

Response to RC2: Peter Land

Dear editor and reviewer. Thank you for the positive feedback and constructive comments on the manuscript. We are glad that you enjoyed the work presented here. We have modified the manuscript in order to address your comments and the ones of Referee #3. Hopefully, the manuscript will appear better organised in its revised form. Our reply to your comments follows in *italic font* below.

This is a thorough and well-presented analysis of a multi-ship campaign measuring waters north of Brazil containing two large eddies (rings), combined with satellite data (including a novel SSS product) to estimate the February air-sea CO₂ flux in the region and the contributions due to the rings and other water masses. It describes a method for estimating flux that could be extended to other years, and validates this using previous cruise data with good agreement. I consider the work novel and important and the argument convincing, and I recommend publication. I have two main issues plus detailed comments.

SST is a fundamental component of your method, albeit with relatively low variability across the region, and is often referred to in the text, but we only ever see SST in TS plots and cruise tracks. I would like at least a February 2020 SST composite so readers can see how features described in the text manifest spatially in SST. You could go further and expand other figures to include maps of SST alongside SSS and chl_a. Speaking of maps, I second Referee #3's request for a geographically-labelled map, including Bermuda, Trinidad & Tobago and any other geographical features mentioned in the text.

We agree, it is a good suggestion. In order to address this issue, we added a geographically labelled map of a snapshot of SSS and of the CO₂ climatology (see below). Then, on a separate figure we added the SST map for the 6th of Feb 2020, together with the Chl_a and SSS maps for the same day.

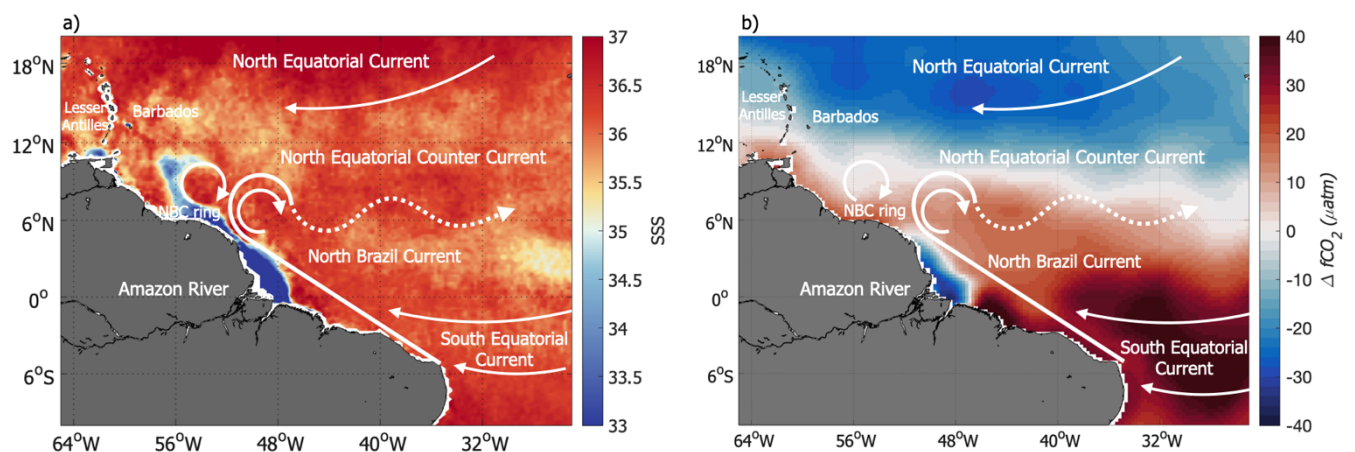


Figure 1: Schematic of the main ocean currents in the western tropical Atlantic superimposed over the SSS field of Feb. 7th 2017 (a) and over the February ΔfCO_2 climatology from Landschützer et al., 2020 (b).

In Section 4.3 and Appendix A, you appear to get to a point where you can address a crucial question, which is whether 2020 was a flux outlier, but you don't present any results! I couldn't understand why that was, the paper would be much better with this information. Are you saving it for another paper? I wouldn't blame you, but then Appendix A seems largely redundant as well as unfair on your expectant readers! You successfully validate in other years with cruise data but you don't go on to process all years since 2010 and present summary statistics on at least the headline regional flux figure.

