Atmospheric Oxygen Measurement across the Atlantic Ocean

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Workshop on Atmospheric Oxygen 4

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MAX PLANCK INSTITUTE FOR BIOGEOCHEMISTRY

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Talk Overview

- Motivations and Background on Atmospheric Measurement over the ocean
- Atmospheric O_2 measurements over the Atlantic
  - Installation of the measurement system on board the Cap San Lorenzo Hamburg Süd Ship)
  - Seasonality in atmospheric O_2, CO_2, and APO across the Atlantic Ocean at different latitudes.
  - Variability in the position of the ITCZ
- Jena CarboScope APO Inversion
- Future ideas for the HAM shipboard data

Motivations

- To fill in a gap in the global network, especially in oceanic regions.
- Key advantages of deploying an in-situ system on a commercial container ship:
  - Multiple measurements can be combined into discrete latitudes so several virtual stations are collected from a single measurement system → cost effective.
  - Avoids technical problems arising from potential calibration offsets between different measurement systems.

Some useful things to know about atmospheric O_2

- Atmospheric O_2 is reported as $\delta(O_2/N_2)$ ratios, because O_2 is not a trace gas, and therefore its mole fraction is affected by small changes in other gas species.
- Atmospheric O_2 is reported in units of 'per meg', a dimensionless unit equivalent to 0.001 per mil.
- 5 per meg change in O_2 ~ equivalent to 1 ppm change in CO_2.
- We can combine measurements of atmospheric O_2 and CO_2 to calculate the tracer '**Atmospheric Potential Oxygen**', known as **APO**:

$$APO \sim O_2 + (\alpha_L \times CO_2)$$

α_L = O_2:CO_2 ratio of terrestrial biospheric processes (-1.1:1.0)

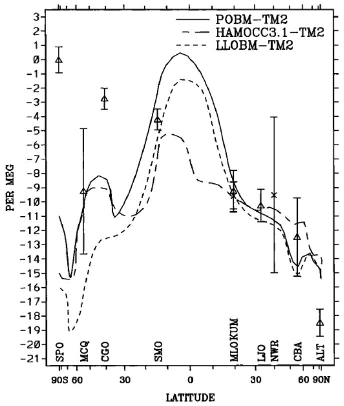
Units of APO are also 'per meg'

- APO is **conservative** with respect to land biospheric processes, and only reflects **oceanic** and **fossil fuel** influences.

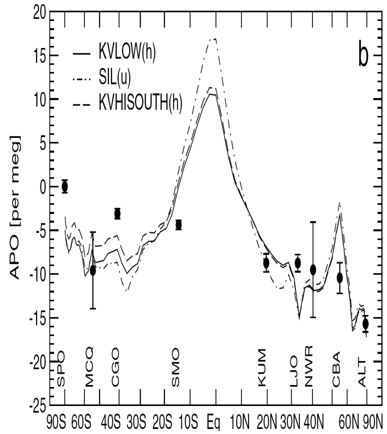
Previous Studies on APO across the Pacific Ocean

Model

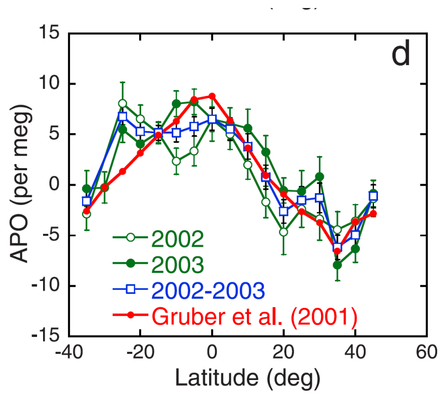
Shipboard Measurement



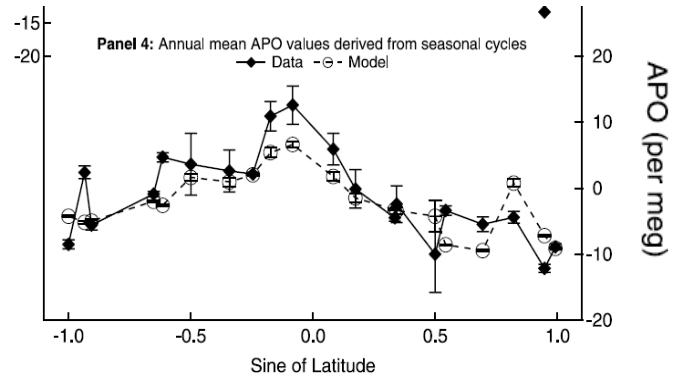
Stephens *et al.*, GBC (1998)



Gruben *et al.*, GBC (2001)



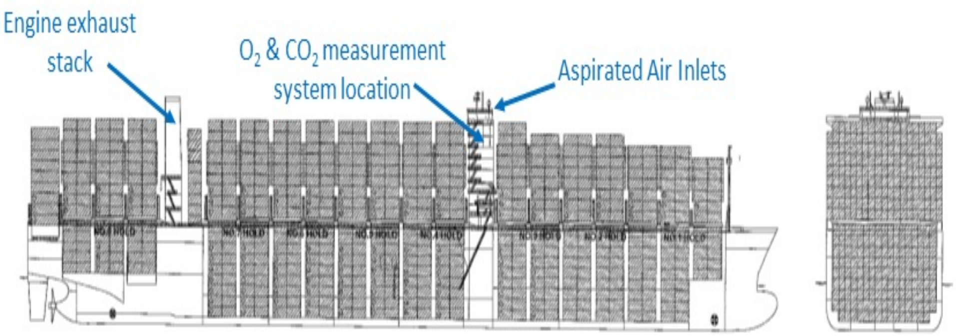
Tohjima *et al.*, GRL (2005)



