Recent (and Future) Advances in Carbon Cycle Synthesis along the North American Pacific Coast

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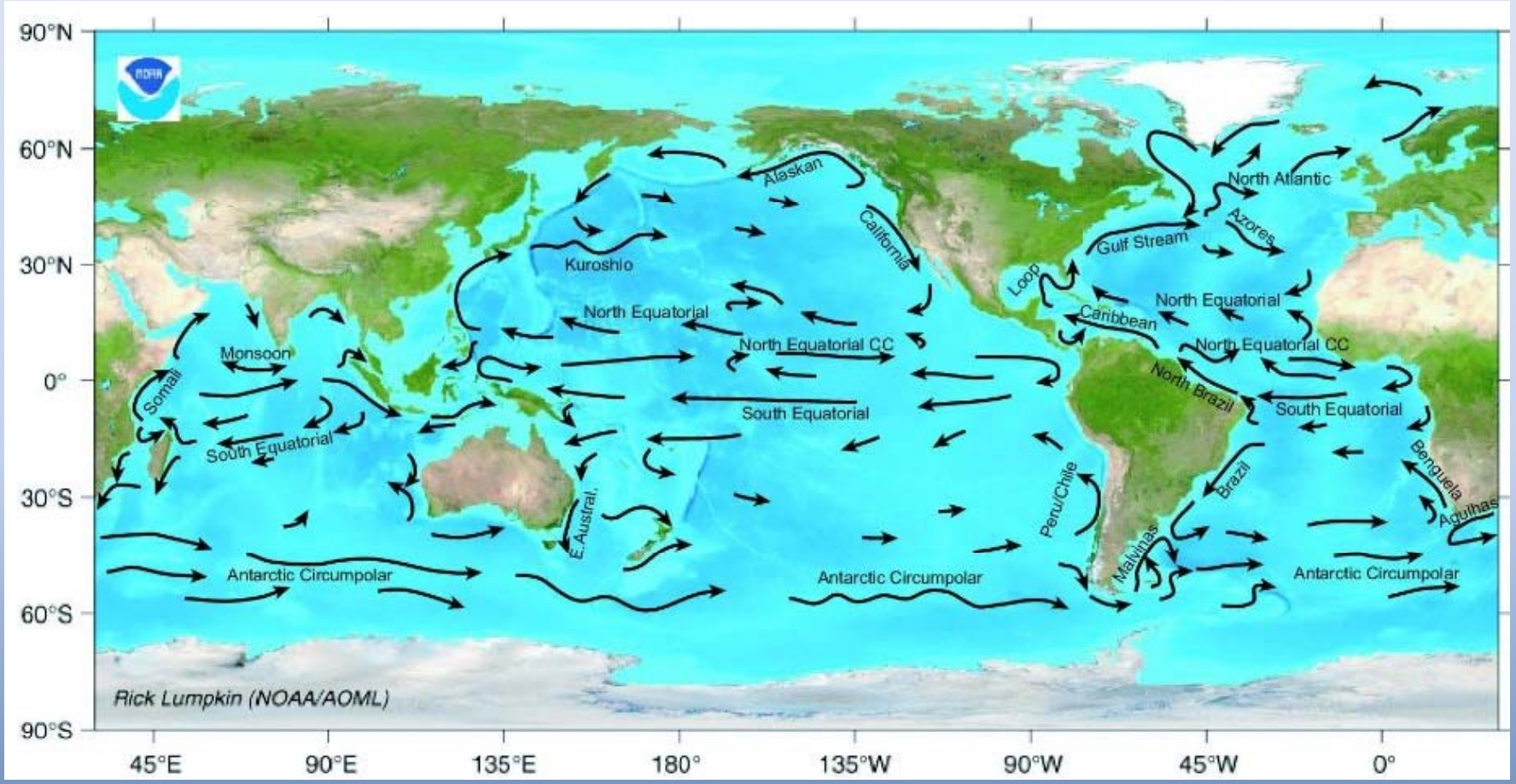
Why study CO_2 in coastal oceans?

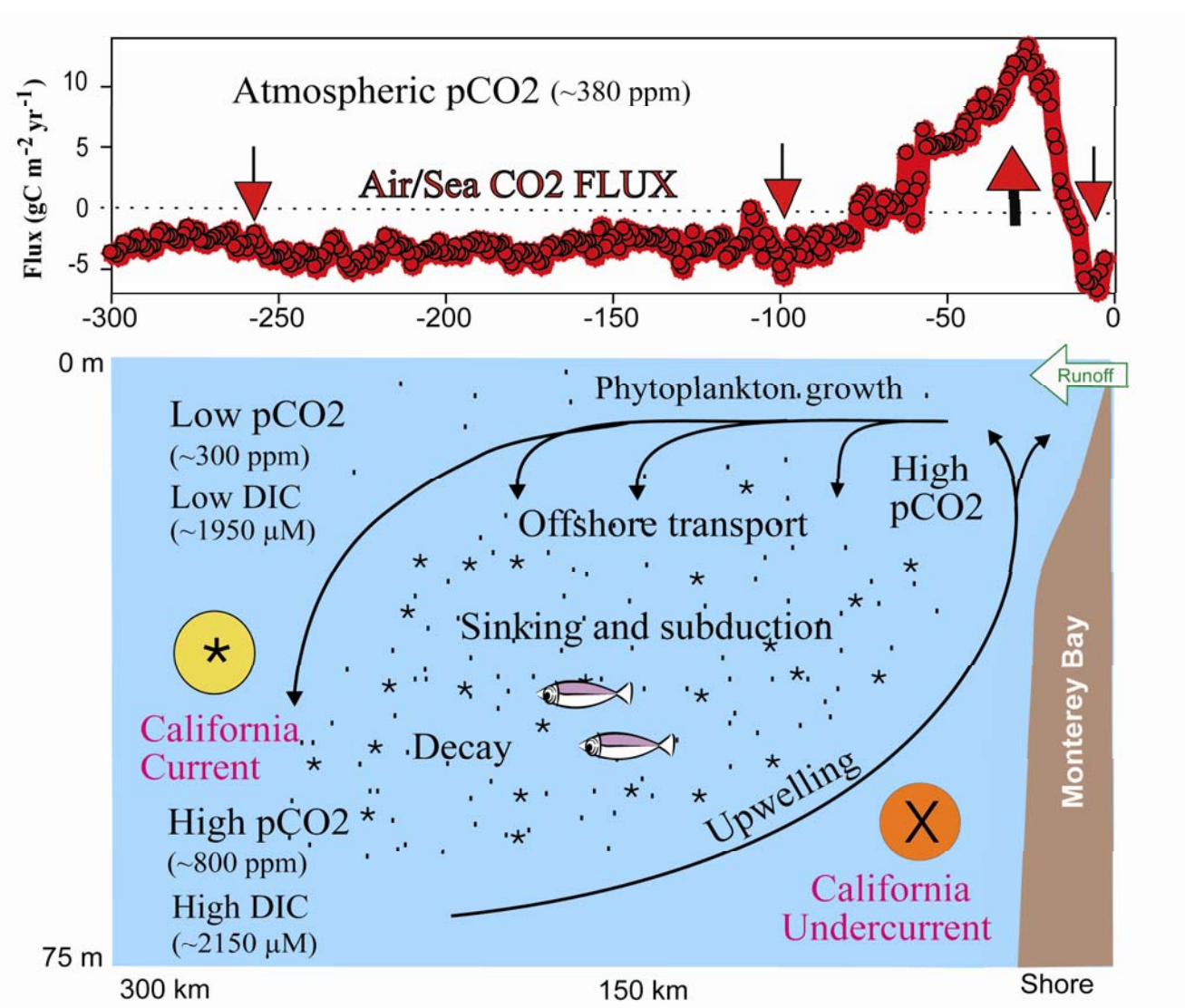
- Coastal carbon cycling reflects strong linkages between land, open ocean, and atmosphere.
- Net air-sea exchange is the small difference between much larger fluxes.
- Little is known about the magnitude, uncertainty, and natural variability of coastal carbon cycling.
- Potential responses/feedbacks to climate change.

What's different about CO_2 on the Pacific Coast?



