Total Column Carbon Observing Network (TCCON)

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Abstract. A network of ground-based, sun-viewing, near-IR, Fourier transform spectrometers has been established to accurately measure atmospheric greenhouse gases such as CO_2, CO, N_2O, and CH_4.

Introduction

The need for accurate column measurements of atmospheric Greenhouse Gases (GHG) is two-fold:
1) To better understand global climate change, in particular, the exchange of GHG between the atmosphere and the biosphere & ocean.
2) To validate current and future satellite measurements of the same GHG (e.g. AIRS, SCIAMACHY, IASI, GOSAT, OCO), which will be essential for monitoring compliance with international agreements (e.g. Kyoto) that will attempt to constrain GHG emissions.

Although these gases are currently measured to very high accuracy by in situ techniques such as Mass Spectrometry, Non-Dispersive Infra-Red (NDIR), there are limitations in the analysis of these data for estimating sources and sinks. Concentrations measured near the surface are significantly influenced by transport between the boundary layer and the troposphere, which is poorly simulated in the global transport models used in such analysis. By contrast, changes in the column are more directly related to the underlying fluxes. In the absence of surface exchange, when CO_2 is redistributed by vertical transport, the column remains invariant and thus provides a more direct means of assessing the source/sink strengths.

Precision and Accuracy requirements

With the exception of H_2O, the GHG that contribute most to global warming (CO_2, CH_4, and N_2O) have long atmospheric lifetimes (decade to centuries). This means that the impact of one year's global emissions/sinks on the total column is quite subtle – at the 0.5% level for CO_2 and N_2O. Thus, to investigate the location and strengths of regional source/sinks requires the ability to measure horizontal gradients that are even smaller than 0.5%.

This level of precision is very difficult to achieve in an “open path” observation geometry since the "sample" conditions (T, P, H_2O, SZA) are uncontrolled. For example, GHG have been measured by NDACC ground-based FTIR spectrometers in the mid-IR region at the 1% level. Although this performance allowed observation of the increase of atmospheric GHG, and in some cases and locations, their seasonal variations, this is insufficient to say anything new about the atmosphere-biosphere exchange.

The superior performance achieved by the TCCON instruments comes not from any single breakthrough. It comes from several incremental improvements:
1) Using simultaneous measurements of the atmospheric O_2 column as a reference [1-3]
2) DC recording of interferograms to allow correction for source brightness variations (e.g. clouds) [4]
3) The use of dedicated, high-quality FTS instruments [5]
4) Consistency of operation, data processing, and analysis between sites
5) Traceability to the global in situ network via airborne profile measurements over TCCON sites [5]
6) Improved spectroscopy [6], enabling the fitting of wider windows

Sites and Instrumentation

There are more than a dozen operational TCCON sites. These are generally at low altitude locations where biosphere/ocean exchange has the most impact on the atmospheric concentrations.

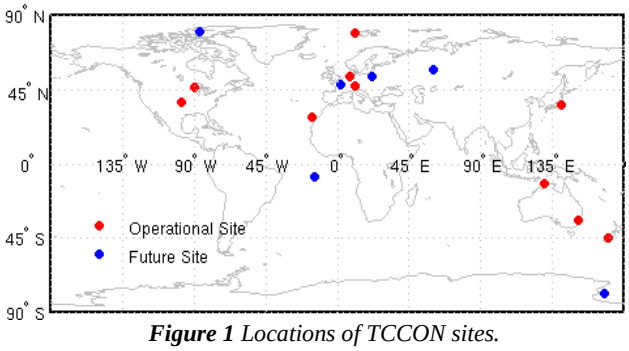

Figure 1 *Locations of TCCON sites.*

Figure 2 *FTS container at Darwin, Australia*

Each TCCON site has a Bruker 120HR or 125HR spectrometer, the majority equipped with room-temperature InGaAs and Si detectors covering the entire 3900 to 15500 cm^{-1} spectral region simultaneously. A suntracker on the roof directs the solar beam into the FTS. For most TCCON instruments, the mirrors are gold coated to minimize the visible radiation which would add photon noise and cause aliasing problems.

A maximum OPD of 45 cm is employed giving a spectral resolution of 0.02 cm^{-1}. The Bruker 125HR spectrometers use the Brault [7] method of data acquisition whereby the interferograms are sampled and digitized by a 24-bit Sigma-Delta ADC, and then numerically resampled at constant intervals of optical delay as defined by the zero-crossings of the 633 nm He:Ne reference laser. This provides a free-spectral range of 15798 cm^{-1}. The signal-to-noise ratio for a single spectrum (75s acquisition) is ~750.

Additional equipment includes a dome to protect the suntracker, a weather station including an accurate surface pressure measurement, and a permanently-mounted, internal, low-pressure HCl cell used to monitor the ILS in the overtone band at 5700 cm^{-1}. Many of the TCCON FTS instruments are located at tall tower sites where in situ measurements are made routinely from inlets at different altitudes on the tower. Further information on the first TCCON instrument, at Park Falls, Wisconsin, USA, can be found in [5].

Data Processing and Analysis

To minimize algorithmic biases between sites, we are using the same software for data processing and analysis. This includes phase-correction, dc-correction, and FFT of the interferograms into spectra. It also includes the GFIT spectral fitting algorithm and the subsequent quality control of the column abundances.

