Diagnosing carbon dynamics in diverse ocean environments using in-situ optical and remotely-sensed data

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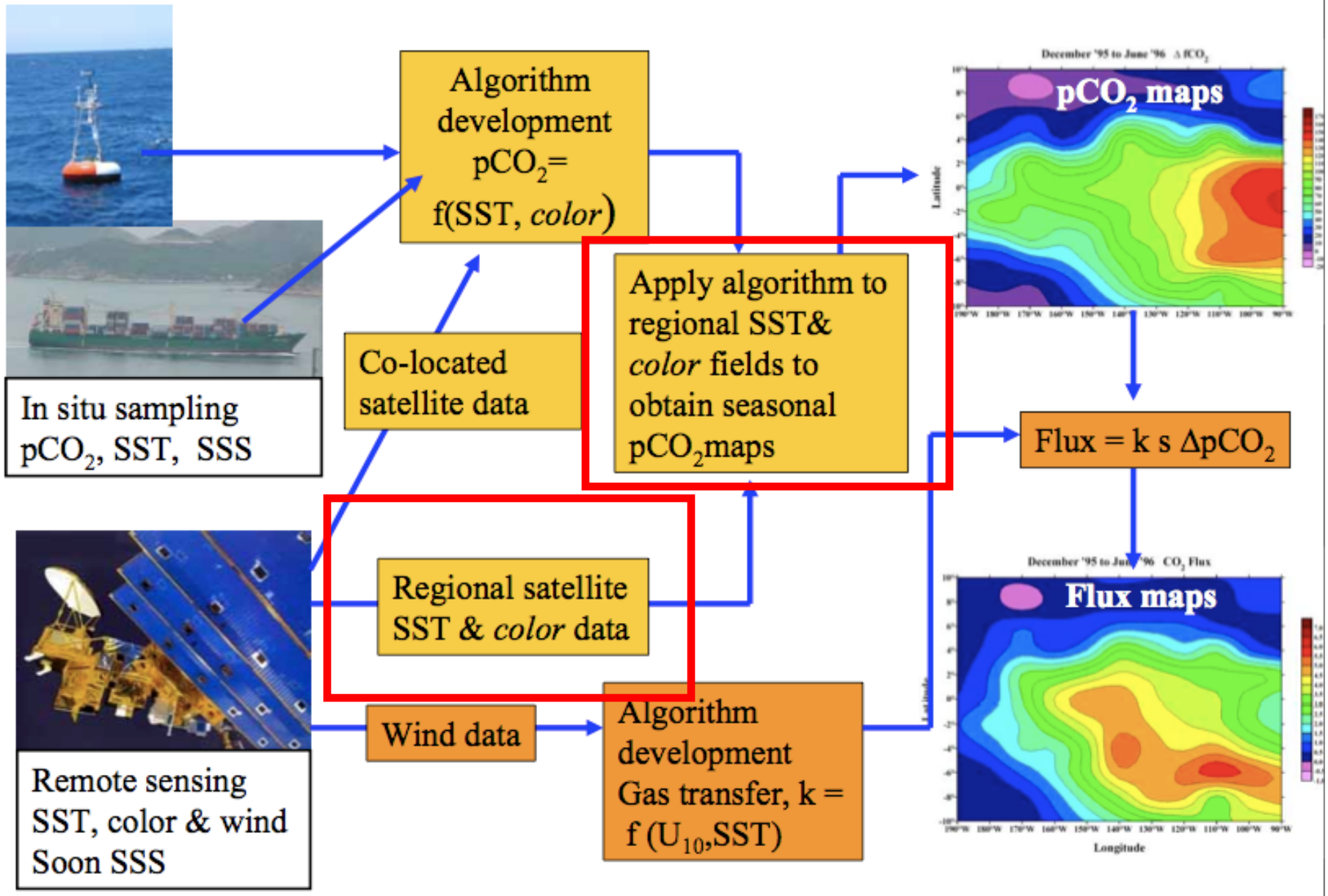
with help from D. Geldhill, B. Hales, S. Lohrenz, ….

Concept: Use Multiple Platforms to Produce Seasonal CO_2 Flux Maps



Outline

1. Exploiting CO2 solubility dynamics using SST

2. Empirical relationships between in-water partial pressure of carbon dioxide (pCO_2) and optical/remote sensing data

3. Efforts aimed at estimating DIC_{bio} at the global scale using satellite data

4. Lagrangian analysis of satellite Particulate Organic Carbon in the Gulf of Maine: Inferring spatial and temporal behavior of surface DIC_{bio}

$DIC_{bio}(t)$ - represents the biologically modulated pool of DIC

$$\mathbf{DIC_{bio}} \approx DIC - (DIC_{a\text{-}s} + DIC_{sol} + DIC_{adv} + DIC_{mix}) \approx NCP$$

Sea–air flux of CO_2 in the Caribbean Sea estimated using in situ and remote sensing data

Are Olsen[a,b,*], Joaquin A. Triñanes[c], Rik Wanninkhof[d]

For the regression with SST from the MODIS using collocation criteria of less than 1.4 km and less than 6 h:

$$fCO_2^{sw} = 9.511\ (\pm 0.06) \times SST_{MODIS} + 0.2643\ (\pm 0.04) \times lat - 0.3923\ (\pm 0.02) \times lon + 70.98\ (\pm 2)$$
$$n = 7020,\ r^2 = 0.80,\ rms = 7.6\ \mu atm. \quad (3)$$

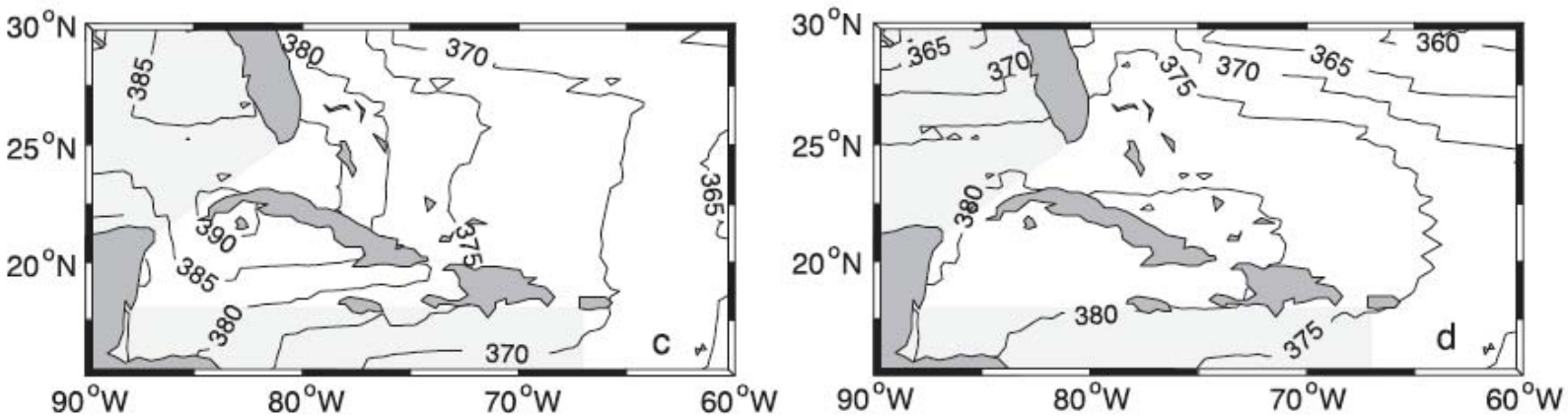


Fig. 9. Seasonal mean maps of fCO_2^{sw} (in μatm) in: winter (a), spring (b), summer (c), and fall (d), 2002. The seasons are defined as winter: January, February, December; spring: March–May; summer: June–August; and fall: September–November. The gray areas are regions where the procedure for calculating fCO_2^{sw} values has not been validated.

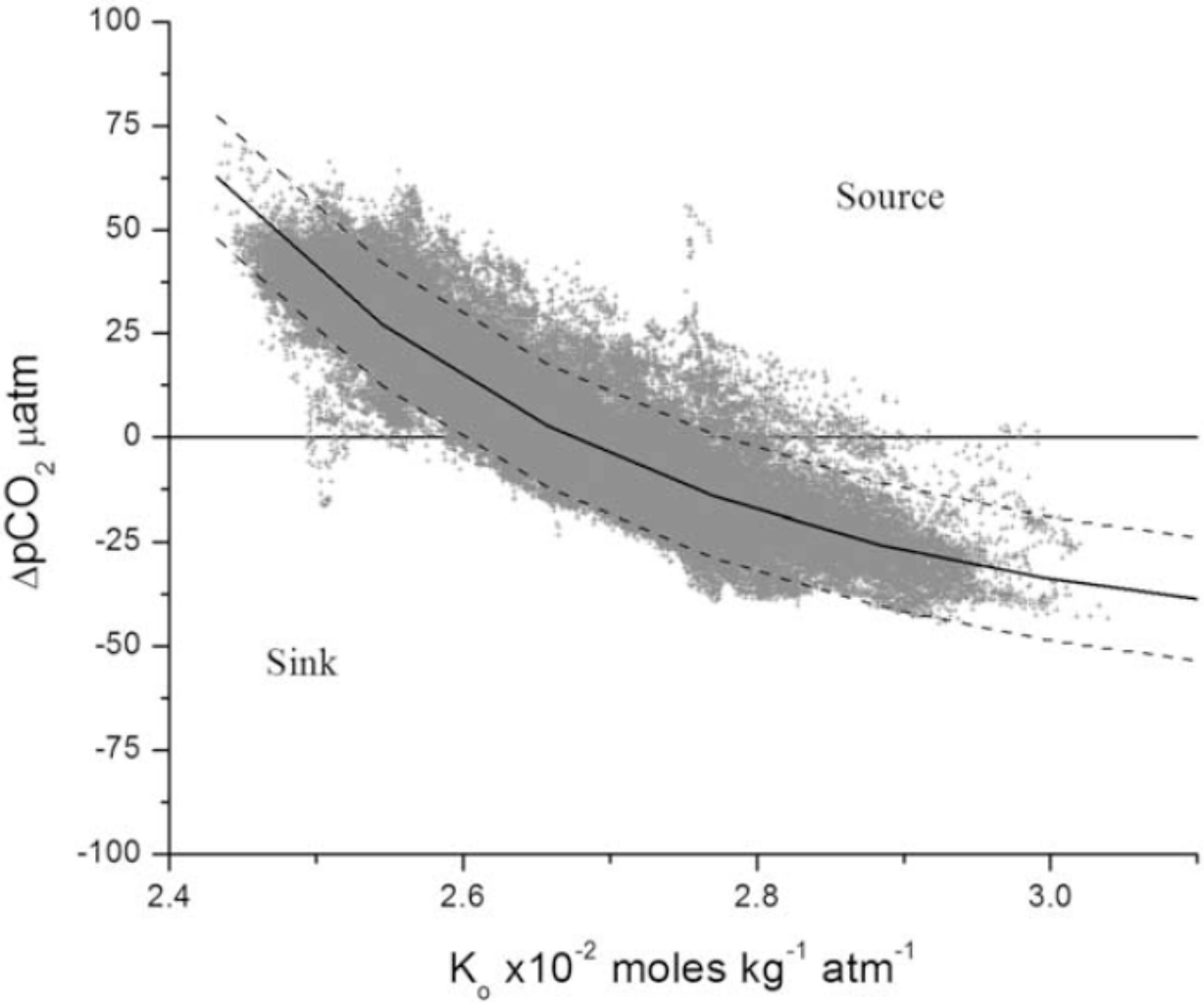
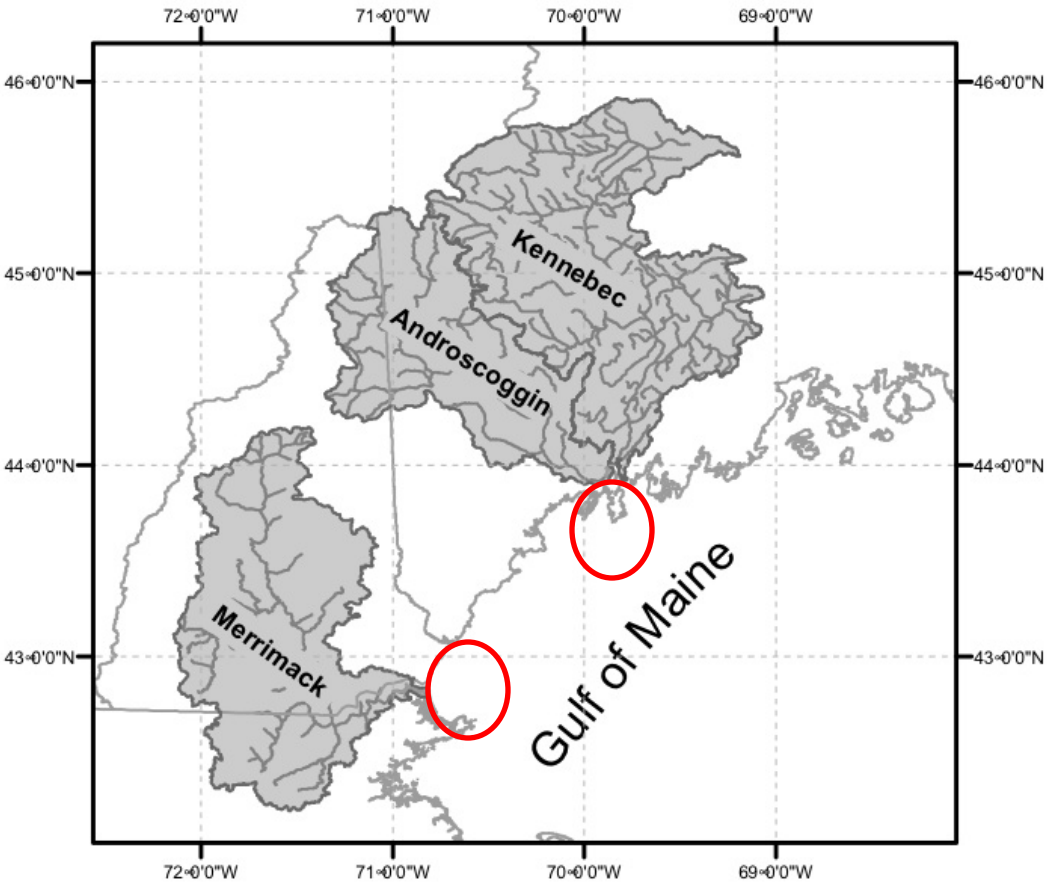


Figure 2. The gas solubility coefficient was calculated for each Explorer of the Seas observation (2002–2006) using the on-board thermosalinograph (TSG) data. Differences between the measured $pCO_{2,sw}$ and atmospheric $pCO_{2,air}$ (ΔpCO_2) are shown as a first-order exponential decay function of increasing gas solubility ($\Delta pCO_2 = y_0 + A_1 EXP(-K_0/t_1)$, $r^2 = 0.85$, 95% prediction bands shown as dashed lines).

