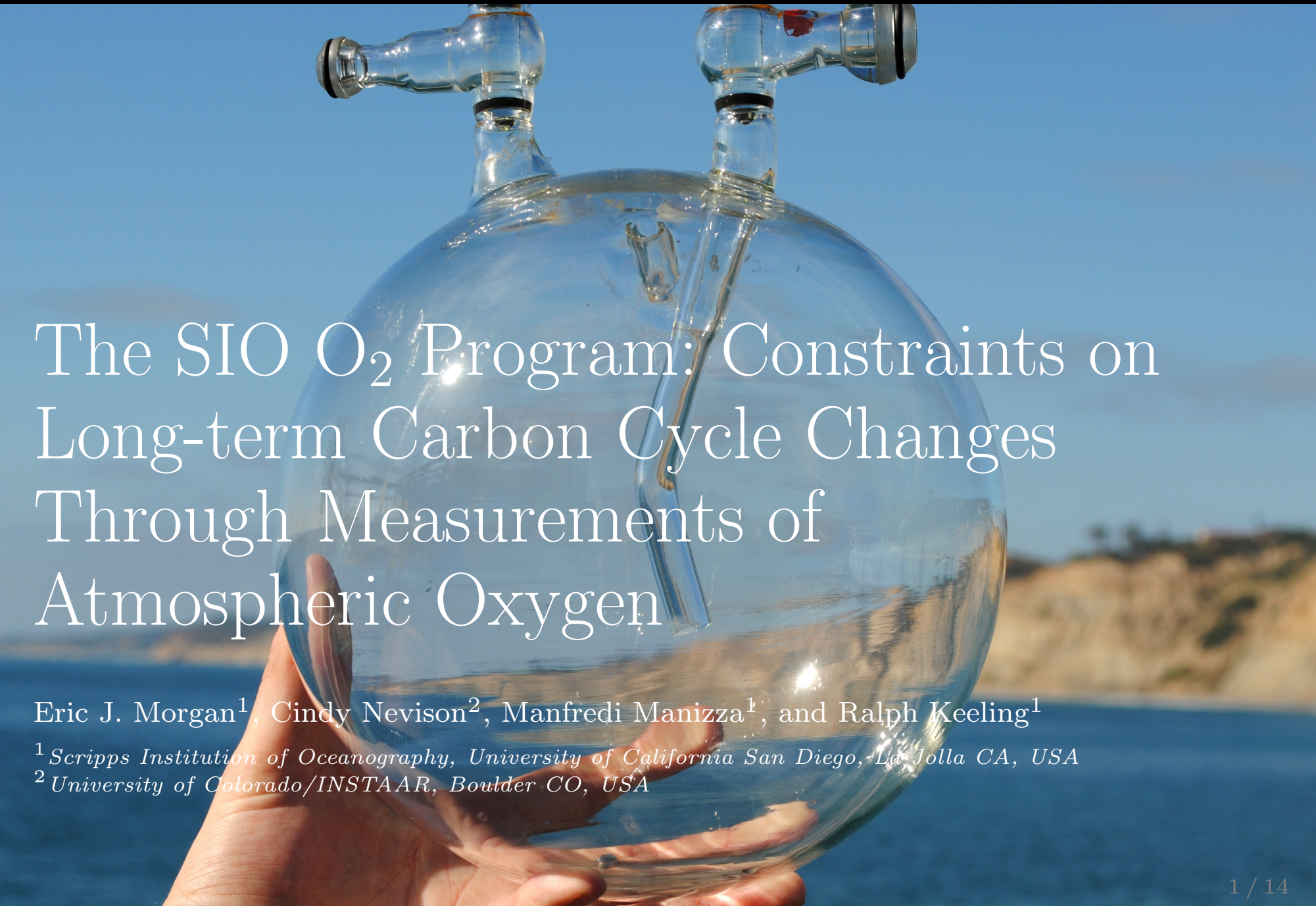

The SIO O_2 Program: Constraints on Long-term Carbon Cycle Changes Through Measurements of Atmospheric Oxygen

