Atmospheric signatures of changing global biogeochemistry

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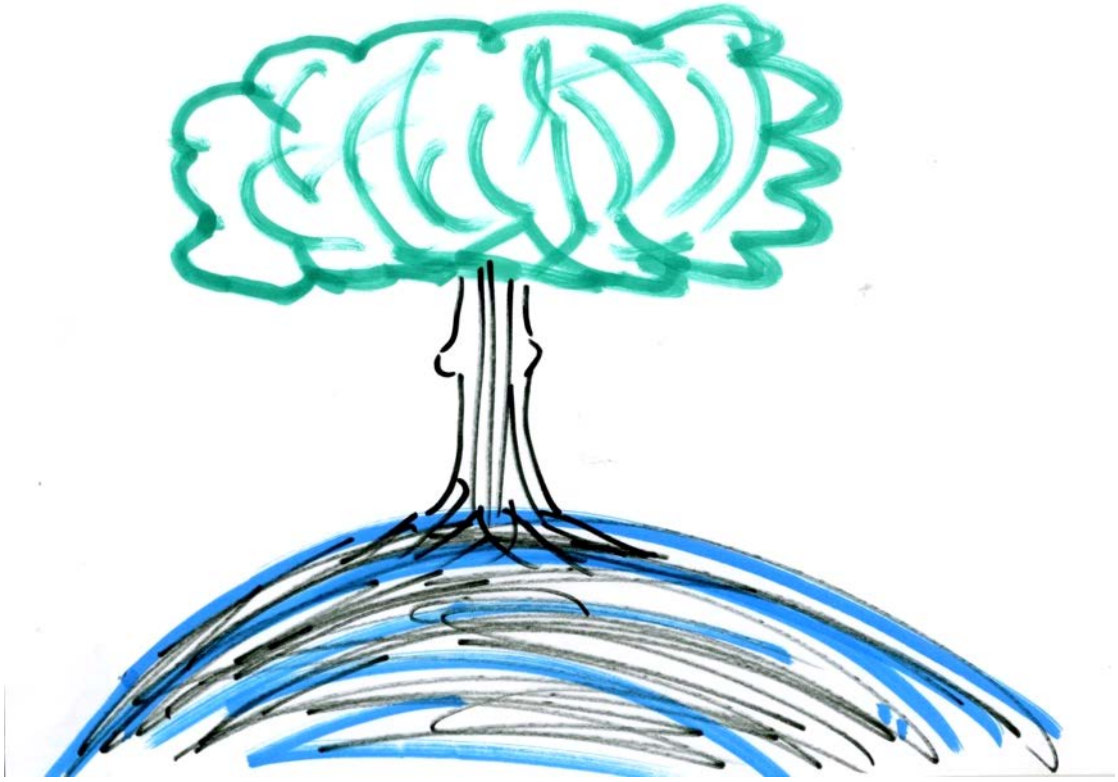
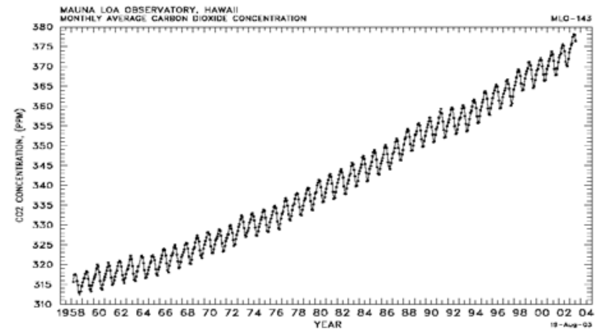
Or "How I learned to stop worrying and love the biosphere"

