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Interactive comment on "Reconstruction of super-resolution fields of ocean pCO$_2$ and air–sea fluxes of CO$_2$ from satellite imagery in the Southeastern Atlantic" *by* I. Hernández-Carrasco et al.

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We thank Dr L. Gregor for his positive and constructive review. Our responses are provided below every comment. Please find enclosed, as supplemental document, a pdf with the new version of our manuscript and a detailed response to the suggestions and comments.

Please also note that we added two co-authors, with their approval, in our publication to be in agreement with the SOCAT atlas rules when using SOCAT in situ data. The

two authors are: M. Gonzalez-Davila and J. M. Santana-Casiano from the Instituto de Oceanografia y Cambio Global, Universidad de Las Palmas de Gran Canaria, 35017, Las Palmas de Gran Canaria, Spain.

GENERAL OVERVIEW

Reviewer: The manuscript uses a combination of remotely sensed low-res air-sea CO2 flux and high-res Chl-a and SST to arrive at high-res air-sea CO2 fluxes. The authors present a method new to this application and the publication fits within the scope of BGD. The manuscript is well written and is relatively error-free with a few inconsistencies in abbreviations. The methodology presented to arrive at a high-resolution air-sea CO2 flux result is comprehensive, but tricky to follow if the reader is not familiar with the jargon. The authors should be aware of this and simplify wording as much as possible. There is no discussion this paper, but given the methodological nature of this study I do not think this is a critical omission. I enjoyed reviewing This manuscript and I think this approach has great potential for high temporal and spatial resolution CO2 surface data with some refinement.

Authors: We appreciate your interest in and support for our work. We have modified the manuscript according to the suggestions and criticisms you have formulated making the manuscript clearer. In particular we have improved the description of the methodology incorporating a scheme of the algorithm so that the reading becomes easier for scientists not familiar with the method.

SCIENTIFIC REMARKS

Title

Reviewer: The title does capture the topic that the paper discusses; however, I do feel that fields of does not contribute to the reader's understanding of the topic.

Authors: We have removed "fields of" in order to make clearer the topic of the paper. The title is now: "Reconstruction of super-resolution ocean pCO2 and air-sea fluxes of

CO_2 from satellite imagery in the Southeastern Atlantic".

Introduction

Reviewer: The introduction introduces the topic well and do reference the appropriate work in most part. However, I feel that the authors should mention statistical learning methods in their introduction. While the approach is quite different it is also a data based approach to derive pCO_2 . Some noteworthy mentions are Landschutzer et al. (2014) and Telszewski et al., (2009). Though none of these methods have focused specifically on coastal regions.

Authors: We have quoted in the introduction (Page 2, lines 77-81) the works by Landschutzer et al, 2014 and Telszewski et al, 2009 on the empirical relationships between ocean variables by using neural networks to estimate maps of pCO_2 .

Data

Reviewer: It is good that the authors use and compare the different datasets.

Authors: We thank the reviewer for this positive comment.

Methods

Reviewer: I like the approach used in this study; however, it is fairly involved and may be confusing for some readers. It is noted that the authors do provide an overview of the methods on page 1415 L21, but it would be useful to have simple overview of the methodology such as that shown below. 1. CarbonTracker provides surface CO_2 fluxes

2. Flux is used to calculate pCO2sea at low resolution (pCO2sea(LR))

3. Use satellite SST, SSS and CCMP for winds

4. F = K(pCO2air -pCO2sea) ==> pCO2sea = pCO2air – F/K

5. Use MMF to extract the dimensionless singularity exponents of SST, Chla, CO2LR

CO2HR from ROMS-BIOEBUS (various resolutions) output

6. Calculate the linear relationship between SST, Chl-a, CO2LR and CO2HR singularity exponents from ROMS-BIOBUS

7. Find singularity exponents of satellite SST, Chl-a and CO2LR

8. Use coefficients from ROMS-BIOEBUS (step 4) and apply to the singularities from the satellite data (step 5) to infer the singularity exponent CO2HR

