Detection of change in ocean carbon uptake: Data and models

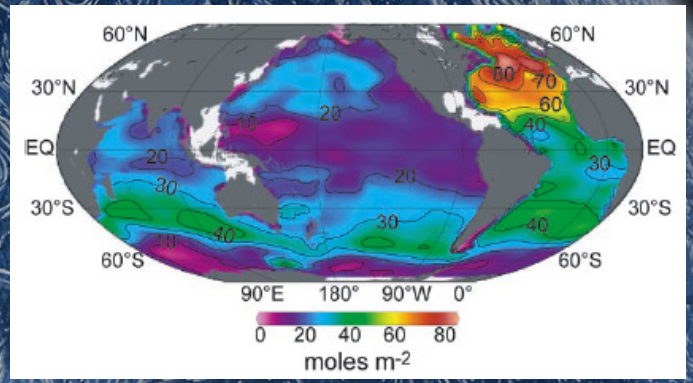
Galen A. McKinley

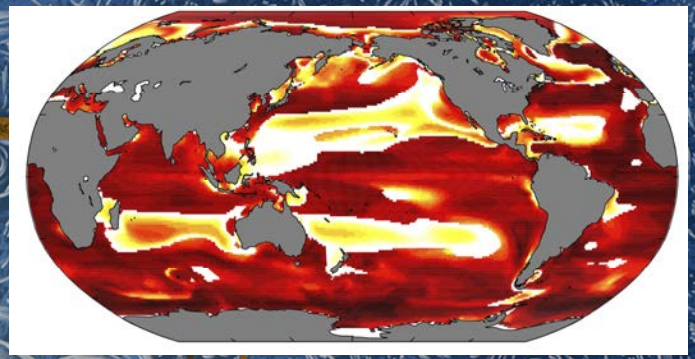
Atmospheric and Oceanic Sciences

University of Wisconsin – Madison

OCB Summer Workshop

July 26, 2016

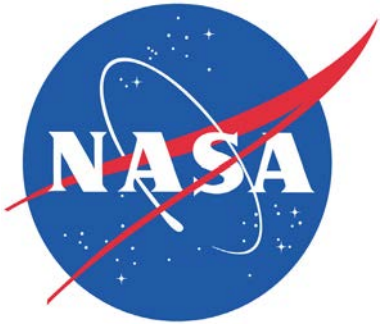




Acknowledgements

- Amanda Fay, research scientist
- Darren Pilcher, PhD 2015; postdoc at NOAA PMEL
- And other members of research group at Wisconsin

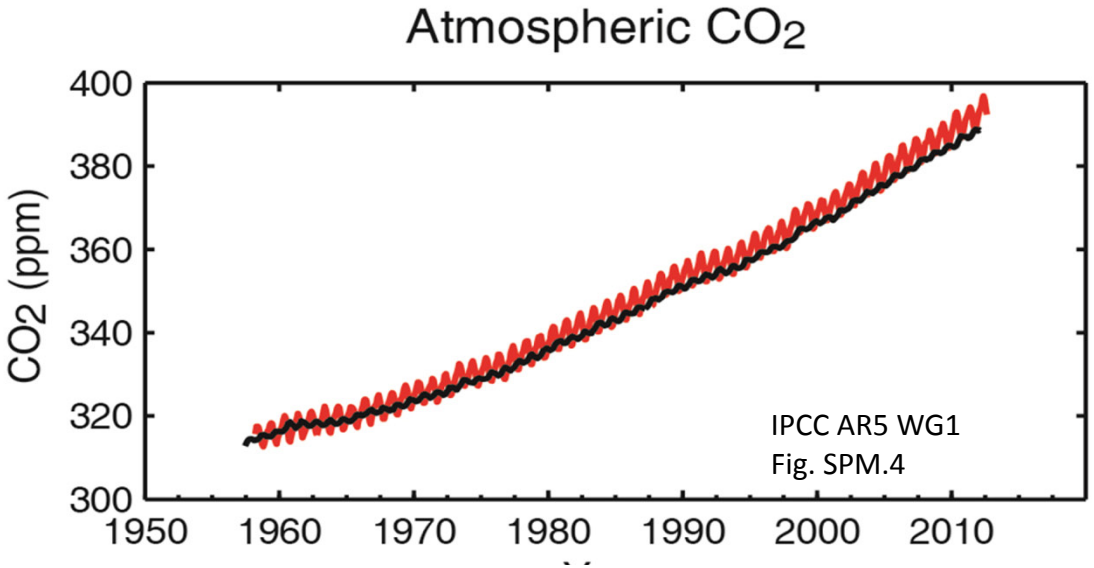
- Nicole Lovenduski, UC-Boulder
- Matt Long and Keith Lindsay, NCAR

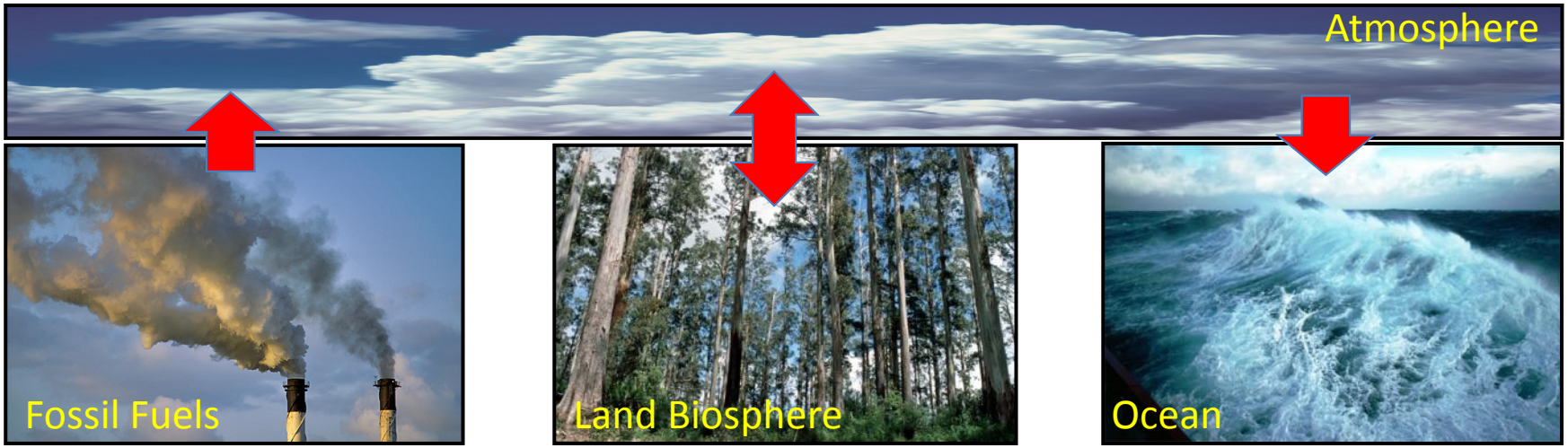


Take home messages

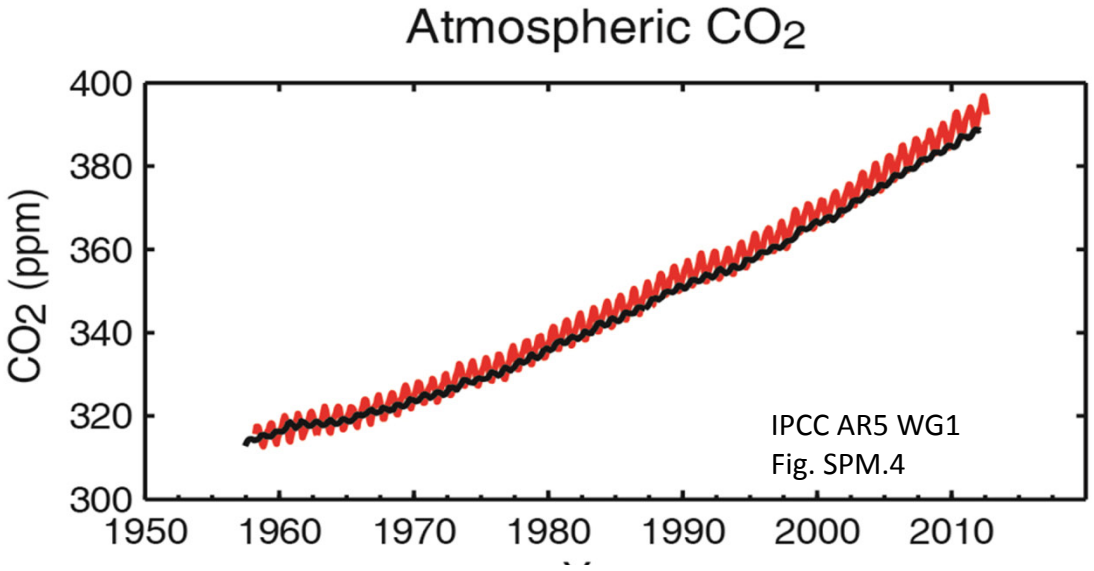
- Since preindustrial times, only the ocean has been a net sink for anthropogenic carbon
- As pCO_2^{atm} increases, this sink should be growing
- Direct detection of ocean carbon sink growth is not yet possible due to internal variability and data sparsity
- Timescales for detection of sink change vary widely

Understanding the carbon cycle is key to diagnosing and predicting climate change

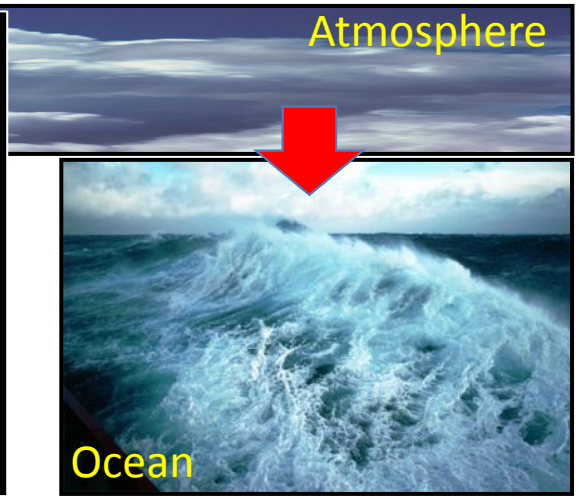




Understanding the carbon cycle is key to diagnosing and predicting climate change



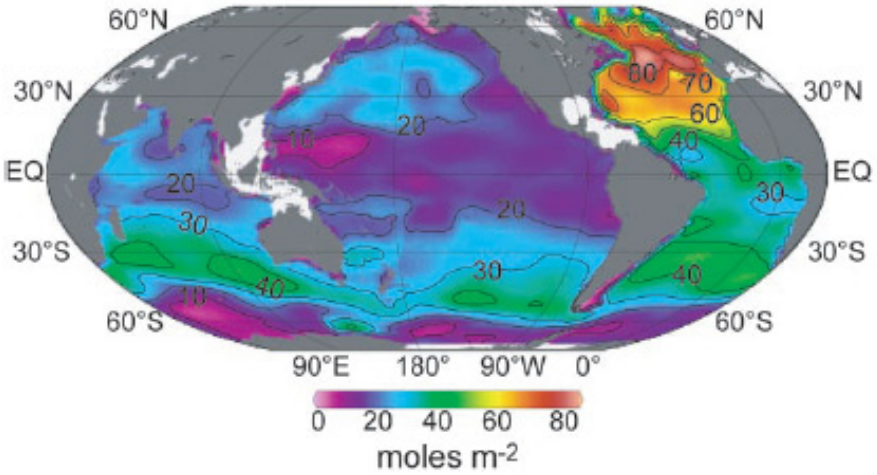
How is the ocean carbon sink evolving?



ASSESSING THE EVOLVING OCEAN CARBON SINK WITH DATA

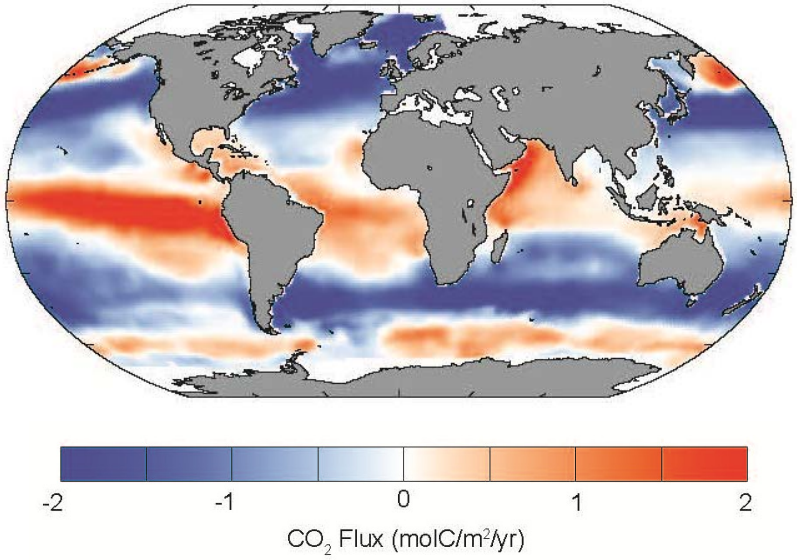
Two views of the ocean carbon sink

Column-integrated **anthropogenic carbon** accumulation, 1994



Sabine et al.(2004), *Science*

Annual sea to air **total CO_2 flux**, 2000



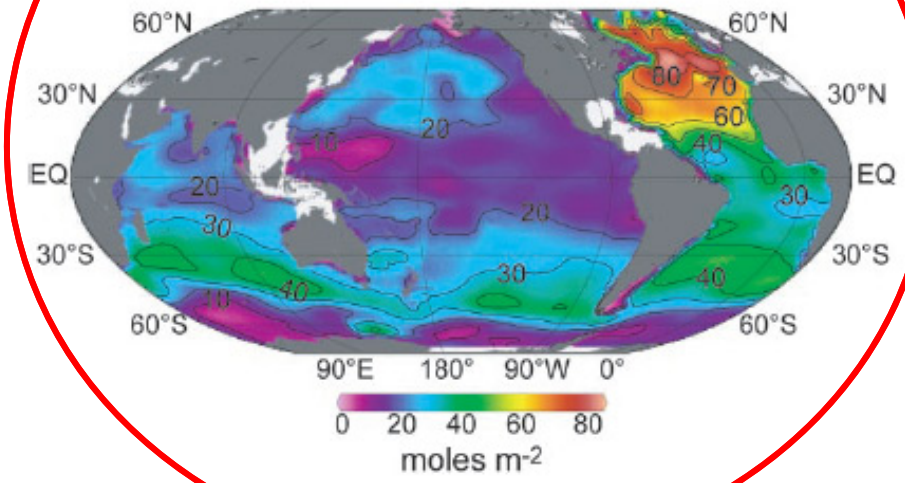
Landschutzer et al.(2014), *GBC*

Total carbon = anthropogenic carbon + natural carbon

3% **97%**

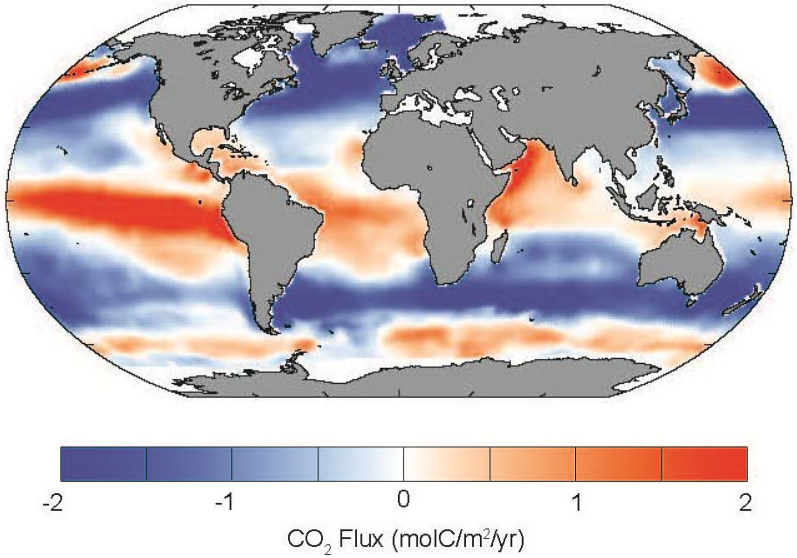
Two views of the ocean carbon sink

Column-integrated **anthropogenic carbon** accumulation, 1994



Sabine et al.(2004), *Science*

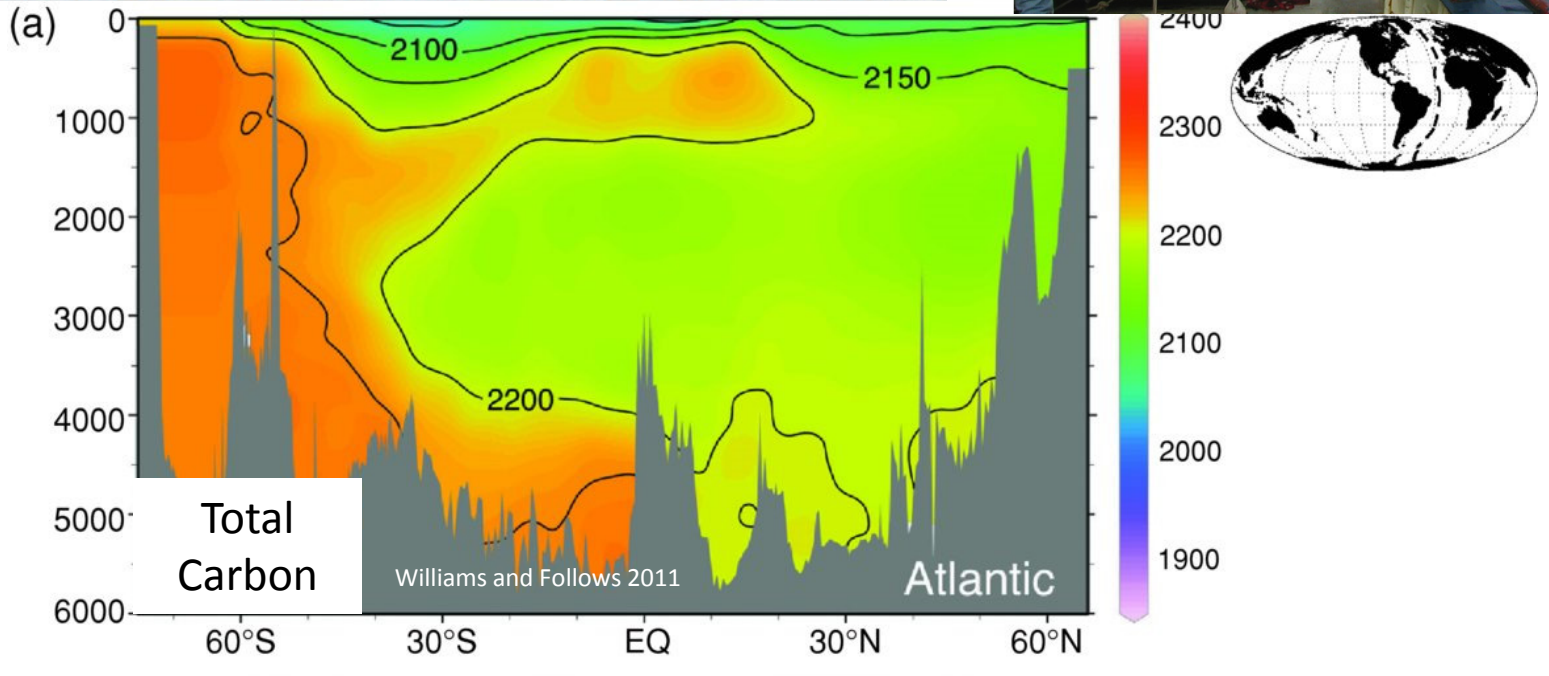
Annual sea to air **total CO_2 flux**, 2000