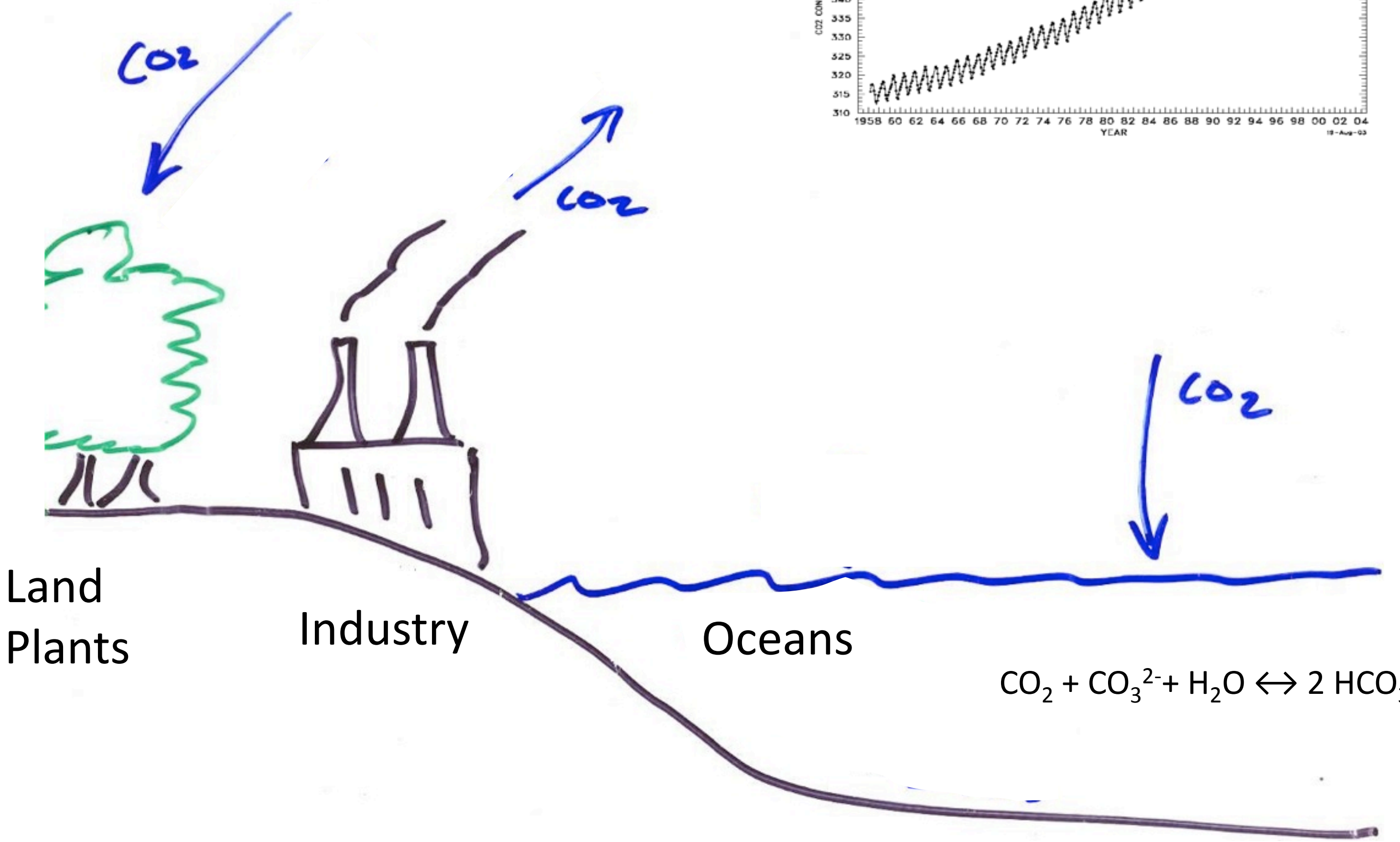


In collaboration with

Lisa Welp, Heather Graven, Steve Piper, Andrew Manning

Controls on atmospheric CO_2 increase

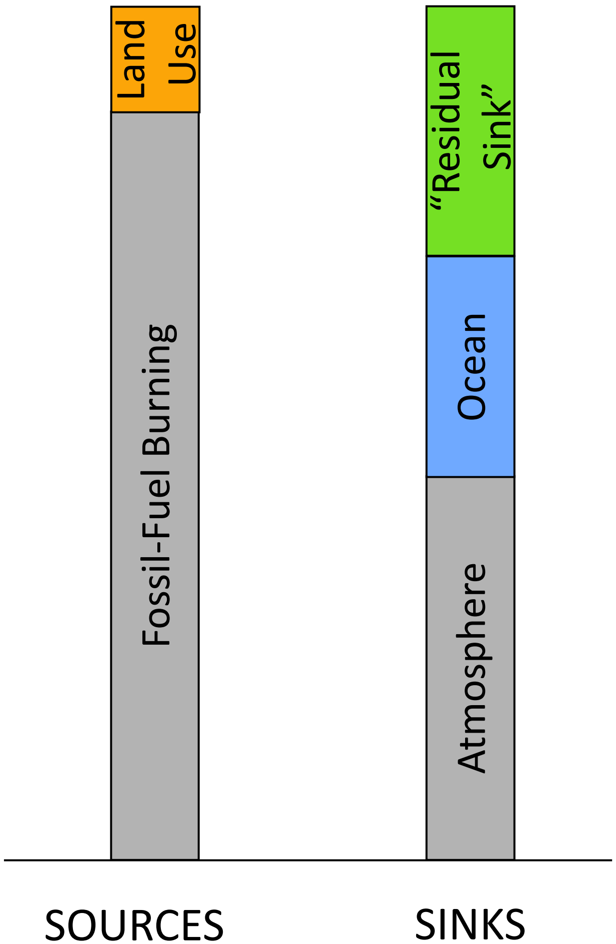




$CO_2 + CO_3^{2-} + H_2O \leftrightarrow 2\ HCO_3^-$

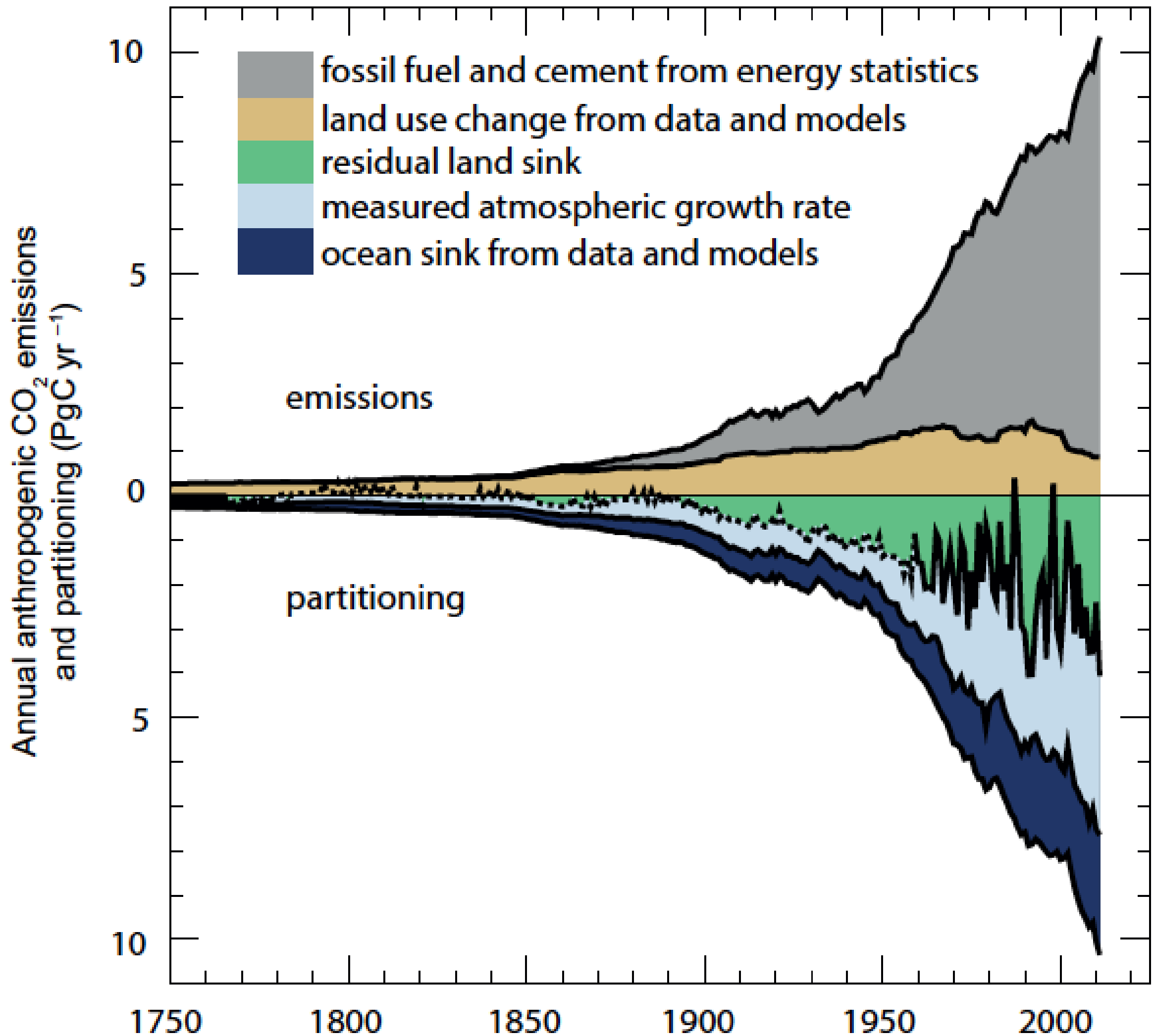
CO_2 budget 2000-2010 (Pg C/yr)

