Quantifying carbon uptake and its trends

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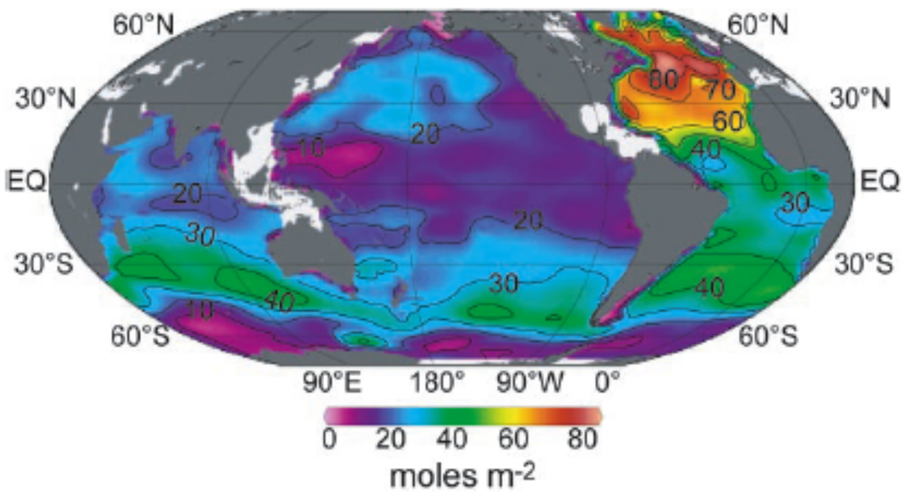
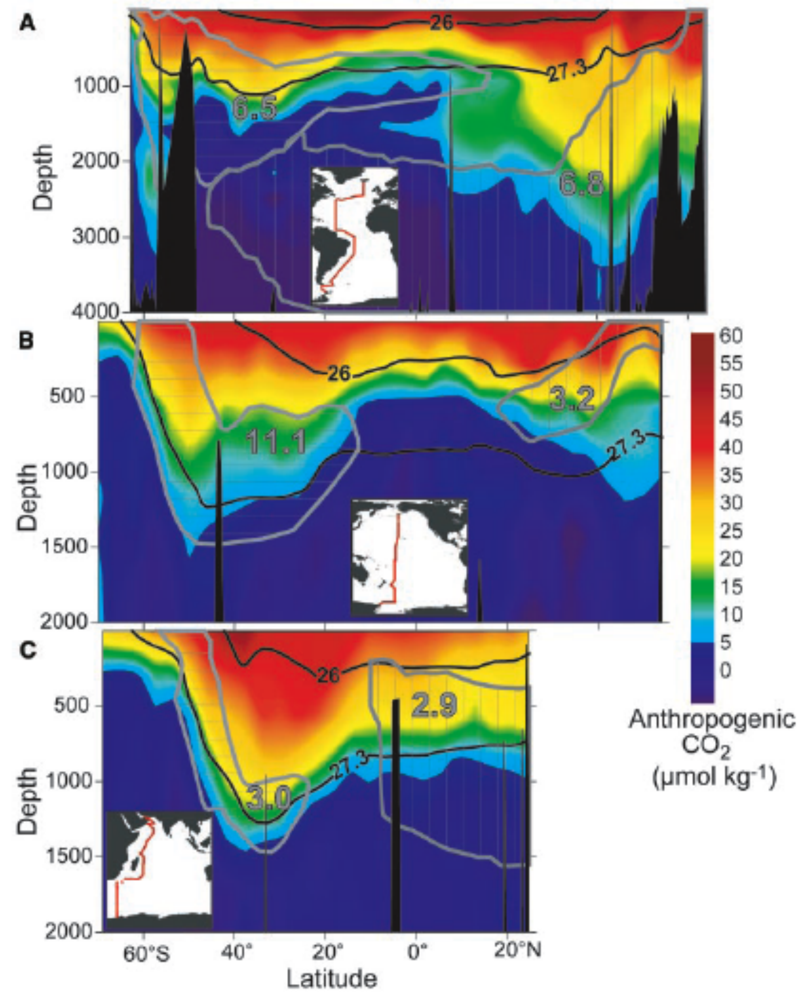
Ocean Carbon Uptake

- Cumulative ocean uptake of anthropogenic carbon
- Current challenges
- Quantifying trends in carbon uptake

CUMULATIVE OCEAN UPTAKE OF ANTHROPOGENIC CARBON

Total ocean anthropogenic CO_2 accumulation through 1994

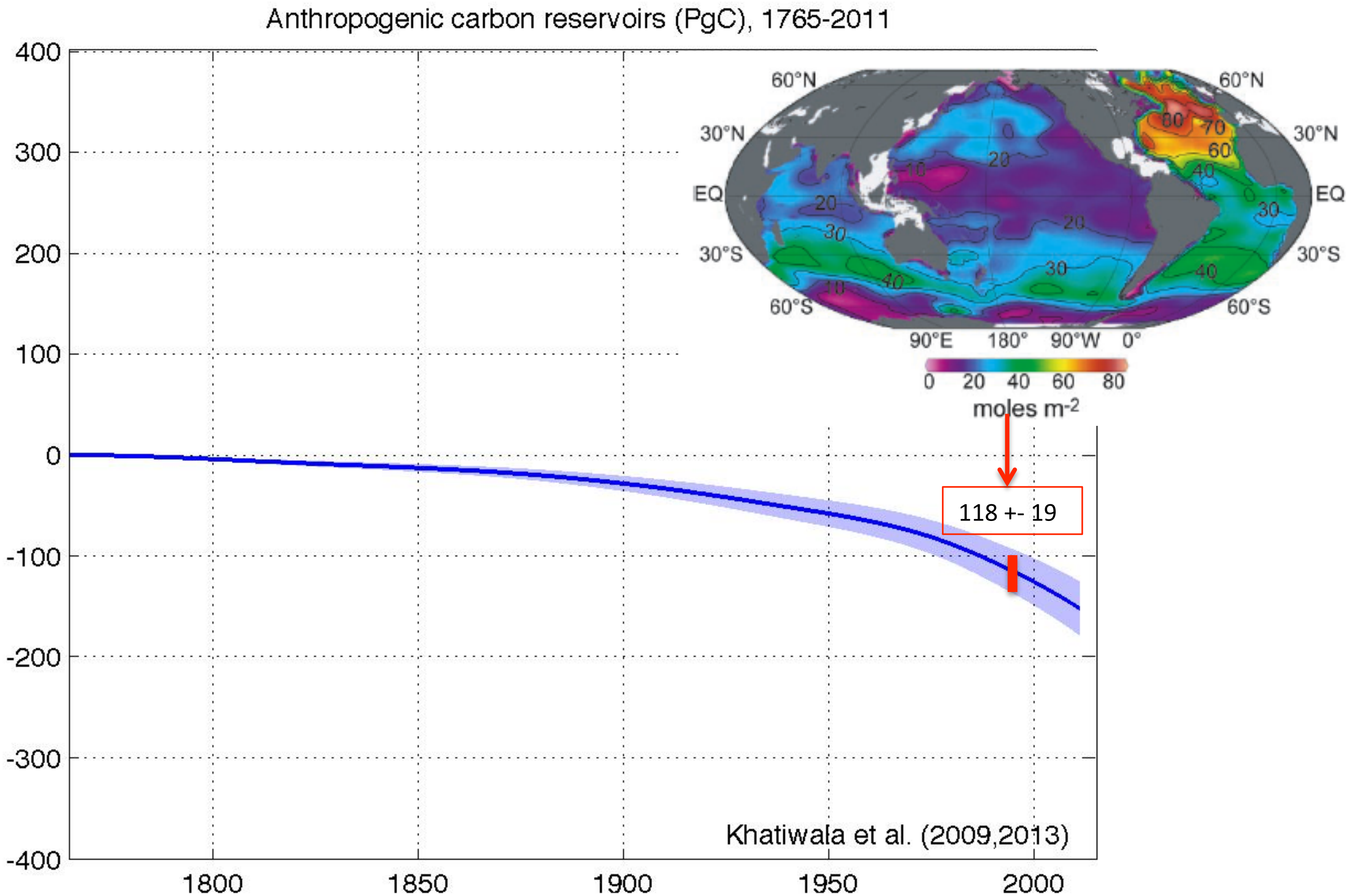




Using multiple tracers, estimate the additional carbon in the ocean due to human activities in 1994

Sabine et al. *Science* 2004

Extension allows for full time-history of carbon accumulation, with uncertainty



Khatiwala et al. *Nature* (2009)

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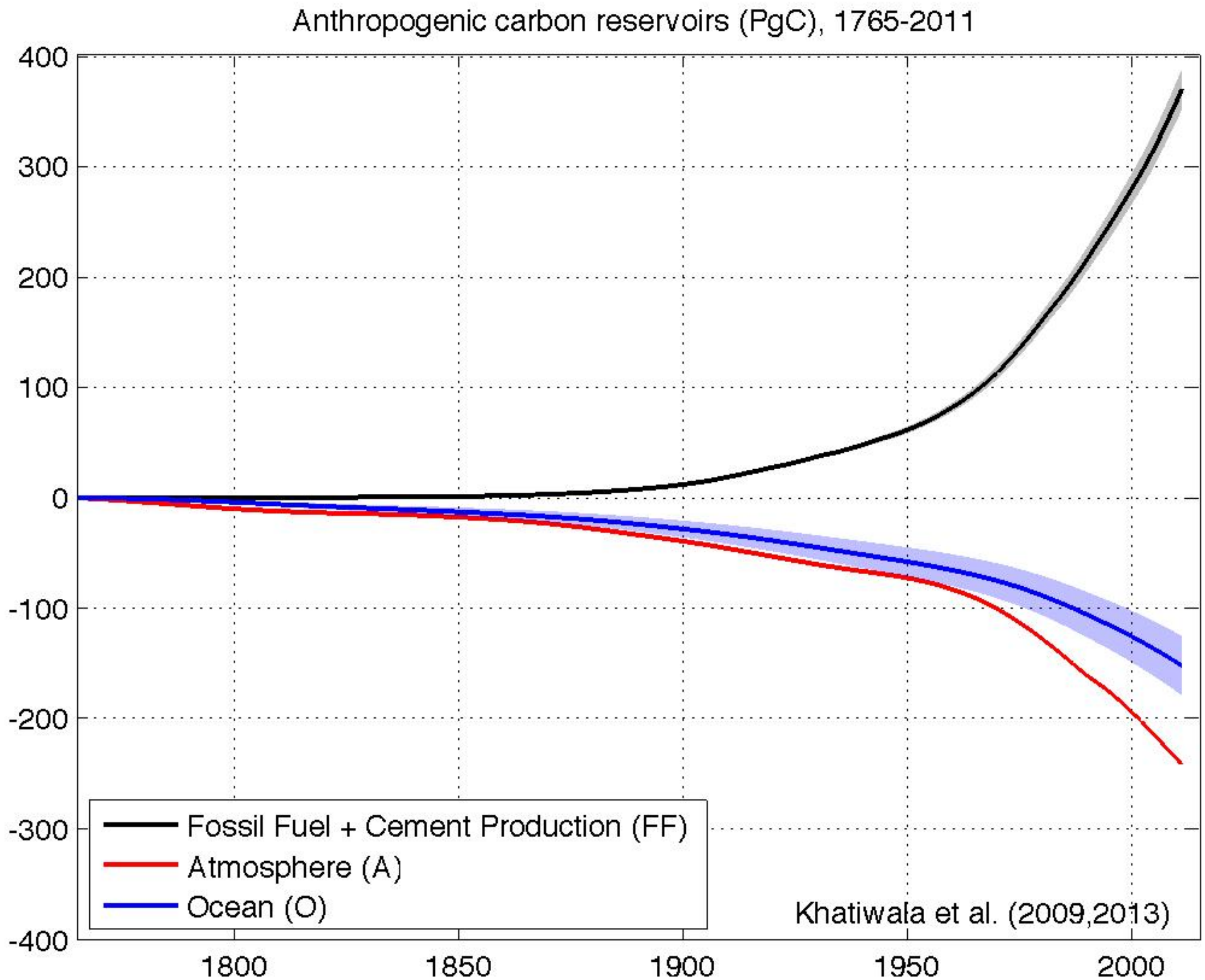

