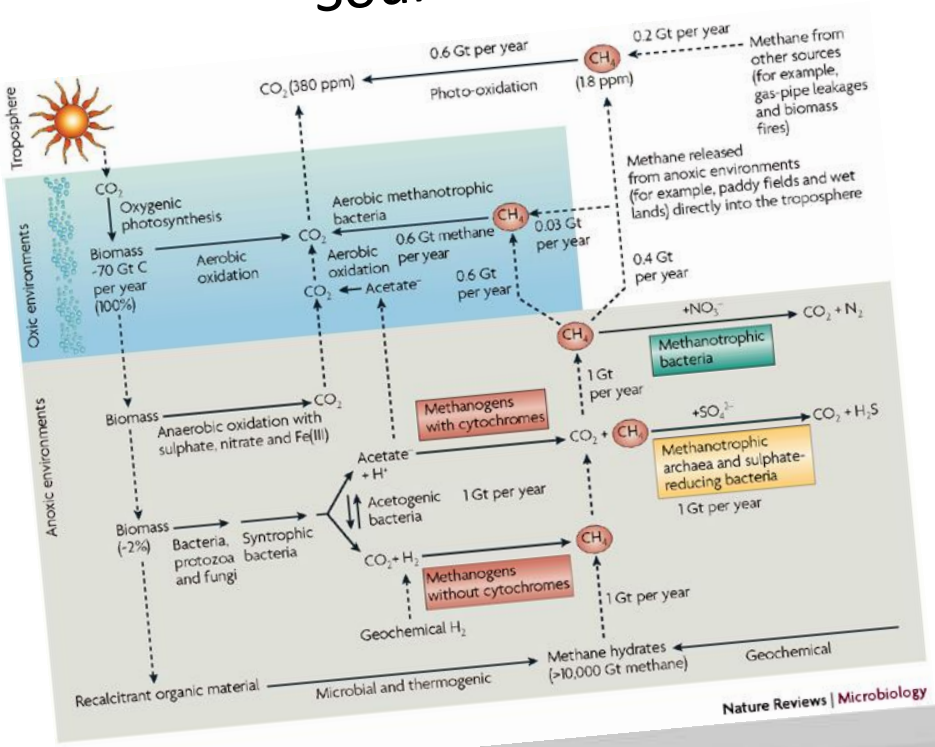
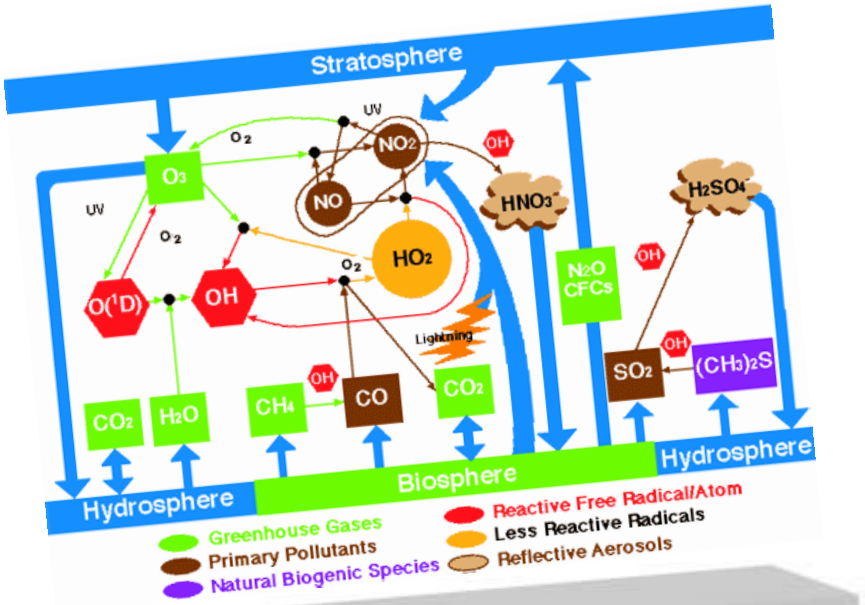
Why Occam's Razor doesn't work for the CH_4 Problem

Martin Manning, Gordon Brailsford, Ed Dlugokencky, Rowena Moss, Euan Nisbet, Hinrich Schaefer, James White

