Response to RC1: Referee #3

Dear editor and referee. Thank you for the very positive feedback and constructive comments on the manuscript. We have modified the manuscript in order to address your comments. Hopefully, the manuscript will appear better organised in its revised form. Our reply to your comments follows in *italic font* below.

Overview

The authors conduct a case study on the air–sea flux in the equatorial Atlantic. They collected pCO2 measurements from several cruises in the under sampled December-February period. They characterise the different water masses they sampled. They develop a relationship to calculate regional pCO2 fields which they use to calculate the regional flux. They identify the flux as being an order of magnitude greater than the Landschützer estimate. They identify the key processes contributing to this flux. This was a really nice paper to read and I found the results interesting. I would suggest publishing this paper following minor revisions.

Major comments

Throughout – At the moment many of your figures are too small. All axis ticks and axis labels need to be much bigger. There are a lot of different colour schemes throughout the figures, e.g. Figure 1 has three different colour schemes. Can they be standardised? Otherwise it is less clear when the colours refer to the regions in figures 4 and 5.

We agree, and all the figures' labels and ticks have been made bigger. Figure 1 has been modified and separated into two figures. We included a panel with the SST on Feb 6th and chose the same colour scheme for SST and SSS in an effort to standardise. We still retained different colour schemes for fCO2 and Chla in order to differentiate these variables.

Title – It would also be nice for the title to reflect the main finding of the paper. At the moment you don't say what the main result was. For example something along the lines of - pCO2 measurements made in the North Brazil Current rings in February 2020 reveals the region as a larger sink for CO2 then predicted by pCO2 climatologies". I am not suggesting using this title but hopefully it points you in the right direction.

We propose:

Wintertime process study of the North Brazil Current rings reveals the region as a larger sink for CO_2 than expected.

Abstract – The abstract needs a bit of work. You have identified the key processes but it isn't clear when and where they are important. This information is in the text but the abstract needs to stand up on its own. You also need 1 sentence at the beginning saying the wider context of the problem, 1 sentence explaining what these eddies are/ how they form and 1 sentence saying how they might impact the flux. Or something along those lines. I would advise using the nature abstract template as a guide on how to improve this section. https://unl.libguides.com/c.php?g=51569&p=2633458

Thank you for the reference, we followed the nature abstract guidelines to propose the new following abstract:

The key processes driving the air-sea CO_2 fluxes in the western tropical Atlantic (WTA) in winter are poorly known. It is a highly dynamic region, with expected large role of ocean physics on the variability of CO_2 air-sea flux. In early 2020, this region was the site of a large in situ survey which was put into a wider context through satellite measurements. In this season, the North Brazil Current (NBC) flows northward along the coast of south America, retroflects close to 8°N and pinches off the world's largest eddies, the NBC rings. The rings are formed to the north of the Amazon River mouth, which freshwater export is still significant in winter, despite being a period of relatively low runoff. We show that in February 2020, the region [50°W-59°W – 5°N-16°N] is a CO_2 sink from the atmosphere to the ocean (-1.7 $TgC.month^{-1}$), a factor of 10 greater than previously estimated. The spatial distribution of CO_2 fugacity is strongly influenced by eddy stirring south of 12°N. During the campaign, a nutrient rich freshwater plume from the Amazon River is entrained by a ring from the shelf up to 12°N leading to high phytoplankton concentration and to a significant carbon drawdown (~20 % of the total sink). Trapping equatorial waters, the NBC rings themselves are a small source of CO_2. The less variable North Atlantic subtropical water extends from 12°N northward. They represent ~60 % of the total sink due to their lower temperature associated with winter cooling and strong winds. Our results, in identifying the key processes influencing the air-sea CO2 flux in the WTA, highlight the role of eddy interactions with the Amazon River plume. It sheds light on how the previous lack of data impeded a correct assessment of the flux, and on the necessity of taking into account features at meso and small scale.

Introduction – A well written introduction. The thing I feel is really missing here is a full size schematic of the region. You need to label all the currents (with arrows) and locations you mention in the introduction. Unless the reader is extremely familiar with the region they will not be able to visualise anything. This becomes important later when you start discussing the cruise track. On a read through it would be great for you to at least label the following North Equatorial Counter Current, NBC retroflection region, the Caribbean, Lesser Antilles, Amazon River plume, Trade wind region, Eddy Boulevard. Currently figure 1 is not that helpful. You show these fields but without a schematic of the circulation/currents it isn't particularly useful. Please add a locations/ currents map as a large subplot to figure 1 at least.

