Carbon Measurements along the North American Continental Margins

NORTH AMERICAN CONTINENTAL MARGINS (NACM)
THE OCCC/NACP COASTAL CO₂ WORKSHOP

Boulder, CO; Sept. 21-23, 2005
Lead Organizer: Burke Hales (OSU)
Other Members of Organizing Committee:
Wei-Jun Cai, Greg Mitchell, Chris Sabine, Oscar Schofield

50 participants
37 scientific inst.
3 gov. agencies
6 countries

Science Implementation Strategy for the North American Carbon Program
Prepared for the
U.S. Carbon Cycle Scientific Steering Group
and Interagency Working Group
by the
North American Carbon Program Implementation Strategy Group
A. Scott Deming
Chair and editor

Ocean Carbon and Climate Change
An Implementation Strategy for U.S. Ocean Carbon Research
Prepared for the
U.S. Carbon Cycle Science Scientific Steering Group
and Interagency Working Group
by the
Carbon Cycle Science Ocean Interim Implementation Group
Scott C. Donnay
Chair and editor
**The NACM workshop: Objectives**

1. Summarize and synthesize the 'state of the art' regarding C cycling on the continental margins (the knowns).
2. Identify the key processes that shape regional C cycling.
3. Identify the most pressing uncertainties in our ability to estimate coastal C fluxes (the known unknowns).
4. Hypothesize about potential responses of coastal systems (and inherent C cycling) to global change.
5. Offer guidelines for future coastal research programs.
6. Present these in a formal report to US funding agencies and the IWG.

Great progress was made at the workshop and the science is now well underway.
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Coastal Oceans

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A First Assessment of NA Air-Sea Fluxes Based on Data Extracted From Global Data-Base

Takahashi, Hales, Chavez

LDEO, MBARI, OSU, AOML, UGA databases contain ~100k coastal surface pCO$_2$ measurements dating to 1979 that were excluded from global compilations.

These data were mapped into 1° x 1° pixels within ~3° from the coastline; and monthly-mean fluxes were calculated for each pixel.
Integrating fluxes from 'coastal' pixels, the bottom line:
Total: $+1.6 \pm 35.6$ Tg C yr$^{-1}$
Mexico: $+44.9 \pm 14.0$, 
US: $-21.0 \pm 17.9$, 
Canada: $-22.4 \pm 27.4$
The coverage problem

But this result is sensitively dependent on near-cancellation of large sources and large sinks, which occur in EXTREMELY low sample-density regions.

<10% have full 12 calendar-month over the aggregate ~25 years of the record. This is because the CO₂ measurements were primarily made on vessels participating in open-ocean programs.
Coastal CO$_2$ Observational Network

- PMEL/OSU
- PMEL/UNH
- WHOI/LDEO
- NOAA moorings
- Other CO$_2$ moorings
- MBARI
- UCLA
- UABC PMEL/USM
- PMEL/UGA
- PMEL/USM

- West Coast Cruise Stations
- East Coast Cruise Stations
- CO$_2$ Moorings
- CO$_2$ Flux Tower
Underway pCO$_2$ network and new data: East and Gulf of Mexico Coasts (2006-2008)

>150,000 new data points
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.

See Poster by Steve Lohrenz
Underway pCO$_2$ network and new data:
West Coast (2006–2008)

>250,000 new data points
See Poster by Simone Alin
Underway pCO$_2$ system observations in 2007
PMEL Moored Autonomous pCO$_2$ (MAPCO$_2$) system

initial design from the MBARI drifters of Gernot Friedrich and Francisco Chavez

The Basics:

- LI-COR 820 NDIR detector to measure air and water CO$_2$.
- Gas calibration traceable to WMO standards.
- Self-contained modular unit designed to fit a range of buoys.
- Daily satellite data transmission.
Average annual $pCO_2$ cycle at coastal moorings (2006–2008)

Northern sites are a $CO_2$ sink in the spring and a source in the winter, while Georgia shows the opposite trend.

