

Dear Editor,

We thank the reviewers for their support and comments. We have modified the manuscript according to these comments and queries and we think that this largely improved our manuscript. Please find a detailed response to each questions/comments point by point below in ***bold blue italics*** (text fragments are *in blue italics*).

My address:

Roland Séférian

Laboratoire des Sciences du Climat et de l'Environnement (IPSL/CEA/CNRS)

L'Orme des Merisiers - bat. 712, point courrier 132

91191 Gif-sur-Yvette / France

Tel: +33 (0)1 6908 4214

Fax: +33 (0)1 6908 3073

Email; [roland.seferian@lsce.ipsl.fr](mailto:roland.seferian@lsce.ipsl.fr)

We hope our manuscript meets the high standards for publication in *Earth System Dynamics* and look forward to your response in due course.

Sincerely,

Roland Séférian

## **Reviewer #1:**

This is a well-written and scientifically sound manuscript that significantly adds to our understanding of internal variability in ocean carbon fluxes on interannual and decadal timescales. I fully support its publication in Biogeosciences, provided that the following minor comments are addressed.

*We thank the reviewer for his/her support.*

*In the following lines, we have addressed the reviewer's requirements point by point.*

Minor comments:

p 1348, Line 17: Remove "But" at the start of the sentence

*done and acknowledged*

p 1350, Line 13: replace "has been an" with "have been"

*done and acknowledged*

p 1351, Line 9: replace "mean" with "way"

*done and acknowledged*

p 1353, Line 23: replace "shows" with "show"

*done and acknowledged*

p 1353, Line 24: replace "compares" with "compare"; replace "term" with "terms"

*done and acknowledged*

p. 1354, Lines 3-5: please describe how the drifts were removed

*We have added a few lines in order to better describe the methodology.*

*Indeed, the drifts have been removed by computing linear trends from ordinary least-squares regression of a given variable against time.*

*"As described in (Boer 2000; 2004), drifts in the variables matter for assessing low-frequency modes of variability. We have therefore removed drifts of ocean carbon fluxes and carbon-related fields, which have been estimated from linear least-square regression in function of time for each variable."*

Table 1 caption: change "solely one drivers" to "solely one driver"

*done and acknowledged*

p. 1354, Lines 15-16: replace two instances of "in average" with "on average"

*done and acknowledged*

p 1354, Line 15: remove the negative sign in front of "40 g C m<sup>-2</sup> yr<sup>-1</sup>"; you have already mentioned that it is a sink, and a negative sink implies a source.

*done and acknowledged*

P 1354, Line 20: replace the comma "," with the word "do"

*done and acknowledged*

P 1354, Line 25: remove "now"; replace "global" with "globally integrated"

*done and acknowledged*

Figure 2a: are you plotting annual mean, globally integrated fluxes here? If so, state this in the caption.

*done and acknowledged*

P 1356, line 26: replace "amounts" with "account"

*done and acknowledged*

Figure 4 caption, second-to-last sentence: change “components” to “component”

*done and acknowledged*

Figure 4: label the x-axis

*done and acknowledged*

P 1359, line 11: change “correlation” to “correlations”

*done and acknowledged*

P 1359, line 17: change both instances of “definition” to “definitions”

*done and acknowledged*

P 1363, line 13: insert “the” before “long-term”; change “profile” to “profiles”

*done and acknowledged*

P 1363, line 19: change “profile” to “profiles”; remove “a” before “strong”; replace “gradient” with “gradients”

*done and acknowledged*

P 1363, line 23: add “The” before “statistical”

*done and acknowledged*

Figure 10: what are the vertical lines in plots j, k, and l?

*The vertical lines indicate 5-95% confidence intervals of the slopes.*

*We have added this information in the text and in the figure’s caption.*

P 1365, line 18: change “others” to “other”

*done and acknowledged*

P 1366, line 13: insert “do” before “modes”

*done and acknowledged*

P 1366, line 17-18: change “as others variables” with “and other variables”

*done and acknowledged*

p 1366, lines 23-27: consider citing (Lovenduski et al., 2013), who examine wind-driven, multi-decadal variability in the Southern Ocean and emphasize the importance of eddies in the transport of natural carbon

*We have added this reference, which clearly fits with the scope of the study.*

p. 1367, line 3: what is meant by “delta or biases correction methods”? Please clarify

*Delta or biases correction methods are usually employed to project model long-term trends on observed fields for a given variables. These methods are derived from perturbation method introduced in (Sarmiento, Orr, and Siegenthaler 1992).*