Sources

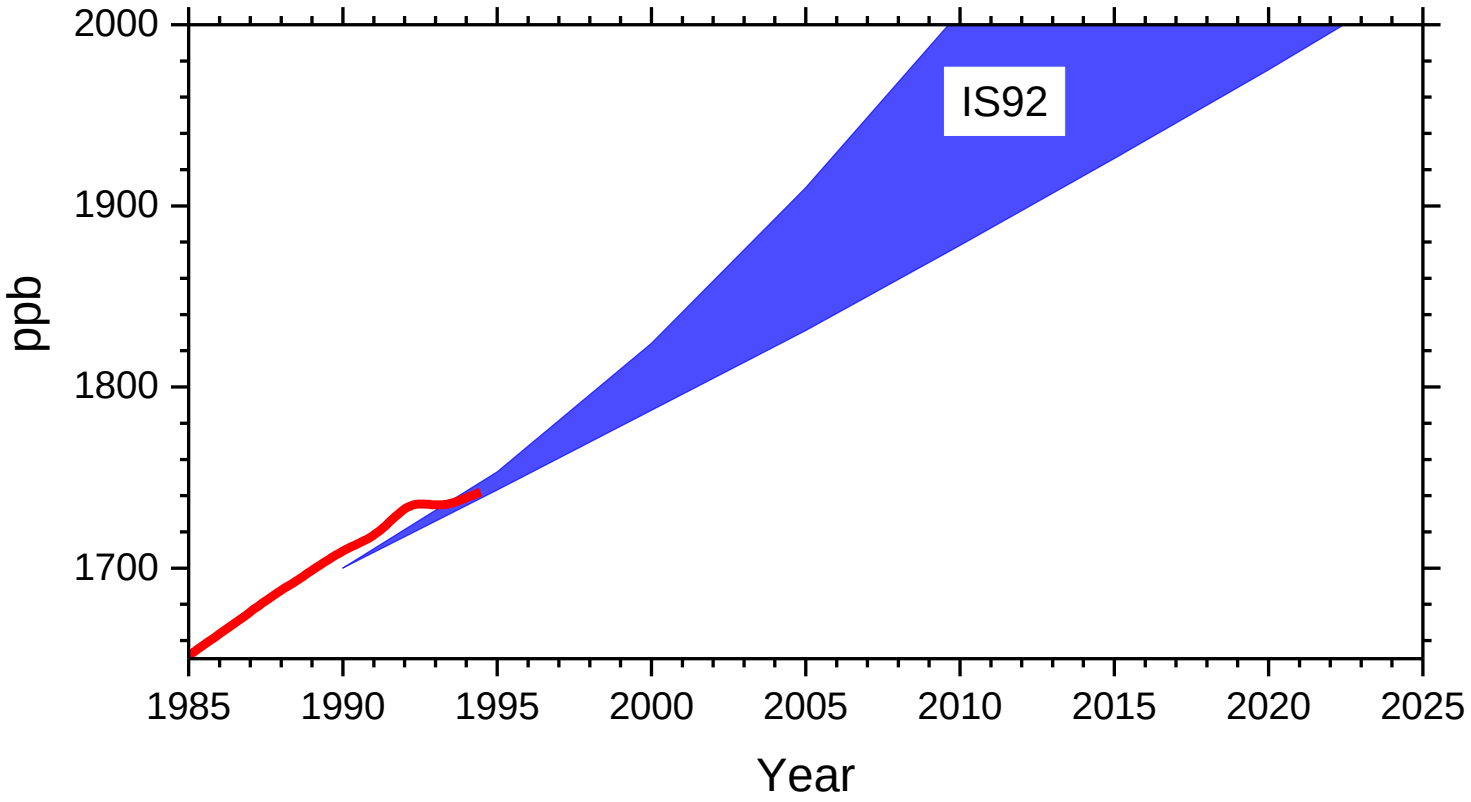


Sinks



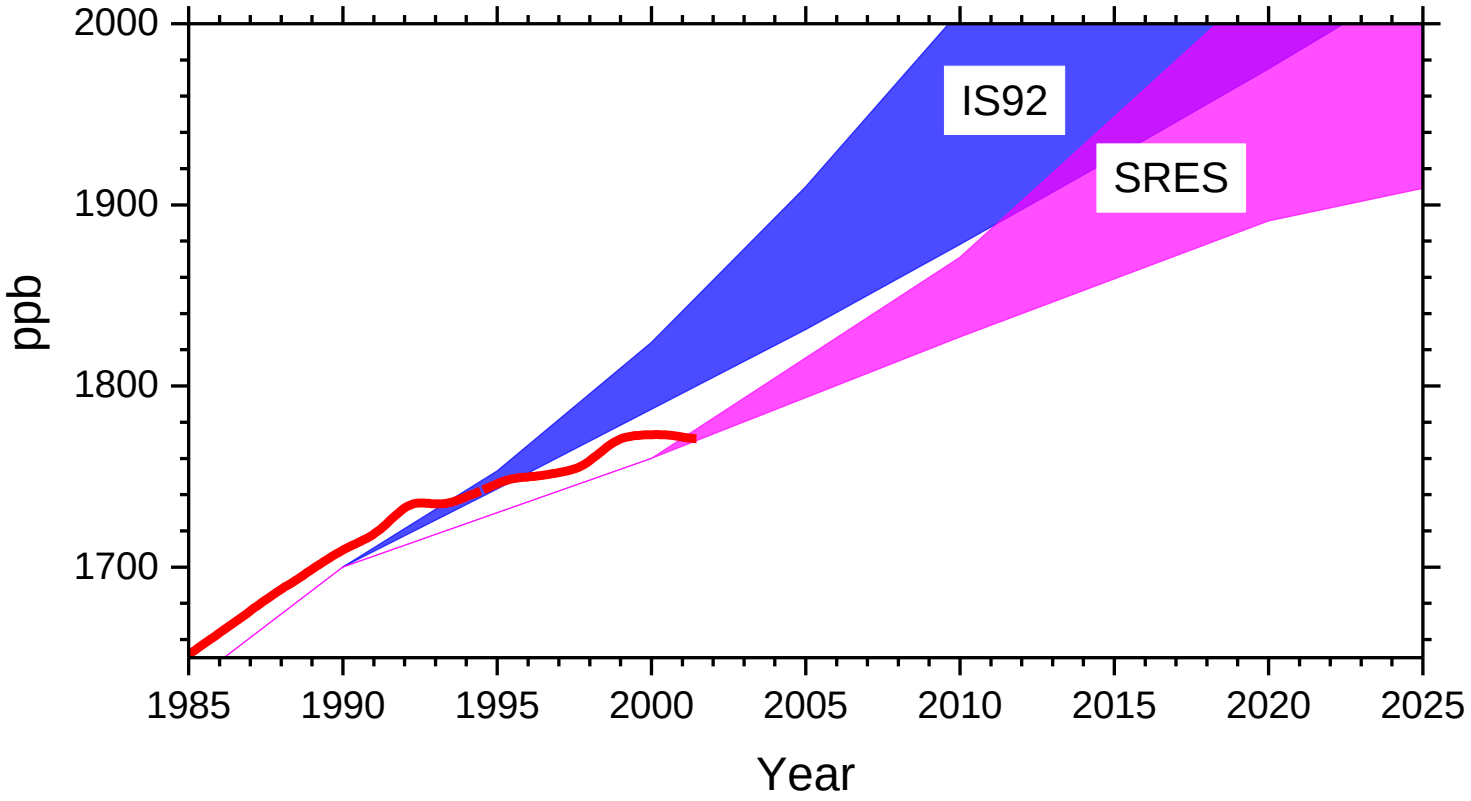
A context: Methane vs IPCC scenarios

IS92 scenarios, used in climate models for the IPCC Second Assessment Report, assumed that CH_4 would continue to increase at rates similar to the 1980s.



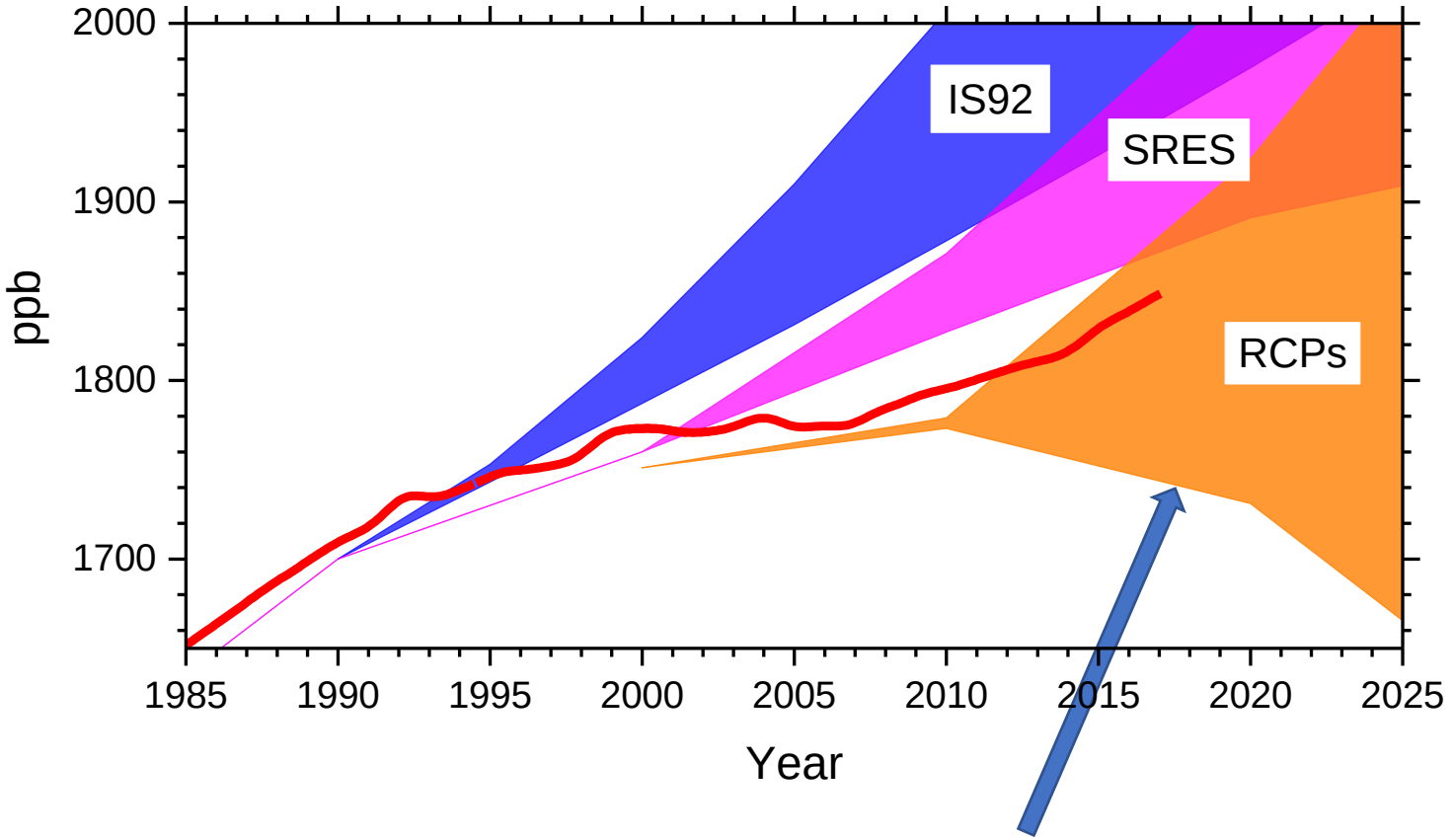
A context: Methane vs IPCC scenarios

IPCC Third and Fourth Assessments had climate models using the Special Report on Emission Scenarios (SRES) covering the non-CO_2 gases in more detail. But still didn't include climate stabilisation, and CH_4 was expected to start increasing again.



A context: Methane vs IPCC scenarios

Representative Concentration Pathways (RCPs) set up for the Fifth Assessment included RCP2.6 that met the target of keeping below 2°C but relied on rapid reduction in CH_4 as the way to buy time needed to stop fossil fuel emissions.



That is not happening, so can CH_4 prevent us keeping to the 2°C target

To know how long CH_4 can continue to move away from the 2°C scenario requires that we know the cause.

