# Atmospheric signatures of changing global biogeochemistry

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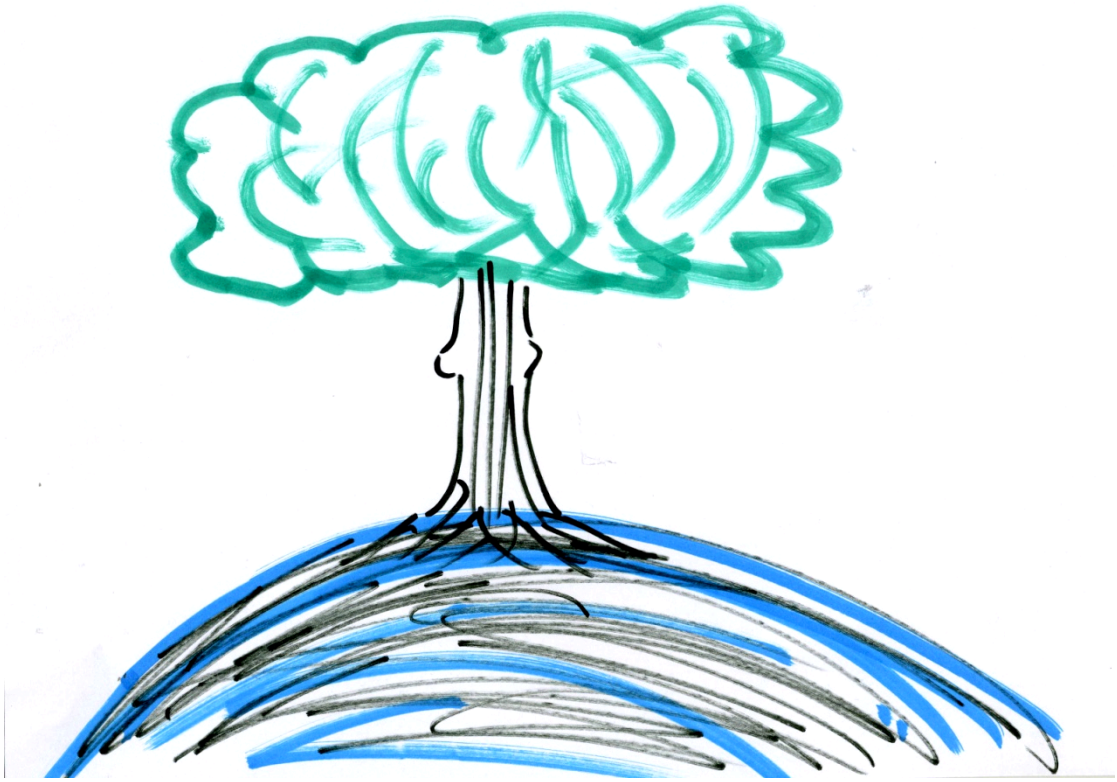
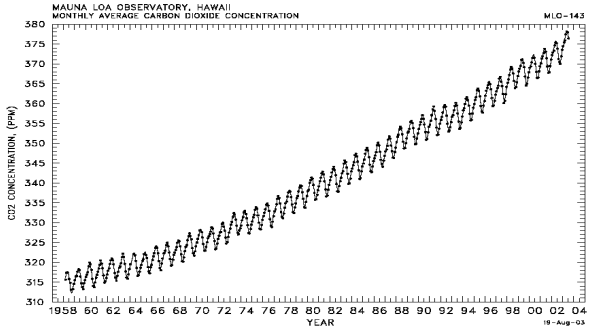
Or "How I learned to stop worrying and love the biosphere"

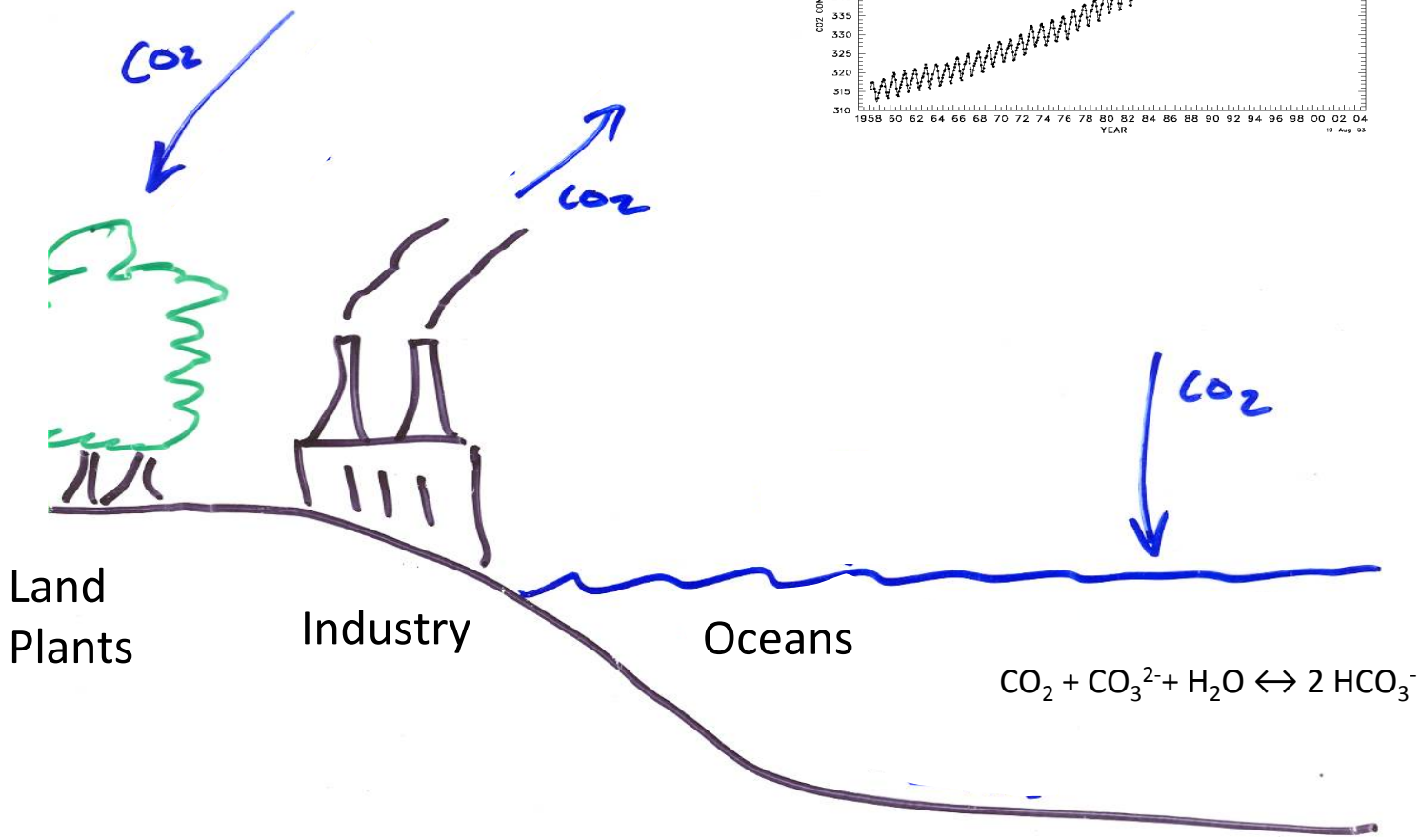


In collaboration with

**Lisa Welp, Heather Graven, Steve Piper, Andrew Manning**

# Controls on atmospheric $CO_2$ increase

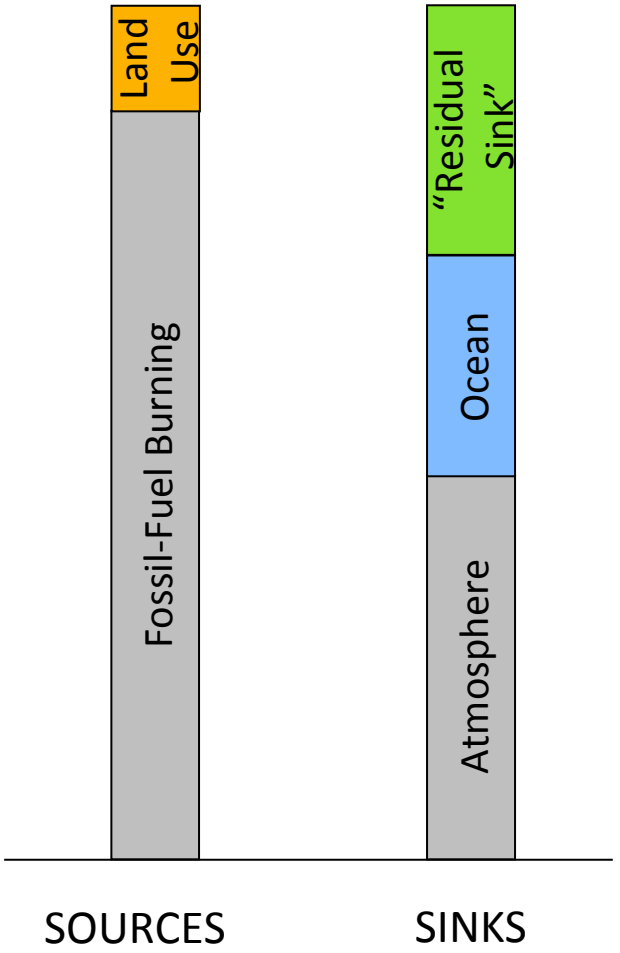



$CO_2 + CO_3^{2-} + H_2O \leftrightarrow 2\ HCO_3^-$

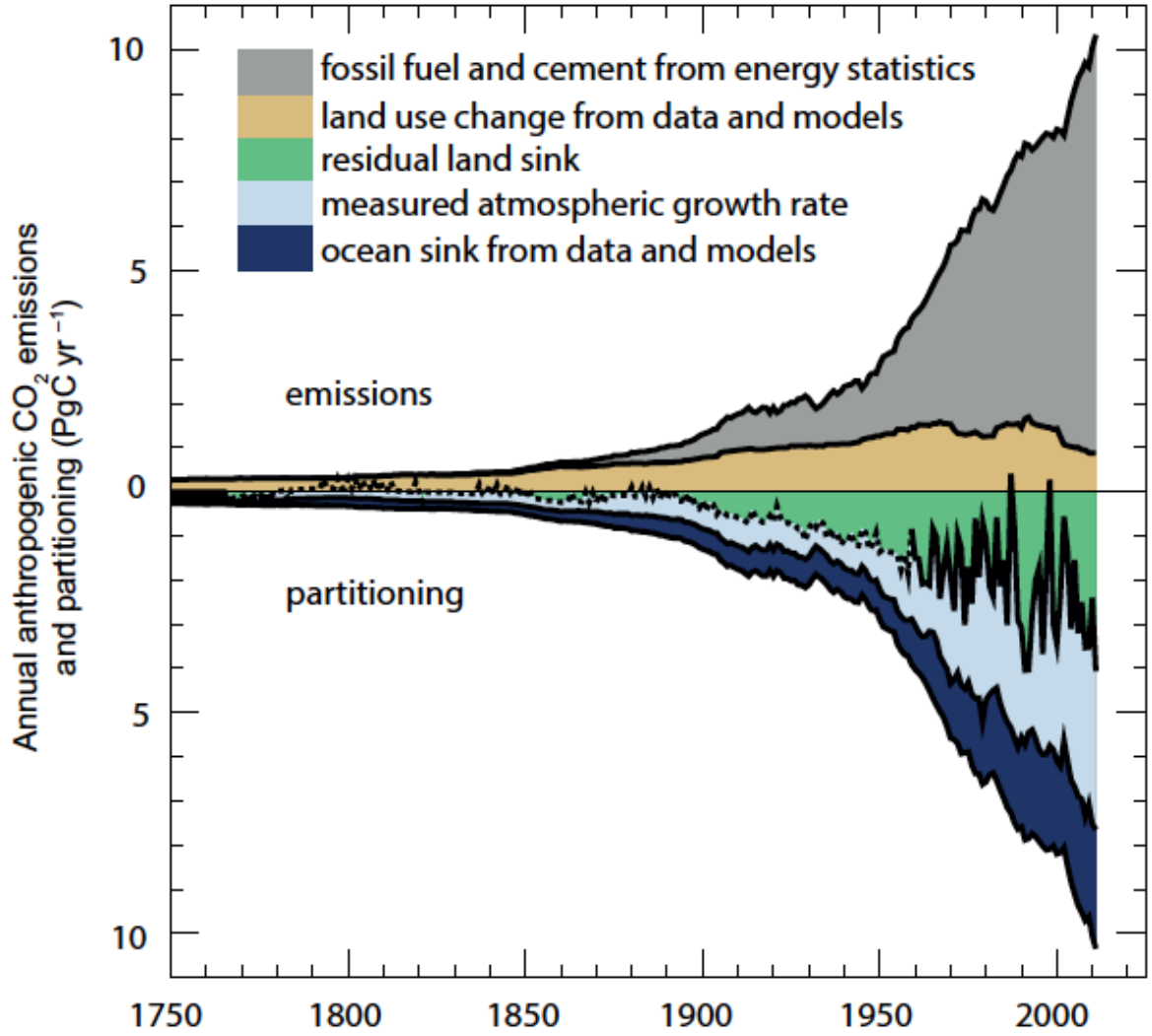
# $CO_2$ budget 2000-2010 (Pg C/yr)

| | |
|---|---|
| Fossil fuel emissions | 7.8 ± 0.6 |
| Land use emissions | 1.1 ± 0.8 |
| Total Sources | 8.9 ± 1.0 |
| | |
| Atmosphere | 4.0 ± 0.2 |
| Ocean sink | 2.3 ± 0.7 |
| Residual land sink | 2.6 ± 1.2 |
| Total Sinks | 8.9 ± 1.0 |