*“Our results demonstrate that care should be taken while analyzing short-term changes with delta or biases correction methods, which consist in applying model anomaly to observed fields (Sarmiento, Orr, and Siegenthaler 1992). Indeed, these methods generally assume that the long-term mean state does not affect the variability, while our results demonstrate that it does matter in some oceanic regions like the Southern Ocean and the North Pacific.”*

p. 1367, line 9: remove “then”

*done and acknowledged*

p 1367, lines 13-15: why is the Lenton et al (2009) a possible alternative? Please clarify

*This statement was referring to the methodology employed in Lenton et al., 2009 to determine an optimal sampling in order to assess long-term changes. This kind of strategy would be useful to assess the minimum number of year needed to disentangle low-frequency variability from year-to-year fluctuations.*

*“Both issues are important, but the observational needs are different. It seems that the observational needs are larger in oceanic regions where low frequency modes of variability take place than in those dominated by the interannual variability. Yet, relevant spatiotemporal scales are unknown to ensure an optimal and efficient sampling strategy.”*

p 1367, line 17: “useful” is misspelled; replace “that” with “this”  
*done and acknowledged*

## **Reviewer #2:**

This is a very interesting paper addressing the decadal variability of carbon fluxes. I enjoyed reading it and support its publication in Biogeosciences, subject to minor revisions.

*We thank the reviewer for his/her thoughtful comments.*

### **Minor comments:**

Throughout the text: the authors use the abbreviation “fCO<sub>2</sub>” for ocean carbon fluxes. This can be misleading since fCO<sub>2</sub> is often utilized as an abbreviation for surface water fugacity of CO<sub>2</sub>. I recommend choosing another abbreviation.

*We agree that the abbreviation fCO<sub>2</sub> is misleading because it refers to the fugacity of CO<sub>2</sub> into seawater. We have changed it for fgCO<sub>2</sub>, which is the abbreviation chosen in CMIP5 for the ocean carbon fluxes.*

p. 1348, lines 4-6: The sentence is ambiguous. Consider reformulating (e.g. “...can really be attributed to anthropogenic climate change or if they have to be attributed to natural climate variability”).

*We have reformulated this sentence:*

*“However, it remains unclear whether detected changes over the recent time period can be attributed to anthropogenic climate change or rather to natural climate variability (internal plus naturally forced variability) alone.”*

p. 1348, line 17: remove “But” at the beginning of the sentence

*done and acknowledged*

p. 1350, line 13: replace “have been” with “has been” and “fields of research” with “field of research”

*done and acknowledged*

pp. 1350-1351, line 25-line 1: consider reformulating the sentence as it is ambiguous (e.g. “This limitation can be illustrated by considering the North Atlantic for investigating.....Here, ocean reanalysis...”).

*done and acknowledged*

p. 1351, lines 4-8: consider reformulating the sentence as it is ambiguous (e.g. “or merely considered in the terms of individual long-term stations ...”).

*done and acknowledged*

p. 1351, lines 10-11: replace “be the minimum amount of data” with “include the minimum years of data”

*done and acknowledged*

p. 1352, line 16: does “their” refer to “macronutrients and iron”? If so, the second part of the sentence is unclear. Consider reformulating.

*We have reformulated the second part of the sentence, which do refer to the HNLC representation.*

*“Macronutrients (nitrate, ammonium, phosphate, and silicate) and the micronutrient iron limit phytoplankton growth and thus ensure a good representation of the high-nutrient low-chlorophyll regions (Aumont and Bopp 2006; Aumont et al. 2003)”*

p. 1352, line 25: replace “assessment of IPSL-CM5A-LR’s marine biogeochemistry modern-state” with “assessment of IPSL-CM5A-LR’s modern state of marine biogeochemistry”

*done and acknowledged*

p. 1353, line 7: add comma after “Secondly” p. 1353, lines 3/ 7/ 14: no comma after “here”

*done and acknowledged*

p. 1353, line 12: replace “the” with “a”  
*done and acknowledged*

Table 1: consider replacing “of solely one drivers (i.e. T/SST, S/SSS, DIC or Alk) compared to the fully-driven ocean carbon fluxes” with “different combinations of temperature (T), salinity (S), dissolved inorganic carbon (DIC), and alkalinity (Alk)”

