Surface Ocean pCO_2 Seasonality and Air-Sea CO_2 flux Estimates for the US East Coast

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Motivation

- Coastal regions play an important role in the global carbon cycle
- High variability and limited data make it difficult to determine the air-sea flux of CO_2 in coastal regions

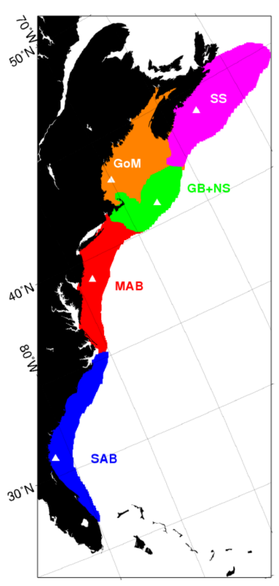
Study Objectives

- Develop an empirical surface-ocean pCO_2 algorithm based on physical and biological proxy parameters: sea surface temperature (SST), salinity (SSS), chlorophyll-a (Chl-a), and particulate organic carbon (POC) for the coastal waters of the eastern U.S.
- Construct maps of pCO_2 and air-sea CO_2 flux for the US East Coast
- Assess the most important factors driving the pCO_2 seasonality in the continental shelf

Data Sources and Methodology

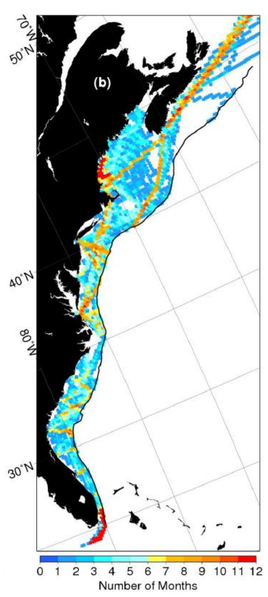
- pCO_2 data from the Surface Ocean CO_2 Atlas (SOCAT) with additional data from W.-J. Cai and J. Salisbury (total of almost 800,000 observations), averaged into 0.15° bins by month and year, adjusted to 2004, and then averaged into a mean annual cycle.
- MODISA (SST, Chl-a, POC), SeaWiFS (Chl-a, POC), and CCMP (winds) products
- SSS climatology made from World Ocean Atlas (2009) using kriging
- Multiple regression of observed pCO_2 vs. proxy *in situ* parameters
- Algorithm application using satellite-based products and evaluation with *in situ* data

Study Domain and Available Ocean pCO_2 Data



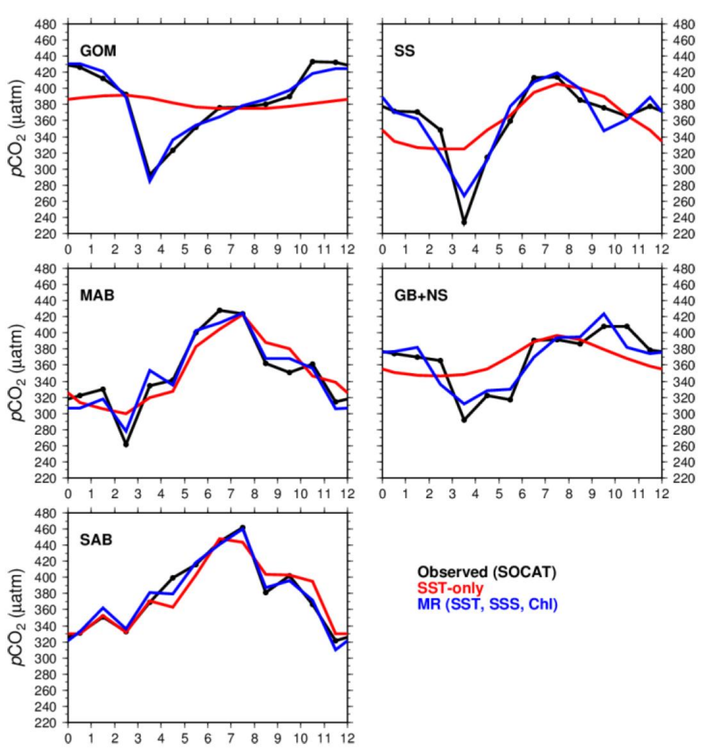
Left: Study domain showing the five sub-regions analyzed: Mid-Atlantic Bight (MAB), South Atlantic Bight (SAB), Gulf of Maine (GOM), Georges Bank + Nantucket Shoals (GB+NS), and Scotian Shelf (SS). Test locations for multiple regression experiments (white triangles) are also shown.

