The CO_2 system in the Gulf of Mexico, a synthesis and modeling effort

Leticia Barbero[1,2], Rik Wanninkhof[2], Lisa Robbins[3], Wei-Jun Cai[4], Ruoying He [5] and Katja Fennel[6]

[1]CIMAS, University of Miami, Miami, FL, USA [2]AOML, National Oceanographic and Atmospheric Administration, Miami, FL, USA [3]CCRMS, United States Geological Survey, St. Petersburg, FL, USA [4]CEOE, University of Delaware, Newark, DE, USA [5]MEAS, North Carolina State University, Raleigh, NC, USA [6]Dalhousie University, Halifax, NS, Canada.

Introduction and rationale

- The US Coastal Carbon component of the North American Carbon Program (NACP) aims to quantify the net sources and sinks of carbon in the ocean. Specific objectives of the ocean margin studies are to improve estimates of air-sea fluxes and their impact on the CO_2 concentrations in the coastal seas along the conterminous USA.
- The NOAA Ocean Acidification Program focuses on the increase of our understanding about how the chemistry of the ocean is changing, how variable that change is by region, and what impacts these changes are having on marine life, people, and the local, regional, and national economies.
- Within the framework of the Gulf of Mexico Coastal Carbon Synthesis effort and the recently funded NASA ROSES project "Air-Sea CO2 Flux and Carbon Budget Synthesis and Modeling in the Entire Gulf of Mexico", work is underway to compile and provide the most comprehensive set of surface ocean carbon measurements available in the region.
- The extensive dataset provides enough information to produce a monthly air-sea CO_2 flux climatology centered on the year 2009 and to analyze seasonal and spatial variability in different Gulf sub-regions, with special attention to the open ocean, Northern Gulf of Mexico (GOM) and West Florida shelf (WFS).
- Model derived estimates will be compared with observation estimates to gain a process-level understanding of the regional controls on the sea-air fluxes.

Data and methods

Data has been collected on board of Ships of Opportunity, NOAA research vessels and dedicated cruises. Publicly available data was obtained from datasets and repositories such as NODC, CDIAC, and SOCAT. Additional data from members of the NASA ROSES "Air-Sea CO2 Flux and Carbon Budget Synthesis and Modeling in the Entire Gulf of Mexico" project, which are not yet publicly available have also been included.

As of December 2014, there were over 400K data points in the Gulf of Mexico with measurements of pCO_2, total alkalinity (TA), pH and Dissolved Inorganic Carbon (DIC) (Fig 1). For flux studies, we have only used data that have pCO_2 air measurements as well as ocean values.

The coastal regions of the Gulf, and in particular the Mississippi and Atchafalaya estuaries, have different biogeochemical regimes and wind fields, and require a separate data treatment.

Here we present results of "open ocean" conditions, defined as the open ocean areas of the Gulf of Mexico with depths deeper than 200 m. Figure 1 shows the location of the 200 m bathymetry line.

For the study of the seasonal air-sea CO_2 flux and aragonite saturation state, Ω_{Ar}, in the open ocean, we partition the data in two prevailing seasons: a warm, rainy "summer" (between June and October) and a cool, dry "winter" (between November and May).

1)

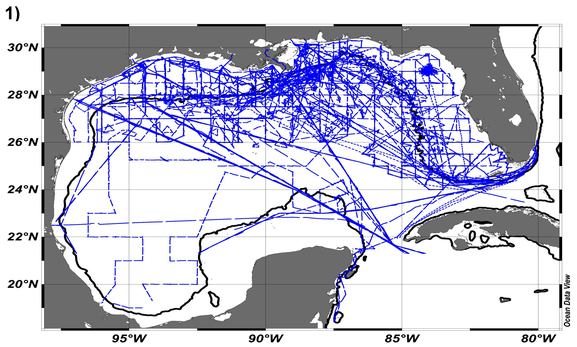


Figure 1) Data coverage up to 2014. The bathymetric line indicates the location of the 200 m depth.