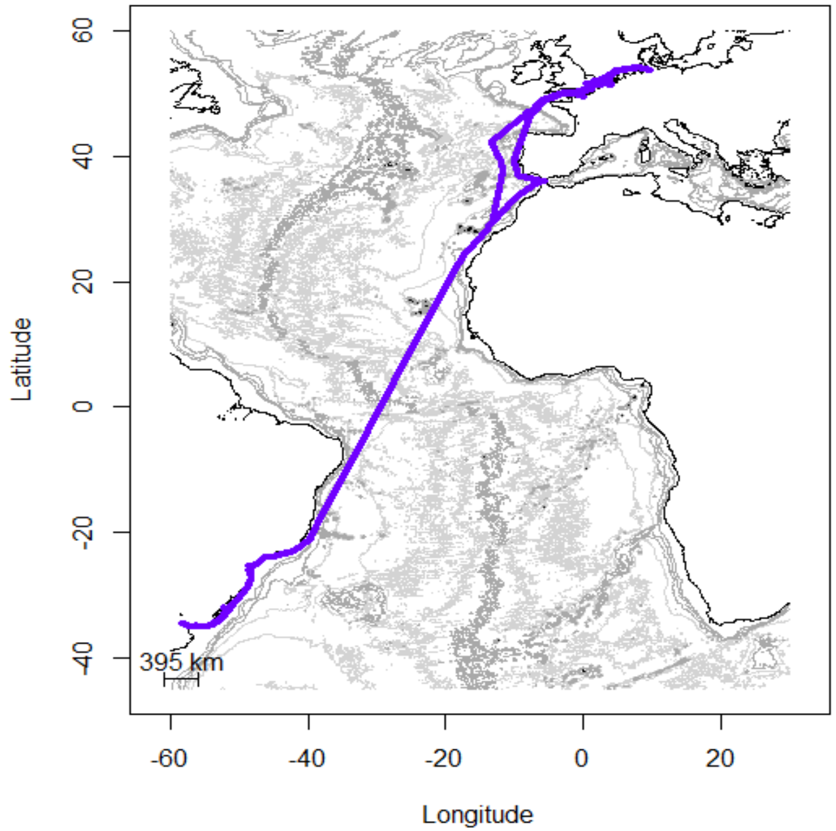
Battle *et al.*, GBC (2006)

- Equatorial APO bulge caused mostly by **thermally induced O_2 outgassing**

Installation of the Shipboard Atmospheric Measurement

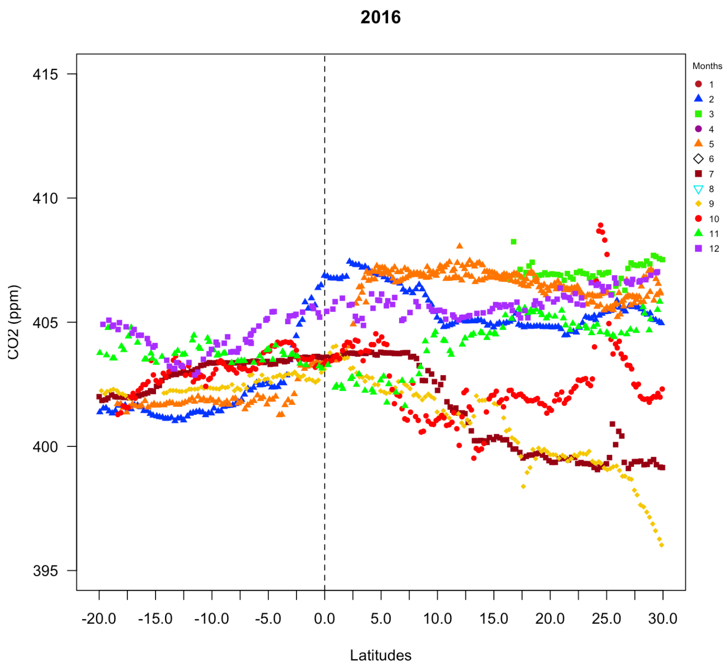


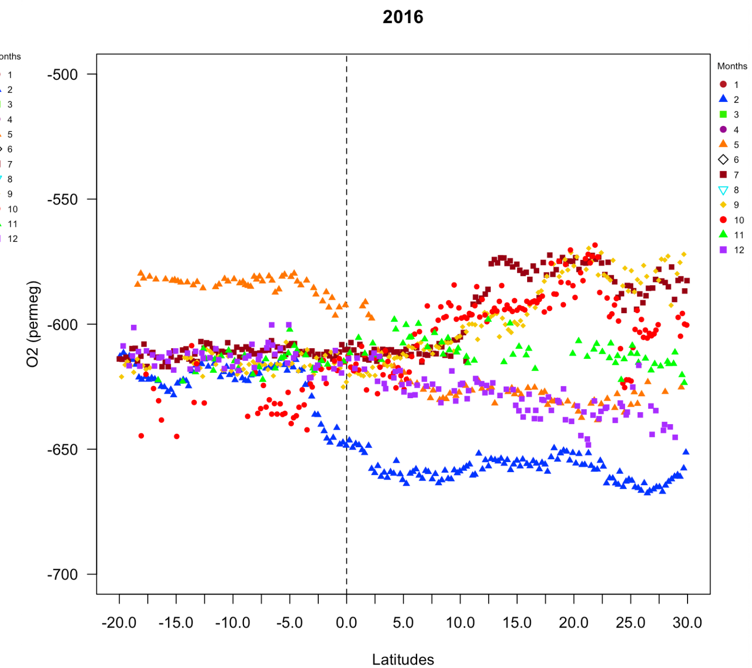
- Takes 8 weeks to travel from Hamburg, Germany, to Buenos Aires, Argentina, and back.
- Stop in port 14 times in 12 different locations during a complete route.
- The port data (i.e. ship's speed < 5 mph) are removed.