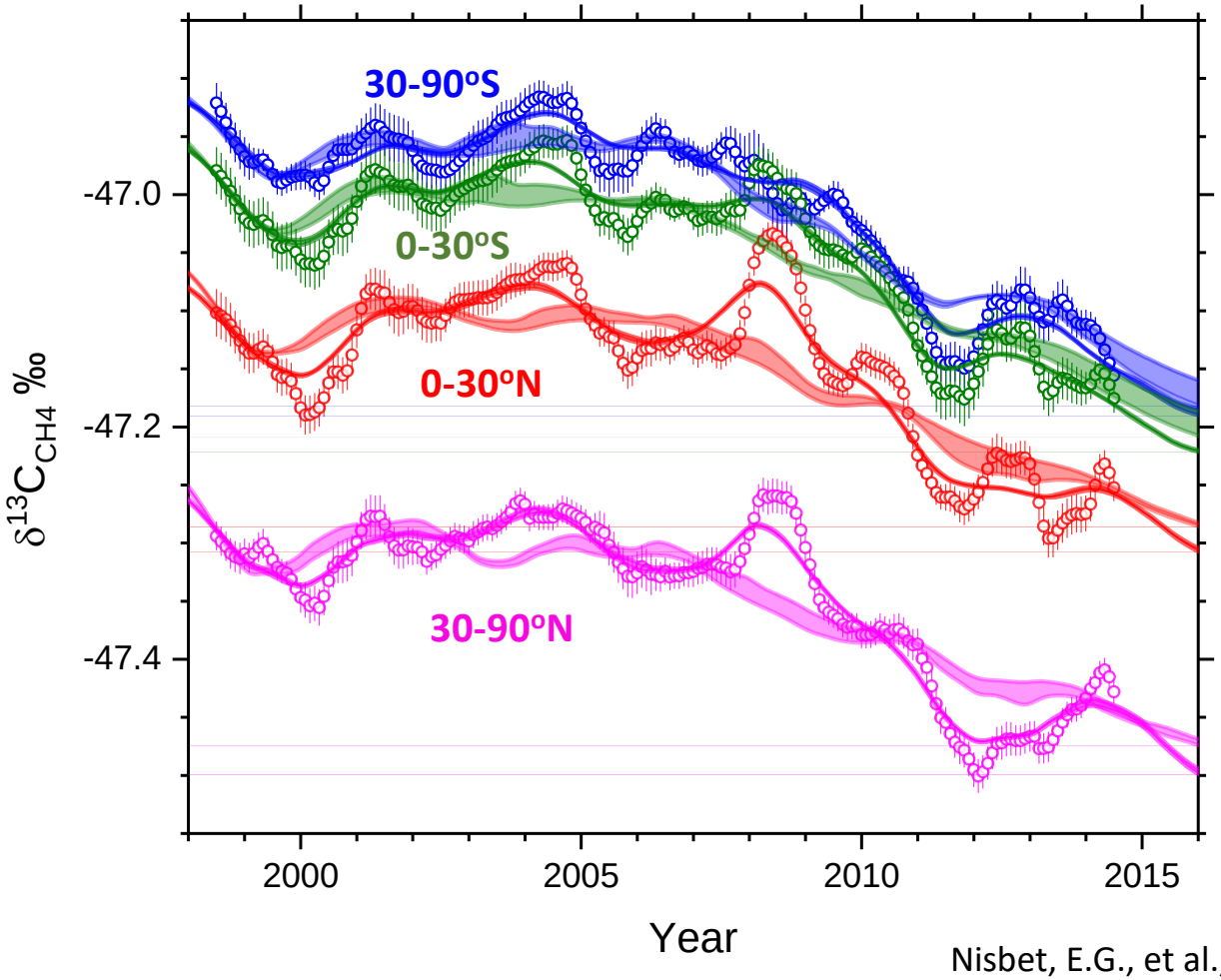
e.g:
Is it increasing agricultural emissions?

Or, if it is a response in wetlands to changes in precipitation, then how long will that continue?

Or is it something else?

Trends and variability in $\delta^{13}CH_4$

This is a slightly revised version of Fig 6 in Nisbet et al, 2016. Fits to semi-hemispheric averages for $\delta^{13}CH_4$ data have been improved by optimising the time of year when inter-annual changes in source, or removal rate, occur.



Fits to the data are for:

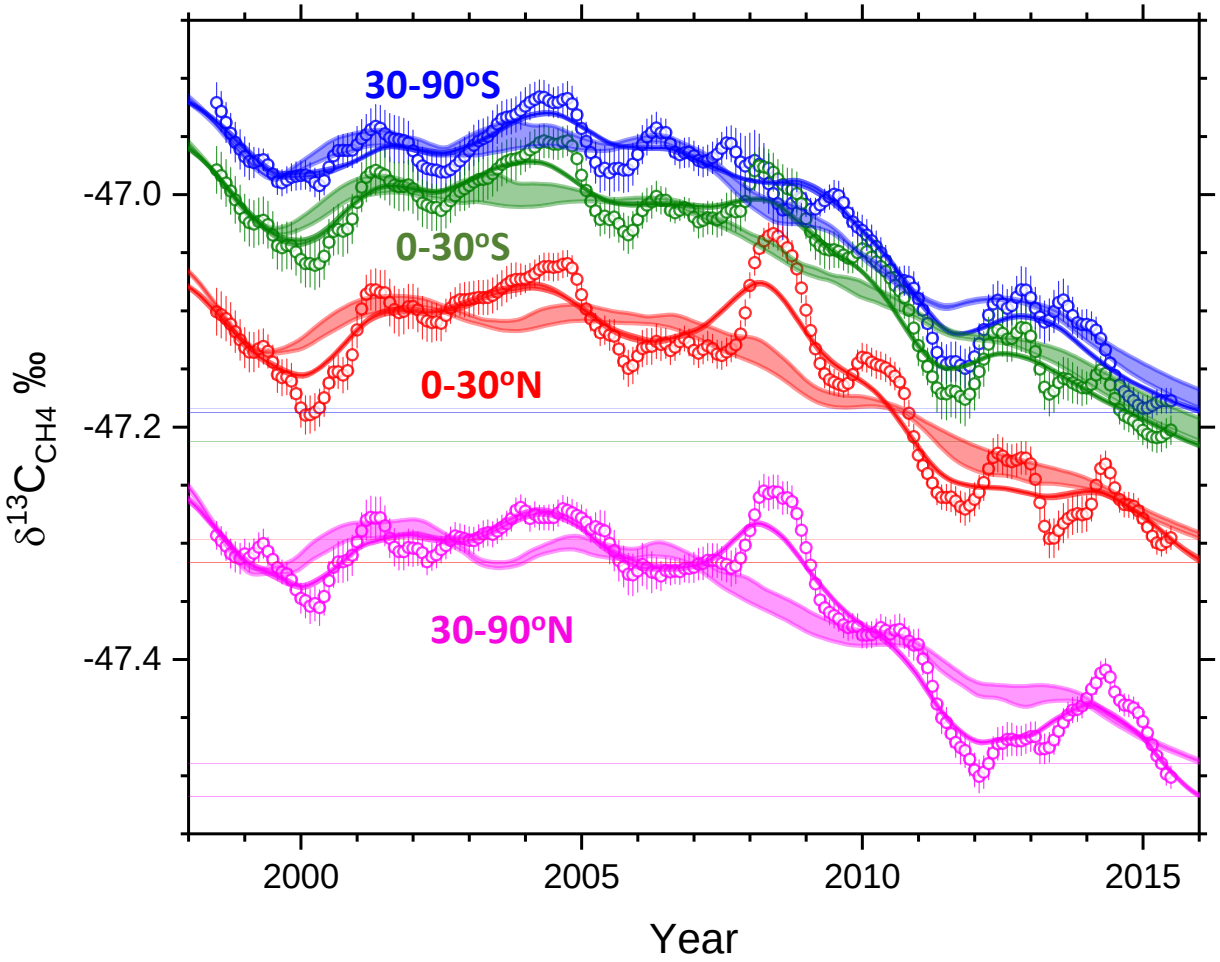
annual changes in sources (thick lines with more interannual variability)

or annual changes in removal rates (broader bands with less short term variation.)

Nisbet, E.G., et al., 2016: Rising atmospheric methane: 2007-14 growth and isotopic shift. *Global Biogeochem. Cycles,* ***30, 1356-1370.***

Trends and variability in $\delta^{13}CH_4$ – updated to include 2015 data

Another year of data has not changed the trends very much and $\delta^{13}CH_4$ is continuing to decrease.



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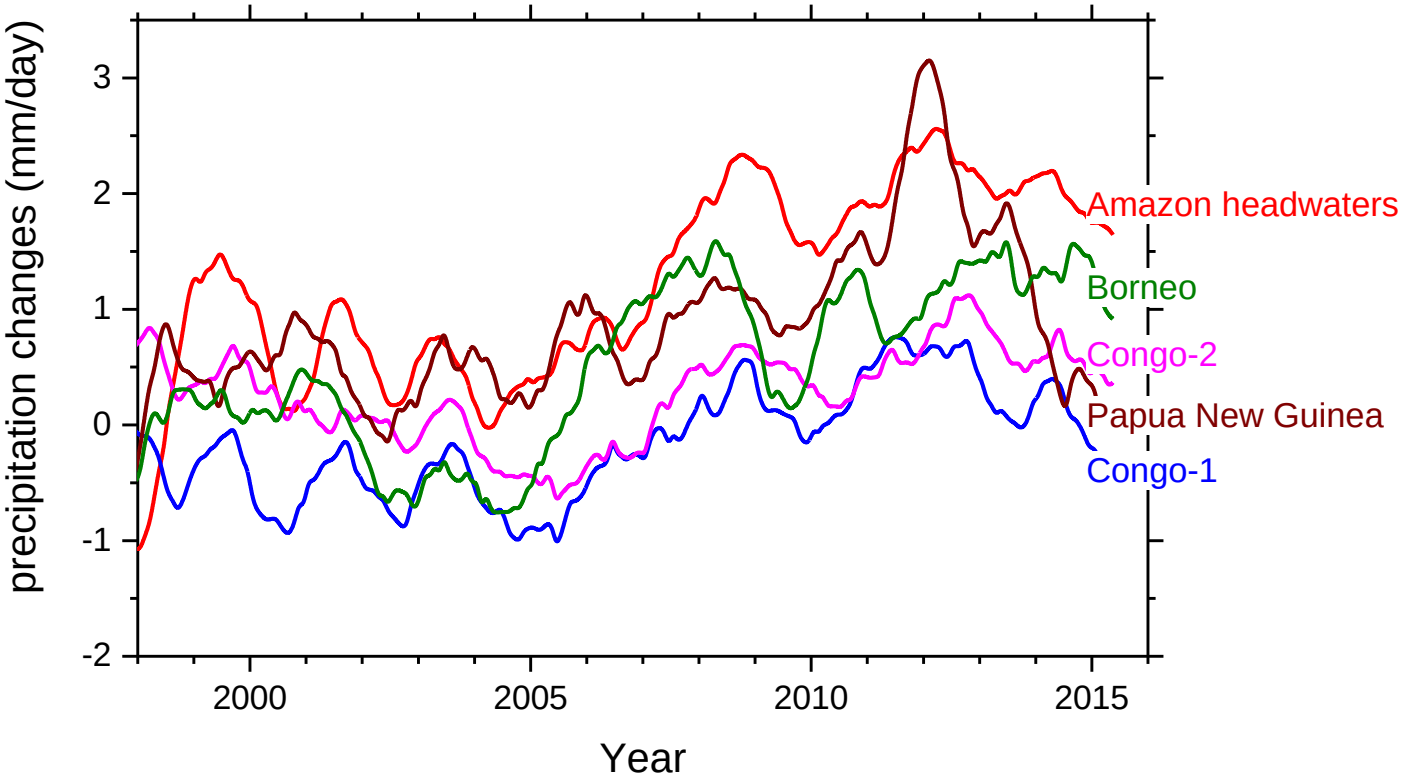
Trends & variability in precipitation