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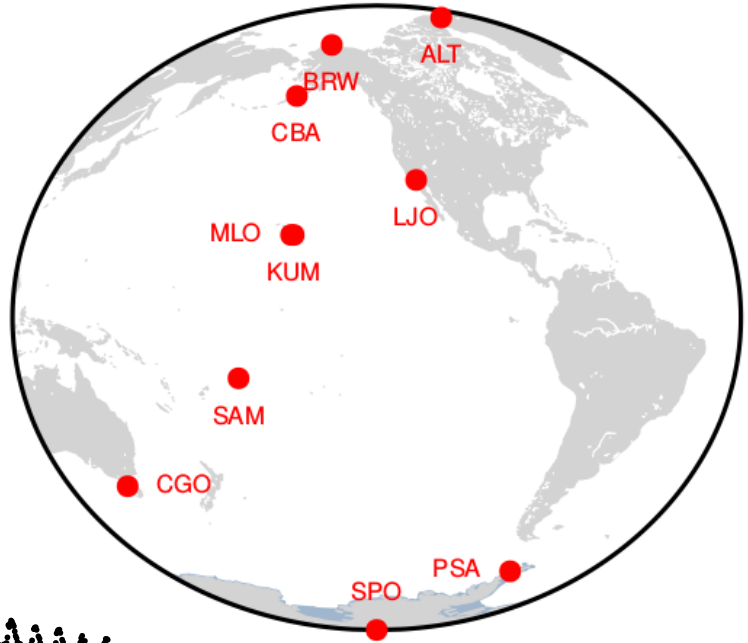
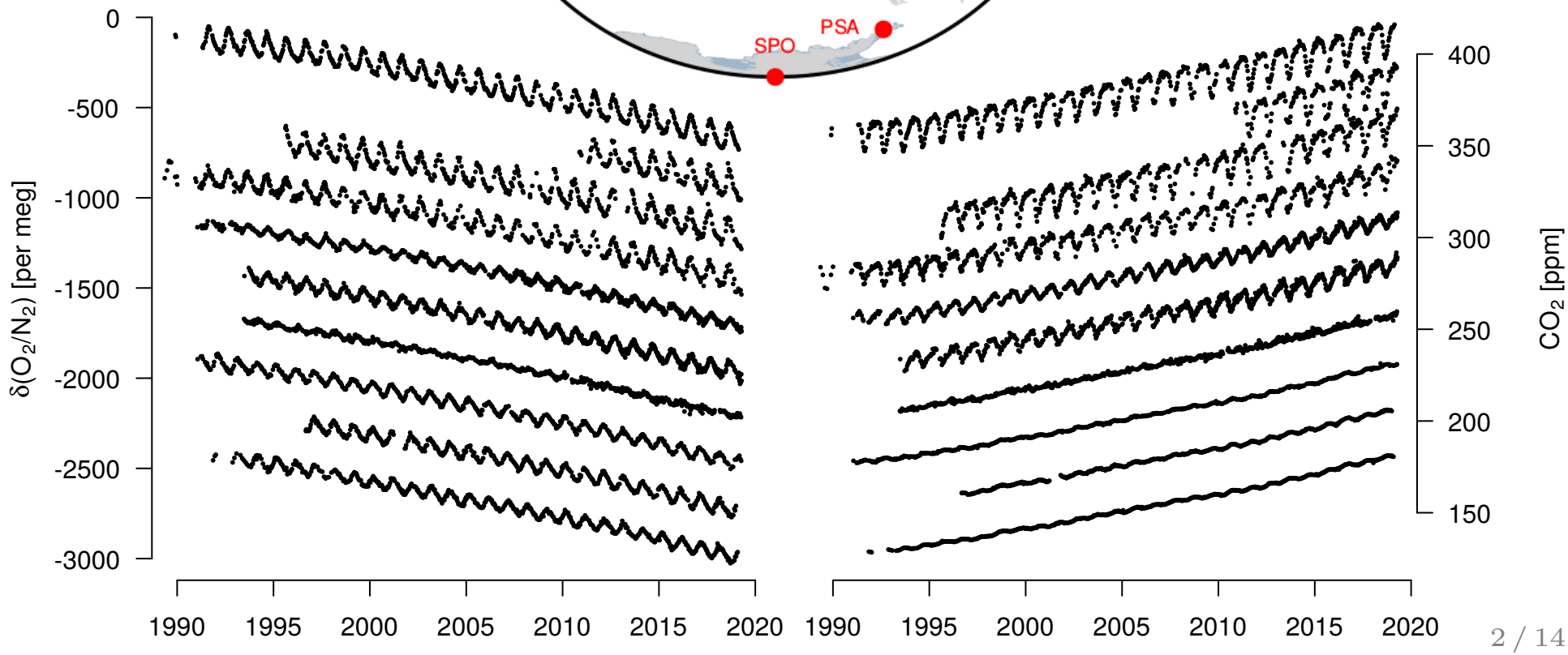
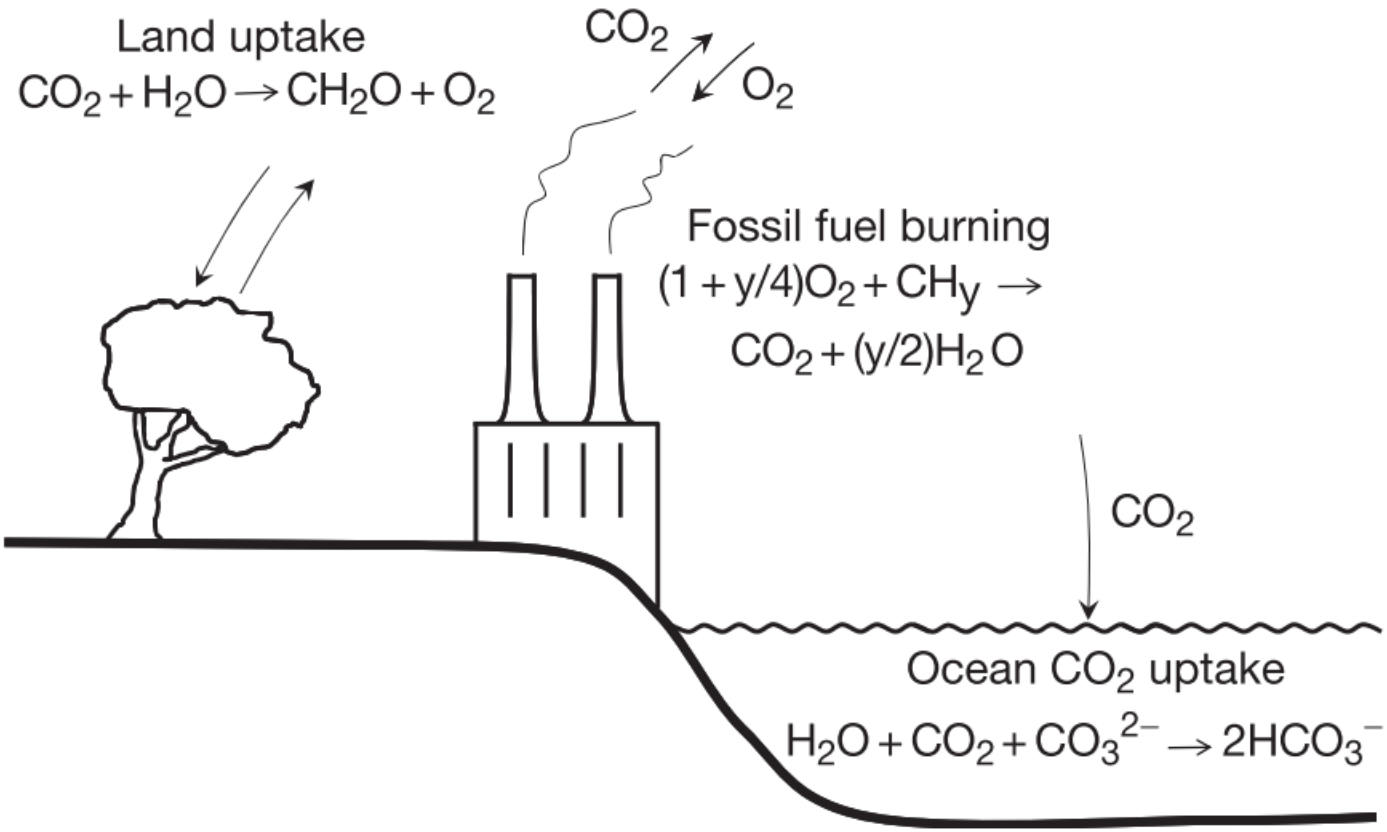
The SIO O_2 Program Flask Network





