Trends in ocean carbon uptake

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Are trends in the global carbon cycle already detectable?

Reduction in fraction stored in the ocean (Canadell et al. 2007)

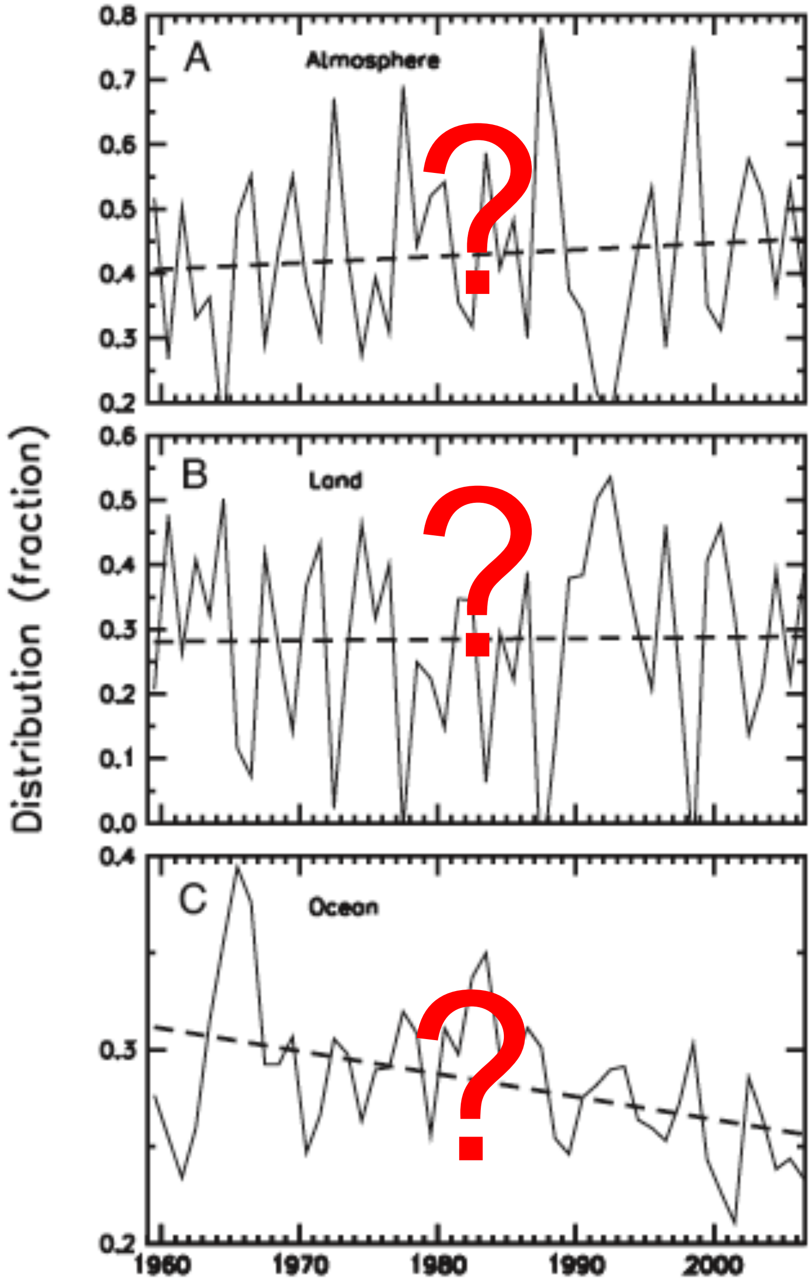


Fig. 2. Fraction of the total emissions (F_{Foss} + F_{LUC}) that remains in the atmosphere (*A*), the land biosphere (*B*), and the ocean (*C*).

Modeled-based assessment of global CO_2 sink impacts due to climate feedbacks: 1981-2007 = -0.20 PgC/decade

Mechanism	Sink impact	Regional notes
Warming	-20%	50% in North Atlantic alone
Wind change	-63%	>80% in Tropical Pacific >30% in S. Ocean Compensation elsewhere
Heat, Freshwater flux	+15%	In Northern Hemisphere
Nonlinear	-32%	>65% in Tropics

LeQuéré et al. 2010

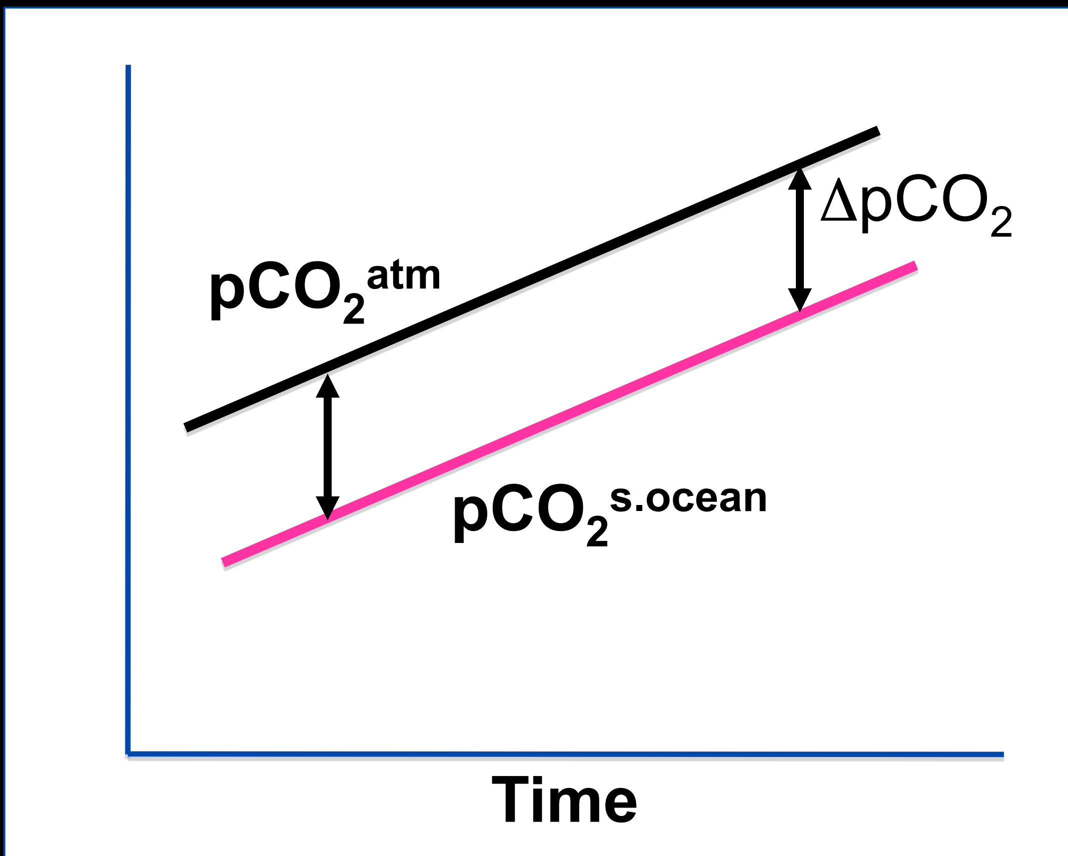
Earlier modeling found that warming to be dominant negative feedback (-84%) on CO_2 sink in first 100yrs after 4xCO2 pulse (Sarmiento and LeQuéré, 1996)

Outline

- Background: Ocean carbon sink trends from surface ocean pCO_2
- N. Atlantic trends from Takahashi database
  - Gyre-scale biomes
  - Distinguishing variability from trends
  - Subtropics: Negative feedback from warming
- Global extension

Trends from surface ocean pCO_2:

If pCO_2^{atm} only change, i.e. circulation, biology constant



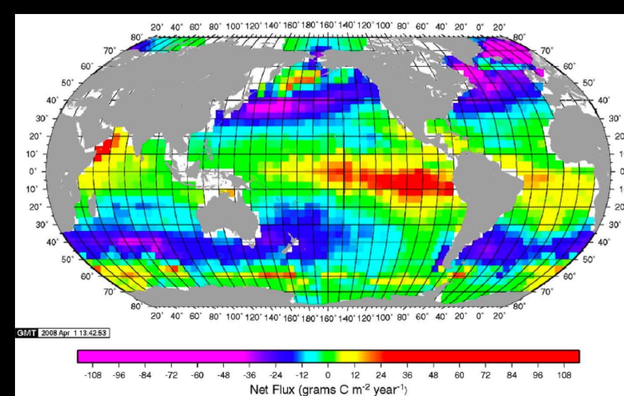
"Equilibration"

$dpCO_2^{s.ocean}/dt = dpCO_2^{atm}/dt$

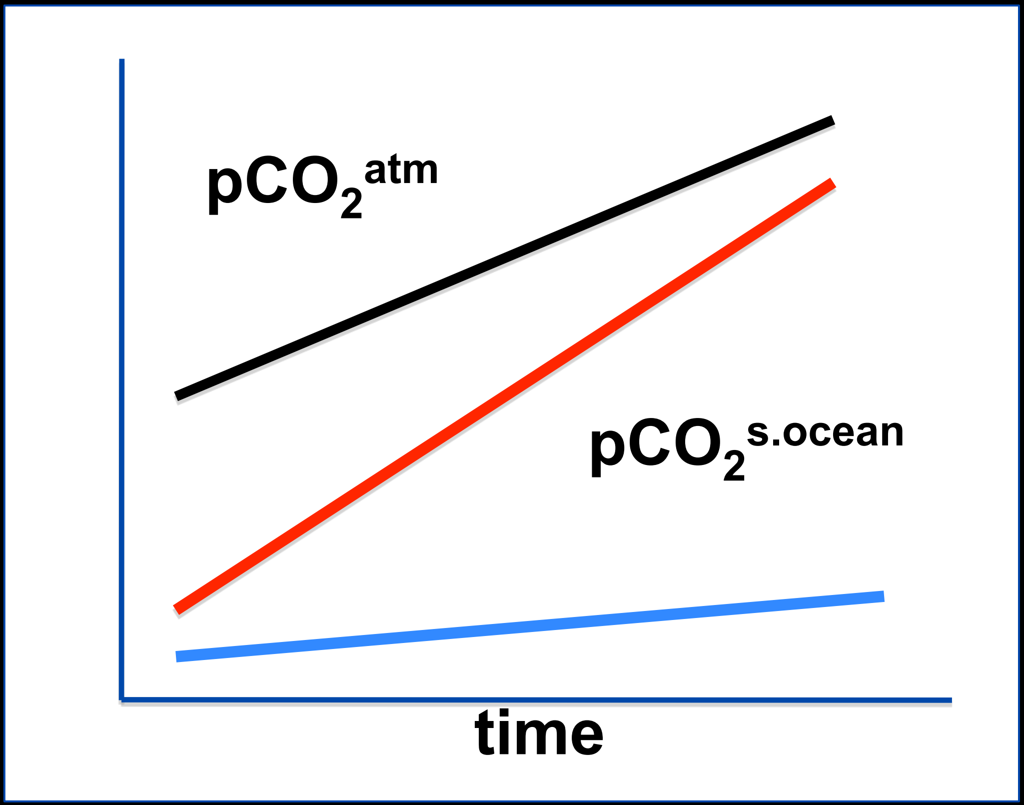
$d\Delta pCO_2/dt = 0$

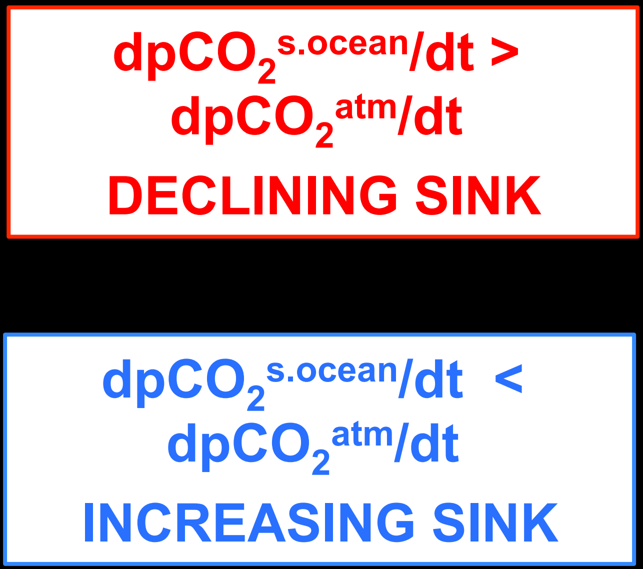
$d(CO_2Flux)/dt = 0$

STEADY SINKS AND SOURCES

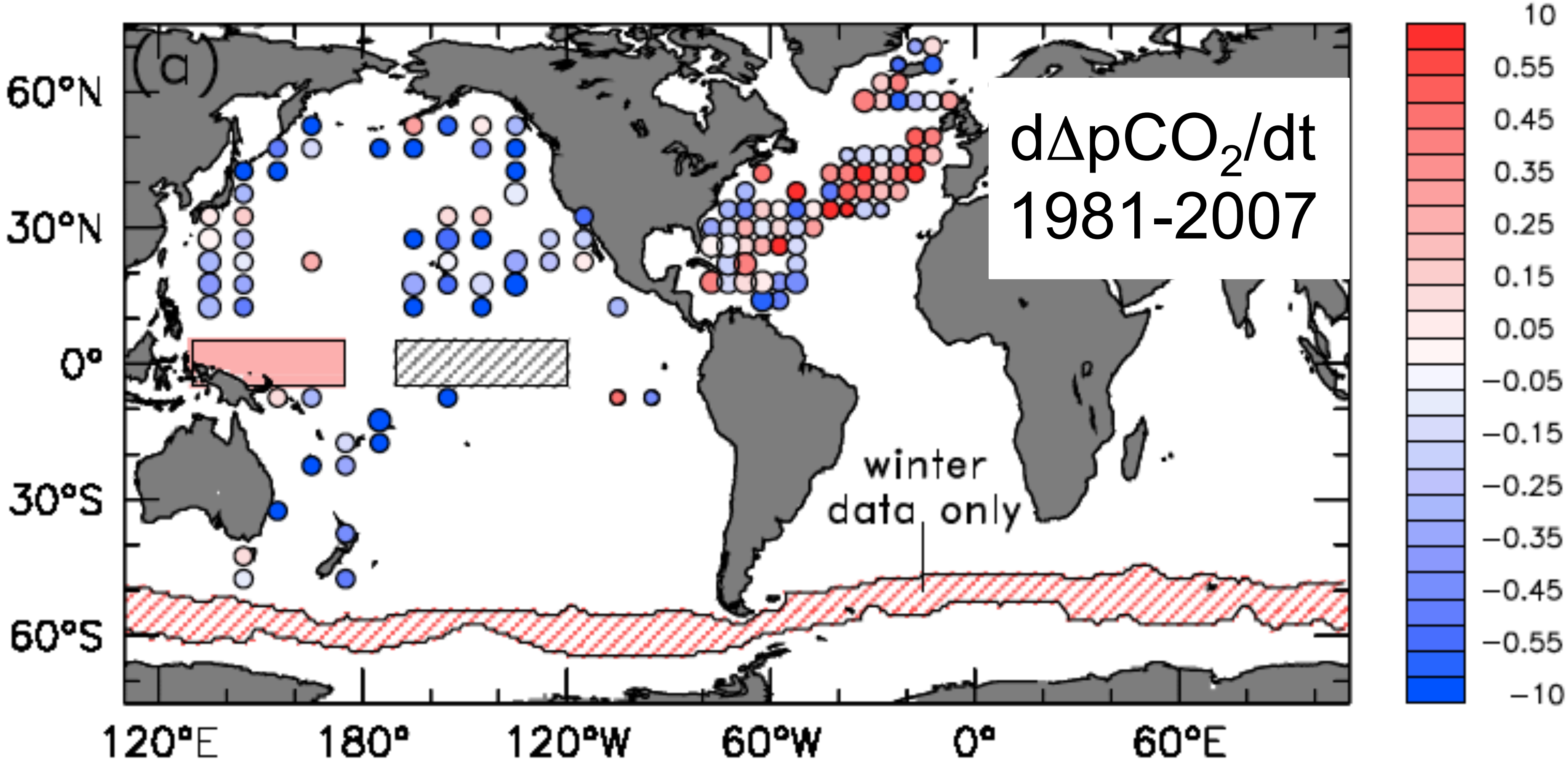


As corollary, $dpCO_2^{s.ocean}/dt \neq dpCO_2^{atm}/dt$ has been interpreted as a change in flux *due to change in biology or circulation*



