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

Estuarine and shelf water fluxes

Air-sea fluxes

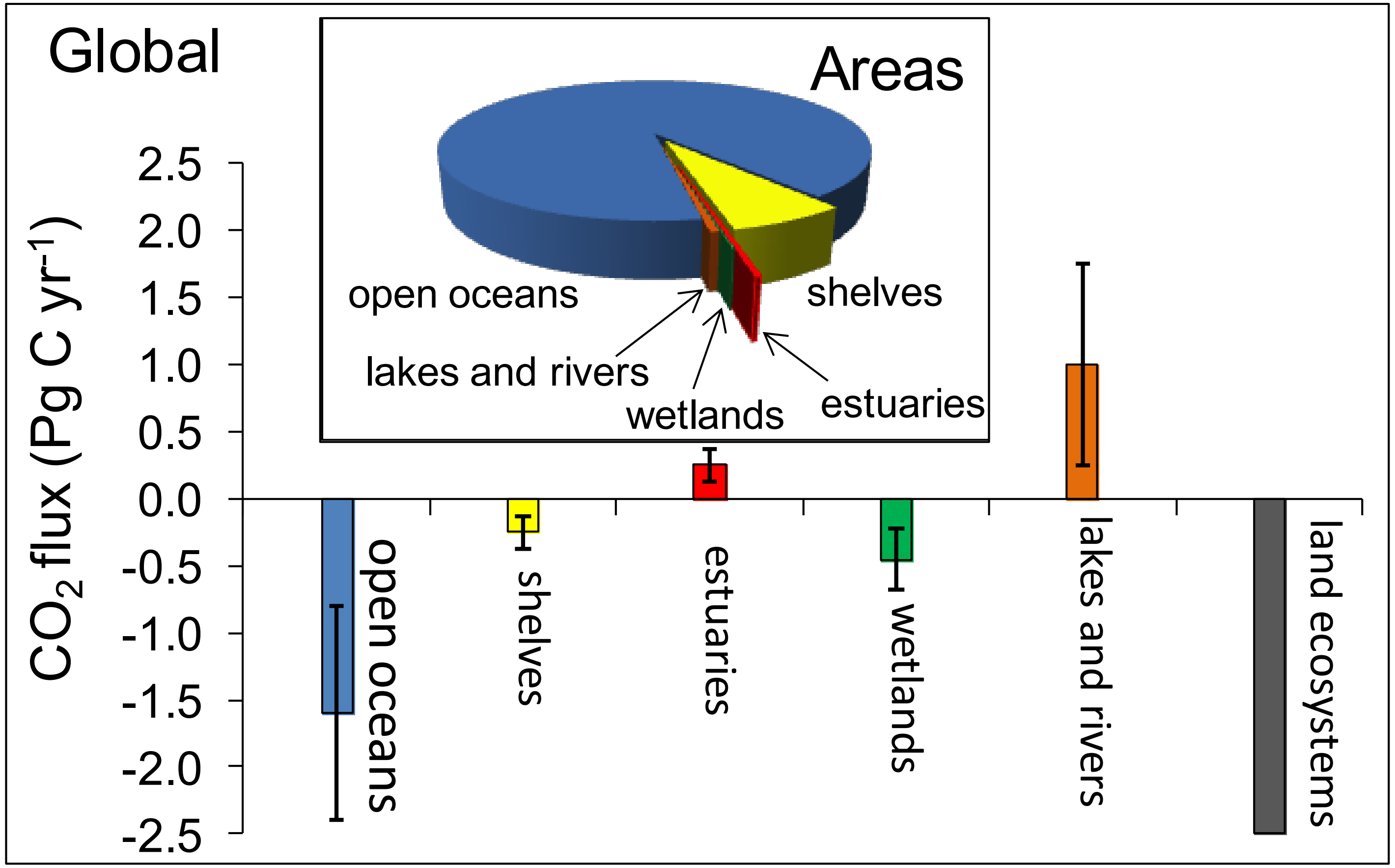
(14:50 to 15:30)

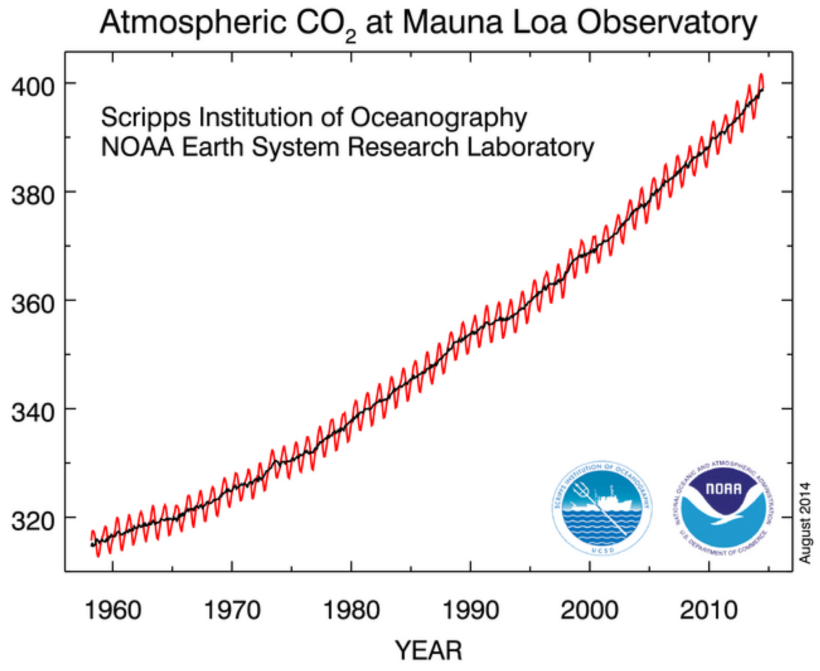
Coastal CARbon Synthesis (CCARS) Community Workshop

Woods Hole Oceanographic Institution, Clark 507

August 19-21, 2014

Importance of the coastal ocean small area, big CO_2 flux!

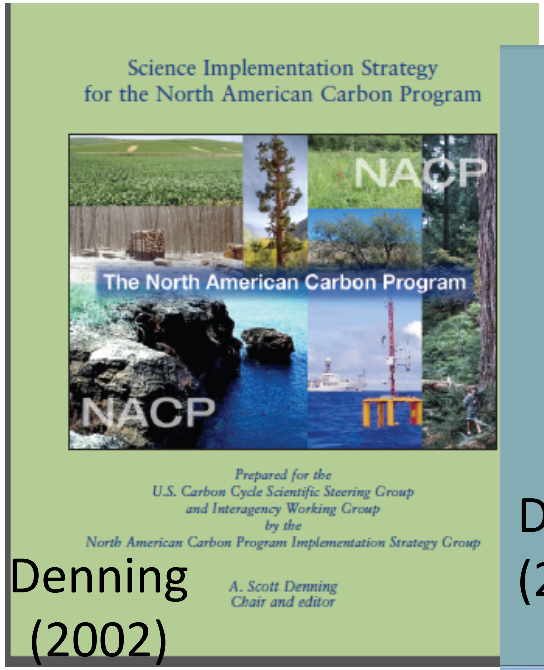




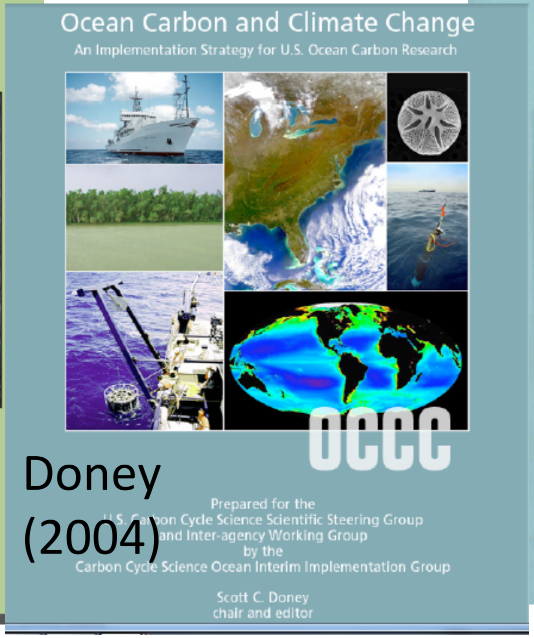
Overall uncertainty in coastal ocean: ±50% or ±0.2 PgC/yr

(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
- 2005 NACM synthesis/planning workshop (charged by NACP-OCB), Report released in 2008
- 2007 SCCR (Chavez, F.P., T. Takahashi, W.-J. Cai, G. Friederich, B. Hales, R. Wanninkhof, and R.A. Feely, 2007. Coastal oceans. In *The First State of the Carbon Cycle Report*)
- 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.



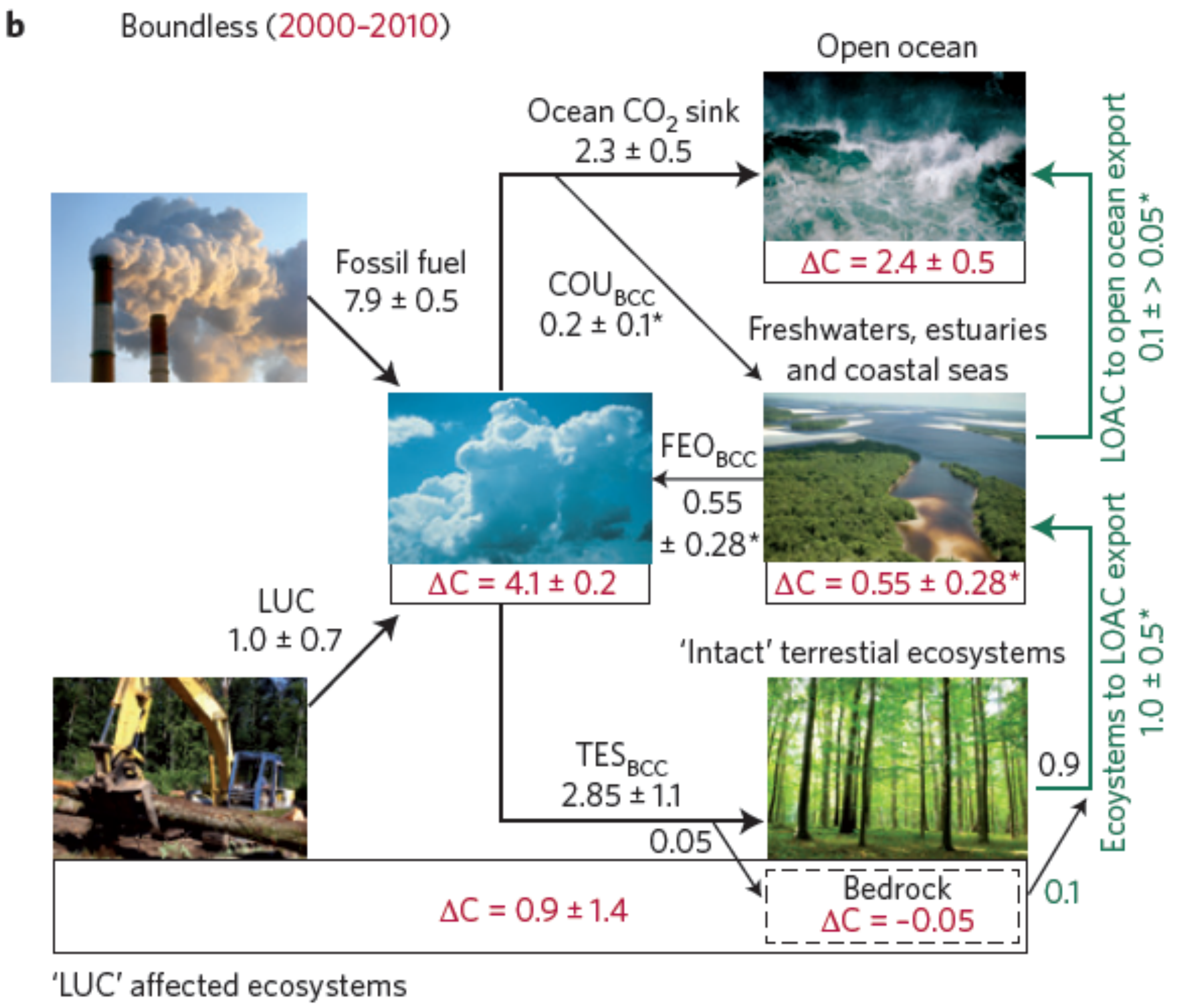
Denning (2002)



Doney (2004)

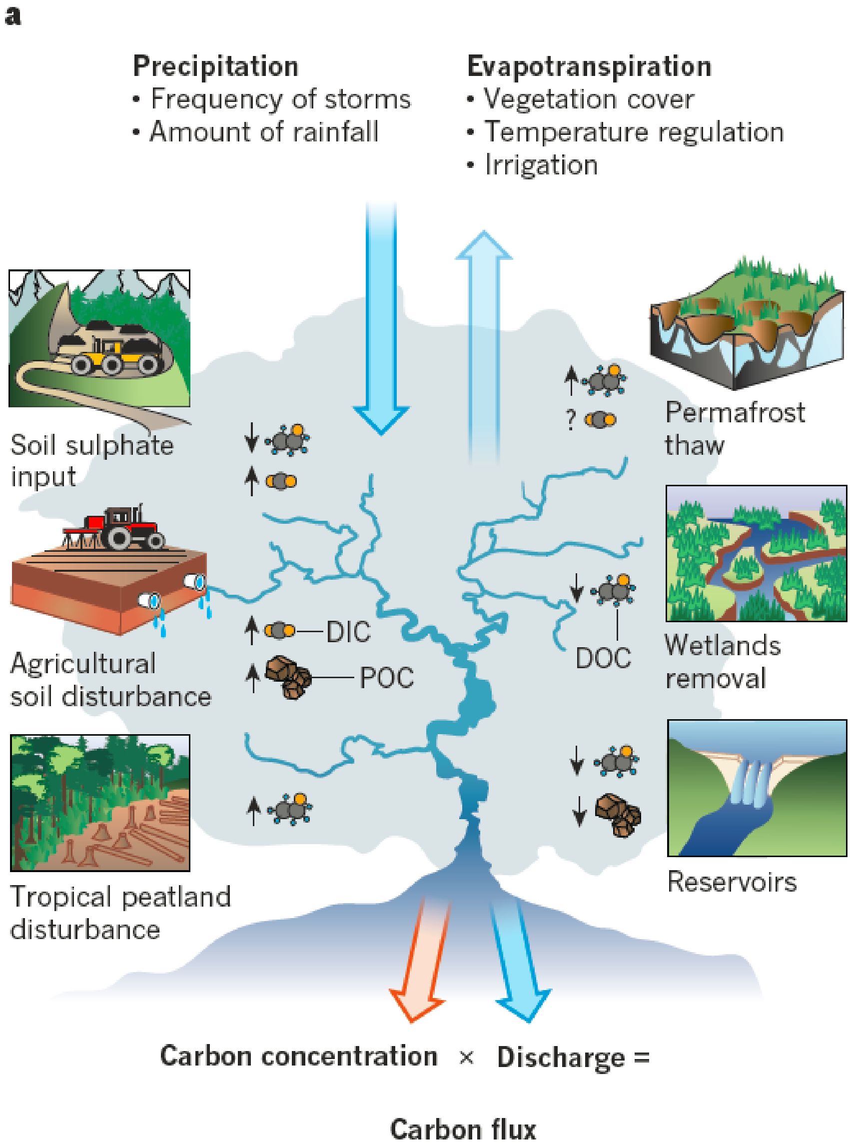
Hales et al. (2008)

