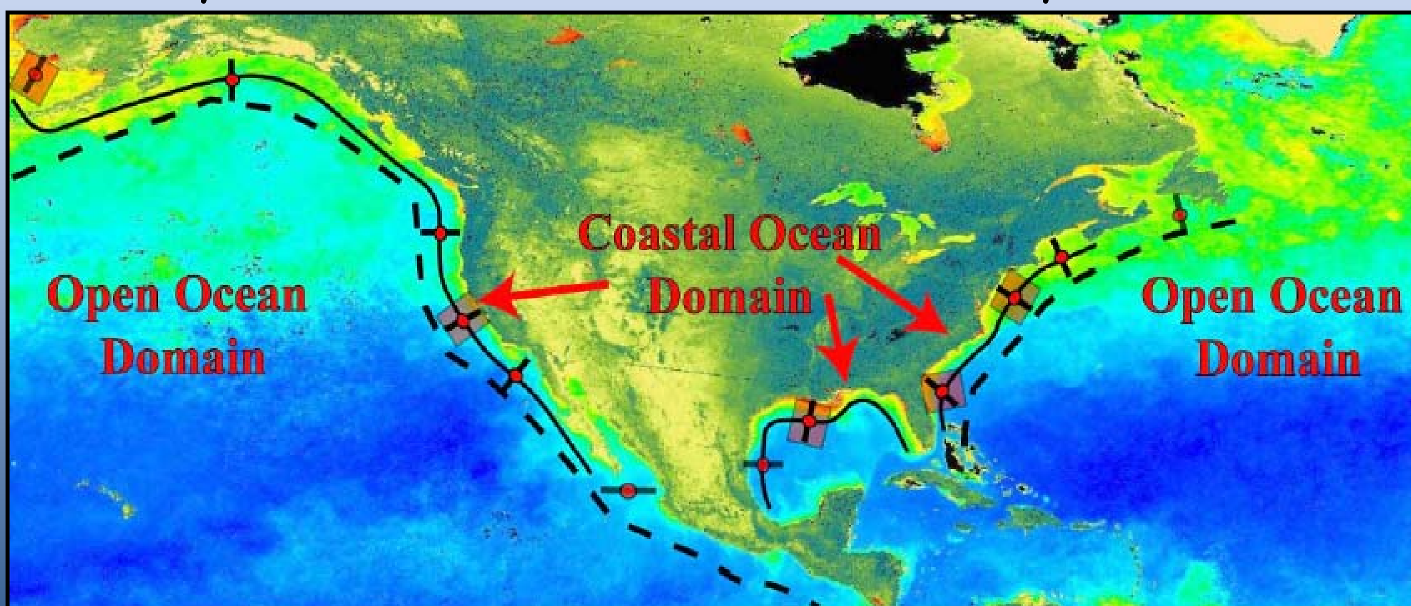
North American Carbon Program

Carbon Measurements along the North American Continental Margins

Christopher L. Sabine, Richard A. Feely, Simone Alin, Burke Hales, J. Martin Hernandez-Ayon, Debby Ianson, Pete Strutton, Rik Wanninkhof, Tsung-Hung Peng, Doug Vandemark, Joe Salisbury, Wei-Jun Cai, Chris Langdon, Stacy Maenner, Taro Takahashi, and Sylvia Musielewicz

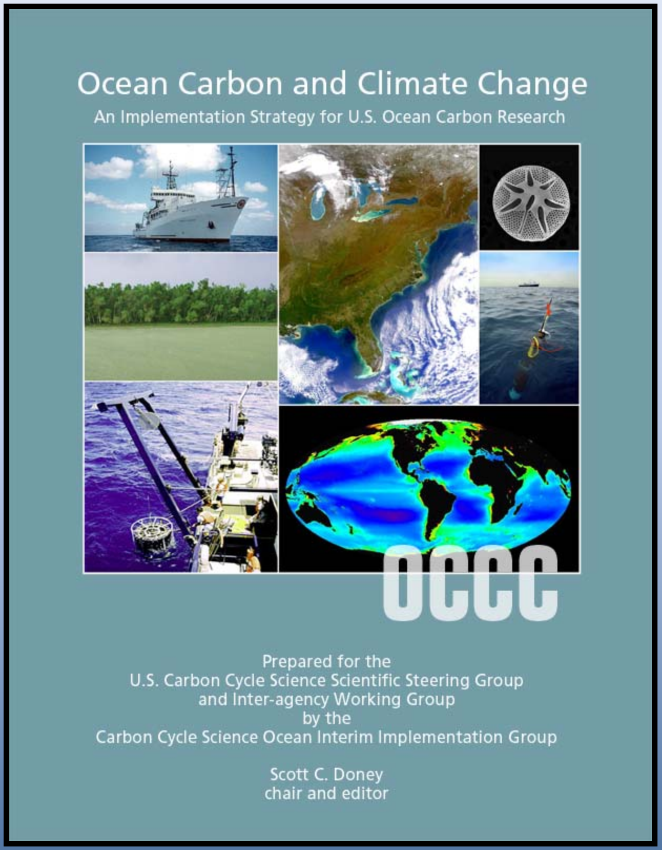


NORTH AMERICAN CONTINENTAL MARGINS (NACM)
THE OCCC/NACP COASTAL CO_2 WORKSHOP

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

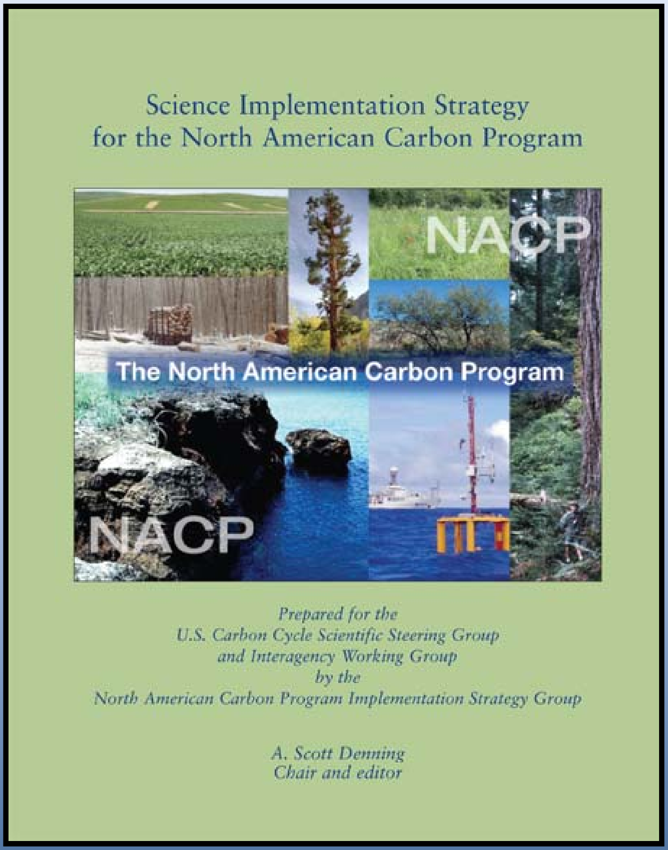


50 participants

37 scientific inst.

3 gov. agencies

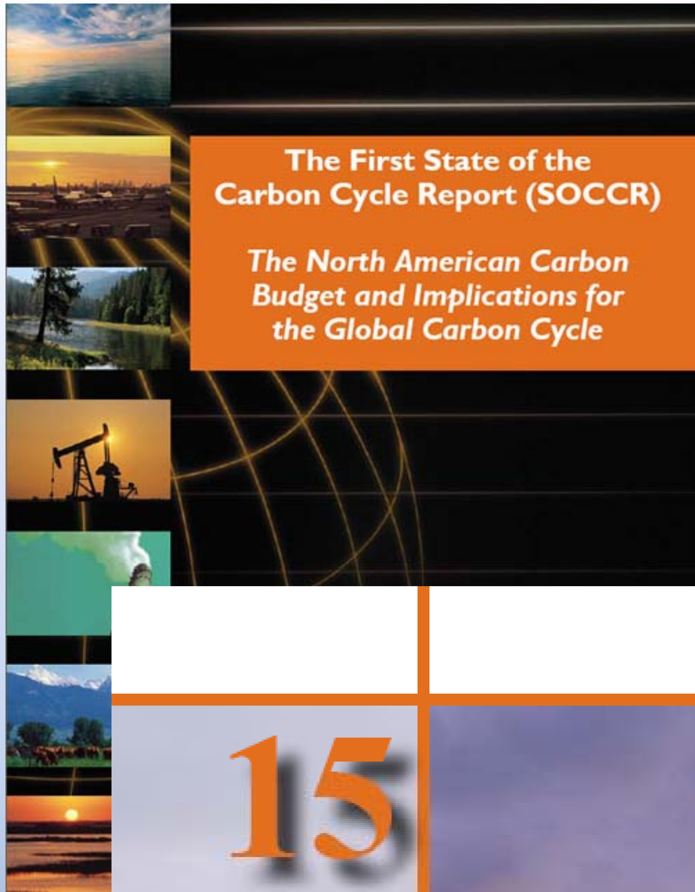
6 countries



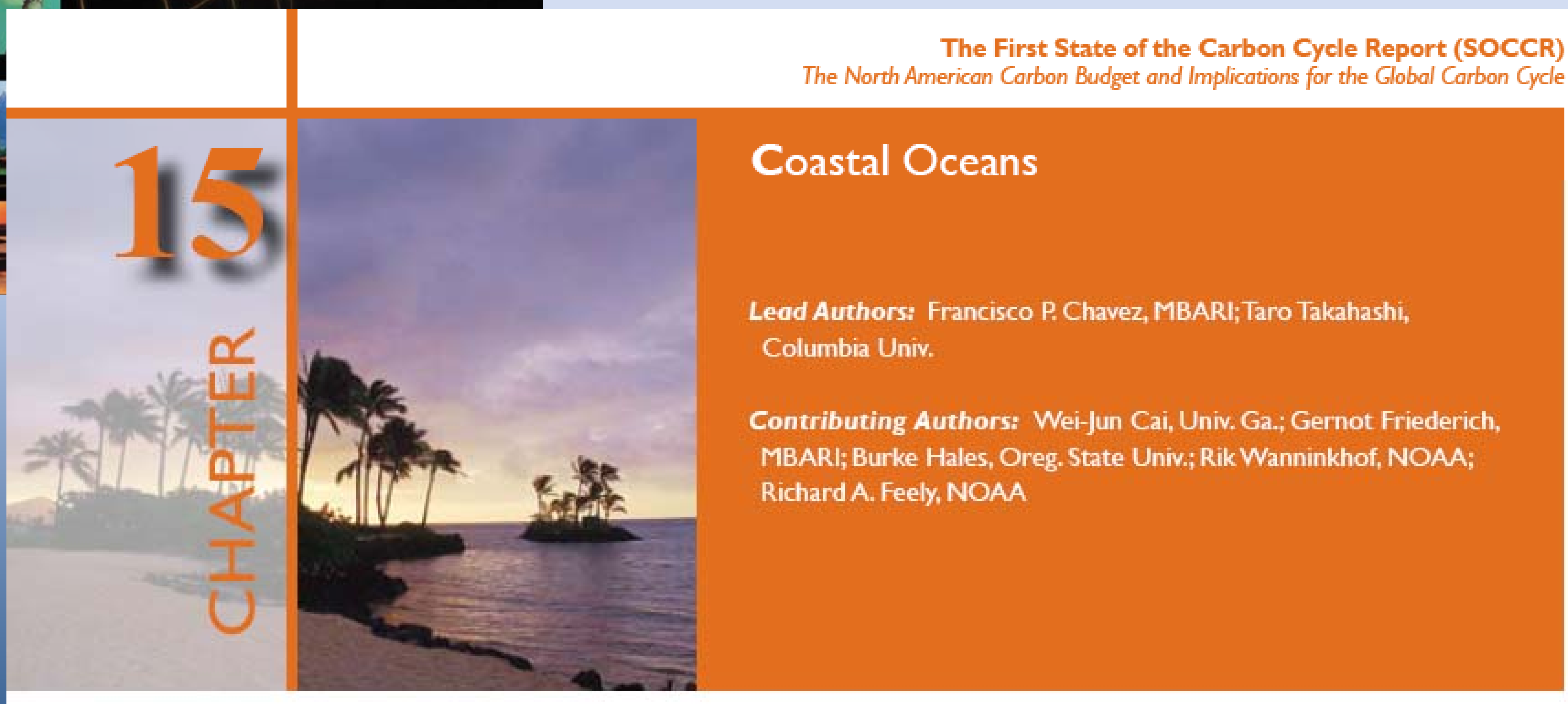
The NACM workshop: Objectives

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.



