**Anonymous Referee #2**
Received and published: 27 July 2009
Review of the manuscript submitted to Biogeosciences
Title: Air-Sea CO2 fluxes in the Atlantic as measured during the FICARAM cruises
Author(s): X. A. Padin et al. MS No.: bg-2009-113
Decision: This manuscript is not acceptable for publication in its present form
General comment:
This paper presents new observations of sea surface pCO2 (or fCO2) in the Atlantic Ocean for the period 2000-2008 from cruises regularly conducted along long transects from Europe to Antarctica during spring and autumn. In the context of international pCO2 data synthesis and global carbon budget estimates, this study represents very important complementary data and should be published. However, the manuscript is somehow presented like a cruise report; discussions and interpretations are lacking, especially regarding previous works in the same regions. It is not easy to know what new results/informations have been obtained from this impressive 8 years of data.

Other comments:
1) Abstract: line 8: Authors indicate: -The obtained spatial and temporal distributions of FCO2 follow the generally expected patterns and annual trends.- However, the paper does not compare the new FCO2 calculations with previous studies and words in the abstract suggest that FCO2 distribution did not really changed over a decade. If this is correct for all regions investigated here, from north to south, this is an important result as this would mean that the ocean carbon sink is not varying, at least in this region.
If this result is robust, authors should highlight this finding in the abstract. However, although the title of the MS calls for FCO2 results, the abstract only recalls one number, the influence of the Amazon River.
**Manuscript has been profusely changed for clarity. The comparison with Takahashi's climatology and other references has been added to the manuscript.**

2) Introduction: authors should recall previous studies that investigate seasonal and interannual variability of FCO2 in the Atlantic ocean. Introduction should include recent observational analysis (e.g. Takahashi et al., 2009; Schuster et al, 2009 and reference herein) and inverse atmospheric methods (e.g. Transcomm). In the atlantic ocean, boardered by continents (large terrestrial source/sink variability) and where few long-term atmospheric CO2 monitoring station exist, oceanic FCO2 observations, as presented in this paper, would greatly help to constraint the global carbon budget. Authors should also indicate what are the current FCO2 errors in the Atlantic Ocean. Is it 0.1 PgC/yr or 1 PgC/yr ? They should also specify what is not known concerning the processes that control FCO2 variability. This would more clearly justify why such long-term oceanic project like FICARAM is

important.
**We have change profusely the text in order to clarity our objectives and the findings of this article.**

**Our study is part of the international effort to achieve the community's goal of being able to constrain the regional fluxes to 0.2 PgC year$^{-1}$ as recommended in Bender et al. (2002). This requires measurements with measurement accuracy of 3-10 µatm (http://www.carboncyclescience.gov). The study of the internal consistence of the *in situ* measurements recorded by our system using alkalinity and pH measurements (Padin et al., 2008) using Lueker et al. (2000) showed a consistence error of ±6 µatm (n = 365; $r^2$ = 0.91).**

3) Introduction page 5591 line 22: authors indicate that FICARAM data are available in several global databases. They should specify where the data are available. For example, using the Mercury search, FICARAM data are not available at CDIAC (see also the link http://cdiac.ornl.gov/oceans/VOS_Program/hesperides.html).
**The Introduction has been modified in order to include the suggestion.**
**The new version of the manuscript is:**

*"The surface $CO_2$ observations collected during FICARAM are part of databases compiled by the projects CARBOOCEAN and SOCAT (Surface Ocean $CO_2$ Atlas)."*

4) Methods: pages 5593 and 5594: during FICARAM, atmospheric CO2 has been regularly recorded (using air pump, DEKABON tube...). However, those data are not used for FCO2 calculations. Instead authors prefered to use NOAA monitoring observations because during some FICARAM cruises atmospheric data are not available (why ?).
**The manuscript has been modified including the explanation of because we use NOAA monitoring observations:**

*"This dataset was preferred to in situ $xCO_2^{atm}$ data due to the lack of these records during the last five cruises on board the B/O Las Palmas. For consistency, measurements from the NOAA/ESRL were used in all cases."*