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



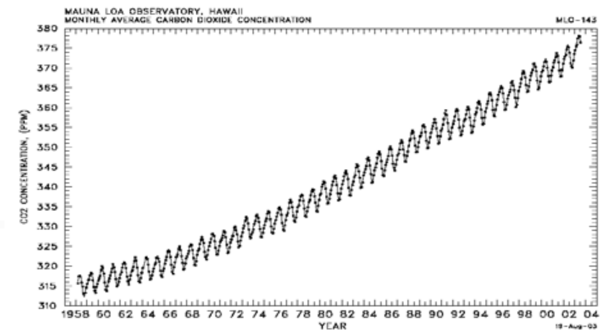
IPCC AR5

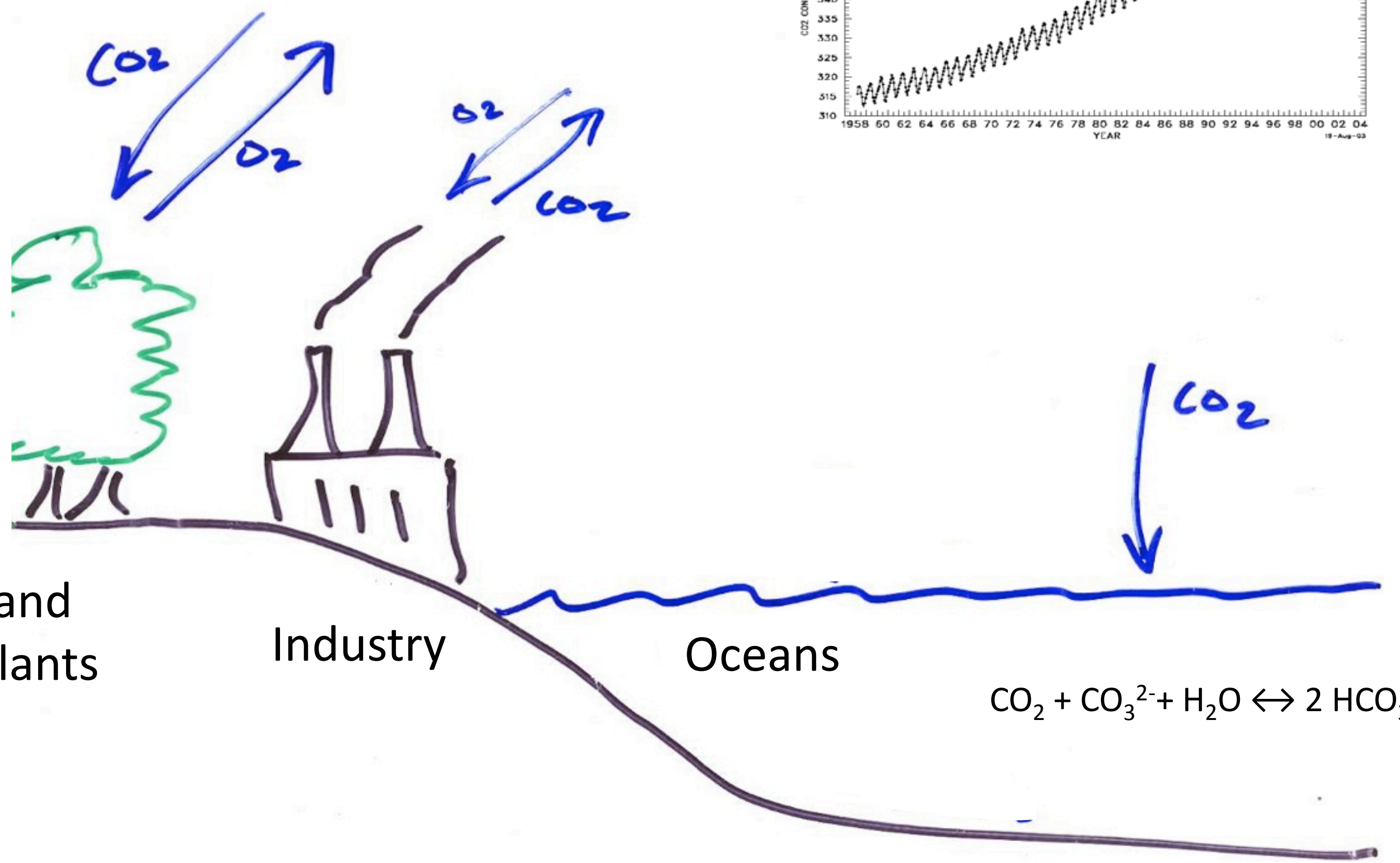
Historic Carbon Sources and Sinks



IPCC Ar5, Figure 6.8

Controls on atmospheric CO_2 and O_2





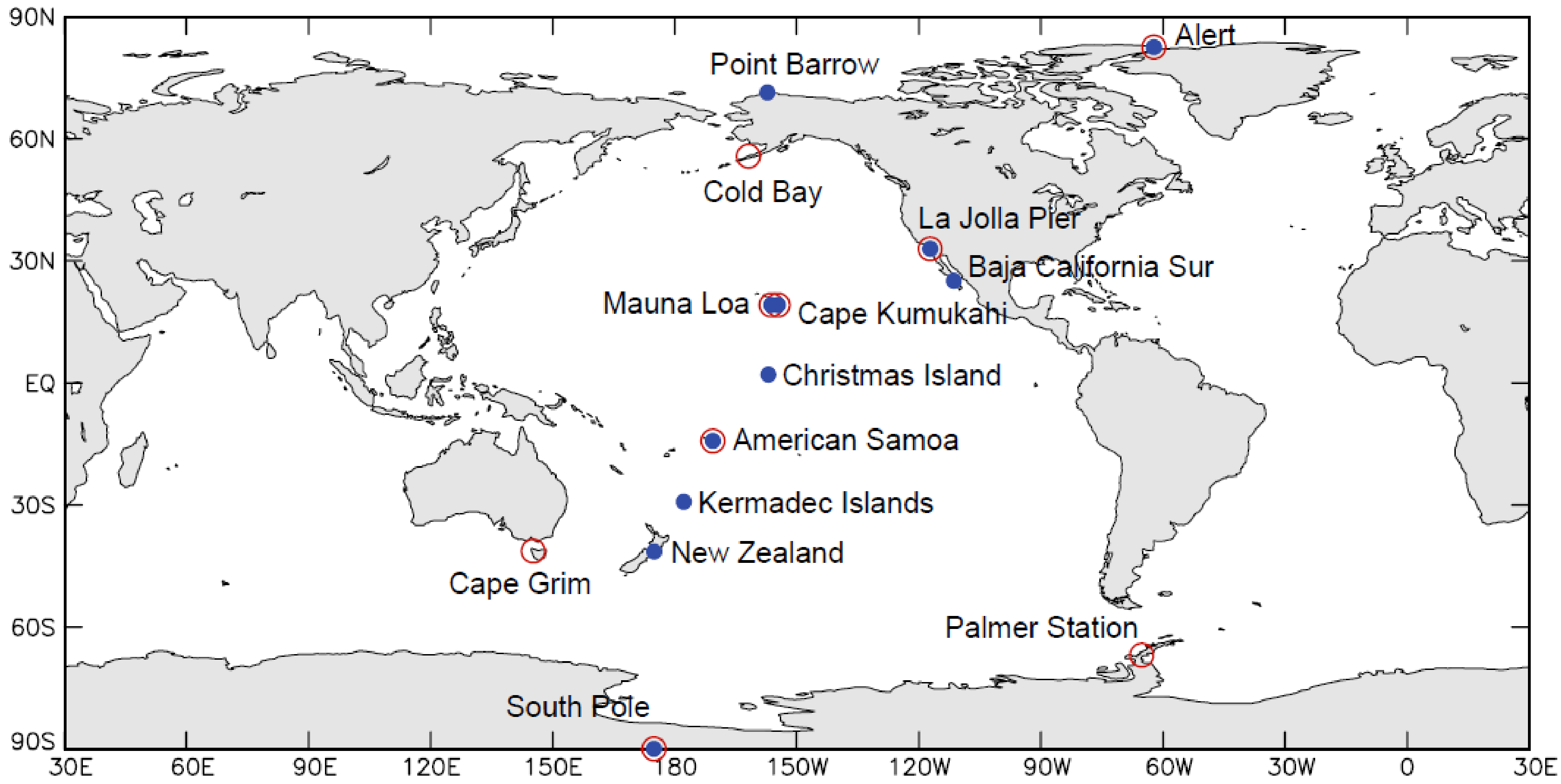
Land Plants

Industry

Oceans

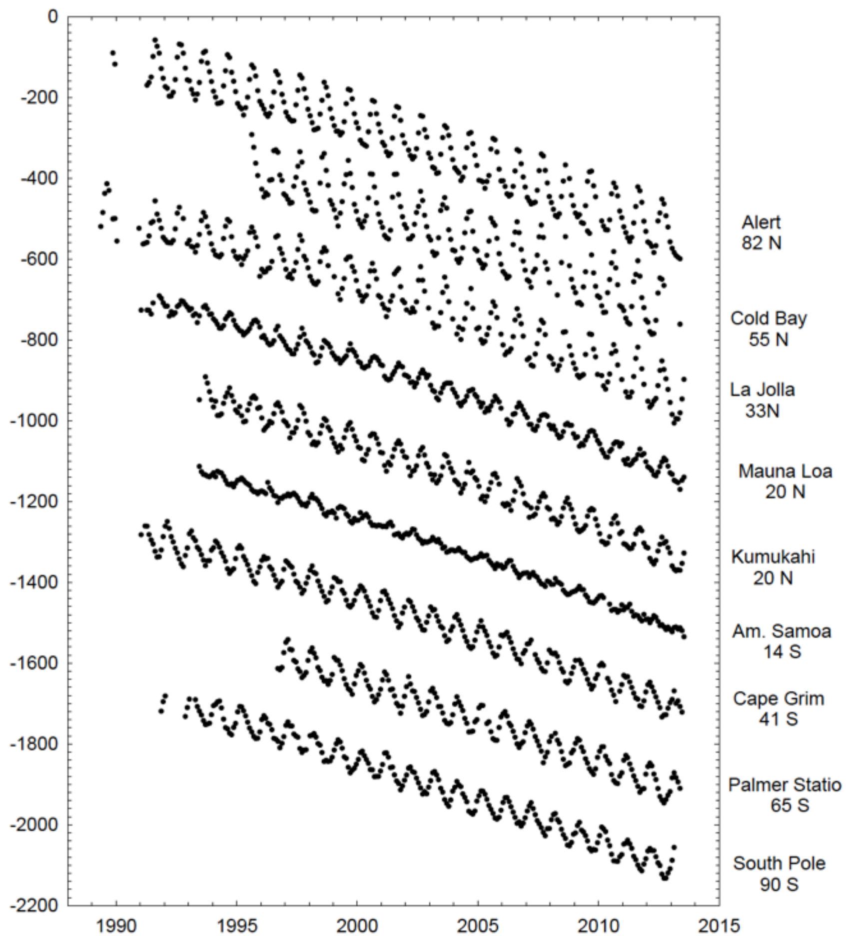
$CO_2 + CO_3^{2-} + H_2O \leftrightarrow 2\ HCO_3^-$

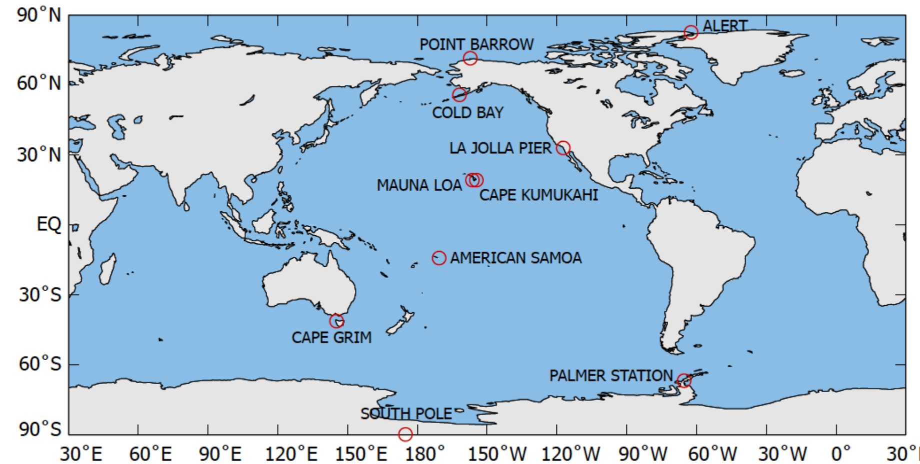
Scripps CO_2 and O_2 Sampling Networks



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

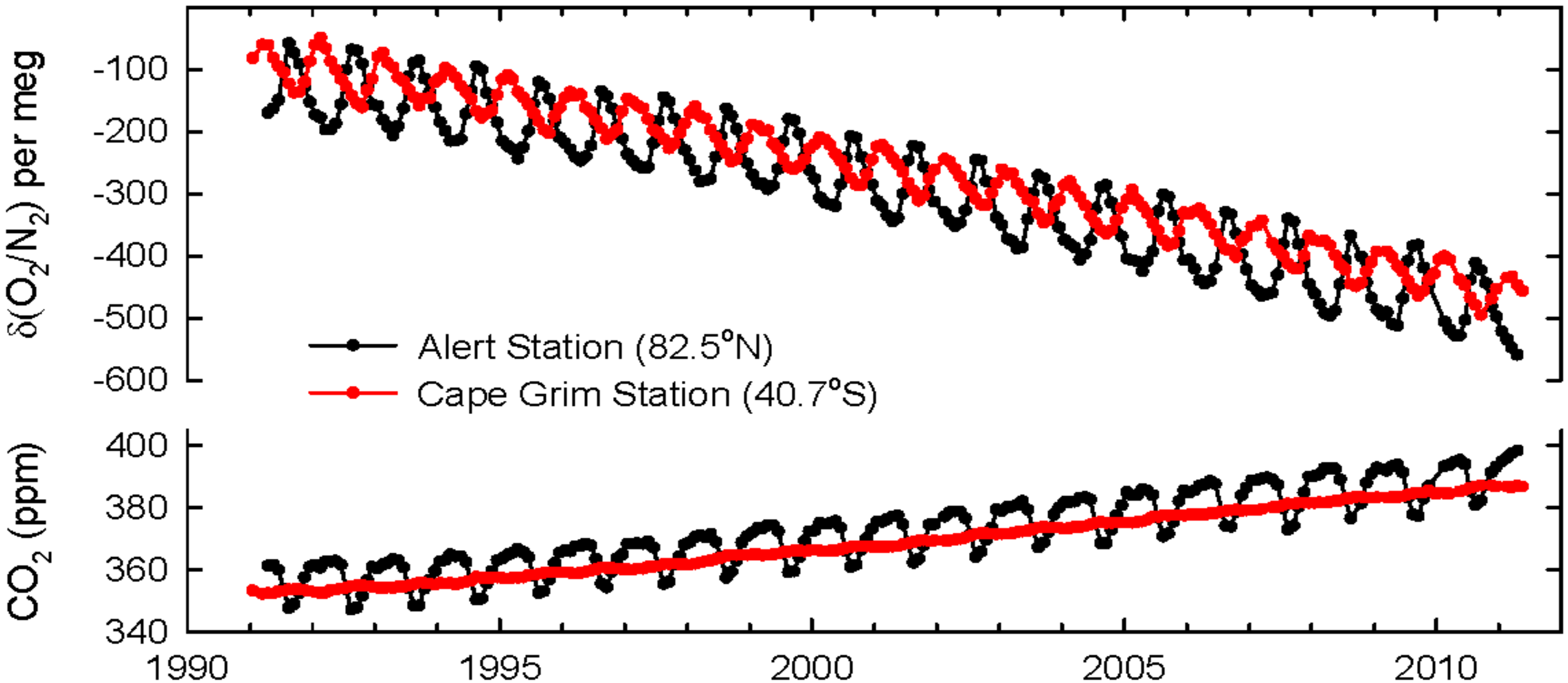
Measure CO_2, O_2/N_2 ratio and Ar/N_2 ratio

