Estimation of atmospheric CO_2 concentrations through the data assimilation of AIRS radiances in the ECMWF 4D-Var system

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ECMWF

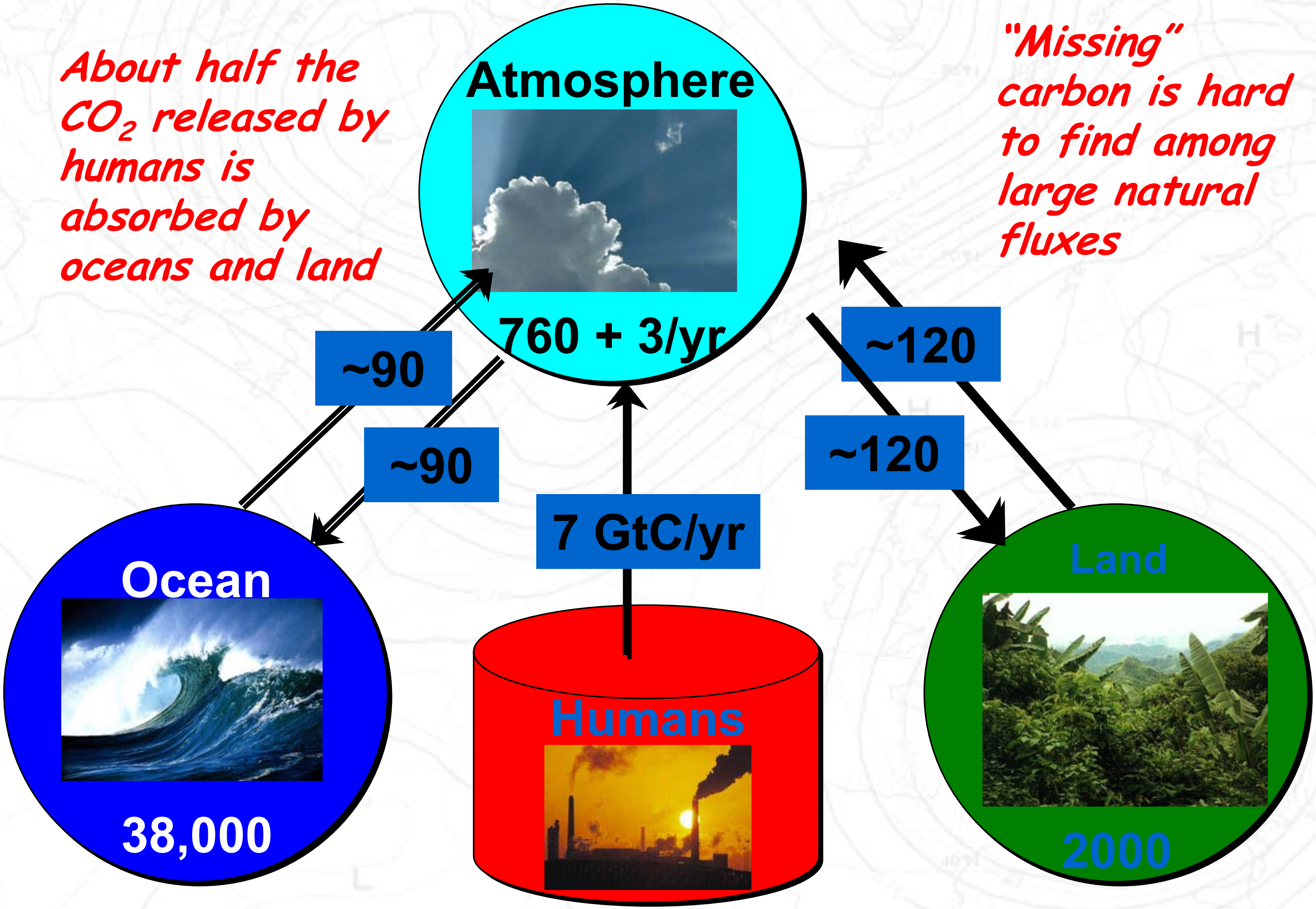
Outline

- Why CO_2 data assimilation?
- Some sensitivity studies
- Description of CO_2 data assimilation system
- Tropospheric results
- Comparisons with independent AIRS retrievals and model simulations
- Separation of signals (CO_2, T, and H_2O)
- Validation efforts
- Conclusions