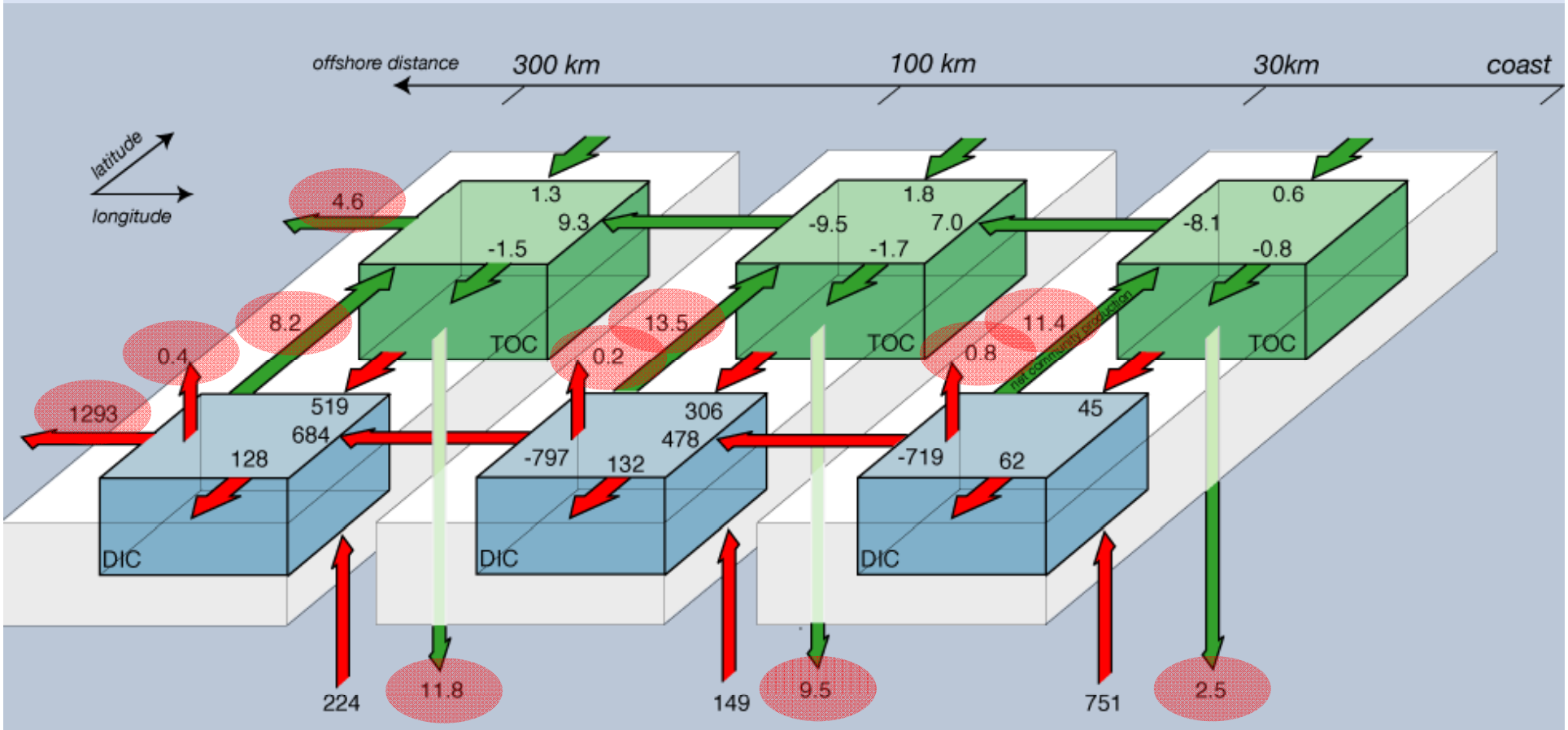
- Eastern Boundary Currents—high nutrient and CO_2 supply from upwelling→high biological productivity
- Large dynamic range of pCO_2 observed (~150–1050 µatm)

California Current: CO_2 flux from 25-year climatology



Chavez et al. (2007)

Carbon budget for Central California upwelling system



fluxes are in kmol C s^{-1}

1 kmol s^{-1} = 0.38 Tg C yr^{-1}

ROMS 15+5km resolution

Courtesy of Kasper Plattner & Niki Gruber

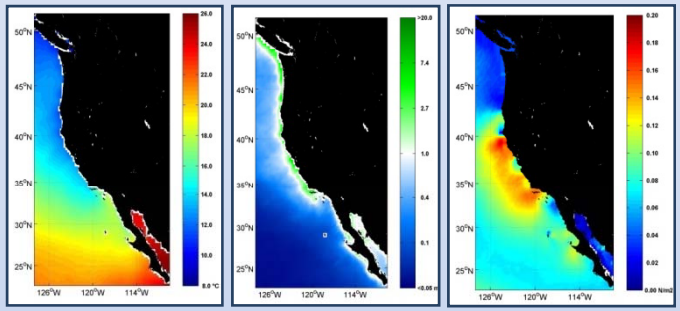
Coastal net air-sea CO_2 exchange

Source	Annual global flux (Tg C)	Upwelling systems (Tg C)
Borges et al. (2005)	– 370	+ 23
Cai et al. (2006)	– 221	+ 12
Chen & Borges (2009)	– 330	– 15

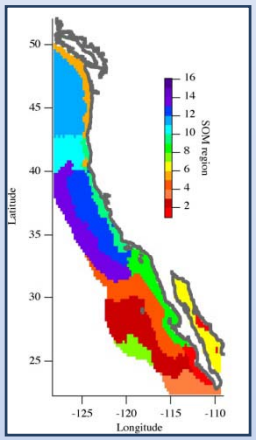
~10–20% of open ocean air-sea exchange flux (–1900 Tg C y^{-1})

Takahashi et al. (2009)

Extrapolation & Synthesis of CO_2 Observations



Remote sensing climatologies



SOM defines regions

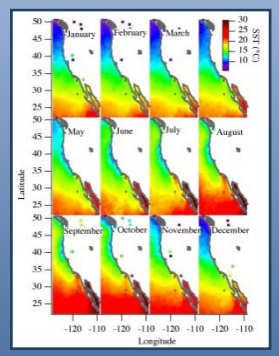
Field CO_2 data assigned to regions

Non-linear model

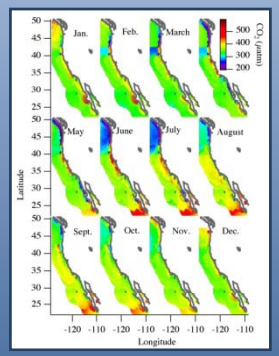
$$pCO_2 = f\left(Alk, TCO_2, T, S\right)$$

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

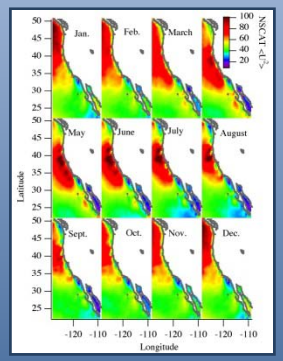
$$Alk \approx Alk_0 - 0.15\Delta TCO_2$$



Remote sensing data

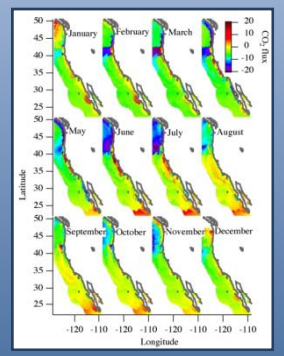


pCO_2 map



Wind speed

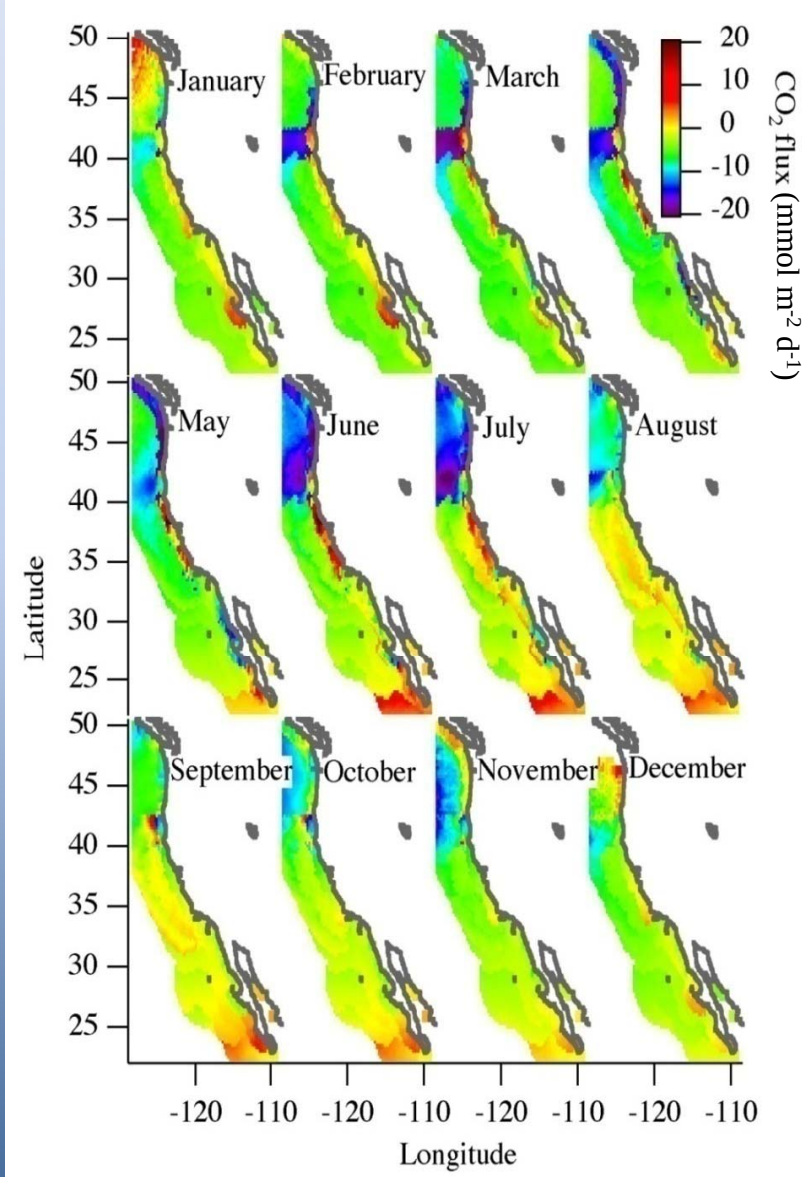
k = f (U_{10},SST)

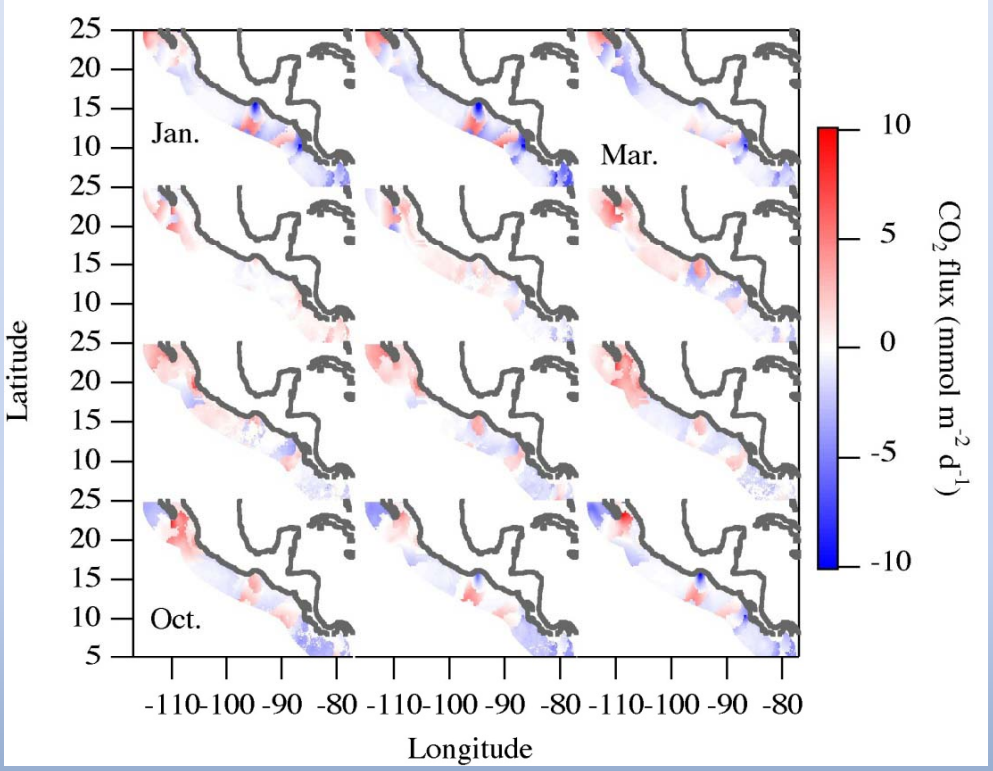


CO_2 flux maps

Flux = k s ΔfCO_2

SOM results based on annual climatologies





SOCCR: +9.5 Tg C y^{-1}

vs.