Remote sensing/optical retrievals of pCO_2 based on empirical relationships (several approaches)

Studies in two nearby estuary-plume systems: Northeast US



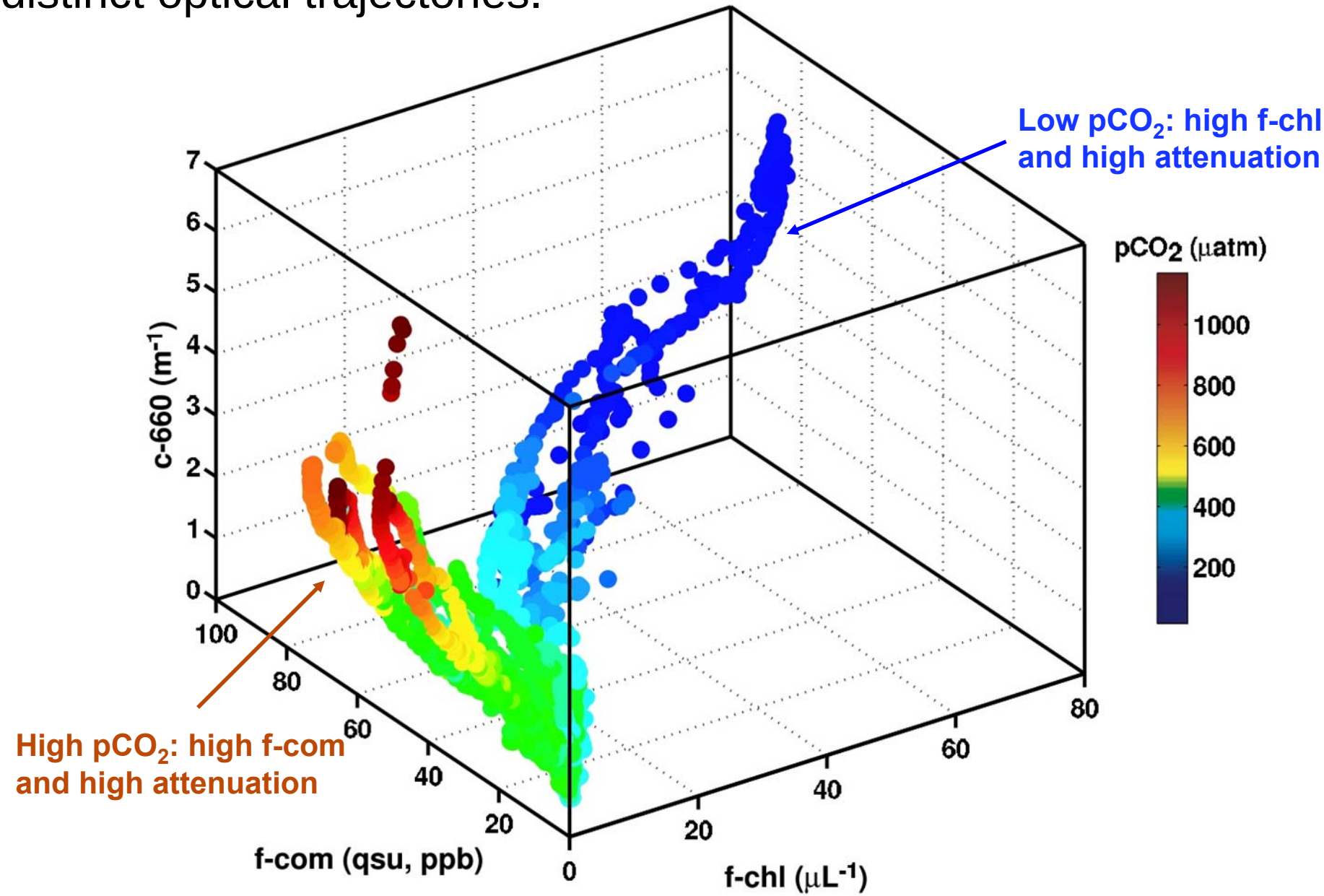
- Compared surface optical properties and pCO_2.

- f-chlorophyll, f-cdom, attenuation (660nm).

- Six cruises, consecutive days to each system in
  - -June
  - -September
  - -November

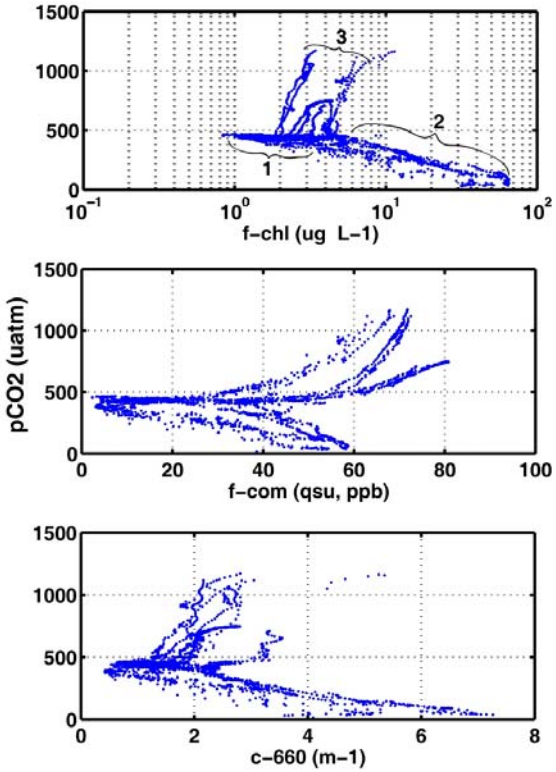
Salisbury et al., 2008, ECSS 77(2)

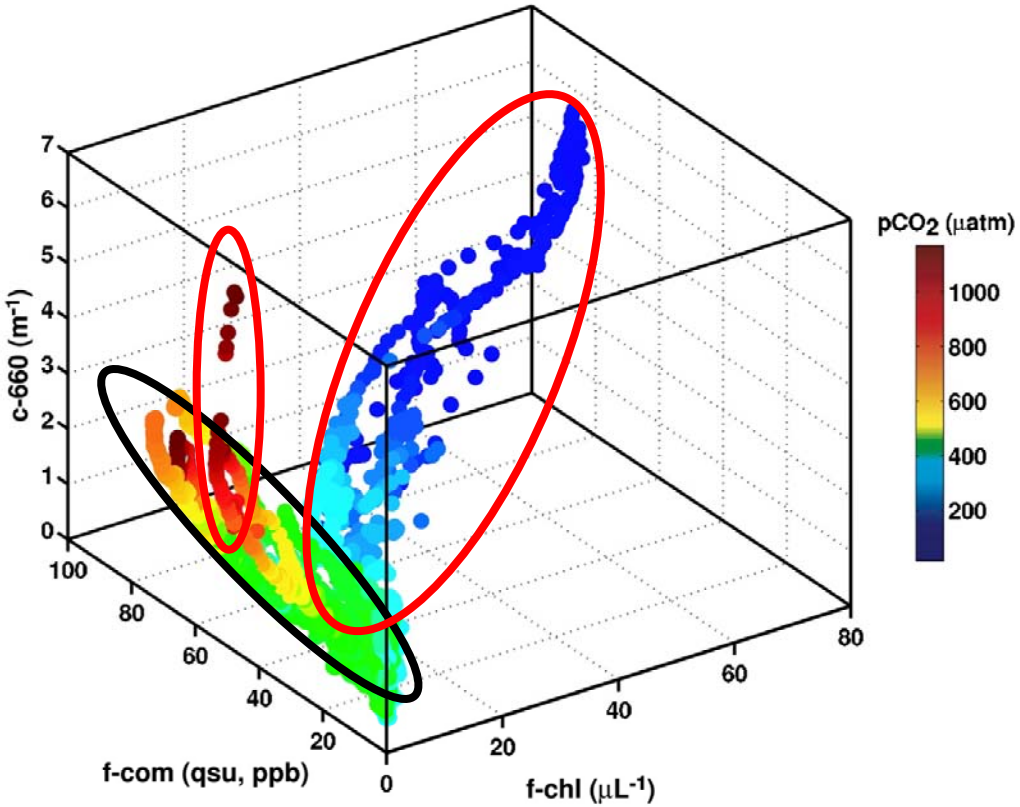
Pooled data from both systems: pCO_2 appears to track two distinct optical trajectories.



Encouragement for an satellite-based coastal pCO_2 algorithm?

Note apparent link between human impact, optics and pCO_2 (at least in the estuaries)



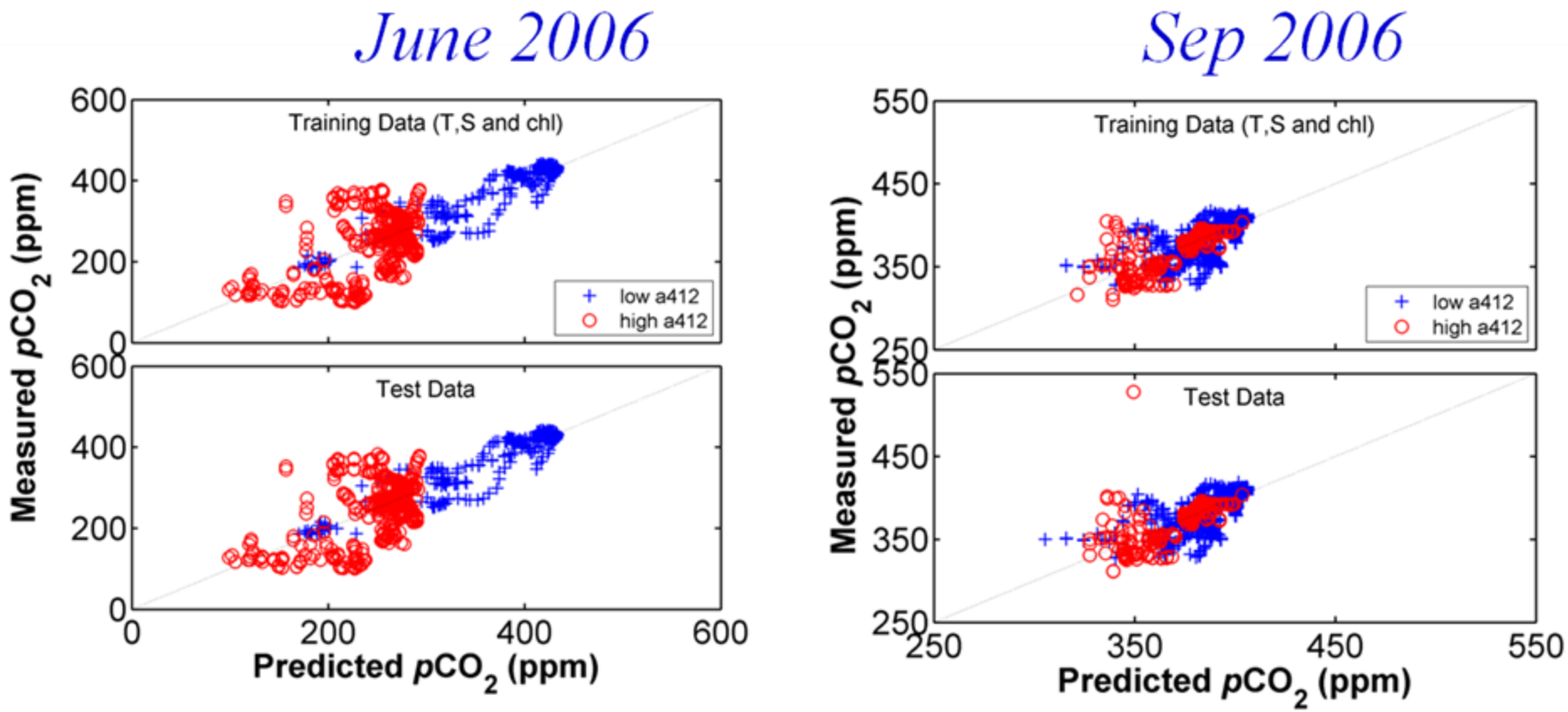


Salisbury et al., 2008, ECSS 77(2)

Next -- Gulf of Mexico and Approach #2 (see Lohrenz and Cai, GRL, 2006)