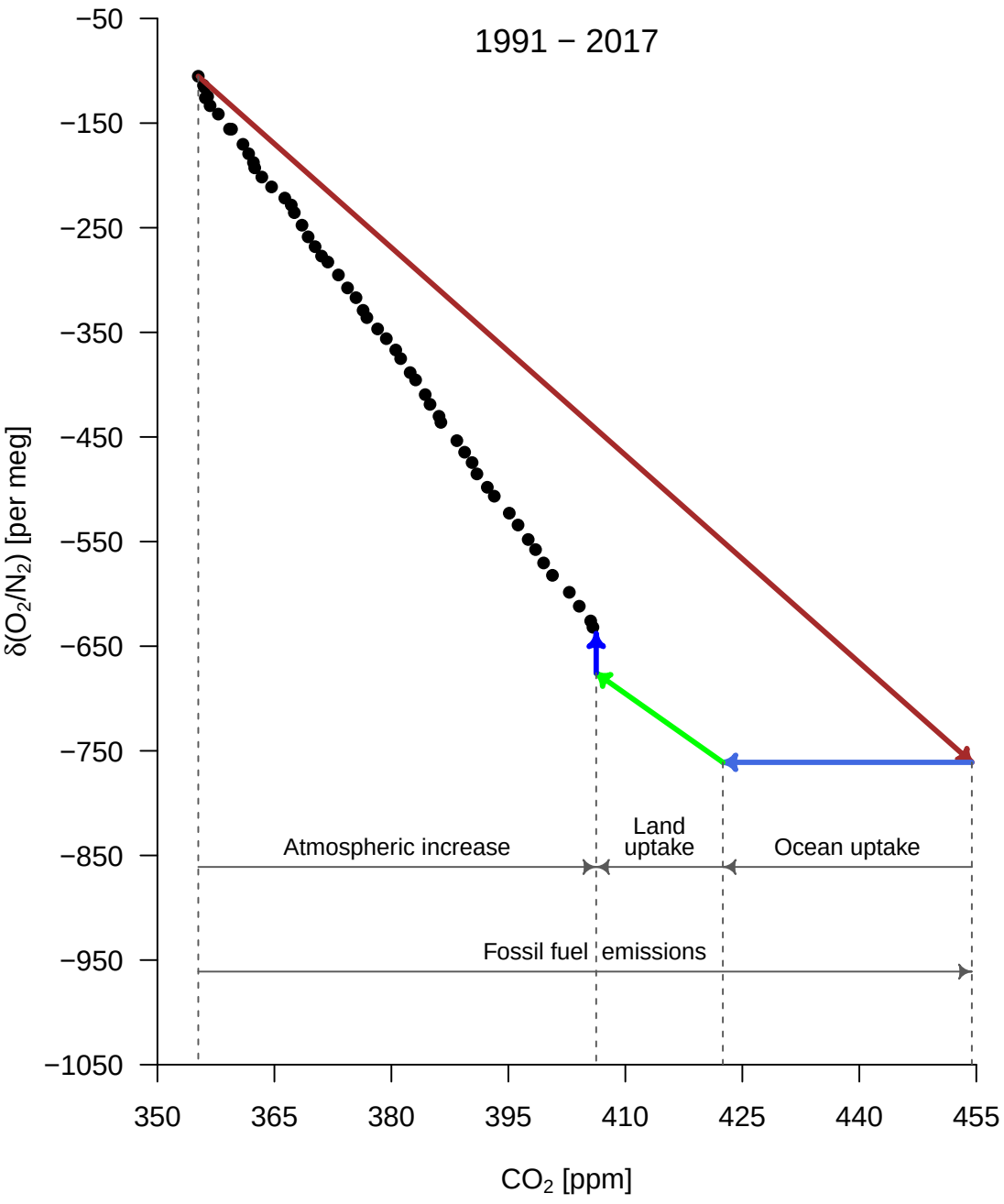
Global Carbon Budget



$$\delta(\mathrm{O_2/N_2}) = \left(\frac{(\mathrm{O_2/N_2})_{sample}}{(\mathrm{O_2/N_2})_{ref}} - 1 \right) \times 10^6$$

$$\mathrm{APO} = \delta(\mathrm{O_2/N_2}) + \frac{\alpha_{lnd}}{X_{\mathrm{O_2}}}(\mathrm{CO_2} - 350)$$