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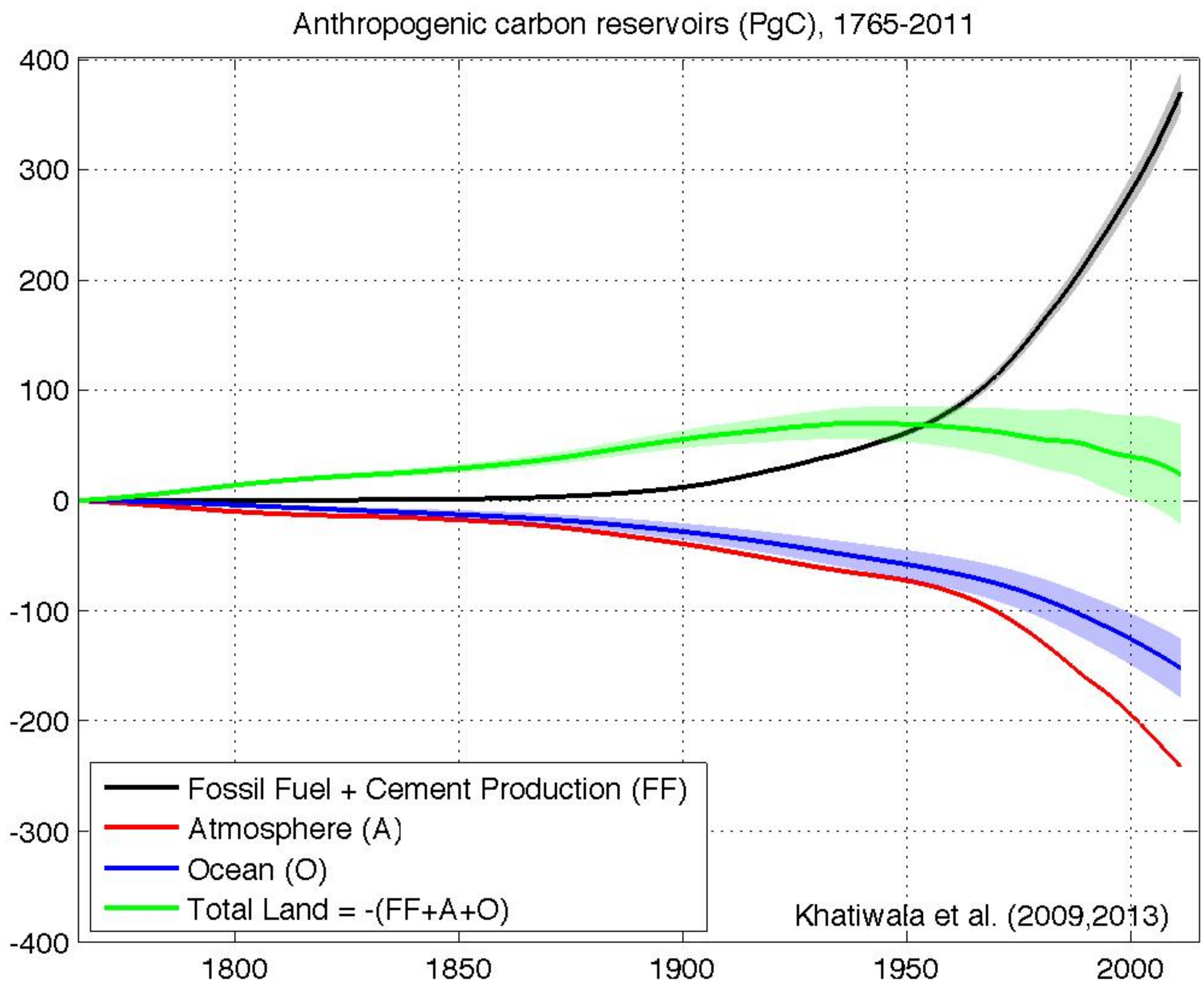
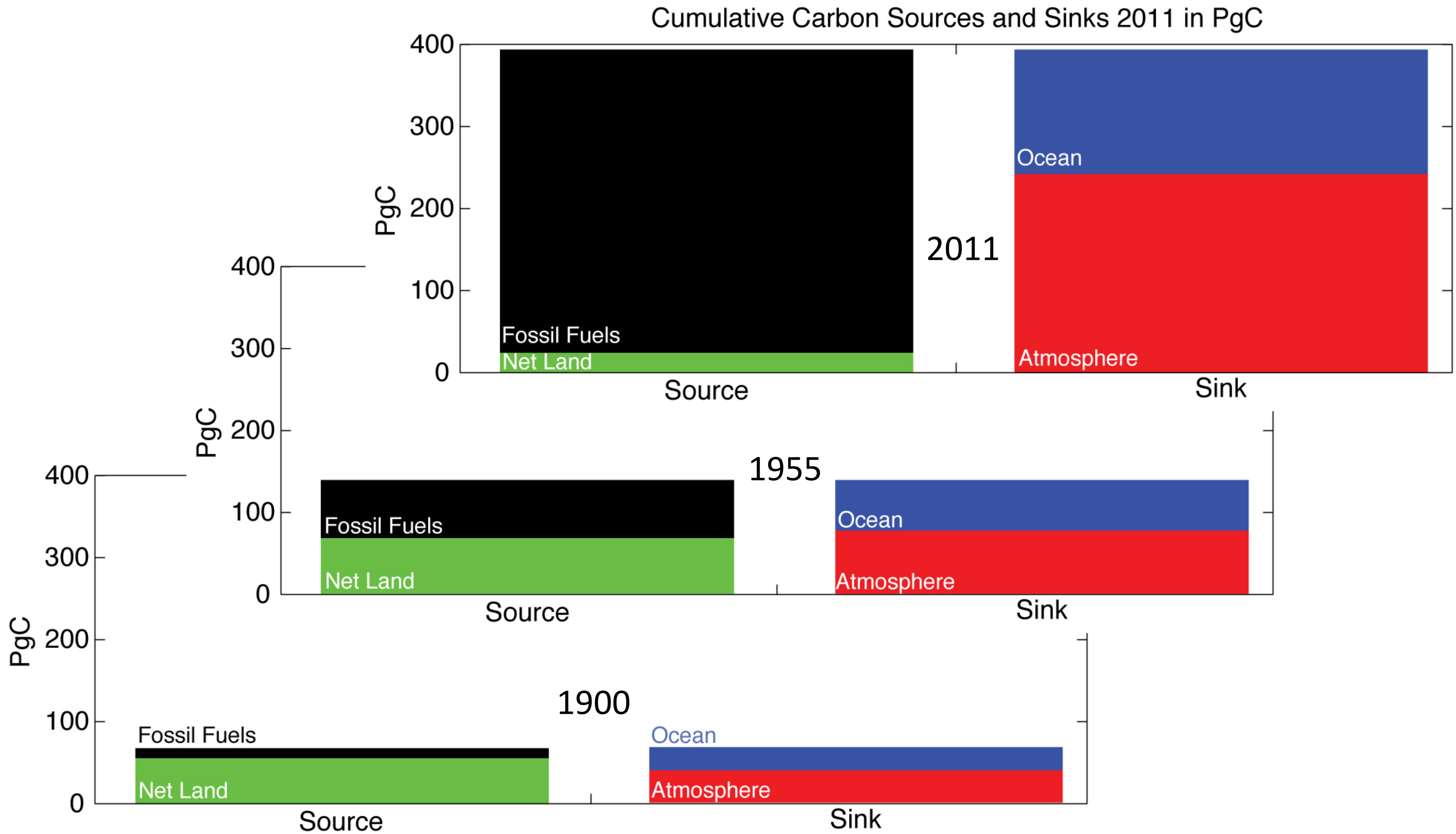
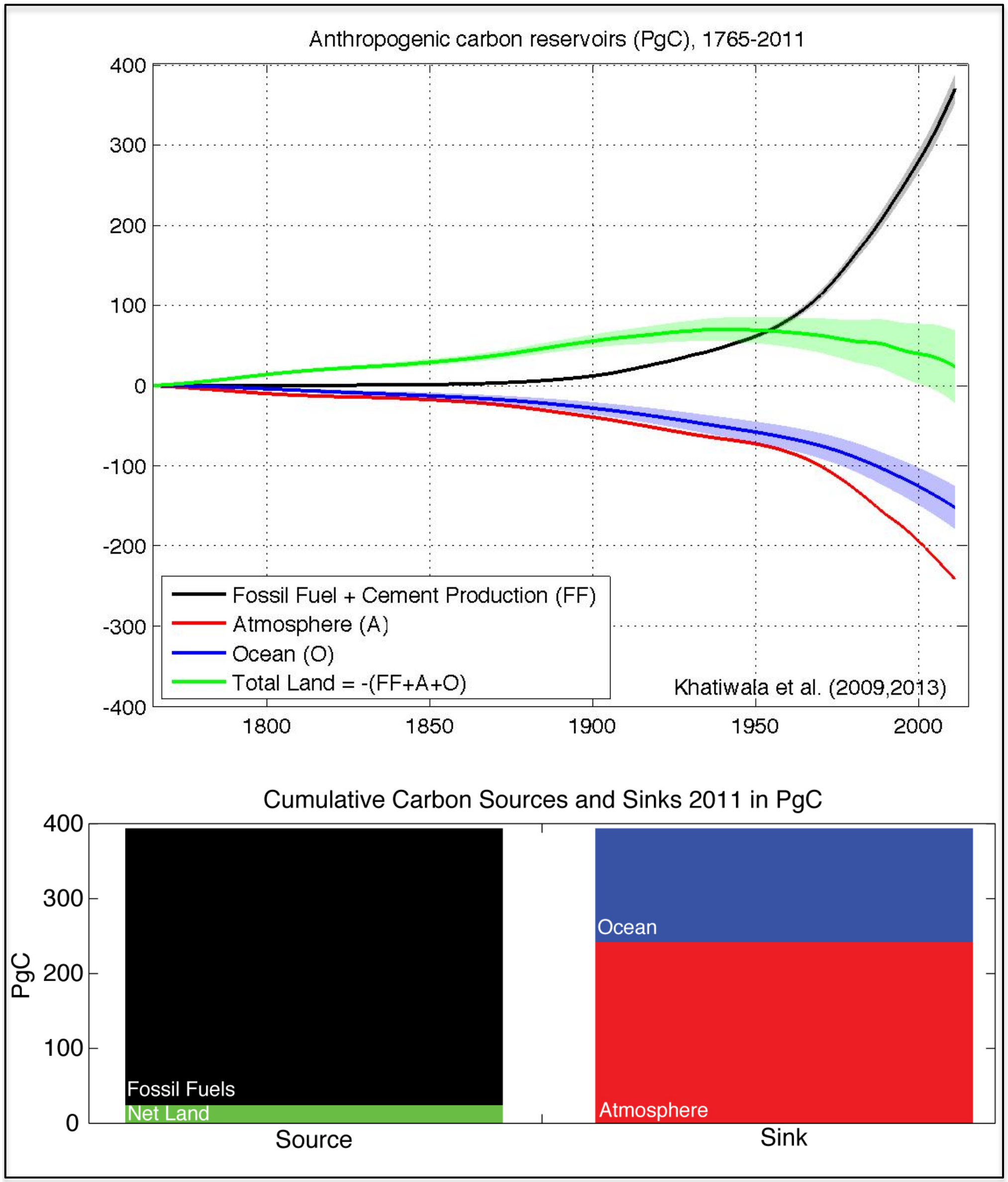


