Development of a Satellite-based Surface Ocean pCO_2 Algorithm with Application to the Mid Atlantic Bight

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Study Objectives

- Develop an empirical surface ocean pCO_2 algorithm based on physical and biological proxy parameters (SST, SSS, MLD, Chl-a, CDOM, POC)
- Construct maps of pCO_2 and sea-air CO_2 flux for the MAB
- Analyze the physical-biogeochemical interactions that control phytoplankton blooms and how they affect the uptake of atmospheric CO_2
- Analyze the effects of the solubility and biological pumps on the surface-ocean pCO_2 variability

Data Sources and Methodology

- MODISA (SST, Chl-a, POC, CDOM) and SeaWiFS (Chl-a, POC, CDOM) products
- 3D Ocean model products (SST, SSS, MLD) and NCEP-2 Reanalysis data
- *In situ* carbon data from available sources (underway pCO_2 and station data)
- Multiple regression of observed pCO_2 vs. proxy *in situ* parameters
- Algorithm application using satellite-based and numerical model products

Physical and Biological Setting

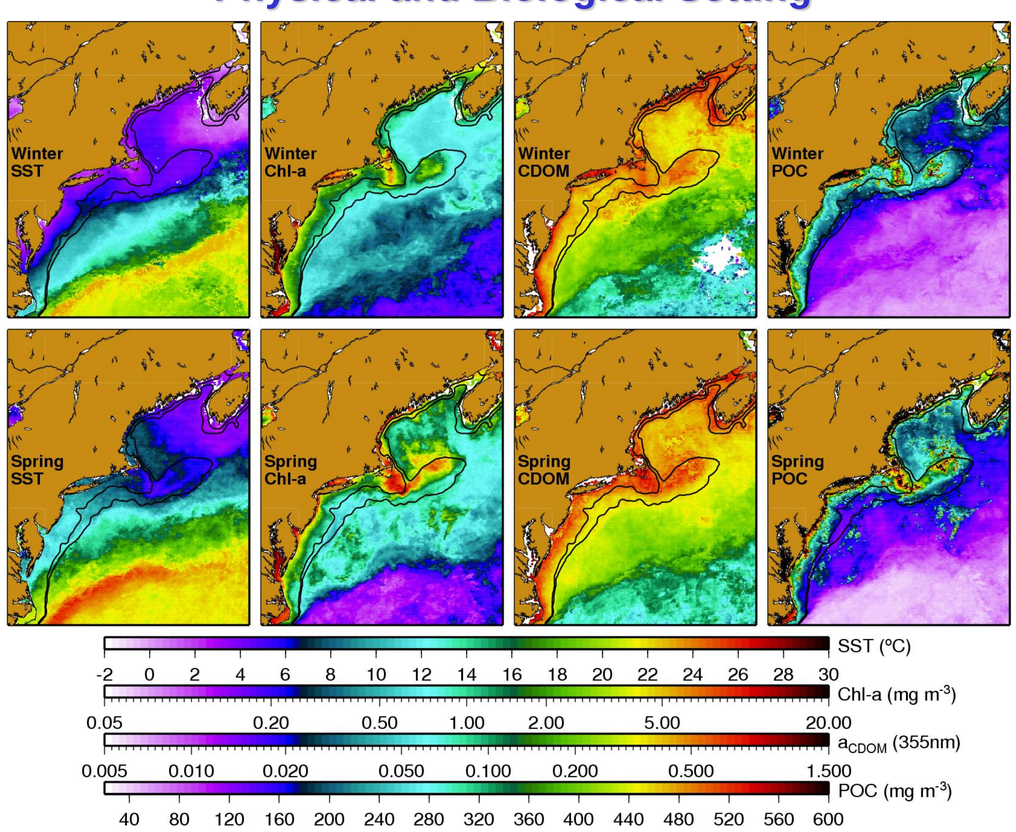
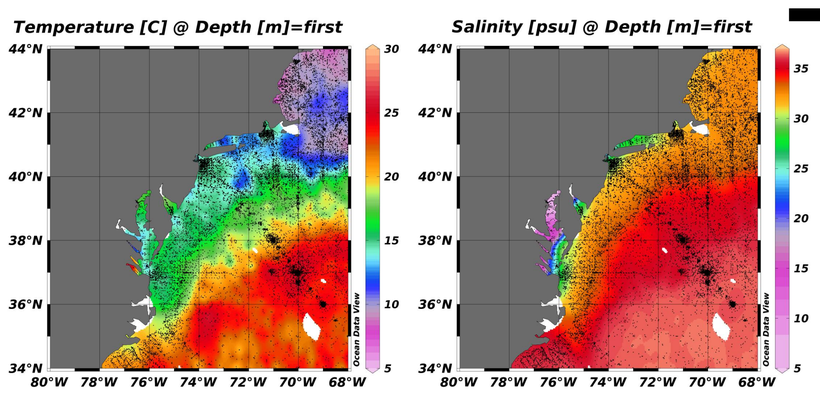


