Re: "Air-sea CO_2 fluxes in the East China Sea based on multiple-year underway observations" by X. Guo et al.

Dear Editor,

Enclosed is a copy of the revised manuscript, "Air-sea CO_2 fluxes in the East China Sea based on multiple-year underway observations" by X. Guo et al. (BG-2015-69).

The revised MS has thoroughly taken into consideration the reviewers' comments and suggestions. Detailed revisions are explained in the enclosure.

We sincerely hope that our revision will meet the reviewers' comments/concerns and the standards at BG. We thank you again for your consideration of this manuscript.

Sincerely,

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Response to reviews

Referee #1

General comments

This paper reports an extensive set of seasonal underway pCO_2 and ancillary data for the East China Sea for 24 cruises over 2006-2011. The authors use these data to constrain seasonal variability in pCO_2 in five spatial zones and to calculate the total CO_2 sink for the East China Sea. This work is valuable, both in providing a robust estimate of the CO_2 sink for this large marginal sea in the context of its biogeochemistry and physical circulation, and in making a large contribution to the global set of pCO_2 data for marginal seas. The work was conducted using standard methods, and the conclusions are well supported by the data. The paper is also well written. I have only minor suggestions for improvement, mainly questions for clarification and suggestions for clearer presentation.

[Response] We thank the positive comments from the reviewer.

Specific comments and questions

p. 5133, line 16: "increasing trend" in air pCO_2. Given the large seasonal variability and sporadic sampling, a five-year time series is not really long enough to demonstrate an increasing trend in atmospheric pCO_2. The comparison with the Mauna Loa time series does draw the eye upward, but without it, it would be difficult to interpret a secular increase from these data. If I had only the red dots, I might draw a horizontal line through the data all the way to June 2009 and then another, higher one through the 2010 and 2011 data. This plot is not important for the rest of the interpretation in the paper, but perhaps it would be better to say that the data were "not inconsistent with the global increase in atmospheric pCO_2," rather than that they showed an "increasing trend."

[Response] We agreed with the reviewer and have revised the MS accordingly.

p.5134 lines 26-29. Why is the intra-seasonal variation within Zone 1 so much smaller in fall than in the other seasons? Are there transitions within the other seasons that might have been sampled at different phases during different cruises, or is there predictable, domain-wide upwelling in autumn?

[Response] We note that this intra-seasonal variation of <10 μatm excluded the data collected during the October 2006 cruise which was substantially different from typical fall cruises as explained in our original MS. We contend that small variability might be a general feature of this domain in fall when cooling and stronger monsoon than summer break the water column stratification. As a result, the CO_2-enriched bottom water mixes upwards to the surface and eventually releases to the atmosphere. According to the literature, there was no upwelling in this area in fall. Unfortunately, we have had no cruise observations during the transition between summer and fall.

p.5137, line 2. Insert range of values observed by Zhai and Dai for comparison.

[Response] Accepted and revised as suggested.

p.5137, lines 10-22. Leave most of these numbers in the tables and just report ranges in the text; it is hard to take in so many numbers in the middle of a paragraph. The values might be better presented as a bar graph.

[Response] Accepted and revised as suggested.

p.5137, line 19: "more than twice the global average for ocean margins." Return to this point in the Discussion and explain (or speculate) why this sea takes up so much more CO_2 than do other marginal seas.

[Response] Accepted and revised as suggested. In Section 5.2, we have elaborated the discussion.

p.5138, lines 3-13. Present your own new work first, before bringing in the work of other authors for context.

[Response] Accepted and revised as suggested.

p.5138, lines17-24. Explain NpCO_2 more clearly - its meaning, calculation and use.

[Response] Accepted and revised as suggested. We added the explanation in the section of "Data processing" of our revised MS.

p.5138, line 25 and Figures 8 and 9: "no trend with SST." It looks as if there might be a trend in some seasons, even if not for the dataset as a whole. This is worth exploring.

[Response] Accepted and revised as suggested. We have described these features in the revised MS.

p.5141, lines13-14: "low in winter (2.1 fold), high in spring (2-3 fold)." These ratios are essentially the same. Why is one "low" and the other "high?"

[Response] We have revised as "The intra-seasonal variation in the CO_2 fluxes was generally low in winter (typically <2 fold variations), but it was very high in summer (4 to 6 fold) and spring (2 to 3 fold).". In winter, the intra-seasonal variation was 1.2-1.4 folds except in Domain 1 where it was 2.1 fold.

p.5142-51243: anomalous results in October 2006 and December 2010. I think that the October 2006 results should be included in the average, since the anomalous values were the result of a natural bloom, which might reasonably be expected to occur again from time to time. In contrast, I agree with the authors' decision to exclude December 2010, since the anomalous values in that case likely resulted from a change in the timing of the winter cruise. That does call into question the use of 2010 as a reference year, however. Was December 2010 included in the calculation of the reference conditions?