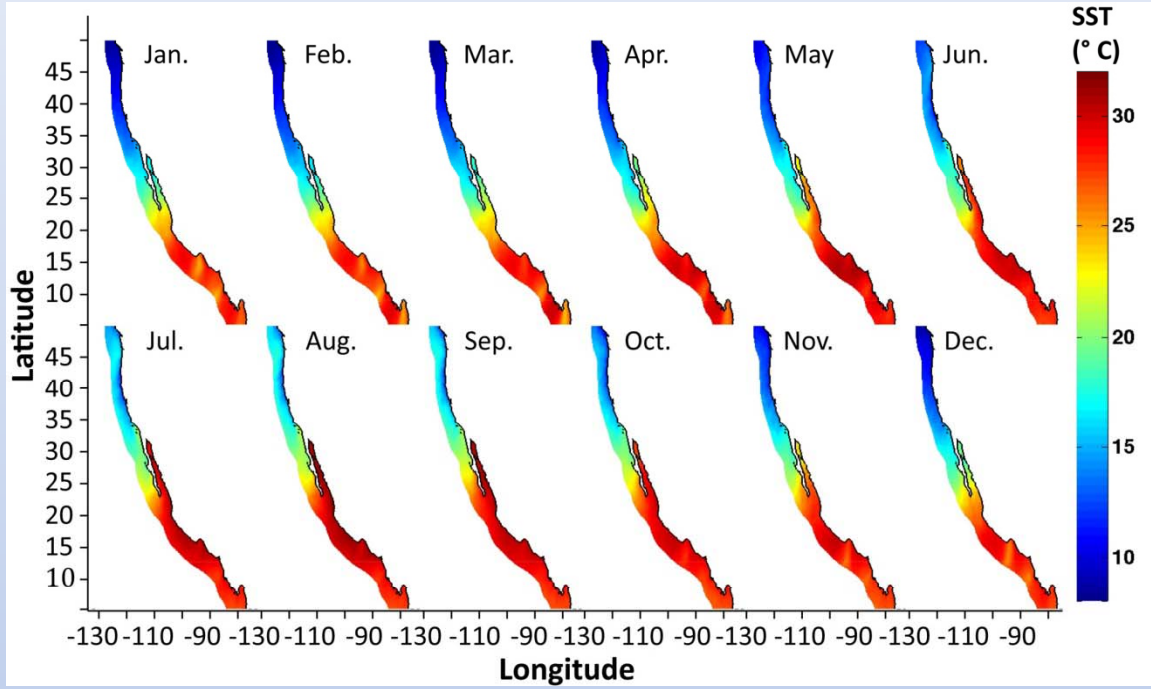
SOM: –18.5 Tg C y^{-1}

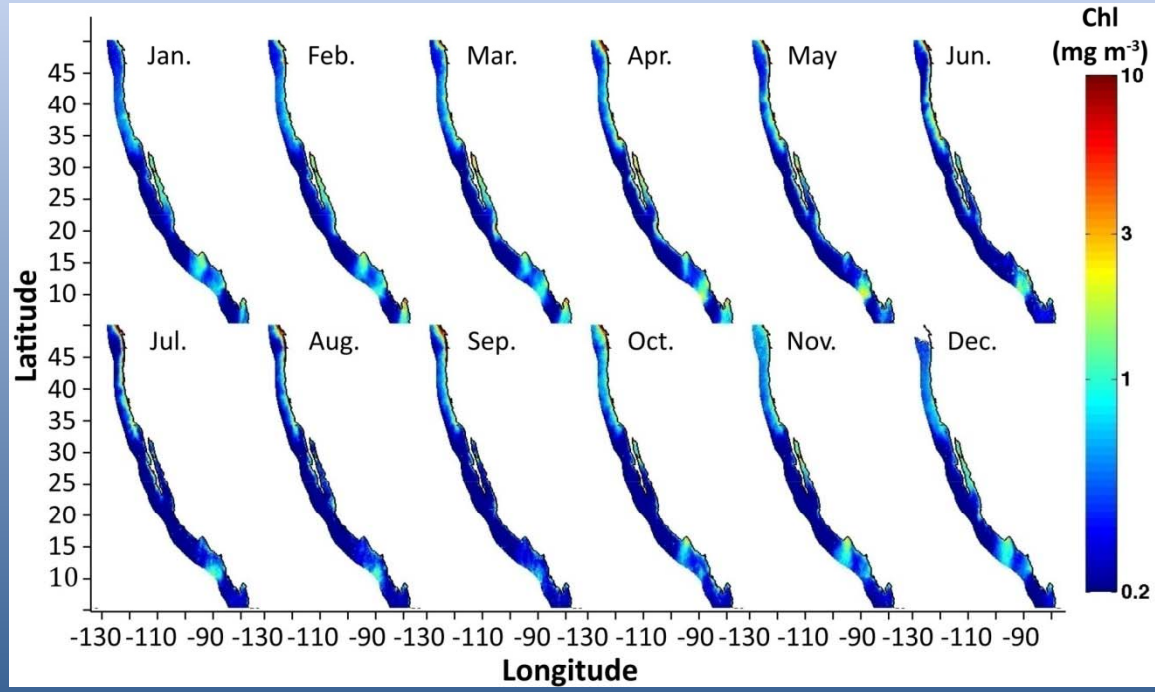
Hales et al. (in prep.)

Seasonal evolution of biogeochemical regions

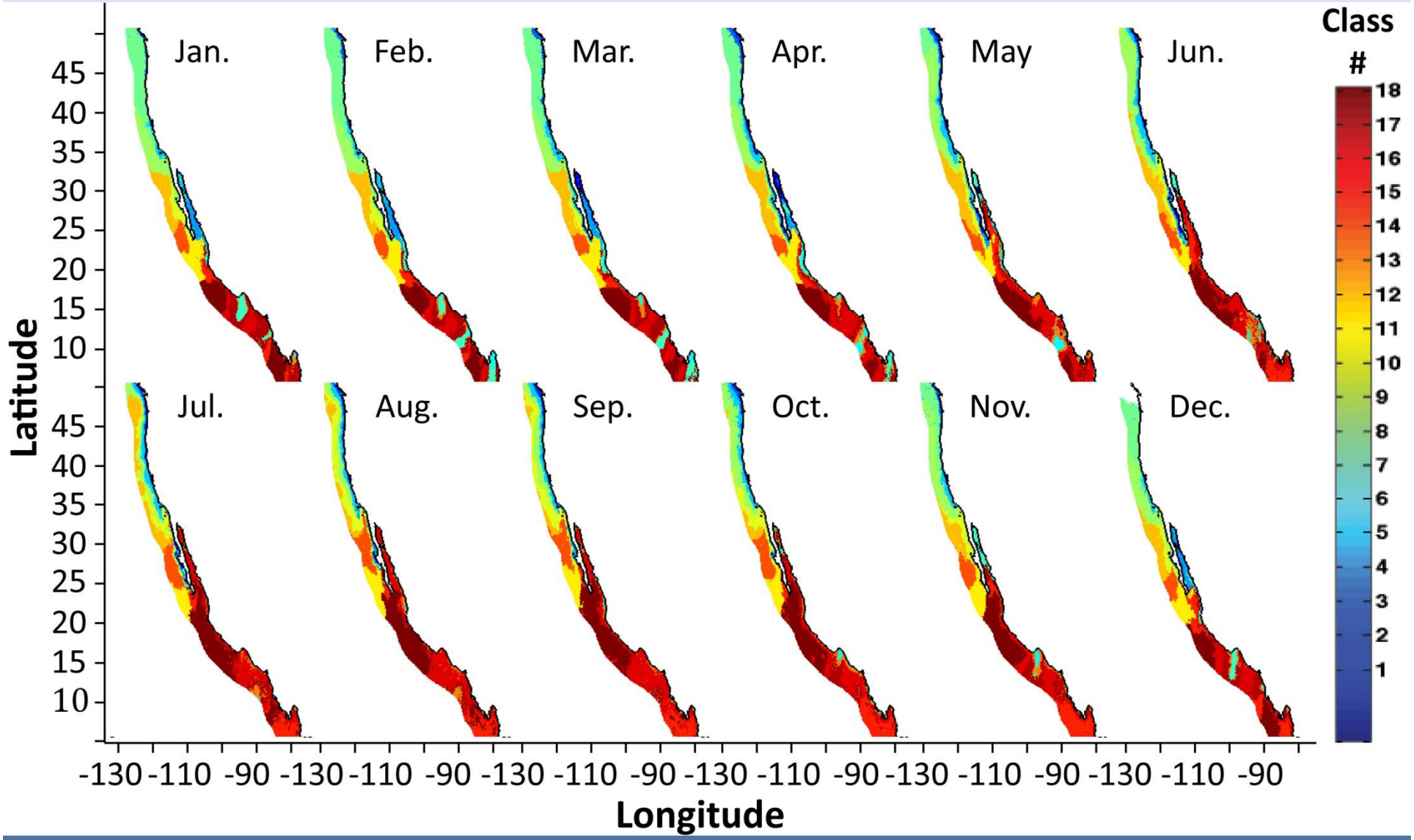
- Monthly inputs and SOMs
- SST shows strong variation with latitude
- Chlorophyll is high nearshore and in wind gap hot spots