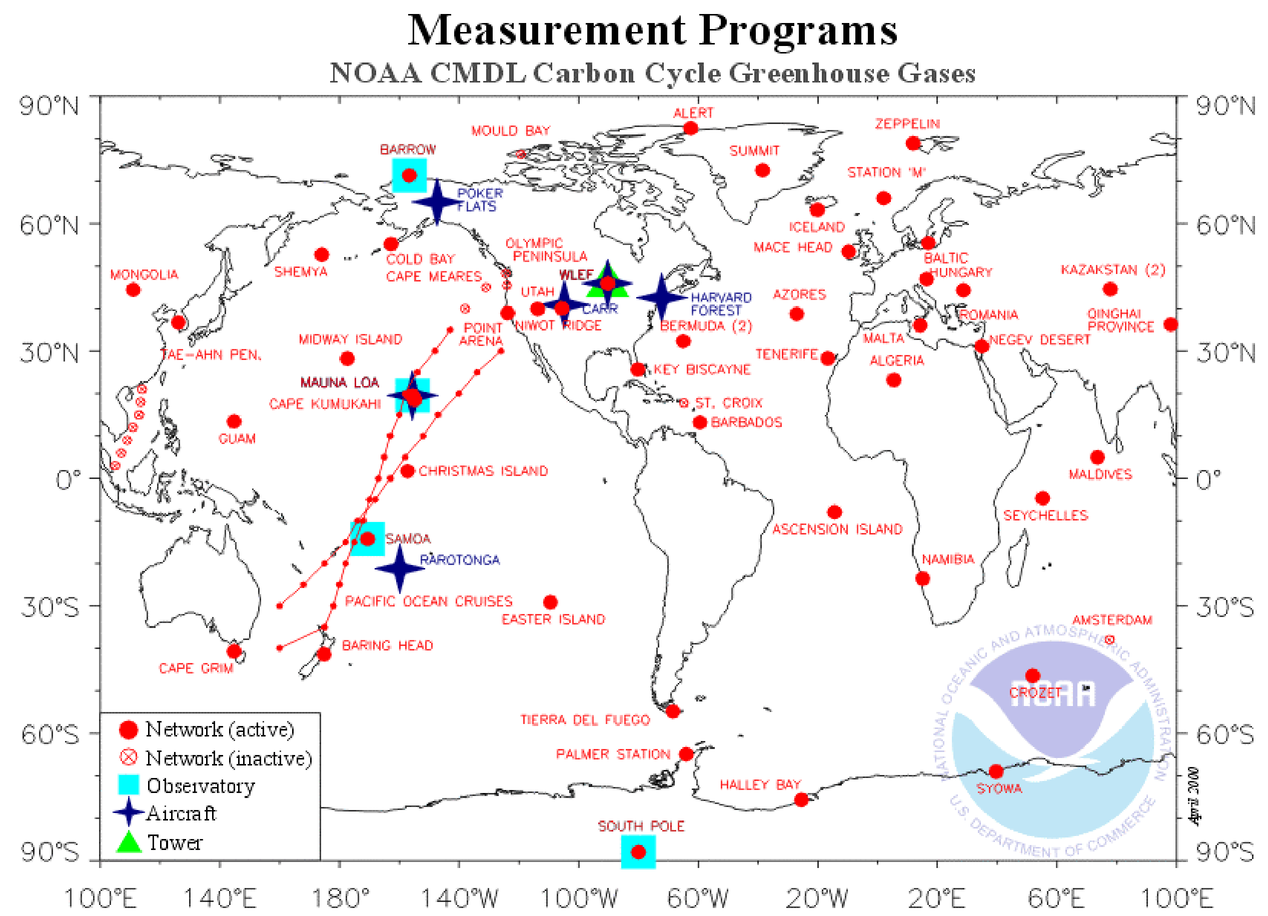
Global Carbon Cycle

About half the CO_2 released by humans is absorbed by oceans and land

"Missing" carbon is hard to find among large natural fluxes

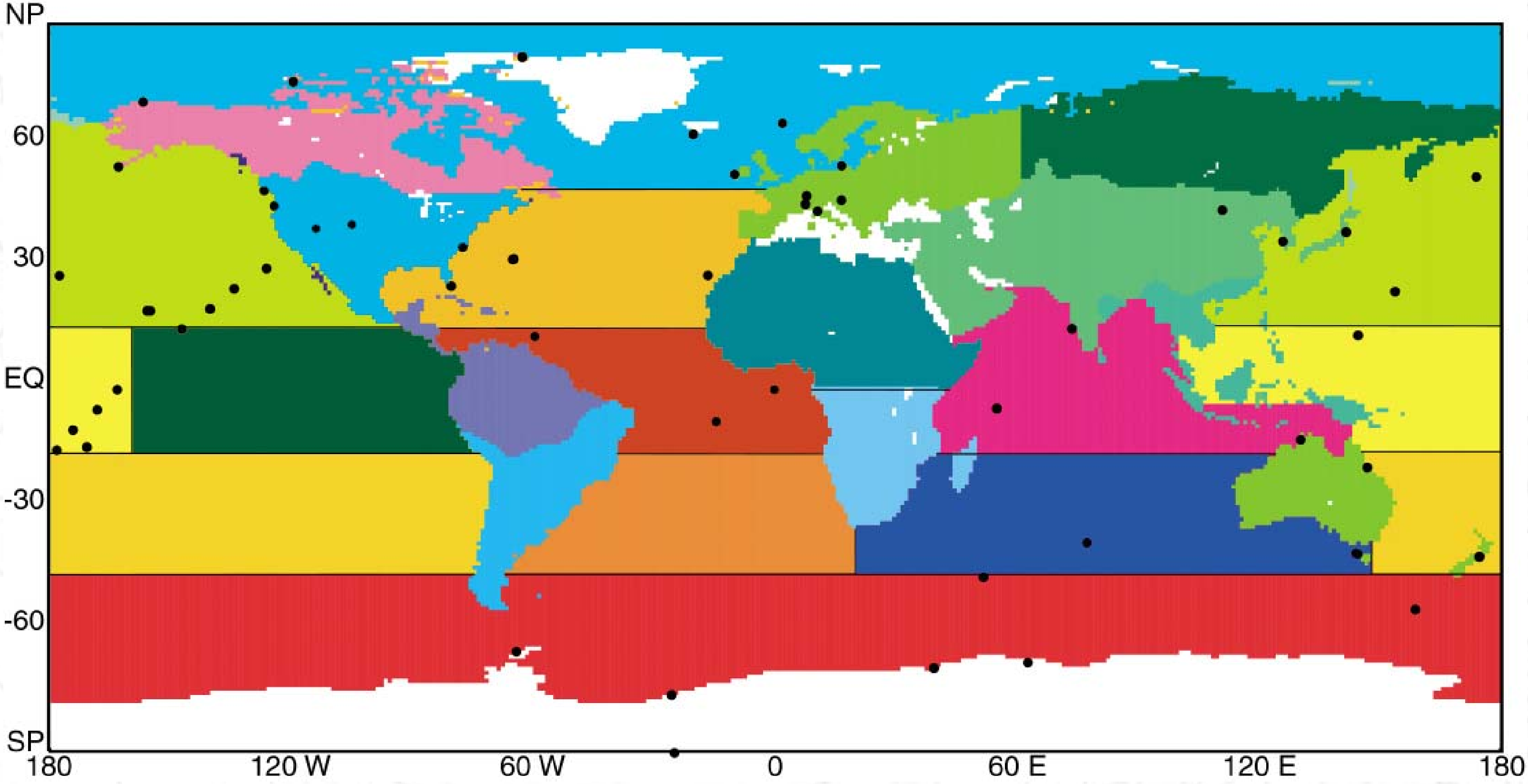


Current NOAA surface flask network



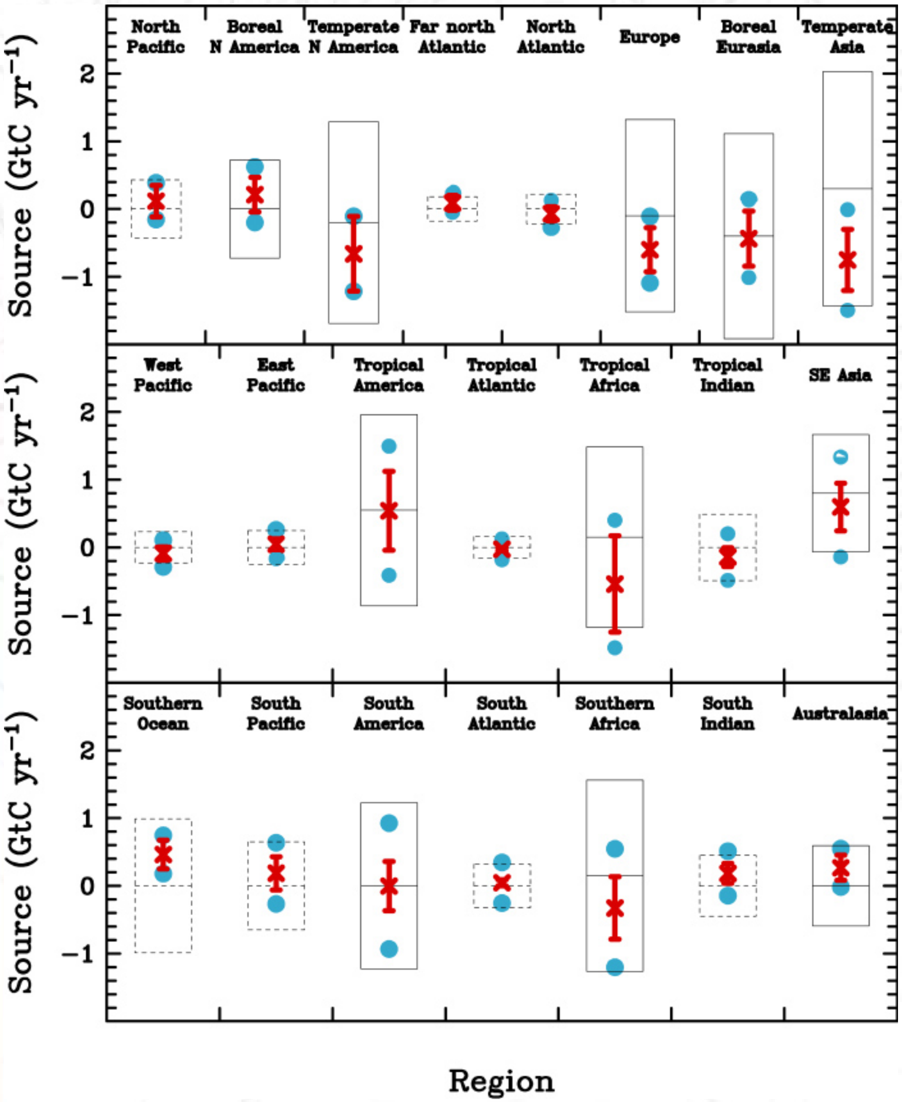
The NOAA CMDL Carbon Cycle Greenhouse Gases group operates 4 measurement programs. In situ measurements are made at the CMDL baseline observatories: Barrow, Alaska; Mauna Loa, Hawaii; Tutuila, American Samoa; and South Pole, Antarctica. The cooperative air sampling network includes samples from fixed sites and commercial ships. Measurements from tall towers and aircraft began in 1992. Presently, atmospheric carbon dioxide, methane, carbon monoxide, hydrogen, nitrous oxide, sulfur hexaflouride, and the stable isotopes of carbon dioxide are measured. Dr. Pieter Tans, Carbon Cycle Greenhouse Gases, Boulder, Colorado, (303) 497-6678. ptans@cmdl.noaa.gov.

Synthesis Flux Inversion



Observations from about 75 flask stations are inverted to surface flux estimates in 22 basis regions. Flux patterns within these regions are prescribed, as are fluxes due to anthropogenic emissions and basic natural processes.