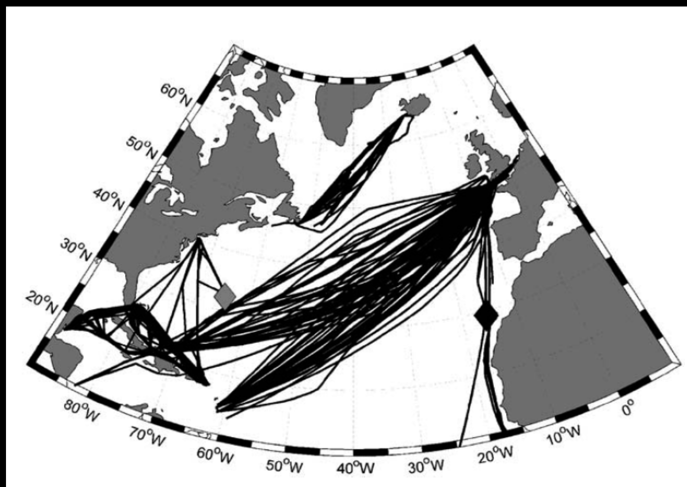


Mostly from Takahashi pCO_2 database, model in S. Ocean

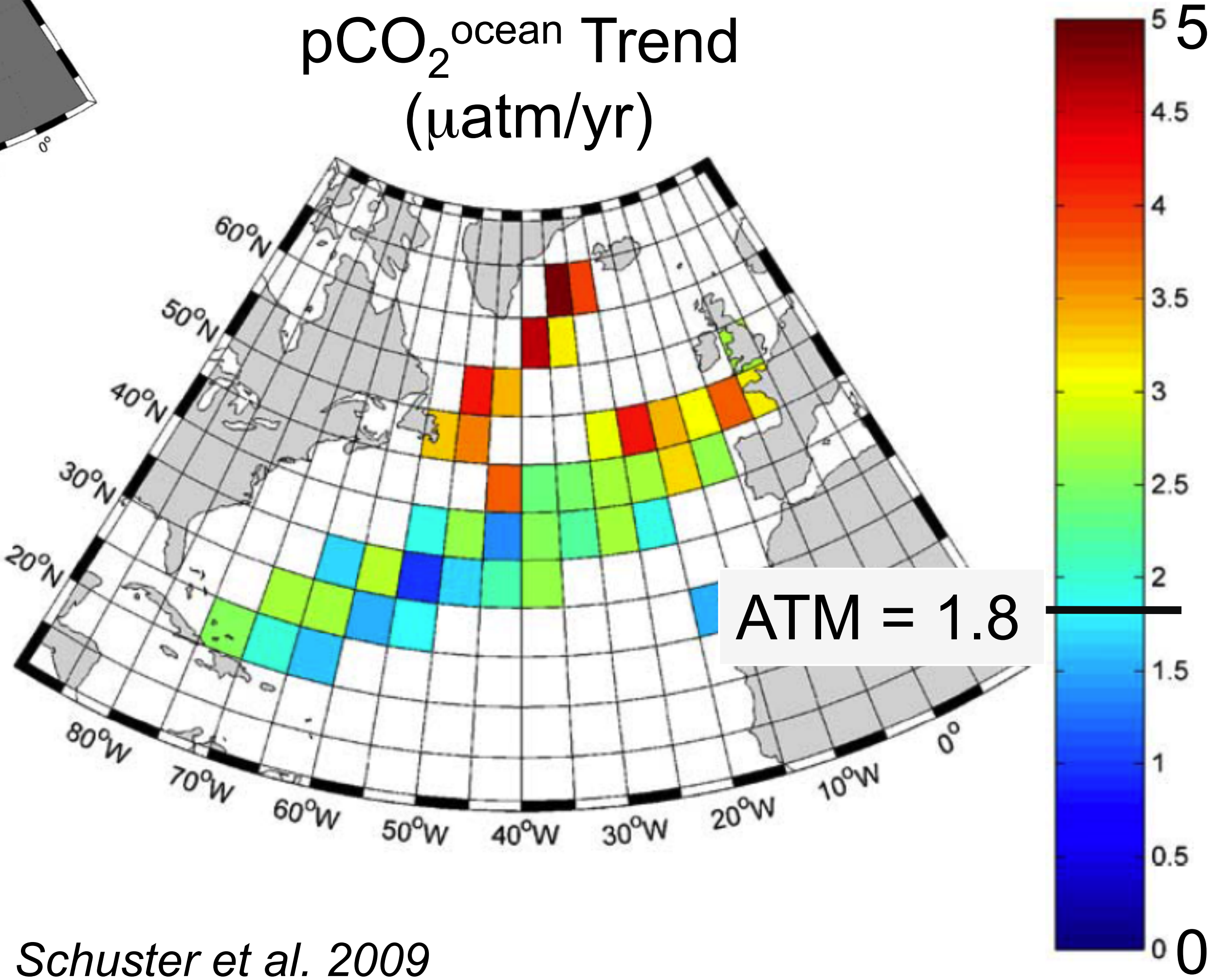


LeQuéré et al. 2010

N. Atlantic: VOS datasets, linear trend 1990-2006

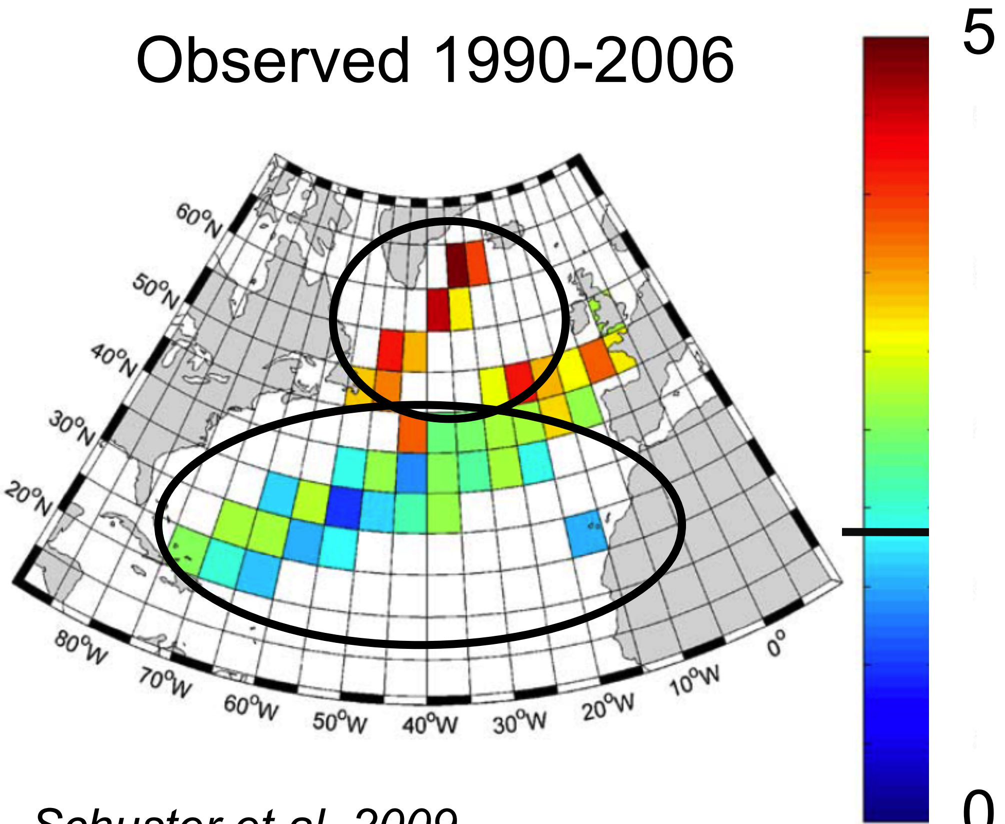


Data of
Corbiere et al. 2007
Shuster & Watson 2007
Bates 2007
Olsen et al. 2004
Santana-Casiano et al. 2007



Schuster et al. 2009

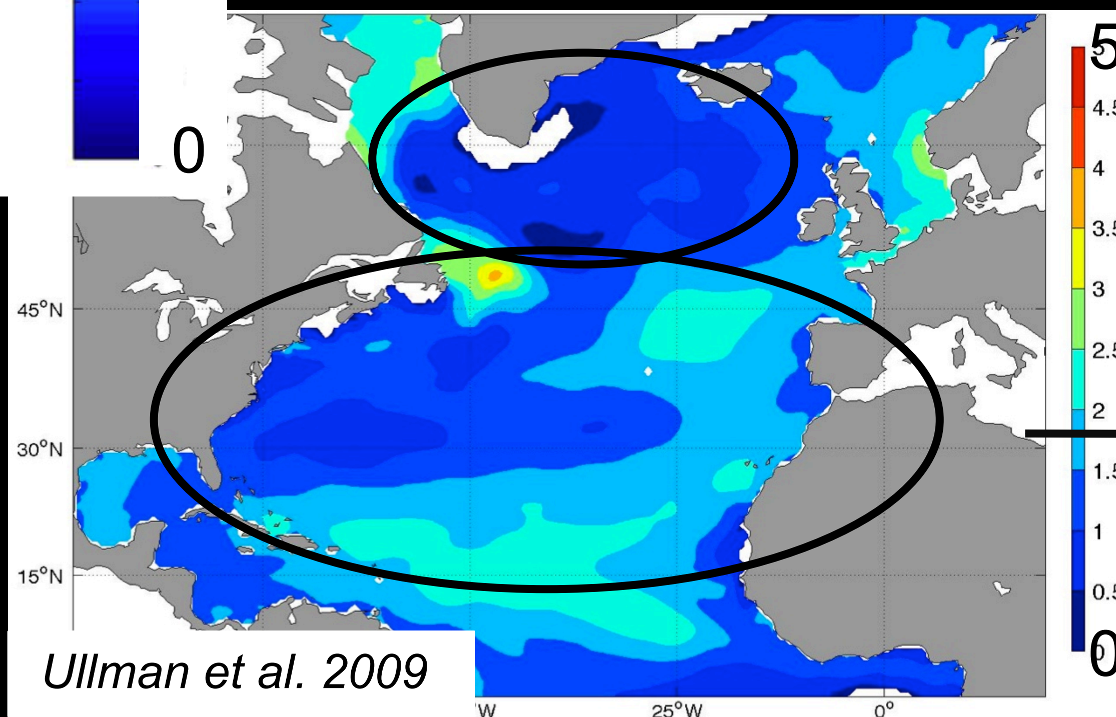
Observed 1990-2006



Schuster et al. 2009

Model: very different subpolar results

Modeled, 1992-2006



Ullman et al. 2009

Generally consistent <45N, but inconsistent >45N

Observed N. Atlantic pCO_2 trends

McKinley et al. 2011

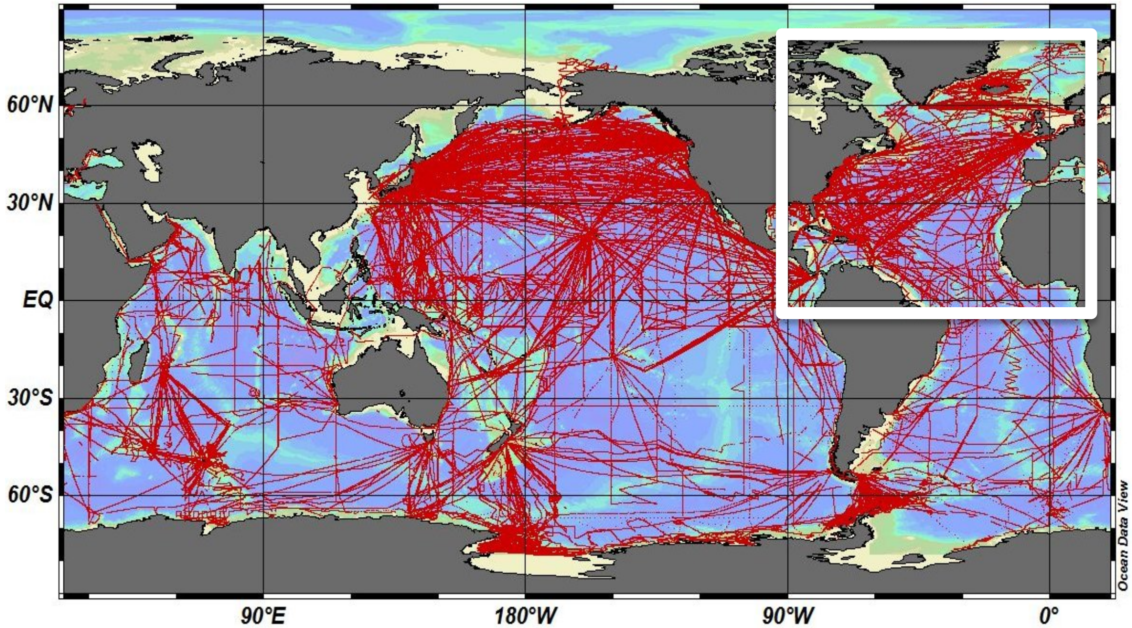
Objectives

with *in situ* pCO_2 data, discern:

- Timescales: variability vs. trends
- Mechanisms: Warming vs. carbon uptake
- Spatial scale: Gyre-size “biomes”

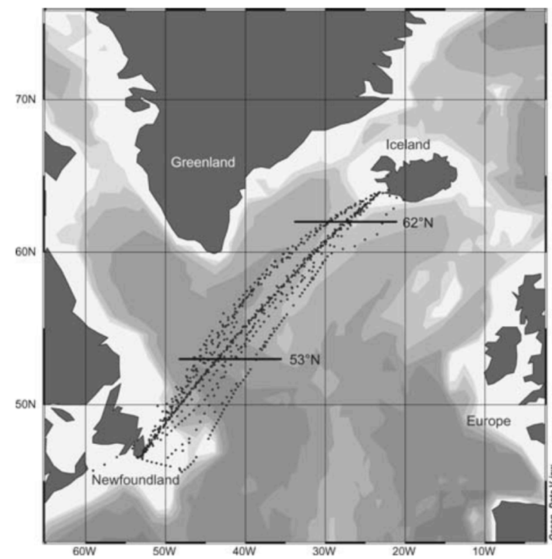
Takahashi et al. 2010 in-situ pCO_2 database

released on CDIAC website



-Over 4.5 million data points globally

-Over 1 million in the North Atlantic



SURATLANT dataset
Calculated pCO_2
(1993-2007)

Corbiere et al. 2007

Objectives

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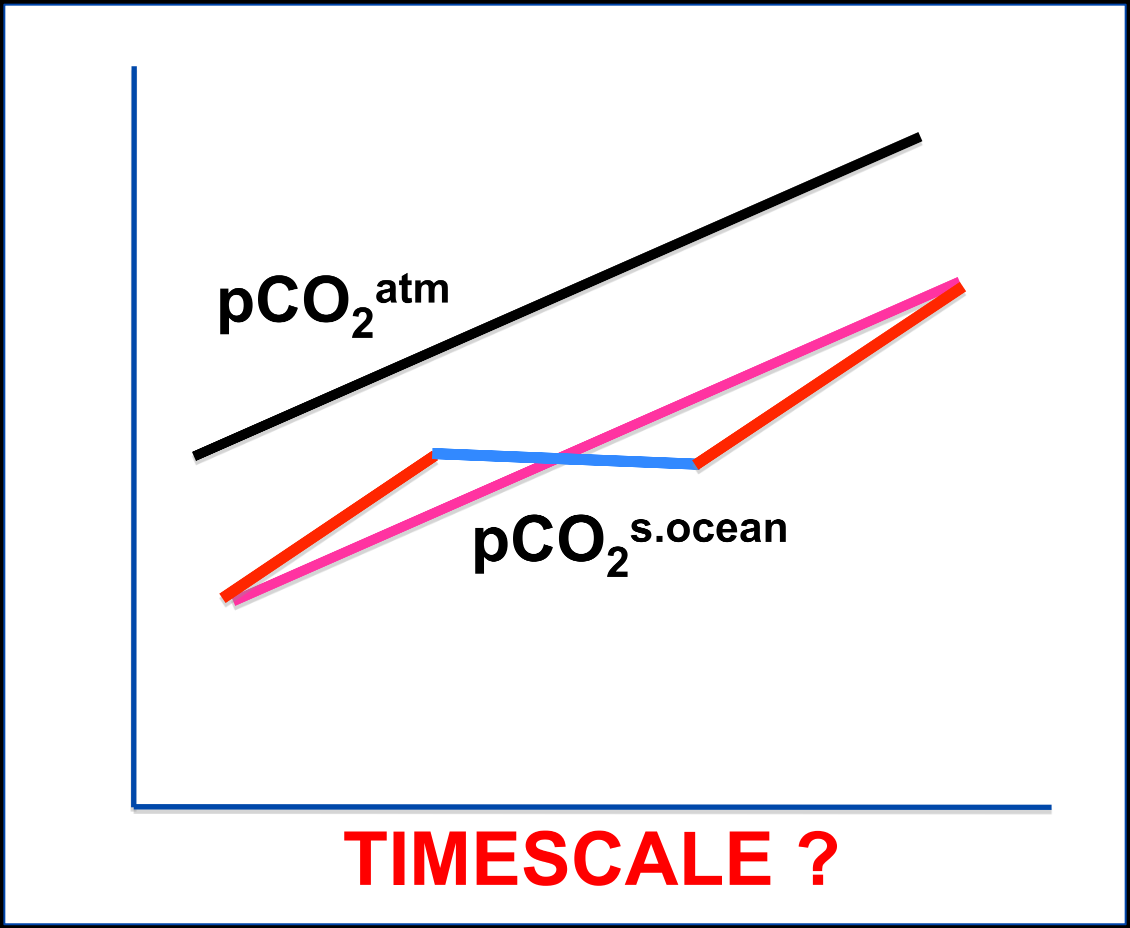
- Mechanisms: Warming vs. carbon uptake
- Spatial scale: Gyre-size “biomes”

On what timescale does the ocean follow the atmosphere?

