Interannual Variability of Primary Production and Carbon Fluxes on Northeast North American Shelf: Impact of Atmospheric Forcing?

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Continental Shelf Carbon Cycling

The role of continental shelf systems as a sink or source of atmospheric CO_2 in global carbon budgets is an open question. Current thinking suggests that some of the factors influencing shelf ecosystem production and CO_2 fluxes include variability in atmospheric forcing.

We use the NENA model to investigate how shelf carbon cycling will be altered by variability in atmospheric forcing. NENA was developed to investigate the transport and cycling of carbon and nitrogen to and within the U.S. east coast coastal ocean margin [2],[3],[4],[5].

Interannual Variability in Primary Production

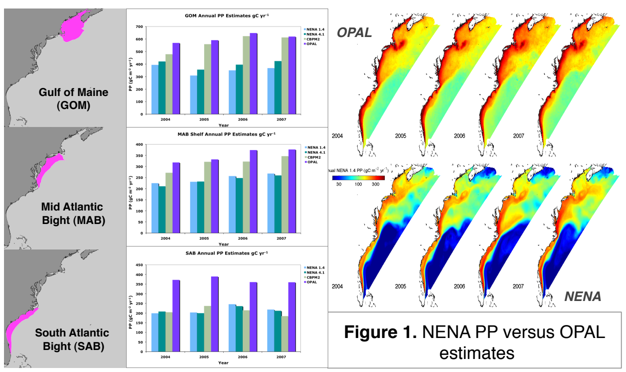


Figure 1. NENA PP versus OPAL estimates

Table 1. Modeled PP & Observations

PP ($gC\ m^{-2}\ yr^{-1}$)	2004 Simulation:	NENA Simulations:
	245 in MAB (Fennel et al., 2008)	2004: 216 in MAB 2005: 221 in MAB 2006: 247 in MAB 2007: 257 in MAB
	Observed*: 310 in MAB; 220 GOM (O'Reilly et al. 1987; Balch et al., 2008) 290 in NY Bight (Malone et al. 1983) 320 in SAB (Menzel et al. 1993) (*refer to Fennel et al., 2006 for reference details)	

The NENA model captures shelf primary production. Modeled estimates are consistent with observations but underestimated especially offshore. However, the biological model contains only 1 phytoplankton group (diatoms) which would account for this.

How will shelf carbon cycling be altered by variability in atmospheric forcing?

We investigate the response of three shelf regions (Gulf of Maine, Mid-Atlantic Bight and South Atlantic Bight) to variability in atmospheric forcing using two model scenarios.

"Present Day" – NENA 1.4

2004 to 2007, HyCOM, NCEP/NARR, pCO_2^{AIR}= 377.4ppm

"Future" – NENA 4.1

as NENA 1.4 except NCEP/NARR+RegCM3 Anomalies, pCO_2^{AIR}=377.4ppm

RegCM3 Anomalies

Atmospheric anomalies derived from two 10-year simulations of the regional climate model, RegCM3 [1] representing present and end of century (doubled) CO_2 levels, forced by 100 year transient run of NCAR climate system model are used to perturb atmospheric forcing.

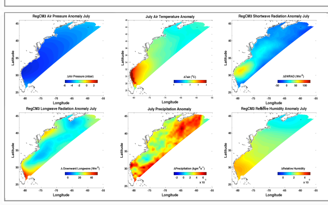


Figure 2. Region will be characterized by increasing temperatures and precipitation, particularly in the summer months.

Dissolved Inorganic Carbon (DIC)

$$\frac{\partial DIC}{\partial t} = -CN_{Phy} \bullet m \bullet Phy + \left(l_{BM} + l_E \frac{Phy^2}{k_p + Phy^2} b\right) \bullet CN_{Zoo} \bullet Zoo + \ ...$$

$$...\ CN_{Det} \bullet r_{SD} \bullet SDet + CN_{Det} \bullet r_{LD} \bullet LDet + \ ...$$

$$...\ \underbrace{\frac{kw^2}{Sc^{1/2}\Delta z}}_{\text{Gas-transfer velocity parameterization}} \underbrace{CO_2^{SOL}}_{CO_2\ \text{solubility}} \underbrace{\left(pCO_2^{air} - pCO_2^{SW}\right)}_{\text{Air-sea } CO_2 \text{ partial pressure difference}} + \nabla DIC \bullet \vec{V} + D_{DIC}$$

$$\delta F \approx \sum_{i=1}^{n} \frac{\partial F}{\partial X_i} \delta X_i + \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \frac{\partial^2 F}{\partial X_i \partial X_j} \delta X_i \delta X_j$$

➔ Apply 1st and 2nd order Taylor Series decomposition to CO_2 flux term to identify processes which dominate CO_2 flux variability [6].