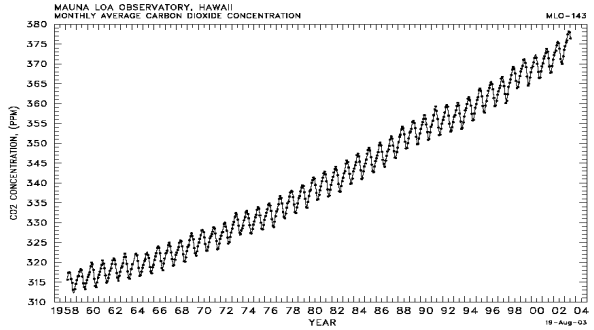

IPCC AR5

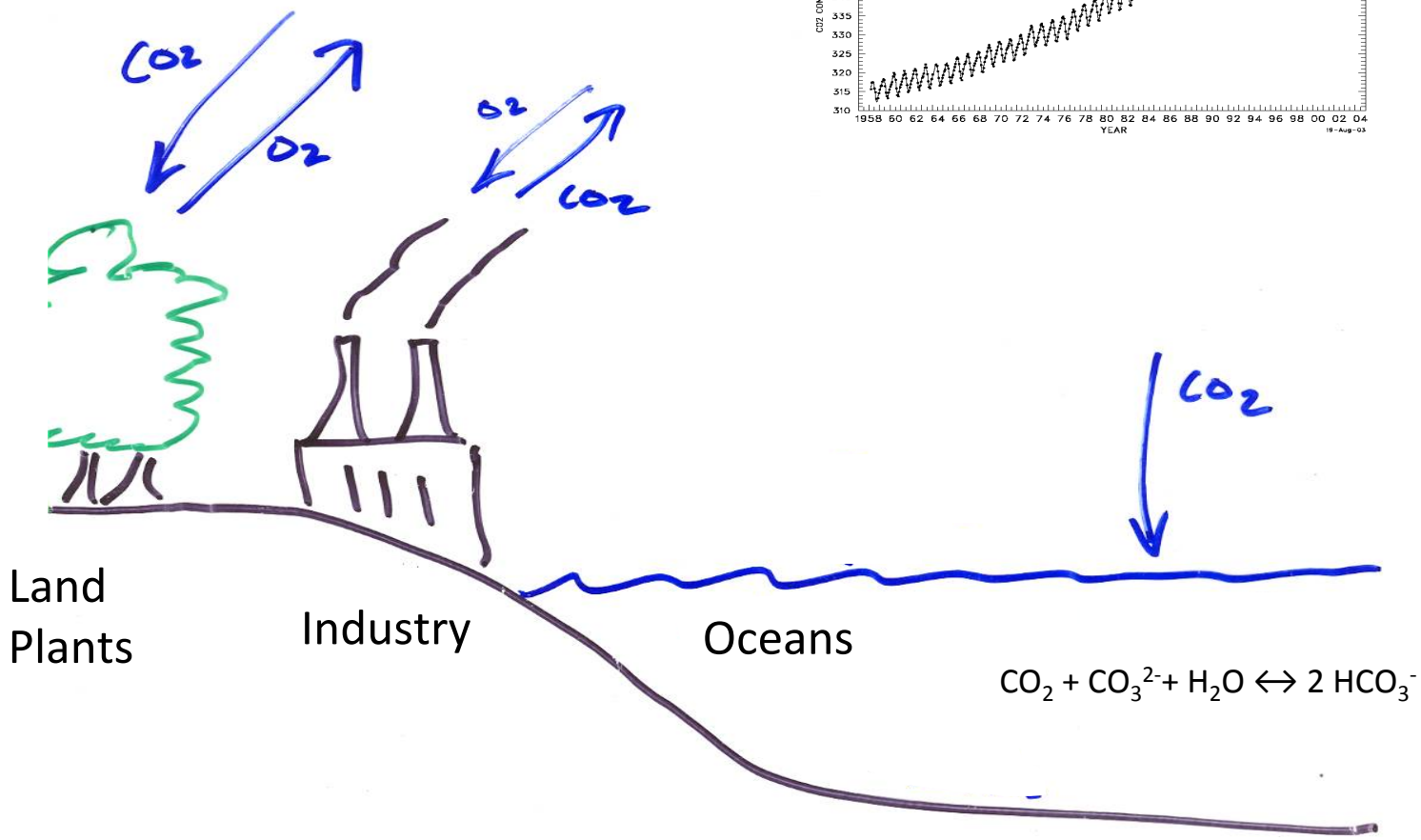
# Historic Carbon Sources and Sinks




IPCC Ar5, Figure 6.8

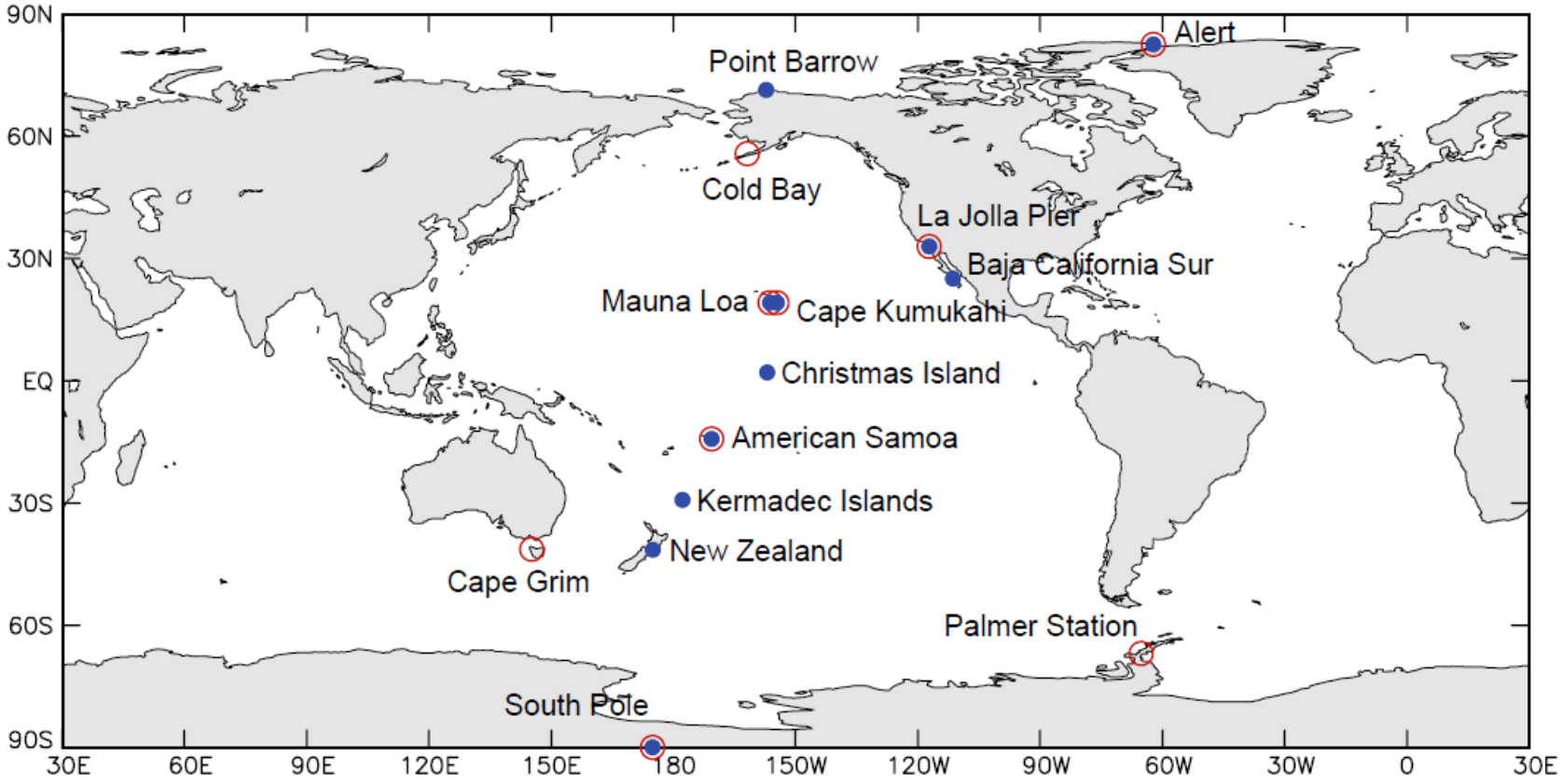
# Controls on atmospheric $CO_2$ and $O_2$



