Biogeosciences Discuss., 12, C5028–C5055, 2015
www.biogeosciences-discuss.net/12/C5028/2015/

Biogeosciences Discussions
Open Access

Interactive comment on "Air–water fluxes and sources of carbon dioxide in the Delaware Estuary: spatial and seasonal variability" *by* A. Joesoef et al.

A. Joesoef et al.

ajoesoef@udel.edu

Received and published: 8 September 2015

Referee #1 Revisions

— I first want to thank you for the very thorough and constructive reviews. These suggestions have greatly strengthened the overall flow and organization of the manuscript. The positive encouragement to expand on certain sections that needed additional explanation or supporting evidence has significantly improved the clarity of the paper and reinforced the validity of our results. Taking all your suggestions into consideration, I have made great efforts to strengthen the methods section, incorporate variability statistics to Table 1 (now Table 2), and expand on why this specific CO2 study (the

Delaware Estuary) is so important. In addition, to help address the uncertainties and limitations to our study, I have composed a new assumptions and limitations section (4.4).

— Major Comments

— My greatest criticism of the manuscript is in the presentation of the data; speciïňĄcally, the lack of information about variability. The most glaring example of this is Table1. The authors present area-averaged pCO2 and CO2 ïňĆux estimates from ïňĄve subsections of the estuary, but present no information about the range of these data, the standard deviation, or the median. These statistics seem vital to include in order to develop a total picture of estuary conditions. This is particularly important in light of the data presented in Figure 5, panel I. Most of the estuary transects follow a general north-south route, presumably following the main channel of the estuary. However, in December 2014 the authors made the wise decision to add some east-west transects as well, which show considerable variability. This makes intuitive sense, as the map of the Delaware Estuary (Figure 1) seems to show a number of smaller contributing rivers ïňĆowing into the bay from the east and west. Presumably if ranges and/or standard deviations were included in Table 1, the results would show much more variability during the December 2014 cruise than other cruises which only followed the north-south line. I suspect that this system is more complex than the presented data indicate, which is interesting! The authors acknowledge this "lack of cross-bay transects" in their Concluding Remarks, but this is a limitation that should be discussed much earlier and much more thoroughly. Some of the pCO2 variability may be distinguishable in Figure 7, but this ïňĄgure is so small, and the error bars so light, that I can't make much sense out of it. The authors even speciïňĄcally mention that standard deviations of atmospheric pCO2 and CO2 ïňĆux were calculated (P10907L2-5), but I do not see these standard deviations presented anywhere. This overall lack of variability discussion really limits the discussion of the data, as well as the relevancy of the results.

BGD
12, C5028–C5055, 2015

I agree that the lack of information about variability is indeed limiting to the discussion and relevancy of our results. To help strengthen our findings, I have followed your suggestions and have added the range and standard deviations to all pCO2 and CO2 flux estimates in Table 2. In addition, I agree that the "lack of cross-bay transects" should be an issue addressed. Incorporating suggestions from both referees, I have added a new section (4.4 Assumptions and limitations) that addresses the various limitations in this study in more detail (please see below). I reference a few studies that investigate the influence of tidal marshes to the carbonate system and some that have done previous cross bay transects in the Delaware Bay to support the issue of cross bay variability.

4.4 Assumptions and limitations

"While this study serves as the first air-water CO2 flux product in the Delaware Estuary, there are several limitations. First, the lack of cross-bay transects (east to west), except in December 2014, limits our knowledge of surface water pCO2 distributions in shallow waters regions of the bay system. Due to various biological and physical processes (i.e. influence from nearby tidal marshes, tributaries, or estuarine circulation forces), surface water pCO2 may vary from within the main channel to the perimeters of the estuary. Jiang et al., (2008a) found that surface water pCO2 and air-water CO2 flux in the marine-dominated Sapelo and Doboy sounds paralleled seasonal temperature changes and net CO2 inputs from within the estuarine zone. Due to intense productivity of vegetation in the surrounding salt marshes, extensive accumulation of organic carbon occurs during spring and early summer (Dai and Wiegert, 1996; Jiang et al., 2008a). During late summer and early fall, increased surface water temperatures coupled with tidal flushing of intertidal marsh waters and the decomposition of dead plants contribute to high CO2 degassing in these estuaries (Dai and Wiegert, 1996; Cai and Wang, 1998; Cai et al., 1999; Neubauer and Anderson, 2003; Wang and Cai, 2004). However, due to the much broader geographic size of the Delaware Bay compared to the marine-dominated Sapelo and Doboy sounds, in-water biological processes are

BGD
12, C5028–C5055, 2015

most likely important. In turn, the impact from the growth and decay of marsh plants on surface water pCO2 and CO2 flux dynamics may not be as influential in the Delaware Bay except near the shorelines where tides regularly flush marsh boundaries. Studies conducted by Culberson et al., (1987) and Lebo et al., (1990) performed several cross bay transects sampled at various depths, over diel cycles, within tributaries, and periodically offshore. Results showed that cross-bay gradients were inconsistent and relatively small, except in shallow waters near the shoreline when total suspended sediment and chlorophyll concentrations were frequently elevated (Culberson et al., 1987; Lebo et al., 1990; Sharp et al., 2009). Thus, the impact from marsh input of DIC to the Delaware Bay on overall pCO2 distributions and associated CO2 degassing fluxes are most likely small. During December 2014, pCO2 measurements were not only collected in the main channel, but also near the Delaware and New Jersey perimeters of the bay (Fig. 6l). While slight variability was observed across the bay, pCO2 values from the lower to upper bay regions remained within about 150 μatm (Fig. 6l and Table 2).

In addition to the lack of cross bay transects, there is a pressing need to conduct more winter and early spring surveys to fully cover seasonal ranges in key properties such as temperature and river discharge rates. Moreover, cruises or moored sensor studies at or around large discharge events are needed. Recent study by Voynova and Sharp (2012) found that in the past century there have been a recorded 54 extreme discharges (defined by the average daily discharge as recorded in Trenton, NJ from 1 Oct 1912 to 30 Sept 2011 plus 10 standard deviations); 46% of these occurring in the past decade (Voynova and Sharp, 2012). With increasing evidence suggesting that extreme weather events will occur more frequently with climate change, it is important to maintain routine seasonal surveys to learn how such subsequent conditions (i.e. increased summer stratification, riverine CO2 fluxes, removal of oxygen in bottom waters) impact various coastal environments (Allan and Soden, 2008; Yoana and Sharp, 2012). Furthermore, more research is needed in the urban and upper river sections of the estuary to better understand CO2 dynamics throughout the whole estuarine gradient.