Another look at same results…

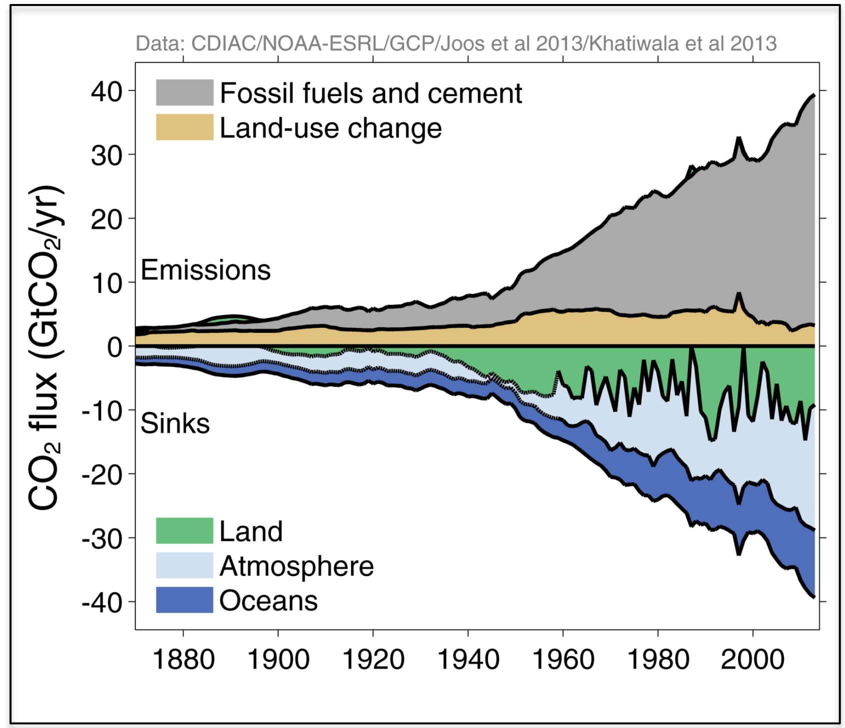


Khatiwala et al. *Nature* (2009)

Putting ocean carbon in the global context

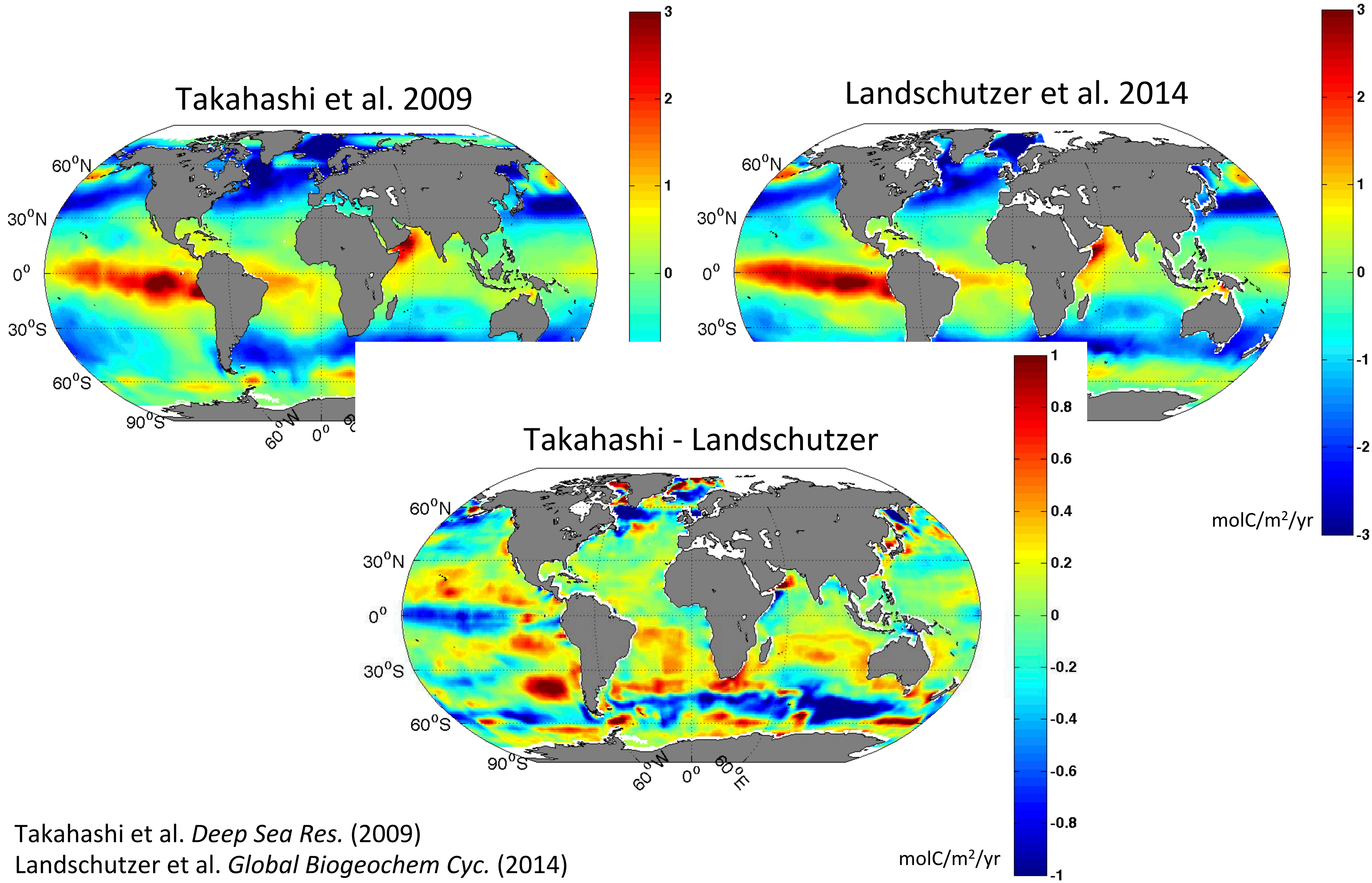


Global Carbon Project
LeQuere et al. 2014



CURRENT CHALLENGES

Climatological CO_2 flux estimates have significant differences

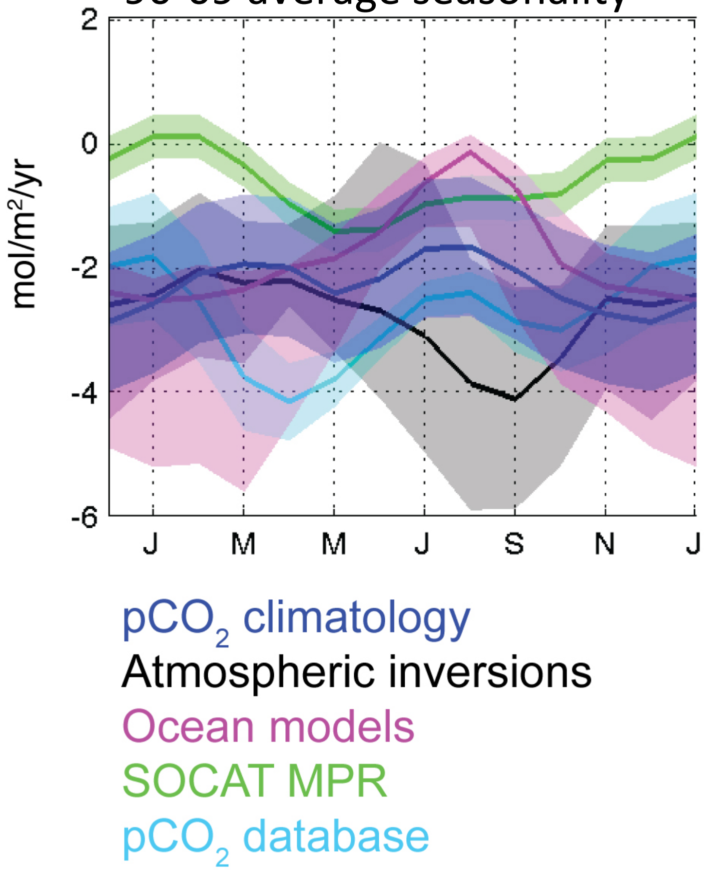


Takahashi et al. *Deep Sea Res.* (2009)
Landschutzer et al. *Global Biogeochem Cyc.* (2014)