Synthesis inversion results

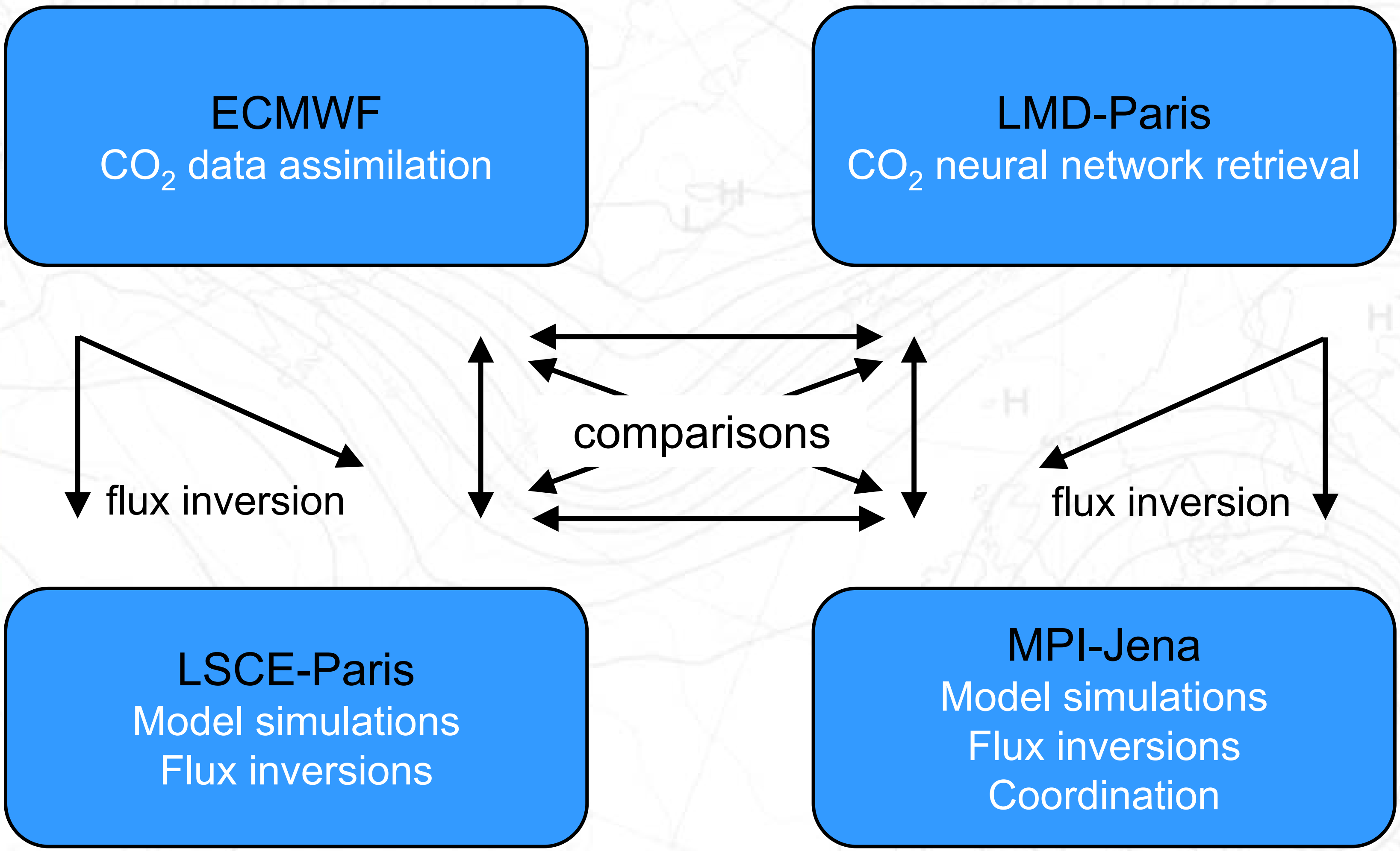


- Red 'x' indicates mean flux across 15 models
- Blue circles indicate mean a posteriori uncertainty ('within' model error)
- Red error bars indicate model spread ('between' model error)
- 'Within' model uncertainty larger than 'between' model uncertainty for most regions

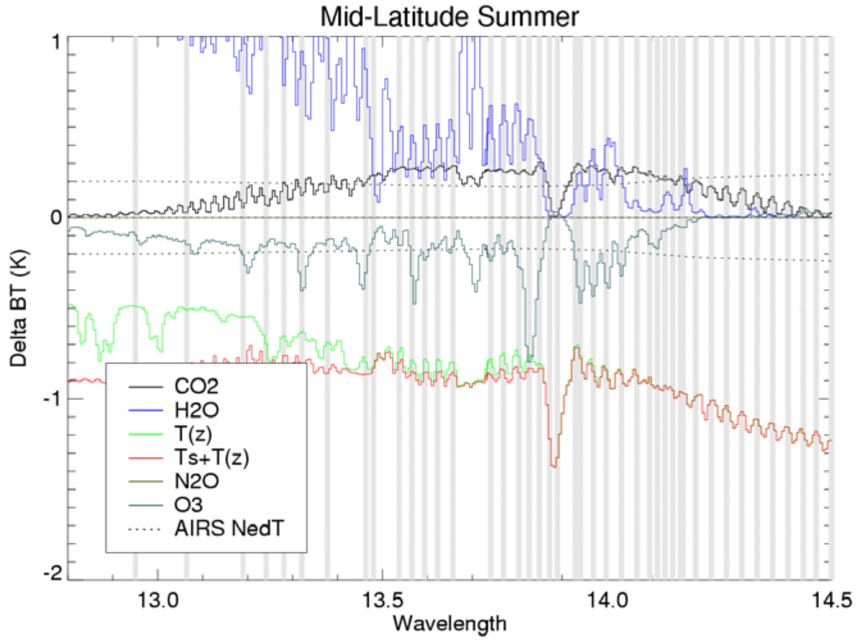
- **Current inversion system is data limited!**

From Gurney et al. (2002)

The COCO Project



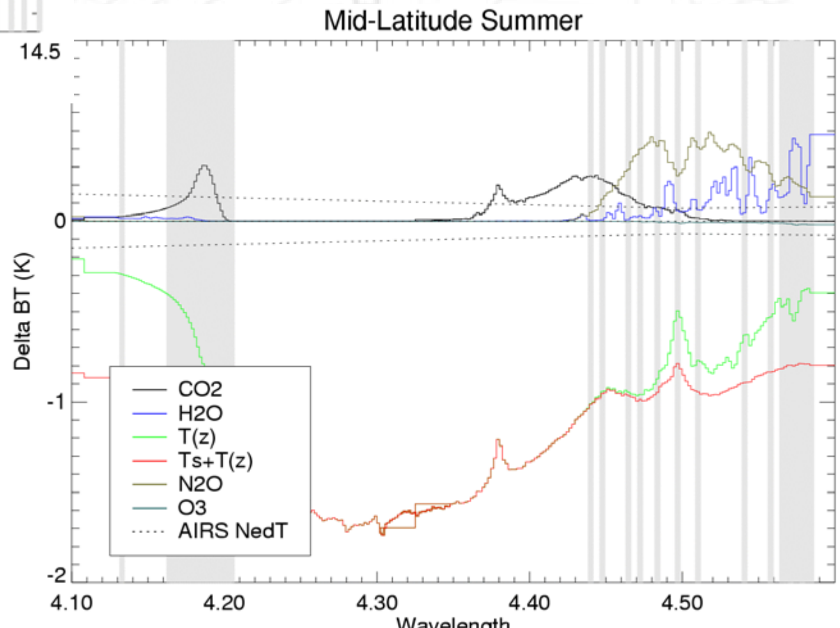
AIRS Channel Sensitivity



T, T_s, H_2O, and O_3 perturbations are based on forecast model error.

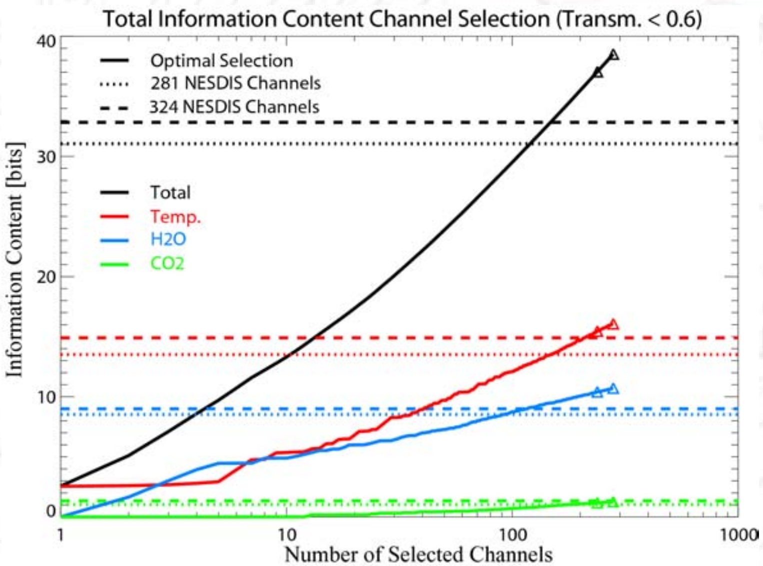
CO_2 and N_2O perturbations are based on seasonal variability.

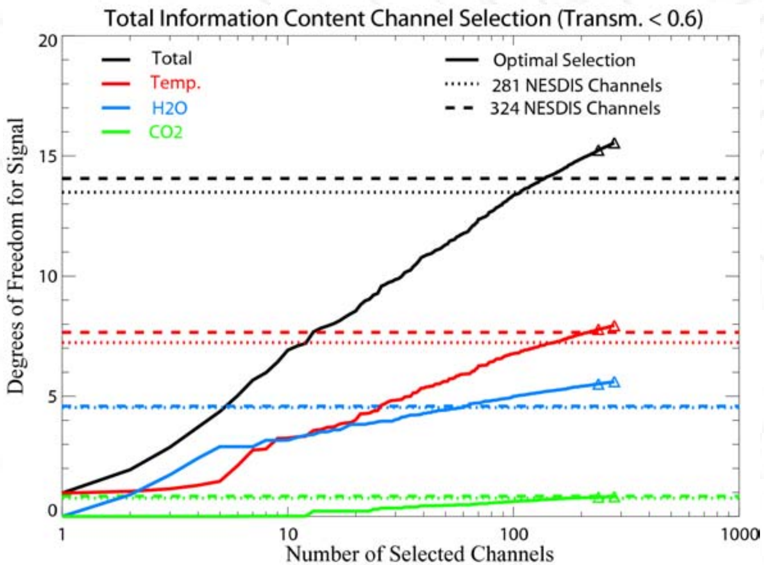
Without the spectral correlation in the absorption spectra, CO_2 would be completely concealed by the other variables.