BGD

12, C5028–C5055, 2015

The lack of inorganic carbon data in these upper regions limits syntheses of regional CO2 fluxes and generalizations to underlying mechanisms. Routine sampling along small tributaries and river systems could provide crucial insight to the biogeochemistry in the upper tidal river.

There are also several limitations to the temperature-normalized and end-member mixing models that need to be addressed. First, knowing the extensively complex nature of estuarine systems, it is important to note that derived variances in temperature-normalized pCO2 provide only a relatively simple analysis of seasonal pCO2 ïňĆuctuations due to thermal and non-thermal processes as it neglects the impact that various physical processes, turbulent forces, and tidal mixing scenarios have on pCO2 dynamics. However, because salinity gradients down the estuary vary greatly depending on the season, river discharge, tidal cycle, precipitation, and other circulation processes, salinity-binned climatologies can provide additional insight to the various physical and biological controls behind observed pCO2 distributions that geographic boundaries may not. Unfortunately, due to the lack of winter surveys and unusually high pCO2 values in December, interpolated temperature-normalized pCO2 during cooler months may be biased and slightly overestimated. Moreover, the temperature derived constants (∂lnpCO2/∂T) derived in this study were based on river and ocean end-member TA and DIC concentrations collected in the Delaware Estuary over the past two years. Thus, it is important to note that derived temperature constants here are applicable for general estuarine systems and may not be suitable for coastal environments with different hydrological and/or geochemical characteristics.

In situ DIC and TA measurements were coupled using the Excel macro CO2SYS (Pierrot, 2006) and inorganic carbon dissociation constants from Millero et al. (2006) for estuarine waters to calculate dissolved CO2 concentrations. While river and ocean end-members were obtained at near zero salinity and at the mouth of the bay, respectively, no fixed end-member sampling locations were established. This marginal difference in end-member location could slightly increase or decrease estimated CO2

BGD
12, C5028–C5055, 2015

concentrations. In the chemical model of the CO2SYS, NH3, NH4+, and organic matter contribution to TA were not included (Cai et al., 1998; Cai et al., 2010b), which were likely high in low salinity waters. Thus, lower calculated CO2 than observed CO2 was expected as the observed TA included other acid-base components (Fig. 3C). However, due to the very high pCO2, such uncertainty is deemed unimportant in our consideration. Another factor that may contribute to the lower calculated CO2 than observed CO2 could be the use of mercuric chloride as a preservative in low salinity samples (S < 10) (Trabalka and Reichle, 2013). Excess alkalinity generated via the dilution of mercuric chloride could contribute to conservative CO2 flux estimates (Trabalka and Reichle, 2013) although due to the relatively high TA in the Delaware River we believe this effect is small."

— The use of interpolation is somewhat unclear in this manuscript, and sometimes may not be appropriate. SpeciïňĄcally, on P10908L15-17 the authors state: "Temperature normalized pCO2 values during months with no surveys were estimated by linearly regressing data from adjacent months with sample measurements." However, Figure 7 does not show this. There were no cruises in January or February, but the plots in Figure 7 clearly show a non-linear patterns between December and March, when the plot should have shown a straight line according to the above description. How is this possible? There were also no cruises in April or May, but the same conïňĆicting pattern is shown in Figure 7.

You are correct. I mistakenly wrote that I interpolated temperature normalized pCO2 when I never intended to. I meant to say that "Observed pCO2 values during months with no surveys were estimated by linearly regressing data from adjacent months with sample measurements." I have corrected these problems in the graph and have made the errors bars darker (black lines) so that they are more visible.

I have also made pCO2(obs) line the boldest. To help highlight times of addition (red) or removal (blue) of CO2, I have inserted colored arrows in the first panel. Moreover, each arrow is accompanied with either a T or B symbol to indicate whether this pCO2

BGD
12, C5028–C5055, 2015

change was governed by thermal or non-thermal processes.

— I am also confused about the '0.01x0.01' latitude by longitude grid (P10906L16, P10904L15-16) employed in the analysis. Does this grid cover the entire Delaware Estuary, including those areas not occupied by the ship? If so, it seems unwise to extrapolate air-water CO2 ïňĆuxes from the center of the estuary out to the eastern and western fringes where no data were taken and conditions may be quite different, and the east-west variability is essentially unknown. It seems much more reasonable to calculate overall pCO2 levels and CO2 ïňĆuxes (with accompanying variability statistics) for each of the ïňĄve estuary sub areas, instead of trying to interpolate the north-south transect data over the entire estuary. But perhaps I misunderstood the manuscript and the grid only covered those areas occupied by the ship.

Yes, you are correct. We did interpolate the data for each section of the estuary to the land-water boundary (perimeter). This is definitely a huge limitation to our study (extrapolating to areas where our ship did not cover) given we were unable to do east and west transects in the bay for all of our cruises except in December 2014. I agree that our data begs for accompanying variability statistics. I have added additional variability statistics to Table 2, which really highlight the north-south variability especially the rapid and extensive range in values in the upper tidal river (as shown above). A reason why I decided to extrapolate to the boundaries is I wanted to account for the extensive size of the bay system. I tried to avoid having our measurements biased or heavily skewed towards the upper estuarine system that is so much smaller in size than the Delaware Bay. As you pointed out, addressing the uncertainties and limitations to our study is crucial. In turn, I have discussed in more detail the limitations to the lack of east to west transects in the new 4.4 limitations section (see above) as well as our lack of winter and upper estuarine data.

— Minor Comments

— Abstract

BGD

12, C5028–C5055, 2015

— P10900L6: change to "the smaller upper tidal river..."

Now reads as, “While the smaller upper tidal river was a strong CO2 source (24.6 ± 2.2 mol-C m-2 yr-1). . .”

— P10900L7: change to "the much larger bay was a weak..."

Now is, “the much larger bay was a weak source (1.8 ± 0.2 mol-C m-2 yr-1). . .”