Many studies have linked large scale changes in Hadley and Walker circulation to an intensification of tropical precipitation over 5°S – 5°N. (e.g. Zhou et al, 2011, JGR Vol 116, D09101).

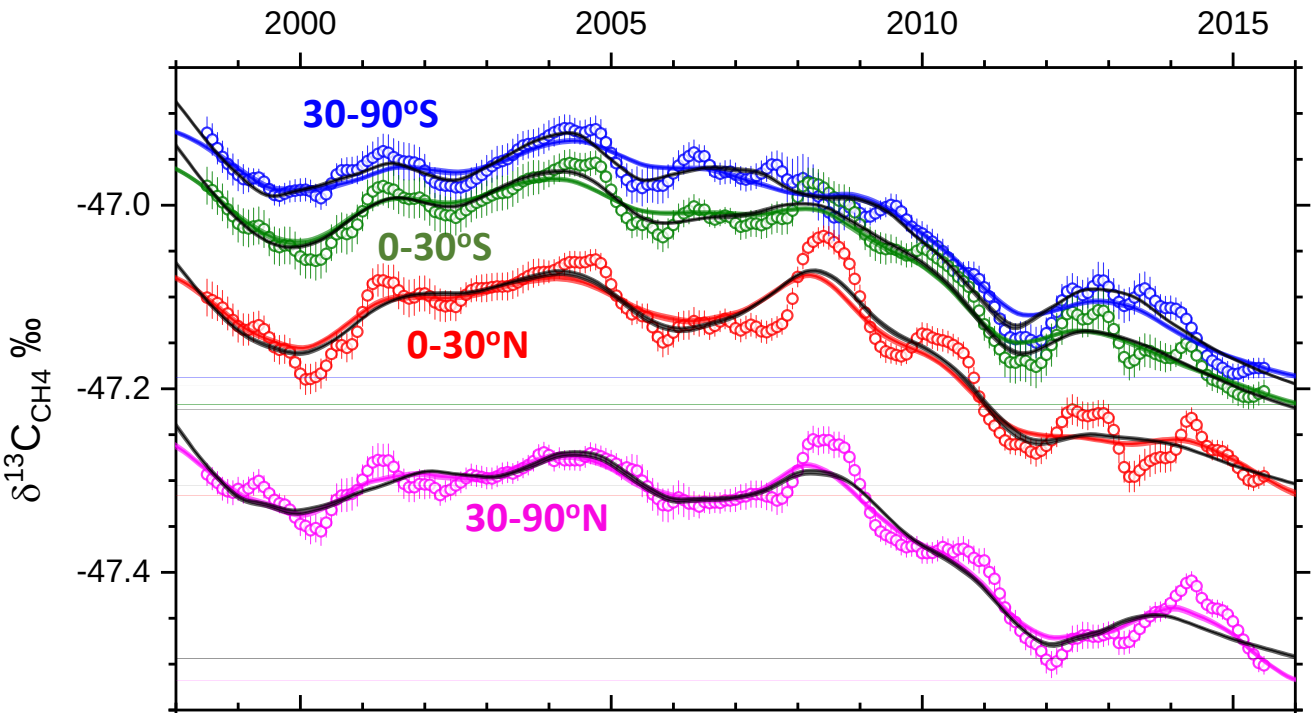
The following shows variations around the 30-year average for NCEP reanalysis precipitation data in five tropical regions associated with wetlands. Widespread changes started around 2005 – 2006. But interannual variations do not match the atmospheric $\delta^{13}CH_4$ anomalies.



But we forgot to test something

This shows new fits to the $\delta^{13}CH_4$ data (in black) that allow annual variations in CH_4 removal by Cl to differ from those for OH and soil removal.

The new fit (black), that has one additional option for variation in removal rates, is now slightly better than the best fit with varying sources and fixed removal rates.



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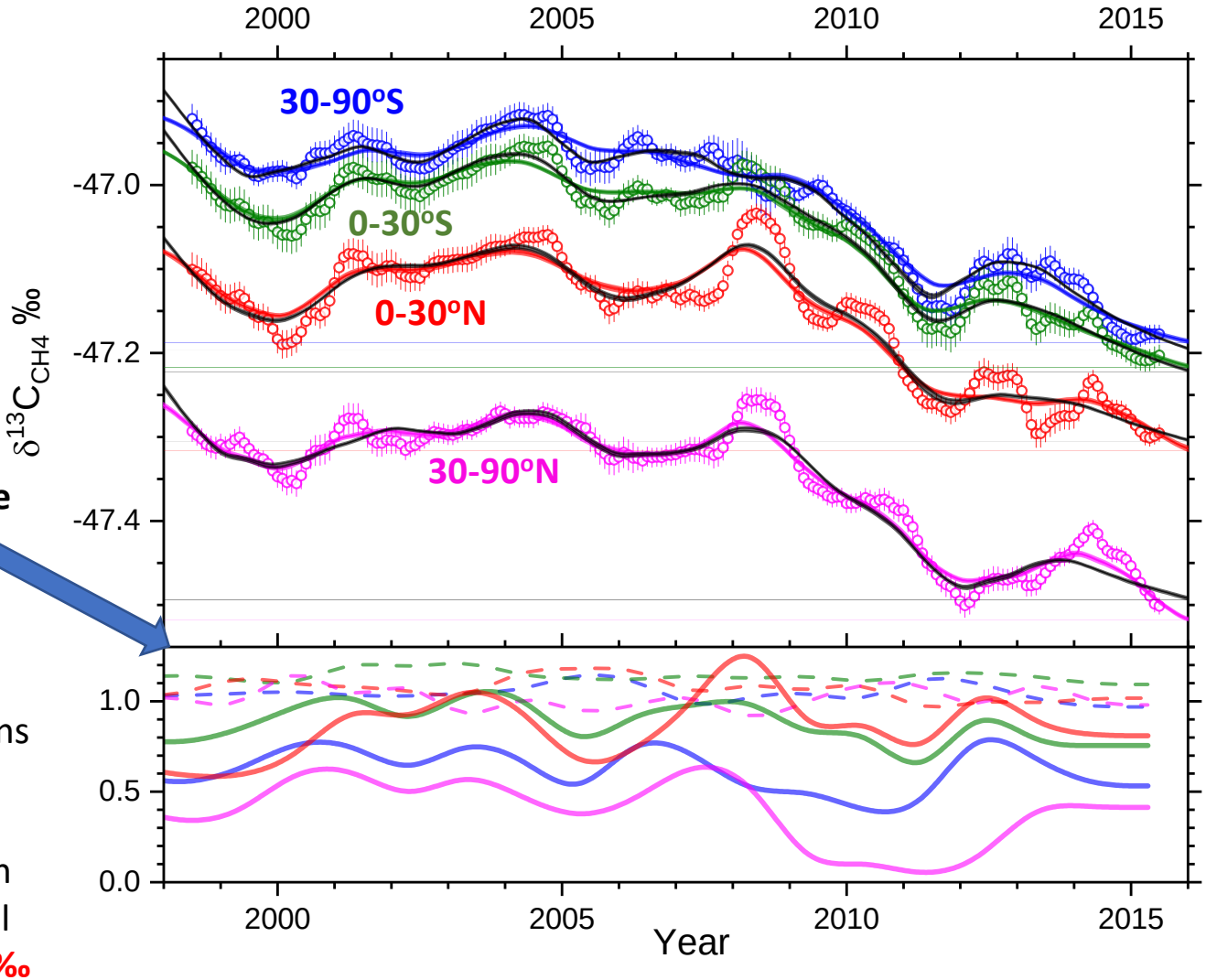
Variations in removal rate

dashed lines are relative variations in annual averages for OH + soil removal with fractionations of -3.9‰ and -22‰

solid lines are variations in annual average Cl removal **with fractionation of -62‰**



But is this variability in Cl removal realistic?