Thank you for this nice comment. We indeed thought the results would go beyond the scope of this paper and might be the subject of some ulterior study. We decided to added one figure to illustrate the strong interannual variability of the fCO_2 in the region linked to the interactions NBC rings – Amazon plume as observed in 2020 (see below). It also highlights changes in the north-eastern part of the domain, but in order to interpret this variability we would need to place it in a longer time scale context. We can nevertheless see the impact of a strong negative SST anomaly in March 2014.

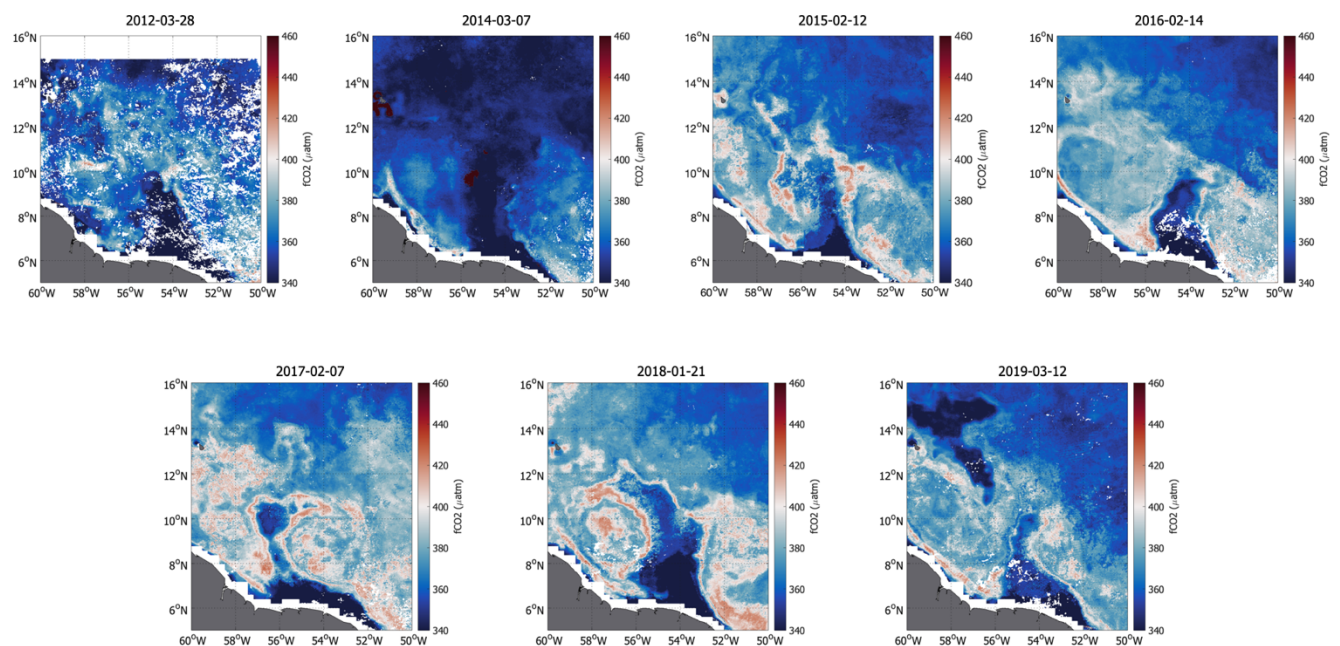


Figure 2: Snapshot of reconstructed fCO_2 for all occurrences of fresh plumes extending at least to 10°N and east of 56°W in January-March 2010-2019 (2010, 2011 and 2013 do not present this type of event).

118-9 This could use more neutral language, eg ' a factor of 10 greater than previously estimated'

We agree and modified the sentence.

l22 causes

Done

1139 Different families of rings exist... (a little more explanation of the families would be nice here for ignorant folks like me, e.g. are they all anticyclonic? I would have thought so, but the next phrase kind of suggests a secret world of cyclonic eddies undetectable by altimetry - maybe I'm letting my imagination get the better of me!)

It is a very interesting subject indeed. The eddies called NBC rings are all anticyclonic. Some cyclonic eddies are also present in the region, but they are not long lived. The different families refer to their depth, some rings are deep and not surface intensified, while the rings with a surface signal are most of the time shallow. The sentence has been changed to avoid confusion and to better explain the subject.

l58 CO2-undersaturated

Done

l72-3 The climatology of difference...

Done

l78 ...due to onshore winds as it travels... (as it stands it sounds like winds ambiguously perpendicular to the coast are travelling NW!)

