# MEASURING ATMOSPHERIC $CO_2$ FROM SPACE

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## ABSTRACT

Atmospheric $CO_2$ concentrations, have been successfully retrieved from spectral measurements made in the near infrared (NIR) by the SCIAMACHY instrument, using a new retrieval algorithm called Full Spectral Initiation Weighting Function Modified Differential Optical Absorption Spectroscopy (FSI WFM-DOAS). Initial results from the algorithm are promising with visible structure within the retrieved spatial distributions. Furthermore, SCIAMACHY/FSI $CO_2$ has been validated against several independent data sets. From these comparisons, the overall precision and bias of the $CO_2$ columns retrieved by the FSI algorithm are estimated to be close to 1.0% and <4.0% respectively.

## INTRODUCTION

Since the launch of the SCIAMACHY instrument on-board ENVISAT there is the ability to measure total vertical columns of $CO_2$ in the near infrared (NIR) using a new retrieval technique called Weighting Function Modified Differential Optical Absorption Spectroscopy (WFM-DOAS) (Buchwitz et al, 2000). The WFM-DOAS method is based on fitting the logarithm of a linearized radiative transfer model plus a low-order polynomial to the logarithm of the ratio of a measured nadir radiance and solar irradiance spectrum as measured by the SCIAMACHY instrument.

An initial assessment of this algorithm's sensitivity, described in Barkley et al, (2006) discovered it is necessary to include suitable *a priori* information within the retrieval in order to constrain the errors on the retrieved $CO_2$ columns. Using this premise, a new $CO_2$ retrieval algorithm called Full Spectral Initiation (FSI) WFM-DOAS has been developed which generates a reference spectrum for each individual SCIAMACHY observation, based on the known properties of the atmosphere and surface at the time of the measurement. As the calculation of radiances is computationally expensive, FSI is not implemented as an iterative scheme rather each reference spectrum only serves as the best possible linearization point for the retrieval. Each spectrum is generated using the radiative transfer model SCIATRAN, using several different sources of atmospheric and surface data that serve as input, the details of which are described in full in Barkley et al, (2006).

The FSI algorithm is only applied to cloud free pixels, determined using a cloud detection method outlined in Krijger et al, (2005), with the retrieved $CO_2$ vertical column density (VCD) normalized using the input a priori surface pressure to produce a column volume mixing ratio (VMR). Only $CO_2$ VMRs where the retrieval

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(statistical) fitting error is less than 5% and which lie in a range 340-400 ppmv are used. To avoid various instrumental issues that have hampered retrievals in the NIR channels the raw SCIAMACHY spectra have been calibrated in-house with corrections applied for non-linearity effects, associated with analogue-to-digital converter, and also the orbit specific dark current. To improve the quality of the FSI spectral fits, the latest version of the HITRAN molecular spectroscopic database has been implemented in SCIATRAN. Unlike other studies, adjustment of the absolute columns values *via* scaling factors, has not been necessary. The advantage of the NIR over the thermal infrared is the sensitivity to changes in the $CO_2$ concentration in the lowermost part of the troposphere. This is demonstrated by the FSI averaging kernels (not shown) which peak in the planetary boundary layer indicating that the FSI algorithm is sensitive to changes in the $CO_2$ near the surface., (i.e. where the signatures of carbon cycle surface fluxes are most evident).

## RESULTS

The first results of the FSI algorithm have been encouraging (see Fig. 1) with SCIAMACHY/FSI $CO_2$ validated using both ground based Fourier Transform Infrared (FTIR) and model data (Barkley et al., 2006b, 2007). Analysis with respect to the FTIR data indicate a bias of between -1% to -4%, whilst comparison to the model data reveal an overestimation of the seasonal cycle by a factor of 2-3 and a smaller bias of about -2%. Evaluation of FSI retrieved $CO_2$ to NOAA/ERSL data (Fig. 2) have also demonstrated that SCIAMACHY is capable of detecting a seasonal signal that is representative of surface $CO_2$. Although retrievals over the oceans have been successfully performed, the coverage is somewhat limited owing to a greater number of retrievals being discarded because of the low surface albedo of the oceans at NIR wavelengths which results in poor quality SCIAMACHY spectra.