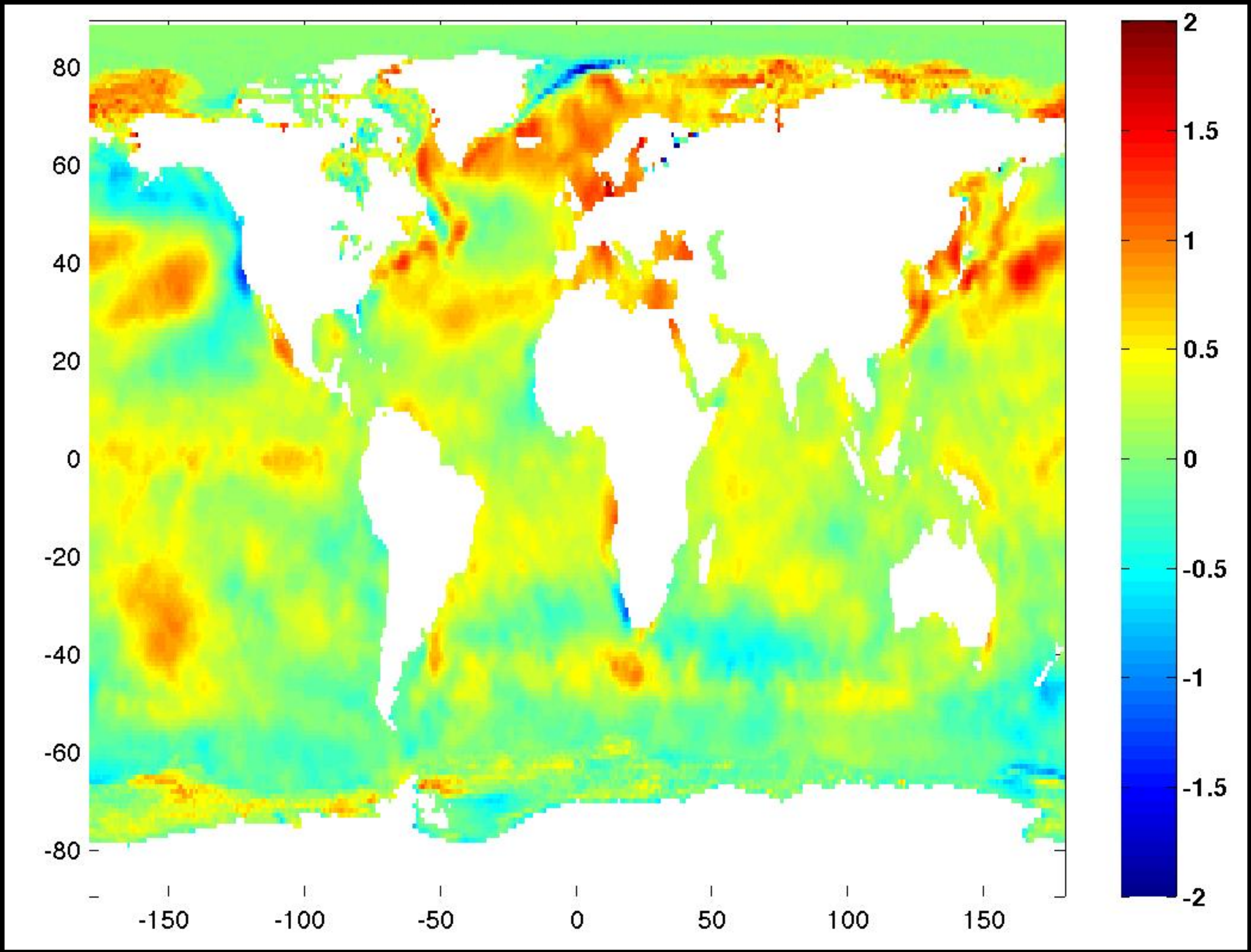


Objectives

with *in situ* pCO_2 data, discern:

- Timescales: variability vs. trends
- Mechanisms: Warming vs. carbon uptake
- Spatial scale: Gyre-size "biomes"

Observed SST change
(2000-09) – (1980-89)



2

0

-2

Degree C

Had1SST; Rayner et al 2003

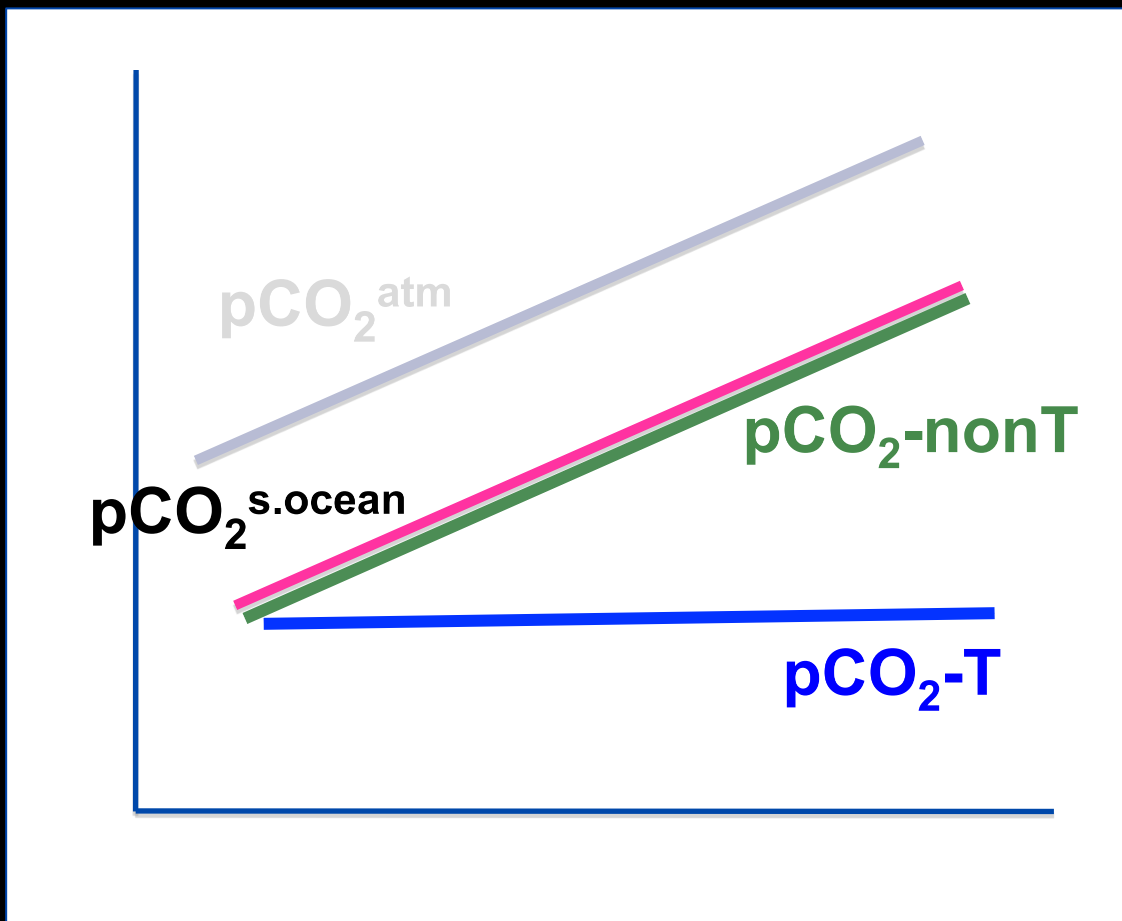
Decompose pCO_2 into temperature driven component (pCO_2-T) and biological/chemical component (pCO_2-nonT)

$$pCO_2 - T = \overline{pCO_2} * \exp(0.0423 * (SST - \overline{SST}))$$

$$pCO_2 - nonT = pCO_2 * \exp(0.0423 * (\overline{SST} - SST))$$

Takahashi et al. 2002

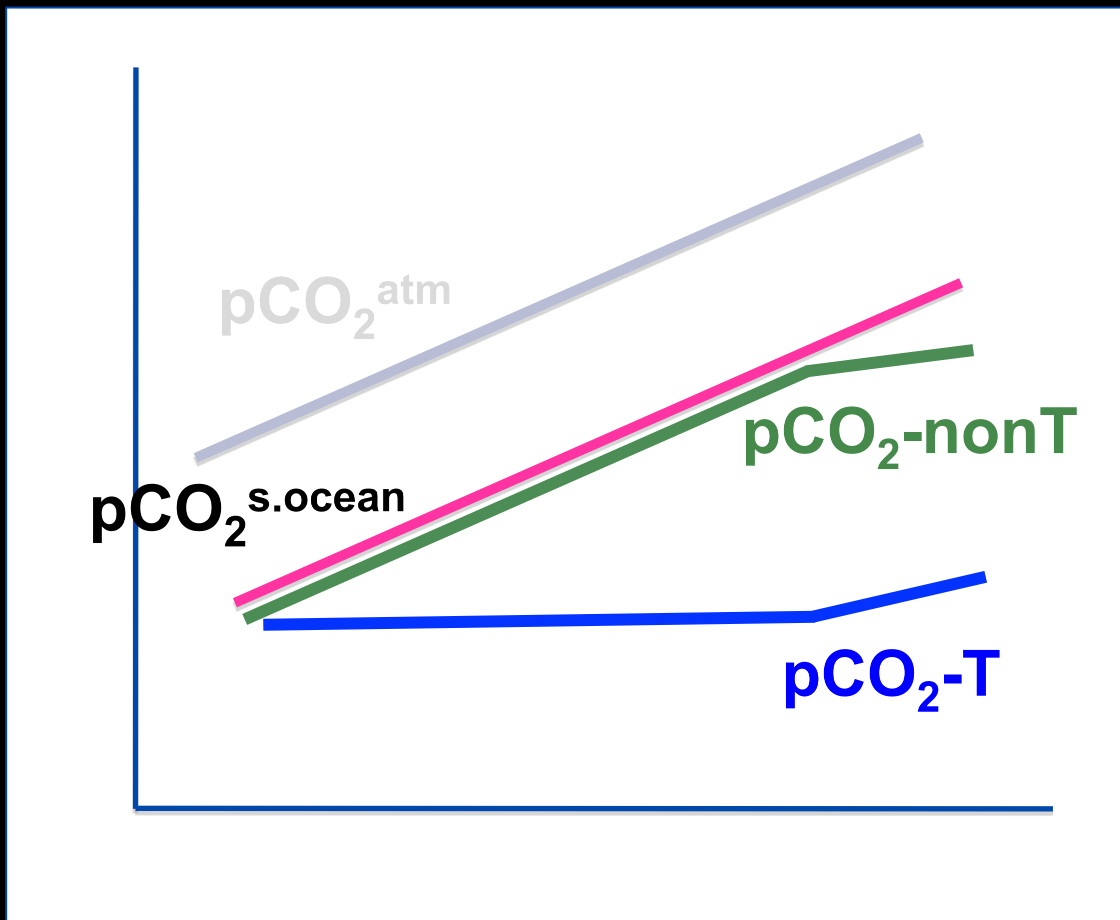
Trend mechanisms



Biogeochemical change only

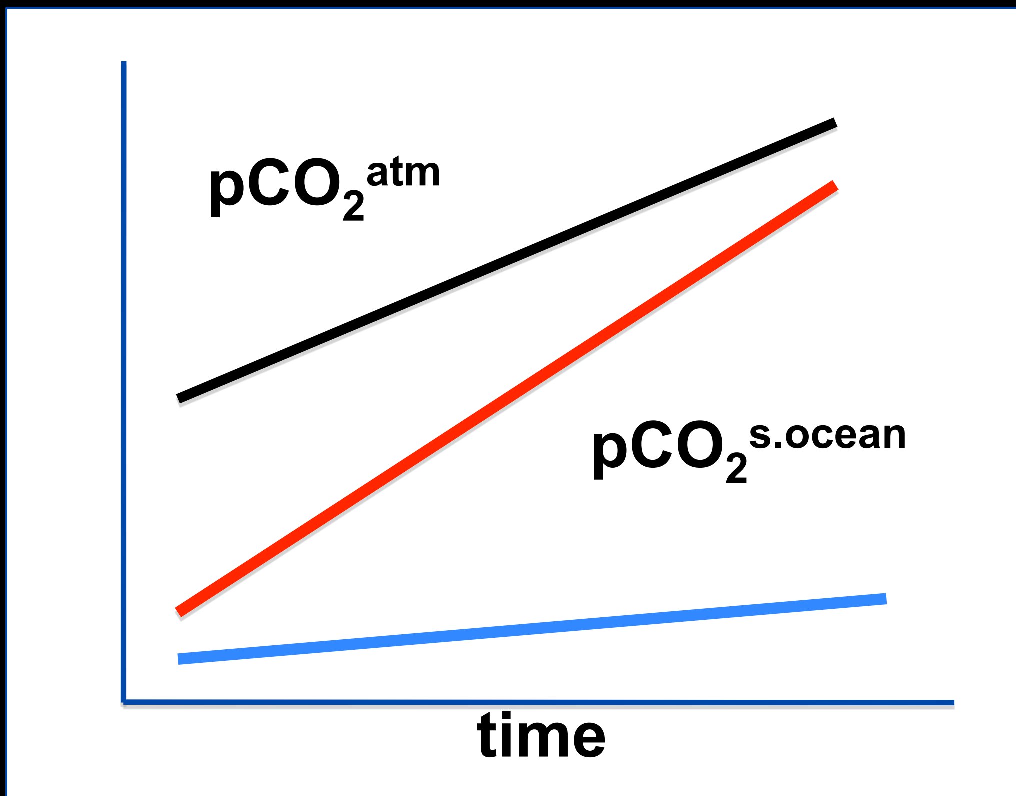
Consistent with carbon uptake

Trend mechanisms



If warming contributes, less carbon uptake required for equilibration with atmosphere

Mechanistic approach allows more nuanced understanding



$dpCO_2^{s.ocean}/dt$ > $dpCO_2^{atm}/dt$

OVER-EQUILIBRATION

$dpCO_2^{s.ocean}/dt$ < $dpCO_2^{atm}/dt$

UNDER-EQUILIBRATION

Objectives

with *in situ* pCO_2 data, discern:

- Timescales: variability vs. trends
- Mechanisms: Warming vs. carbon uptake
- Spatial scale: Gyre-size "biomes"

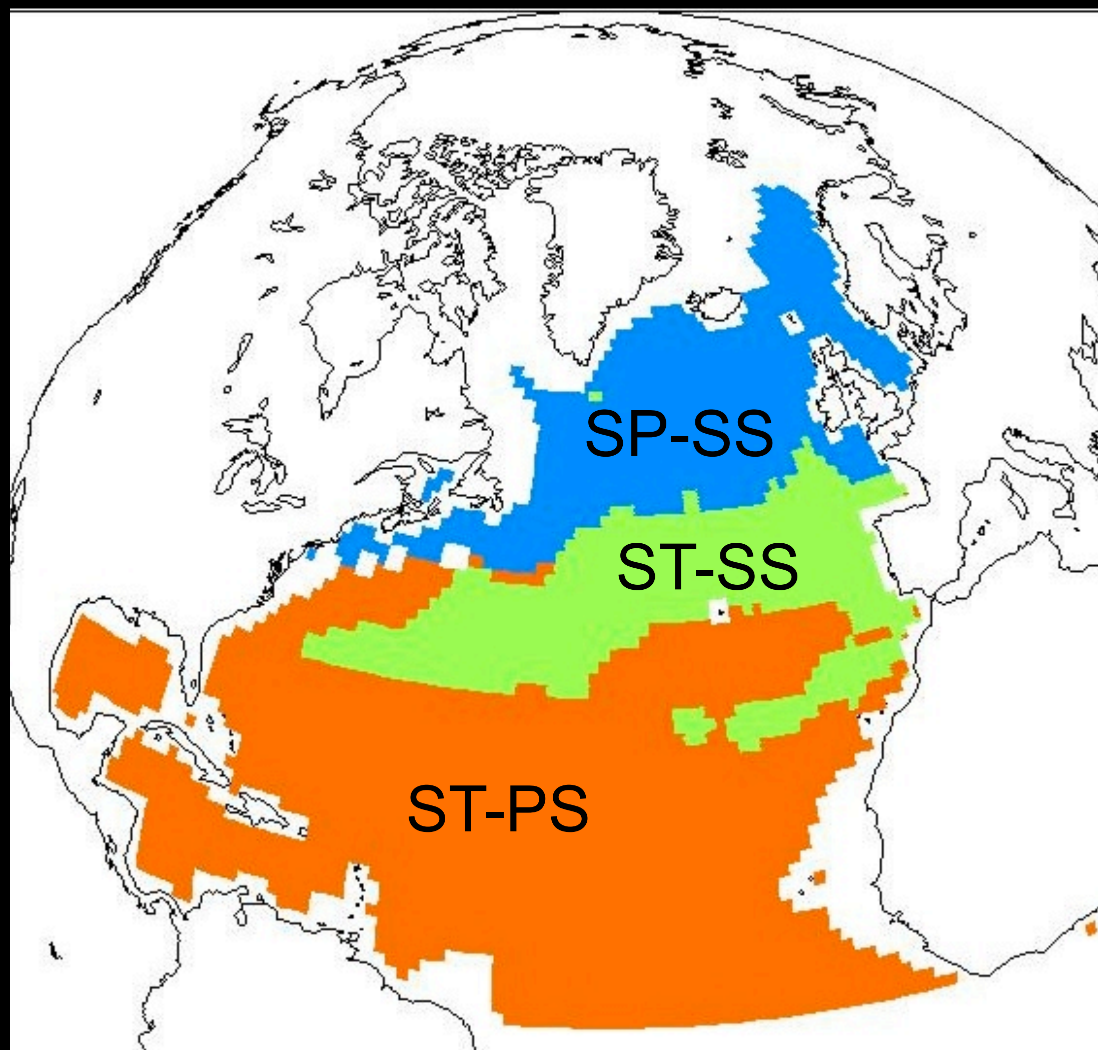
Biomes

- Gyre-scale biogeographic regions (Sarmiento et al (2004)
- Selection criteria: observed climatological SST, max MLD, and chlorophyll-a

Seasonally Stratified Subpolar (SP-SS)