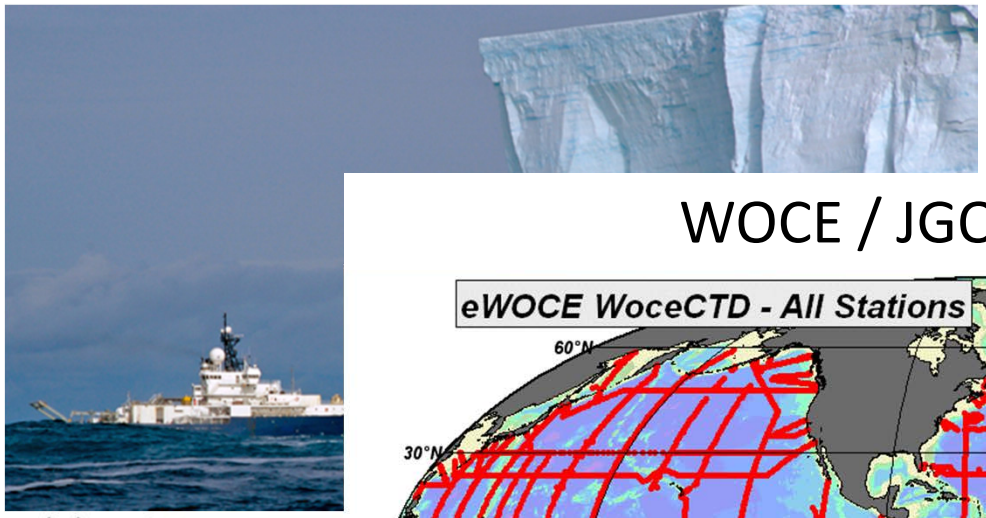
Landschutzer et al.(2014), *GBC*

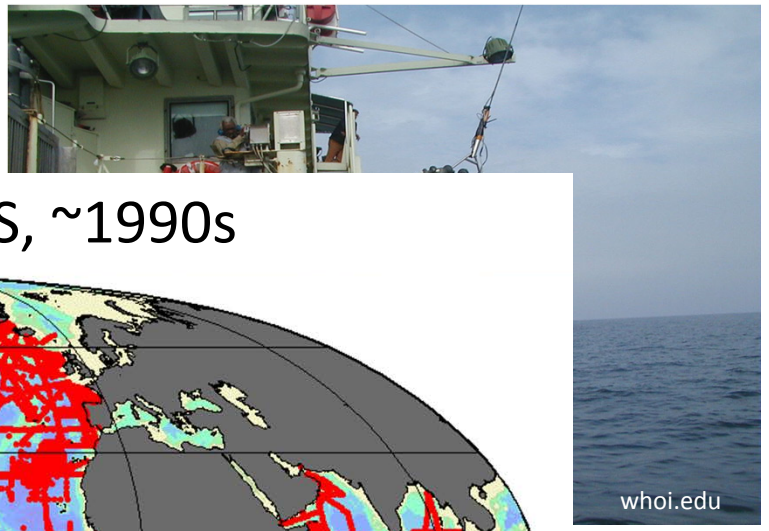
Total carbon = anthropogenic carbon + natural carbon

Interior data to find **anthropogenic carbon**

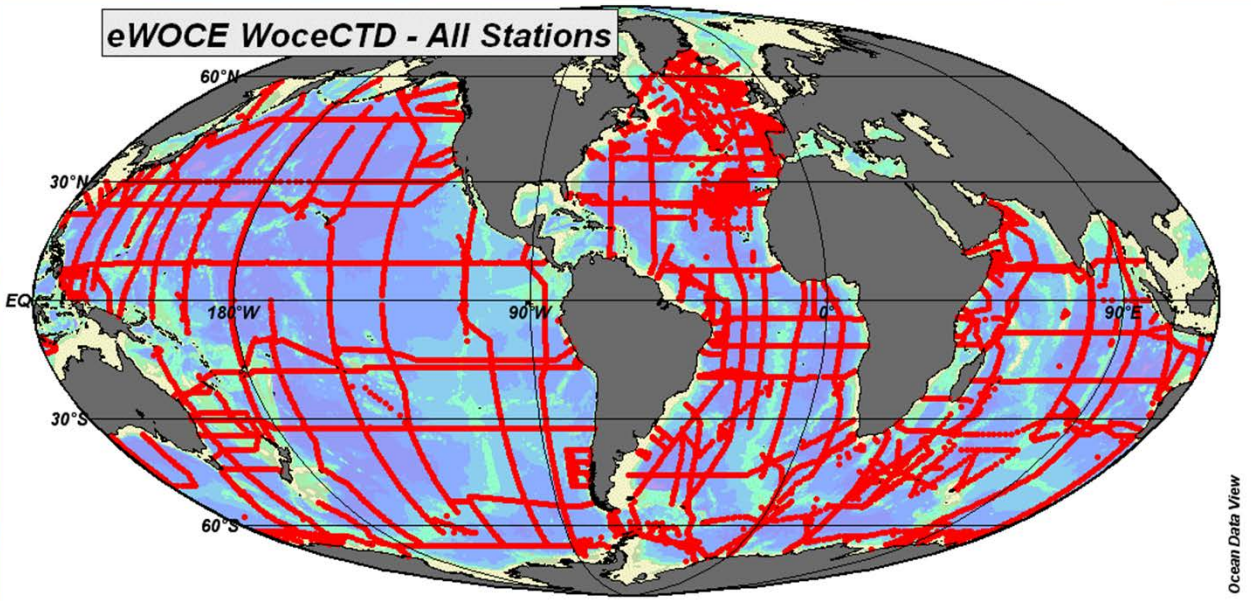


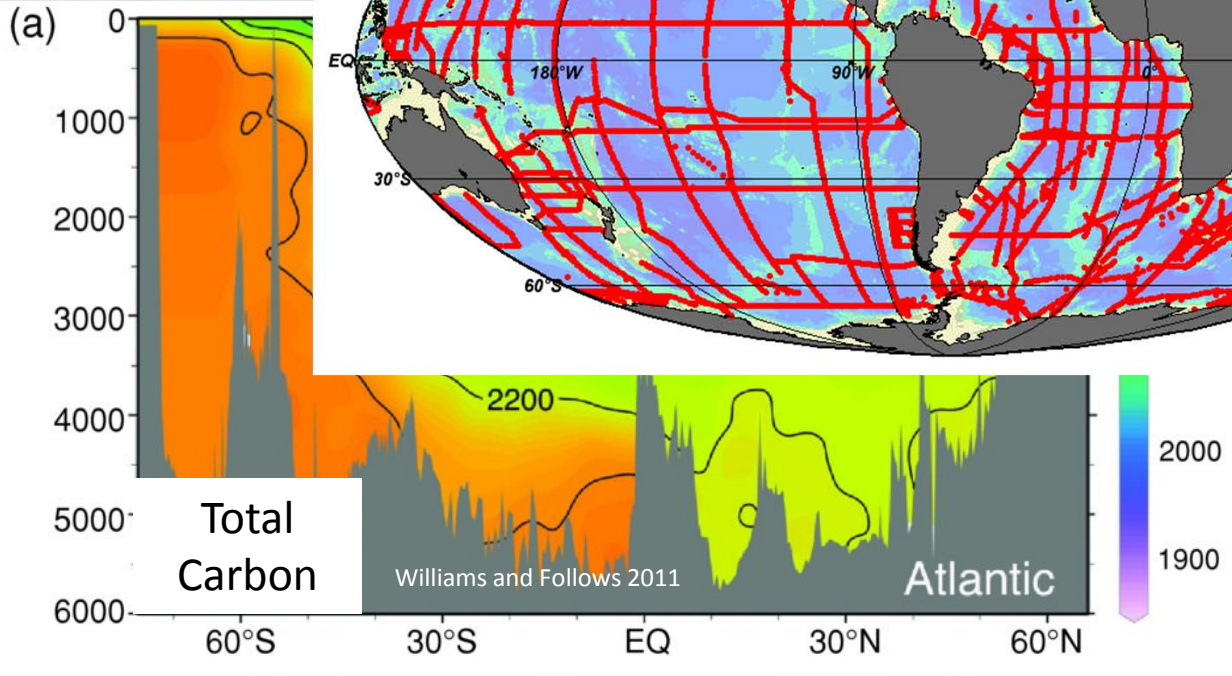
Interior data to find **anthropogenic carbon**



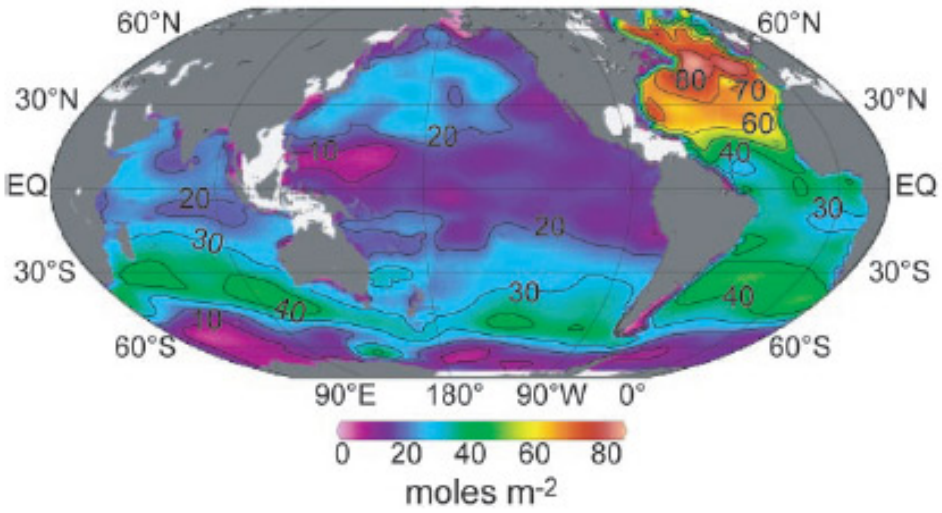


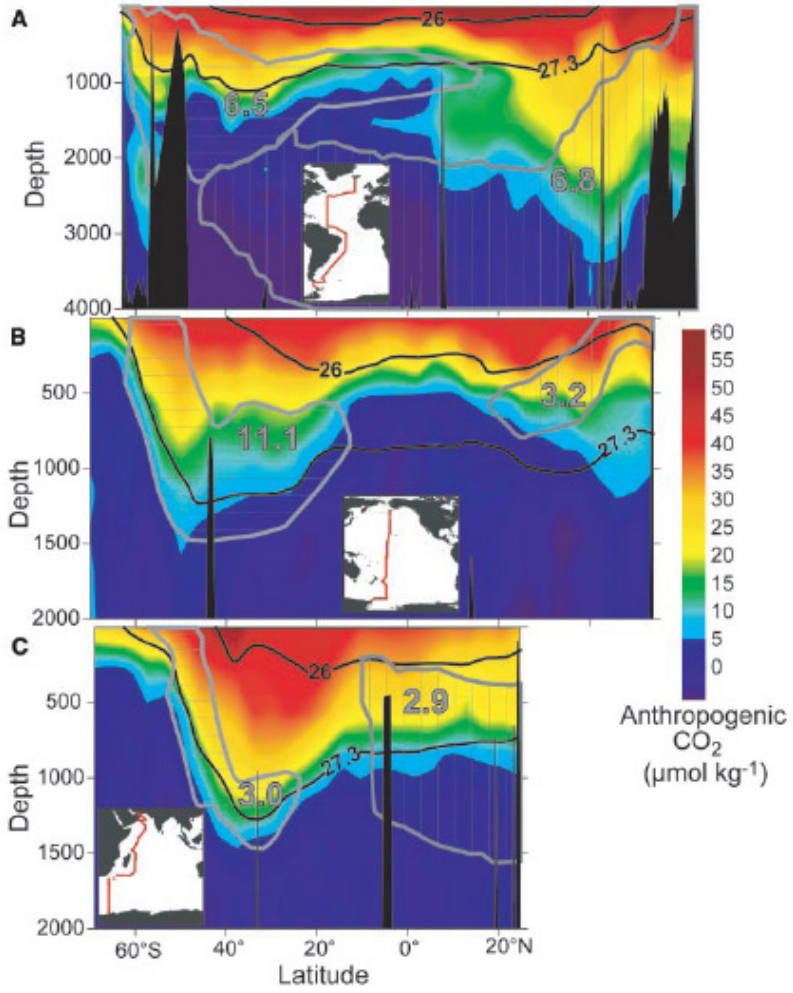
WOCE / JGOFS, ~1990s





Total ocean **anthropogenic CO_2** accumulation through 1994

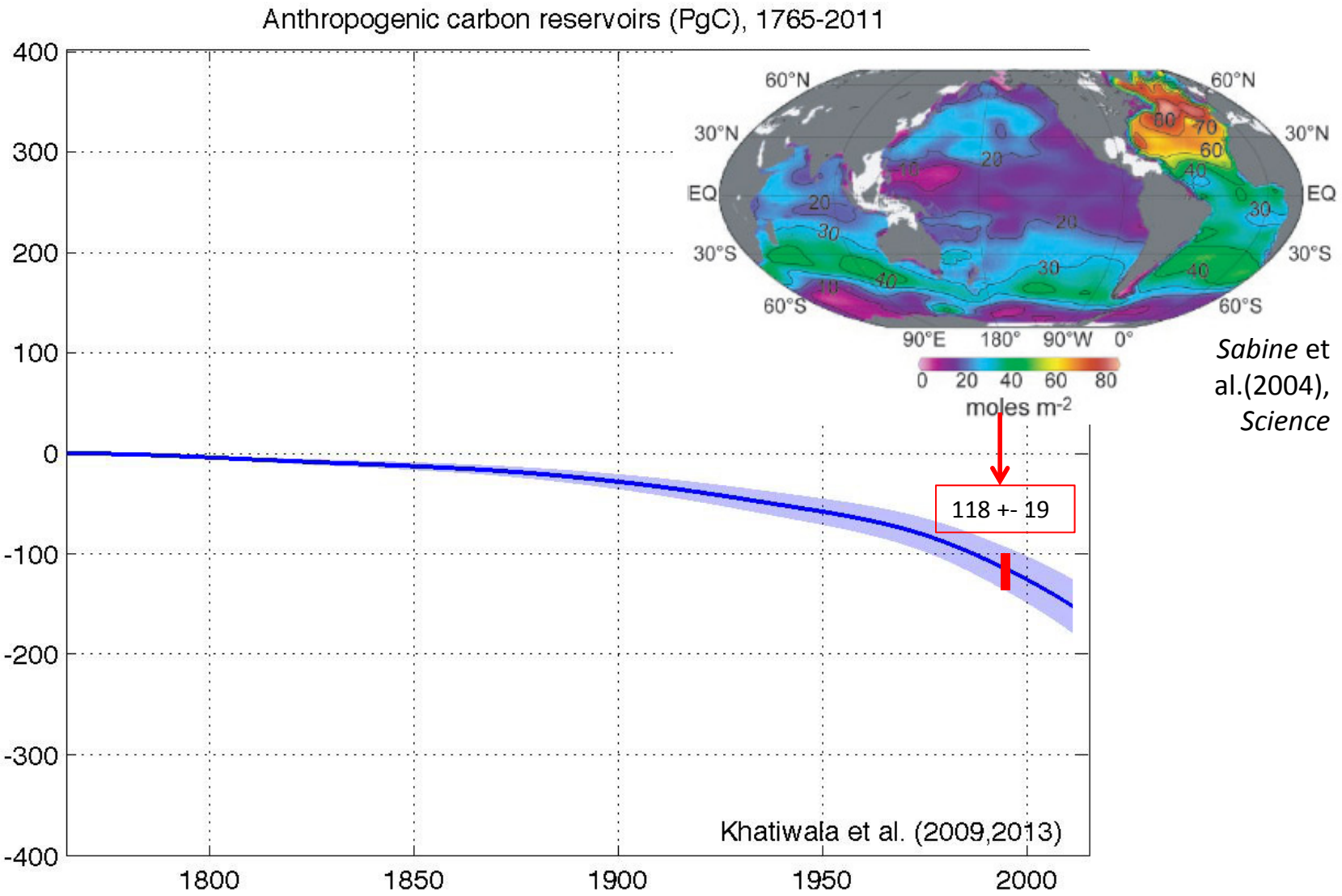




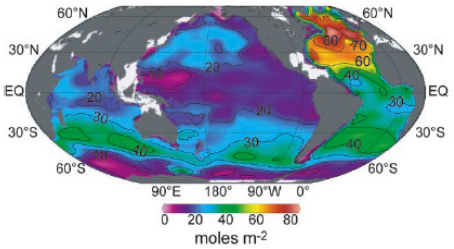
Using multiple tracers, estimate the additional carbon in the ocean due to human activities in 1994