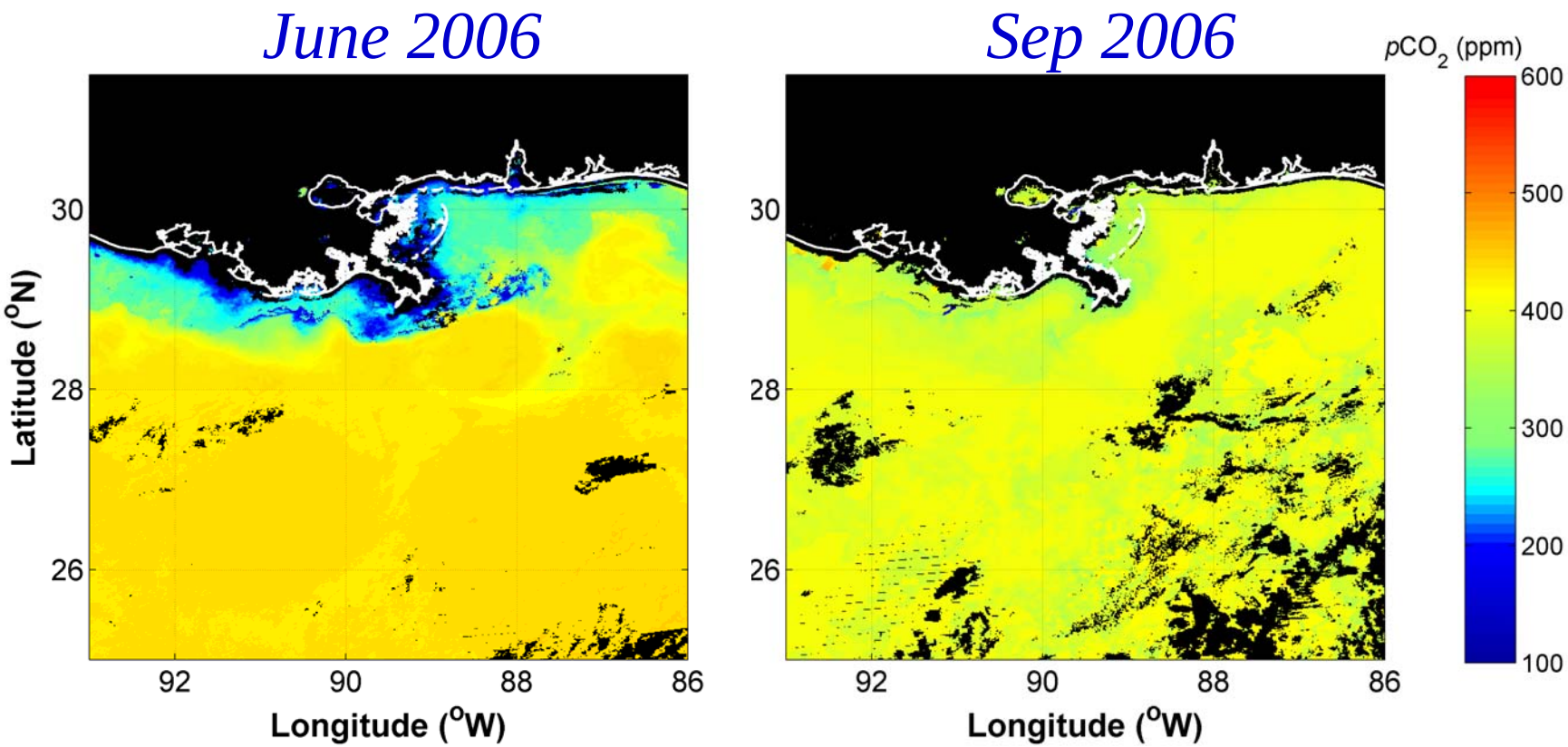
- **Used MODIS based products: Chlorophyll, SST and ag412 to infer salinity**

- **Estimates of pCO_2 from PCA-derived empirical algorithms showed significant correlations between measured and predicted pCO_2**

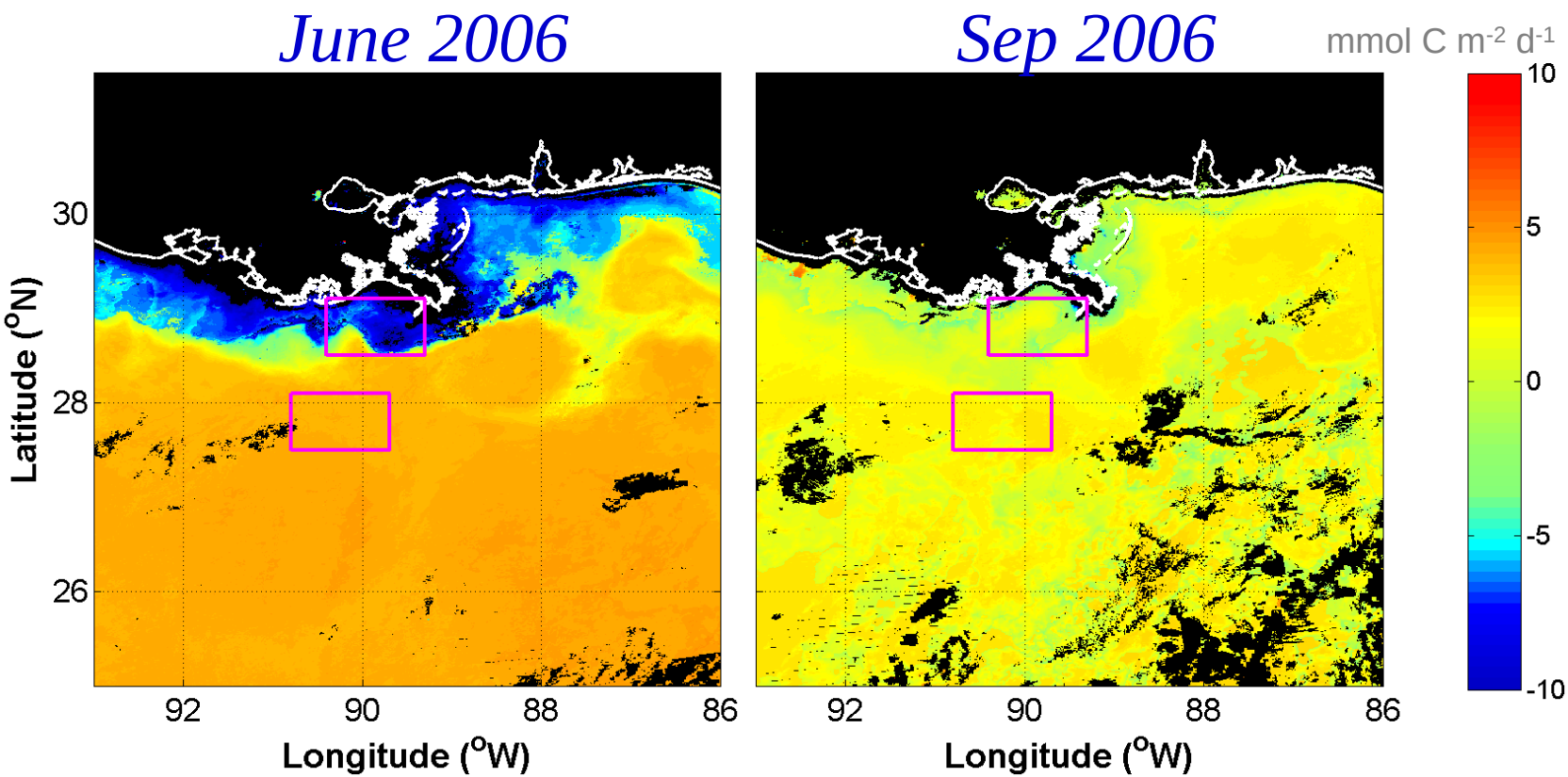


R-squared values were 0.782 in June and 0.512 in September 2006

- The empirical algorithms were used to produce pCO_2 images
- An area of low pCO_2 is evident in coastal waters during June, consistent with a strong seasonal sink
- In contrast, there was an absence of a strong gradient



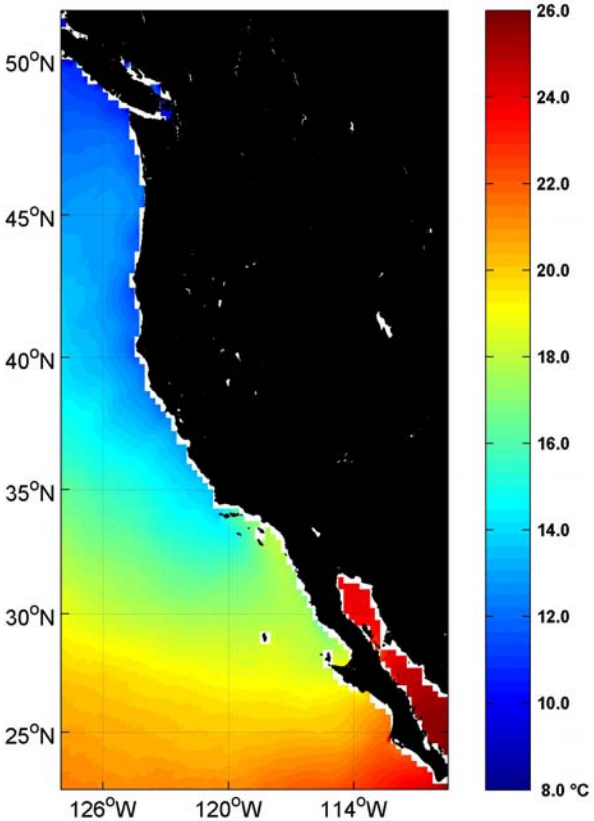
- **Estimates of air-sea flux of CO_2 were determined using a thin layer diffusion calculation following the parameterization of McGillis et al. (2001)**
- **Results showed a strong CO_2 sink in coastal waters, but net offshore source during June**



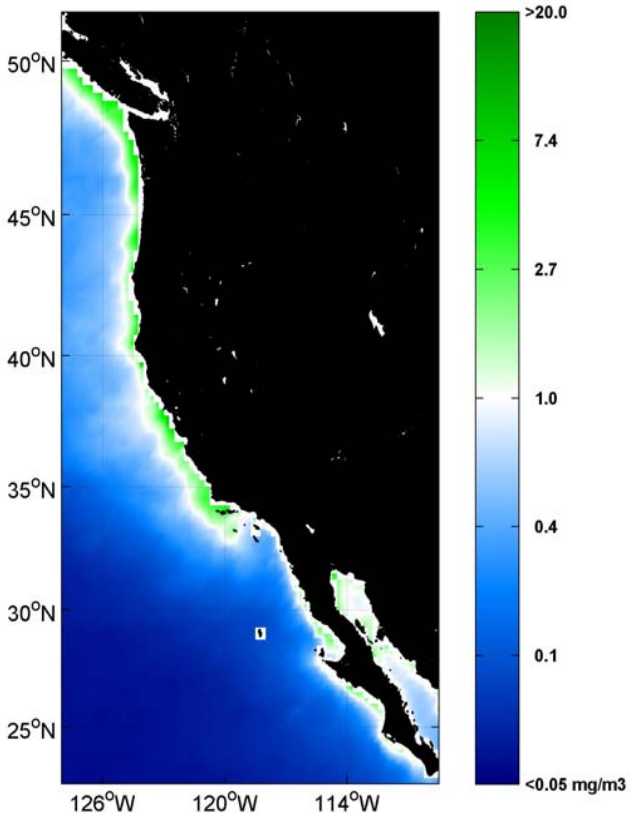
Divide and conquer: Hales et al. - Self Organizing Maps

Can we use satellite to delineate to objectively identify biogeochemical regimes related to pCO2(t)?