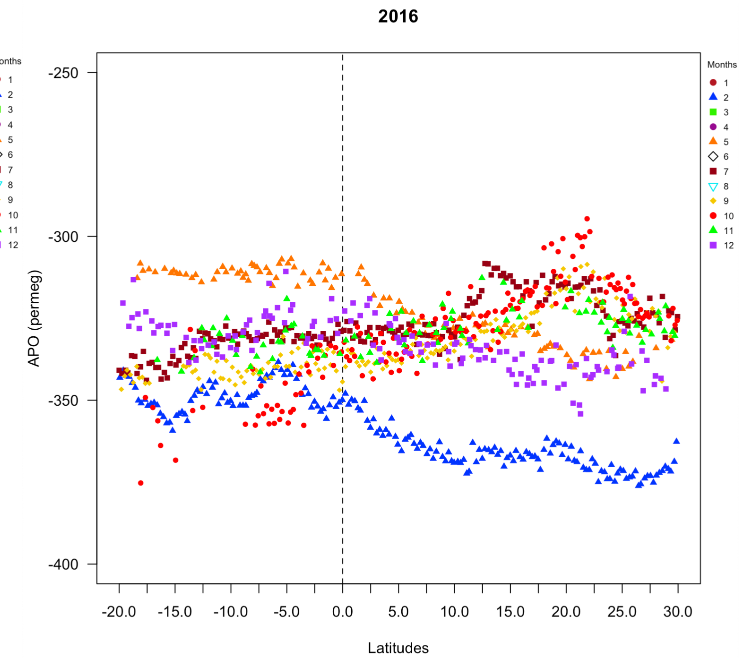


Pickers, 2016.