Published in November 2007



The First State of the Carbon Cycle Report (SOCCR)

The North American Carbon Budget and Implications for the Global Carbon Cycle

CHAPTER 15

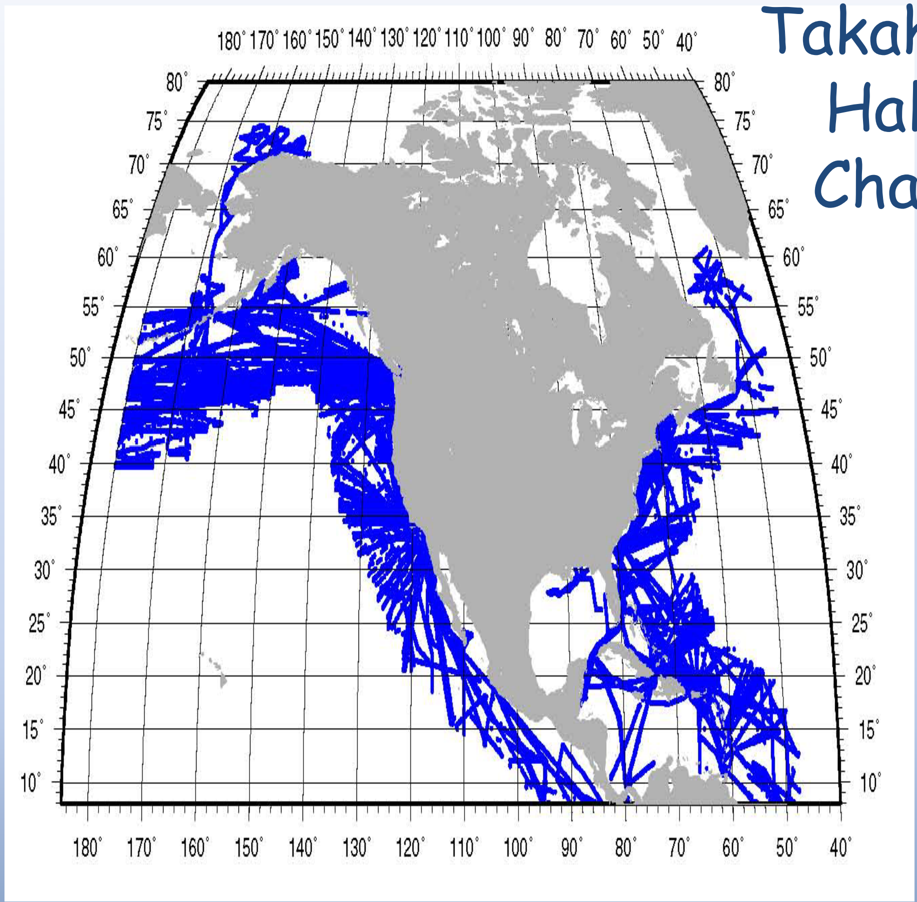
Coastal Oceans

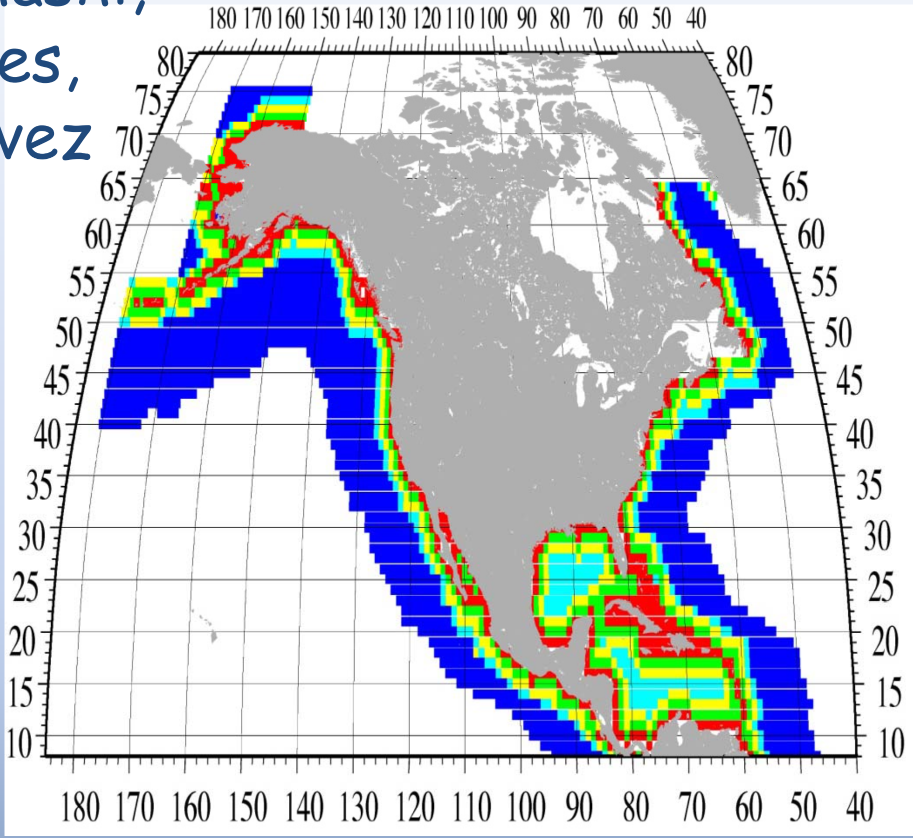
Lead Authors: Francisco P. Chavez, MBARI; Taro Takahashi, Columbia Univ.

Contributing Authors: Wei-Jun Cai, Univ. Ga.; Gernot Friederich, MBARI; Burke Hales, Oreg. State Univ.; Rik Wanninkhof, NOAA; Richard A. Feely, NOAA

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

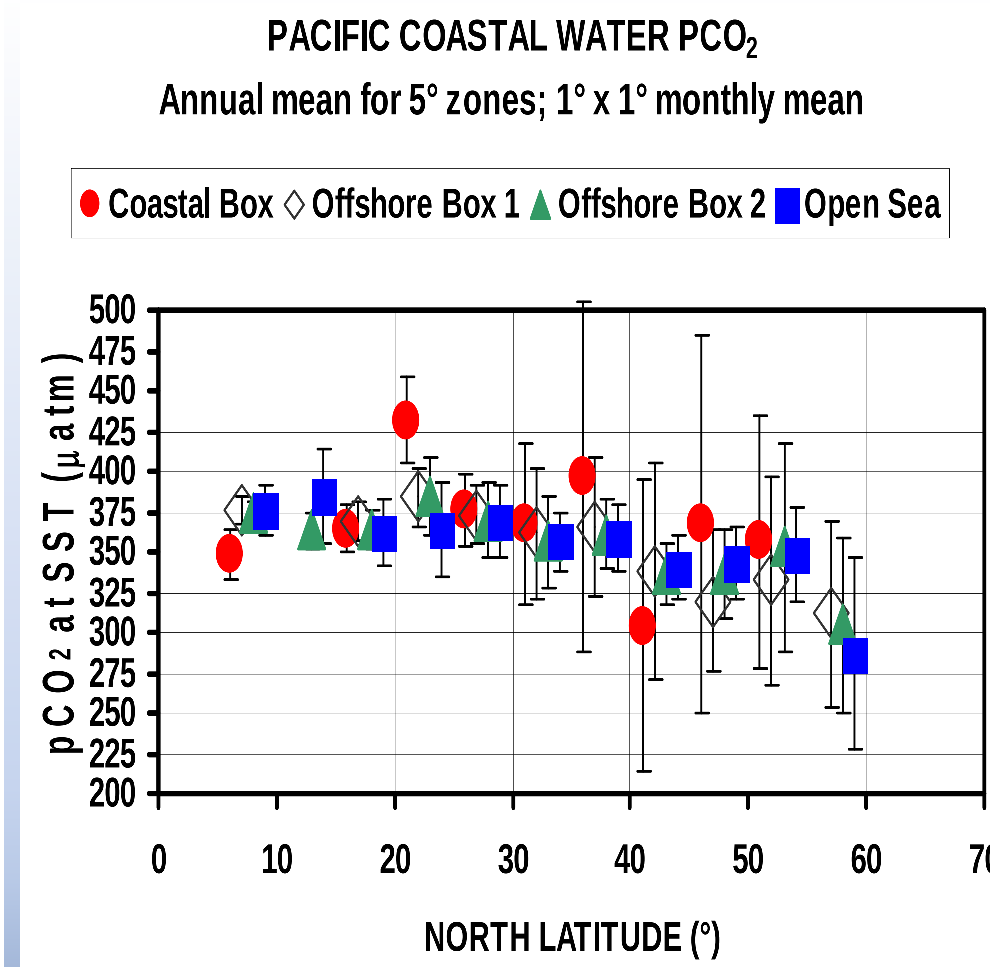
Takahashi,
Hales,
Chavez

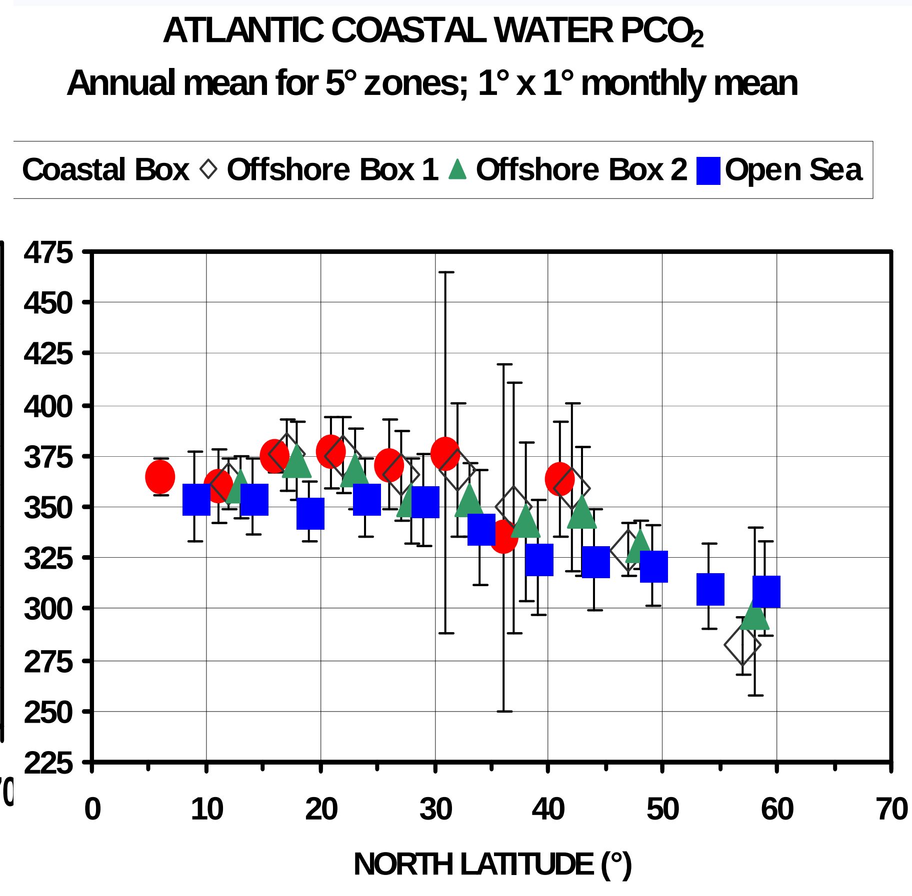




LDEO, MBARI, OSU, AOML, UGA databases contain ~100k coastal surface pCO_2 measurements dating to 1979 that were excluded from global compilations.