Washington strongly influenced by spring and summer upwelling

NH sees spring bloom drawdown and mixing in the winter

Georgia is primarily temperature controlled with some river influences

$\sim 50,000$ new data points
5 Years at a Northeast U.S. Coastal Site - G. of Maine Vandemark, Salisbury, McGillis, Sabine and many other collaborators

- Rich data set for C monitoring and process studies
- Monthly cruise data (2004-) and daily CO₂ buoy obs. (2006-)
- Hourly inshore and offshore surface atmos. CO₂ data
- Substantial snowmelt and river discharge

UNH shipboard pCO₂ and in situ data at www.cooa.unh.edu and soon at CDIAC

we acknowledge NOAA/PMEL, UMaine, NDBC, USGS
Extrapolation & Synthesis of CO₂ Observations

Field CO₂ data assigned to regions

Remote sensing climatologies

SOM defines regions

Non-linear model

\[ pCO_2 = f(Alk, TCO_2, T, S) \]

\[ TCO_2 \approx TCO_{2,0} + \left( \frac{\partial TCO_2}{\partial T} \right)_{mix} \Delta T_{mix} + \left( \frac{\partial TCO_2}{\partial Chl} \right)_{bio} \Delta Chl_{bio} \]

\[ Alk \approx Alk_0 - 0.15 \Delta TCO_2 \]

Flux = \( k \cdot \Delta fCO_2 \)

\[ k = f(U_{10}, SST) \]

CO₂ flux maps

Wind speed

pCO₂ map

Remote sensing data
Observation vs. SOM-based CO$_2$ maps

SOM pCO$_2$ maps for same season

Cruise pCO$_2$

Hales et al. (in prep.)
Monthly pCO$_2$ and CO$_2$ Flux Maps

SOCR: +0.5 Tg C y$^{-1}$ vs. SOM: -17 Tg C y$^{-1}$

Hales et al. (in prep.)
SOCCR: +9 Tg C y⁻¹ vs. SOM: -1.5 Tg C y⁻¹

Hales et al. (in prep.)
Linkages with other coastal issues & processes

**Hypoxia**

Sources: Hales et al. (2006), Doney et al. (2007), Donner & Kucharik (2008)

**Land-use**

**Acidification**

Sources: Hales et al. (2006), Doney et al. (2007), Donner & Kucharik (2008)
Coastal Cruises 2007:
West Coast (May–June) & Gulf/East Coast (July–August)

• 111 stations on 13 transects on West Coast cruise and 90 stations on 9 transects on Gulf of Mexico and East Coast Carbon cruise
• Depth profile measurements include: temperature, salinity, dissolved inorganic carbon, alkalinity, nutrients, oxygen, organic carbon, oxygen isotopes, ...

Evidence for Upwelling of Corrosive “Acidified” Water onto the Continental Shelf

Richard A. Feely,1* Christopher L. Sabine,1 J. Martin Hernandez-Ayon,2 Debby Ianson,3 Burke Hales4
Upwelling Induced Acidification of the Continental Shelf

The 'ocean acidified' corrosive water was upwelled from depths of 150-200 m onto the shelf and outcropped at the surface near the coast.

Red dots represent sample locations. Feely et al. (2008)
Ocean Acidification of the North American Continental Shelf

NACP Coastal Survey: 11 May - 14 June 2007

Distribution of the depths of the corrosive water (aragonite saturation < 1.0; pH < 7.75) on the continental shelf of western North America from Queen Charlotte Sound, Canada to San Gregorio Baja California Sur, Mexico.

On transect lines 5 and 6 the corrosive water reaches all the way to the surface in the inshore waters near the coast.

Feely et al. (2008)
The coverage problem
But this result is sensitively dependent on near-cancellation of large sources and large sinks, which occur in EXTREMELY low sample-density regions.

We have made good progress in improving our data coverage which, in turn, has greatly improved our ability to detect and attribute changes. However, we still have a long way to go.
Conclusions

1. Since the NACP and OCCC programs started, there have been many new resources deployed in the coastal ocean making important carbon observations and new discoveries.

2. We are also developing new approaches for interpreting these observations to get improved regional flux estimates.

3. The new data and analyses indicate that annual regional CO$_2$ fluxes are substantially different than initially estimated in the SOCCR.

4. We are also finding new links between coastal carbon processes and important phenomena such as hypoxia and ocean acidification.

5. The coastal carbon program needs further development and funding solidified to fully contribute to the NACP and OCB goals.