Decadal variability and long-term trend in the northern APO deficit

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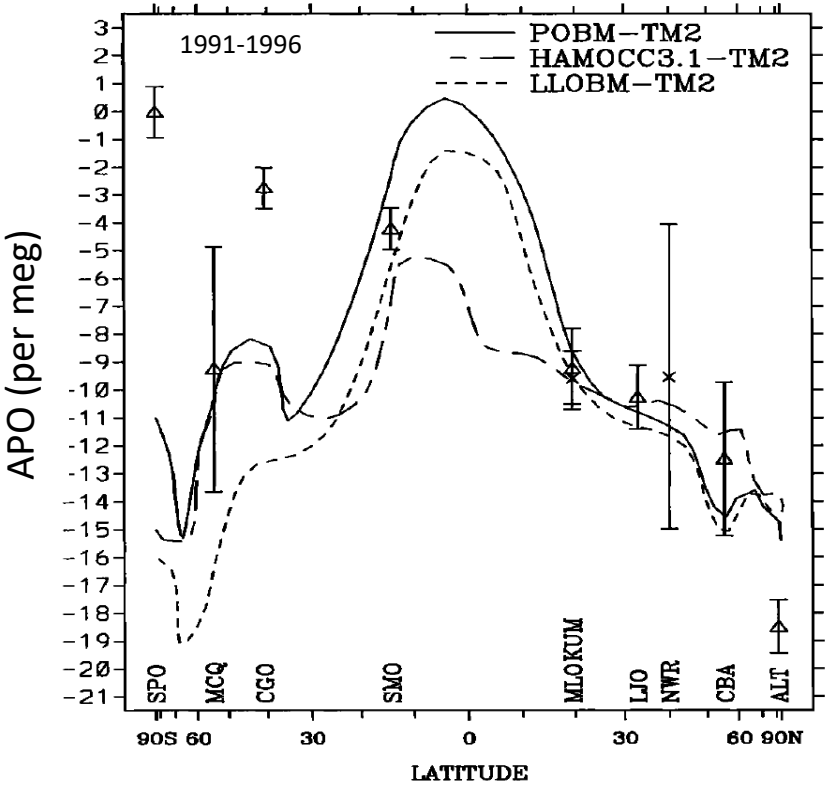
Stephens et al. 1998



Stephens, B. B., R. F. Keeling, M. Heimann, K. D. Six, R. Murnane and K. Caldeira (1998). "Testing global ocean carbon cycle models using measurements of atmospheric O2 and CO2 concentration." Global Biogeochemical Cycles 12(2): 213-230.

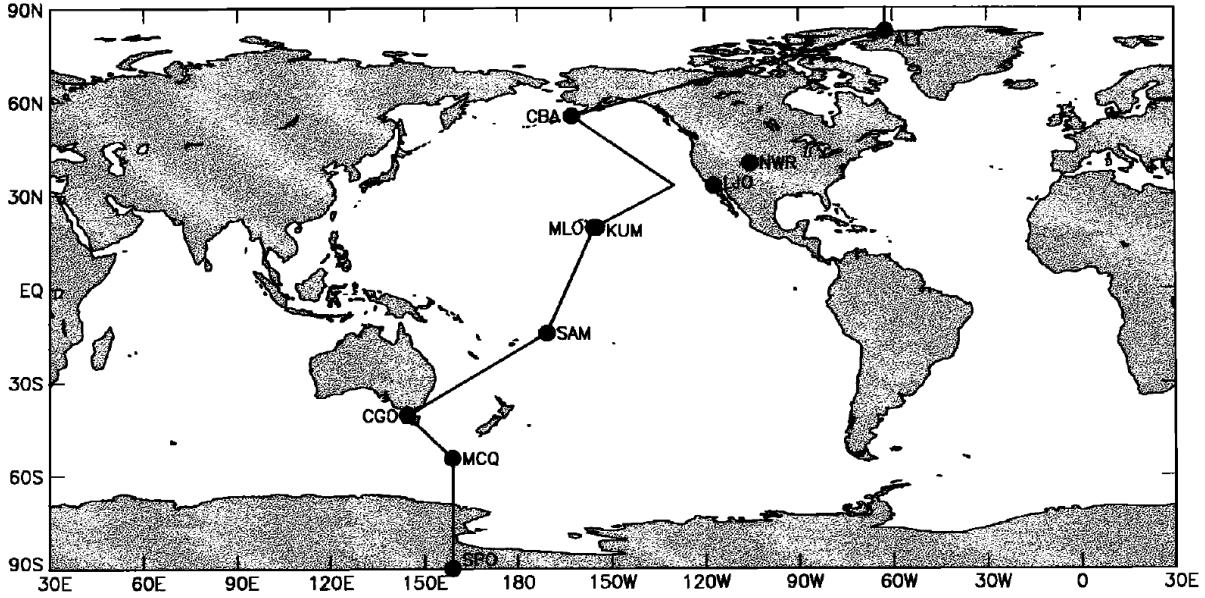
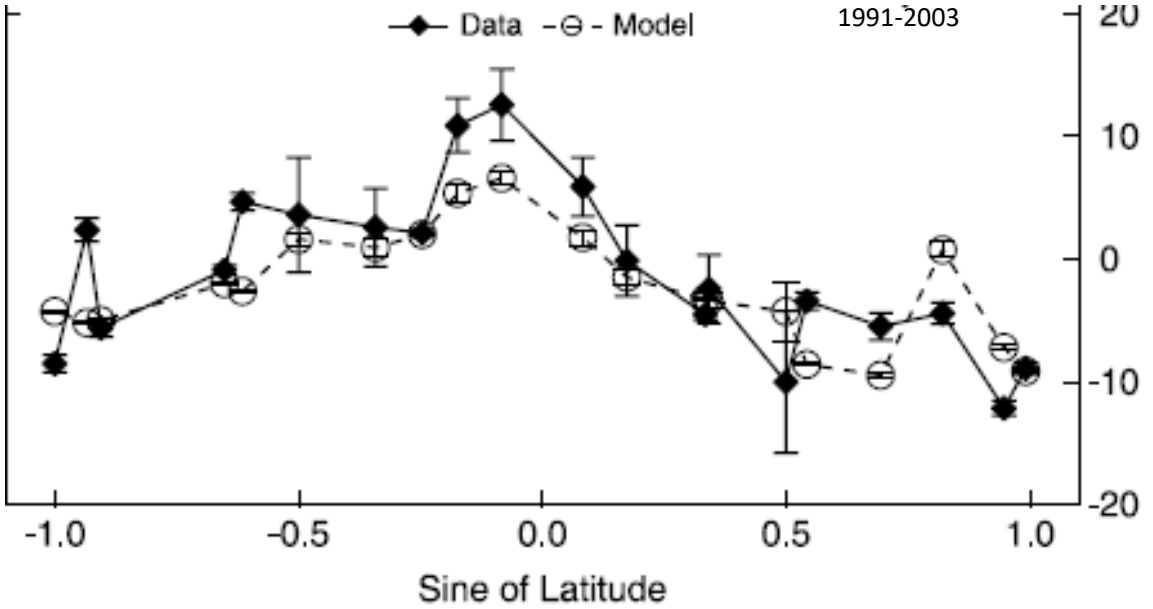


Figure 1. Showing the locations of the stations in the Scripps O_2/N_2 sampling network as listed in Table 1. The solid line indicates the surface transect used to present the model predictions in Figures 2-6.

