Carbon Sink Trends in the Northern Oceans

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OCB Workshop

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- David Ullman, Val Bennington: Wisconsin
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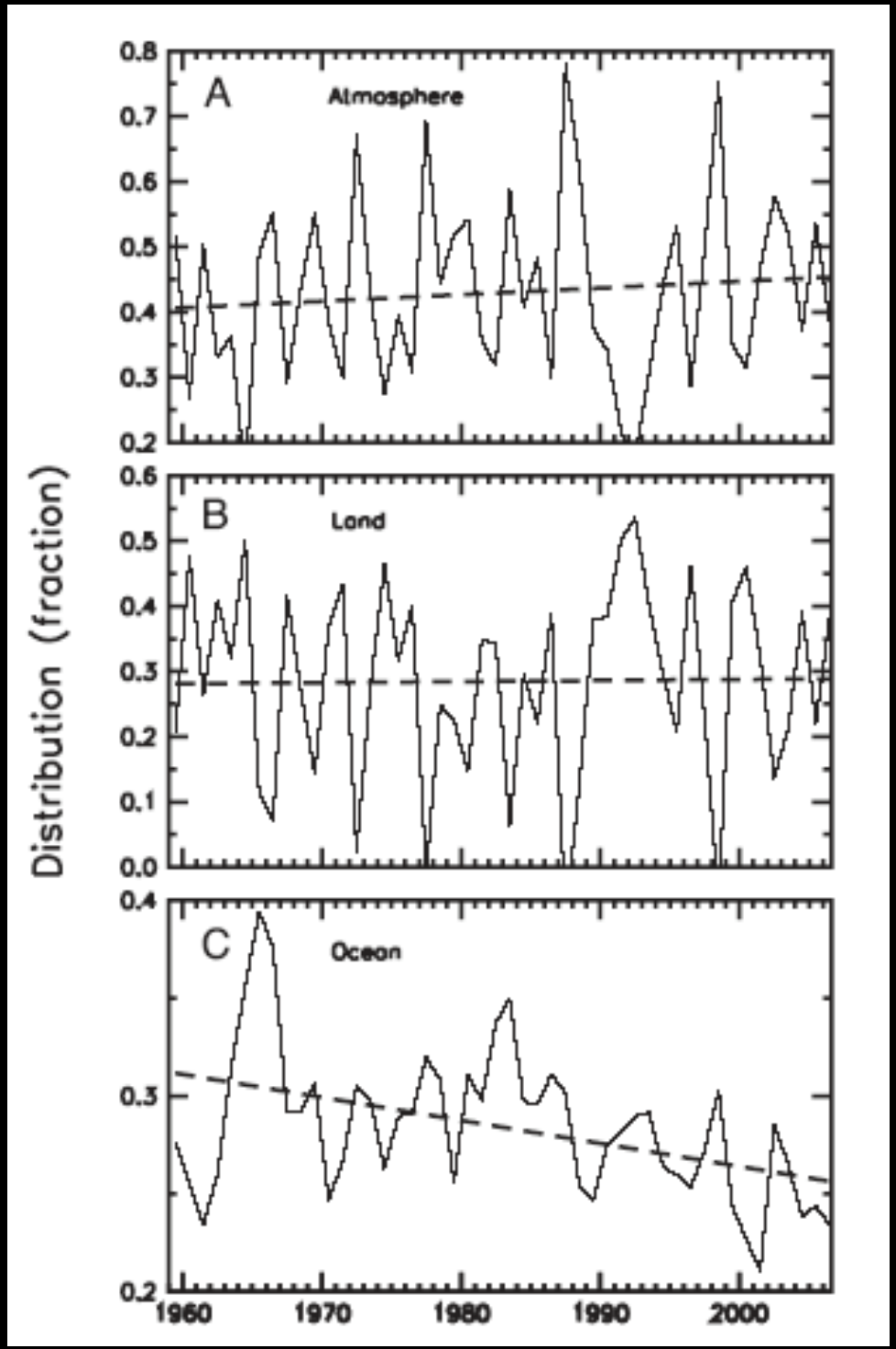
- Nick Bates: BIOS
- Corinne LeQuéré: BAS & UEA

- Funding from NASA

Context

- The ocean sink appears to be in decline
- What is the role of the Northern Oceans?



Canadell et al. 2007

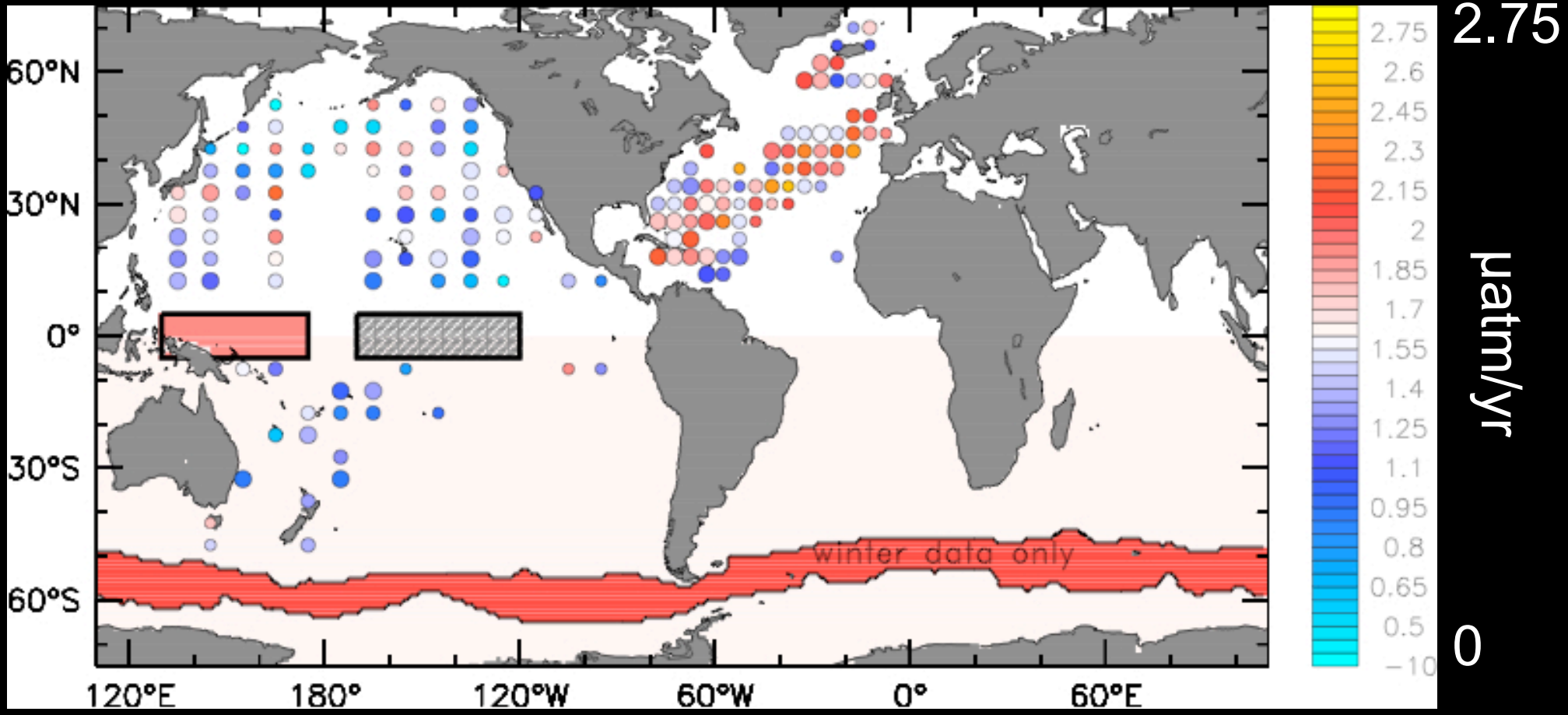
Take-Home Messages

- Regional trends can be identified in data
- Models capture some observed trends and elucidate mechanisms
- North and equatorial Pacific sink is steady
- Atlantic sink trend – methodologies disagree

- Need for additional analyses, including more joint model-data efforts

Observed trend in surface ocean pCO_2, 1981-2007

unpublished figure from C. LeQuéré and collaborators

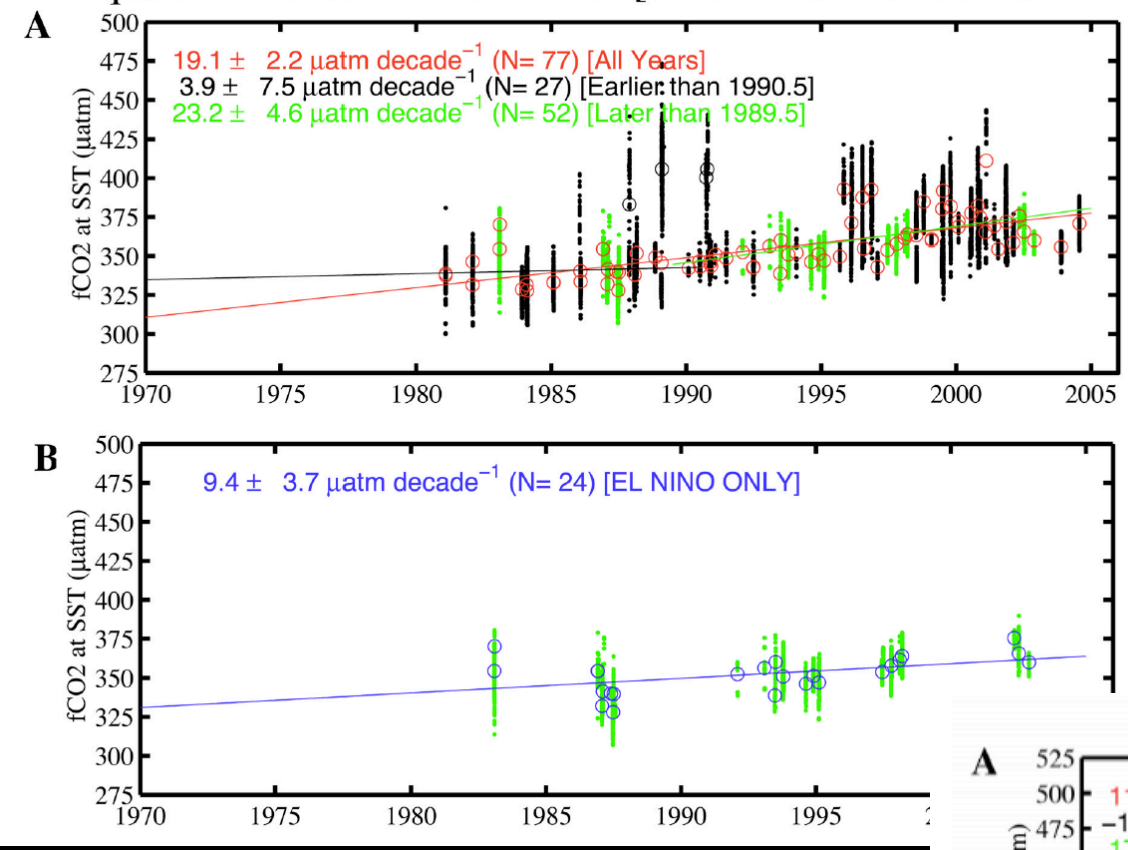


- White shading is 1.6 µatm/yr, the global atmospheric trend
- Larger dots have smaller error