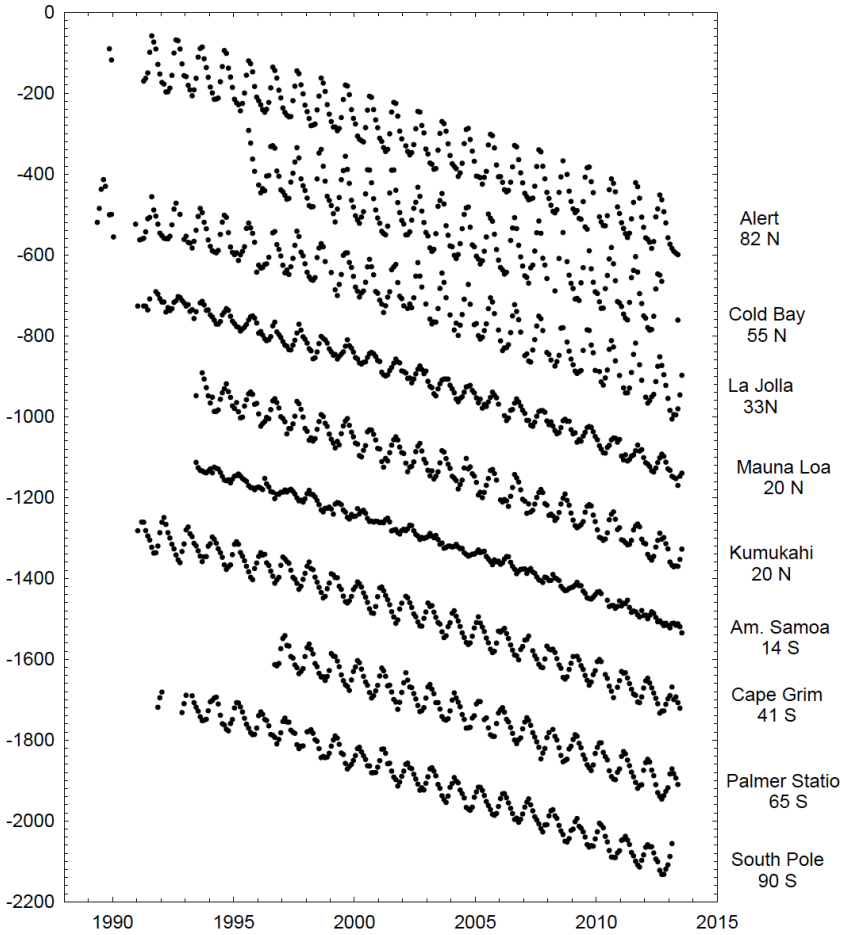

$CO_2 + CO_3^{2-} + H_2O \leftrightarrow 2\ HCO_3^-$

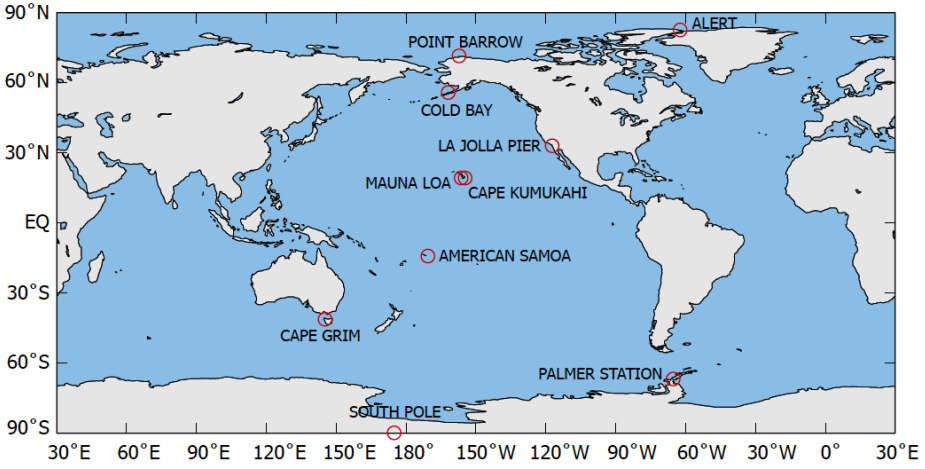
# Scripps $CO_2$ and $O_2$ Sampling Networks




Measurements of $CO_2$ Concentration and isotopes: $^{13}C/^{12}C$, $^{18}O/^{16}O$, $^{14}C$
Measurements of $O_2/N_2$ ratio and $Ar/N_2$ ratio
Archive of pure $CO_2$ extracted from samples

# Scripps $O_2$ Program




**Scripps $O_2$ Program Elements**

Flask network, 10 stations

Continuous measurements at La Jolla

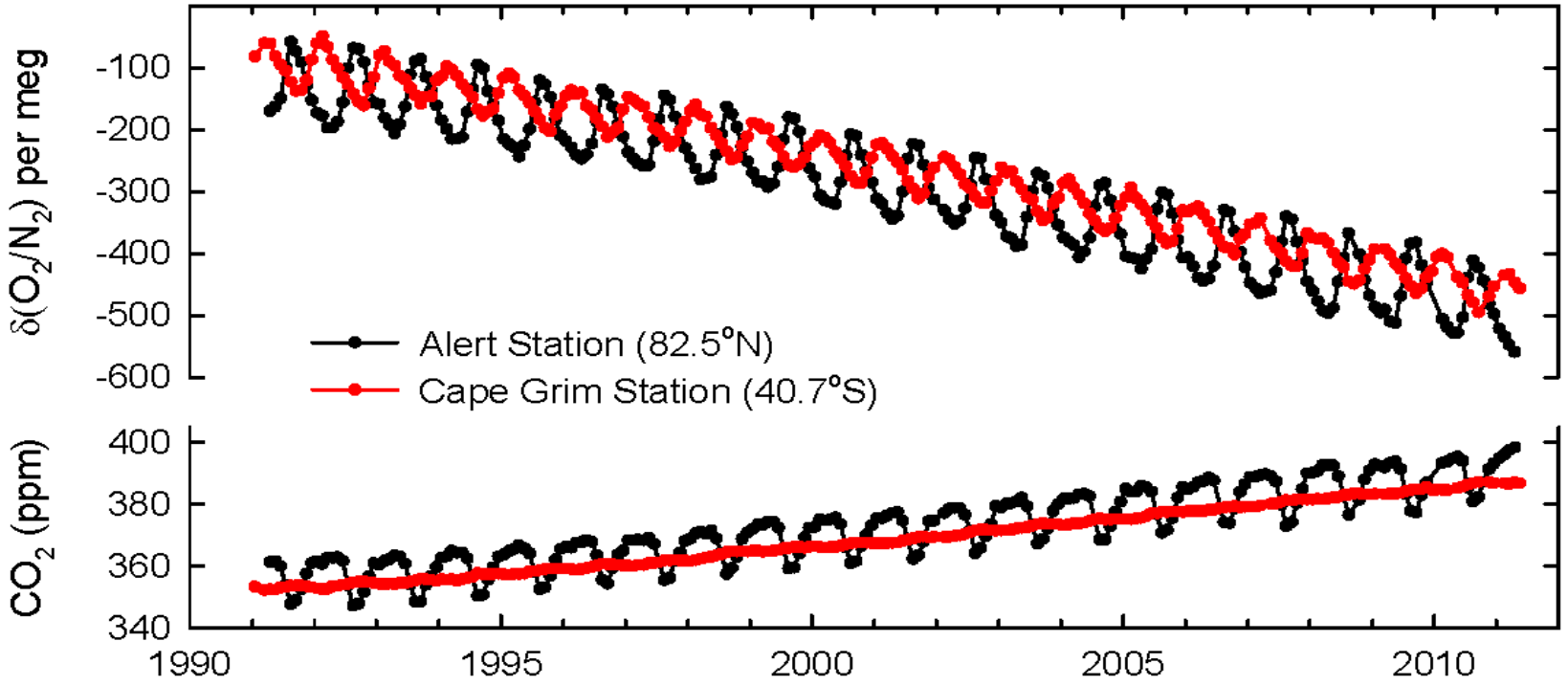
Measure $CO_2$, $O_2/N_2$ ratio and $Ar/N_2$ ratio

Methods development

Calibration facility

Project Website: ScrippsO2.ucsd.edu

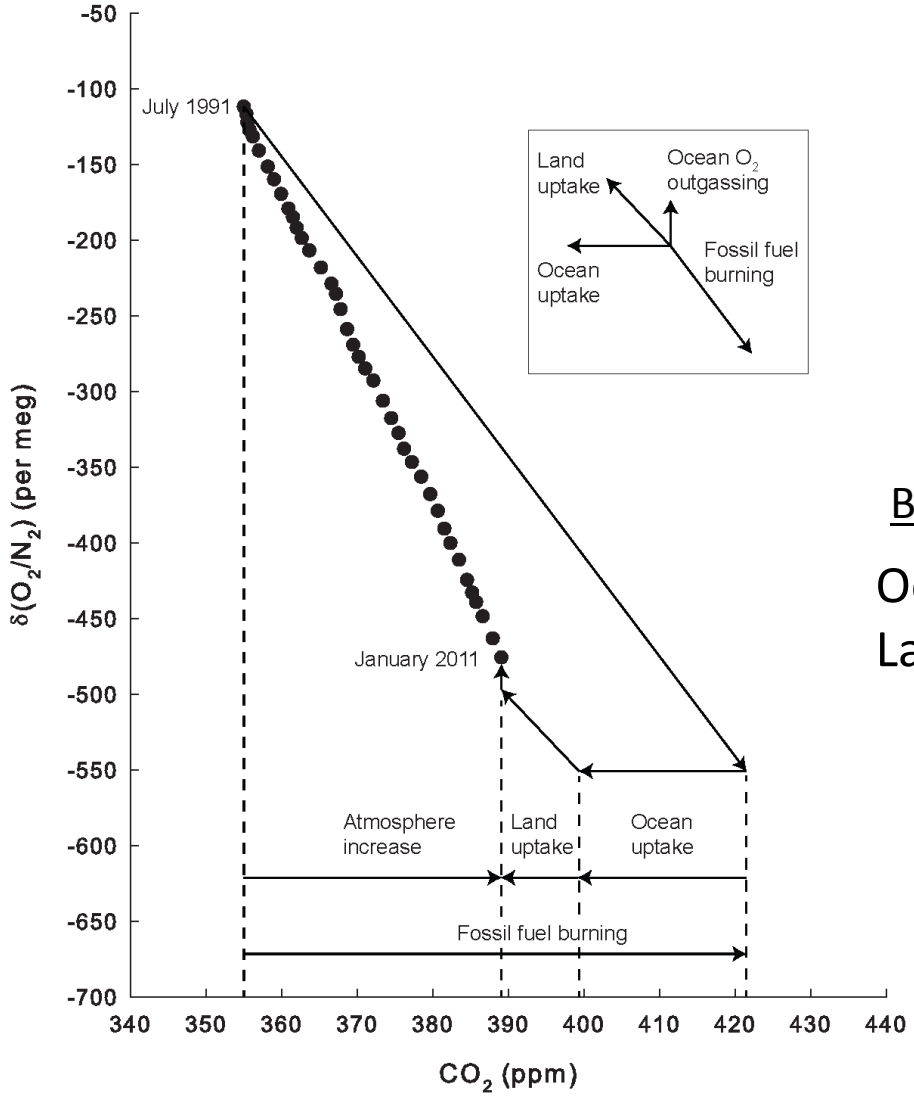
# $O_2/N_2$ and $CO_2$ trends




$$\delta(O_2/N_2) = \frac{(O_2/N_2)_{sample} - (O_2/N_2)_{reference}}{(O_2/N_2)_{reference}}$$