Battle et al. 2006

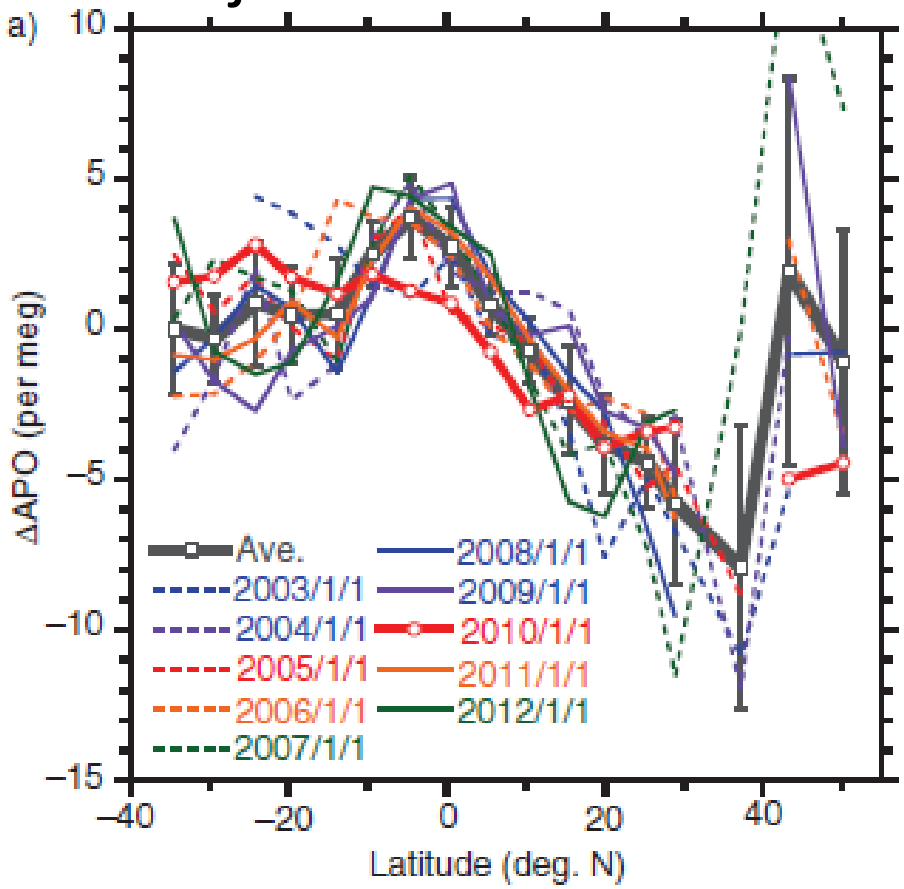


Battle, M., S. E. Mikaloff Fletcher, M. L. Bender, R. F. Keeling, A. C. Manning, N. Gruber, P. P. Tans, M. B. Hendricks, D. T. Ho, C. Simonds, R. Mika and B. Paplawsky (2006). "Atmospheric potential oxygen: New observations and their implications for some atmospheric and oceanic models." Global Biogeochemical Cycles **20(1): GB1010.**

Found Equatorial bulge

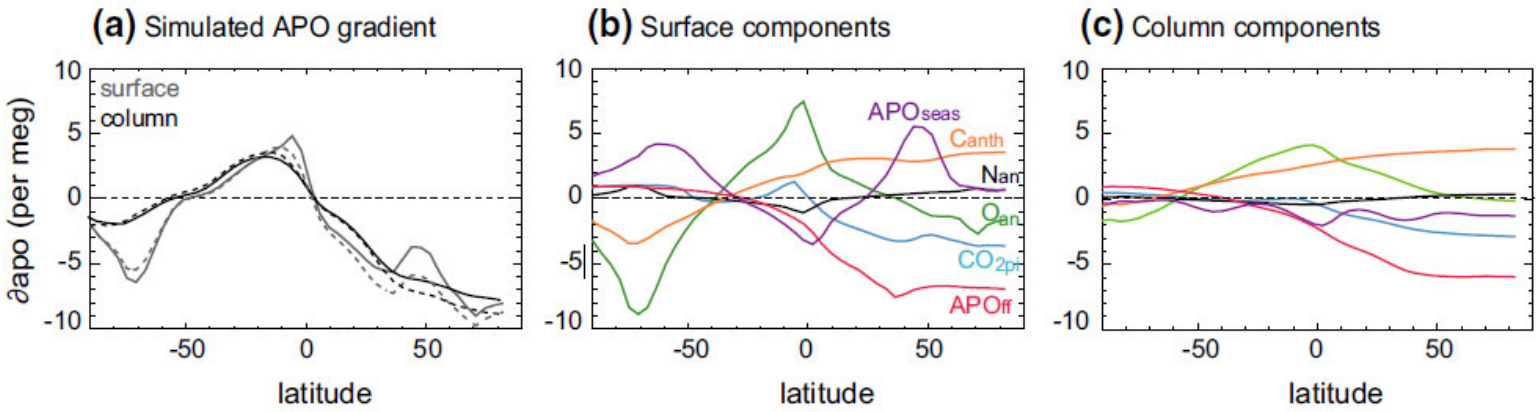
Confirmed and better quantified N deficit

Tohjima et al 2015



Tohjima, Y., Y. Terao, H. Mukai, T. Machida, Y. Nojiri and S. Maksyutov (2015). "ENSO-related variability in latitudinal distribution of annual mean atmospheric potential oxygen (APO) in the equatorial Western Pacific." Tellus B **67.**

Resplandy et al. 2016

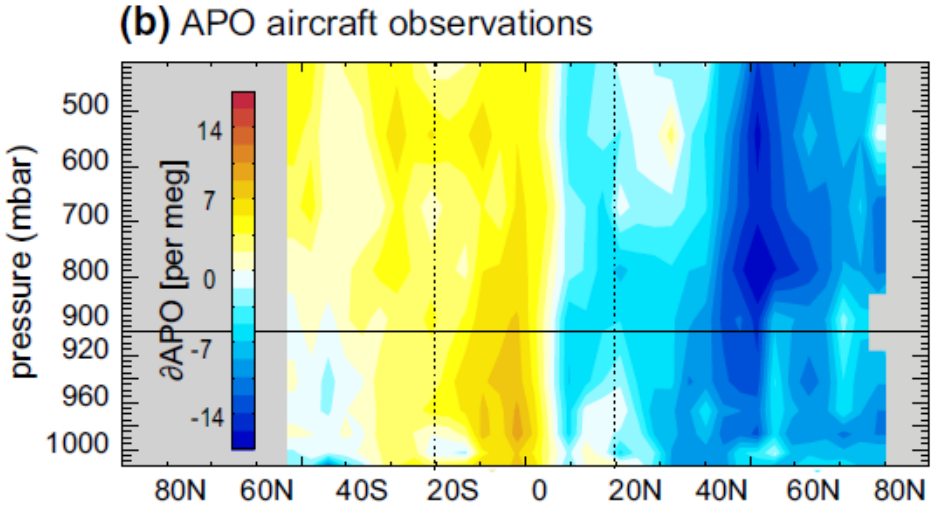


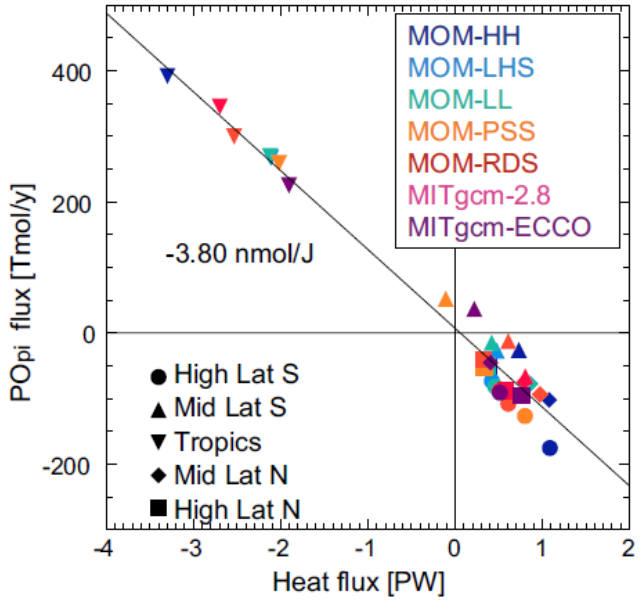
TM3 transport model. MITgcm-ECCO ocean fluxes

Resplandy, L., R. Keeling, B. Stephens, J. Bent, A. Jacobson, C. Rödenbeck and S. Khatiwala (2016). "Constraints on oceanic meridional heat transport from combined measurements of oxygen and carbon." Climate Dynamics 47: 3335-3357.