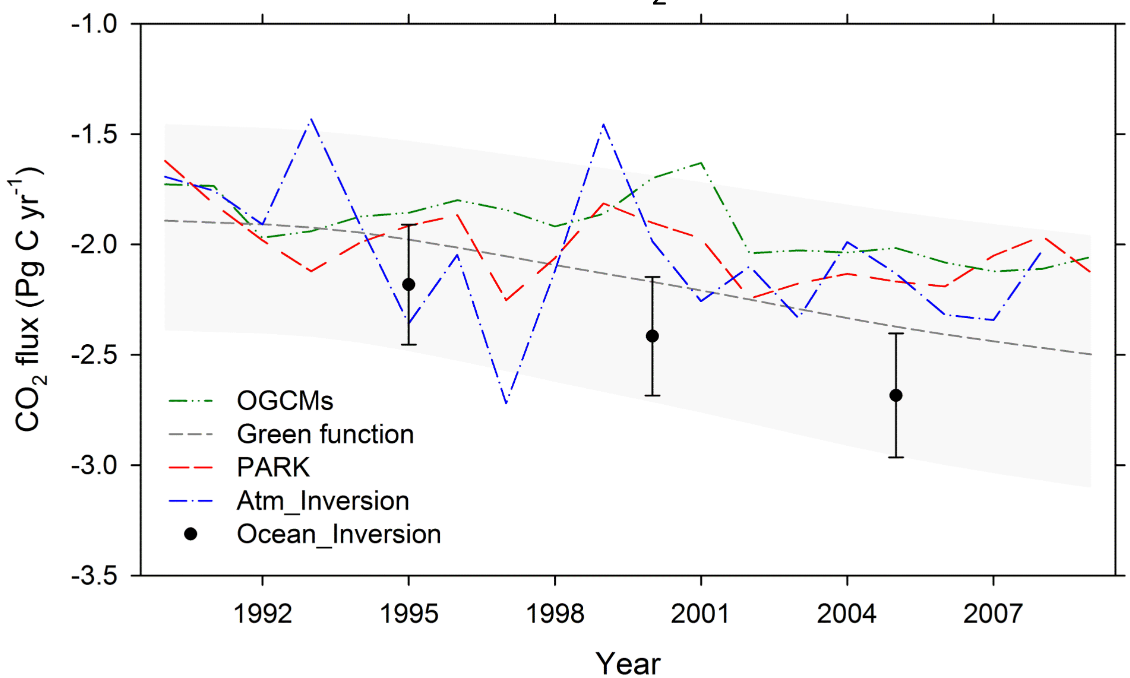
CO_2 flux uncertainty remains large at regional scales and for temporal variability

RECCAP

SUBPOLAR N. ATLANTIC CO_2 FLUX, 90-09 average seasonality



GLOBAL CO_2 FLUX

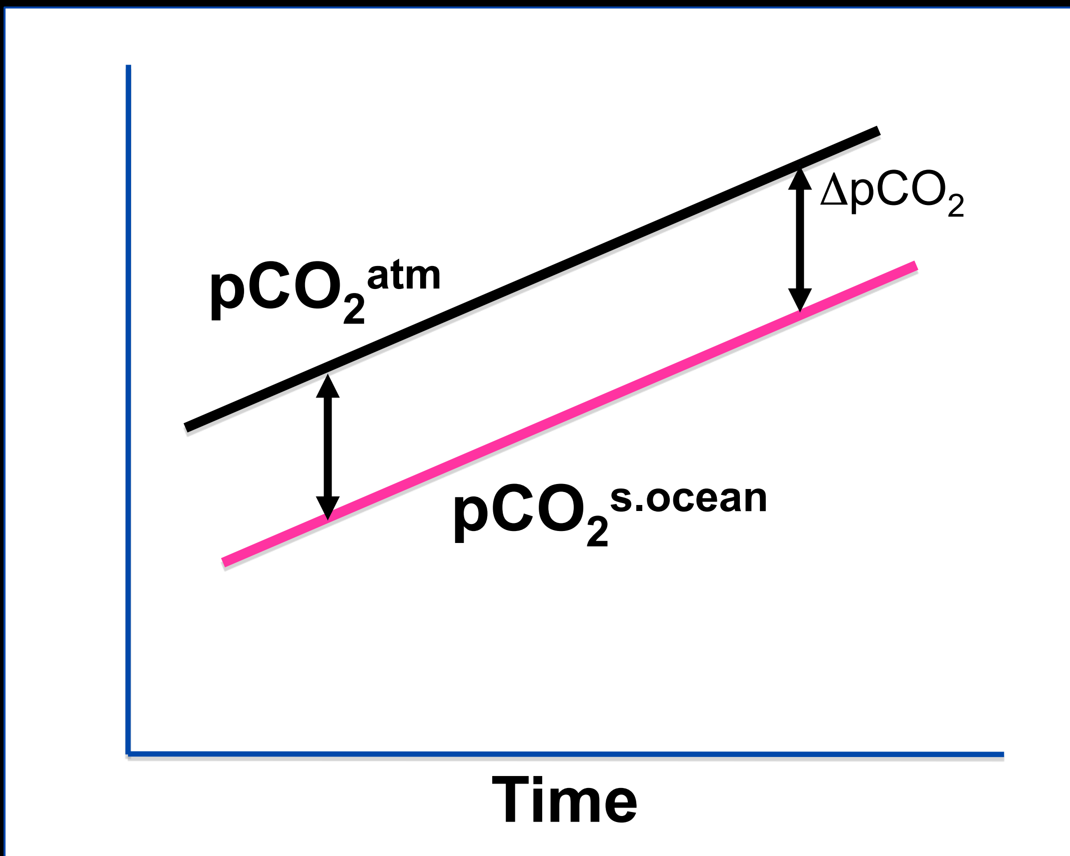


Schuster et al. *Biogeosciences* (2013)
Wanninkhof et al. *Biogeosciences* (2013)

QUANTIFYING TRENDS IN CARBON UPTAKE

Trends from surface ocean pCO_2:

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



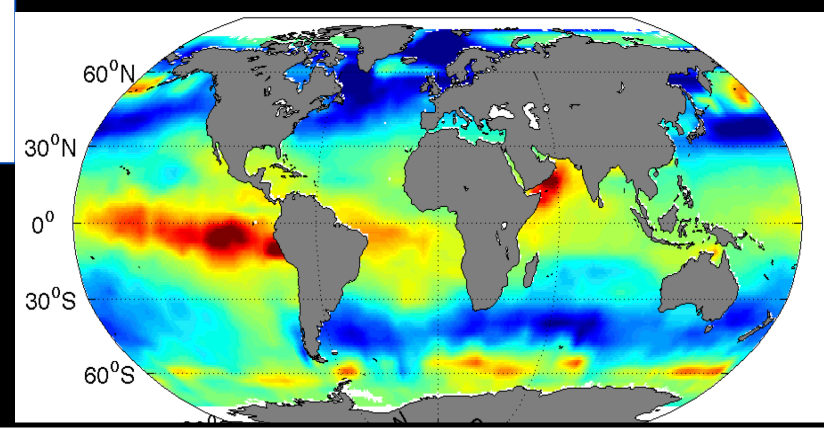
Parallel Trends

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

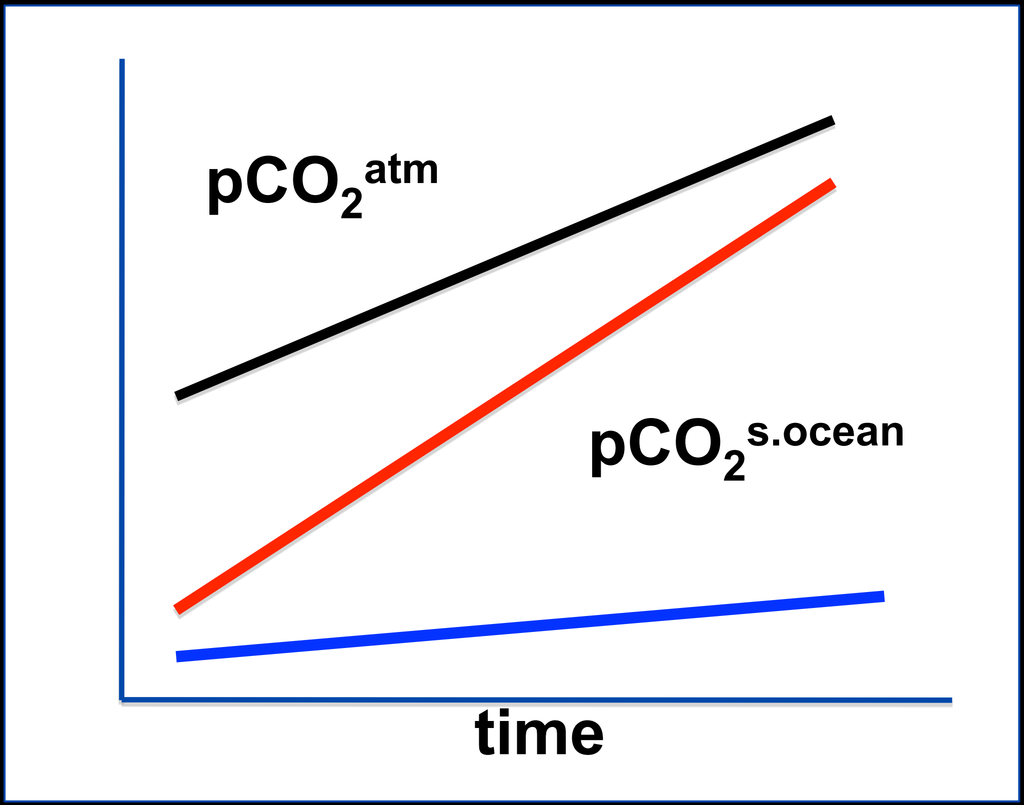
$d\Delta pCO_2/dt = 0$

$d(CO_2Flux)/dt = 0$

STEADY SINKS AND SOURCES



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*



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

steeper $pCO_2^{s.ocean}$ trend

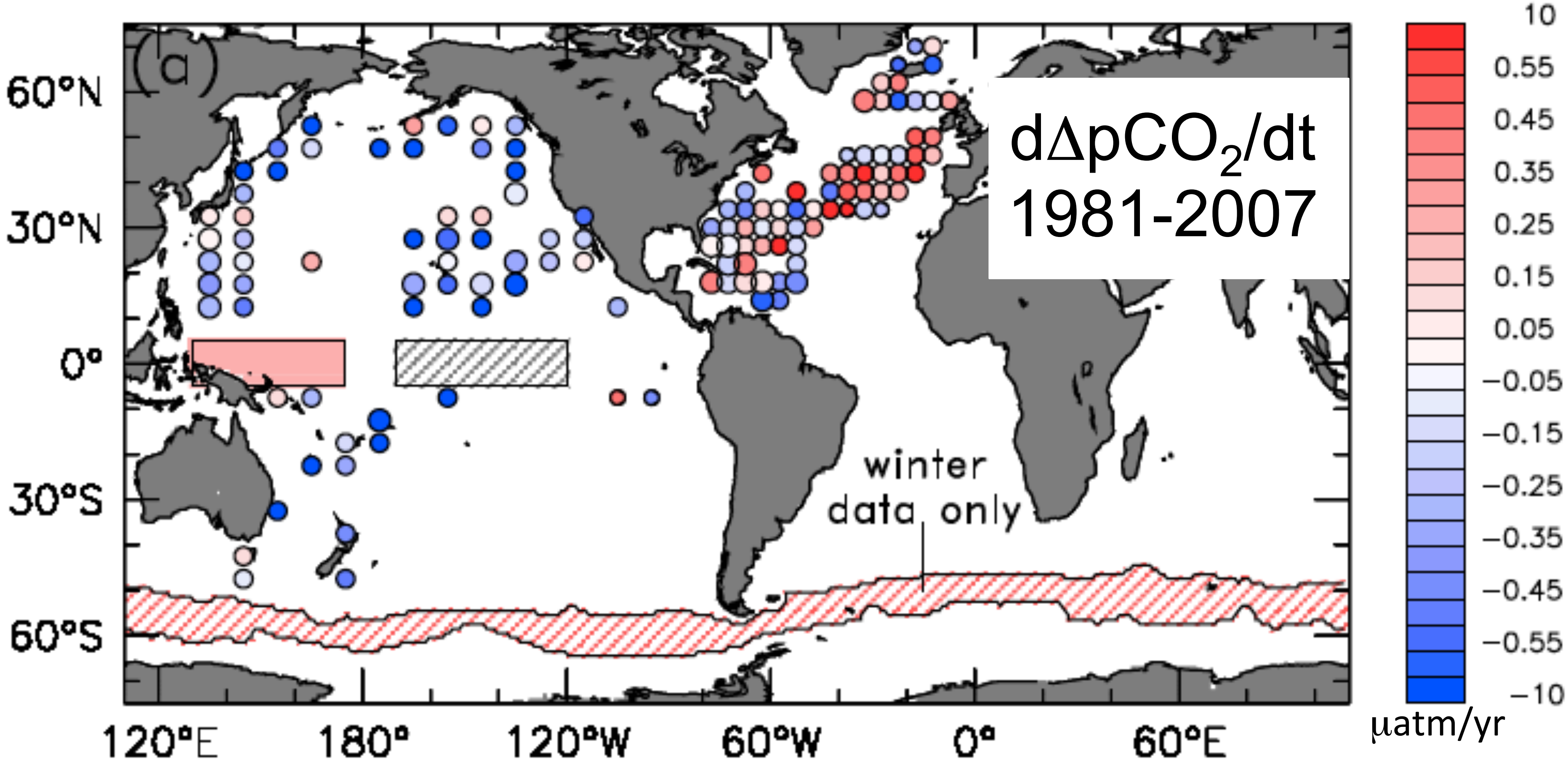
DECREASING ΔpCO_2

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

shallower $pCO_2^{s.ocean}$ trend

INCREASING ΔpCO_2

Trends in air-sea ΔpCO_2, 1981-2007



LeQuéré et al. 2009, 2010

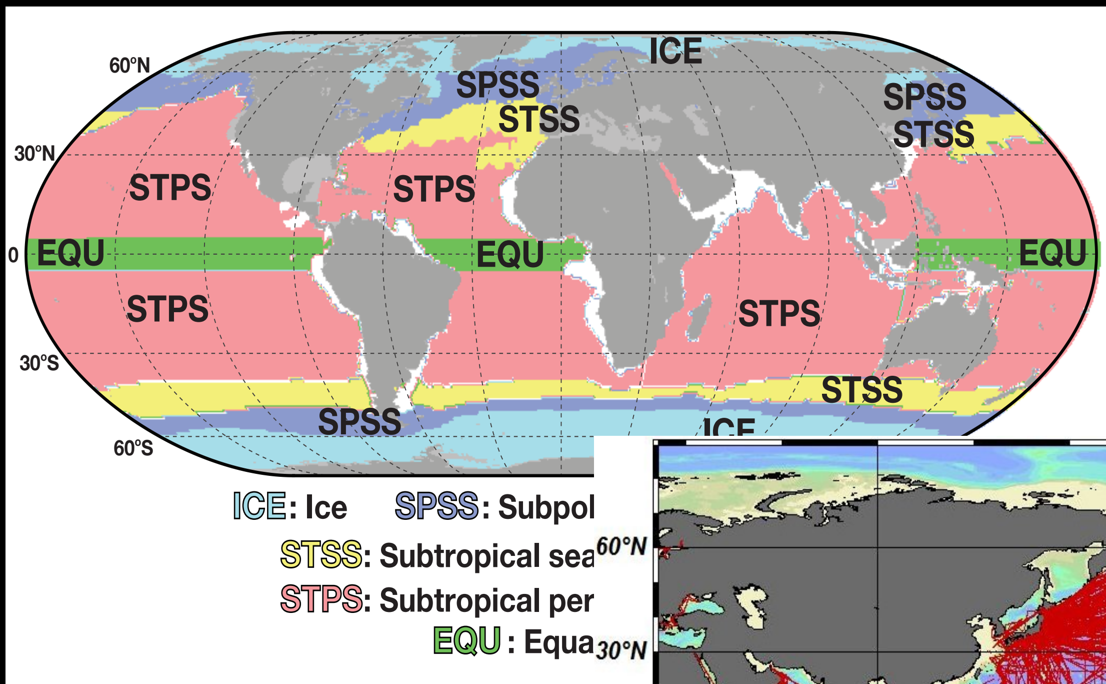
Our approach: Evaluate trends in surface ocean pCO_2 at large spatial scales to assess

– Variability vs. trends

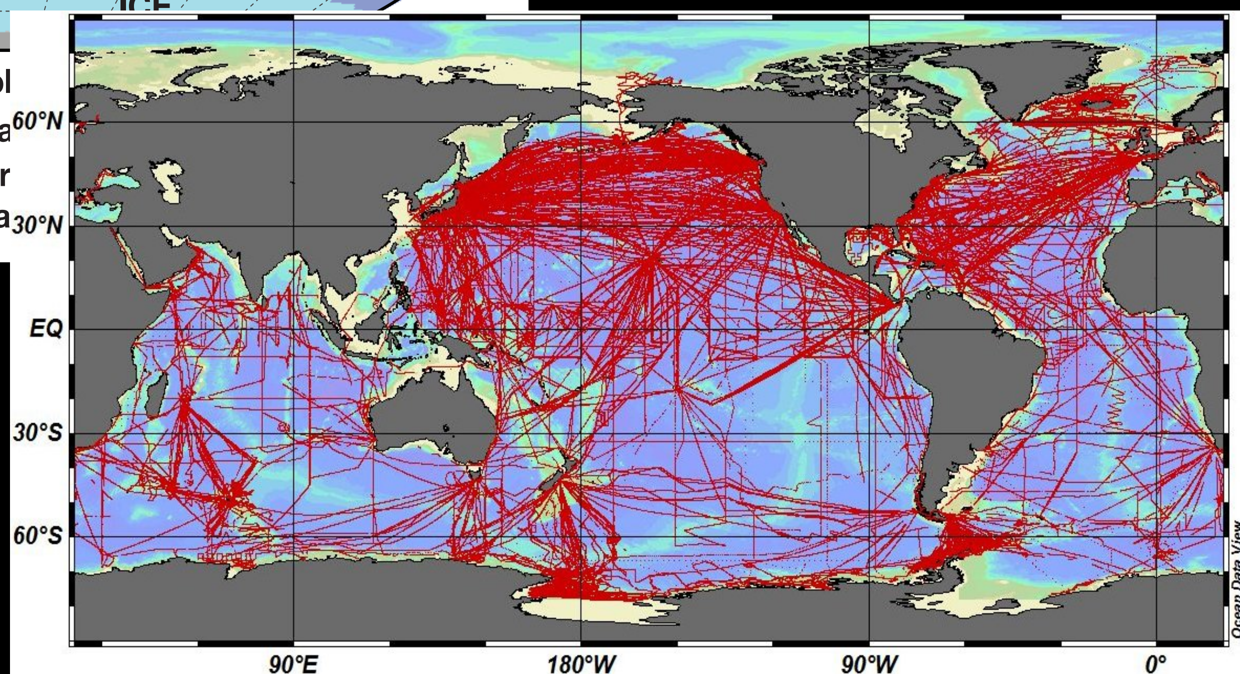
– Mechanisms
  - Carbon uptake
  - Long-term warming

McKinley et al. (2011)
Fay and McKinley (2013, 2014))
Fay et al. (2014), Lovenduski et al. (2014)