4.8 per meg ~ 1 ppm

# Vector diagram of $O_2$ and $CO_2$ changes



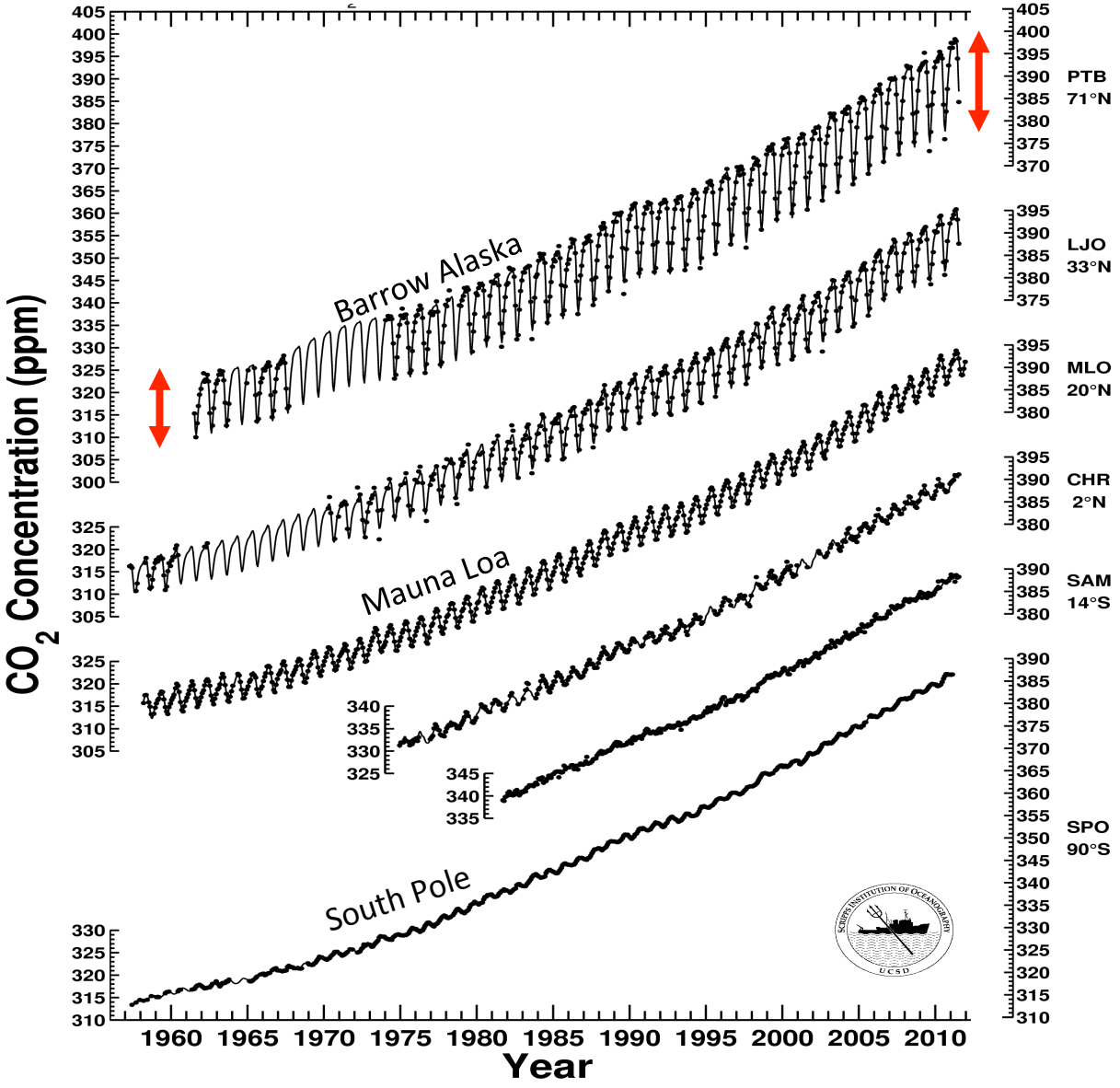

Budget for 1991 to 2001

Ocean uptake = 2.45 ±0.58

Land uptake = 1.05 ± 0.80

Pg C $yr^{-1}$

# $CO_2$ concentration at selected stations




Cycle at Barrow driven mostly by boreal and temperate forests

Amplitude increase over 50 years ~ 50% or 0.8% /yr

# Arctic landscapes

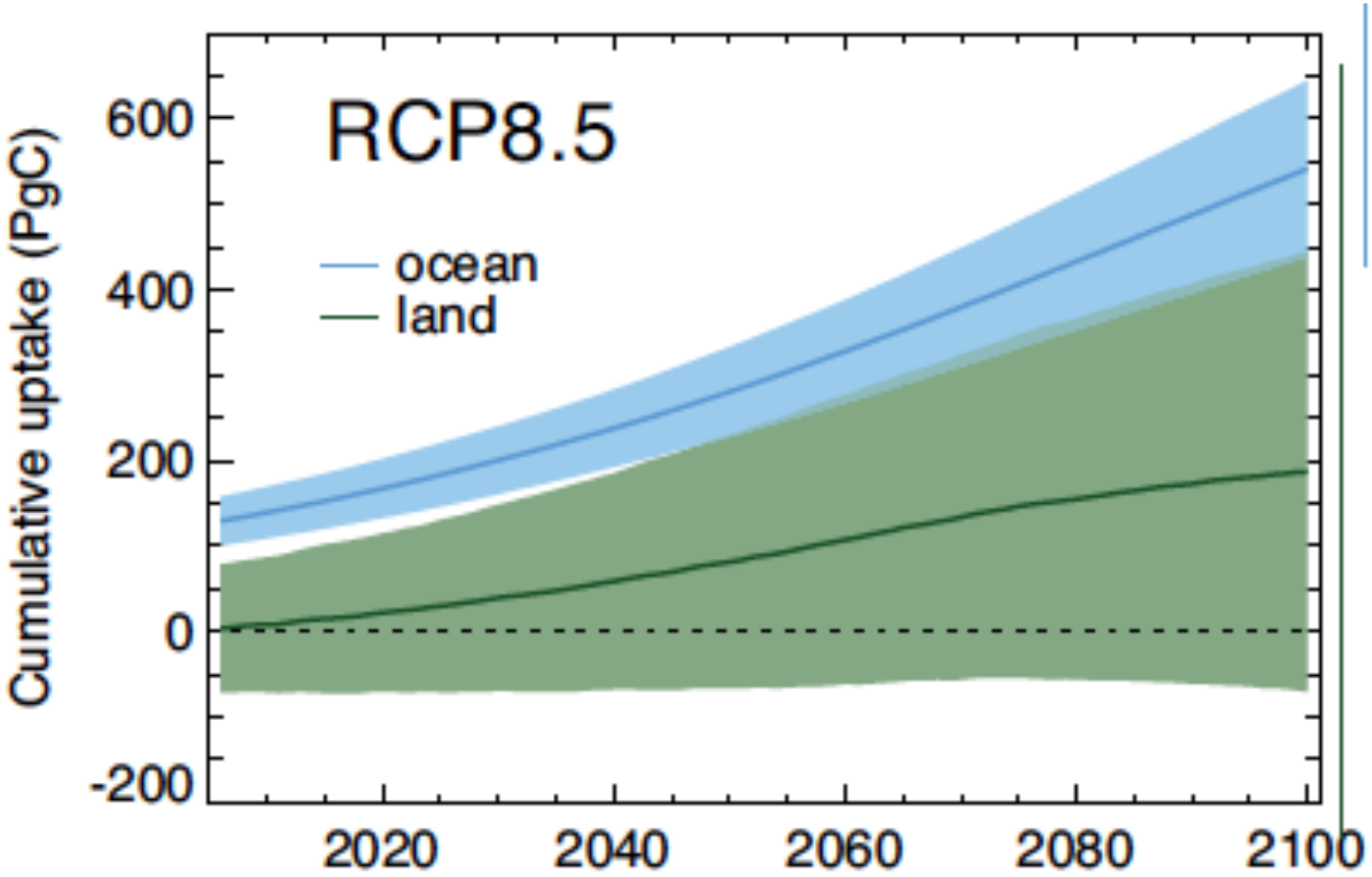
# High Arctic in the Eocene

**Figure 7. Reconstruction of Eocene High Arctic rain forest environment with hippo-like *Coryphodon* in the foreground; inset shows detail of Eocene Arctic tapir *Thuliadanta*. Both images are courtesy of the American Museum of Natural History (© AMNH/D. Finnin).**

What role does ocean biogeochemistry play in $CO_2$ uptake, beyond a passive response to rising $CO_2$?

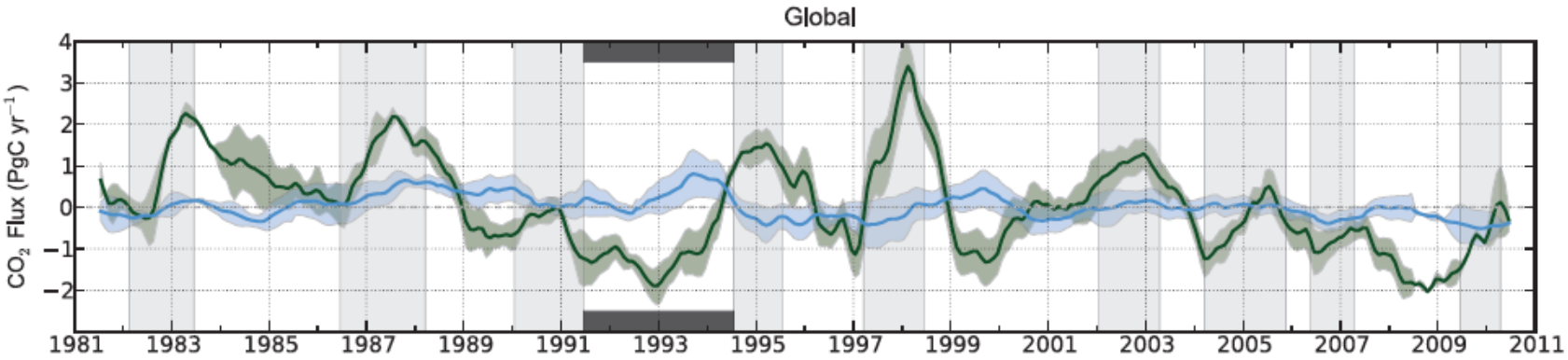
-> Conventional wisdom is a rather small role.

# Future projections show only small range in ocean responses




IPC

# “Observations” support much smaller ocean than land variability in recent past




Ocean interannual variability = ~±0.2 Pg C $yr^{-1}$

Ocean models typically also yield ~± 0.2 Pg C $yr^{-1}$*

IPCC AR5, Figure 6.9

*Wanninkhof et al, 2013, Biogeosciences

# But… Ocean biogechemical response to climate changes may be underestimated.

(1) Glacial-interglacial $CO_2$ "puzzle".

(2) Magnitude of interannual variability might be larger than estimated by models and "observation"

Roedenbeck et al. (2013, BGD) ~ ±0.31 Pg C $yr^{-1}$

(3) Ocean models underestimate variability in "atmospheric potential oxygen"

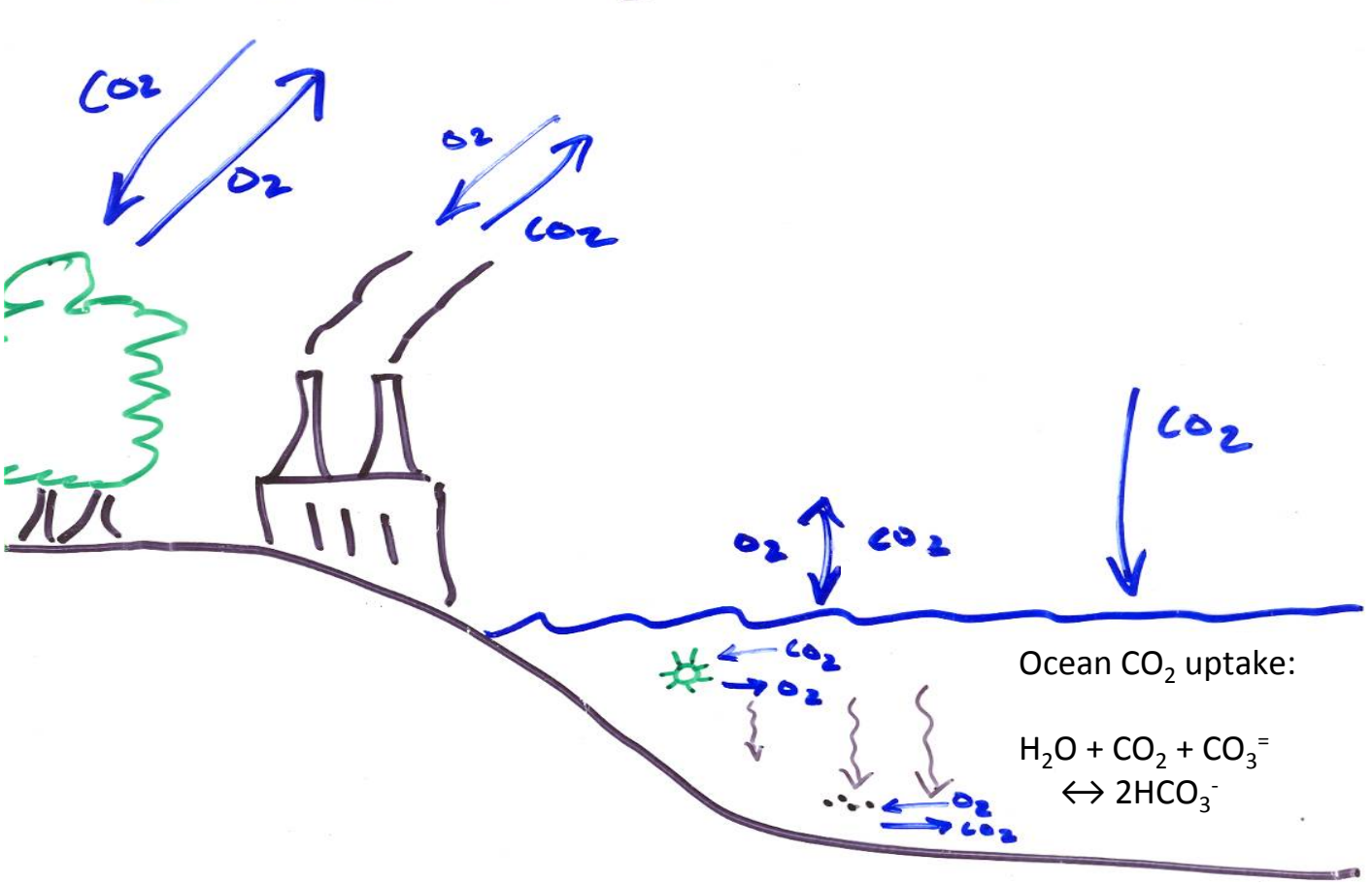
(4) Largest perturbation to $CO_2$ growth rate in 1940s might have been (mostly) oceanic.

