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Interactive comment on "Climate change impacts on sea-air fluxes of CO_2 in three Arctic seas: a sensitivity study using earth observation" *by* P. E. Land et al.

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We thanks the reviewer for his/her comments.

The paper is focused on net fluxes across each of the three seas and their sensitivity to changes in environmental conditions, whereas the reviewer's comments mainly focus on the gas transfer velocity in the sea-ice margins and areas of ice. We acknowledge that our method simplifies or neglects many processes within sea ice. However, we also note that the data on these processes in the published literature is far too scant to produce parameterizations applicable to the whole region, and these issues are currently the focus of considerable international effort. The main evidence seems to be that gas transfer velocities are greatly enhanced locally in regions of broken sea ice, i. e. marginal ice zones (e. g. Else et al 2011). It may also be the case that transfer velocities are reduced in the open water adjoining the marginal ice zone, where the fetch is low (Woolf, 2005). It is unclear how most of the effects mentioned by the reviewer could be parameterized in terms of variables available from satellite remote sensing. Information on this will be added into the discussion.

In addition, the main thrust of our approach was to use remote sensing to estimate the sensitivity of open ocean CO2 flux to long-term temperature and salinity changes, rather than to produce an authoritative estimate of the air-sea flux itself. In all but the Kara Sea, ice covered regions are smaller than open ocean areas for most of the year (annual mean ice cover 27%, 16% and 57% for the Greenland, Barents and Kara Seas), and the Kara Sea has by far the smallest magnitude of CO2 flux of the three seas due to its low concentration difference, so contributes very little to the regional flux. Information on this will be added into the discussion.

Our assumption thus far has been that total flux is linearly proportional to open water fraction down to 10%, after which it remains at 10% to account for leads, polynyas etc. This is the assumption made by Takahashi et al 2009, which also supplies the CO2 climatology on which our study is based. To address the reviewer's concerns about non-linearity, we will replace this with the parameterization of sea ice effect on gas transfer suggested by Loose et al 2009, which is that flux is proportional to (open water fraction)ˆ0.4. This is then combined with the Takahashi et al 2009 limit that open water fraction can be no less than 10% to account for leads, polynyas etc. The methods and results will be updated accordingly.

The reviewer's concerns about linear interpolation of the Takahashi et al 2009 dataset are unfounded. We are not trying to infer higher resolution changes than are present in Takahashi et al 2009, but simply representing the given data in a way that doesn't introduce artificial discontinuities. For example, consider two Takahashi cells with delta_pCO2 values of 0 and 30 uatm. The best estimate of the delta_pCO2 varia-

BGD

9, C9487–C9491, 2013

tion between the two is not values of 0 up to the midpoint followed by a discontinuous jump to 30 uatm (as the reviewer implies by their comment), but rather a smooth variation between 0 and 30 uatm. The shape of the variation can be argued over, but not its smoothness. Interpolation is absolutely standard practice when converting data to a higher resolution, eg in map projection. For example, A 2009 paper in EGU Atmosheric Chemistry and Physics interpolates the Takahashi dataset to higher spatial resolution than we do, and also extrapolates it into waters with no Takahashi data (Kettle et al., 2009). The important issue is to highlight this assumption within the paper. We will do this and we thank the reviewer for highlighting this.

The concerns about the replacement of data with the regional average are more well founded, and this can indeed introduce a bias, though the magnitude or even sign of this bias is not clear. While Else et al (2011) report enhanced fluxes in polynyas, Woolf (2005) reports reduced transfer velocities (hence fluxes) in open water areas close to the ice with low fetch. Clearly our methods for handling missing data will not cover all eventualities. That said, the missing data cells need to be filled in order to produce a spatially complete estimate of the sea-wide flux. A very similar assumption and approach to ours is often made implicitly to a far greater spatial extent whenever (single point) in situ data are extrapolated to produce regional flux estimates (e.g. those summarized in Bates and Mathis 2009) and so one could argue that our approach is producing a more spatially complete approach in comparison to any in situ based analysis. In this way, the work presented here is highly complementary to that of purely in situ based studies. This was one of the drivers for this study. Additionally, the missing cells are a small proportion of the total area in most months in all but the Kara Sea, the flux from which is the most challenging of the three seas to estimate, but is also by far the smallest contribution to the total regional flux due to the low concentration difference (see Table 6 and Figure 12A). The reviewer suggests use of ice thickness. This is already included in Section 4.3 as further work, as we consider the use of sea ice thickness to predict future melting to be beyond the scope of the present work. It is not clear how ice thickness could be used in any other way to refine our flux estimates.

BGD

9, C9487–C9491, 2013

Interactive Comment

The comments about Fig 12 are also misplaced. The historical data have error bars where errors are given by the original references, otherwise the values are represented by crosses. This is standard practice. The two values per sea from our own data are very similar and have identical error bars, as is shown clearly in Table 9. Our purpose in presenting them as we did was to show one value with its (and the other's) error bar, and to show the small difference between the two values. We tried plotting both with error bars, but they were overlaid on each other so closely that no differences were discernible! We will clarify the figure caption and relevant text, but leave the figure unchanged.

We intend to implement the change in ice effect and reprocess all of our data and update the results accordingly. We will correct any identified typographic errors. We will also expand the discussion to include comments about all of the sea ice issues that the reviewer has mentioned. We will include information in the discussion about the interpolation of the Takahashi data.

References

B.G.T. Else, T.N. Papakyriakou, R.J. Galley, W.M. Drennan, L.A. Miller, H. Thomas, Wintertime CO2 fluxes in an Arctic polynya using eddy covariance: Evidence for enhanced airâĂŘsea gas transfer during ice formation, Journal of Geophysical Research: Oceans (1978–2012), 116 (2011).

D.K. Woolf, Parameterization of gas transfer velocities and seaâĂŘstateâĂŘdependent wave breaking, Tellus B, 57 (2005) 87-94.

T. Takahashi, S.C. Sutherland, R. Wanninkhof, C. Sweeney, R.A. Feely, D.W. Chipman, B. Hales, G. Friederich, F. Chavez, C. Sabine, A. Watson, D.C.E. Bakker, U. Schuster, N. Metzl, H. Yoshikawa-Inoue, M. Ishii, T. Midorikawa, Y. Nojiri, A. Körtzinger, T. Steinhoff, M. Hoppema, J. Olafsson, T.S. Arnarson, B. Tilbrook, T. Johannessen, A. Olsen, R. Bellerby, C.S. Wong, B. Delille, N.R. Bates, H.J.W. de Baar, Climatological mean and decadal change in surface ocean pCO2, and net sea–air CO2 flux over the global oceans, Deep-Sea Res. Pt II, 56 (2009) 554-577.

H. Kettle, C.J. Merchant, C.D. Jeffery, M.J. Filipiak, C.L. Gentemann, The impact of diurnal variability in sea surface temperature on the central Atlantic air-sea CO2 flux, Atmos. Chem. Phys, 9 (2009) 529-541.

N.R. Bates, J.T. Mathis, The Arctic Ocean marine carbon cycle: evaluation of air-sea CO2 exchanges, ocean acidification impacts and potential feedbacks, Biogeosciences, 6 (2009) 2433-2459.

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BGD

9, C9487–C9491, 2013

Interactive Comment