PLENARY 1. Carbon Fluxes in North American Coastal Systems: Key Processes

Estuarine and shelf water fluxes

Air-sea fluxes

(14:50 to 15:30)

Coastal CARbon Synthesis (CCARS) Community Workshop
Woods Hole Oceanographic Institution, Clark 507
August 19-21, 2014
Importance of the coastal ocean small area, big CO$_2$ flux!

Overall uncertainty in coastal ocean: ±50% or ±0.2 PgC/yr
(recent) History of Coastal Carbon Synthesis
(Cai talk at CO-GRC, 2009)

- DOE Ocean Margin Program (OMP) 1993-1996; data have not adequately synthesized.
- 2005 OCCC/OCB summer workshop
- 2007 NACP meeting
- 2008 NACM Report
- 2008 GOM-C OCB Scoping workshop
- 2008 OCB summer workshop
- 2009 NACP meeting
- 2009 OCB summer workshop
- Many spl sessions at AGU, OSM, etc.

Denning (2002)

Doney (2004)

Hales et al. (2008)
A global journey of carbon flow across land-ocean interfaces

Regnier et al. (2013)
Anthropogenic perturbation of the carbon fluxes from land to ocean.
_Nature Geosci._ 6, 597–607 (2013).)
Factors regulating riverine carbon fluxes

1. Changes in the water balance (precipitation and evapotranspiration)
2. Carbon stocks and flows in watersheds
   - Precipitation is more important than temperature
   - Extreme rainfall events (from tropical storms) carry disproportionately high amount of C to the ocean.
3. Human interventions (wetland removal, building reservoirs/dams)

Bauer et al. (2013) Fig. 1a
Physical and biogeochemical processes control the source, transport and fate of organic carbon on continental shelves.
Coastal ocean C fluxes—across the subsystem boundaries

Bauer et al. (2013) Fig. 2
Coastal ocean C fluxes—estuarine

Total estuarine degassing flux is ~ 0.25 PgC/yr

Bauer et al. (2013) Fig. 3a
Coastal ocean C fluxes—continental shelves

Total shelf CO$_2$ uptake flux is $\sim$ 0.25 PgC/yr

Bauer et al. (2013) Fig. 3b
What we learned from the flux analysis?

This synthesis shows that the present-day coastal ocean is
• a net sink for atmospheric CO$_2$ and
• a burial site for organic and inorganic carbon, and
• represents an important global zone of carbon transformation and sequestration.

Climate change and human activities have a clear impact on coastal ocean C cycle and fluxes
Major processes affecting air-sea CO$_2$ flux in North American margins

- **West Coast**: Eastern boundary current and upwelling system
- **Alaskan and Arctic**: Seasonal sea-ice melt and biological production/respiration plus seasonal river inputs
- **northern Gulf of Mexico**: Marginal sea and larger river inputs
- **East coast**: River- and wetland-impacted broad shelves interacting with alongshore currents (Gulf Stream and Labrador Current)
- **Carbonate banks/coral reefs**: (southern GOM, FL shelf; etc.)?
- **Large estuaries**: (Chesapeake Bay, etc.)?
- **The Great Lakes**?
Eastern boundary current and upwelling system (West Coast)

$\text{CO}_2$ uptake in offshore zone

Release $\text{CO}_2$ in nearshore zone

Feely et al. Science (2008)
Eastern boundary current and upwelling system (West Coast)

Hales et al. 2012. Prog Oceanography

Fig. 3. Input data used for generating the self-organizing map (SOM) of Pacific coastal waters. Left, Sea-Surface Temperature (SST); middle, sea surface chlorophyll; right, net southward wind stress.

Self-organizing map of biogeochemical regions in the study area.
SOM-based model predicted monthly $p$CO$_2$

- Annual average sink of 1.8 mmol/m$^2$/d
- (or 14 ±14TgC/yr)
Seasonal sea-ice melt and biological production/respiration plus seasonal river inputs (Alaskan and Arctic)

(Mathis et al. 2011; JGR)

Low $pCO_2$  
High pH

High $pCO_2$  
Low pH

Wind-driving upwelling lead to high $pCO_2$  
Mathis et al. 2012; GRL
The Gulf of Alaska coastal ocean as an atmospheric CO$_2$ sink

Wiley Evans and Jeremy T. Mathis, 2013, CSR, 65, 52-63

Couple with monthly data from Scatterometer Climatology of Ocean Winds (SCOW; Risien and Chelton, 2008)

Area-weighted fluxes scaled to surface area of coastal ocean and continental margin amount to 36 and 14 Tg of atmospheric C uptake yr$^{-1}$

![Monthly climatologies of ΔpCO$_2$, SST, salinity, pCO$_2$ solubility on 0.1° by 0.1° grid](image1.png)