— Introduction

— P10902L10-13: are there any estimates of how far up the Delaware River the tidal prism extends?

Pass studies have recognized Trenton, NJ as the head of the tide (Sharp et al., 2009; Sharp, 2010).

Now reads as, “The tidal freshwater portion of the Delaware River flows from the head of the tide near Trenton, NJ through the greater Philadelphia area, the sixth largest municipal region of the U.S., before passing into the saline Delaware Bay (Fig. 1) (Sharp et al., 2009; Sharp, 2010).”

— P10902L16-18: this dynamic interaction can be a common feature in smaller estuary systems as well, depending on river ïňĆow and geomorphology

Good point. I have incorporated this idea and now reads as follows:

“Thus, the Delaware Estuary is governed by the dynamic interaction between a river dominated upper estuary and an ocean dominated lower bay. This feature, typical for other large estuaries, and depending on river ïňĆow and geomorphology, smaller estuarine systems as well, provides us the opportunity to examine how contrasting geographical settings, physical mixing processes, and ecosystem metabolism in an extensive bay system can affect CO2 gas exchange.”

— P10919L17-19: What does this sentence mean? Where is the evidence for this?

BGD
12, C5028–C5055, 2015

“Due to increasing urbanization and industrial activities, the biogeochemistry of the Delaware Estuary may respond diïňĂerently to the rapidly changing environment than it did in the past.”

I have edited this and inserted it into the Introduction along with some supporting evidence of how the urban river is continuously responding to a rapid changing environment.

“The tidal freshwater portion of the Delaware River flows from the head of the tide near Trenton, NJ through the greater Philadelphia area, the sixth largest municipal region of the U.S., before passing into the saline Delaware Bay (Fig. 1) (Sharp et al., 2009; Sharp, 2010). In turn, the upper Delaware River is heavily influenced by major industrial activity and continuously responding to a rapidly changing environment. For example, in the mid-20th century, the urban river of the Delaware Estuary suffered from severe hypoxia with average summer dissolved oxygen (DO) concentrations near zero value (Sharp, 2010). Fortunately, the implementation of the Clean Water Act (CWA) in the early 1970s helped promote efforts to improve water quality conditions in the Delaware River. With major upgrades to large sewage treatment plants, DO concentrations since the early 1990s have consistently been above the CWA standard of 3.5 mg L-1 ($\sim$219 μmol L-1) illustrating significant recovery from post hypoxic conditions (Sharp, 2010). Nonetheless, high pCO2 is still expected to associate with strong respiratory O2 consumption in the upper estuary.”

— P10919L17-25: This last paragraph seems ill-conceived. Are there historical data in the Delaware Estuary? If so, why were they not mentioned in the Introduction? If not, how are the past conditions known?

I have moved part of the last paragraph (as shown above) to the Introduction. I have also added more information on why we should study the Delaware Estuary to emphasize the importance of this research.

“Thus, there is limited research on CO2 dynamics in large estuaries or bay systems

BGD

12, C5028–C5055, 2015

with long freshwater residence times in the U.S. Mid-Atlantic coast (most notably the Chesapeake and Delaware estuaries). Presumably, these large estuaries have lower pCO2 than small estuaries or bay systems with rapid freshwater transit times (Borges and Abril, 2011; Cai, 2011). Except for a few recent studies and the pioneering work of Sharp and Culberson, over the past 30 years there have been few inorganic carbon studies in the Delaware Estuary (Culberson, 1988; Sharp, 2009). Air-water COÂň2 fluxes, total DIC fluxes, and ongoing evaluations of water acidification have not been consistently (via annual and seasonal surveys) studied. Overall, there is a lack of data and pressing need to synthesize and expand global research to larger estuaries. Furthermore, of past estuarine CO2 studies, many lack spatial and seasonal coverage of surface water pCO2 and air-water CO2 fluxes, making flux estimates highly uncertain."

— Methods

— How deep was the seawater intake on the ship?

About 1 to 2 meters below the sea surface. I have added this and now reads as:

"To monitor levels of pCO2, surface water was directly pumped from 1 to 2 meters below the sea level through an underway pCO2 analyzer"

— Some description of the equilibration method used by the AS-P2 is needed

Agreed. I have expanded on this section.

"To monitor levels of pCO2, surface water was directly pumped from 1 to 2 meters below the sea level through an underway pCO2 analyzer (AS-P2, Apollo Scitech) installed in the shipboard laboratory (Huang et al., 2015). Surface water flowed into a 1 L volume shower head equilibrator at a minimum rate of 1.7 L min-1 to facilitate rapid gas exchange. A water-drain system is attached to the equilibrator to insure balanced pressure (Jiang et al., 2008b). The equilibrated gas was pumped through a water trap (Peltier cooler), which removed most of the water vapor, and then into a drying tube packed with magnesium perchlorate [Mg(ClO4)2] or Nafion tubing. Surface water

BGD
12, C5028–C5055, 2015

CO2 (mole fraction of dry air [xCO2]) was measured approximately every one and a half minutes using an underway flow-through system equipped with a non-dispersive infrared (NDIR) gas analyzer (Li-Cor Model Li-7000, Lincoln, NE, USA)."

— P10903L16- The LI-7000 is not a spectrometer

Now reads as, "underway flow-through system equipped with a non-dispersive infrared (NDIR) gas analyzer. . ."

— P10906L5-9: Can you show the NOAA buoy locations on the map in Figure 1?

Good idea. I have put them on the map.

— P10908L5: pCO2 was presumably normalized to the annual mean temperature, and temperature was not normalized to the annual mean temperature as indicated

The sentence is now, "We first normalized pCO2 to the annual mean temperature of 13.3°C via the following. . ."

— P10908L5: Give the mean annual temperature (13.3âŮęC) here.

Now is, "We first normalized pCO2 to the annual mean temperature of 13.3°C via the following. . ."

— P10908L11: Change 'as a result of" to "to be the result of"

Now reads, "we attributed any differences between calculated and observed pCO2 values to be the result of biological activity and/or physical mixing processes (non-thermal)."

— P10908L12-13: "pCO2 data obtained during each cruise was rarely stationary..." What does this mean?