[Response] In the section of Results, we excluded the October 2006 cruise in calculating the CO_2 flux. However, in the Discussion (Section 5.2), we did compare and discuss the seasonal and annual average CO_2 fluxes with and without the data from this October 2006 cruise. We fully agreed that the low pCO_2 in October 2006

was a result of a natural bloom, but fall blooms are rather atypical in the region to our best knowledge.

The December 2010 cruise has no influence on the calculation of values in the reference year (please also refer to our response to Review #2).

p.5144, lines 8-12. Future work will probably not need to be as comprehensive as this study. Now that this study has illustrated the range of values and the degree of variability in different locations and at different seasons, future sampling could concentrate on those seasons and locations where the variability is greatest or the mechanisms controlling pCO_2 the least understood. It would be worthwhile to say that here, instead of just saying that future work must reduce the error from undersampling.

[Response] The suggestion has been well taken. We have revised as "High-frequency observations in the seasons and/or locations with largest variability and/or with poor understanding in the mechanisms controlling pCO_2 are clearly needed to reduce the error from undersampling so as to further improve the estimates of CO_2 fluxes".

Figure 1. Note non-linear depth scale for colour bar.

[Response] Accepted and revised as suggested.

Figure 3. Darken zone boundary lines. They are hard to see, especially in the NW corner, where the colours change. Enlarge the whole figure to clarify labels.

[Response] Accepted and revised as suggested.

Figure 4. Clarify the timescale. Add more month labels, or add vertical lines to mark every January 1 or in some other way make it easier for readers to associate the variations in SST and SSS with the month or season. Also, plot labels (A,B) are uppercase, while in the caption they are lowercase (a,b).

[Response] Accepted and revised as suggested. We added vertical lines to show the months. We changed "a" and "b" to "A" and "B".

Figure 5. Same comment about the timescale as for Figure 4.

[Response] Accepted and revised as suggested. We added vertical lines to show the months.

Figure 6. This is a very useful figure that captures both the mean and the variability. Explain in the caption why October 2006 and December 2010 are treated differently from the other seasons in the figure, and whether December 2010 was included in the calculation of the 2010 reference year.

[Response] Accepted and revised as suggested. We have explained why we excluded the data from the October 2006 and November 2010 cruises in the caption of Fig 6 in the revised MS. The abnormal pCO_2 in December 2011 cruise has no influence on the values corrected to the reference year (Please also see our response above).

Figures 8 and 9. See comments above about possible relationships with SSS and SST one season at a time.

[Response] Accepted and revised as suggested. We have revised in Section 5.1.

Figure 10. It looks as if there could be a quantifiable relationship between NpCO_2 and chl in zone 3 for all seasons at once. It seems odd that the chlorophyll is highest in fall in Zone 4 in one year. Is that value correct?

[Response] (1) NpCO_2 decreased linearly with Chla in Domain III, but there was not such quantifiable relationship in other domains. (2) We checked the data. There were two stations with high Chl-*a* (2.0 μg L^{-1}) in Domain IV in fall. At both stations, pCO_2 was 338 μatm, and dissolved oxygen was slightly oversaturated (101-103%). Therefore, the high Chl-*a* values were reasonable.

References

Takahashi, T., Sutherland, S.C., Wanninkhof, R., Sweeney, C., Feely, R.A., Chipman, D.W., Hales, B., Friederich, G., Chavez, F., Sabine, C., Watson, A., Bakker,

D.C.E., Schuster, U., Metzl, N., Yoshikawa-Inoue, H., Ishii, M., Midorikawa, T., Nojiri, Y., Kortzinger, A., Steinhoff, T., Hoppema, M., Olafsson, J., Arnarson, T.S., Tilbrook, B., Johannessen, T., Olsen, A., Bellerby, R., Wong, C.S., Delille, B., Bates, N.R. and de Baar, H.J.W., 2009. Climatological mean and decadal change in surface ocean pCO_2, and net sea-air CO_2 flux over the global oceans. Deep-Sea Research II, 56 (8-10): 554-577.

Review #2

This is a very well written manuscript with a wealth of data. I read it with interest and have only minor comments:

1. It is not clear how exactly the surface water pCO_2 data were corrected to 2010.

[Response] The increasing rate of surface water pCO_2 in the East China Sea reported by Tseng et al. (2014) was 2.1 μatm yr^{-1} based on the observations in 1998-2012. We assumed that this yearly change rate was evenly distributed to each month, based on which we corrected all of the pCO_2 data to June 2010. Similarly, the atmospheric pCO_2 data were corrected to June 2010. This information has been added to the revised MS.

2. It is not clear why the authors chose to explain the low pCO_2 in Oct., 2006 based on the oxygen data. Why not use the chlorophyll data which is more directly related to blooms?

[Response] We agreed with the reviewer that Chl-a data would be direct evidence to show phytoplankton blooms, which are unfortunately not available. Oxygen saturation is alternatively very sensitive to demonstrate levels of biological productivity. For example, sites with blooms are often characterized by super-saturation of oxygen.

3. I think there are more data in the literature giving CO_2 fluxes in the East China Sea. A more detailed comparison is warranted.