A global journey of carbon flow across land-ocean interfaces

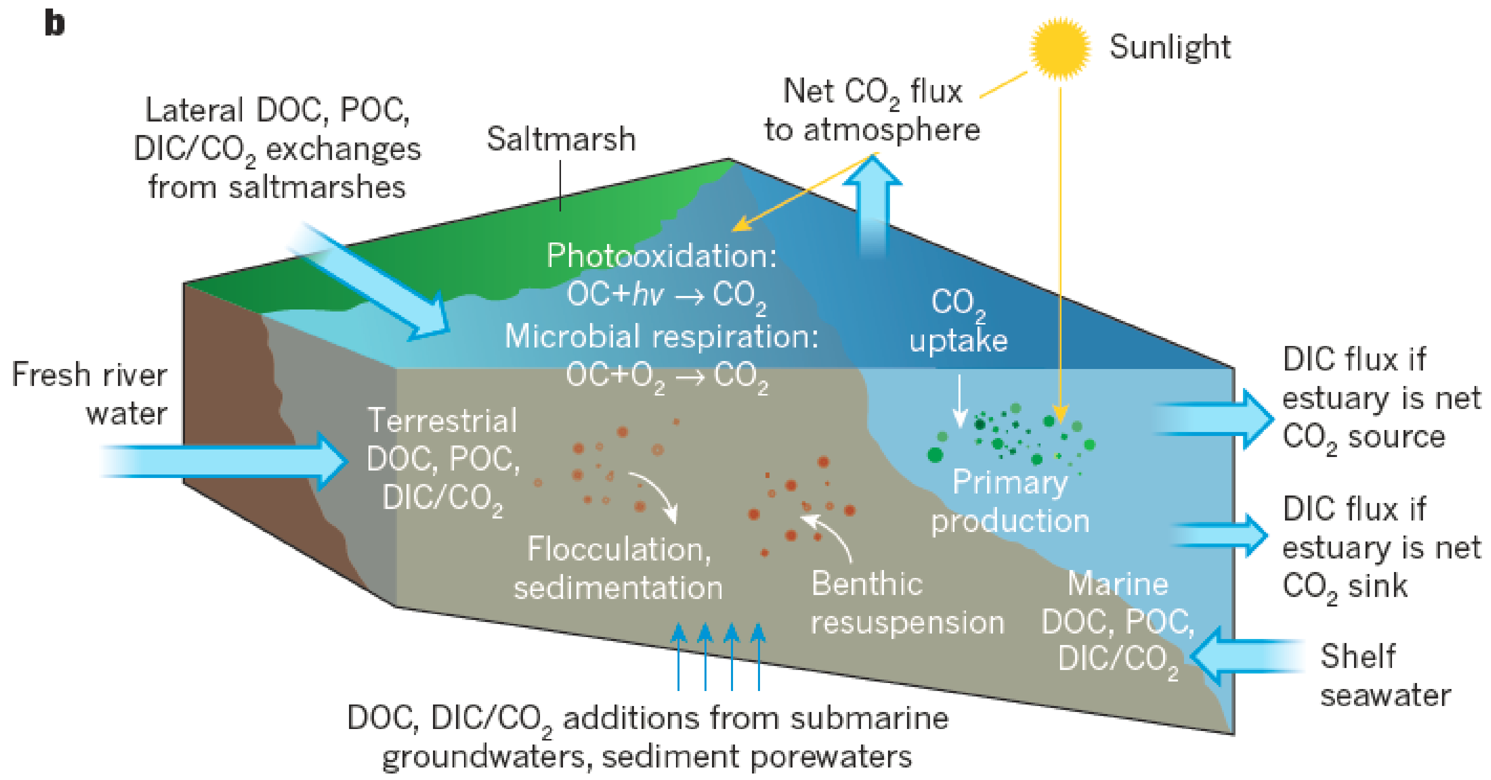


Regnier et al. (2013) Anthropogenic perturbation of the carbon fluxes from land to ocean. *Nature Geosci*. **6,** 597–607 (2013).)

Factors regulating riverine carbon fluxes

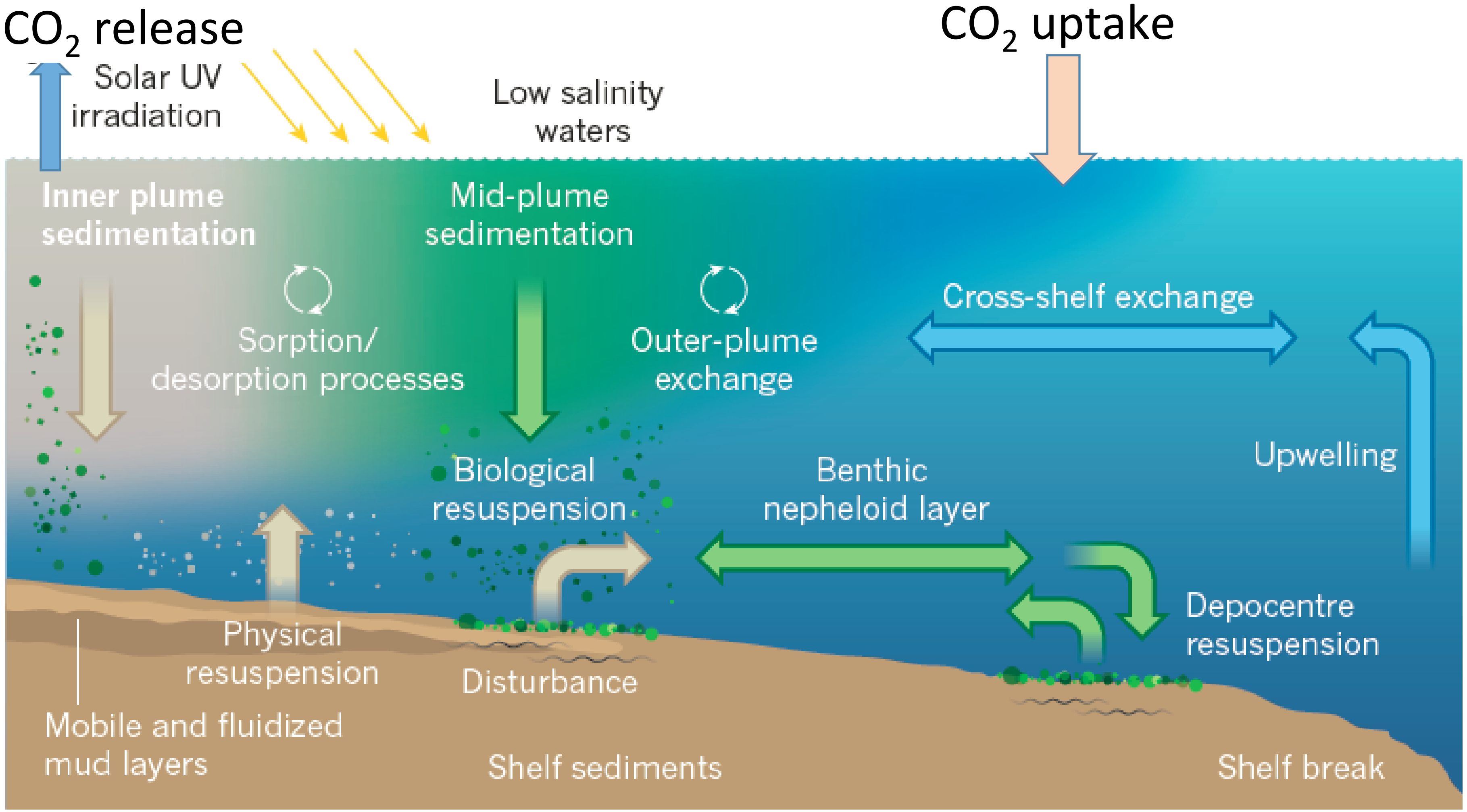


Major processes affecting carbon sources and fluxes in estuaries



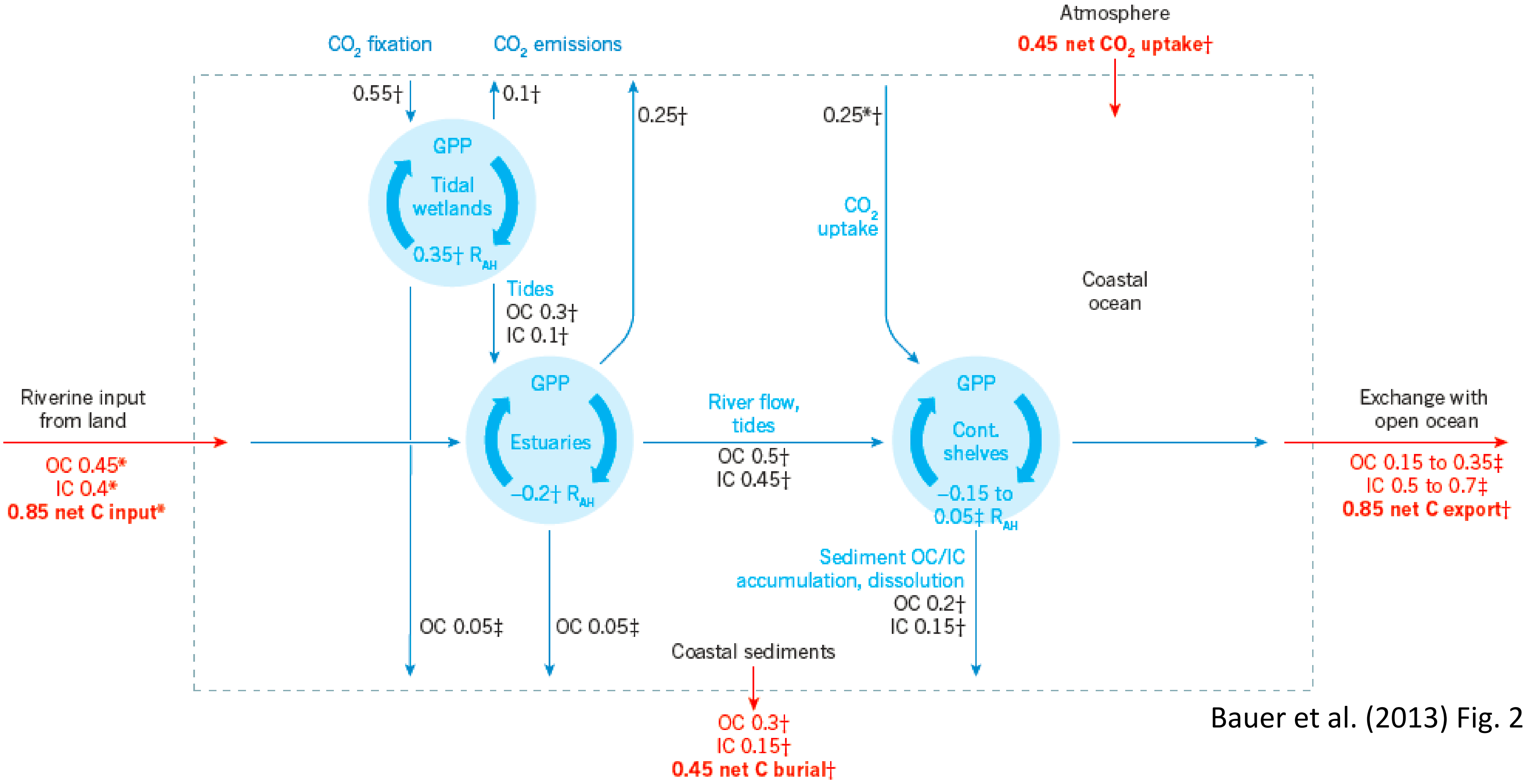
Bauer et al. (2013) Fig. 1a

Carbon on continental shelves



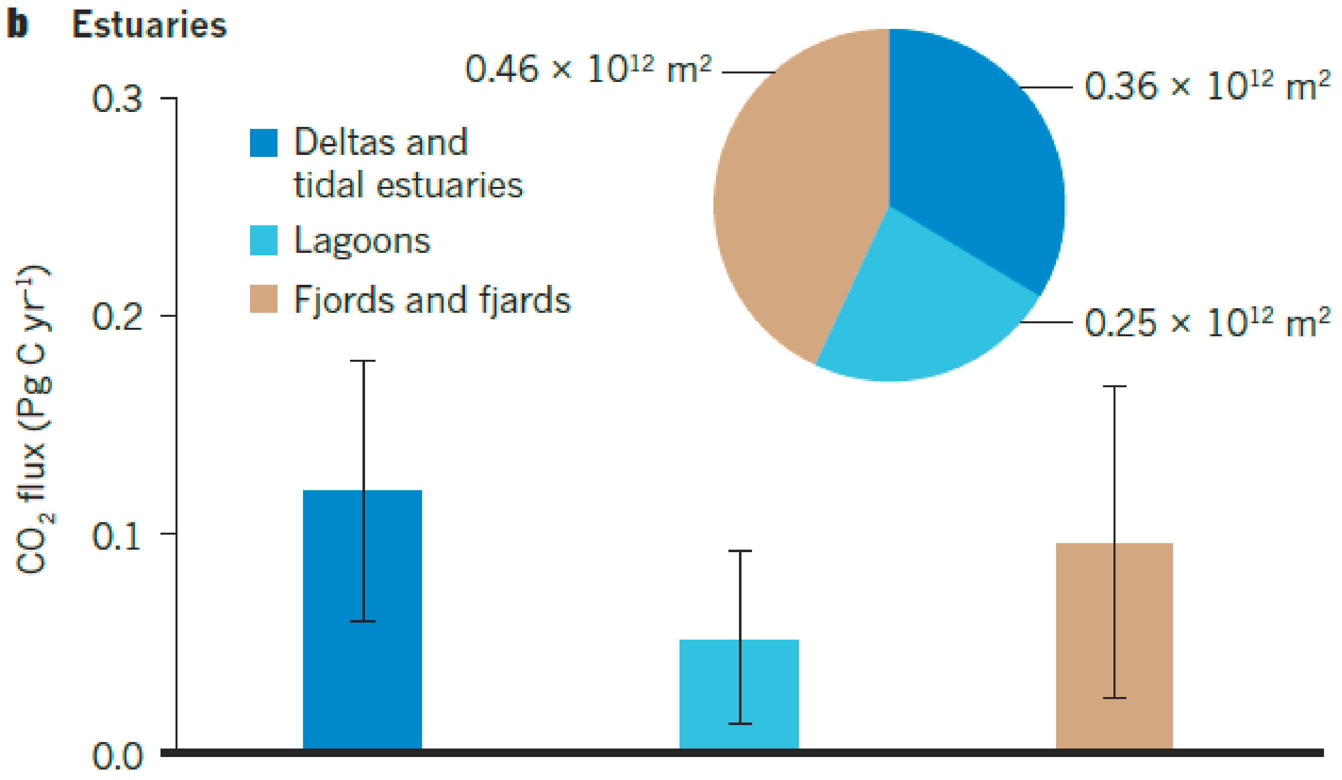
Physical and biogeochemical processes control the source, transport and fate of organic carbon on continental shelves

Coastal ocean C fluxes—across the subsystem boundaries



Bauer et al. (2013) Fig. 2

Coastal ocean C fluxes— estuarine

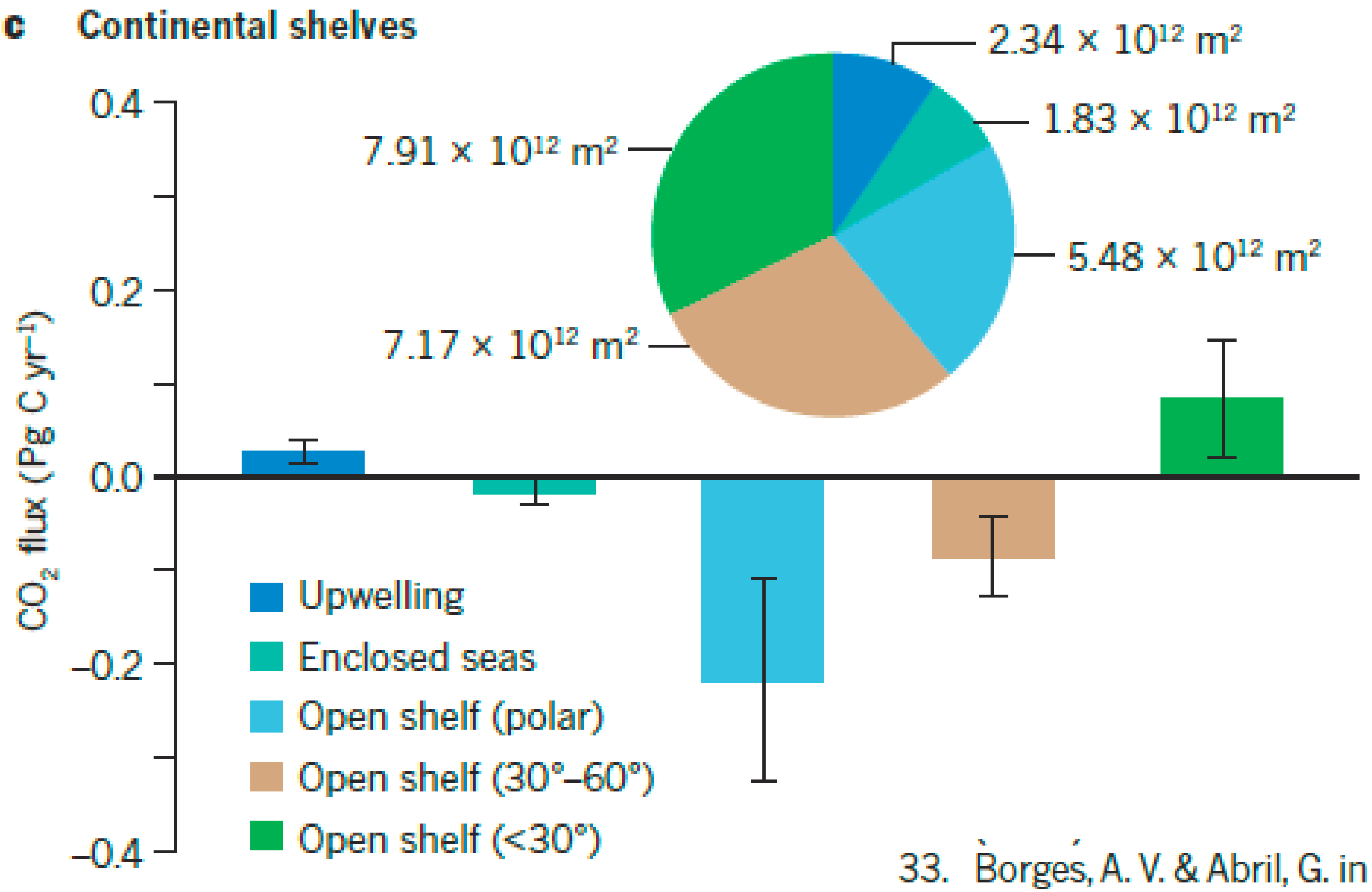


Total estuarine degassing flux is ~ 0.25 PgC/yr

Bauer et al. (2013) Fig. 3a

40. Laruelle, G. G. & Dürr, H. H. Slomp, C.P. & Borges, A.V. Evaluation of sinks and sources of CO_2 in the global coastal ocean using a spatially-explicit typology of estuaries and continental shelves. *Geophys. Res. Lett.* **37**, L15607 (2010).

