Interactive comment on "Seasonal variations of sea – air CO_2 fluxes in the largest tropical marginal sea (South China Sea) based on multiple-year underway measurements" by W. Zhai et al.

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Response to Anonymous Referee #2

General Comment:

The authors present a large and interesting dataset for the South China Sea with 14 surveys realized from 2003 to 2008 and a revised estimate of the CO2 flux in this region. The objective of the paper is to assess the seasonal variability of the air-sea CO2 fluxes in 4 different physical-biogeochemical domains. The scientific approach and the methods are valid but the data should be better synthetized to support the points the authors want to make. As it stands the paper does not sufficiently highlight the main features of the dataset. The paper requires some rearrangement before being published.

Response: We thank the reviewer for his/her generally positive reviews. We have made efforts in better presenting the highlights of the paper.

As the paper focuses on the seasonal variability using data from 14 surveys from 2003 to 2008 there is the implicit assumption that the year-to-year variability is negligible. I think this should be discussed and if this hypothesis is validated, four seasonal maps could be presented instead of 3 figures for winter, 2 for summer, and 3 for autumn (figure 2).

Response: In the modified MS, we have discussed inter-annual and/or intra-seasonal variations of sea surface $p\mathrm{CO_2}$ in section 4.4. We conclude that we can reveal distinct seasonal cycles of sea surface $p\mathrm{CO_2}$ in the four domains, despite the heterogeneity of sea surface $p\mathrm{CO_2}$ spatial-temporal distributions. Figure 2 also clearly showed the data coverage of individual cruises, which we believe is helpful for readers to obtain the accurate information. In addition, per the suggestion of the reviewer, we have added a new figure showing the composite seasonal changes (new Fig. 6). To summarize, nearly air-equilibrated and/or relatively low survey-averaged sea surface $p\mathrm{CO_2}$ values of 330 to 350 μatm were observed in domain A in all four seasons; in domain B, a typical seasonal cycle of CO_2-supersaturation in the warm seasons (survey-averaged $p\mathrm{CO_2}$ from 383 to 404 μatm) and nearly air-equilibrated and/or relatively low averaged $p\mathrm{CO_2}$ of 344 to 376 μatm in the cold seasons was revealed; in domain C, relatively high sea surface $p\mathrm{CO_2}$ values of 360 to 425 μatm were observed all round a year; and in domain D, $p\mathrm{CO_2}$ was particularly dynamic in winter.

The data of the Pearl River plume should be studied separately as it is difficult to identify the effect of this river on the figures presented. Also the paper should show only the relevant correlations (e.g. fCO2-SST) with the corresponding equations and quality of the fit, rather than plotting the whole dataset, which makes the figures difficult to read (figures 7-10).

Response: We have revised the original Figures 7-10 into a $p\mathrm{CO_2}$-SST plot (new Fig. 9) and an

N$p$$CO_2$-Salinity plot (new Fig. 10). The latter plot only shows relevant correlations in domains A and C. As for the Pearl River plume issue, we have previously studied its effects on nutrient and carbon chemistry (i.e. Dai et al., 2008; Cao et al., 2011; Han et al., 2012). In this paper, we focus on the data synthesis on basin scale.

Specific Comments:

Introduction

p. 7035: Figure 2 should not be mentioned here as it is not commented before section 4.4.

Response: In the modified MS, we introduce the data maps (Fig. 2) in the "Study area" (Section 2) and our sampling sites in the "Sampling and methods" (Section 3).

Sampling and methods

3.3. pCO2 determination

p 7039 "CO2 concentration in the air near the sea surface was typically determined every 1 to 3h in the day and 4h in the night" The atmospheric air is sampled at 10m, which is not near the sea surface. This should be referred to as atmospheric CO2 throughout the text.

Response: Corrected accordingly.

4 results

4.1. SST and salinity

P 7040 "Generally the seasonal variations of SST in domains A, B, and D followed the seasonal cycle of long-term monthly mean SST at 20oN, 116oE (Fig. 3a)": Why is the location 20oN, 116oW chosen? It is hard to see the seasonal cycle for each domain on figure 3a. The seasonal cycle of SST in each domain should be shown based on the SST data of Tables 3, 4, 5 and 6. The same applies for salinity and wind speed.

Response: Modified accordingly. See the new Figure 3.

4.2. Wind speed

Do the color bars on figure 4b correspond to QuickScat data? If so, what is the spatial and temporal average? If QuickScat data are used as mentioned in section 3.2, field data should be compared to QuickScat data. What is the purpose of comparing the field data with the NCEP winds at 20oN, 116oE?

Response: The reviewer is right. We have changed the time series plots into comparison of the field data with QuikScat data. See our new Figure 4.