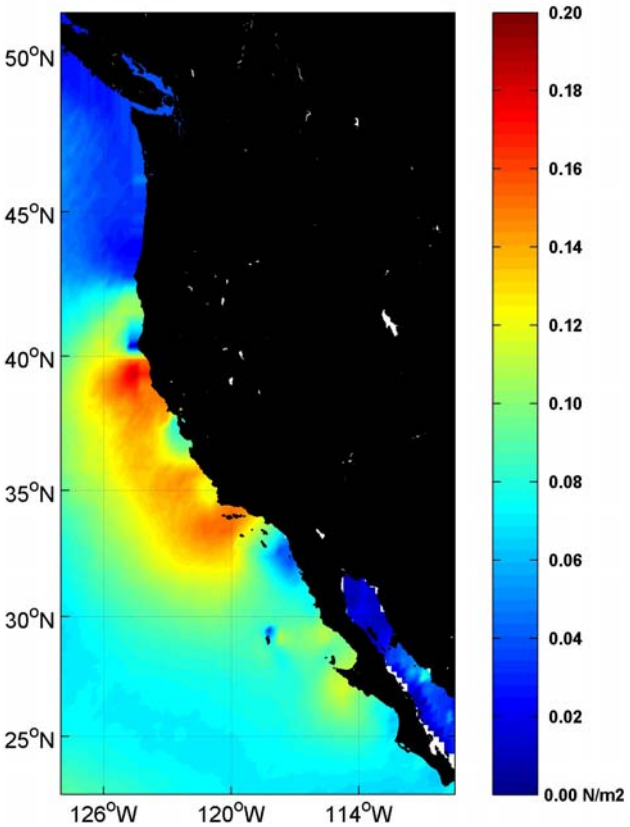
SST

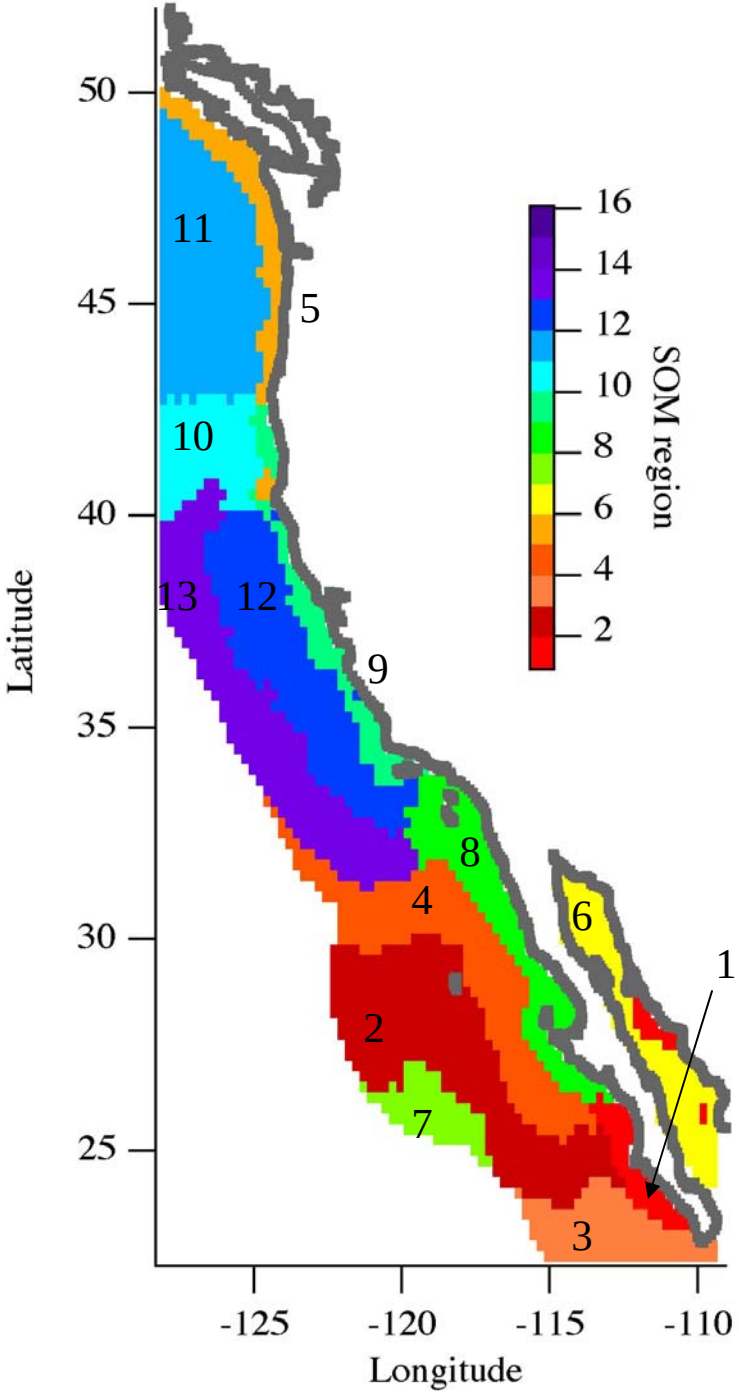


Chl



τ





Using the approach of Saraceno et al. (2006), we find a 13-region map of the Pacific coast:

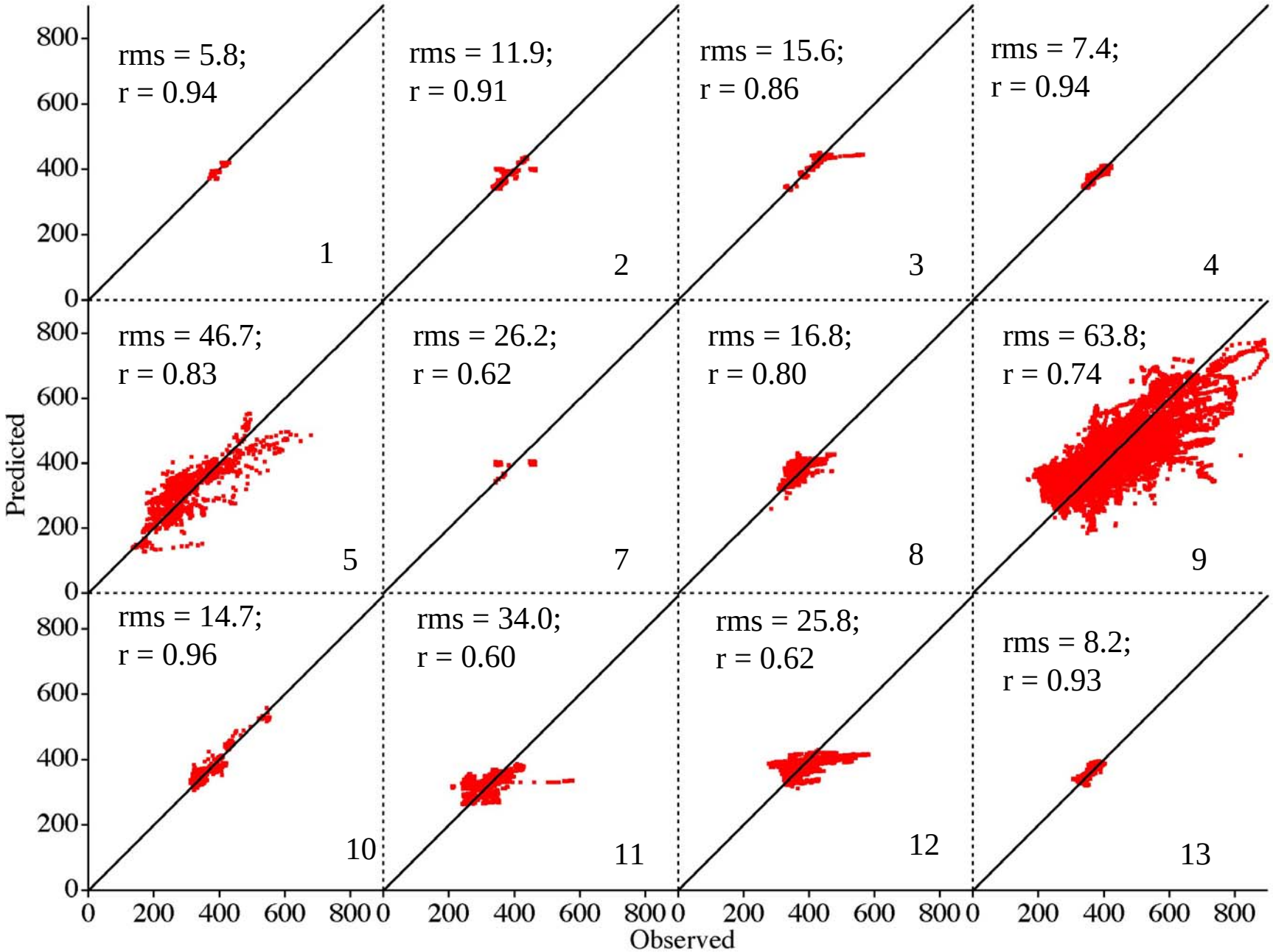
Distinguishes OR/WA/BC, NoCal, SoCal, S. Baja, and Sea of Cortez nearshore regions;

Distinguishes different offshore regions in both latitude and cross-shelf dimensions;

Justifies distinct property dependences in separate regions, but with >10x fewer regions than in the binning of Chavez et al. (2007);

Enables easy identification of understudied regions/times.

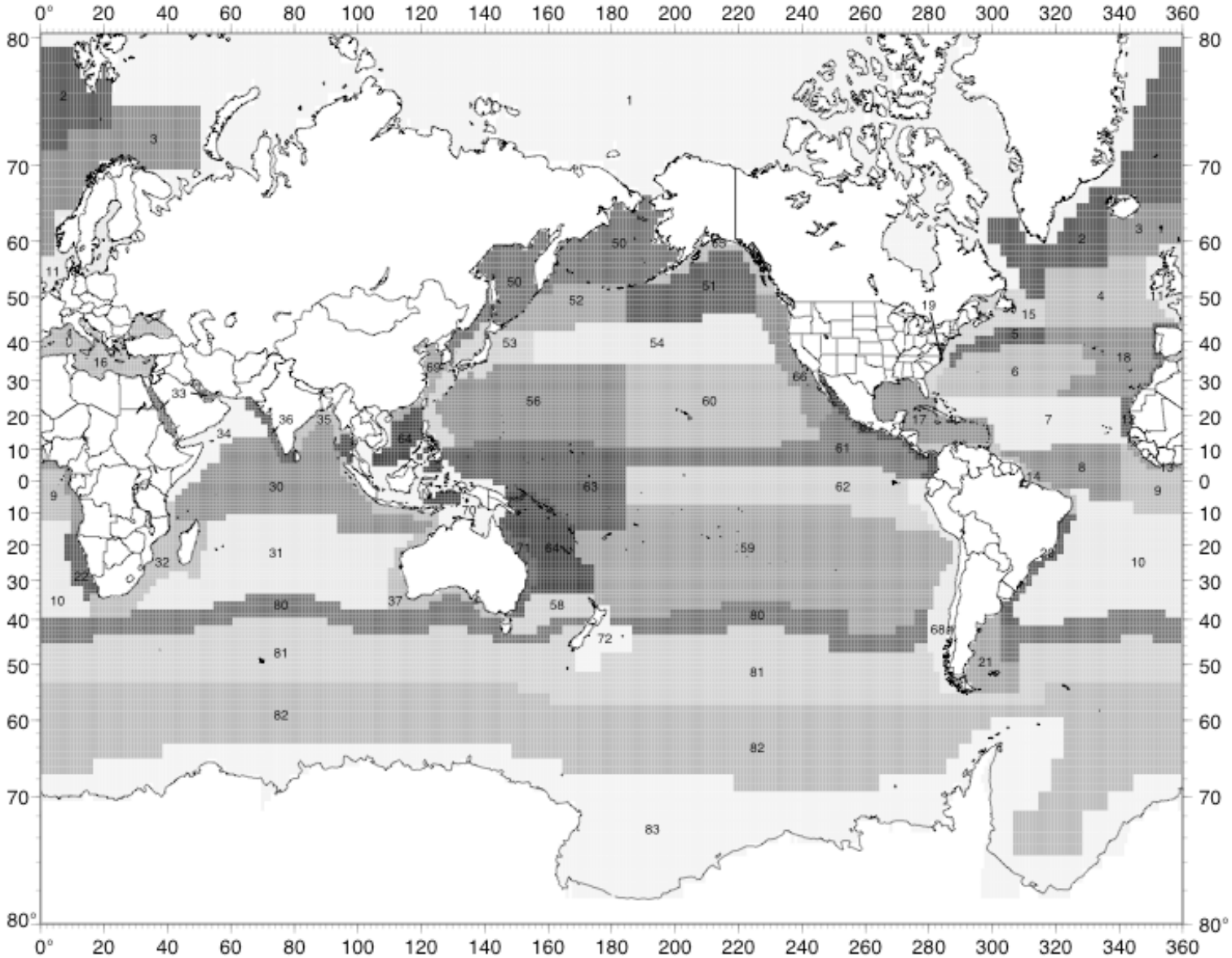
Within-province retrievals are encouraging !



Preliminary efforts aimed at estimating DIC_{bio} at the global scale using satellite data

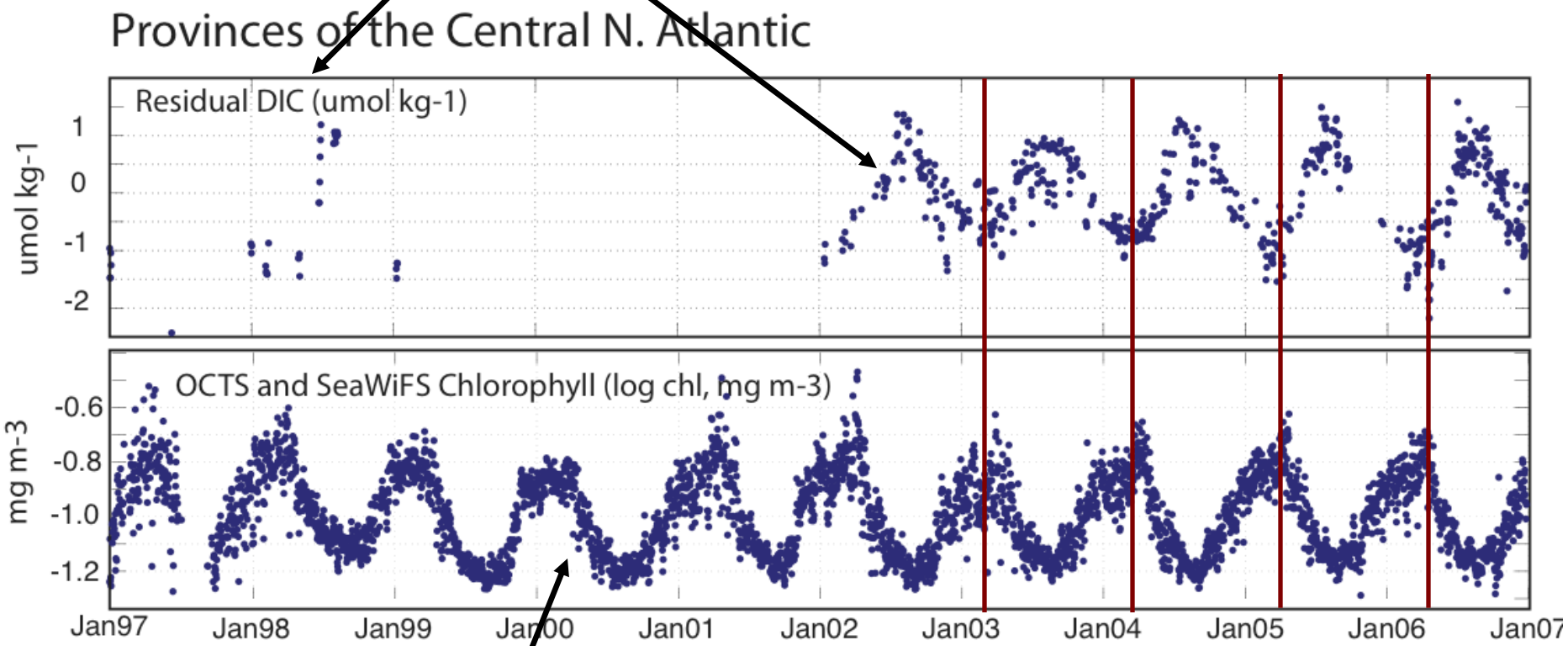
NASA-NNH07ZDA001N-Carbon:
Salisbury, Mahadevan. Vandemark, Jonsson

