Title: Sensitivity of the air-sea CO_2 exchange in the Baltic Sea and Danish waters to atmospheric short term variability

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General comments:

This article is an interesting study demonstrating the importance of including short-term (hourly) variability in atmospheric CO_2 concentrations in calculations of air-sea CO_2 flux for the Baltic Sea and Danish inner waters. Currently, large-scale air-sea CO_2 exchange estimates for coastal margins and seas are poorly constrained due to large spatial and temporal variability in these environments and a lack of measurements. Past studies presenting estimates of air-sea CO_2 flux both in this study region and in coastal regions generally use low temporal resolution atmospheric CO_2 (i.e., averaged weekly, monthly, or yearly) in addition to low temporal resolution surface ocean pCO_2. Recent studies have shown that atmospheric CO_2 concentrations can vary significantly over marine areas that border populated regions and/or regions with large fluxes between the atmosphere and terrestrial biosphere. This study uses a model with nests over Europe and northern Europe capable of reproducing variability in the atmospheric CO_2 concentrations on a 16.7 x 16.7 km grid over the study region at hourly intervals. The authors acknowledge that even at this resolution the model underestimates the diurnal variability in atmospheric CO_2 during the Northern Hemisphere summer. The study also provides an estimate for the contribution of air-sea CO_2 exchange for the territorial waters of Denmark to its national carbon budget.

The study region is found to be an annual sink for CO_2 with strong summer uptake partially offset by winter outgassing. The magnitude of the sink from a simulation including short-term atmospheric CO_2 variability is significantly smaller than the magnitude of the sink in a simulation where constant (i.e., monthly averaged) atmospheric CO_2 values are used. The authors indicate that this bias is due in part to diurnal boundary layer dynamics where constant atmospheric CO_2

values are too high relative to observations during the day when wind speeds are typically strongest. The authors emphasize that since diurnal variability in the model is smaller than observed, the magnitude of this bias may be larger than indicated in the current study. The choice of gas exchange parameterization has an even larger impact on the magnitude of the regional CO_2 sink – the parameterization of Weiss et al. (2007) yields a CO_2 sink more than three times greater than a simulation using the Wanninkhof (1992) parameterization. This study represents a contribution to the growing literature on air-sea CO_2 exchange in coastal regions and inland seas.

Specific comments:

p. 4, line 3: What about the impact of short-term variability in atmospheric CO_2 concentrations on large-scale estimates of air-sea CO_2 flux? Are there studies that demonstrate the potential bias of omitting short-term atmospheric CO_2 variability on estimates of air-sea CO_2 flux for the coastal seas as a whole?

p. 10, lines 24-26: Wanninkhof (1992) is now out of date (use Sweeney et al. 2007 or another more recent parameterization) – the Sweeney et al. (2007) parameterization was used by Wanninkhof himself in a recent study of global air-sea CO_2 flux (Wanninkhof et al., 2013). See discussion of the gas transfer coefficient (k) in section 3.1 p. 1988-1989 of this paper. The Nightingale et al. (2000) parameterization yields k values for wind speeds from 5 to 10 m s^{-1} that are close to Sweeney et al. (2007) and could also be appropriate since it is based on experiments conducted close to the study region. The Weiss et al. (2007) parameterization yields k values that are significantly greater than all other parameterizations typically used for open ocean studies; this should be mentioned in the text.

Citations:

Sweeney, C., Gloor, E., Jacobson, A. R., Key, R. M., McKinley, G., Sarmiento, J. L., and Wanninkhof, R.: Constraining global air-sea gas exchange for CO_2 with recent bomb C-14 measurements, Glob.

Biogeochem. Cy., 21, GB2015, doi:10.1029/2006GB002784, 2007.

Wanninkhof, R., Park, G. -H., Takahashi, T., Sweeney, C., Feely, R., Nojiri, Y., Gruber, N., Doney, S. C., McKinley, G. A., Lenton, A., Le Quéré, C., Heinze, C., Schwinger, J., Graven, H., and Khatiwala, S.: Global ocean carbon uptake: magnitude, variability and trends, Biogeosciences, 10, 1983-2000, doi:10.5194/bg-10-1983-2013, 2013.

p. 15, line 23: Could indicate the interannual variability in the air-sea CO_2 flux for the study region here and mention whether this is believed to represent method uncertainty or the actual interannual variability.

p. 20, lines 9-10: Isn't there a reduction in winter outgassing in the CAT simulation relative to the VAT simulation (i.e., seen from comparison of Fig. 3b top left panel and Fig. 8)?

p. 22, line 16: Since the Nightingale et al. (2000) gas exchange parameterization typically yields smaller k values (except at wind speeds lower than 4 m s^{-1}) in comparison to Wanninkhof (1992) I would have thought that the magnitude of the uptake using N00 would be smaller than the simulation using W92. I also would have thought that the magnitude of uptake calculated using the Weiss et al. (2007) parameterization would have been nearly twice that calculated with N00.