Air-sea CO_2 fluxes in the open ocean

Air-sea CO_2 fluxes for the open ocean have been estimated using the following expression:

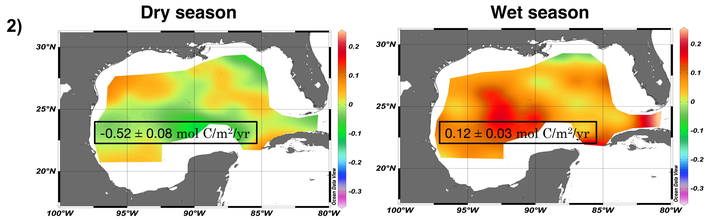
$$F = k \cdot s \cdot (fCO_2sw - fCO_2air)$$

where s is the gas solubility and k is the gas transfer velocity. We have used a gas exchange coefficient of 0.251 and the second moment of CCMP wind speeds (Atlas et al., 2011).

The results suggest that the Gulf acts as a sink for atmospheric CO_2 during the winter months and is mostly a source for CO_2 during the warm period. Regional variability is observed (Fig. 2).

We have averaged our data set per month and computed the net annual flux. We compare our results with the estimate by Takahashi et al. (2009), based on only two cruises and only summer data (Fig 3). Our results suggest the open ocean of the GOM is a sink for atmospheric CO_2 with a net flux of -0.41 ± 0.08 mol C/m²/year compared with Takahashi's estimate of a source of 0.03 mol C/m²/year.

2)



3)

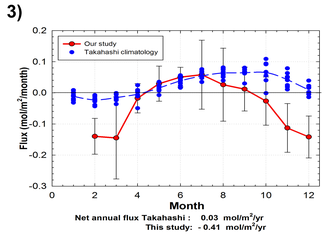


Figure 2) Seasonal air-sea CO_2 flux maps for the GOM in the cool/dry season (left) and warm/wet season (right). Fluxes are expressed in mol/m²/month.

Figure 3) Net annual air-sea CO_2 flux in the Gulf of Mexico, based on the climatology from Takahashi et al (2009), in blue, and estimated from our dataset, in red.

Aragonite saturation state (Ω_{Ar}) in open ocean surface waters

A first estimate of the calcite and aragonite saturation states in surface waters of the open ocean region of the Gulf of Mexico is obtained from pCO_2 and total alkalinity values (estimated from the equation by Lee et al. 2006).

Data points close to the Mississippi estuary region with low salinities were discarded for this calculation.

In open ocean waters, aragonite saturation state values increase with higher temperatures in the warm season. Regional variability is observed in the area, with higher saturation states observed in the southeast Gulf region.

Values decrease during the dry season as a result of lower temperature (and thus alkalinity). The GOM is oversaturated in aragonite at all times.

4)

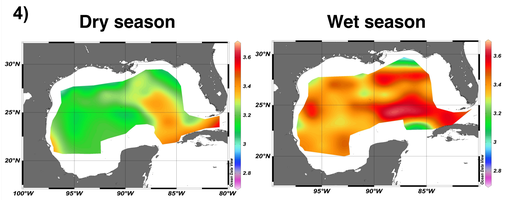
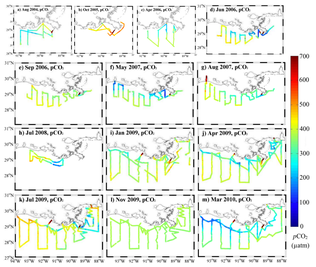


Figure 4) Ω_{Ar} in surface waters of the open ocean region of the GOM in the cool/dry season (left) and warm/wet season (right).

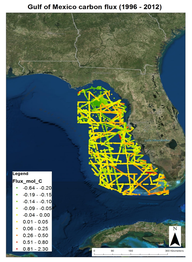
Coastal studies

In depth analyses of the northern Gulf and West Florida Shelf are taking place. The northern GOM has significant spatial and seasonal variations in surface water pCO_2 distribution (Fig. 5, Huang et al. 2015). More details can be found in the poster by Cai et al., "Determining sea surface pCO_2 distribution, flux and variability in the GOM with implications for a regional carbon budget" (Poster NACP #33).

5)



6)



A concerted effort has been made to collect pCO_2 and other carbon data in the waters on the WFS in the last decade (Fig. 6). For further details on variability, please see the poster by Robbins et al., "Carbon Fluxes on the West Florida Shelf" (Poster NACP #8).

Figure 5) Surface water pCO_2 (matm) collected in the northern GOM between August 2004 and March 2010. Under-saturated pCO_2 usually mirrored the freshwater distribution along the plume trajectories (Huang et al., 2015).
Figure 6) Map of the WFS study area and air-sea CO_2 fluxes (9 years and 39 cruises).