It would have been interesting to compare FICARAM atmospheric xCO2 data (when available) with those derived from NOAA atmospheric stations. Are the atmospheric data obtained onboard present or not significant deviations from continental and islands records. Are atmospheric xCO2 data selected at monitoring stations have been filtered following air-mass trajectories to discard continental signal? If atmospheric data recorded onboard are not used, why authors describe these data in the methods section?
**The M&M has been rewritten in order to resolve these questions though we**

**do not include description of in situ measurements and the comparison between these and the ones from NOAA atmospheric stations. In any case, the difference between both datasets is 0.0±8.5 µatm (n = 33507; $r^2$ = 0.72)**

5) Methods: page 5595: authors convert pCO2 to fCO2, and then used Takahashi et al 1993 equation (but expressed for pCO2, not fCO2) to correct for temperature (SSTEq). This has certainly no impact on results but this is not recommanded and should be revised.
**The equation has been included as originally described Takahashi et al. (1993).**

6) Methods: page 5595. FCO2 is calculated following equation (3), where "a" is a unit conversion factor. Could you please indicate what is the value used for "a"
**The parameter a is a unit conversion factor that has been removed from this Eq. 3 like most of the papers including the estimation of air-sea $CO_2$ fluxes. *a* is 0.0877 when you use mol $m^{-2}$ $yr^{-1}$.**

7) 2.4 Biogeochemical oceanographic provinces: authors separate different regions based on SST/SSS distribution and some known features such as upwelling, equatorial current, etc... I don't see where biogeochemistry is refered when you select the provinces? Change the title of section 2.4.
**The Introduction has been modified in order to include the suggestion.**
**The new version of the manuscript is:**

*"The study of the meridional distribution of the $fCO_2^{sw}$ measurements in the Atlantic Ocean (excluding the Mediterranean basin) focuses on selected biogeochemical provinces established after Longhurst et al. (1995) and Hooker et al. (2000). Different sections of the FICARAM tracks were allocated in the appropriate following ten regions according to average boundaries established from SST–SSS relationships (Fig. 1)"*

8) 3 Results and discussion: part 3 of the MS presents data and FCO2 calculation, there is no discussion. Change the title of section 3.
**In spite of the manuscript shows a minor discussion, we have kept the name of this section.**

9) Page 5601, line 19: need a reference when quoting upwelling system along Mauritanian coast.
**The text has been modified. The new version of the manuscript is:**

*"...remotely sensed chl a observations that exceeded -50 µatm (Fig. 3d) and 1.3 mg $m^{-3}$ (data not shown) respectively were also observed along the Mauritanian coast (Wooster et al., 1976)."*

10) Page 5601, line 22-23: Authors compare their results for autumn with

annual flux from Takahashi et al. They should compare the results for the same seasons and using the same units.
**In this sense, the article has been modified in order to include the suggestion. So, the new Table 3 shows the comparison of the FICARAM measurements in the ocean waters with the values of the climatology of Takahashi et al. (2009).**

11) Page 5601, line 26-27: Authors compare their seasonal results for the NEC (16N-8N) with annual flux from Takahashi et al over 14N-14S. They should compare the results for the same seasons and regions. By the way, are the FICARAM data included in Takahashi's pCO2 synthesis. If yes, this is strange to obtain different results. If not, I strongly suggest authors to send their data in global databases (as it has been indicated by authors in the introduction, see comment 3 above).
**The FICARAM dataset was not included in the measurements used in the computation of Takahashi's climatology (Takahashi et al., 2009) because of we analyzed only two standard during the calibration and he demands at least three of them. Up to now, the measurements of FICARAM cruises are being flagged in the 2nd level quality control of SOCAT and the preliminary results pointing out the validity of this dataset.**

12) Page 5603: line20-24: authors refered to several studies concerning the Livingston Island but those studies did not investigate this region.
**We agree with your comments. We have decided to modify the manuscript eliminating these references. The new version of the manuscript is:**