*The caption of the Table 1 has been made clearer thanks to the comment of the reviewers #1.*

p. 1353, line 23: replace “shows” with “show”  
*done and acknowledged*

p. 1353, line 24: replace “compares” with “compare” and “term” with “terms”  
*done and acknowledged*

p. 1353, line 24: add “with a correlation of” in front of “R”  
*done and acknowledged*

p. 1353, line 26: the abbreviation “fCO<sub>2</sub>” is not introduced in the text  
*done and acknowledged*

p. 1354, line 3: please add a short description of the approach  
*done and acknowledged*

p. 1354, lines 15/ 16: replace “in average” with “on average”  
*done and acknowledged*

p. 1354, line 14: please specify what is illustrated in Figure 1a (the inverse modeling estimate? The simulated carbon fluxes?)  
*done and acknowledged*

p. 1354, line 19: add “simulated” in front of “ocean carbon fluxes”  
*done and acknowledged*

Figure 1: please specify in the caption where the ocean carbon fluxes in Figure 1a) originate from (the inverse modeling estimate? the simulated carbon fluxes?) and enlarge the labeling  
*done and acknowledged*

Figure 1b: parts of the labeling are cut off  
*done and acknowledged*

p. 1354, lines 23-24: compared to Figure 1b, it looks like there is stronger outgassing of carbon in the southern sub-polar Atlantic than in the polar southern Pacific (and not in the southern sub-polar Pacific)  
*done and acknowledged*

p. 1354, line 27: please state shortly how the variances were time-filtered  
*done and acknowledged*

Figure 3: please correct the caption (the second reference to Figure 3a is incorrect and the reference to Figure 3b is missing “...and (b) the area-weighted carbon fluxes....”)  
*done and acknowledged*

Figure 3: please replace “a) Ocean carbon uptake Variance” with “a) Ocean carbon fluxes Variance” and “b) Variance of ocean carbon fluxes” with “b) Variance of area-weighted ocean carbon fluxes”  
*done and acknowledged*

Figure 3: please enlarge the labeling

*done and acknowledged*

p. 1355, line 24: clarify in the caption that the tracking is regional (e.g. “Tracking the decadal mode of variability of regional ocean carbon fluxes”)

*done and acknowledged*

p. 1356, lines 3-4: Figure 3a doesn't justify this statement. In the Pacific, the variances of the low latitude North West Pacific are stronger than those found in high latitude regions. And what about the variances of the Arctic?

*This is right. Yet, compare to the other high latitude oceanic regions the Arctic is an exception. We have therefore reformulated this sentence in order to mention the Arctic exception.*

*“Except in the Arctic, the 1-, 5- and 10-yr variances of the high latitude oceans are stronger compared to those found in mid and low-latitude regions.”*

p. 1356, line 4: Is 0.01Pg C yr<sup>-1</sup> the mean difference between variances of high latitude oceans and mid/low-latitude oceans?

*We have removed this number, which does not add further informations than the figure 3.*

p. 1356, line 4: replace “low-latitudes” with “low-latitude”

*done and acknowledged*

p. 1356, line 8: add “which are” in front of “much larger”

*done and acknowledged*

p. 1356, line 26: replace “amounts” with “accounts”

*done and acknowledged*

p. 1357, line 18: add “the” in front of “North Pacific”

*done and acknowledged*

Figure 4a: there is no title

*done and acknowledged*

Figure 4: the x-axis is not labeled

*done and acknowledged*

Figure 4: replace “is indicated by vertical bars” with “are indicated by vertical bars”

*done and acknowledged*

Figures 5/ 6/ 7: replace “into brackets” with “in brackets”

*done and acknowledged*

Figures 5/ 6/ 7, caption: do “spatial correlations” refer to correlations of spatial EOF patterns? Do “temporal correlations” refer to correlations of PCs? Please specify.

*done and acknowledged*

p. 1359, line 10: add “the” in front of “North Pacific”

*done and acknowledged*

p. 1359, line 11: replace “correlation” with “correlations”

*done and acknowledged*

p. 1359, lines 15-16: consider reformulating the sentence (e.g. “AMO and PDO have been estimated from the leading EOF and PC of SST, while NAM and SAM are calculated from those of SLP.”)

*done and acknowledged*

p. 1359, lines 20-24: I am not sure if a correlation of .42 is a good approximation. Please include as well the correlations for NAM and SAM.