Methods development

Calibration facility

Project Website: ScrippsO2.ucsd.edu

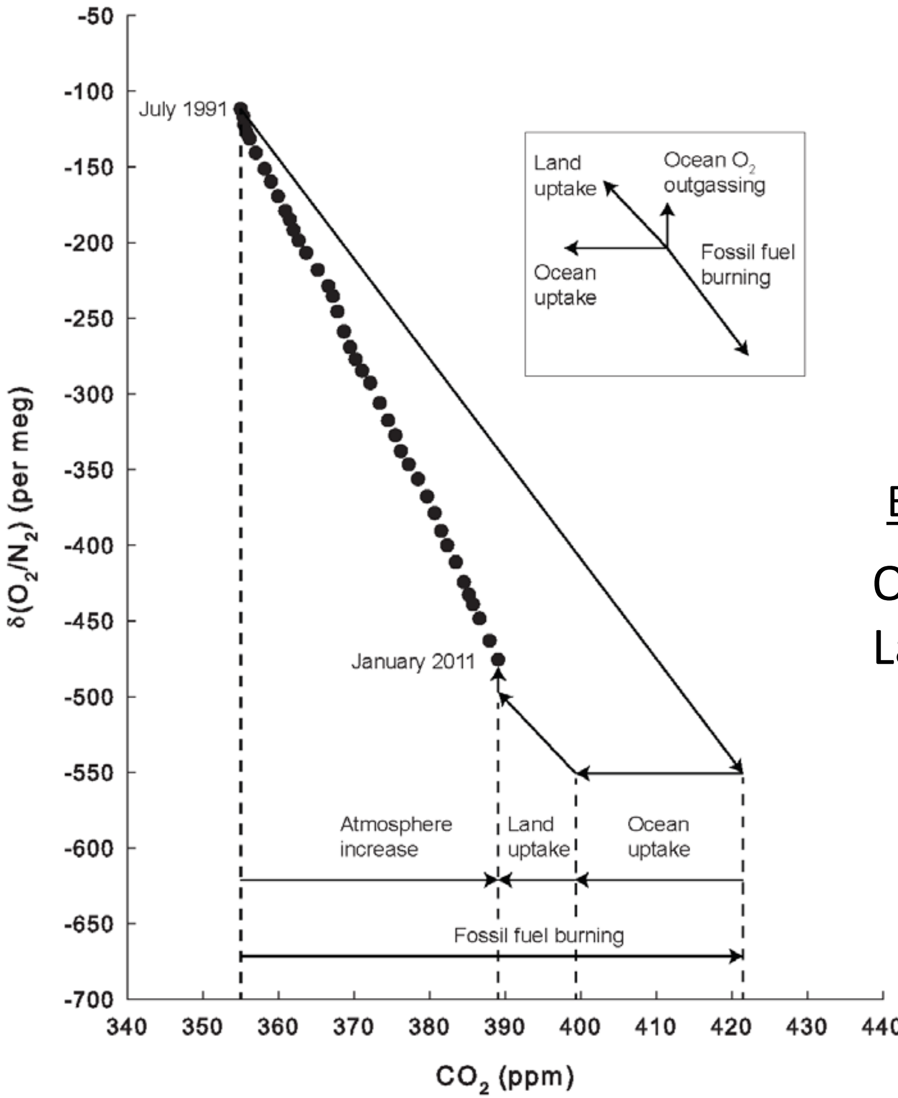
O_2/N_2 and CO_2 trends



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

4.8 per meg ~ 1 ppm

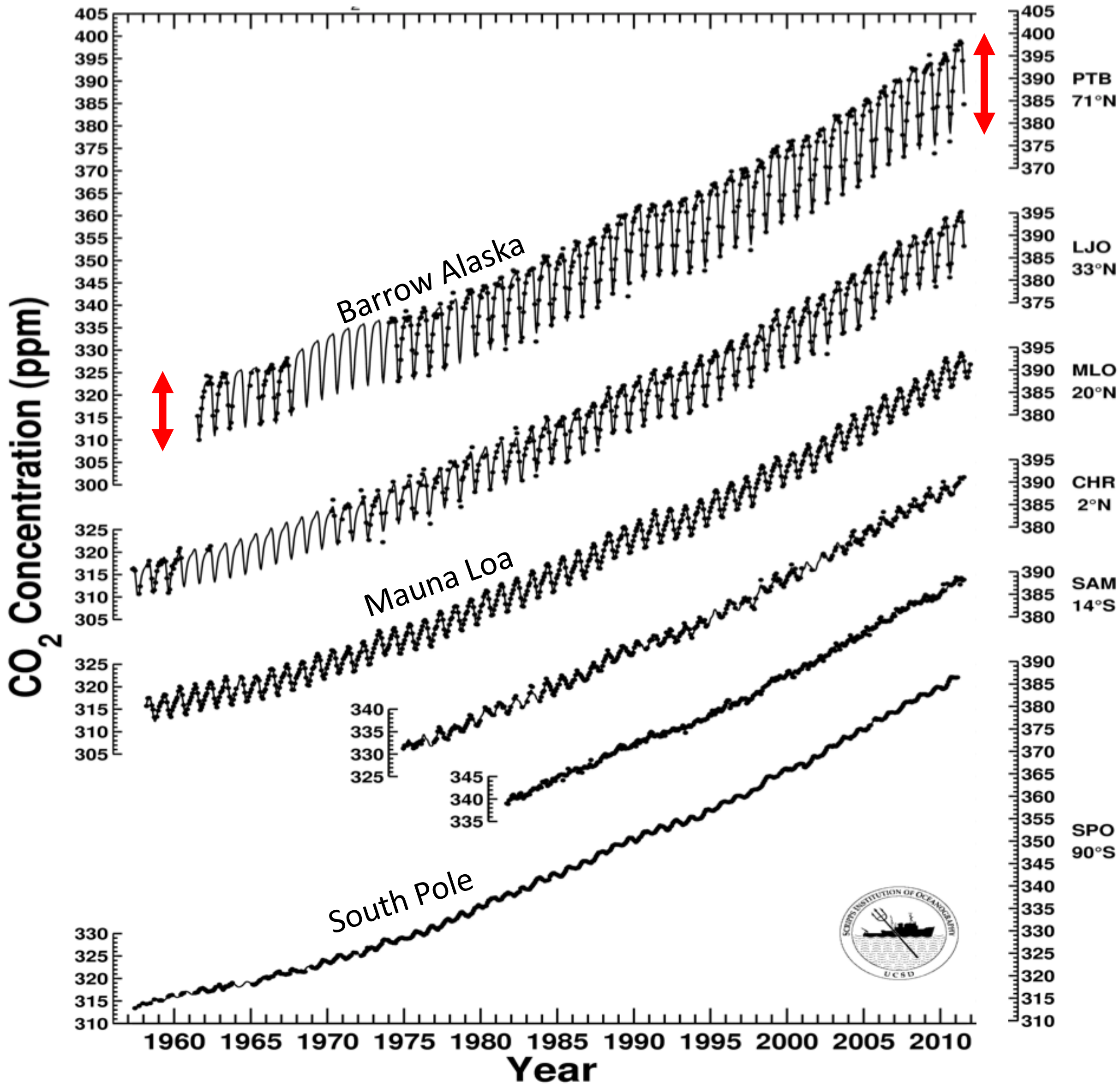
Vector diagram of O_2 and CO_2 changes



<u>Budget for 1991 to 2001</u>

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

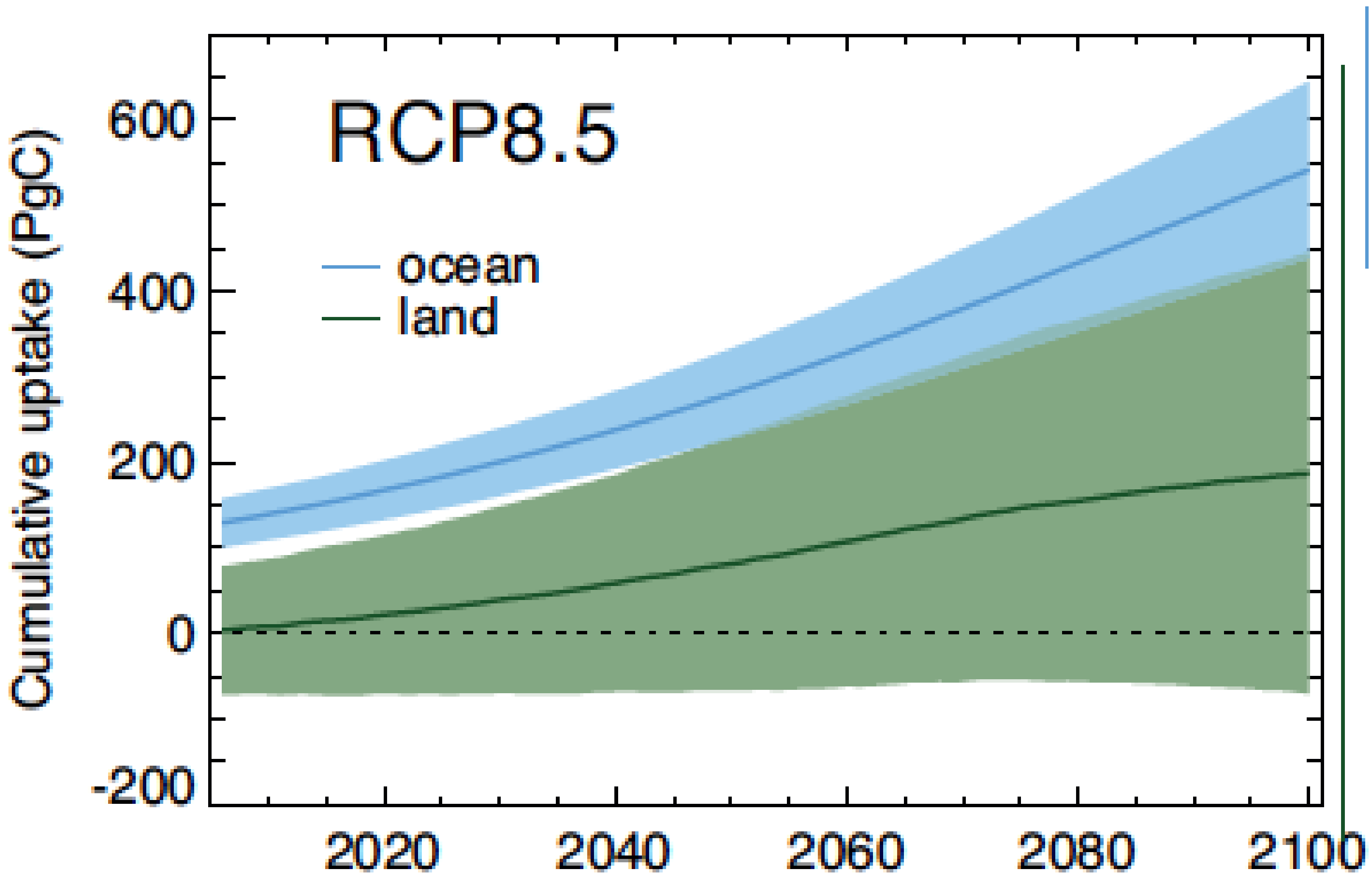
High Arctic in the Eocene

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



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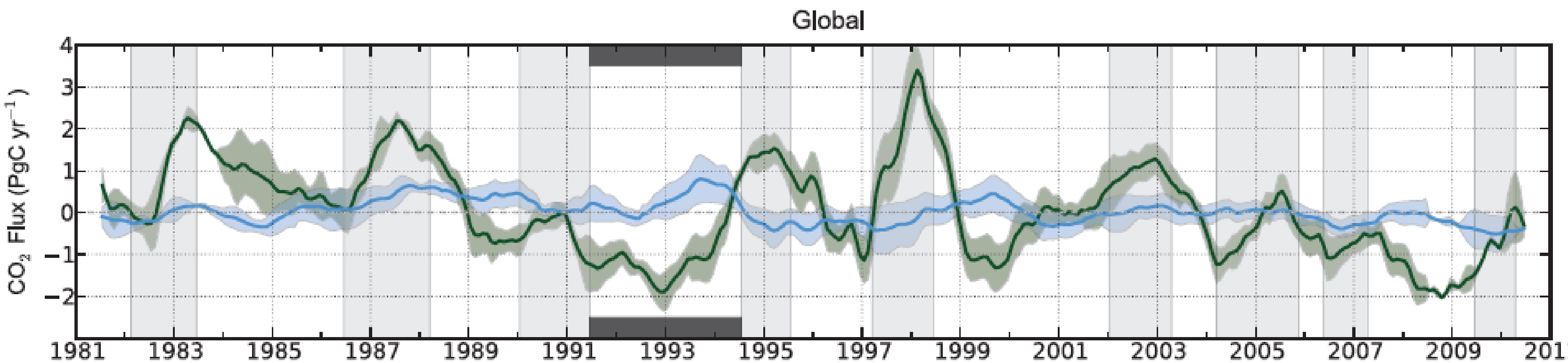