# Also… improved ocean fluxes needed for inverse calculations of land fluxes

Repeat hydrography and surface ocean $pCO_2$ measurements won't fully address need on decadal time scale.

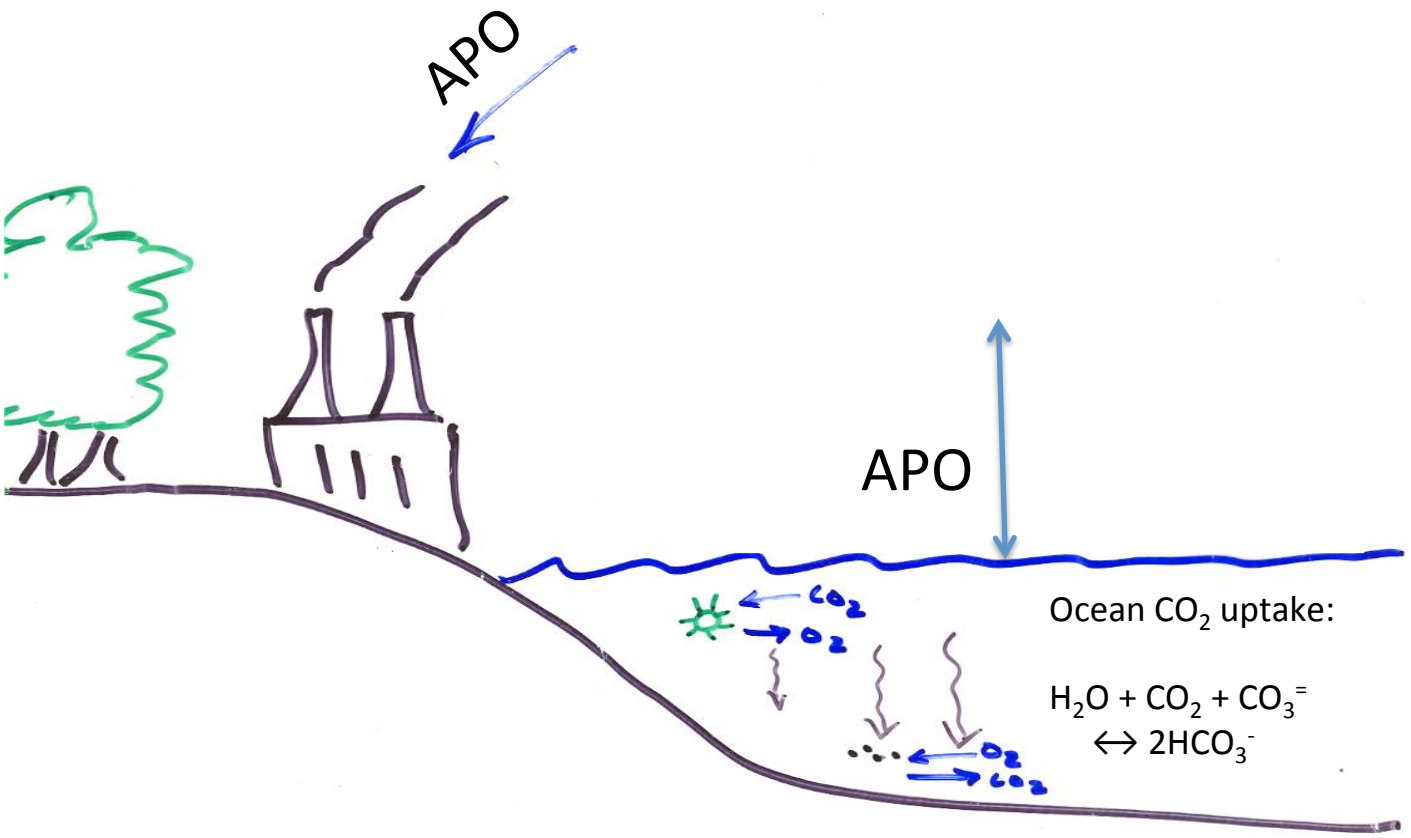
Measurements of atmospheric $O_2$ may help fill this gap.

# Atmospheric $CO_2$ & $O_2$ coupling

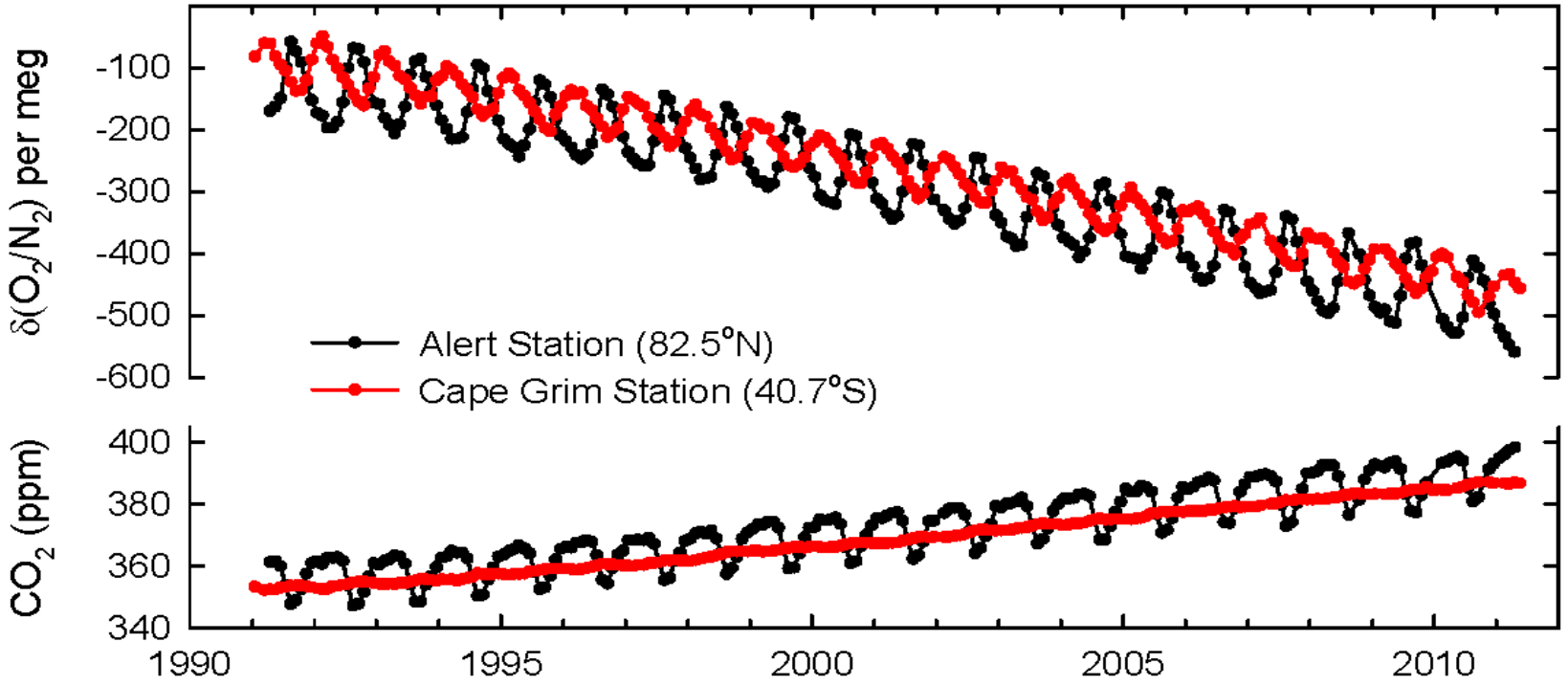


# Atmospheric potential oxygen

$APO \sim O_2 + CO_2$



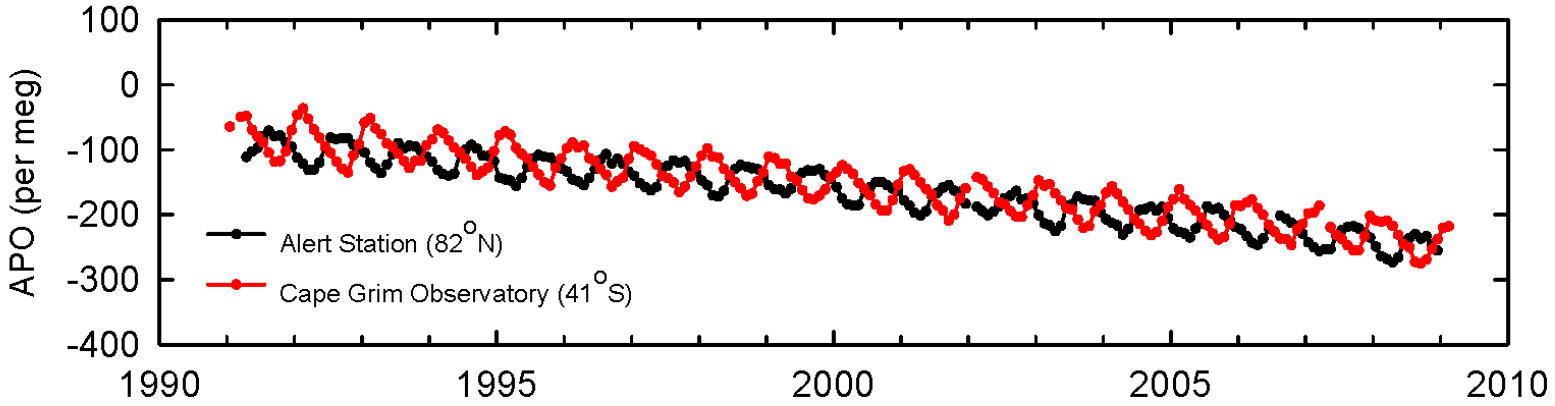
# What about changes in functioning of ocean biota?