So do we have enough information and constraints to diagnose the cause of recent changes in atmospheric methane?

… or is it actually a combination of multiple causes?

Explanations now need to merge several lines of evidence.

^{14}C in CO as the more direct tracer for OH

The importance of short lived ^{14}CO as a tracer for oxidation by OH was recognised in the early 1970s.

Weinstock, B., and H. Niki, Carbon monoxide balance in nature, *Science*, *176*, 290-292, 1972

Early measurements using radiocarbon dating methods became much more effective through the use of accelerator mass spectrometry.

Brenninkmeijer, C.A.M., Measurement of the abundance of ^{14}CO in the atmosphere and the $^{13}C/^{12}C$ and $^{18}O/^{16}O$ ratio of atmospheric CO with applications in New Zealand and Antarctica, *Journal of Geophysical Research*, *98* (D6), 10,595-10,614, 1993.

More recently ^{14}C production rates and their modulation by solar activity have become very much better defined.

Poluianov, et al., 2016: Production of cosmogenic isotopes ^{7}Be, ^{10}Be, ^{14}C, ^{22}Na, and ^{36}Cl in the atmosphere: Altitudinal profiles of yield functions. *Journal of Geophysical Research: Atmospheres, 121, 8125-8136.*

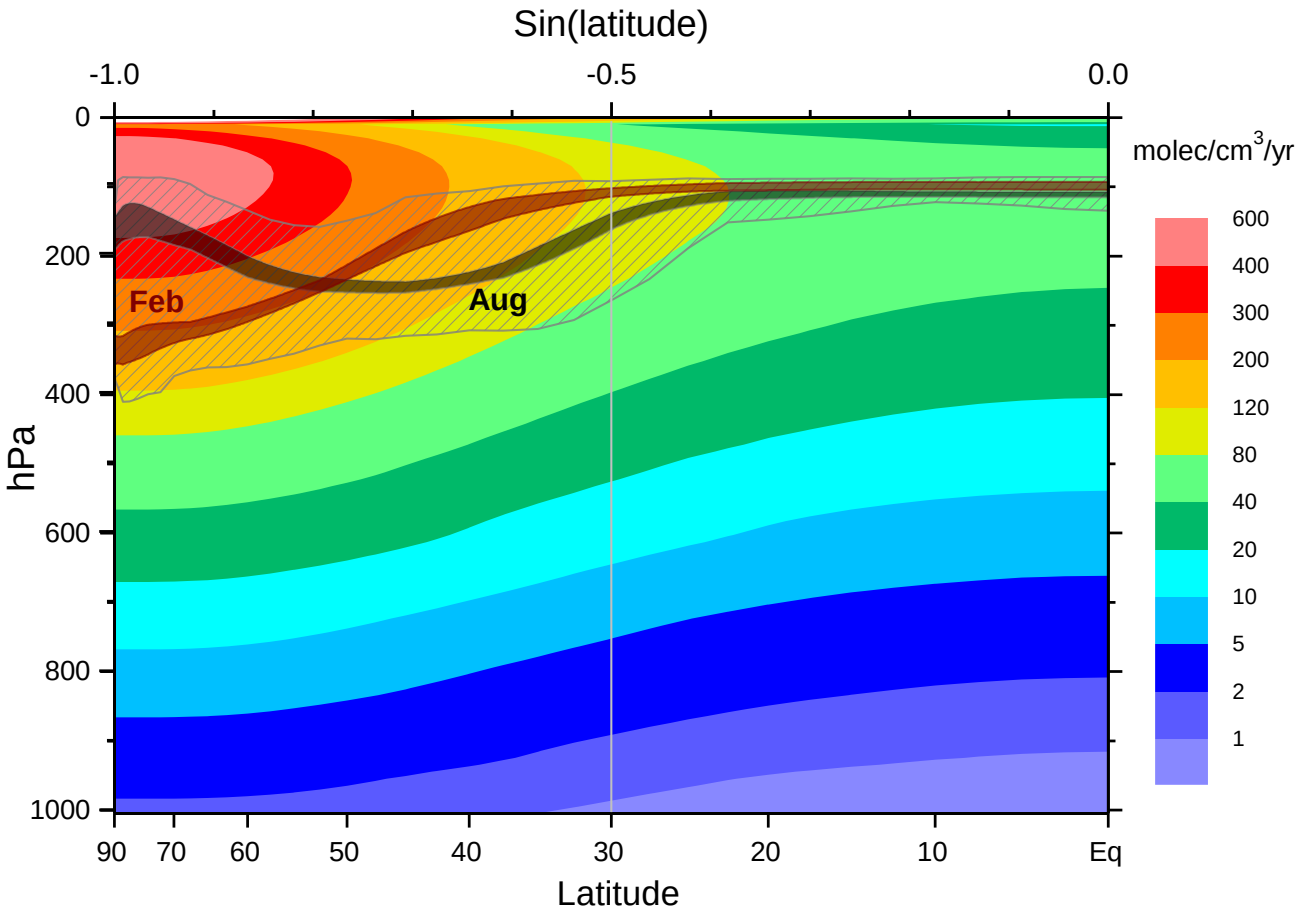
The New Zealand, NIWA, ^{14}CO measurement project, started by Carl Brenninkmeijer, now covers more than two solar cycles of production in the southern hemisphere. Also aircraft samples set clear constraints on cross tropopause transport.

Latitude × altitude distribution of ^{14}C production and tropopause distributions

New ^{14}C production rates from Ilya Usoskin's group have resolved a long standing problem for radiocarbon, and the spatial distribution together with its variation over solar cycles are now better defined than ever before.

This shows the production distribution and tropopause heights, averaged over longitude and solar modulation for the last 26 years.

The lightly cross-hatched area shows the full range of tropopause heights.



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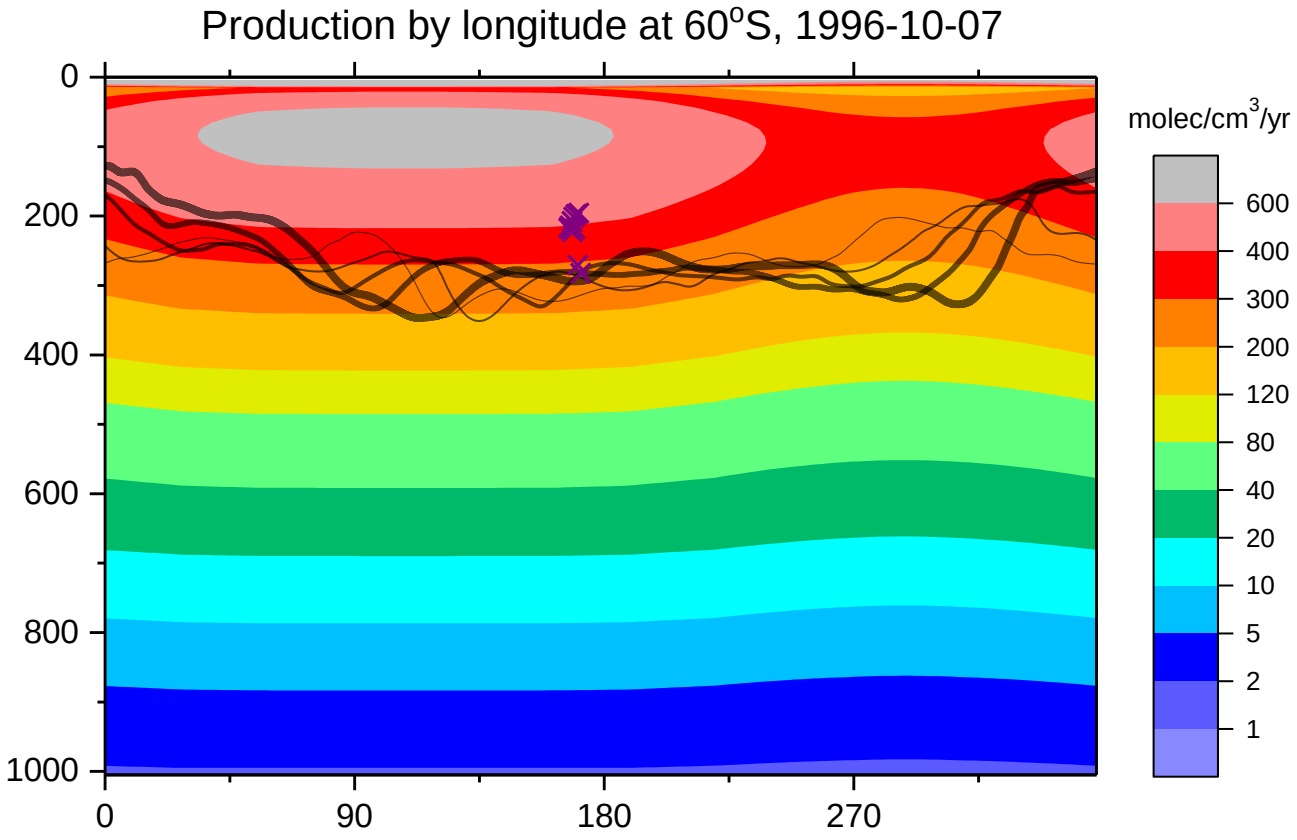
Longitude × altitude distribution of ^{14}C production and daily variations in tropopause

This shows the distribution for ^{14}C production at the time of a flight from Christchurch to McMurdo, Antarctica, with X's showing sample locations.