*"Despite a $\Delta fCO_2$ value close to the air-sea equilibrium, high WS of up to 10 m $s^{-1}$ through the "furious fifties" of the Southern Ocean resulted in relatively high $CO_2$ emmissions to the atmosphere in the order 1.2±2.5 mol $m^{-2}$ $yr^{-1}$ (Table 2)."*

13) Page 5605: authors refere to decreasing NAO index during the FICARAM experiment; however, in 2001-2008 the NAO index moved from negative to positive values.
**According to Osborn (2007), NAO winter index has declined from the early 1990s until 2005/2006. Moreover SST changes in the North Atlantic Ocean from 1990 to 2006 also showed the influence of this decline (Schuster et al., 2009), with a warming in northern latitudes, no change or a cooling in the mid-latitudes, and a warming in the tropical and eastern subtropical gyre. So, we are not agreeing with your comments.**

14) Page 5606: authors indicate that increase of rainfall and riverine inputs from Amazon explain the observed decrease of SSS. Please add a reference.
**The manuscript has been changed. I have tried to include a significant date or reference showing growing discharges from Amazon River but I did not find anyone of them. In any case, I have consulted Prof. Nathalie Lefevre**

**who deeply studied air-sea CO2 exchanges of tropical waters in the Atlantic Ocean about it. She answered me she found similar results but it is quite complicated identify the forcing of this decline of SSS in the NECC waters.**

**The new version of the manuscript is:**

*"The NECC showed a sustained interannual decrease in SSS (-0.16±0.01 $yr^{-1}$) during the autumn season (Fig. 4d). The low SSS at these latitudes has been attributed to freshwater discharges from the Orinoco and Amazon rivers (Körtzinger, 2003; Ternon et al., 2000; Wanninkhof et al., 2007). The observed SSS drop coincided with a large $\Delta fCO_2$ reduction of -3.5±0.9 μatm $yr^{-1}$, which increased the oceanic $CO_2$ uptake by -0.09±0.03 mol $m^{-2}$ $yr^{-2}$. The continental inputs acted as fertilizers for the tropical surface waters of the NECC region, stimulating the biological drawdown of $CO_2$ (Lefevre et al., 1998; Subramanian et al., 2008)."*

15) 3.4: could you explain why you are using an empirical algorithm to detect the forcing of fCO2 variability.

**Empirical algorithm had been frequently used in order to reproduce the $fCO_2^{sw}$ variability and as extrapolation technique to different geographical scales that included geographical information, temperature, salinity, chlorophyll a, winter mixed layer in different polynomials (Olsen et al., 2004; Wanninkhof et al., 2007; Lueger et al., 2008; Padin et al., 2008; Padin et al., 2009). Furthermore the development of empirical and mechanistically based numerical methods for extrapolating in situ pCO2 data and air-sea flux is recommended to model the upper ocean physics/biogeochemistry and sea surface $pCO_2$ (Bender et al., 2002).**

16) Page 5607: could you justify the use of Lat/Long, SST and SSS second and third polynomials? What are the physical/biogeochemical justifications (meaning) of such selection in the diagnostic model.

**The algorithm is designed to explain the most part of the $fCO_2^{sw}$ variability beyond identify the processes governing these changes. Millero et al. (1998) fitted alkalinity distribution in several oceans using quadratic equation.**

17) Page 5607: I understand you are first normalizing fCO2 at constant SST to establish Equation (4). How this helped to investigate thermodynamic processes?

**The normalizing $fCO_2^{sw}$ at constant SST is done to remove the thermodynamic effect. So, the correlation SST – 'fCO2sw would reflect in certain extend the pH variability of the water masses in relation to SST changes.**