Global Carbon Budget



$$\Delta \mathrm{CO}_2 = F - O - L$$

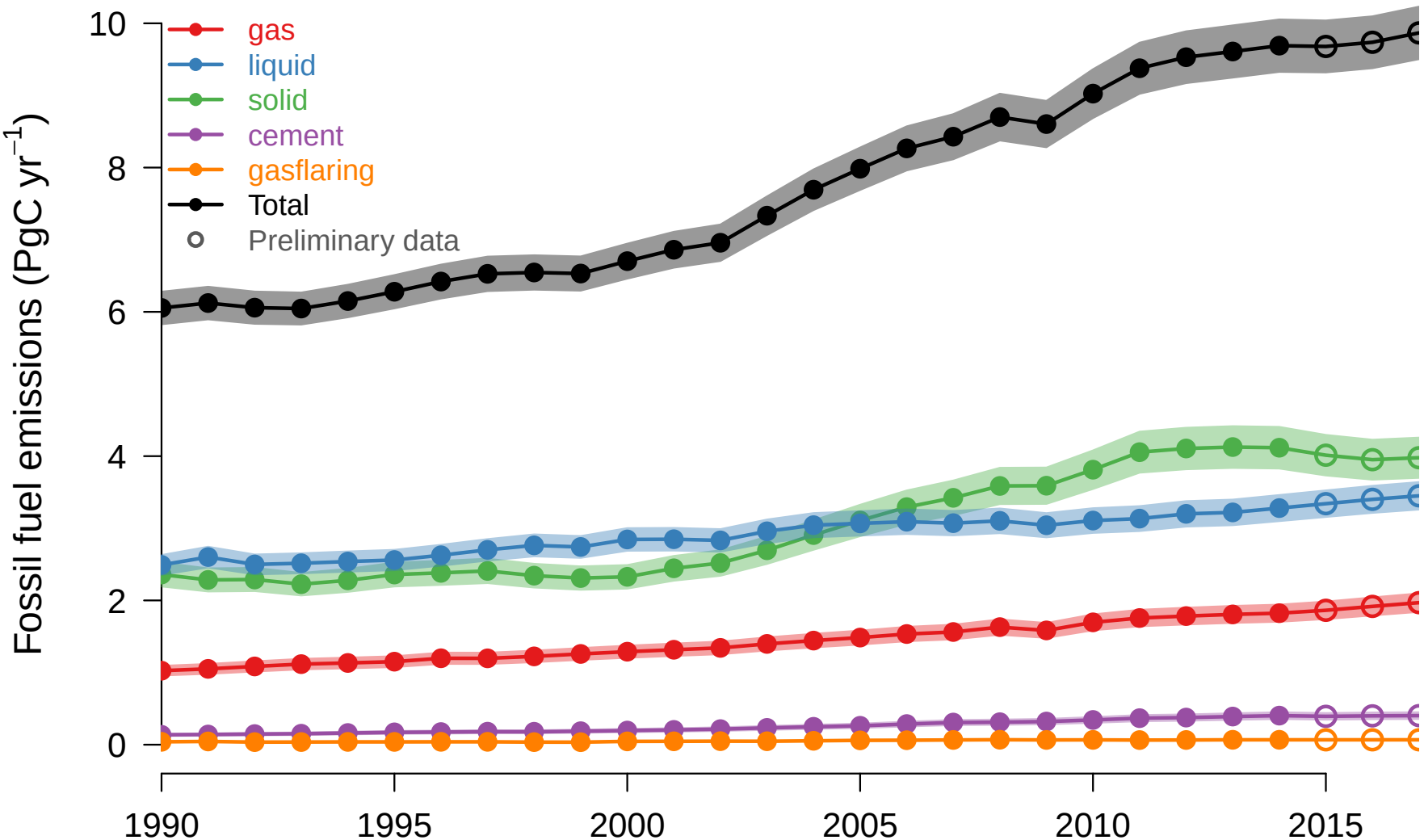
$$\Delta \mathrm{O}_2 = -\alpha_F F + \alpha_L L + Z_{eff}$$

$\Delta \mathrm{CO}_2$ = atmospheric CO_2
$\Delta \mathrm{O}_2$ = atmospheric O_2
F = Fossil fuel emissions
O = Net ocean sink
L = Net land sink
α_{lnd} = stoichiometry of terrestrial exchange
α_F = stoichiometry of FF burning
Z_{eff} = ocean outgassing of O_2