For the purpose of flux calculation, satellite-derived monthly mean wind speeds (QuikSCAT, Level 3) referenced at 10 m above the sea surface were used. NASA's Quick Scatterometer covers the region twice a day at 6:00 AM and 6:00 PM. The spatial resolution is 25 km. The monthly mean wind speed for a specific domain was calculated by averaging all of the available wind speeds in the month. This issue has been clarified in the revised MS.

4.4. Distributions of sea surface pCO2

Figure 2 should be renamed to be introduced here. Each panel should be described: why is there 3 panels for winter, 1 for Spring etc: : :? The legend should be completed to describe the different panels. As the objective is to show the seasonal cycle, 4 seasonal maps should be presented. This section is tedious to read: it is a list of pCO2 values. It should be rewritten to highlight the main features of the pCO2 distribution.

Response: In this paper, the data maps of pCO_2 (Fig. 2) firstly serve as description of sampling sites and cruise tracks. In the modified MS, we introduce them both in section 2 (Study area) and in section 3 (Sampling and methods).

As per our responses above, we present in Fig.2 the data from individual cruises to fully illustrate our data base and the variability. In addition, we have created a new figure (Figure 6 in the revised MS) to see the composite seasonal changes.

As for the legend in Figure 2, it is the same for all 9 panels. In the modified MS, we have clarified this issue in the caption.

In the modified MS, we have rewritten the section 4.4 so as to highlight the main features of pCO_2 distribution.

4.5. Air-sea flux estimation

"The pCO2 variability was still remarkable both in terms of time and space": what does it mean?

Response: In the modified MS, we have moved this sentence into section 4.4, where we have discussed this issue in details.

5 Discussion

5.1. Factors influencing sea surface pCO2

This section should focus on the findings. All the cruises are plotted on the figures showing the pCO2 as a function of SST and pCO2 at 26oC as a function of salinity. This section should be rewritten to show only the relevant information, i.e. pCO2-SST when there is a relationship. There is no discussion on the impact of biology although this factor is mentioned p. 7046 ("biological productivity was enhanced") and p. 7049 ("upwelled nutrients driven primary production", "intensive phytoplankton blooms in the Luzon Strait"). In domain C, the influence of the MKRDW is mentioned but it would be interesting to specifically study the river plume.

Response: We have restructured the MS per the suggestions from both reviewers and have now better focuses of the section. We have revised the original figures 7-10 into a pCO_2-SST plot (new Fig. 9) and an NpCO_2-Salinity plot (new Fig. 10). The latter plot only shows relevant correlations in domains A and C.

In this paper, we focus on data synthesis on the SCS proper scale. In this section, we reveal a diverse relationship between pCO_2 and SST in the four different domains of the SCS proper as illustrated in the new Fig. 9. We have demonstrated that, besides the general pattern of temperate controlled seasonal variation of sea surface pCO_2 in the SCS, the influences of river plume with low pCO_2, water mixing between surface water and CO_2-rich subsurface waters in cold seasons, CO_2 degassing from the surface water in warm seasons, and episodic events of eddy and upwelling around the SCS also impose high variability on surface pCO_2 distribution, as well as sea – air CO_2 flux estimation.

As for the Pearl River plume issue, we have previously studied its effects on nutrient and carbon chemistry (i.e. Dai et al., 2008; Cao et al., 2011; Han et al., 2012). In the modified MS, we have added more discussion for domain A. In domain C, both the meso-scale eddies and the MKRDW have impacts on the pCO_2 dynamics in a very complex way, which is however hard to be accommodated in this paper.

Concluding remarks

Given the variability described in this work, the last paragraph is very speculative.

Response: Deleted.

Figures

Figure 1 is difficult to read as there are so many things on it.

Response: We agree with the Reviewer that this figure contains quite a bit of the information, which is however needed.

Figure 2. Missing legend for the 9 different panels a to i.

Response: The legends for panels (a) to (i) are the same. In the modified MS, this issue has been clarified.

Figure 3a. If the purpose of this figure is to show the seasonal cycle it would be better to report the SST data on a monthly climatology.

Response: Modified accordingly.

References:

Cao, Z.-M., Dai, M.-H., Zheng, N., Wang, D.-L., Li, Q., Zhai, W.-D., Meng, F.-F., and Gan, J.-P.: Dynamics of the carbonate system in a large continental shelf system under the influence of both a river plume and coastal upwelling, J. Geophys. Res., 116, G02010, doi:10.1029/2010JG001596, 2011.

Dai, M.-H., Zhai, W.-D., Cai, W.-J., Callahan, J., Huang, B.-Q., Shang, S.-L., Huang, T., Li, X.-L., Lu, Z.-M., Chen, W.-F., and Chen, Z.-Z.: Effects of an estuarine plume-associated bloom on the carbonate system in the lower reaches of the Pearl River estuary and the coastal zone of the northern South China Sea, Cont. Shelf Res., 28, 1416-1423, 2008.

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