Thank you for the suggestion. We now dedicate one Figure to a schematic figure (see below), where we describe the circulation and add the name of most places discussed in the paper on top of a snapshot of SSS and of the Landschützer20 climatology.

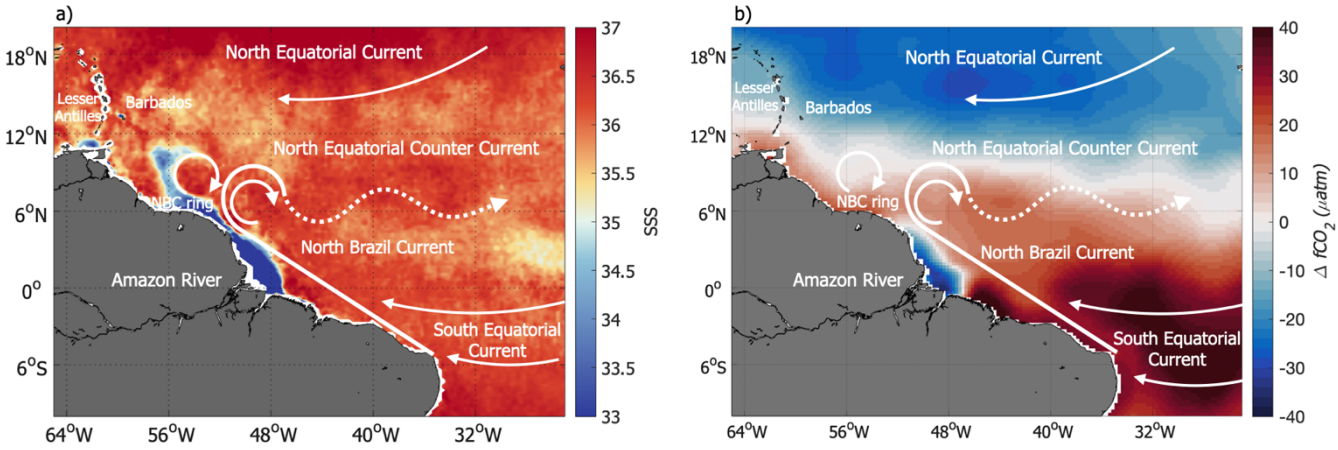

Figure 1: Schematic of the main ocean currents in the western tropical Atlantic superimposed over the SSS field of Feb. 7th 2017 (a) and over the February ΔfCO_2 climatology from Landschützer et al., 2020 (b).

Methods – You need to provide a date for the data, at the moment you state January and February. Either as another subplot by day of year or state them in the text and figure cation. As it stands we don't know how far apart the measurements were made from each other, they could be 1 week or 8 weeks. Figure 2a - c are very much results, so move them there. Perhaps have a cruise track by DOY here instead. Then move Figs 2a-2c to the results. Section 2.2 is nicely written. I feel there is some missing detail here on justifying the choice of datasets though, you need to rationalise why you have used SMAP over ESA CCI SSS for example. In section 2.3.2 you verge into results and begin to discuss them. Be careful of doing this. See lines 214 to 226. I realise you use fig 3 to get the relationship you use to generate your maps but consider moving it to the results.

The cruise dates for all ships have been included in the text, and we added as suggested a panel with the cruise track coloured with the DOY. We detailed a bit more our choice of the salinity product in the manuscript. The SMOS/SMAP blend from Reverdin et al., 2021 used in this study has been developed especially for this cruise at a shorter temporal resolution than the ESA CCI SSS product. It provides the salinity at a temporal resolution of 1 day, combining 6 am and 6 pm measurements. The ESA CCI SSS has a temporal resolution of 7 days, therefore is less adapted to study the fast-varying Amazon plume in our study.

A part of 2.3.2 has been moved to results, as well as Figure 3 that has been combined with Figure 4, thank you for the suggestion.

Results – If you talk about Figure 1 here bring it down to results. Figure 4 and 5 are really great. It would be nice if you had a table describing the criteria for each of the 6 water masses. This will make it easier to quickly reference backwards and forwards.

Please number and or define the water masses as you introduce them. It isn't clear whether lines 290 to 203 describe some of these water masses. Section 3.3,3.4,3.5,3.6 are nicely done. Figure 10 is also really nice, maybe you can discuss this further.

Figure 1 has been moved to results. Thank you for the nice comments on the figures. A table with the water mass criteria is a great idea and is now added.