Biomes and heterogeneous pCO_2 data



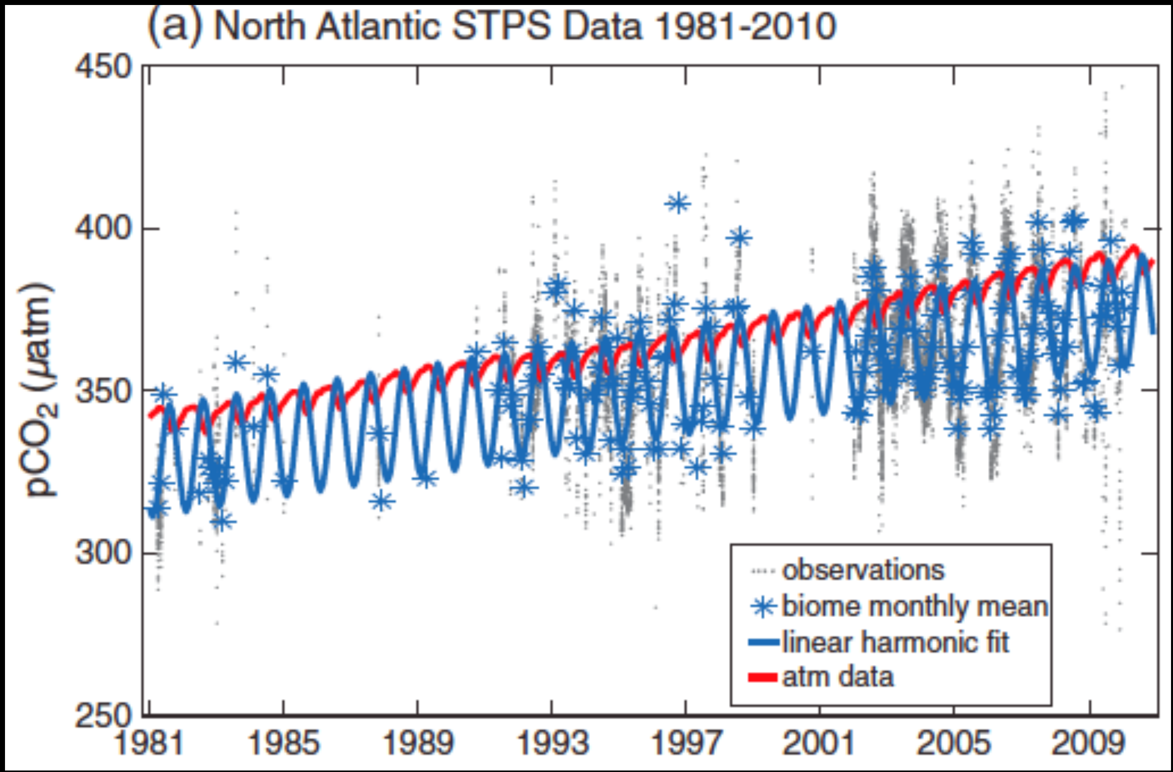
Fay and McKinley, 2014



LDEO: *Takahashi et al. 2010*, SOCAT: *Sabine et al. 2013*

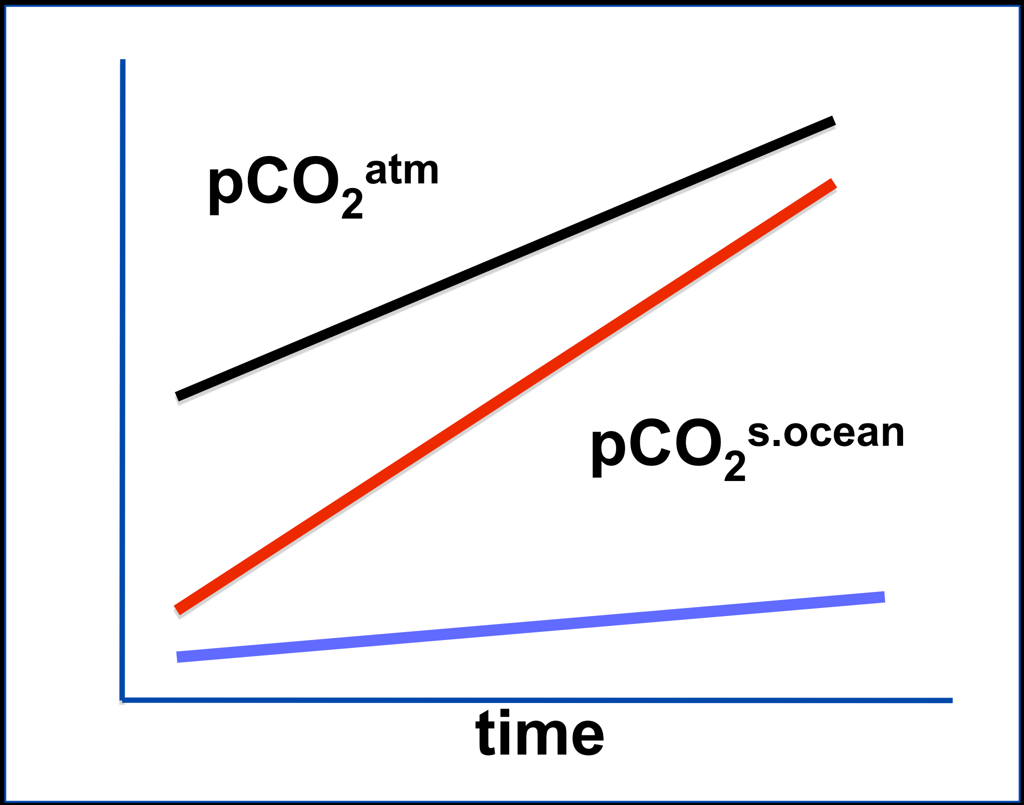
Data Analysis

1. Calculate monthly means for 1°x1° boxes
2. Aggregate to large regions (global biomes)
3. Fit single harmonic + trend
4. Test large-scale representativity using ocean models



Results

pCO_2^{atm} trend vs. $pCO_2^{s.ocean}$ trend



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

steeper $pCO_2^{s.ocean}$ trend

DECREASING ΔpCO_2

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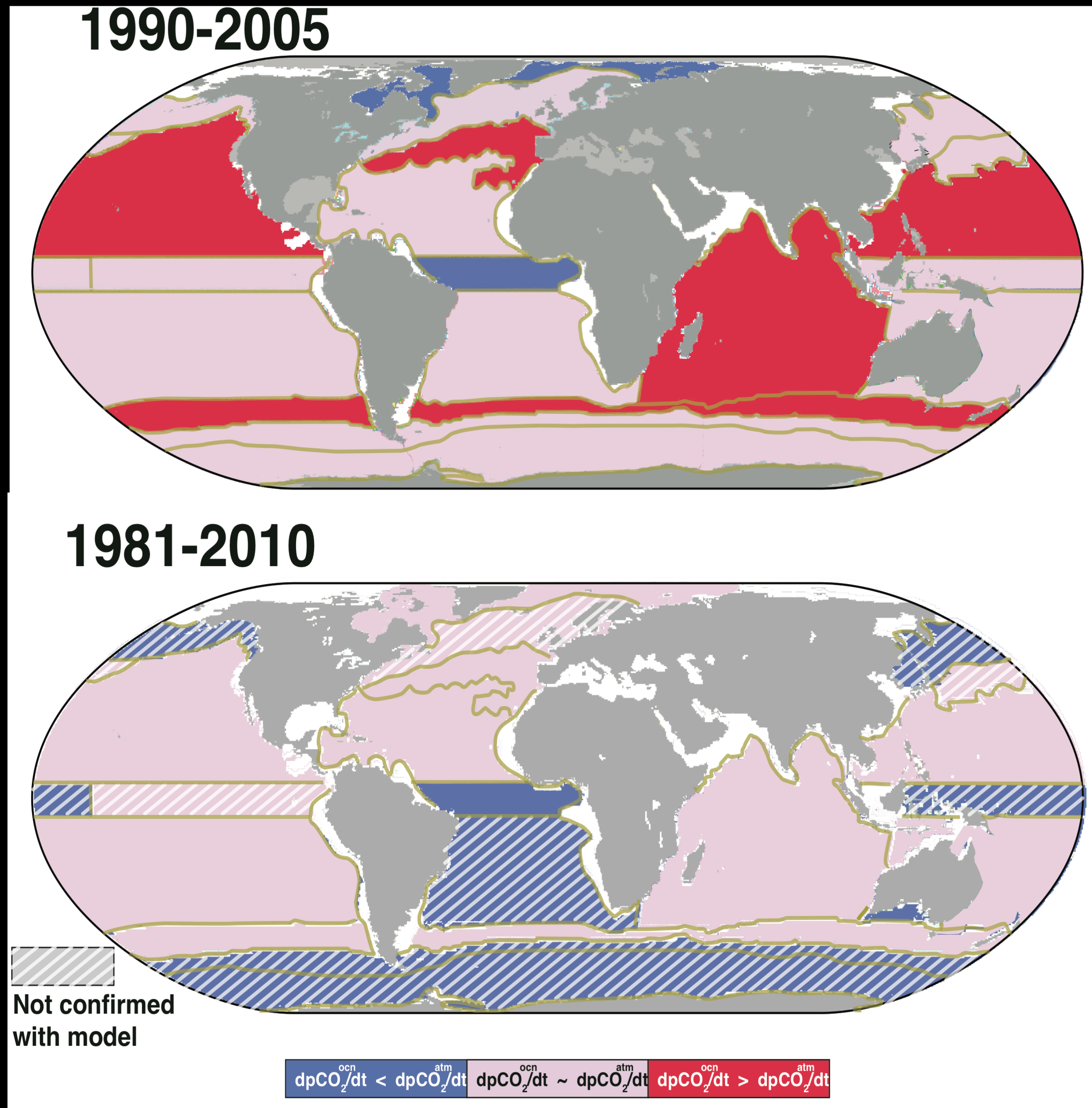
INCREASING

