Satellite Assessment of CO_2 Distribution, Variability and Flux and Understanding of Control Mechanisms in a River Dominated Ocean Margin

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INTRODUCTION

Margin ecosystems receive massive inputs of terrestrial organic and mineral matter and exhibit intense geochemical and biological processing of carbon and other elements. In addition, they exchange large amounts of matter and energy with the open ocean. An argument can be made that increasing terrestrial inputs associated with land use change, increasing discharge of sewage and other anthropogenic materials, and changes in the terrestrial hydrological cycle would tend to shift the coastal oceans in particular toward being a source of CO_2. The fate of terrestrial carbon that is subsequently transported via rivers into the ocean is uncertain. It may be buried or metabolized back to inorganic carbon and either released back to the atmosphere or exported into the deep ocean. Coastal margins may also play a key role in influencing boundary conditions for air masses that transport carbon dioxide onto and away from land masses.

The highly temporally and spatially variable nature of coastal waters has presented serious challenges for estimating regional scale fluxes using discrete shipboard measurements. Novel approaches are needed to expand the temporal and spatial coverage in margin environments (Hales et al., 2008). Satellite-based approaches for estimating pCO_2 distributions have been used successfully in coastal waters (LeFevre et al., 2002; Ono et al., 2004; Lohrenz and Cai 2006; Jiang et al., 2008), and have tremendous potential for extending temporal and spatial coverage.

The Mississippi and Atchafalaya rivers are responsible for one of the largest signals for coastal carbon cycling in the North American continent, indeed, of the world. Total annual input of terrestrial organic and inorganic carbon for these rivers exceeds 25 Mt (25 Tg) C. In addition, the large amounts of dissolved inorganic nitrogen associated with river discharge enhance the effects of the biological pump and have been implicated in the recurrent hypoxia observed in the northern Gulf. Recent estimates of air-sea flux of carbon dioxide in the vicinity of the Mississippi River plume demonstrate the potential for this system to act as both sink and source. These results also reveal the highly variable nature of carbon fluxes in this system, and the need for both greater spatial and temporal coverage as well as an assessment of the underlying community metabolism driving patterns in surface CO_2.

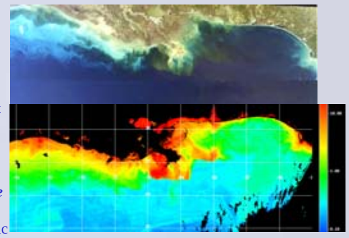


Fig. 1. High resolution true color MODIS Aqua image of northern Gulf of Mexico for 7 Jan 2009 (top) and of chlorophyll in mg m^{-3} (bottom).

Here, we summarize progress of ongoing research to characterize air-sea fluxes of CO_2 and underlying control mechanisms (Fig. 2). Our specific objectives involve characterizing spatial gradients and seasonal variations in air-sea fluxes of CO_2 in relationship to spatially varying effects of mixing of river and ocean water (solubility pump) and the variable intensity of the biological pump as mediated by the balance between photosynthesis and respiration. Our methods will encompass a combination of intensive field surveys, process studies, satellite-based assessments of regional scale distributions, and application of a mechanistic box-model to aid in understanding of key biogeochemical processes that determine sea surface pCO_2 variability.

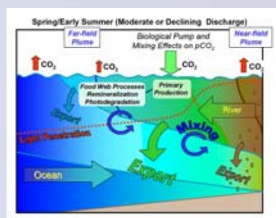


Fig. 2. Conceptual representation of major plume processes and hypothetical relationships to air-sea fluxes of CO_2.

CURRENT FINDINGS

An extensive series of cruises were conducted from Jun 2003 through Aug 2007 in conjunction with a NASA-funded project entitled "Ocean Color Assessment of pCO_2 in a River-Dominated Coastal Margin". These cruises spanned a range of river discharge and seasonal conditions (Fig. 3). Our approach involved a combination of shipboard observations of in situ properties and satellite-extrapolation. Areal distributions of pCO_2 were derived from MODIS imagery in the northern Gulf of Mexico based on empirical relationships of in situ measurements of surface pCO_2 to environmental variable. Principal component analysis was applied to the T, S and chlorophyll data and regression relationships with the derived orthogonal components were used to produce an empirical algorithm for the satellite estimation of pCO_2 (Fig. 4).

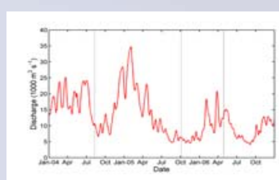


Fig. 3. Mississippi River discharge observations reported for Tarbert Landing, MS (data courtesy of U.S. Army Corps of Engineers). Vertical lines indicate cruise periods.

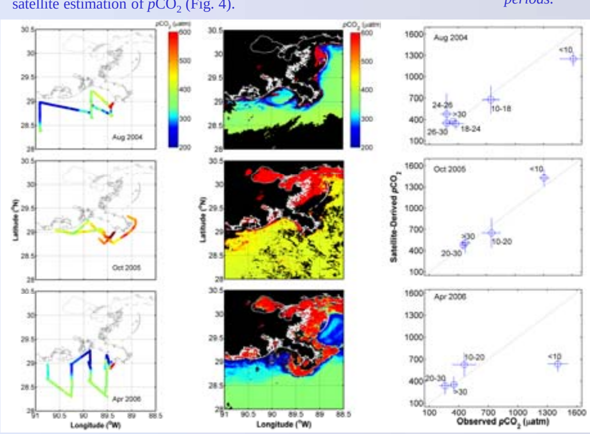


Fig. 4. Scatter plots of pCO_2 from underway shipboard surveys (left column) along with satellite derive maps of pCO_2 illustrate temporal and spatial variation in pCO_2. Match-ups between satellite and in situ pCO_2 are shown in the right column binned by salinity range. Satellite-derived pCO_2 showed reasonable agreement in many cases, but differences were evident for some salinity intervals. Differences were partially attributable to temporal offsets between the time of in situ data collection and image acquisition in some instances.