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 ± 35.6 Tg C yr^{-1}

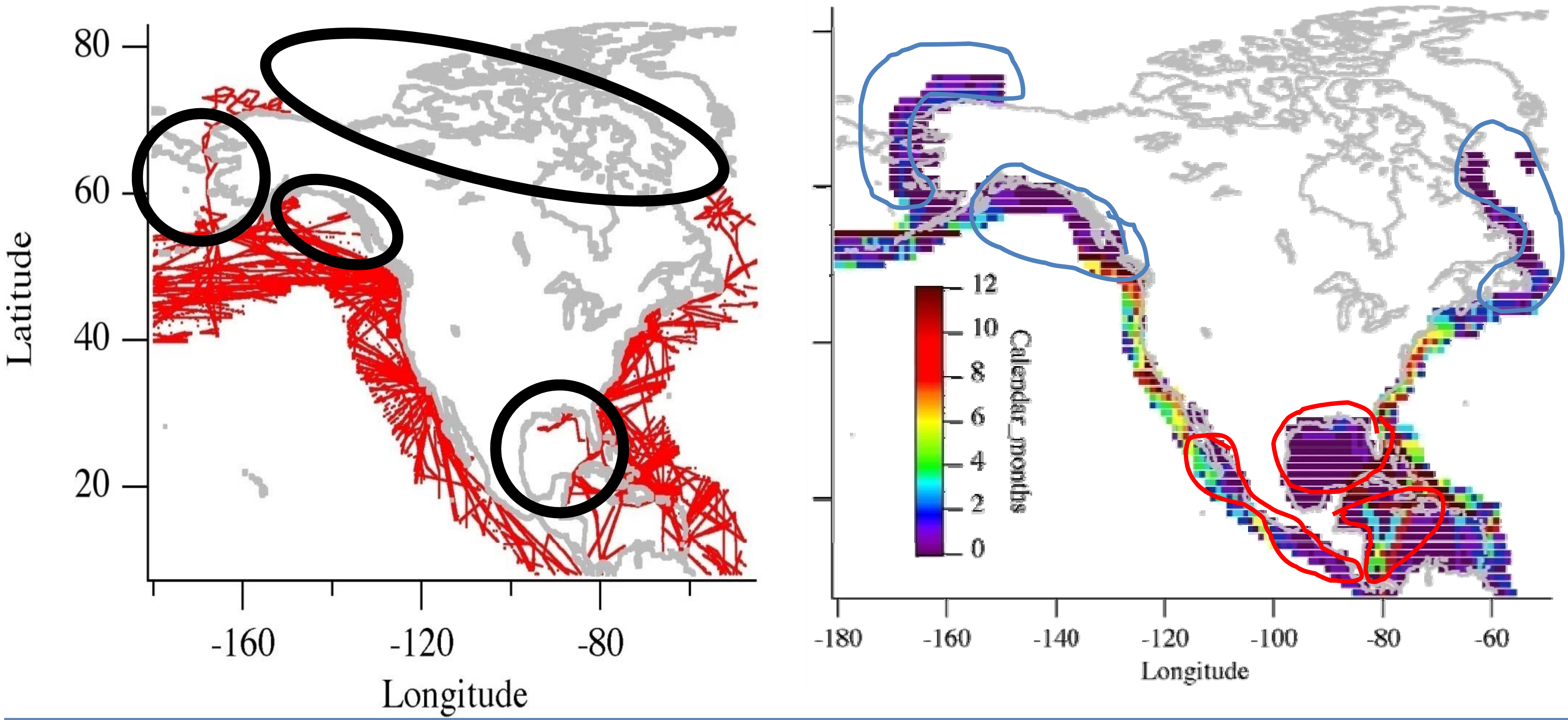
Mexico: +44.9 ± 14.0,

US: -21.0 ± 17.9,

Canada: -22.4 ± 27.4

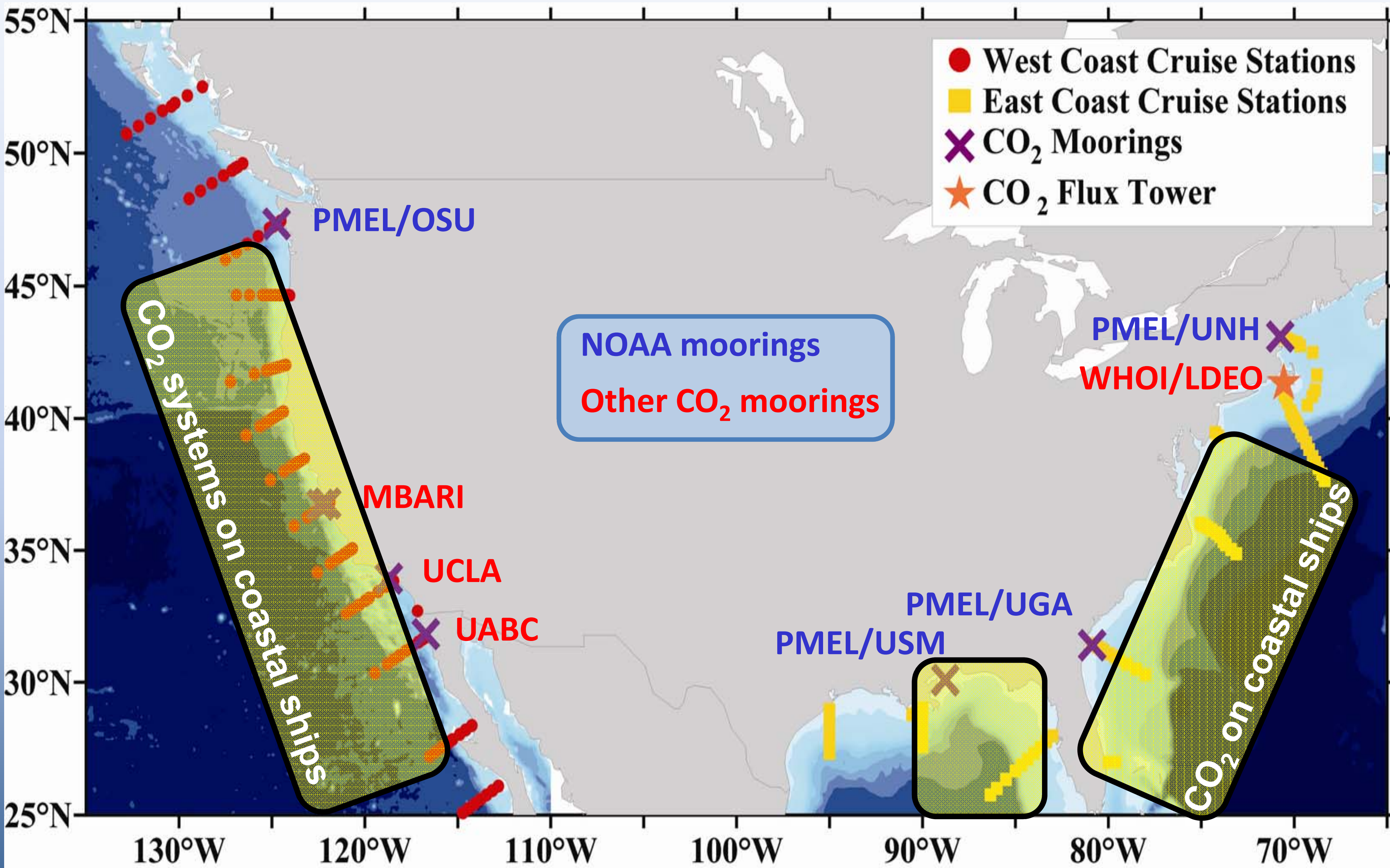
The coverage problem

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 CO_2 measurements were primarily made on vessels participating in open-ocean programs.