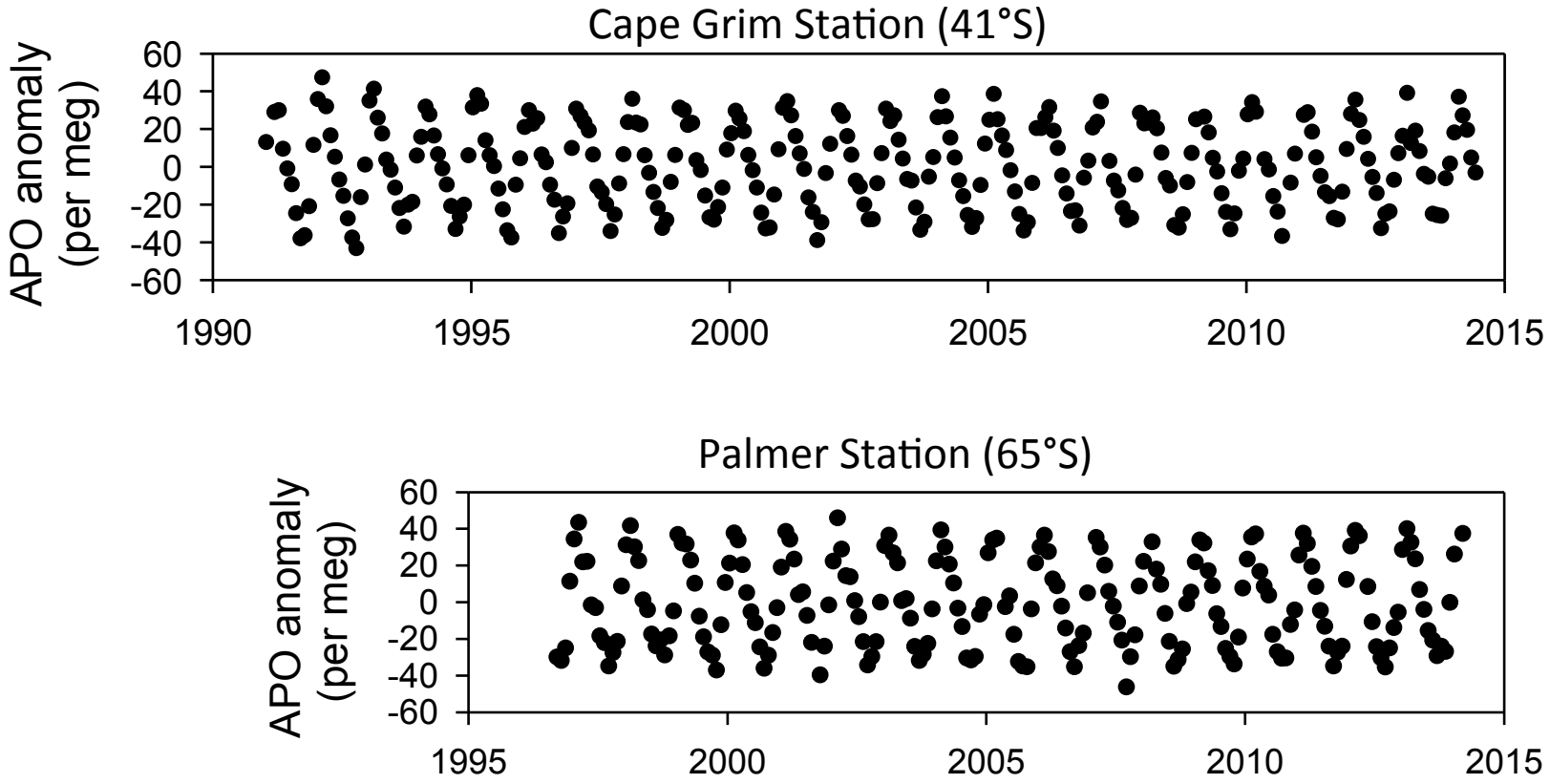

$$\delta(O_2/N_2) = \frac{(O_2/N_2)_{sample} - (O_2/N_2)_{reference}}{(O_2/N_2)_{reference}}$$

4.8 per meg ~ 1 ppm

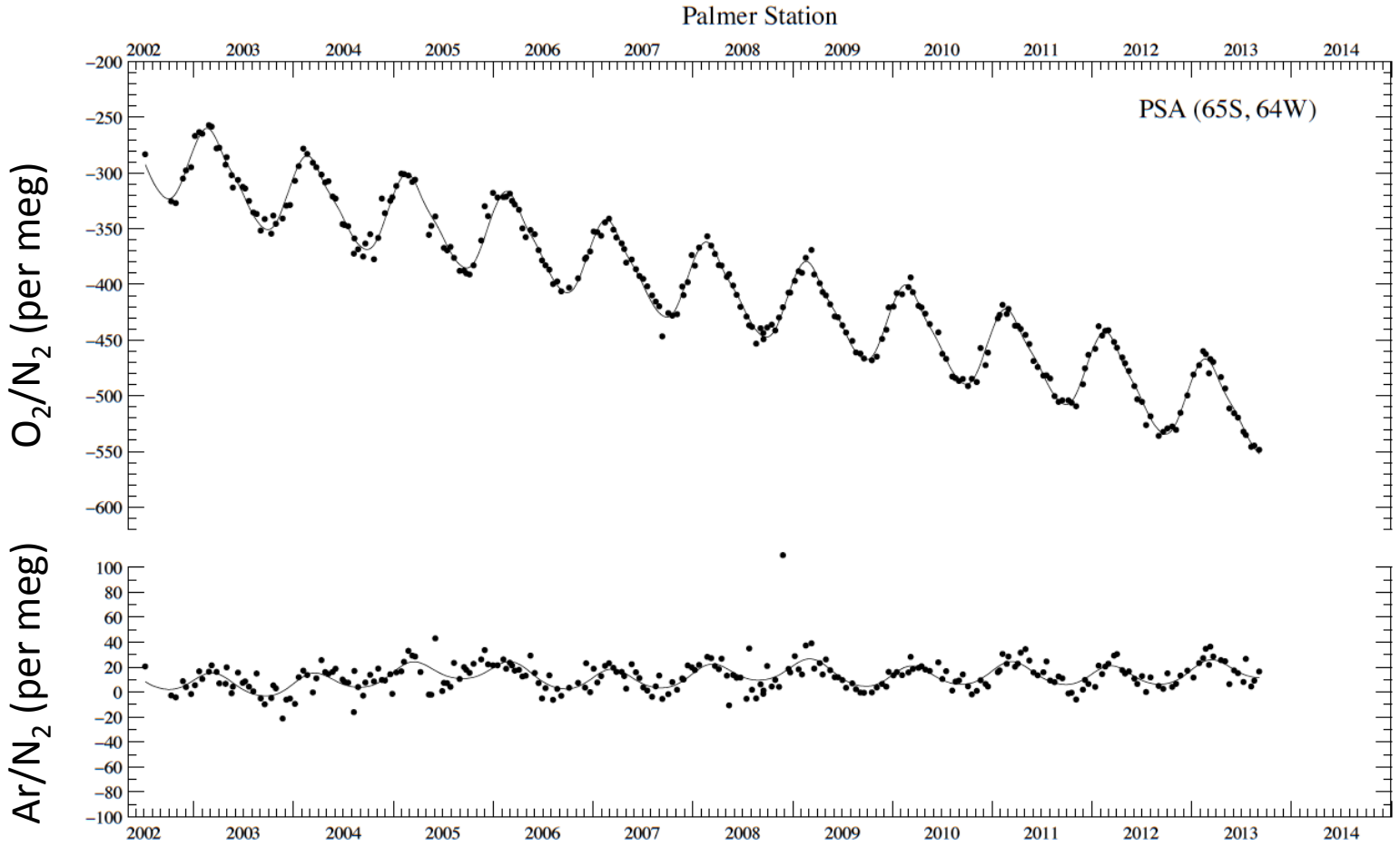
# APO: a tracer of oceanic exchanges



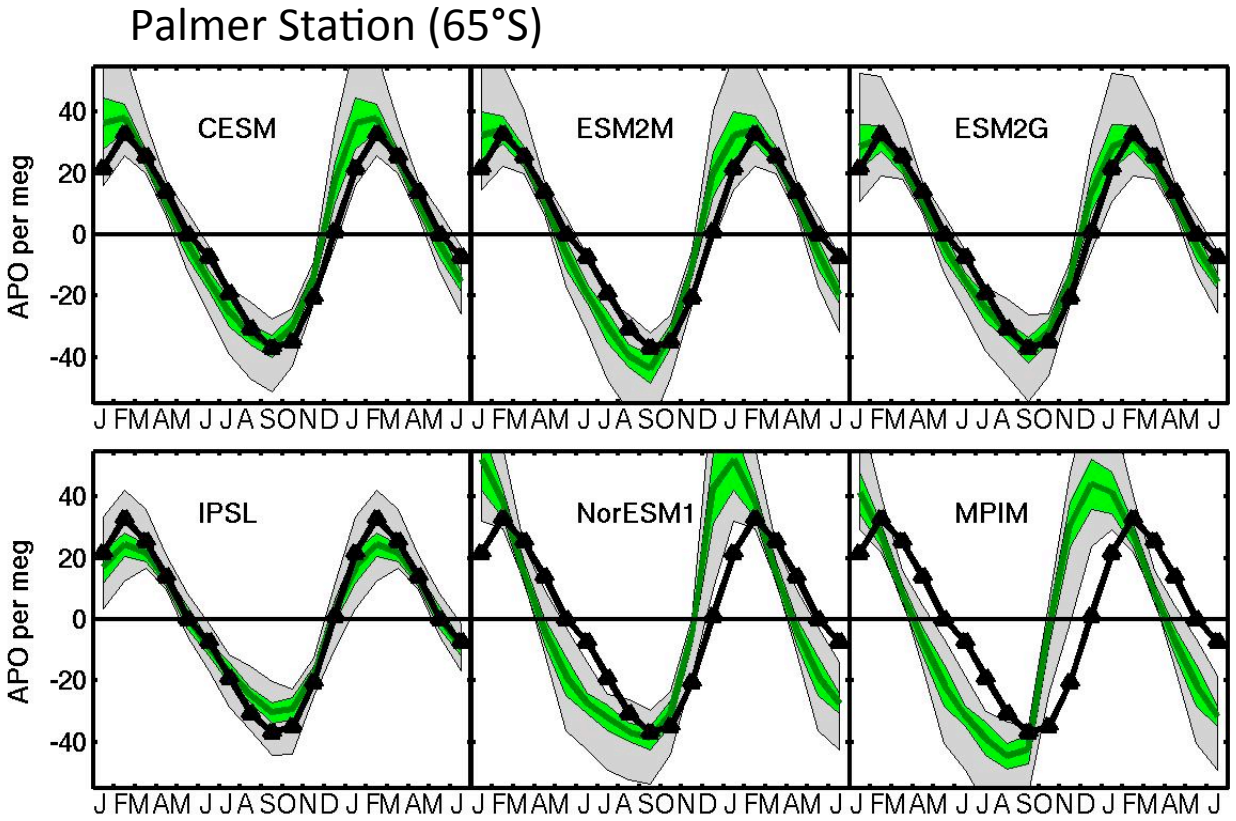
# Ocean “metabolism” from seasonal cycles in APO.