Shows northern deficit at mid latitudes similar to column average

Resplandy et al. 2016

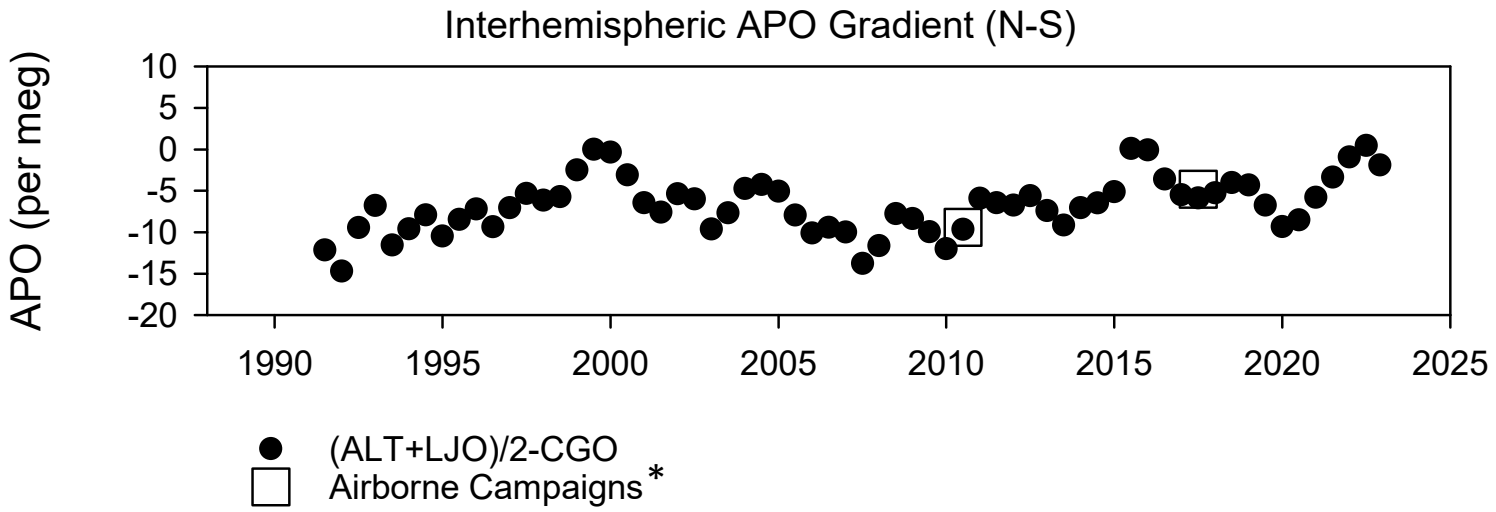




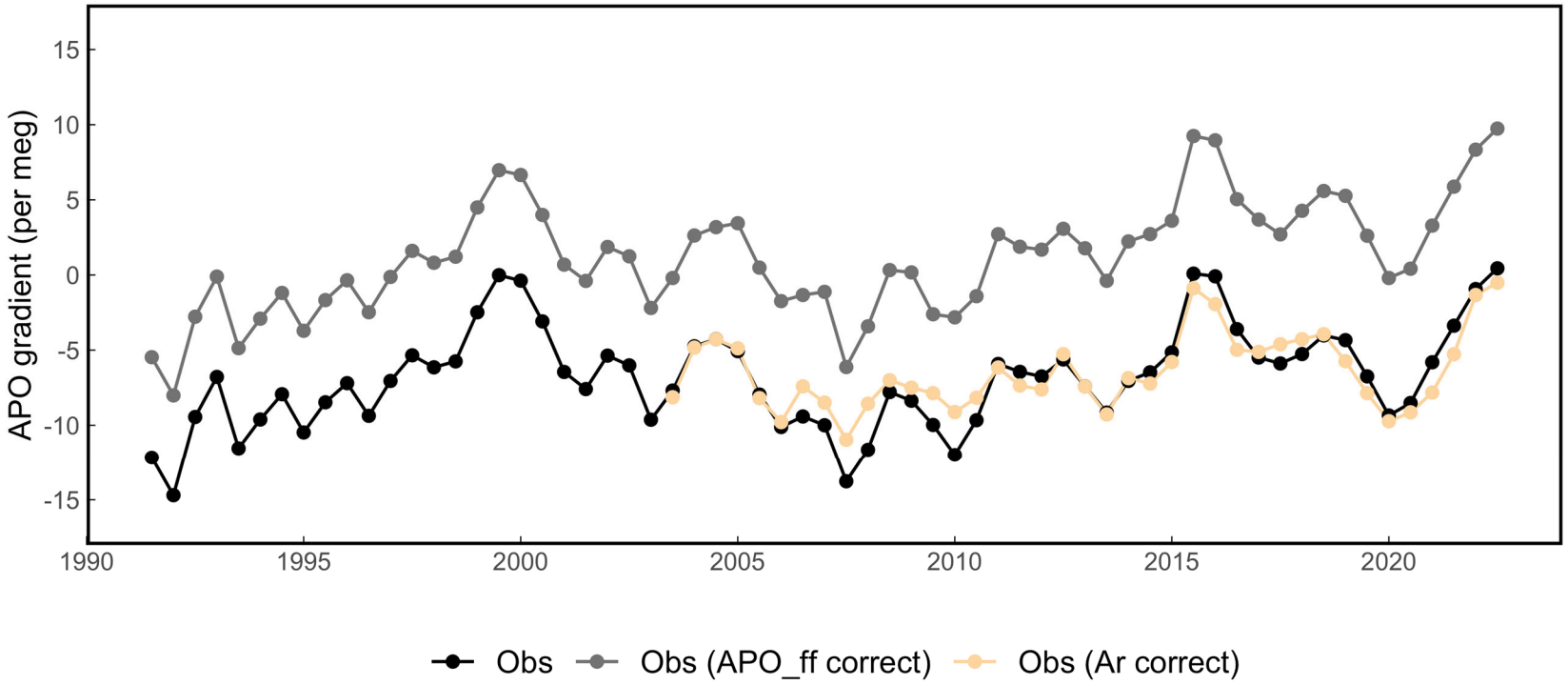
Shows northern deficit at mid latitudes similar to column average

Natural APO fluxes in different basins strongly correlated with air-sea heat fluxes
The sensitivity of -3.8 nmol/J largely explained by solubility alone, as expected because solubility impacts on O2 and CO2 add, while biological impacts partly cancel in APO.