Modeling efforts

7)

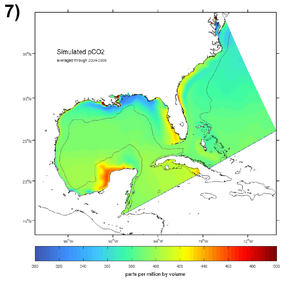


Figure 7) SABGOM ROMS simulated mean pCO_2 (averaged over 2004-2010) in the Southeastern U.S. coastal ocean.

A 3D regional marine ecosystem model covers the entire South Atlantic Bight and its upstream GOM areas (ROMS circulation model coupled with a marine ecosystem model), (Xue et al., 2013, Fennel et al. 2008).

Model simulated mean pCO_2 fields reproduce general features observed by satellite and in situ ship surveys (Fig 7).

The coupled physical-biogeochemical model is capable of resolving the main spatiotemporal variations of circulation and biogeochemical variables in the Gulf.

Summary and prospects

- ✓ Intense sampling effort in the GOM in the last decade has resulted in improved spatial and temporal coverage (400K datapoints).
- ✓ Preliminary results indicate the open ocean area is a sink for CO_2, high seasonal and spatial variability is observed in coastal regions.
- ✓ OA products in open ocean show changes associated to temperature. The GOM is oversaturated in aragonite.
- ✓ Modeling output indicates that the coupled model can resolve the major physical and biogeochemical dynamics of the GOM.

Next steps:
- ✓ Climatology of air-sea CO_2 flux in the GOM centered on the year 2009.
- ✓ OA product comparison with model outputs.
- ✓ Detailed regional studies in data rich Northern GOM and WFS
- ✓ Model validation using the extensive dataset collected.
- ✓ Inorganic carbon budget based in observational and modeling approach.

References:
- Atlas, R. et al. (2011). A cross-calibrated multiplatform ocean surface wind velocity product for meteorological and oceanographic applications, Bull. Amer. Meteor. Soc., 92, 157-174, DOI:10.1175/2010BAMS2946.1.
- Cai, W.-J. et al. (2010), Alkalinity distribution in the western North Atlantic Ocean margins, J. Geophys. Res., 115, C08014, doi:10.1029/2009JC005482.
- Fennel, K. et al. (2008) Denitrification effects on air-sea CO2 flux in the coastal ocean: Simulations for the Northwest North Atlantic. Geophysical Research Letters 35, L24608, doi:10.1029/2008GL036147
- Huang, W-J. et al. (2015). The carbon dioxide (CO2) system on the Mississippi River-dominated continental shelf in the northern Gulf of Mexico: 1. Distribution and air-sea CO2 flux. Journal of Geophysical Research-Oceans DOI: 10.1002/2014JC010498
- Lee, K., et al. (2006). Global relationships of total alkalinity with salinity and temperature in surface waters of the world's oceans. Geophys Research Letters 33, L19605, doi:10.1029/2006GL027207.
- Pierrot, D., et al. (2009). Recommendations for autonomous underway pCO_2 measuring systems and data-reduction routines. Deep Sea Research Part II 56:8-10, pp 512-522. doi:10.1016/j.dsr2.2008.12.005
- Takahashi, T. et al. (2009). Climatological mean and decadal change in surface ocean pCO_2, and net sea–air CO_2 flux over the global oceans. Deep Sea Research Part II 56:8-10, pp 554-577. doi:10.1016/j.dsr2.2008.12.009
- Xue, Z. et al. (2013), Modeling Ocean Circulation and Biogeochemical Variability in the Gulf of Mexico, Biogeosciences Discuss., 10, 1-46, doi: 10.5194/bgd-10-1-2013.

Acknowledgements: We are grateful for the help from the crews of the NOAA vessels, R/V Ronald H. Brown and R/V Gordon Gunter toward the maintenance of underway pCO_2 systems. We are indebted to Hapag Lloyd and Methanol Holdings for allowing us to install autonomous systems on their vessels, M/V Barcelona Express and M/V Las Cuevas. This work was funded through the NOAA Climate Observation Division of Climate Program Office, the NOAA Ocean Acidification office and the NASA ROSES program.

CONTACT: leticia.barbero@noaa.gov