Sabine et al. *Science* 2004

Increasing rate of **anthropogenic CO_2** uptake from interior data, *assuming constant circulation and biology*

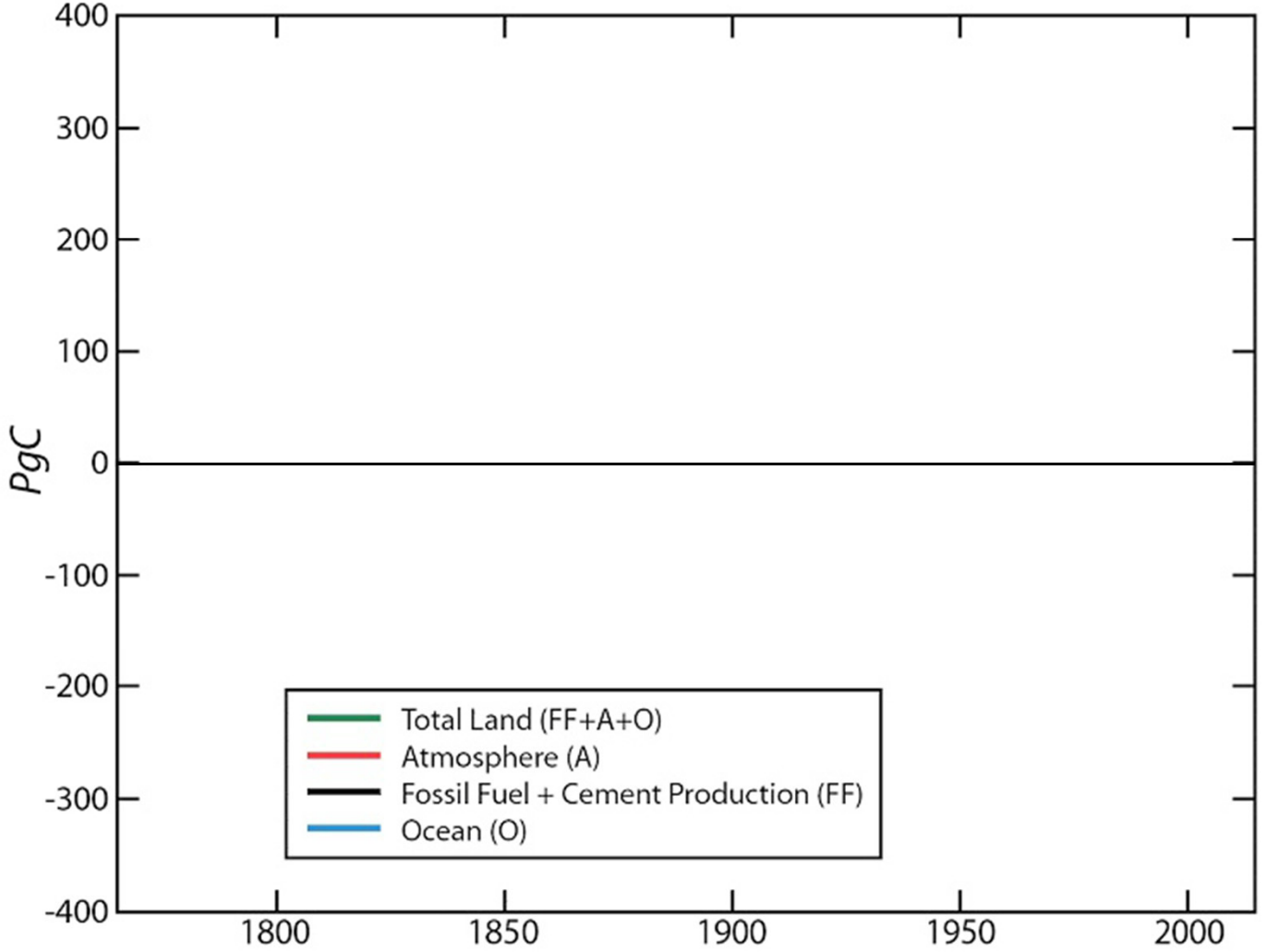


Sabine et al.(2004), *Science*



Temporal Evolution of Carbon Accumulation

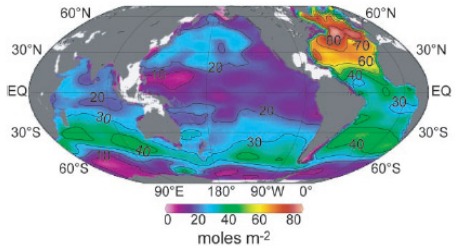
Anthropogenic Carbon Reservoirs, 1765-2011

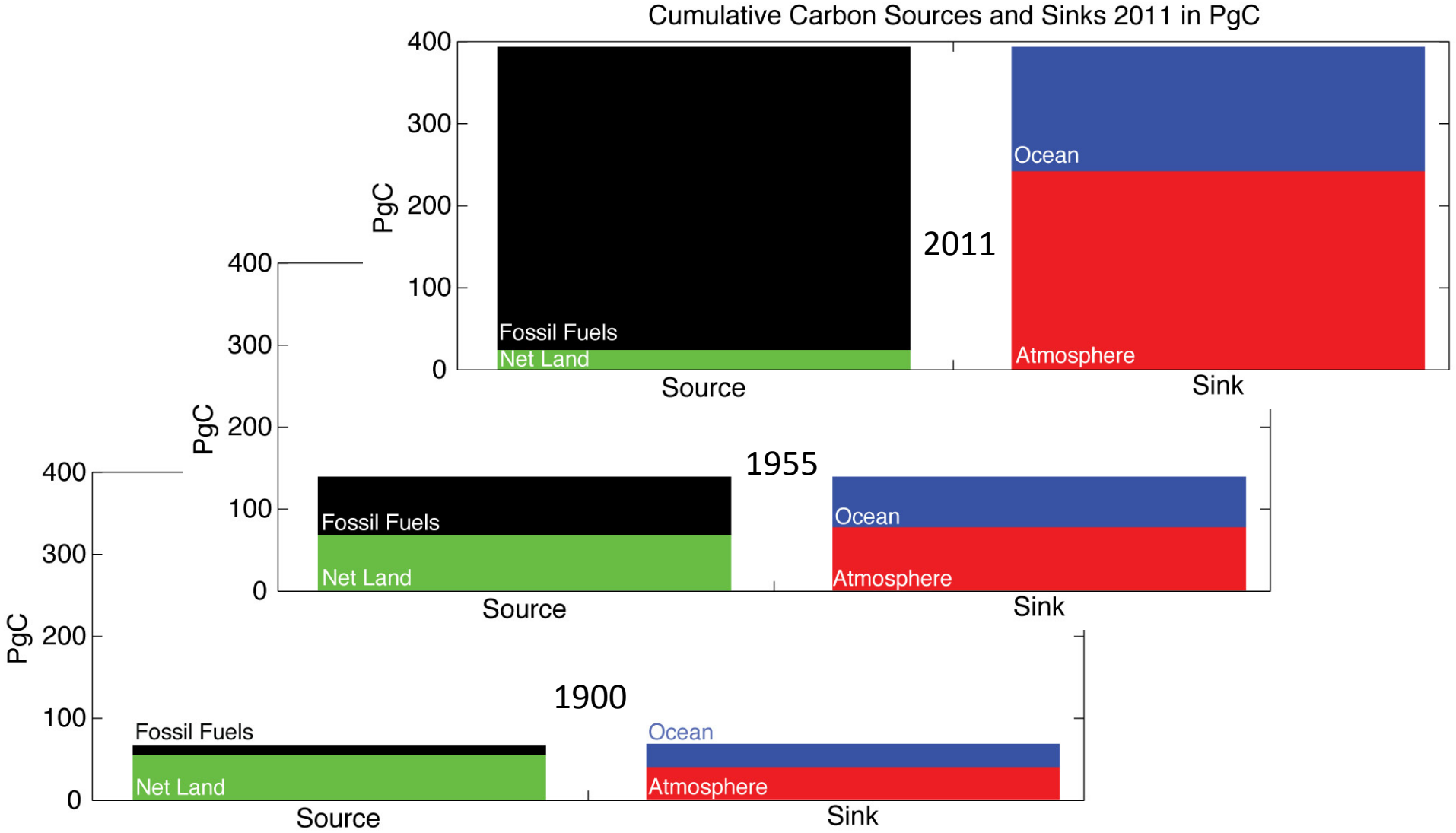


Khatiwala et al. *Nature* (2009); *Biogeoscience* (2013)

Movie credit: OCB

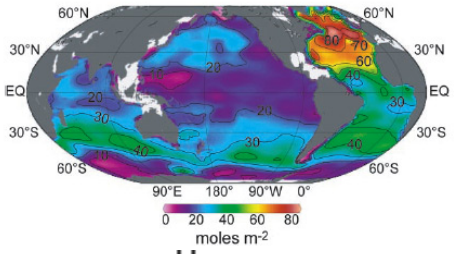
Cumulatively, only the ocean and atmosphere have absorbed **anthropogenic carbon**

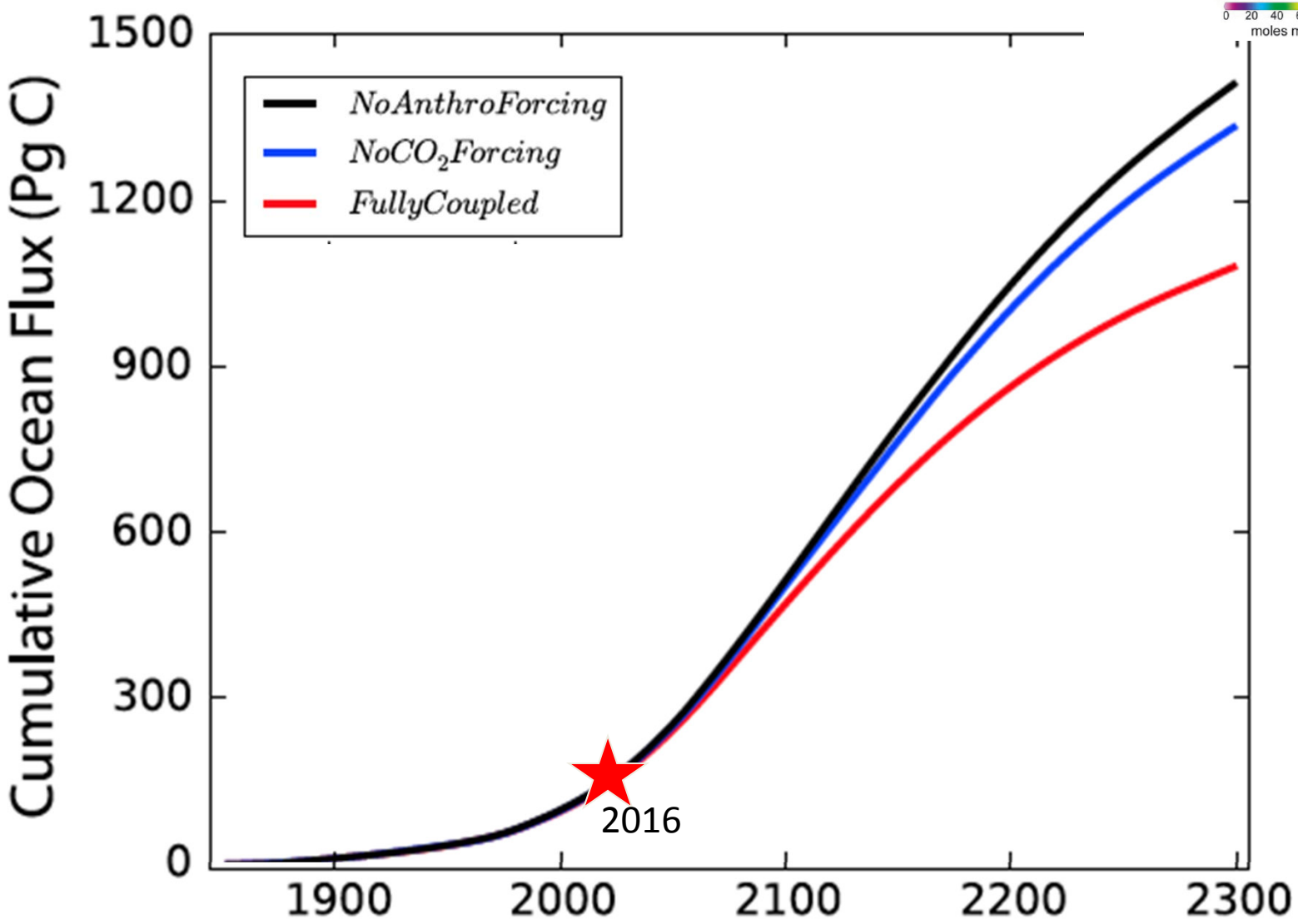




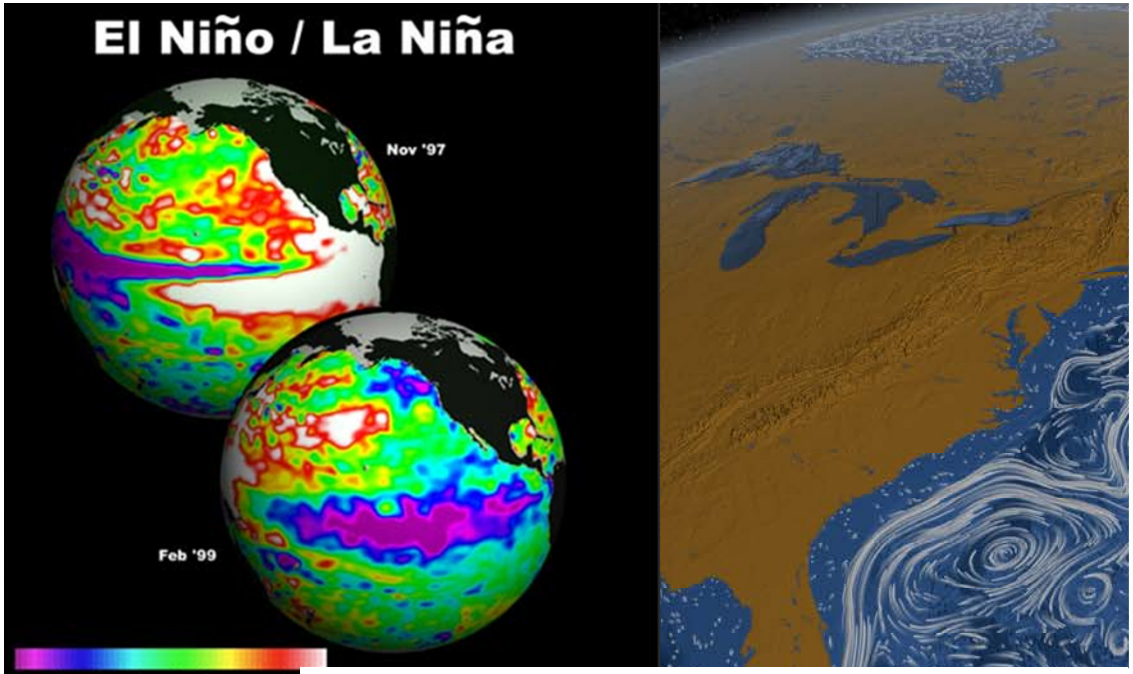
Khatiwala et al. *Nature* (2009); *Biogeoscience* (2013)