CO_2 Data Assimilation at ECMWF

Effects of channel selection



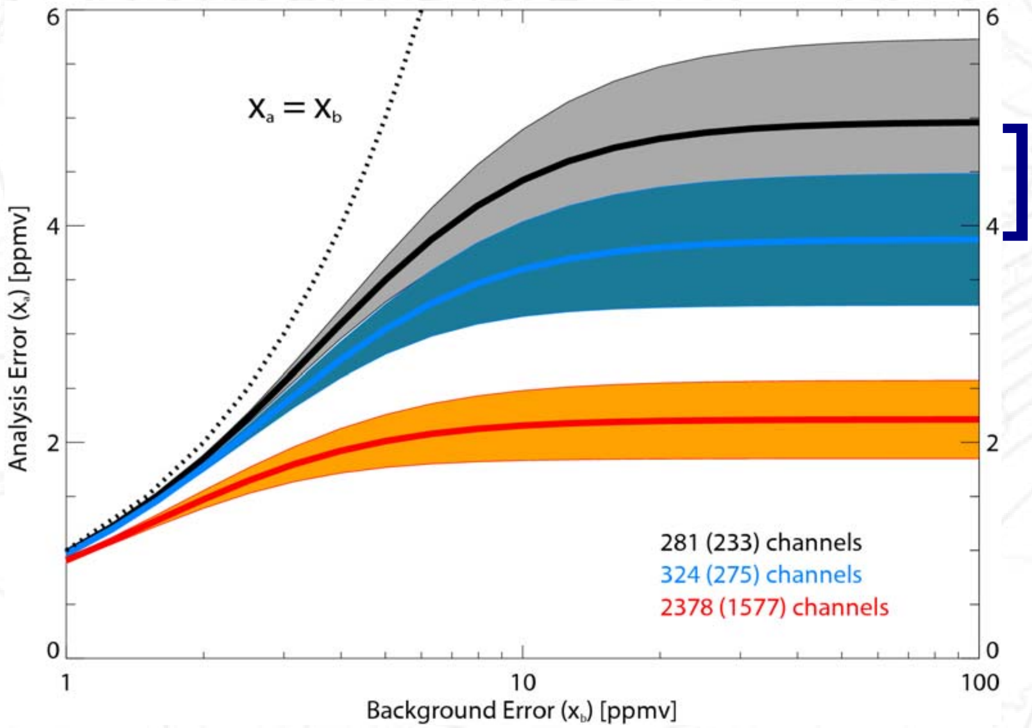


A channel selection purely based on the ECMWF background covariance information could retrieve more information with the same number of channels than the NESDIS selection.

However, this is very model specific. The NCEP forecast model would probably generate a different selection that is equally justifiable.

The added CO_2 channels, selected by LMD, provide more CO_2 information per channel than the optimal selection, because the latter is dominated by T and q.

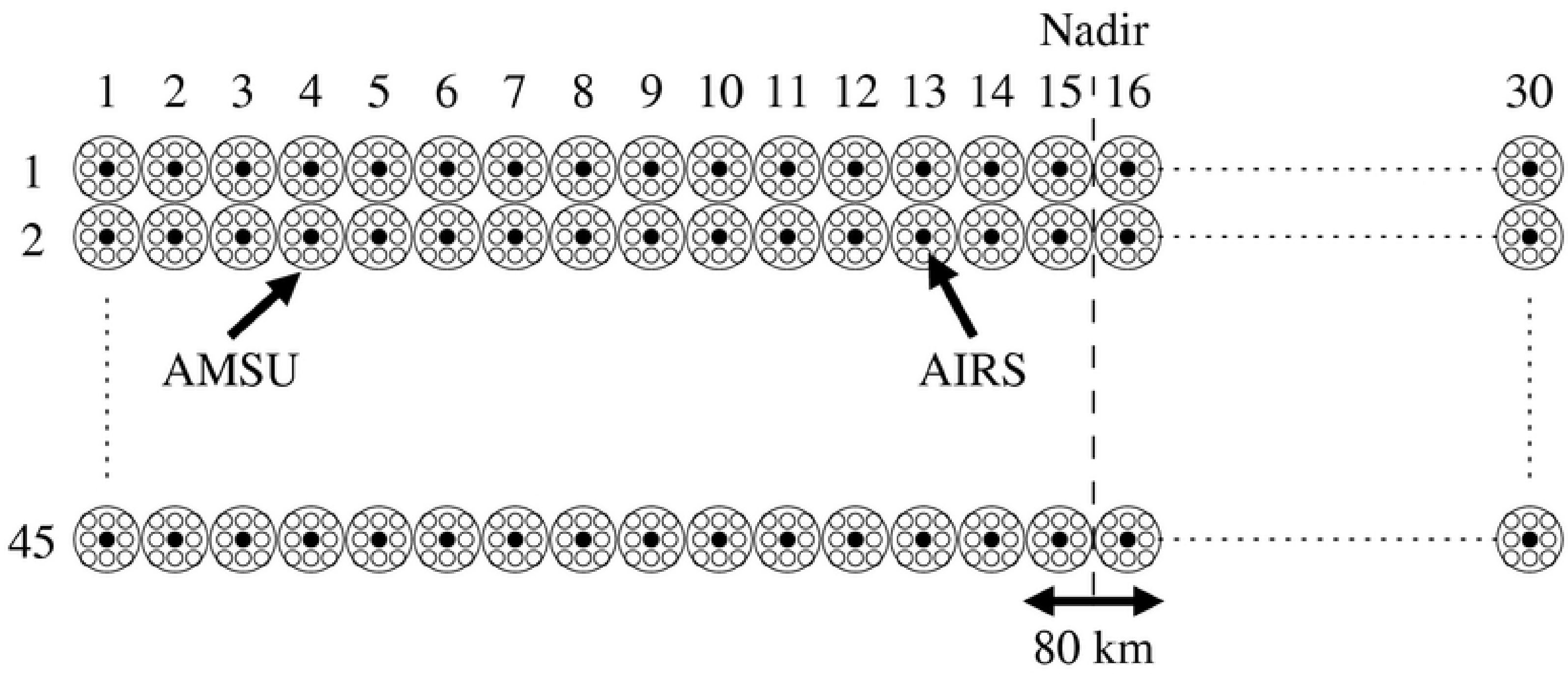
CO_2 Error limits



Notice the large improvement by the extra CO_2 channels compared to the original 281 channels.

Based on 1D-Var simulations we see that when CO_2 is retrieved as a column-averaged mixing ratio, the analysis error reaches a limit that depends on the number of spectral channels and on the specified observational error. The shaded areas around the mean show the variability due to various atmospheric profiles.

AIRS data usage at ECMWF



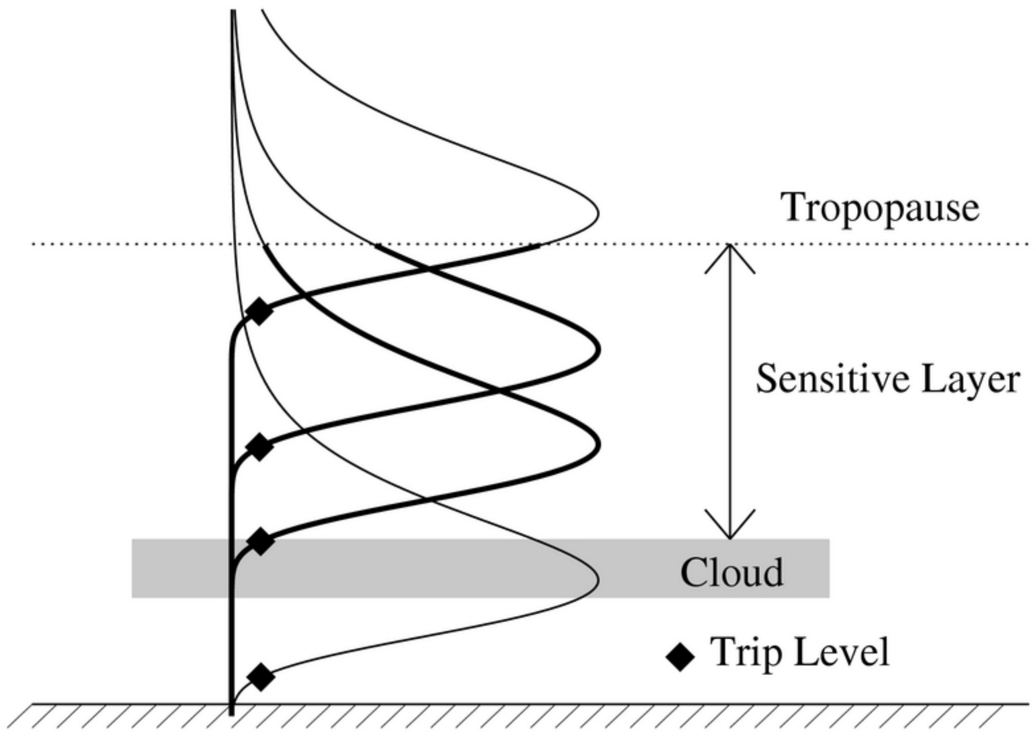
For the CO_2 data assimilation 1 out of every 9 AIRS footprints is used. No additional thinning is used in contrast to the operational set-up. This was done to ensure as many observations with low or no cloud cover as possible.