Coastal CO_2 Observational Network



NOAA Ship *McArthur II*

NOAA Ship *David Starr Jordan*

NOAA Ship *Gordon Gunter*

NOAA Ship *Ronald H. Brown*

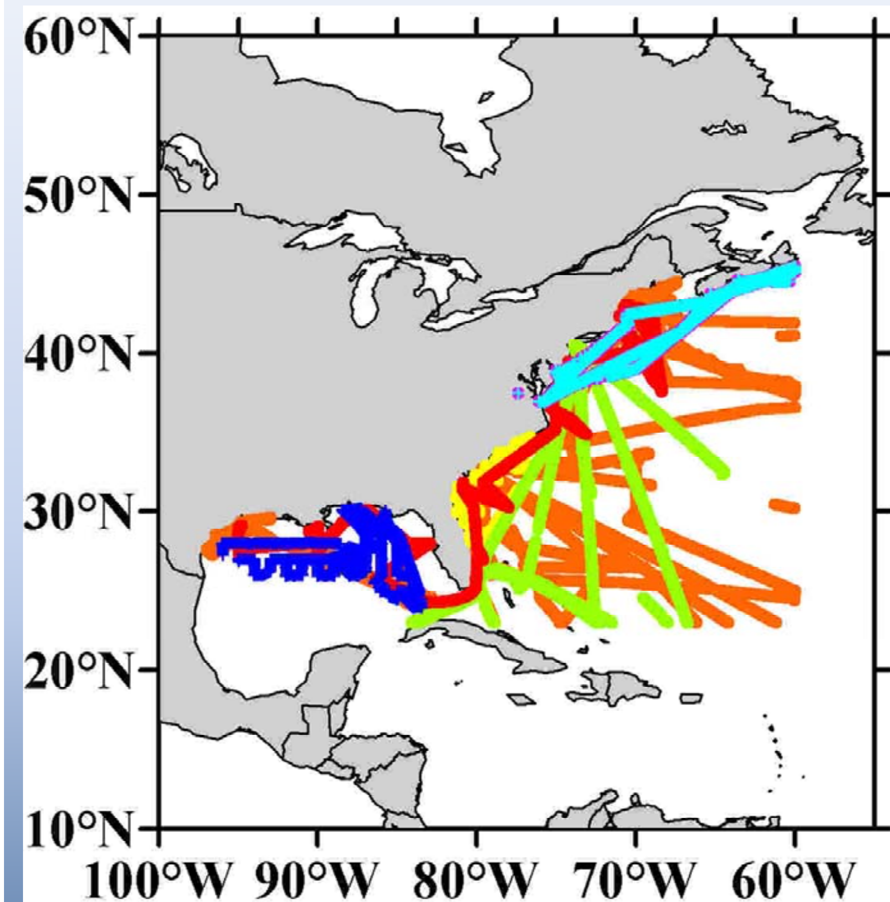
Container Ship *Skogafoss*

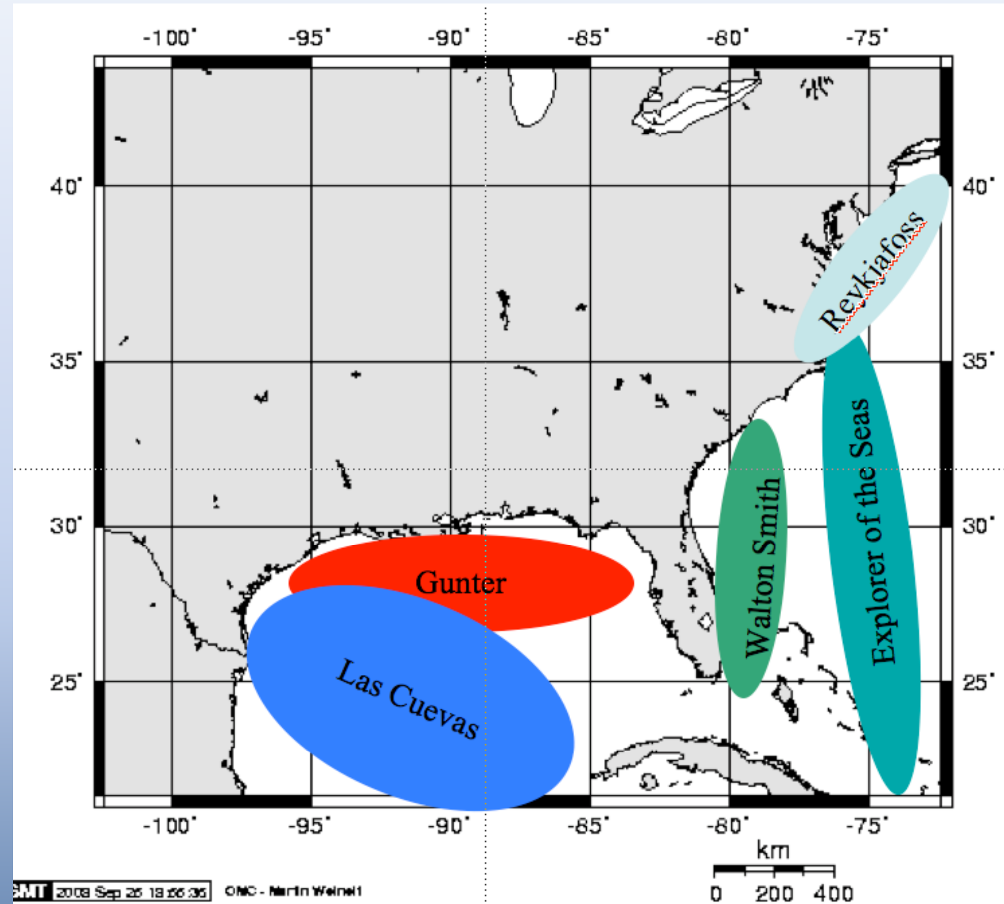
Container Ship *Cap Van Diemen*


Cruise Ship *Explorer of the Seas*

Container Ship *OOCL Tianjin*

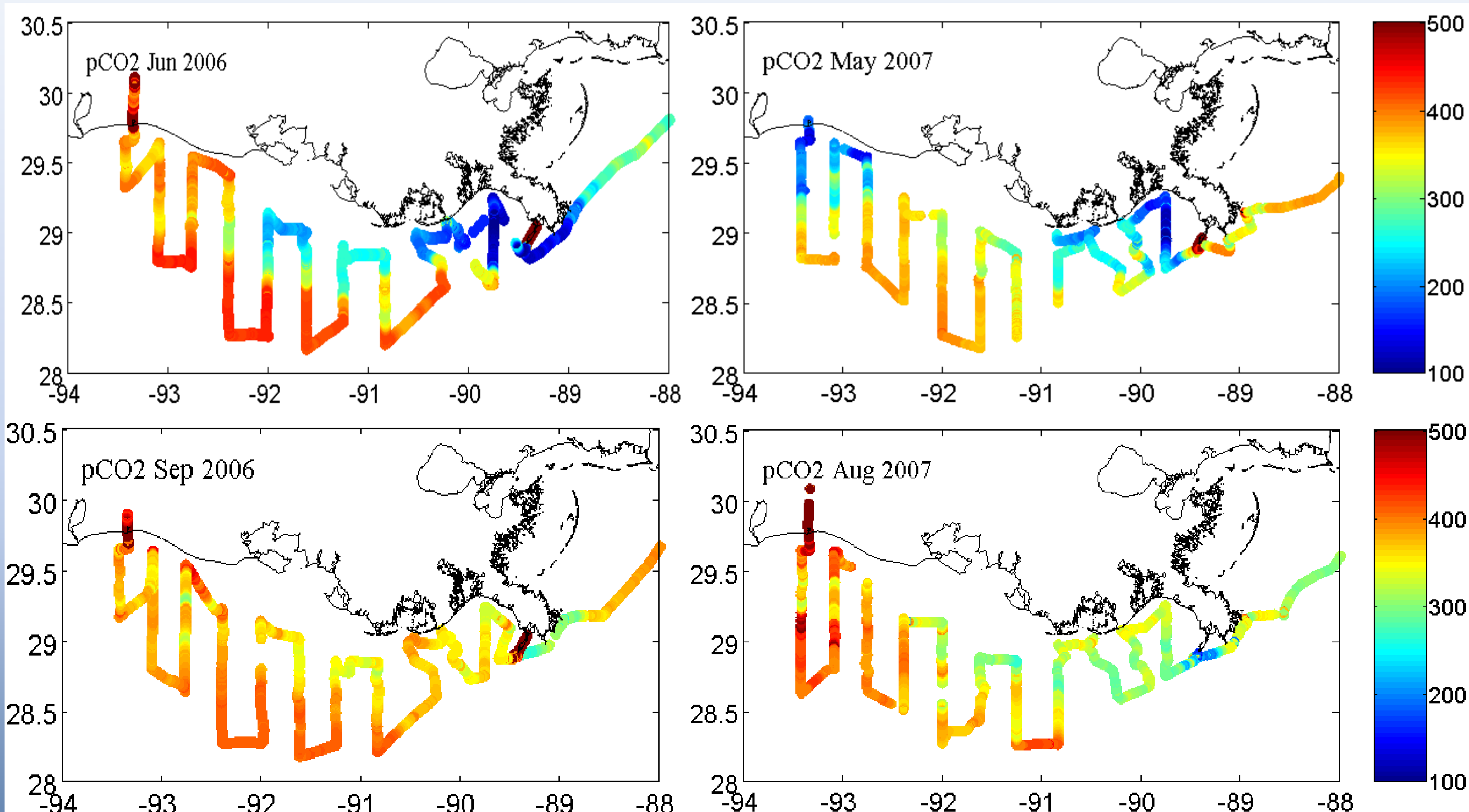
Underway pCO_2 network and new data: East and Gulf of Mexico Coasts (2006-2008)





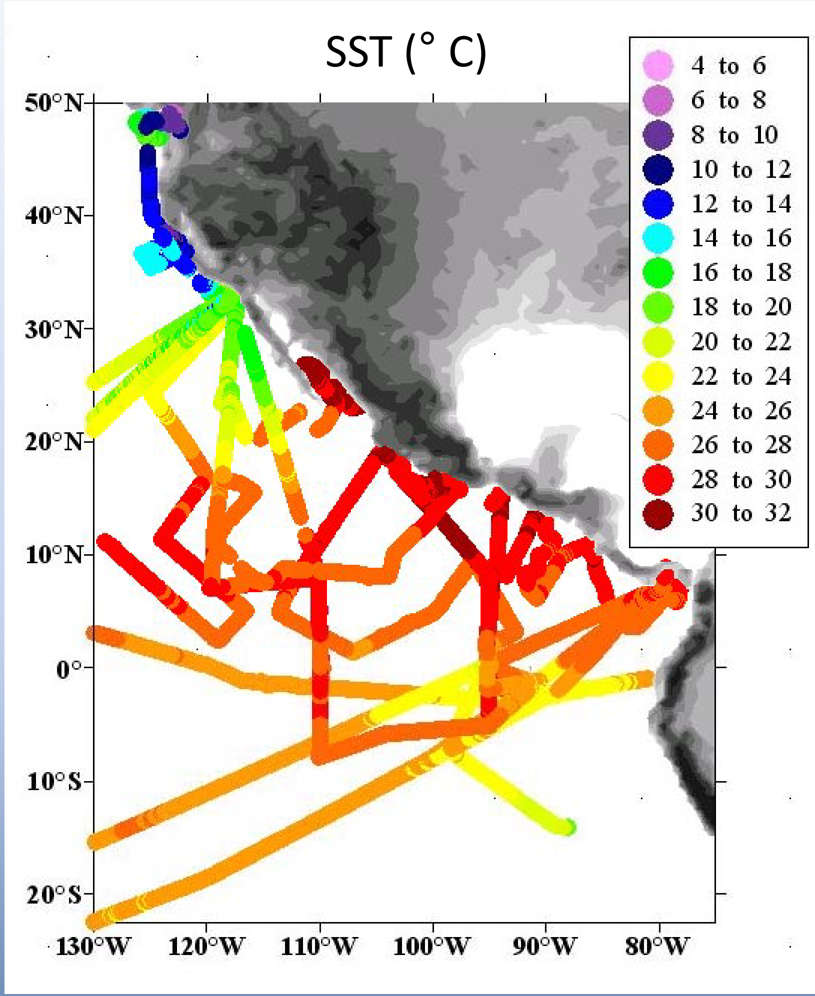
>150,000 new data points

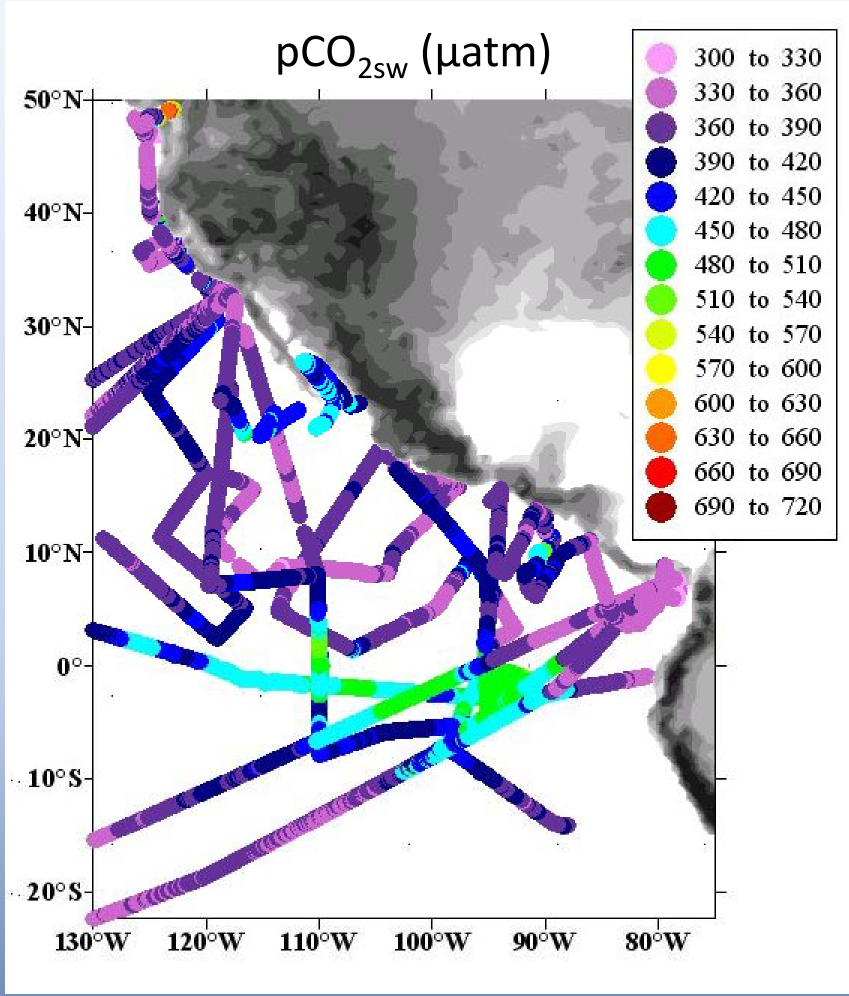
Scatter plots of pCO_2 from underway shipboard observations conducted in conjunction with EPA hypoxia survey cruises. Values of pCO_2 were consistently low in regions influenced by river outflow.



See Poster by Steve Lohrenz

Underway pCO_2 network and new data: West Coast (2006–2008)