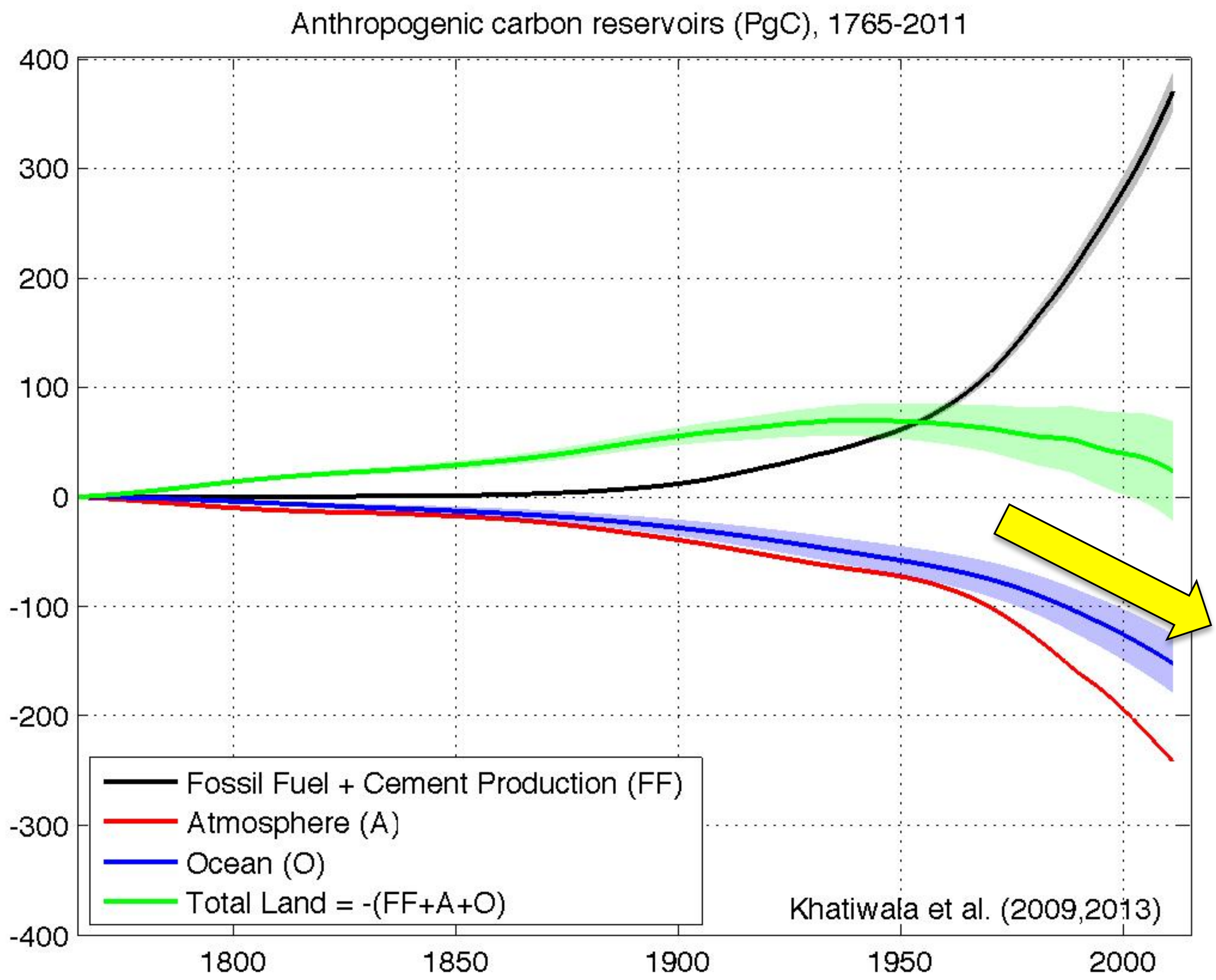
ΔpCO_2



Fay and McKinley 2013

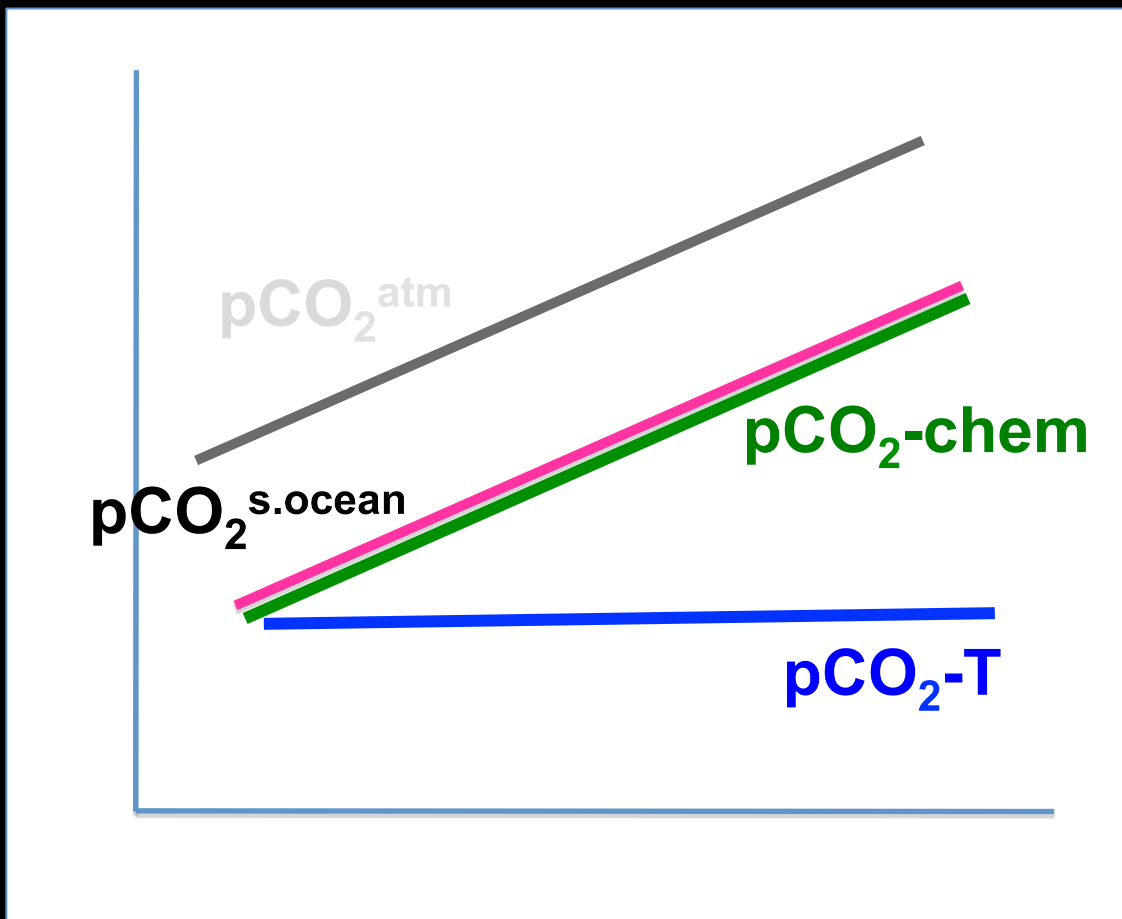
LDEO data

Extension allows for full time-history of carbon accumulation, with uncertainty



Surface data consistent with estimate from interior data

Trend mechanisms

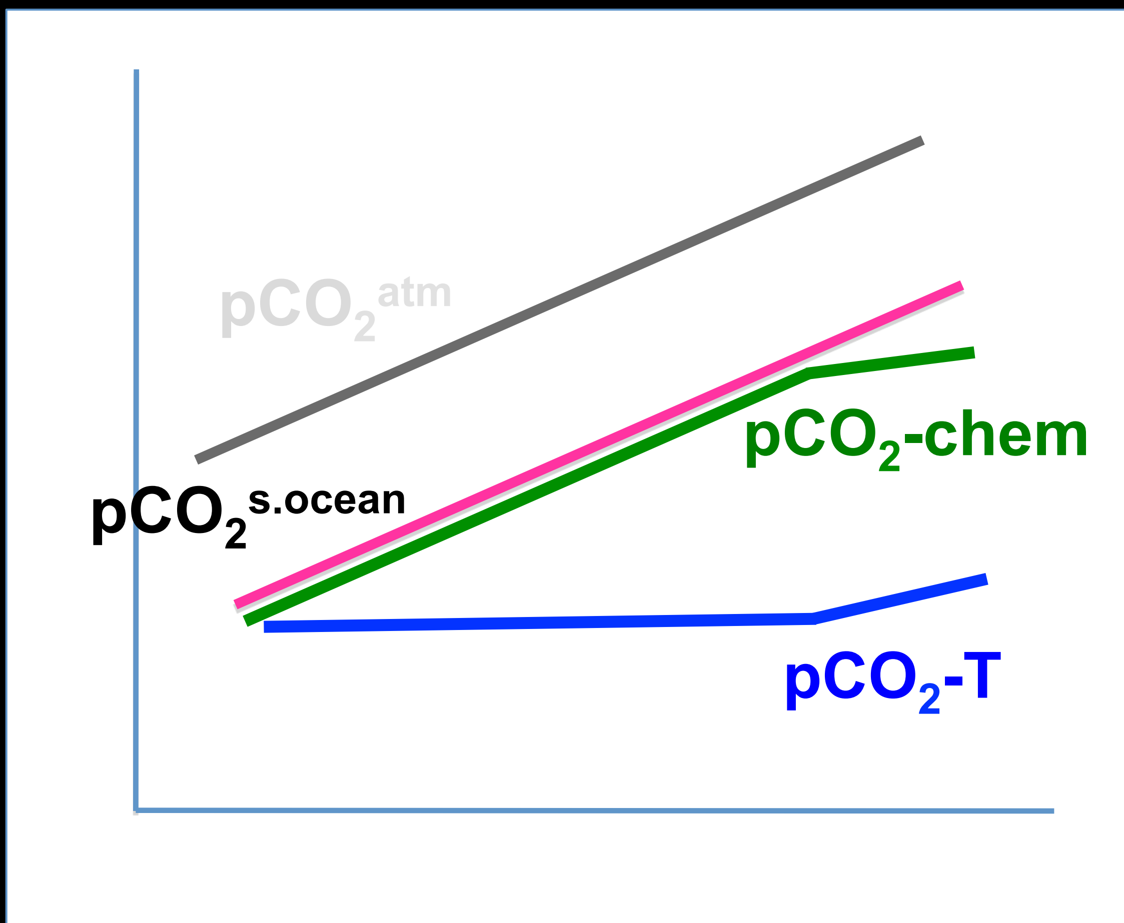


Biogeochemical change only

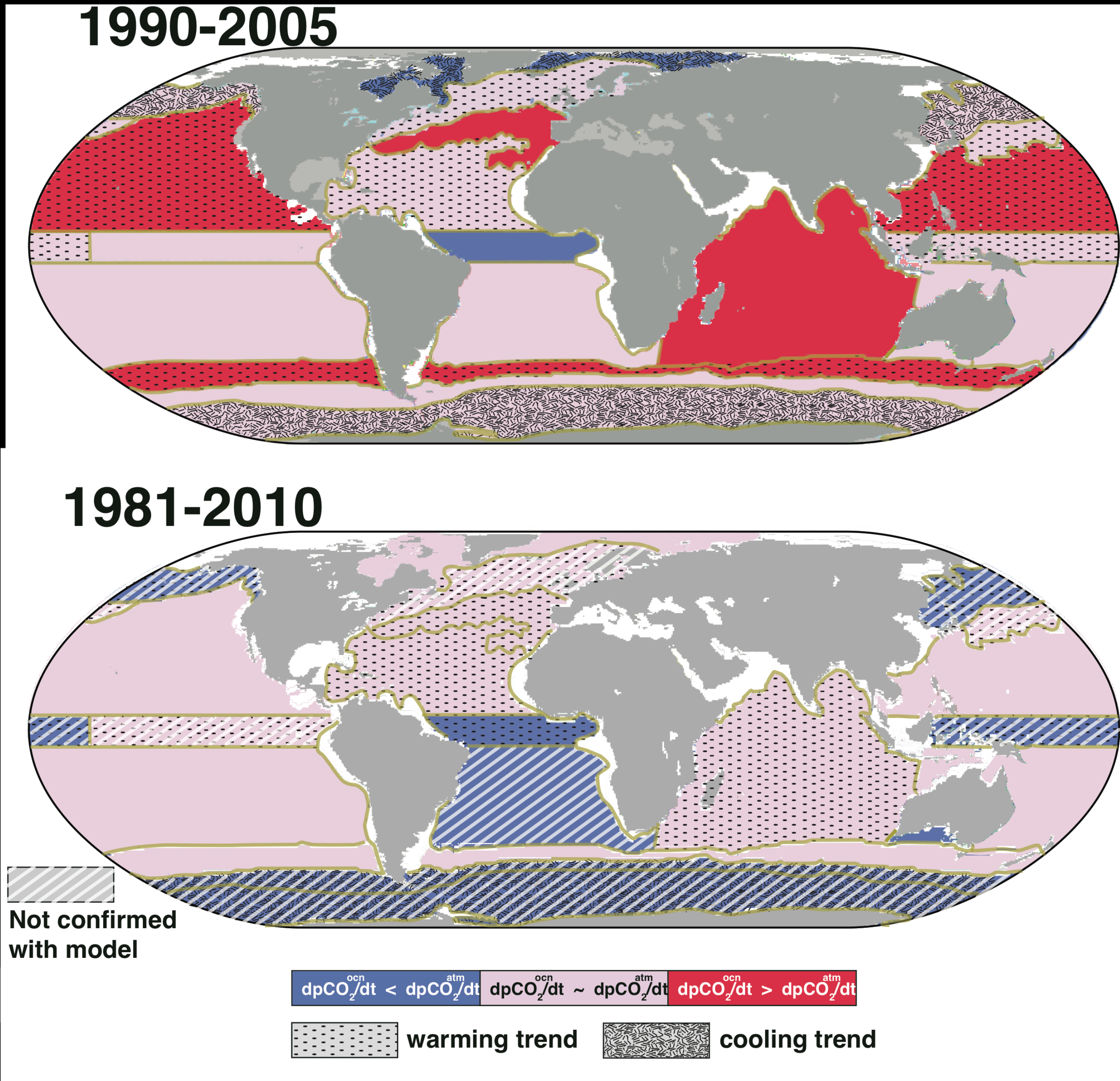
Consistent with carbon uptake

Takahashi et al. 2002

Trend mechanisms

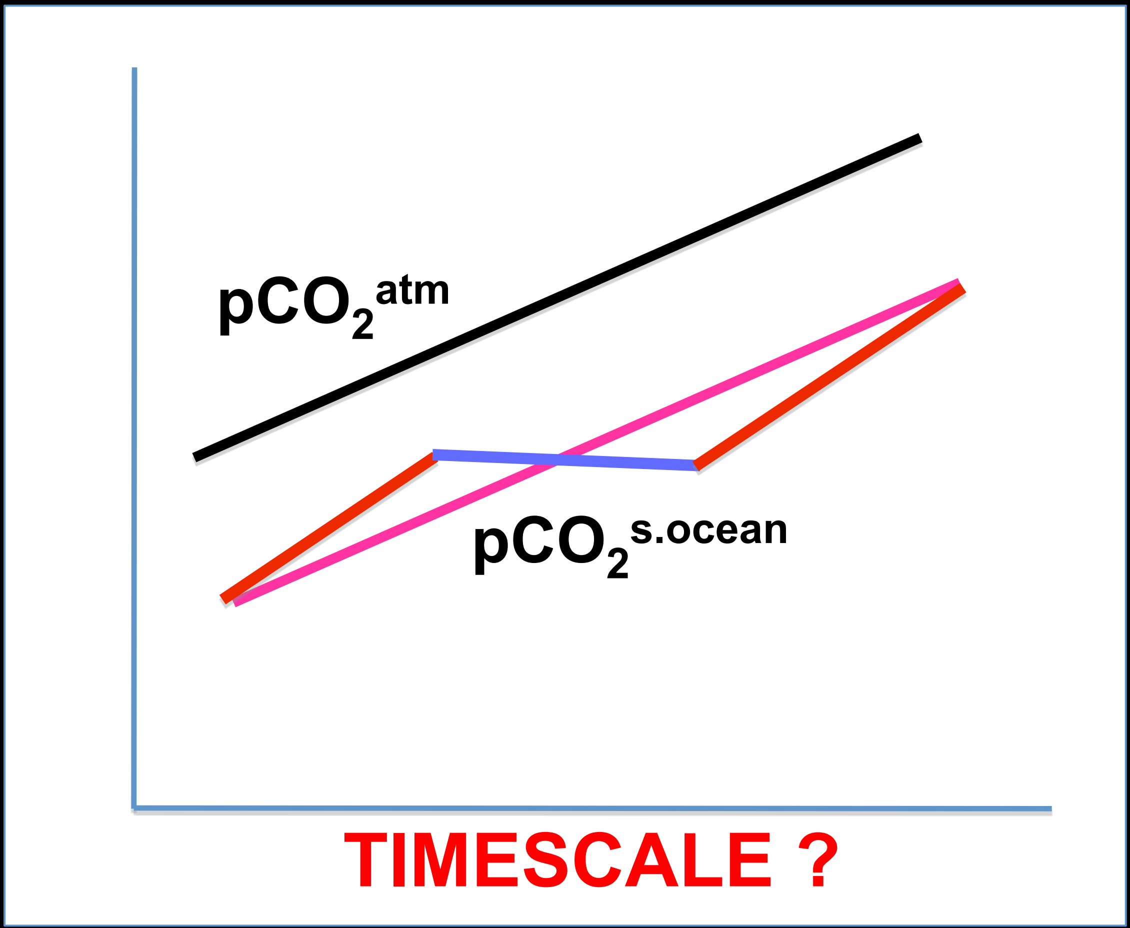


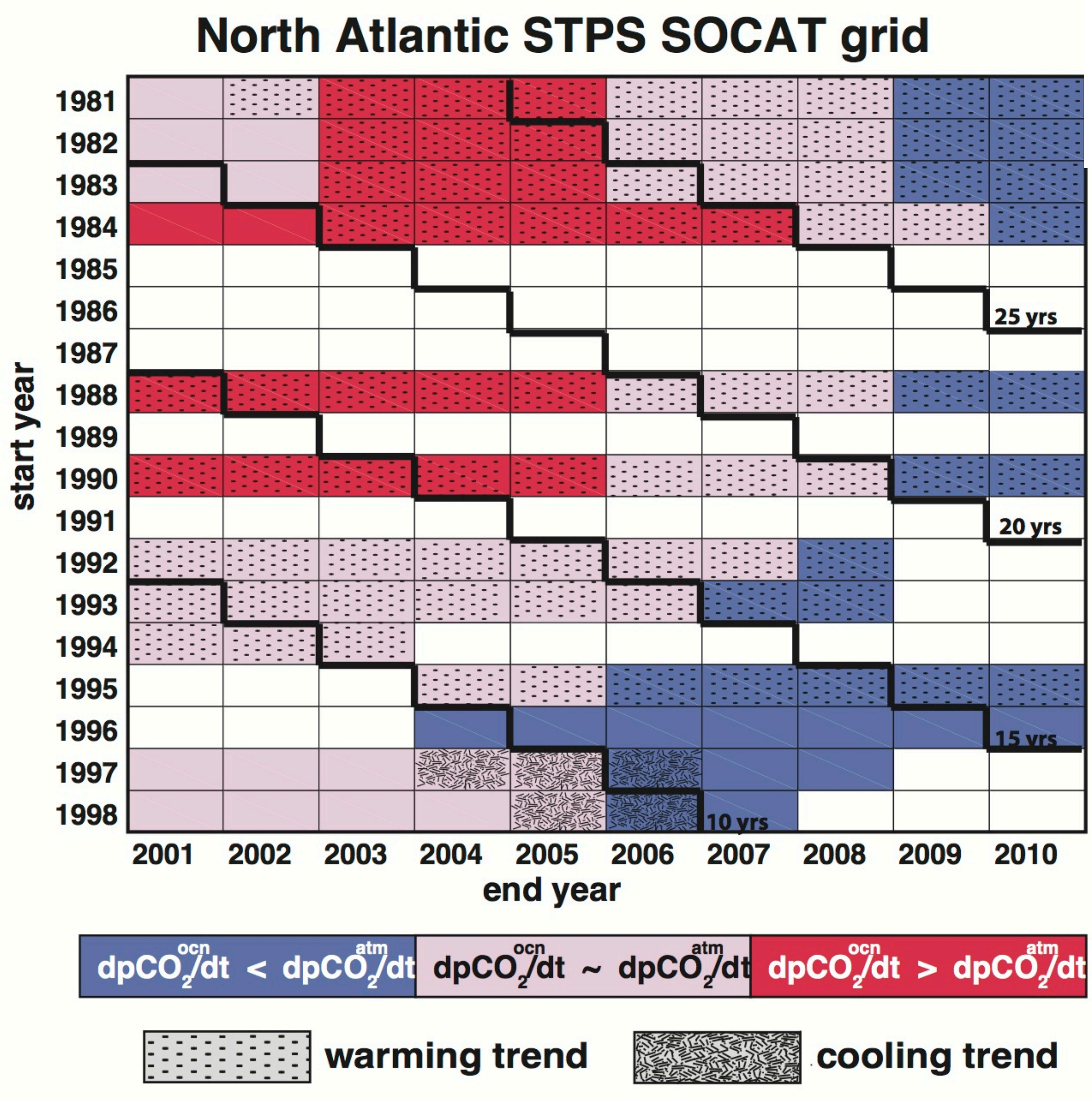
If warming contributes, carbon uptake will diminish

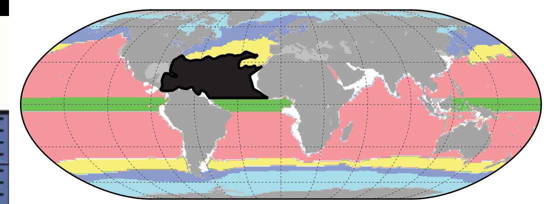


1990-2005
1981-2010
Not confirmed with model