*This is right.*

*We have indeed computed these indices with larger boundaries. The canonical boundaries used to computed, i.e., 0°-80°N, gives higher correlations for both climate indices ( $R > 0.7$ ).*

*We have thus reformulated the text in order to add this latter information and also to mention the correlations for NAM and SAM.*

*Here, our definition of AMO and PDO indices on the basis of PCA analysis show a significant correlation ( $> 0.42$ ) with their canonical index estimated from the same 1000-yr long preindustrial simulation. Yet, the computation of these indices is sensitive to the latitudinal boundaries. By computing these climate indices within 0°-80°N, comparison between our definition and their canonical definition gives higher correlations ( $> 0.6$ ). That is, our definition of AMO and PDO mode of variability can be understood as a good approximation of their canonical definition. Same conclusions can be drawn with the NAM and SAM indices since correlations between our definitions and their canonical definition is high ( $R > 0.7$ ).*

Figure 8: replace “compenents” with “components” and “t-test” with “T-test”

*We have added few words to make this sentence clearer.*

*Indeed, the horizontal dashed lines indicate the smallest correlation needed to reject the null hypothesis. In other words, if correlations fall in the interval delimited by theses horizontal dashed lines, they cannot be considered different to 0 at the 95% level of confidence.*

*“Null hypothesis assessed with a t-test...”*

Figure 8: add “and” in front of “sea-level pressure” and remove “carbon fluxes” after “Southern Ocean”

*done and acknowledged*

Table 2: Clarify in the caption how the correlations are calculated. Are the AMO-, PDO-, NAM-, and SAM-indexes correlated with the globally integrated carbon flux or with the regionally integrated carbon flux or with the corresponding leading PC of a specific region? If the table considers regional carbon fluxes, then please specify which region is considered for the displayed correlations. The high correlations between SST-fCO<sub>2</sub> and AMO / PDO are expectable if the AMO and PDA indexes estimated from the leading EOF and PC of SST are correlated to the leading PCs of SST-fCO<sub>2</sub>.

*The carbon fluxes are integrated regionally. Comparison between dynamical indices and carbon fluxes are done in the same region. This means, for example, that the ocean carbon fluxes are integrated with the 20°N-80°N Atlantic region (AMO box) in order to assess the correlation with the AMO.*

*This clarification has been done in the figure’s caption.*

p. 1360, lines 5-6: the correlations between time variability of fCO<sub>2</sub> and fCO<sub>2</sub>-DIC/fCO<sub>2</sub>-Alk/fCO<sub>2</sub>-SSS show approximately the same order of agreement (with negative correlations between time variability of fCO<sub>2</sub> and fCO<sub>2</sub>-Alk/fCO<sub>2</sub>-SSS), while the text seems to suggest that the correlation between fCO<sub>2</sub> and fCO<sub>2</sub>-DIC is better than the correlation between fCO<sub>2</sub> and fCO<sub>2</sub>-Alk/fCO<sub>2</sub>-SSS. Please specify this. Furthermore, a correlation of  $R \sim 0.3$  is still considerable and does not justify the usage of the term “poorly correlated”.

*We agree that the order of agreement between all of these correlations is the same. But, while looking at variability, what matter is the phasing of the fluctuations. In that case, a positive correlation can be understood as a better correlation than a negative correlation. This is the reason why we have concluded that correlation between fgCO<sub>2</sub>-DIC and fgCO<sub>2</sub> is higher than those obtained with fgCO<sub>2</sub>-Alk and fgCO<sub>2</sub>.*

*Finally, we have reformulated the last sentence:*

*“Regarding fgCO<sub>2</sub>-Alk and fgCO<sub>2</sub>-SSS, the leading EOF spatial patterns and the respective PCs do not display correlations as strong as fgCO<sub>2</sub>-DIC and fgCO<sub>2</sub>-SST with the fgCO<sub>2</sub> (Fig.~5b and~d).”*



p. 1360, line 13: replace “index” with “indices”  
*done and acknowledged*

p. 1360, line 18: add “a” before “strong correlation”  
*done and acknowledged*

p. 1360, lines 18-19: replace “Correlation” with “Correlations”  
*done and acknowledged*

p. 1360, lines 21: replace “several site” with “several sites”  
*done and acknowledged*

p. 1360, line 27: add “as well” in front of “for fCO<sub>2</sub>-DIC”  
*done and acknowledged*

pp. 1360-1361, line 28-line 3: The leading EOF of fCO<sub>2</sub>-SST has a spatial correlation of 0.07 and a temporal correlation of -1.e-5 with the fully driven carbon fluxes. How can that imprint a low-frequency signature on the carbon fluxes?