Annual sea to air flux of CO_2 computed from the satellite maps of pCO_2 and buoy winds exhibited large variations between cruises. Various sets of the gas transfer velocity, k, vs. wind speed relationships (Wanninkhof and McGillis, 1999; Nightingale et al., 2000; McGillis et al., 2001; Ho et al., 2006) were used to provide a range of values to bracket the gas flux. Satellite-derived values have high uncertainty in estuarine and inland waters because of lack of sufficient data.

Table 1. Daily sea to air flux of CO_2 in the Mississippi River outflow region (mmol C m^{-2} d^{-1})

Date	Sea to air flux of CO_2	
	Plume	Shelf
Jun 2003	-3.7 – -6.8	-2.7 – -4.9
Aug 2004	-1.0 – -1.3	0.39 – 0.48
Oct 2005	6.4 – 7.9	9.7 – 11.9
Apr 2006	-2.7 – -3.3	0.44 – 0.50

CURRENT FINDINGS (continued)

An additional series of observations was conducted in conjunction with EPA Hypoxia Survey cruises which provided a more extensive mapping of surface pCO_2. The results show a consistent pattern of low pCO_2 in river-influenced regions, supporting the view that these areas of the northern Gulf of Mexico are a sink for atmospheric CO_2.

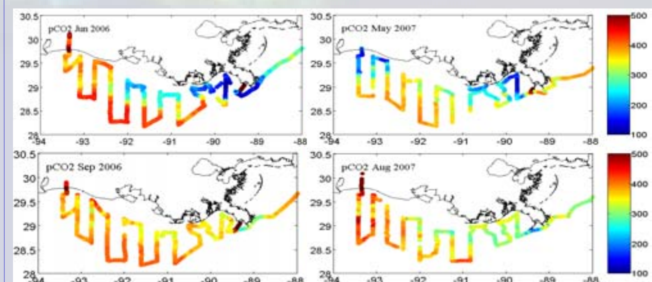


Fig. 5. Scatter plots of pCO_2 from underway shipboard observations conducted in conjunction with EPA hypoxia survey cruises. Values of pCO_2 were consistently low in regions influenced by river outflow.

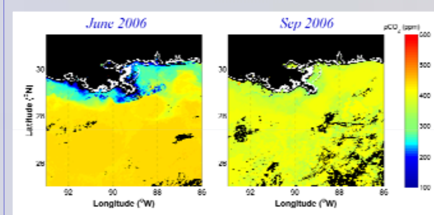


Fig. 6. Satellite derived images of surface pCO_2 developed using a modified PCA-based empirical algorithm. The satellite images allow for extrapolation over a much larger area. The comparison between June and September highlight the seasonality of the river outflow and the associated impacts on the biological pump.

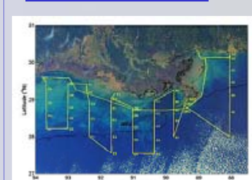
Satellite mapping of pCO_2 was consistent with the in situ observations, characterized by lower levels of surface pCO_2 in June 2006 consistent with a strong biological pump and relatively high rates of autotrophic carbon fixation. The biological pump appeared to be less active in September 2006, which could likely be attributed to relatively low river discharge and correspondingly low rates of autotrophic carbon fixation.

Measured rates of sea-to-air flux for the river outflow region were comparable to those previously reported including Chavez and Takahashi (2006) for the Gulf of Mexico and Carribean (2.2±5.5 mmol C m^{-2} d^{-1}) and Cai et al. (2006) for low latitude western boundary current shelves (2.7±1.1 mmol C m^{-2} d^{-1}).

Table 2. Daily sea to air flux of CO_2 for the Jun and Sep 2006 cruises (mmol C m^{-2} d^{-1})

Date	Sea to air flux of CO_2	
	Plume	Shelf
Jun 2006	-5.2	4.1
Sep 2006	0.25	2.2

FUTURE DIRECTIONS



Our ongoing research continues with a series of NSF-funded cruises which will provide more extensive spatial and seasonal coverage and begin to examine underlying chemical and biological drivers regulating surface water pCO_2. A successful cruise was recently completed on the R/V Cape Hatteras from 8-20 Jan 2009 (cruise track on left). Additional cruises are planned for 2009 and 2010.

A website about the GulfCarbon project is located at:

http://ocean.otr.usm.edu/~w301130/research/gulfcarbon_new.htm

CONCLUSIONS

Our findings suggest the late spring and early summer is a period of lower surface pCO_2 corresponding to a strong biological pump and net fixation of inorganic carbon. In addition to effects of the biological pump, key environmental drivers appear to be seasonal variations in temperature and freshwater discharge. Our research also highlights sources of uncertainty in coastal carbon flux estimates including a lack of information from winter months and limited observations in inland and estuarine waters.

More information is needed over a larger region in the Gulf of Mexico and other coastal regions to better constrain CO_2 fluxes at the continental margins. Such information should help to refine models estimating North American carbon fluxes and improve their performance for predicting change and management strategies. Ongoing and future studies funded through NASA, NOAA and NSF will address some of these issues.

ACKNOWLEDGEMENTS

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