“Observations” support much smaller ocean than land variability in recent past



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

*Wanninkihof 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"

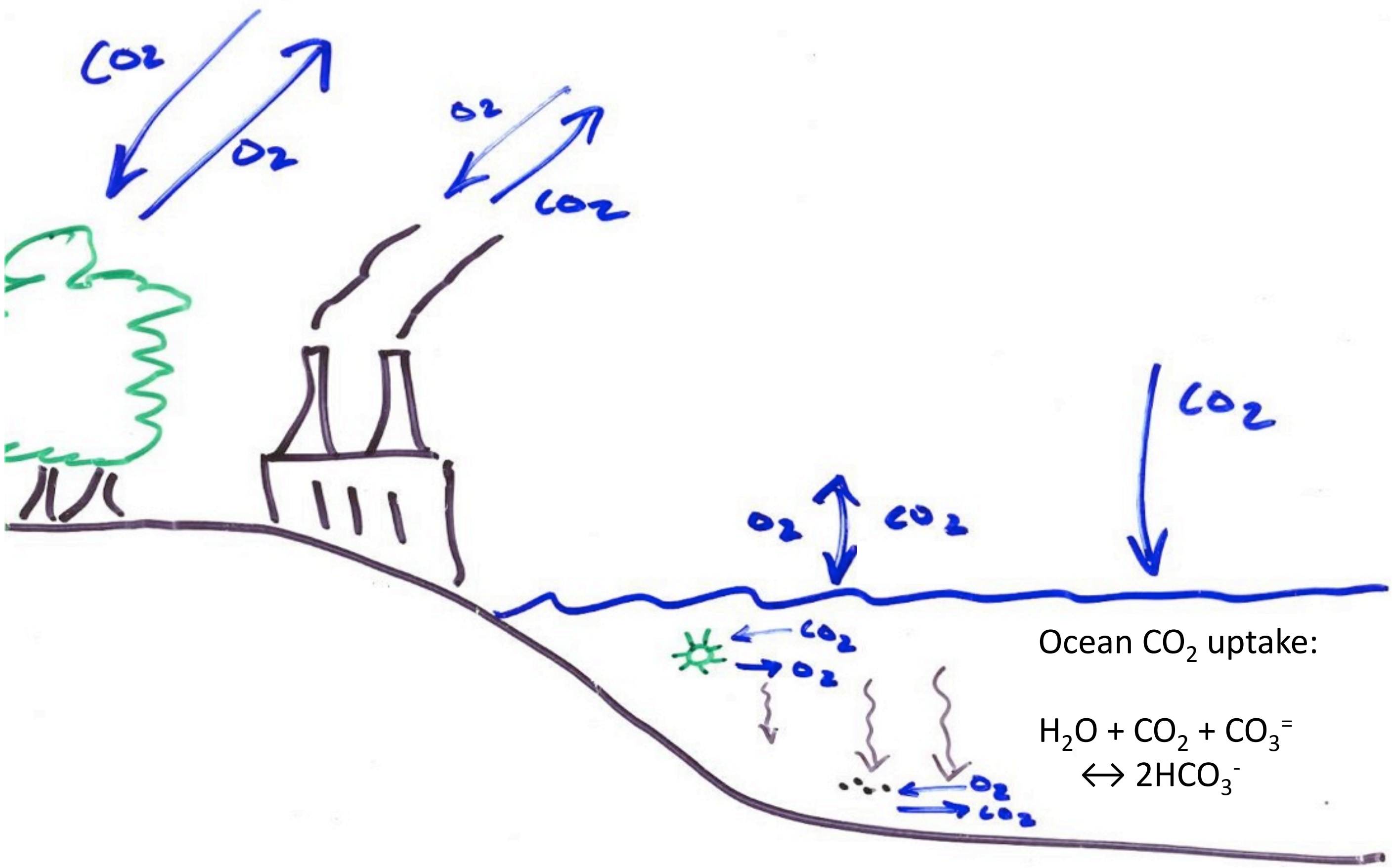
(4) Largest perturbation to CO_2 growth rate in 1940s might have been (mostly) oceanic.

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

Repeat hydrography and surface ocean pCO2 measurements won't fully address need on decadal time scale.

Measurements of atmospheric O2 may help fill this gap.

Atmospheric CO_2 & O_2 coupling

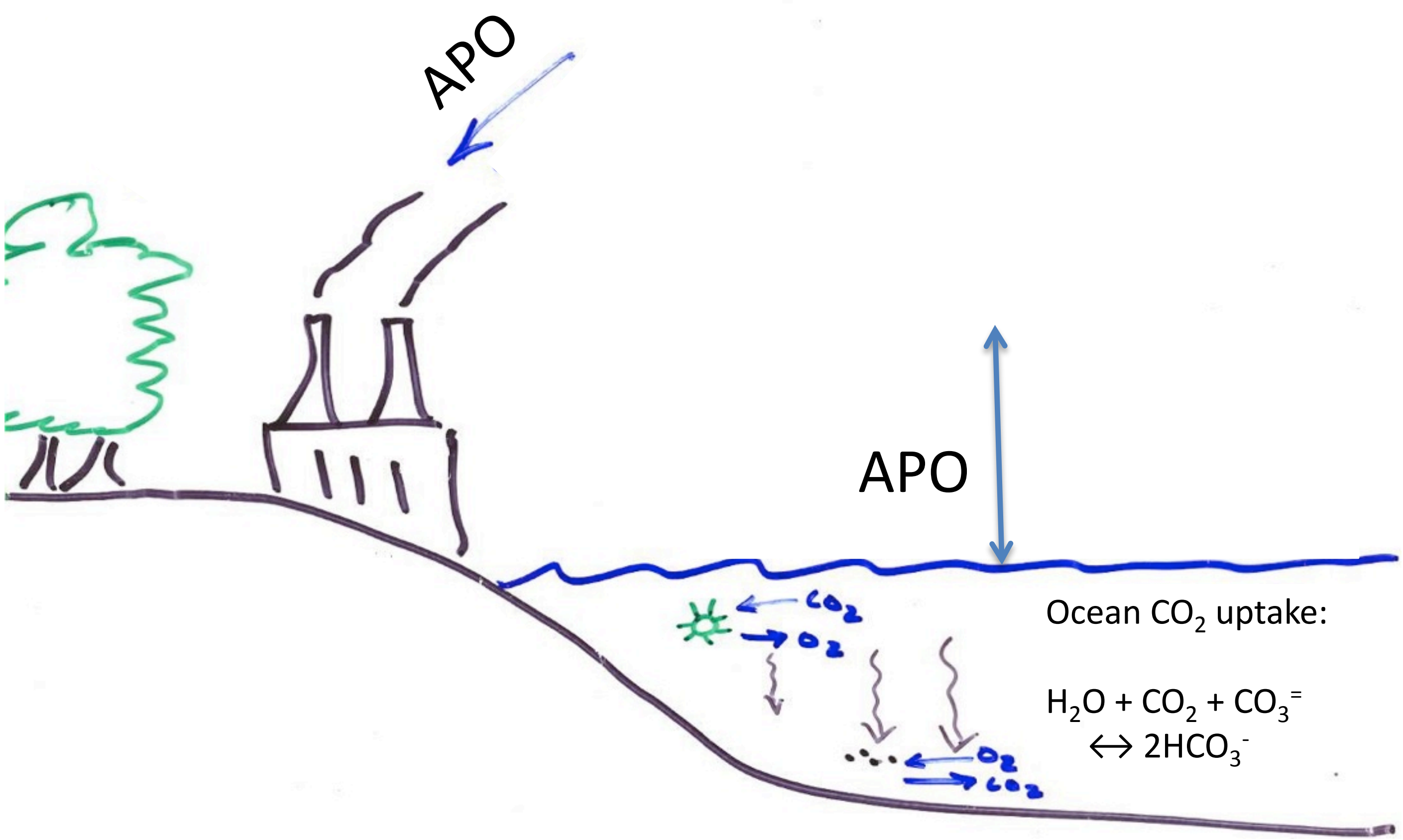


Ocean CO_2 uptake:

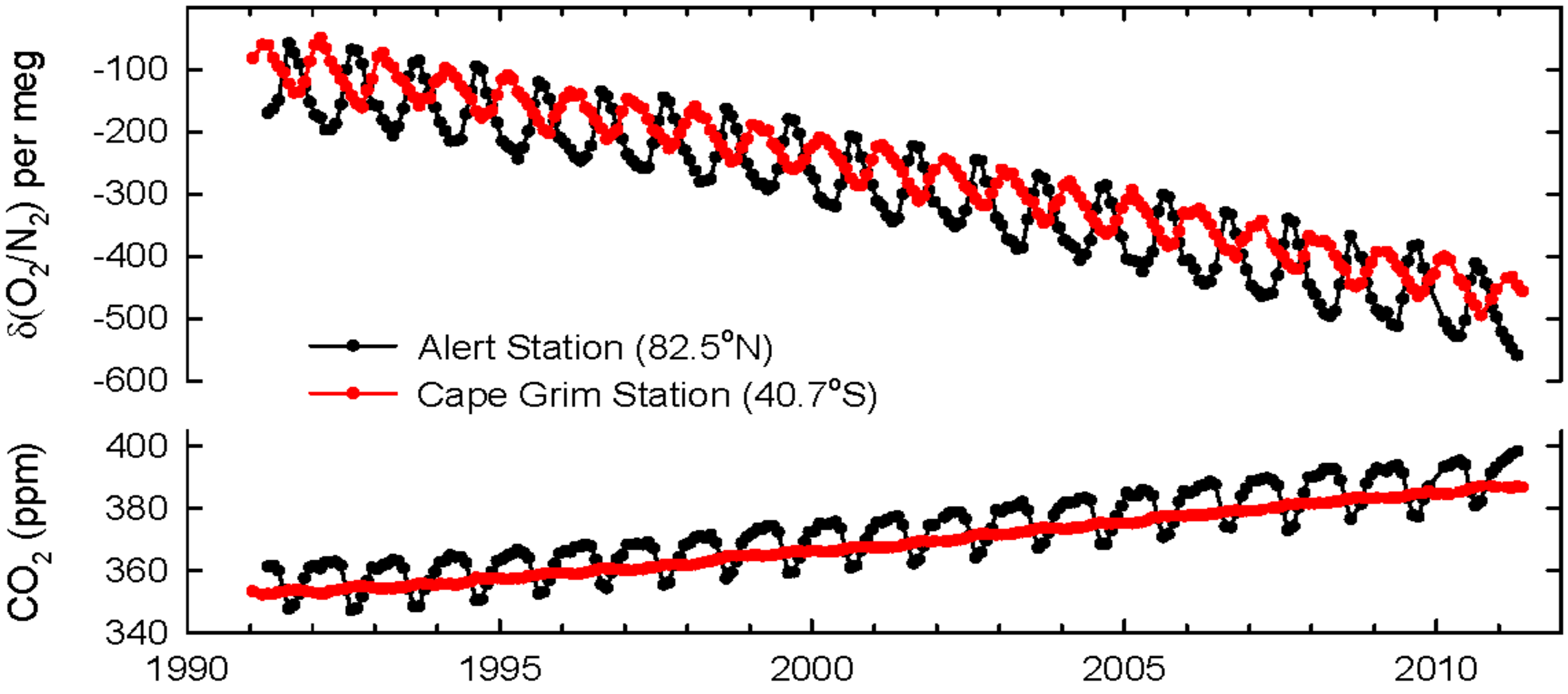
$$H_2O + CO_2 + CO_3^{=} \leftrightarrow 2HCO_3^{-}$$

Atmospheric potential oxygen

$$APO \sim O_2 + CO_2$$



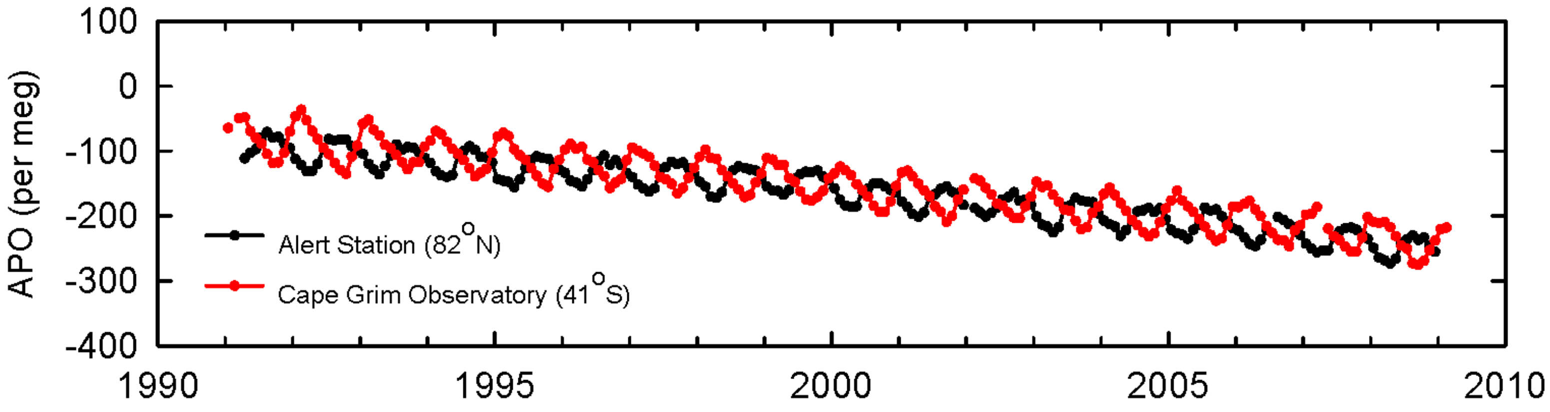
What about changes in functioning of ocean biota?



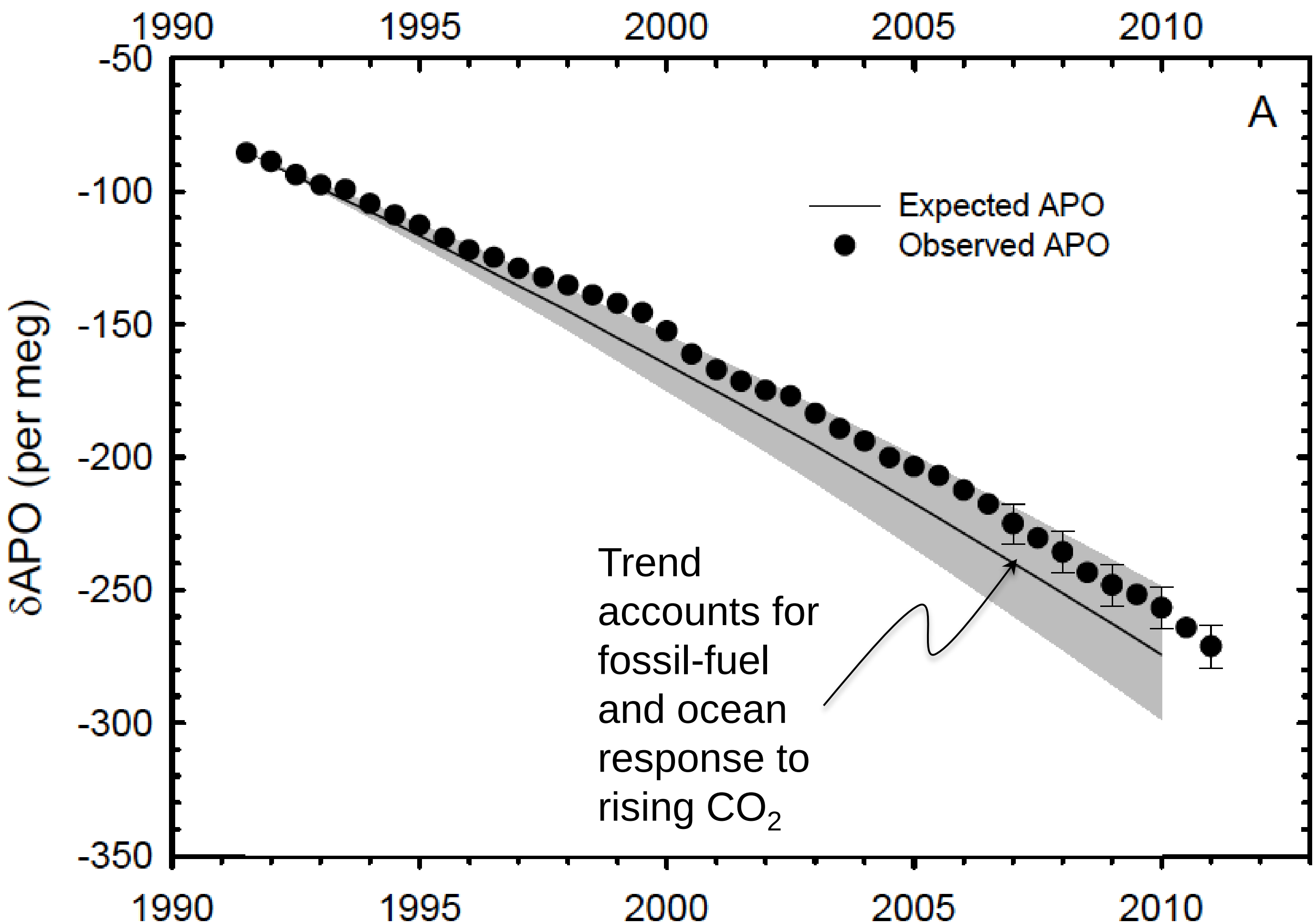
$$\delta(O_2/N_2) = \frac{(O_2/N_2)_{sample} - (O_2/N_2)_{reference}}{(O_2/N_2)_{reference}}$$