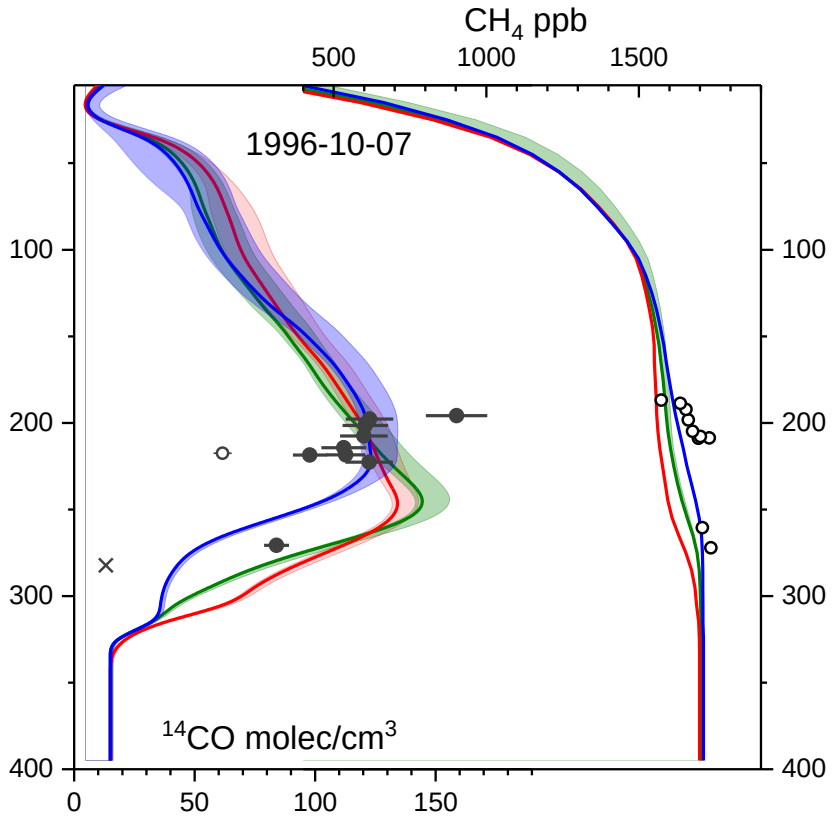
Dark brown lines show the tropopause position on the day of the flight and for four preceding days – lines get thinner as they go back in time.

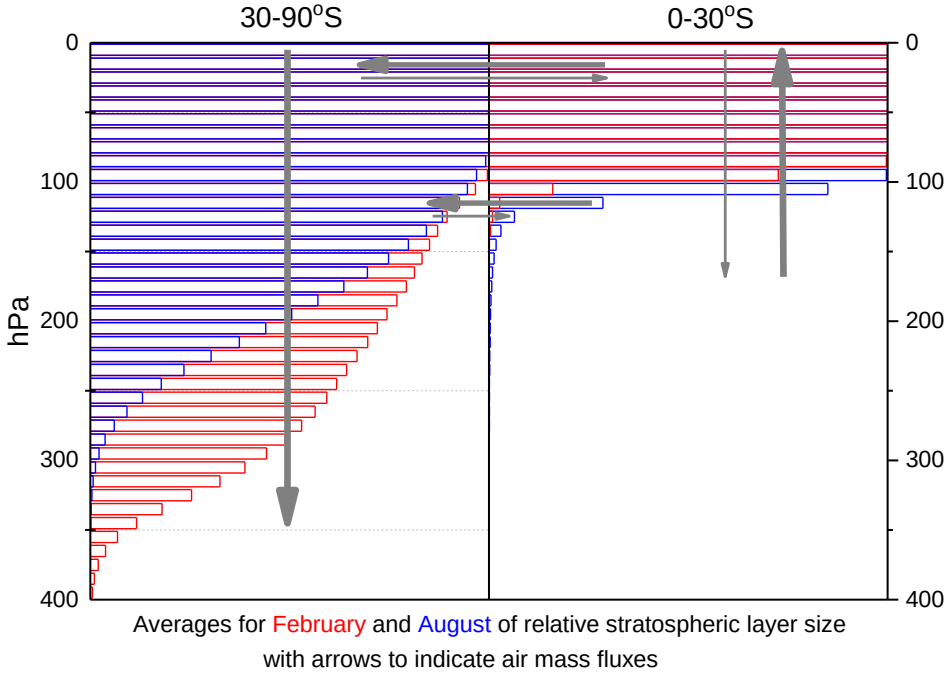
About 30% of ^{14}CO measured in the troposphere was created in the stratosphere, so cross tropopause transport is a key issue.



Stratosphere – Troposphere exchange

The Brewer-Dobson circulation and the seasonal cycle in tropopause heights cause stratosphere – troposphere exchange that is not the same as a simple box model.





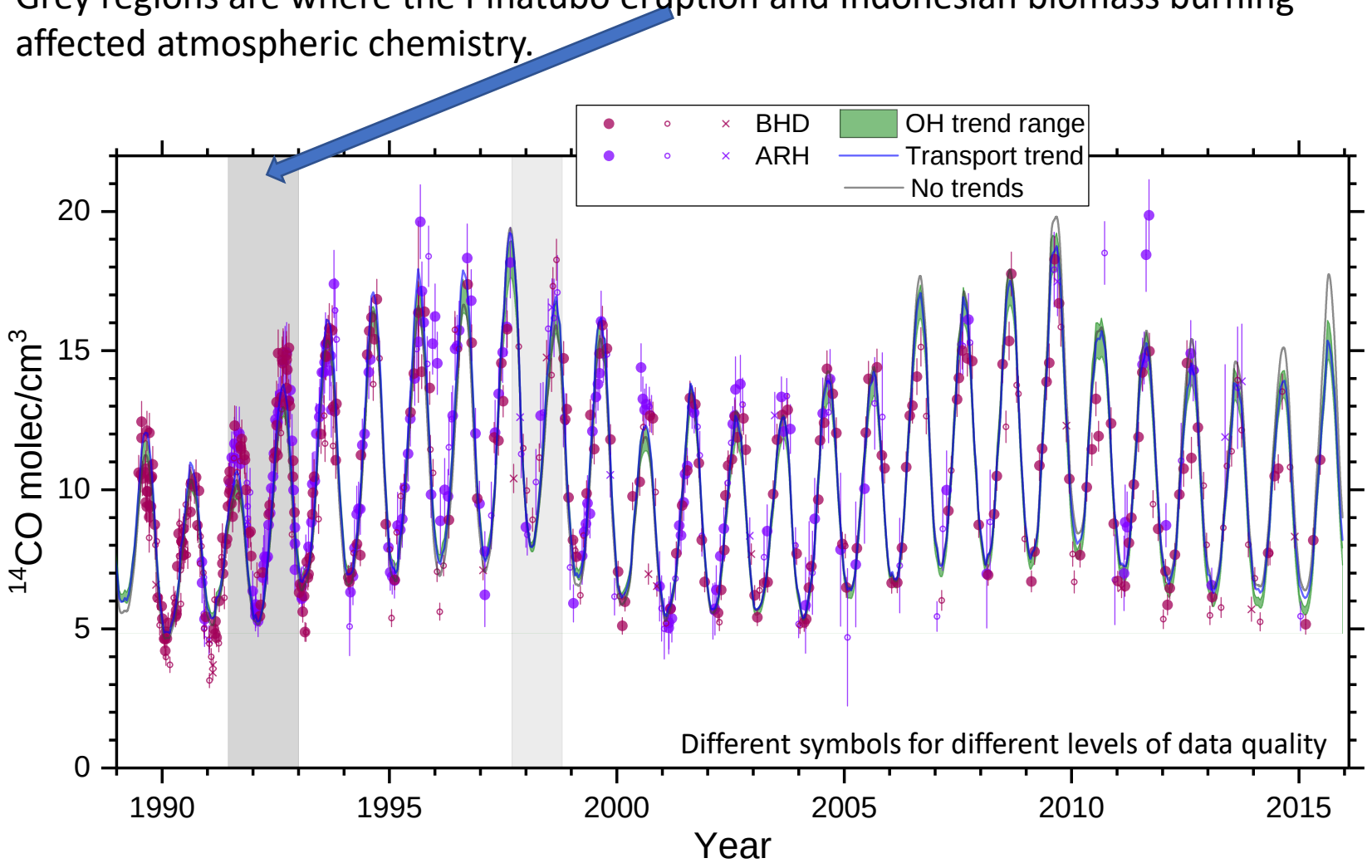
Averages for February and August of relative stratospheric layer size with arrows to indicate air mass fluxes

Using reanalysis data for tropopause height with a 2.5° resolution, together with cross tropopause mixing times of 5 – 20 days we can now reproduce the vertical profiles for ^{14}CO and CH_4 better than other atmospheric chemistry – transport models have so far.