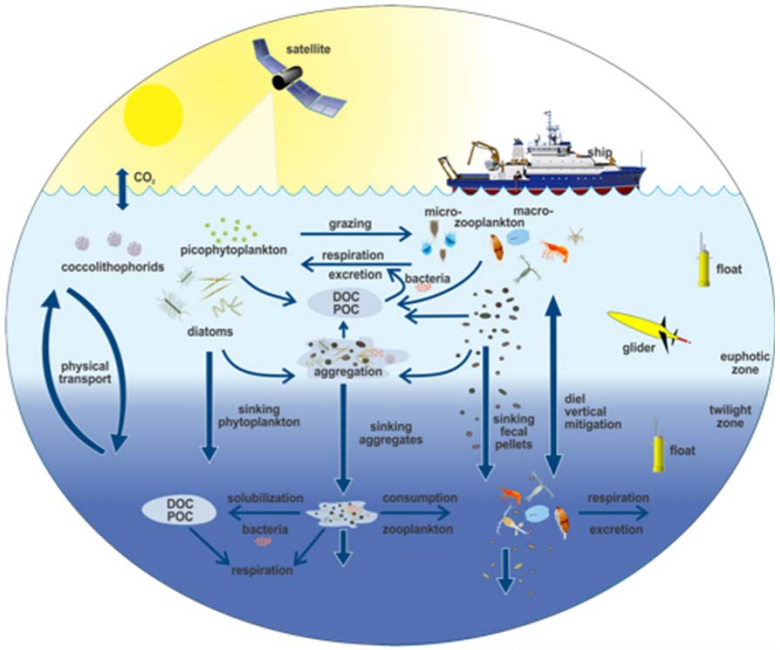
RCP 8.5 model projection, cumulative **anthropogenic carbon** uptake by ocean

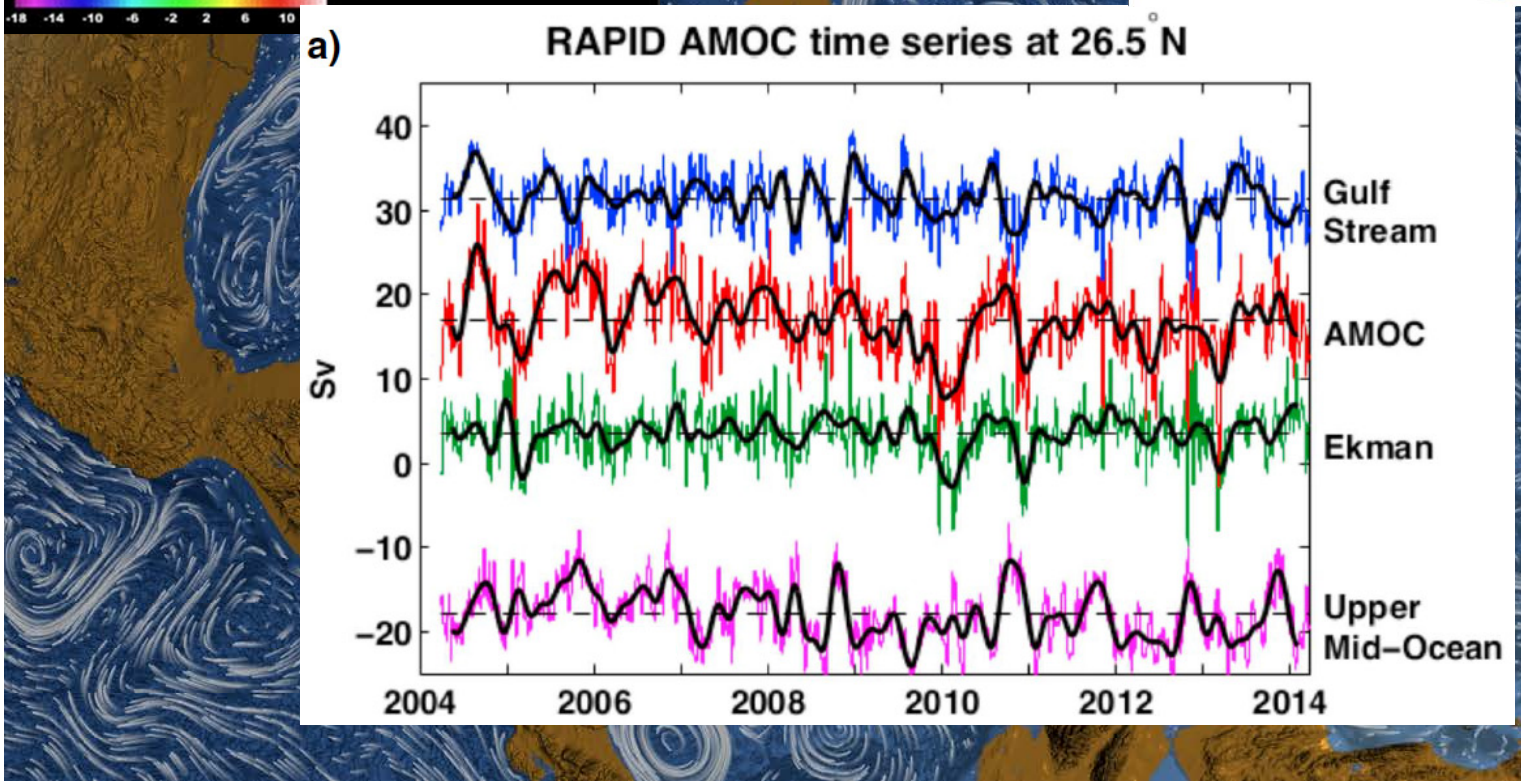




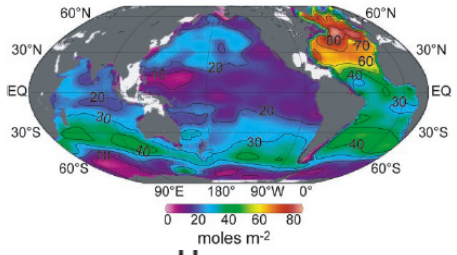
Randerson et al. 2015, GBC

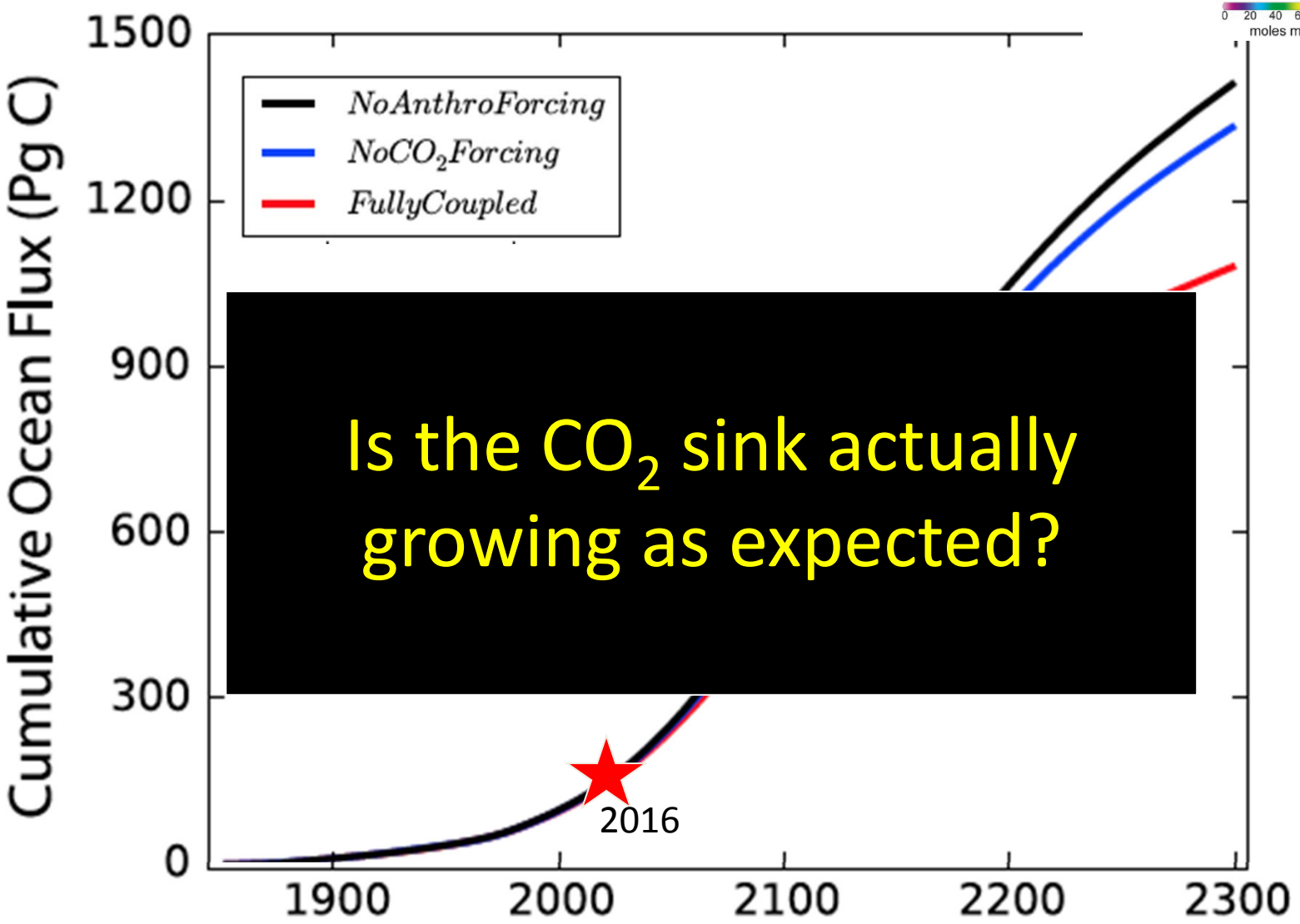

El Niño / La Niña
Nov '97
Feb '99
-18 -14 -10 -6 -2 2 6 10


satellite
ship
CO_2
picophytoplankton
coccolithophorids
diatoms
grazing
respiration
excretion
micro-zooplankton
macro-zooplankton
bacteria
DOC
POC
aggregation
physical transport
sinking phytoplankton
sinking aggregates
sinking fecal pellets
diel vertical mitigation
float
glider
euphotic zone
twilight zone
solubilization
consumption
zooplankton
excretion


a)
RAPID AMOC time series at 26.5° N
Sv
40
30
20
10
0
−10
−20
2004
2006
2008
2010
2012
2014
Gulf Stream
AMOC
Ekman
Upper Mid−Ocean

RCP 8.5 model projection, cumulative **anthropogenic carbon** uptake by ocean



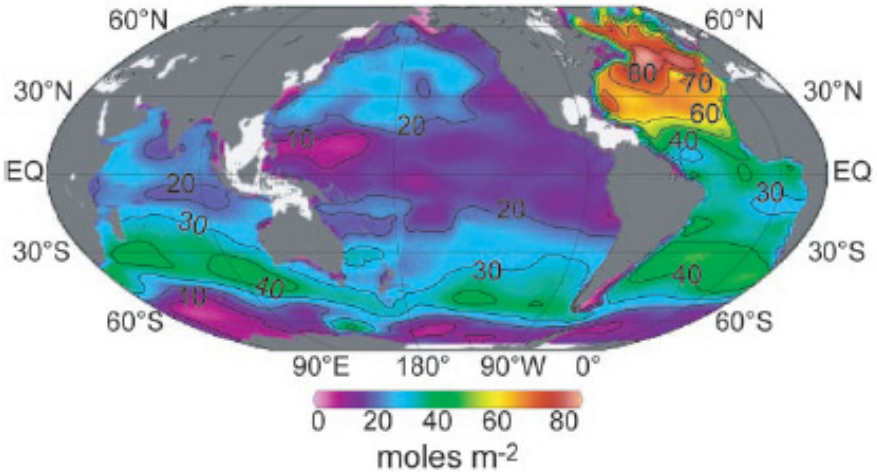


Is the CO_2 sink actually growing as expected?

Randerson et al. 2015, GBC

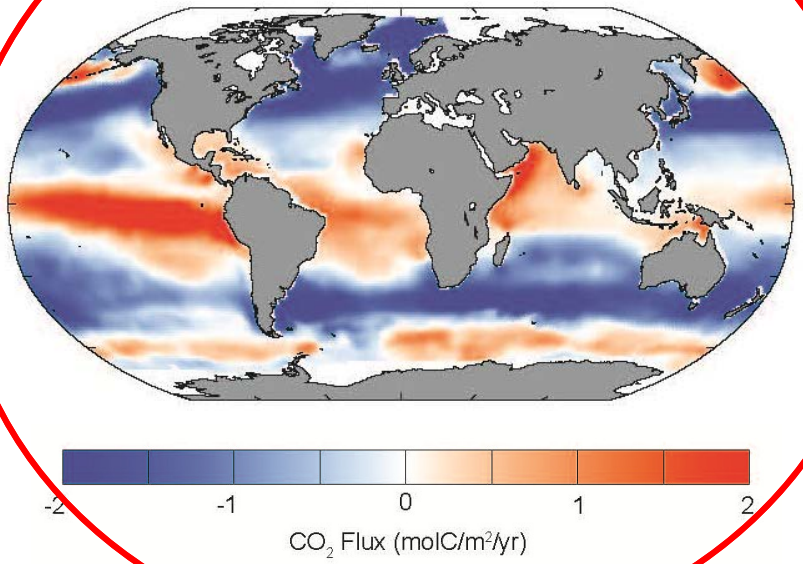
Two views of the ocean carbon sink

Column-integrated **anthropogenic carbon** accumulation, 1994



Sabine et al.(2004), *Science*

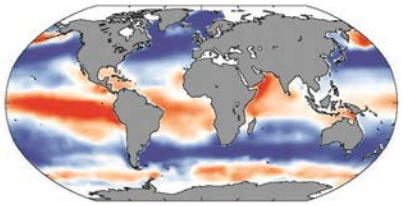
Annual sea to air **total CO_2 flux**, 2000



