Constraints on global carbon and heat exchanges from measurements of atmospheric O_2 and related tracers.

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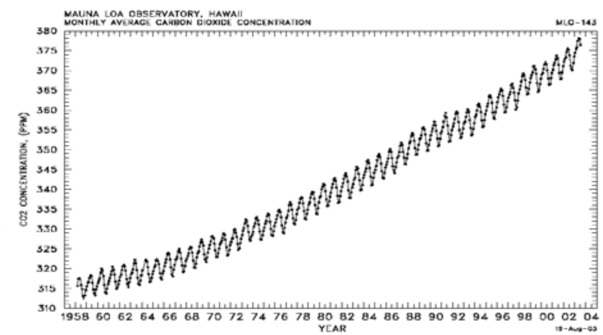
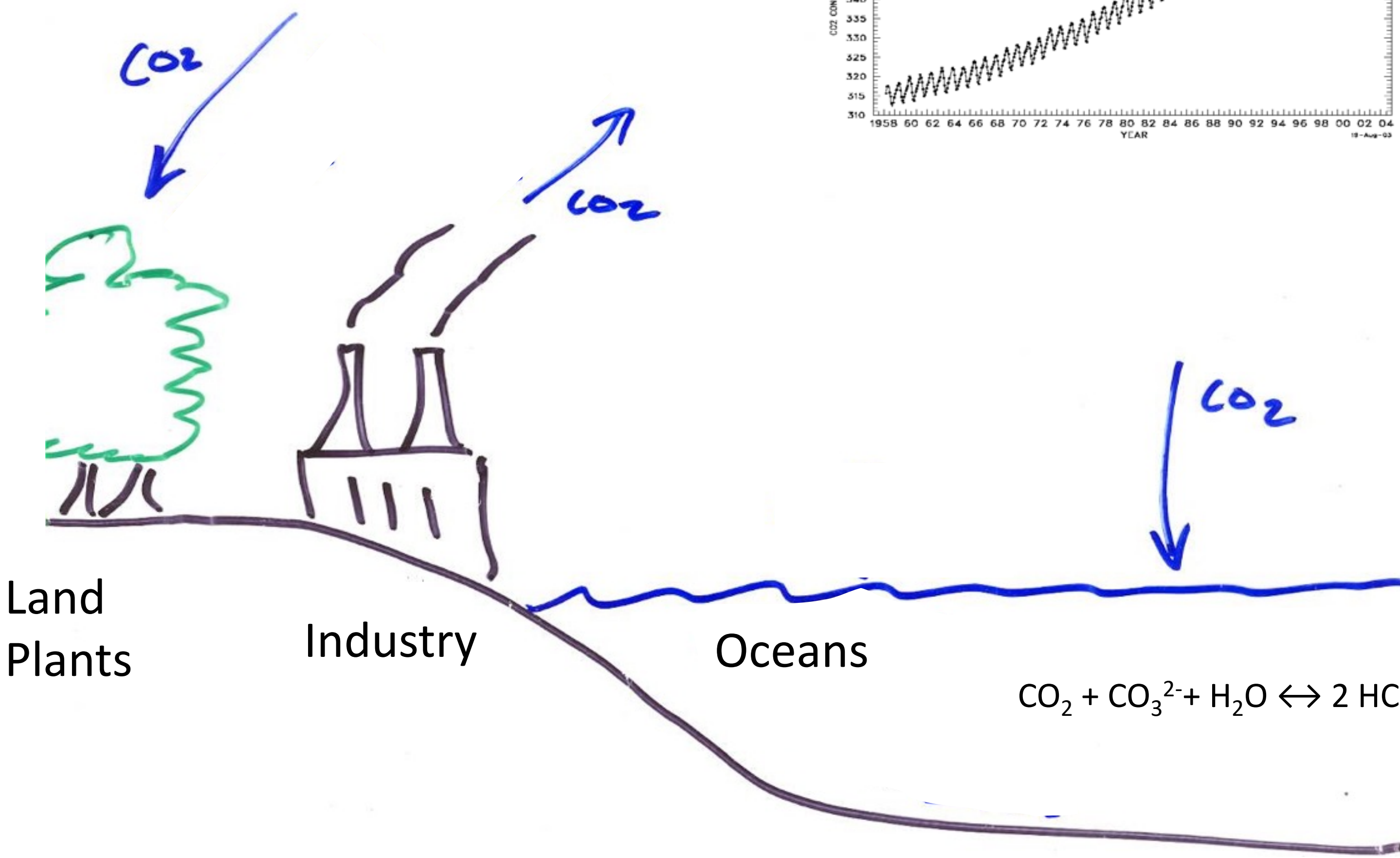
Credits to Laure Resplandy, Yassir Eddebbar