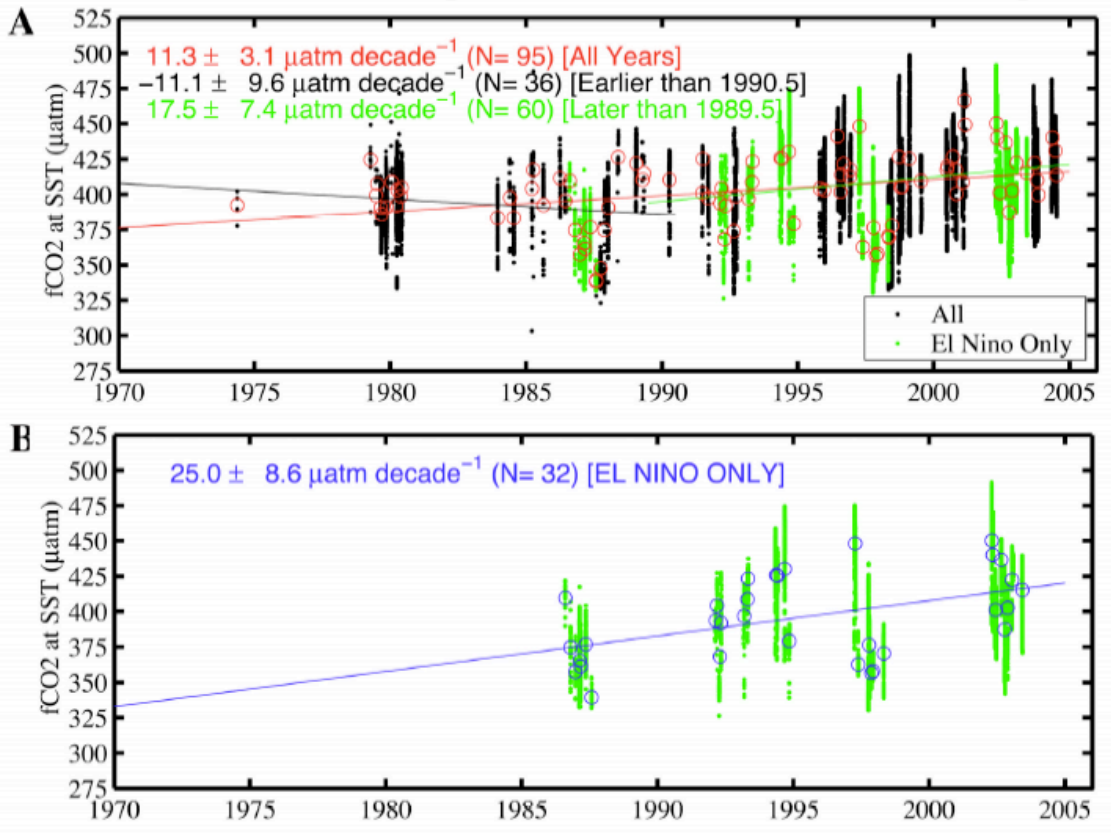
Equatorial Pacific

Feely et al. (2006)

Equatorial Western Warm Pool [5°N – 5°S and West of 175°E]



Nino 3.4 Area [5°N – 5°S and 170°W – 120°W]

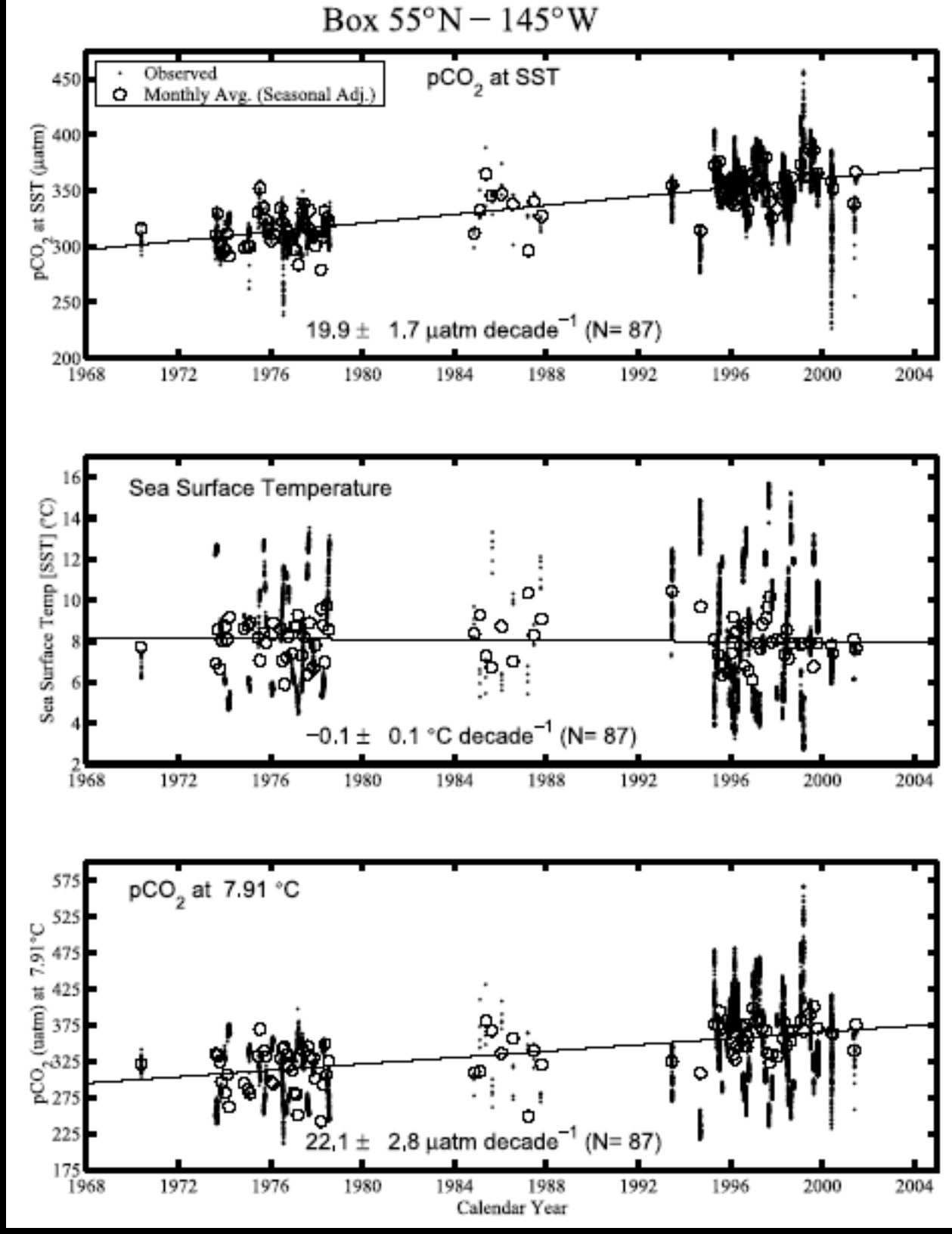


Atmosphere:
16 ± 3 µatm/yr

North Pacific

Takahashi et al. (2006)

Basin mean rate = 12.0 ± 4.8 µatm/yr



Observed trend in surface ocean pCO_2, 1981-2007

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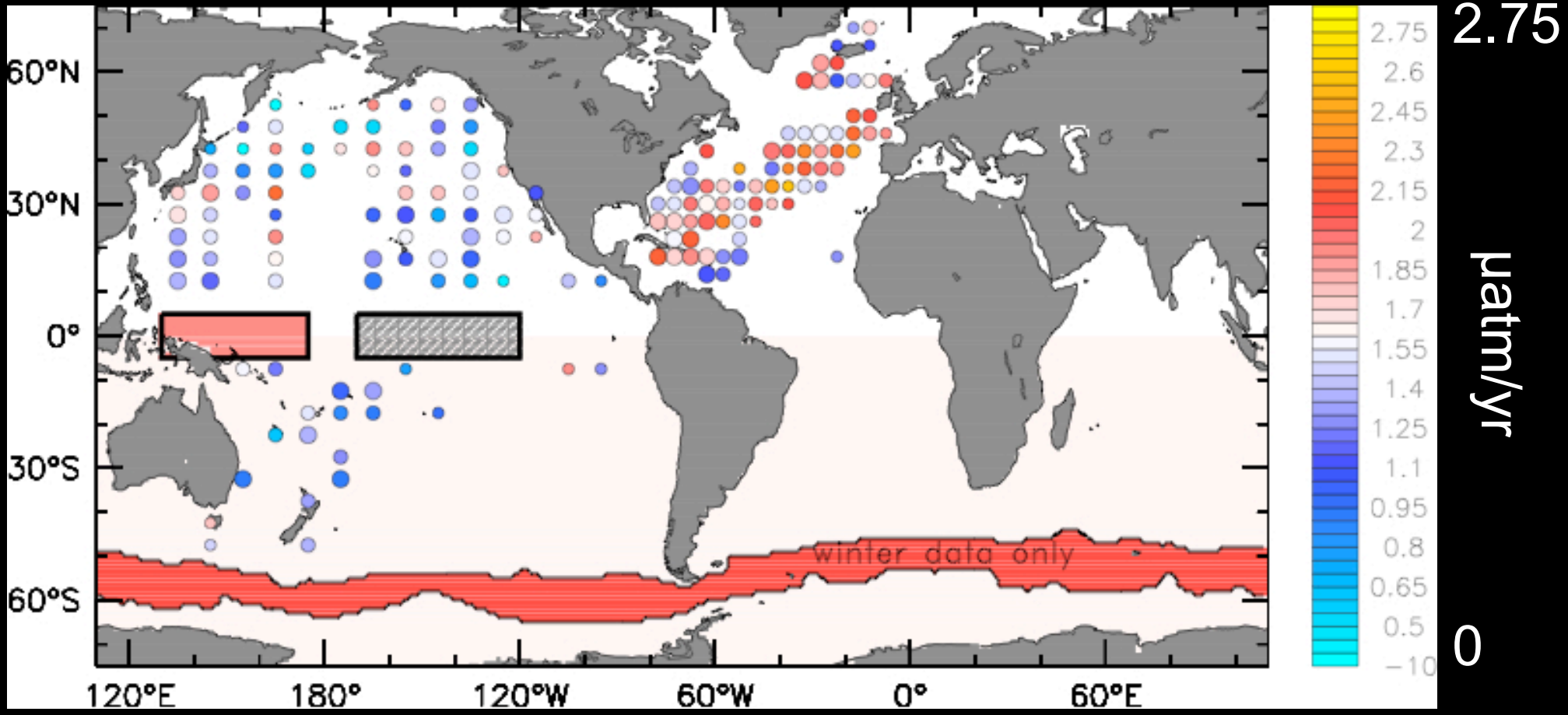