	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 < Chl*a* < 0.25**	**> 0.25**	**> 0.25**	**> 0.25**

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

Discussion – Section 4.1 seems out of place. Combine with section 3.2 at the start of the results where you define the water masses. In lines 477 and 478 you say that the inter annual signal can't explain the entirety of the differences, this is a really important point but you don't back this up with hard evidence. Did you try to do an extrapolation for any other years? The appendix figure and table are proof of the method working and I feel justify their place in the main manuscript. The appendix figure is not clear, there doesn't appear to be anything superimposed on it? What is missing is a 10 year timeseries of the winter pCO2 fields using your relationship, it would be nice to visualise the interannual flux variability as a bar chart (maybe split by your 6 regions).

As suggested, we combined part of section 4.1 with section 3.2. Regarding the interannual signal, we decided to add a Figure presenting the fCO2 reconstructed at chosen dates over the last 10 years (see below). They are chosen to highlight the variability of the fCO2 in the region linked to the interactions between the NBC ring and the Amazon plume. The figure illustrates the different fresh plumes observed for different years and the impact on the fCO_2. It also shows the smaller variability of the northern part. The in-depth study suggested here is a very good idea, and will be the object of future research. The appendix figure has the fCO_2 measured by the ship superimposed over the map of reconstructed fCO2. They matched quite well and so were hard to distinguished. We added a black contour to delineate the ship track.

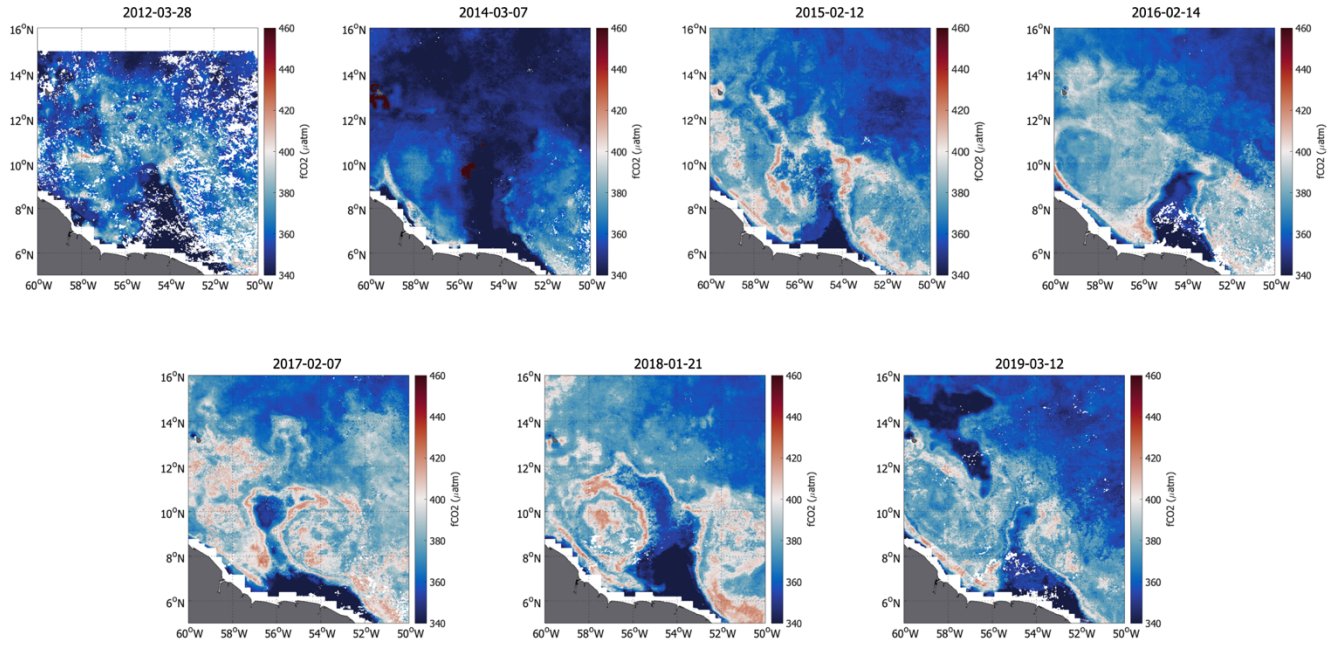

Figure 2: Snapshot of reconstructed fCO2 for all occurrences of fresh plumes extending at least to 10°N and east of 56°W in January-March 2010-2019 (2010, 2011 and 2013 do not present this type of event).

Minor comments

- Line 1 - The title should read as "The" Impact of North Brazil Current rings on air-sea CO2 flux variability in winter 2020.