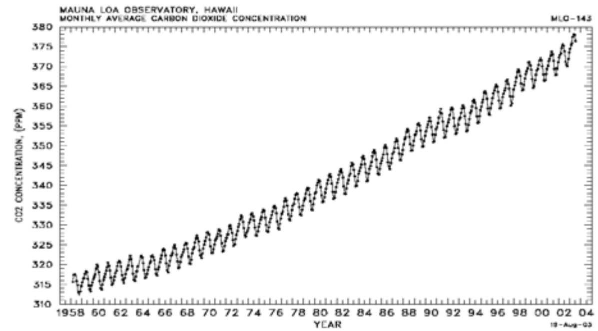
Controls on atmospheric CO_2 increase

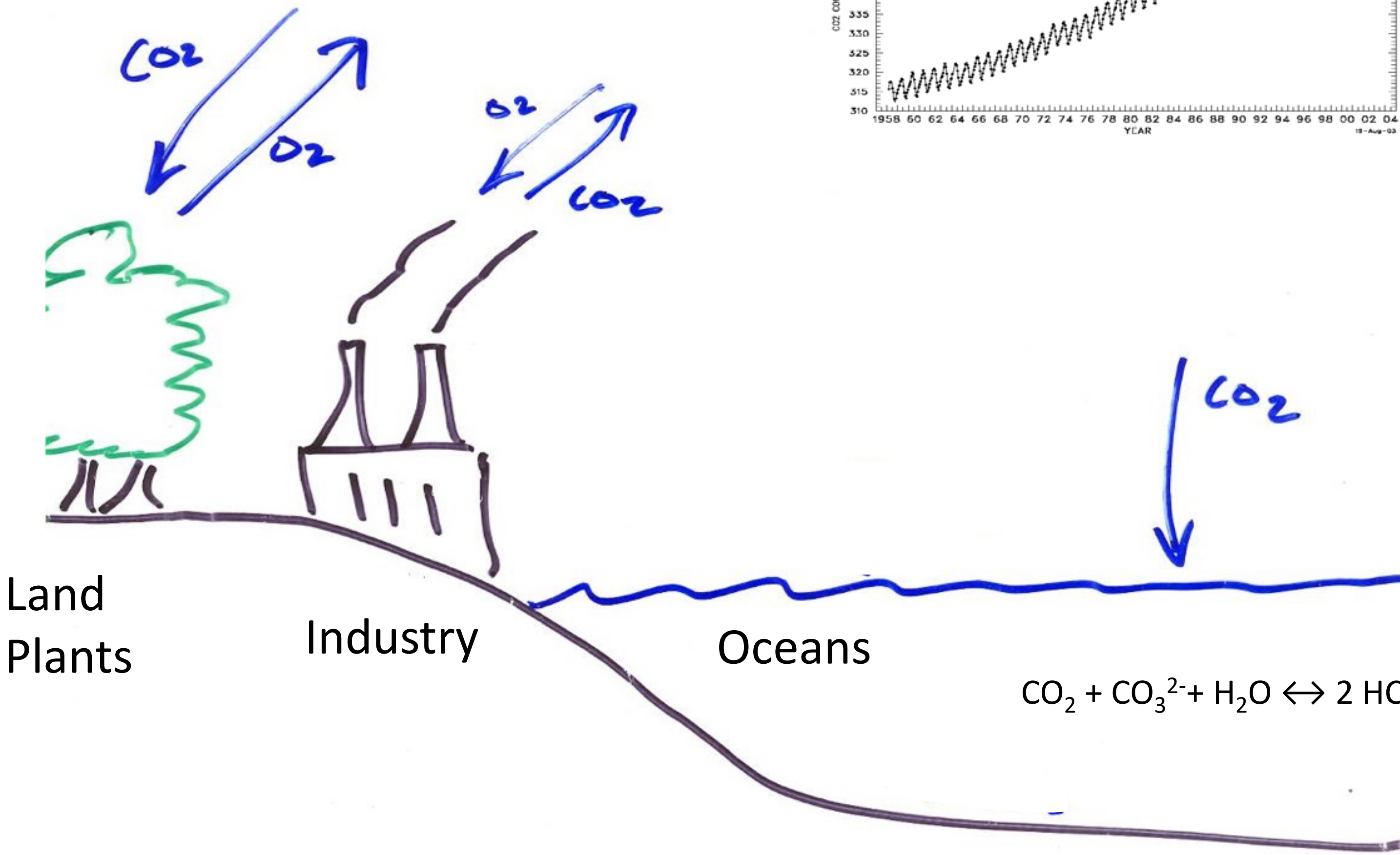




$CO_2 + CO_3^{2-} + H_2O \leftrightarrow 2\ HCO_3^-$

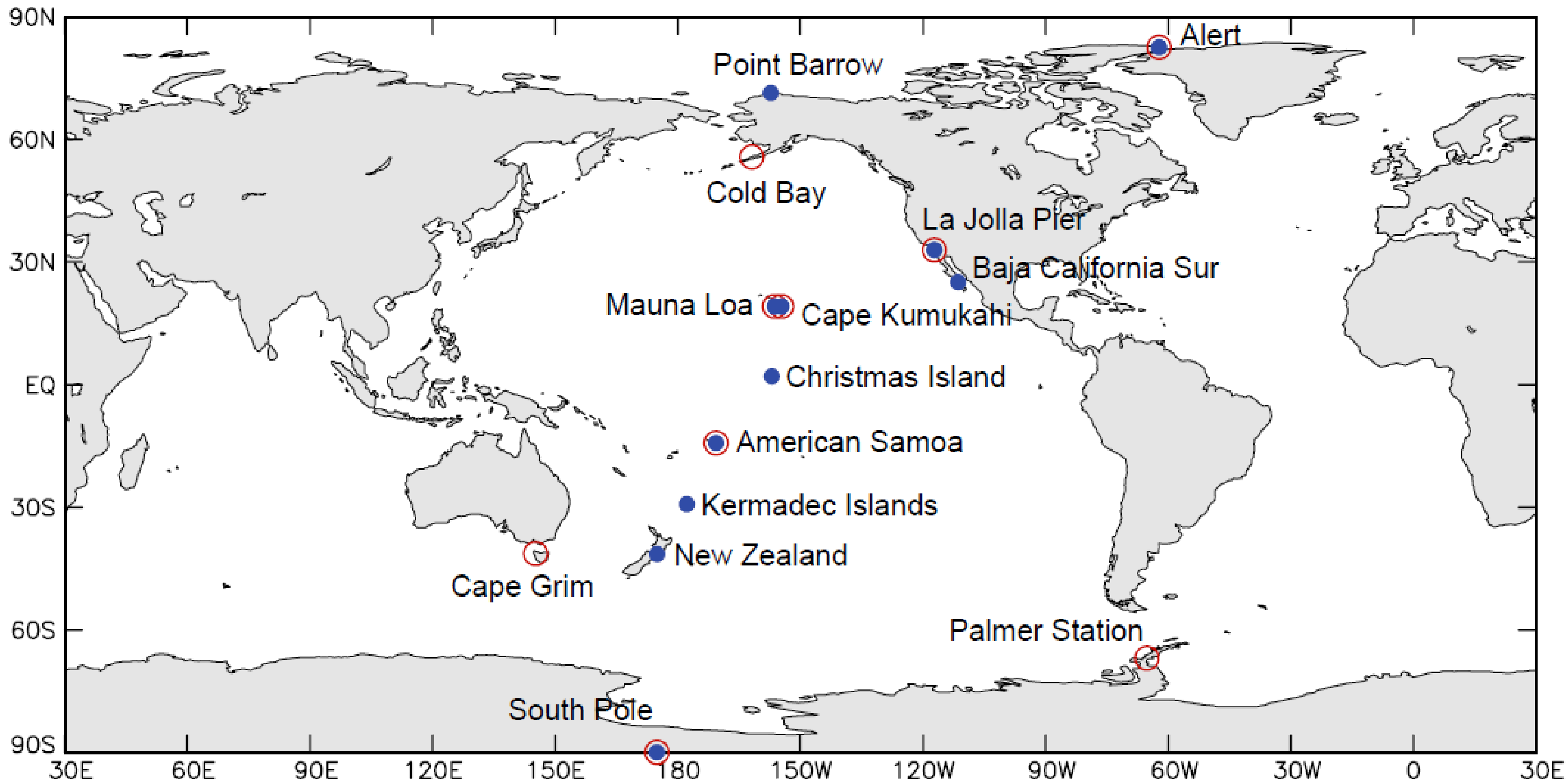
Controls on atmospheric CO_2 and O_2





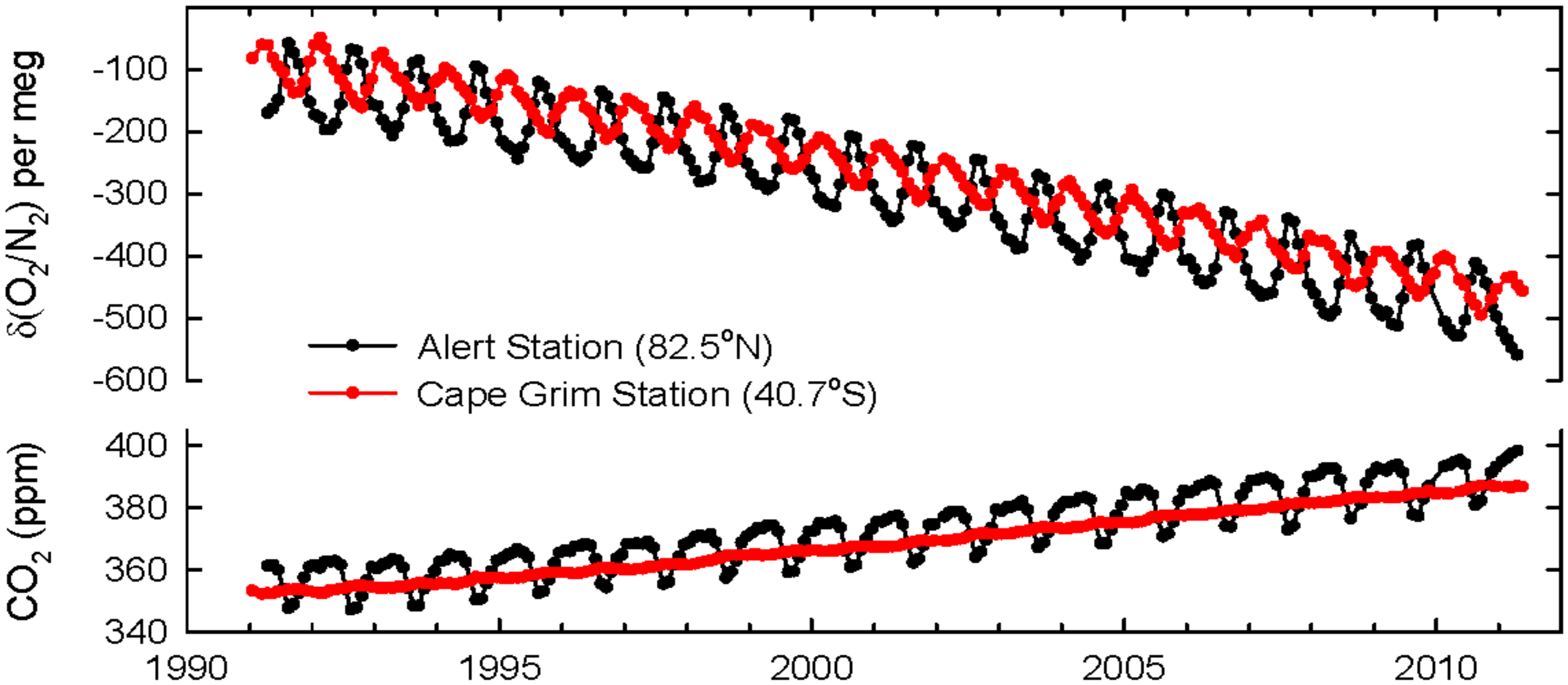
$CO_2 + CO_3^{2-} + H_2O \leftrightarrow 2\ HCO_3^-$