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North Atlantic

Observations and Models

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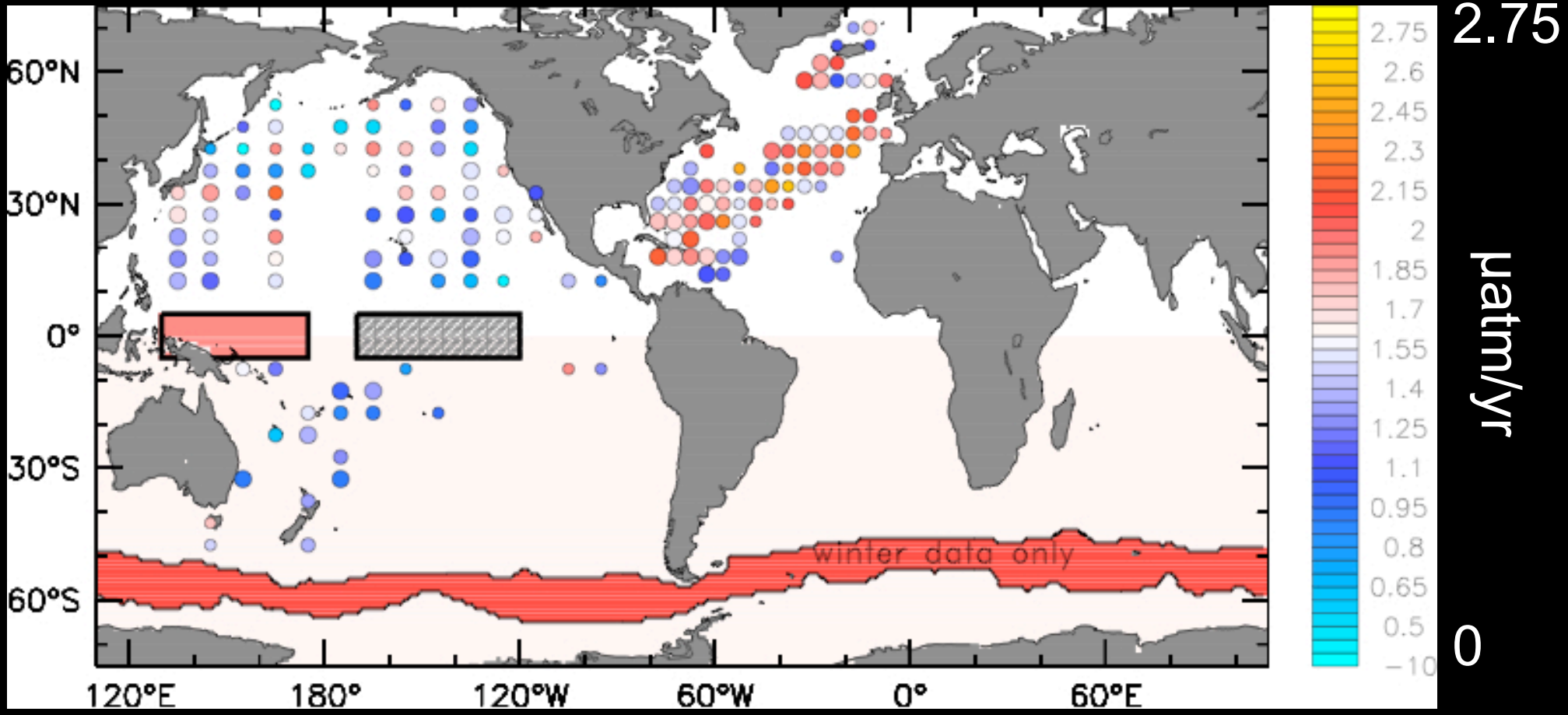

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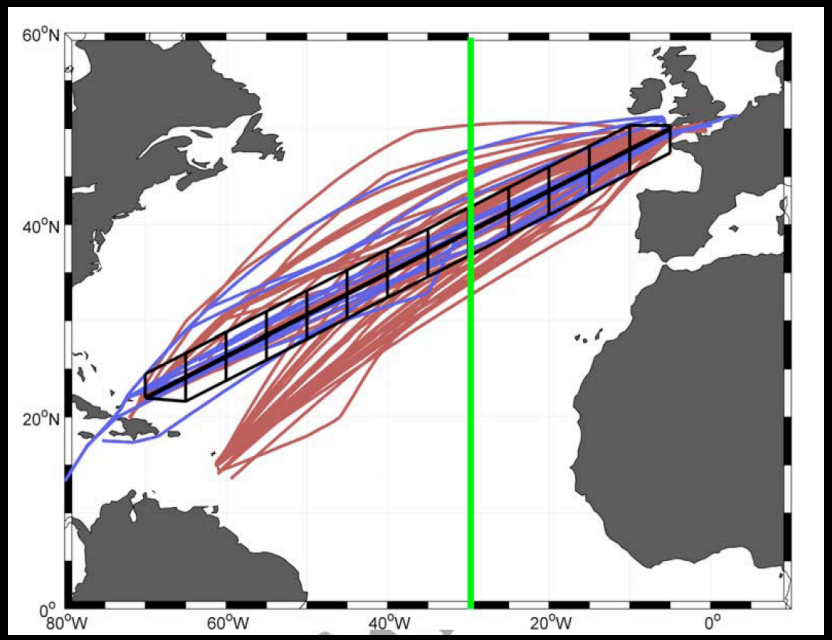
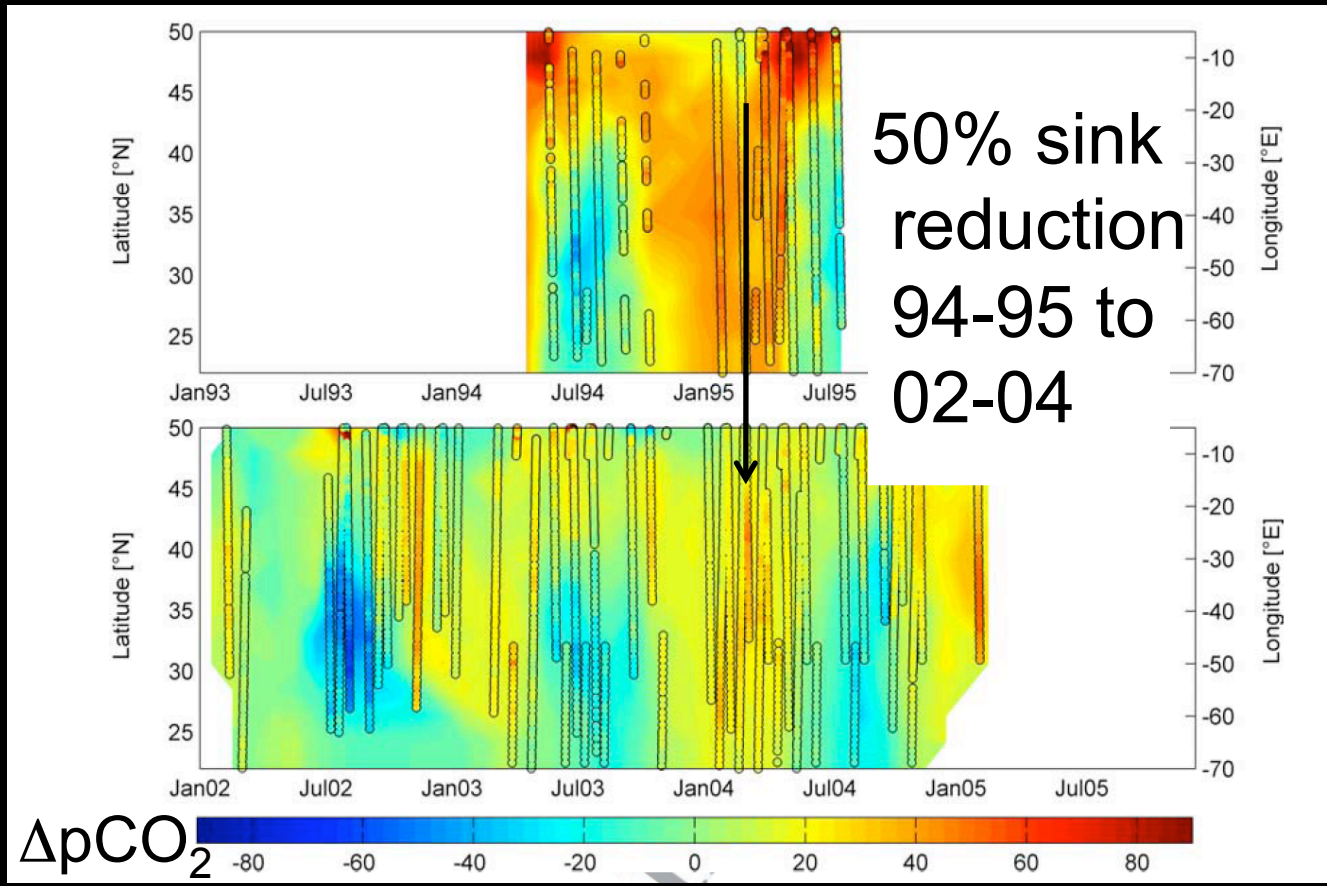