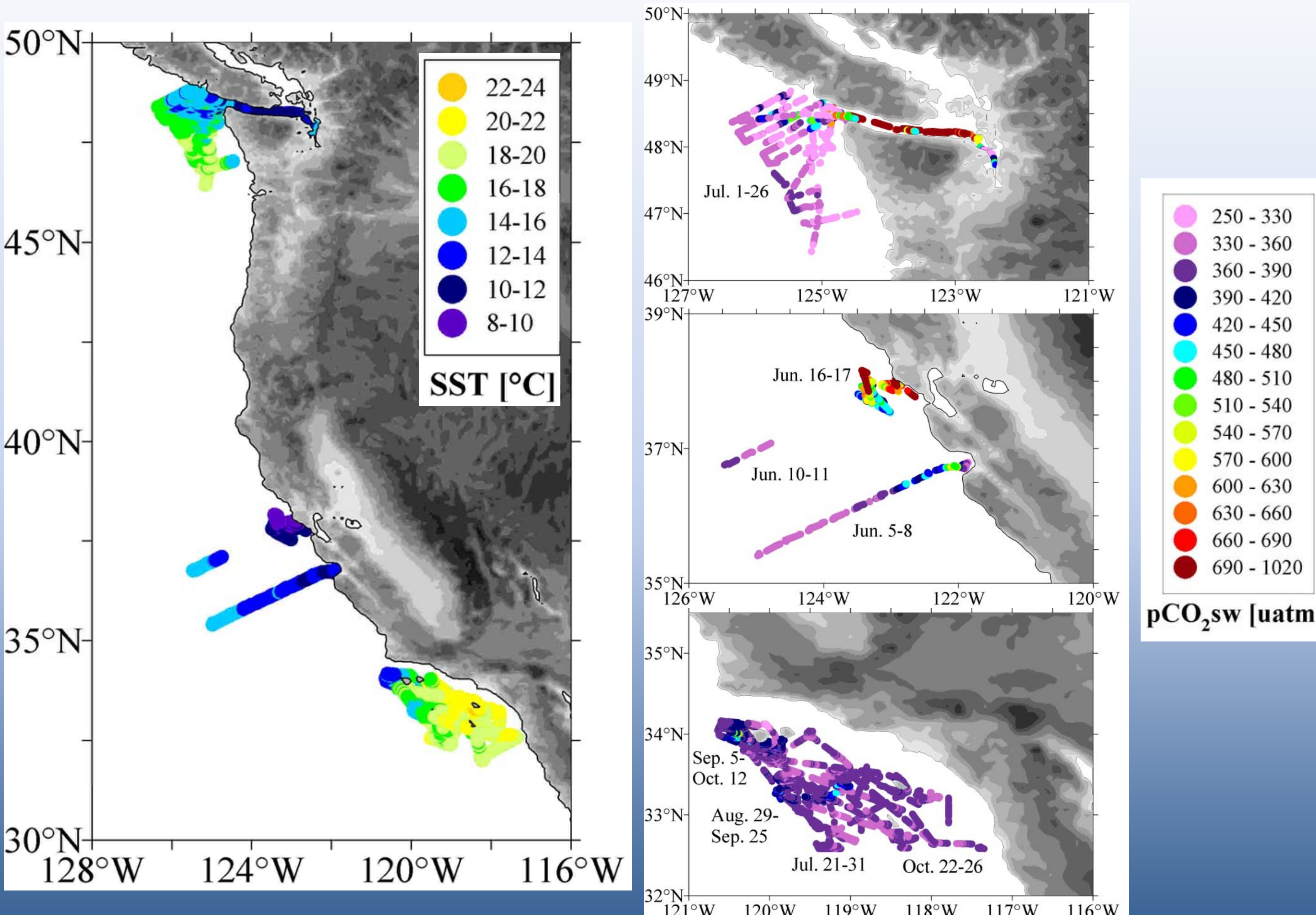




>250,000 new data points

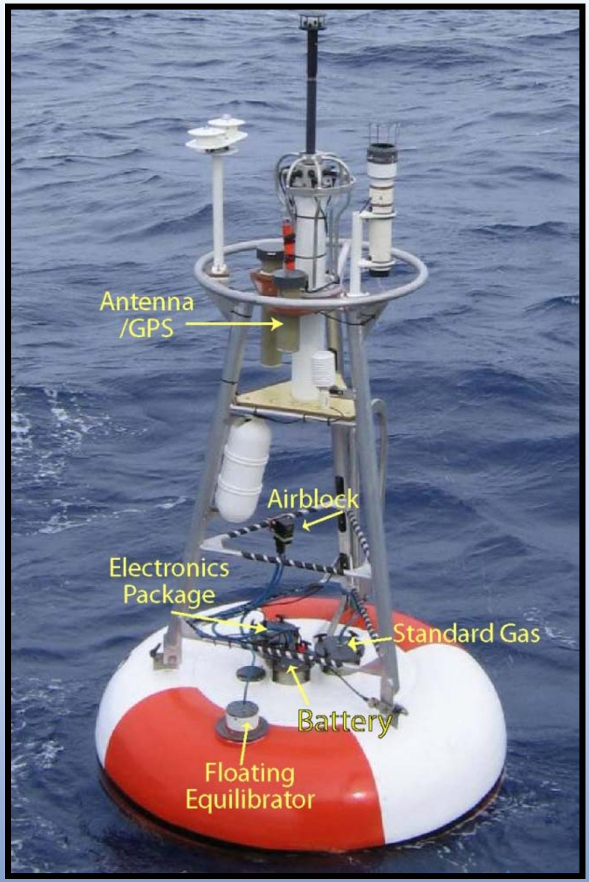
See Poster by Simone Alin

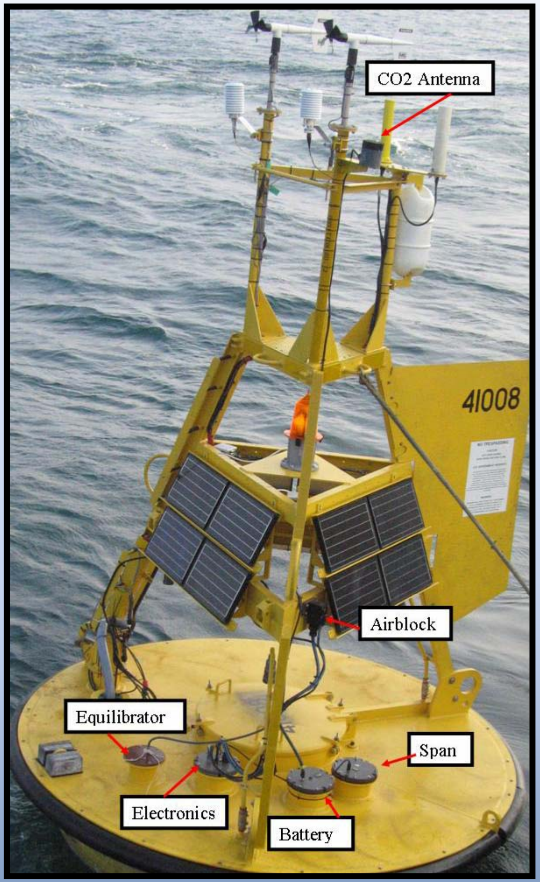
Underway pCO_2 system observations in 2007

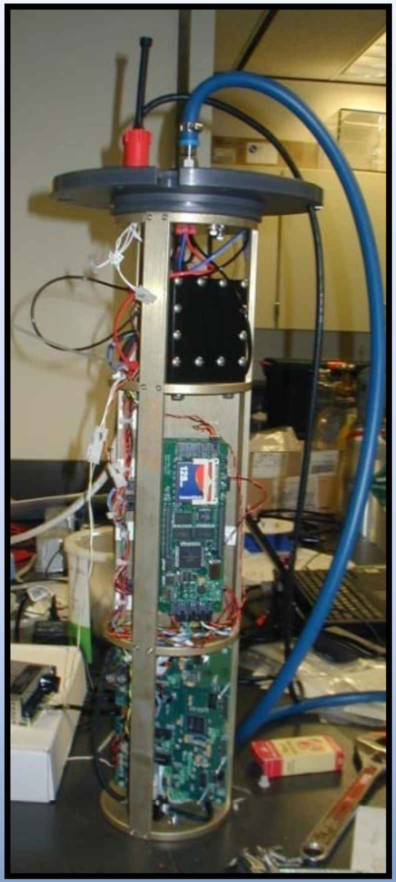


PMEL Moored Autonomous pCO_2 ($MAPCO_2$) system

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

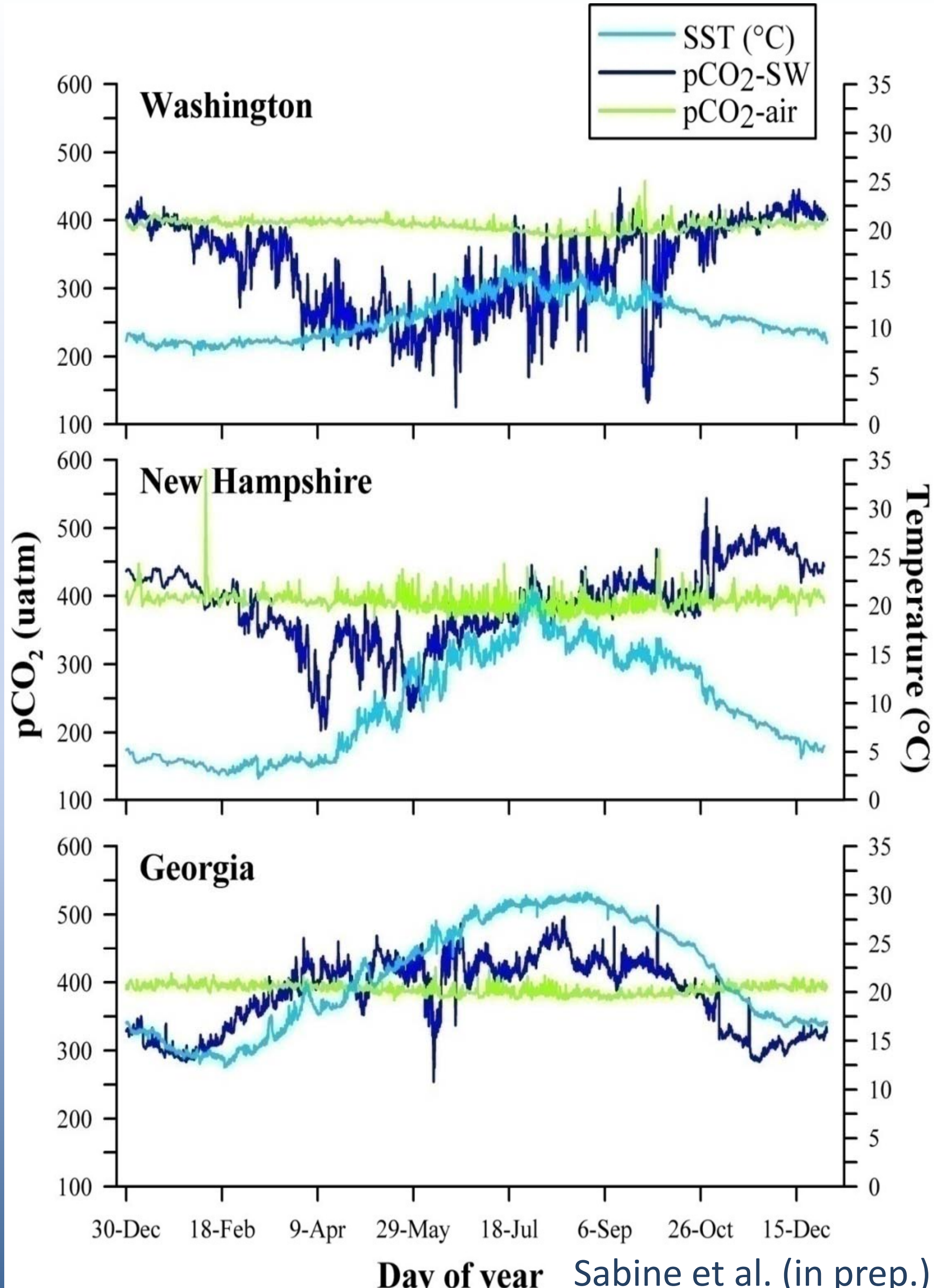






The Basics:

- 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.



Sabine et al. (in prep.)

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.

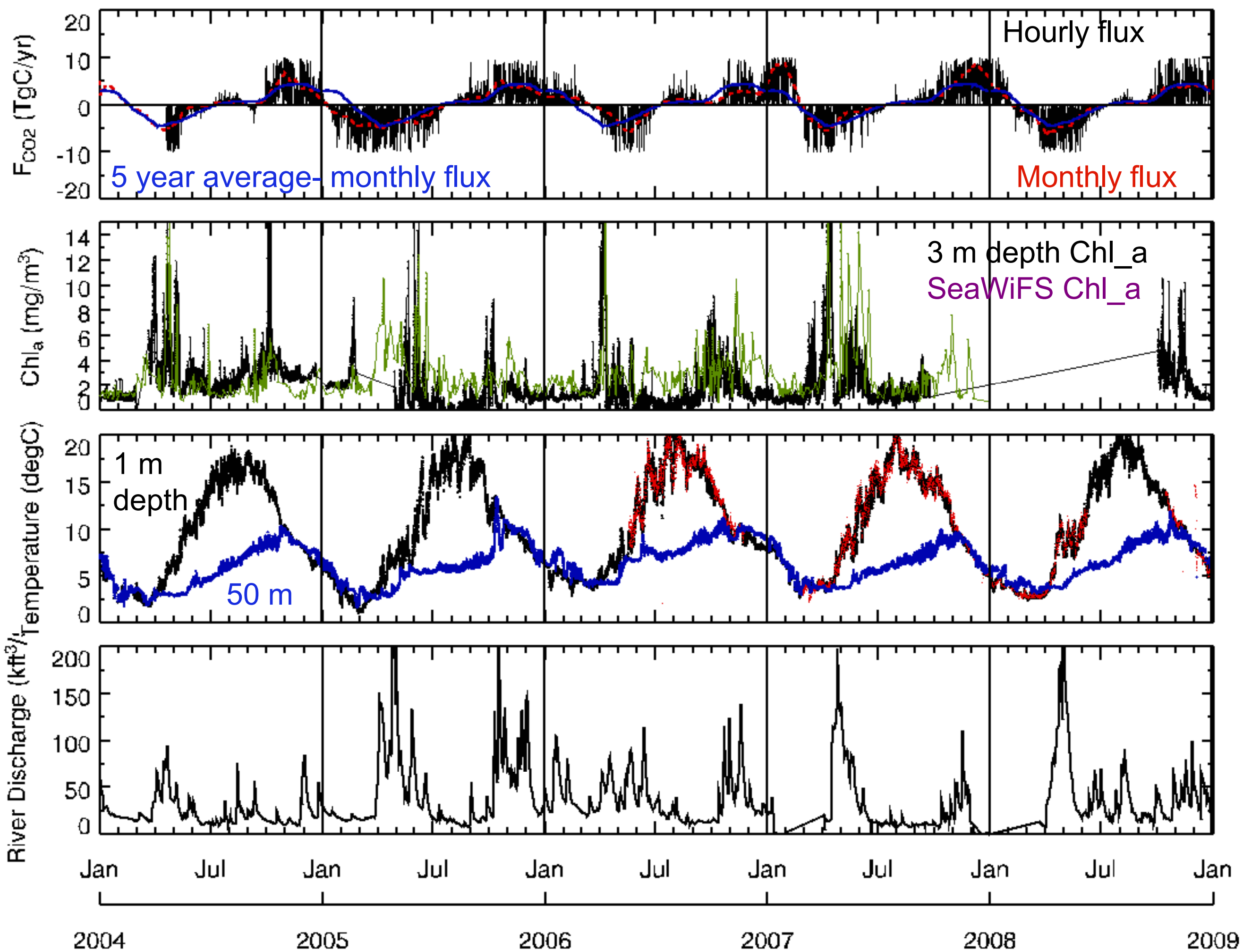
Washington strongly influenced by spring and summer upwelling

NH sees spring bloom drawdown and mixing in the winter

Georgia is primarily temperature controlled with some river influences

~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

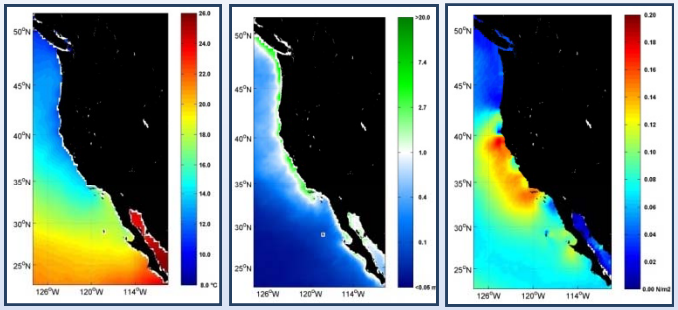


- Rich data set for C monitoring and process studies
- Monthly cruise data (2004-) and daily CO_2 buoy obs. (2006-)
- Hourly inshore and offshore surface atmos. CO_2 data
- Substantial snowmelt and river discharge