Air-Sea CO_2 Flux

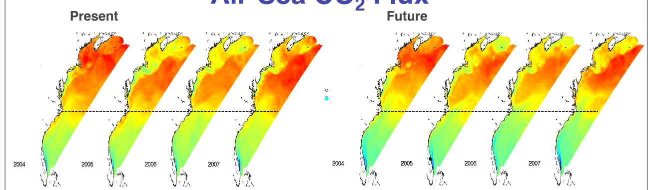
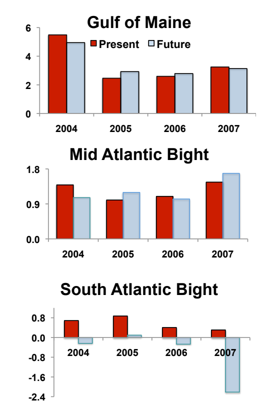


Figure 3. Model Scenarios "Present" (left) &"Future" (right) Air-Sea CO_2 Fluxes 2004 to 2007

Table 2. Air-Sea CO_2 Fluxes (Mt C yr^{-1}); "Present-day" ("Future")

CO_2 FLUX (Mt C yr^{-1})	GOM	MAB	SAB
2004	5.49 (4.95)	1.39 (1.06)	0.69 (-0.24)
2005	2.46 (2.92)	1.00 (1.19)	0.87 (0.09)
2006	2.59 (2.79)	1.09 (1.03)	0.40 (-0.27)
2007	3.25 (3.14)	1.46 (1.69)	0.31 (-2.22)
Other studies	5.6[1], -0.76[3]	2.6[1], 0.6-1.7[2]	-4.2[1], 0.96[4]

Positive ➔ ocean is a sink of CO_2 ; Negative ➔ ocean is a source of CO_2



"Future" simulations

- ➔ *variability in atmospheric forcing can significantly alter regional CO_2 flux.*
- ➔ *GOM & MAB: important processes affecting interannual variability.*
- ➔ *SAB regime shifts from sink to source!*

Work underway …

Investigating processes which dominate CO_2 flux variability:

- ➔ *Winds*
- ➔ *pCO_2 (T, S, NEP, TIC/TA mixing)*

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References:

[1] Chen, M., D. Pollard, E.J. Barron, 2003. Comparison of future climate change over North America simulated by two regional models. *J. Geophys. Res.*, 108, 4348, doi:10.1029/202JD002738.
[2] Fennel, K., J. Wilkin, J. Levin, J. Moisan, J. O'Reilly, D. Haidvogel, 2006. Nitrogen cycling in the Middle Atlantic Bight: Results from a three-dimensional model and implications for the North Atlantic nitrogen budget. *Global Biogeochem. Cycles*, 20, GB3007, doi: 10.1029/2005GB002456.
[3] Fennel K, Wilkin J. 2009. Quantifying biological carbon export for the northwest North Atlantic continental shelves. *Geophys. Res. Lett.* 36:L18605
[4] Fennel, K., J. Wilkin, M. Previdi, and R. Najjar (2008), Denitrification effects on air-sea CO_2 flux in the coastal ocean: Simulations for the Northwest North Atlantic. Geophysical Research Letters, 35, L24608, doi:10.1029/2008GL036147.
[5] Hofmann, E., B. Cahill, K. Fennel, M.A.M. Friedrichs, K. Hyde, C. Lee, A. Mannino, R. G. Najjar, J. E. O'Reilly, J. Wilkin, and J. Xue (2011), Modeling the Dynamics of Continental Shelf Carbon, *Annual Review of Marine Science*, Vol. 3: 93-122.
[6] Previdi, M., K. Fennel, J. Wilkin, and D. Haidvogel (2009), Interannual variability in atmospheric CO2 uptake on the northeast U.S. continental shelf, J. Geophys. Res., 114, G04003, doi:10.1029/2008JG000881.
[7] DeGrandpre MD, Olbu GJ, Beatty CM, et al. 2002. Air-sea CO2 fluxes on the US Middle Atlantic Bight. *Deep-Sea Res.* II 49:4355–67