  The title has been modified.

- Line 13 – this should just be pass

  This line has been changed

- Line 19 – factor of 10 might be changed. You could also say underestimated by 1 order of magnitude. You also need to be clear this is WRT to L20 climatology.

  Done

- Line 22 – is this 20% of the -1.7Tg month? May say the size as well as the percentage?

  It is 20% of the -1.7 Tg month^{-1}

- Line 23 - The spatial distribution of

Done

- Line 23 – 'On the other hand' is not really the right term here. You mean 'in contrast'. Where is the detrital material acting as a CO2 source?

  We removed this part from the abstract. The detrital material from the shelf stirred into the open ocean acts as a CO_2 source.

- Line 24 – It is not clear why 12 degrees north is an important threshold from the abstract.

  Barbados island at ~12°N approximately delimits the trade wind influenced region from the NBC influenced one.

- Line 30 –"retroflects" is a term I've never heard before. Be aware that some readers even with a strong oceanography background may not be familiar with this. I strongly recommend explaining it here or using another description like " doubles back on its self".

  We added a definition of the word in the introduction.

- Line 35 – Is the NBC retroflection region where the rings pinch off or where they travel across?
  The retroflection pinches the rings: this is mentioned in more details on line 60.
- Line 37 – For something extensively studied is there not more recent literature? A 2002 reference predates satellite salinity
  It is a valuable comment: we cite papers on the NBC rings up until 2020 (Aroucha et al., 2020, line 73). Line 37 emphasizes the important work done during the NBC ring experiment period, described in the paper of Wilson et al, 2002.
- Line 52 – please edit this, the way it is written makes it sound like the ocean is causing ocean acidification.

  True, thank you, we modified.

- Line 54 – remove "continuously". It is technically not correct as there is a seasonal signal each year that reduces atmosphere global pCO2.

  Indeed, thank you for noticing.

- Line 71 – edit needed. "The minimum plume extend occurs ". Please be careful when referring to seasons near the equator, it may be better to do month X–month Y.

  Agreed, replaced by month X to month Y.

- Line 109 – why is this separate paragraph. You can merge it with the paragraph before.

  Done

- Line 127 – Should this not reference Takahashi 1993?

  This references the online pCO2 dataset used in this study (Olivier et al., 2020). We modified a bit the sentence to avoid confusion, and added the reference to Takahashi 1993.

- Line 128- Can you state the style so the reader doesn't have to look it up e.g. showerhead, membrane, bubble?

  Done

- Line 133/134 – You need to describe the methods here. At least one reference to another paper is required.

  We added this information to the manuscript: DIC and TA were measured at the SNAPOCO2 by potentiometric titration using a closed cell, following the method of Edmond (1970). Nutrients were conserved by heat pasteurization and analysed by colourimetry at IRD LAMA service in Brest.

- Line 141 – 142 – Can you provide a reference here please
  Reference added: Tennekes 1973
- Line 145 - replace "inferior" with "less than" . Also was this comparison at the same time? Hours apart days?
  Replaced. It was at the same time, we added this information to the text, and it is now visible on the new Figure 2 with the DOY period.
- Line 154 – How did you check this? Please add the details here or the supplement

  Thank you. We checked it by removing a bias of 6muatm on the Merian data and reconstructing again the flux over our region. We then analysed the differences between the maps with and without the bias. We added the information in the text.

- Line 170 – convention to not use PSU or pss. Please check throughout for this

  Checked and modified, we still mention that practical salinity is used in this study.

- Line 243 – Would be really nice for you to give the relationship here. Other researchers may want to use it.

The method does not produce a direct relationship but rather a mathematical object called "interpolant" that can be used as to compute the fCO2 for a combination of T,S,Chla.

- Line 258 – it is hard to visualise this grid without drawing it on a map

  Thank you for the interesting suggestion, this grid is interesting to observe in 3D indeed.

- Line 264- Comparisons with the Landschützer product would be best saved for the discussion.

  Thank you for the comment, most of the comparison with the Landschützer product is indeed saved for the discussion.

- Lines 265 -268 and 274-275– This is introductory material. Why is it in results?

  This part describes the dynamics of the region, it is indeed a bit introductory and we moved some of it in the introduction.

- Line 302 – Can you change your dates to mmm-dd. Some American readers are confused by dd/mm.

  Done

- Line 507 – Are there really only 4 cruises over this time period?

  We chose one cruise per water mass we described. For some water masses (such as the shelf one), no cruise was available