Poster by Alin, Vander Woude, Hales, and Strutton



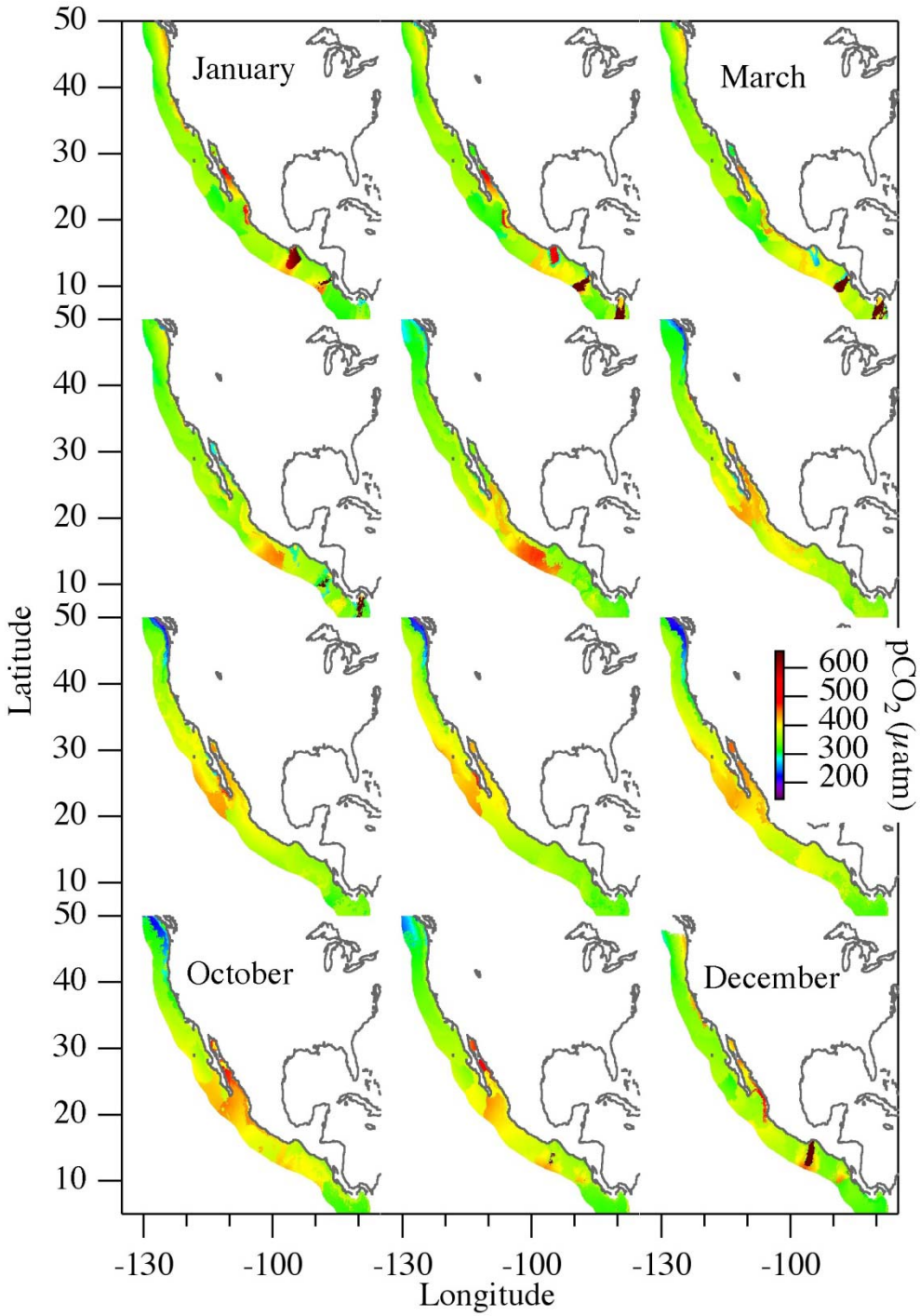


Monthly SOMs of biogeochemical regions



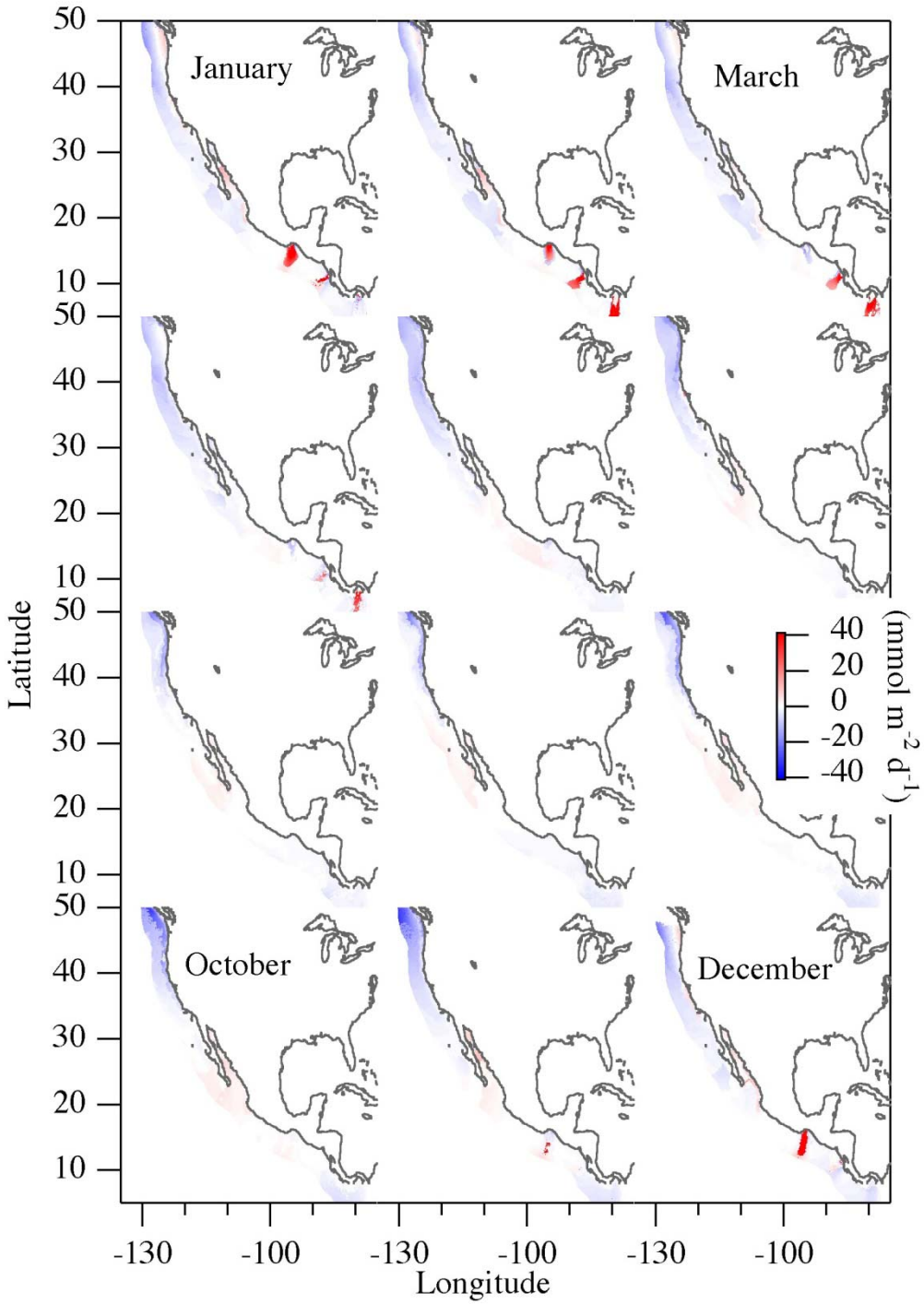
Monthly pCO_2 maps

- Most of Pacific Coast appears to be neutral to slightly undersaturated.
- Strongly supersaturated pCO_2 in Central American wind gap hot spots.
- Strongly undersaturated along northern coast during upwelling season.