The northern deficit also exhibits considerable interannual variability

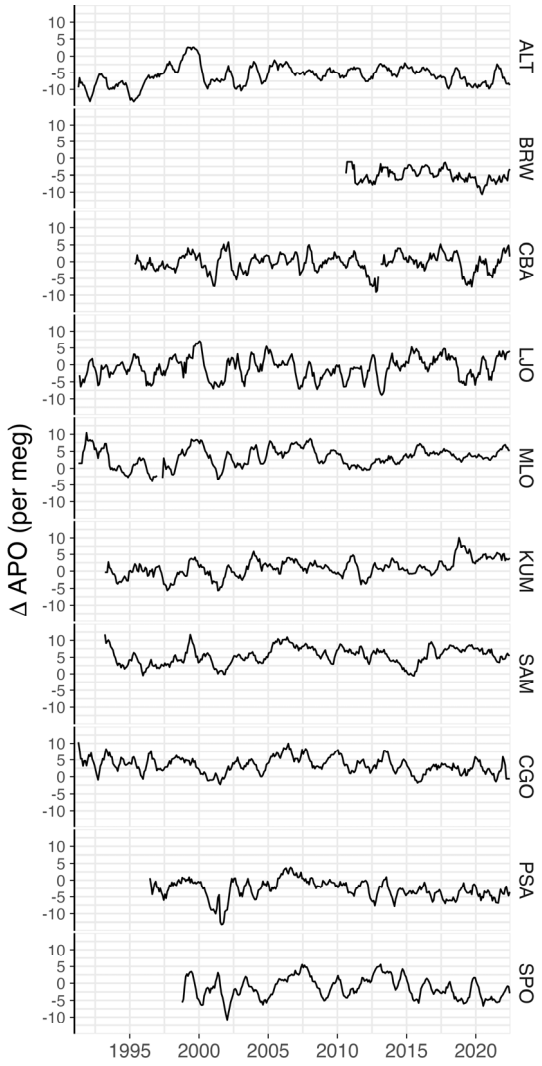


*HIPPO and AToM campaigns. N-S differences in column averages from 20° to Pole, 900-400mb



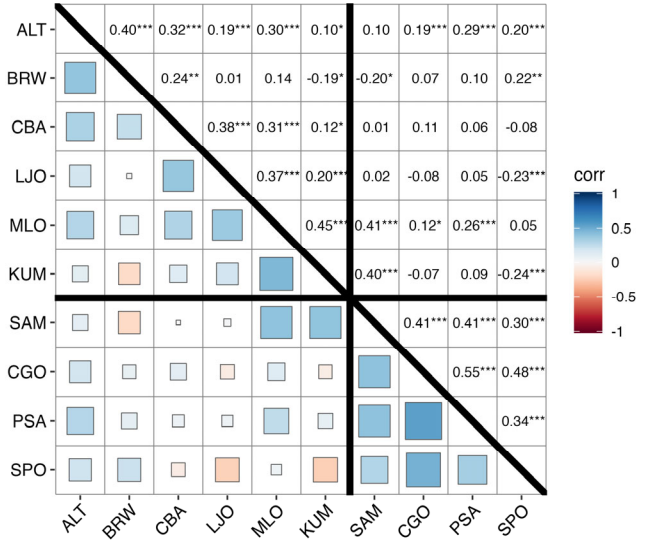
*Corrected data APO – $(1/3)*\delta(Ar/N_2)$

Seasonally detrended APO has considerable interannual variability

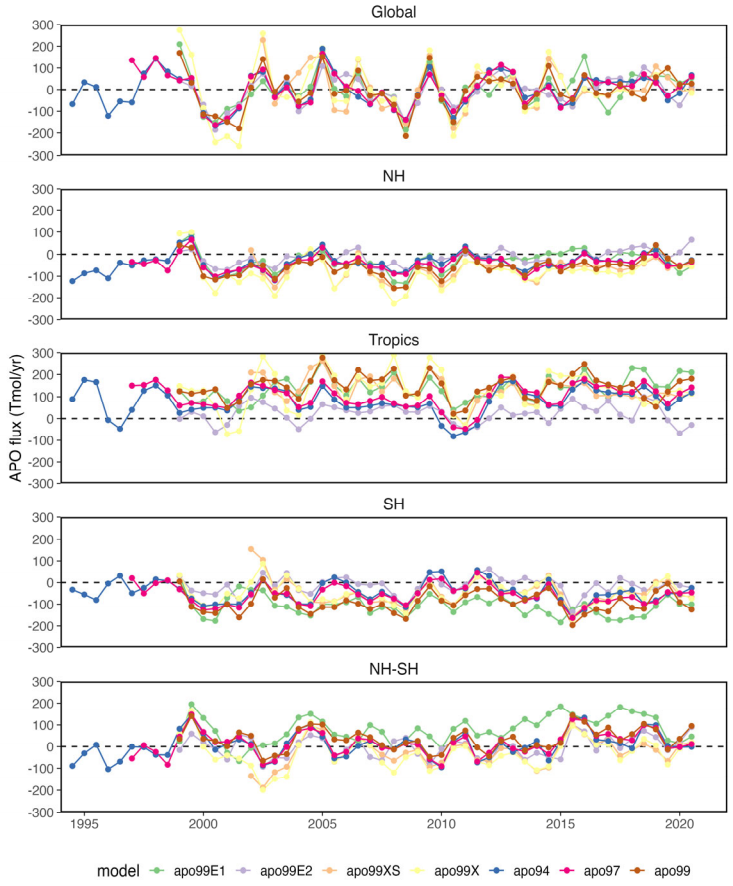


APO anomalies have been calculated relative to a global trend that accounts for fossil-fuel emissions and ocean uptake of anthropogenic CO2 (Joos pulse model, scaled to match Devries estimate)

Measurement artifacts? We believe much of the variability is real in part because stations that are close in latitude tend to have more shared variance



Christian Roedenbeck's APO inversions



	E1	E2	XS	X	94	97	99
ALT	✓		✓	✓	✓	✓	✓
CBA		✓	✓	✓		✓	✓
COI			✓	✓			
LJO	✓		✓	✓	✓	✓	✓
HAT			✓	✓			
MLO	✓		✓	✓			✓
KUM		✓	✓	✓	✓	✓	✓
SMO	✓		✓	✓	✓	✓	✓
CGO		✓	✓	✓	✓	✓	✓
PSA	✓		✓	✓		✓	✓
SPO		✓	✓	✓			✓
Ship			✓				

apo99E1 apo99E2 apo99XS apo99X apo94 apo97 apo99

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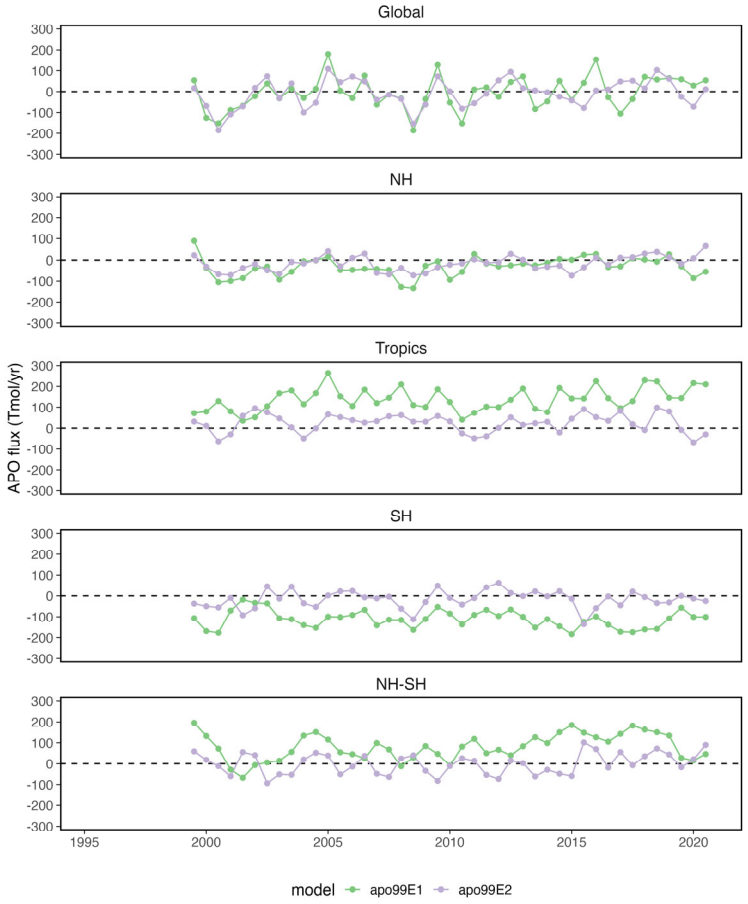