Coastal ocean C fluxes— continental shelves



Bauer et al. (2013) Fig. 3b

Total shelf CO_2 uptake flux is ~

0.25 PgC/yr

33. Borges, A. V. & Abril, G. in *Treatise on Estuarine and Coastal Science*, Vol. 5 (eds Wolanski, E. & McLusky, D. S.) 119–161 (Academic, 2011).
This article is a synthesis of the state of our knowledge of the inorganic carbon cycle in coastal waters.

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

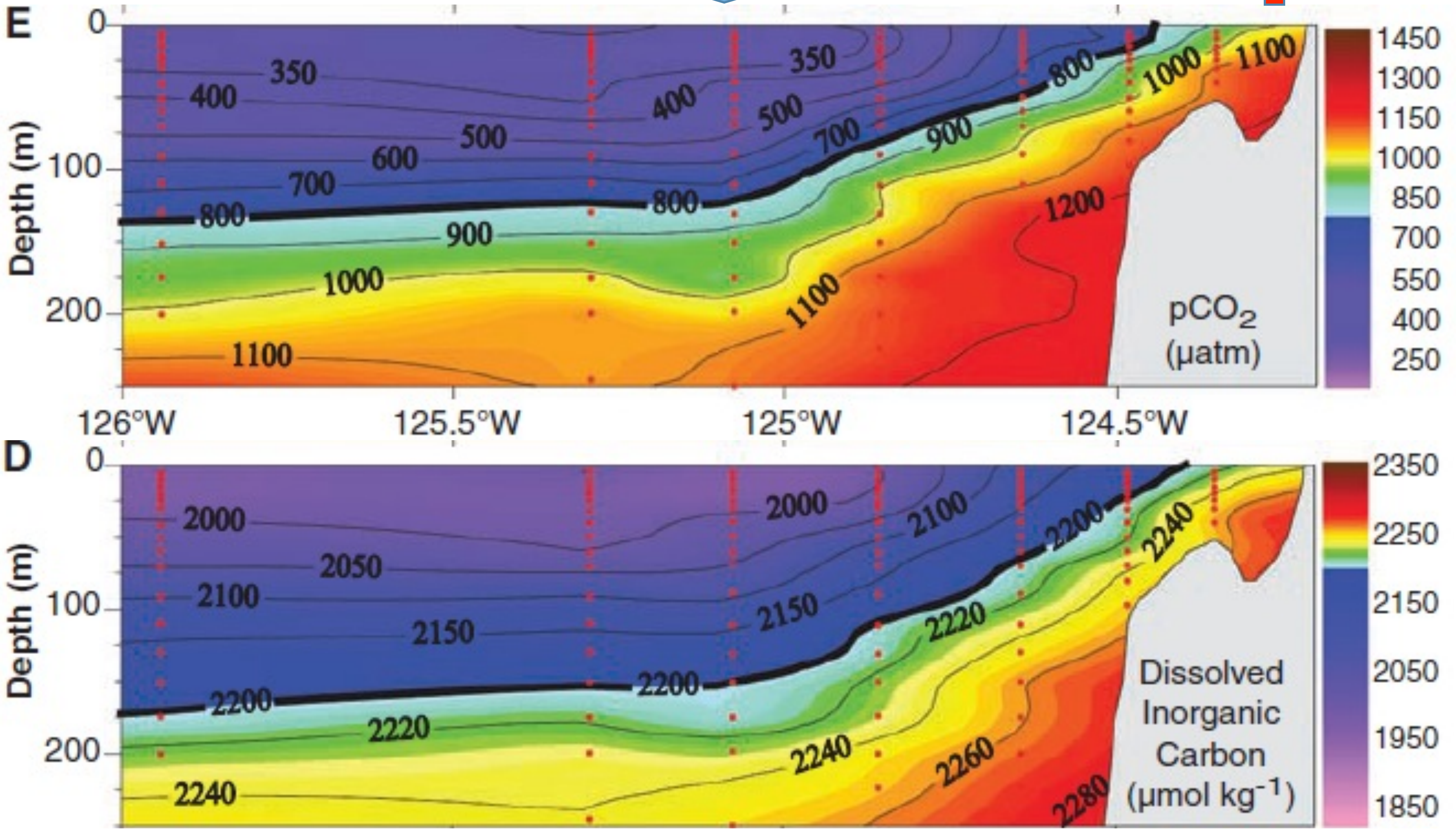
Major processes affecting air-sea CO_2 flux in North American margins

- **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)

CO_2 uptake in offshore zone

Release CO_2 in nearshore zone



Feely et al. Science (2008)

Eastern boundary current and upwelling system (West Coast)

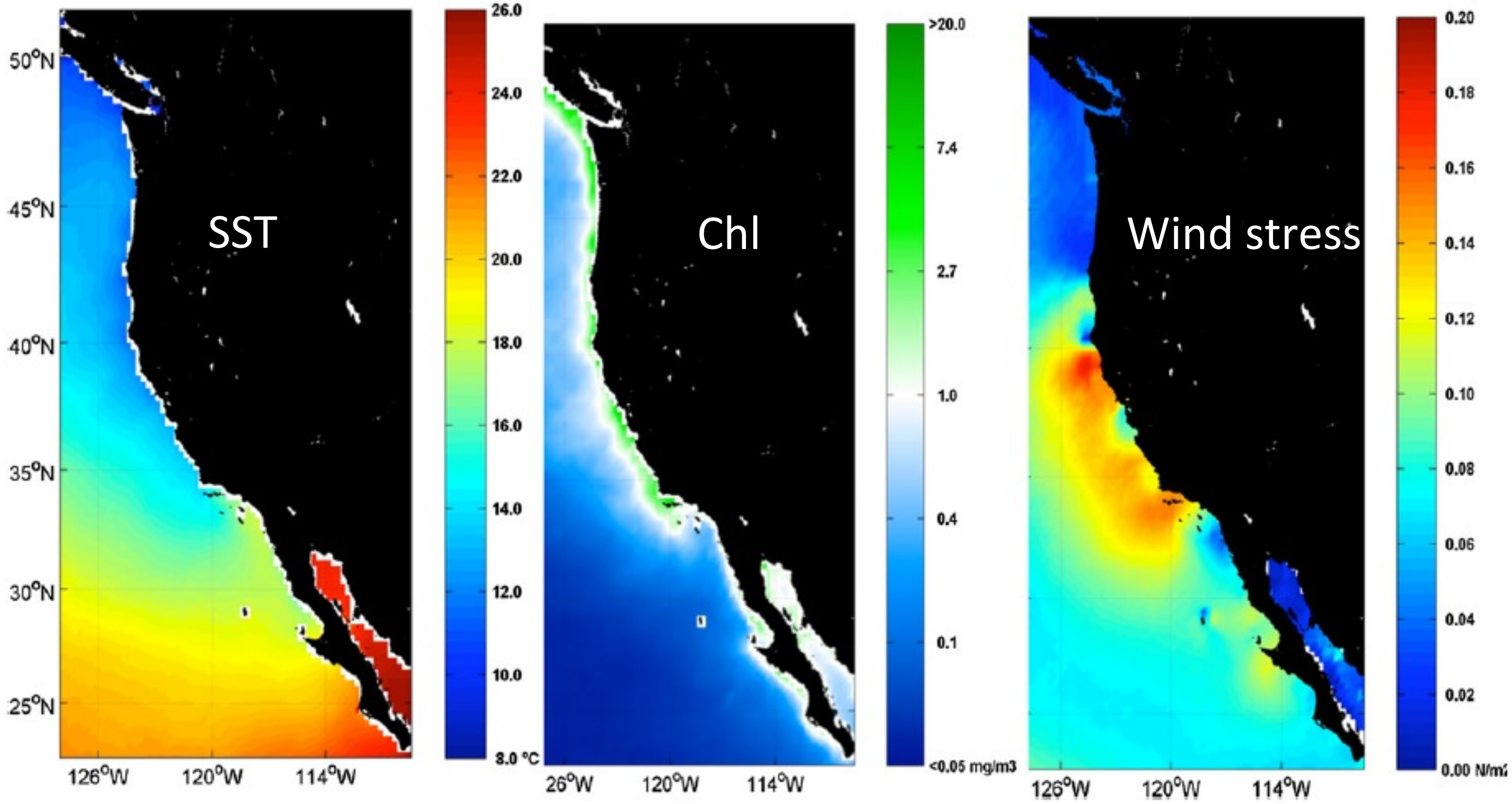
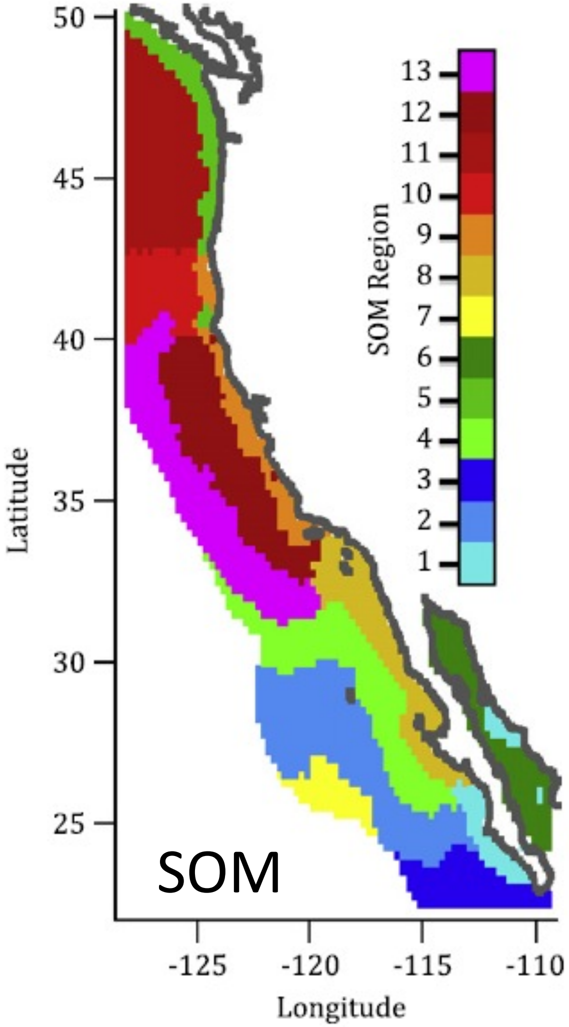
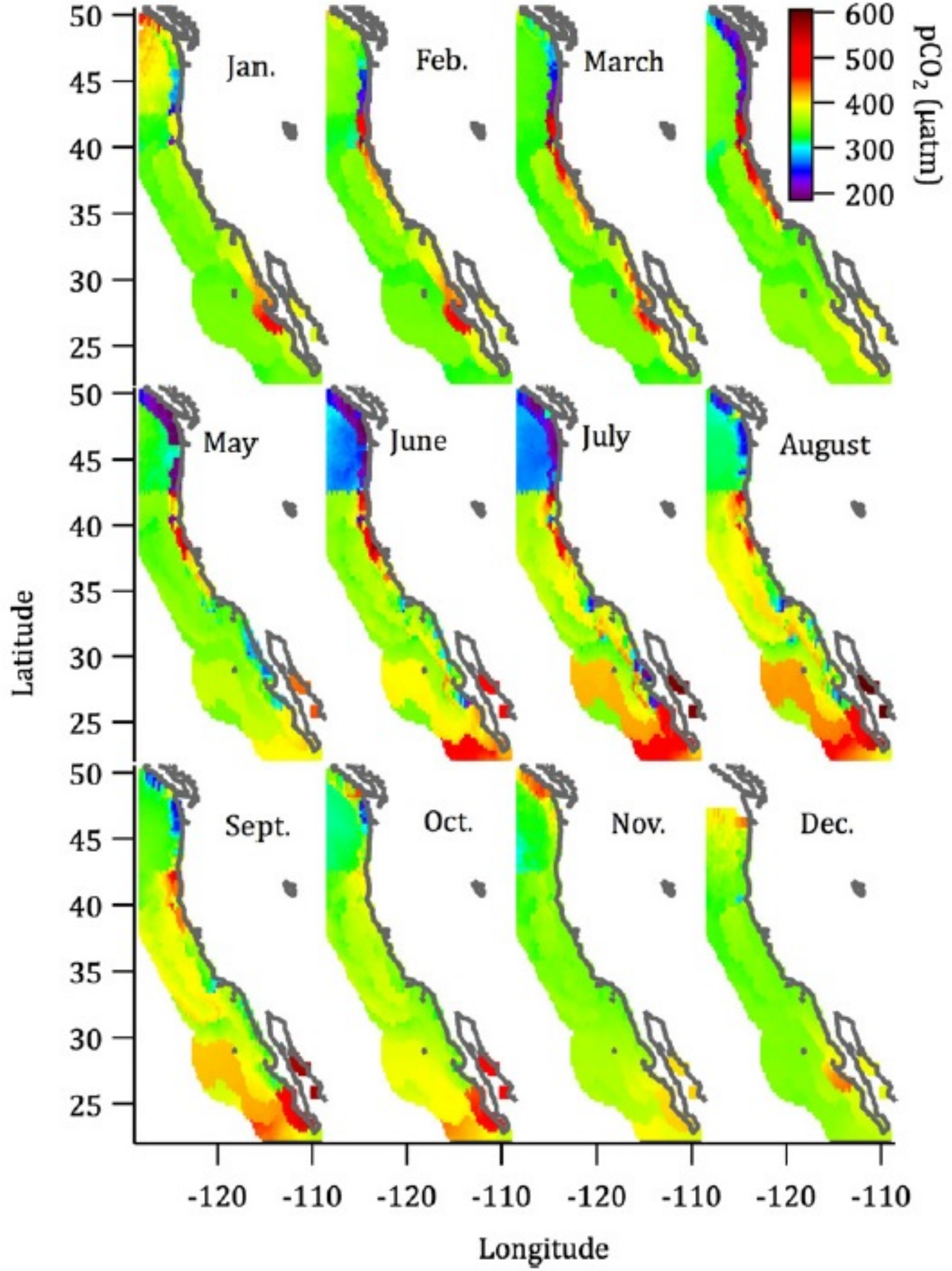


Fig. 3. Input data used for generating the self-organizing map (SOM) of Pacific coastal waters. Left, Sea-Surface Temperature (SST); middle, sea surface chlor right, net southward wind stress.



. Self-organizing map of biogeochemical regions in the study area.