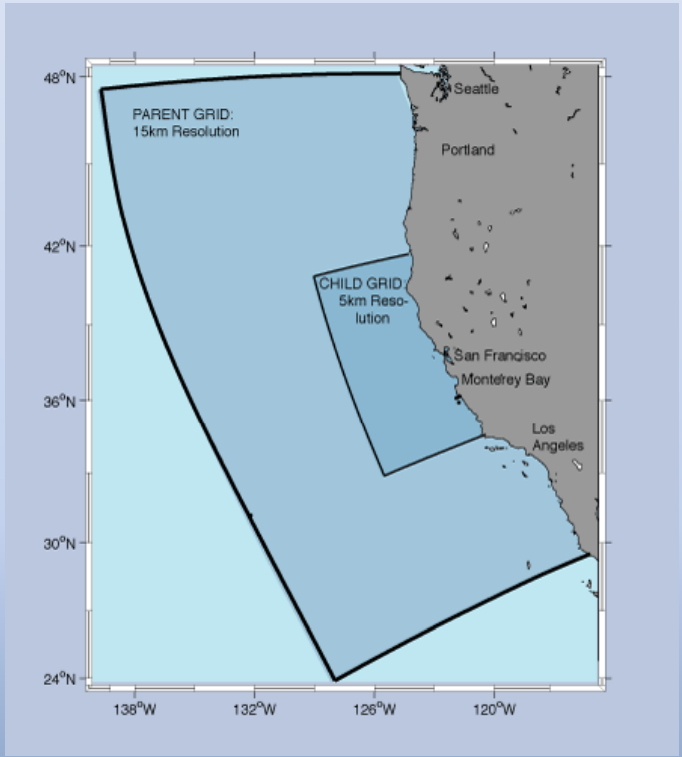


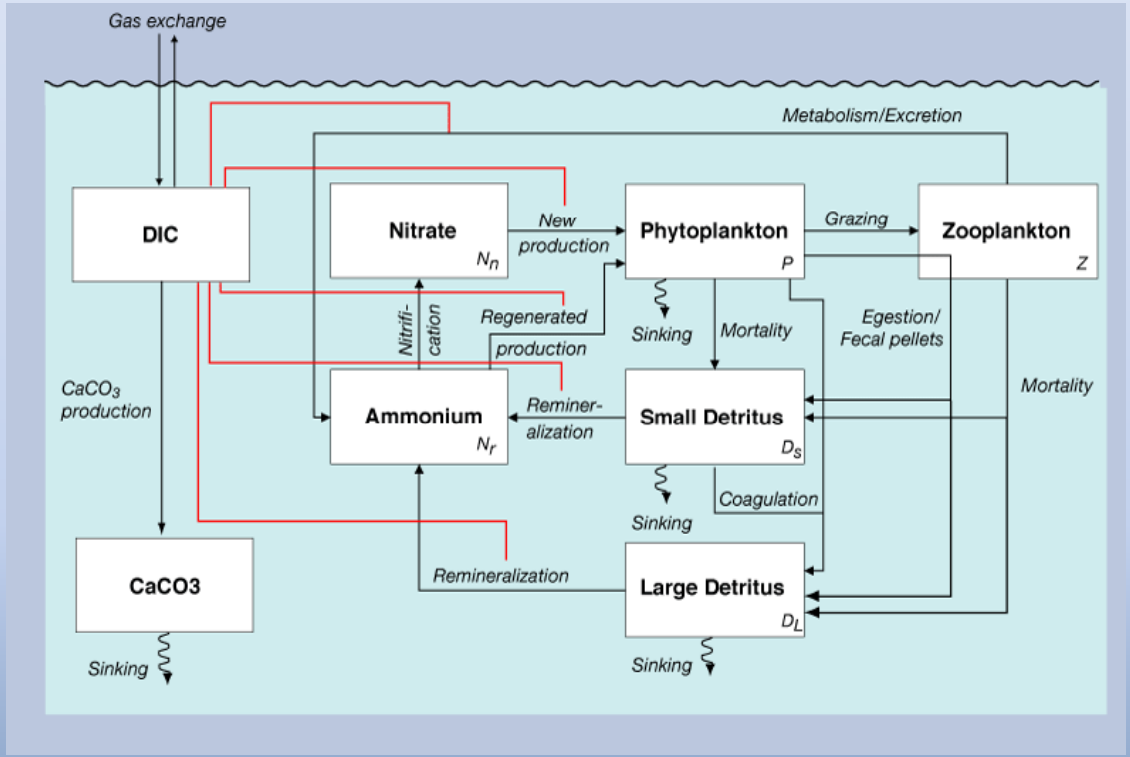
Monthly CO_2 flux maps

- Most of Pacific Coast is net neutral or a sink during most of the year.
- Wind gap hot spots stand out as strong sources.
- Net sink (–30 Tg C yr^{-1}).
- Much greater sampling needed in hot spot areas!



U.S. West Coast configuration of ROMS



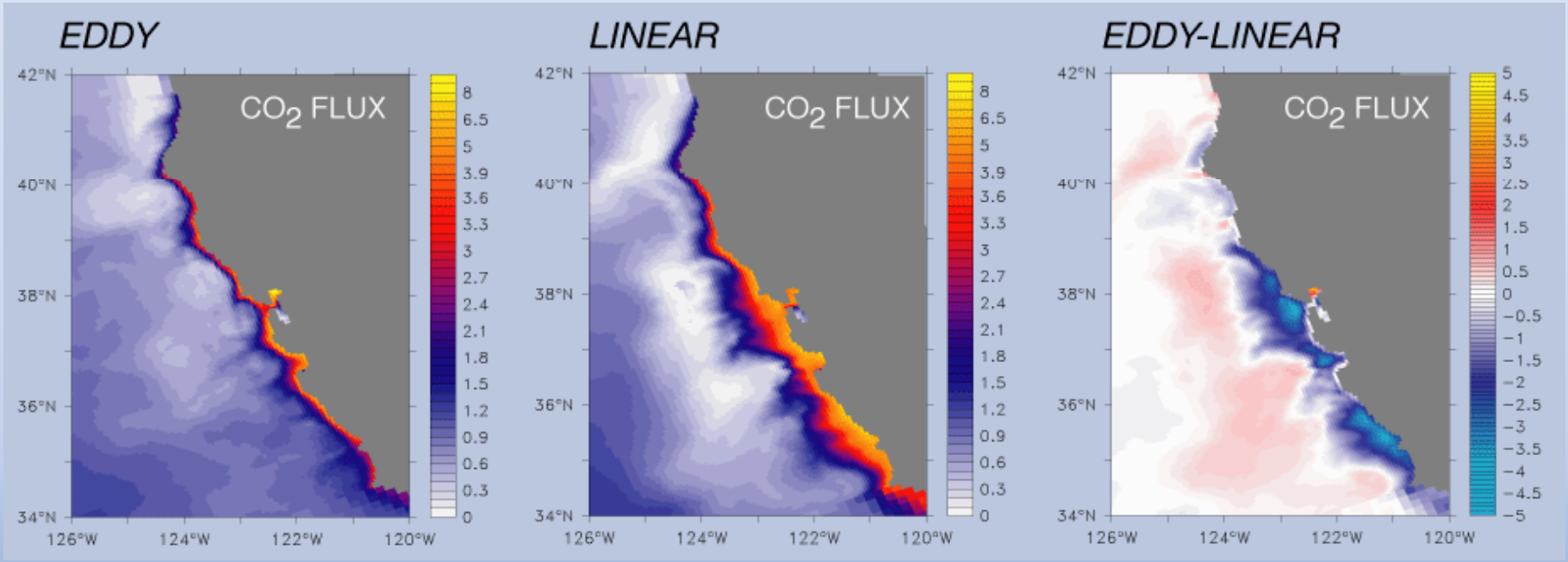


- Horizontal resolution: 15+5 km
- Vertical resolution: 20 levels
- Climatological forcing:
  - WOA01 for T,S;
  - COADS for winds

- NPZD model
- Nitrogen based (no iron limitation)
- Upwelling system focused
- Fixed stoichiometric ratios

Courtesy of Plattner & Gruber

Effect of mesoscale dynamics on CO_2 flux



- Mesoscale eddies tend to suppress coastal upwelling and reduce CO_2 outgassing near-coast. Offshore, the CO_2 uptake is increased.

- **Their models suggest the Central California upwelling system is a weak net source.**

Courtesy of Kasper Plattner & Niki Gruber

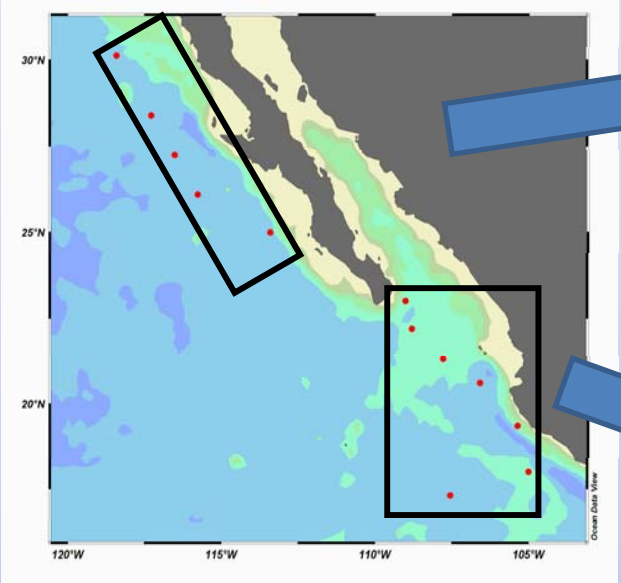
Estimates of West Coast CO_2 fluxes

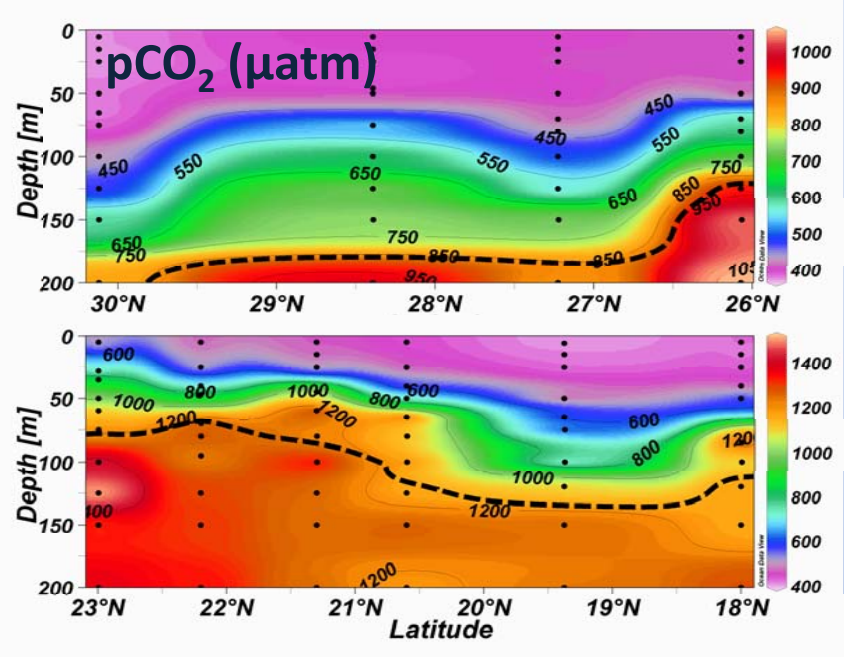
Method	Latitude N	Annual flux (Tg C)	Source
Climatology	~8–55°	– 13 ± 26	Chavez et al. (2007)
SOM (U.S. West Coast–Baja)	22–50°	– 17	Hales et al. (2007)
SOM (Mexico–Panama)	5–25°	-0.5	Hales et al. (2008)
ROMS (U.S. West Coast)	24–48°	weak net source	Plattner et al. (2008)
SOM (U.S.–Central America)	5–50°	– 30	***See poster session***