Meridional Transects of O_2, CO_2 and APO across the Atlantic

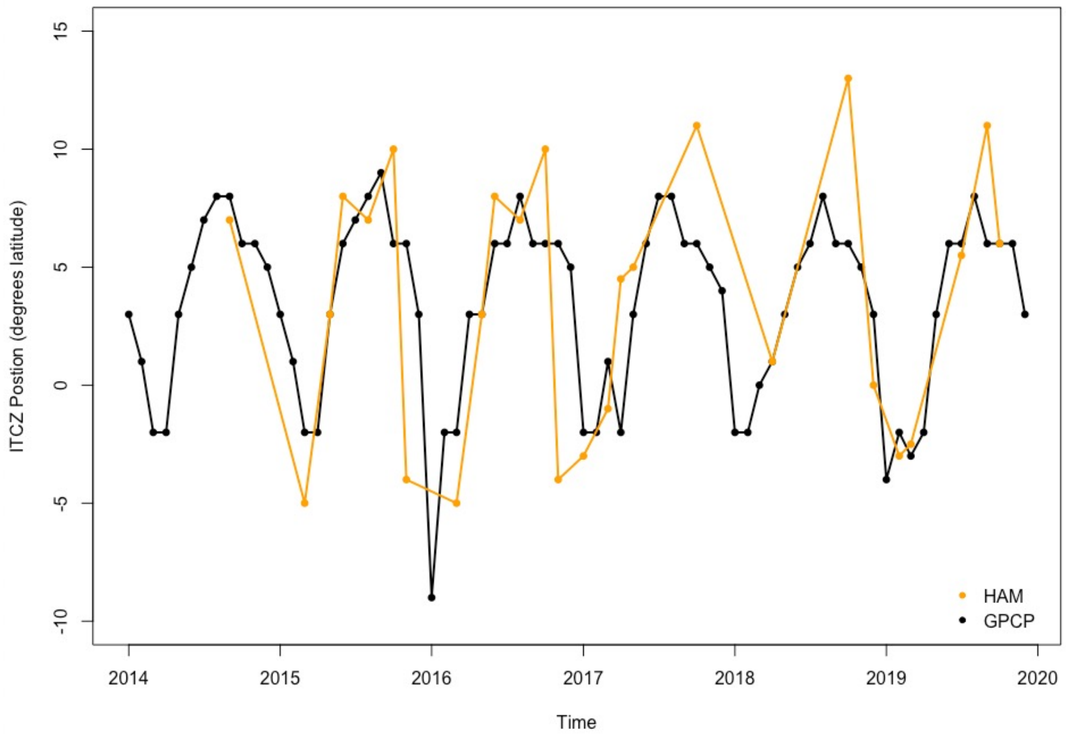


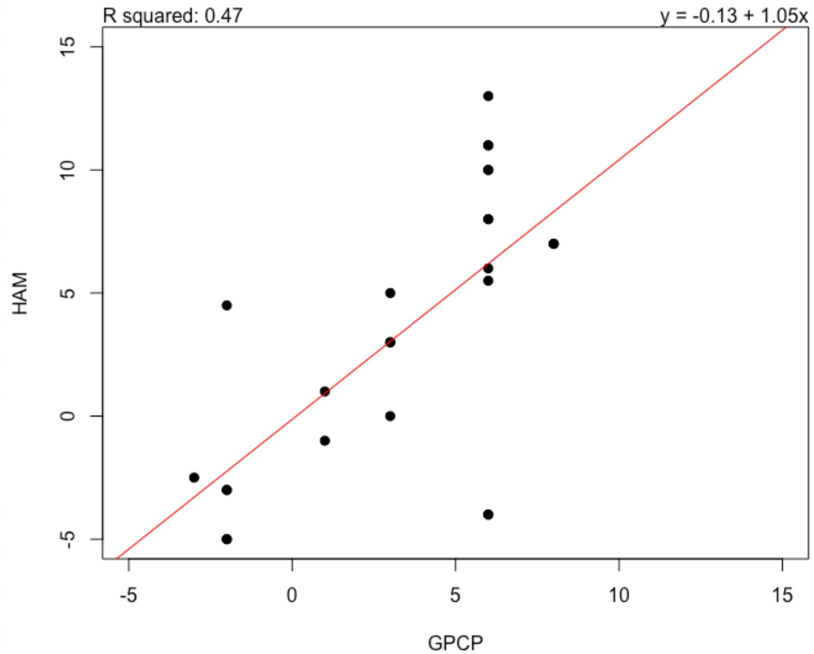




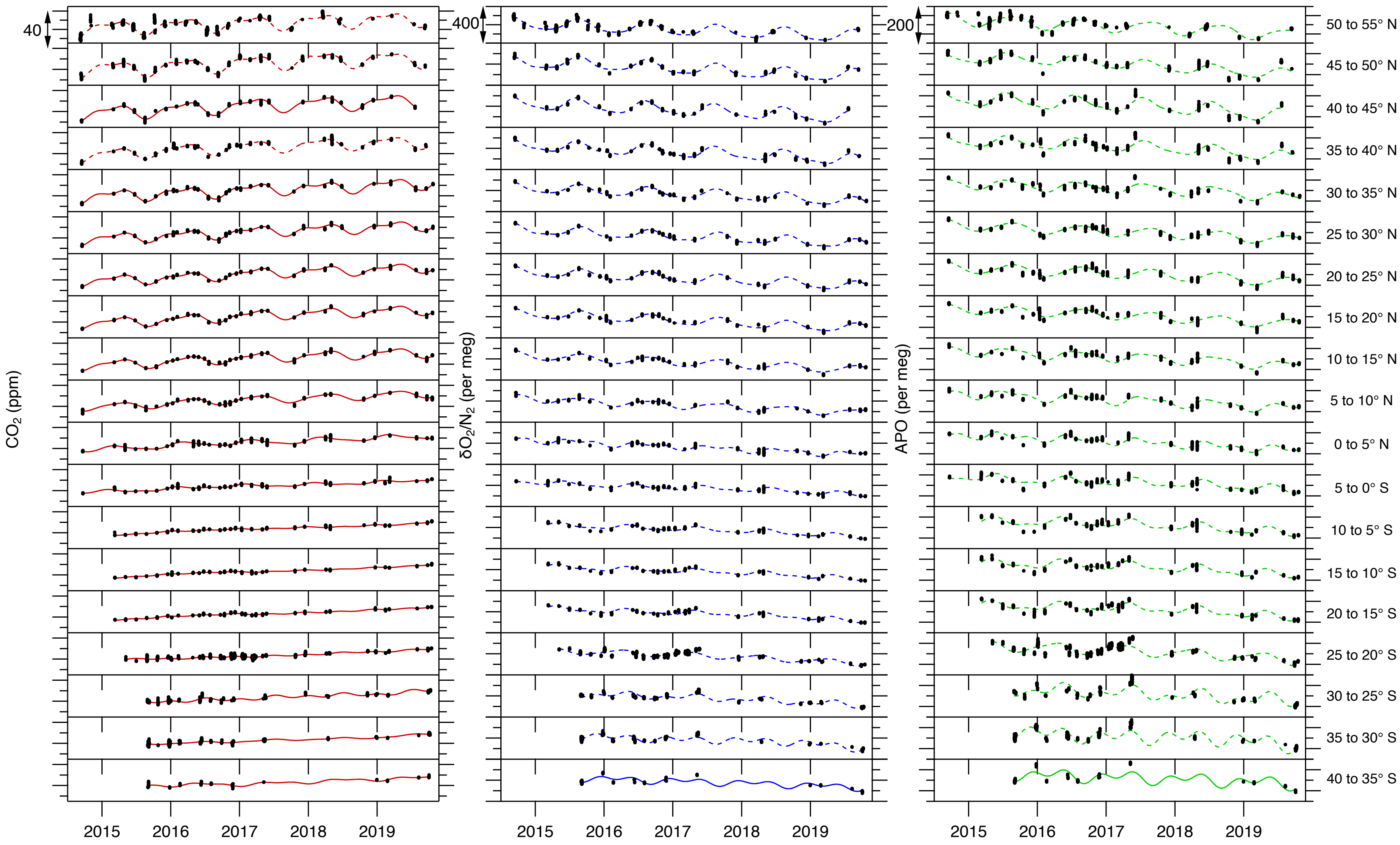
Variations in ITCZ Positions

- Derived from HAM CO_2 Concentration data:
  - Step changes in the concentration indicate the ITCZ positions.
- Derived from daily precipitation data from Global Precipitation Climatology Project (GPCP):
  - The maximum zonal mean precipitation between 20°S–20°N.