Fig. 1. Climatologic maps of MODIS Aqua SST, Chl-a, CDOM absorption at 355 nm (A. Mannino personal communication), and POC for winter and spring. Note the sharp Gulf Stream SST front, the onset of the spring bloom south of Cape Cod, Georges Bank, and Gulf of Maine, and the winter-spring coastal productive zones shown in the Chl-a maps. Near-surface CDOM in offshore regions is more concentrate in winter than summer due to stronger vertical mixing (see Fig. 2), reduced photo-degradation and remineralization. POC concentration is highest in the coastal productive areas. The contour lines are the 50m and 100m isobaths.

Figure 2. Annual maps of surface temperature (SST) and salinity (SSS) derived from World Ocean Data (WOD) 2005. The SST signature of the Gulf Stream Front and colder Gulf of Maine water are clearly shown. Also note the fresh water signature of coastal waters identified by the lower SSS, especially in the vicinity of the Chesapeake Bay plume. This freshwater coastal boundary is where the highest CDOM concentrations are found (see Fig. 1).



Algorithm Development and Application Strategy

- Continue to assemble, process, and analyze available fCO_2, DIC, TA, pH, SST, SSS, and Chl-a in situ data.
- Use satellite ocean color imagery to expand algorithm development data base (e.g., Chl-a matchups).
- Derivation of surface water fCO_2 equations as a function of proxy physical and biological variables using multiple regression approach (for example, Chierici et al., 2009; Chierici et al., 2011; Olsen et al., 2004).
- Algorithm is currently under development; a first attempt using *in situ* GOMECC fCO_2, SST and Chl-a resulted in the following equation for July:

  $fCO_2 = a + b*lon + c*lat + d*SST + e*SST^2 + f*Chl\text{-}a + g*\log_{10}(Chl\text{-}a)$, $r^2=0.37$, $N=1181$, RMSE=14.8 µatm

- The above equation was used to generate a fCO_2 map for the MAB based on July 2009 MODISA composite of SST and Chl-a (see Fig. 6).
- Further data sets for algorithm development are being assembled and analyzed to improve accuracy and extend seasonal coverage.

Acknowledgements: We want to acknowledge the NASA Ocean Biology and Biogeochemistry Program for supporting this work under the USECoS project. We are also thankful to all the agencies, universities, and scientists who made the *in situ* data sets available to the community and that are being used in this study. The GOMECC underway data (fCO_2 and SST from W. Wanninkhof, NOAA, and Chl-a from J. Salisbury, UNH) were obtained from http://www.aoml.noaa.gov/ocd/gcc/GOMECC. The temperature and salinity historical station data were obtained from World Ocean Data 2005 (http://www.nodc.noaa.gov/OC5/WOD05/pr_wod05.html).

