Western Gulf of Maine as an Annual Source of CO_2 to the Atmosphere

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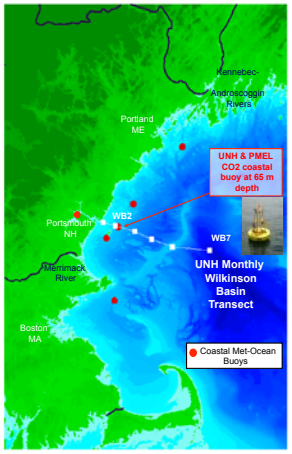
Objectives

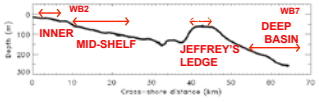
Goals within the NACP program include developing a robust understanding of where, when and how carbon is transferred between reservoirs. The sign, magnitude and variability of ocean-atmosphere carbon flux along our coastlines is largely unresolved and this project is focused on both maintaining a coastal CO2 time series data set over 5-10 years and developing a mechanistic understanding of CO_2 air-sea flux in the Northwest Atlantic. The central study site is the Western Gulf of Maine but ongoing data collection across the wider Gulf of Maine and Scotian Shelf (UNH, Dalhousie Univ., NOAA) are helping to provide solid observational basis for refining these flux estimates and future prediction at a regional scale.

Some core questions we are addressing here:

- Does the Gulf of Maine (temperate latitude, Northeastern U.S.) act as a net atmospheric carbon dioxide source or sink?
- What is the temporal variability in the air-sea flux at hourly to interannual time scales?
- Which processes dominate the annual cycle of CO2 air-sea exchange?
- What is the spatial variability in the carbon pool and its controls?

Methods





Regional sampling of ocean and atmospheric carbon in space and time

Fig at left – Central study region in the Western Gulf of Maine, as well as coastal shelf bathymetry (lower panel) versus distance from the coast along the Wilkinson Basin transect – a single day cruise executed monthly since April 2004.

The UNH/PMEL MAP-CO2 buoy time series station near WB2 starting in May 2006. A SAMI -pH was added to this buoy in August 2010 as part of ocean acidification monitoring efforts.

Data Collection

Monthly shipboard data collected aboard UNH R/V Gulf Challenger, 2004-present

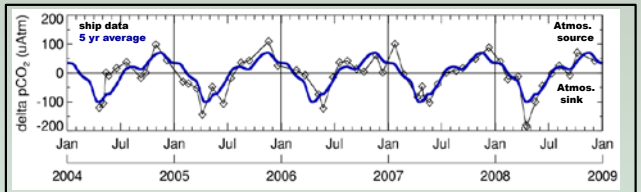
- Underway pCO_2 via fast-rate Weiss-type equilibrator system, sea surface temperature and salinity
- Atmospheric pCO_2 via the flow through system
- Profiles of TA and DIC with depth as well a suite that include pigments, zooplankton, and nutrients
- Ancillary physical fields from the GoMPOM model as well as USGS river discharge data (for open data access visit: www.cooa_unh.edu)

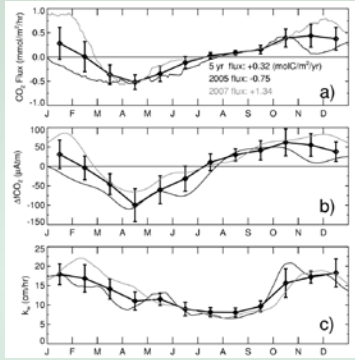
Hourly/daily buoy data

- Met. & Wind speed from the NDBC and nearby coastal buoys
- Water Temp, Salinity, Chl_a, currents, light field data from GoMOOS buoys
- pCO2, pH, diss. oxygen, temperature, salinity from the UNH CO_2 buoy
- Sub-layer oceanic pCo2 from a SAMI-Co2 at 36 m depth at this buoy
- Hourly atmos. CO_2 from several surrounding stations

CO_2 Air-Sea Flux Variations 2004-2008

Vandemark et al. (2011) documents the first five years of our time series observations (2004-2008) and we find that, on average, the Western Gulf of Maine region was a net source to the atmosphere at the level of +0.4 molC m^{-2} yr^{-1}(+- 0.3). Several figures from that paper are provided below to summarize results pertaining to key project objectives.





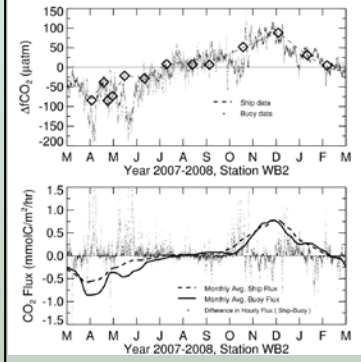
Source or Sink of CO_2?

The primary study data set for oceanic CO_2 data was the monthly shipboard transect data on the WB transect that including near, mid and outer shelf depths. Multi-year data allowed us to determine the system to be a weak net atmospheric source over 5 years but there was considerably year-to-year variability including 2005 as a sink year. Overall, it appears that monthly or finer sampling is required to adequately resolve this system.

Table 1. Annual and Multiyear Sea-Air CO_2 Flux Estimates for the Study Region[a]

	2004	2005	2006	2007	2008	5 Year
Inner	0.91	0.31	0.38	1.37	1.07	0.81
Middle	0.51	−0.75	0.14	1.34	0.35	0.32
Outer	0.75	−0.15	0.02	0.69	0.47	0.35
Region[b]	0.74/0.68	−0.11/−0.10	0.05/0.05	0.71/0.65	0.49/0.46	0.38/0.35

[a]With units mol m^{-2} yr^{-1} and with positive values being a source to the atmosphere. Estimates for the inner, middle, and outer shelf as well as a weighted average representing the seasonally stratified Gulf of Maine are provided.
[b]The second values are derived from an ensemble average of fluxes separately estimated using the five k_w algorithms discussed in section 2. All other values utilize *Wanninkhof* [1992].