Hales et al. 2012. Prog Oceanography

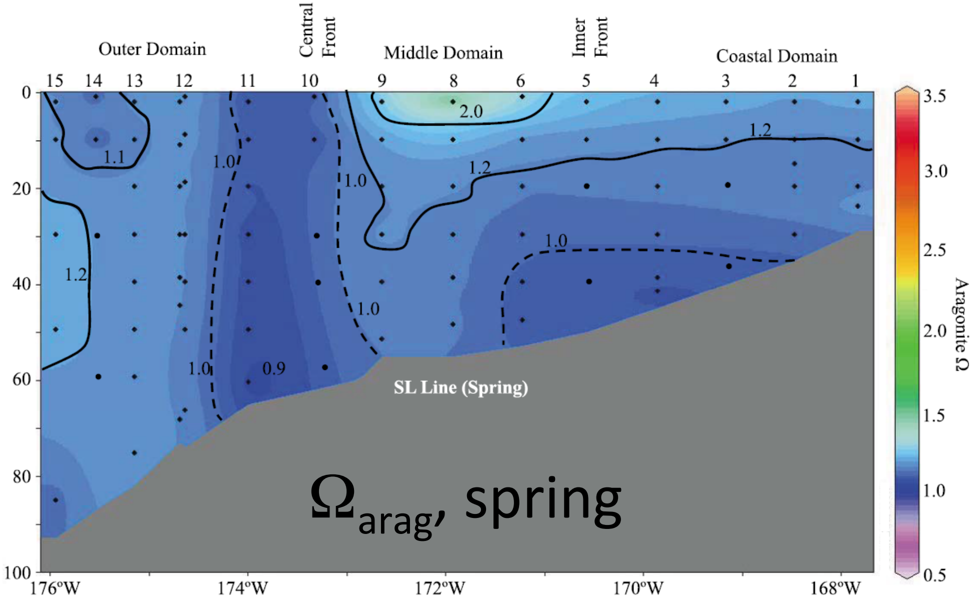


SOM-based model predicted monthly pCO_2

- Annual average sink of 1.8 mmol/m2/d
- (or 14 ±14TgC/yr)

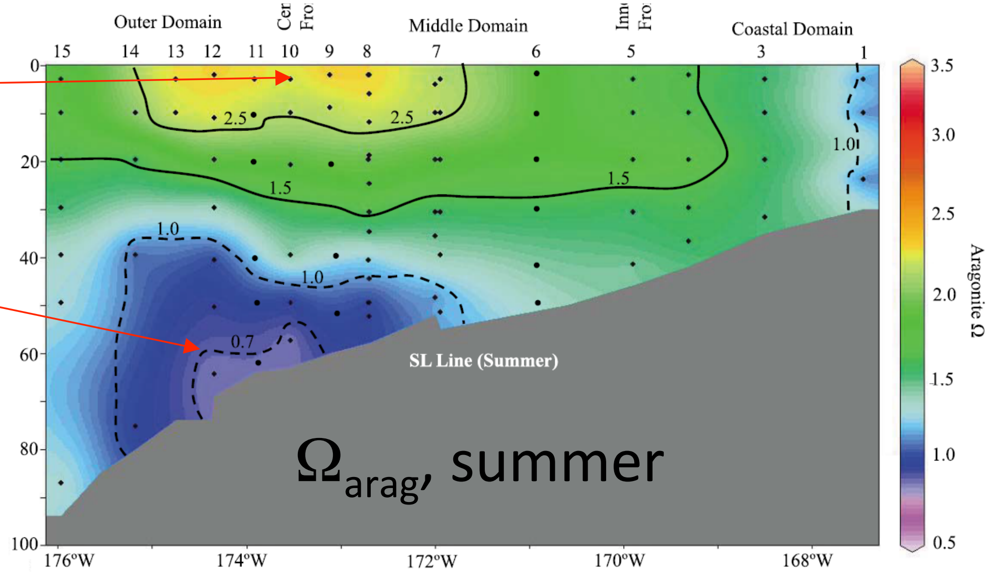
Seasonal sea-ice melt and biological production/respiration plus seasonal river inputs (Alaskan and Arctic)

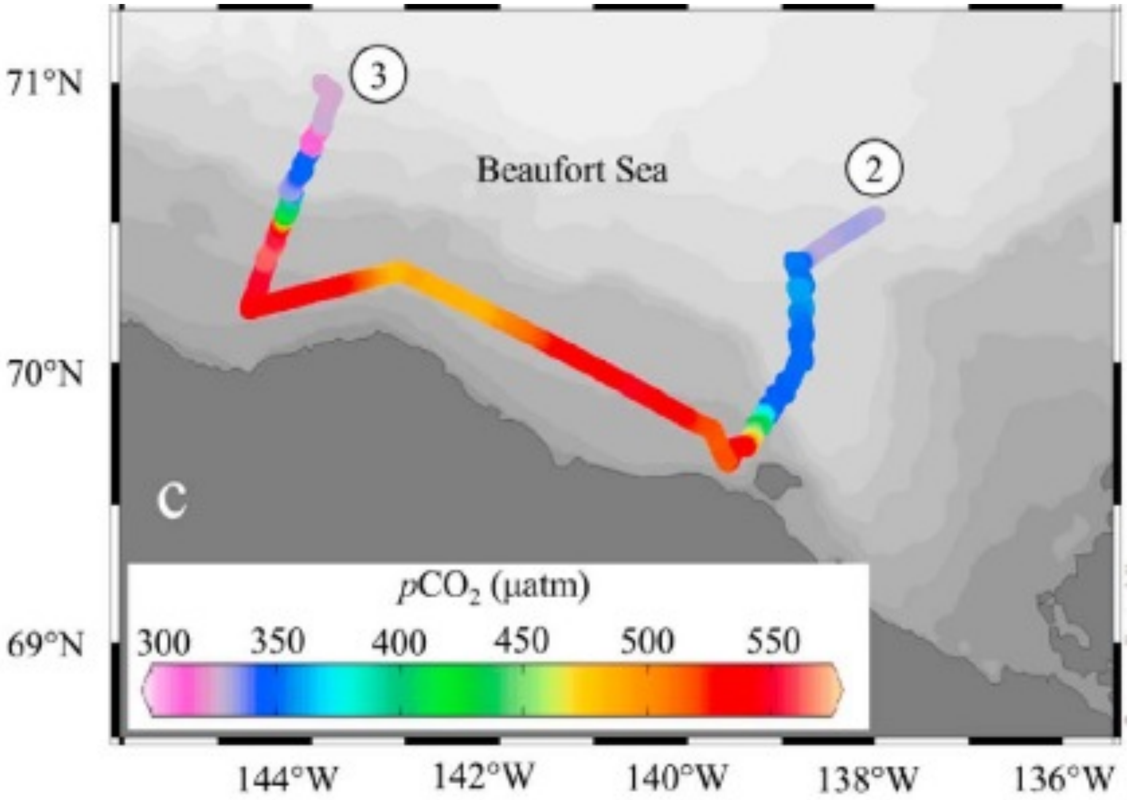
(Mathis et al. 2011; JGR)



Low pCO_2
High pH

High pCO_2
Low pH

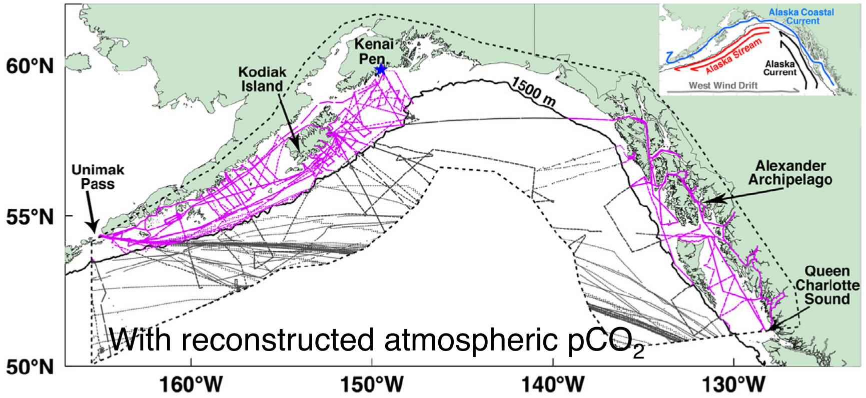




Wind-driving upwelling lead to high pCO_2
Mathis et al. 2012; GRL

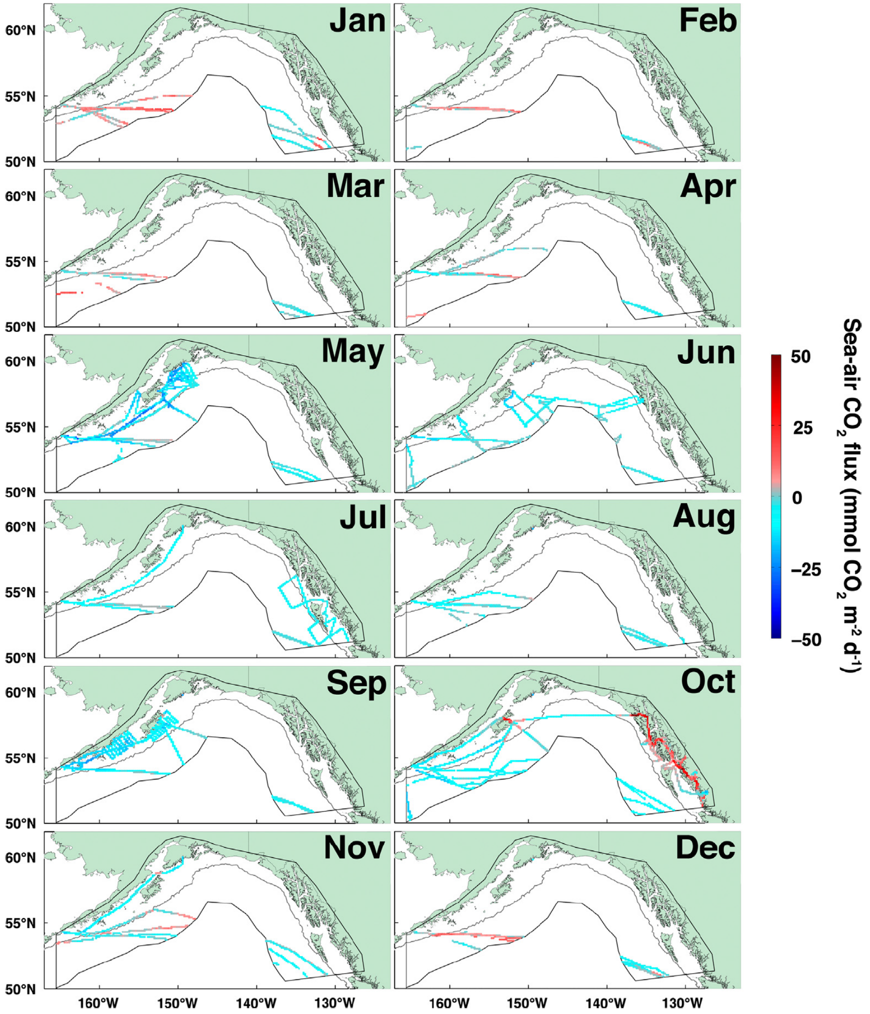
The Gulf of Alaska coastal ocean as an atmospheric CO_2 sink

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

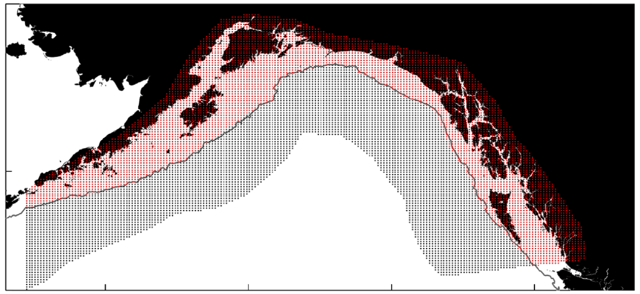


Coastal ocean (80k) vs. continental margin (60k)

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



Monthly climatologies of ΔpCO_2, SST, salinity, pCO_2 solubility on 0.1° by 0.1° grid



Month	Coastal ocean $F_{CO_2(aw)}$	Continental margin $F_{CO_2(aw)}$
January	3.5	3.2
February	3.4	3.3
March	2.0	−0.1
April	−0.4	−2.2
May	−10.0	−13.0
June	−5.2	−12.0
July	−5.1	−7.0
August	−4.4	−8.7
September	−10.4	−12.5
October	−2.1	3.2
November	−3.0	−6.1
December	1.9	4.6
Annual mean	**−2.5**	**−4.0**

mmol CO_2 m^{-2} d^{-1}

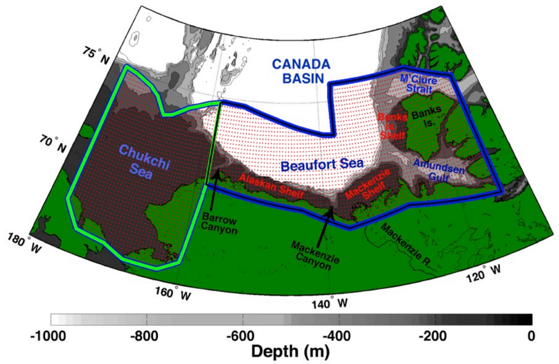
Spring Uptake (May)

Autumn Uptake (September)

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***

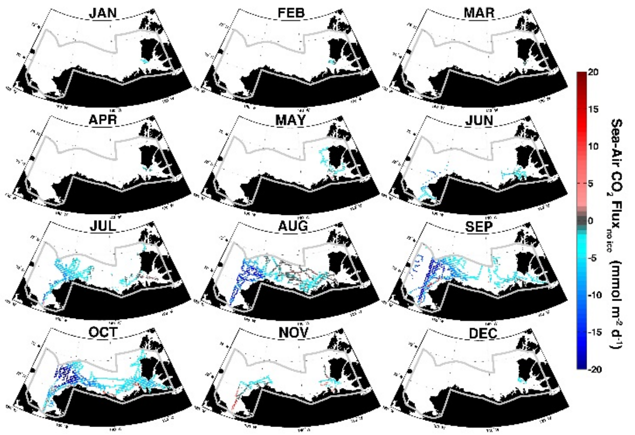
Assessing sea-air CO_2 exchange in the coastal Arctic Ocean surrounding Canada Basin

Wiley Evans, Jeremy T. Mathis, Jessica N. Cross, Nicholas R. Bates, Karen E. Frey, Brent G. T. Else, Tim N. Papkyriakou, Mike D. DeGrandpre, Brittany Petterson, Wei.-Jun. Cai, Baoshan Chen, Michiyo Yamamoto-Kawai, Lisa A. Miller, Eddy Carmack, William. J. Williams, and Taro Takahashi, to be submitted to *Prog. Oceanogr.*

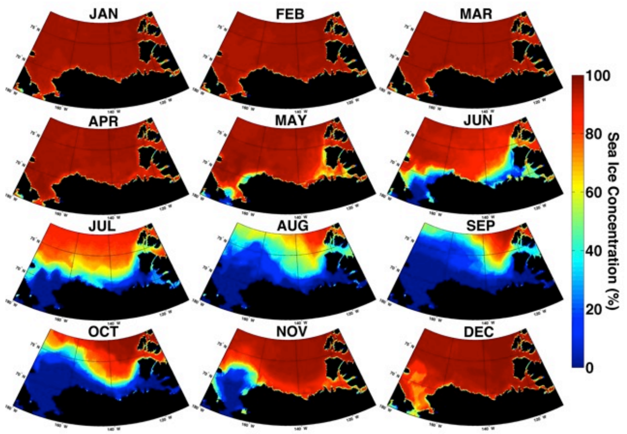


Coastal Arctic Ocean surrounding Canada Basin = Chukchi Sea and Beaufort Sea (inclg: Amundsen Gulf & M'Clure Strait)

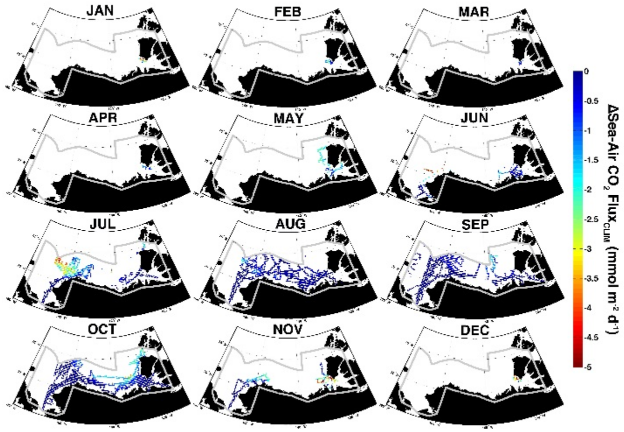
Sea-Air CO_2 flux (no ice)