Deleted. "Stationary" didn't mean anything and was unnecessary. Now reads:

"Through this approach, we attributed any differences between calculated and observed pCO2 values to be the result of biological activity and/or physical mixing pro-

Full Screen / Esc
Printer-friendly Version
Interactive Discussion
Discussion Paper

cesses (non-thermal). Because salinity gradients down the estuary vary greatly depending on the season, river discharge, tidal cycle, precipitation, and other circulation processes, salinity-binned climatologies can provide crucial insight and a different perspective to the various physical and biological controls behind observed pCO2 distributions that geographic boundaries may not. In turn, pCO2 values from each survey were constructed into salinity-binned climatologies (intervals of five units from 0-30) to better isolate and interpret the thermal versus non-thermal effects on seasonal pCO2 fluctuations."

— P10910L3: This is the ïňĄrst mention of the Schuylkill river, which is not shown on the map. Were some river sites samples which are not discussed?

I have inserted the Schuylkill River on the map. River samples were not collected here only along the Delaware River. I used river discharge from the Schuylkill River to get a more accurate estimate of total river discharge out of the system (together the Delaware and Schuylkill River combine for about 75% of the total discharge).

— P10910L7-8: How were in situ DIC and TA measurements coupled? In CO2SYS or some other program? Which carbonate K values were used? Much more description is needed here.

I have added some more description and now reads as:

"In situ DIC and TA measurements were coupled using the Excel macro CO2SYS (Pierrot, 2006) and inorganic carbon dissociation constants from Millero et al. (2006) for estuarine waters to calculate dissolved CO2 concentrations."

— P10910L8: awkward: "The CO2 production or its contribution..."

Agreed. I have deleted "production" to avoid confusion

"The CO2 contribution from within the estuarine zone ([CO2]est) was estimated as follows. . ."

BGD
12, C5028–C5055, 2015

— Results

— P10910L21-24: These water temperatures are just for the Delaware River, right? Show the USGS gage used for these measurements on the map.

Correct. These water temperature are only for the Delaware River. I have inserted the USGS gage station located at the head of the tide on the map.

— P10911L1: "The Delaware River discharged was..."

Now reads, “The Delaware River discharge was greatest during March 2014 and June 2013”

— P10912L20-21: Why did pCO2 go up in December 2014? It looks like low-salinity waters from the Delaware River stretch further south that usual, and ïňĆow in Figure 3 seems pretty high. Did a storm precede the survey that month?

No storm was observed only increased (strong) winds. Reasons to explain the high pCO2 are still unclear but we have some theories.

“While reasons to support the elevated pCO2 values remain unclear, stratification of subsurface waters in late fall followed by strong winter mixing during winter (December 2014) and a two-fold increase in river discharge could explain the elevated pCO2 values observed throughout the mid- and the lower bay systems (Fig. 4).”

— P10912L24: "atmosphere positive during all..."

The sentence is now, “The urban river and turbidity maximum zone served as strong sources of CO2 to the atmosphere and was positive during all months”

— P10913L25: Give the magnitude of the contribution, even if it is minor.

Now reads as, “In turn, their contribution (24.6 $\pm$ 2.2 mol-C m$-$2 yr$-$1) to overall regional flux (2.4 $\pm$ 0.3 mol-C m-2 yr-1) is minor.”

— Discussion

BGD

12, C5028–C5055, 2015

— P10915L13: How is the removal of CO2 attributed to biology here? No evidence of biological activity is presented. Were oxygen data taken as well? O2 data are mentioned later (P10916L18), but never presented.

I agree we cannot attribute any removal or addition of CO2 to biology without substantial evidence. I realized that in this paragraph I want to contrast the thermal versus non-thermal effects (which includes mixing) on pCO2. Thus, I attributed any reduction or elevation of pCO2 in pCO2obs at 13.3°C to be the result of various non-thermal processes. I also added some historical data on biological activity throughout the system.

"For example, in the urban river and turbidity maximum zones (S < 5), high pCO2obs at 13.3 °C in the spring and winter may reflect both river inputs and strong respiratory CO2 production. Low pCO2obs at 13.3 °C during the warmer months likely reflect the removal of CO2 due to various non-thermal processes. During the warmer months from May to October, Yoshiyama and Sharp (2006) found elevated nitrite (NO2) concentrations in the urban river when nitrification and primary production were highest. In addition, high NO2 concentrations were observed in the mid-bay in summer when primary production was maximal (Pennock and Sharp, 1994). Comparably, pCO2mean at Tobs (changes due to the seasonal thermal cycle) trends were opposite to that of pCO2obs at 13.3 °C with lower than pCO2obs values in the winter and higher than pCO2obs values in the summer. These opposing signals suggest that increases in surface water pCO2 due to winter-to-summer warming are partially compensated by the reduction of surface water pCO2 due to mixing processes and/or biological removal of CO2 (Takahashi et al., 2002). Sharp et al. (2009) found that during the March-April period ammonium (NH4), phosphate (PO4), and silicate (Si) concentrations were heavily depleted in the mid and lower bay regions due to extensive spring blooms. Similarly, but in the opposite direction, the reduction in surface water pCO2 due to fall-to-winter cooling is partially compensated by the elevation of surface water pCO2 caused by various non-thermal processes (Fig. 8)."

— P10916L11-14: I don't understand what these percentages represent, or how they

BGD
12, C5028–C5055, 2015

were calculated. This section could use some work to make the terms discussed more clear.

Agreed. I have added some more details/information to this section and now reads as:

"The potential emission of river-borne CO2 was estimated based on the concept of excess CO2, the difference between the in-situ DIC at zero salinity and a theoretical DIC value at atmospheric equilibrium (ΔDIC) (Abril et al., 2000; Borges et al., 2006). The theoretical DIC was computed using in-situ TA values and an atmospheric pCO2 of 395 μatm. River-borne CO2 fluxes were calculated as the product of ΔDIC and the combined river discharges from the Schuylkill and Delaware Rivers for each month divided by the estuarine surface area. Generally, as freshwater residence time increases (river discharge decreases) river-borne CO2 fluxes decrease (Borges et al., 2006). As more river-borne CO2 is released into the atmosphere in the upper estuary due to increased residence time, leaving less river-borne CO2 for degassing in the lower estuary, the overall contribution of CO2 emissions are largely shaped by the net community production in the mixed layer (ML NCP) in the mid- to high salinity estuarine zones (Abril et al., 2000; Borges et al., 2006). In comparison, as freshwater residence time decreases (river discharge increases), DIC enrichment from ML NCP is reduced and river-borne CO2 fluxes increase. In certain cases, such as the Rhine estuary or other systems with extremely rapid flushing times, residence time is so short that not all of the river-borne CO2 is ventilated to the atmosphere in the estuarine zone (Borges and Frankignoulle, 2002; Borges et al., 2006). In turn, the potential emission of river borne CO2 is higher than the actual observed air-water CO2 fluxes from the estuary (Borges et al., 2006)."