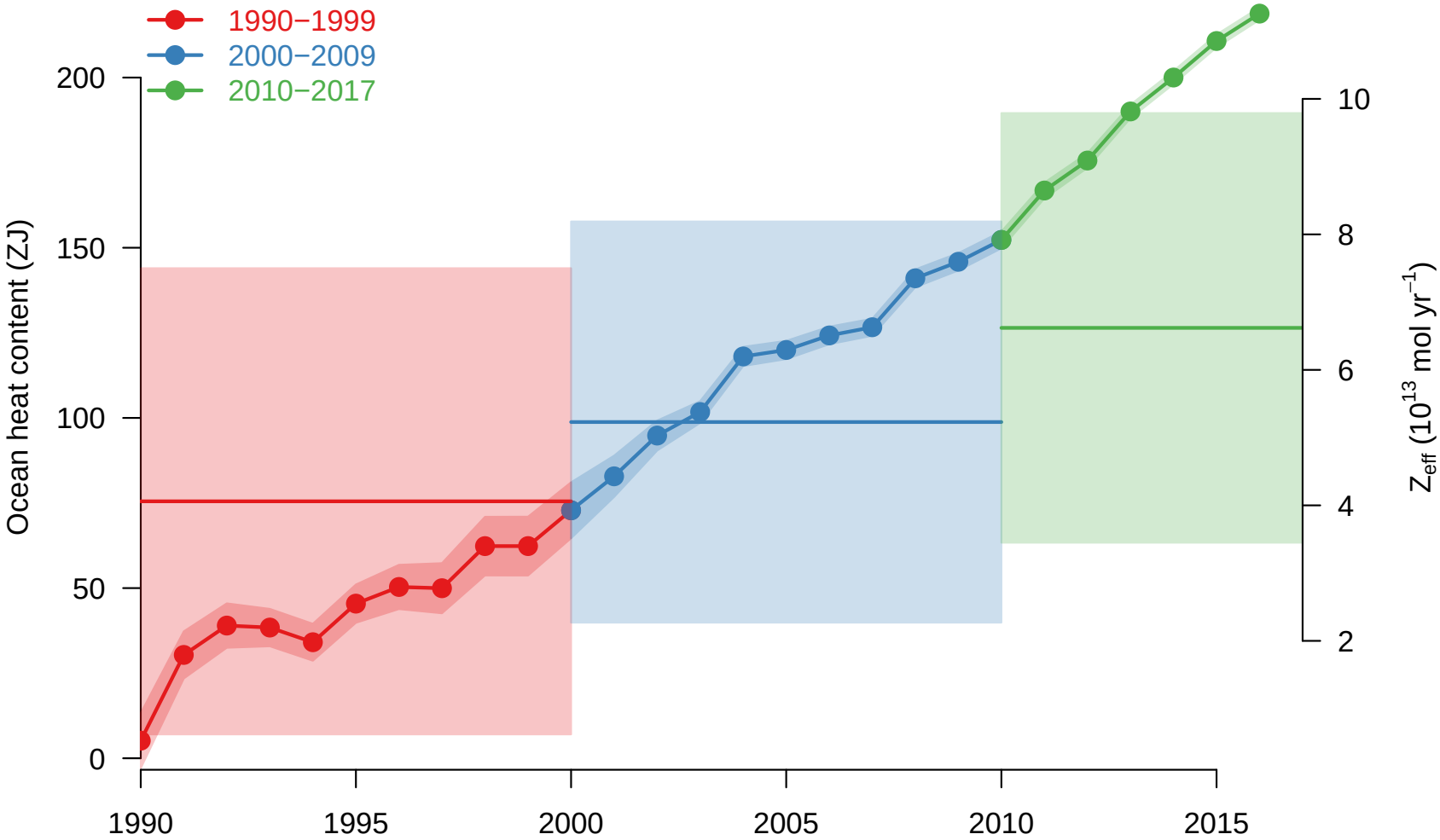
INPUTS

- $\Delta\delta(O_2/N_2)$ from SIO O_2 Program
- ΔCO_2 from SIO O_2 Program and NOAA
- F from GCP (CDIAC/BP)
- Z_{eff} from NOAA/NCEI ocean heat content