Seasonal Variability and Example of Algorithm Application

Seasonal Cycle

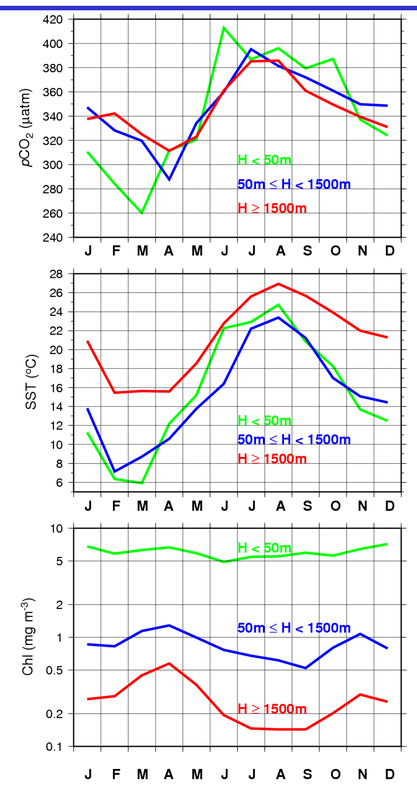


Fig. 5. Seasonal cycles of pCO_2 and SST *in situ* data, and MODIS Chl-a, based on averages within bathymetric regions with boundaries at the 50m and 1500m isobaths. Note that the SST seasonal amplitude is reduced offshore, while the annual mean values increase. These changes have a direct impact on the pCO_2 seasonality. The annual mean Chl-a decreases offshore, while the signature in Chl-a during spring and fall blooms becomes more distinct offshore. The blooms occur during the cold phase of the SST cycle when vertical mixing increases and contribute to the drawdown of CO_2.

Satellite-derived fCO_2

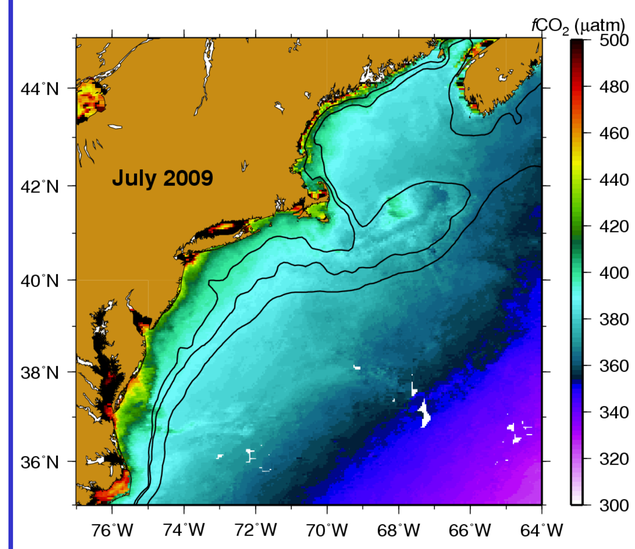


Fig. 6. Algorithm-derived fCO_2 using MODISA SST and Chl-a composite for July 2009. Values inside Chesapeake Bay, Delaware Bay, Long Island Sound, and Buzzards Bay have the highest values but should be interpret with caution as no data from those areas entered in the derivation of the algorithm. The same applies for the region offshore of the 1500m isobath. The three contour lines shown in the image are the 50m, 100m, and 1500m isobaths. This is an initial example of algorithm application. The data sets need to be expanded temporally and geographically to increase algorithm accuracy and seasonal coverage. Although a single algorithm is desirable, multiple equations may be required to distinguish the different biological and physical provinces within the MAB on a seasonal basis.