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

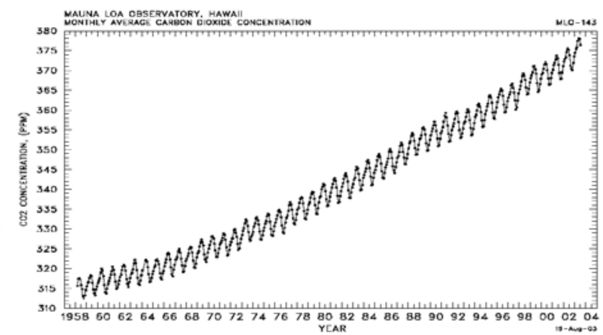
O_2/N_2 and CO_2 trends

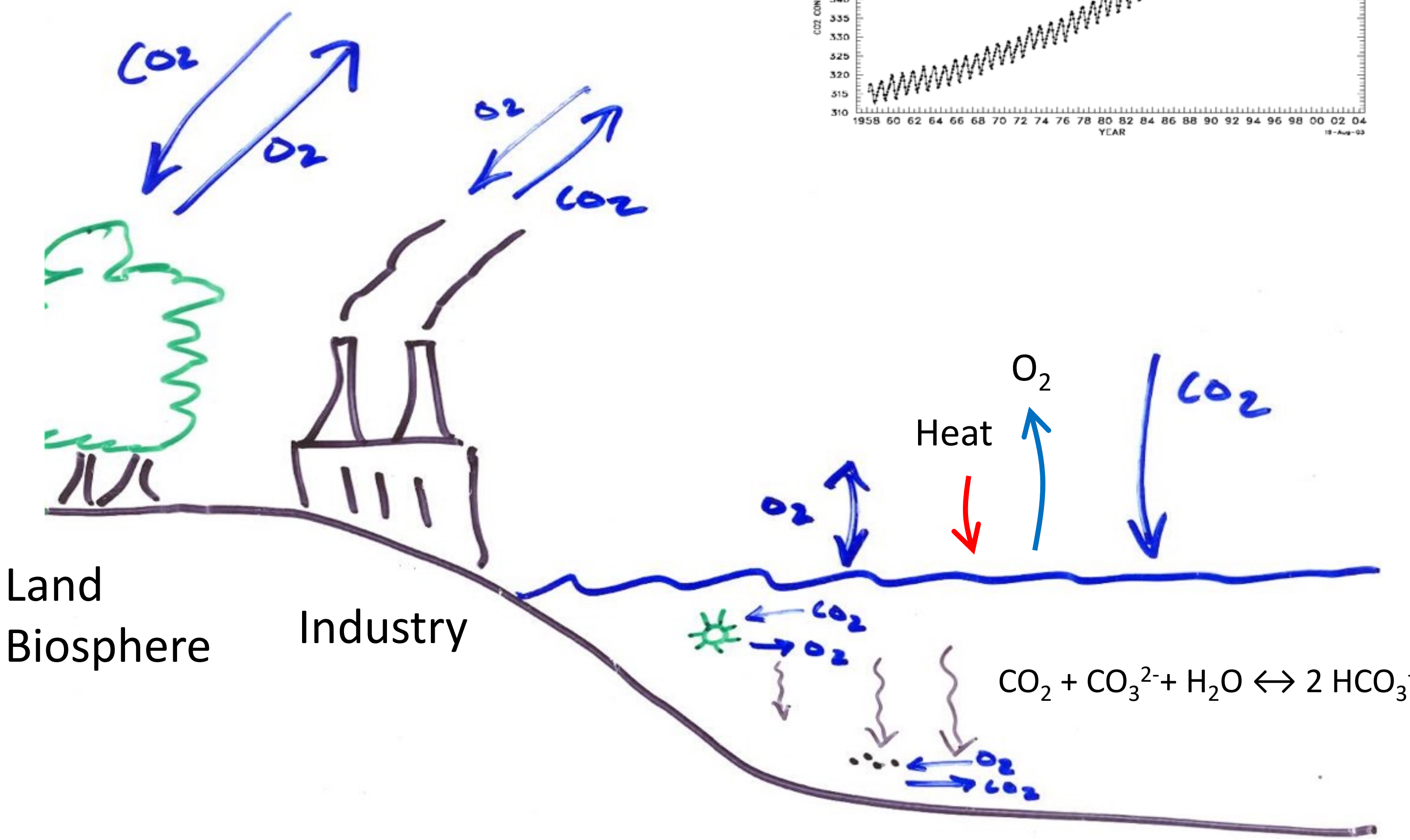


$$\delta(O_2/N_2) = \frac{(O_2/N_2)_{sample} - (O_2/N_2)_{reference}}{(O_2/N_2)_{reference}}$$

4.8 per meg ~ 1 ppm

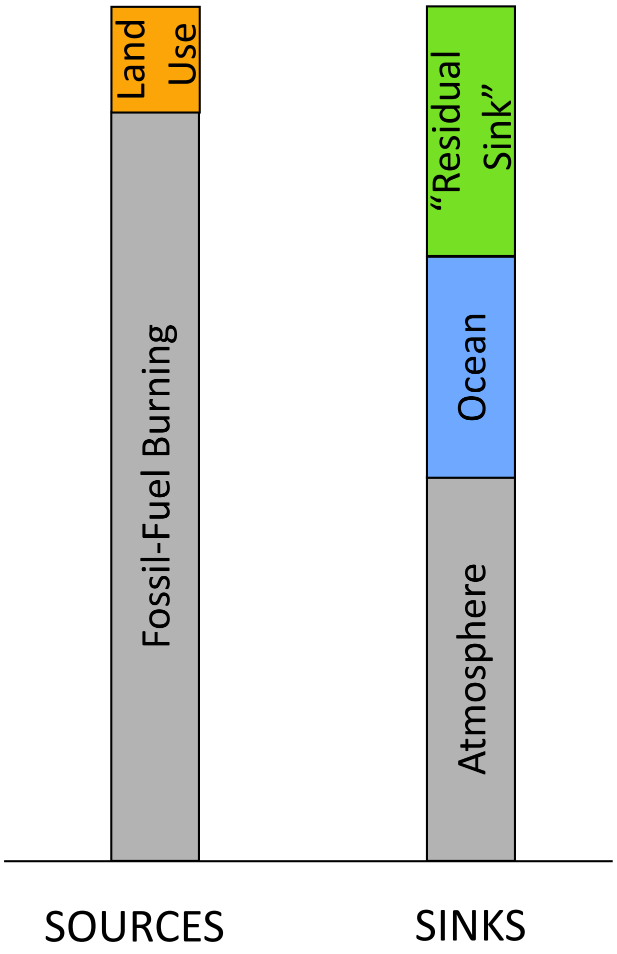
Controls on atmospheric CO_2 and O_2





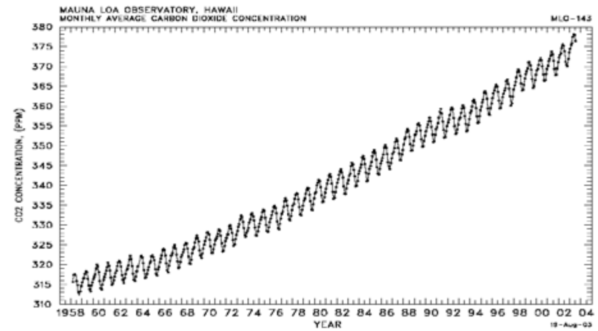
CO_2 budget 2000-2010 (Pg C/yr)