Longhurst Ocean Ecological Provinces:



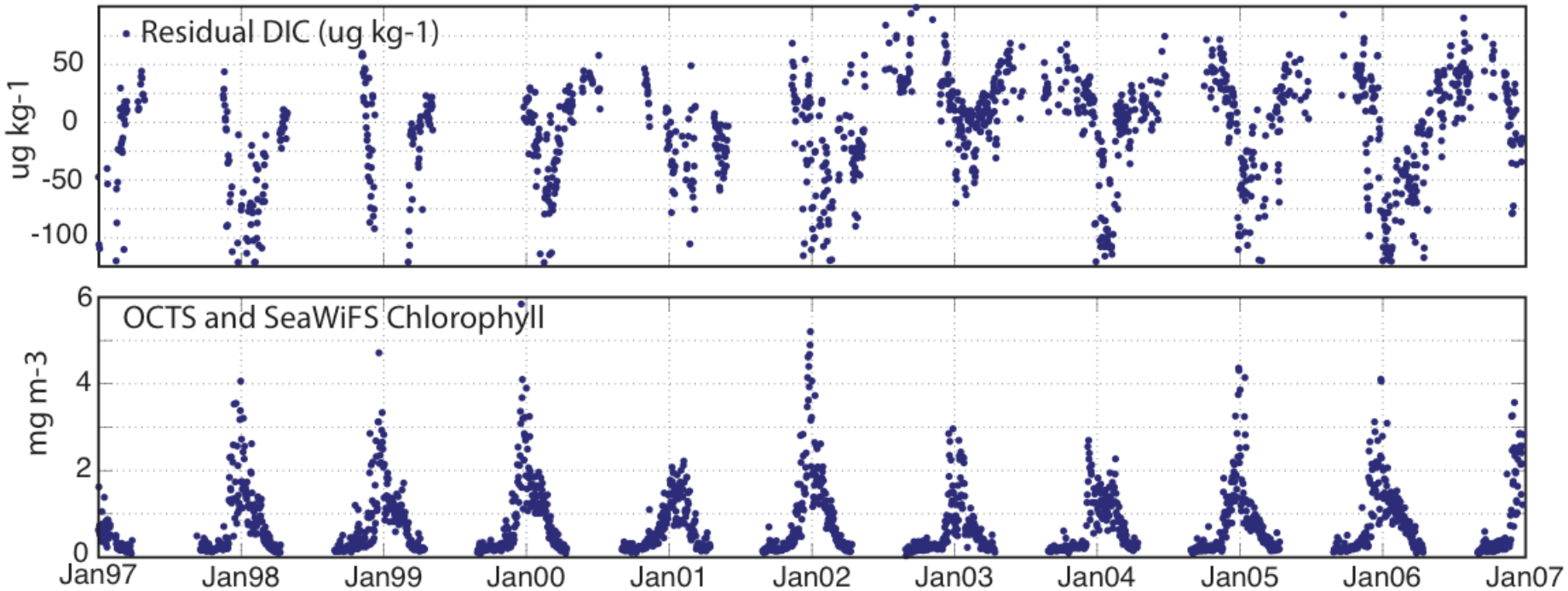
For each day, the median of all DIC_{bio} data within the province

Residual DIC' is an estimate of DIC_{bio} using in-water pCO_2 data, from CDIAC -solubility term is removed

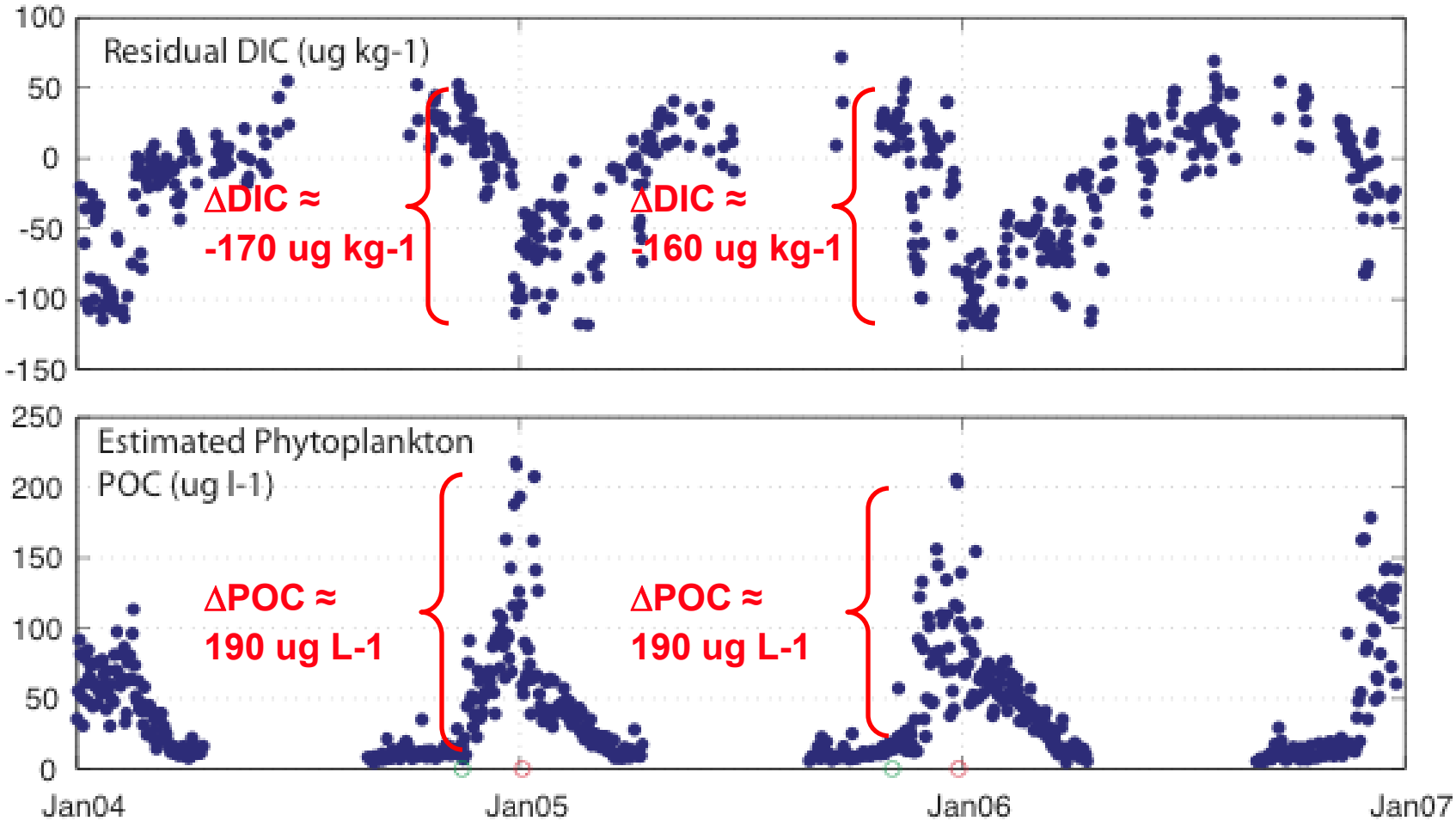


Likewise, the median of all OCTS ('96-97) and SeaWIFS ('97-'07) data (for each day, within the provinces)

Provinces of the Southern Ocean



S. Ocean: Seasonal dDIC(bio)/dt accords well with dPOC/dt



Concluding notes:

1. Ocean viewing satellites collect information that can aid in the estimates of surface CO_2 through info on solubility and biology.

2. Space and time scales of ocean satellite observations are appropriate for scaling sparse observations.

3. Progress is being made - in situ data is certainly key

Lagrangian analysis of satellite POC to track DIC_{bio} in the advective Gulf of Maine

Static premise:

If we could keep a parcel of surface ocean water still, then to the first order:

$\Delta POC(\text{e.g. MODIS}) \approx \Delta DIC_{bio} \approx NCP$

NASA-NNH07ZDA001N-Carbon:

Jonsson, Salisbury, Mahadevan, Campbell, (2008a, 2008b)

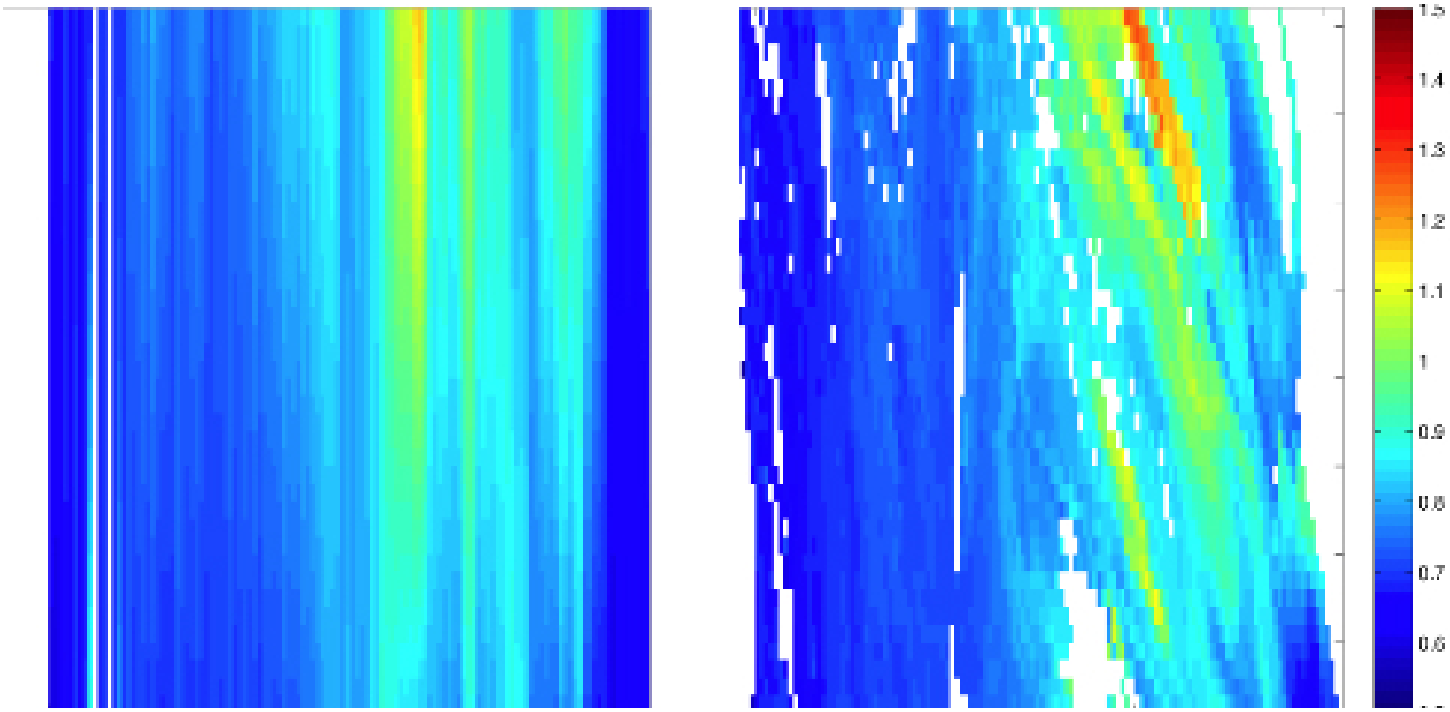
but water moves (esp. near the coast) …..