Technical/grammatical corrections/suggestions:

Throughout paper: Could use "pCO_{2surf}" to represent surface ocean pCO_2

p. 2, line 19: "Biogeochemical" should be "biogeochemically"

p. 3, line 4: "though" should be "through"

p. 3, line 28: Could change "not always can be ignored" to "can't always be ignored"

p. 3, line 29: For clarity, indicate that uncertainty in the transfer

velocity is much greater than the uncertainty related to temporal variability in atmospheric CO_2.

p. 4, lines 5-8: Could combine these two sentences. Example: "The present study aims to determine the importance of variability in atmospheric CO_2 concentrations on the net air-sea CO_2 flux of the Baltic Sea and Danish inner waters (which consist of Kattegat, the Danish Straits, Oresund and the Belt Seas)."

p. 4, line 12: "resolutions" should be "resolution"

p. 4, line 13: "did" should be "do"

p. 4, line 16: "details" should be "detail"

p. 4, line 19: "in" should be "for"

p. 4, line 24-26: This description of the organization of the paper could be omitted.

p. 5, line 3-4: It's already been indicated that the Danish inner waters consist of Kattegat and the Danish Straits. Could simply state: "The marine areas investigated in this study are shown in Fig. 1."

p. 5, line 9: "relative" should be "relatively"

p. 5, line 10: "low-saline" should be "low-salinity"

p. 5, line 11: "high-saline" should be "high-salinity"

p. 5, line 23: No need to capitalize "Northern" (This is the case when direction refers to a general area)

p. 6, line 23: "Kortzinget" should be "Kortzinger"

p. 8, line 3: "month" should be "months"

p. 8, line 5: "value increase," should be "increases" with no comma

p. 8, line 7: "particularly" should be "particular"

p. 8, lines 10-11: Could rewrite sentence for clarity.

p. 8, line 22: “use” should be “uses”

p. 9, line 3: delete “in the present study”

p. 9, lines 5-6: No need for a new paragraph for this statement.

p. 9, lines 23-24: Could rewrite for clarity. Example: “For the European area, CT values are replaced by a fossil fuel emission inventory …”

p. 13, line 22: “is contributing” should be “contributes”

p. 13, line 23: Could insert “atmospheric” before “CO_2” for clarity.

p. 13, lines 27-29: This sentence should be rewritten for clarity. Example: “In order to investigate the effect of short-term variability in atmospheric CO_2 concentration on the air-sea CO_2 flux, two different model simulations were conducted.”

p. 14, line 17: Insert “the” before “east”

p. 15, line 10: “has” should be “have”

p. 15, line 12: Could also indicate the interannual variability in this section

p. 15, line 27: “EZZ” should be “EEZ”

p. 16, line 15: “represent” should be “represents”

p. 16, line 17: Replace “Further” with “In addition” or “Furthermore”

p. 16, line 20: “determines” should be “determine”

p. 17, lines 3-5: These two sentences could be combined for clarity

p. 17, line 25: Conclude sentence with a period

p. 18, line 16: Remove “Although,”

p. 18, line 22: Could replace “across the marine areas in focus here.” with “ across the study area.”

p. 19, lines 8-10: Could indicate the range of annual estimates either here or in section 3 above.

p. 19, line 11: Delete “as”

p. 19, line 12: Reference Table 3

p. 19, line 14: Insert “the” before “eddy”

p. 19, line 25: “while” should be “and”

p. 19, line 26: delete “in”

p. 19, line 27: “Additional” should be “Additionally”

p. 20, line 5: insert “in this region” after “annual air-sea CO_2 flux”

p. 20, lines 7-8: This sentence could be clarified since wind speeds are the same in both simulations.

p. 21, line 11: “arears,” should be “areas” with no comma

Fig. 3b: Indicate in the caption for this figure that fluxes are from the VAT simulation.

Fig. 7: Indicate in the caption and/or title which simulation (i.e., VAT or CAT) these fluxes represent.

Table 3: Column heading to the far right should be “Present study” or “This study”