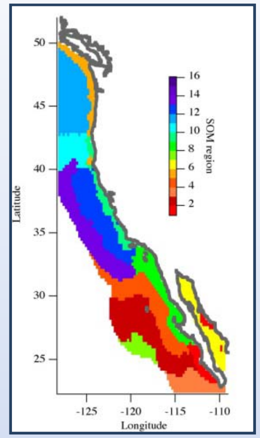
UNH shipboard pCO_2 and *in situ* data at
www.cooa.unh.edu and soon at CDIAC

we acknowledge NOAA/PMEL, UMaine, NDBC, USGS

Extrapolation & Synthesis of CO_2 Observations



Remote sensing climatologies



SOM defines regions

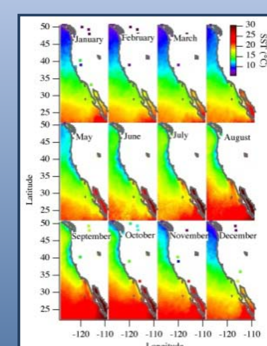
Field CO_2 data assigned to regions

Non-linear model

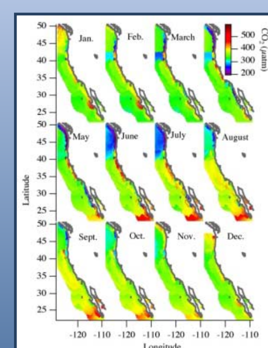
$$pCO_2 = f\left(Alk, TCO_2, T, S\right)$$

$$TCO_2 \approx TCO_{2,0} + \left.\frac{\partial TCO_2}{\partial T}\right|_{mix} \Delta T_{mix} + \left.\frac{\partial TCO_2}{\partial Chl}\right|_{bio} \Delta Chl_{bio}$$

$$Alk \approx Alk_0 - 0.15 \Delta TCO_2$$

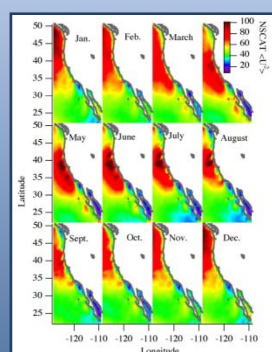


Remote sensing data



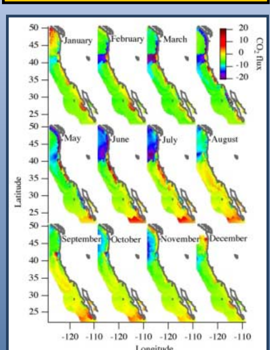
pCO_2 map

k = f (U_{10},SST)



Wind speed

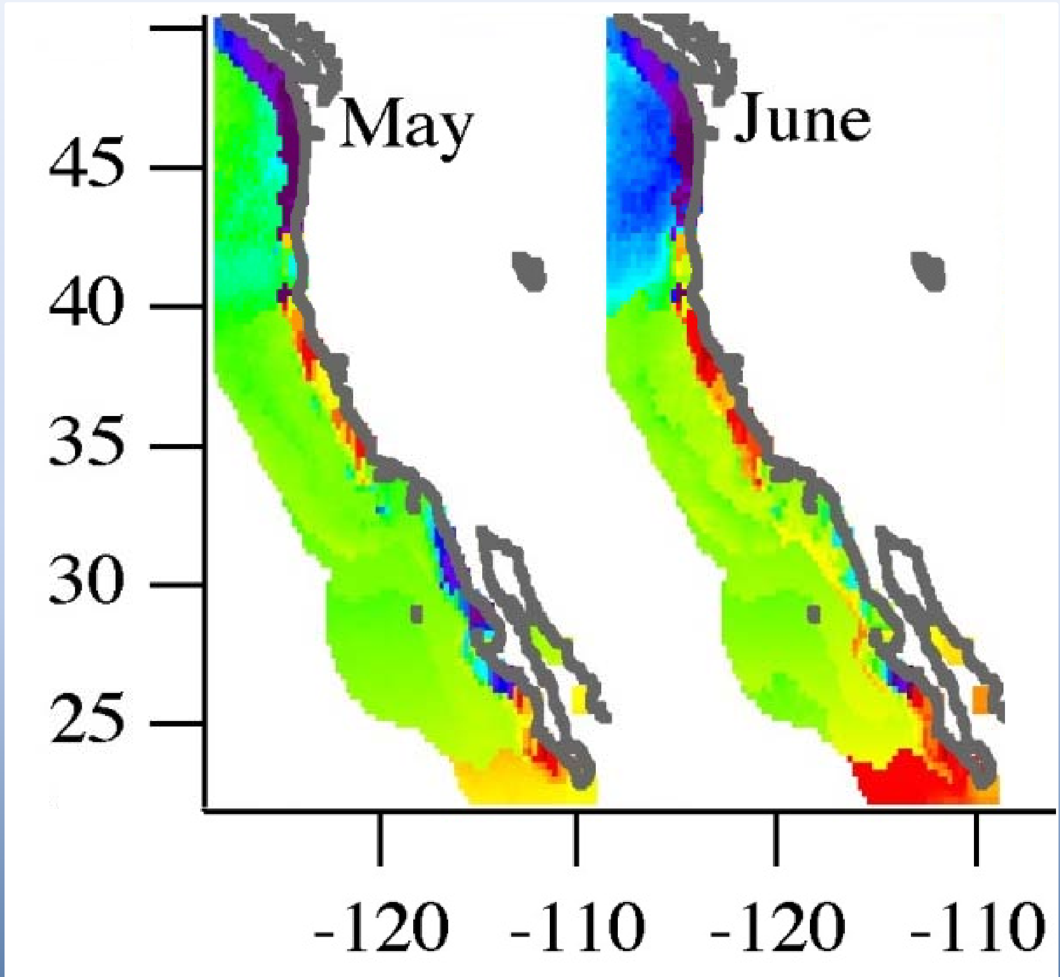
Flux = k s $\Delta f CO_2$



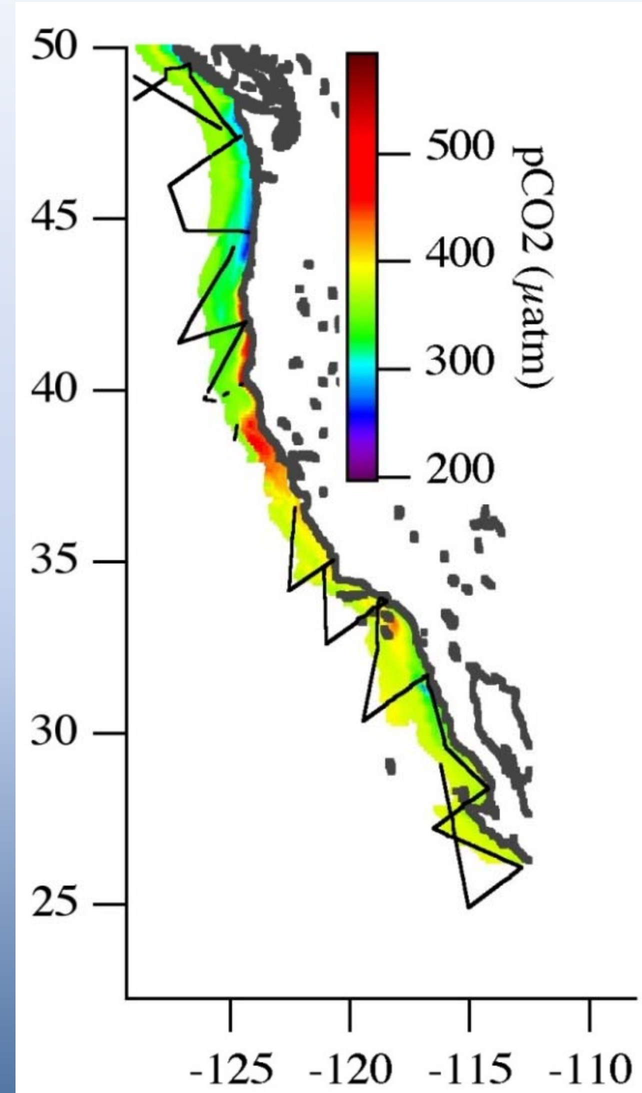
CO_2 flux maps

Observation vs. SOM-based CO_2 maps

SOM pCO_2 maps for same season

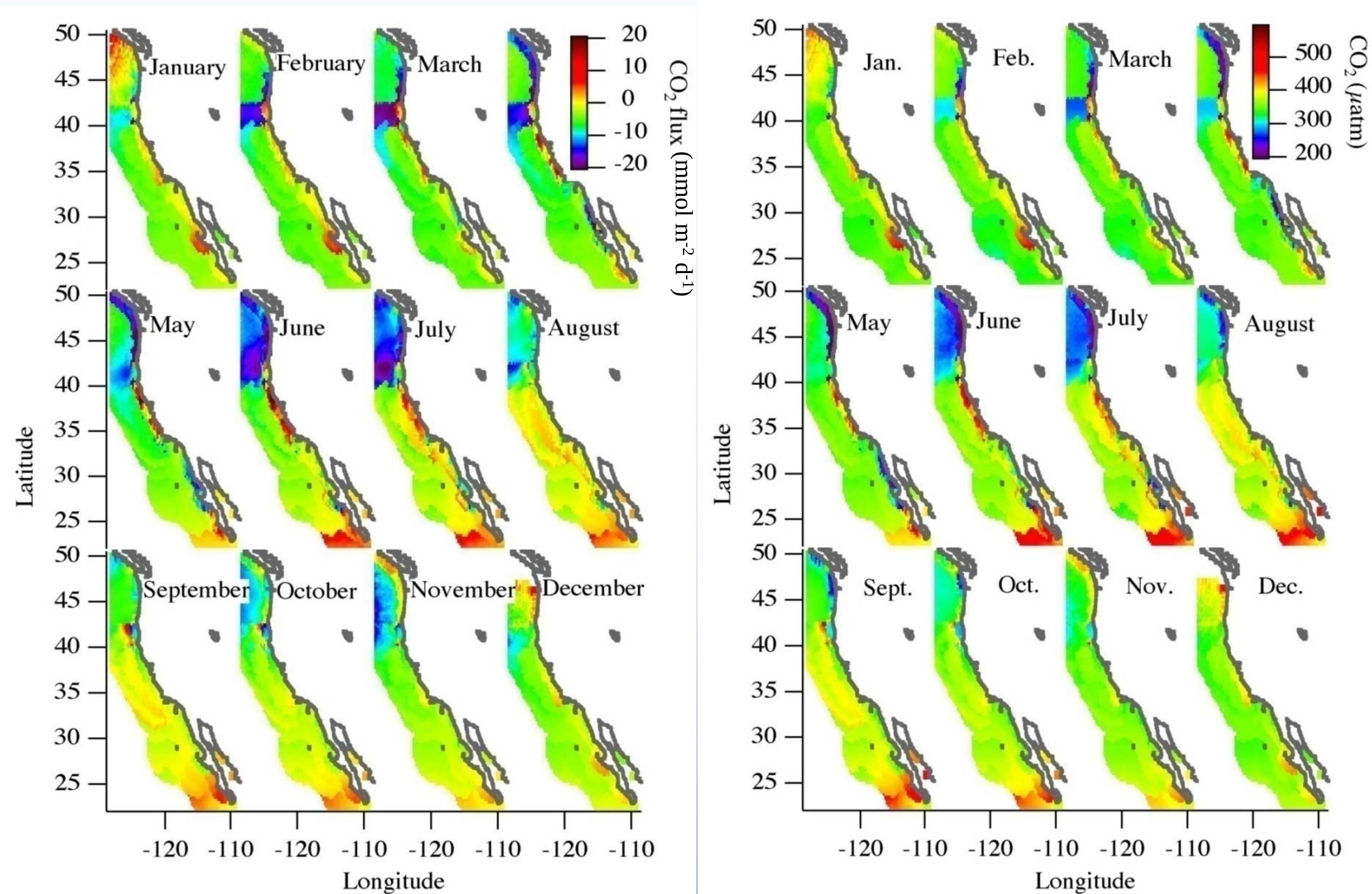


Cruise pCO_2



Hales et al. (in prep.)