Global Carbon Budget: Inputs

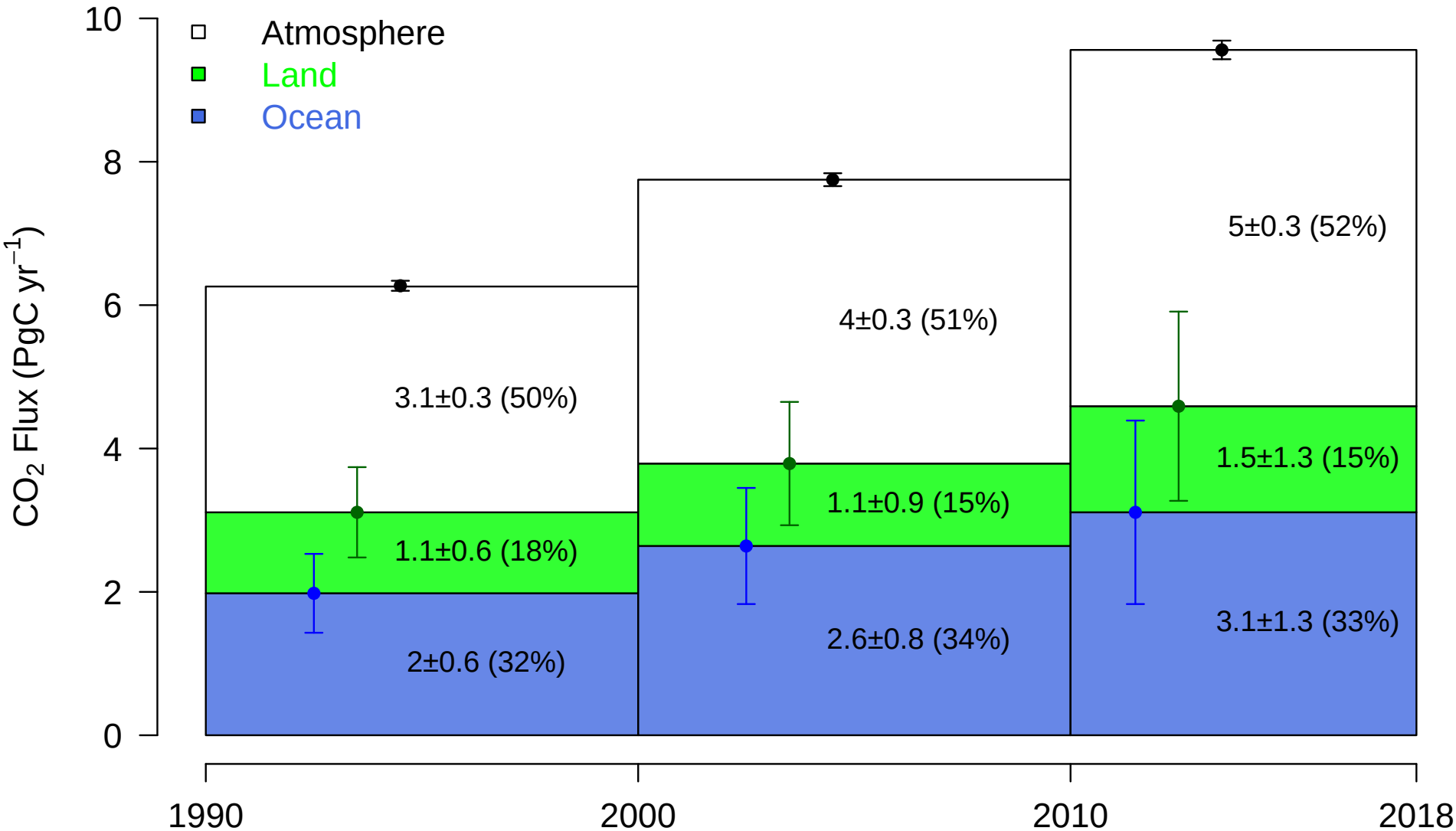


Global Carbon Budget: Inputs

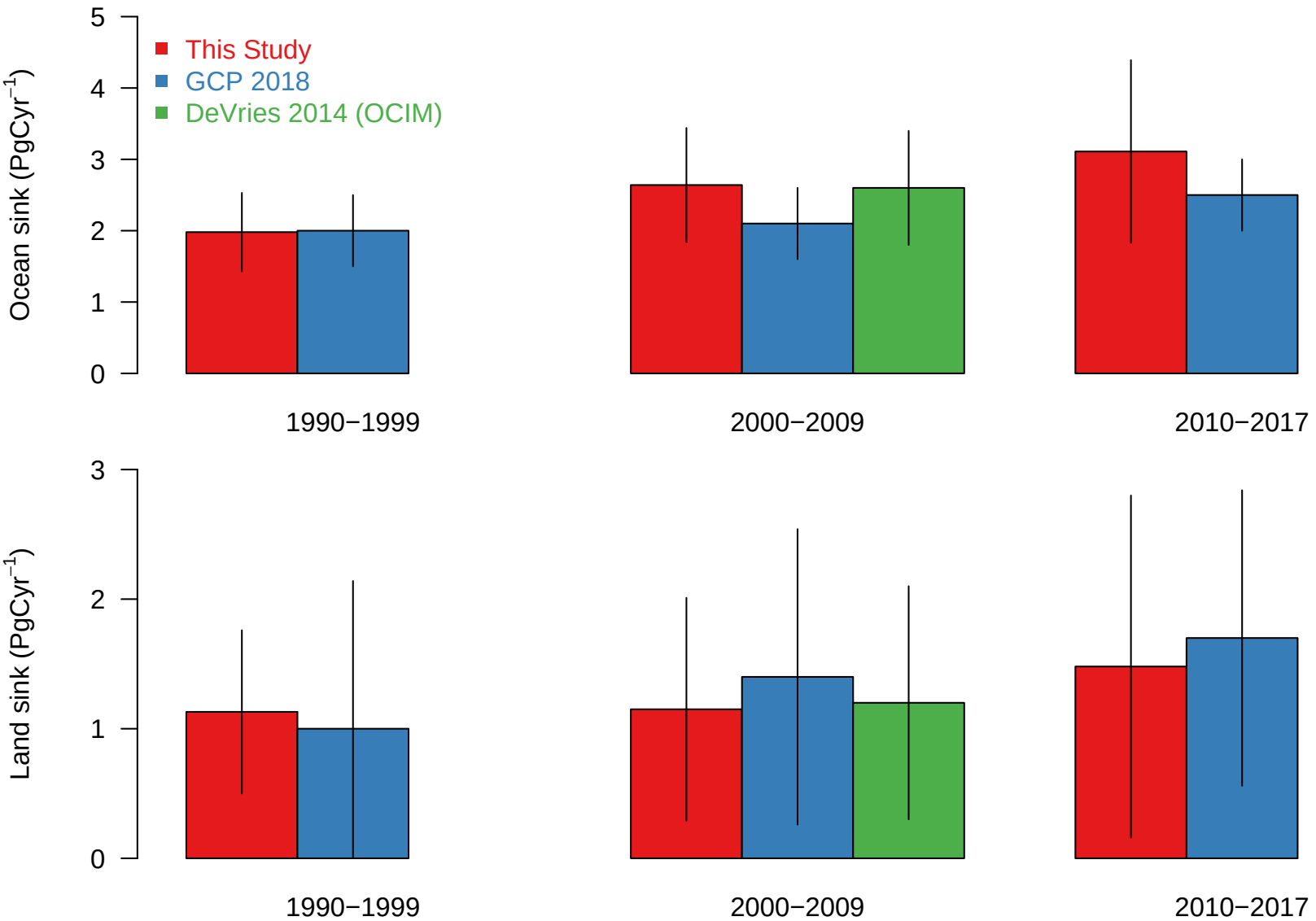


$$Z_{eff} = \left(\gamma_{O_2} - \frac{X_{O_2}}{X_{N_2}}\gamma_{N_2}\right)Q + Z_{atmD}$$