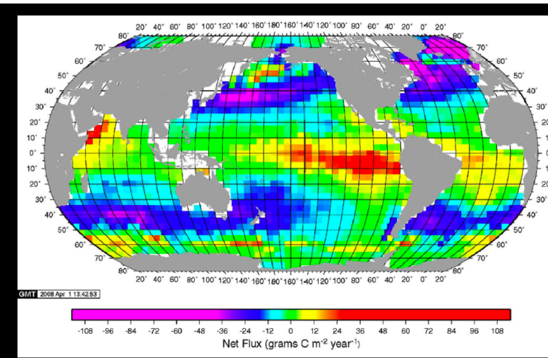
Seasonally Stratified Subtropical (ST-SS)

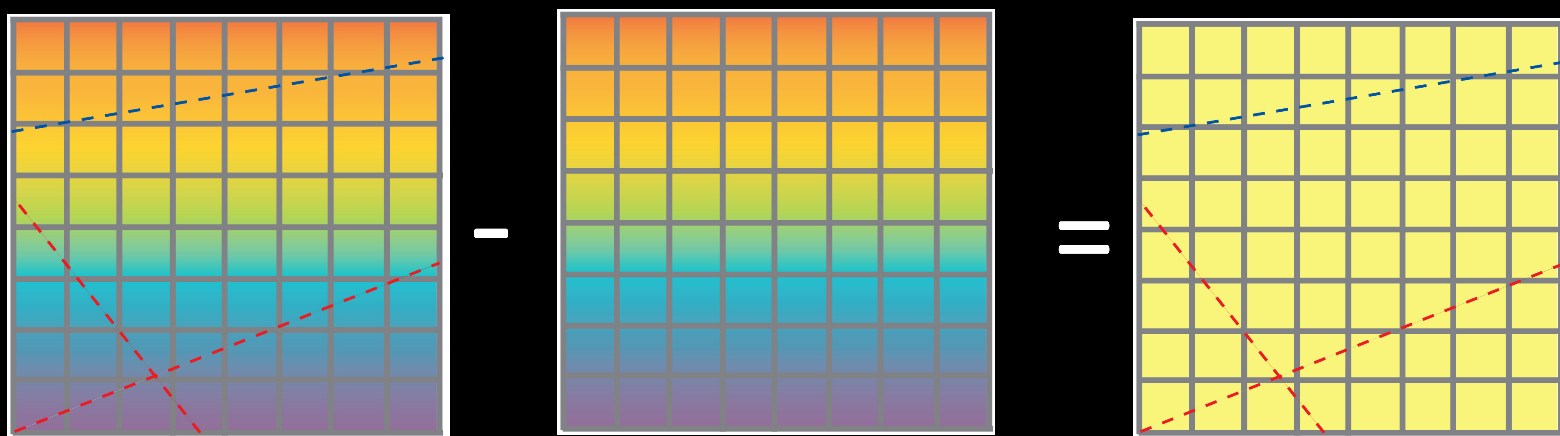
Permanently Stratified Subtropical (ST-PS)

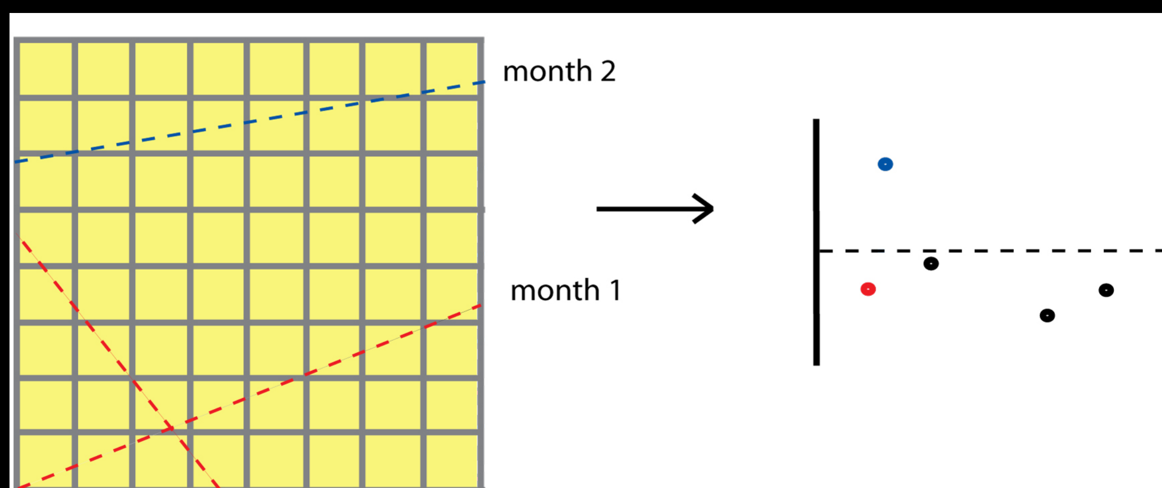


1. Subtract background mean to address spatial aliasing

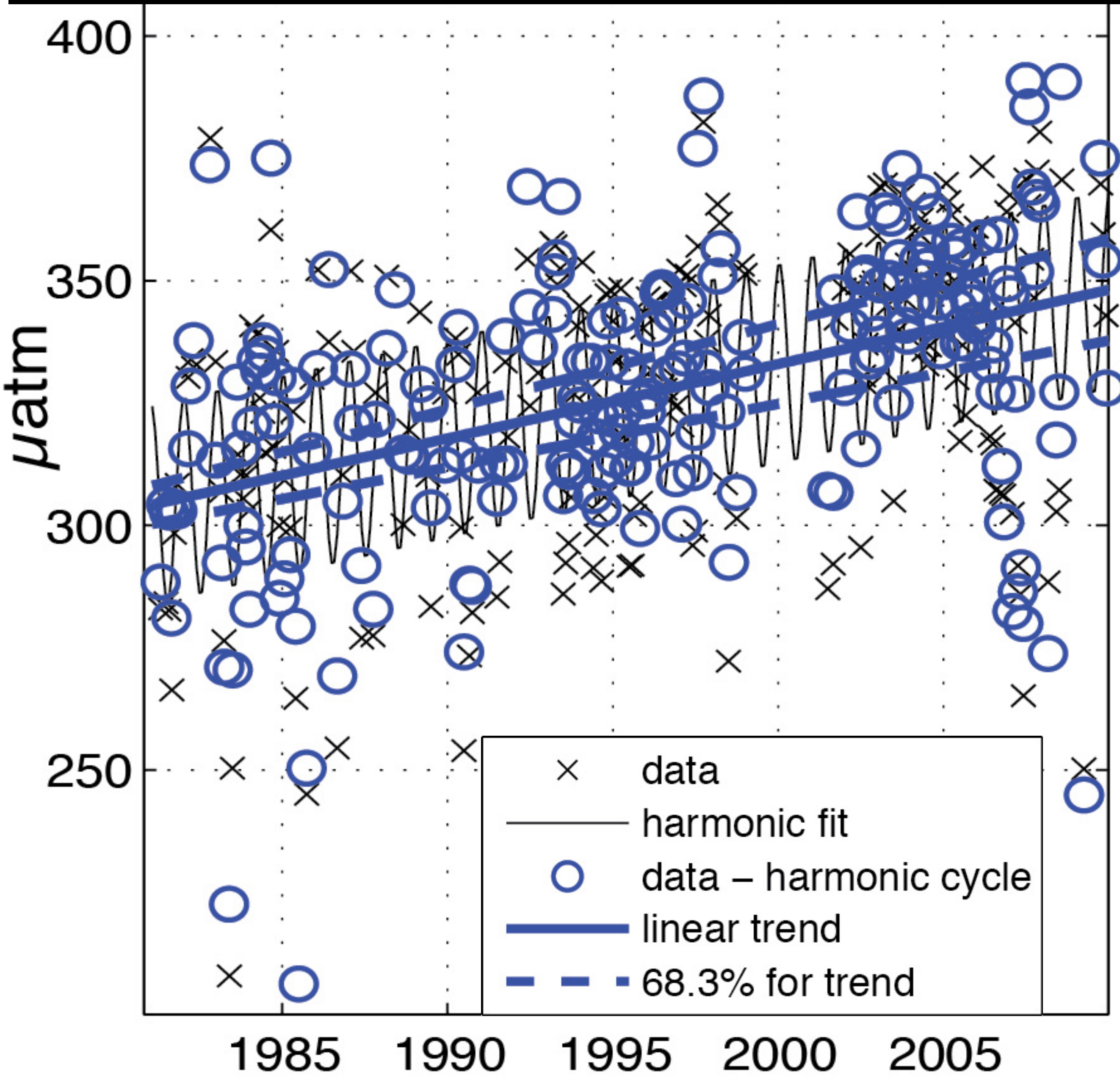
2. Average to biome timeseries

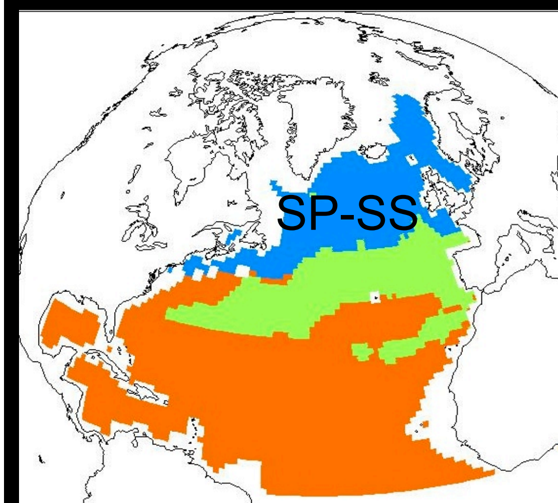




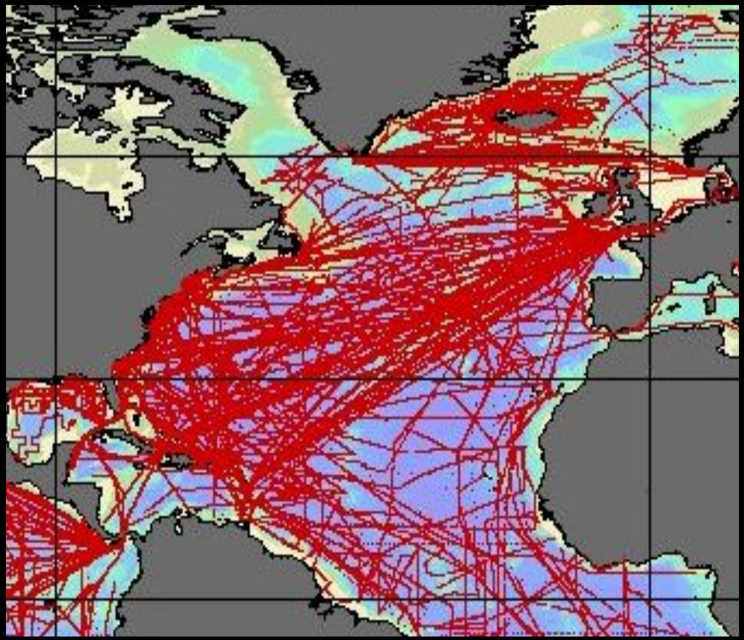


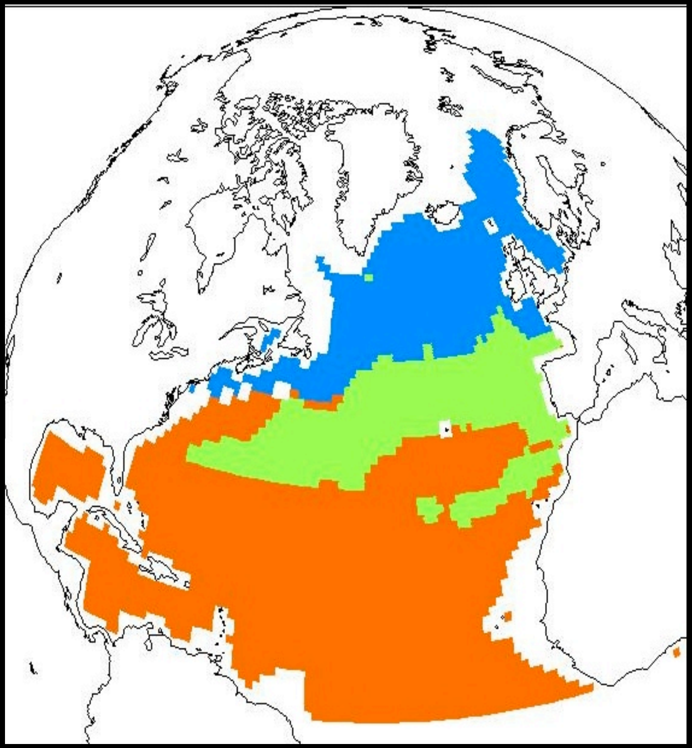
Resulting pCO_2 timeseries, subpolar N. Atlantic

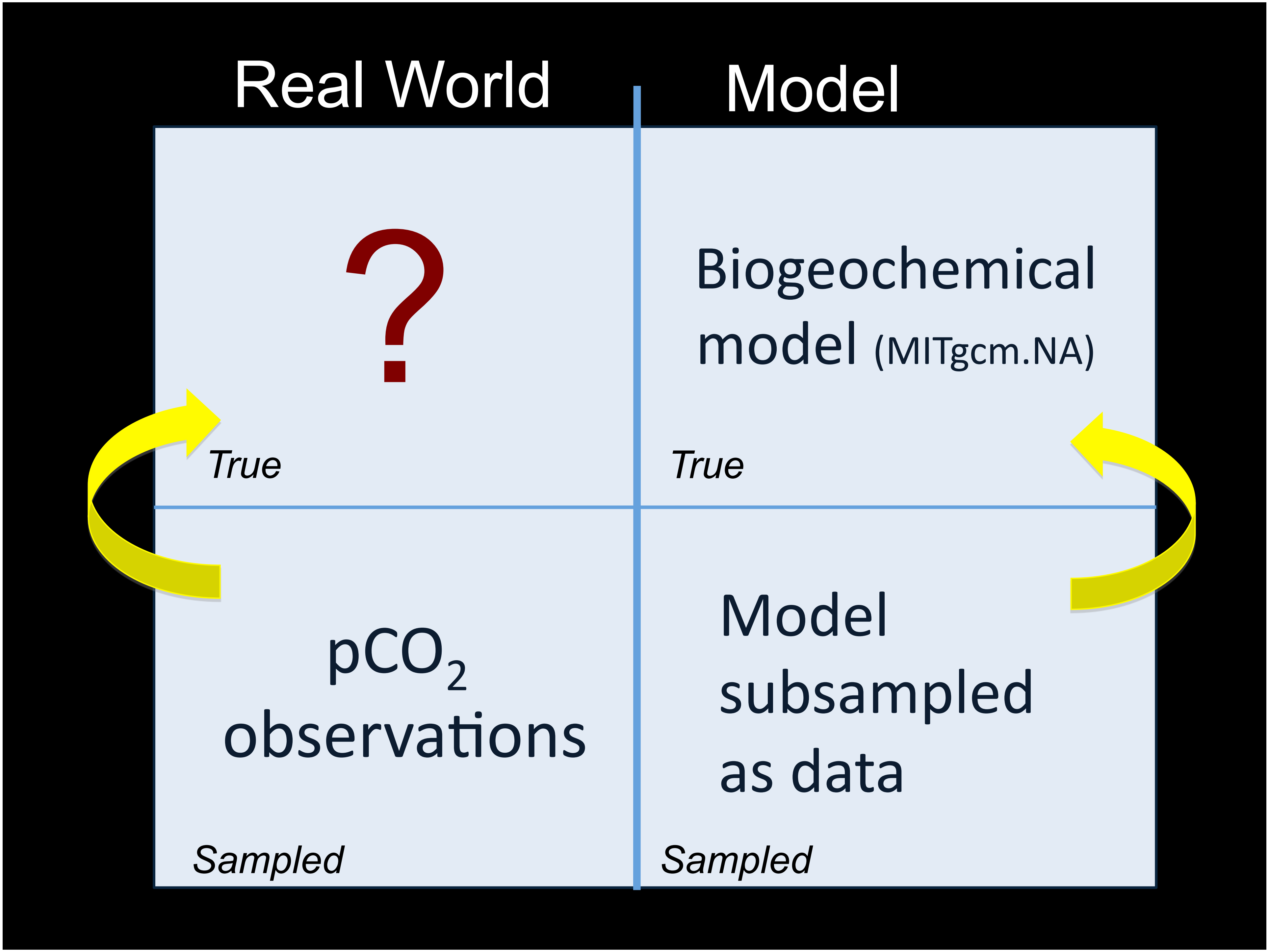




How representative are these trends of the biome?