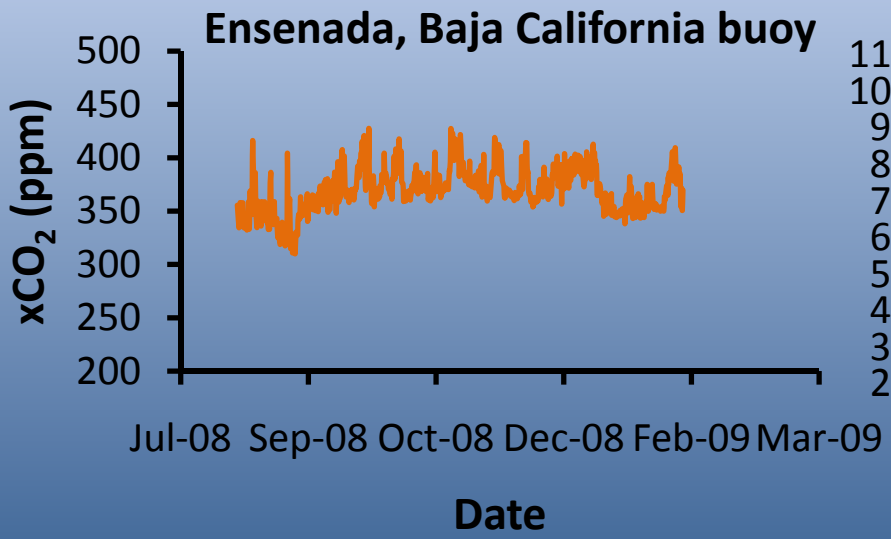
Synthesis: challenges and opportunities

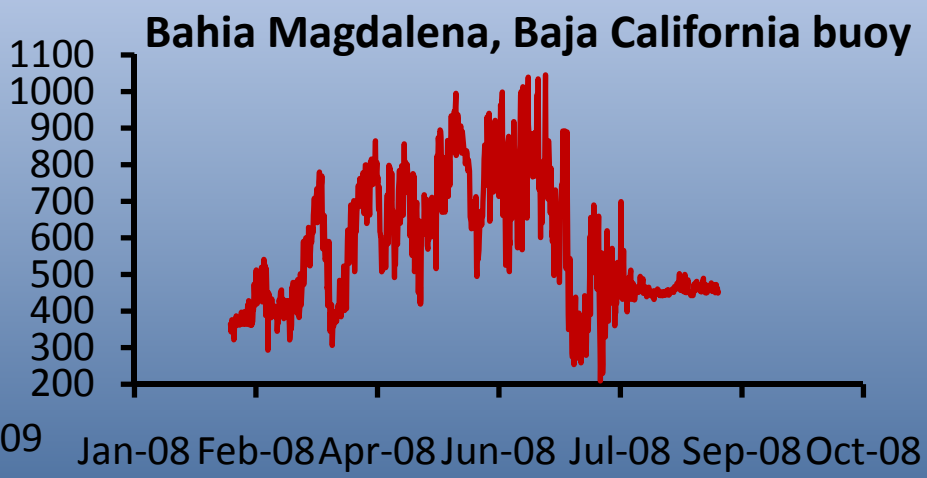
1. **Significant observational gaps remain.**
2. **Consistency in area/units of outputs presents a challenge to true model-data comparisons.**
3. **Define questions and products.**
4. **Take advantage of synergistic observational efforts.**