Interpolation of a MODIS Chl cut over 5 days

Linear

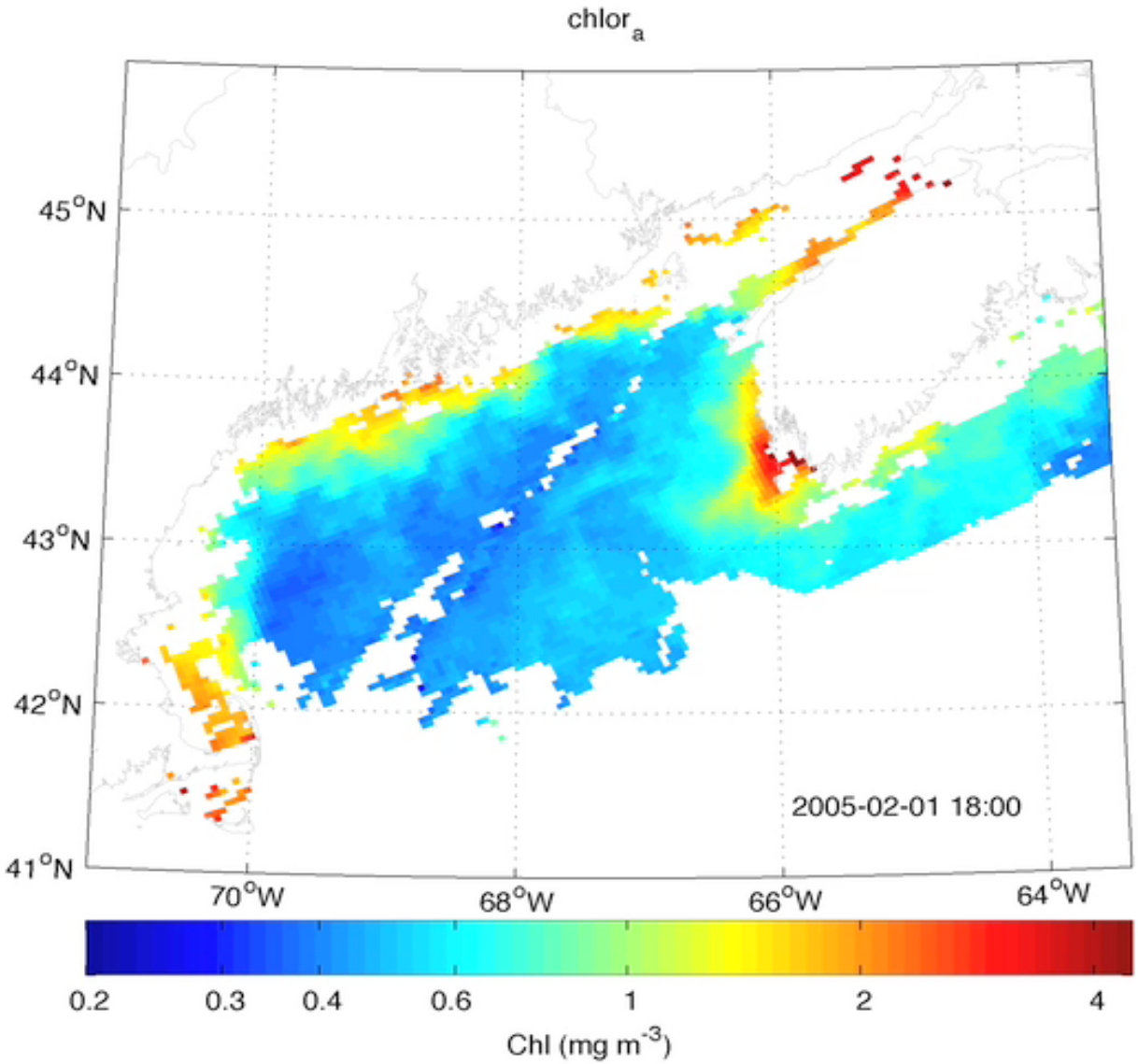
Lagrangian

Time (5days)



L = 200 km

Longitude


chlor a
45°N
44°N
43°N
42°N
41°N
70°W
68°W
66°W
64°W
2005-02-01 18:00
0.2
0.3
0.4
0.6
1
2
4
Chl (mg m-3)

So, can we assume production within a parcel travels with that volume and track the temporal evolution of POC across a region?

Ocean color (MODIS) derived products to estimate [POC] in euphotic zone

POC_{t1}

$$\frac{(POC_{t2} - POC_{t1})}{(t2 - t1)} = \Delta DIC_{bio}$$

… and use a circulation model to advect the water mass

Ocean color (MODIS) derived products to estimate [POC] in euphotic zone

POC_{t2}

Jonsson, Salisbury, Mahadevan, Campbell: 2009 IJRS (in press), and 2009 (in revision)

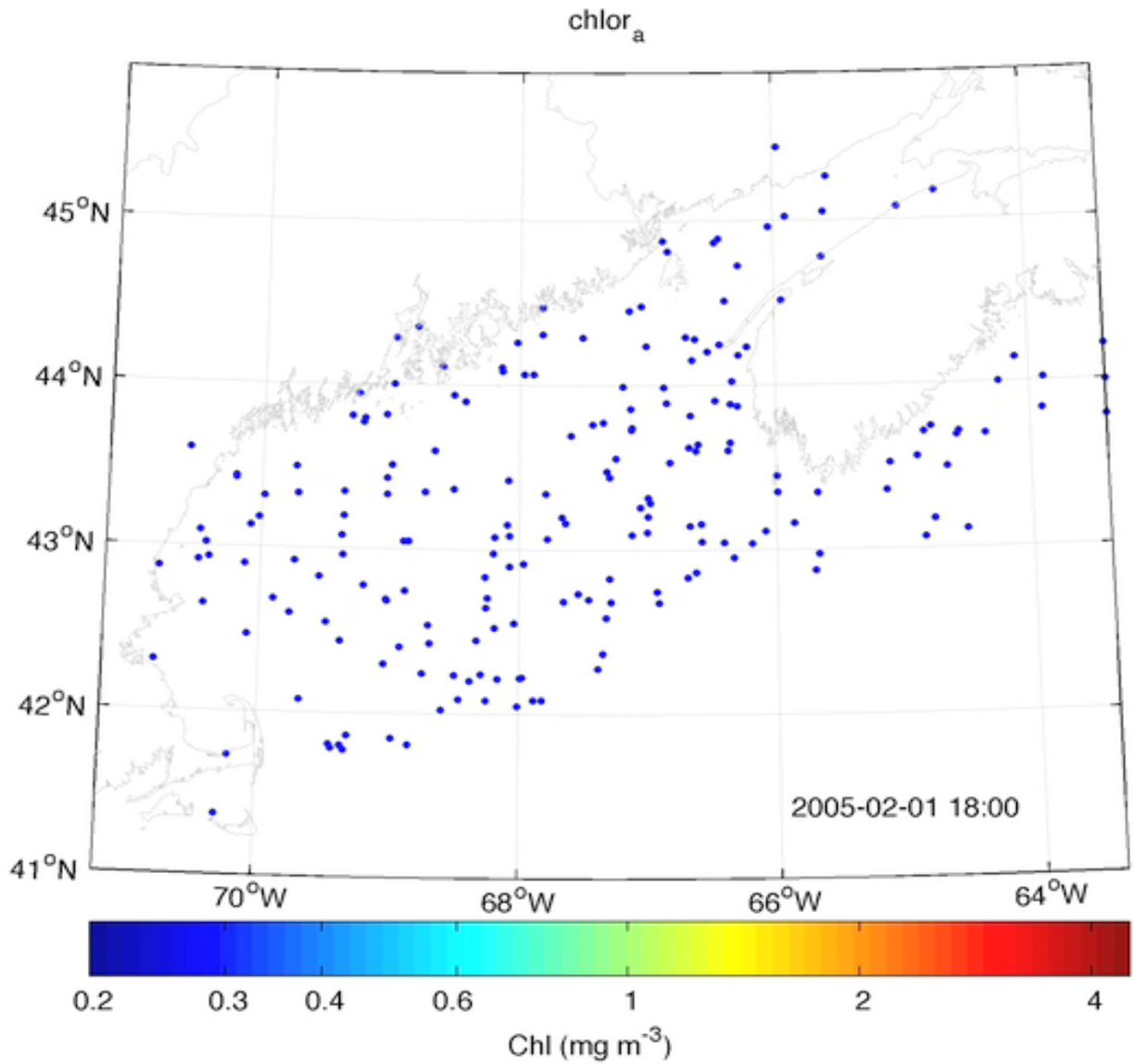
More assumptions:

1. Phytoplankton POC : Chl is constant (= 53)

2. Sinking, vertical mixing and DOC production by phytoplankton “excess production” are minimal, over short (2-7 day) time scales

Lagrangian analysis methods

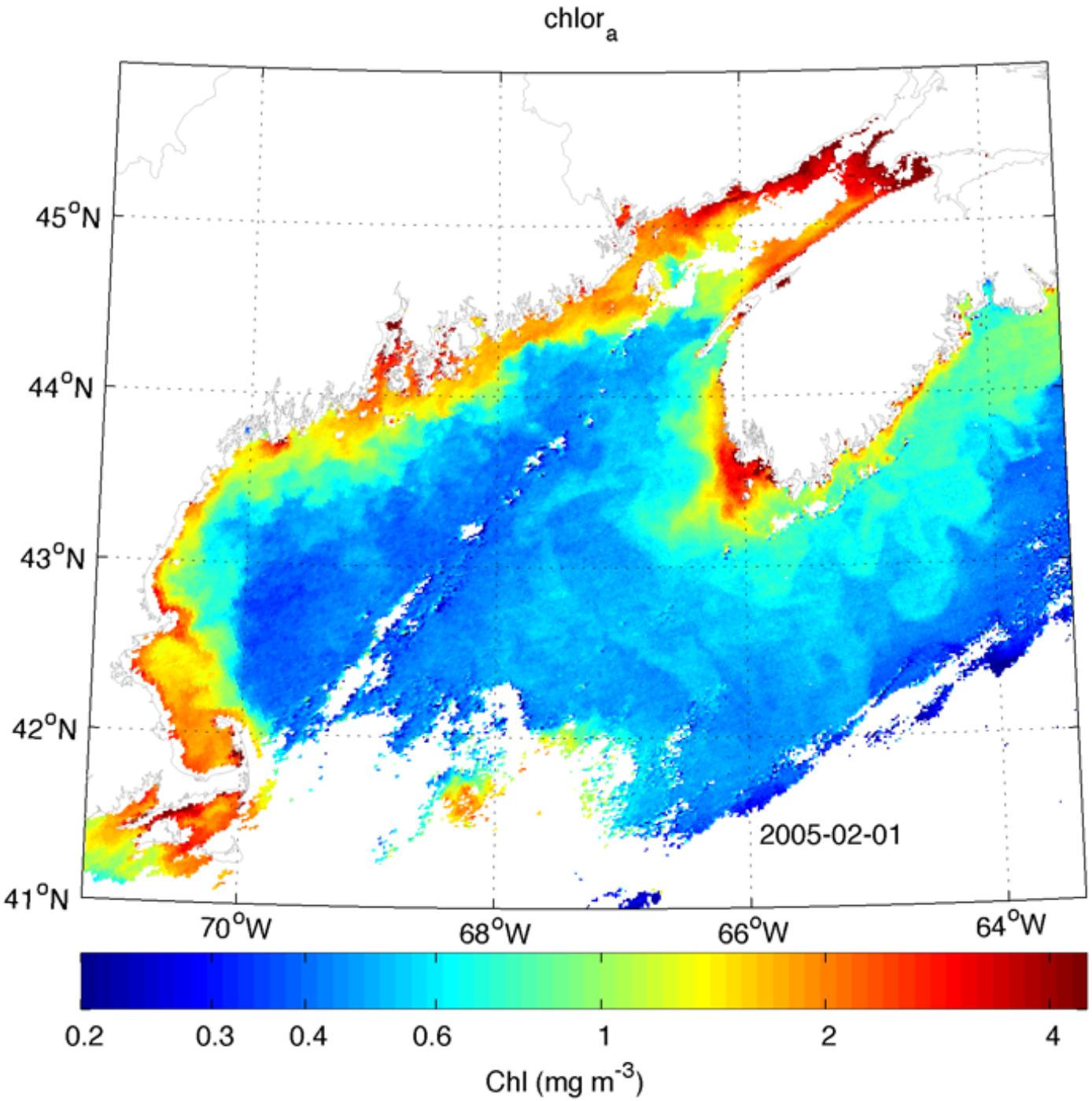
a. Characterize advection in two dimensions using an ocean circulation model

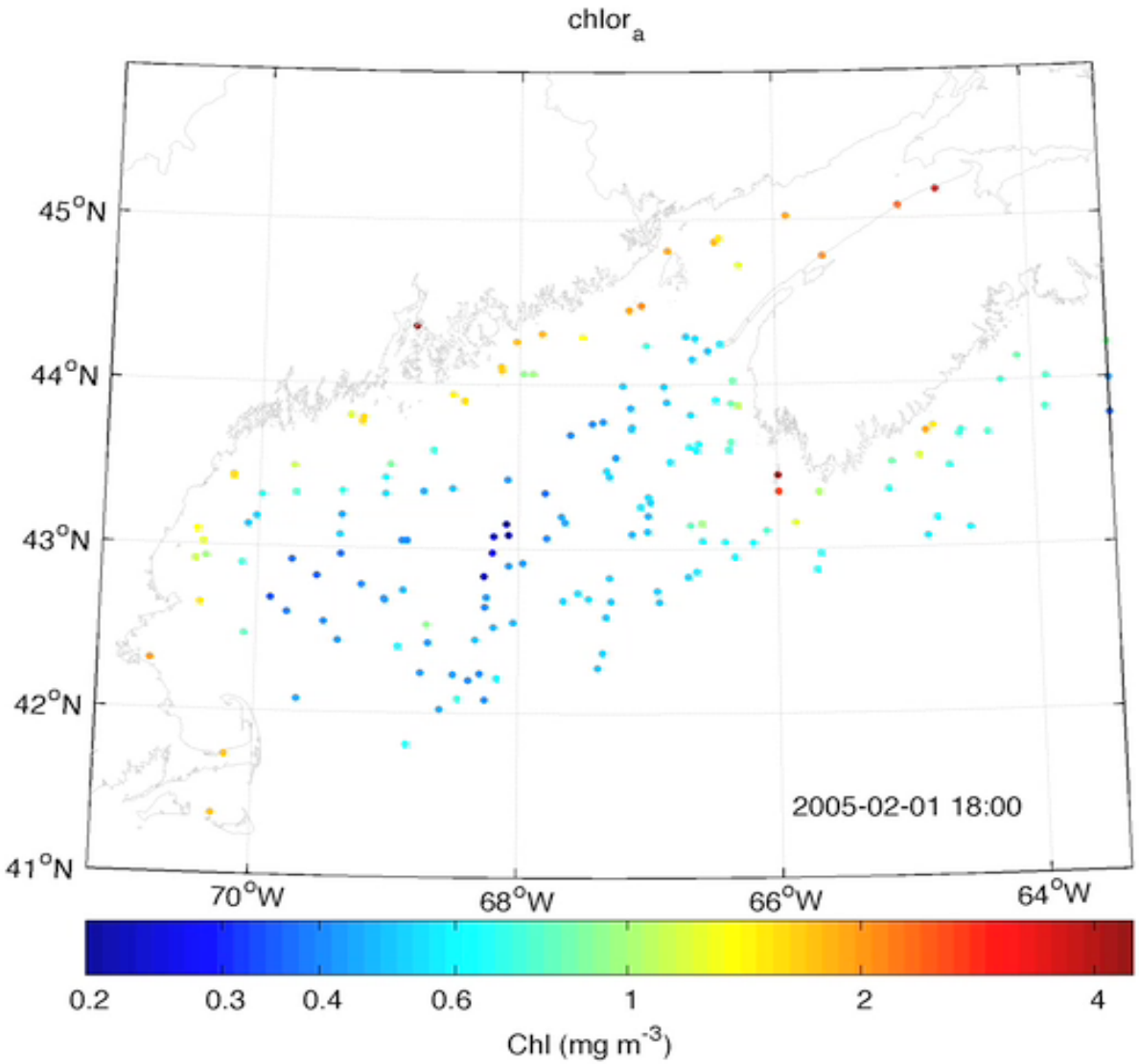

chlor$_a$
45°N
44°N
43°N
42°N
41°N
70°W
68°W
66°W
64°W
2005-02-01 18:00
0.2
0.3
0.4
0.6
1
2
4
Chl (mg m^{-3})