— P10917L13: "during spring season..."

Now reads, "In addition, during spring season (March) high CO2 consumption was also observed. . ."

— P10917L23: Strong Co2 sources to the atmosphere, or the Delaware Estuary?

BGD

12, C5028–C5055, 2015

The sentence is now, “While the urban river and turbidity maximum zone are strong CO2 sources to the atmosphere, these upper regions are small in comparison to the bay regions of the Delaware Estuary.”

— P10917L25: relatively weak compared to what? Put this number in some context. The following paragraph discusses relative CO2 sources in some other estuaries, but gives no actual numbers.

Good point. I have added relevant values and comparisons and now reads as follows:

“While the urban river and turbidity maximum zone are strong CO2 sources to the atmosphere, these upper regions are small in comparison to the bay regions of the Delaware Estuary. Thus, overall the Delaware Estuary acts as a relatively weak CO2 source (2.4 $\pm$ 4.8 mol-C m-2 yr-1) in comparison to many other estuarine systems that serve as strong CO2 sources to the atmosphere (26 $\pm$ 21 mol-C m-2 yr-1) (Borges and Abril, 2011). Of the 62 estuaries compiled in Borges and Abril (2011), only the Aby Lagoon, a permanently stratified system, served as a sink for atmospheric CO2.”

— P10918L24: "to the rapid ïňĆushing..."

Now is, "Similarly, and in contrast to the rapidly flushing Altamaha Sound. . .”

— P10918L4-5: "to overall CO2 ïňĆuxes". Are these ïňĆuxes for the entire estuary, or just these smaller sub-sections?

These fluxes are just for these smaller sub-sections.

“Moreover, positive correlations between river-borne and air-water CO2 fluxes in the upper tidal river emphasize the significance of river-borne CO2 degassing to overall CO2 fluxes in the upper sub-sections of the estuary (the urban river and turbidity maximum zone).”

— P10918L26-29: This section is awkwardly written. “Due to its extensive geographic size, one may conceptually model the Delaware Estuary, and in some circumstances,

BGD
12, C5028–C5055, 2015

other large estuarine systems as being a funnel-shaped estuary."

The sentence now reads, "With its extensive geographic size, the Delaware Estuary features both a river dominated upper estuary and an ocean dominated lower bay."

— FIGURE 7- The error bars on this plot are unreadable. In general, this plot is too small.

I agree. I was also a little disappointed in the "readability"of the figures. I will try to increase figure and text sizes.

— FIGURE 8- Is a linear ïňĄt in the top panel really appropriate for ïňĄve data points? Also, the different a-axis and y-axis scales should be clearly noted, or the panels should be depicted on the same scales. It might be interesting to plot the data from both panels in one plot- how would the Urban River points line up with those from the Turbidity Maximum Zone?

Good call. I have clearly noted the different x-axis and y-axis. I believe the smaller ratio of river borne to air water CO2 fluxes in the Turbidity Maximum Zone illustrates the rapid degassing of CO2 in the upper estuary. When plotting data from both panels in one plot we can see this as all the data points from the Turbidity Maximum Zone fall to the left of the Urban River points. However, when using the same axes, the Turbidity Maximum points become clumped and it's hard to distinguish between the various months. Because of this, I have kept the data in separate panels.

— FIGURE 9-This figure is totally unreadable – the colors of the bars are indistinguishable from one another. The different y-axis scales need to be noted. Also, are some data omitted from this ïňĄgure? Table 1 shows data from June 2013 and December 2014, but those months have no results in Figure 9

I have changed the colors of the bars and have noted the different y-axis scales. For the months of July and December, we were unable to reach near zero salinity or the river-end member. So I was unable to accurately produce theoretical dilution

BGD
12, C5028–C5055, 2015

and river mixing lines for DIC and TA since we had no end-member data. In turn, I could not accurately calculate river nor estuarine CO2 contributions and thus I had to unfortunately omit these months.

Please also note the supplement to this comment:
http://www.biogeosciences-discuss.net/12/C5028/2015/bgd-12-C5028-2015-supplement.pdf

---

Interactive comment on Biogeosciences Discuss., 12, 10899, 2015.

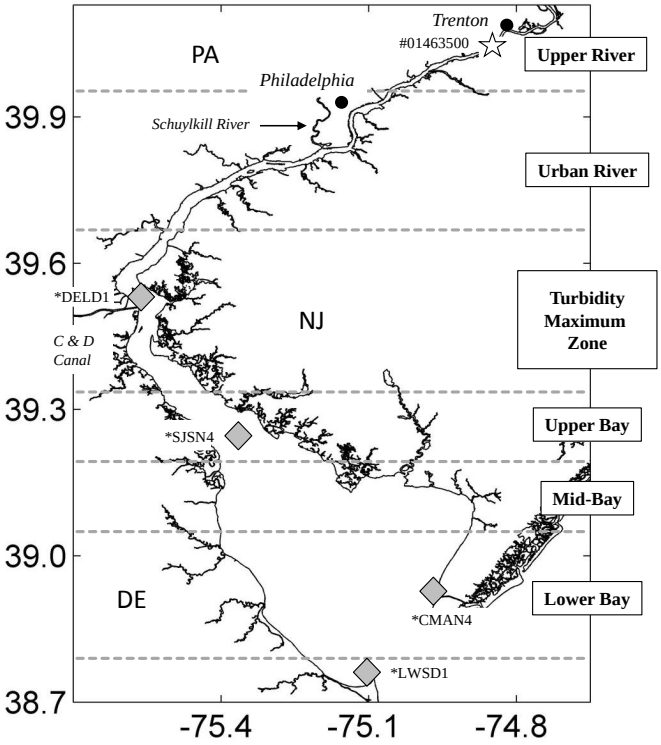

Fig. 1. Map of the Delaware Estuary divided into six zones from the head of the tide in Trenton, NJ to the mouth of the bay as defined in Sharp et al. (2009).

