present the resulting global mean CO2 flux timeseries here (dashed lines) along with the flux with filling by the SeaFlux package area-filling method employing MPI-UMB-SOMFFN (solid lines).



R3: It is also unclear why the authors use an ensemble mean scaling factor when individual scaling factors for each data product may be more appropriate as it would allow more data to be used (i.e., a consistent mask wouldn't be required) to determine the scaling factor for most products. I can understand the desire to maintain consistency in the data extrapolation between products, but it's not clear that this approach makes more sense than creating individual scaling factors for the data extrapolations. More information is needed to explain why this decision was made.

Response: We considered the option of calculating individual scaling factors but opted to present the ensemble approach for it provides strengths with regard to capturing a forced signal common to all products. We acknowledge that a scaling factor for each product would be much more sensitive to interannual variability in the products however we don't see that as a strength when considering long-term global mean averages. We present here a comparison of a scaling factor for various products to that of the ensemble mean.



Scaling factors for the ensemble product (thick grey line). We only show NIES, Jena and JMA methods. The remaining methods are more similar to the ensemble scaling factor than the methods shown in the figure above. The JMA-MLR approach shows the largest difference from the ensemble mean, which is on average 0.6% (max of 1.7%) for pCO2. When propagated through to fluxes, this equates to an average difference of 0.04 Pg yr^{-1} when compared with the scaling factor computed with the ensemble. For reference, filling results in a ~0.25 Pg yr^{-1} larger uptake by the ocean (as shown in the figure on the following page). Thus, even in the worst case scenario, the difference is small.

Further, using the ensemble approach makes the SeaFlux data product less product specific, as new surface pCO2 products can also apply the approach without having to perform the calculation.

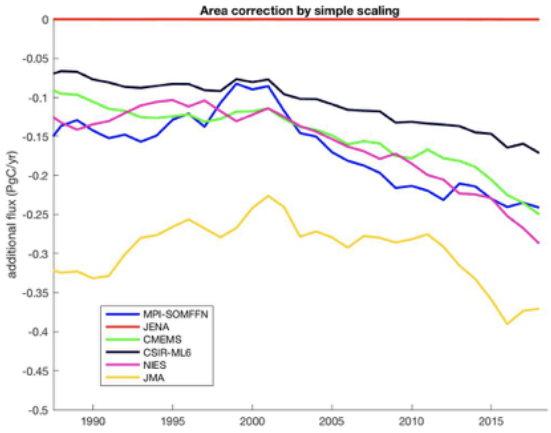
R3: As a sensitivity test, the authors could apply their methodology using JENA-MLS to scale MPI-ULB-SOMFFN (and vice versa) directly AND using an ensemble mean, to see which yields a better result. They could also do this using (1) the common missing data mask as well as (2) each missing data mask from the four other data products to evaluate whether the resulting extrapolation bias is sensitive to the extrapolation area. The authors could also apply the linear-scaling approach used in the Global Carbon Budget (GCP) to MPI-ULBSOMFFN and JENA-MLS (using the missing data masks from the four other products) to quantify the resulting extrapolation biases and determine whether their approach is indeed more accurate than the GCP method. The suggested analyses may help clarify which approach is best for achieving data product comparability.

Response: We thank the reviewer for these ideas.

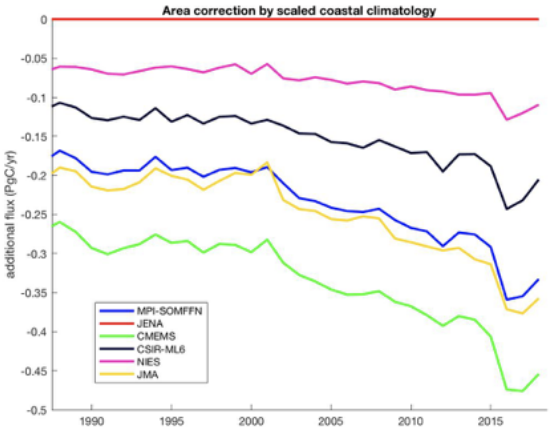
For the first comment regarding a sensitivity test, we have shown the comparison in resulting flux when using the Jena-MLS product to fill in missing areas of all the other products, however

we remind the reviewer that this is simply a comparison but not the preferred method as Jena-MLS is an open-ocean product and should not be used as a parameterization for coastal regions. However we also question how one would define "a better result" as suggested by the reviewer as the "truth" is of course unknown.