4.8 per meg ~ 1 ppm

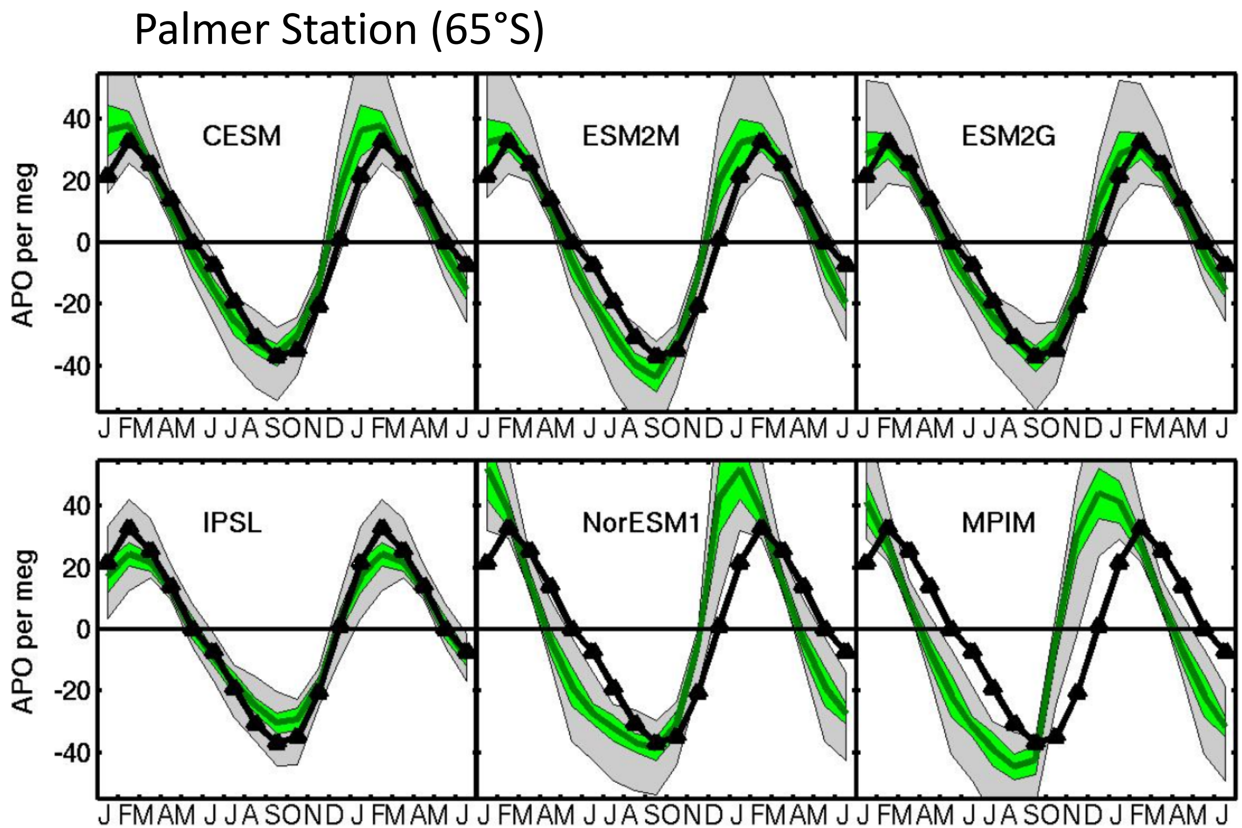
APO: a tracer of oceanic exchanges



Long-term trend in APO

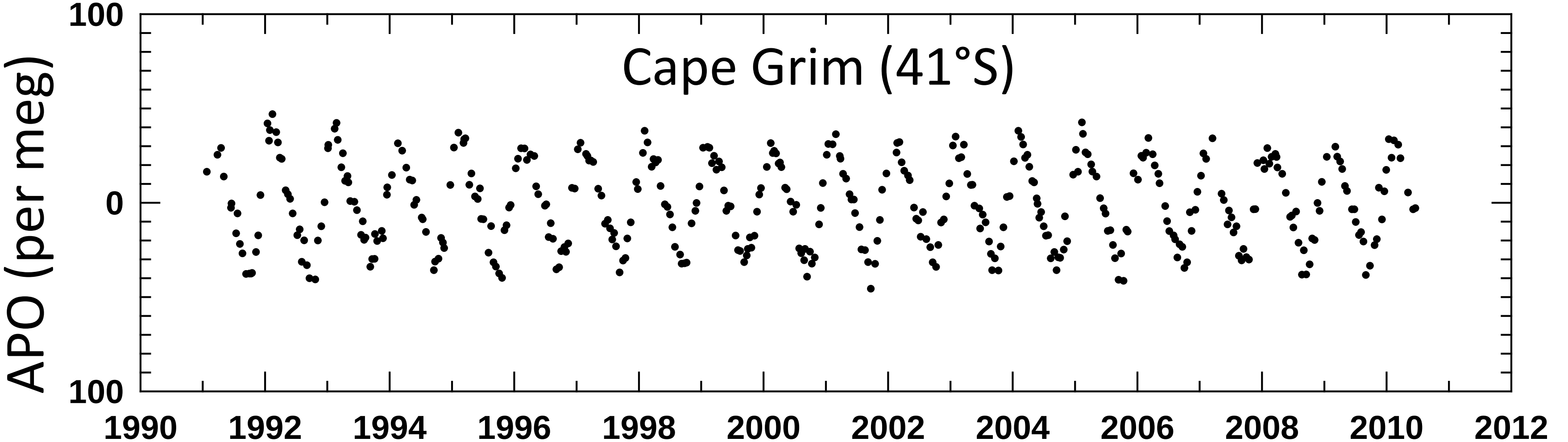


Seasonal APO cycles as model test



Nevsion et al., in prep, 2013

Seasonal cycles as metric of long-term changes



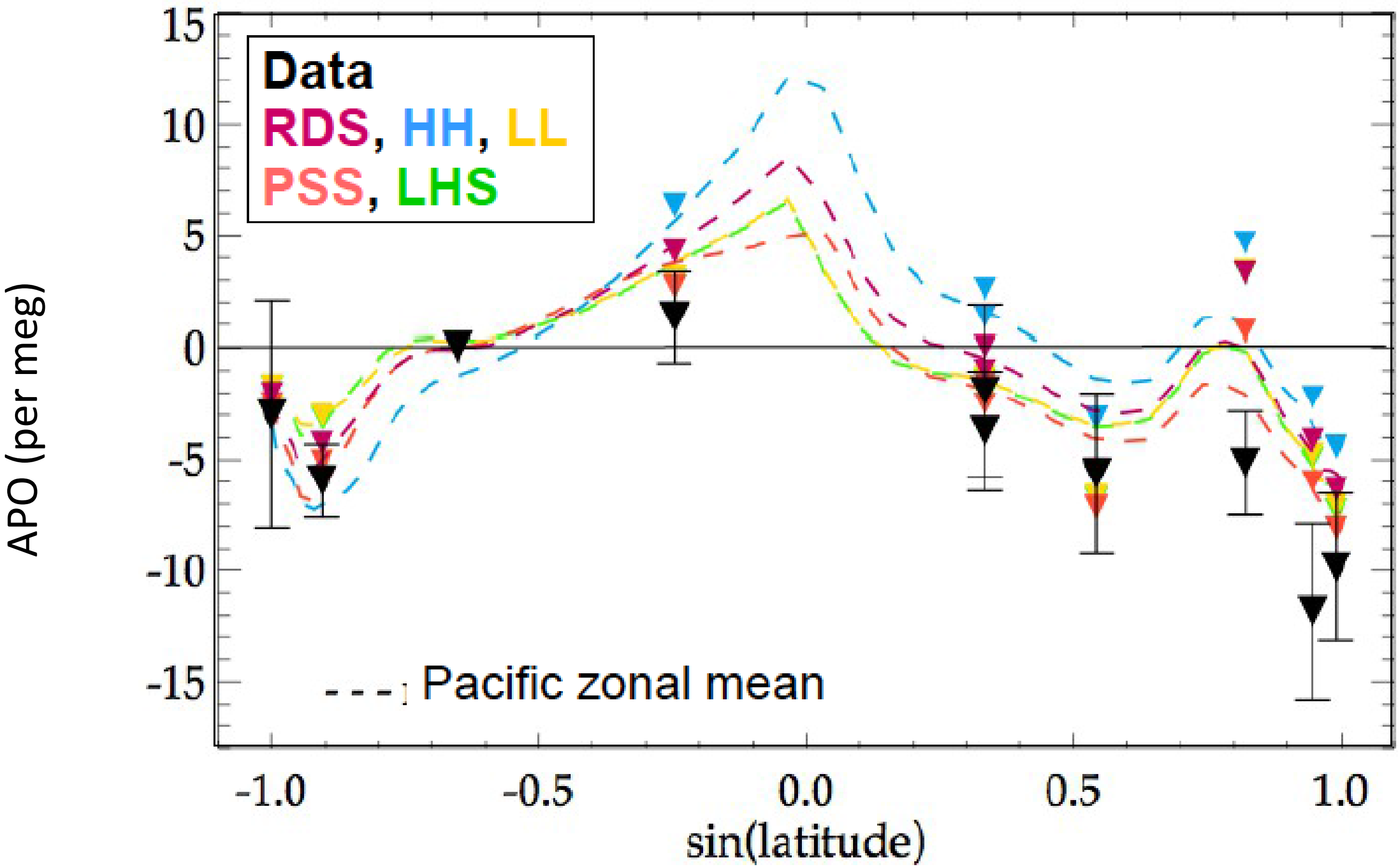
Programmatic Needs:

(1) Sustain O_2 observations as part of carbon observing system

(2) Incorporate O_2 constraints into CarbonTracker and other assimilation systems.

Ongoing Collaboration to take first steps by using APO to improve Carbon Tracker “priors”
Laure Resplendy, Ralph Keeling SIO
Andy Jacobsen, NOAA-GMD
Samar Khatiwala, Oxford
Christian Roedenbeck, Martin Heimann (MPI, Jena)