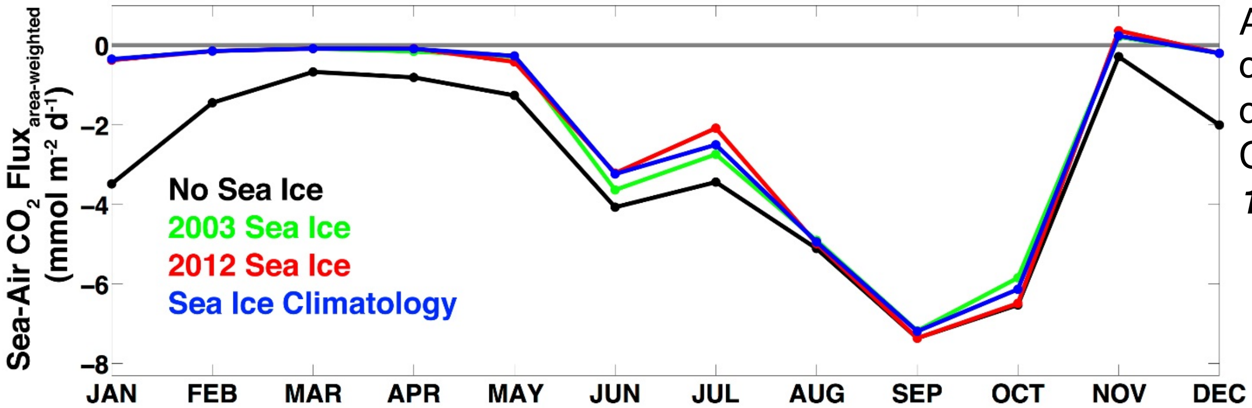


SSM/I Monthly Sea Ice



Ice-dampened CO_2 flux





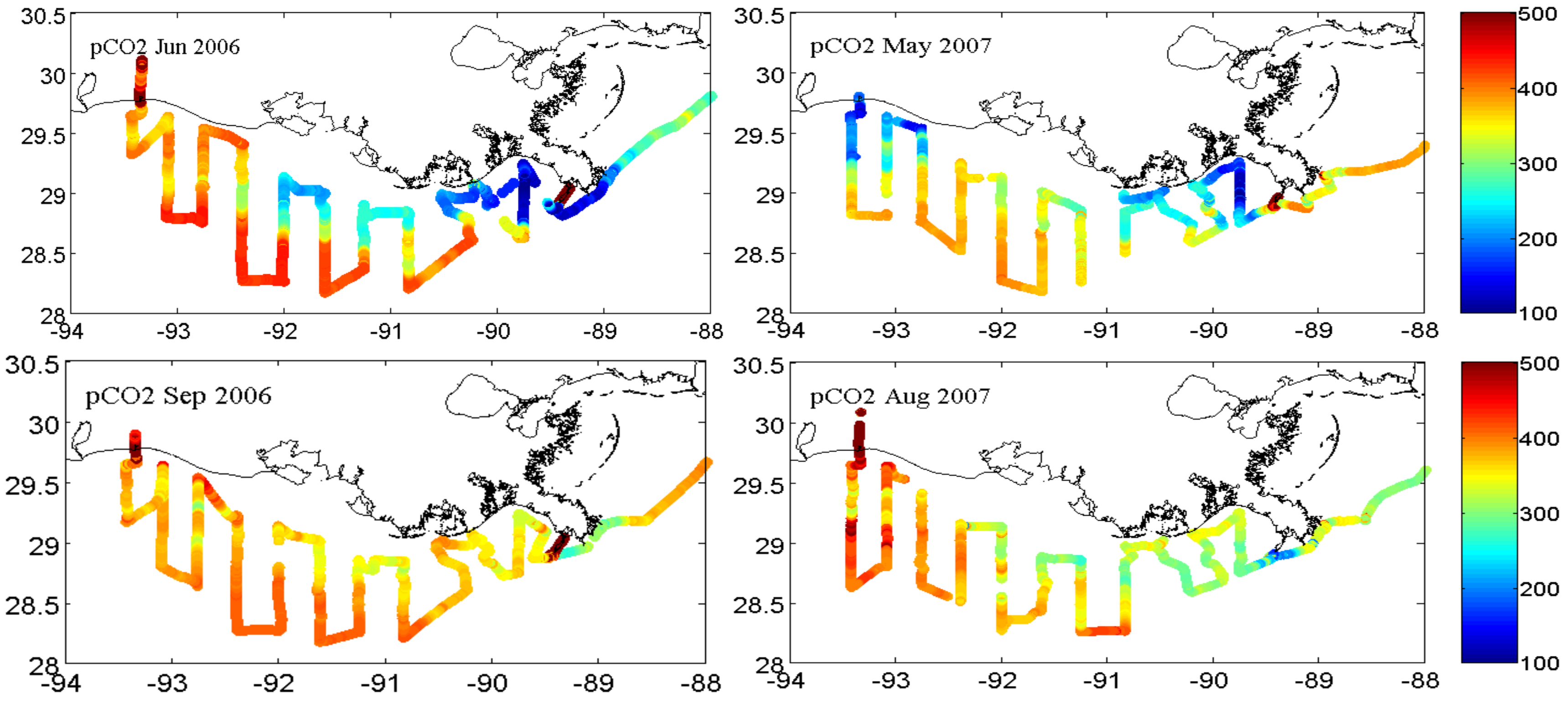
Area-weighted flux with the sea ice climatology scaled to surface area of coastal Arctic Ocean surrounding Canada Basin =

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

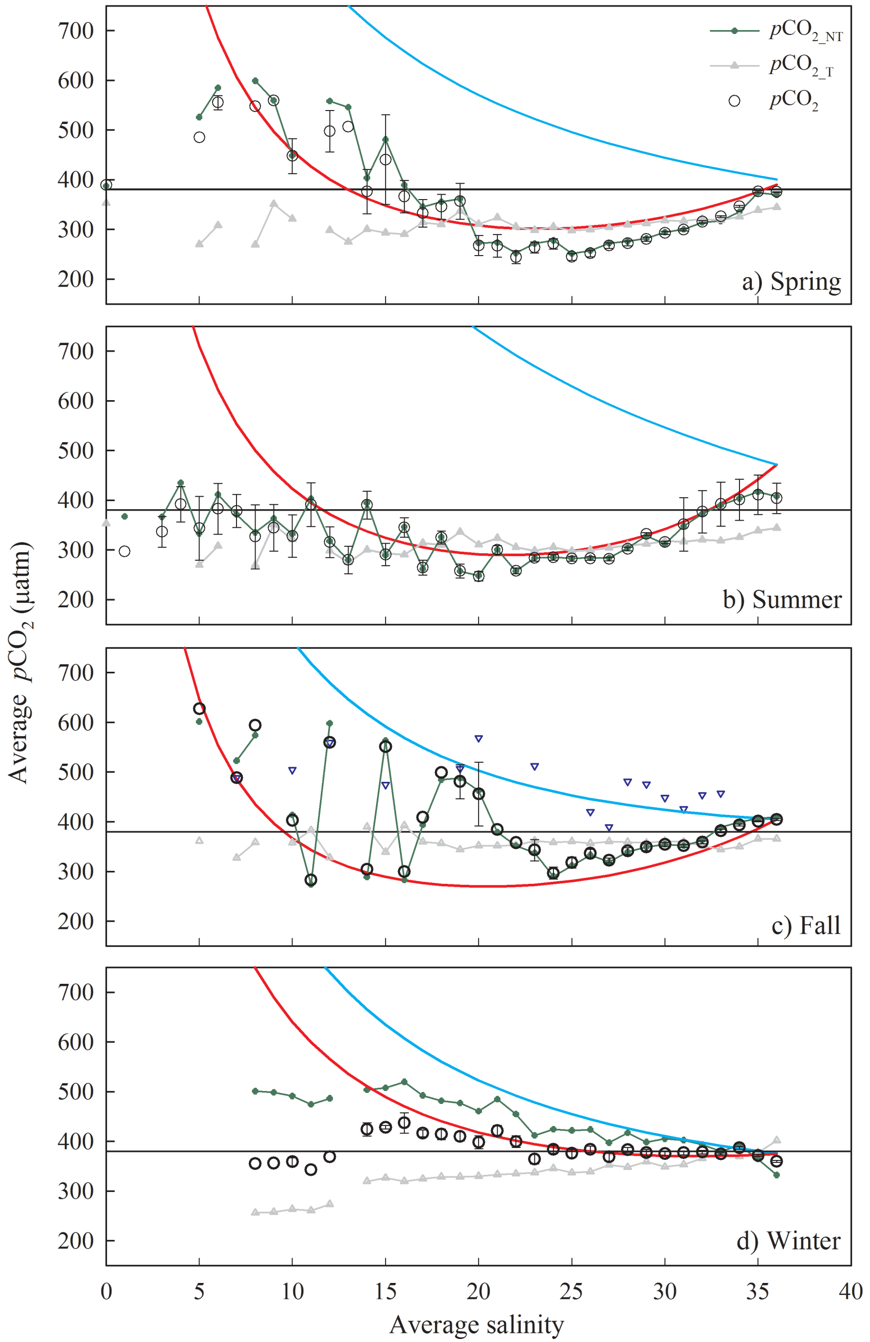


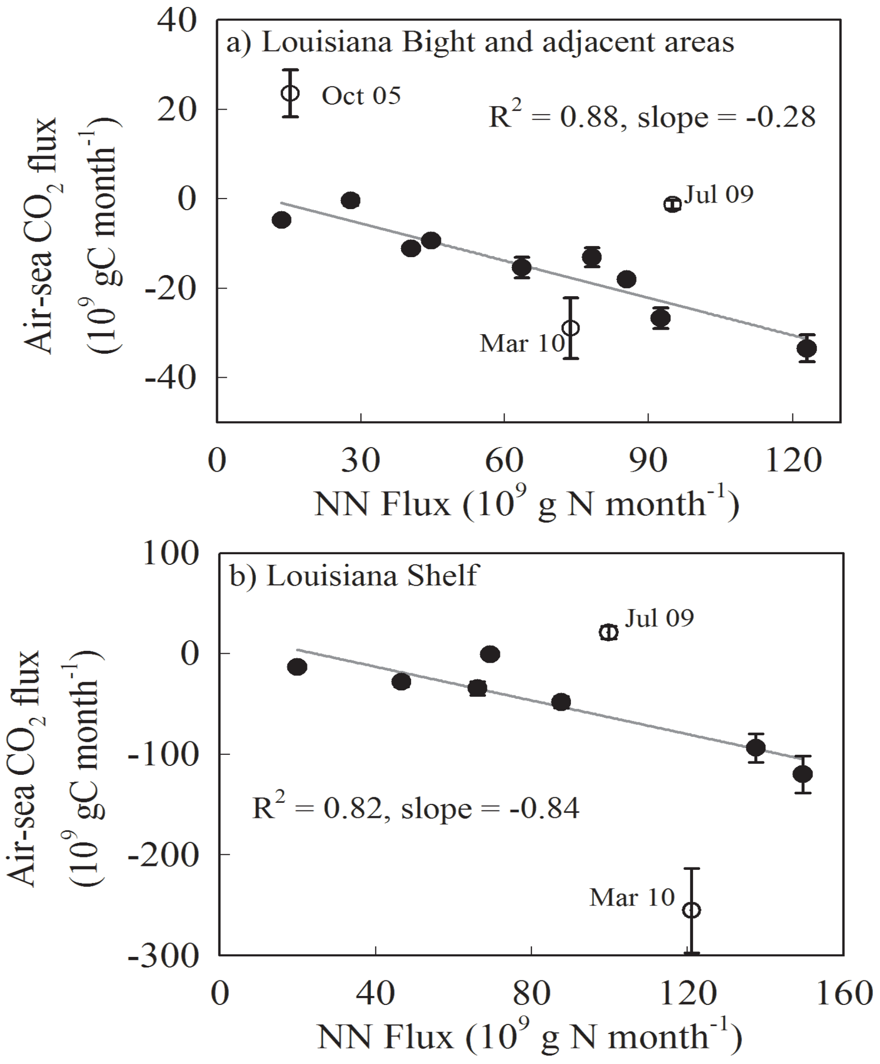
a net CO_2 sink of
0.96 ± 3.7 mol C m^{-2} yr^{-1}
or
2.63 mmol m^{-2} d^{-1}
1.15 ± 4.4 g C yr^{-1}
(Huang et al. in prep)