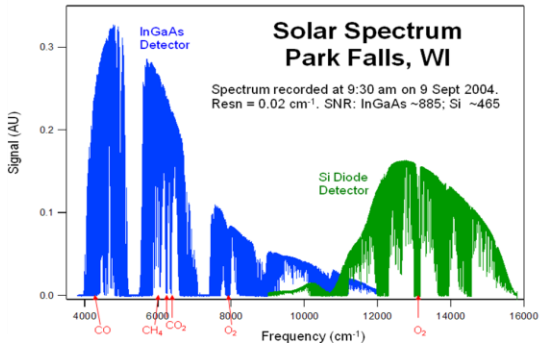

Figure 3 *Typical TCCON FTS spectral domain*

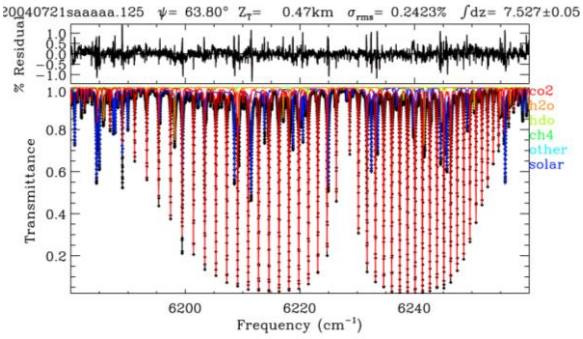

Figure 4 *Spectral fit to the 6220 cm^{-1} CO_2 band*

The slant column of each absorber is obtained by least-squares spectral fitting, an example of which is shown in Fig 4. To convert the slant columns into a mean dry-air mole fraction the slant column of the GHG is divided by the O_2 slant column and multiplied by the dry-air mole fraction of O_2 (0.2095). This ratioing process helps cancel several potential systematic errors, to the extent that they affect the gas of interest (e.g. CO_2) and O_2 equally. For example, pointing errors (i.e., tracking away from the center of the solar disk) will cause systematic errors in the CO_2 and O_2 column abundances, especially at high zenith angles. But this error source is the same for CO_2 and O_2 and therefore cancels after taking the ratio. Other important error sources that mostly cancel include: ILS uncertainty, zero level offsets, source brightness fluctuations (e.g. clouds).

The precision of the resulting mole fractions retrieved from single spectra is about 0.15% for CO_2, 0.2% for CH_4, 0.3% for N_2O and 0.5% for CO. The absolute accuracy is limited by spectroscopic

inadequacies (~1% for CO_2, ~2% for CH_4), but this can be substantially reduced by validation, i.e., airborne profiling using accurate in situ sensors.

Results and Discussion

Figure 5 shows 3½ years of CO_2 results from the Park Falls FTS instrument (red) at Park Falls. These data are over-plotted with the surface in situ data from the same site (black). These are not supposed to agree – their averaging kernels are completely different – and so the variations in the column-average CO_2 are muted in comparison with those at the surface. The large seasonal cycle of CO_2 over Park Falls is immediately obvious, as is the long-term increase of ~0.5%/year. Less obvious is the increased variability of CO_2 during the summertime minimum -- a result of N/S gradients in CO_2. Keppel-Aleks et al. [8] showed that these summer CO_2 variations correlate well with tropospheric potential temperature, which allows estimation of the meridional gradient in CO_2 concentration and hence surface fluxes. Yang et al. [9] also used TCCON data to show that the net ecosystem exchange was 25% larger then model predictions.

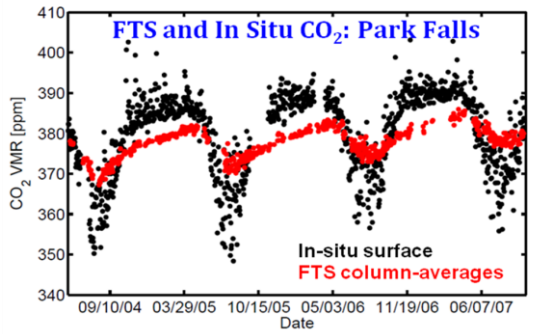

Figure 5 *Park Falls time series of FTS and in situ CO_2*

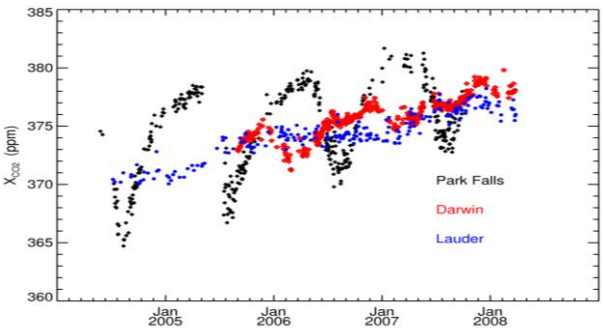

Figure 6 *Time series of FTS XCO2 from 3 sites*

Fig 6 shows comparisons of CO_2 results from Park Falls (46°N, black), Darwin (12°S, red), and Lauder (45°S, blue). It is immediately evident that the seasonal cycle is much smaller in amplitude in the SH, due to the much smaller land area at mid-latitudes in the SH. All sites show similar increasing CO_2 trends.

In terms of satellite validation the TCCON data has already been used for validation of SCIAMACHY (see references in http://tccon.caltech.edu/publications/index.html) and will be the mainstay of efforts to validate the OCO and GOSAT satellite sensors, due to be launched in early 2009.

Conclusions

TCCON demonstrates the ability of ground-based FTS to make highly precise and accurate column measurements of atmospheric GHG. This capability is not only useful for validation of satellite sensors, but it also enables useful scientific investigations.

Acknowledgements

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