Only the long-wave CO_2 band is used for these initial experiments to avoid problems with some of the other parts of the spectrum.

Description of CO_2 assimilation system

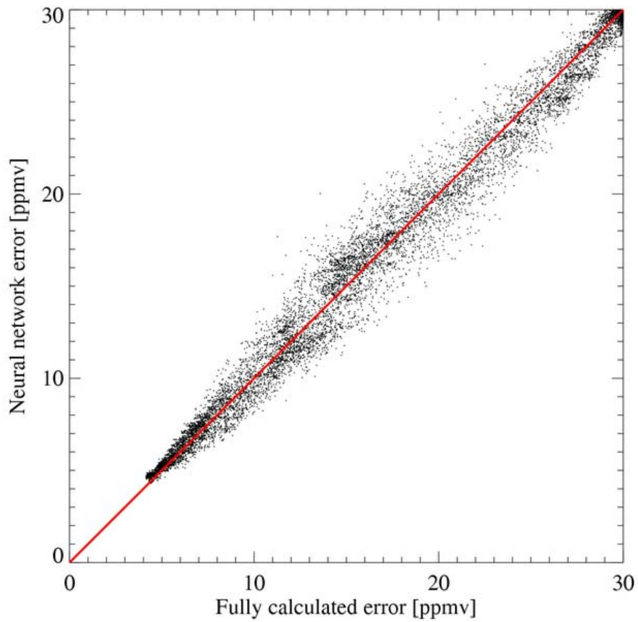
- CO_2 is currently treated as a so-called 'column' variable within the 4D/3D-Var data assimilation system.
- This means that CO_2 is not a model variable and is therefore not moved around by the model transport.
- For each AIRS observation location a CO_2 variable is added to the control (minimisation) vector. The CO_2 estimates therefore make full use of the 4D/3D-Var fields of temperature, specific humidity and ozone.
- The CO_2 variable itself is limited to two column-averaged mixing ratios (1 for the troposphere and 1 for the stratosphere) with fixed profile shapes, but a variable tropopause.
- Zonal mean, monthly averaged background values estimated from flask observations are used with a background error of 30 ppmv.

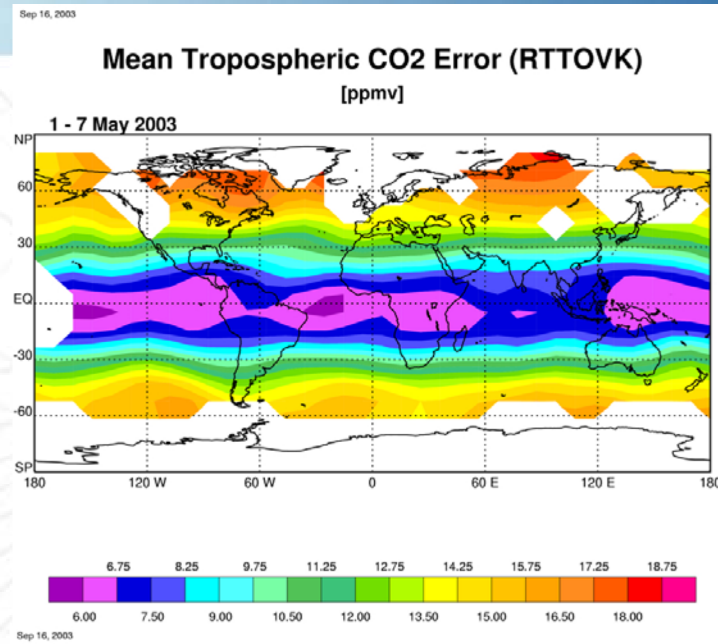
Definition of Sensitive Layer

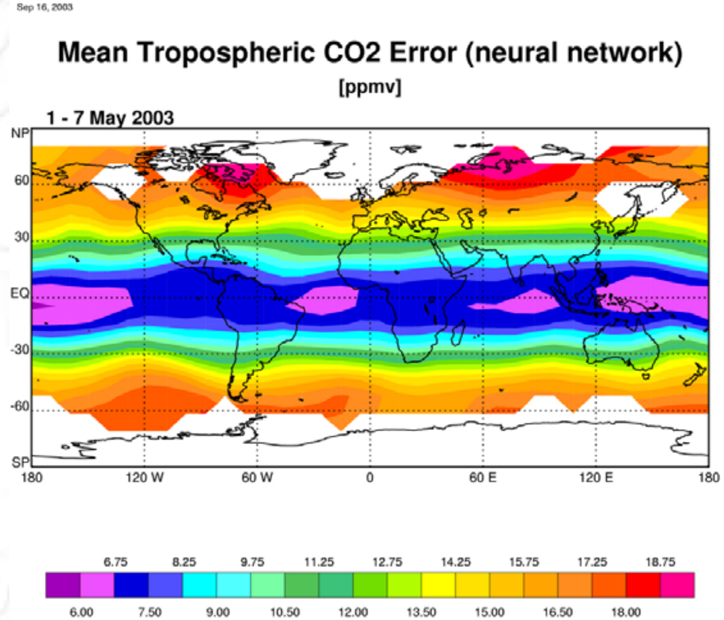


All channels that are not affected by clouds are used in the assimialtion. The tropopause splits the channel sensitivty between the troposphere and the stratosphere in the adjoint calculations.

Error Estimation







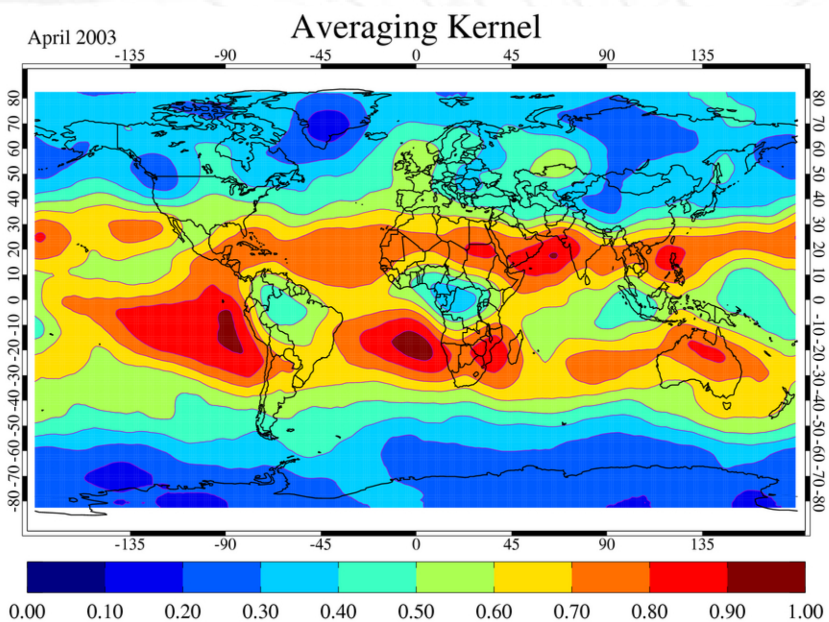
A neural network is used to estimate the CO_2 analysis error as a function of lapse rate and number of channels. This avoids heavy calculations of Jacobians and therefore enables a larger amount of AIRS data in the analysis system.