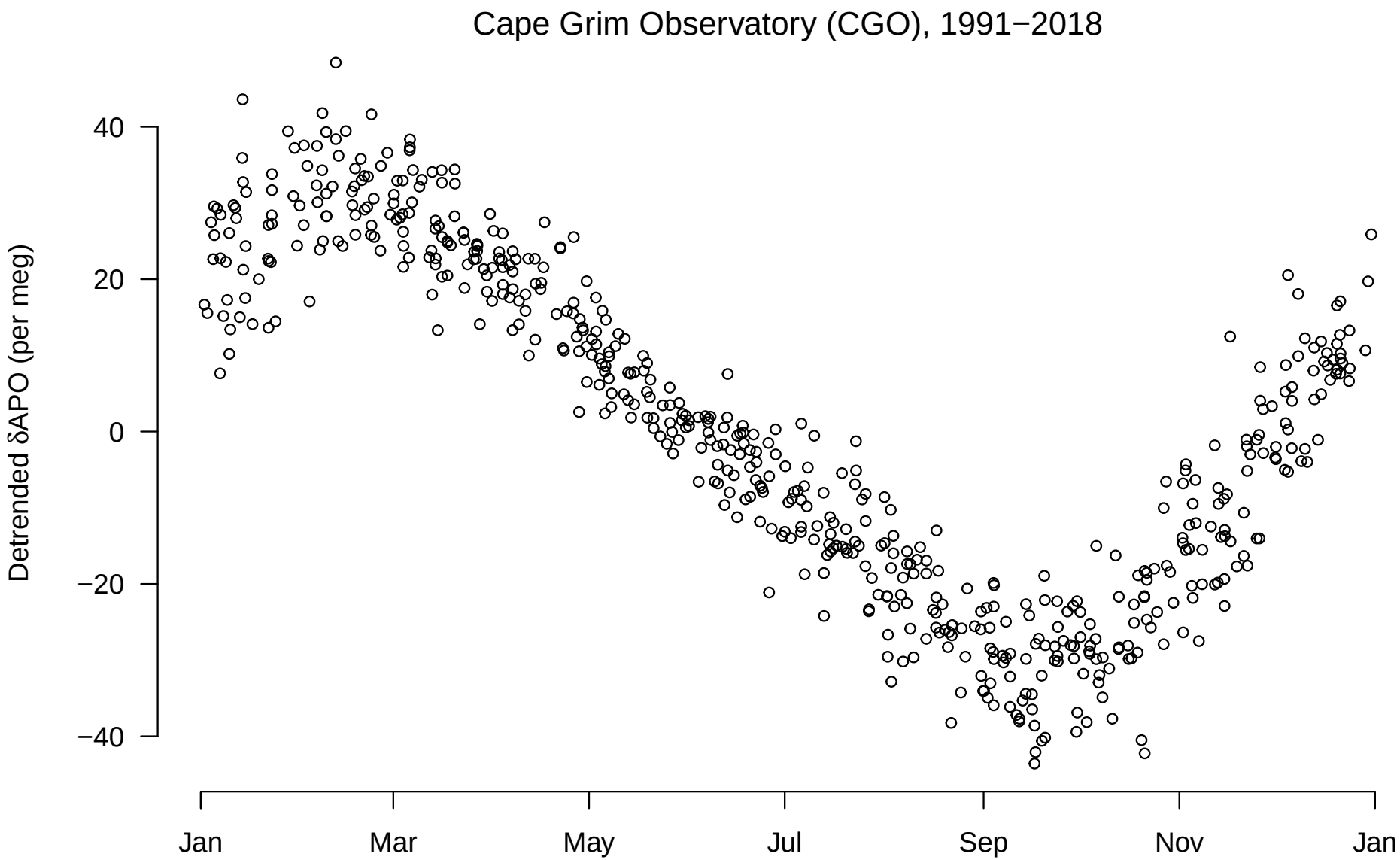
Global Carbon Budget: Results



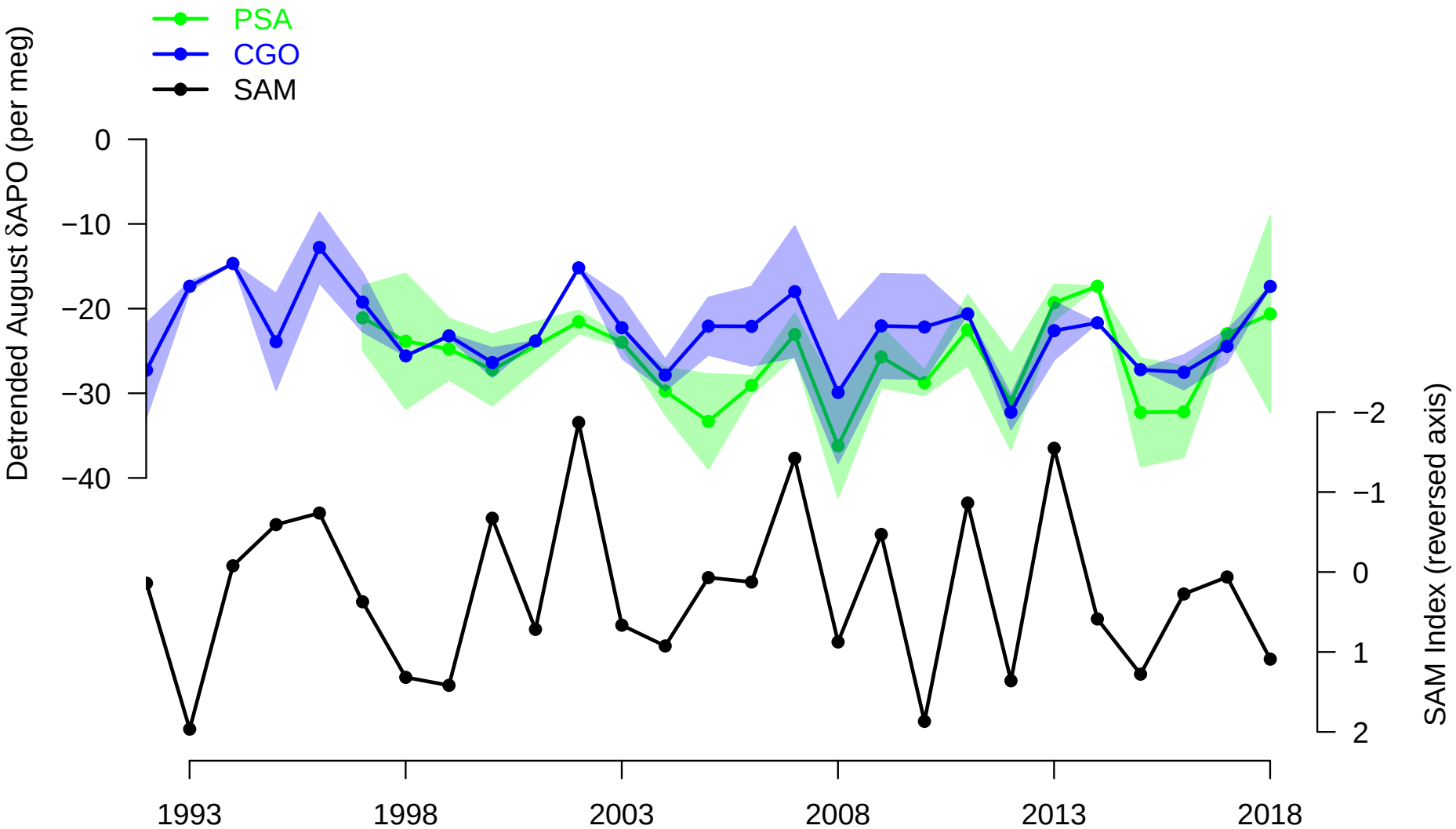
Global Carbon Budget: Comparisons to Other Estimates