Right: Monthly distribution of available underway surface ocean pCO_2 within the study region. The black line is the 500-m depth contour. Regions in orange and red are more frequently covered and indicate the most traveled ship routes and most visited study sites.



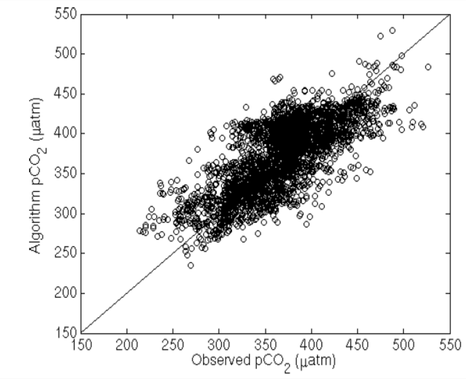
Regional Multiple Regression Sensitivity Experiments Based on Single Locations

The panels show the mean annual cycles of pCO_2 that are observed (black), statistically modeled as a function of SST only (red), and statistically modeled as a function of SST, SSS, and Chl. See study domain for station locations. The statistical models are region-specific. There are significant improvements when SSS and Chl are added as predictors, particularly in the Gulf of Maine.



Model evaluation over the whole domain

In addition to SST, SSS, and Chl, we added day of year, latitude, longitude, and POC as predictors of pCO_2. A separate model was developed for each region and parameters were determined using bins containing at least six months of data. The remaining bins were used for model evaluation, shown to the right. About 86% of the residuals are within one standard deviation (49 µatm).

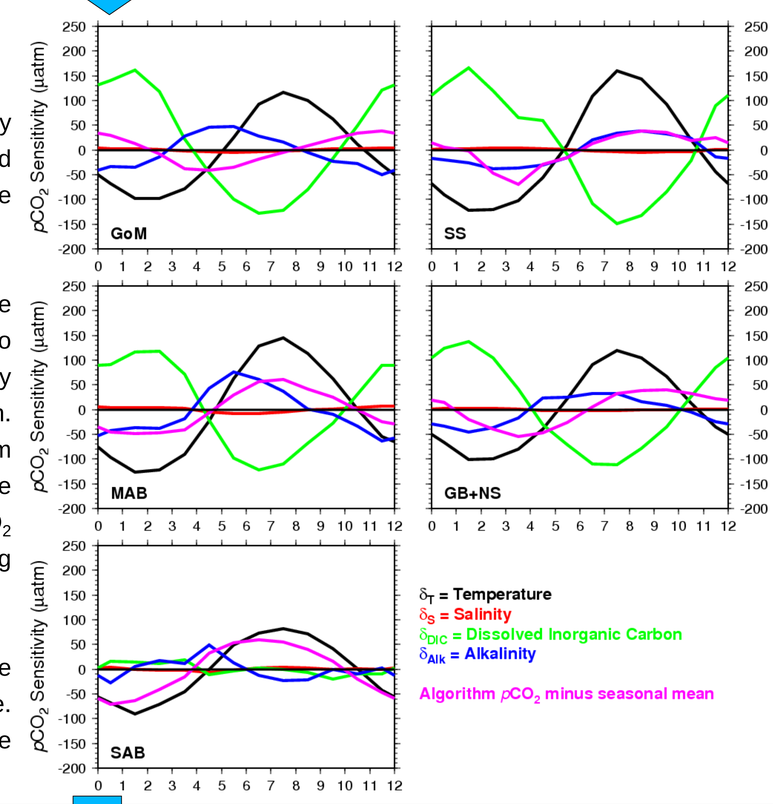


Factors controlling the surface ocean pCO_2

Surface-ocean pCO_2 is a function of alkalinity (Alk), dissolved inorganic carbon (DIC), SST, and SSS. To determine the controlling factors, we estimated the Alk and DIC distributions.

Alk closely follows salinity in the study area. We used an observed relationship between these two variables (Cai et al. 2010) and our salinity climatology to determine the alkalinity distribution. Then we computed DIC from the carbonate system equilibria using the CO2SYS program. Finally, we determined the separate contributions to the pCO_2 annual cycle from SST, SSS, Alk, and DIC using CO2SYS.