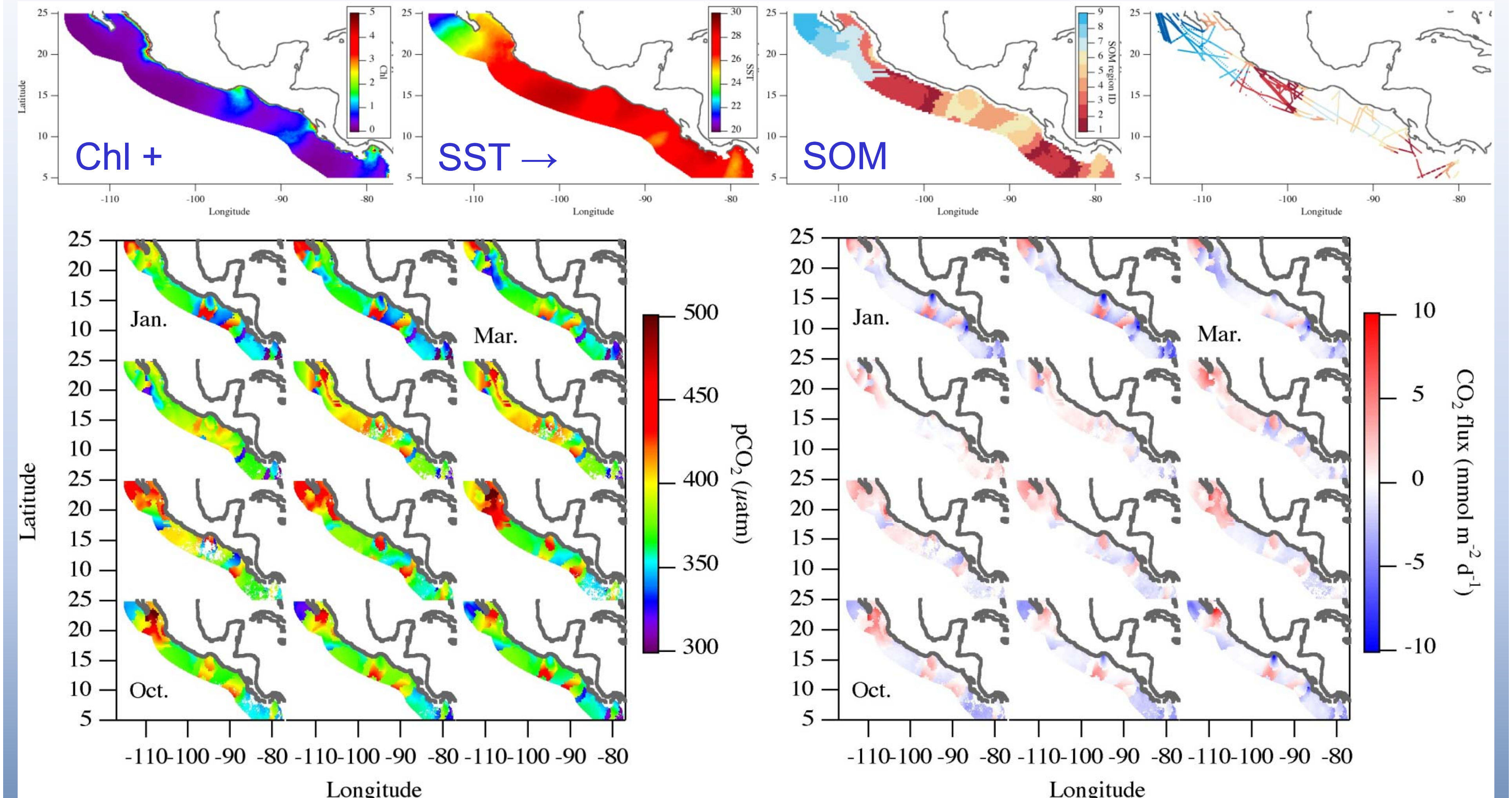
Monthly pCO_2 and CO_2 Flux Maps



SOCCR: +0.5 Tg C y^{-1} vs. SOM: –17 Tg C y^{-1}

Hales et al. (in prep.)

Pacific Central American Coast Fluxes

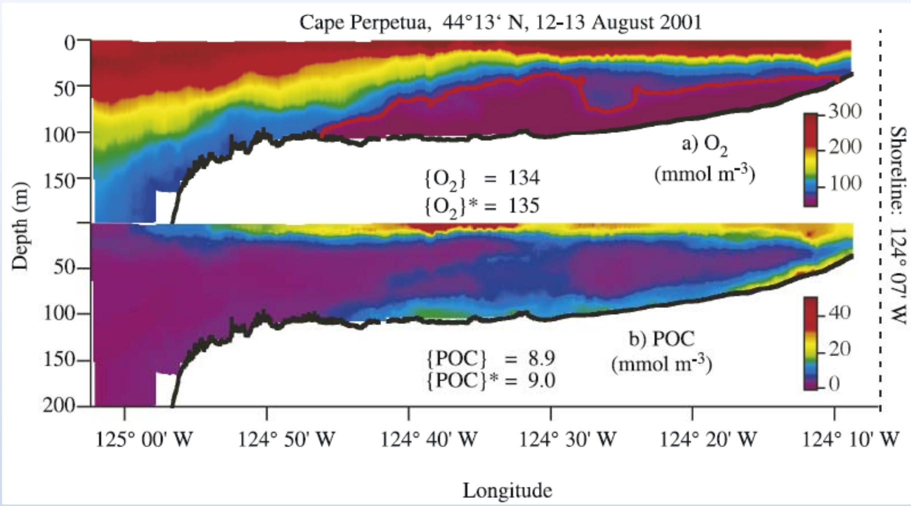


SOCCR: +9 Tg C y^{-1} vs. SOM: –1.5 Tg C y^{-1}

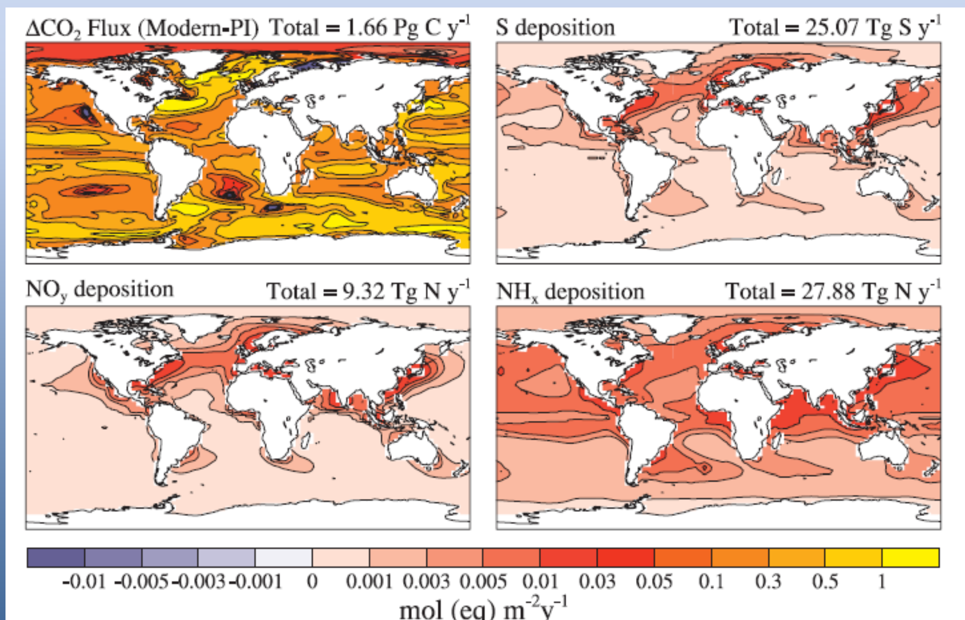
Hales et al. (in prep.)