9. Reconstruct pCO2HR from the cross-scale inference of pCO2LR

10. Calculate air-sea CO_2 fluxes from pCO2HR temperature and wind.

Authors: According with the reviewer suggestion, we have included the following scheme of the algorithm, step by step, at the end of Sect. 3 in order to clarify the methodology used in this study.

i) After selecting a given area of study, compute the singularity exponents of SST, Chl and pCO_2 at low and high resolution from ROMS-BIOEBUS outputs. This is done once and then they can be used for every computation performed over the same area.

ii) Using Eq. 2 estimate ocean pCO_2 at low resolution: pCO2sea = pCO2air – F/aK , where:

- F is the surface CO_2 fluxes provided by CarbonTracker product. - K is the gas transfer velocity obtained by the parametrization developed by Sweeney et al, 2007, as a function of wind. - a is the gas solubility derived according to Weiss 1974. - pCO2air is provided by Globalview-CO2 product.

iii) Obtain the regression coefficients a, b, c and d of Eq. 3 for the singularity exponents obtained in step i).

iv) Calculate the singularity exponents of available satellite SST, Chl at high resolution and pCO2sea at low resolution (step ii).

v) Use coefficients obtained in step iii) and apply Eq. 3 to the singularity exponents from satellite data (step iv) to estimate a proxy of singularity exponents of high resolution ocean pCO2 , S(pCO2).

vi) Using Eq. 4 reconstruct p CO2 at high resolution from the multiresolution analysis computed on signal S(pCO2) and cross-scale inference on p CO2 at low resolution.

vii) Use Eq. 2 to calculate air-sea CO2 fluxes from the inferred high-resolution pCO2 obtained in step vi).

Reviewer: I like the use of model data (ROMS-BIOEBUS) to estimate the MLR coefficients and estimating the accuracy of the method. This does make the assumption that dynamics of SST, Chl-a and pCO2 in the model and satellite data operate on the same scale. The authors do allude to this and justify the adequacy of ROMS-BIOEBUS. It would be good if this inference were stated a bit more explicitly. Perhaps a figure showing the PDFs of the ROMS-BIOEBUS data would address this concern?

Authors: The use of ROMS-BIOEBUS outputs to obtain the regression coefficients does not make the assumption that dynamics of physical and biogeochemical variables of the model and satellite data operate at the same scale. However the singularity exponents (dimensionless values) of these variables (pCO2, SST, Chl) do present a functional relationship between them, whether we look at model outputs or satellite data. The ROMS-BIOEBUS capability to represent SST, SSS and density fields in the Benguela has been evaluated comparing the outputs of the model with annual and seasonal CARS climatologies (see Gutknecht et al., 2013 for more details).

Reviewer: The authors mention an error of 2.4 matm when the method is applied to ROMS data. A relative error of 0.6% is given - relative to the pCO2 range? This is a small error relative to the range of pCO2 . What is this average difference/error between the ROMS high-res and the ROMS low-res data? An error relative to the (high-res/low-res) may be more telling.

Authors: We have recomputed the mean absolute error over the 10 years climatology for the dual ROMS simulations and found 3.02 μatm and a relative error of 0.89%. These values are slightly higher than those mentionned in the original manuscript since we had only considered the last year of simulations. We have included these new results in the corrected manuscript (lines 582, 583). As suggested by the reviewer, we have computed the absolute and relative errors between High-Resolution/Low-resolution ROMS to compare with the result obtained by our method. First, we resize the low resolution to the high resolution grid without any interpolation (1 pixel of low resolution is resized in 4x4 pixels of the new grid). After this, we compute absolute error = ABS(ROMShr – ROMSlr resized) and the relative error = absolute error / ABS(ROMShr) in each pixel, and finally we compute the mean of absolute and relative error for all pixels of the 360 images corresponding to the ROMS outputs. In doing so, we obtain for the absolute error 12.1 matm and for the relative one 3.6%. In conclusion, our method allows to decrease the relative error from 3.6 to 0.89% when going from ROMS low resolution to reconstructed ROMS high resolution.