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

Gulf of Mexico

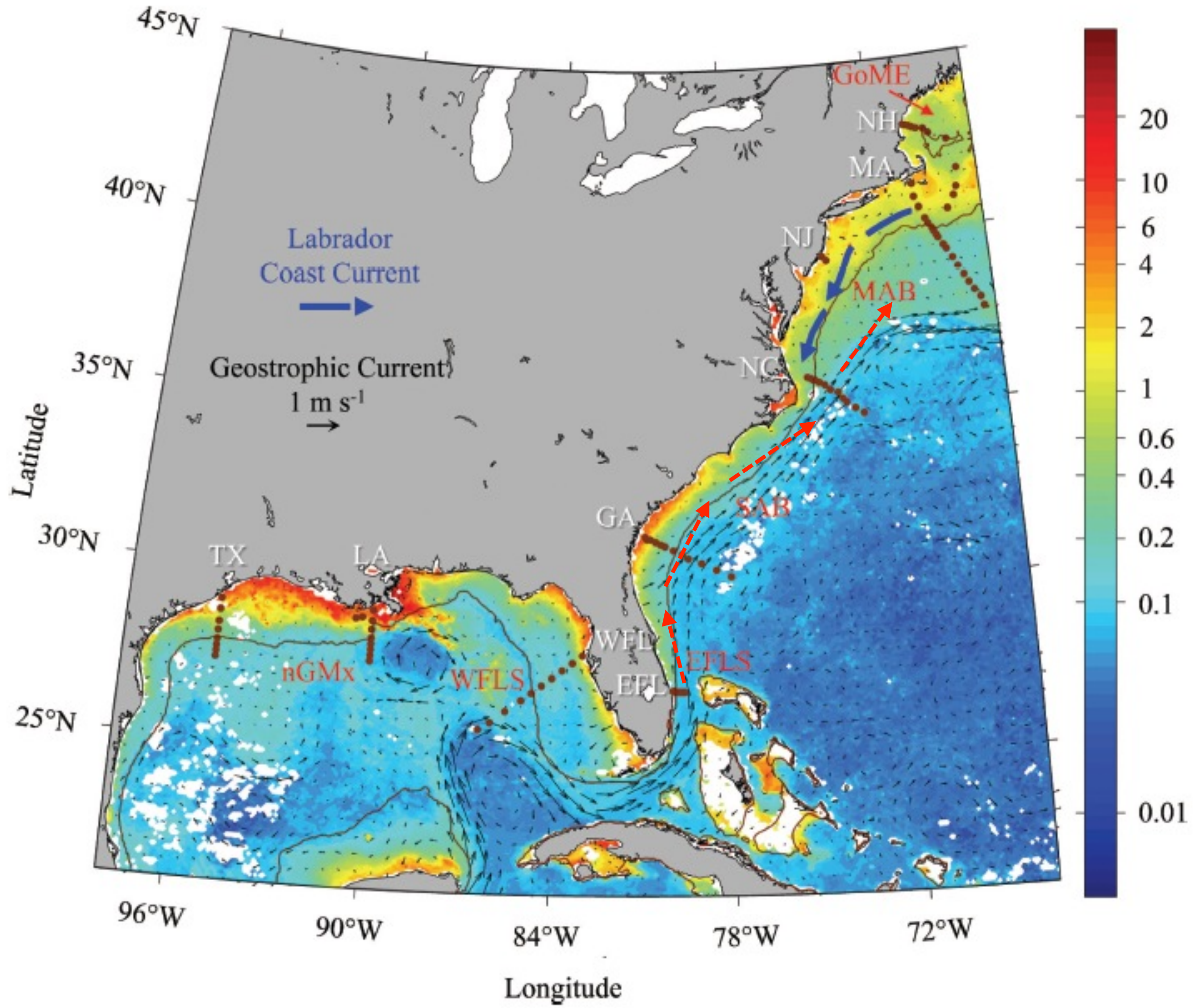


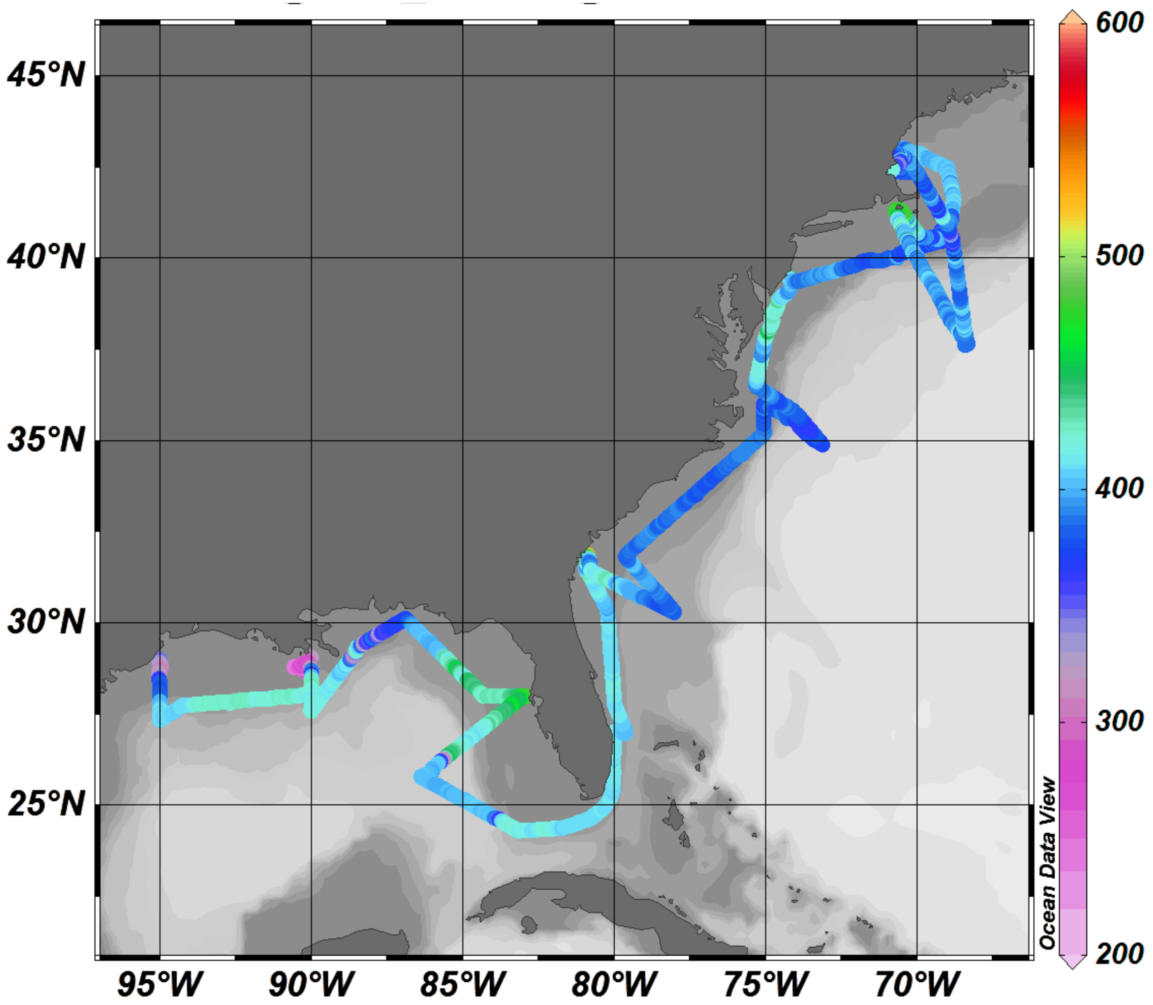


Huang et al. in prep

GOMECC (Gulf of Mexico and East Coast Carbon) Cruises (summer 2007, 2012, 2015/2017)

Lead PI: Rik Wanninkhof

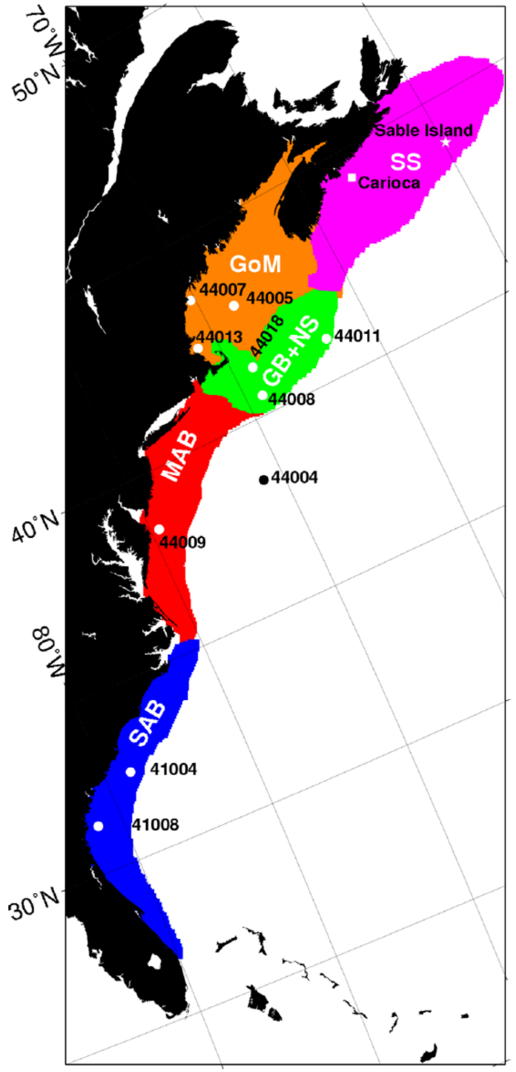


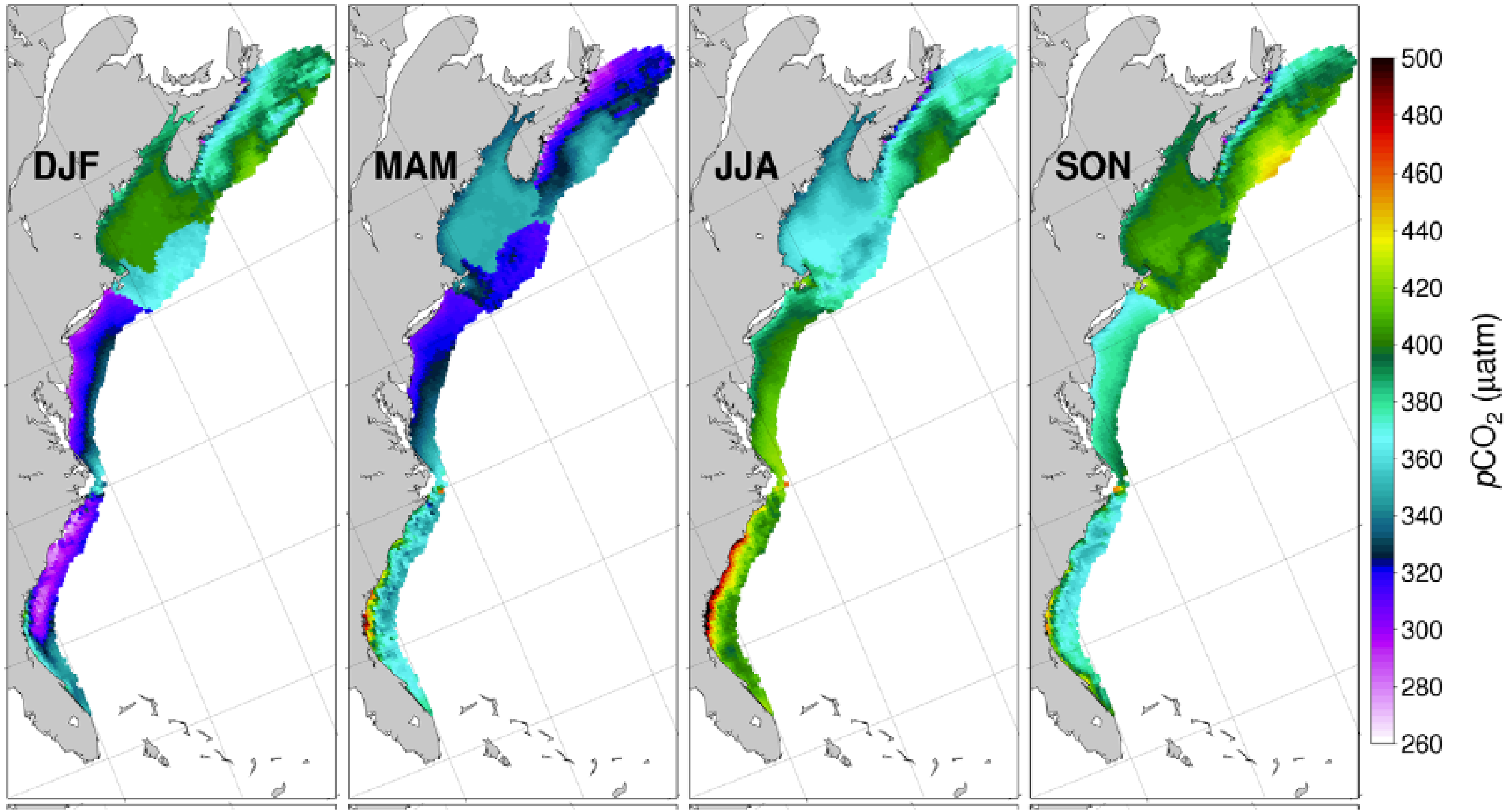


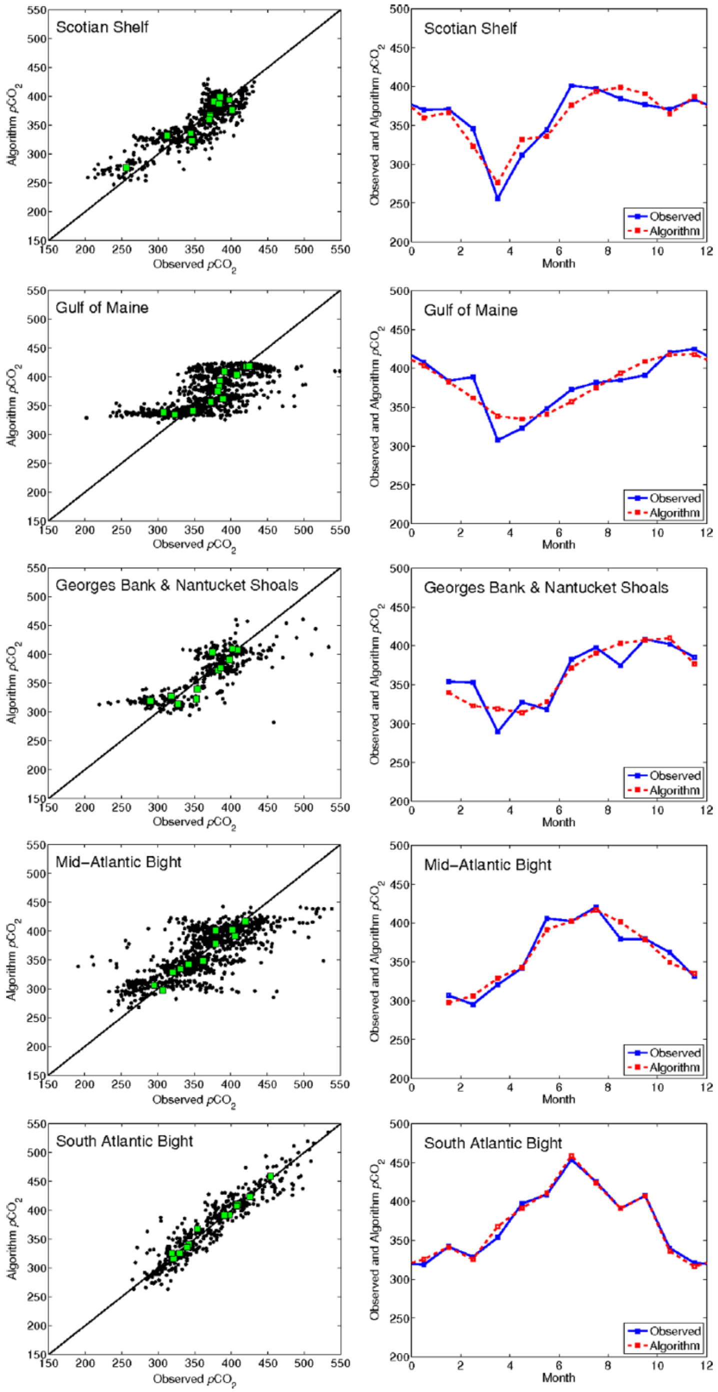
Signorini et al. (2013) JGR-O

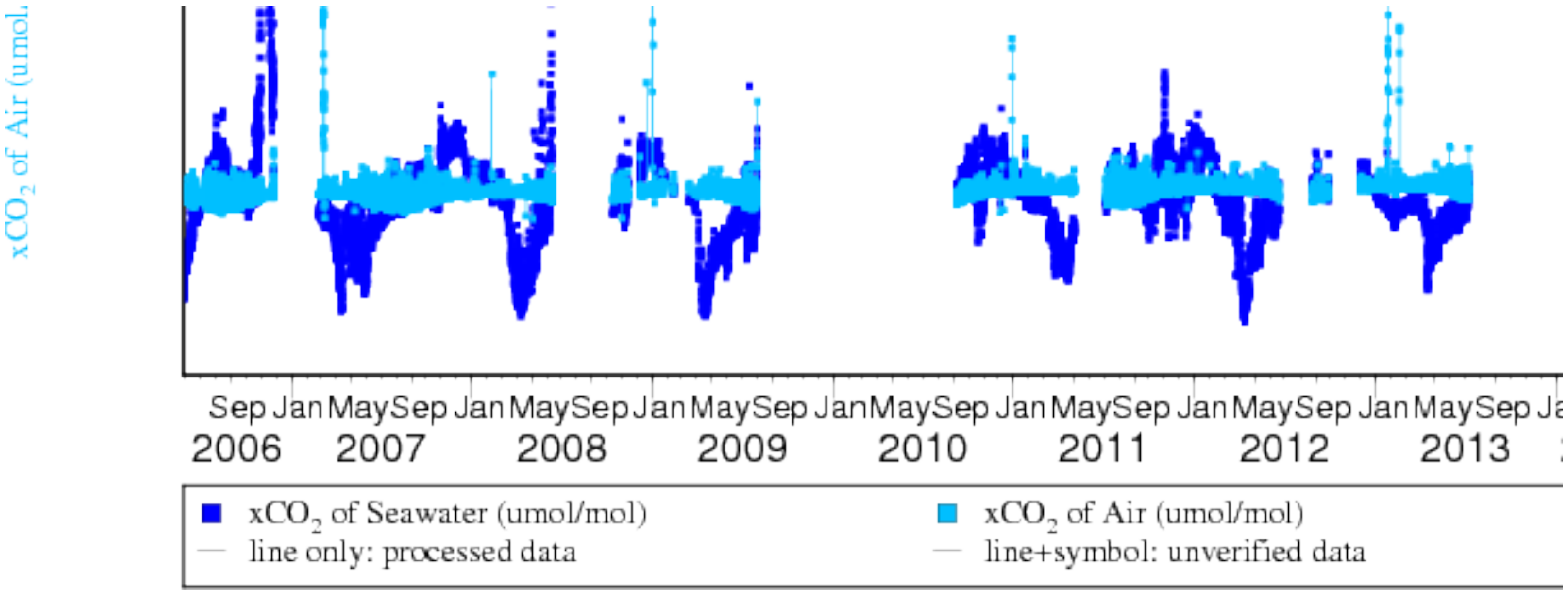
FCO2 = -0.7 to -1.0 molC/m2/yr or -1.9 to -2.74 mmol/m2/d