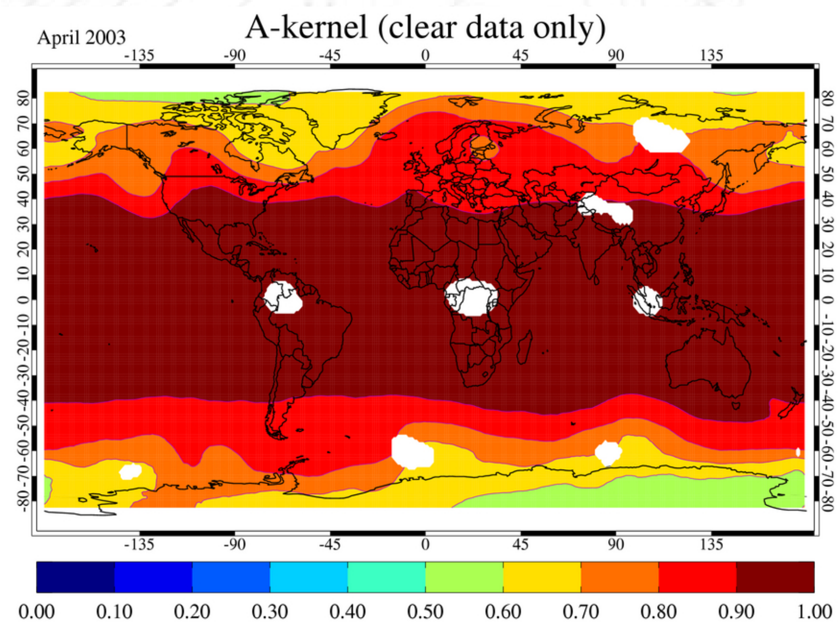
Measure of Information Content

The averaging kernel ($A = I - S_a S_b^{-1}$) is used as a relative measure of the information retrieved from the observations. After linearisation around the background we obtain the following equation (1-dimensional case):

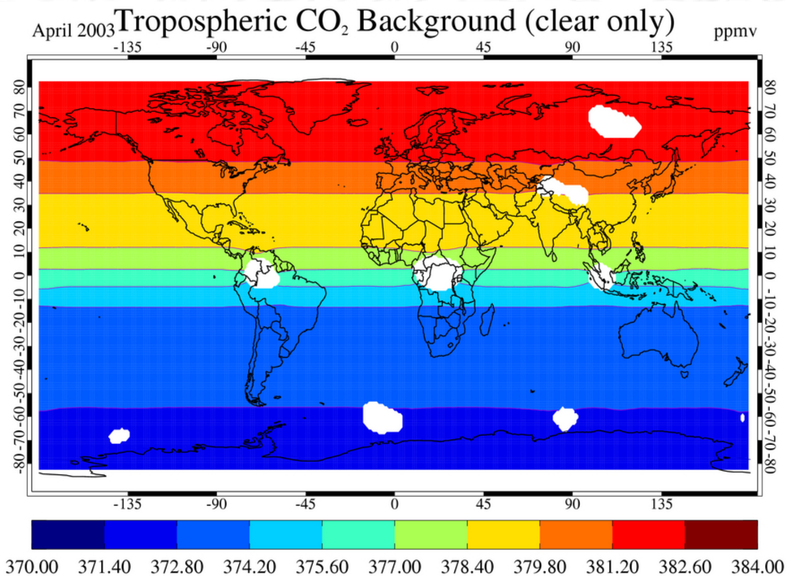
$$CO_2(\text{analysis}) = A * CO_2(\text{real}) + [1 - A] * CO_2(\text{background}) + D_y \varepsilon_y$$

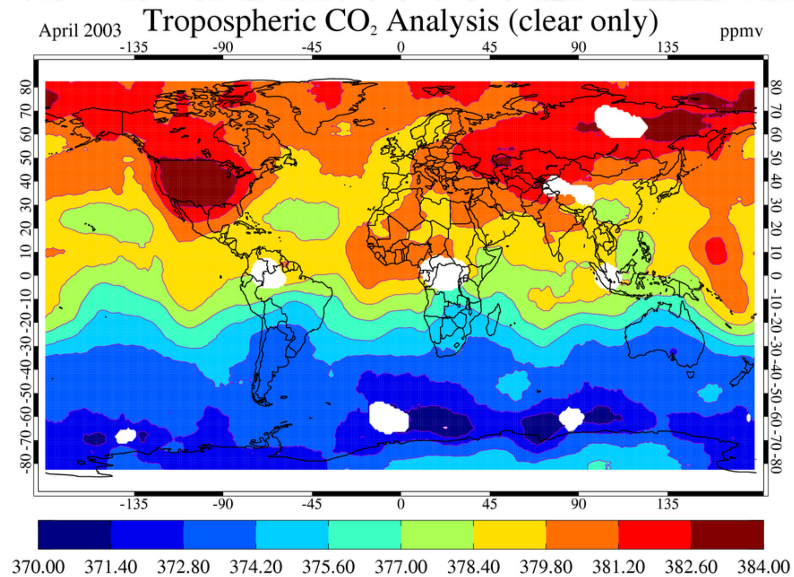
So, A=1: no background bias; A=0: analysis=background



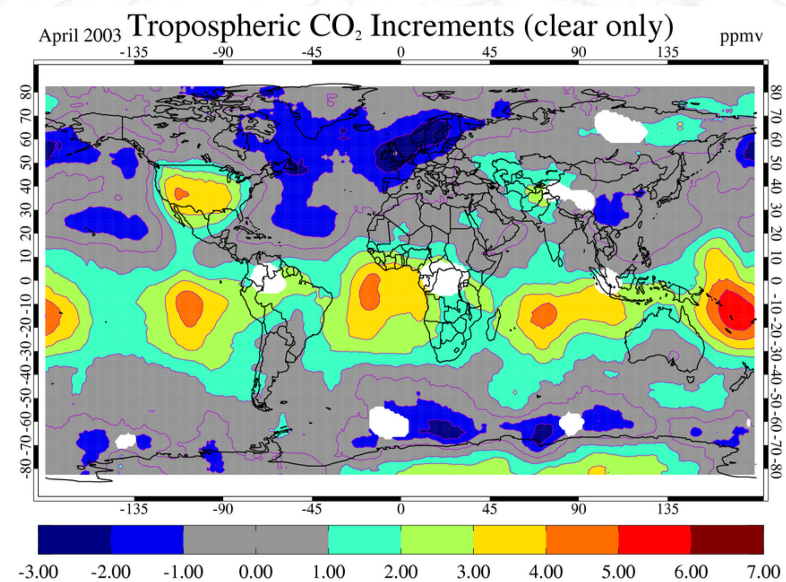


Global Results

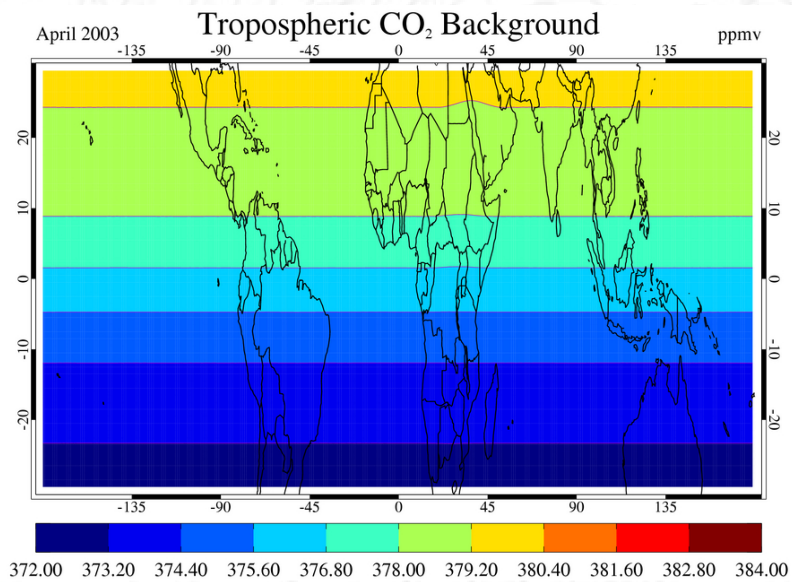


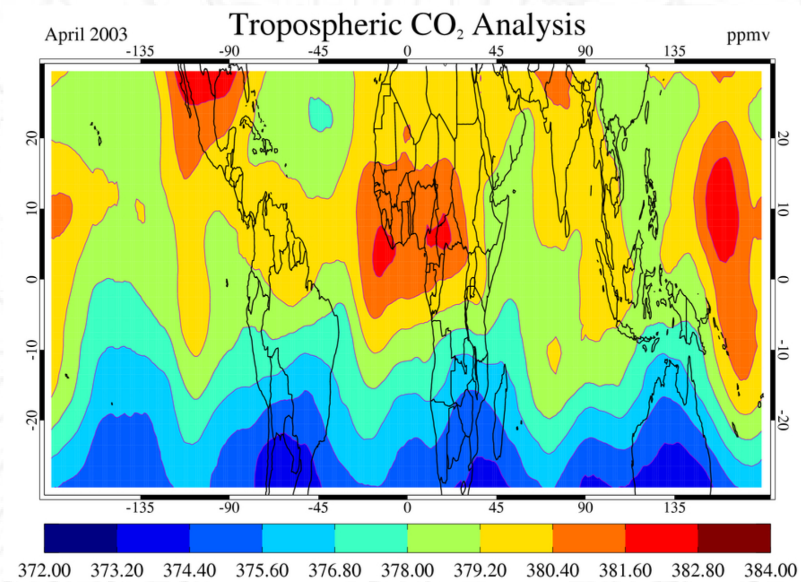


When we look at global CO_2 increments, most changes to the background are made in the tropics, where the information content of the observations is largest. Therefore, main focus will be on tropical results.