Observed trends in ΔpCO_2

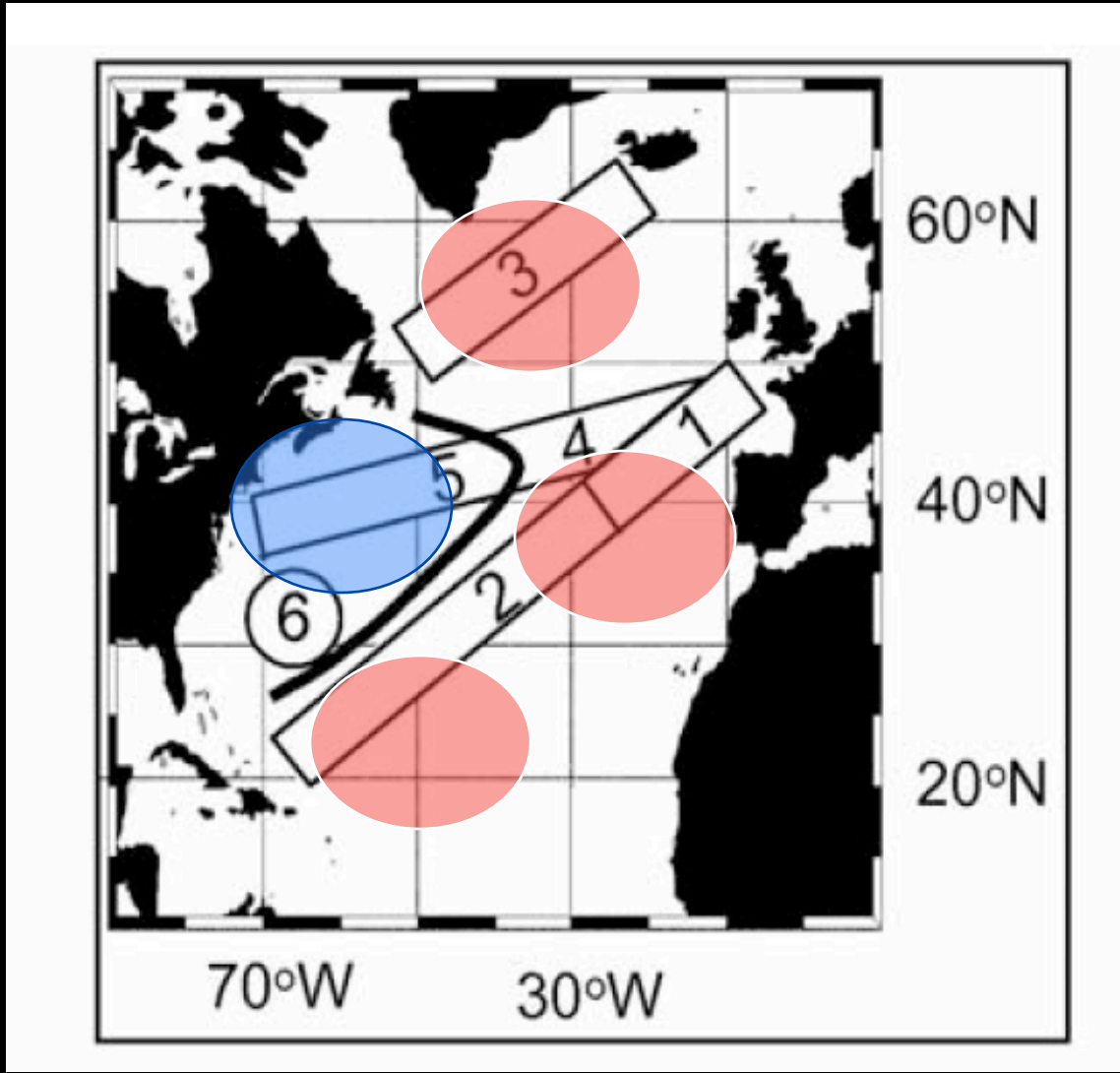
mid-1990's – mid-2000's

Schuster and Watson, 2007



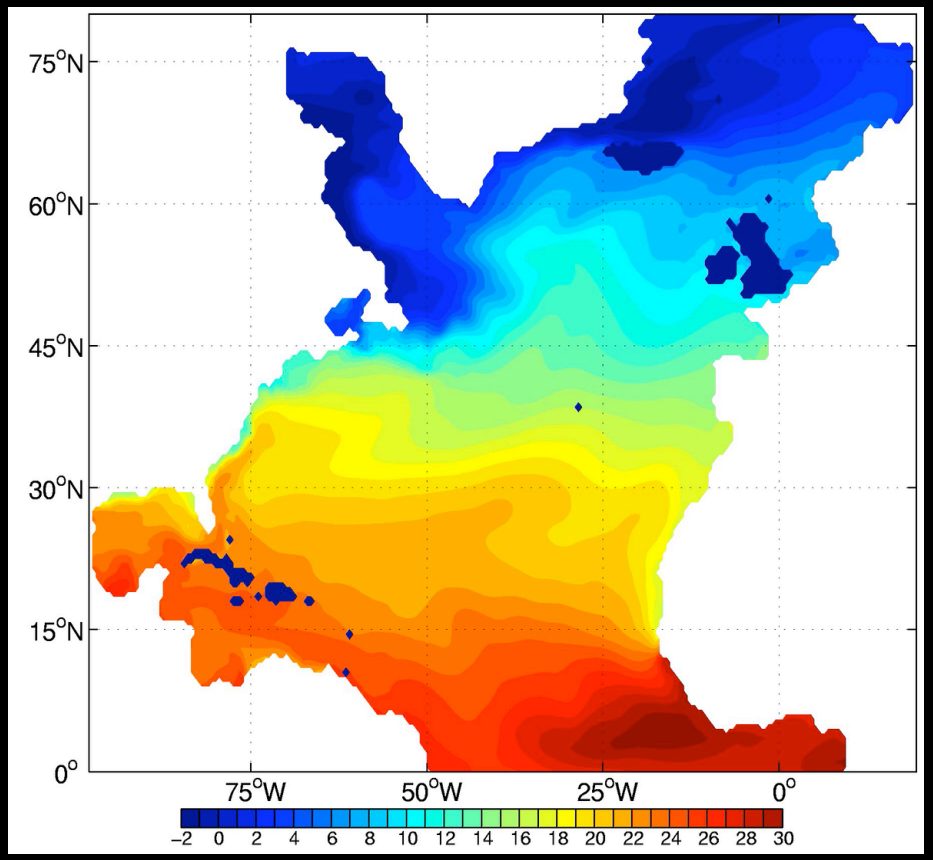
Summary for mid-1990's to early 2000's (Schuster and Watson, 2007)

- Regions 1-4 are declining in CO_2 uptake
- Region 5, 6 are neutral or increasing
- Conclusion: the basin-wide sink is declining



Modeling the North Atlantic carbon cycle

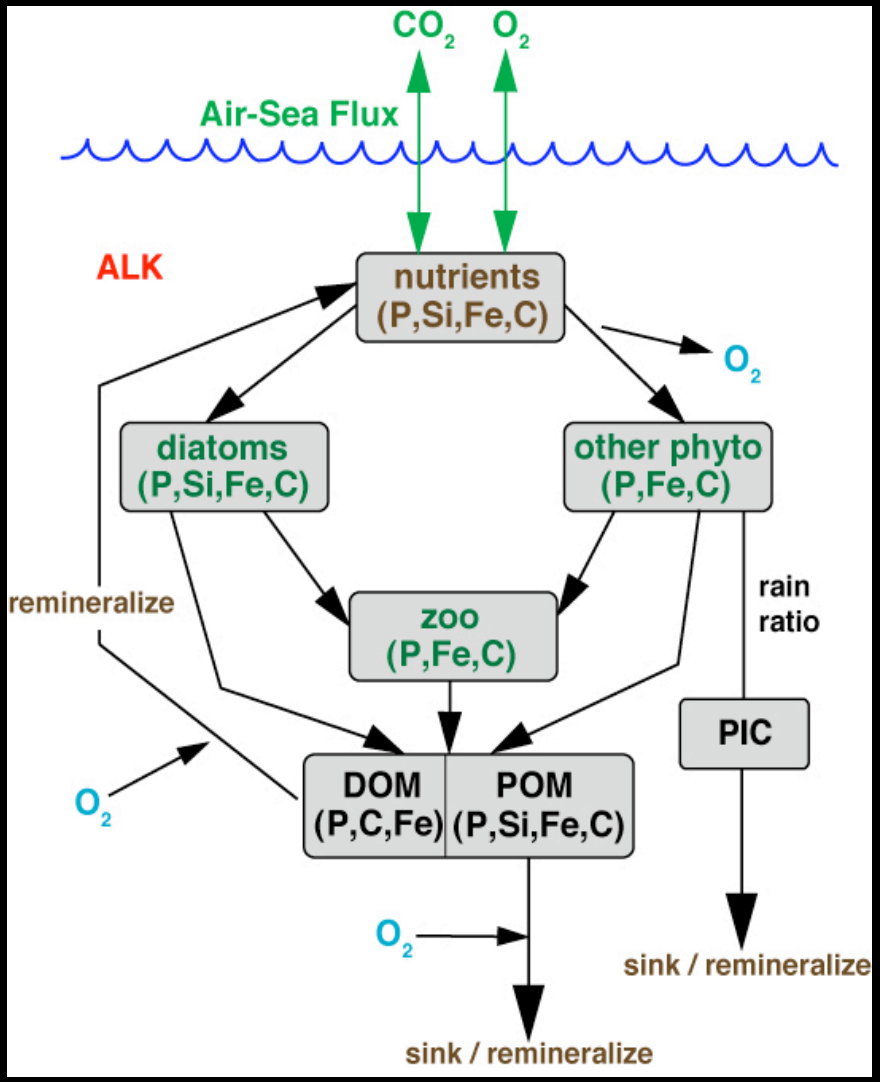
A North Atlantic regional model…



Sea Surface Temperature

- MITgcm, 20S-80N
- 0.5 x 0.5 horizontal, 23 vertical
- Parameterizations
  - GM-Redi (isopycnal mixing)
  - KPP (mixed layer)
- Forcing:
  - daily NCEP, 1992-2006
  - SST restored to Reynolds et al 2002
- Scenarios:
  - Modern (pCO_2^{atm} from Mauna Loa)
  - Preindustrial (pCO_2^{atm} = 280ppm)

Ecosystem and carbon cycle



- Dutkiewicz et al. (2005) ecosystem
- 2 phytoplankton, 1 zooplankton class, dissolved and particulate detritus
- Explicit silica and iron
- Coupled carbon and oxygen cycles

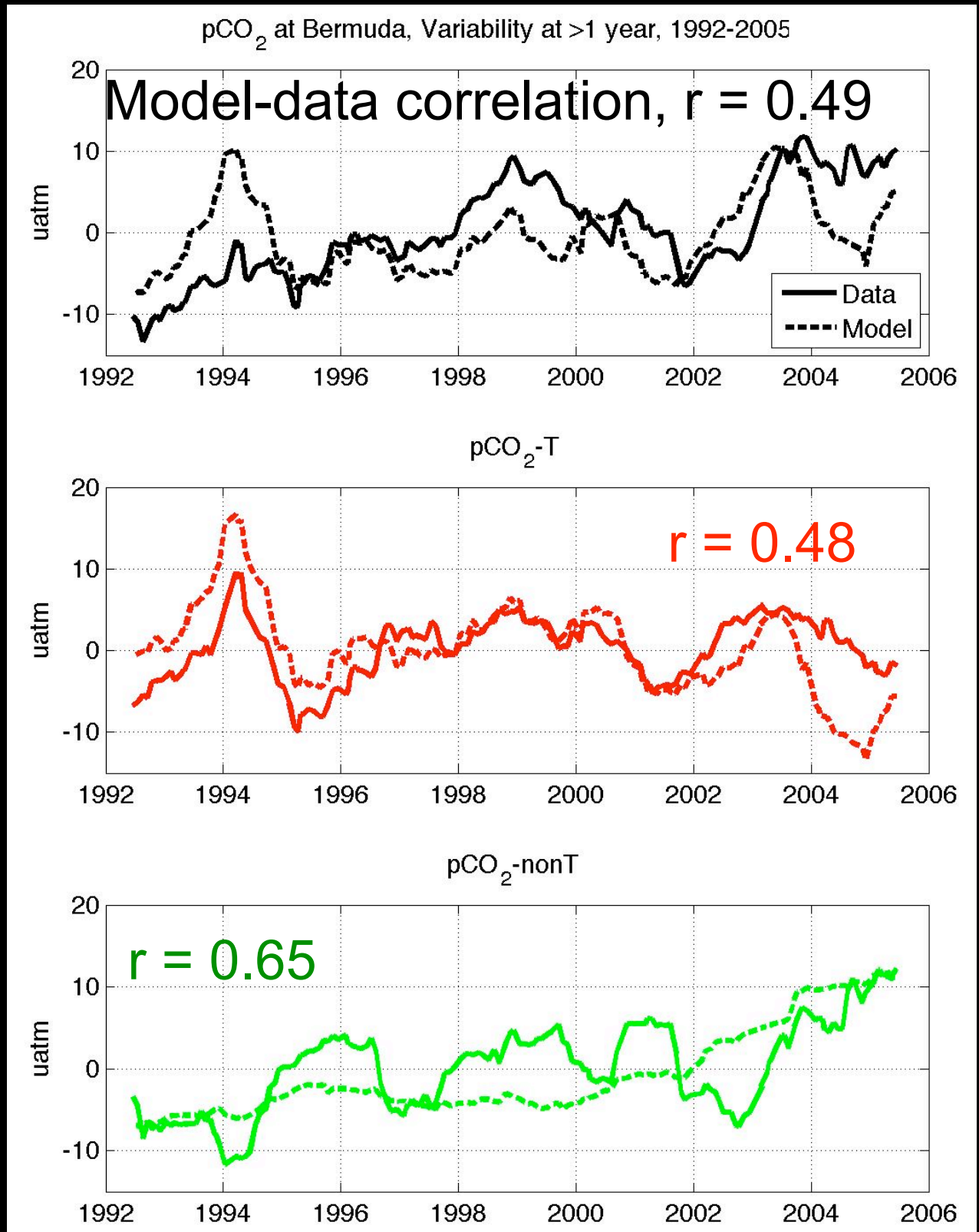
Low frequency (>1 year) pCO_2 variability at Bermuda