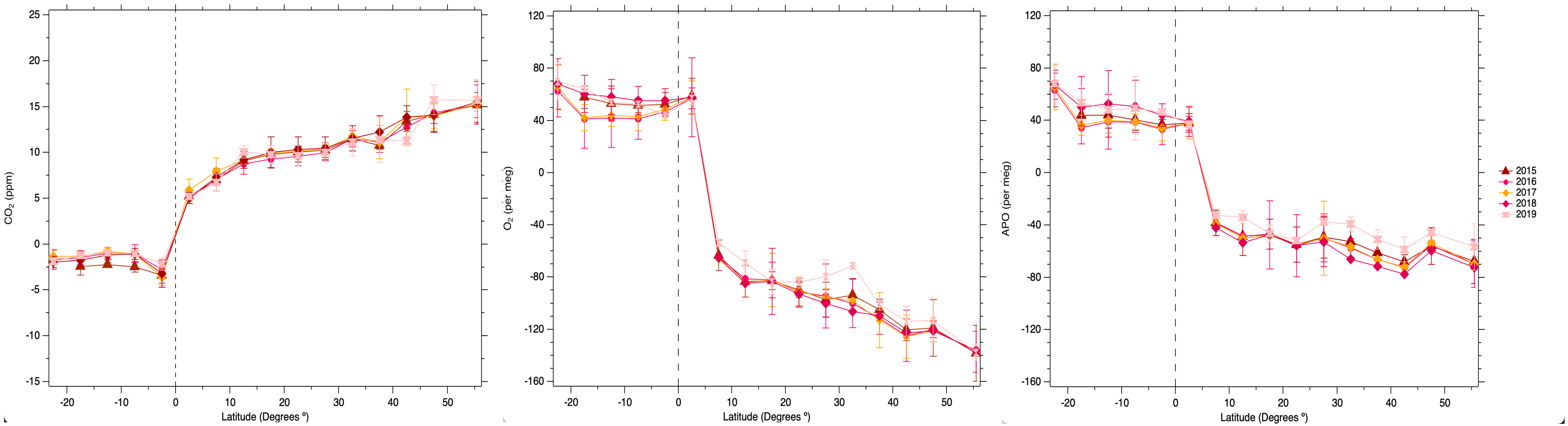




Seasonal Cycles in CO_2, O_2 and APO

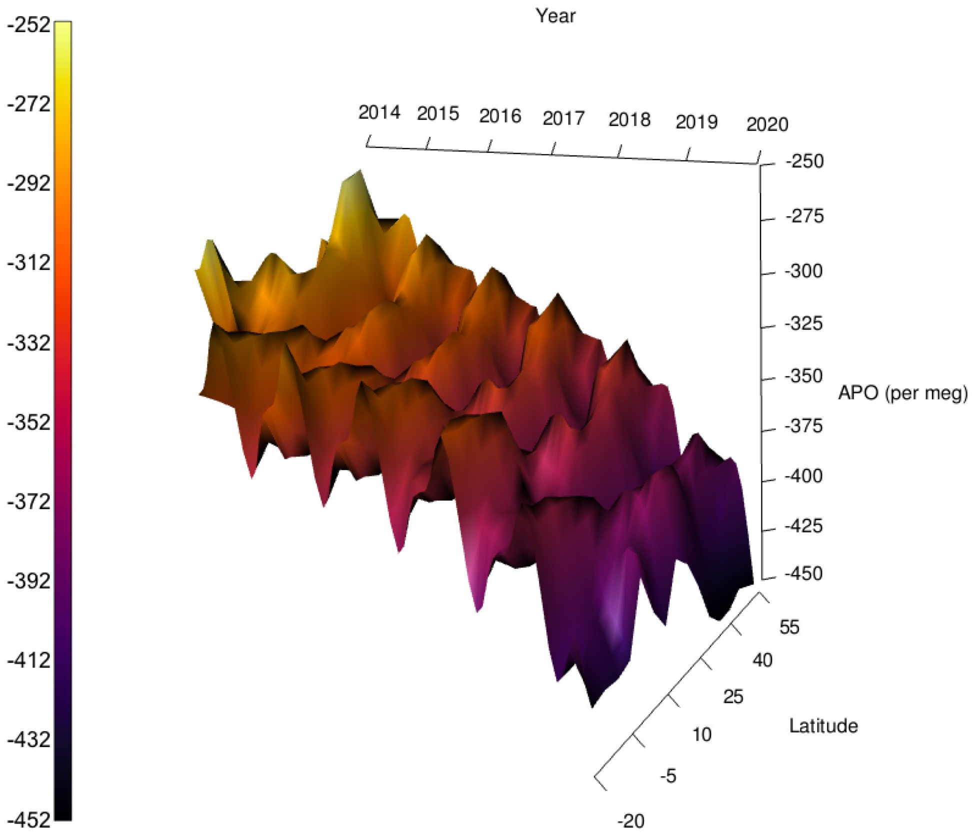


Seasonal Amplitude of CO_2, O_2 and APO

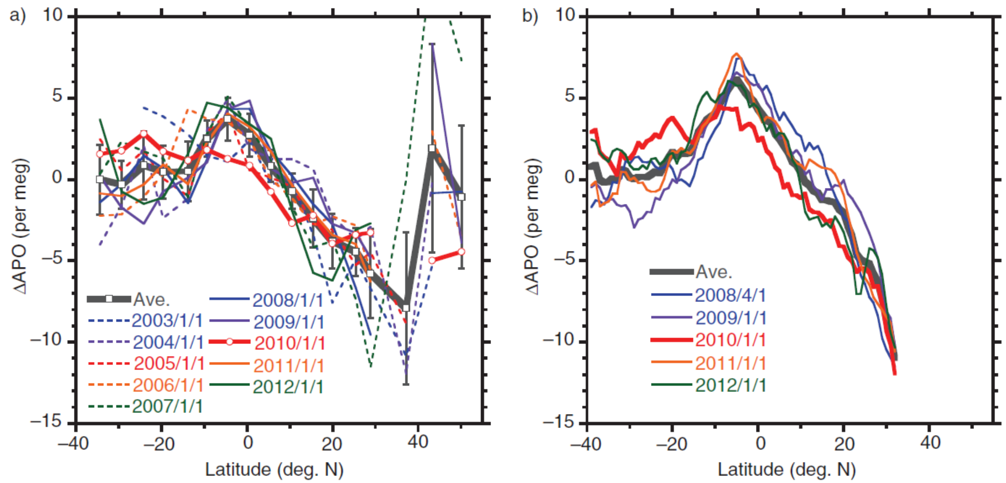


- A distinct change in the sign of the seasonal cycle amplitude at about 5°N for all three species
- At ~50°N, APO seasonal cycle magnitude is ~46% of O_2 seasonal cycle amplitude → half of O_2 seasonal cycle can be attributed to ocean processes, and half to land processes.
- At ~50°N The difference in magnitude between the APO and O_2 seasonal cycle amplitudes = 70 per meg = 14.6 ppm → similar to the observed CO_2 seasonal cycle amplitude
- At ~15°S APO seasonal cycle magnitude is ~ 82% of O_2 seasonal cycle amplitude, → majority of the O_2 seasonal cycle can be attributed to ocean processes, and 20% attributed to land processes.

Latitudinal Distribution of CO_2, O_2 and APO across the Atlantic Ocean



- Annual mean CO_2 in SH is ~2 ppm < NH
- 30-55°N, APO follows a similar pattern to O_2
- Annual mean APO in SH is > NH (2-3 per meg) which is also most likely due to fossil fuel burning.
- 4-6 per meg in magnitude bulge in APO at 10°N
- Similar magnitude compared to the Pacific shipboard data of (Tohjima et al., 2015)