New CO_2 observations in southern waters



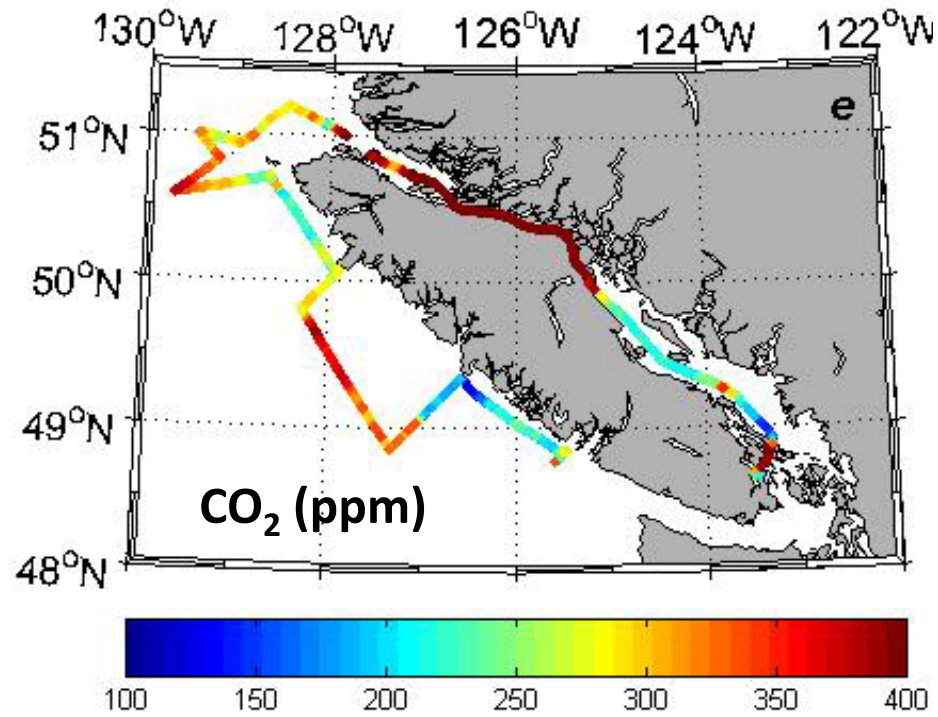


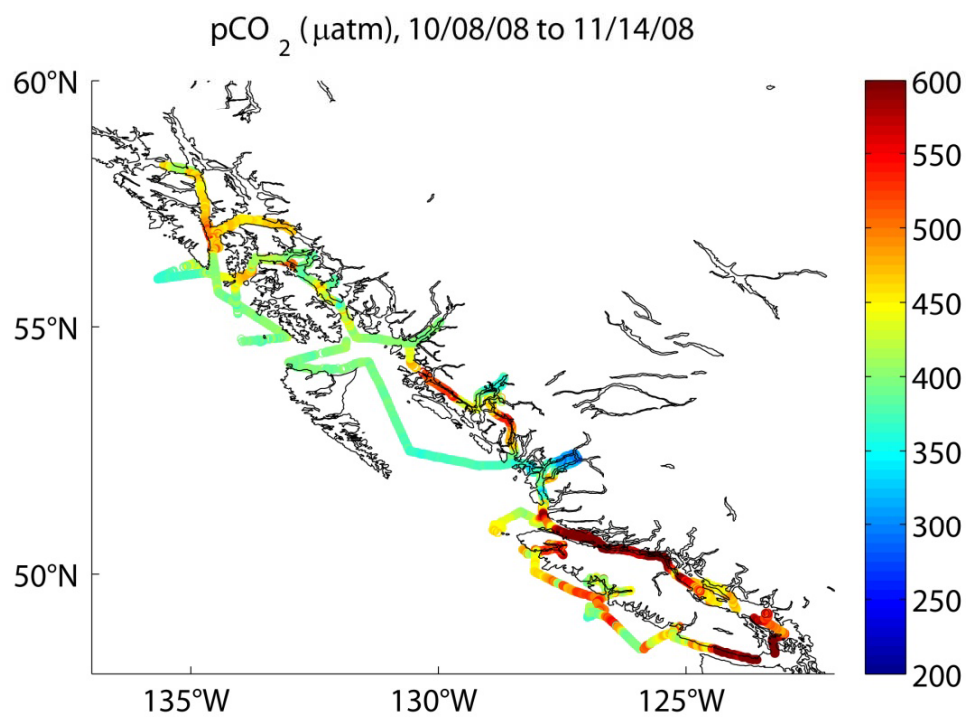




See poster of Martin Hernandez

New CO_2 observations in northern waters

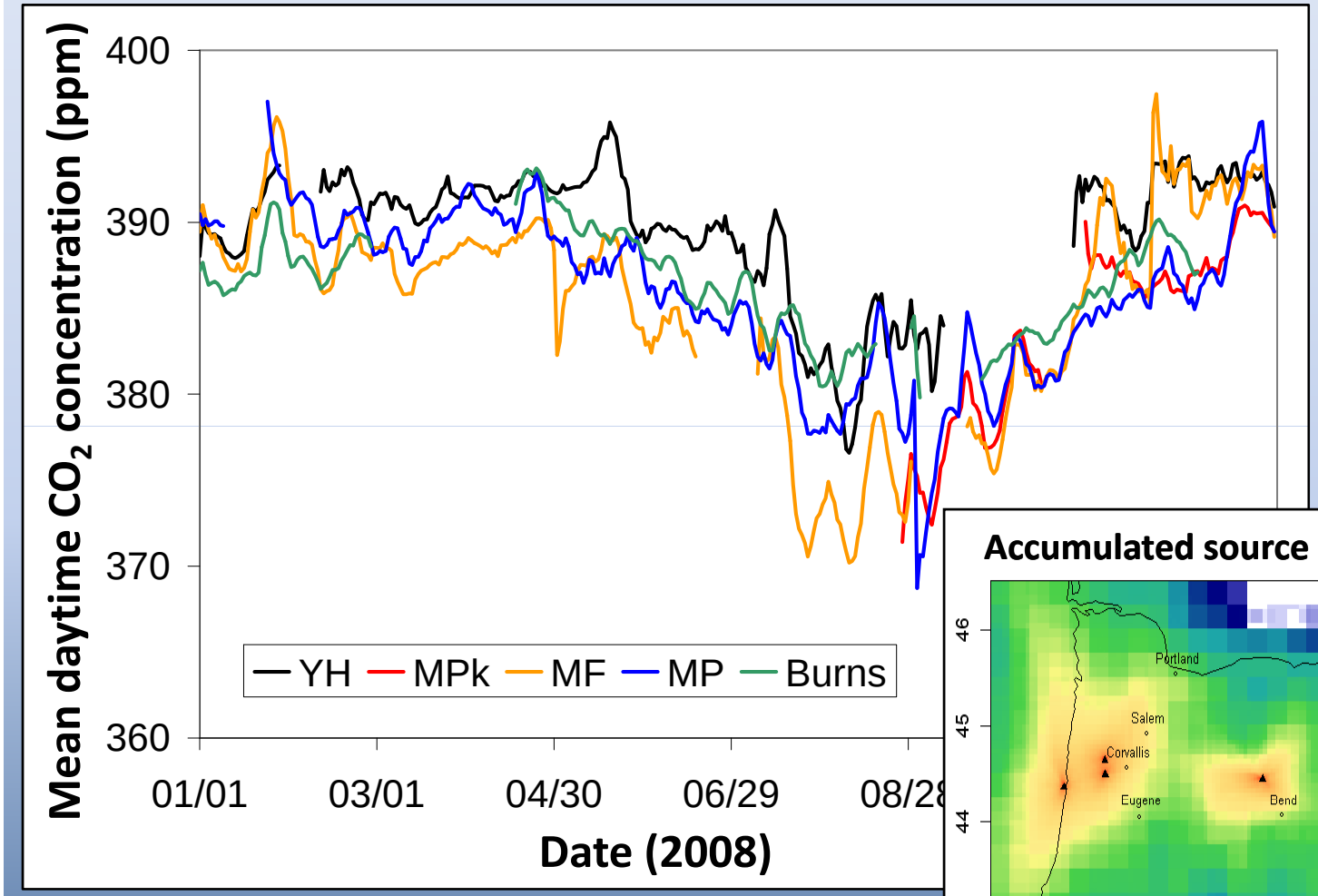


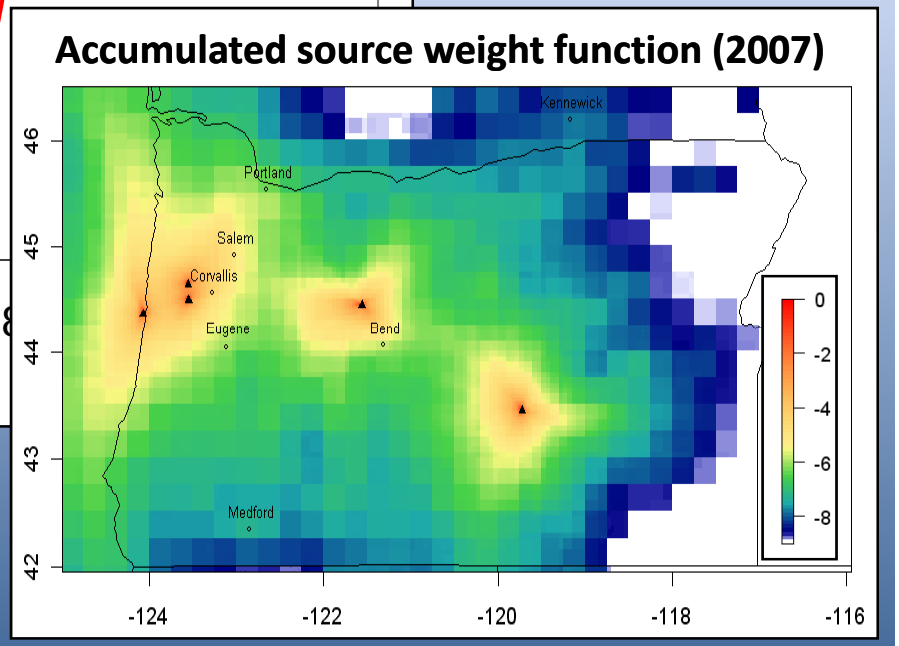


Courtesy of Philippe Tortell

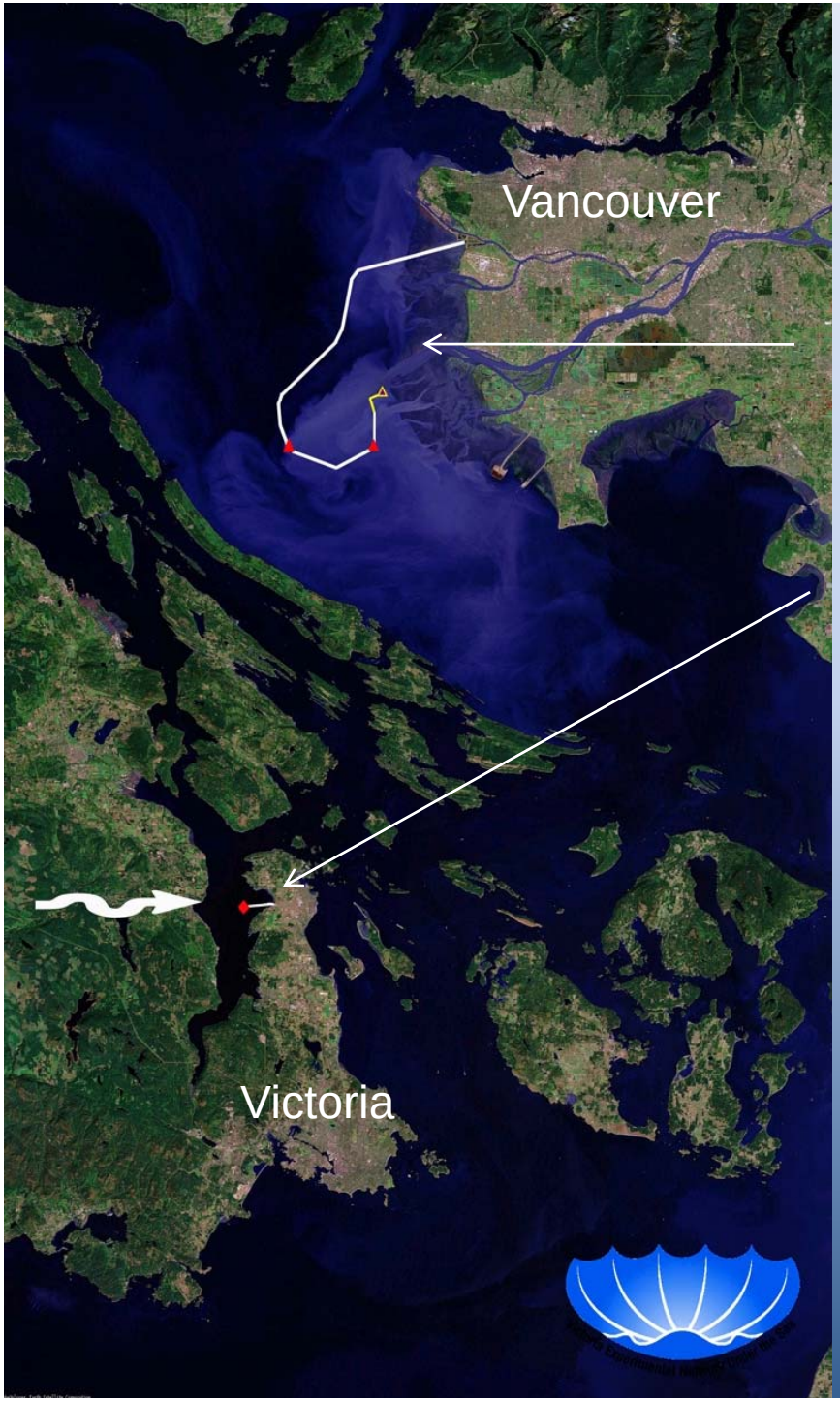
See Wiley Evans poster

Influence of upwelling on terrestrial air masses



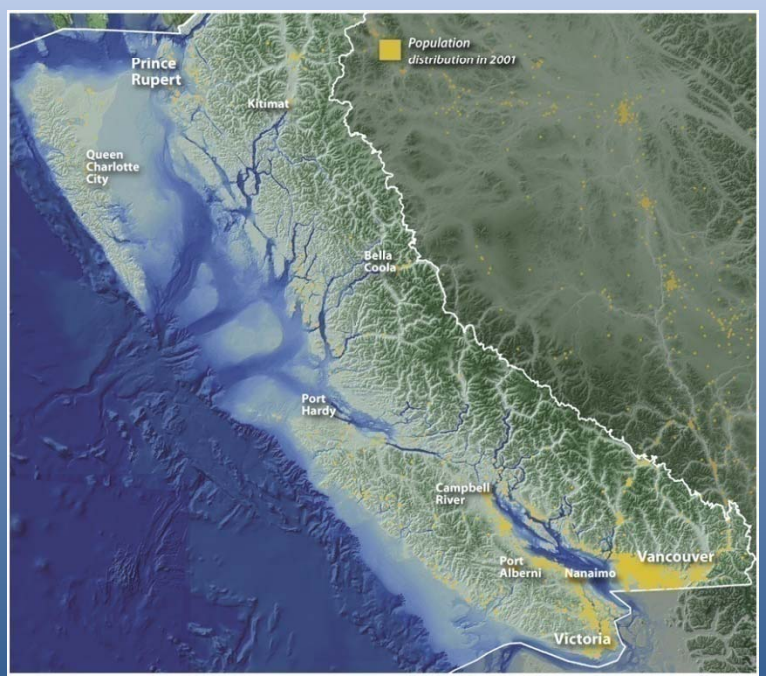


Courtesy of Mathias Goeckede and Bev Law



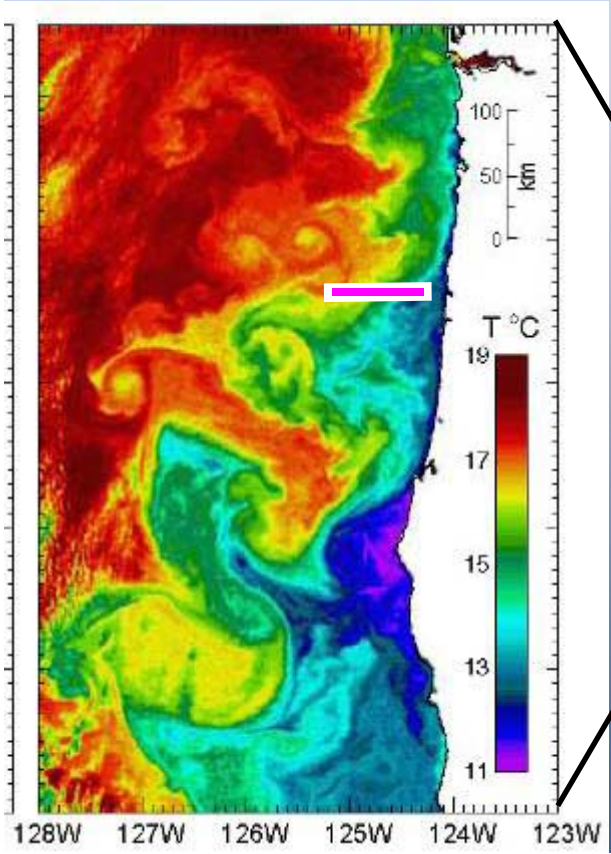
VENUS is a cabled ocean observatory

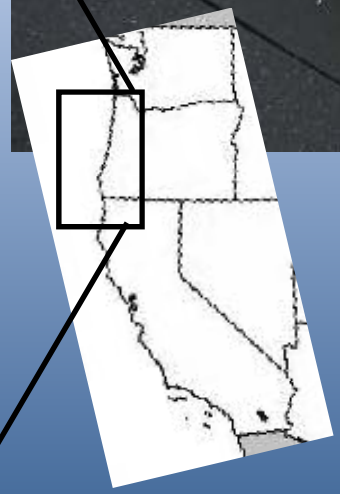