Data: Bates, 2007

$$pCO_2 - T = \overline{pCO_2} \cdot \exp[0.0423(T - \bar{T})]$$

$$pCO_2 - nonT = pCO_2 \cdot \exp[0.0423(\bar{T} - T)]$$

Takahashi et al, 1993

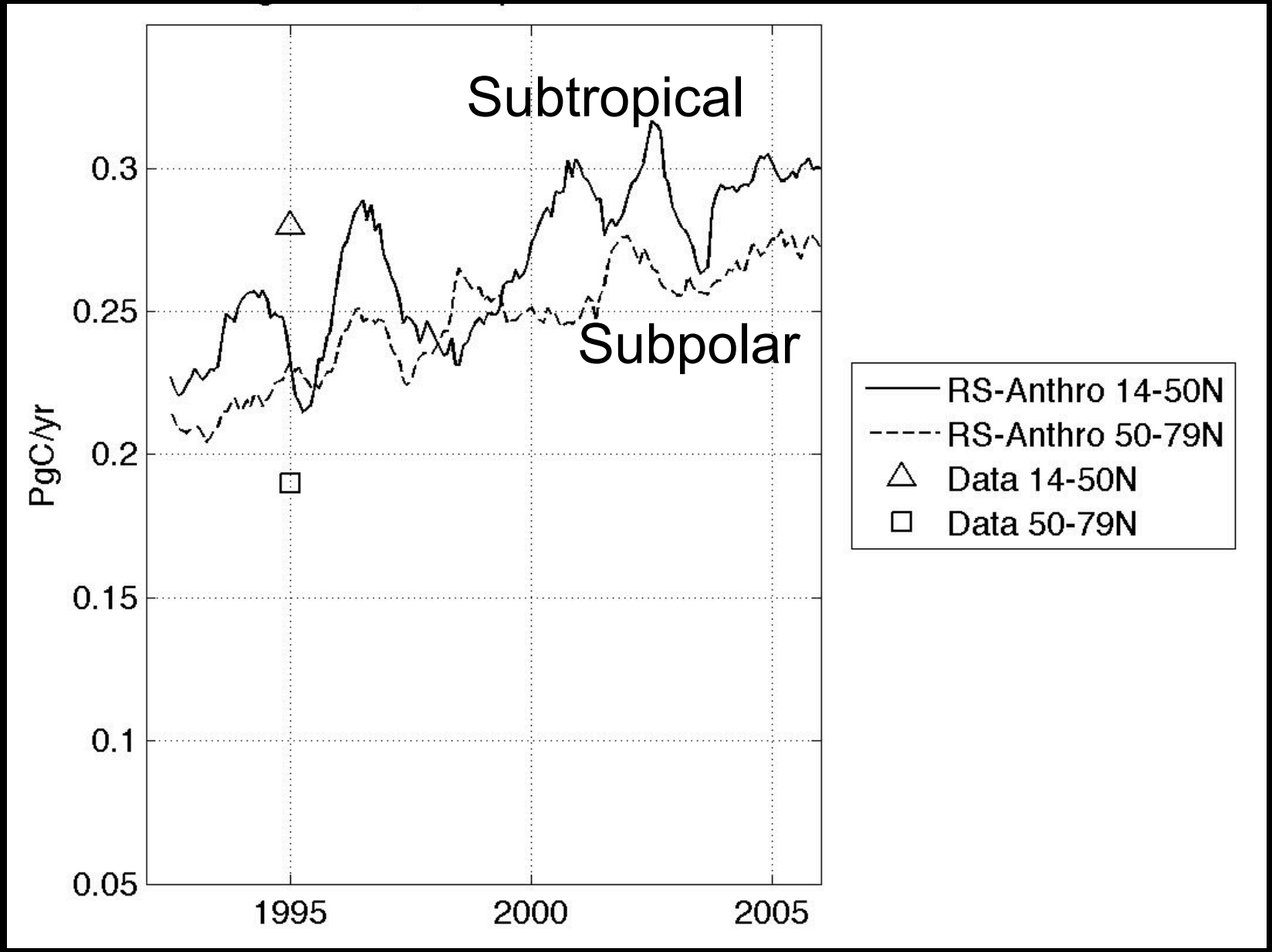


Variability and trends across the North Atlantic

1992-2006

Basin-scale CO_2 flux variability

compared to Takahashi et al. 2002 in 1995



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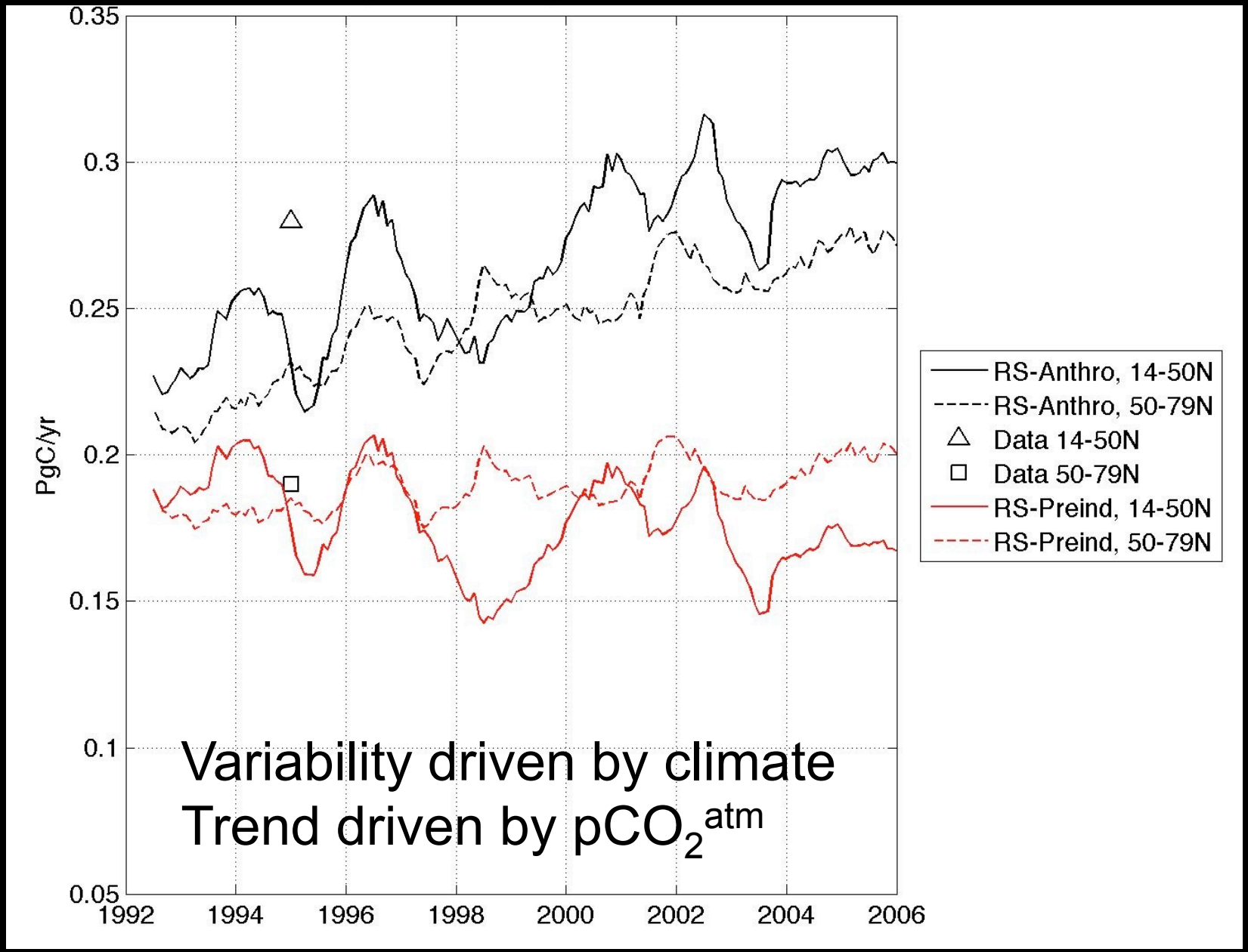
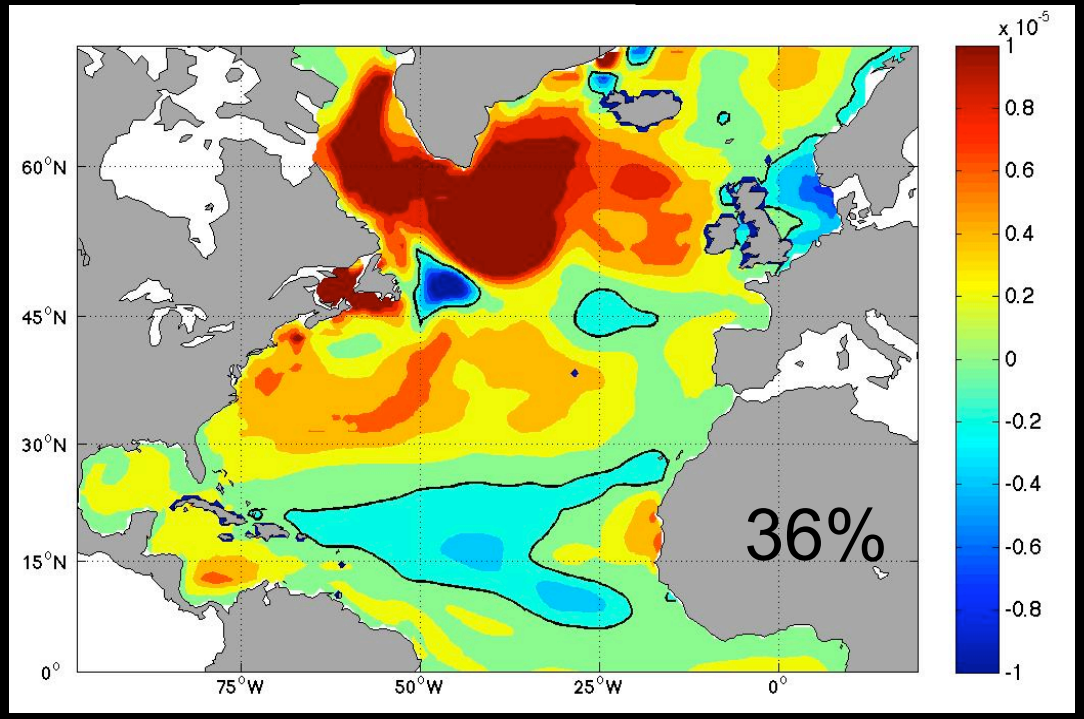