Linkages with other coastal issues & processes

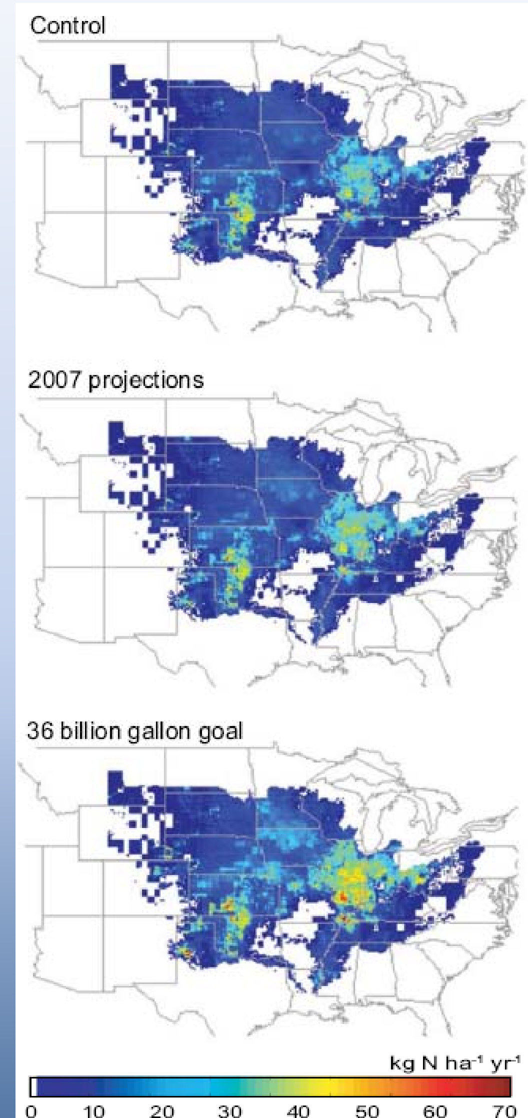
Hypoxia



Acidification

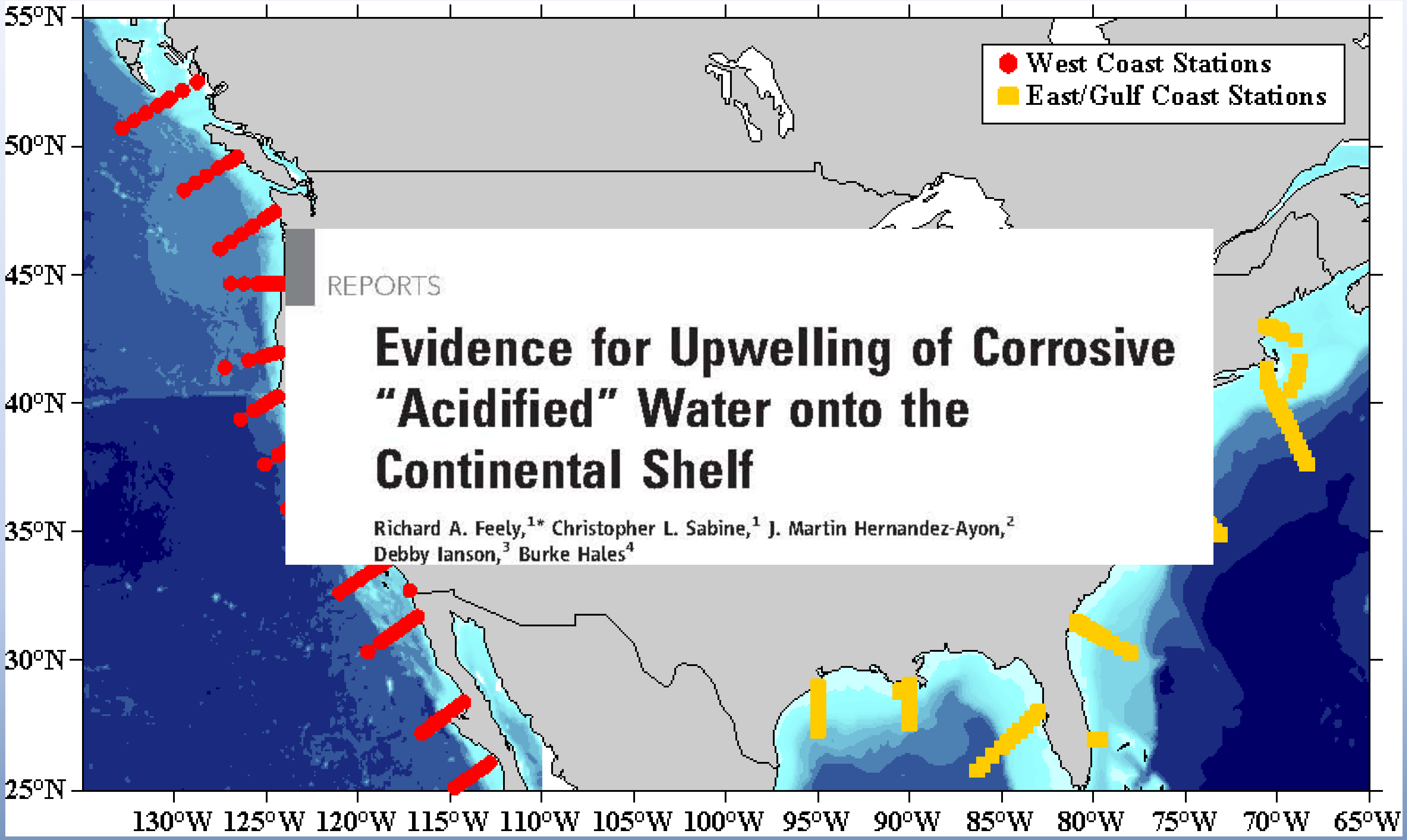


Land-use



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

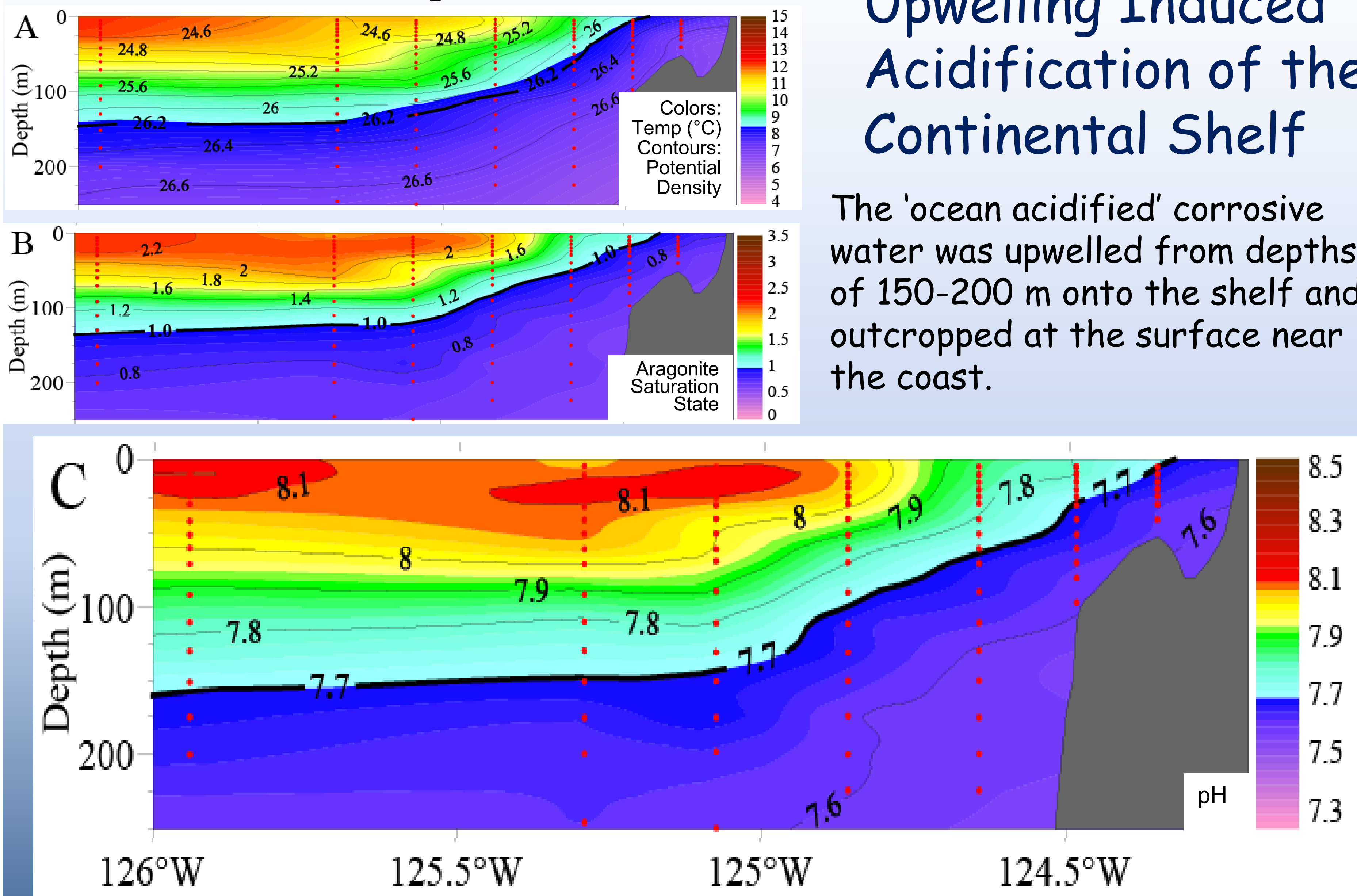
Coastal Cruises 2007:
West Coast (May-June) & Gulf/East Coast (July-August)



- 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, ...

Upwelling Induced Acidification of the Continental Shelf

Line 5 (Pt. St. George, California)

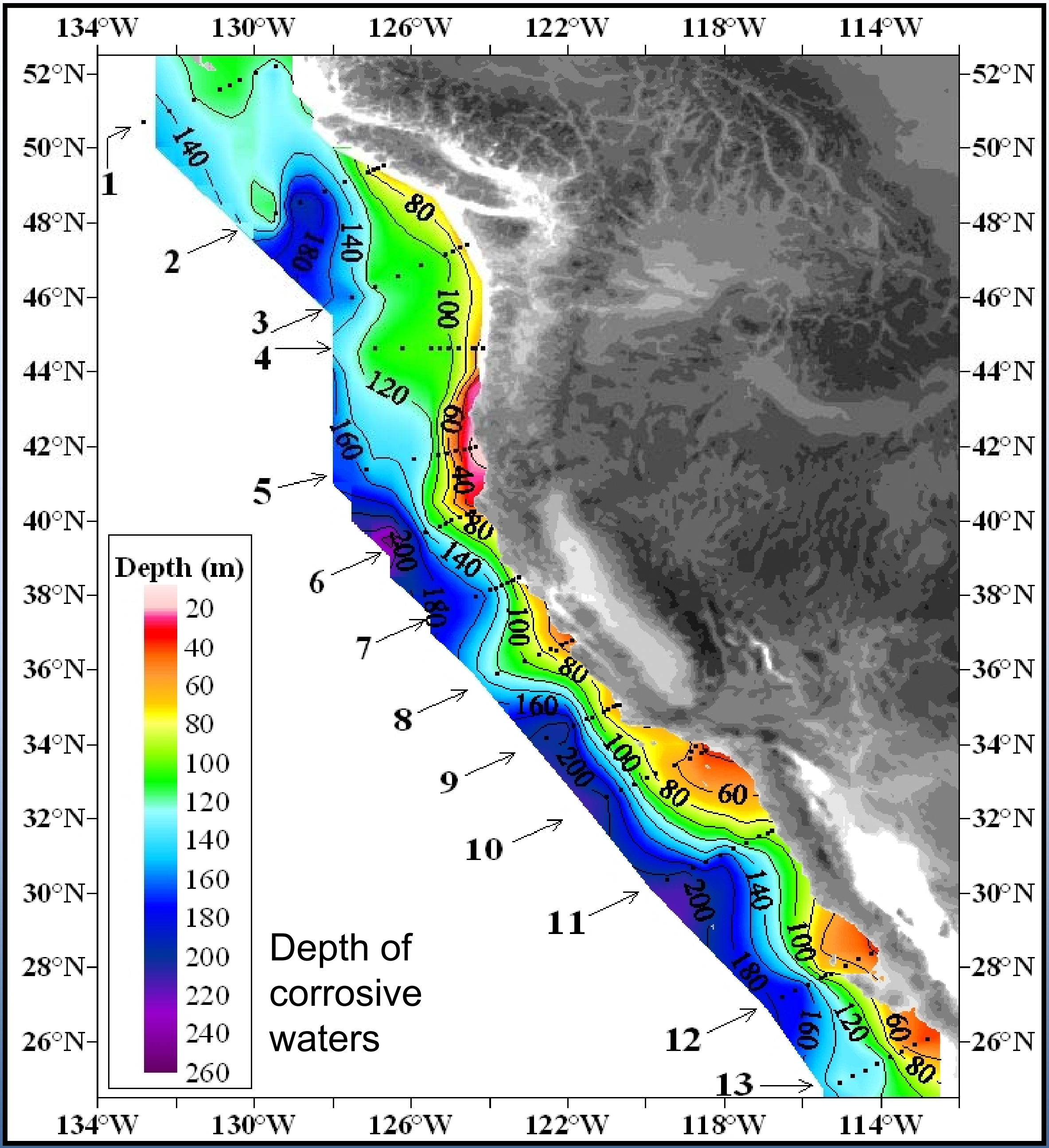


The ‘ocean acidified’ corrosive water was upwelled from depths of 150-200 m onto the shelf and outcropped at the surface near the coast.

Red dots represent sample locations.

Feely et al. (2008)

Ocean Acidification of the North American Continental Shelf



Feely et al. (2008)

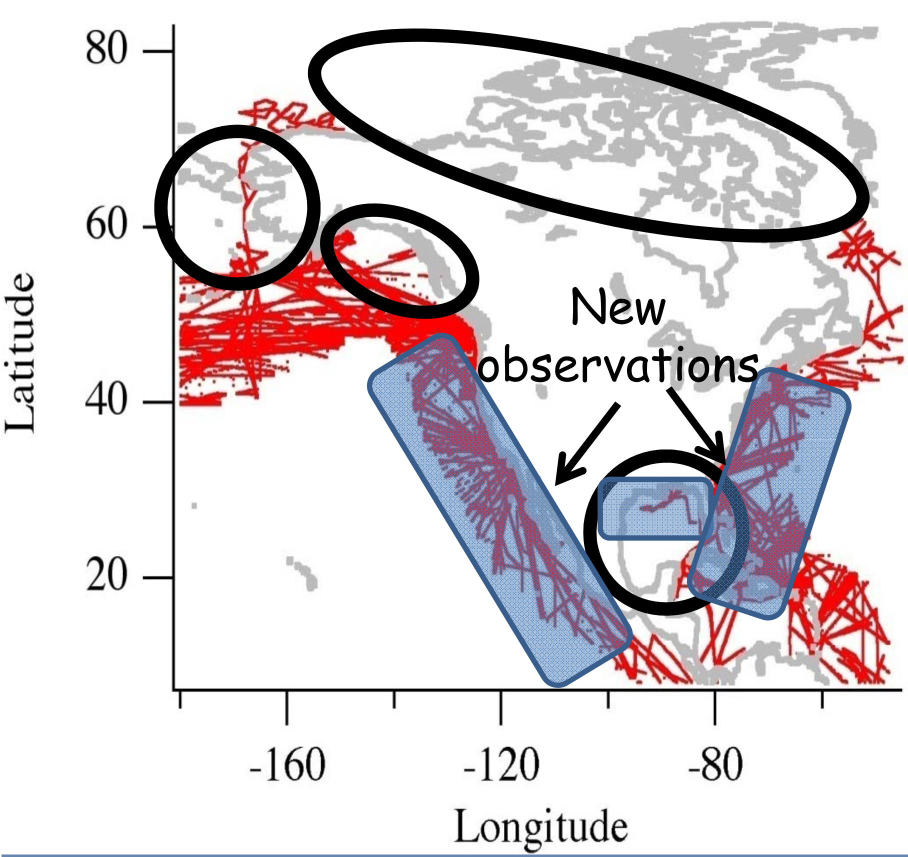
NACP Coastal Survey:
11 May - 14 June 2007

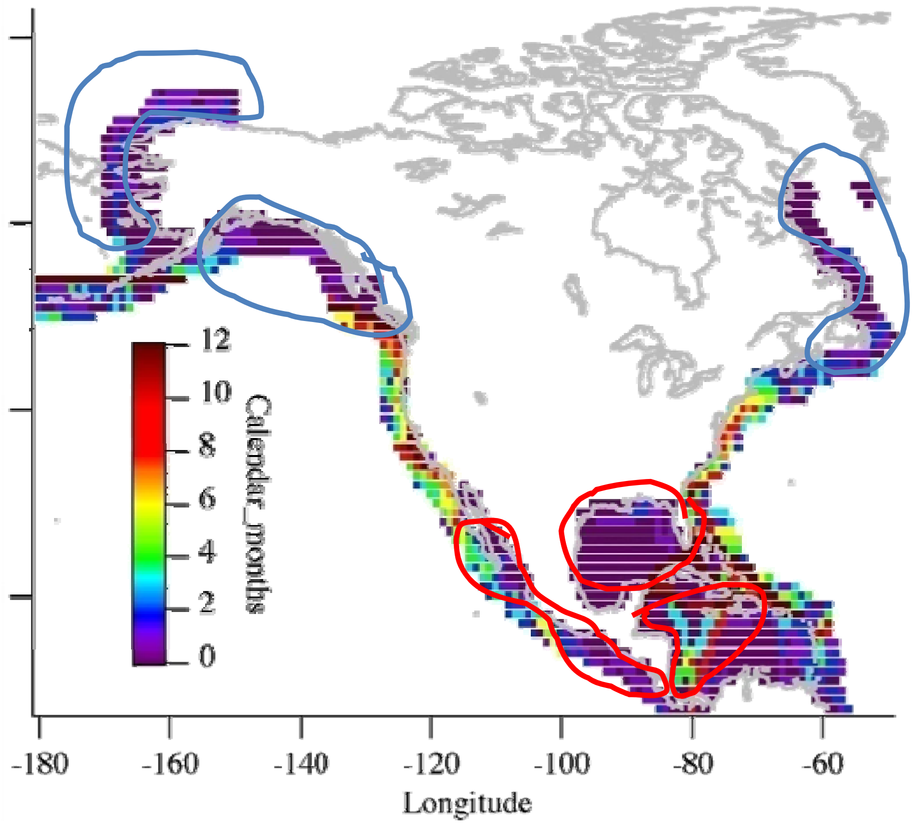
Distribution of the depths of the corrosive water (aragonite saturation < 1.0; pH < 7.75) on the continental shelf of western North America from Queen Charlotte Sound, Canada to San Gregorio Baja California Sur, Mexico.

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

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.