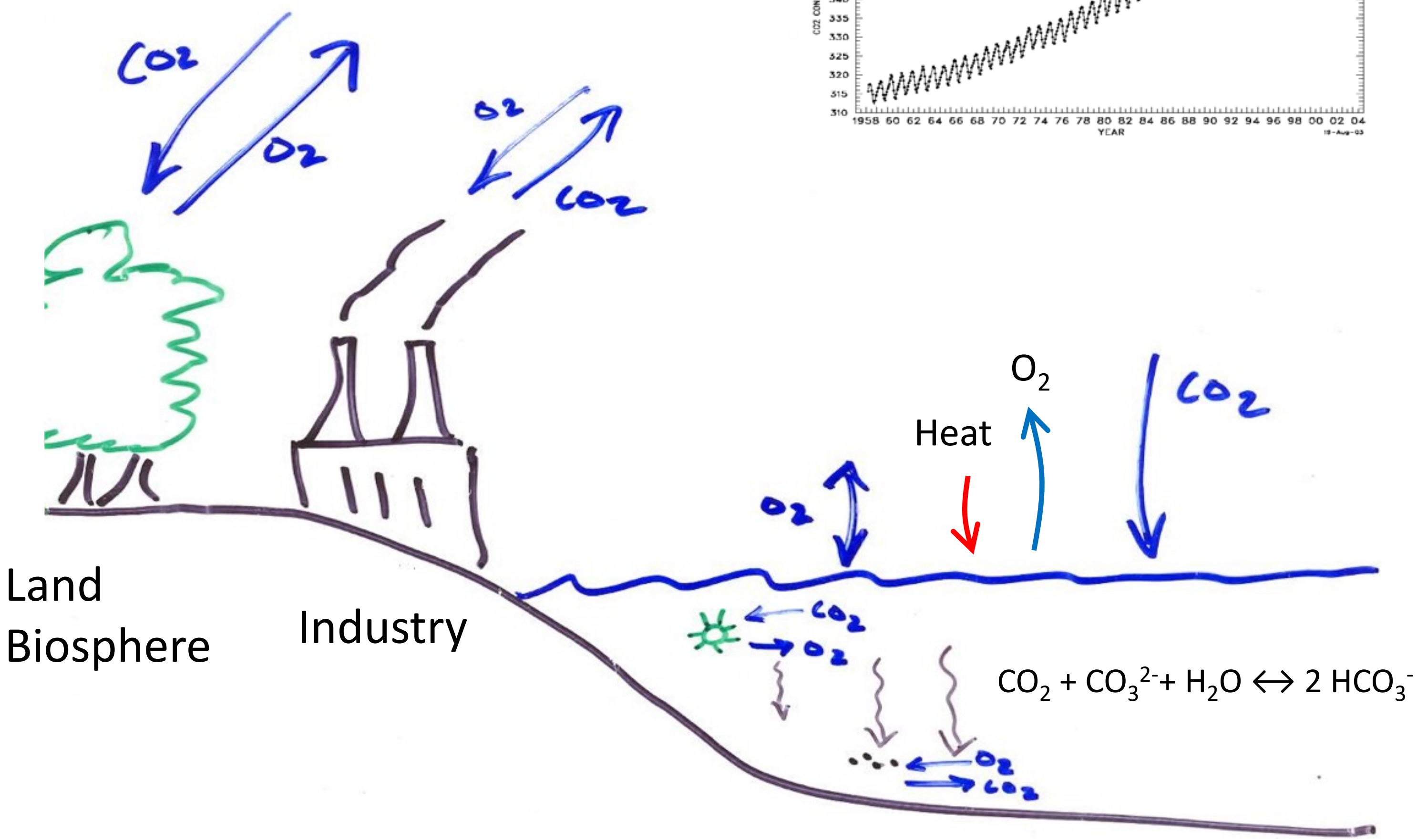
Fossil fuel emissions	7.8 ± 0.6
Land use emissions	1.1 ± 0.8
Total Sources	8.9 ± 1.0
Atmosphere	4.0 ± 0.2
Ocean sink	2.3 ± 0.7
Residual land sink	2.6 ± 1.2
Total Sinks	8.9 ± 1.0