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ALT	✓		✓	✓	✓	✓	✓
CBA		✓	✓	✓		✓	✓
COI			✓	✓			
LJO	✓		✓	✓	✓	✓	✓
HAT			✓	✓			
MLO	✓		✓	✓			✓
KUM		✓	✓	✓	✓	✓	✓
SMO	✓		✓	✓	✓	✓	✓
CGO		✓	✓	✓	✓	✓	✓
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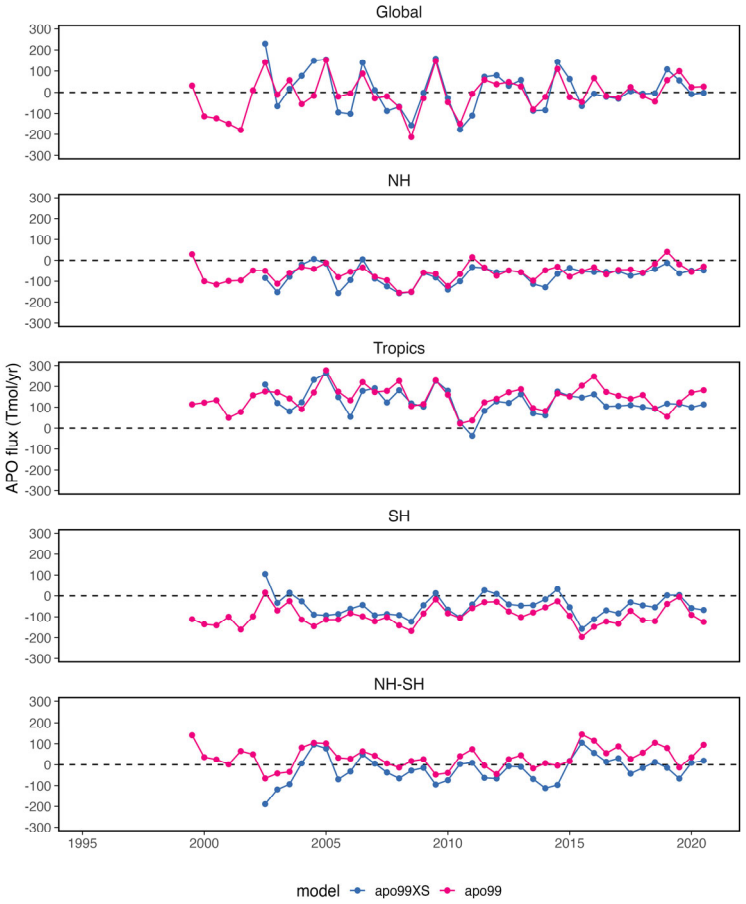

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KUM		✓	✓	✓	✓	✓	✓
SMO	✓		✓	✓	✓	✓	✓
CGO		✓	✓	✓	✓	✓	✓
PSA	✓		✓	✓		✓	✓
SPO		✓	✓	✓			✓
Ship			✓				

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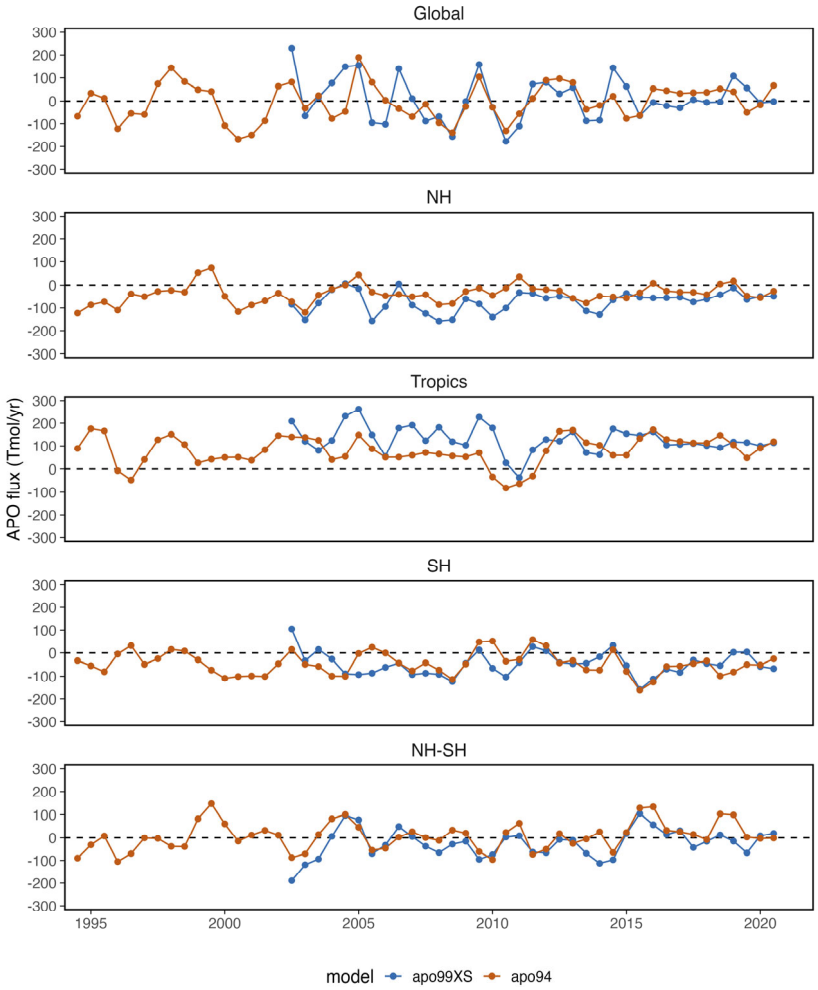


	E1	E2	XS	X	94	97	99
ALT	✓		✓	✓	✓	✓	✓
CBA		✓	✓	✓		✓	✓
COI			✓	✓			
LJO	✓		✓	✓	✓	✓	✓
HAT			✓	✓			
MLO	✓		✓	✓			✓
KUM		✓	✓	✓	✓	✓	✓
SMO	✓		✓	✓	✓	✓	✓
CGO		✓	✓	✓	✓	✓	✓
PSA	✓		✓	✓		✓	✓
SPO		✓	✓	✓			✓
Ship			✓				

apo99E1 apo99E2 apo99XS apo99X apo94 apo97 apo99

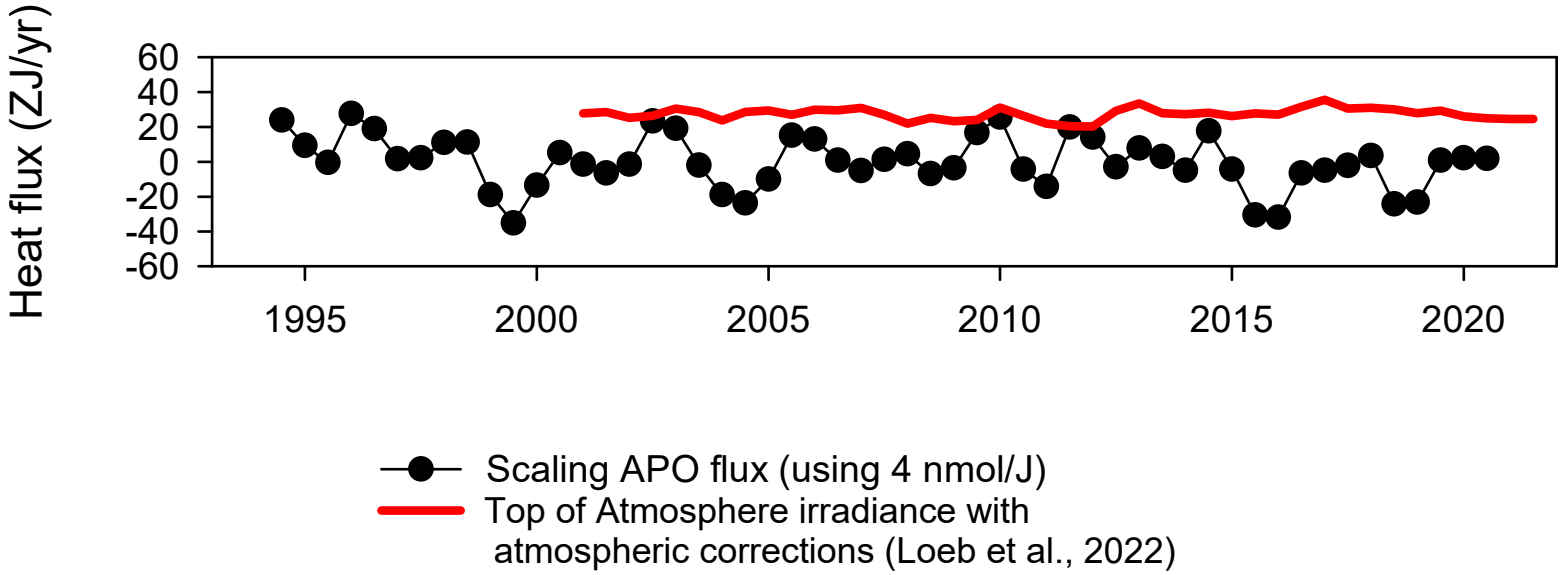
Comparing APO inversion results to heat-flux data