Full Screen / Esc
Printer-friendly Version
Interactive Discussion
Discussion Paper

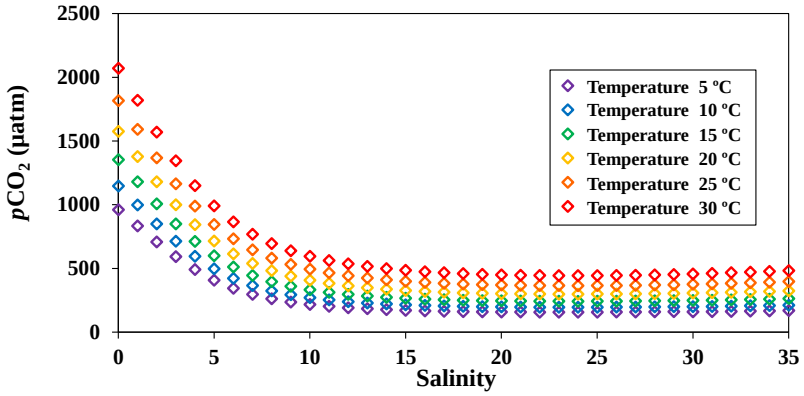

Fig. 2. Simulated surface water pCO2 against salinity grouped by temperature bins. Surface water pCO2 values were calculated using river and ocean end-member TA and DIC values of 900 and 960 μmol kg-1 and 230

Full Screen / Esc
Printer-friendly Version
Interactive Discussion
Discussion Paper

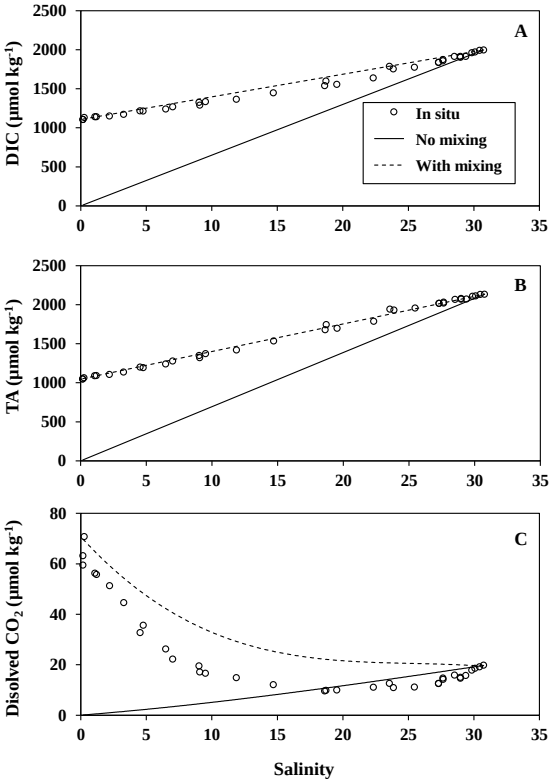

Fig. 3. Concentrations of (A) DIC, (B) TA, and (C) dissolved CO2 in the Delaware Estuary during March 2014. Open circles represent in situ concentrations. Solid lines represent values after the ocean end-memb

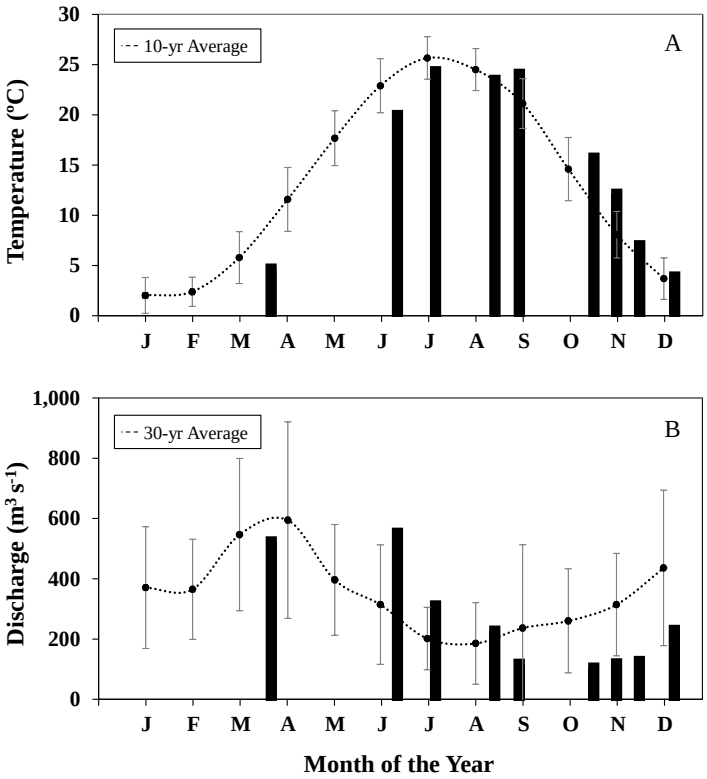

Fig. 4. (A) Surface water temperatures and (B) Delaware River discharge rates recorded in the Delaware Estuary during each sampling month. Error bars represent standard deviations of the 10-year (2004-2014) a

BGD
12, C5028–C5055, 2015

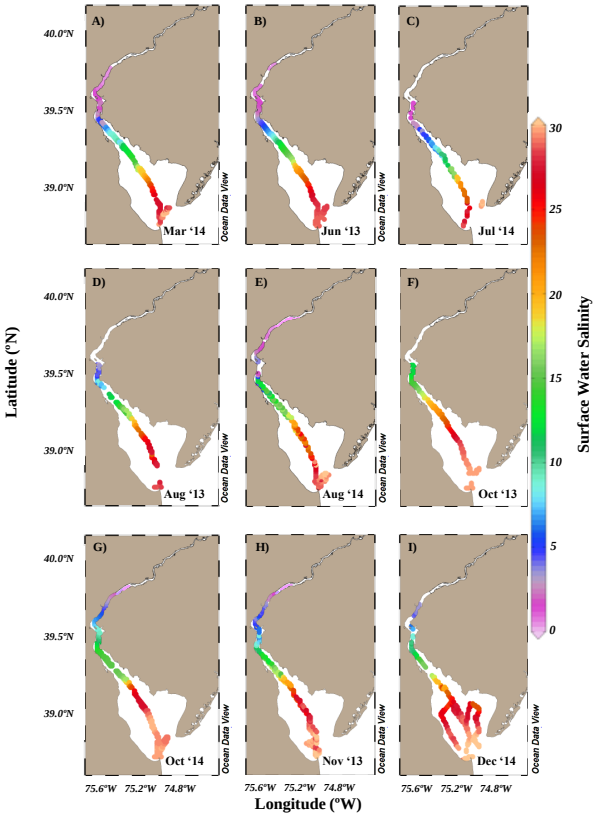

Fig. 5. Spatial distributions of surface water salinity in the Delaware Estuary measured during each sampling month. The map was designed with the ODV software by R. Schlitzer (Ocean Data View software, 2015,