Reviewer: The authors also mention a paper by in review Sudre et al. (2015) on several occasions. I do not feel that this will be a problem once this paper has been published; otherwise I do not feel the authors should cite this work.

Authors: The paper by Sudre et al. (2015) was with minor revision and the present status on line in the journal is "with Editorial decision", so we think we can leave it and quote this work.

Results

Reviewer: The use of mean error (ME) here is unusual. For their purpose of use, the use of ME seems OK, but it is essentially the difference of the means of the two datasets (the inference bias). Given its similarity in nomenclature to Mean Squared Error (MSE analogous to AE), I think that the authors should consider a different name for this error. This is especially true, as they do not use it for the same purpose as one would use MSE.

Authors: To avoid misunderstanding, we have modified the nomenclature and in the new manuscript we use mean differences (MD) instead of mean error (ME) for the average of the difference point by point of the different data sources.

Reviewer: It would be good to see (pCO2insitu vs. pCO2ctrack) and (pCO2insitu vs. pCO2infer) plots for more data. Points could be coloured by longitude.

Authors: As suggested by the reviewer we have plotted (pCO2insitu vs. pCO2ctrack) and (pCO2insitu vs. pCO2infer) using all the CarbonTracker and inferred pCO2 values in the intersections with in-situ pCO2 for 2006 and 2008. In Fig. 1 (not included in the manuscript) we show the case for Globcolour OC and OSTIA SST data product combinations. This figure shows that correlation is not entirely satisfactory for both pCO2ctrack and pCO2infer , even if there are more points of pCO2insitu - pCO2infer closer to the diagonal straight line (in black), for instance the cloud of points around 360-370matm. Fig. 2 shows the same as plotted in Fig. 1 but points colored as a function of longitude. For longitudes greater than 10 degrees East (closer to the coast) pCO2ctrack and pCO2infer values are overestimated with more points closer to the diagonal for longitudes smaller than 10 degrees (open ocean region). This can be a sign that near the coast the available input CarbonTracker data are possibly not good enough to capture the variability, whereas the more open ocean areas are better represented in this product.

Reviewer: The comparison of in-situ, inferred and CarbonTracker data shows the potential of the method presented in this manuscript as well as the shortcomings of using Carbon-Tracker data for the estimation of air-sea CO2 fluxes. I think that the authors should briefly state that the output will only be as good as the input.

Authors: As suggested by the reviewer we have added the following sentence in the conclusions (Page 18 and lines 977-983): “The statistical comparison of inferred and CarbonTracker pCO2 values with in-situ data shows the potential of our method as well

as the shortcomings of using CarbonTracker data for the estimation of air-sea CO2 fluxes. From these results it can be said that the outputs of our algorithm will only be as good as the inputs.”

Figures

Reviewer: General comment on line figures: as a colour-blind reader, I struggle to see yellow lines on white background. It is not imperative that this changed, but would be better in a darker shade.

Authors: We have changed the background of the figures with gray colour as suggested by the reviewer.

SPECIFIC COMMENTS

1. Reviewer: P1406 L26. interacts interact

Response: This has been corrected

2. Reviewer: P1407 L19. Let’s cite here the work of. . .This sentence seems a little clumsy

Response: We have reworded the sentence and now it reads: “Among others, we can find the work by. . ..” (Page 2, lines 63-64)

3. Reviewer: P1407 L17-L25. Possible missing citations. The authors fail to mention statistical learning methods and associate literature (Lachkar and Gruber, 2012; Landschutzer et al., 2014; Telszewski et al 2009 and several others)

Response: We have added new references on statistical neural networks (Page 2, line 77-81).

4. Reviewer: P1409 L7. has been proved to be innovative. . . has been proven innovative . . .

Response: Corrected

5. Reviewer: P1409 L16 relates closely the relates closely the - a bit clumsy otherwise

Response: The sentence has been improved

6. Reviewer: P1410 L4 Section 3. Inconsistent abbreviation

Response: Corrected

7. Reviewer: P1411 L12. sea-state Sea state should not be included here as this is part of the parameterisation wind accounts for this.