Available Carbon Data Sets

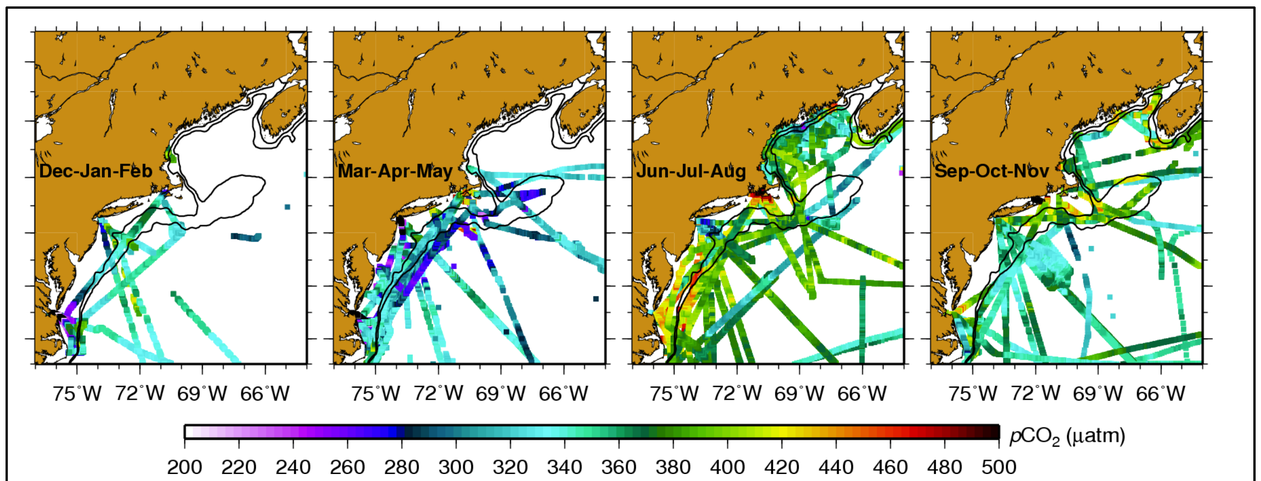
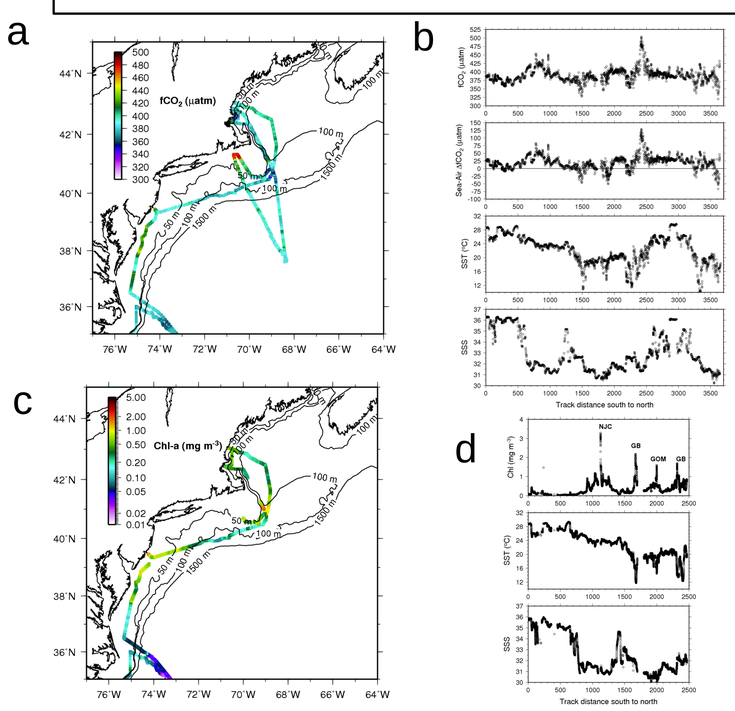


Fig. 3. Seasonal distribution of underway pCO_2 observations obtained from the Takahashi V2009 dataset (Takahashi et al., 2009). There are 80,327 observations available within the MAB region shown in the maps. The data covers years 1981 to present.



Gulf of Mexico and East Coast Carbon Cruise (GOMECC) Data

Cruise onboard R/V Ronald H. Brown, RB-07-05, 10 July to 4 August 2007: Galveston, TX – Boston, MA.

Project in support of the NACP with multi-institutional collaboration: NOAA, ESRL, RSMAS, USF, UNH, Texas A&M, U. Georgia, U. Colorado, U. Southern Miss., Loyola College MD, and LDEO.

Underway measurements of fCO_2, pH, DIC, DOC, SST, SSS, O_2, Chl-a, CDM.

CTD and Bottle dataset: T, S, O_2, Nutrients, DIC, TA, DOC, pH, Pigments.

Fig. 4. MAB map showing the GOMECC cruise track during which measurements of underway pCO_2, SST, SSS (a), and Chl-a (c) were made. The along-track measurements are shown in (b) and (d). The measurements shown in (c) and (d) were made from seawater pumped into a black 80-liter tank in which instruments were submerged. The measurements shown in (a) and (b) were made along the same track but with different instruments and different pumped seawater samples. The labels NJC, GB, and GOM in the Chl-a plot in (d) mark the productive regions of the New Jersey Coast, Georges Bank, and Gulf of Maine. Note that the productive GB region was visited twice. The data sets were obtained from http://www.aoml.noaa.gov/ocd/gcc/GOMECC/.

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