Landschutzer et al.(2014), *GBC*

Total carbon = anthropogenic carbon + natural carbon

Surface pCO_2 observations
….. CO_2 flux proportional to ΔpCO_2

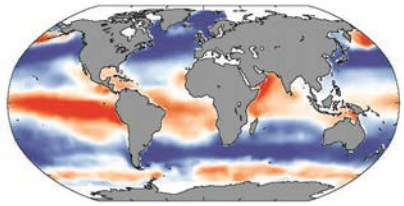


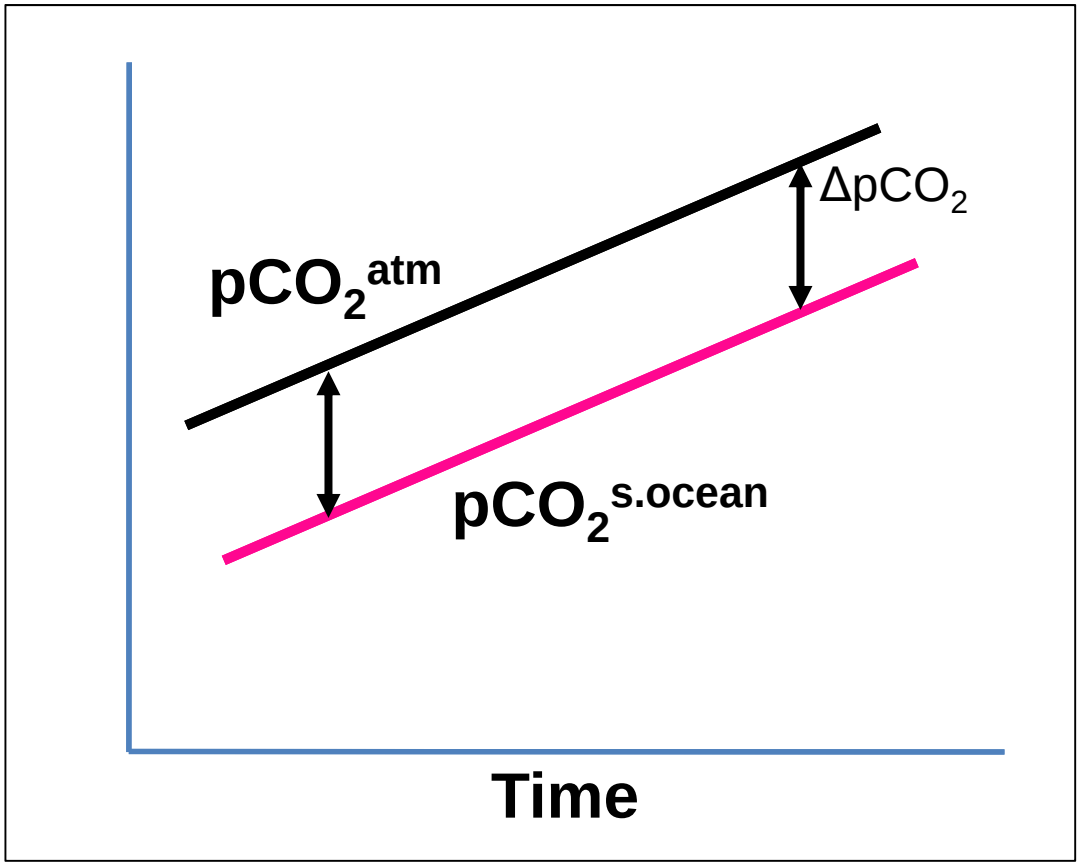
LDEO and SOCAT
pCO_2 databases

60°N
30°N
EQ
30°S
60°S
°W
0°
Ocean Data View

Takahashi et al. 2010, 2014, 2015, CDIAC
Pfeil et al., Sabine et al. 2013, ESSD

CO_2 flux trends from surface pCO_2





Parallel Trends

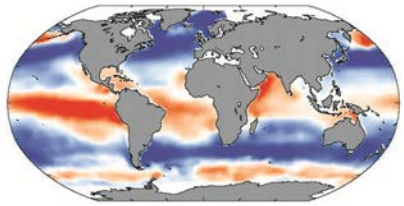
$dpCO_2^{s.ocean}/dt = dpCO_2^{atm}/dt$

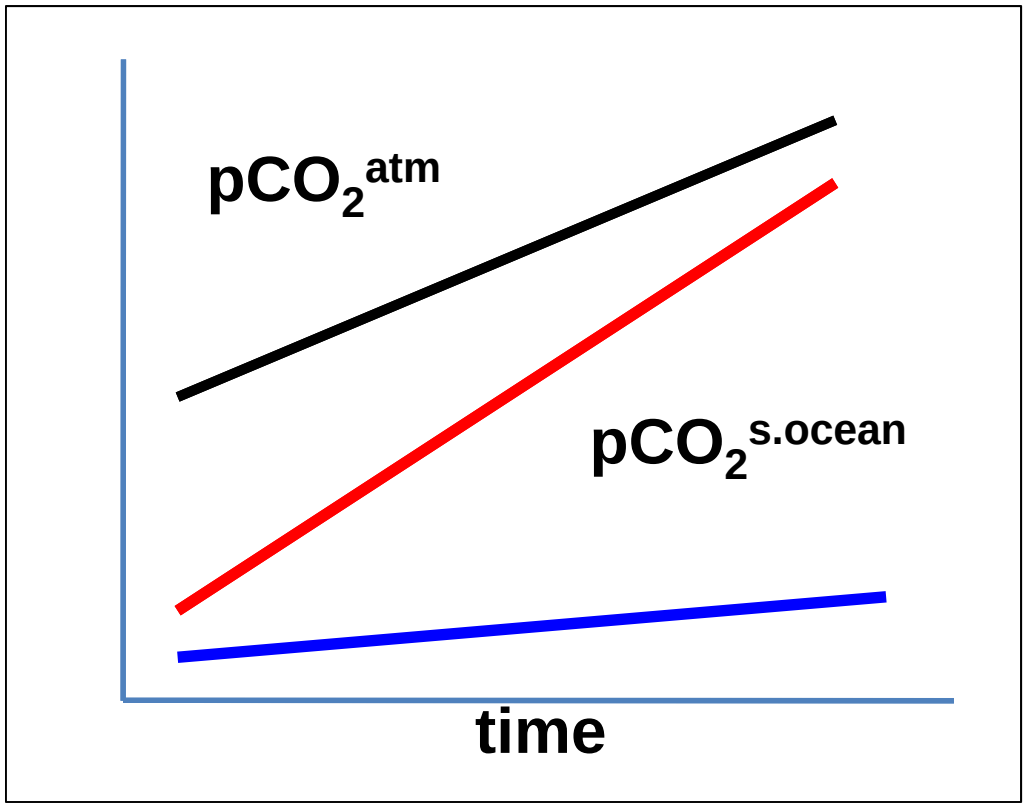
$d\Delta pCO_2/dt = 0$

$d(CO_2Flux)/dt = 0$

STEADY SINKS AND SOURCES

$pCO_2^{s.ocean}$ trend different from pCO_2^{atm} trend indicates change in CO_2 flux





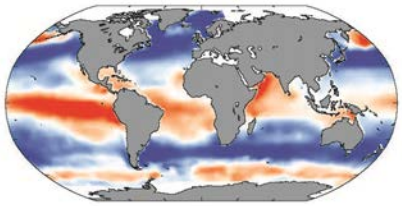
$dpCO_2^{s.ocean}/dt > dpCO_2^{atm}/dt$

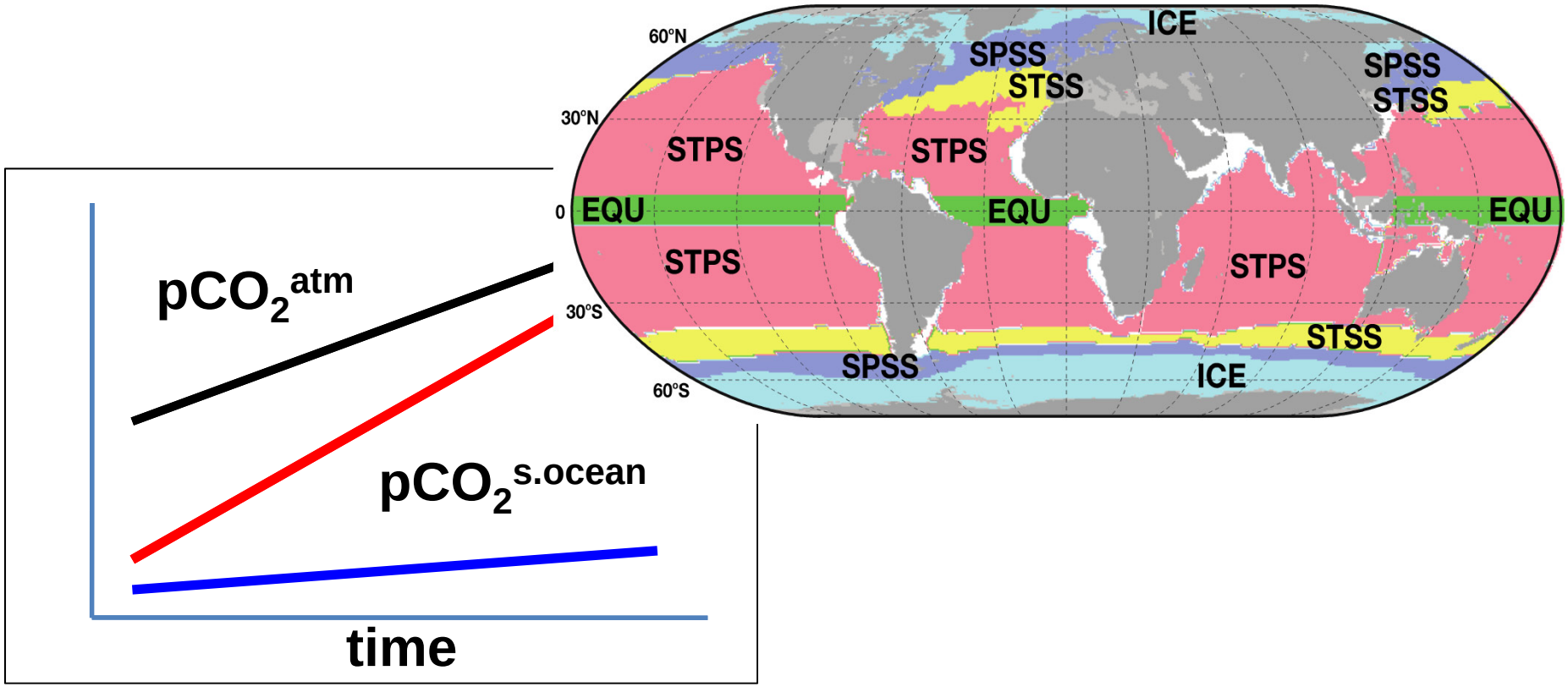
DECLINING SINK

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

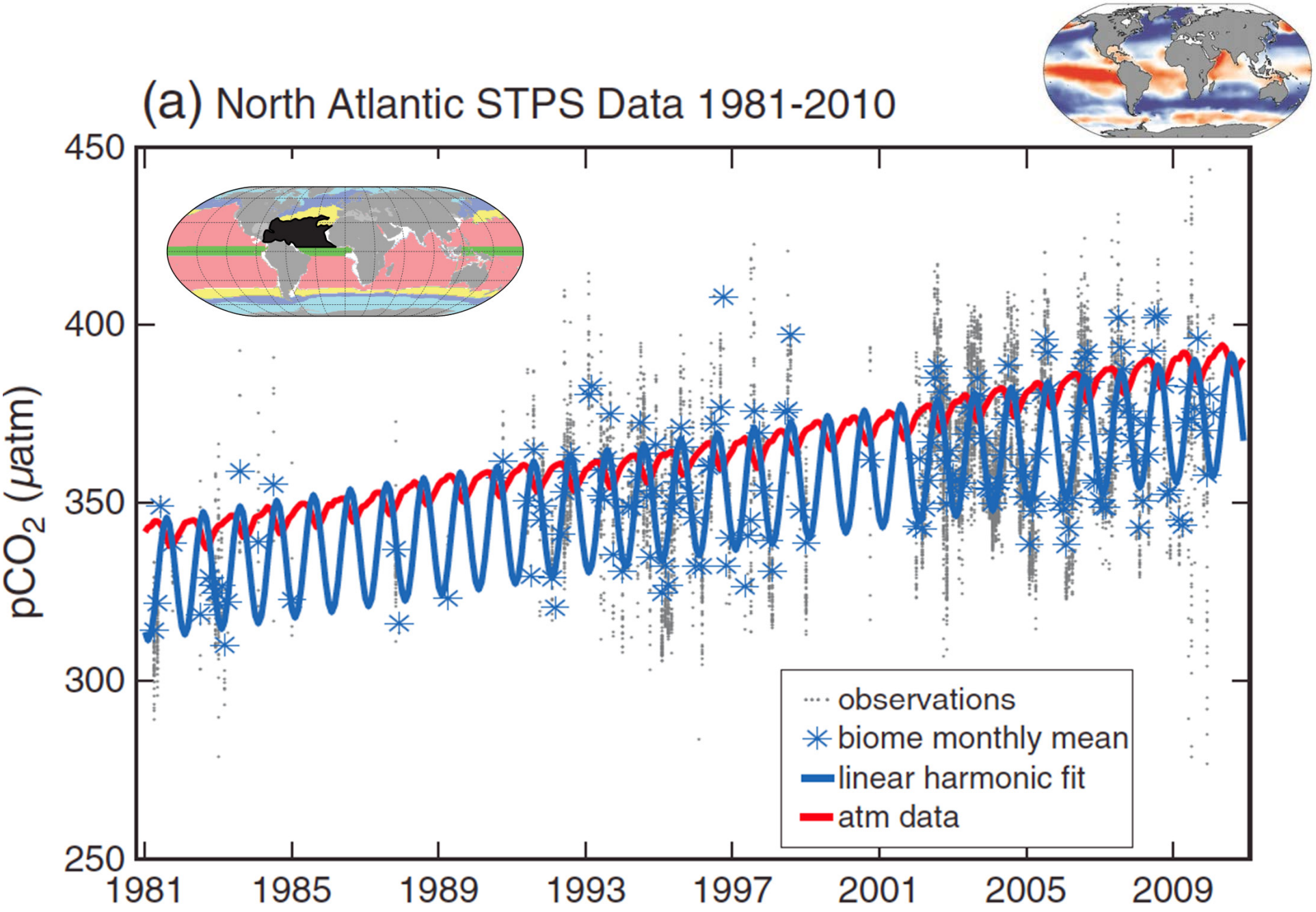
GROWING SINK

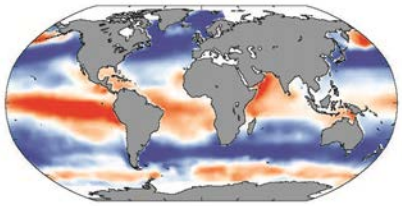
Trends in pCO_2 for gyre-scale biomes



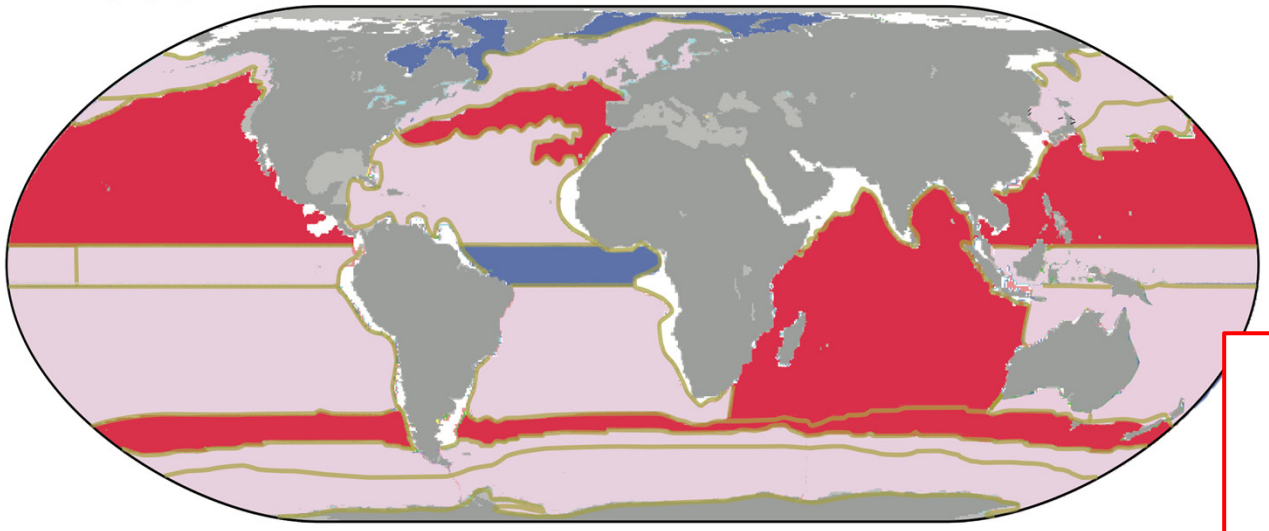


McKinley et al. (2011) Nature Geosci.
Fay and McKinley (2013) Global Biogeochem Cycles
Fay and McKinley (2014), Earth System Sci. Data
Fay et al. (2014) Geophys Res. Lett
Lovenduski et al. (2015) Global Biogeochem Cycles


(a) North Atlantic STPS Data 1981-2010
450
400
350
300
250
pCO2 (μatm)
1981
1985
1989
1993
1997
2001
2005
2009
observations
biome monthly mean
linear harmonic fit
atm data