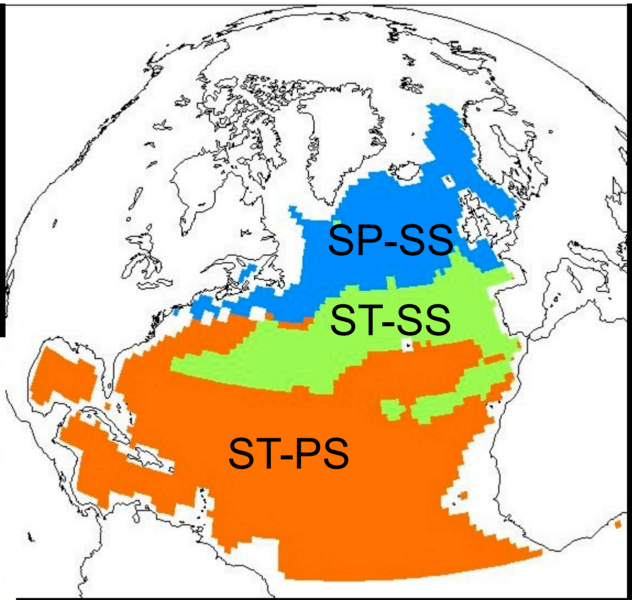


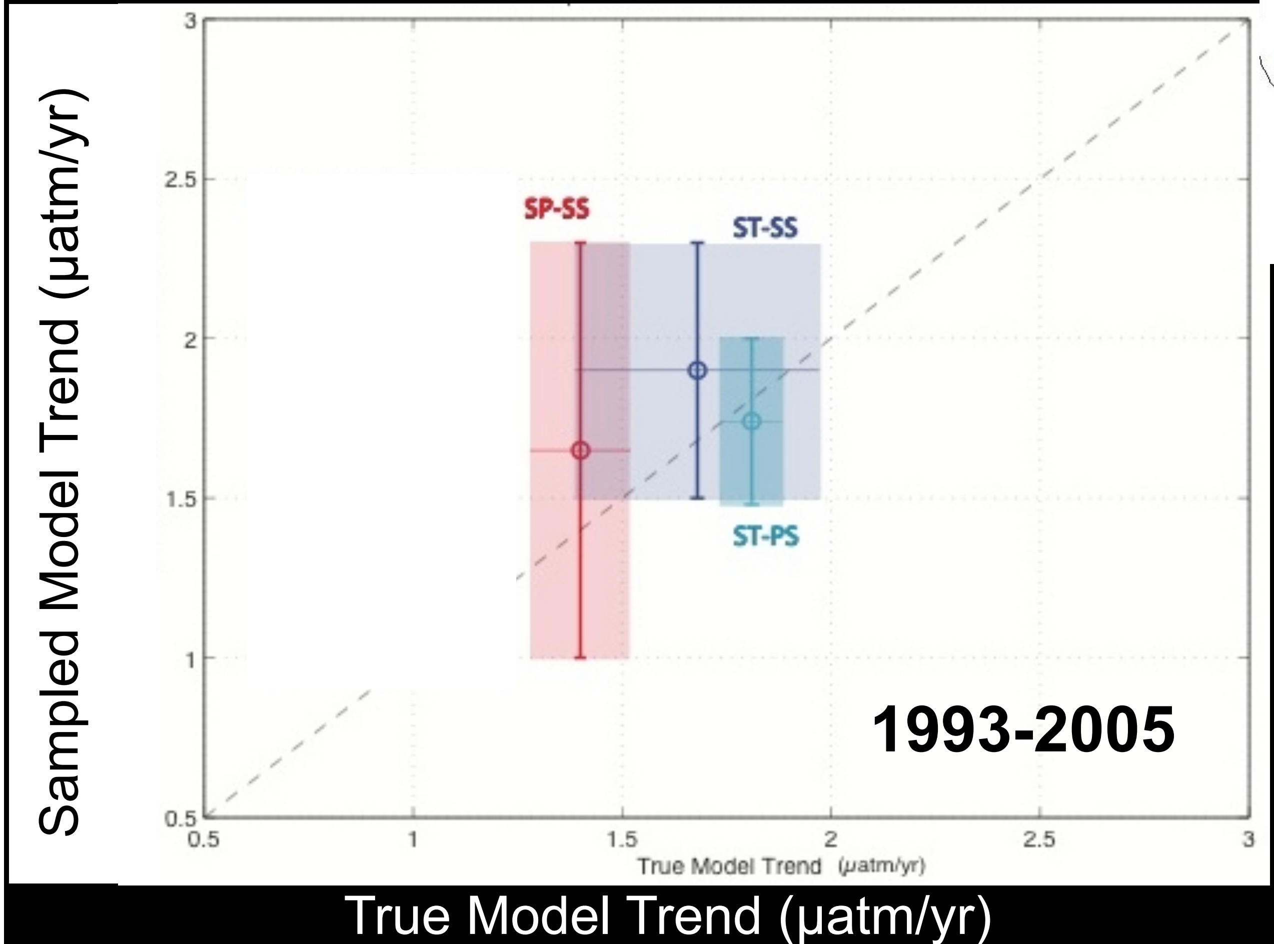




Real World
Model
?
Biogeochemical model (MITgcm.NA)
True
True
pCO_2 observations
Model subsampled as data
Sampled
Sampled

Model Confirmation

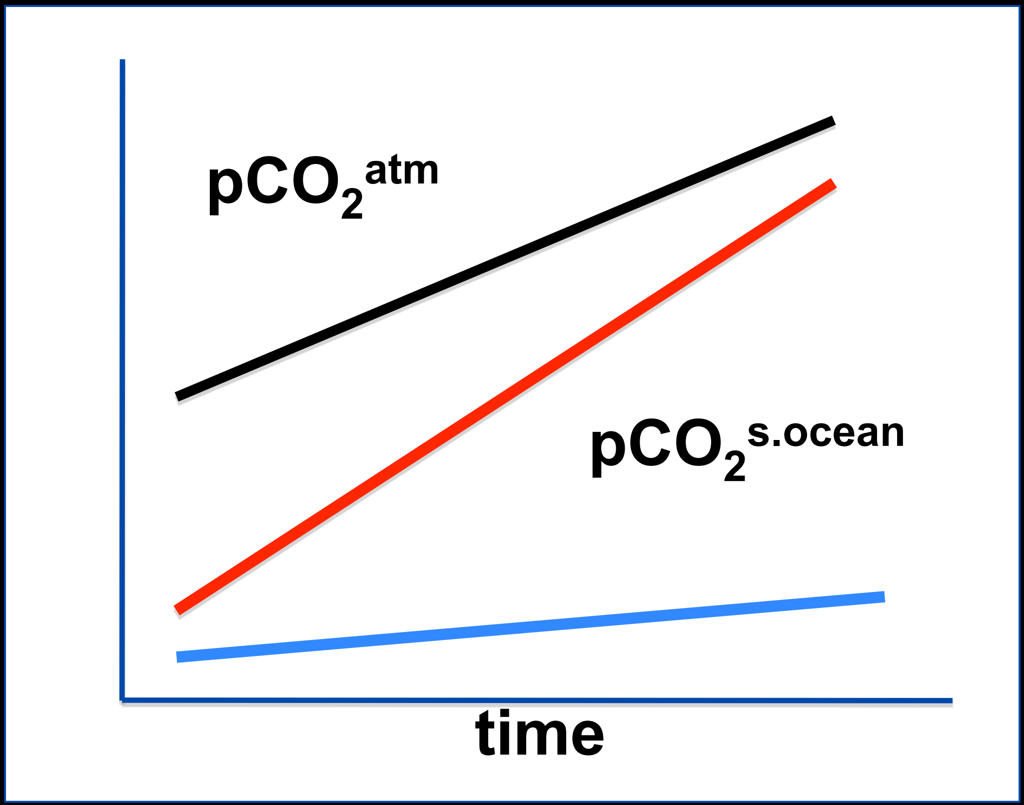




Sampled, analyzed model captures trends from all model output at 1σ level

Indicates that sampling and analysis technique are representative

Results



$dpCO_2^{s.ocean}/dt$ > $dpCO_2^{atm}/dt$

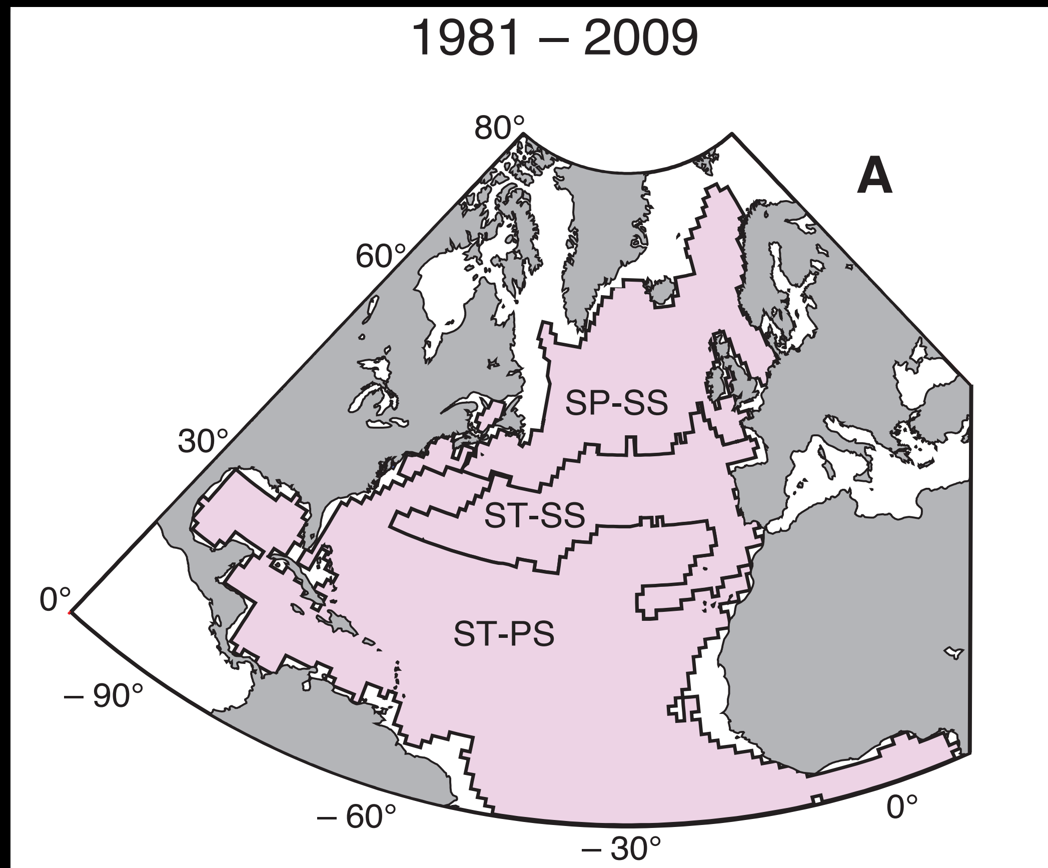
OVER-EQUILIBRATION

$dpCO_2^{s.ocean}/dt$ < $dpCO_2^{atm}/dt$

UNDER-EQUILIBRATION

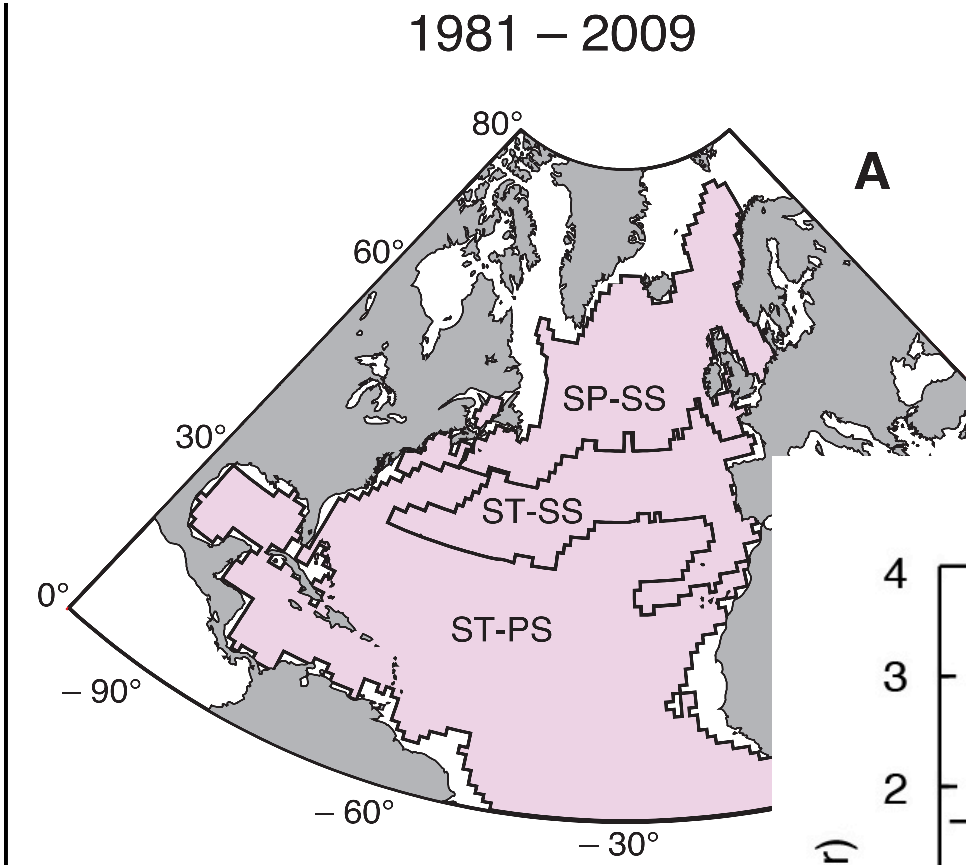
Trend in pCO_2^{ocean} compared to pCO_2^{atm}

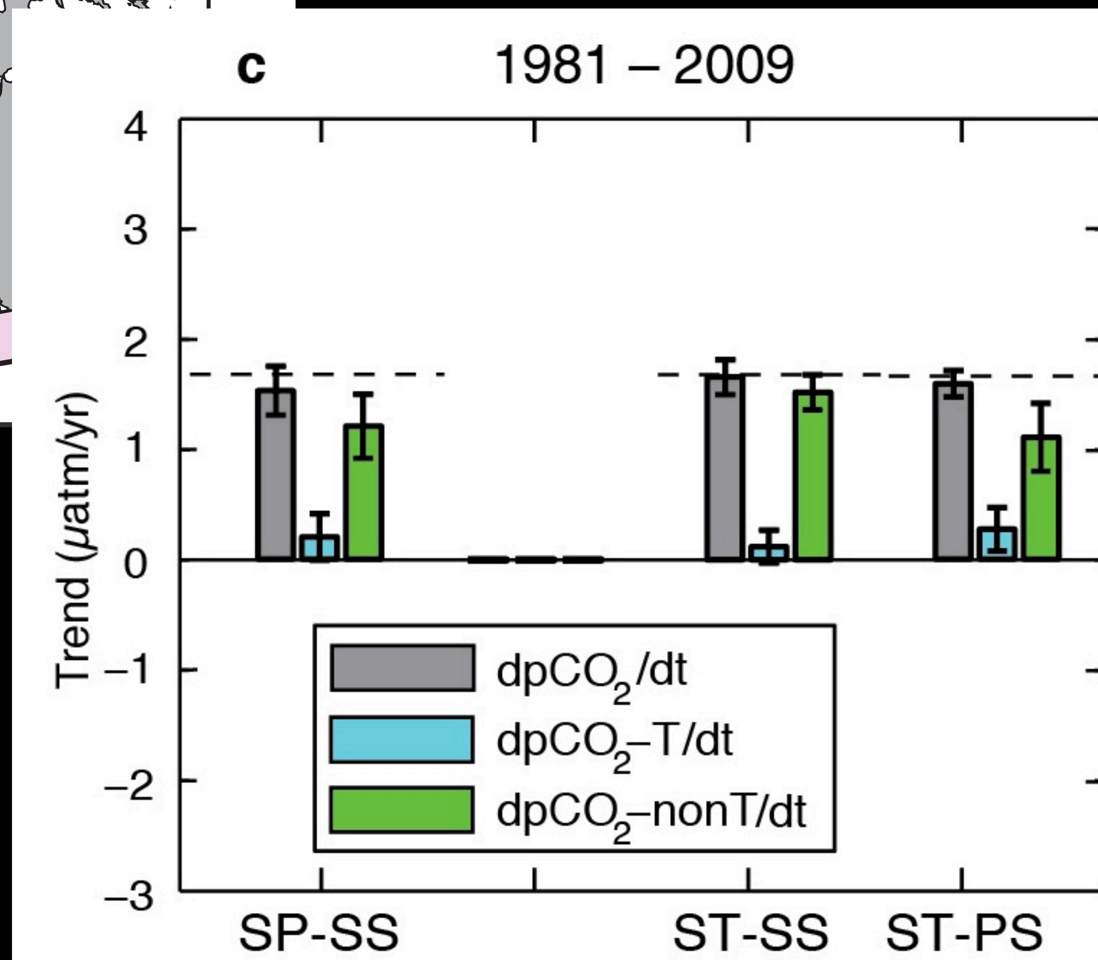
Multi-decadal:
1981-2009



$dpCO_2^{ocn}/dt < dpCO_2^{atm}/dt$	$dpCO_2^{ocn}/dt \sim dpCO_2^{atm}/dt$	$dpCO_2^{ocn}/dt > dpCO_2^{atm}/dt$
under-equilibration	equilibration	over-equilibration