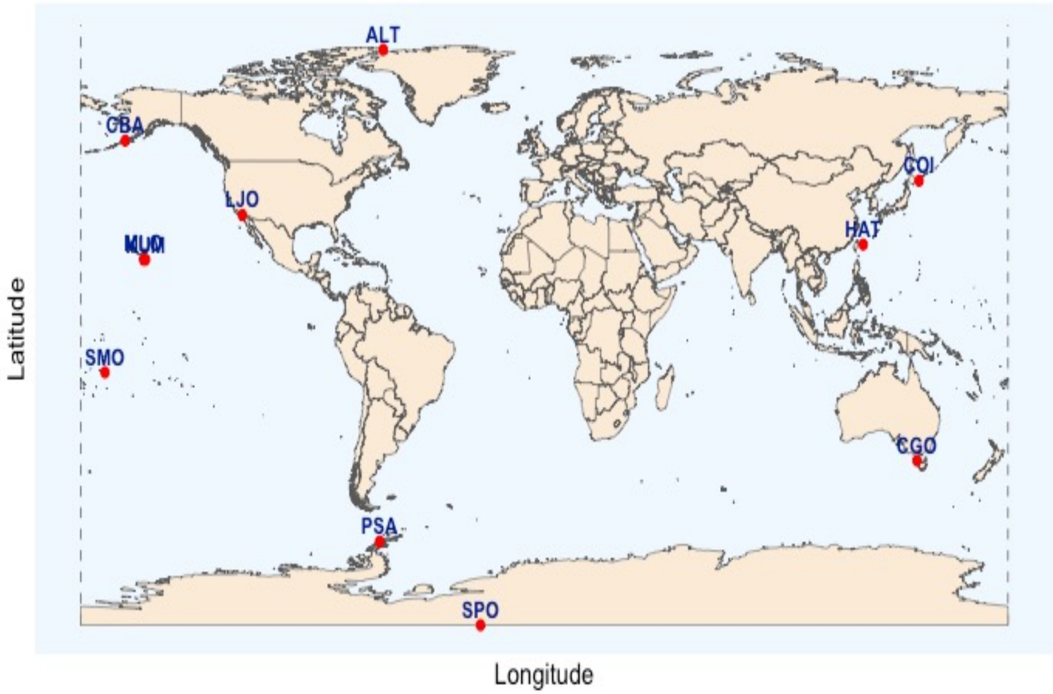
Jena CarboScope APO Inversion

- Surface APO fluxes supplied to the model are the inverse flux estimates, based on atmospheric observations and a transport model

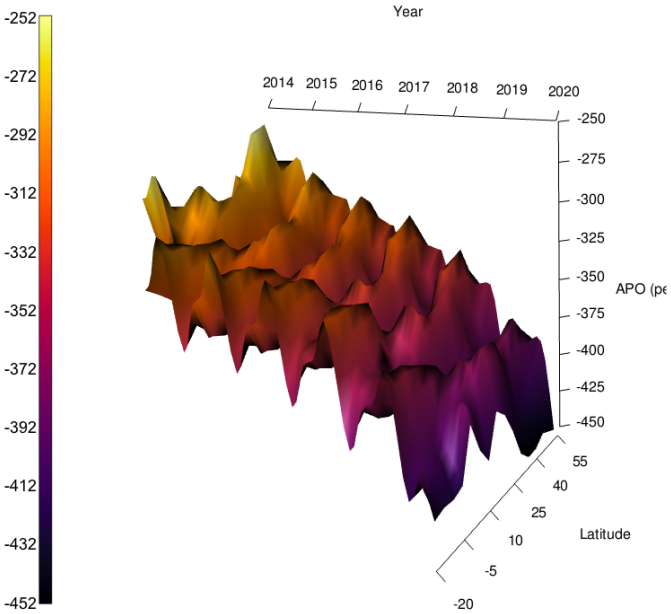
- Atmospheric observations
  - apo99X_v2022 (i.e. 11 stations)
  - apo99X_v2022 +HAM (i.e. 11 stations + HAM)

- Transport model (TM3, 4° x 5° x 29 layers)

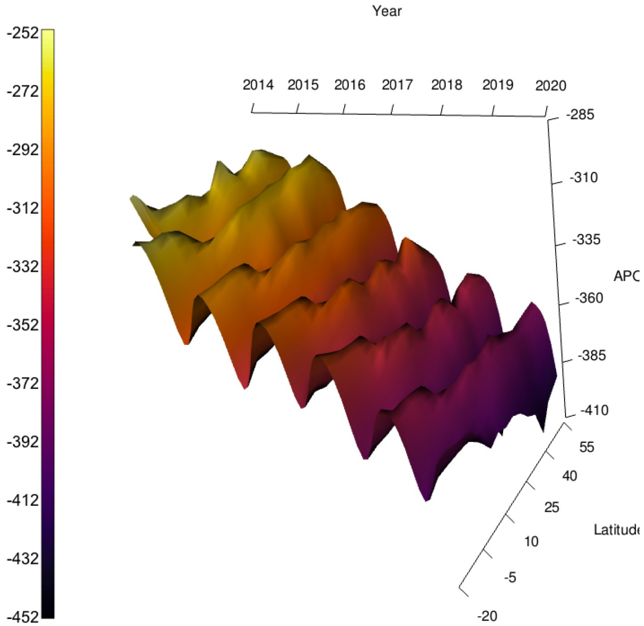
- These estimated APO fluxes is then used in a forward simulation run (FWD) to calculated HAM modelled mixing ratio.



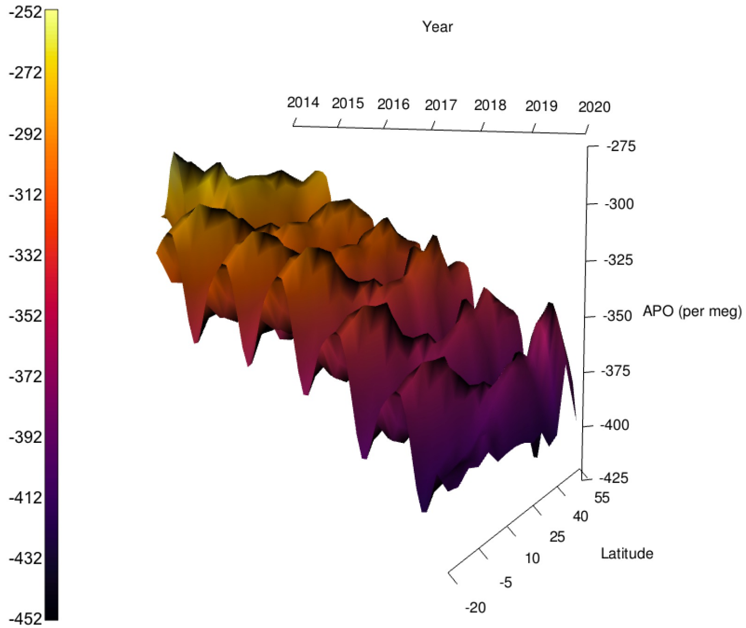
Comparing mole fractions: Obs vs. Forward (FWD) output