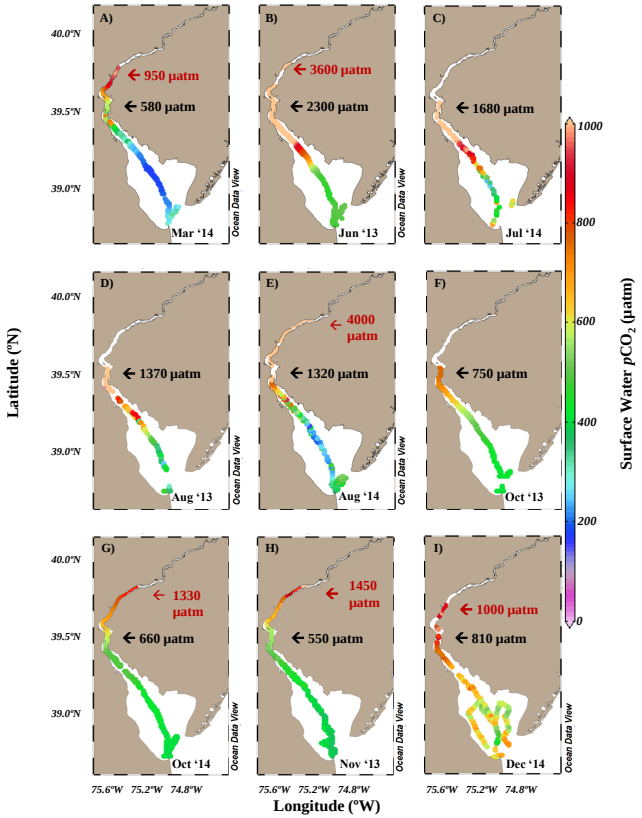

Fig. 6. Spatial distributions of surface water pCO2 in the Delaware Estuary measured during each sampling month. Black and red arrows show surface water pCO2 values at the Chesapeake-Delaware Canal and the no

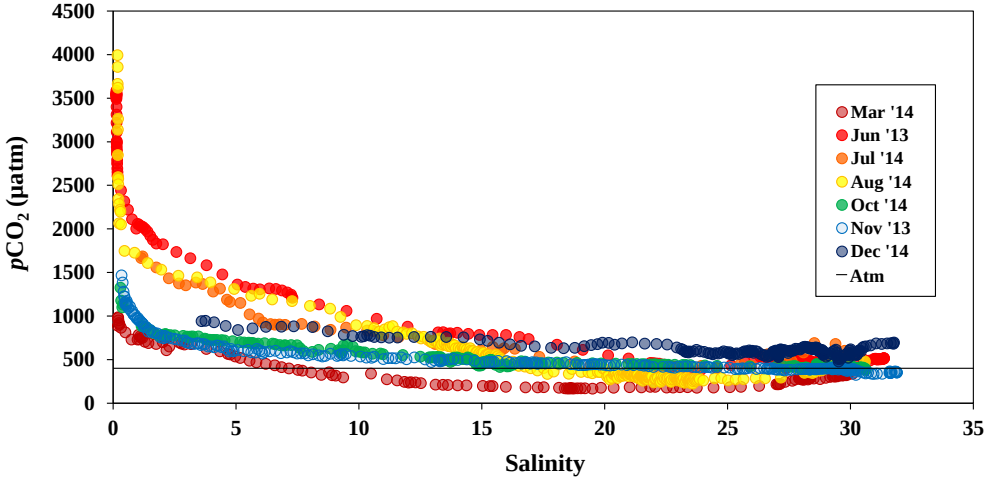

Fig. 7. Measured surface water pCO2 against the salinity gradient during each sampling month in the Delaware Estuary.