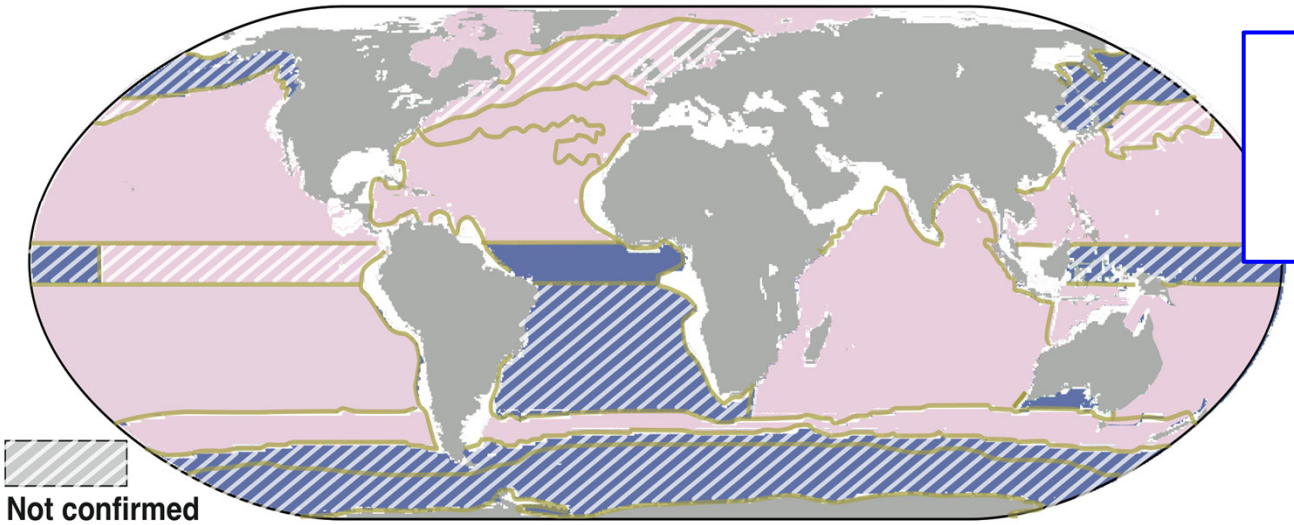
1990-2005



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

DECLINING SINK

1981-2010



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

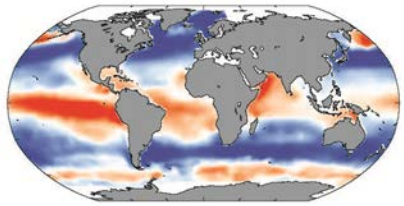
GROWING SINK

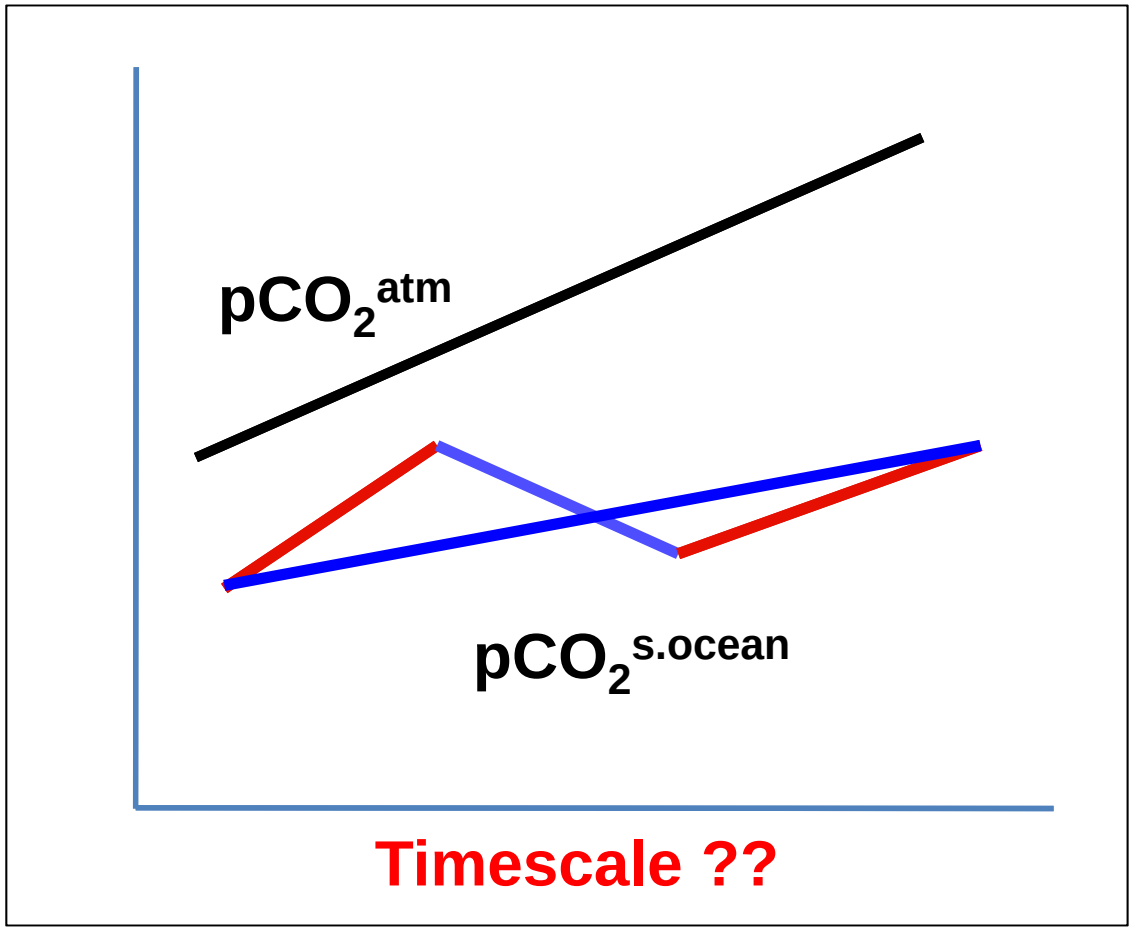
Not confirmed with model

$dpCO_2^{ocn}/dt < dpCO_2^{atm}/dt$ | $dpCO_2^{ocn}/dt \sim dpCO_2^{atm}/dt$ | $dpCO_2^{ocn}/dt > dpCO_2^{atm}/dt$

Fay and McKinley, 2013, GBC

On what timescale does the ocean response to pCO_2^{atm} forcing become clear?



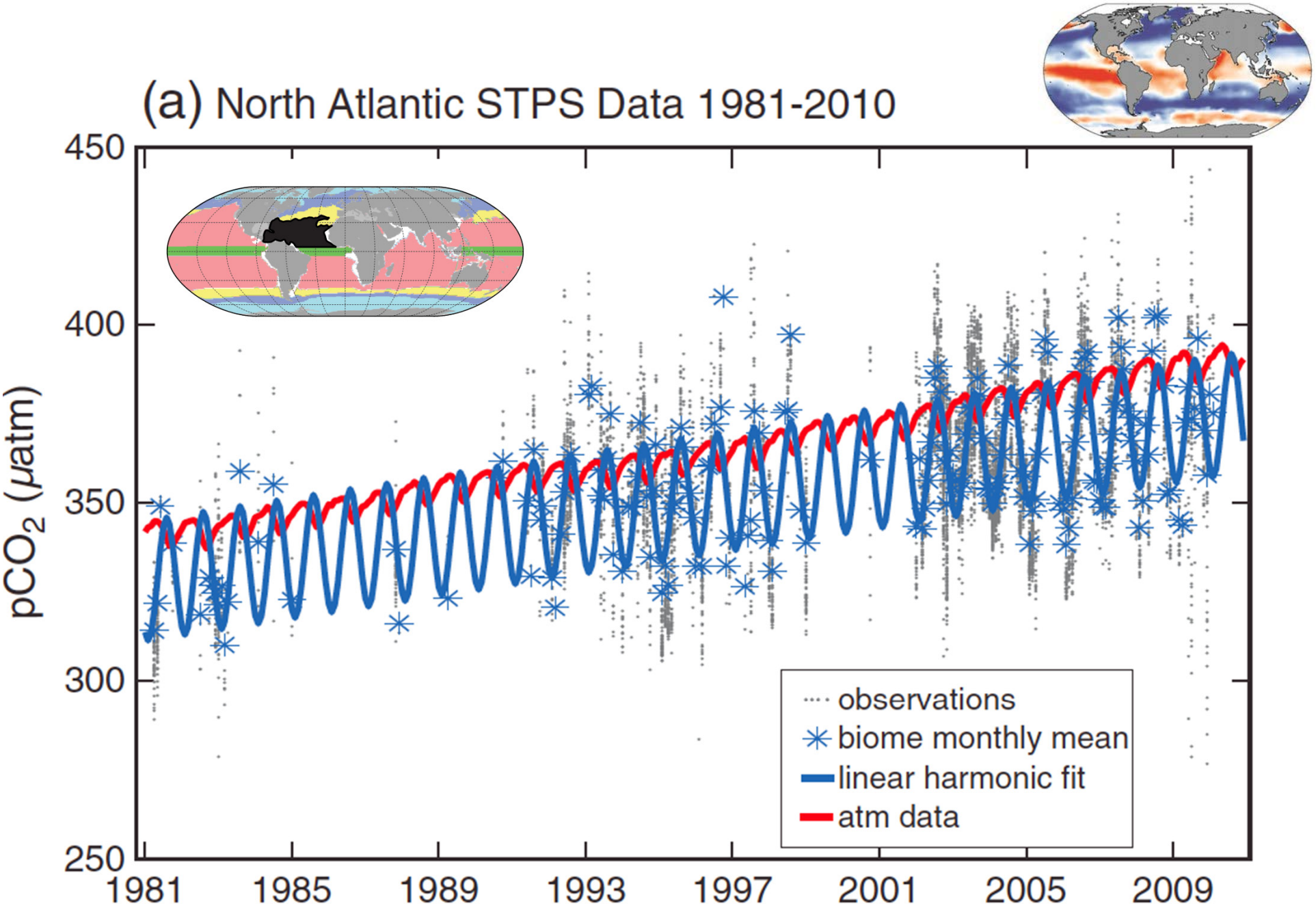


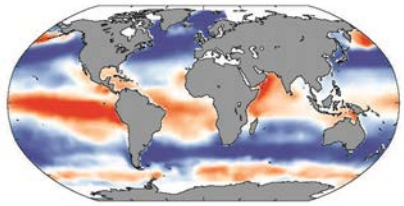
$dpCO_2^{s.ocean}/dt > dpCO_2^{atm}/dt$

DECLINING SINK

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

GROWING SINK


(a) North Atlantic STPS Data 1981-2010
450
400
350
300
250
pCO2 (μatm)
1981
1985
1989
1993
1997
2001
2005
2009
observations
biome monthly mean
linear harmonic fit
atm data



(d) NA-STPS

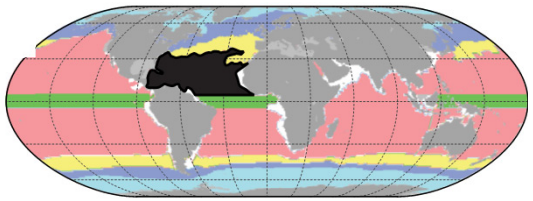
start year

1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998

25 yrs
20 yrs
15 yrs
10 yrs

2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

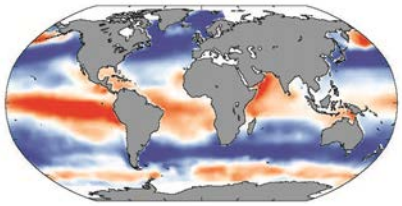
end year



$dpCO_2^{ocn}/dt < dpCO_2^{atm}/dt$ | $dpCO_2^{ocn}/dt \sim dpCO_2^{atm}/dt$ | $dpCO_2^{ocn}/dt > dpCO_2^{atm}/dt$

warming trend

cooling trend



(b) NA-SPSS

start year

1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998

25 yrs
20 yrs
15 yrs
10 yrs

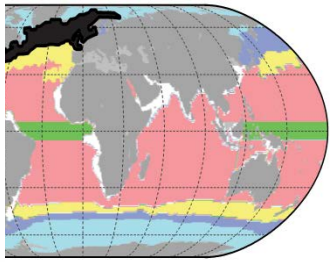
2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

end year

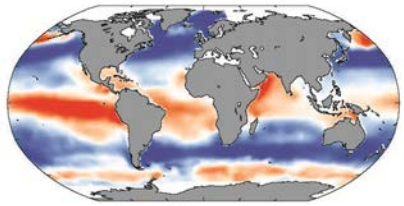
$dpCO_2^{ocn}/dt < dpCO_2^{atm}/dt$ | $dpCO_2^{ocn}/dt \sim dpCO_2^{atm}/dt$ | $dpCO_2^{ocn}/dt > dpCO_2^{atm}/dt$

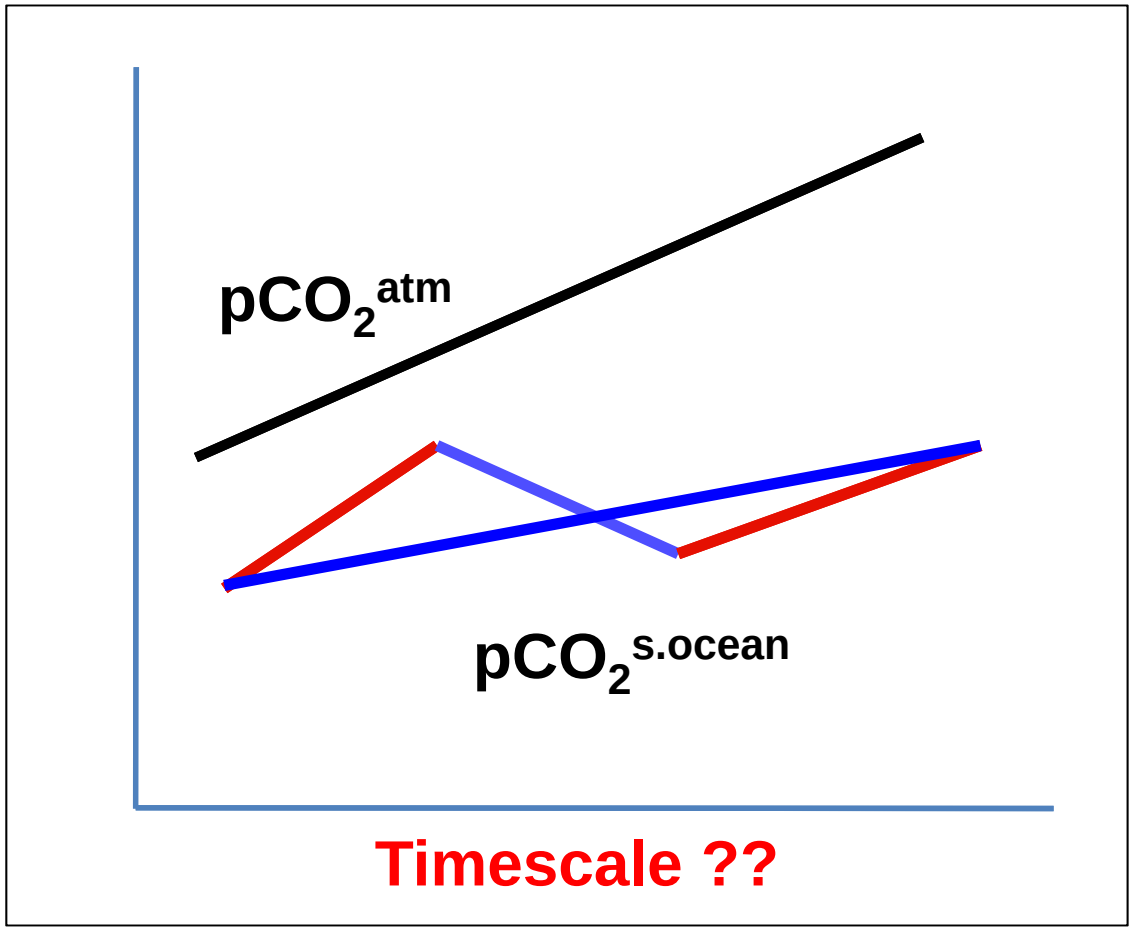
warming trend

cooling trend



When should growth in the sink be detectable?





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

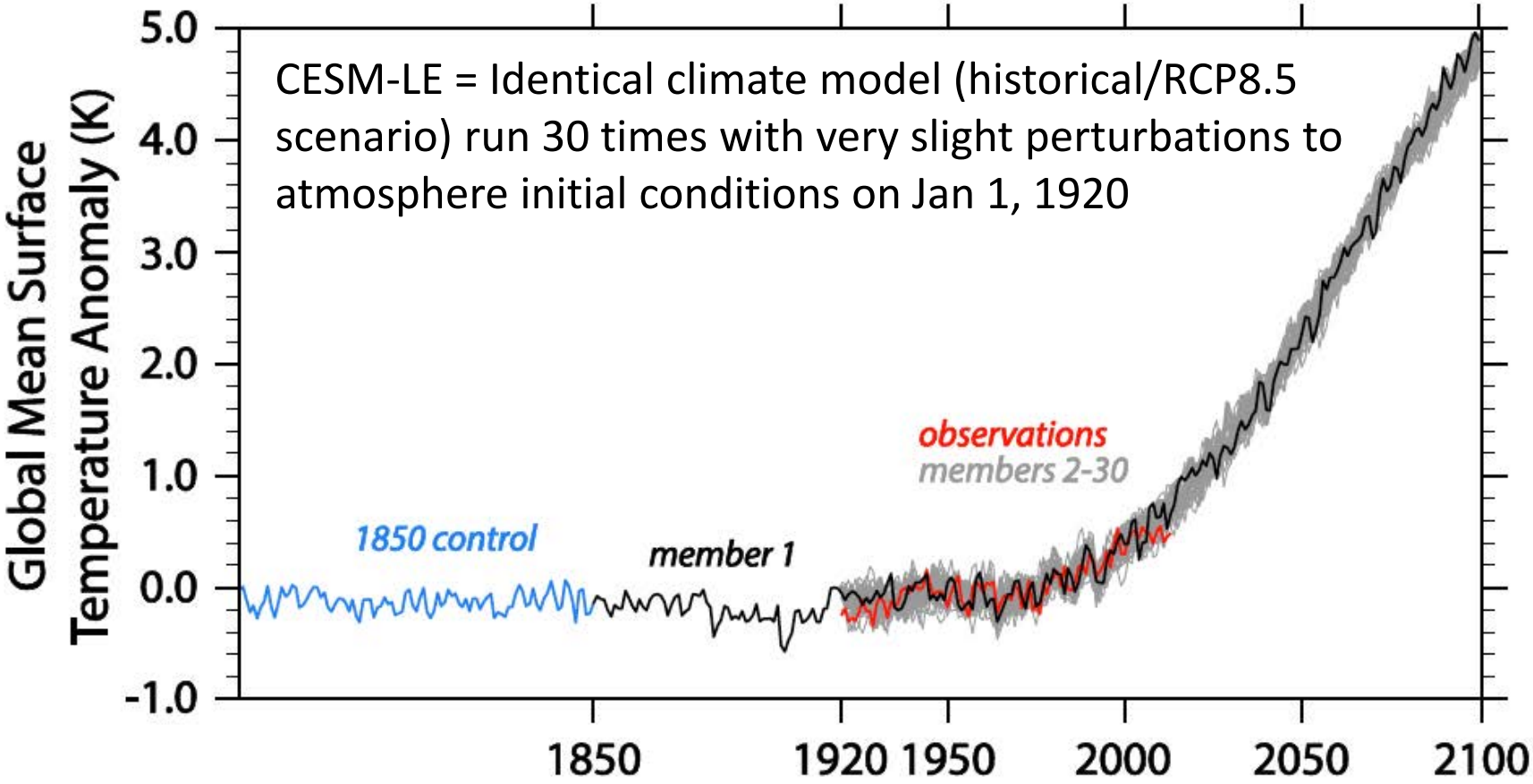
DECLINING SINK

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

GROWING SINK

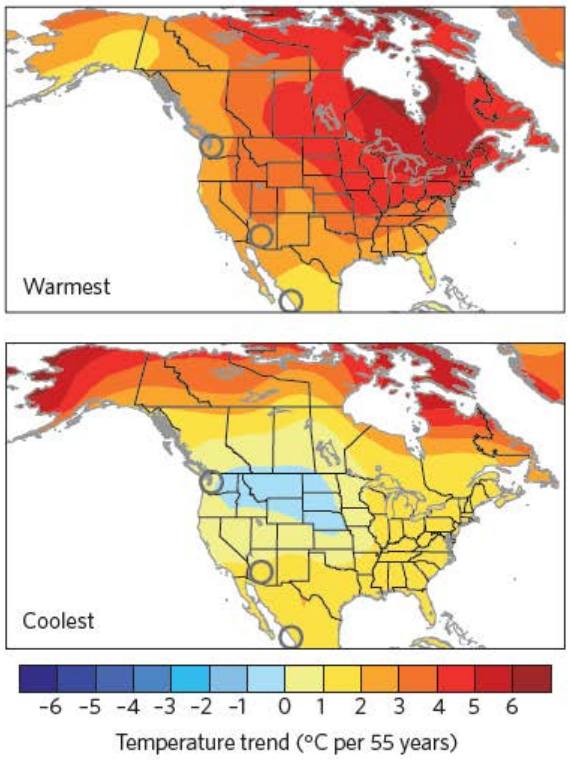
USE A EARTH SYSTEM MODEL TO ASSESS DETECTION TIMESCALES