# Time series at Palmer Station

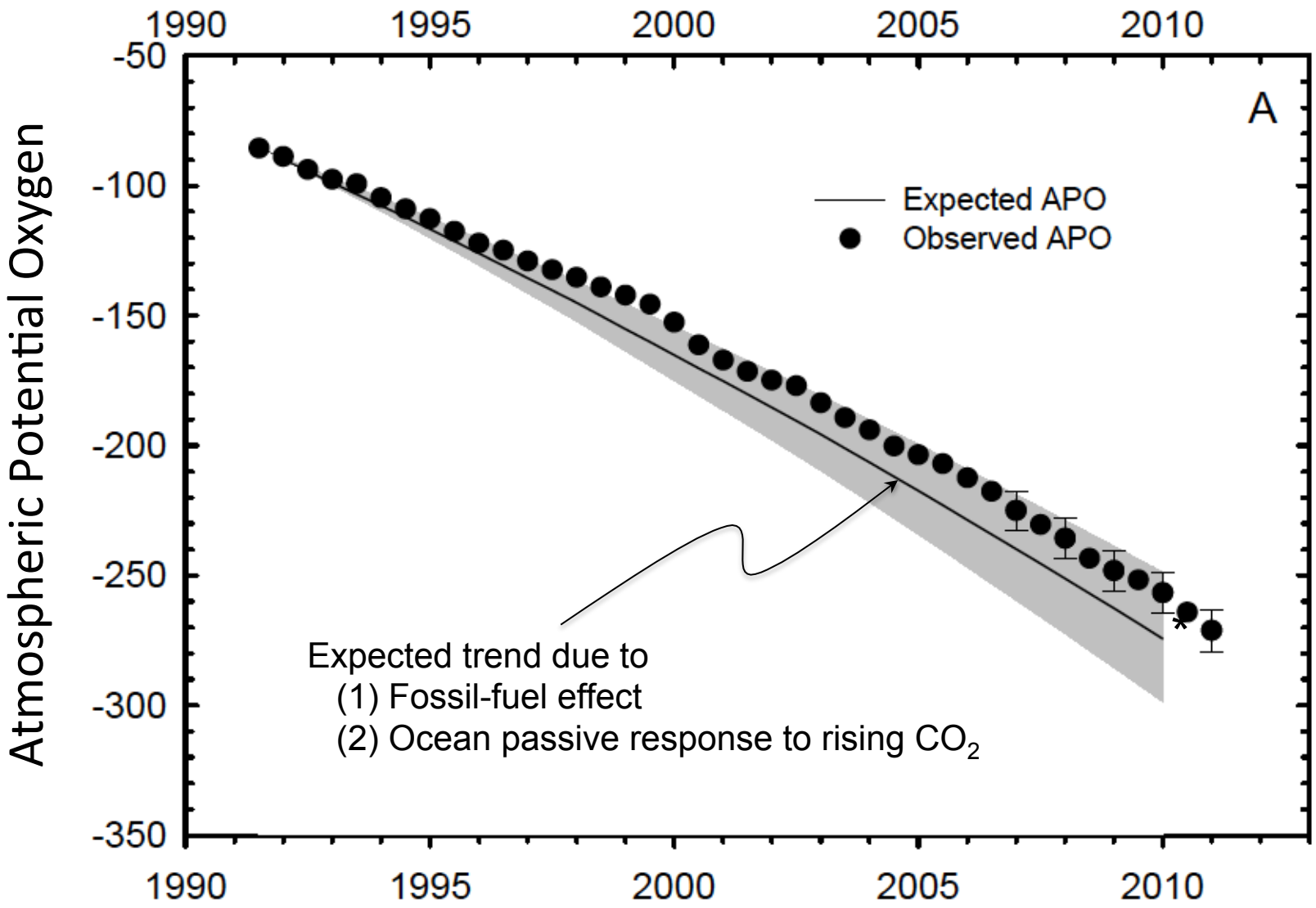


# Seasonal APO cycles as model test

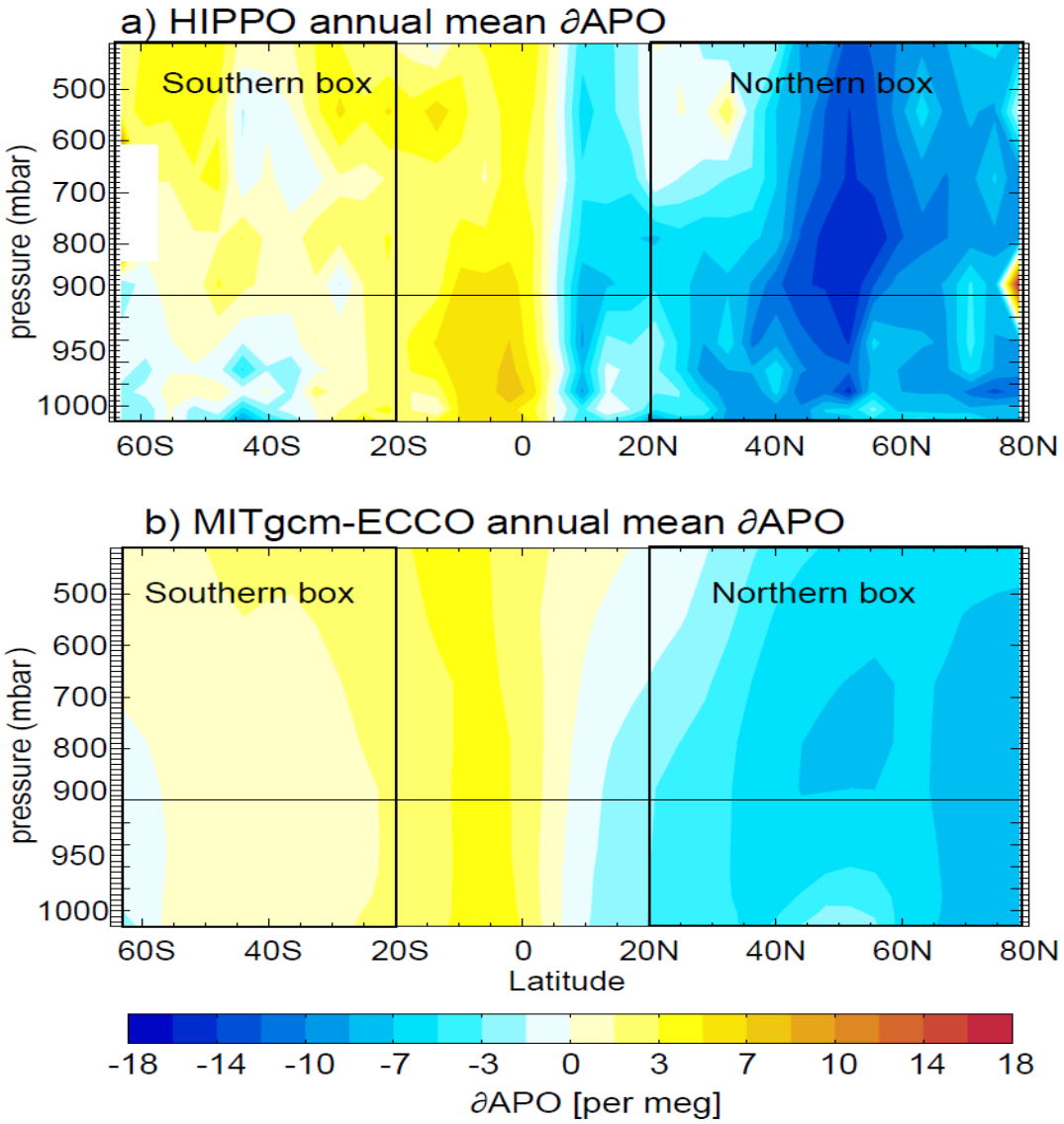



Nevsion et al., in prep, 2013

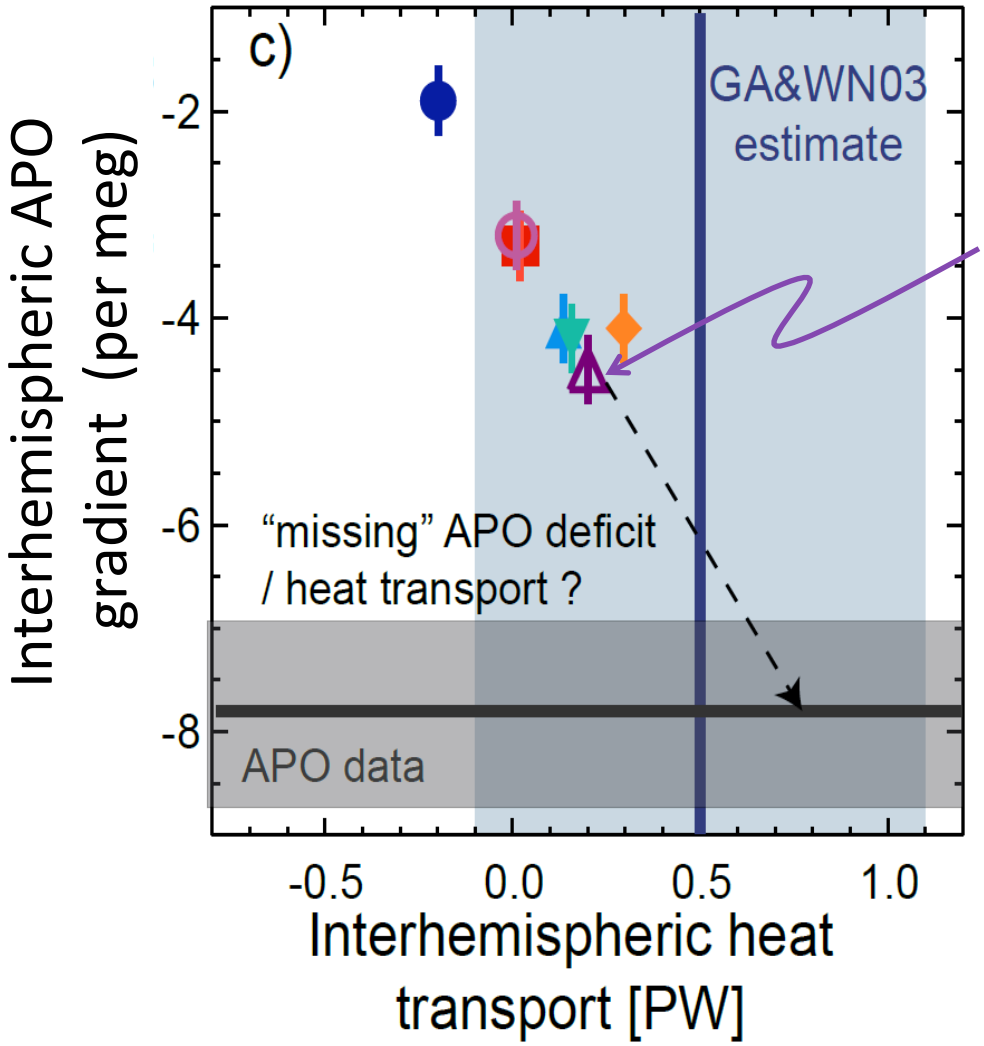
# Trend in Atmospheric Potential Oxygen



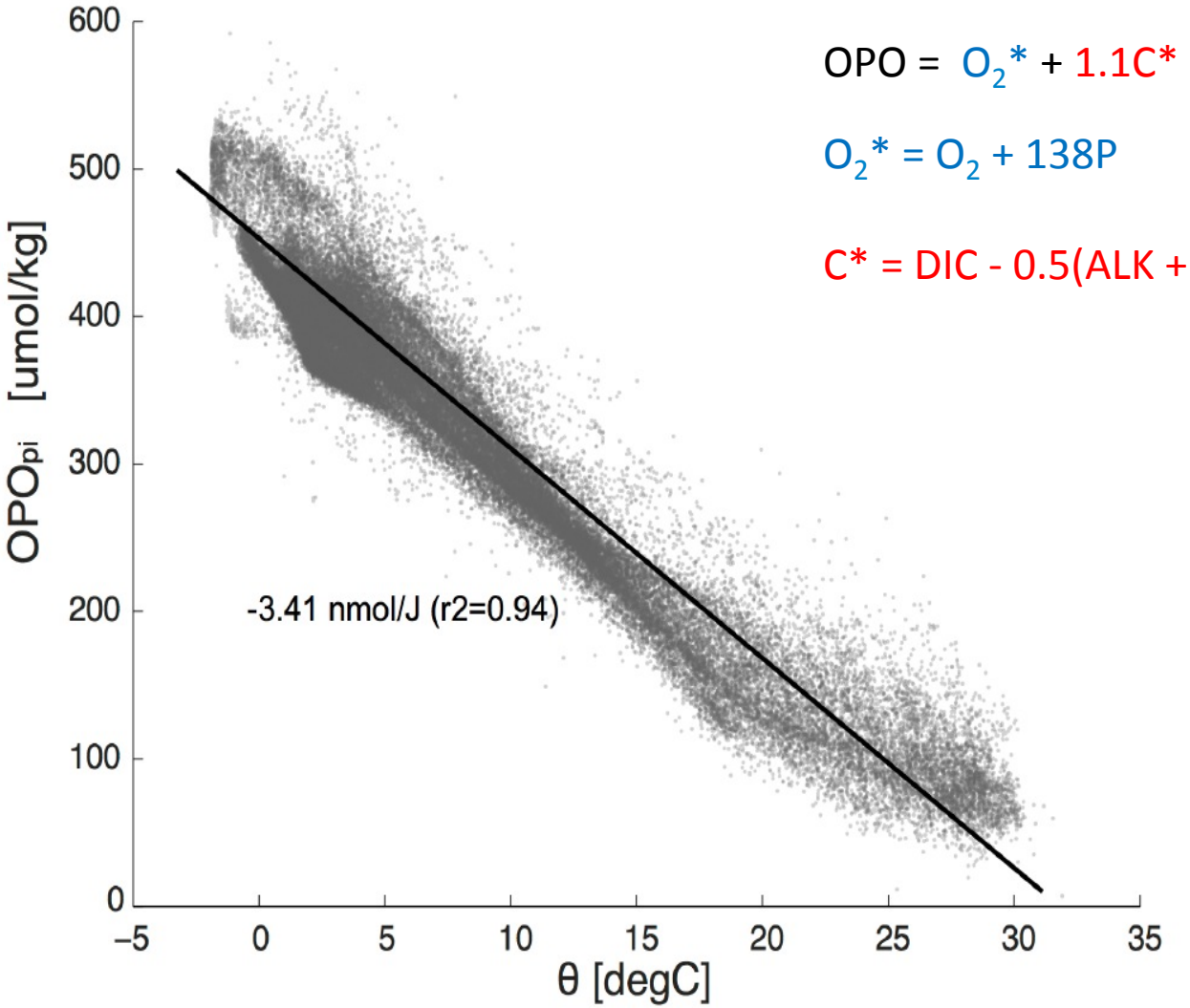
# APO cross section



# APO and ocean heat transport



# Why is APO so closely tied to heat?



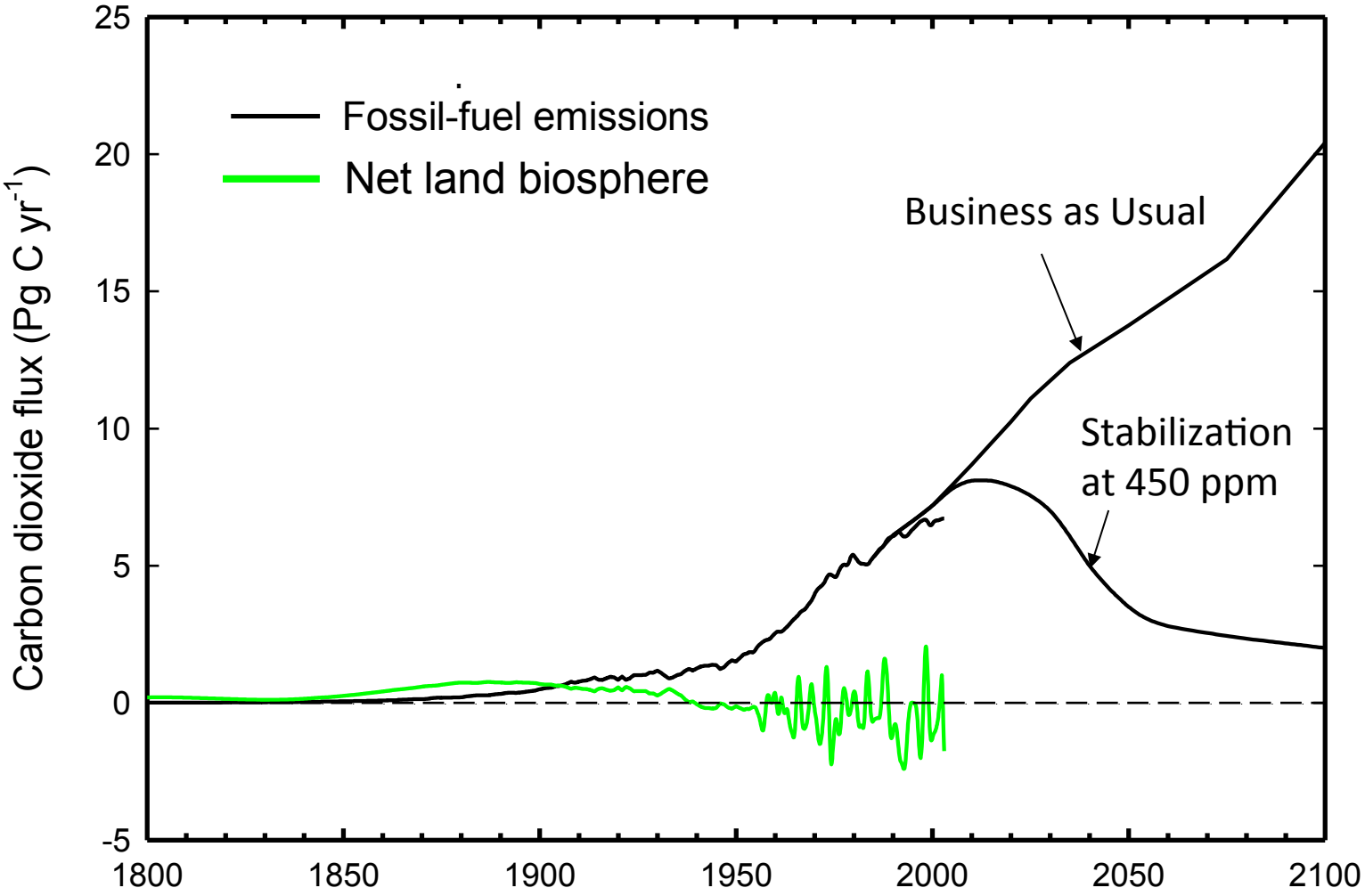