Cross tropopause mixing times of 5-days, 10-days and 20-days are compared with flight sample data.

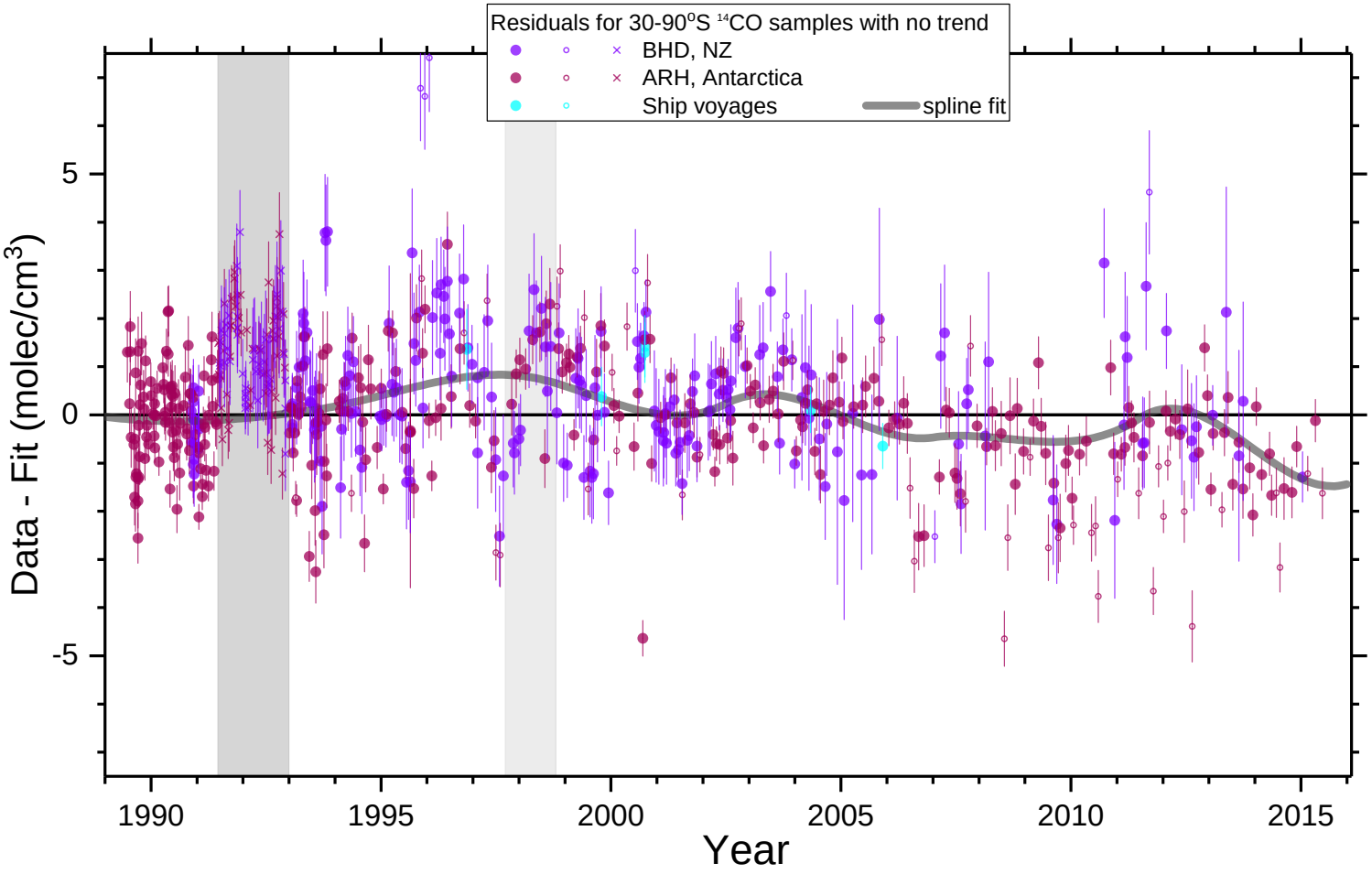
Cosmogenic ^{14}CO data in 30-90^{o}S over two solar cycles of production

Annual cycles are determined by OH and longer term variations by solar modulation of cosmic ray production of ^{14}C. Data is for surface samples from Baring Head and Arrival Heights together with fits to the data that have no change in OH or transport. Grey regions are where the Pinatubo eruption and Indonesian biomass burning affected atmospheric chemistry.



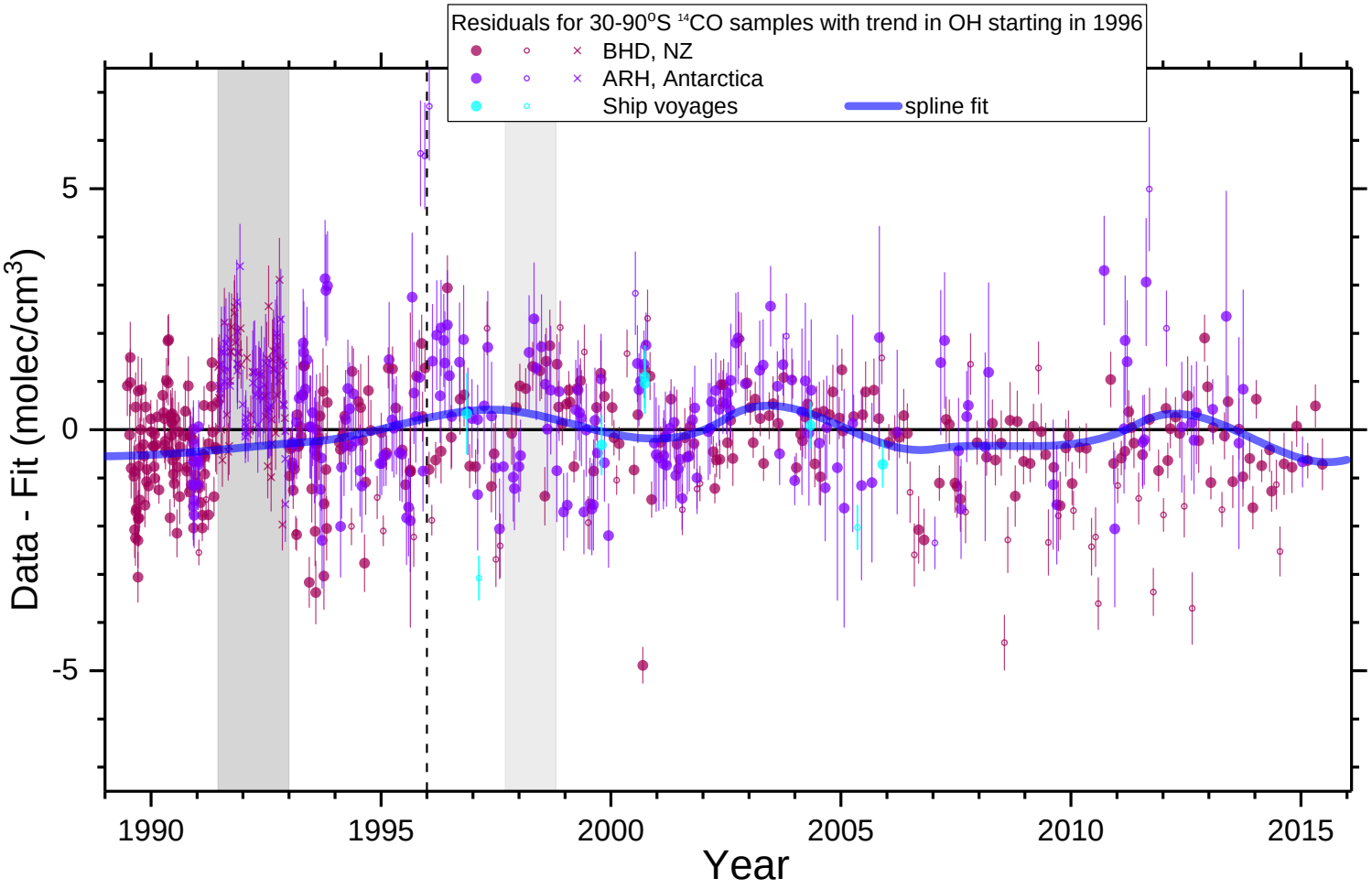
^{14}CO residuals for no change in OH or atmospheric transport

Note: The spread of residuals is reduced when transport between the low and high latitude regions has a seasonal cycle, but by even more when this tropospheric mixing rate is also modulated by ENSO.