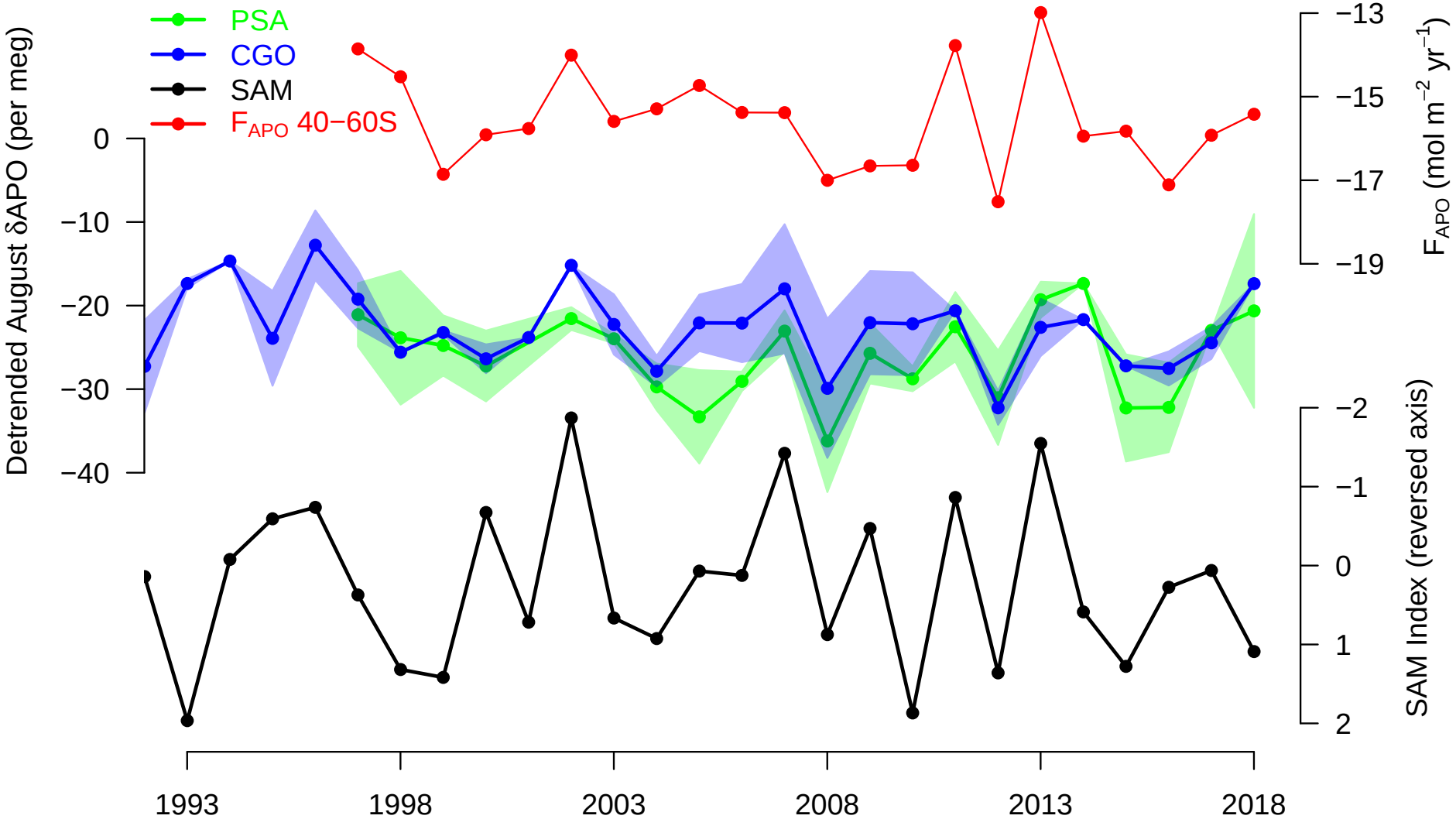
APO and the Southern Annular Mode



APO and the Southern Annular Mode



APO and the Southern Annular Mode



F_{APO} is inferred flux of APO from global atmospheric inversion of SIO data, using the Jena inversion scheme. Data courtesy of C. Rödenbeck of MPI-BGC.

- $\delta(O_2/N_2)$ and CO_2-based carbon budgets can constrain the land and ocean uptake over decadal time scales

- These data suggest an increasing ocean sink over the 1990–2017 period

- Small increase in land sink, but not well resolved given uncertainty

- Stations PSA and CGO show wintertime correlations of APO with the Southern Annular Mode

- Evidence suggests this is related to Southern Ocean ventilation

Global carbon budget terms, with $\alpha_{lnd} = 1.1$

Term	Symbol	Unit	1990–1999	2000–2009	2010–2017
CO_2 trend	ΔCO_2	ppm yr^{-1}	1.5 ± 0.1	1.9 ± 0.1	2.3 ± 0.1
APO trend	ΔAPO	per meg yr^{-1}	-8.0 ± 0.9	-10 ± 2.0	-12 ± 3
Ocean O_2 outgassing	Z_{eff}	10^{13} mol yr^{-1}	4.1 ± 3	5.2 ± 3	6.6 ± 3
OR of fossil fuels	α_F	mol mol^{-1}	1.40 ± 0.06	1.39 ± 0.06	1.37 ± 0.06
Fossil fuel emissions	F	Pg C yr^{-1}	6.3 ± 0.07	7.8 ± 0.1	9.6 ± 0.1
Atmospheric CO_2	A_{CO_2}	Pg C yr^{-1}	3.2 ± 0.3	4.0 ± 0.3	5.0 ± 0.3
Net land sink	L	Pg C yr^{-1}	1.1 ± 0.6	1.2 ± 0.9	1.5 ± 1.3
Net ocean sink	O	Pg C yr^{-1}	2.0 ± 0.6	2.6 ± 0.8	3.1 ± 1.3