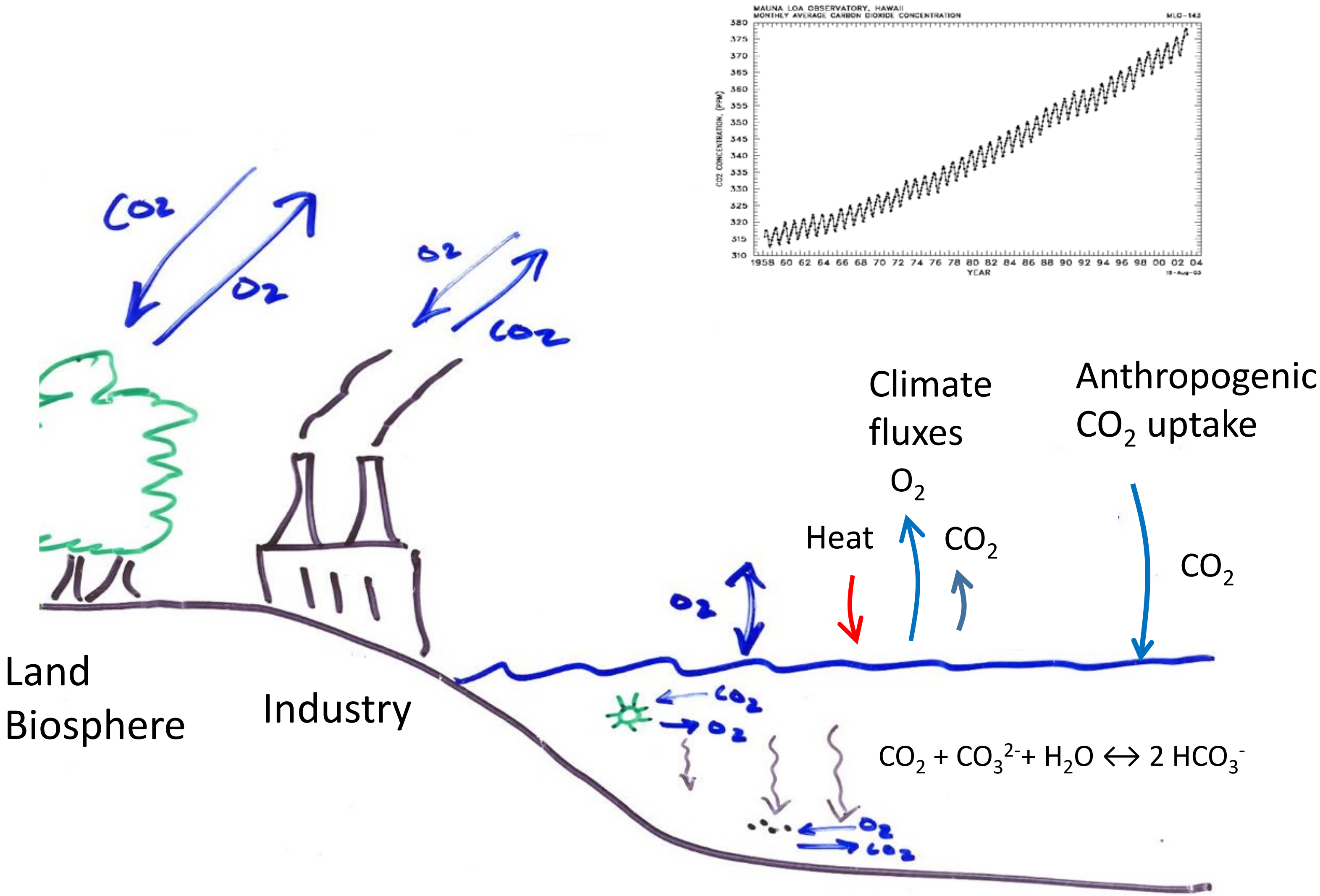
IPCC AR5

Controls on atmospheric CO_2 and O_2





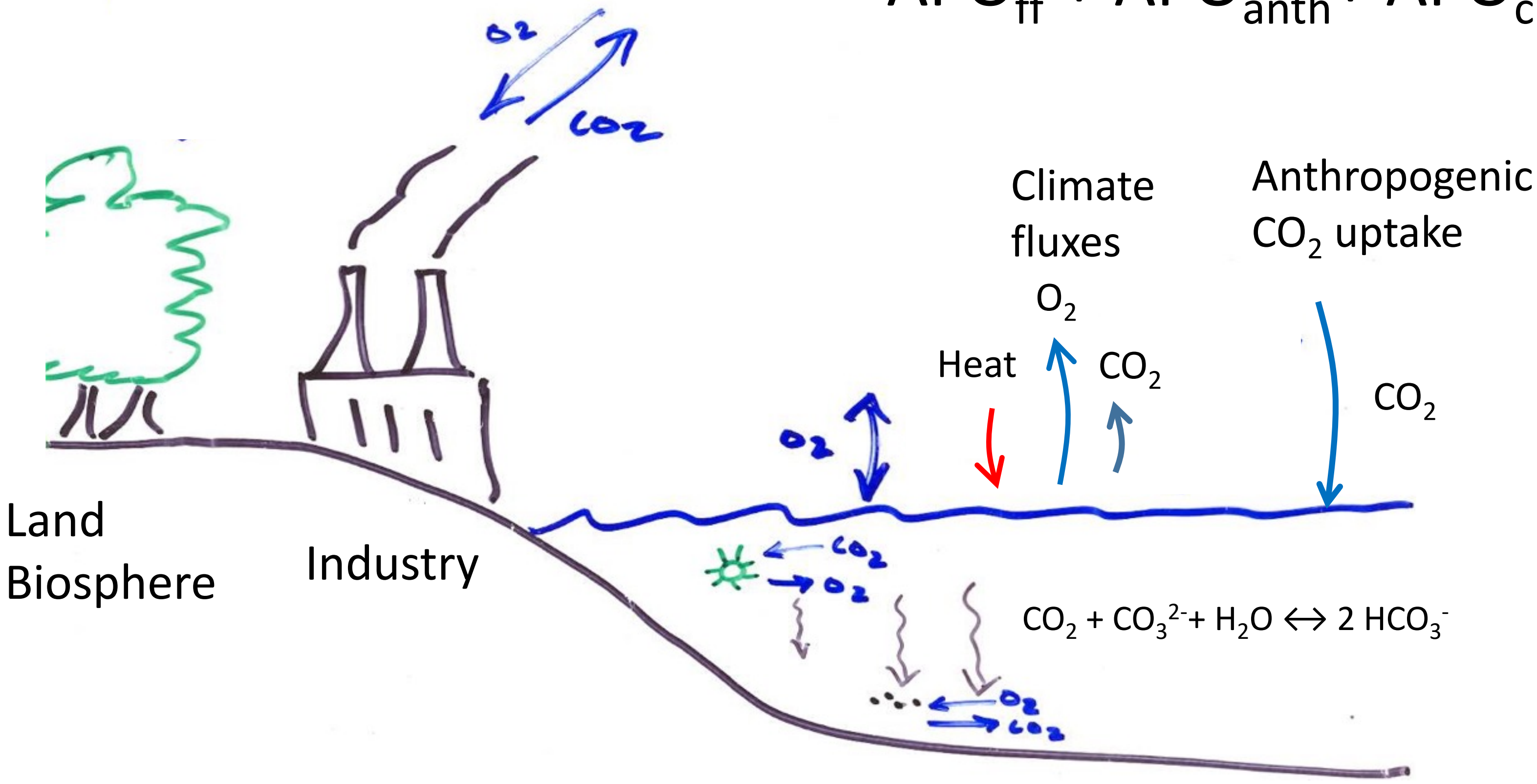
Controls on atmospheric CO_2 and O_2



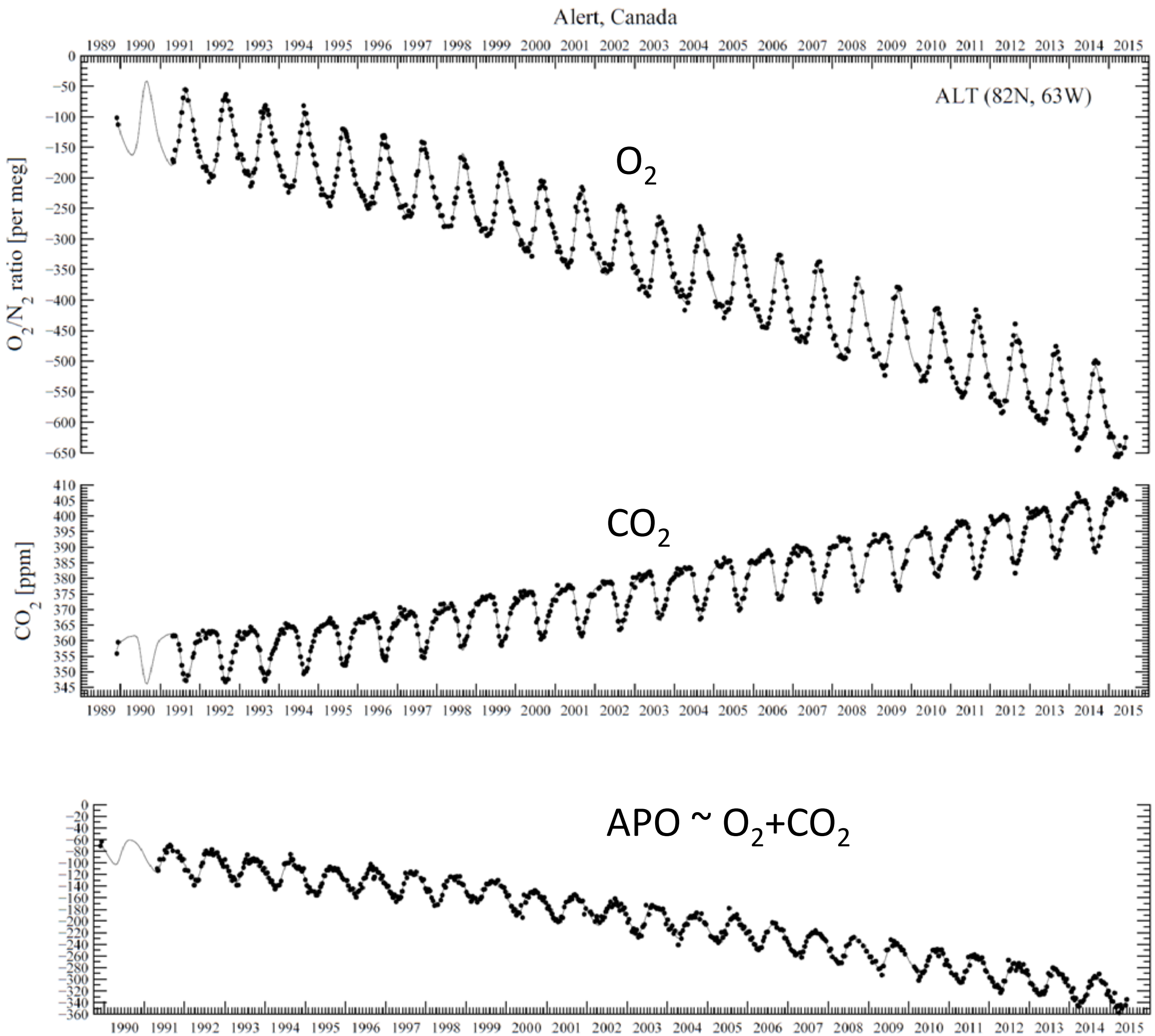
Controls on atmospheric CO_2 and O_2

Atmospheric Potential Oxygen

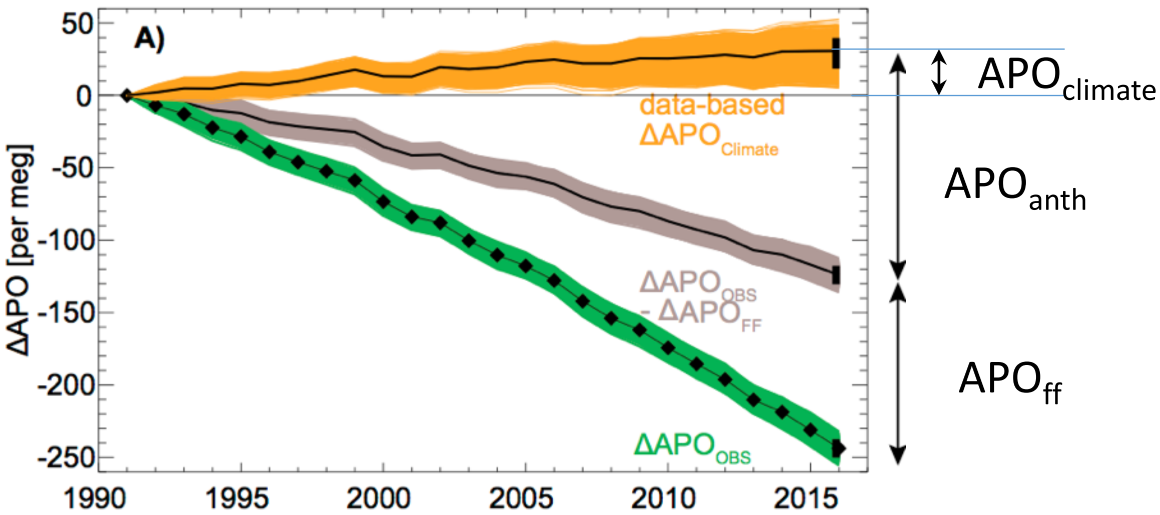
$$APO \sim O_2 + CO_2$$
$$= APO_{ff} + APO_{anth} + APO_{climate}$$