NCAR Community Earth System Model Large Ensemble (CESM-LE)



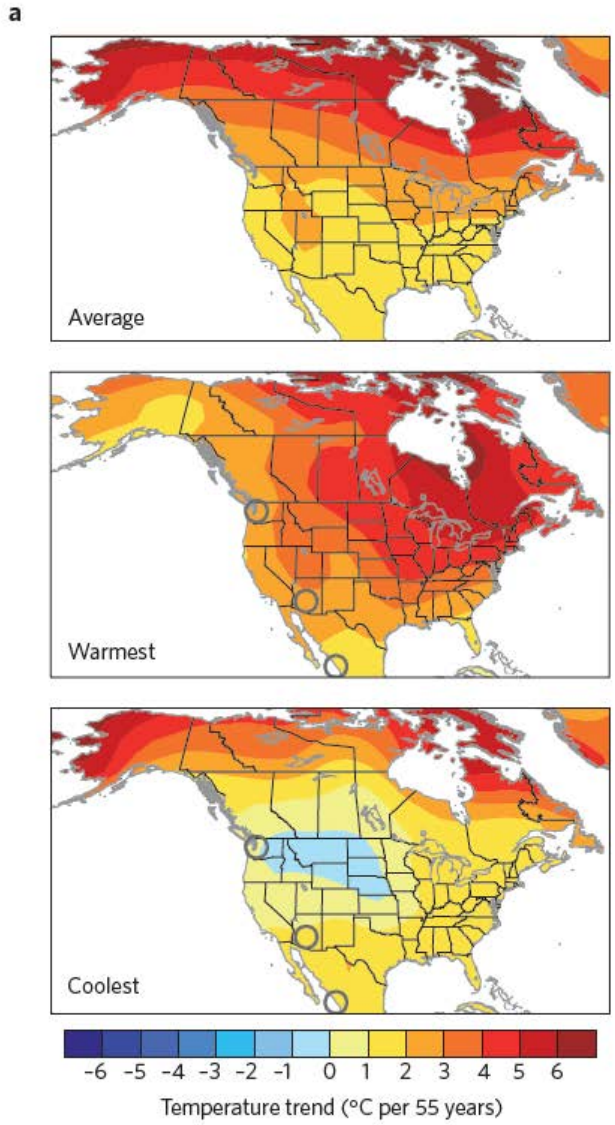
Kay et al. 2014 BAMS

N. America DJF Temperature 55 year trend, 2005-2060



Deser et al. 2012, Nature Climate Change

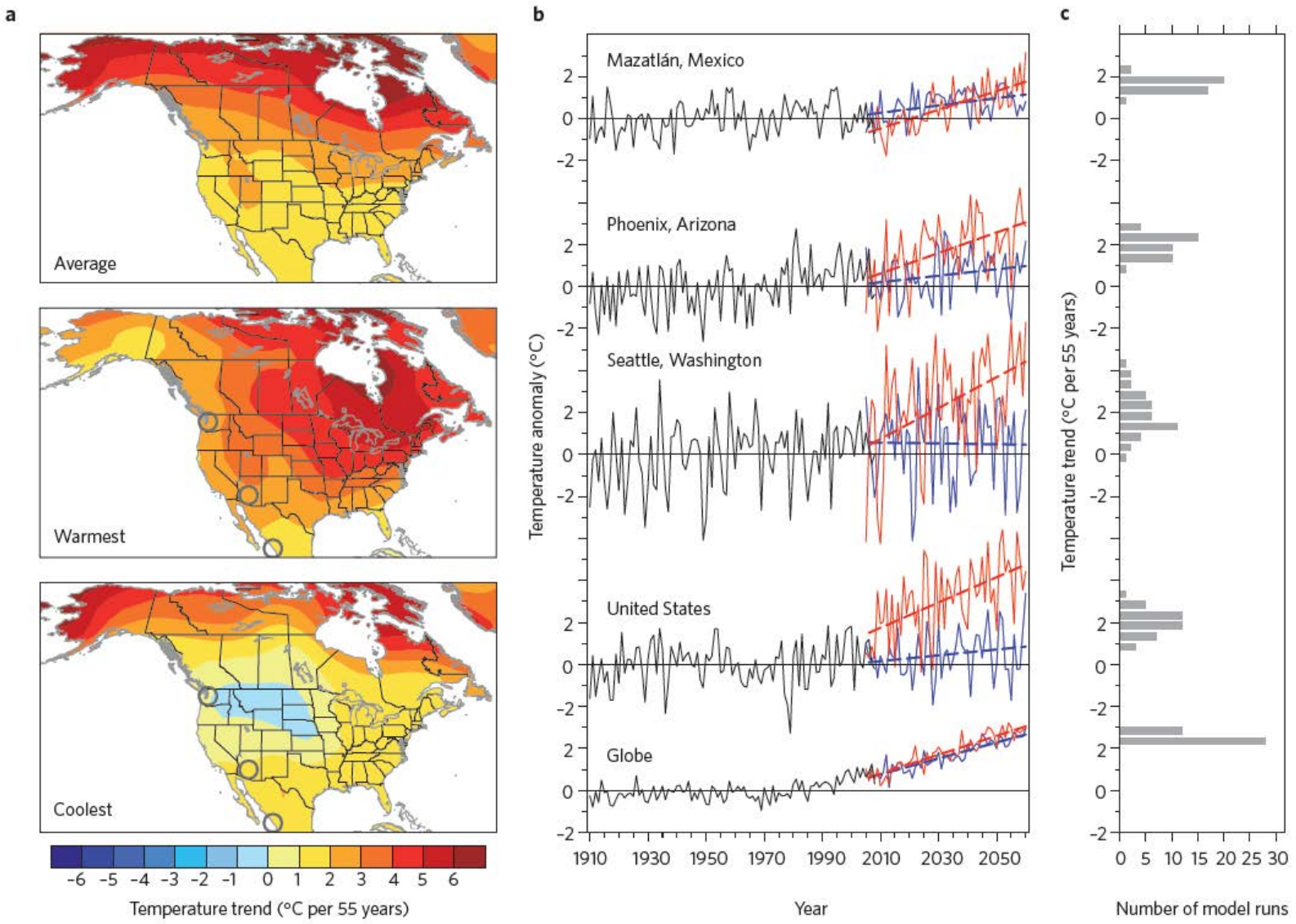
N. America DJF Temperature 55 year trend, 2005-2060



Average = Average trend across all ensembles
= "Forced trend" that is commonly driven by the anthropogenic forcing

Deser et al. 2012, Nature Climate Change

N. America DJF Temperature 55 year trend, 2005-2060



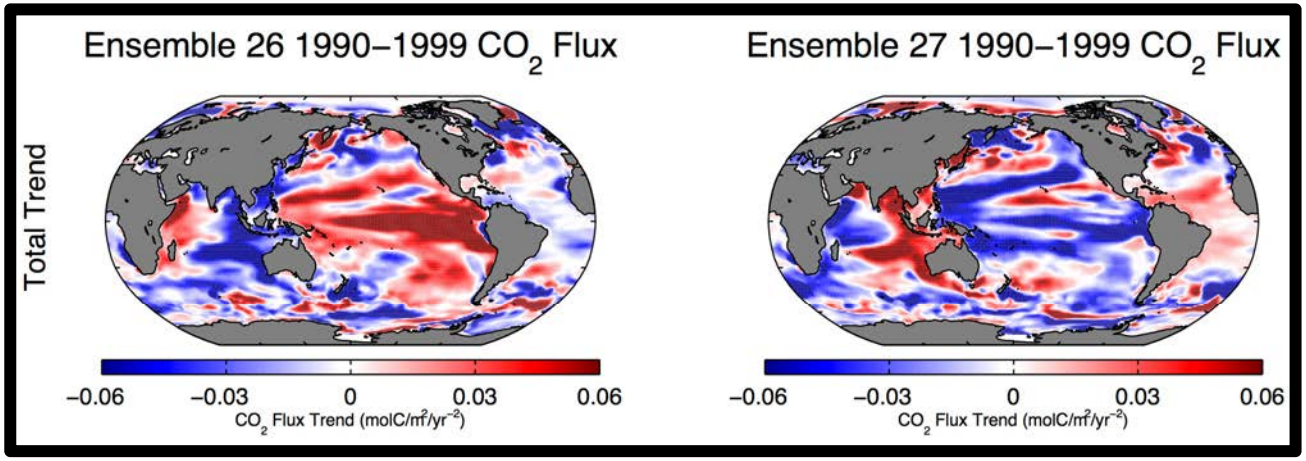
Deser et al. 2012, Nature Climate Change

CO_2 flux trend in a Large Ensemble, 1990-99

Total Trend = Forced Trend + Internal Trend

DECLINING SINK

GROWING SINK

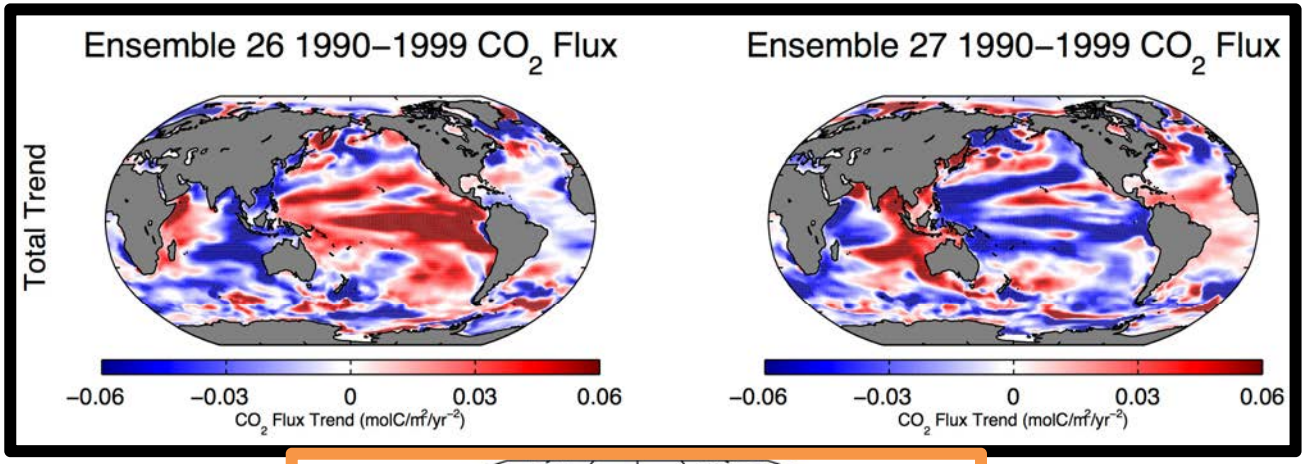


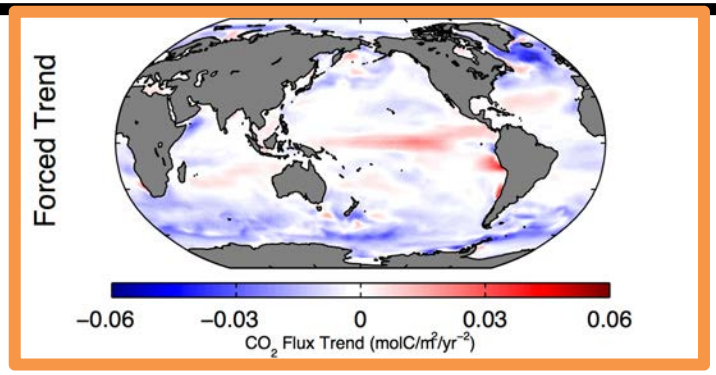
CO_2 flux trend in a Large Ensemble, 1990-99