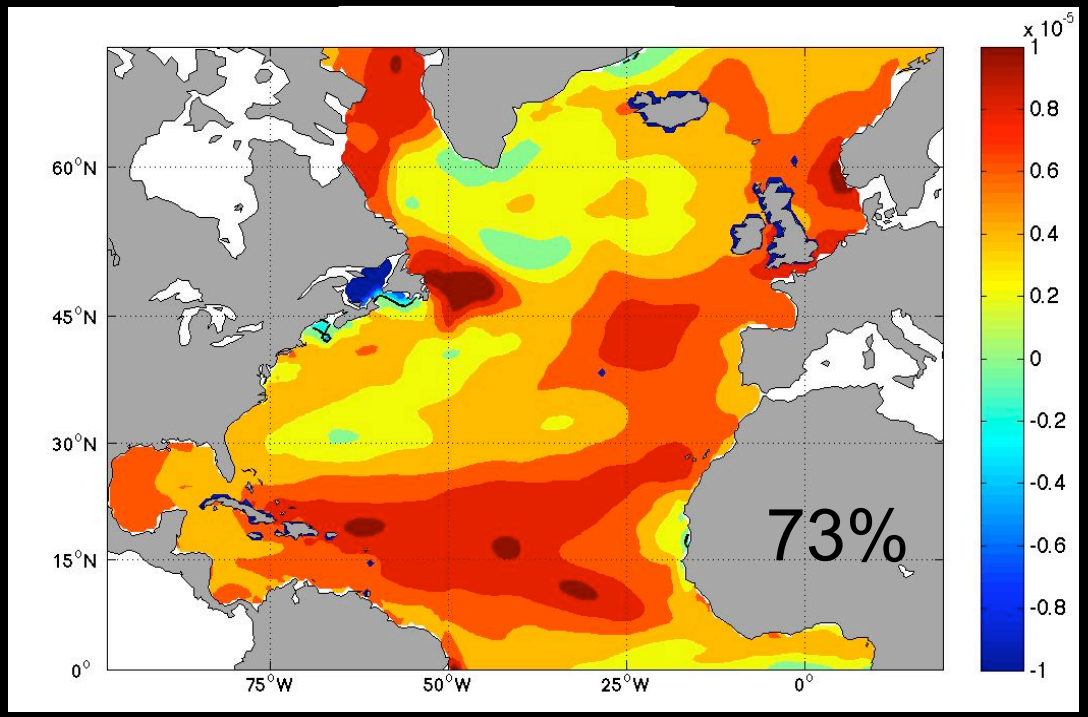
What are the patterns of change?

EOF1 CO_2 flux and pCO_2

CO_2 FLUX



pCO_2



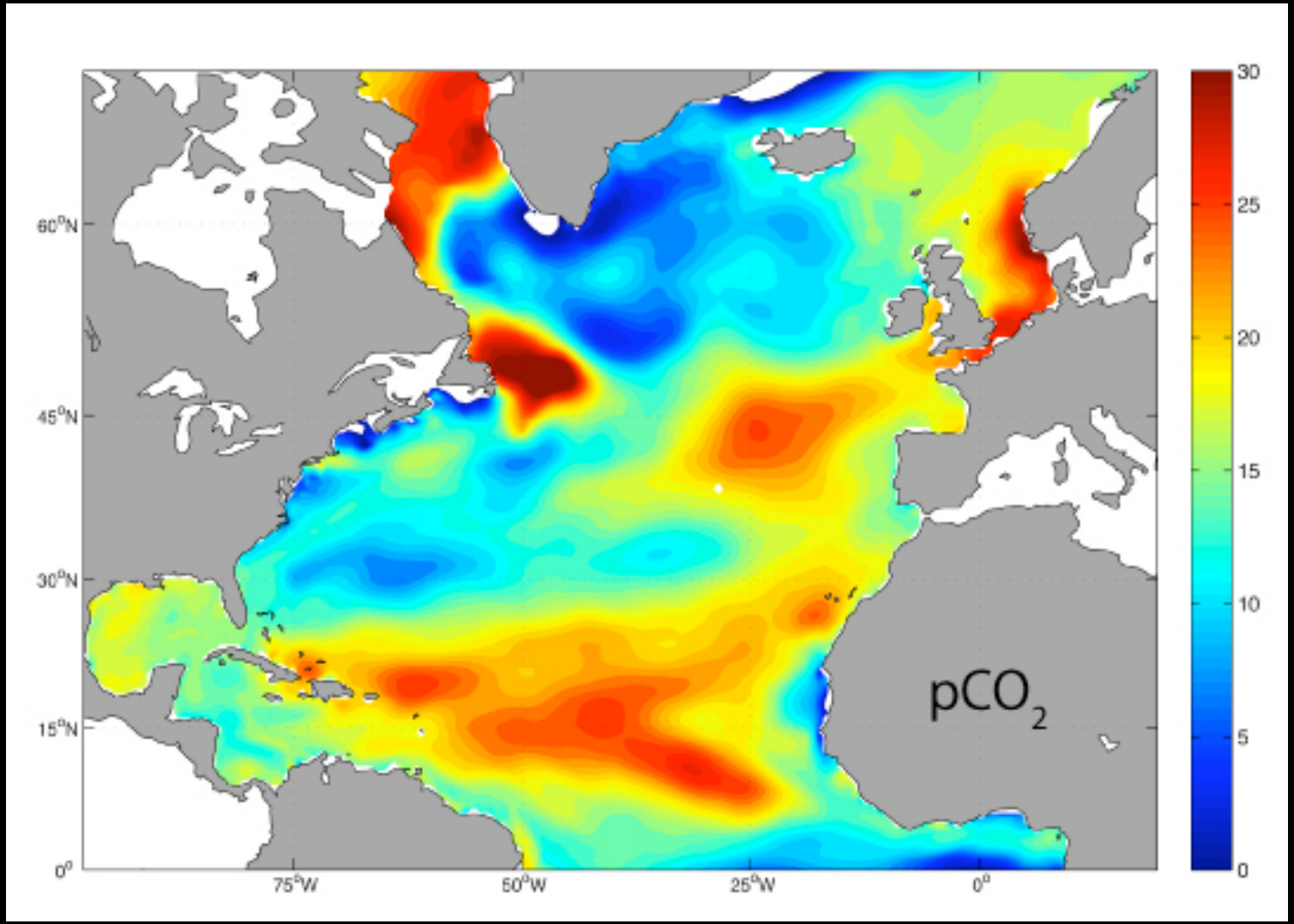
PC1 of pCO_2 (blue) and flux (red) r = 0.87

What drives the modeled trend?

Consider difference of 4yr means
(2003-2006) – (1992-1995)

Ocean pCO_2 trend

(2003-2006) – (1992-1995)

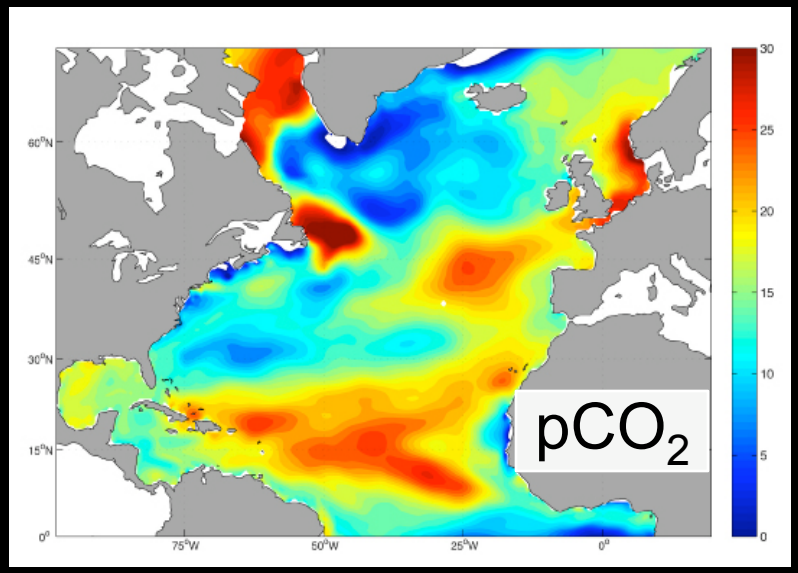


30 uatm

0 uatm

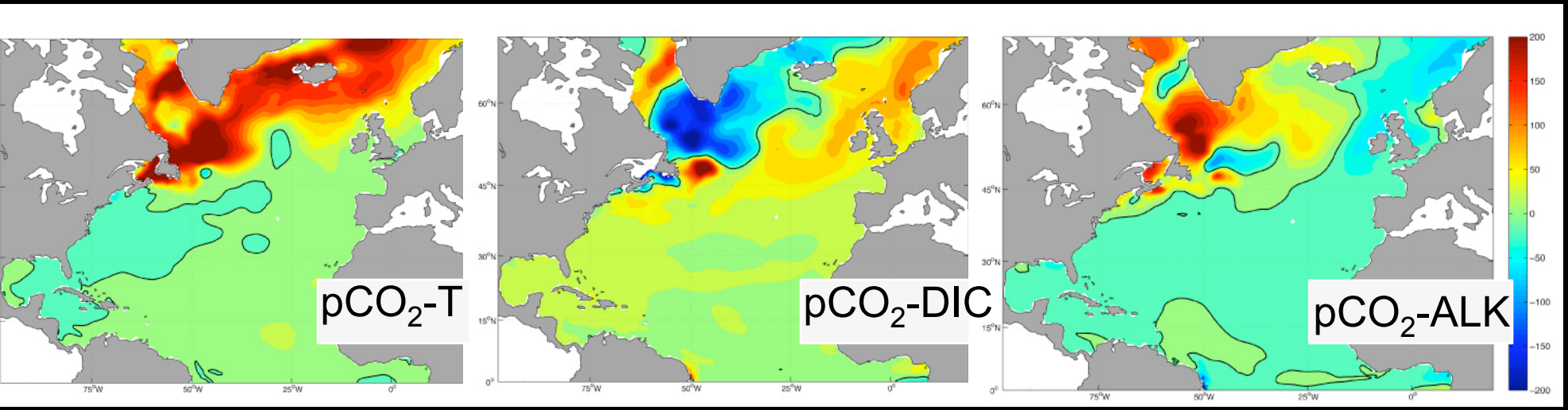
pCO_2 and component trends

(2003-2006) – (1992-1995)



30 uatm

0 uatm



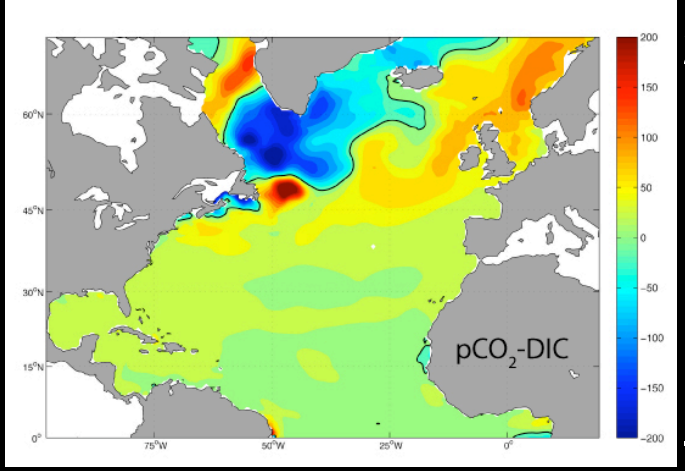
200 uatm

-200 uatm

pCO_2 Trends

- Model illustrates Northwest/Southeast asymmetry in flux trend

- Due to combined effect of SST, DIC and ALK on ocean pCO_2
  - SST change consistent with data
  - What drives DIC change?