Response: We wrote K, the gas transfer velocity, is a function of wind, salinity, temperature, sea state, which can be obtained from satellite data. Here we meant K is a function of all these parameters in a general sense. Since bubble mediated gas transfer depends on wave breaking, whitecapping and dispersion by mixing processes in the upper ocean, its environmental dependence (on wind speed, sea state, water temperature..) is a function of the environmental dependence of these processes.

8. Reviewer: P1411 L24 pCO2 -air Authors use Ascension Island as a reference. Would Cape Point, South Africa not be a closer reference? http://www.esrl.noaa.gov/gmd/ccgg/obspack/labinfo.html

Response: Reviewer is right and the Ascension Island station is not the closest one. The Ascension Island station is located at 7.97°S and 14.4°W with an elevation of 54m above the sea level, closer to the equator than our area of study. Another station is located at Gobabed (23.58°S, 15.03°E) but at 456m above sea level. The station at Cape Point in South Africa is closer but at 300m above sea level. We chose to use the Ascension Island because it is closer to sea level. We have clarified this point in Page 4, line 239.

9. Reviewer: P1411 L26. Garbe and Vihharev (2012) approach. Briefly mention what their approach is reader does not know what this approach is.

Response: We have replaced the sentence "For this reason, an approach similar to

Garbe and Vihharev (2012) has been developed and applied to the CarbonTracker data set." by "Garbe and Vihharev (2012) have developed an optimal control approach to invert interfacial fluxes using a simplified inverse problem of atmospheric transport. The inverse problem is solved using the Galerkin finite element method and the Dual Weighted Residual (DWR) method for goal-oriented mesh optimization. An adaptation of this approach has been applied to the CarbonTracker data set." (lines 250-256)

10. Reviewer: P1412 L5 retain very well the structure of the CarbonTracker fluxes. retain the structure of the CarbonTracker fluxes very well

Response: The sentence has been corrected

11. Reviewer: P1415 L21. The idea. Be a little more specific about which idea

Response: The idea refers to the idea behind the methodology. We have clarified this in the manuscript (see line 391).

12. Reviewer: P1415 L26. Partial pressure pCO2. Partial pressure (pCO2)

Response: Corrected

13. Reviewer: P1416 L1. good characteristics. What are good characteristics of a linear regression in this case?

Response: We have removed "with good characteristics".

14. Reviewer: P1420 L11. relative error. Relative to total pCO2. See scientific remarks section for more on this.

Response: We refer reviewer to the detailed response described in the section methods of the scientific remarks.

15. Reviewer: P1424 L18. how different can be the coverage of the pCO2 field can be depending. . .how different coverage of pCO2 can be in the field depending. . .

Response: The sentence has been reworded.

16. Reviewer: P1426 L28. Abbreviations. Why not apply these from the start. They make it much easier to follow the discussion.

Response: As recommended, in the new manuscript we use these abbreviations from the beginning of Sect. Results.

17. Reviewer: P1427 L24. Showing that have of the measurements is geographically in the coastal region of Benguela, outside the. . .Showing that half of the measurements fall within the coastal region of the Benguela (land masked by CarbonTracker)

Response: The sentence has been modified as suggested by the reviewer.

18. Reviewer: P1428 L8. study qualitatively. qualitatively study

Response: Corrected: quantitatively study

19. Reviewer: P1440 Tab4. No valid intersections. Should this be number? If so add No.

Response: 'No' is number. We have replaced 'No' with 'Nb' in order to avoid typing errors in the production process.

20. Reviewer: P1444 Fig3. a, b. Make colour scales the same

Response: In the new Fig. 3a and 3b we have used the same colour scale.

21. Reviewer: P1446 Fig5. c, d, e, f. Ensure that scales are the same for pCO2 and FCO2 for inter-comparison.

Response: We have used the same colour scale pCO2 plots and the same colour scale for maps of CO2 fluxes.