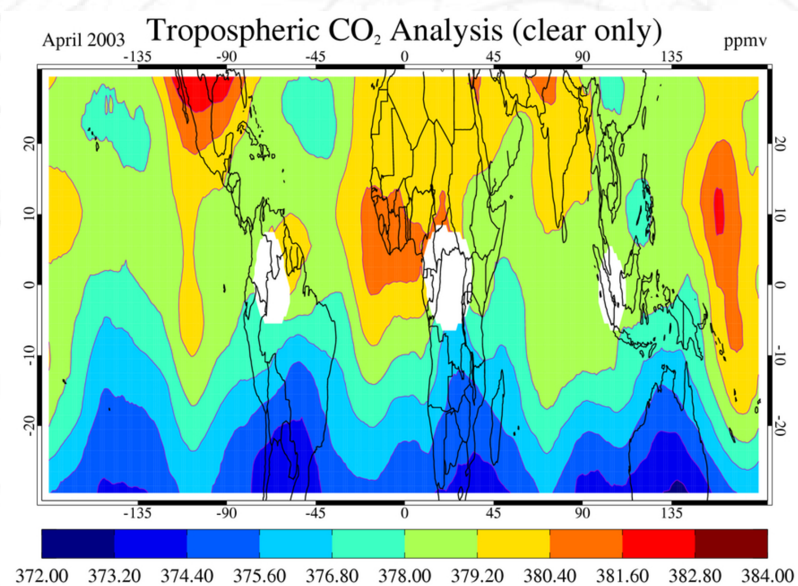


Results troposphere

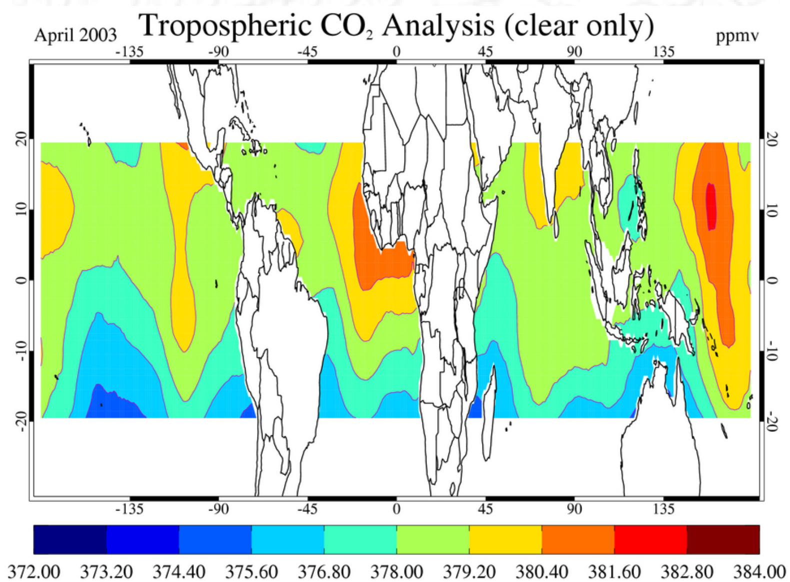


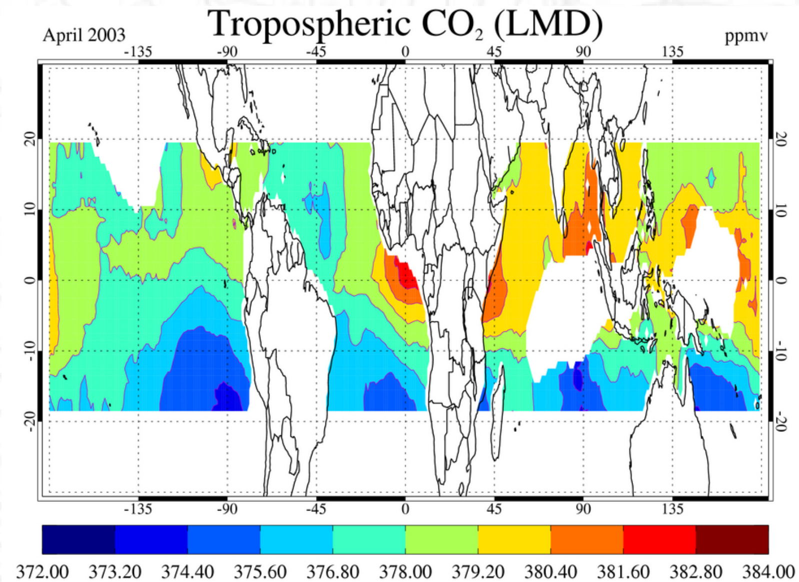


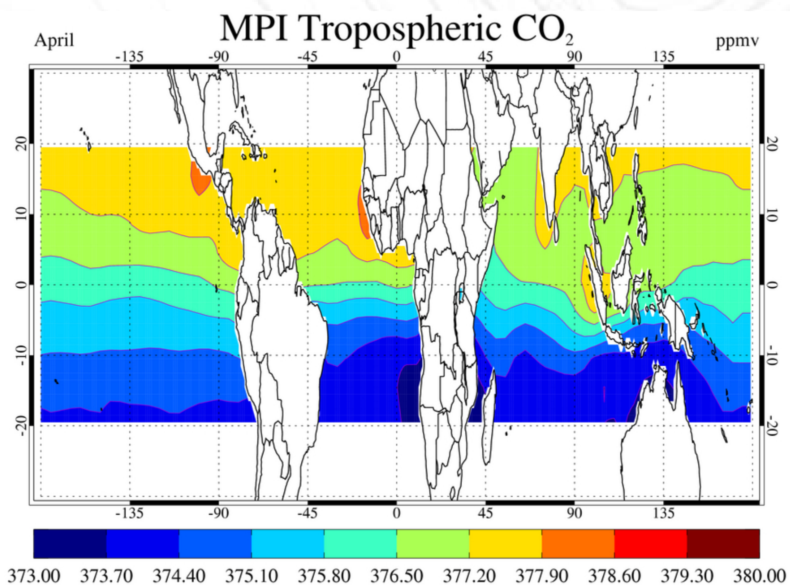
For April 2003, wave-like patterns are produced in the southern hemisphere. More complicated patterns are found in the northern hemisphere, possibly caused by biomass burning and fossil fuel emissions.