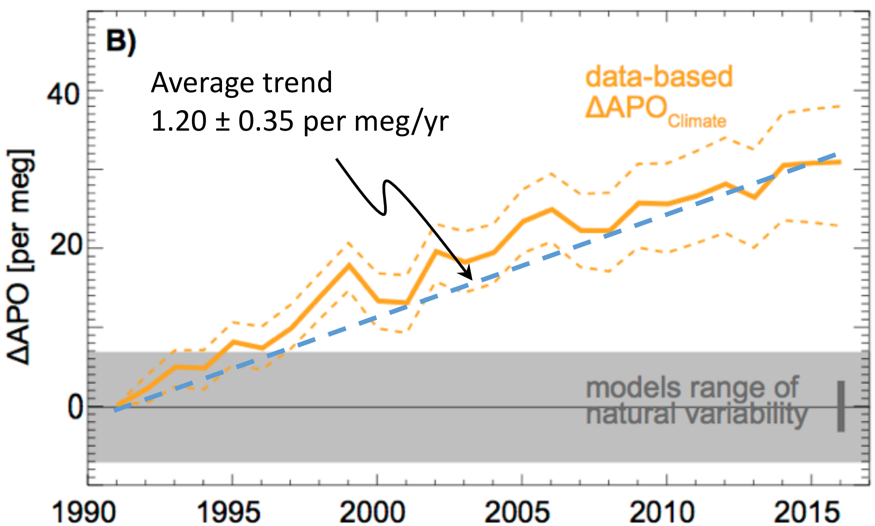


O_2, CO_2, and APO trends



APO constraint on warming



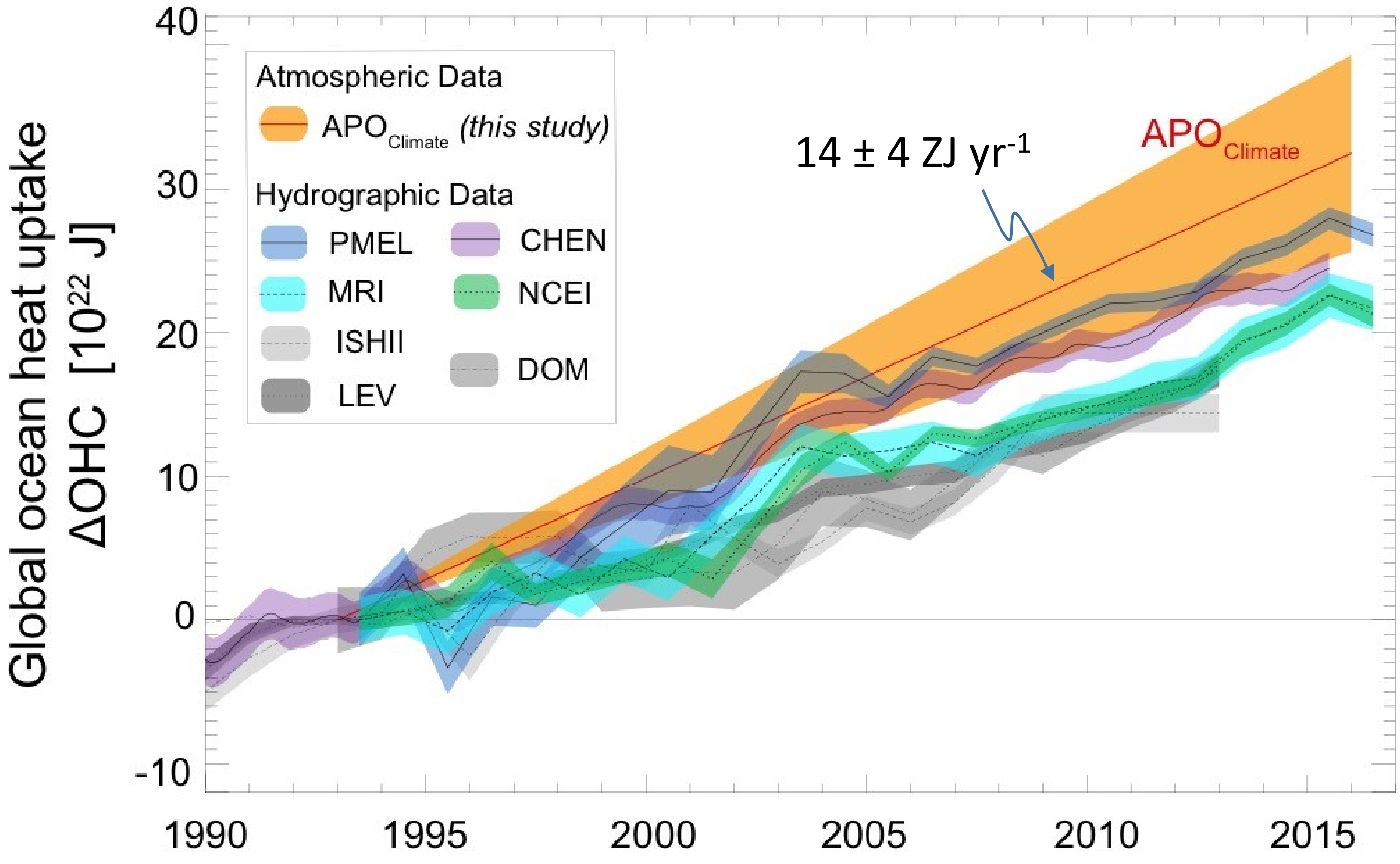


Ocean warming calculation:

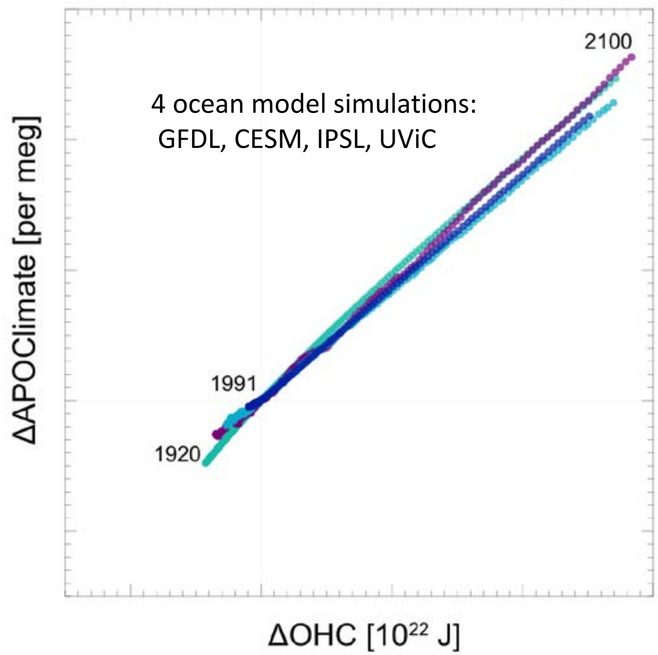
$$\frac{(1.2 \text{ per meg/yr})}{(0.87 \text{ per meg}/10^{22}\text{J})} = 14 \text{ ZJ yr}^{-1}$$