[Response] Accepted and revised as suggested. We expanded the comparison in Section 5.2 in the revised MS.

4. It should be discussed why the ECS flux is so large.

[Response] Accepted and revised as suggested. Please also see our response to Review 1.

References

Takahashi, T., Sutherland, S.C., Wanninkhof, R., Sweeney, C., Feely, R.A., Chipman, D.W., Hales, B., Friederich, G., Chavez, F., Sabine, C., Watson, A., Bakker, D.C.E., Schuster, U., Metzl, N., Yoshikawa-Inoue, H., Ishii, M., Midorikawa, T., Nojiri, Y., Kortzinger, A., Steinhoff, T., Hoppema, M., Olafsson, J., Arnarson, T.S., Tilbrook, B., Johannessen, T., Olsen, A., Bellerby, R., Wong, C.S., Delille, B., Bates, N.R. and de Baar, H.J.W., 2009. Climatological mean and decadal change in surface ocean pCO_2, and net sea-air CO_2 flux over the global oceans. Deep-Sea Research II, 56 (8-10): 554-577.

Tseng, C.M., Shen, P.-Y. and Liu, K.-K., 2014. Synthesis of observed air-sea CO_2 exchange fluxes in the river-dominated East China Sea and improved estimates of annual and seasonal net mean fluxes. Biogeosciences, 11: 3855-3870.

Referee #3

The paper by Guo et al., aims at estimating the air-sea CO_2 fluxes in the East China Seas based on 24 cruises carried out between 2006 and 2011. Given the heterogeneity of the area, the authors chose to separate the ECS in 5 domains to compute the air-sea CO_2 fluxes and discuss the main drivers of their variability in each region. I think the paper is generally well written, based on a comprehensive dataset and that the choice of the 5 domains is relevant. I have only minor comments listed below. The page and line numbers below correspond to the printer-friendly version of the manuscript.

[Response] We thank the positive comments of the reviewer.

P5125, line 16: Give a reference for this statement.

[Response] Accepted and revised as suggested.

P5126, line 7: Use the past in this sentence: Tseng et al., 2011 investigated: : ;

[Response] Accepted and revised as suggested.

P5127, lines 5 to 8: Do not end your introduction by the main results of the paper, rather, make a brief introduction of the content of the paper.

[Response] Accepted and revised as suggested.

P5129, section 3.1: Indicate accuracies of the 2 pCO_2 instruments used.

[Response] Accepted and revised as suggested.

P5132, lines 18 to 20: Rephrase sentence, unclear.

[Response] Accepted and revised. Initially, we intended to present the seasonal average SSS, which was however a repetition and thus was deleted in our revised MS.

P5142, lines 19 to 24: Rephrase to facilitate the comparison of the fluxes with or

without the October 2006 cruise.

[Response] Accepted and revised as suggested:

"If this survey was included into the flux estimation, the seasonal average CO_2 flux in Domain I in fall would be 1.2±6.4 mmol m^{-2} d^{-1}. This CO_2 source strength was ~ 54% of the average of the other fall cruises in Domain I. However, inclusion of the October 2006 survey into the fall category would result in an annual CO_2 flux of -7.1±3.9 mmol m^{-2} d^{-1}, which is not significantly different from the estimate of -6.9±4.0 mmol m^{-2} d^{-1} excluding the October 2006 cruise. This was because we had multiple cruise observations in fall and the fall bloom was only observed in a very small area of the ECS"

Section 5.2: The main goal of this section is to discuss the intra-seasonal variability and how very specific events or cruises can impact the air-sea fluxes budgets annually. This discussion stays very focus on the ECS, it would be relevant to add some general recommendations on how to tackle this issue and take into account these special events in global estimates of air-sea CO_2 fluxes in marginal seas.

[Response] Accepted and revised as suggested. We stated in the revised MS that it remains difficult to fully resolve the intra-seasonal variations in dynamic shelf seas, in particularly in areas such as Domains I and II. High-frequency observations in the seasons and/or locations with largest variability and/or with poor understanding to the mechanisms controlling pCO_2 are clearly needed to reduce the error from undersampling so as to further improve the estimates of CO_2 fluxes.

Section 6. Conclusion: The authors come out with a new estimate of -6.9 (±4.0) mmol m^{-2} d^{-1} for the CO_2 sink of the entire ECS compared to the previous estimates of Tseng et al., 2011 and 2014. Could they also provide some comparison with the export of carbon from the shelf or to the seafloor?

[Response] We appreciate the suggestion from the reviewer. However, we believe that it is premature to do such comparison because of the lack of data in export fluxes and accurate estimates of carbon burials.

Figures: Figures are generally clear and relevant, only Figure 9 needs some reprocessing for clarity: alignment and frame lines.

Accepted and revised as suggested.

Tables:

Tables 3 to 7: Do not use decimals for pCO_2, ΔpCO_2 and SD, as it is related to the accuracies of your pCO_2 instruments (see above). For clarity of the table, give only 1 decimal for SST and FCO_2 as in table 8.

Accepted and revised as suggested.