Comparisons



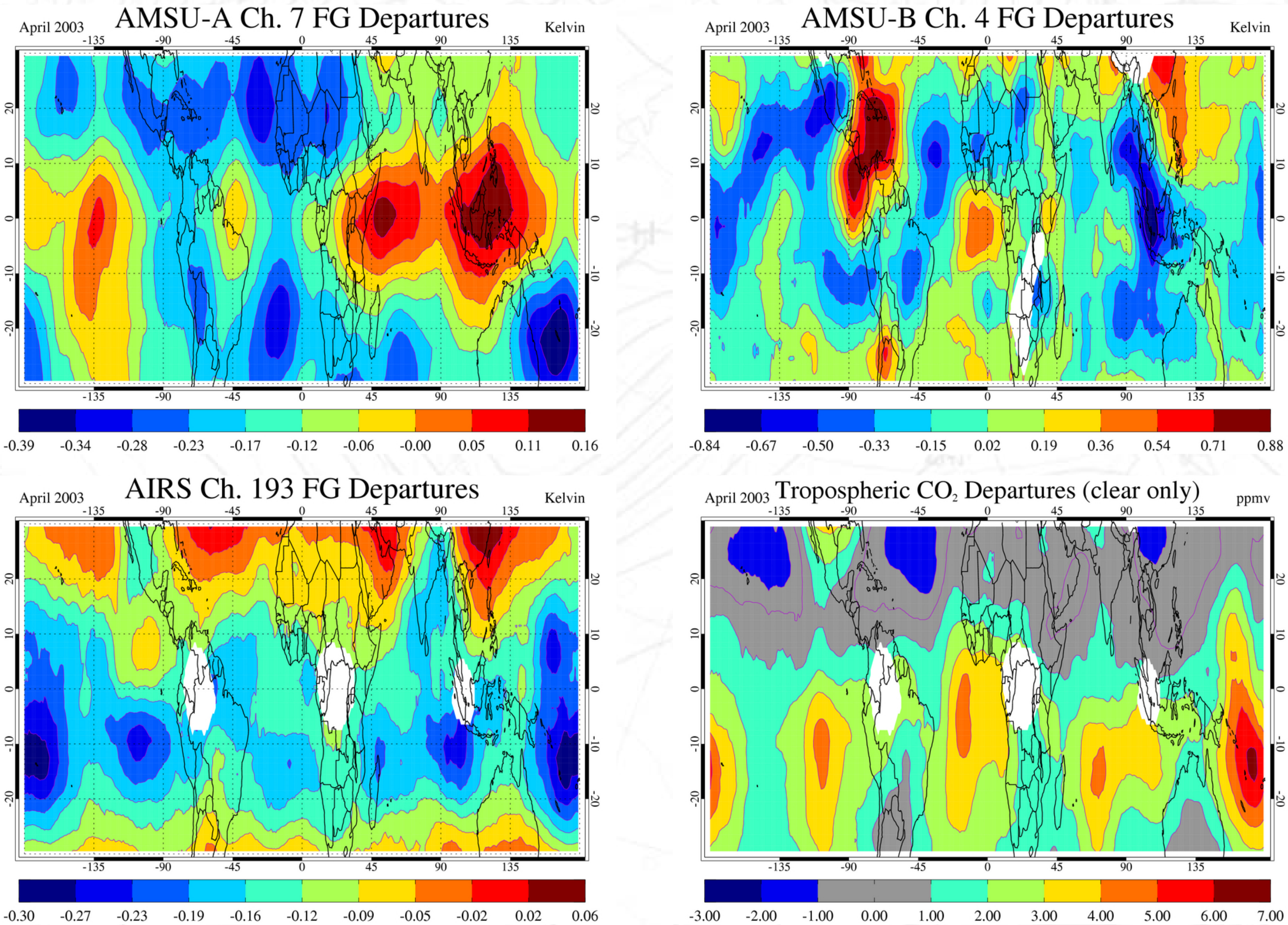




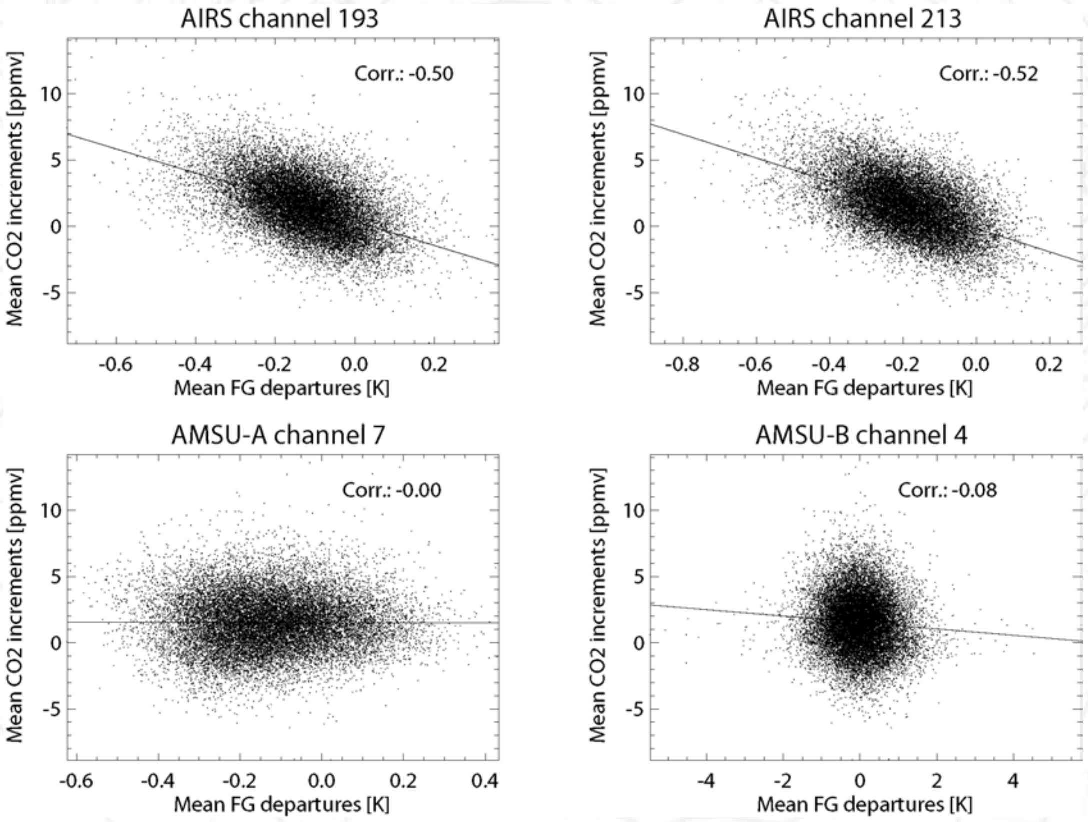
Comparisons with independent retrieval results (above) and model simulations (left) show similarities and differences.

Scale is smaller to allow comparison of patterns rather than amplitudes of gradients!

Separation of signals?

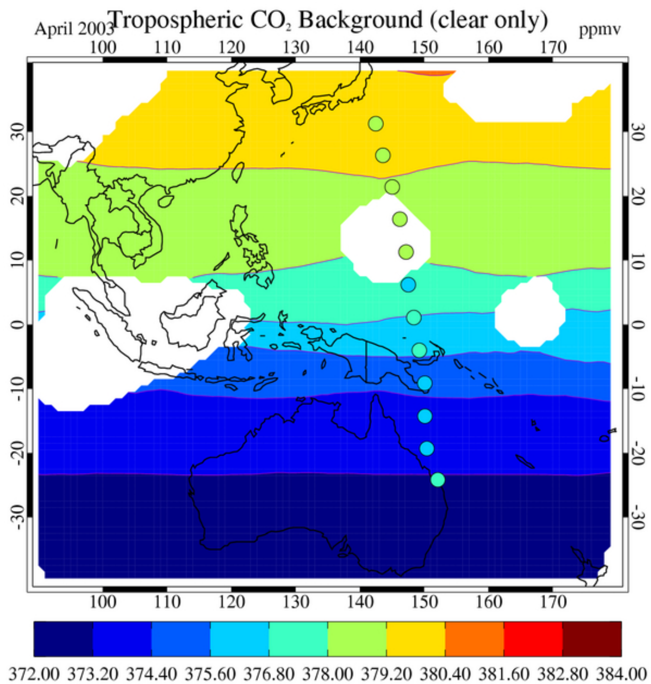


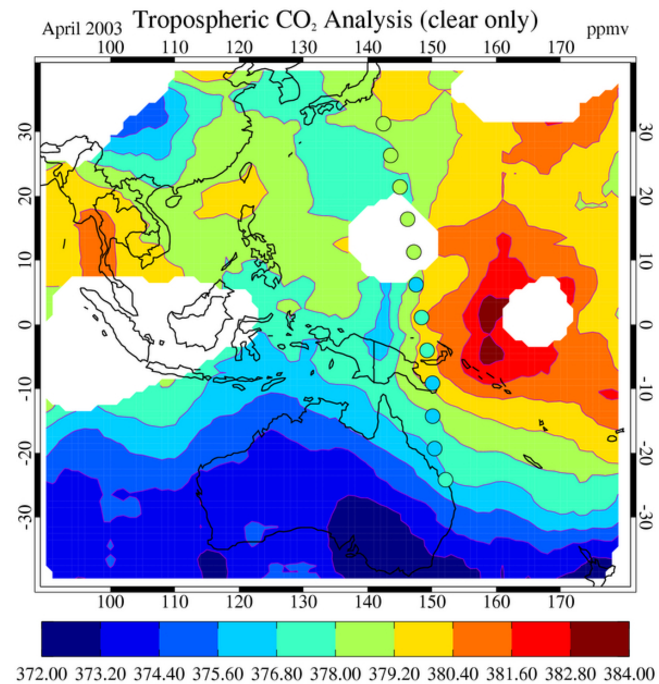
T and H_2O aliasing?



In the tropics there is a clear correlation between the AIRS FG departures and the CO_2 increments. This correlation is absent for the AMSU-A (temperature) and AMSU-B (water vapour) FG departures. Although not conclusive, the plots show that the possible aliasing effect is small.

Validation with JAL observations





First validation efforts with flask measurements from Japanese commercial aircraft are encouraging. CO_2 analysis is within a few ppmv from the flight measurements and compares better than the background field.

Many thanks to Hidekazu Matsueda (MRI/GRD, Japan) for kindly providing the JAL CO_2 observations!

Conclusions

- First results of tropospheric CO_2 data assimilation are encouraging.
- Assimilation performs best in the tropical region. This is exactly were the surface flask network is very sparse.
- Validation with more in-situ flight observations is highly needed to verify results.
- Accounting for all possible bias errors is a tough undertaking and needs more scrutinizing of the results.
- Including the short-wave band should improve the CO_2 estimates, because this spectral band is cleaner.
- Work has now started to include CO_2 as a tracer in the forecast model, enabling a full 4D-Var CO_2 analysis. This will allow a transport model constraint on the CO_2 analysis that will probably reduce the horizontal scatter.