$dpCO_2^{ocn}/dt < dpCO_2^{atm}/dt$
$dpCO_2^{ocn}/dt \sim dpCO_2^{atm}/dt$
$dpCO_2^{ocn}/dt > dpCO_2^{atm}/dt$
warming trend
cooling trend

What is the timescale of ocean adjustment to the atmospheric trend?



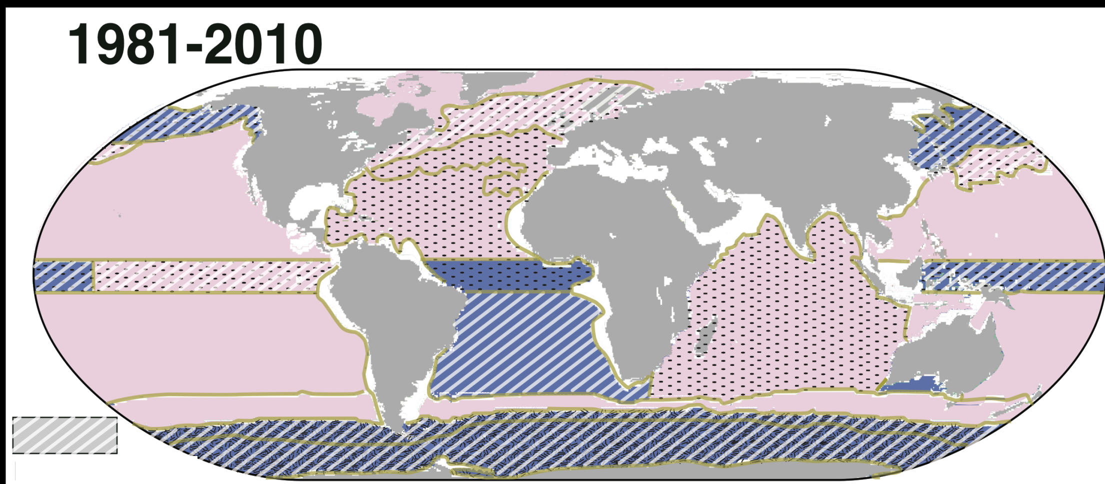




Fay and McKinley, in prep
SOCAT data

Conclusions

- The ocean has absorbed 1/3 of anthropogenic carbon
- *In situ* pCO_2 data confirm an increasing global carbon sink
- Warming impacts recent pCO_2 trends, esp. N. Atlantic



- More!
  - This meeting: Talk by Lovenduski (Sun 9:20); Posters by Fay and Pilcher
  - AGU: N. Atlantic mechanisms: AMO, NAO, AMOC (OS42B-04 Thu AM)

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