BGD
12, C5028–C5055, 2015

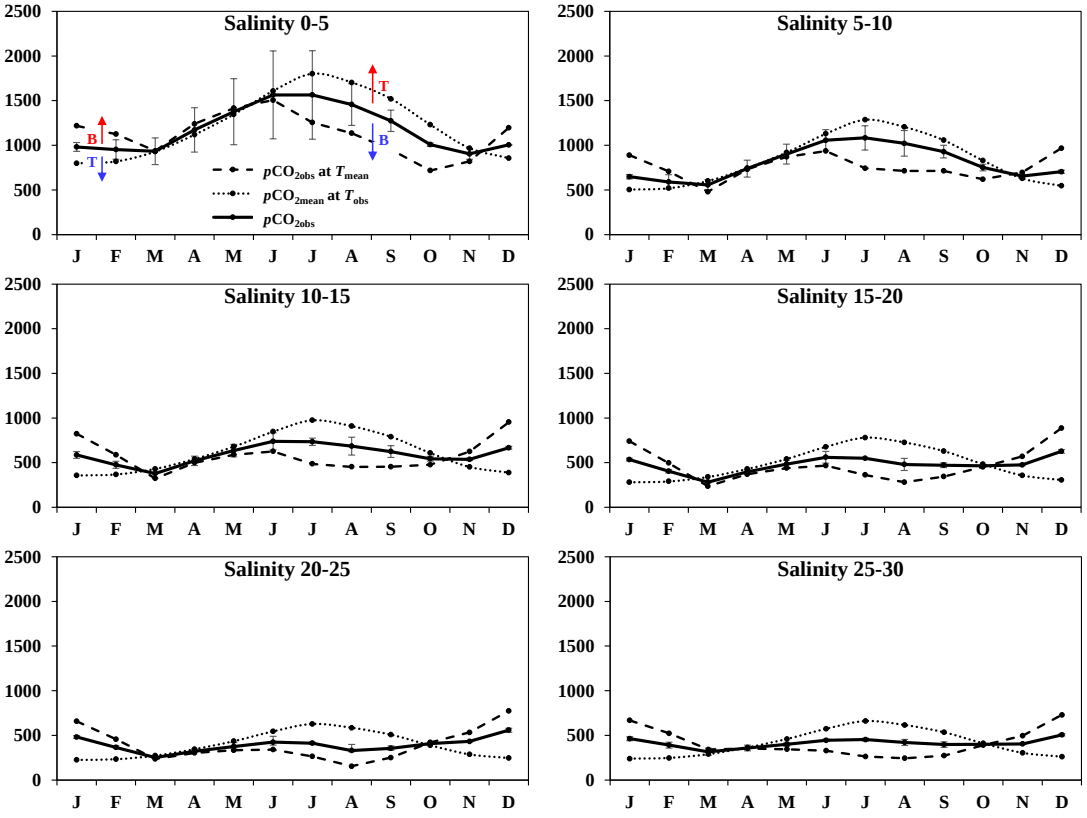

Fig. 8. Salinity-binned intervals of temperature-normalized observed pCO2 values at 13.3 °C, annual mean, area-averaged pCO2 values at in situ temperature, and observed pCO2 values in the Delaware Estuary ove

Full Screen / Esc
Printer-friendly Version
Interactive Discussion
Discussion Paper

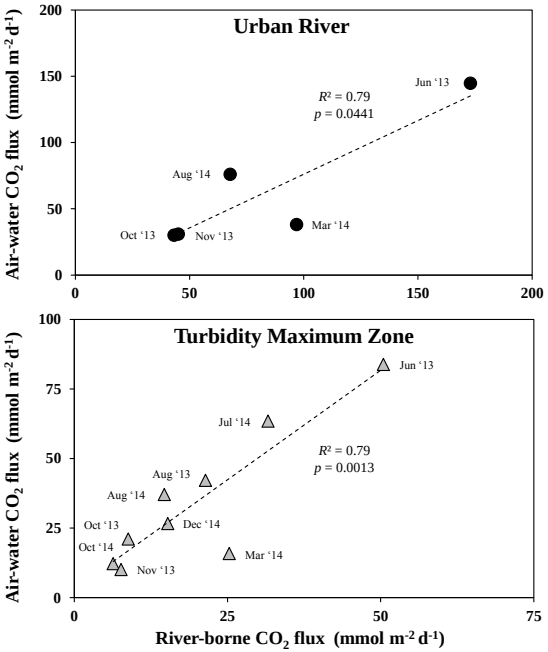

Fig. 9. Air-water CO2 fluxes against river-borne CO2 fluxes in the urban river and turbidity maximum zone of the Delaware Estuary. Note the different axes used for the urban river and turbidity maximum zone.

Full Screen / Esc
Printer-friendly Version
Interactive Discussion
Discussion Paper

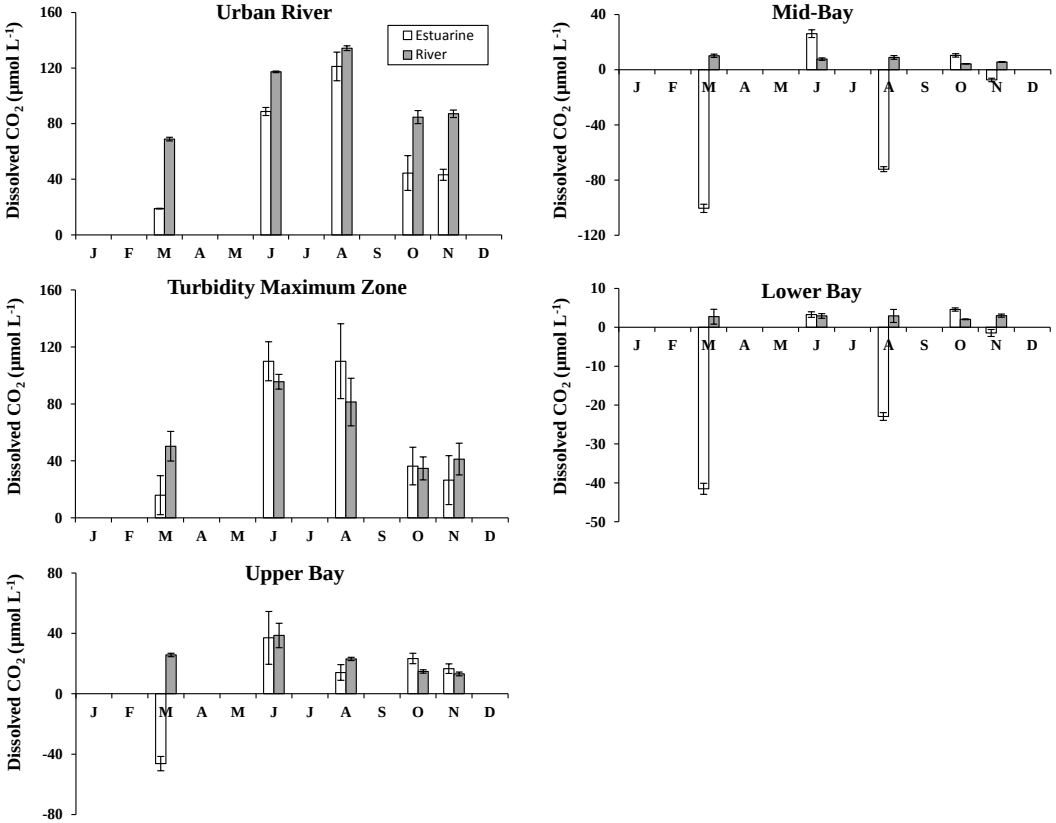

Fig. 10. Dissolved CO2 concentrations (normalized to 13.3 °C, area averaged) due to river inputs and internal estuarine sources in each region of the Delaware Estuary. Note the different axes used across all r

Full Screen / Esc
Printer-friendly Version
Interactive Discussion
Discussion Paper