Total Trend = Forced Trend + Internal Trend

DECLINING SINK

GROWING SINK



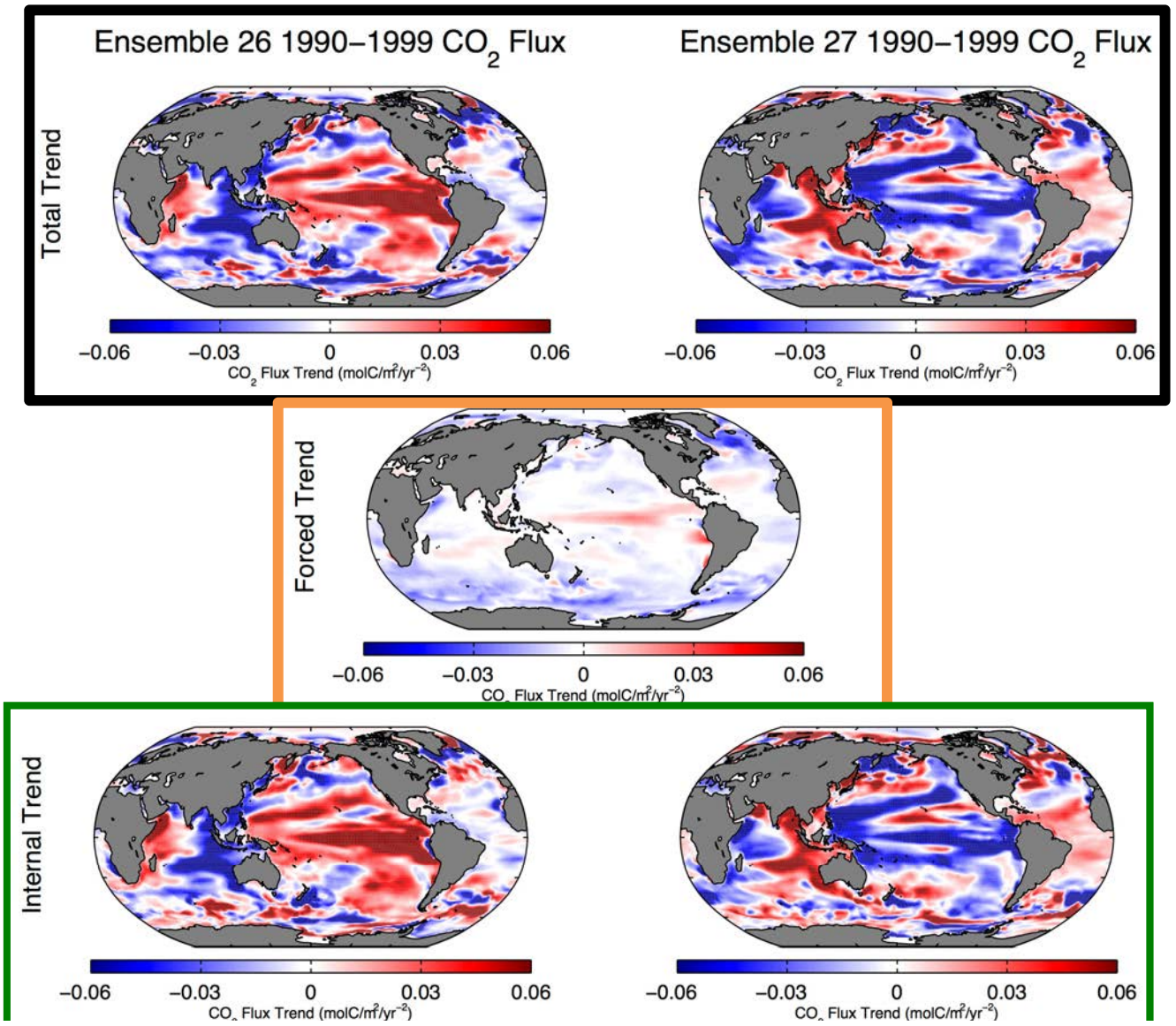


CO_2 flux trend in a Large Ensemble, 1990-99

Total Trend = Forced Trend + Internal Trend

DECLINING SINK

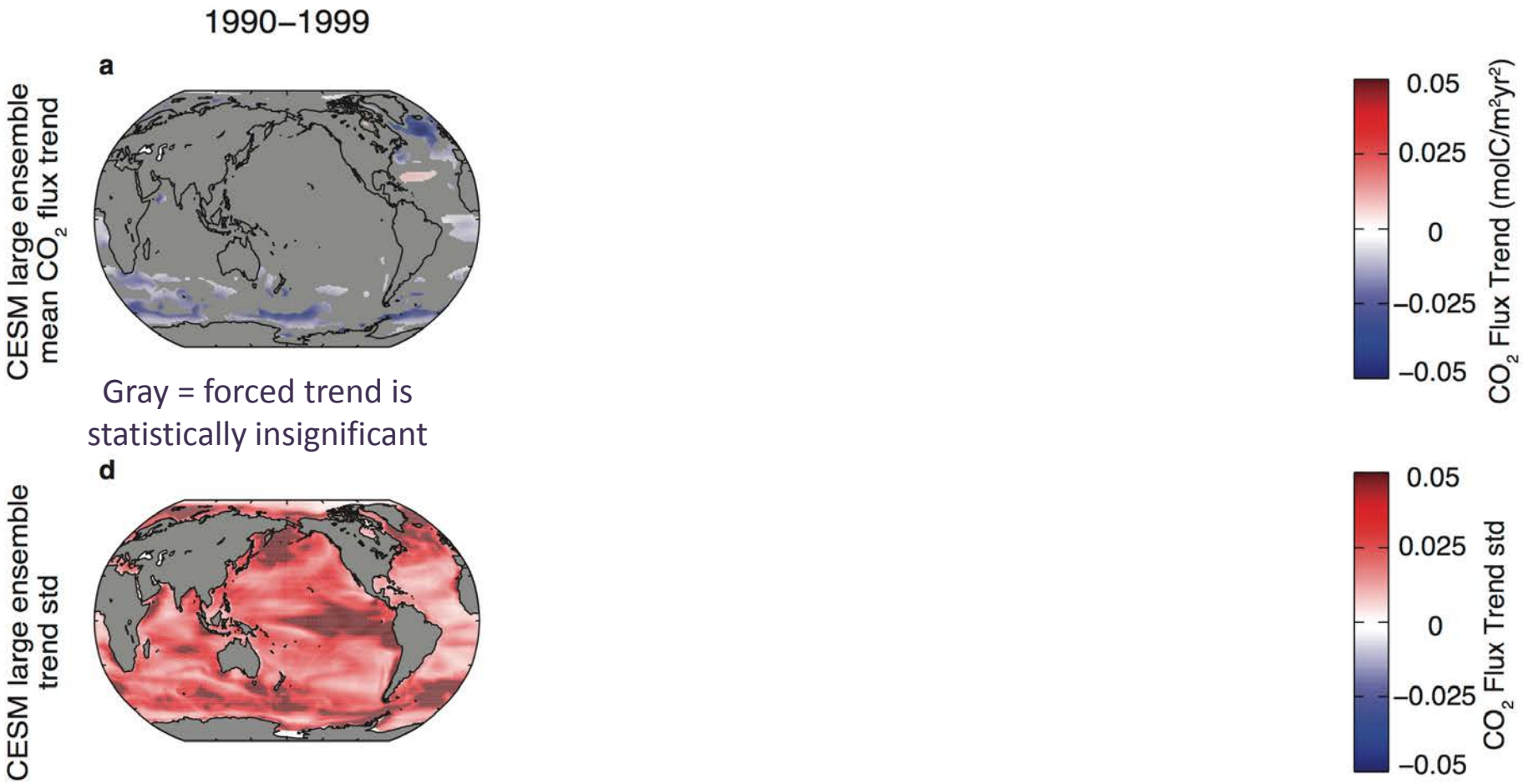
GROWING SINK



CO_2 flux forced trend vs. Trend variability across ensemble

DECLINING SINK

GROWING SINK

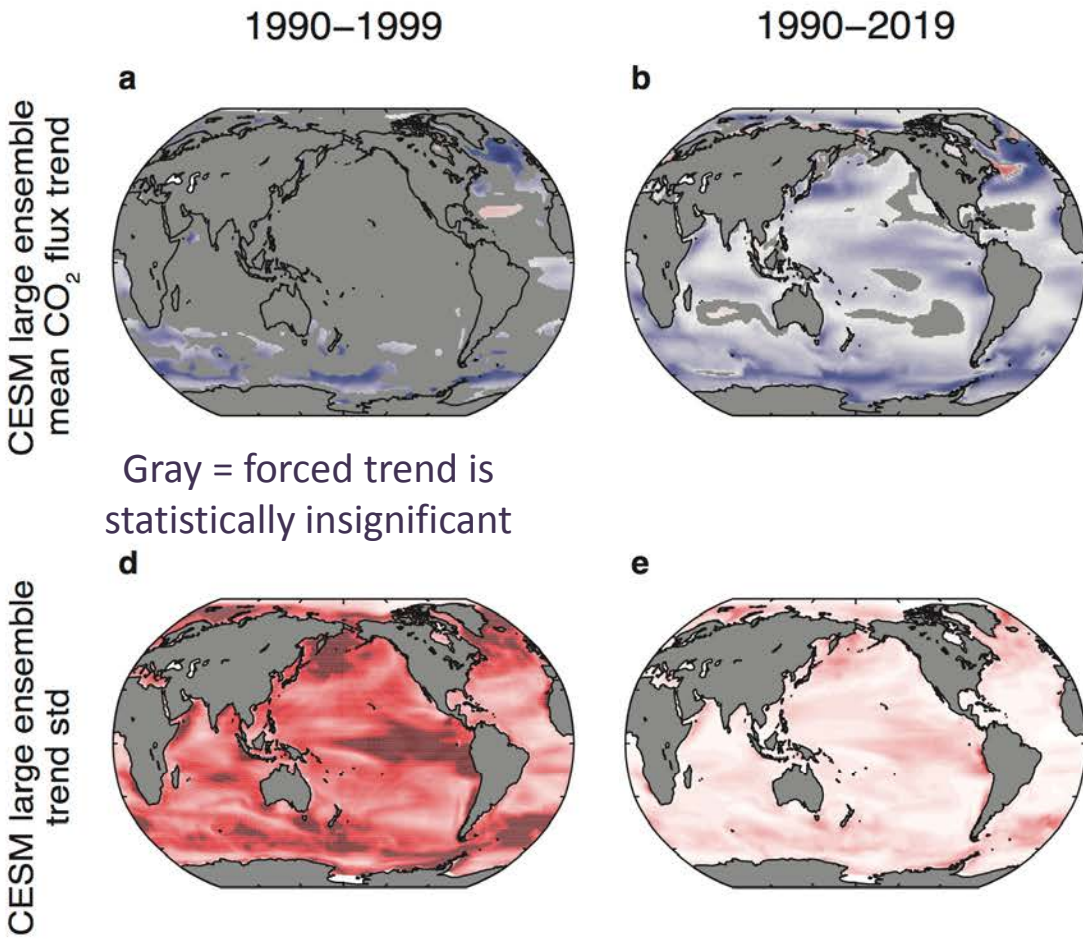


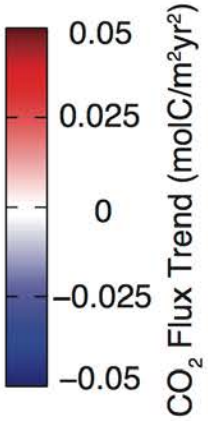
McKinley et al. 2016, Nature

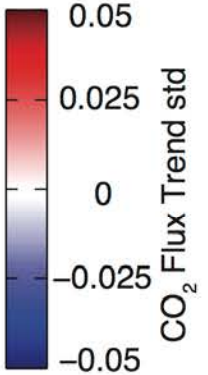
CO_2 flux forced trend vs. Trend variability across ensemble

DECLINING SINK

GROWING SINK





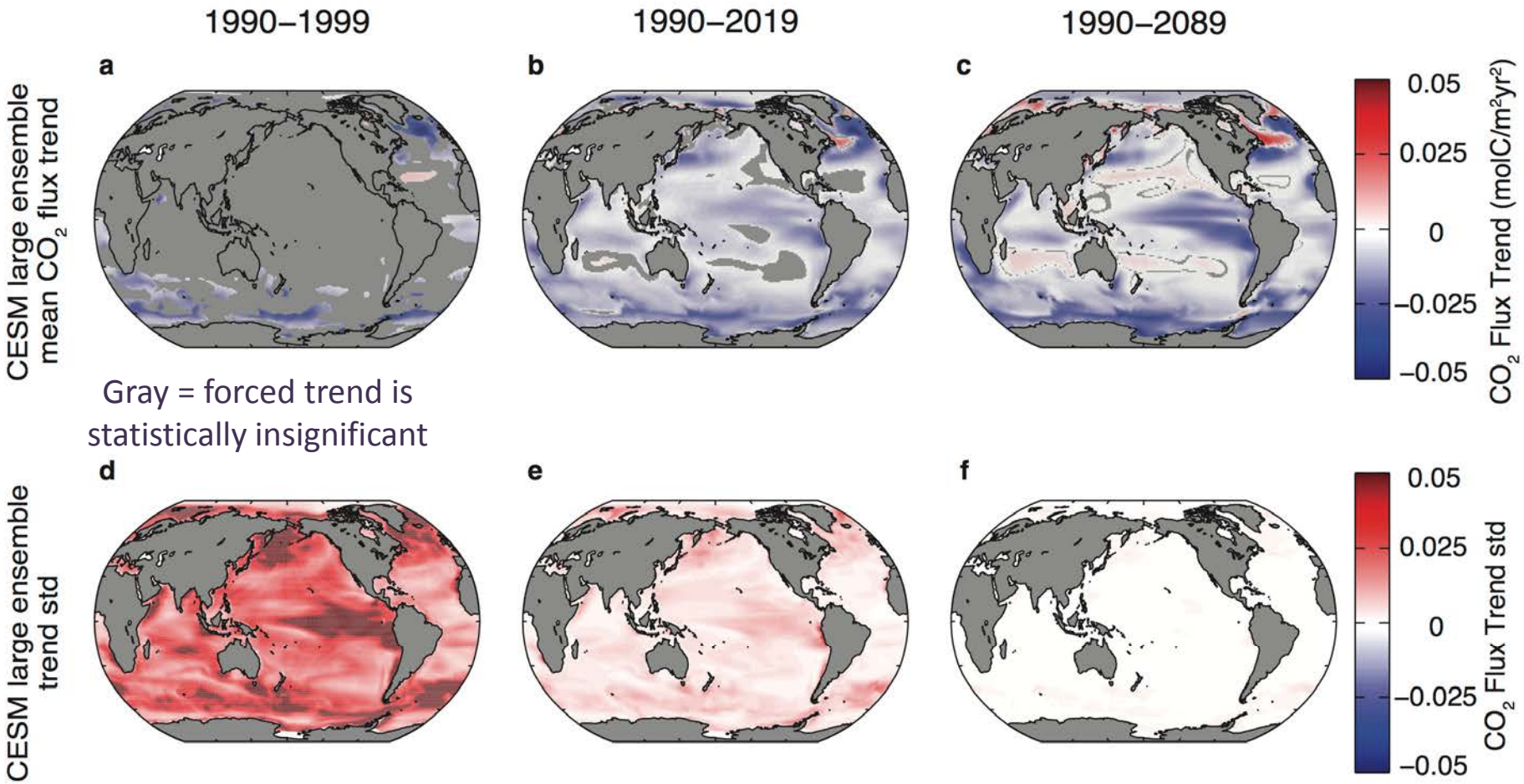


McKinley et al. 2016, Nature

CO_2 flux forced trend vs. Trend variability across ensemble

DECLINING SINK

GROWING SINK



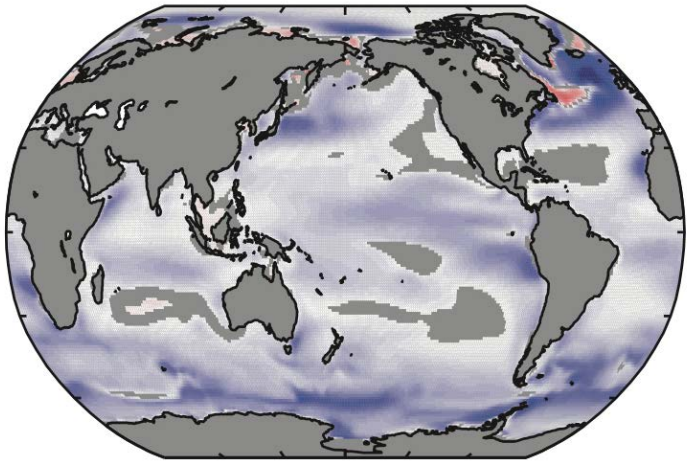
McKinley et al. 2016, Nature

CO_2 flux forced trend vs.
Trend variability across ensemble

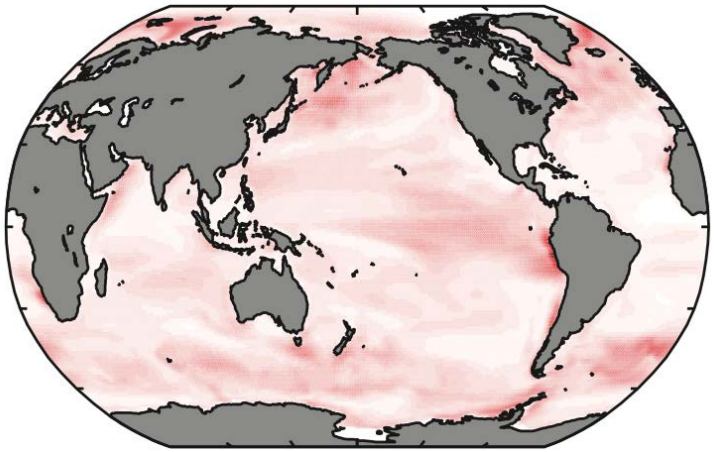
DECLINING SINK

GROWING SINK

When does this



← SIGNAL

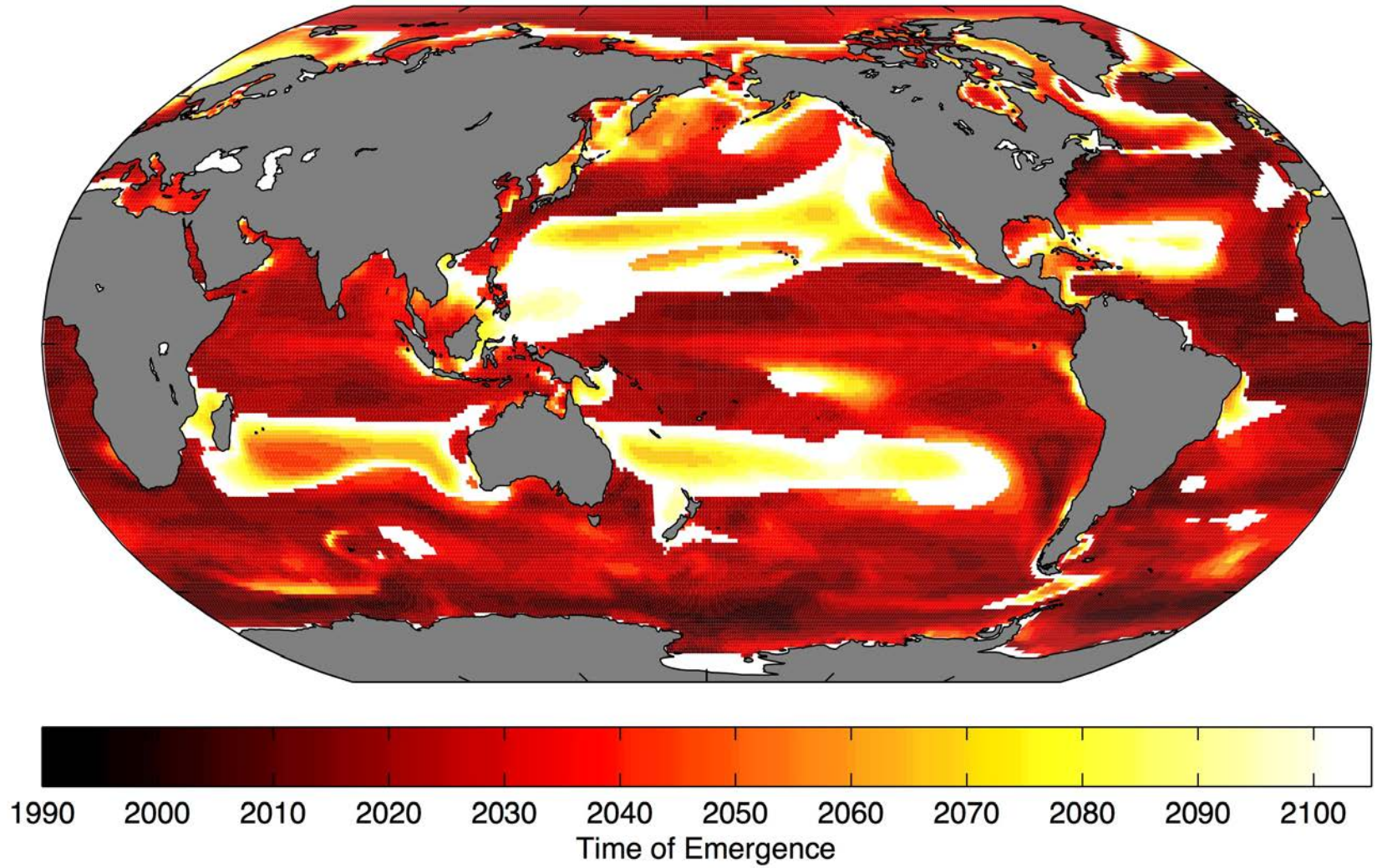


← NOISE?

Time of Emergence =
Year when Signal/Noise > 2

Time of Emergence for CO_2 flux

= year sink change detectable if data since 1990



McKinley et al. 2016, Nature

Take home messages

- Since preindustrial times, only the ocean has been a net sink for anthropogenic carbon
- With rapid pCO_2^{atm} growth, the sink should be growing
- Direct detection of ocean carbon sink growth is not yet possible due to data sparsity and internal variability
- Timescales for detection of sink change vary widely

THANK YOU