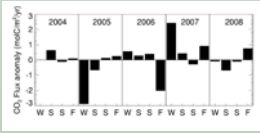


Magnitude of Temporal Variability

One benefit of the repeated cross-shore transects plus a dedicated buoy site are their utility for determining daily to interannual surface layer CO2 changes.

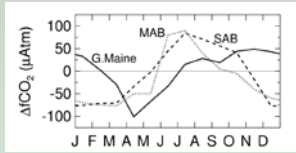
At left – Monthly ship data (symbols) and bi-hourly buoy data along with coincident estimates of sea-air flux. While these two fluxes agree fairly well at a monthly time step the annual net did disagree by ~0.4 molC m^{-2} yr^{-1}.

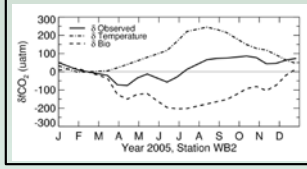
At bottom – Observed **seasonal deviation** in the sea-air flux from the five-year average at the central study site. Winter and fall periods exhibit largest anomalies in 04-08.



Scaling Out Along the Atlantic Seaboard

Separate dedicated observational efforts in the South Atlantic Bight (W.J. Cai group, Jiang et al., 2008), the Mid Atlantic Bight (OMP, LEO-15, and DeGrandpre et al. (2001)) and the Gulf of Maine and Scotian Shelf regions (Shadwick et al. (2010), Vandemark et al. (2011)) provide some basis for comparison and contrast of the annual cycle surface layer CO_2 cycles. These efforts provide considerably finer time resolution than ship-based compilations (cf. Chavez and Takahashi (2007)) and should complement such data in coastal carbon synthesis efforts. Below we highlight some aspects of the East coast data sets that may prove useful in modeling and C budget synthesis efforts.





South to North, a substantial change in the annual cycle

The average annual cycle of ΔfCO_2 (sea-air) is shown **at left** per the papers cited above. In general, the annual minima and maxima are similar, but while the phase of the annual cycle is the SAB and MAB is similar, the GoMaine differs strongly with these systems in the fall -to-winter period. Shadwick et al. (2010) found results on the Scotian shelf (not shown here) that are closer to the W. G. of Maine.

A central conclusion related to this key observed phase difference is that temperature control of the CO_2 disequilibrium via solubility is much more dominant in the SAB and perhaps the MAB. For the G. Maine and Scotian Shelf, biological and advective controls of the TCO_2 pool (**at lower left**) play a stronger role (see Vandemark et al. 2011).

In progress – examining controls within the NE region: three ongoing time series for use in refined predictive ocean C modeling (Dalhousie/U. Mont)

These figures include and follow Fig. 11b of Shadwick et al. (2010) to display temperature-normalized pCO2 as one means to illustrate controls other than T during each season. Ongoing work will compare data from three CO2 time series sites (Halifax=Carioca Buoy; WGoM=this study, NorthEast Channel=SAMI-CO2), all with at least 24 months of data.

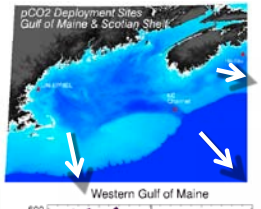
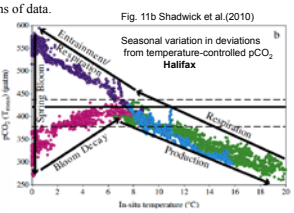
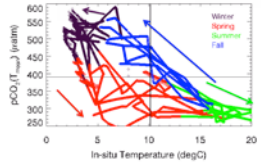
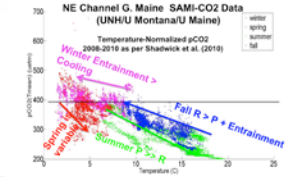


Fig. 11b Shadwick et al.(2010)







References

Chavez, F. and T. Takahashi (2007), Coastal oceans, Chapter 15, in "The First State of the Carbon Cycle Report (SOCCR): North American Carbon Budget and Implications for the Global Carbon Cycle". pp. 83-92.

DeGrandpre, M.D., G. J. Olbu, C. M. Beatty, and T. R. Hammar (2002), Air-sea CO_2 fluxes on the U.S. Middle Atlantic Bight. Deep-Sea Research Part II-Topical Studies in Oceanography, 49: 4355-4367.

Jiang, Li-Q., W.-J. Cai,, R. Wanninkhof, Y. Wang, and H. Luger, Air-sea CO_2 fluxes on the U. S. South Atlantic Bight: Spatial and seasonal variability (2008), J. Geophys. Res.-Oceans, 113, C07019, doi:10.1029/2007JC004366.

Shadwick E. H., H. Thomas, K. Azetsu-Scott, B.J.W. Greenan, E. Head, and E. Horne (2010), Seasonal variability of dissolved carbon and surface water pCO2 in the Scotian Shelf region of the Northwestern Atlantic, Mar. Chem., 10.1016/j.marchem.2010.11.004.

Vandemark, D., J. E. Salisbury, C. W. Hunt, S. Shellito, J. Irish, C. L. Sabine, S. Maenner, W. R. McGillis (2011), Temporal and spatial dynamics of CO_2 air-sea flux in the Gulf of Maine, J. Geophys. Res., 116, C01012, doi:10.1029/2010JC006408.

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