Heat flux asymmetry = $F_{>20°N} - F_{<20°S}$

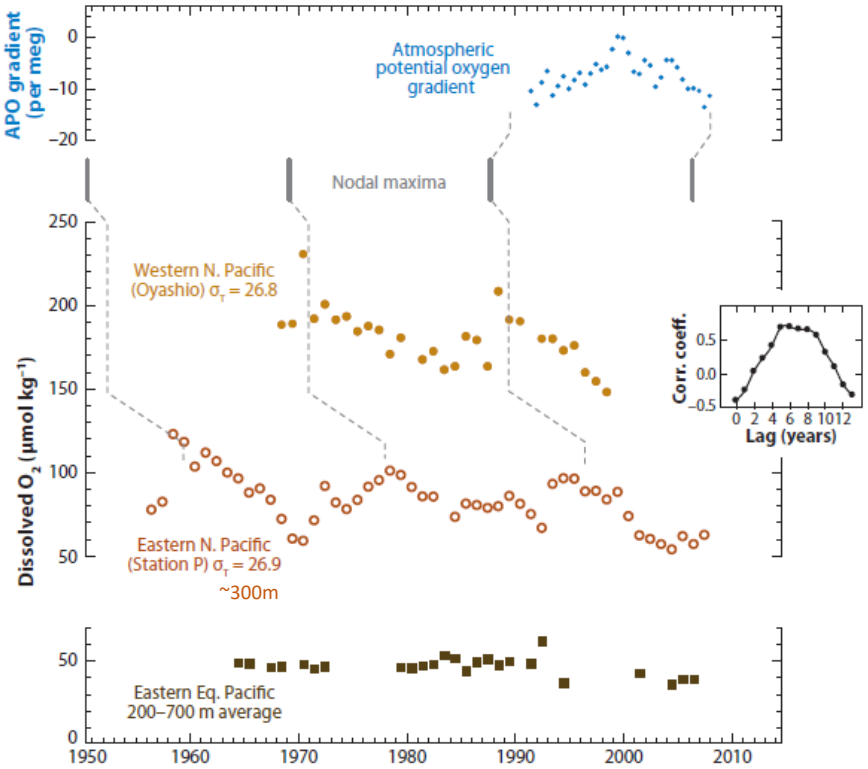
F = flux into atmosphere from ocean

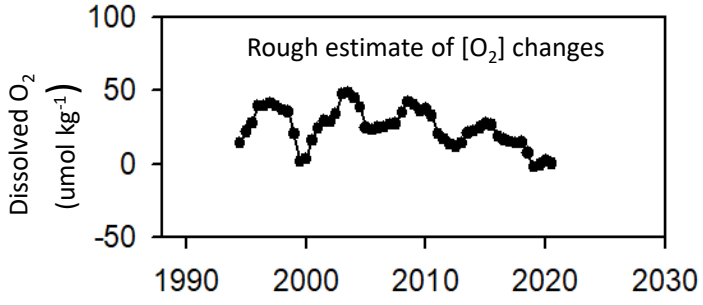
Positive: Extratropical oceans are warming atmosphere more in NH than SH

Resplandy et al 2016 relates steady state flux asymmetry in APO to heat flux assymmetry



Comparing APO fluxes for northern hemisphere >20N with dissolved O2 data





<u>Basis of rough estimate :</u>

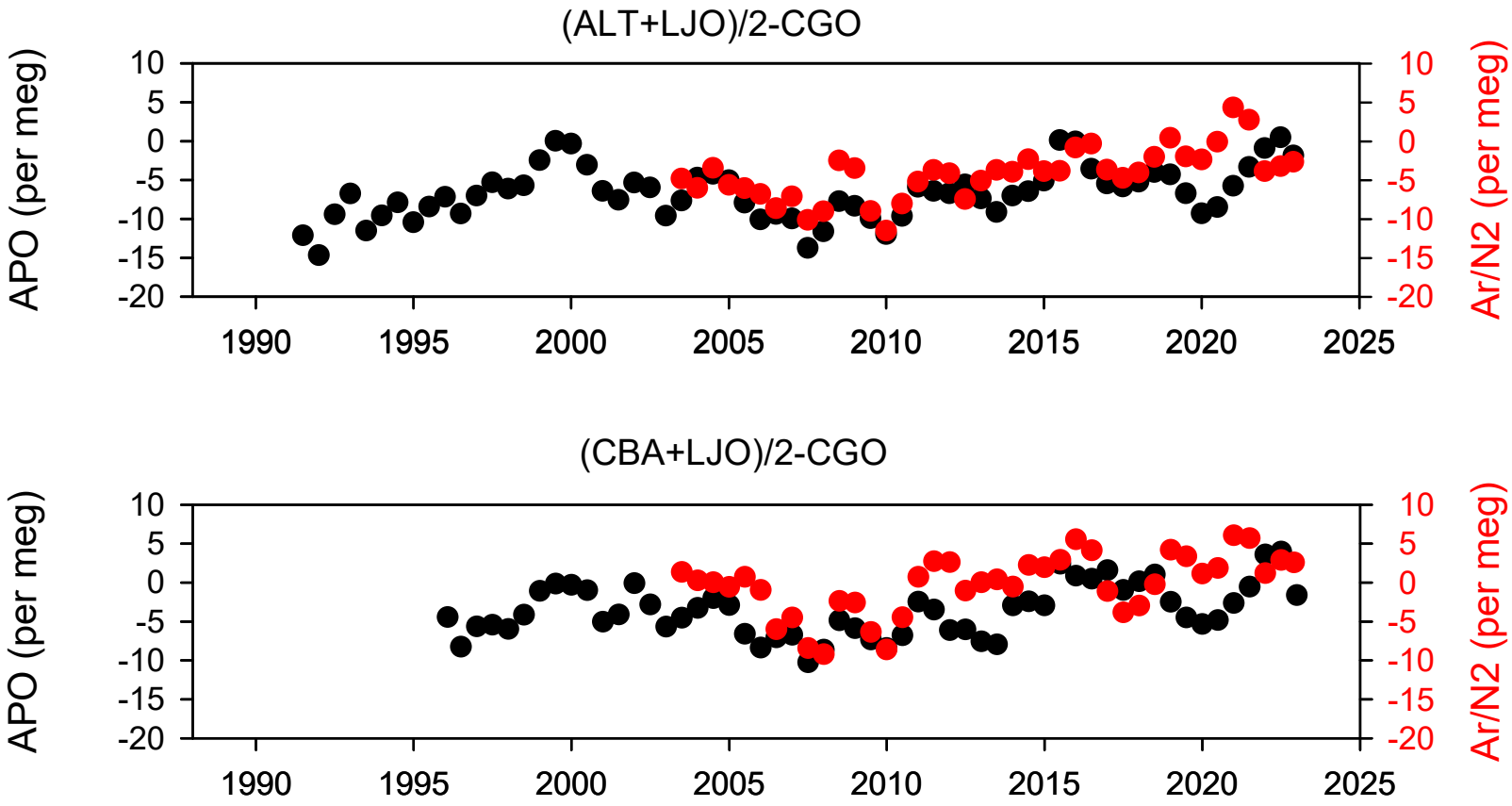
Integrate APO94 fluxes from 20-90N

Spread cumulative flux over ocean volume:

Ocean area 7.5 million sq km

Depth 400m

Ar/N2 data offer a puzzling complement



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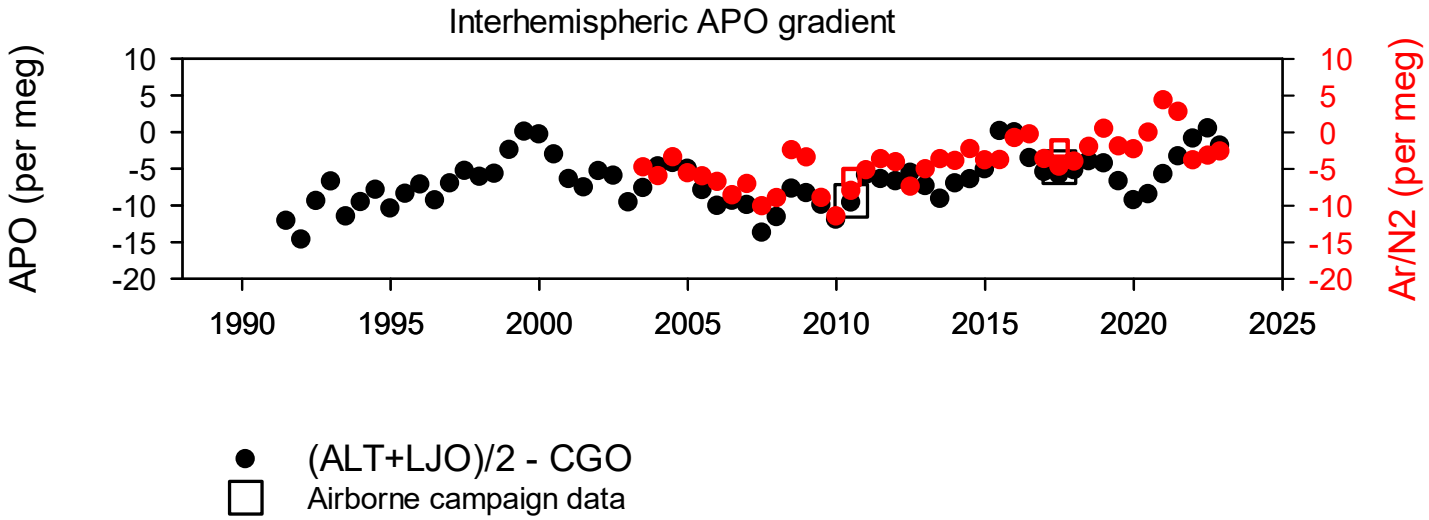
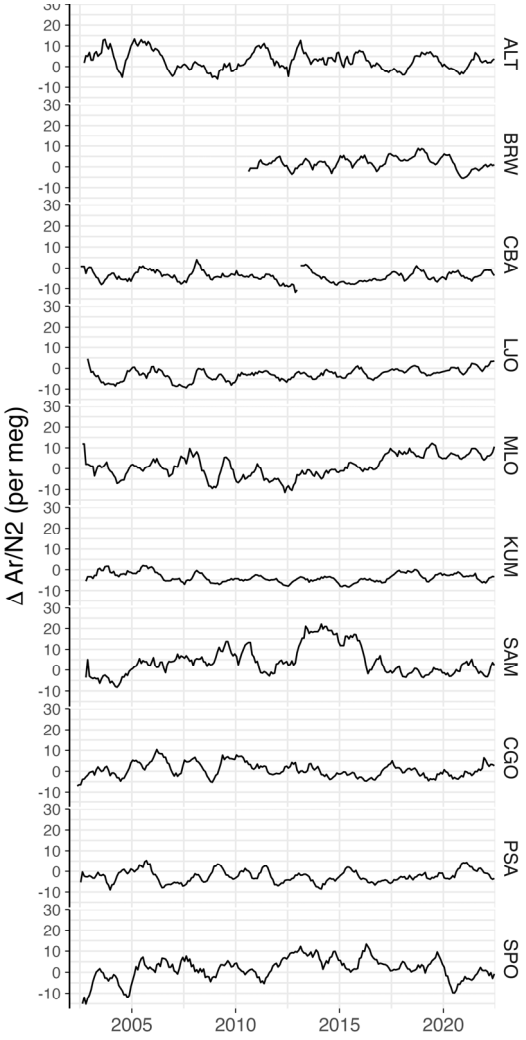
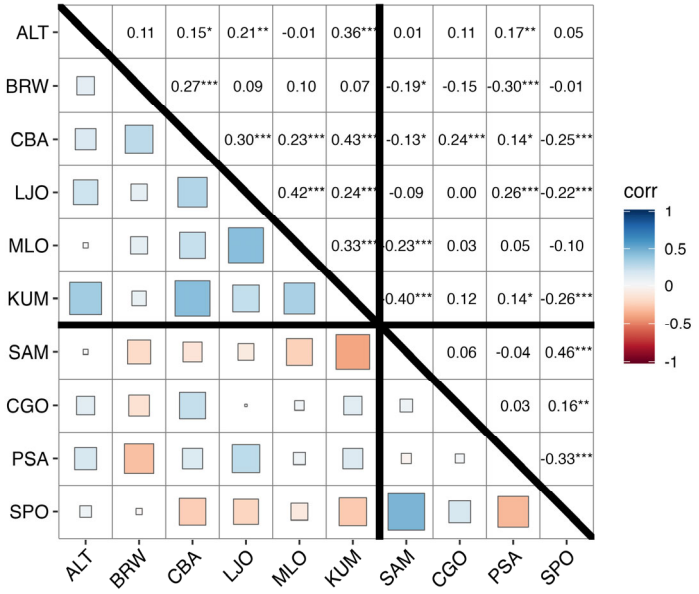


Seasonally detrended Ar/N2 also has considerable interannual variability



APO anomalies have been calculated relative to a stiff spline to remove global trend

Measurement artifacts? Unlike for APO, we don't have strong indications that these signals are real atmospheric variability.



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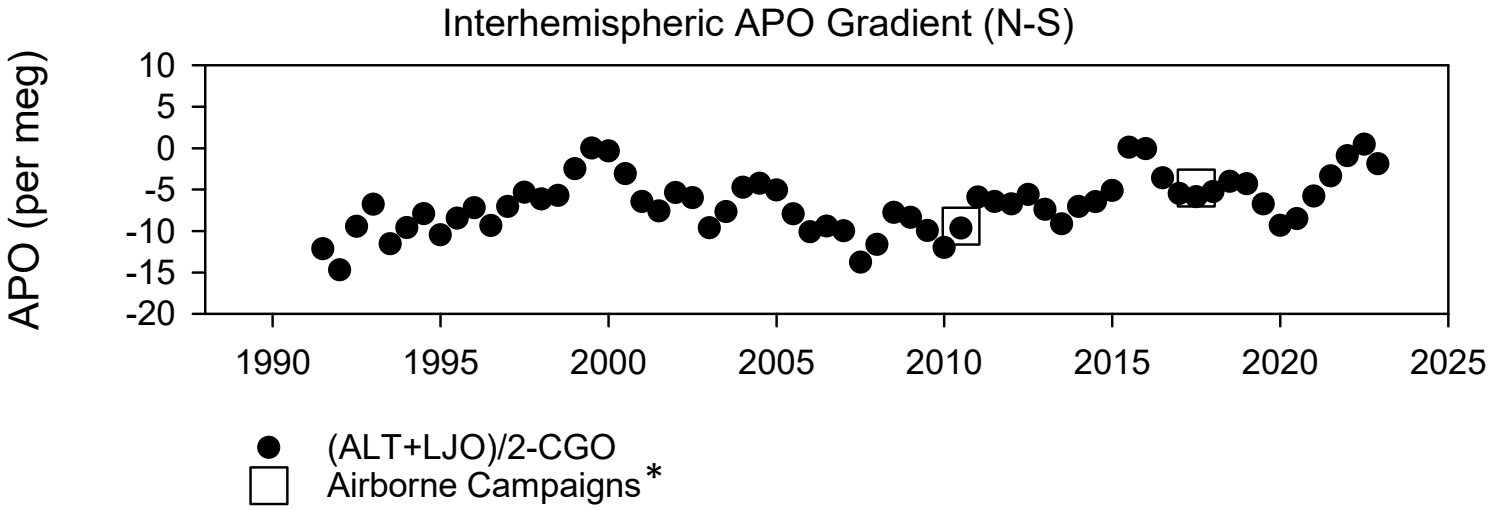