OPO = $O_2$* + 1.1C*

$O_2$* = $O_2$ + 138P

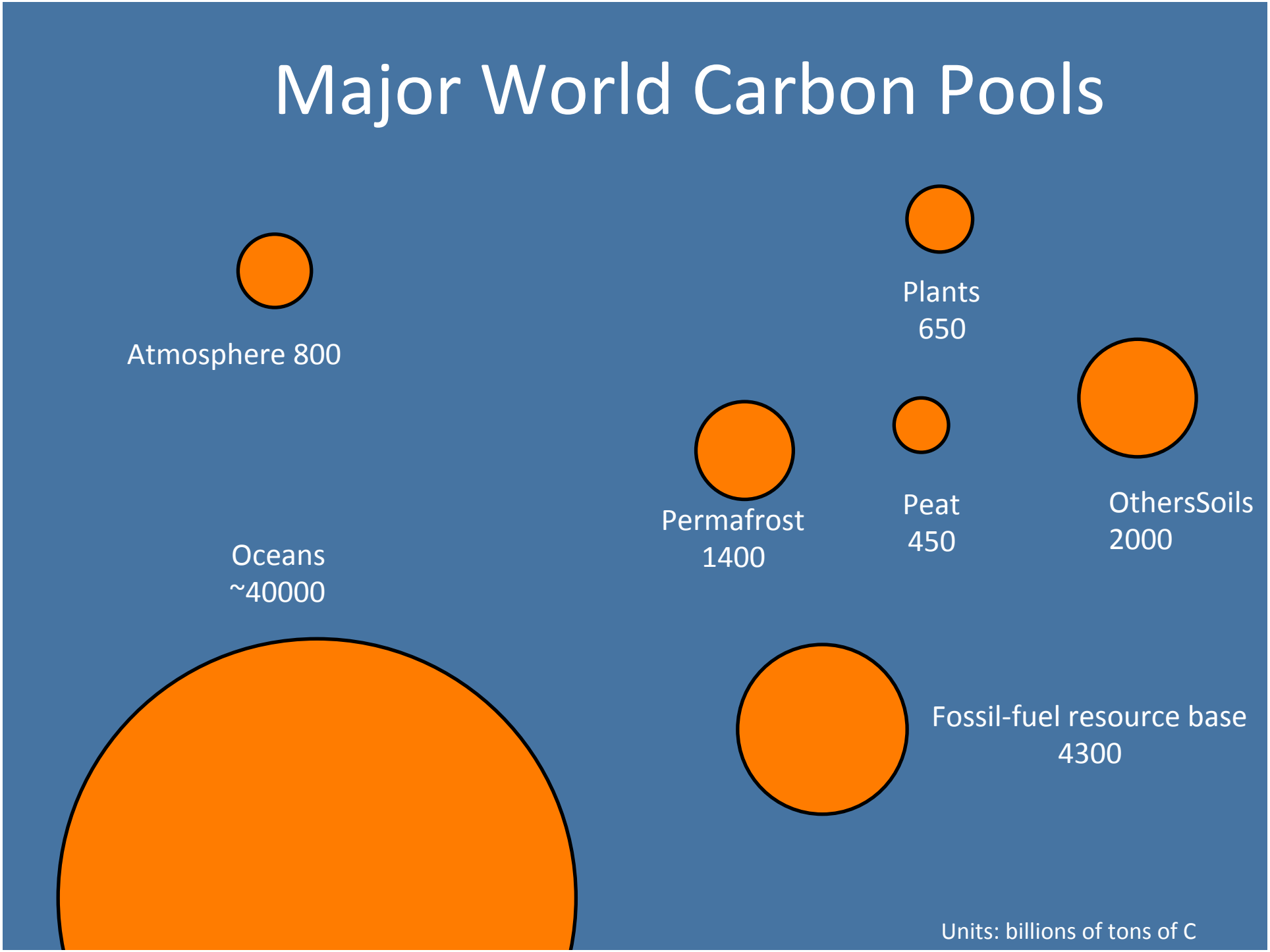
C* = DIC - 0.5(ALK + N) - 106P

Thank You

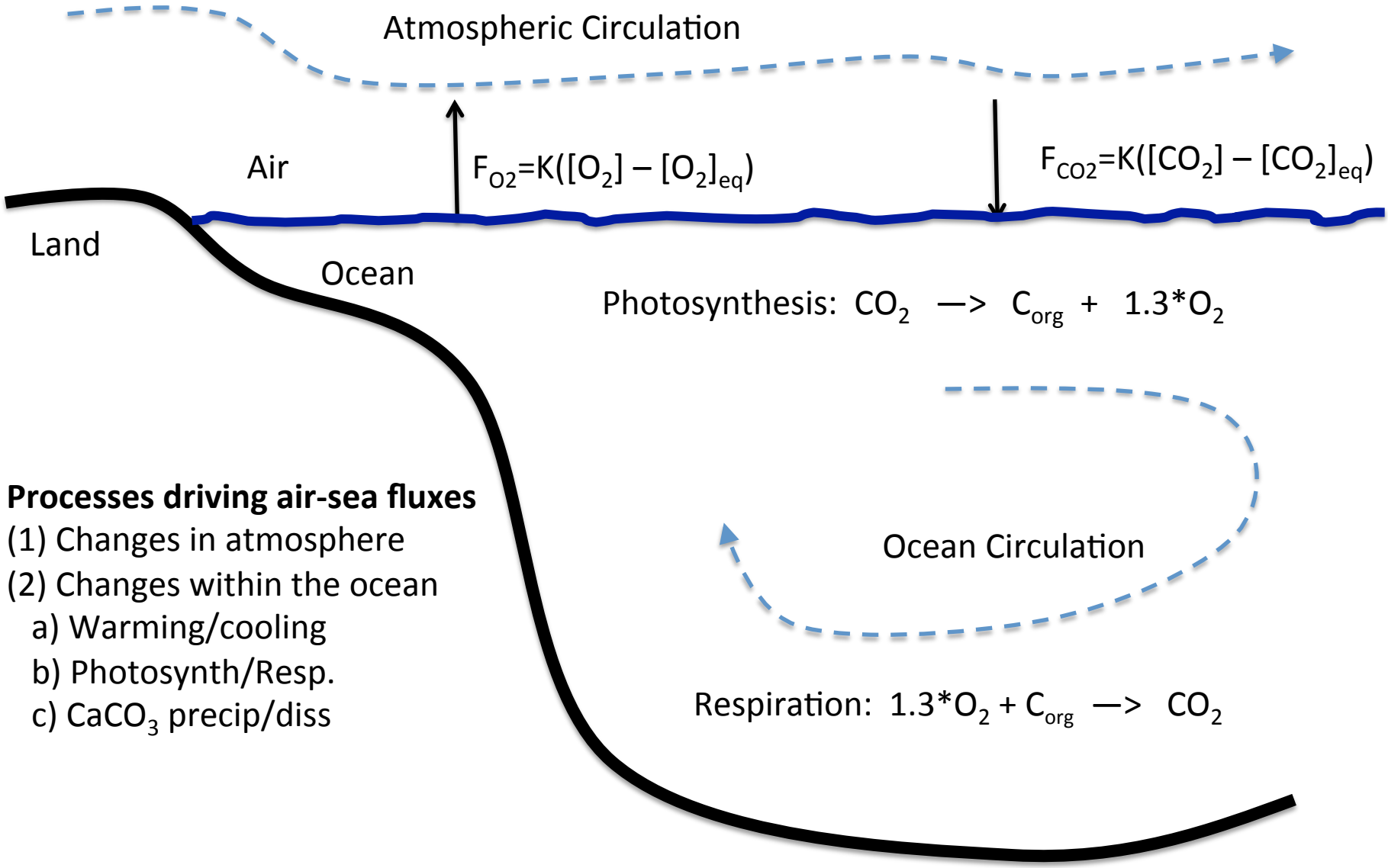
# Future $CO_2$ fluxes



# Major World Carbon Pools



# Linking air-sea $O_2$ and $CO_2$ fluxes 1. Mechanistic Framework




**Processes driving air-sea fluxes**

(1) Changes in atmosphere

(2) Changes within the ocean

a) Warming/cooling

b) Photosynth/Resp.

c) $CaCO_3$ precip/diss