Please also note the supplement to this comment:
http://www.biogeosciences-discuss.net/12/C1685/2015/bgd-12-C1685-2015-supplement.pdf

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Interactive comment on Biogeosciences Discuss., 12, 1405, 2015.

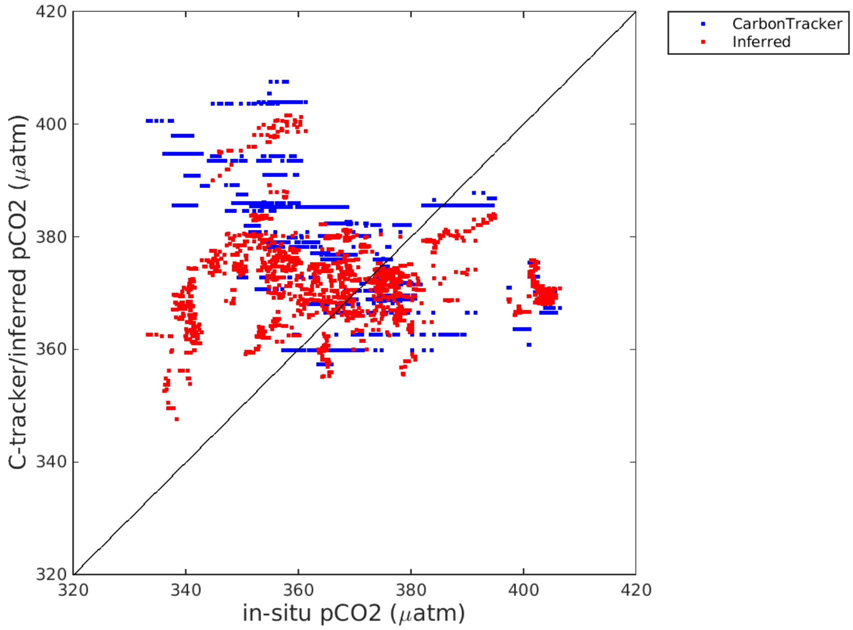

Fig. 1. Scatter plot showing pCO2 values from CarbonTracker vs in-situ (in blue) and inferred vs in-situ (in red) at the intersections.

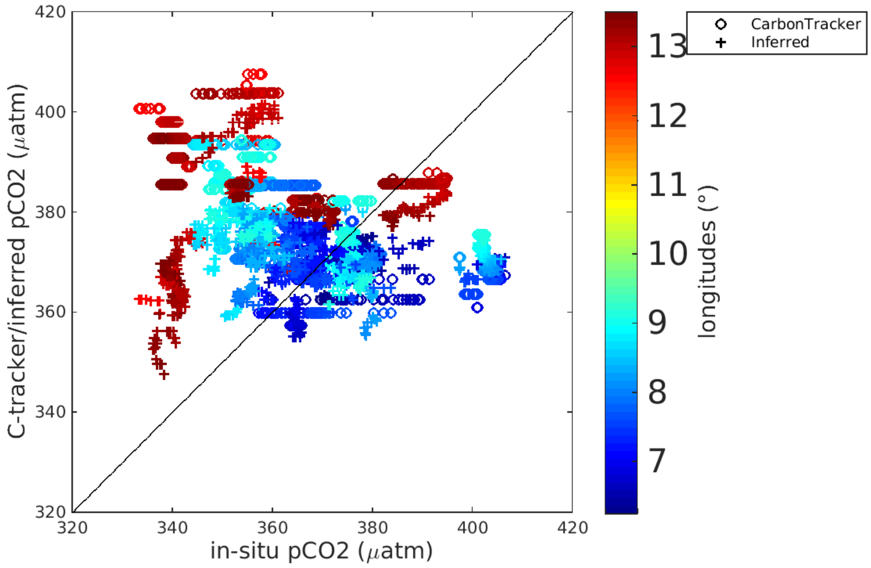

Fig. 2. The same as Fig. 1 but coloured as a function of longitude.