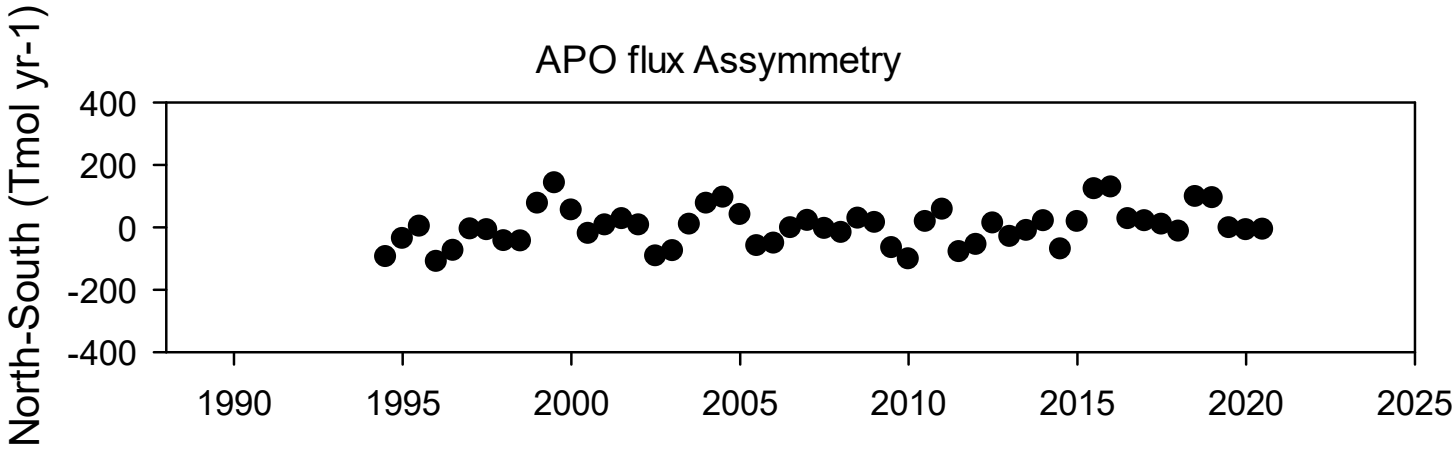

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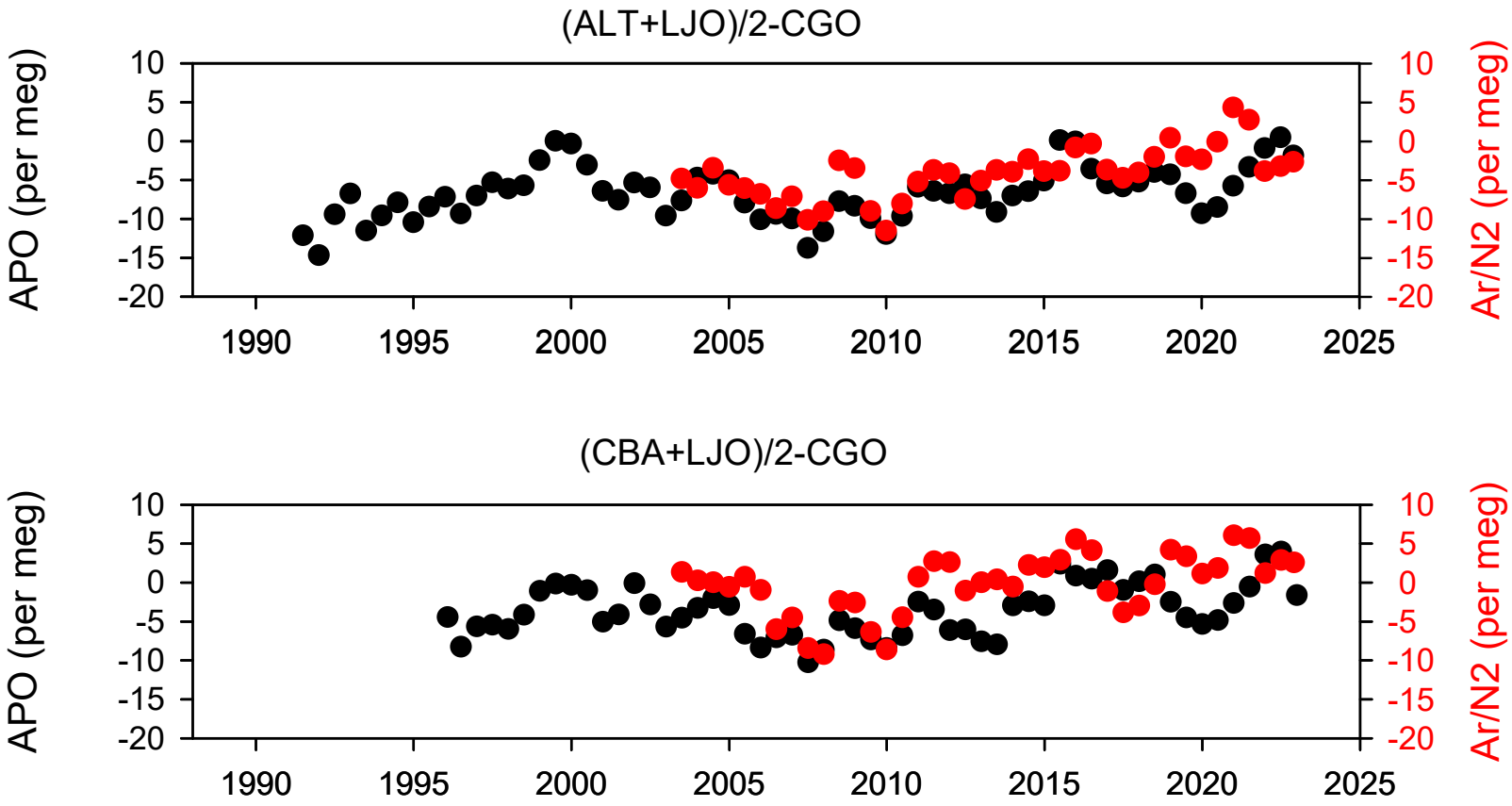

Summary

- A deficit of ~ 5 to 10 ppm in Northern Hemisphere APO is found in station date, ship, and airborne measurements.
- The deficit has components from fossil-fuel burning, uptake of anthropogenic CO2, and natural ocean fluxes.
- The natural component seems strongly tied to hemispheric ocean heat flux asymmetry
- The deficit also varies on interannual and decadal timescales
- Much of this variability appears robust (not artifact)
- Variability does not seem connected to heat flux variability, but perhaps could be due to ventilation changed not tied to heat. North Pacific shows variations in ventilation of similar (?) magnitude.
- Ar/N2 also exhibits northern deficit which is also variable. Ar/N2 gradient is hard to understand based on ocean heat fluxes. Correlates with APO changes at ratio of ~ 1 permeg/permeg.