Results (right) show that DIC and SST are the dominant controls, often acting equal and opposite. DIC variations are likely a result of wintertime mixing and summertime biological drawdown.



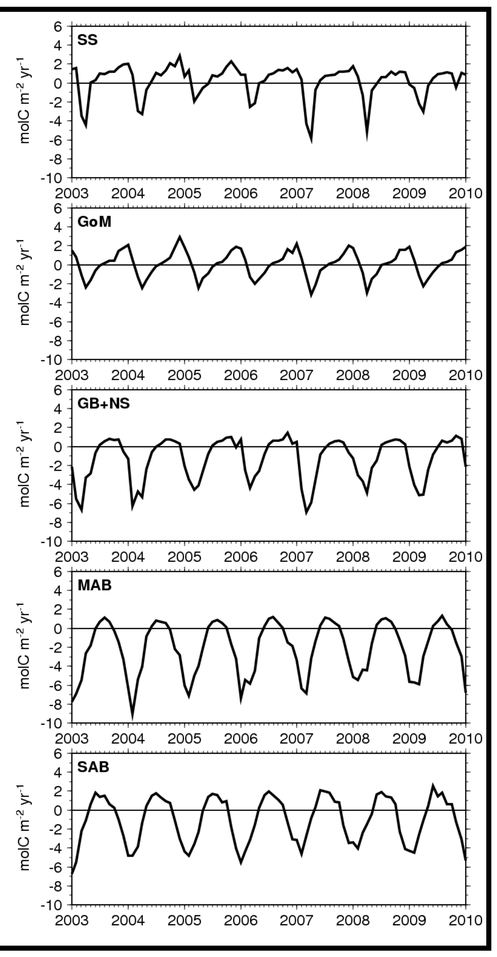
Air-Sea Flux Estimates

To compute the air-sea flux, we use the algorithm of Wanninkhof (1992) for the transfer velocity and atmospheric pCO_2 at Grifton, NC from GLOBALVIEW. Results for each subregion are shown to the right (negative values are uptake by the ocean). There is strong seasonality in the flux, which is dominated by the ocean pCO_2. Interannual variability is modest.

The table below shows the mean fluxes for each region, with a comparison to estimates made without the algorithm (binned data alone) and estimates from the literature. The three estimates are similar, except for the Scotian Shelf. The algorithm estimates are based on the 2004 climatology. Results are different when fluxes for individual years are averaged.

Region	Area 10^{10} m^2	Data Tg C yr^{-1}	Algorithm Tg C yr^{-1}	Literature Tg C yr^{-1}
SS	12.1	-2.0 ± 0.4	+0.4 ± 0.4	+2.1 ± 0.4 (*d*)
GoM	11.5	-0.2 ± 0.3	+0.1 ± 0.4	-0.2 to +1.0 (*c*)
GB+NS	5.2	-0.6 ± 0.2	-0.8 ± 0.1	-
MAB	8.6	-1.4 ± 0.3	-1.9 ± 0.4	-1.0 ± 0.6 (*a*)
SAB	9.2	-0.9 ± 0.3	-0.8 ± 0.4	-0.5 ± 0.2 (*b*)
Total	46.6	-4.9 ± 0.3	-3.0 ± 0.3	-

(*a*) *deGrandpre* [2002]; (*b*) *Jiang et al.* [2008]; (*c*) *Vandemark et al.* [2011]; (*d*) *Shadwick et al.* [2011]. Values for (b), (c), and (d) were converted from mol C m^{-2} yr^{-1} to Tg C yr^{-1} (×12×area×10^{-12}).



Summary and Conclusions

- Temperature and dissolved inorganic carbon are the primary drivers of the surface ocean pCO_2 annual cycle along the US East Coast
- The Mid-Atlantic Bight, South Atlantic Bight, and Georges Bank-Nantucket Shoals area are sinks of atmospheric CO_2. The air-sea flux for the Gulf of Maine is neutral. The Scotian Shelf is poorly constrained, likely a result of poor pCO_2 data coverage.
- For 2003-2010, the region as a whole removes between 3.4 to 4.6 Tg C yr^{-1} from the atmosphere as CO_2.

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