- Strait of Georgia: influenced by tides, wind, and river forcing.
  At 40m, 170m and 300m
- Saanich Inlet: a restricted low oxygen basin. At 100 m depth
- A coastal sea with great human influence and fed from offshore upwelling



Autonomous Underwater Vehicle Gliders

cross-margin transect twice per week since April 2006

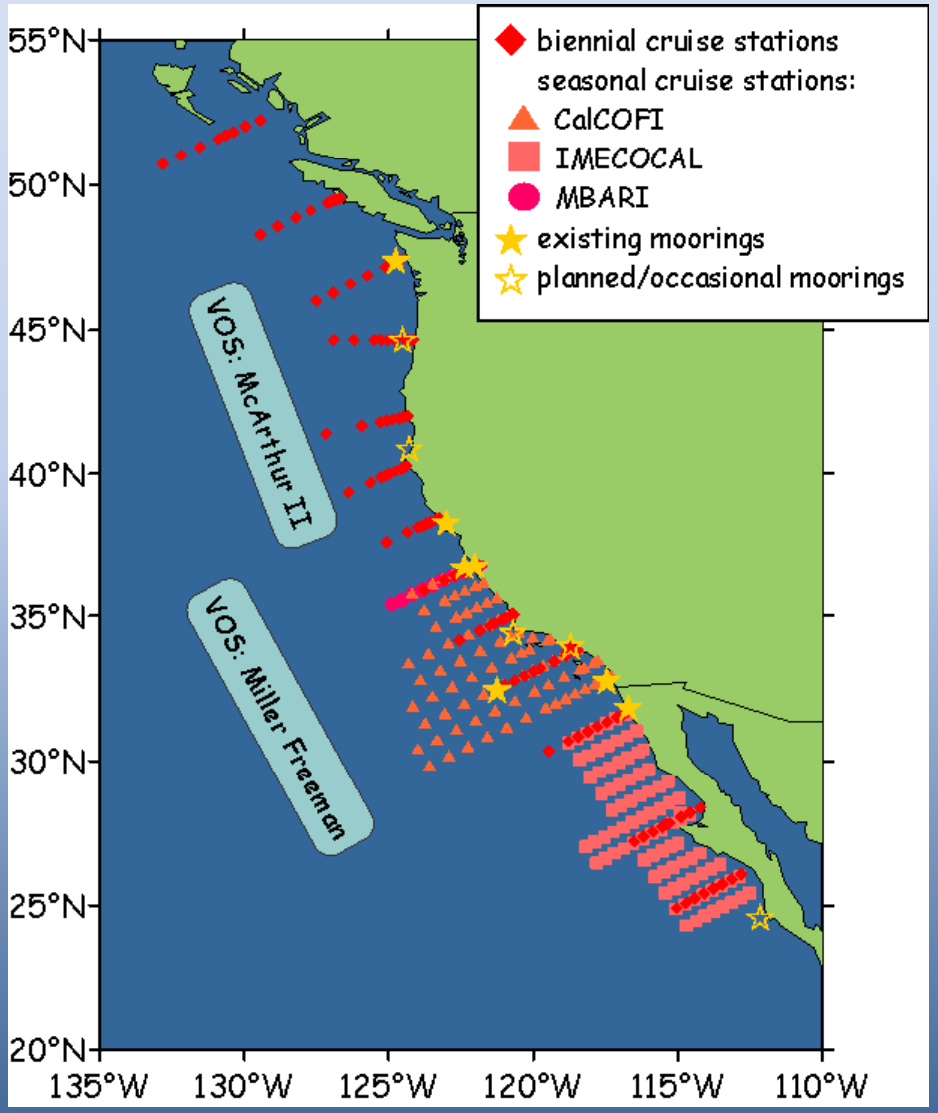


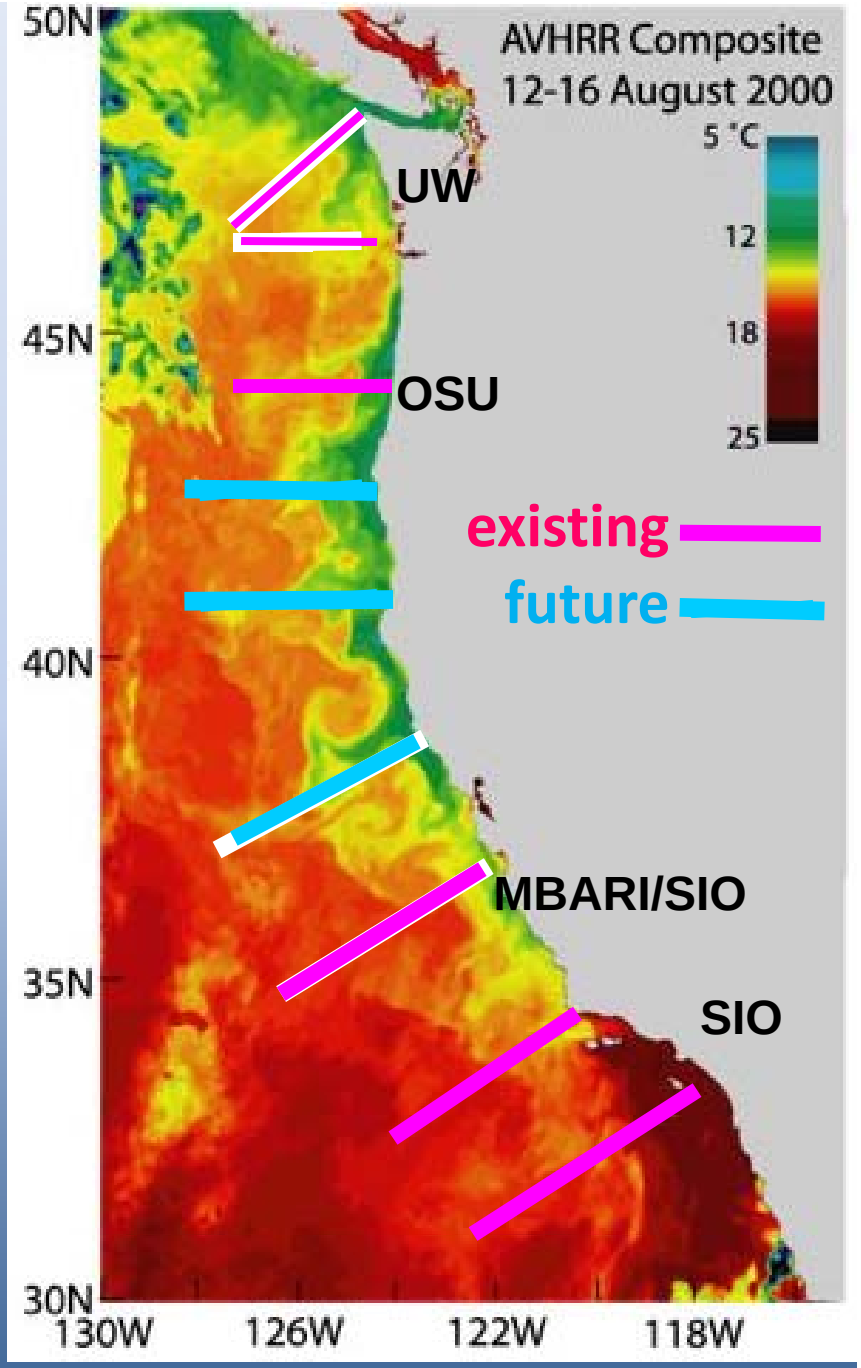


CTD
dissolved oxygen
chlorophyll fluorescence
CDOM fluorescence
light backscatter

Courtesy of Barth, Shearman, and Erofeev (OSU)

Existing & Future West Coast Carbon Network





Courtesy of J. Barth (OSU)