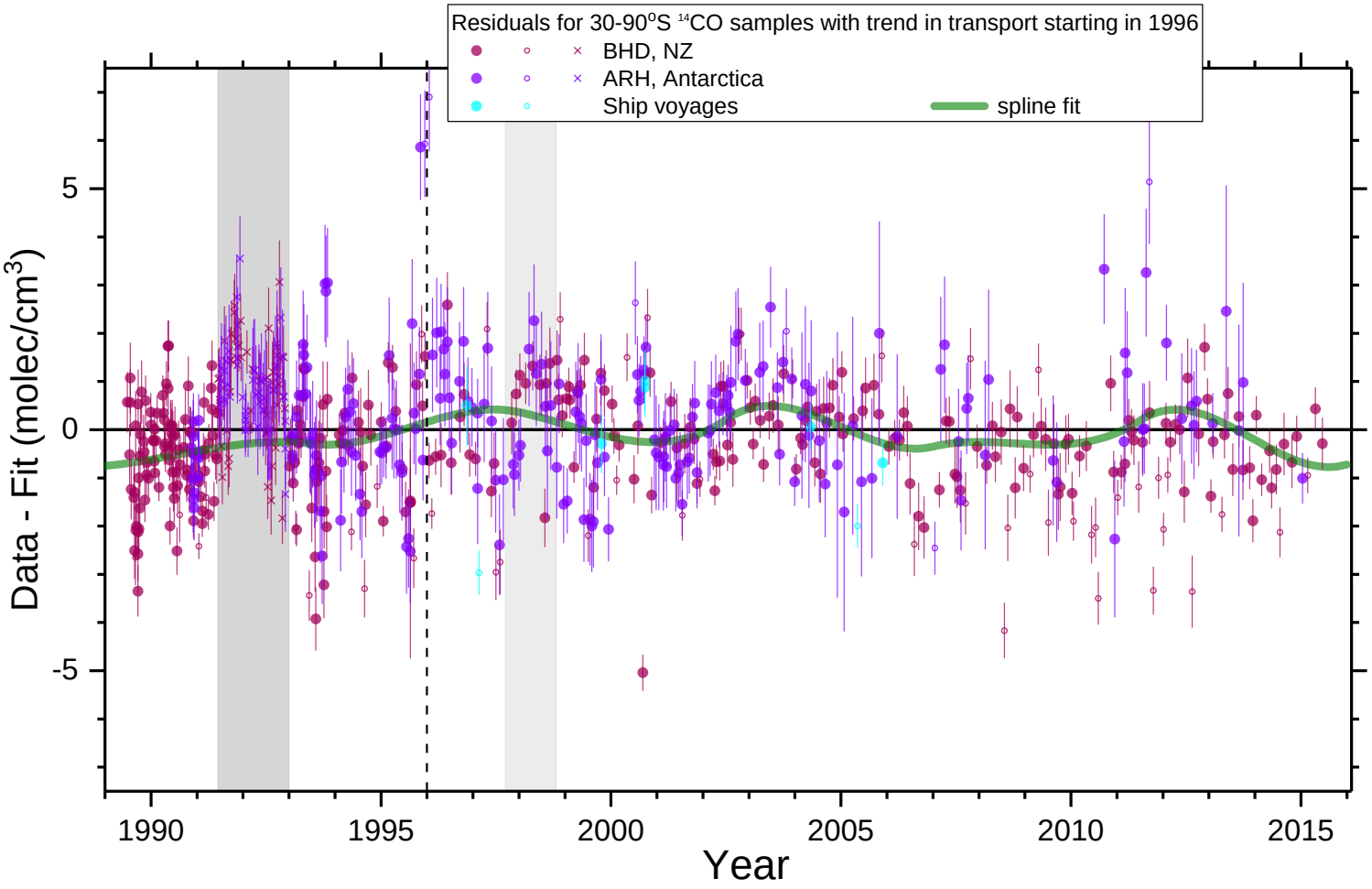
^{14}CO residuals for a positive trend in OH

These residuals in the fit now include a linear trend in OH from 1996 on, and re-adjust the other parameters in the model. The fitted tropospheric OH trend is +1.1% per annum.



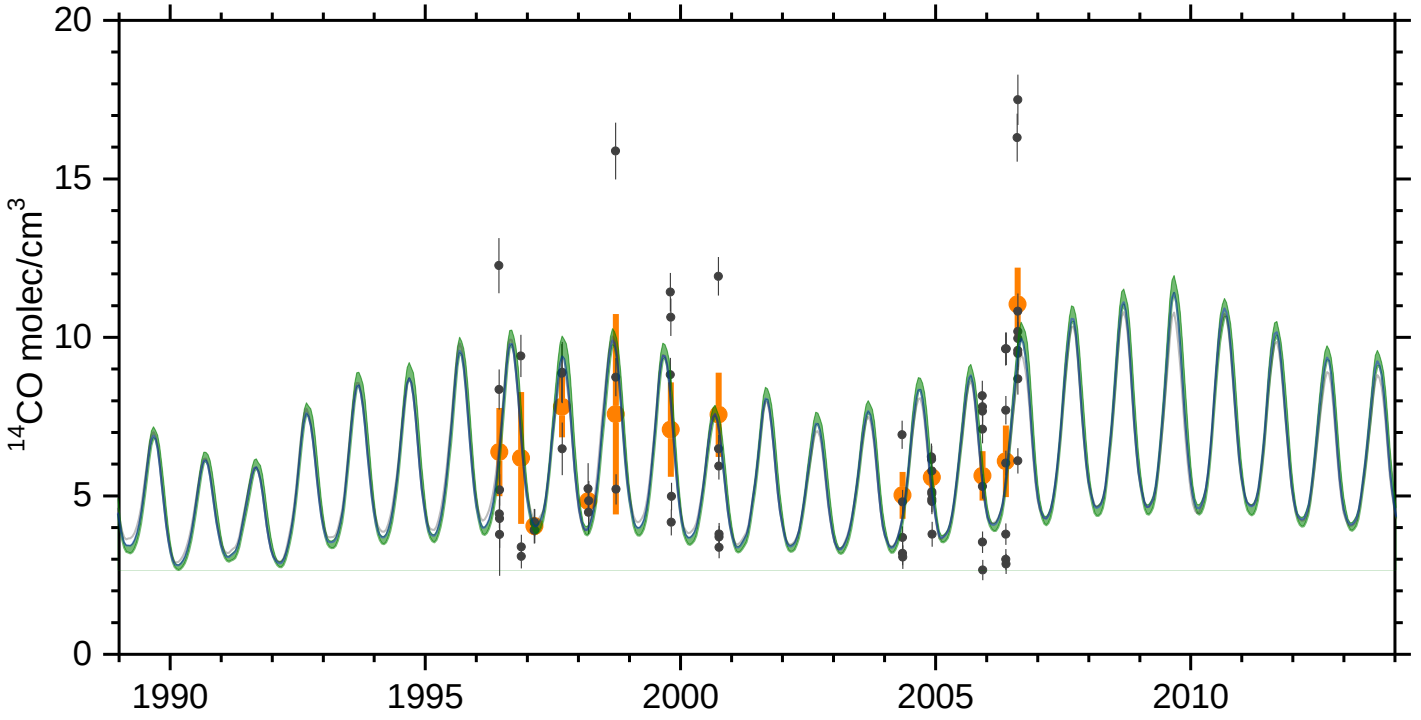
^{14}CO residuals for trend in mixing between 30-90°S and 0–30°S

Tropospheric mixing is increasing here by 4.3% per annum from 1996 on. This would be a large change overall, but is only an approximation in this analysis for changes in transport in the upper troposphere where ^{14}CO production rates are large, and where an increase in Brewer-Dobson circulation occurs in stratospheric models.



^{14}CO data over 0–30°S from ship samples in the Pacific

Data for 1996 – 2000 is on voyages between NZ and California, and for 2004 – 2006 between NZ and Japan. These show a large latitudinal gradient and a seasonal cycle that decreases with latitude. Averages shown in orange have been used in the model that is shown in green.



August 2006 samples do not have the usual very low ^{14}CO concentrations around the equator. This is in the region around Indonesia where Markus Rex et al found an O_3 (and therefore OH) hole in the tropics in 2009.

Rex, M., et al., 2014: A Tropical West Pacific OH minimum and implications for stratospheric composition. *ACP, 14:4827-4841.*

Some conclusions

- Uncertainties in bottom-up analyses of the CH_4 budget are >20% and the recent trend in atmospheric CH_4 is ~0.3%/yr.

- Nevertheless the current CH_4 trend is starting to raise major questions about its causes and how much it may disrupt the UNFCCC target of keeping global warming to <2^{o}C.

- The large number of source and removal processes affecting atmospheric CH_4 make attribution of its recent changes a major challenge.

- Independent evidence from ^{14}CO shows that OH is not decreasing in the extra-tropical southern hemisphere, but supports evidence for an OH-hole in the equatorial Pacific and suggests this started in mid-2006.

- Structural changes in the OH distribution with increases in some places and decreases in others were proposed by Jos Lelieveld et al in 2004. Are there also interannual variations in OH that could explain the "wobbles" in $\delta^{13}CH_4$?