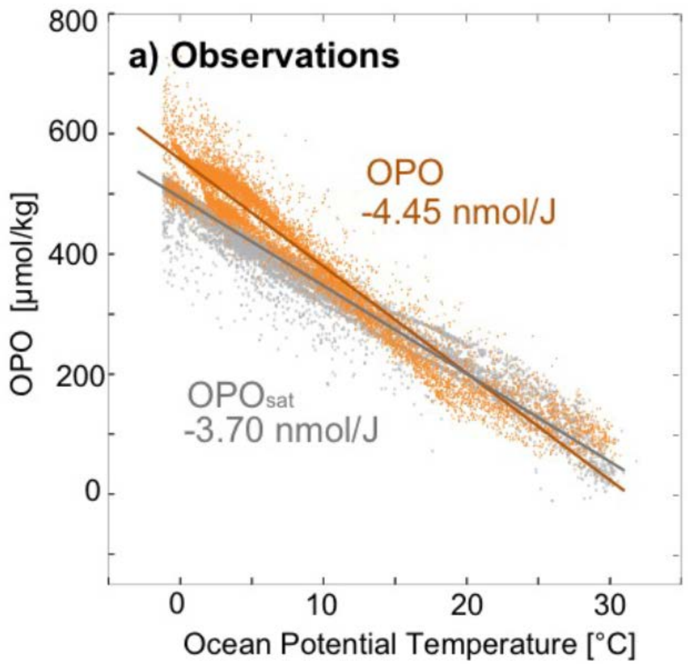
$(1 \text{ ZJ} = 10^{21} \text{ J})$

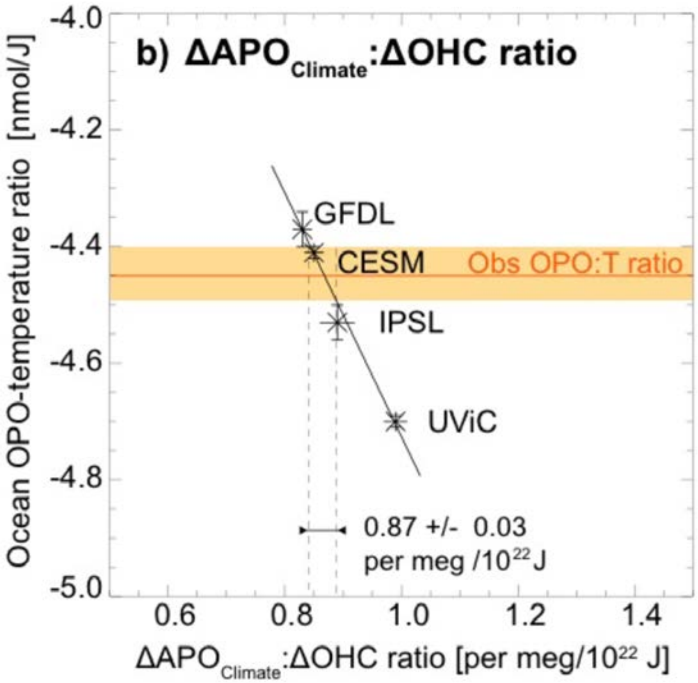
Increase in global ocean heat content



Establishing the connection between $APO_{climate}$ and ocean warming



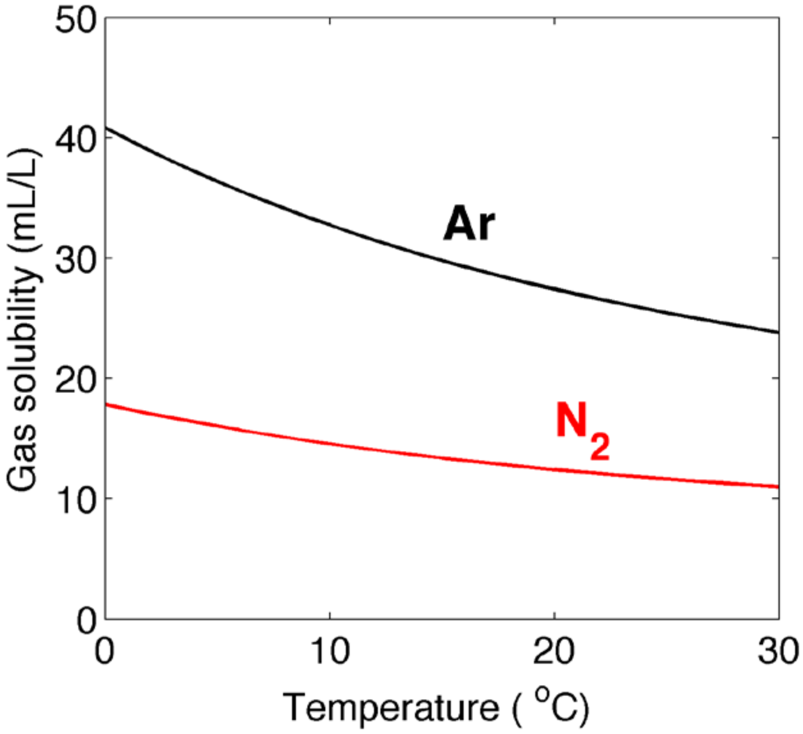


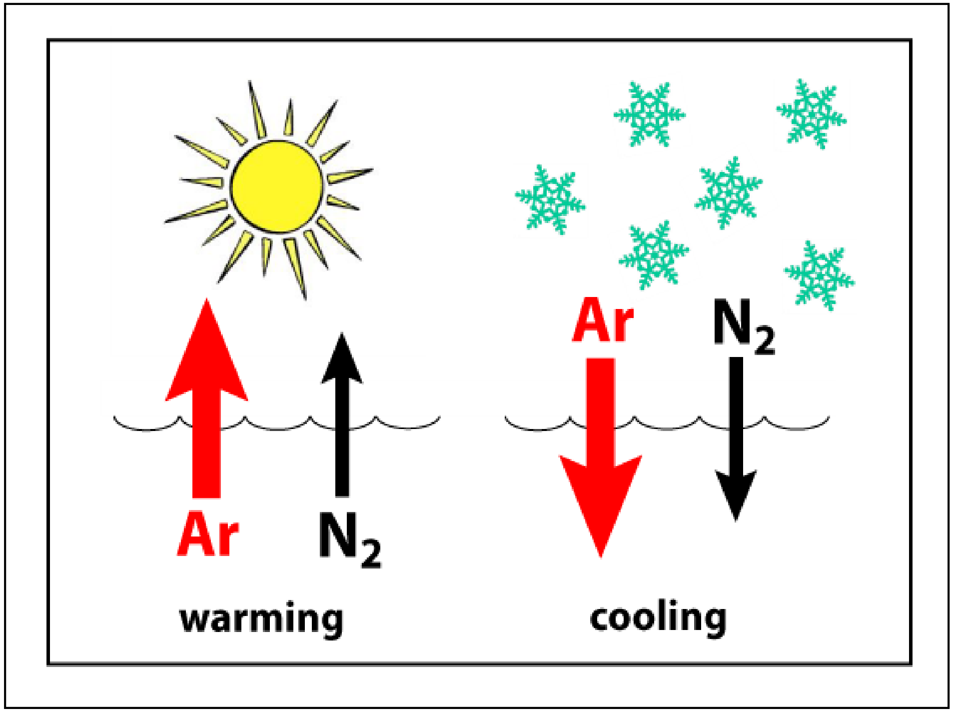


Manuscript in Review:

L. Resplandy, R. F. Keeling, Y. Eddebbar, M. Brooks, R. Wang, L. Bopp, M. C. Long, J. P. Dunne, W. Koeve, A. Oschlies, "Quantification of ocean heat uptake from changes in atmospheric O_2 and CO_2 composition", Nature Geosciences