Lagrangian analysis methods

a. Characterize advection in two dimensions using a circulation model

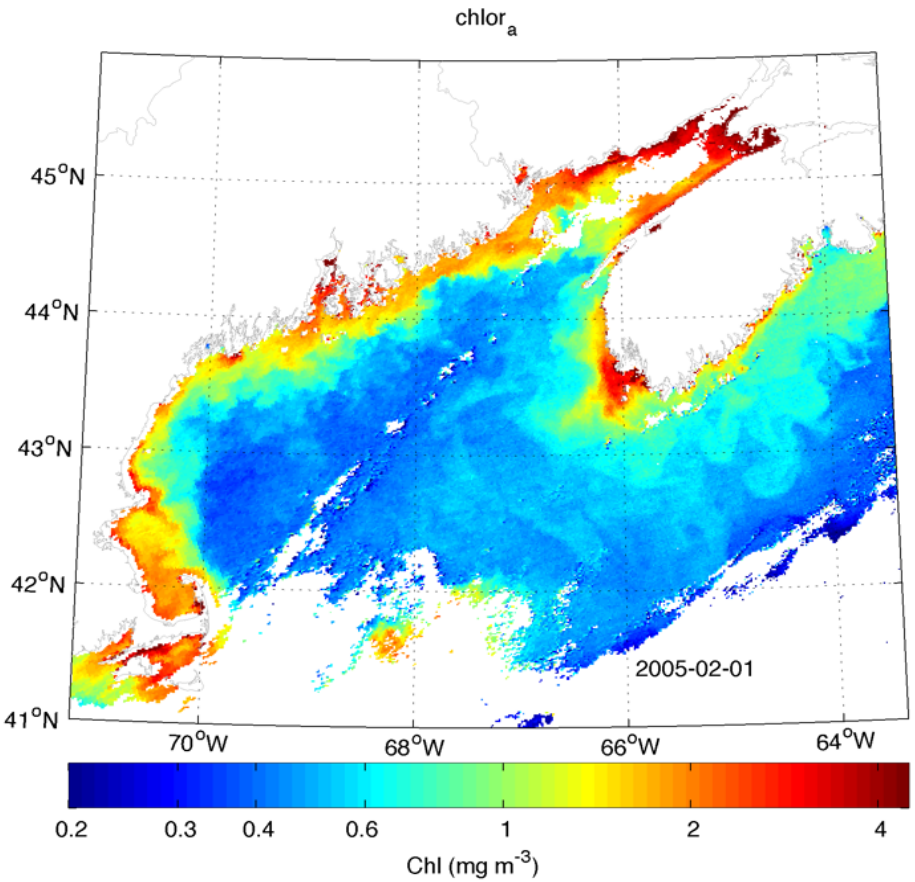
b. Seed the model with MODIS-derived POC values (POC based on chlorophyll:C)


chlor a
45°N
44°N
43°N
42°N
41°N
70°W
68°W
66°W
64°W
2005-02-01
0.2
0.3
0.4
0.6
1
2
4
Chl (mg m-3)

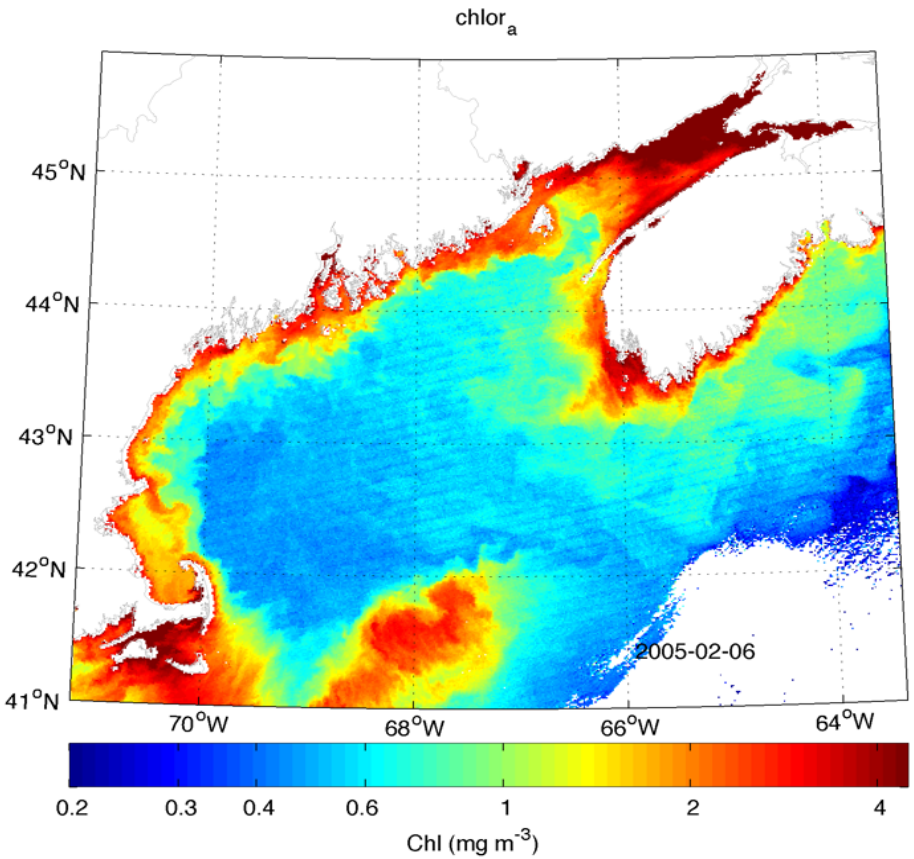

chlor a
45°N
44°N
43°N
42°N
41°N
70°W
68°W
66°W
64°W
2005-02-01 18:00
0.2
0.3
0.4
0.6
1
2
4
Chl (mg m-3)

Compute the difference with MODIS POC along the advective flow path at some later time (2-7 days)

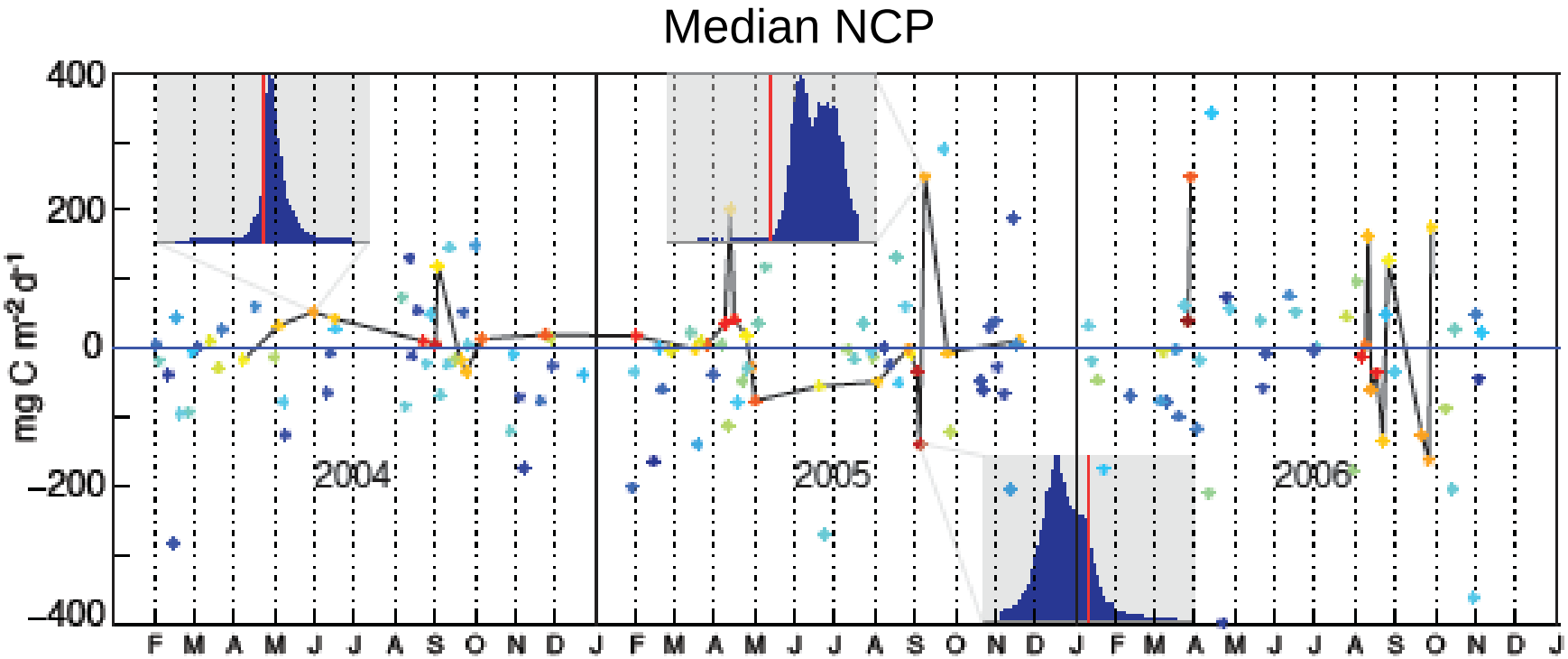
POC at t_1 (Day 1)



POC at t_2 (Day 6)



The 5 day differences provide estimates of Gulf of Maine NCP over a 3 year period …



- numbers are reasonable (relative to UNH ship data)

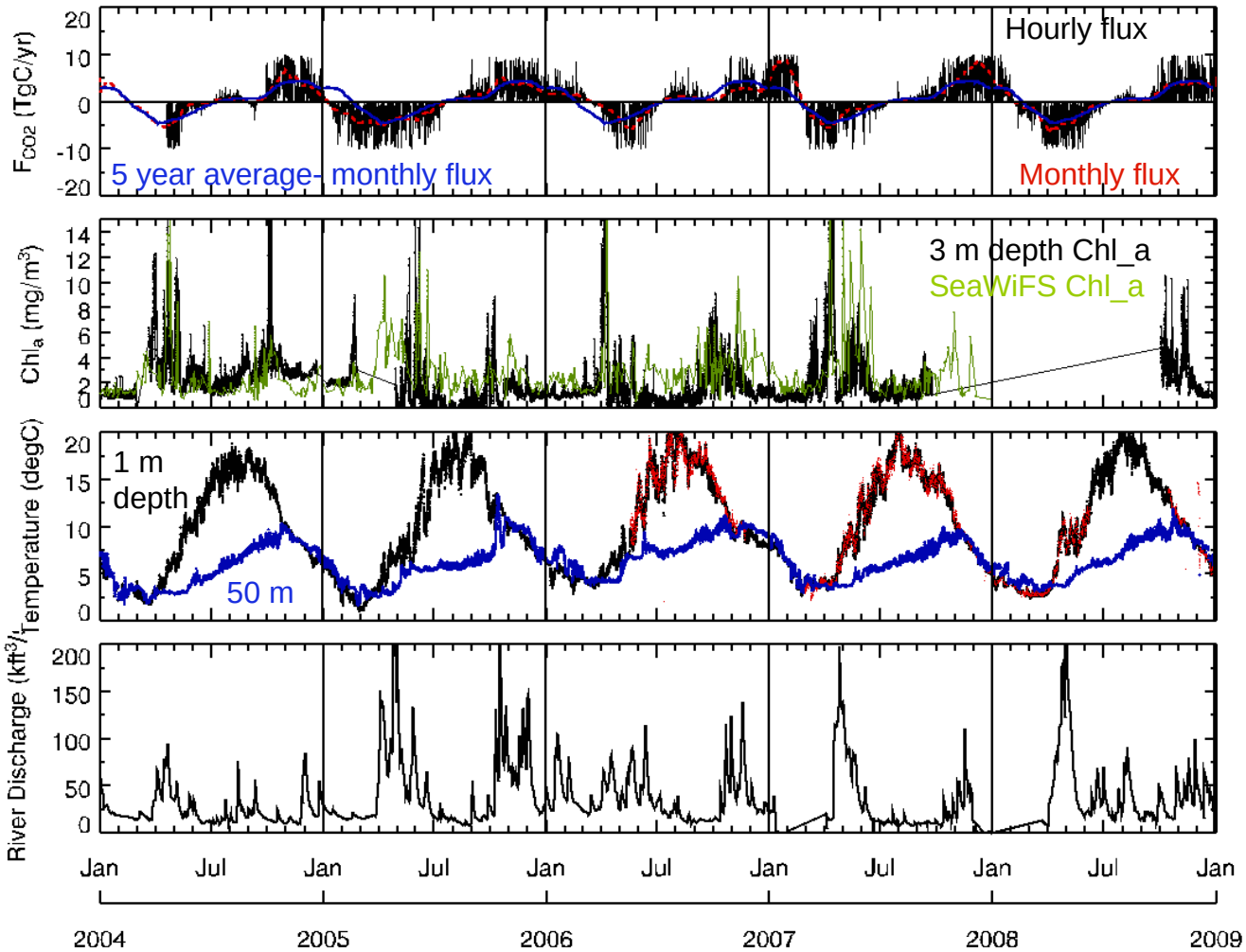
- slightly above zero (inferred heterotrophic) over 3 years (like UNH ship data)

- as always, cloud cover is a significant problem

Jonsson et al., 2009

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

we acknowledge NOAA/PMEL, UMaine, NDBC, USGS

We deeply appreciate the support of our funding agencies:

NASA

NASA-NNH07ZDA001N-Carbon
NASA - NNX06AE29G -NIP

- and NOAA
NOAA NA05NOS4731206

Also - Stan Glidden, Alex Prussevitch, Shawn Shellito and the awesome crew of the UNH Gulf Challenger
Thanks!