<table>
<thead>
<tr>
<th>Month</th>
<th>Coastal ocean $F_{\text{CO}_2(aw)}$</th>
<th>Continental margin $F_{\text{CO}_2(aw)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>3.5 mmol CO$_2$ m$^{-2}$ d$^{-1}$</td>
<td>3.2</td>
</tr>
<tr>
<td>February</td>
<td>3.4</td>
<td>3.3</td>
</tr>
<tr>
<td>March</td>
<td>2.0</td>
<td>-0.1</td>
</tr>
<tr>
<td>April</td>
<td>-0.4</td>
<td>-2.2</td>
</tr>
<tr>
<td>May</td>
<td>-10.0</td>
<td>-13.0</td>
</tr>
<tr>
<td>June</td>
<td>-5.2</td>
<td>-12.0</td>
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<tr>
<td>July</td>
<td>-5.1</td>
<td>-7.0</td>
</tr>
<tr>
<td>August</td>
<td>-4.4</td>
<td>-8.7</td>
</tr>
<tr>
<td>September</td>
<td>-10.4</td>
<td>-12.5</td>
</tr>
<tr>
<td>October</td>
<td>-2.1</td>
<td>3.2</td>
</tr>
<tr>
<td>November</td>
<td>-3.0</td>
<td>-6.1</td>
</tr>
<tr>
<td>December</td>
<td>1.9</td>
<td>4.6</td>
</tr>
<tr>
<td>Annual mean</td>
<td>-2.5</td>
<td>-4.0</td>
</tr>
</tbody>
</table>
Assessing sea-air CO$_2$ exchange in the coastal Arctic Ocean surrounding Canada Basin


Coastal Arctic Ocean surrounding Canada Basin = Chukchi Sea and Beaufort Sea (inclg: Amundsen Gulf & M’Clure Strait)

Sea-Air CO$_2$ flux (no ice) vs SSM/I Monthly Sea Ice vs Ice-dampened CO$_2$ flux

Area-weighted flux with the sea ice climatology scaled to surface area of coastal Arctic Ocean surrounding Canada Basin = 11 Tg of atmospheric C uptake yr$^{-1}$

In the absence of sea ice, this sink increases by 5 Tg C yr$^{-1}$
Marginal sea and larger river inputs (northern Gulf of Mexico)
Spatial and seasonal pattern of pCO$_2$ in the nGOM

Spatial variation
1. Low pCO$_2$ at mid-salinity (mid-field)
2. High pCO$_2$ at low (river mouth) and high salinity (offshore)
3. West (high) to east (low) contrast

Seasonal variation
1. Low pCO$_2$ in spring and early summer
2. High pCO$_2$ in late summer and fall

A net CO$_2$ sink of
0.96±3.7 mol C m$^{-2}$ yr$^{-1}$
or
2.63 mmol m$^{-2}$ d$^{-1}$
1.15±4.4 g C yr$^{-1}$
(Huang et al. in prep)
Gulf of Mexico