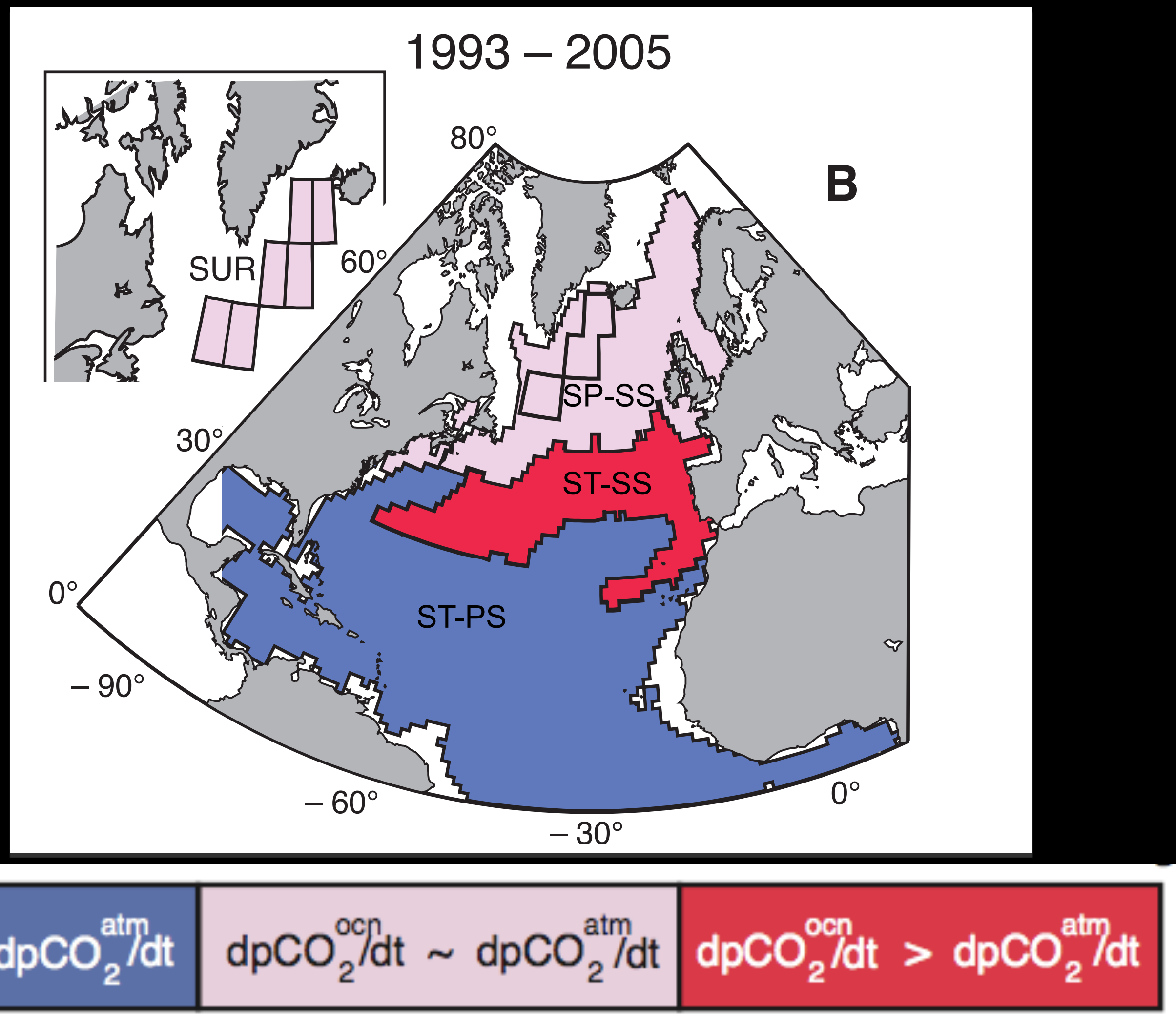
Chemical change dominates on multidecadal timescale





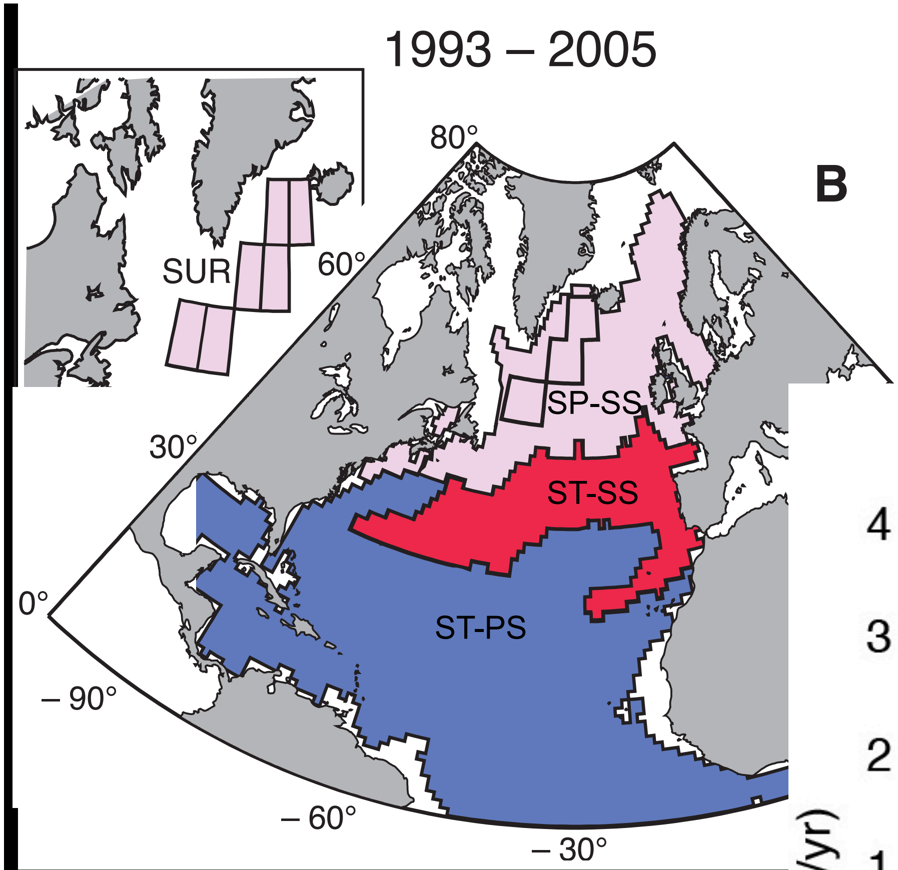
Trend in pCO_2^{ocean} compared to pCO_2^{atm}

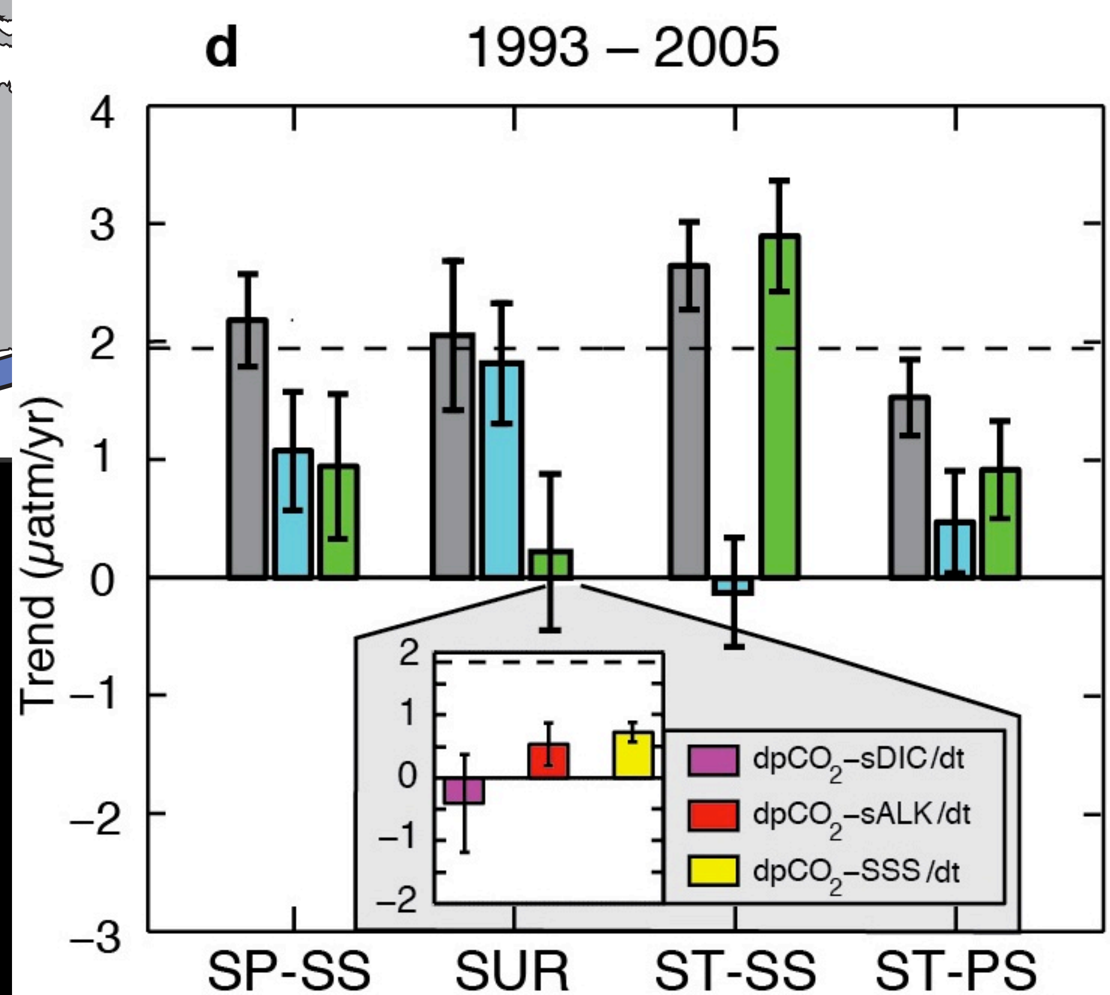
Decadal:
1993-2005



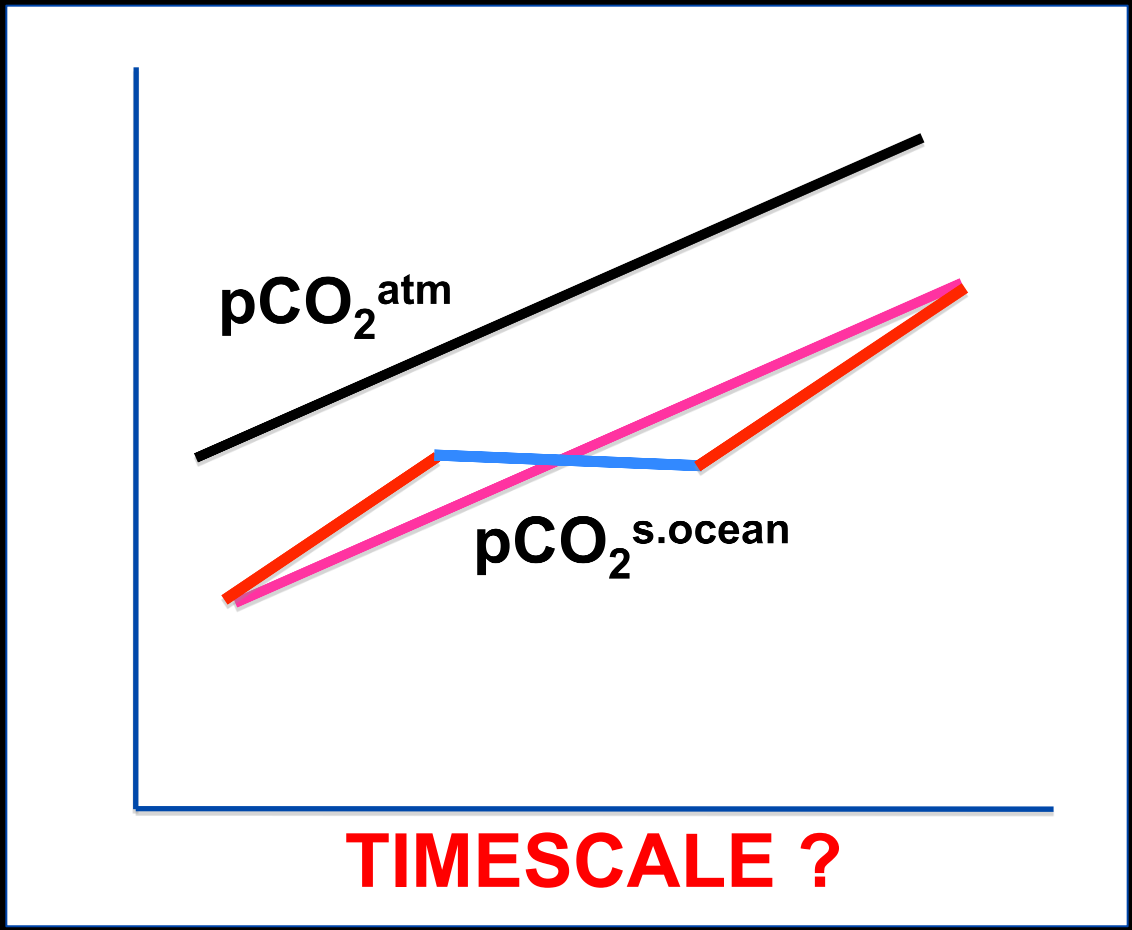
under-equilibration equilibration over-equilibration

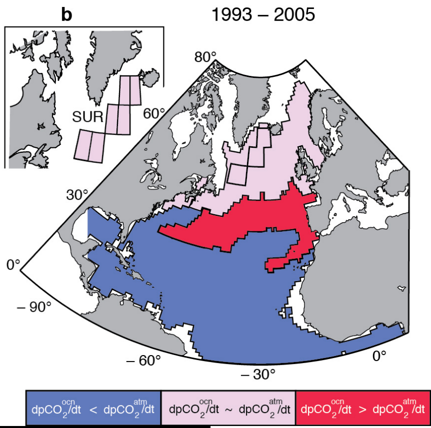
Influence of climate variability appears on decadal timescales



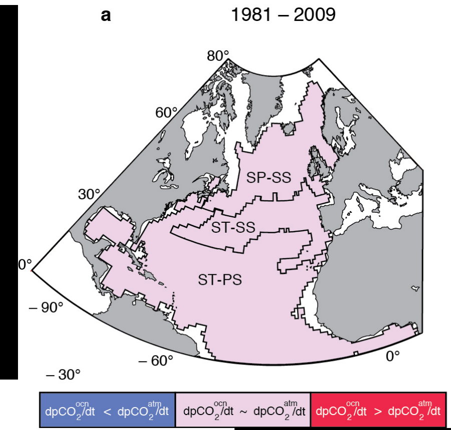


On what timescale does the ocean follow the atmosphere?