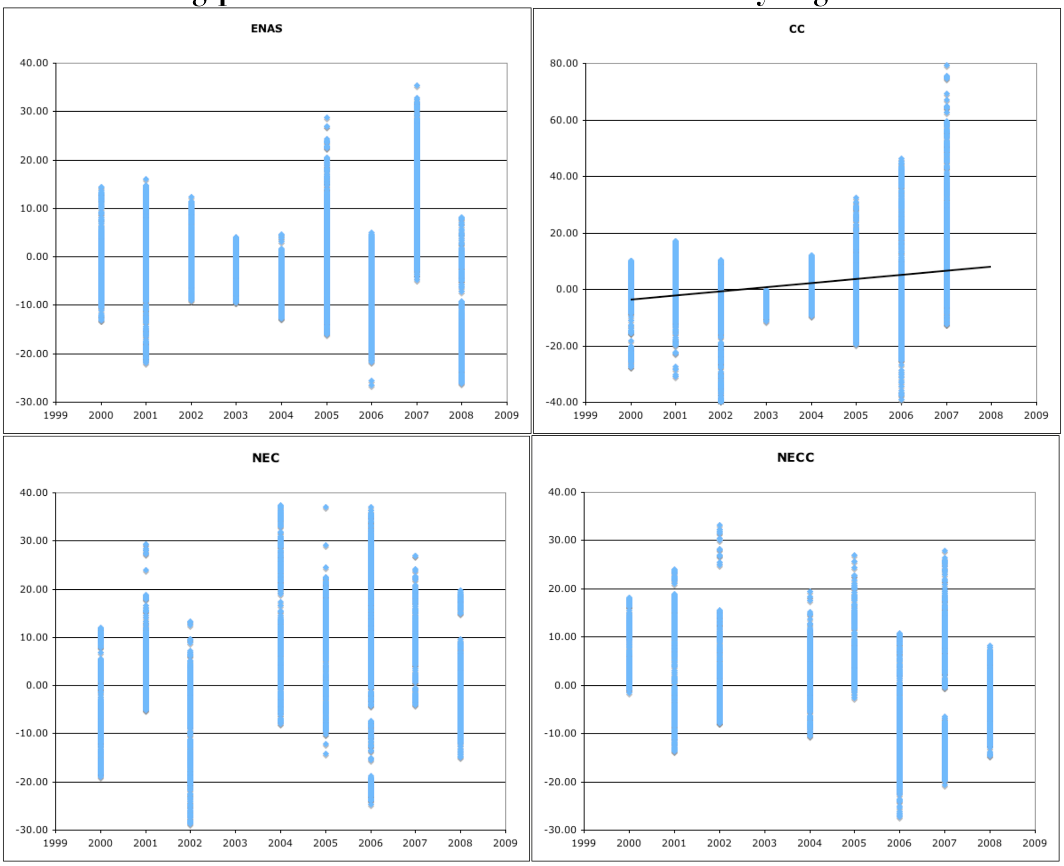
18) Page 5607: before establishing Eq 4, authors adjust fCO2 data to a reference year 2005, i.e. they assume ocean CO2 follows atmospheric trend