Huang et al. in prep
Signorini et al. (2013) JGR-O

FCO2 = -0.7 to -1.0 molC/m²/yr or -1.9 to -2.74 mmol/m²/d
Area total: -3.4 to -5.4 TgC/yr
<table>
<thead>
<tr>
<th>Region</th>
<th>Area (1010 m²)</th>
<th>( k_{660}^1 ) (mol CO₂ m⁻² yr⁻¹/ Tg C yr⁻¹)</th>
<th>( k_{660}^2 ) (mol CO₂ m⁻² yr⁻¹/ Tg C yr⁻¹)</th>
<th>( k_{660}^1 ) (mol CO₂ m⁻² yr⁻¹/ Tg C yr⁻¹)</th>
<th>( k_{660}^2 ) (mol CO₂ m⁻² yr⁻¹/ Tg C yr⁻¹)</th>
<th>Literature (mol CO₂ m⁻² yr⁻¹/ Tg C yr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS</td>
<td>12.82</td>
<td>−1.10 ± 0.25</td>
<td>−1.21 ± 0.27</td>
<td>−0.39 ± 0.34</td>
<td>−0.42 ± 0.36</td>
<td>+1.42 ± 0.28b</td>
</tr>
<tr>
<td></td>
<td></td>
<td>−1.69 ± 0.39</td>
<td>−1.87 ± 0.42</td>
<td>−0.56 ± 0.50</td>
<td>−0.60 ± 0.53</td>
<td>+2.19 ± 0.43</td>
</tr>
<tr>
<td>GoM</td>
<td>12.77</td>
<td>+0.11 ± 0.21</td>
<td>+0.04 ± 0.22</td>
<td>+0.01 ± 0.08</td>
<td>+0.01 ± 0.08</td>
<td>+0.38 ± 0.26c</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+0.17 ± 0.32</td>
<td>+0.06 ± 0.34</td>
<td>+0.02 ± 0.12</td>
<td>+0.02 ± 0.12</td>
<td>+0.58 ± 0.40</td>
</tr>
<tr>
<td>GB+NS</td>
<td>5.83</td>
<td>−0.65 ± 0.20</td>
<td>−0.71 ± 0.22</td>
<td>−1.27 ± 0.23</td>
<td>−1.37 ± 0.24</td>
<td>+1.1 ± 0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>−0.46 ± 0.14</td>
<td>−0.50 ± 0.15</td>
<td>−0.79 ± 0.16</td>
<td>−0.86 ± 0.16</td>
<td>−1.0 ± 0.6d</td>
</tr>
<tr>
<td>MAB</td>
<td>9.31</td>
<td>−0.95 ± 0.24</td>
<td>−1.07 ± 0.27</td>
<td>−1.58 ± 0.19</td>
<td>−1.78 ± 0.19</td>
<td>−0.48 ± 0.21e</td>
</tr>
<tr>
<td></td>
<td></td>
<td>−1.06 ± 0.27</td>
<td>−1.12 ± 0.30</td>
<td>−1.63 ± 0.21</td>
<td>−1.83 ± 0.22</td>
<td>−0.59 ± 0.26</td>
</tr>
<tr>
<td>SAB</td>
<td>10.20</td>
<td>−0.79 ± 0.26</td>
<td>−0.68 ± 0.24</td>
<td>−0.61 ± 0.17</td>
<td>−0.67 ± 0.16</td>
<td>−0.59 ± 0.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>−0.97 ± 0.31</td>
<td>−0.83 ± 0.29</td>
<td>−0.67 ± 0.20</td>
<td>−0.74 ± 0.20</td>
<td>−0.59 ± 0.26</td>
</tr>
<tr>
<td>Total</td>
<td>50.63</td>
<td>−4.01 ± 0.30</td>
<td>−4.26 ± 0.31</td>
<td>−3.63 ± 0.24</td>
<td>−4.01 ± 0.25</td>
<td>−3.63 ± 0.24</td>
</tr>
</tbody>
</table>
Seasonal response of air-water CO$_2$ exch along the LOAC of the NE Am coast

G.G. Laruelle et al. Biogeosciences Discuss., 11, 11985

Air-water CO$_2$ flux
Rivers: $3.0 \pm 0.5$ TgC/yr
Estuaries: $0.8 \pm 0.5$ TgC/yr
Shelves: $-1.7 \pm 0.3$ TgC/yr
Estuarine degassing flux in the East Coast from modeling activities

Goossens, N. et al. ms in prep.

- East Coast estuaries are net emitters of CO₂ to the atmosphere with a total outgassing of ~2 Tg C yr⁻¹ for a total carbon input of ~4.5 Tg C yr⁻¹.

From Signorini et al. 2013: 
FCO₂ = -3.4 to -5.4 TgC/yr.

The estuaries and the shelves are a sink of CO₂.
Control volume approach to coastal C cycle (NA East Coast margins)

- **Tidal wetlands**: Degassing (POC burial)
- **Estuaries**: 2 Tg C yr\(^{-1}\) Air-water exchange (POC burial)
- **Continental shelf**: FCO\(_2\) = -3.4 to -5.4 TgC/yr

**Sediments**: NPP, R, DOC, DIC

**River input**: NPP, R, POC burial

**Open Ocean**: BPP, Resuspension

**Advective exchange**: DOC, DIC

**Field capacity output (FCO)**: -3.4 to -5.4 Tg C yr\(^{-1}\)
Pre- and post-industrial shelf carbon flux

- Shelves turn from a CO$_2$ source into a sink,
- Why?
  - Increasingly more productive?
  - Higher atm-$p$CO$_2$.
Large estuaries in the east coast
$pCO_2$ in Chesapeake Bay

August 2013

Potomac R.

York R.

James R

October 2013

Potomac R.

York R.

James R
Biology and tidal driven pCO2 variations in CB
Metabolic balance in the Delaware Estuary

- Upper estuary is heterotrophic & a CO₂ source
- Lower bay is autotrophic & a CO₂ sink
- Middle bay is autotrophic BUT a CO₂ source.
Summary and remarks

• We know well CO2 distribution and air-sea CO2 fluxes on North American continental shelves.

• We also know the major processes determining the distribution and fluxes on shelves and upper slopes, but we do not know them well enough to predict how the systems have changed and will change in the context of anthropogenic and climate changes.

• We do not know CO2 distributions and air-water CO2 fluxes in estuaries well enough to describe spatial and temporal variations and to provide a reliable annual flux. (let alone how they have change and will change)

• We are somewhat confident that the coastal zone (wetlands, estuaries and shelves and upper slopes) are a sink of CO2 for the atmosphere; but we still are not sure the size and uncertainty of the numbers.