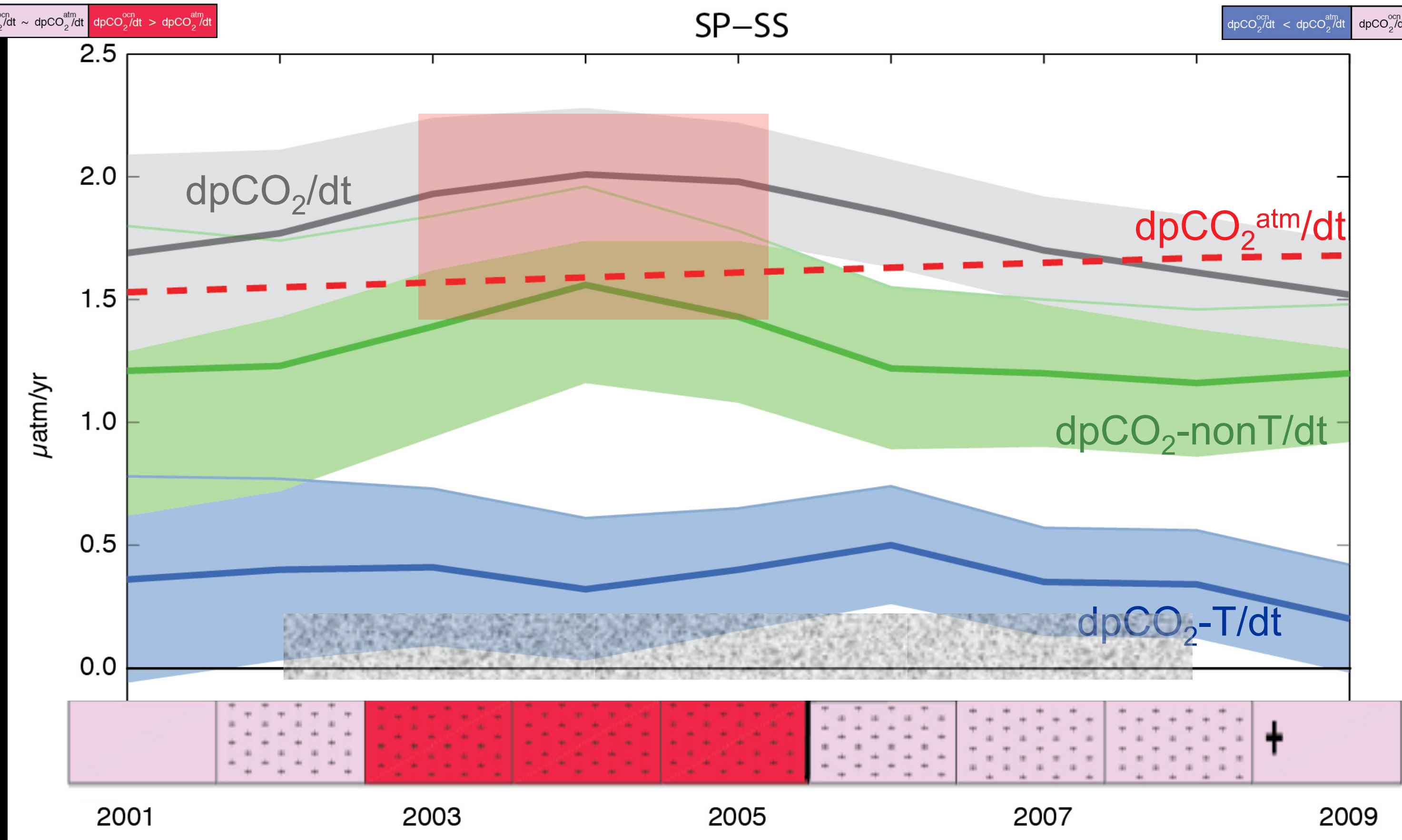




Evaluate transition from decadal to multidecadal



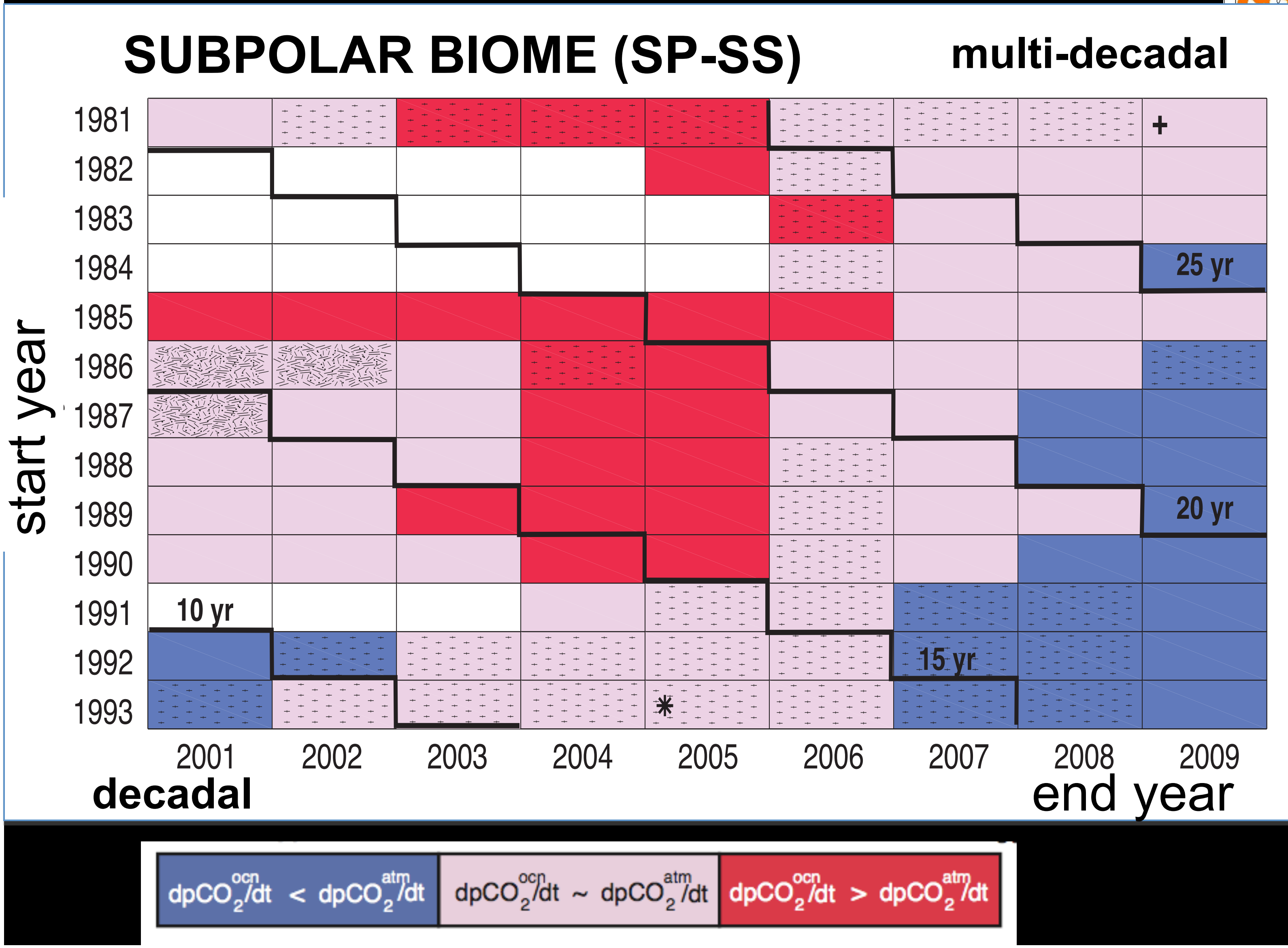
pCO_2 trend
STARTYEAR = 1981

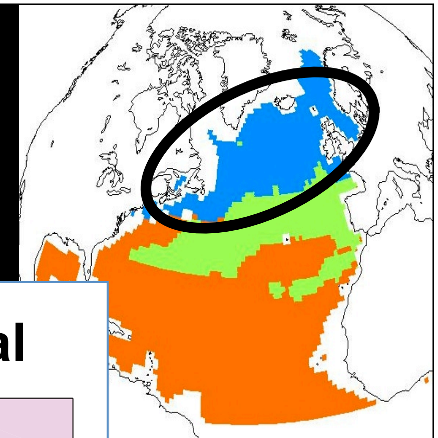


ENDYEAR

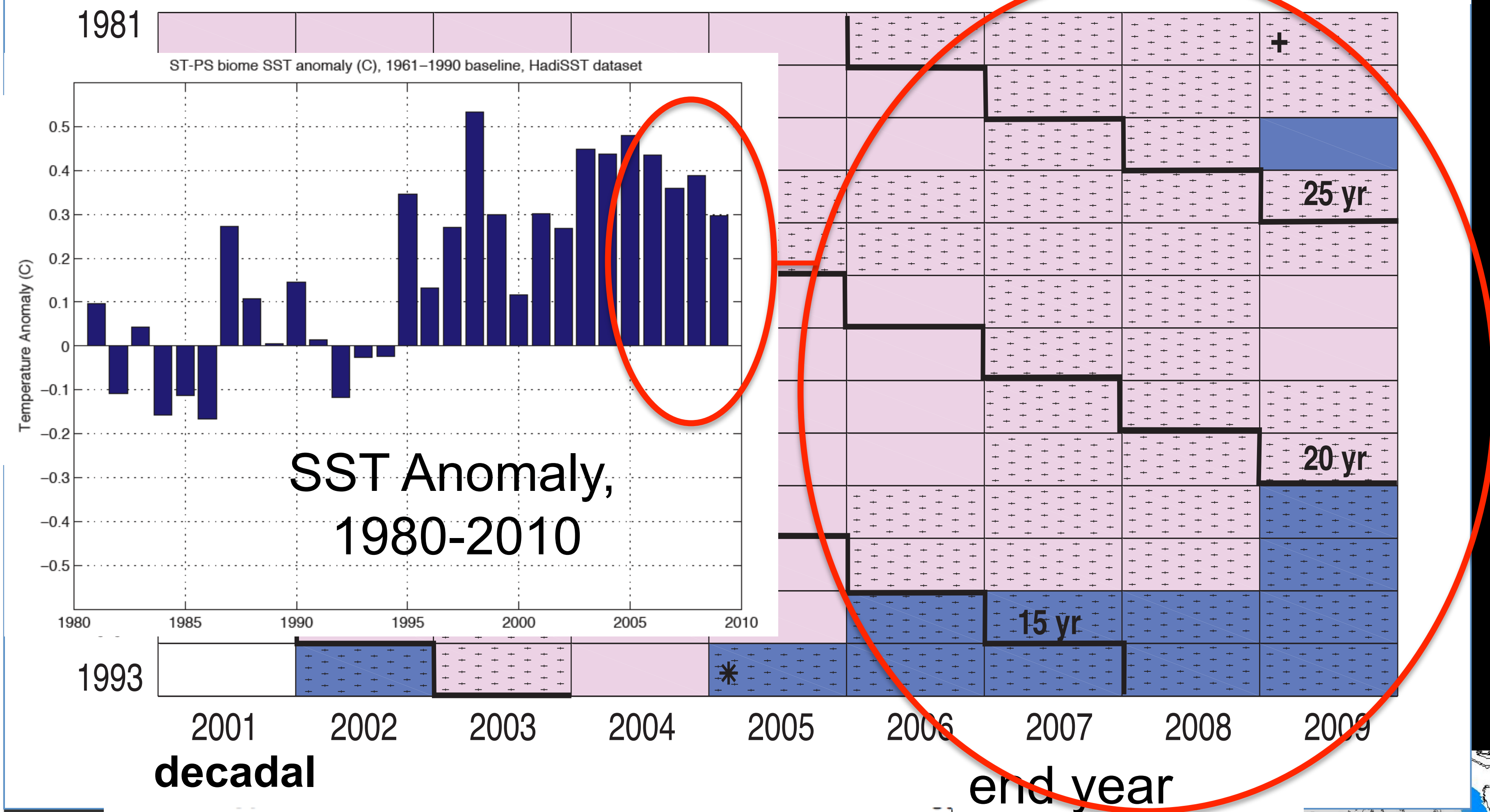
Considering varying timescales

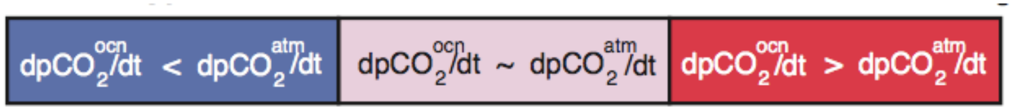
Dotted = warming influence significant



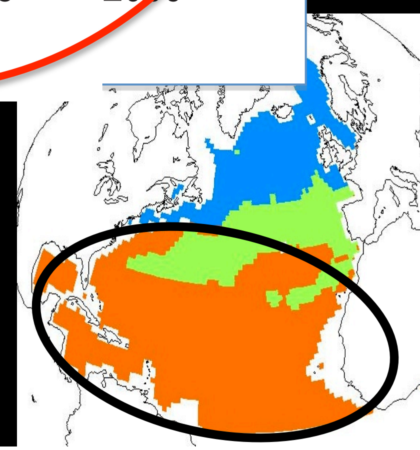


SUBTROPICAL PERMANENTLY STRATIFIED (ST-PS)



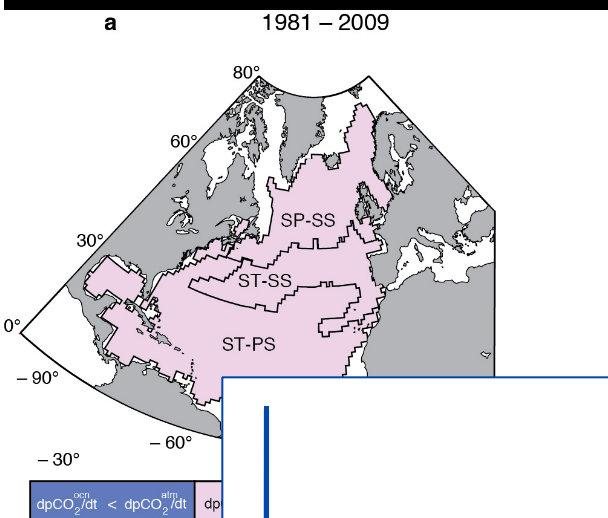


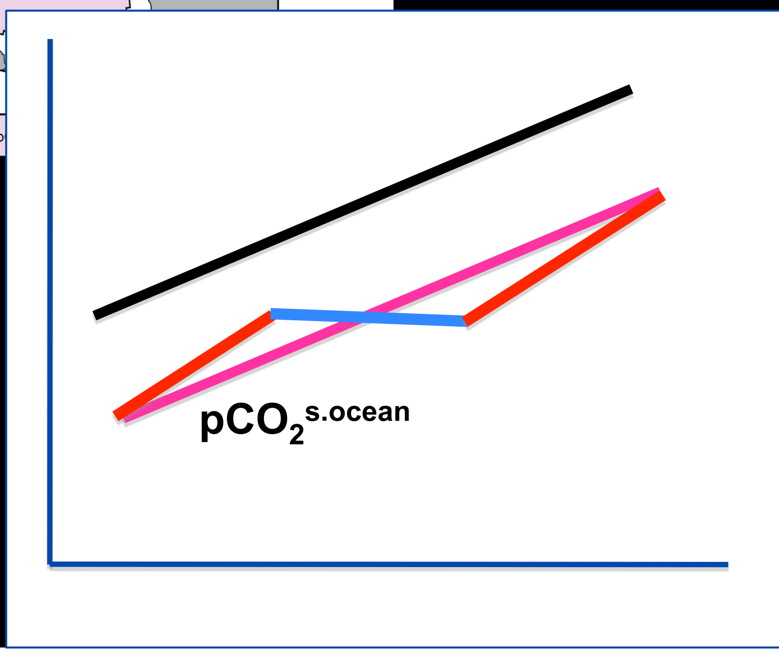
under-equilibration equilibration over-equilibration

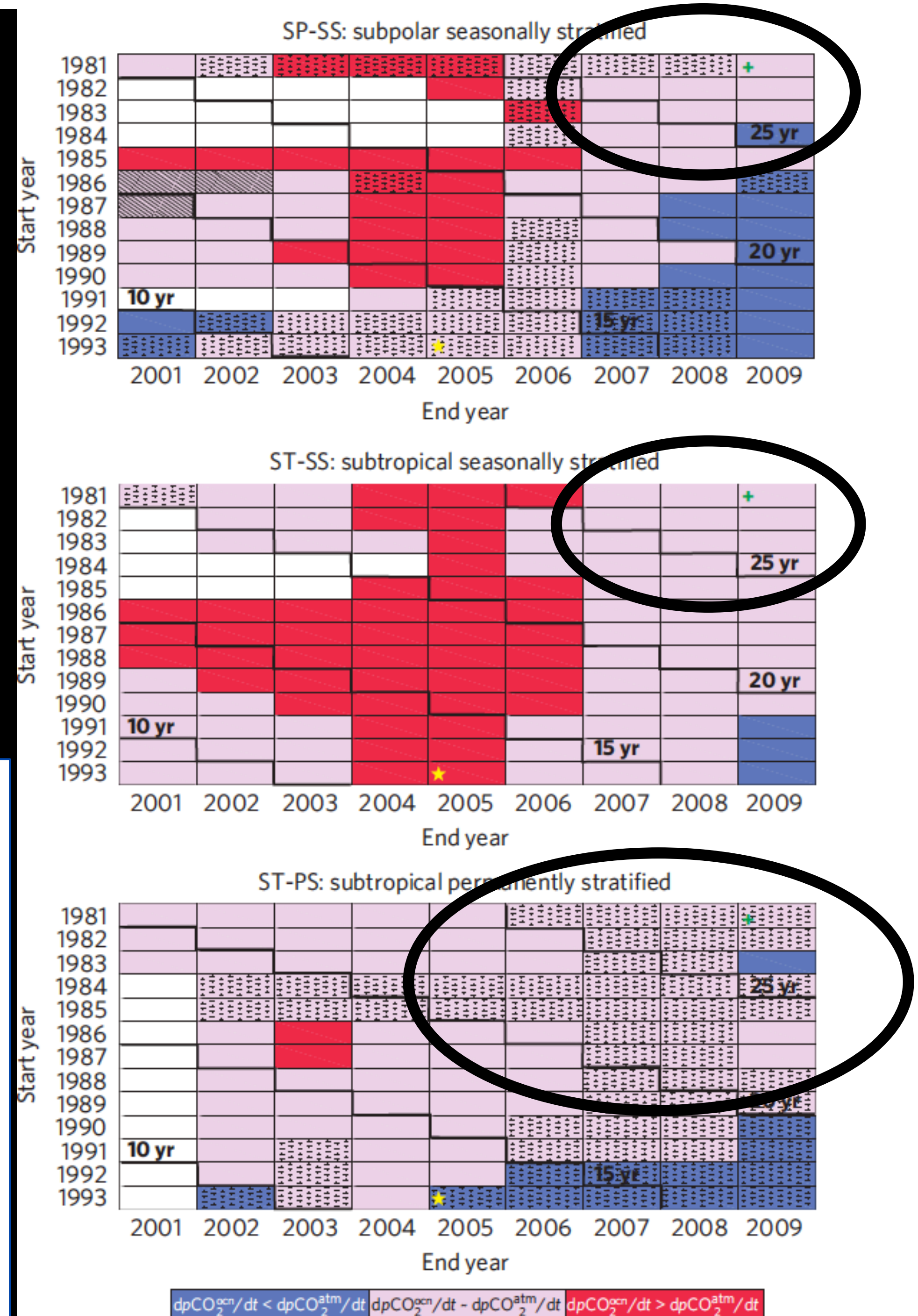


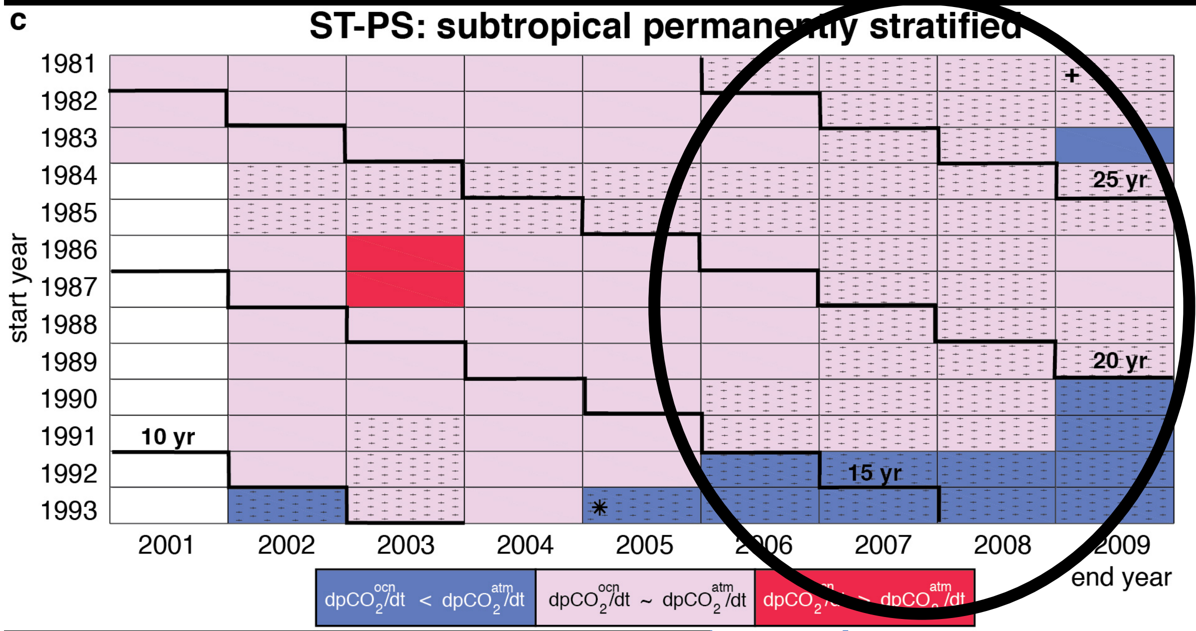
Conclusions: North Atlantic

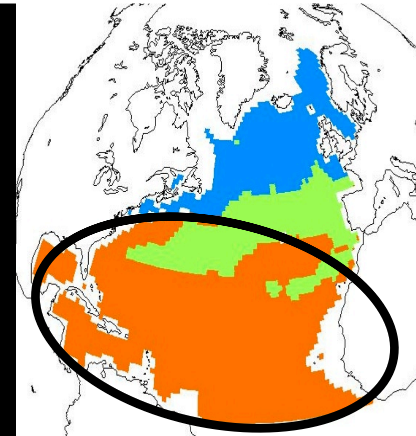
At least 20-25 years for carbon accumulation to dominate $pCO_2^{s.ocean}$ trend