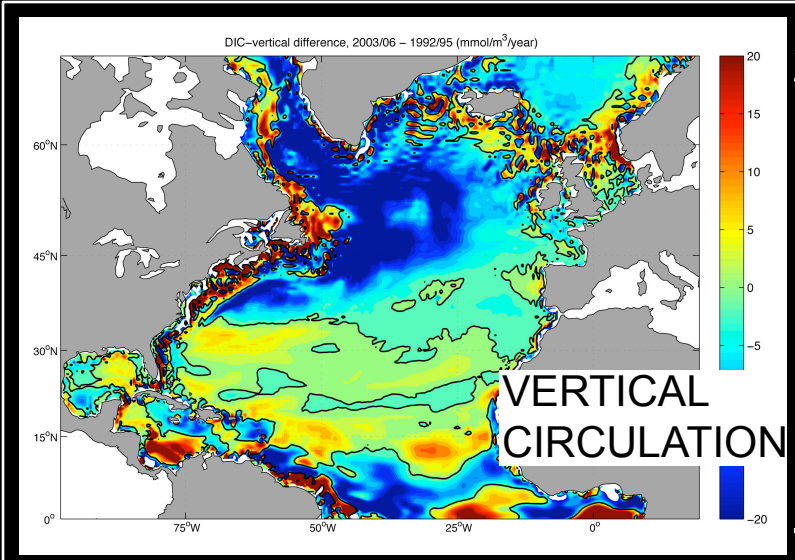


200 uatm

-200 uatm

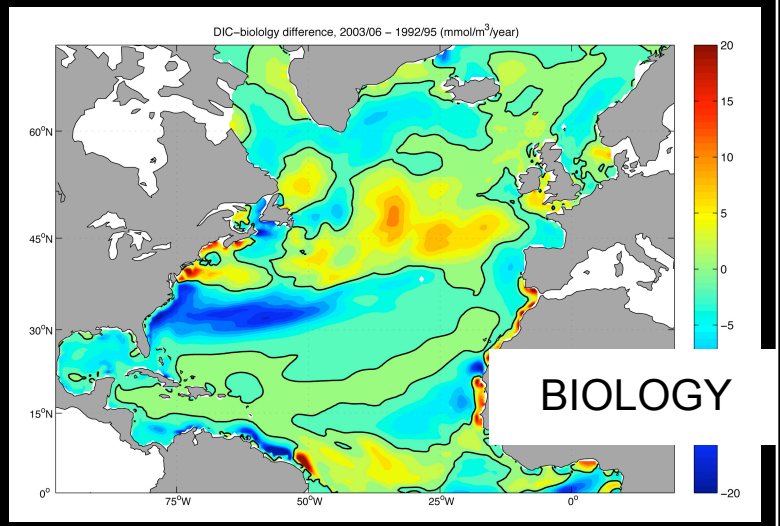
Difference in rates of DIC change

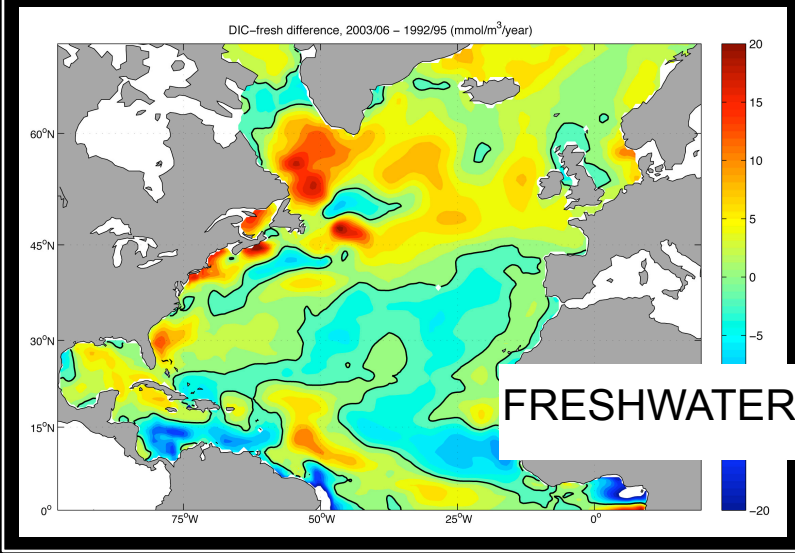
(2003-2006) – (1992-1995)

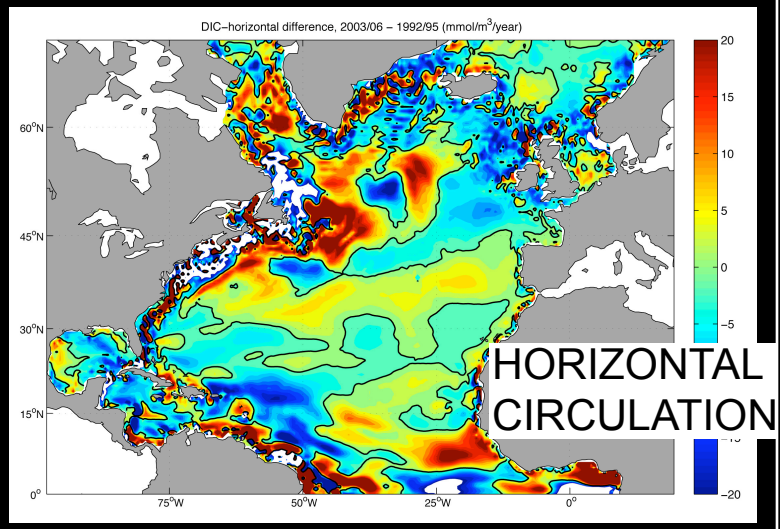


20 mmol/m^3/yr

-20 mmol/m^3/yr







Summary

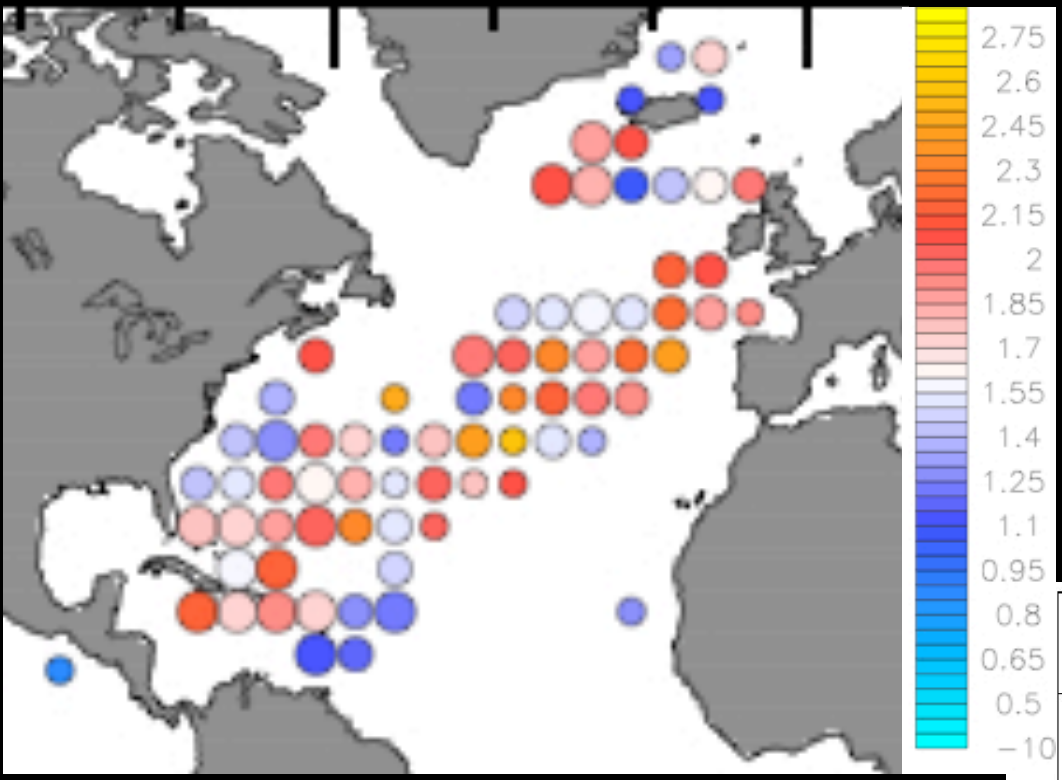
Surface ocean carbon cycle trends North Atlantic, 1992-2006

- pCO_2 increase spatially variable, max 30 μatm
- pCO_2-SST, pCO_2-ALK, pCO_2-DIC trend ±200 μatm, but largely counteract each other
  - SST change consistent with observations
  - Vertical mixing, biology, freshwater and horizontal transport all contribute to pCO_2-DIC trend

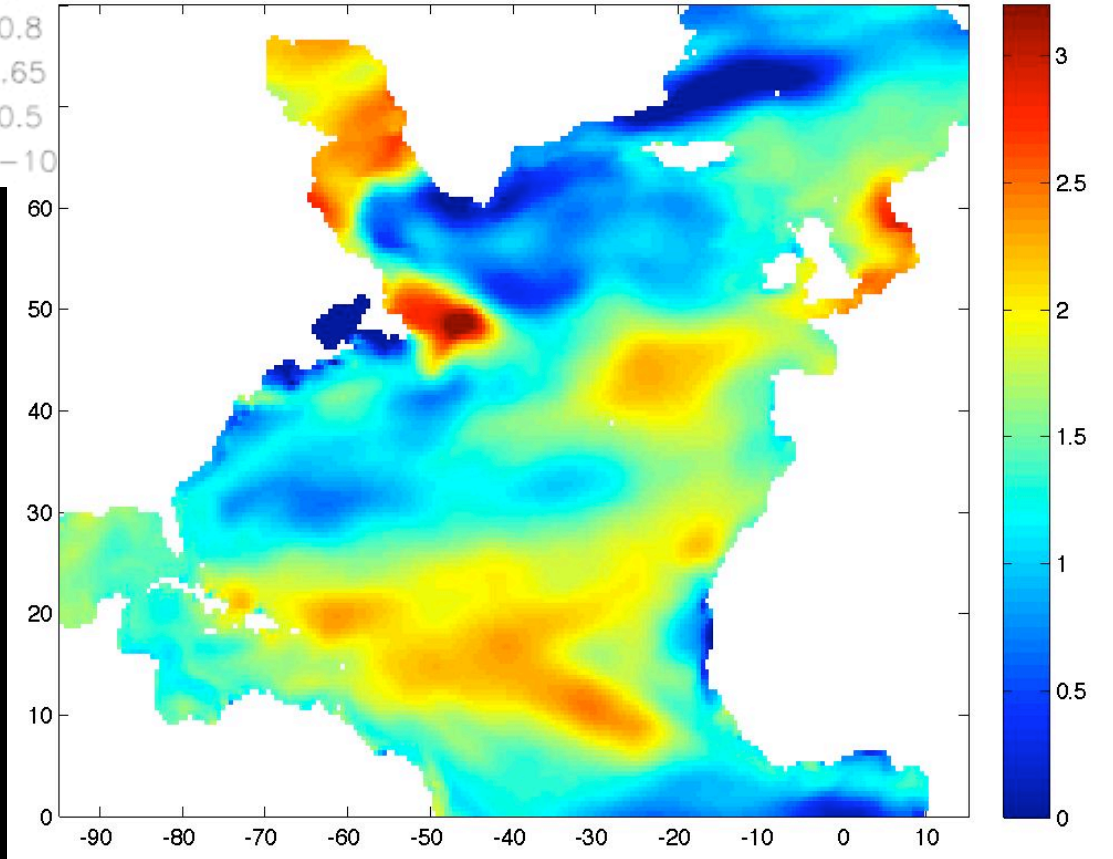
Does the model agree with observations?