Extras…

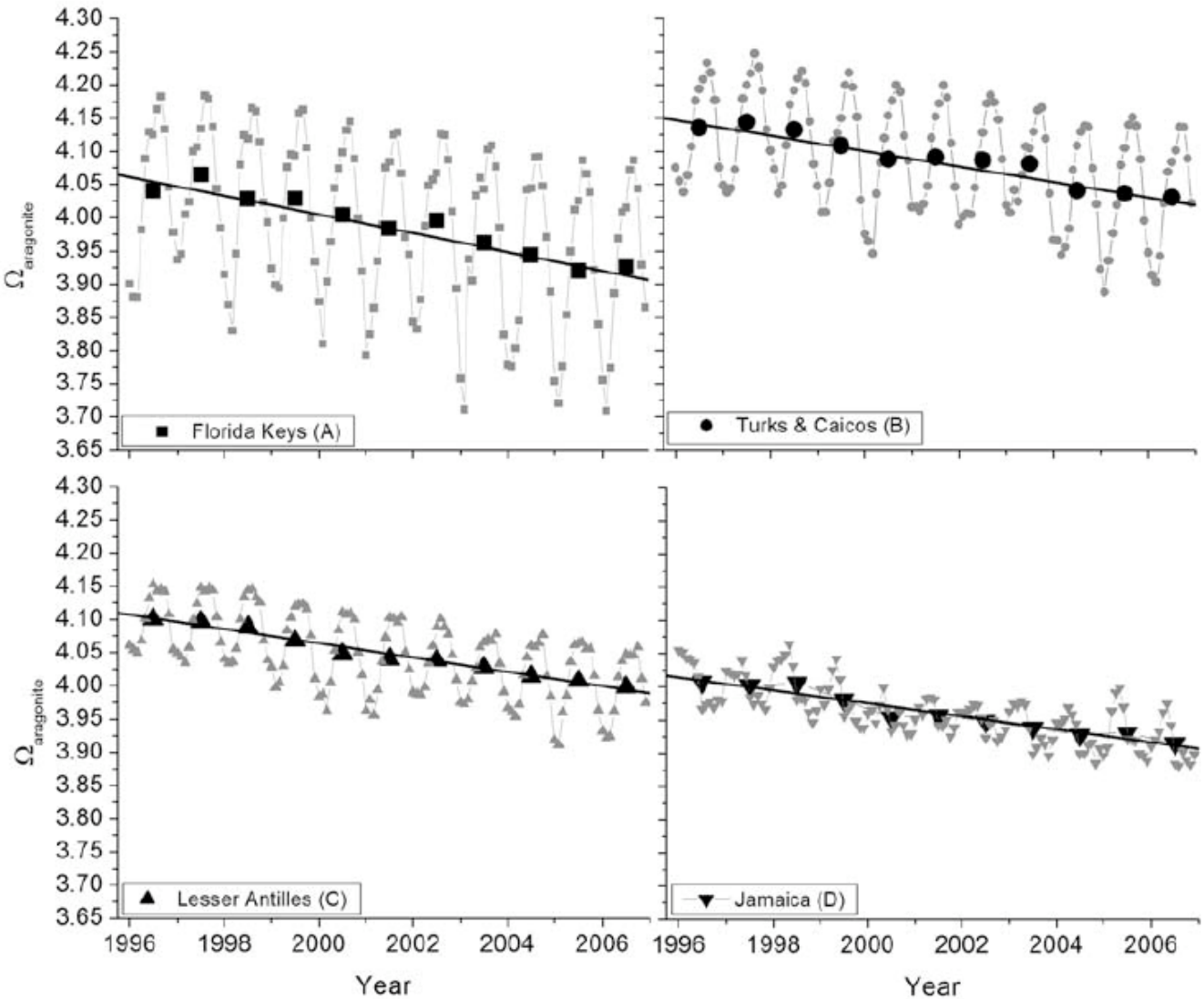
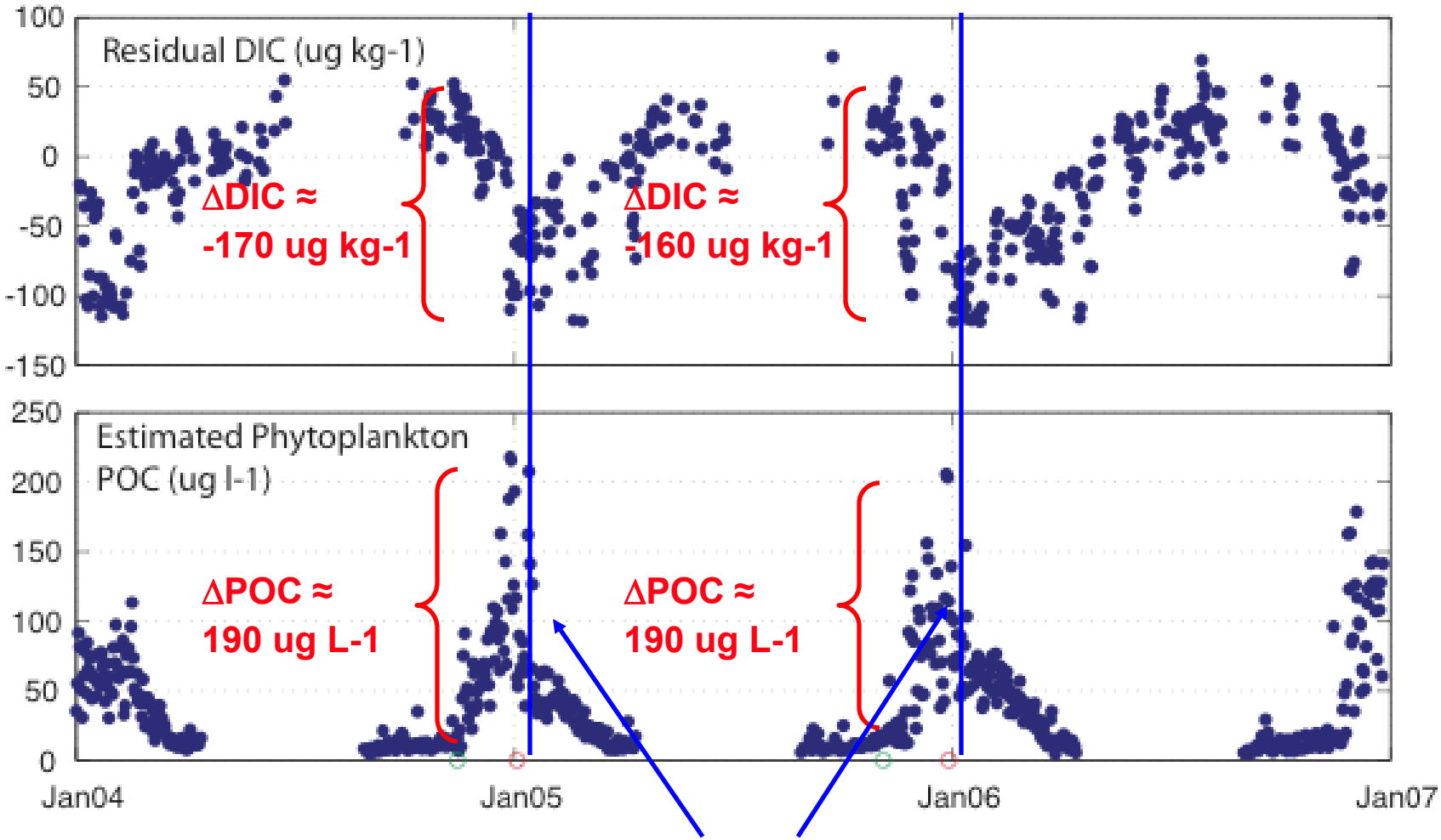
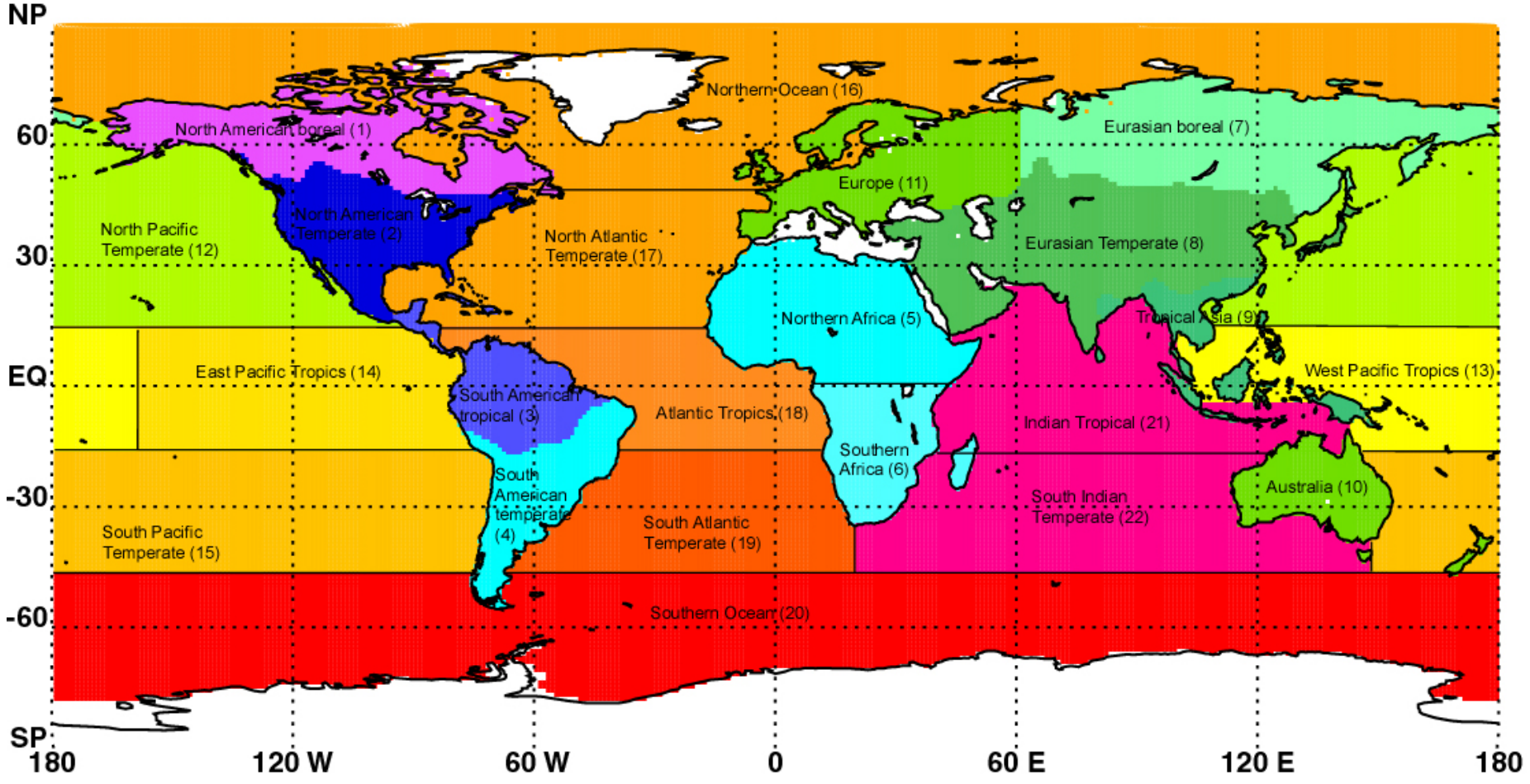


Figure 7. Trends in annual (black symbols) and monthly (grey symbols) mean sea-surface aragonite saturation state (Ω_{arg}) for the four regions occupied by prominent coral reefs denoted in Figure 6A. (A) Florida Keys. (B) Turks and Caicos. (C) Lesser Antilles. (D) Jamaica. Rates of change range from $-0.014 \pm 0.001\ \Omega_{arg}\ yr^{-1}$ for the Florida Keys region to $0.010 \pm 0.001\ \Omega_{arg}\ yr^{-1}$ for the Jamaica region.

Seasonal dDIC(bio)/dt fairly close to dPOC/dt



Note lags between min DIC_{bio} and max chl


NP
60
30
EQ
-30
-60
SP
180
120 W
60 W
0
60 E
120 E
180
Northern Ocean (16)
North American boreal (1)
Eurasian boreal (7)
Europe (11)
North American Temperate (2)
North Pacific Temperate (12)
North Atlantic Temperate (17)
Eurasian Temperate (8)
Northern Africa (5)
Tropical Asia (9)
East Pacific Tropics (14)
West Pacific Tropics (13)
South American tropical (3)
Atlantic Tropics (18)
Indian Tropical (21)
Southern Africa (6)
South American temperate (4)
Australia (10)
South Indian Temperate (22)
South Pacific Temperate (15)
South Atlantic Temperate (19)
Southern Ocean (20)