Thank you, done

l83 Later you only refer to the western one as a filament and to the eastern one as a plume - be consistent please

Indeed, we chose to refer them differently to avoid the confusion between the two in the manuscript. Moreover, the scales of the two filaments are different, the eastern one is almost a mesoscale feature (100km wide) so is referred as a plume.

l124 Temperature and salinity...

Done

l133-4 At what depth? If similar to the intake, one thing these might be used for is to

shed further light on the $f\text{CO}_2$ comparison (or muddy the waters!) by calculating $f\text{CO}_2$.

Some of them were surface, but none was taken in the shelf waters. We compared measured $f\text{CO}_2$ on RV Atalante with DIC and Alkalinity samples, which confirms that the Atalante data is correct. However, it doesn't bring additional information as it was taken along track.

I169 Was the extra data only used to fill gaps, or were all data from the three passes averaged? If the latter, for consistency I'd be tempted to treat all days the same, and either use 6AM the next day all the time or not at all. Could the two missing days be recovered by using 6PM from the previous day? If so, again I'd be tempted to do the same throughout.

Thank you for the suggestion. The inclusion of extra data (next day 6 am) was only done in the rare cases when there were major gaps in the usable satellite track coverage of the day. In this case, although the method applies a weighted mean of all the data with its estimated error variance, there is little overlap (and none in the 'gap') and thus the averaging does not 'reduce' the error of the product. We could have included the 6pm data from the previous day, and done this systematically, but then the period representative of the product starts to be much longer than the roughly 12-16 hours of the data usually included for a specific day, and we lose some of the snapshot vision that the product provides. We believe that this 'time-smoothing/filtering' will be better done by future dedicated products that are currently developed at CATDS.

I203-4 Brief comparison stats could be included here, eg bias and RMSE.

Thank you for the comment. It is indeed interesting, in our study however only the flux computed from the ERA5 windspeed is use quantitatively (comparison between the reconstructed flux and Landschützer 2020 climatology, both computed from ERA5 windspeed). The process study based on the ship data is done using $f\text{CO}_2$, so the ship winds will not influence the results of our study. We now precise it in the manuscript.

I220-1 This sentence doesn't make sense - my guess as to your meaning would be something like 'Chl-a is hard to distinguish from terrigenous detrital material using ocean colour where both are present as they have similar spectral effects' or similar. Phytoplankton produce their own detritus, the effect of which is included in satellite chl-a algorithms.

Indeed, thank you for the better phrasing.

l235 ...prevents oscillations...

Done

l237 ...is ~4 uatm (or is 4 uatm if the 'of' was just a typo)

Done (its ~4uatm)

l248 ...over... It might be interesting to check the sensitivity to these extrapolations by calculating the mean fCO₂ and/or flux without the extra points, equivalent to setting pixels outside the in situ range to the mean so they don't affect the result.

Thank you for the suggestion, it was done in the first place, and the only effect is too fill gaps.

l255 Rather vague and irreproducible with different data as it stands. Did you have a threshold of coverage? Given that in the end you average over all days, why do you not average all valid fCO₂ values in a given pixel, regardless of coverage? If there's a specific reason (e.g. strong, consistent temporal gradients of gap location, which could bias the results), please state it clearly along with your exclusion criterion. Alternatively, how about doing it both ways, the difference suggesting a lower limit to uncertainty?

It is indeed an interesting suggestion, that can work for the cloud gaps in chla and SST. However, the main problem is the absence of salinity data, and in this study, the threshold was based on salinity (no track in the area covering the plume). With the new product in development at CATDS, missing SSS data won't be a problem anymore and we agree that we should compute fCO₂ for every pixel, regardless of coverage in SST and CHLA.

l284 I agree with Referee #3. This amounts to a 3D classification of your data, and there are many ways to achieve this. How did you do it? Manually? How did you arrive at 6 classes? What are the thresholds? Some are scattered through the text, but not in sufficient detail for me to be able to uniquely assign a (S,T,C) triplet to a class (or none). A simple table or a decision tree would suffice to make them reproducible. Do you have any interpretation at all of the grey data, which constitute a large proportion of the warmer waters?

Indeed, we identified the 6 water masses manually, and defined thresholds. A table has been added with the different criteria for each water masses. Our interpretation for the grey data is mainly mixed water between several water masses. Some grey data (near Guadeloupe for example) might belong to another water mass, but in this study, we don't analyse the near-island water properties (mainly because satellite SSS might be doubtful there).