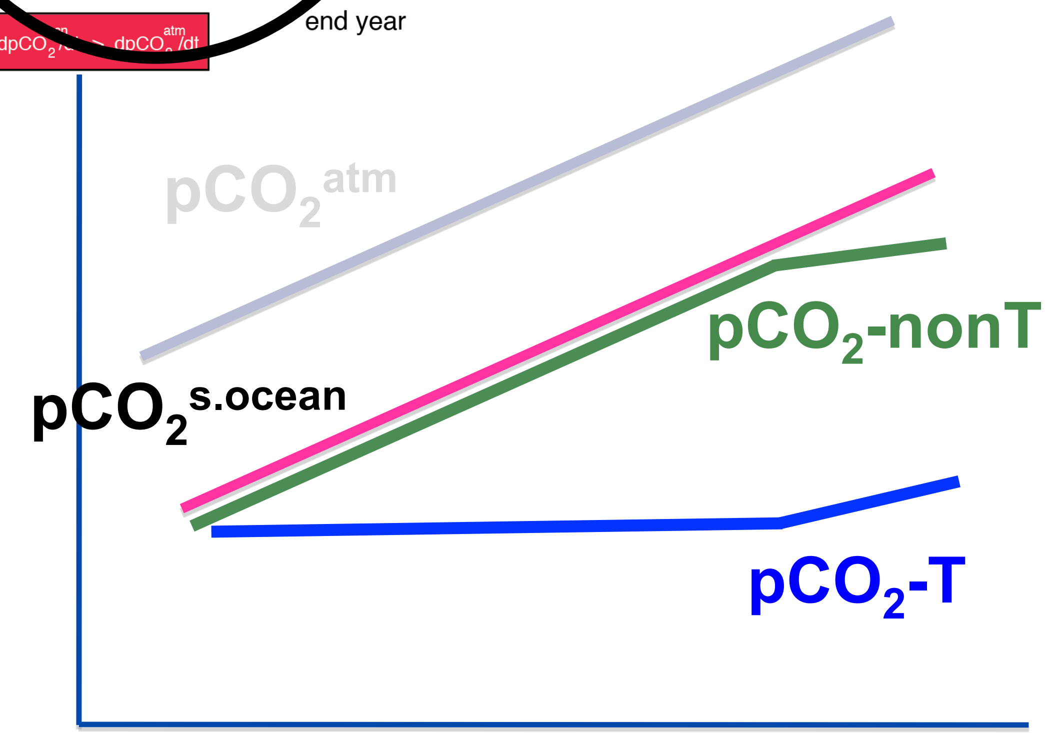








Warming beginning to reduce subtropical N. Atlantic carbon sink



Modeling assessment of global CO_2 sink impacts due to climate change:
1981-2007 = -0.20 PgC/decade

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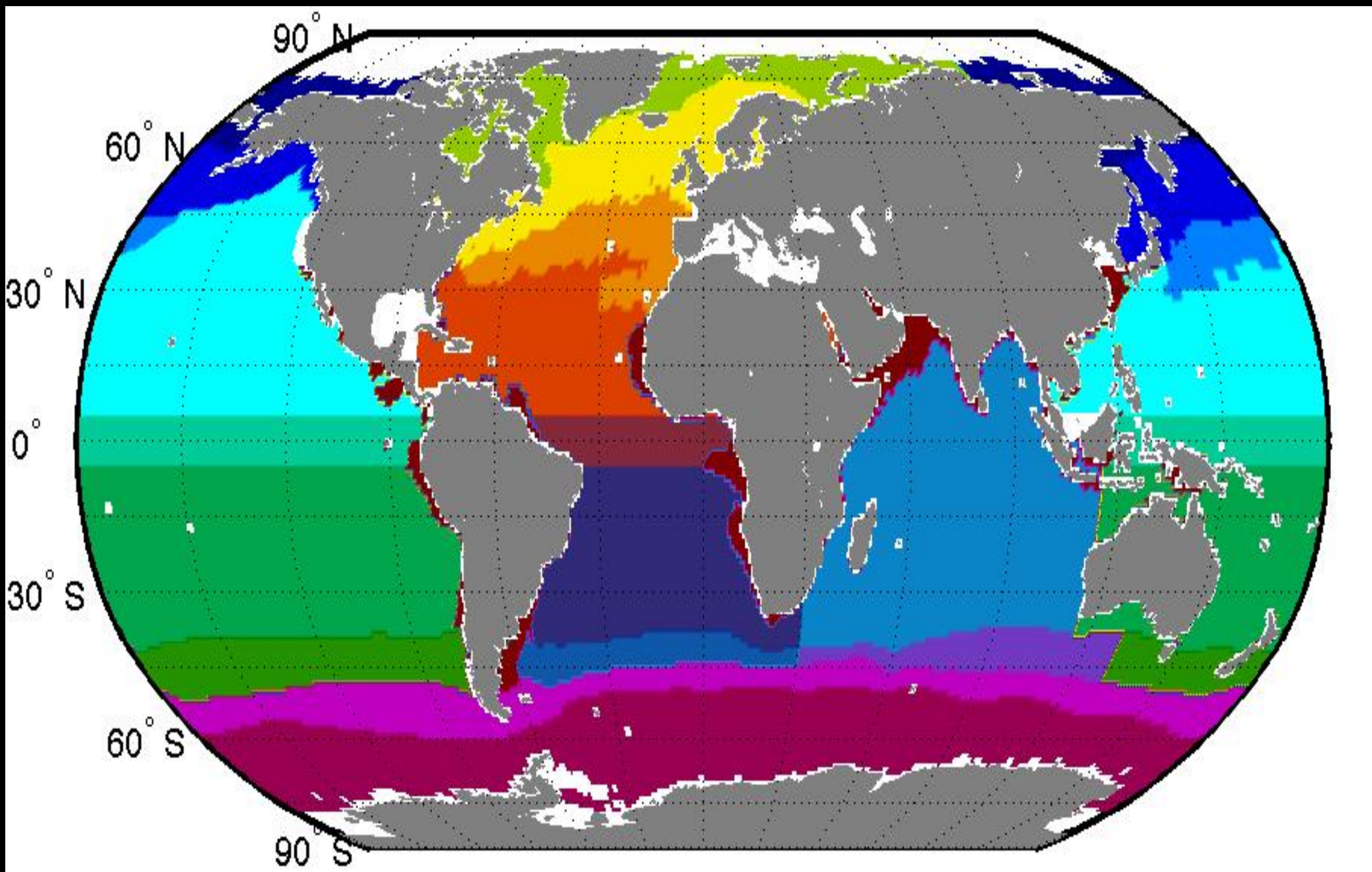
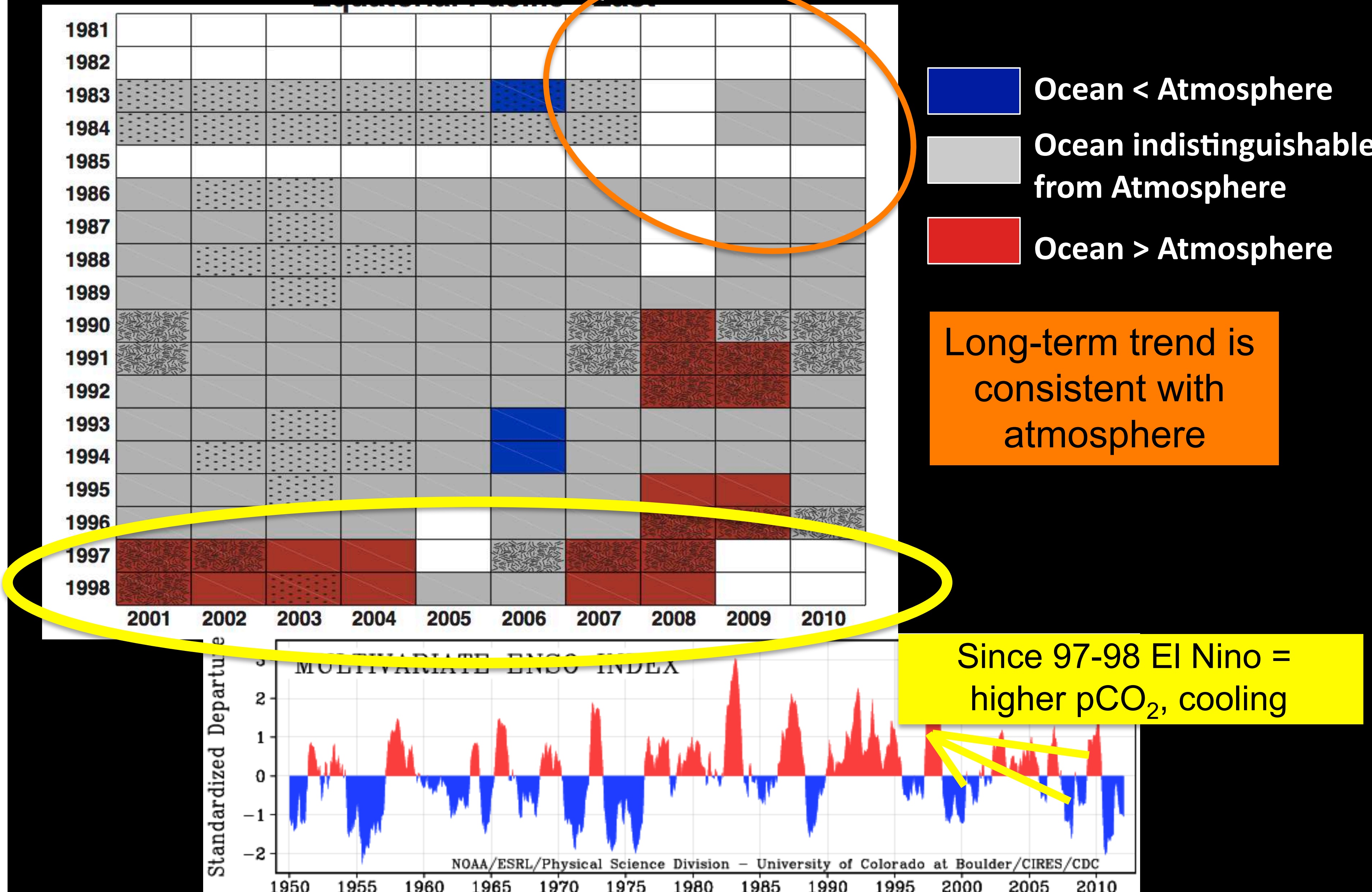
LeQuéré et al. 2010

Current Work: Global Extension

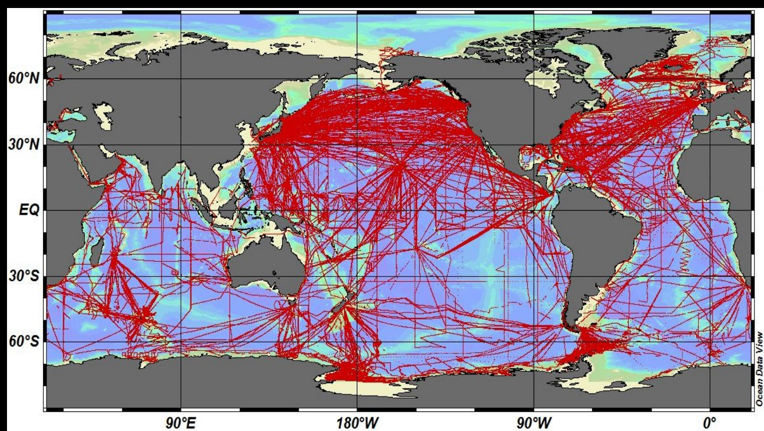
(also see poster by Fay)

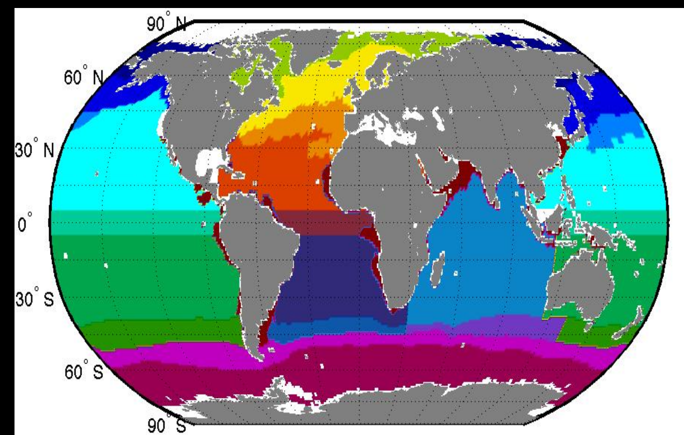


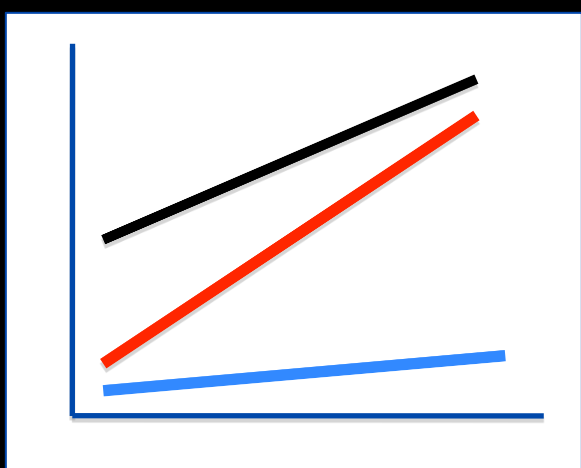
EASTERN EQUATORIAL PACIFIC

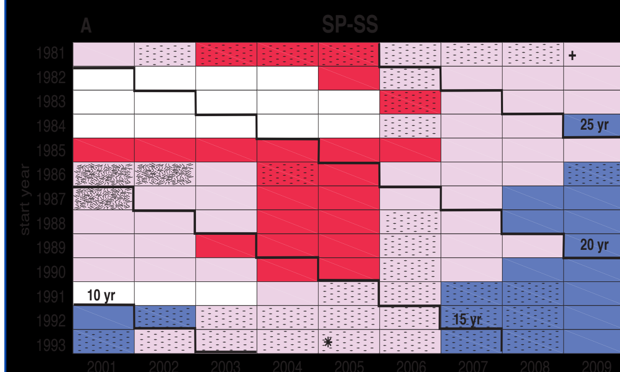


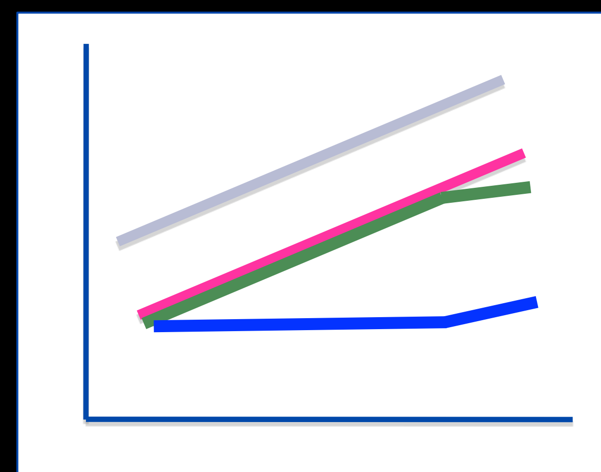
Questions?


60°N
30°N
EQ
30°S
60°S
90°E
180°W
90°W
0°
Ocean Data View


90° N
60° N
30° N
0°
30° S
60° S
90° S




A
SP-SS
start year
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
2001
2002
2003
2004
2005
2006
2007
2008
2009
25 yr
20 yr
10 yr
15 yr



[redacted]