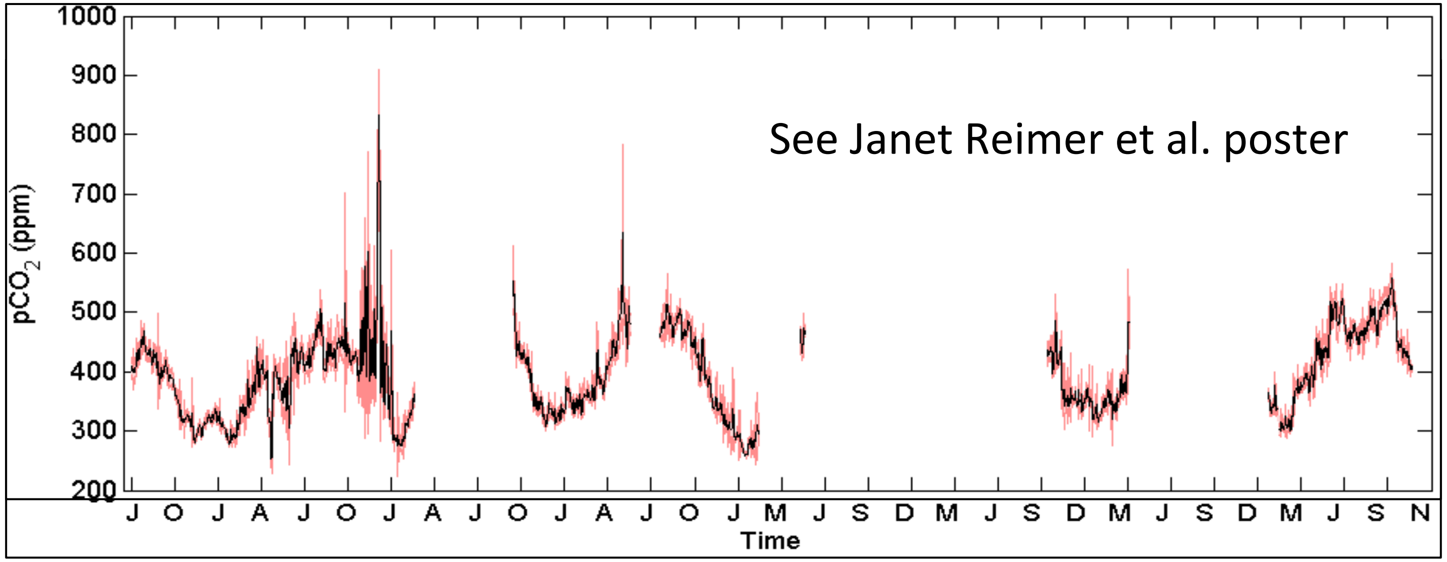
Area total: -3.4 to -5.4 TgC/yr






Scotian Shelf
Gulf of Maine
Georges Bank & Nantucket Shoals
Mid–Atlantic Bight
South Atlantic Bight
Algorithm pCO2
Observed pCO2
Observed and Algorithm pCO2
Month
Observed
Algorithm


xCO2 of Air (umol
Sep Jan May Sep Jan May Sep Jan May Sep Jan May Sep Jan May Sep Jan May Sep Jan May Sep Ja
2006 2007 2008 2009 2010 2011 2012 2013
xCO2 of Seawater (umol/mol)
line only: processed data
xCO2 of Air (umol/mol)
line+symbol: unverified data

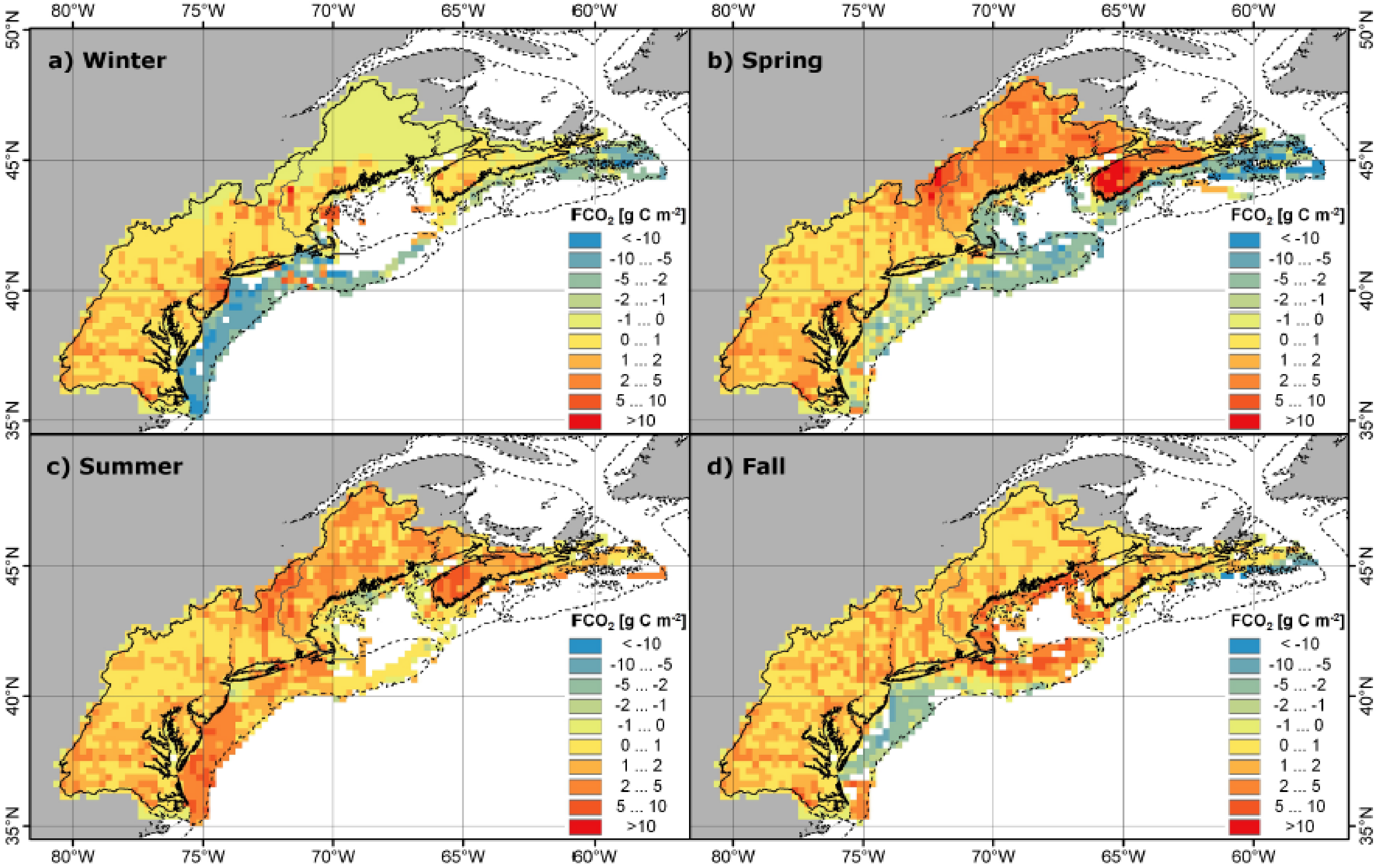

See Janet Reimer et al. poster
pCO2 (ppm)
1000
900
800
700
600
500
400
300
200
J O J A J O J A J O J A J O J M J S D M J S D M J S D M J S N
Time

Time (months)

Table 2. Sea-Air CO_2 Flux for Reference Year 2004 From Binned Data, Algorithm for Year 2004, and Previous Studies (Literature)[a]

Region	Area (1010 m^2)	Data (mol CO_2 m^{-2} yr^{-1}/ Tg C yr^{-1})		Algorithm (mol CO_2 m^{-2} yr^{-1}/ Tg C yr^{-1})		Literature (mol CO_2 m^{-2} yr^{-1}/Tg C yr^{-1})
		k^1_{660}	k^2_{660}	k^1_{660}	k^2_{660}	
SS	12.82	−1.10 ± 0.25	−1.21 ± 0.27	−0.39 ± 0.34	−0.42 ± 0.36	+1.42 ± 0.28[b]
		−1.69 ± 0.39	−1.87 ± 0.42	−0.56 ± 0.50	−0.60 ± 0.53	+2.19 ± 0.43
GoM	12.77	+0.11 ± 0.21	+0.04 ± 0.22	+0.01 ± 0.08	+0.01 ± 0.08	+0.38 ± 0.26[c]
		+0.17 ± 0.32	+0.06 ± 0.34	+0.02 ± 0.12	+0.02 ± 0.12	+0.58 ± 0.40
GB+NS	5.83	−0.65 ± 0.20	−0.71 ± 0.22	−1.27 ± 0.23	−1.37 ± 0.24	
		−0.46 ± 0.14	−0.50 ± 0.15	−0.79 ± 0.16	−0.86 ± 0.16	
MAB	9.31	−0.95 ± 0.24	−1.07 ± 0.27	−1.58 ± 0.19	−1.78 ± 0.19	−1.1 ± 0.7
		−1.06 ± 0.27	−1.12 ± 0.30	−1.63 ± 0.21	−1.83 ± 0.22	−1.0 ± 0.6[d]
SAB	10.20	−0.79 ± 0.26	−0.68 ± 0.24	−0.61 ± 0.17	−0.67 ± 0.16	−0.48 ± 0.21[e]
		−0.97 ± 0.31	−0.83 ± 0.29	−0.67 ± 0.20	−0.74 ± 0.20	−0.59 ± 0.26
Total	50.63	−4.01 ± 0.30	−4.26 ± 0.31	−3.63 ± 0.24	−4.01 ± 0.25	

Northeast Margins



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 ±0.5 TgC/yr

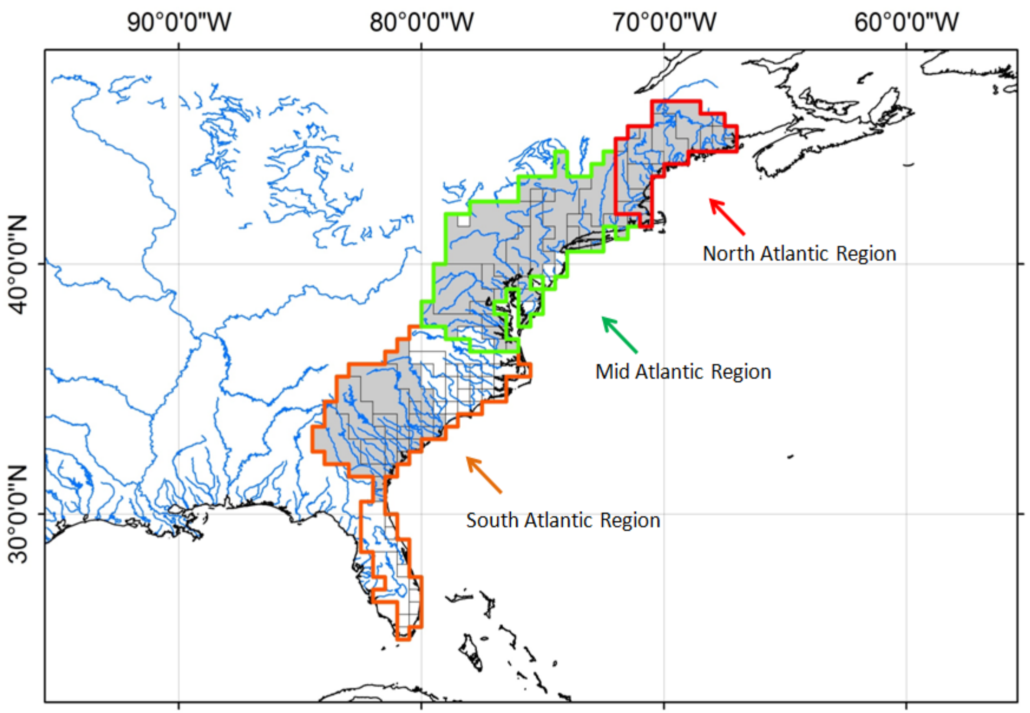
Estuaries: 0.8 ±0.5 TgC/yr

Shelves: -1.7 ±0.3 TgC/yr

Estuarine degassing flux in the East Coast from modeling activities

Goossens, N. et al. ms in prep.

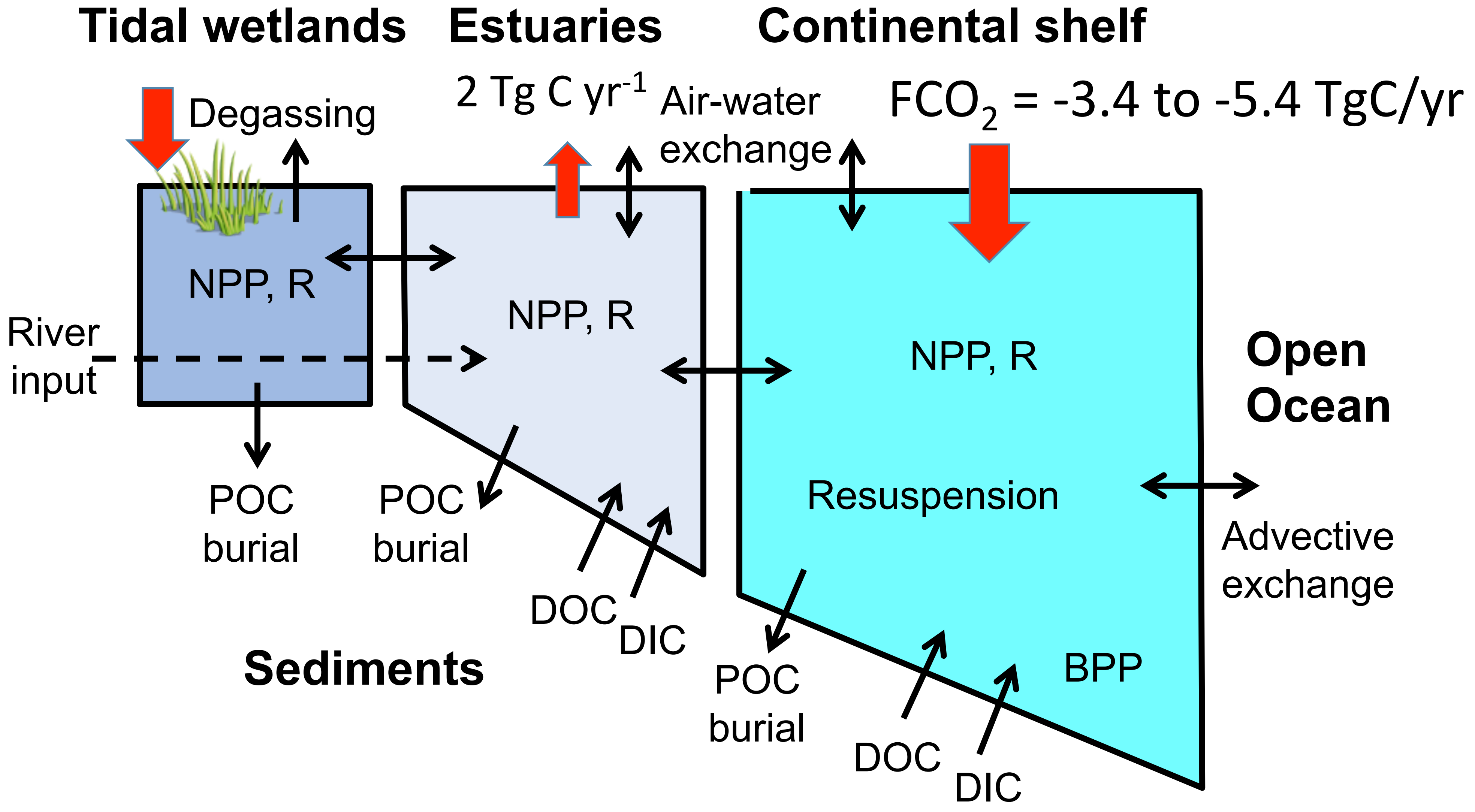
- East Coast estuaries are net emitters of CO_2 to the atmosphere with a total outgassing of ~2 Tg C yr^{-1} for a total carbon input of ~4.5 Tg C yr^{-1} .