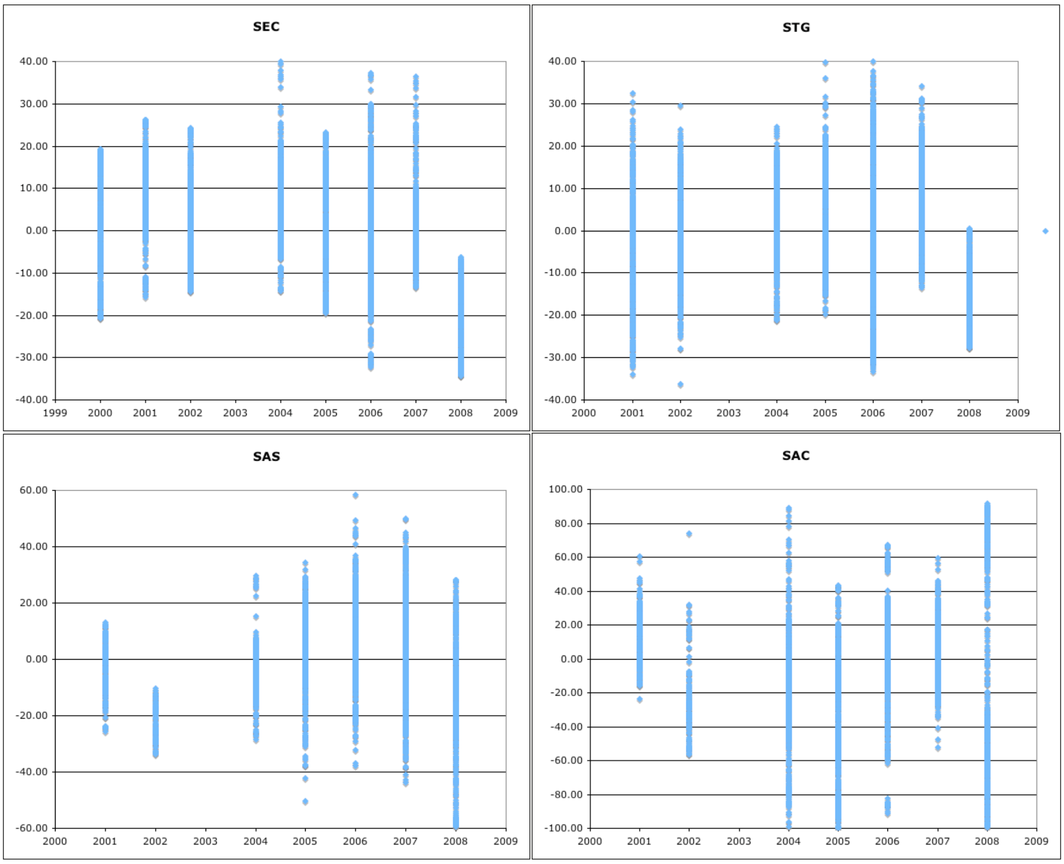
but is it correct ? Recent studies suggest that oceanic fCO2 growth rate is different depending the region and period. Is it realistic to apply the same correction in the Atlantic basin, from North to South? Why not including the period (year) in Equation 4 that may help to separate natural versus anthropogenic CO2 signals.

**Considering the $xCO_2^{atm}$ changes in the different points we are including a particular interannual trend of $xCO_2^{atm}$ that is linearly interpolated from the one observed in the NOAA/ESRL Global Monitoring Division at each latitude of the Atlantic track. Thus, we are considering the spatial and temporal variability of the $CO_2$ increase in the atmosphere.**

**We assume $fCO_2^{sw}$ follows the long-term trend of $CO_2$ in the atmosphere and this is confirmed by the null correlation between the differences between the modelled $fCO_2^{sw}$ and in situ $fCO_2^{sw}$ that means, a similar trend. The exception was found in the CC region that anomalies showed significant changes of $0.60 \pm 0.05$ µatm $yr^{-1}$.**

**The following picture shows these residual for every region:**






19) Page 5608, line 14: authors indicate that in the southern hemisphere fCO2 variability was poorly resolved with the model (their Eq 4) likely due to a larger coastal influence. However, on page 5598, authors specified that they have excluded data in coastal waters. Should you test another data selection for the southern hemisphere?

**The manuscript is refereed to the influence of continental inputs, upwelling events and shelf fronts. Such as it was pointed out on page 5598, we exclude data in proximal coastal waters that is located in a depth shallower than 50 meters. For clarity, the manuscript has been changed:**

*"Consequently, surface (<50 m) coastal waters that corresponded mainly to harbour areas were excluded from the database."*

*"The* $fCO_2^{sw}$ *measurements obtained during the FICARAM cruises were modelled with an empirical algorithm according to their biogeochemical variability and geographical position (Olsen et al., 2004; Wanninkhof et al., 2007; Lueger et al., 2008; Padin et al., 2008; Padin et al., 2009) with emphasis on distinguishing ocean from distal shelf areas."*

20) Figures: figures 2 and 3 are very small; difficult to see all details.

**The Figures have been enlarged for clarity.**

21) There are many references in the text that are not in the reference list: Cooper et al 1998; Richardson and Reverdin, 1987; Richardson and McKee, 1984; Klinck and Nowlin, 1986; Poisson et al., 1994; Pakhomov and Froneman, 1999; etc....

**References has been changed**

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