Observation



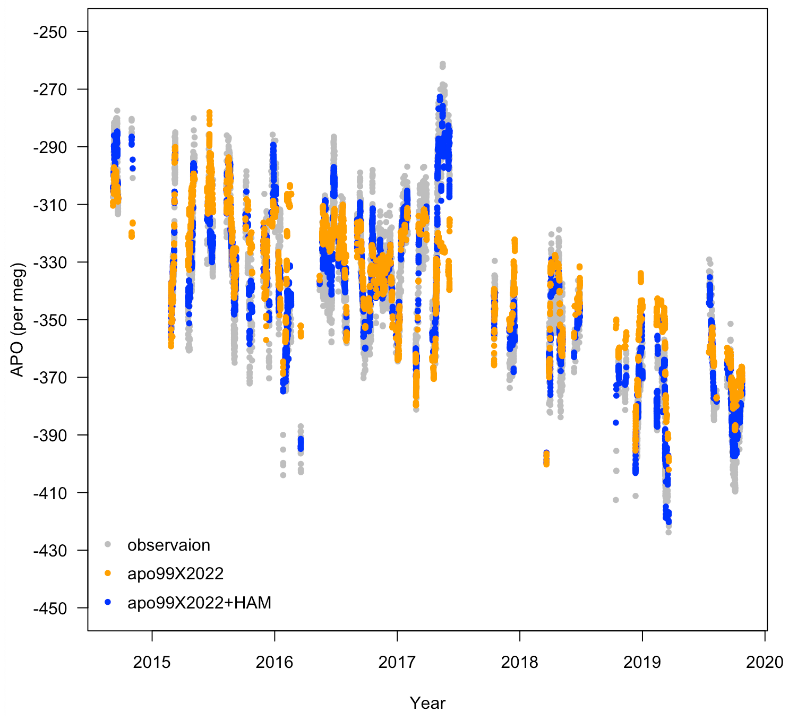
apo99Xv2022

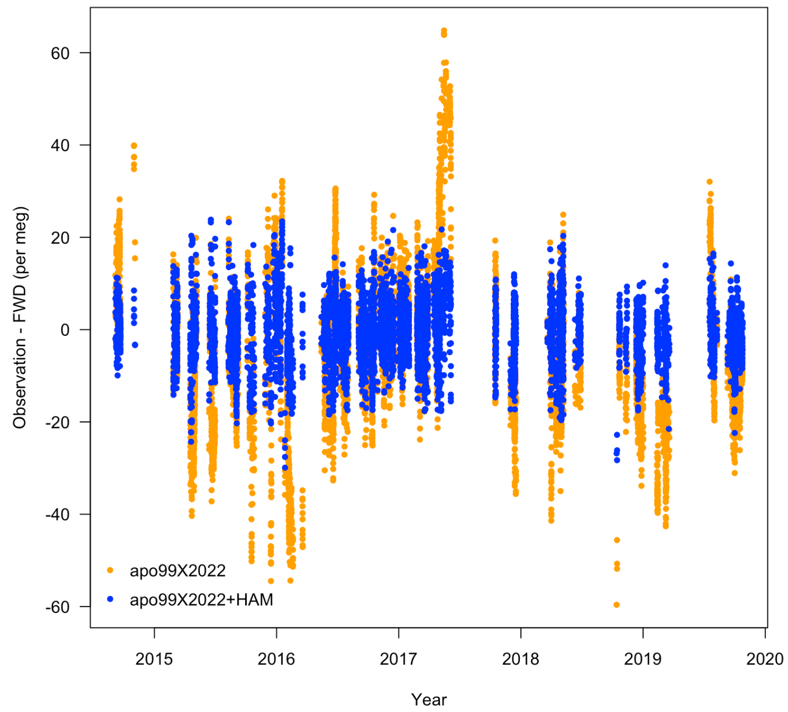


apo99Xv2022+HAM

- Modelled APO does not exhibit a bulge over the Atlantic in any year.
- Suggests that either there are inaccuracies in the oceanic flux data products in the equatorial Atlantic Ocean region, or that there are atmospheric transport inaccuracies in the model, or a combination of both.