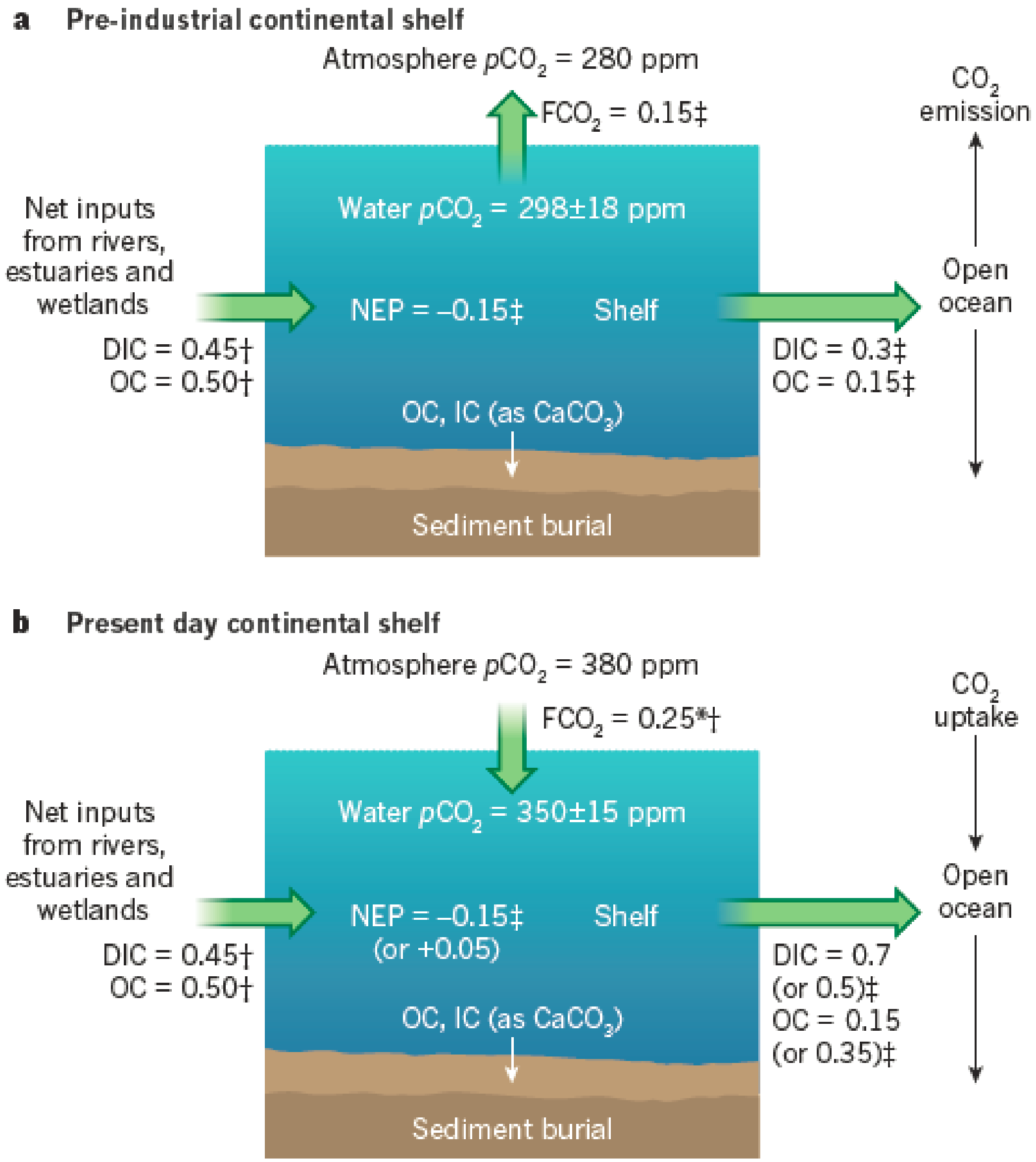
From Signorini et al. 2013:
FCO_2 = -3.4 to -5.4 TgC/yr.

The estuaries and the shelves are a sink of CO_2.

Control volume approach to coastal C cycle (NA East Coast margins)



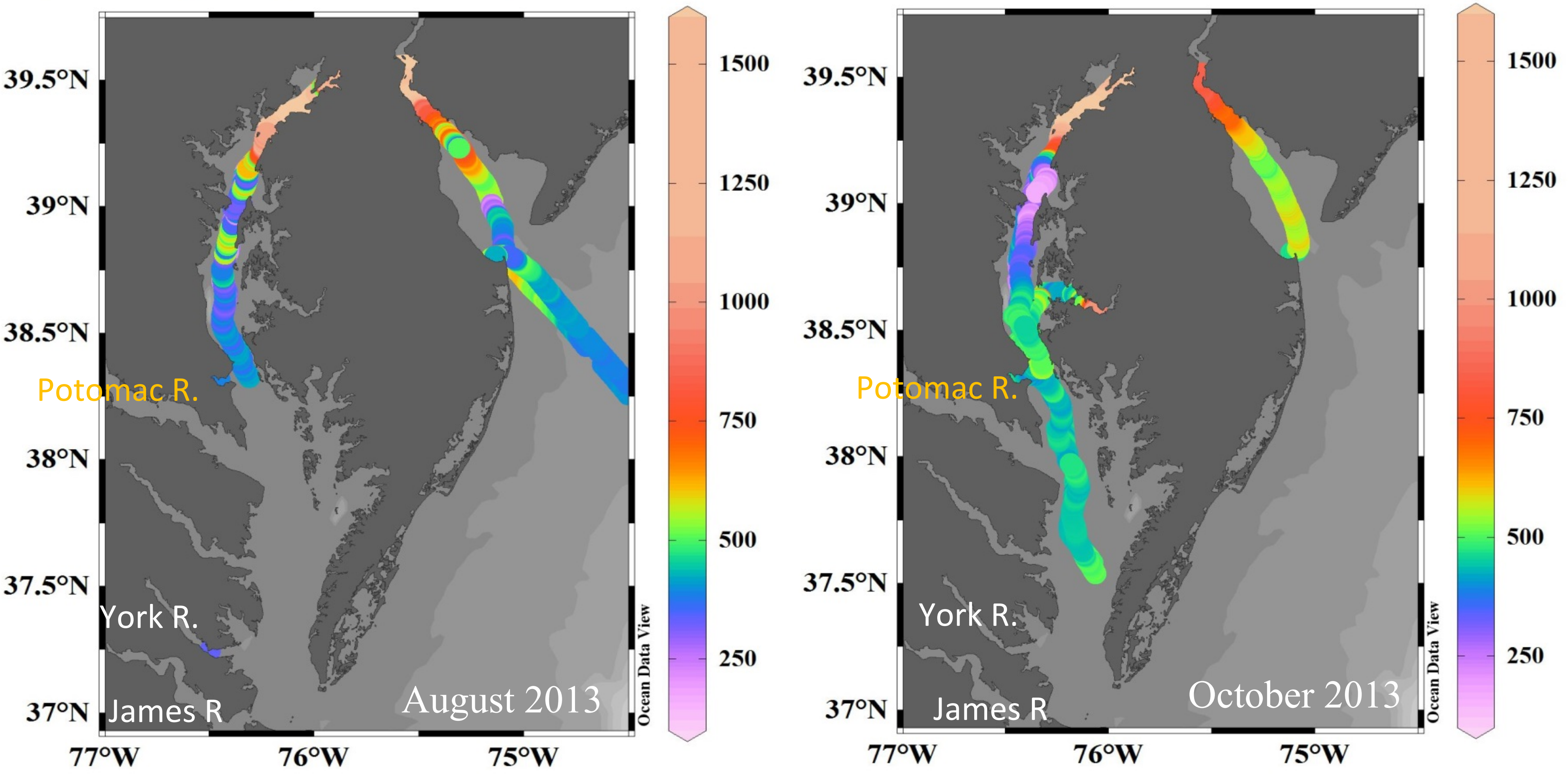
Pre- and post-industrial shelf carbon flux



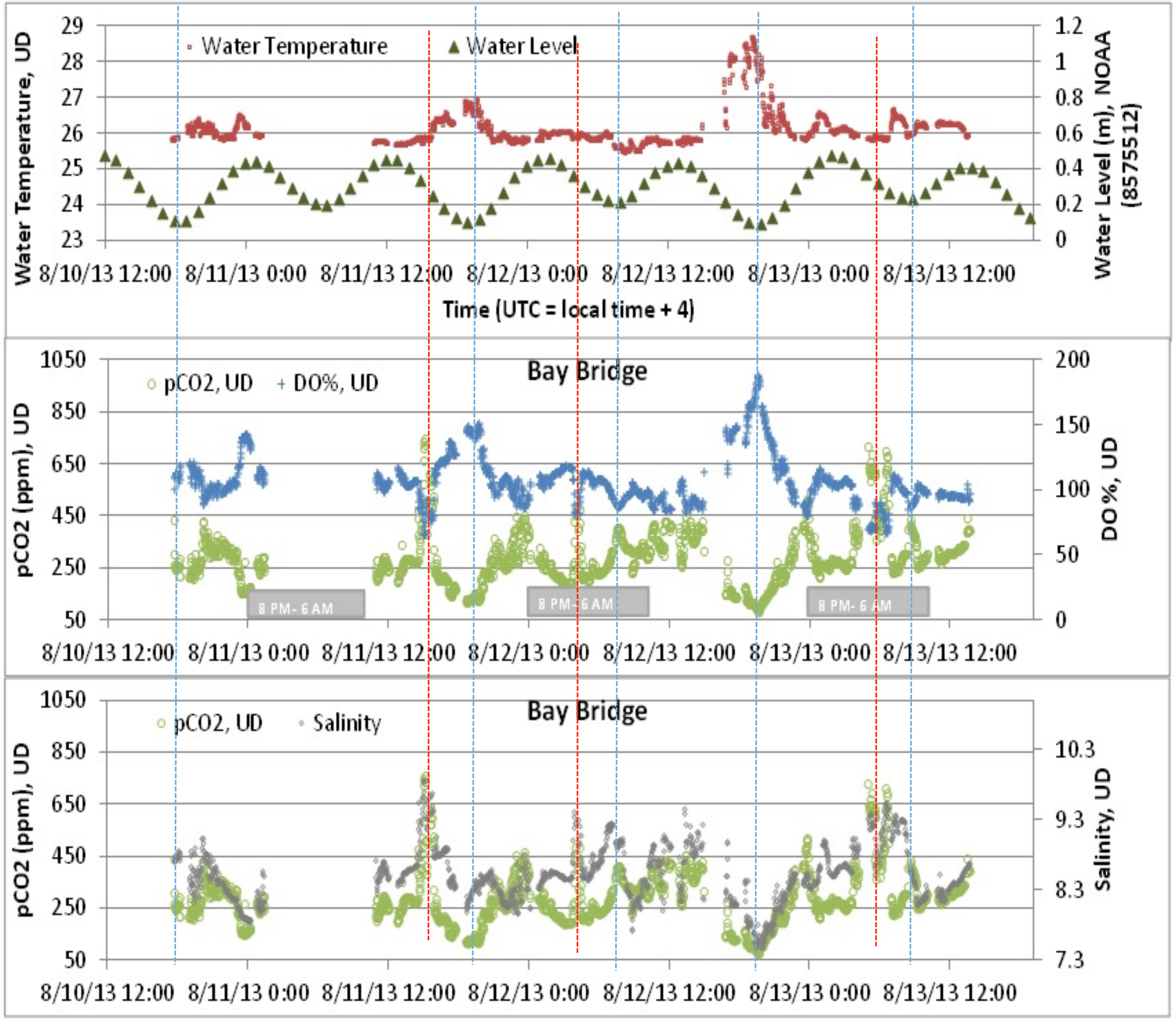
- Shelves turn from a CO_2 source into a sink,
- Why?
  - Increasingly more productive?
  - Higher atm-pCO_2.


Large estuaries in the east coast

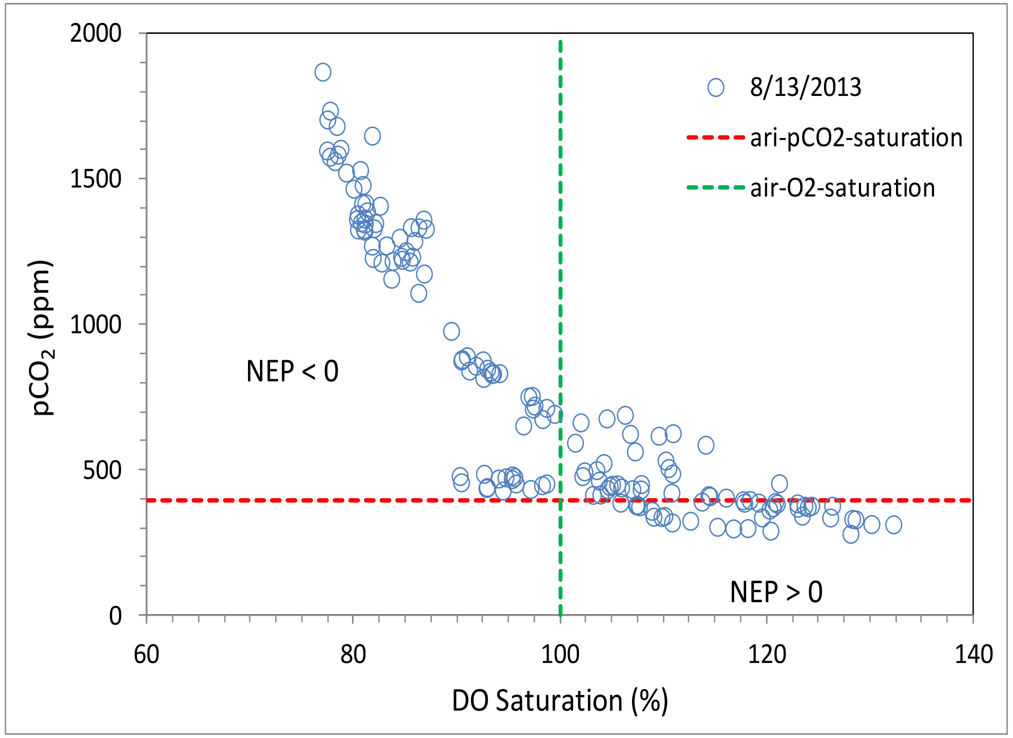
pCO_2 in Chesapeake Bay

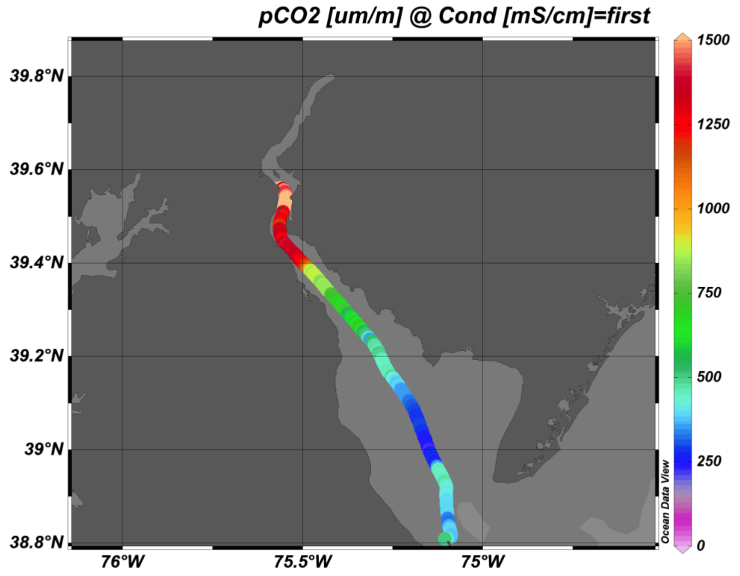


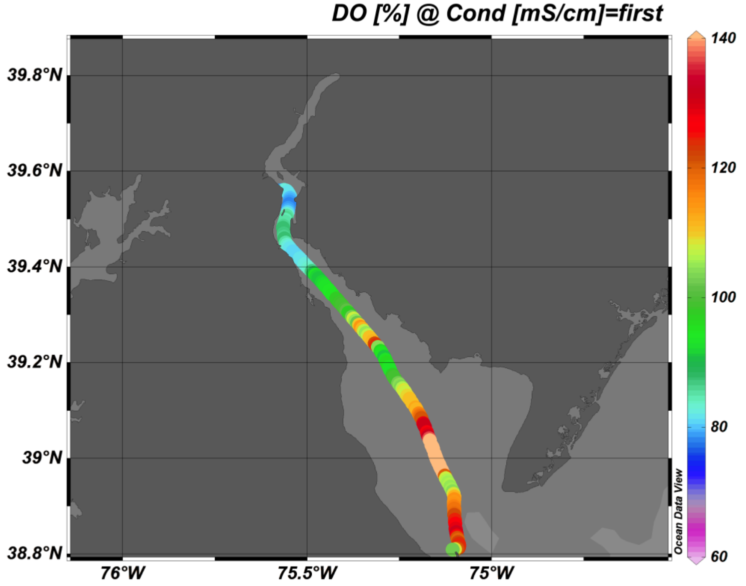
Biology and tidal driven pCO2 variations in CB



Metabolic balance in the Delaware Estuary







- Upper estuary is heterotrophic & a CO_2 source
- Lower bay is autotrophic & a CO_2 sink
- Middle bay is autotrophic BUT a CO_2 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.