pCO_2 trends
µatm/yr

Observed Trend, 1981-2007

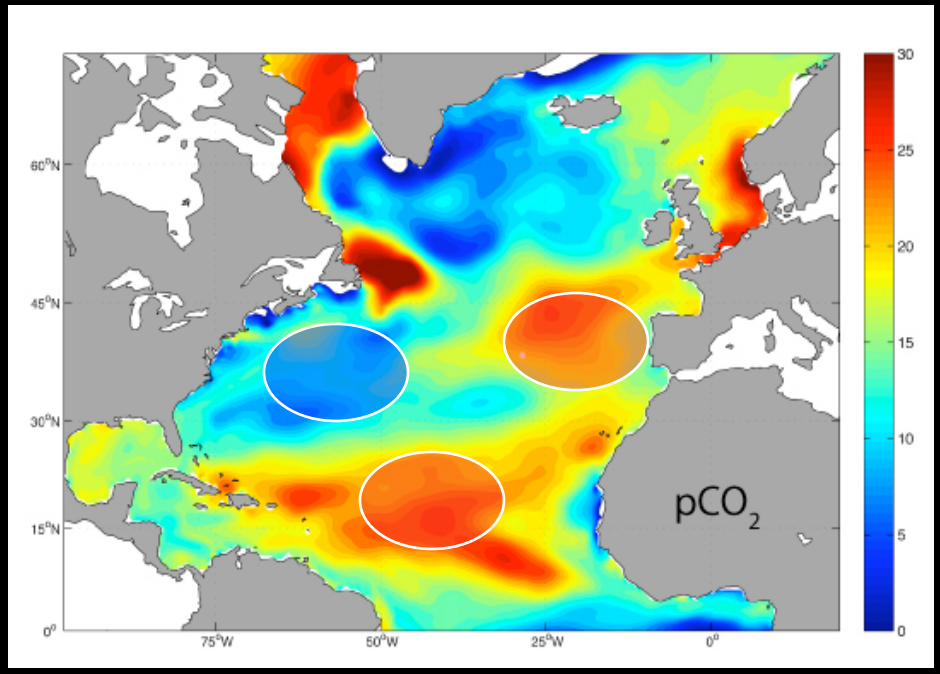


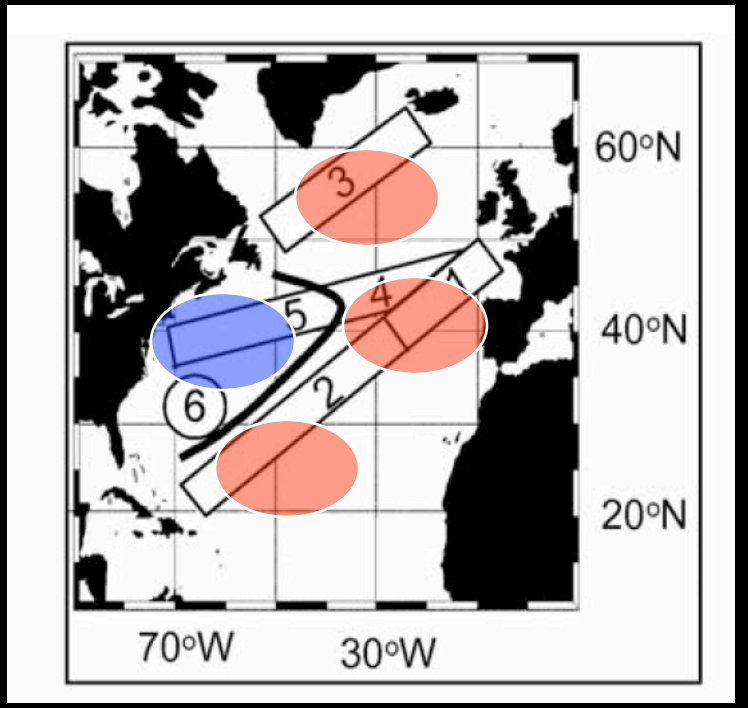
Modeled Trend, 1992-2006



Integrated model trend,
>15N = 1.43 uatm/yr

mid-1990's – mid-2000's

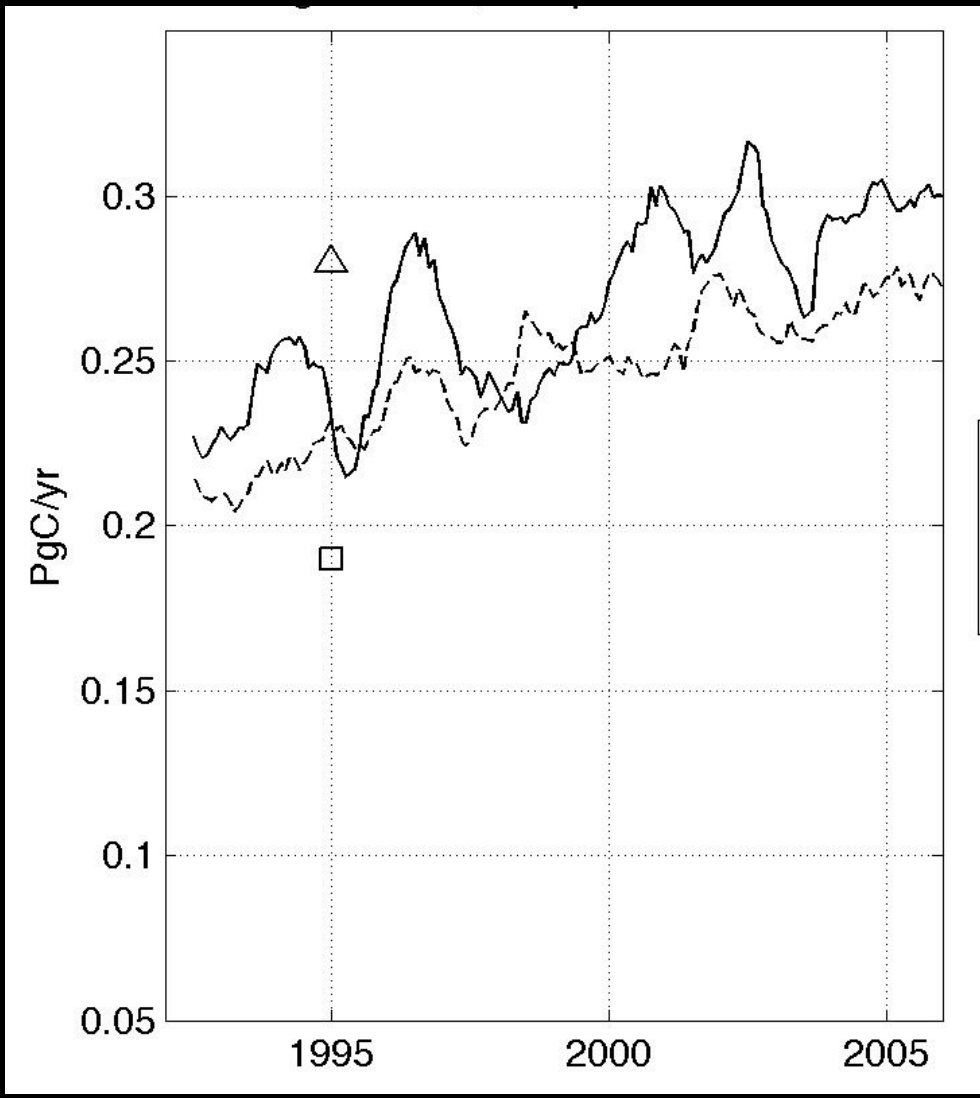




- Consistent in West, East, South
- Not consistent in North

How is the subpolar sink changing?

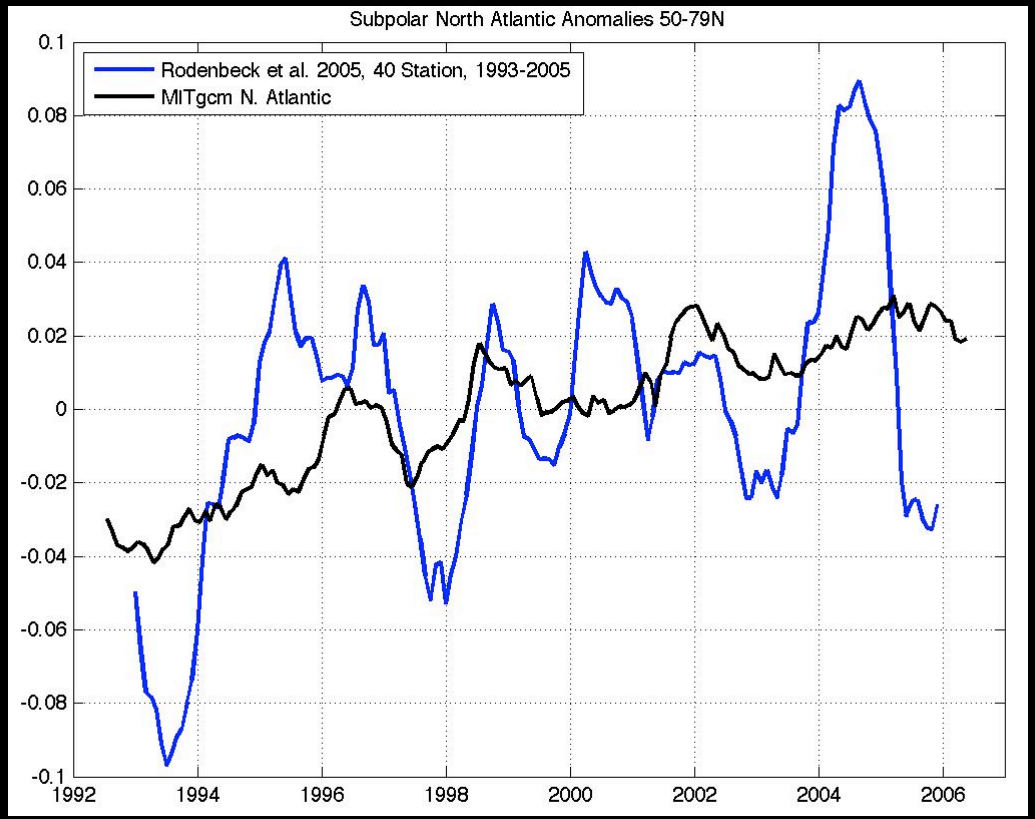
- MITgcm: increasing
- Shuster and Watson (2007): declining
- Atmospheric inversion?



Carbon sink trend

Subpolar N. Atlantic (50-79N)

	93–96 mean	02-05 mean	Percent change
MITgcm	0.22 PgC/yr	0.26	**+18%**
Rodenbeck et al. ‘05	0.15	0.18	**+20%**



Conclusions

- Pacific –
  - $pCO_2^{ocean} \sim pCO_2^{atm}$
  - Variability dominant feature of equatorial
- North Atlantic
  - Heterogeneous pattern in pCO_2^{ocean} trend
  - mid-1990's to mid-2000's
    - $pCO_2^{ocean} > pCO_2^{atm}$ in south and east
    - $pCO_2^{ocean} < pCO_2^{atm}$ in western subtropics
    - Methodologies disagree in western subpolar

Fall AGU

Decadal Trends in the Ocean Carbon Cycle

Session OS14

Take-Home Messages

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- Models capture some observed trends and elucidate mechanisms
- North and Tropical Pacific sink is steady
- Atlantic sink trend – methodologies disagree

- Need for additional analyses, including more joint model-data efforts