Measurements of Ar/N_2
Quantifying global ocean heat content changes

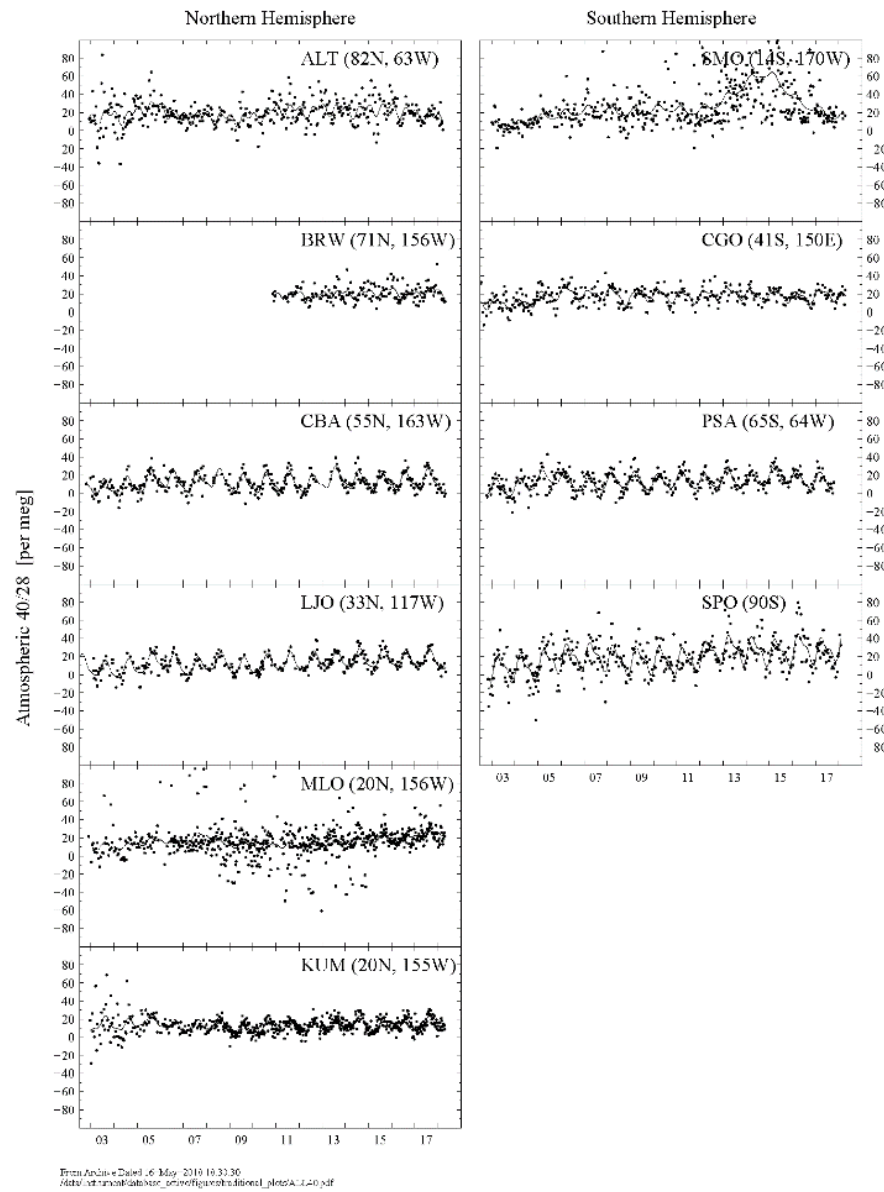




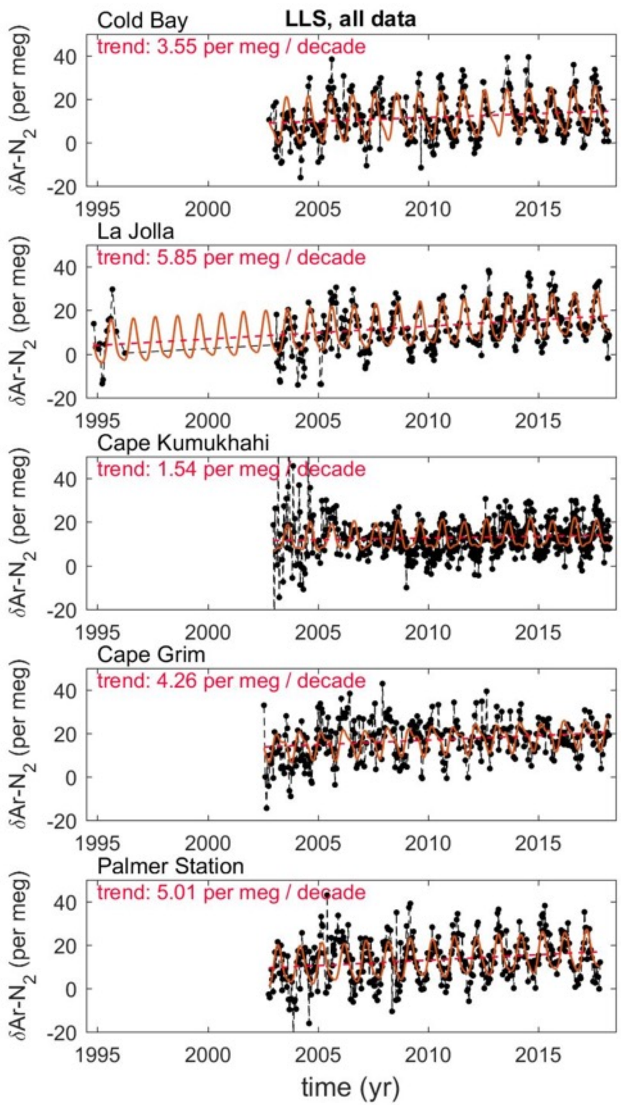
Measurements of trends in Ar/N_2 ratio

$\delta(Ar/N_2)$ (per meg) =

$$\left(\frac{(Ar/N_2)_{sample}}{(Ar/N_2)_{reference}} - 1 \right) \times 10^6$$



Measurements of trends in Ar/N_2 ratio



$$\frac{(4.0 \pm 1.6 \text{ per meg/decade})}{(2.57 \text{ per meg/100 ZJ})(10 \text{ year/decade})}$$

$$= \quad 15 \pm 6 \text{ ZJ/yr}$$

Global energy balance equation

$$\textit{Heat Storage} + \alpha \Delta T_s = G$$

IR to space due to T_s increase

Radiative forcing (GHG)

$$1/\alpha = \text{climate sensitivity}$$

°C per W/m^2 of forcing, or
°C per CO_2 doubling

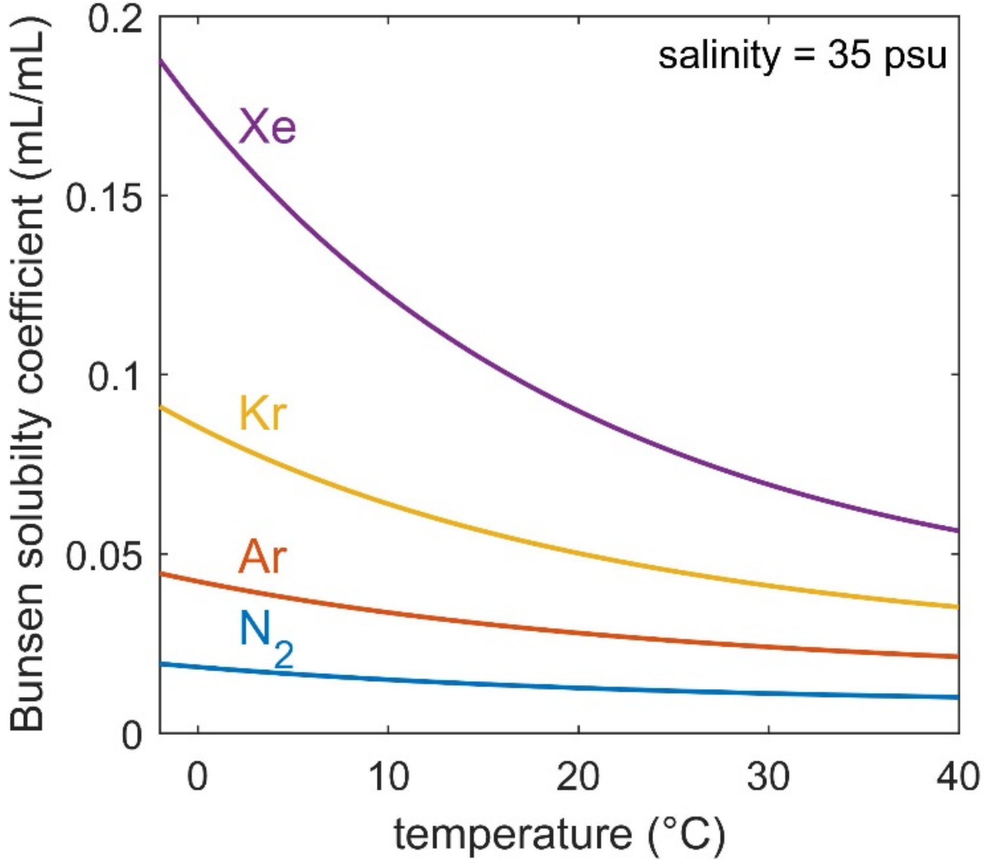
Larger *Heat Storage* implies higher climate sensitivity

- IPCC AR5 sensitivity range +1.5K to +4.5K per doubling

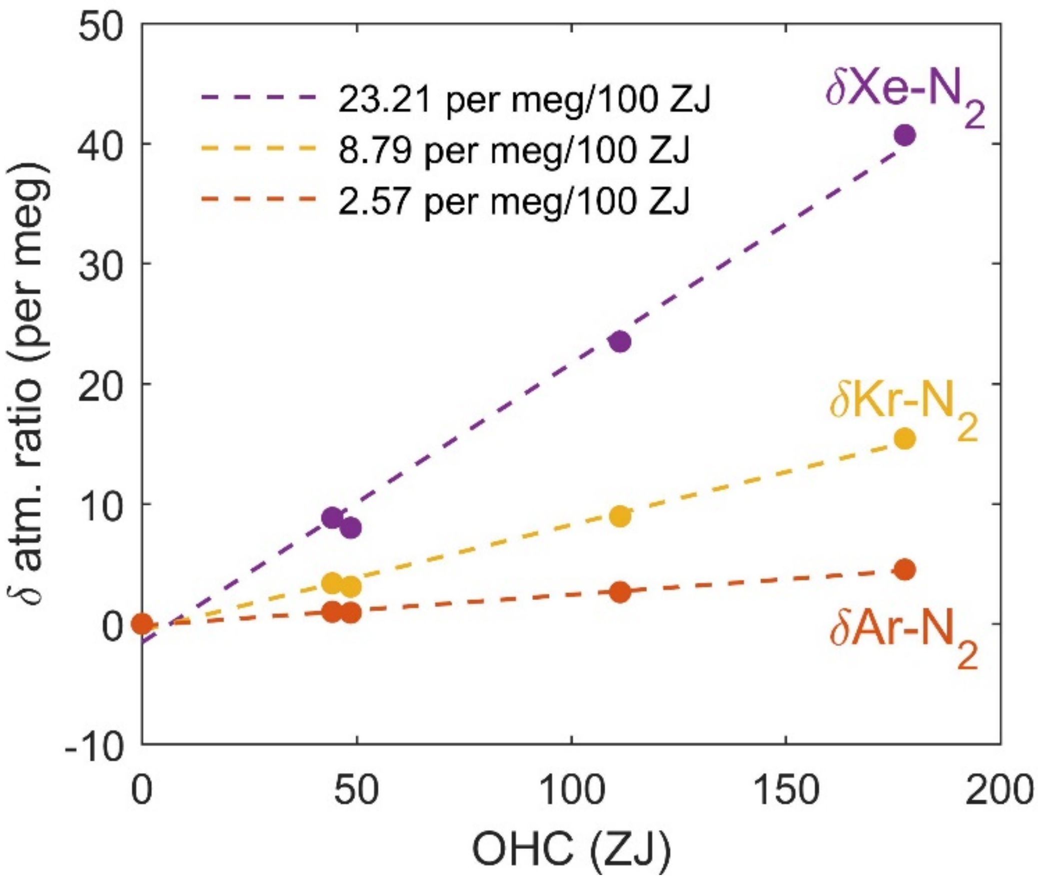
  Used ~8 ZJ/yr for heat storage

- Upwards revision of heat storage by 5 ZJ/yr increases lower bound from 1.5 to 2.0 K per doubling.

Thank you



Temperature (^oC)	0	10	20
$\delta(Ar/N_2)$ sensitivity (per mg/ 100 ZJ)	3.9	2.6	1.8



23.21 per meg/100 ZJ
8.79 per meg/100 ZJ
2.57 per meg/100 ZJ
δXe-N2
δKr-N2
δAr-N2
δ atm. ratio (per meg)
OHC (ZJ)
50
40
30
20
10
0
-10
0
50
100
150
200