	NASW	NBC	Modified NBC	Freshplume	Shelf	Filament
Temperature (°C)	<27.2	> 27	27.16 < SST < 27.6		< 26.6	< 27.4
Salinity	35 < SSS < 36	> 36	> 35.6	< 34.5		35.8 < SSS < 36.3
Chlorophyll-a (mg.m ⁻³)	< 0.14	< 0.14	0.11 < Chla < 0.25	> 0.25	> 0.25	> 0.25

Table 1. Thresholds in SSS, SST and Chla used to define the 6 water masses identified.

I297 You should refer to this as simply 'NBC' rather than surface-intensified. It took me awhile to work out that this wasn't 'modified NBC' with a different name. Or rephrase along the lines of 'The NBC, intensified at the surface,...'

Thank you, we rephrased.

I334 was it likely to be affected by topography in this area?

Yes, indeed, we reckon that its stationary position is driven by the topography as well.

I345 ...processes are...

done

I355 SSS<34.5 appears to be the only necessary criterion in Fig 4b - is the chla limit a threshold or an observation?

It is an observation, so we removed the chla value as it is not a threshold.

I366-7 please quote the background silicate for comparison

done

I371 ...and modifies...

done

I380 Are you confident it's both? I don't think you have any independent measurements. If not, I suggest 'and/or'.

done

I386 ...A2's westward...

done

I387 from Fig 4b it looks like SST goes down to about 26.8C. Which of these are thresholds and which observations?

All thresholds are now mentioned in a table, so the text is observations.

I399 ...CO2 flux maps... Are these calculated from mean dfCO2 and everything else daily?

We first computed CO2 flux maps for every available day (so that eventual correlation between dfCO2 and exchange coefficients are taken into account), and then averaged over the month of February. The only parameter constant is the atmospheric CO2 concentration, taken as the value in Barbados for February 2020, while other parameters are at a daily resolution.

I400 Oddly vague - what is the resolution?

The resolution is a blend of the resolution of the 3 satellites product used, so on the order of 60km for salinity, whereas data are reported at higher resolution (~2.5 km) for SST and Chla. We expect the fCO2 product to have therefore a resolution close to 2.5 km, but changing depending on the dominant relation (fCO2 to T,S or Chla). We added this precision to the manuscript.

I407 (and abstract) personally, I consider /month to be a mangled unit, especially since your data comprise a subset of February! Why not quote /day, valid over the day range used for the calculation?

Thank you for this interesting comment, we chose this unit to facilitate the comparison with other studies.

I411 Not Feb but Feb 2-19

Done

I420 ditto

Done

I424 The two NBC...positive air-sea CO2 flux average in early to mid-February.

Done

l427-8 ...over 18 days

Done

l430 ...on average in early to mid-February...

Done

l441 ...in early to mid-February

Done

l456-7 ...associated with...

Done

l459 Is this how you did it? I thought it was T, S and C thresholds!

Indeed you are right, it is through T,S and C thresholds. The boundaries are time varying and we removed the word "geographical" that could confuse the reader.

l464-8 It would be easy to calculate overlaps between your water masses and the relevant Longhurst provinces, e.g. 90% of the pixels we classify as NASW are in the NATR province.

Thank you for this interesting suggestion. This part has been modified and included in part 3.2, following the suggestions of the referee#3, and is now a bit less at the heart of our study. It would be nevertheless interesting, but a bit challenging since the NATR boundaries are quite vague.

l471 ...presents...of air-sea CO2...

Done

l472 ...and in February 2020 we estimate the 5-16N, 59-50W domain to be a...

Done

l473 ...large-scale...

Done

l475 ...considerably smaller in...

Done

l476-8 can you quantify this?

The new figure added gives a qualitative overview of the interannual variability of the fCO₂ in the region to address this issue.

l481 ...and is...

Done

l491 ...current...

Done

l496 ...due both...

Done

l551 ...filaments...

Done

l554 ...plume, water...

Done

l558 ...regimes...

Done

l560 ...in early to mid-February...

Done

l561 You quote 10 times smaller earlier, which is it?

Ten, thank you for noting this mistake.

l561 ...contributes most... or ...is responsible for...

Done

1564 ...contributes almost... or ...is responsible for almost...

Done

1574 ...than those of temperature and...

Done

1588 ..., sampled daily on a 25 km x 25 km grid,...

Done