To respond to the idea of applying the linear-scaling approach used in the GCB, one strength of the SeaFlux approach is that it deals directly with the pCO2 in the various pCO2 interpolation products rather than adjusting their fluxes after the fact. These products are created to represent (nearly) full coverage pCO2. They often will also calculate a flux field and report it as well, but the approach itself is developed and tuned to represent pCO2 values. So by calculating a global flux and then adjusting it by a missing area factor you are skipping over the point that there are pCO2 values missing and how that unknown could cascade in the flux calculation itself. Here we show that the additional flux for each product resulting from the area-filling method proposed here in the SeaFlux package is on the same scale and magnitude as the method utilized by the GCB. Below is an annual time series of the additional flux amount calculated by the area-weighted method used in the Global Carbon Budget (a) and a similar plot showing the annual additional flux using the SeaFlux methodology (b).



(a)



(b)

Technical Corrections

R3: Title: The 2 in pCO2 should be subscripted.

Response: Thank you for this correction.

R3: Line 36: pCO2 is not yet defined.

Response: Thank you for pointing this out. We define pCO2 in the first sentence of the Introduction but opt to not define it in the abstract as we aim to be as concise as possible in that section.

R3: Line 37: Add "modern" before "global mean uptake"

Response: Thank you for this suggestion. The referenced sentence has been removed from the manuscript but we have added this designation in other sections.

R3: Line 43: "variations" should be "variation." It seems that the atmospheric pCO2 growth
rate is the largest driving force governing the net exchange of CO2 across the air-sea interface unless you're talking about sub-annual or pre-industrial timescales. Please clarify.

Response: We have edited this sentence to include the importance of the growing atmospheric pCO2 levels and its variability as the driving force for variability in surface ocean pCO2 levels.

R3: Line 57: How about: "These differences in flux calculations introduce uncertainty in comparisons between the products and with Global Ocean Biogeochemistry Models (GOBM)."

Response: We have changed the sentence to read as suggested.

R3: Line 95: pCO2 was already defined.

Response: Thank you for pointing out this repetition. We have omitted the definition.

R3: Line 97: A "we" seems to be missing.

Response: We have added the missing word.

R3: Line 100: Satellite SST and EN4 subsurface salinity data are used to calculate parameters required for the air-sea flux calculations. What depth are the EN4 salinity data from?

Response: We have included that we use the near-surface salinity from EN4.2.1 that is an estimate of salinity at ~5 m.

R3: Line 108: Slightly awkward wording. What about: "Flux is defined as being positive when CO2 is released from the ocean to the atmosphere and negative when CO2 is absorbed by the ocean from the atmosphere."

Response: We thank the reviewer for this suggestion and have reworded the sentence as such.

R3: Line 117: "…relationships between pCO2 and proxy variables are expected". The next sentence starting on this line doesn't seem to make sense. Maybe get rid of "in contrast."

Response: Thank you for this suggestion. We have removed the "In contrast" from the beginning of that sentence and improved the flow between the two sentences.

R3: Line 130: "net global(?) fluxes"?

Response: This sentence has been removed from the manuscript.

R3: Line 159: There seems to be a formatting issue. Additionally, it's not clear if you are talking about the original global flux for each model, or not.

Response: Thank you for this comment. We have amended this sentence to make clear that we are discussing the impact of the area-filling method on the resulting global mean flux values for each of the six products, and the product ensemble mean.

R3: Line 160: Is this because some products are missing the Arctic? That seems important to clarify.

Response: Yes, the Arctic is a common area missing from most pCO2 product maps, but also there are a few products that are missing portions of the North Pacific region (Figure 1) which also adds to this adjustment. We have added sentences to further discuss this large adjustment in the Northern Hemisphere for specific products.

R3: Line 162: "…the final CO2 flux also depends on the…"

*Response: inserted "also" in the sentence: "...the final CO2 flux **also** depends on the…"*

R3: Line 182: Remove equal sign.

Response: Done.

R3: Line 330: Typo.

*Response: Revised to "...presented standardized flux calculations to **their** own data-based pCO2 reconstructions."*

R3: Figure 2: I would recommend converting this a four-panel figure with the inset graph having its own panel since there is space. Add a-d lettering to match the caption.

Response: We have converted this figure to a 4 panel figure as suggested by the reviewer.

R3: Table 1: It is not clear what "unfilled area listed" means. Should this be "Area coverage"?

Response: We have revised this sentence in the Table caption to read "Area coverage listed represents average annual area covered for 1988-2018 as this value changes monthly for many products."

R3: Table 2: Should the 3rd row be titled "Mean Annual Global Flux"

Response: We assume that the reviewer is referring to the 3rd column in this table, currently labeled "Mean flux difference: scaled – unscaled wind". It is indeed the difference in mean 1988-2018 flux when using a scaled coefficient of gas transfer versus a set coefficient of 0.26. We have added to the Table caption to clarify what is reported within: "Column 1 lists the scaled coefficient of gas transfer for each of 3 wind reanalysis products; column 2 includes the global mean flux using each wind product. Column 3 shows the difference in resulting flux when using a scaled coefficient of gas transfer versus a set value of 0.26."