*This statement was referring to the contribution of the PDO fluctuations to the carbon fluxes variability within the North Pacific.*

*We have reformulated this sentence:*

*“This implies that PDO imprint a low-frequency signature on the ocean carbon fluxes (Valsala et al. 2012), which is perturbed by the contribution of the other drivers to the variability of the North Pacific carbon flux.”*

p. 1361, line 20: Figure 7b exhibits a spatial correlation of 0.33, therefore it should be  $R \geq 0.33$ .  
*done and acknowledged*

p. 1361, line 22: please mention the temporal variability of the other CO<sub>2</sub>-fluxes  
*We have added reference to the figure 7 in which all of the correlations are given.*

p. 1362, line 4: add comma in front of “respectively”  
*done and acknowledged*

p. 1362, lines 23-24: replace “long-term mean and variance concentration” with “long term mean concentrations and associated standard deviations”  
*done and acknowledged*

Figure 9: add the unit to the labeling of the color scale Figure 10: please enlarge the labeling Figure 10: Does variability refer to standard deviation? Please specify.  
*In this figure, variability refers to standard deviation.*  
*We have added this information in the caption.*

Figure 10: remove “the” from “variance of the Alk, DIC, S and T”  
*done and acknowledged*

Figure 10: please specify that the confidence intervals are marked by vertical error bars  
*done and acknowledged*

Figure 10: please add vertical space between the panels  
*done and acknowledged*

p. 1363, lines 13-14: the convention up to this point was to first name pCO<sub>2</sub> and then the driving variable, but here it is the other way around. Please correct this.

*done and acknowledged*

p. 1363, line 13: replace “profile” with ”profiles”

*done and acknowledged*

p. 1363, line 13: add “The” in front of “statistical” and replace “each” with ”a”

*done and acknowledged*

p. 1365, line 8: do the values (~30-40%) arise from Figure 3c? If so, ~20-40% seems to be more accurate for the North Atlantic.

*done and acknowledged*

p. 1365, line 14: in case of the Subpolar and Polar regions of the Antarctic sector, I would encourage the authors to include furthermore the lower boundaries (25%?)

*done and acknowledged*

p. 1365, line 18: replace “others” with ”other”

*done and acknowledged*

p. 1365, line 25: add comma after “Interestingly”

*done and acknowledged*

p. 1366, line 6: add “and” in front of “not”

*done and acknowledged*

p. 1366, line 13: add “do” in front of “modes” and replace “a given Earth System Model” with “different Earth System Models”

*done and acknowledged*

p. 1366, line 19: add “the considered” in front of “ocean model”

*done and acknowledged*

p. 1366, line 21: replace “region” with “regions”

*done and acknowledged*

p. 1367, line 11: remove “Then,”

*done and acknowledged*

p. 1367, line 13-15: please specify how the study of Lenton et al. differs from this study

*This statement was also pointed out by the reviewer #1.*

*We have answered to his/her questions in the following section:*

*This statement was referring to the methodology employed in Lenton et al., 2009 to determine an optimal sampling in order to assess long-term changes. This kind of strategy would be useful to assess the minimum number of year needed to disentangle low-frequency variability from the year-to-year fluctuations.*

*“Both issues are important, but the observational needs are different. It seems that the observational needs are larger in oceanic regions where low frequency modes of variability take place than in those dominated by interannual variability. Yet, relevant spatiotemporal scales are unknown to ensure an optimal and efficient sampling strategy.”*

p. 1367, line 17: replace “usefull” with “useful” and “that” with “this”

*done and acknowledged*

*References:*

- Aumont, O., and Laurent Bopp. 2006. "Globalizing Results From Ocean in Situ Iron Fertilization Studies." Global Biogeochemical Cycles 20(2): GB2017.*
- Aumont, O., Ernst Maier-Reimer, Stéphane Blain, and P. Monfray. 2003. "An Ecosystem Model of the Global Ocean Including Fe, Si, P Colimitations." Global Biogeochemical Cycles 17(2): 1060.*
- Boer, G J. 2000. "A Study of Atmosphere-Ocean Predictability on Long Time Scales." Climate Dynamics 16(6): 469–77.*
- Boer, G J. 2004. "Long Time-Scale Potential Predictability in an Ensemble of Coupled Climate Models." Climate Dynamics 23(1): 29–44.*
- Sarmiento, Jorge L, James C. Orr, and Ulrich Siegenthaler. 1992. "A Perturbation Simulation of CO<sub>2</sub> Uptake in an Ocean General Circulation Model." Journal of Geophysical Research 97(C3): 3621–45.*
- Valsala, V, S Maksyutov, M Telszewski, S Nakaoka, Y Nojiri, M Ikeda, and R. Murtugudde. 2012. "Climate Impacts on the Structures of the North Pacific Air-Sea CO<sub>2</sub> Flux Variability." Biogeosciences 9(1): 477–92.*