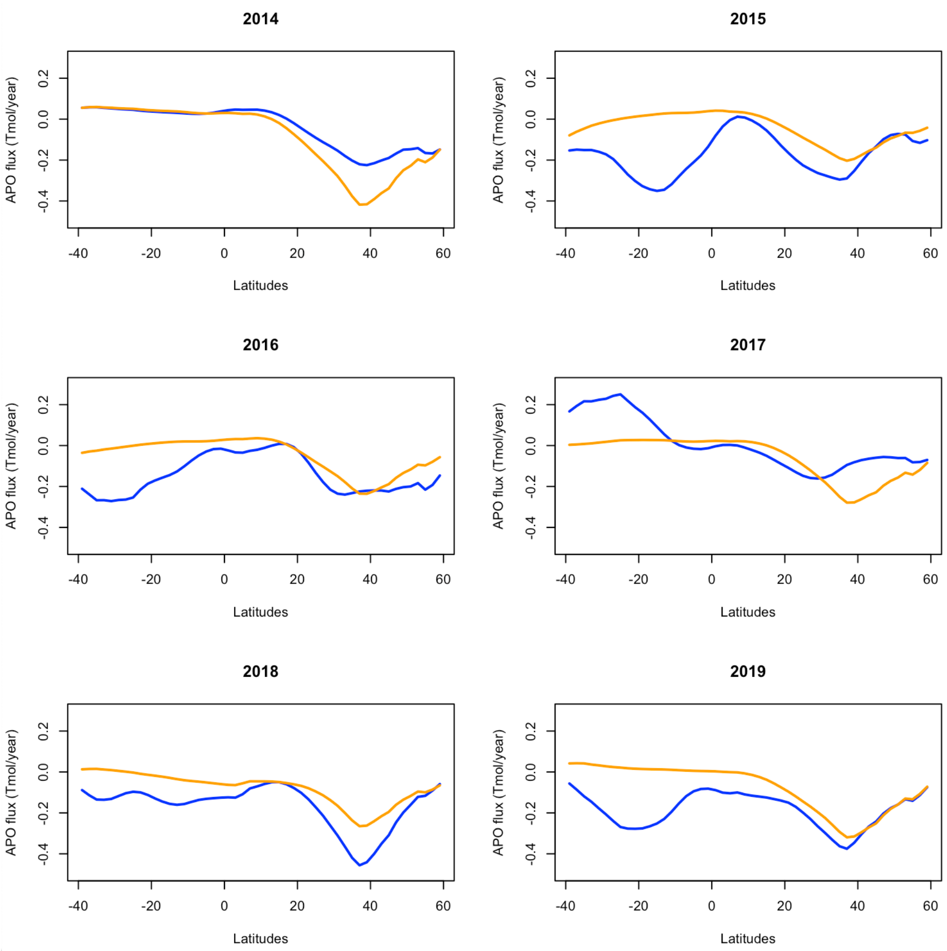
Comparing mole fractions: Obs vs. Forward (FWD) output





Adding HAM data provides better constrains to the model

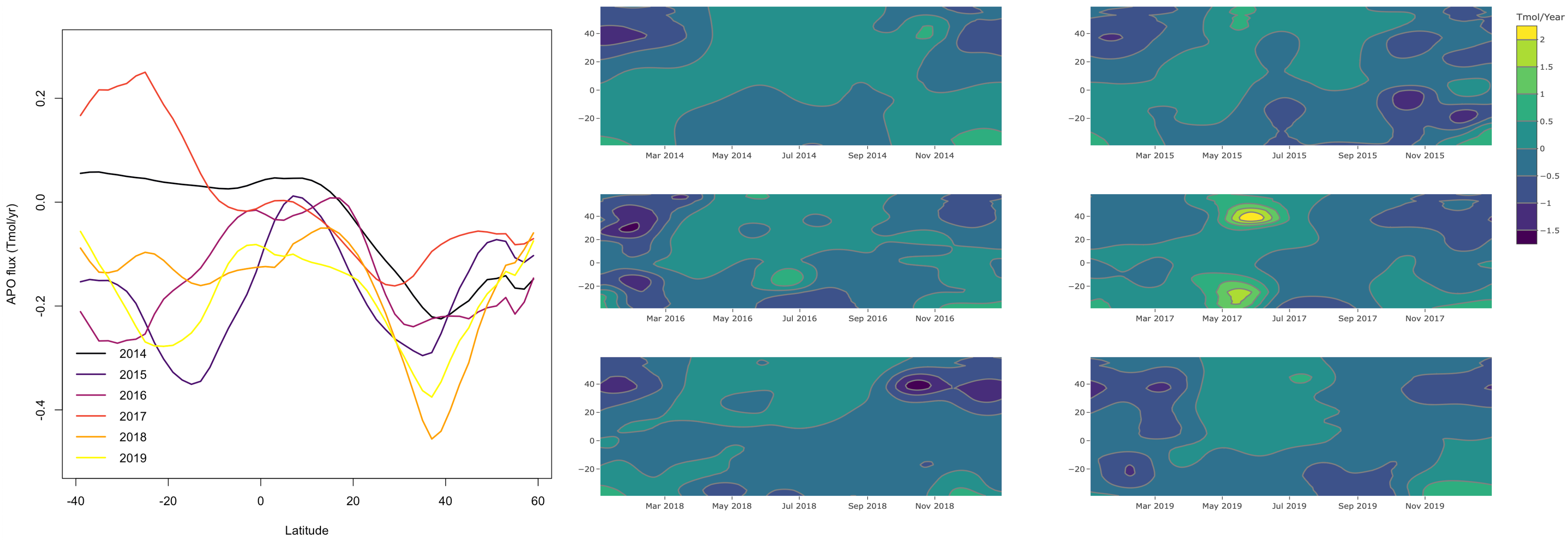
Comparing APO flux from two inversion runs



- no HAM
- with HAM

- Without HAM in the dataset:
  - A decrease in APO flux around 30-40° North
  - No variation in the SH fluxes
- With HAM in the dataset:
  - Increase in APO fluxes around the equator
  - A decrease in APO flux around 30-40° North
  - Abnormal positive flux in the SH in 2017

APO Flux Using apo99X_v2022 +HAM Set



- APO ingassing ~40°N during winter time, this mid-tropic deficit in APO could be influenced by the deficit in $\Delta O_2/N_2$ in the winter in the NH.
- No deficit in 2015, 2016 APO quatorial flux.
- Deficit in mid-tropic APO ingassing during winter 2016/2017.
- Strong outgassing in spring-to-summer 2017 in both hemisphere.

Conclusions and Future Outlooks

- Step-changes in both atmospheric O_2 and CO_2 time series corresponding to the (seasonally-varying) position of the Intertropical Convergence Zone (ITCZ).
- APO concentration data also show significant equatorial outgassing bulges in most years, but not during 2015 and 2016. However, APO fluxes derived from inversion model still show equatorial outgassing during these two years.
- There is an APO in-gassing in NH mid-tropic during the winter.
- **<u>Outlooks:</u>**
  - Examine why TM3-modelled APO under-estimates the interhemispheric APO gradient concentration over the Atlantic.

  - ITCZ position and heat transport: Potential to use the Hamburg Süd APO data to constrain ocean model meridional transport of heat and carbon in the Atlantic Ocean, since the thermally-induced gas fluxes of O_2 and CO_2 are closely tied to the net air–sea heat flux.

Constraints on oceanic meridional heat transport from combined measurements of oxygen and carbon

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