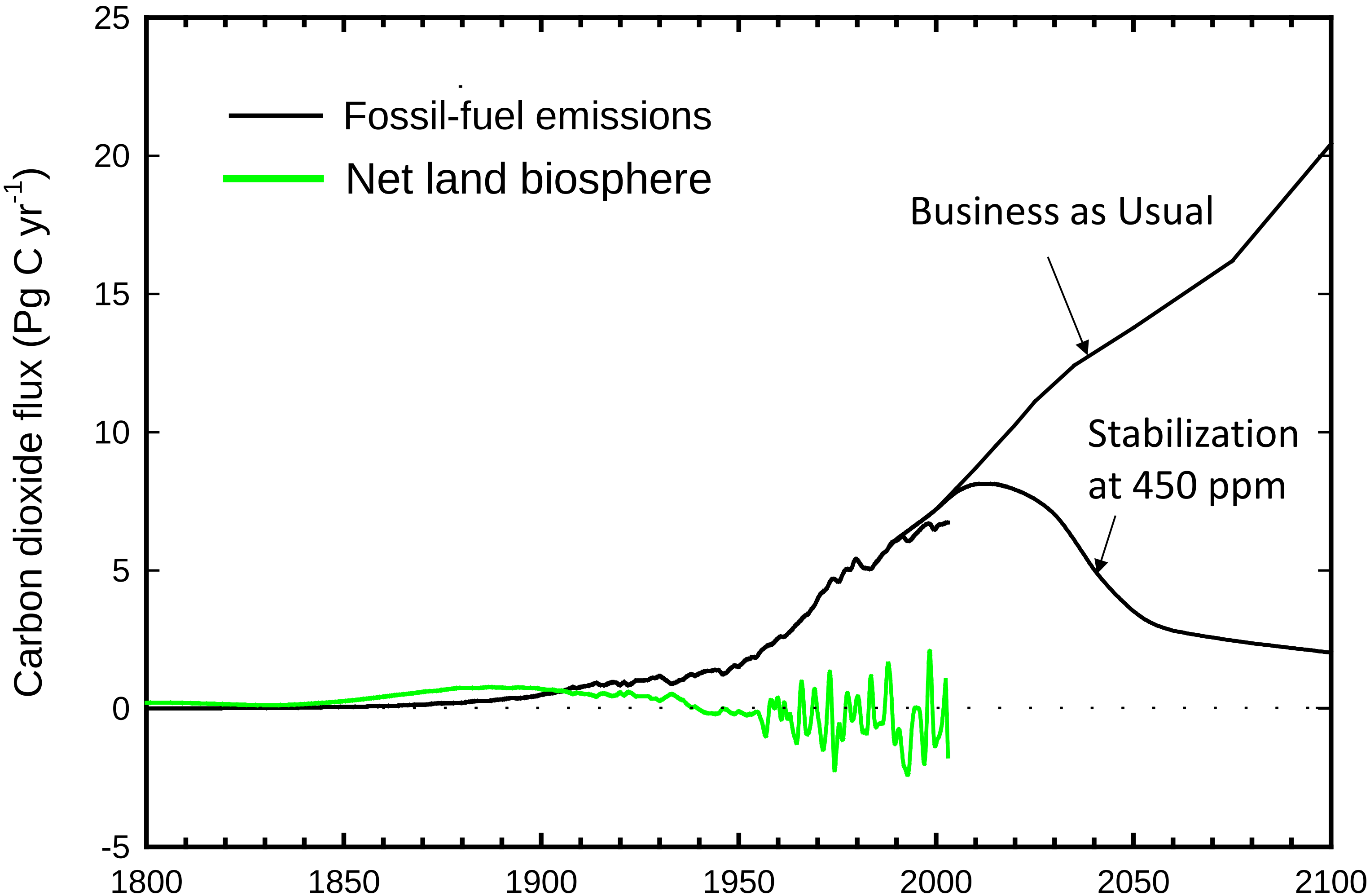
APO gradient with latitude*



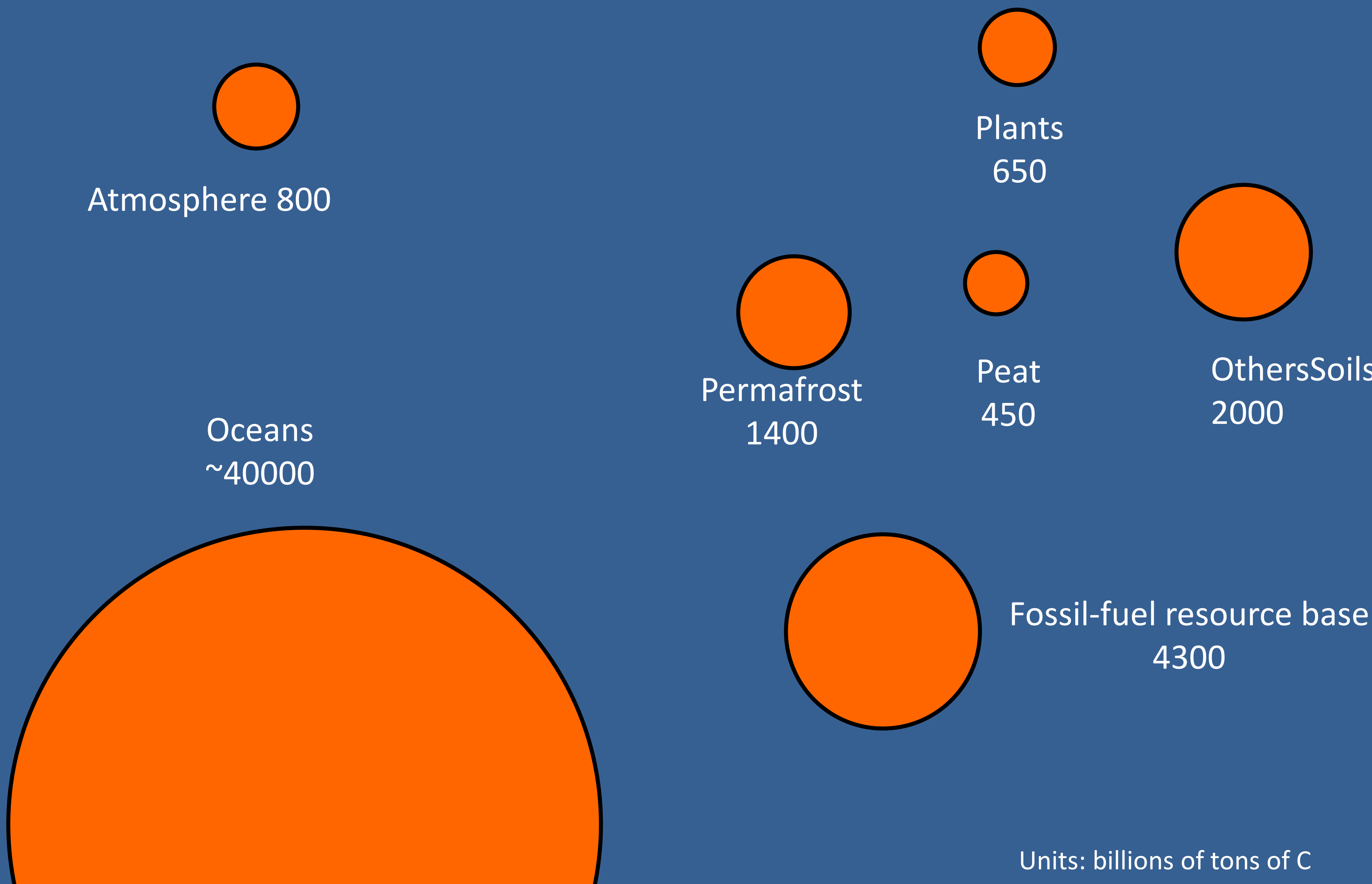
See poster by Laure Resplandy

Thank You

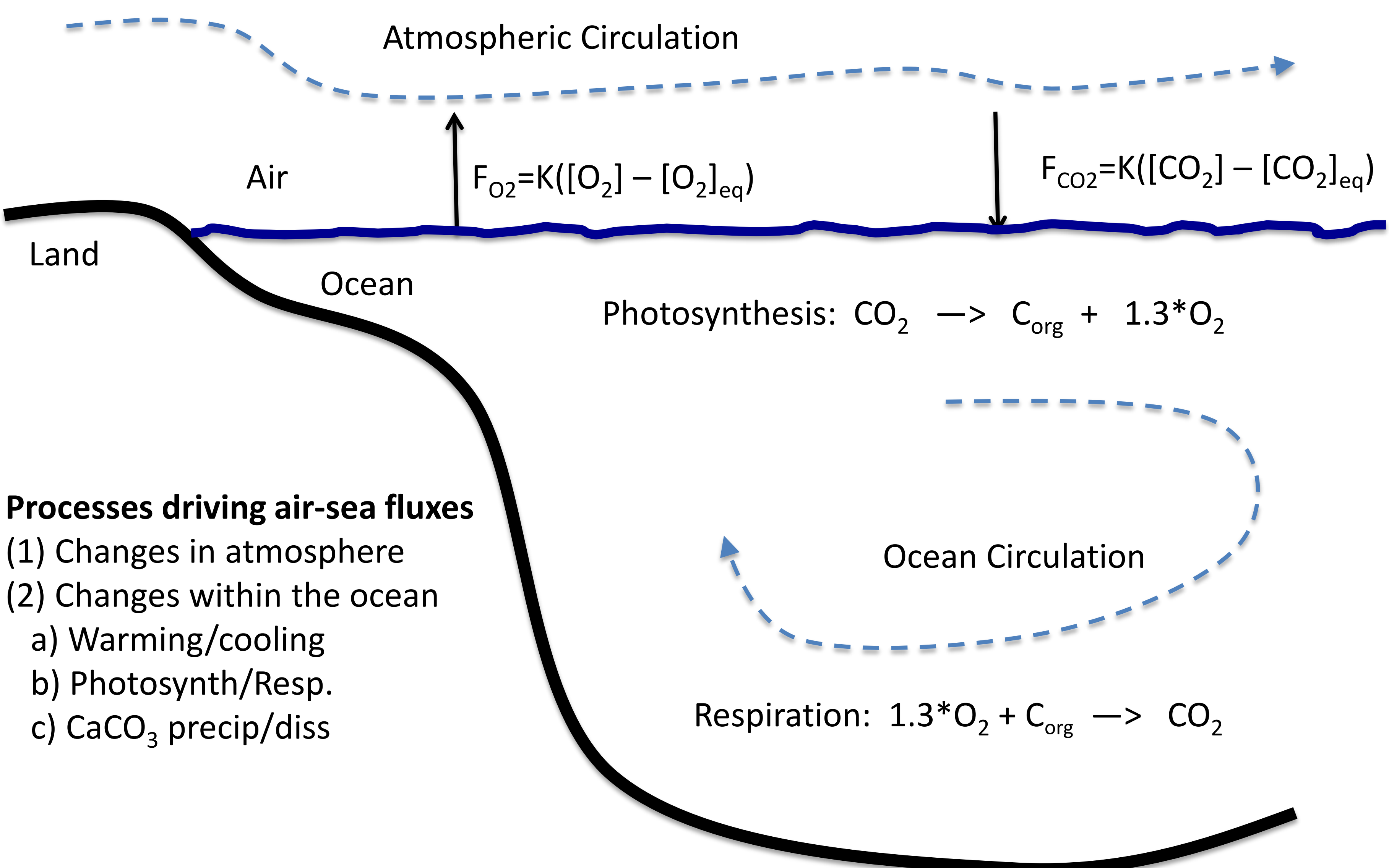
Future CO_2 fluxes



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