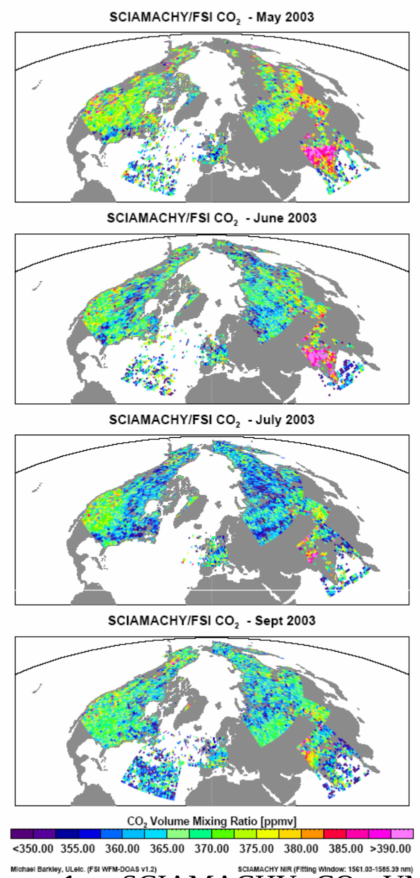


**Figure 1:** SCIAMACHY $CO_2$ VMRS averaged onto a 1°×°1 grid.

This is an area the team are currently working on.

Furthermore, comparisons to $CO_2$ retrieved by the AIRS instrument also show good qualitative agreement of large scale features over North America during 2003 (Barkley et al., 2006c).

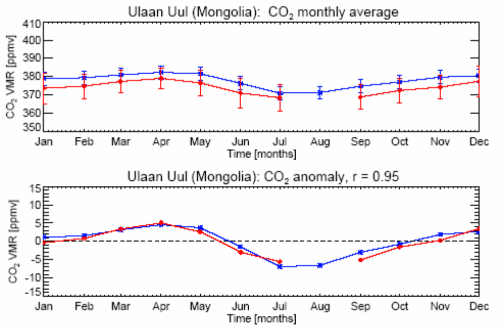


**Figure 2:** Top Panel: Time series of monthly $CO_2$ averages for SCIAMACHY (red) and NOAA/ESRL surface data (blue) over Ulaan Uul, Mongolia during 2003. Bottom Panel: The corresponding $CO_2$ anomalies

The comparison with AIRS demonstrates for the first time some general consistency in the retrieved $CO_2$ distributions measured by two different sensors (Fig. 3). In addition, both AIRS and SCIAMACHY detect seasonal signals that are representative of the upper and lower troposphere to which they are both respectively sensitively to.

The potential ability of SCIAMACHY to identify sub-continental scale sources/sinks at the surface is illustrated in Fig. 4, which shows the land vegetation type verses FSI retrieved $CO_2$ over North America during July 2003.

There is a clear correlation between the low $CO_2$ concentrations found over the Canadian Shield and down the eastern side of the US in contrast to the higher $CO_2$ found over the grass plains and croplands of the mid-west US.

This suggests greater $CO_2$ uptake by the forests as compared to the crop lands which implies that SCIAMACHY is capable of detecting the signatures of $CO_2$ surface fluxes.

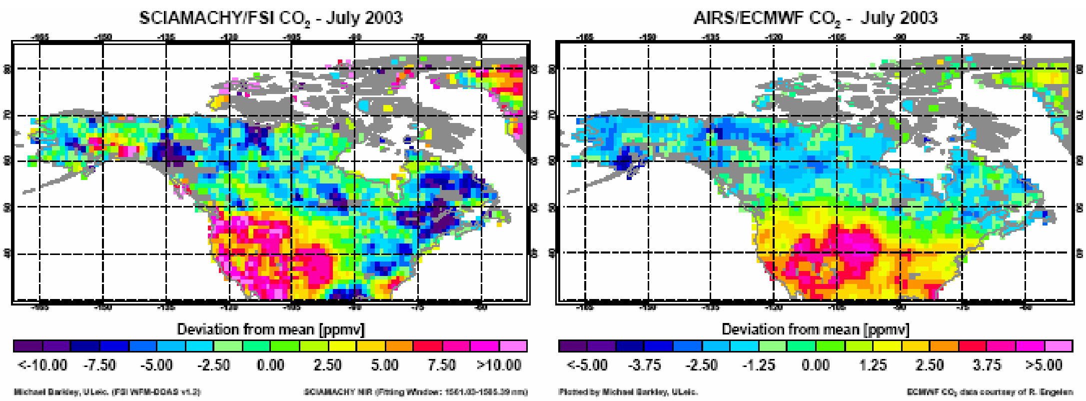


**Figure 3:** SCIAMACHY and AIRS $CO_2$ for July 2003 over North America plotted as the deviation from the respective scene average for each instrument. Both sensors agree on a very large enhancement over the central and western US.

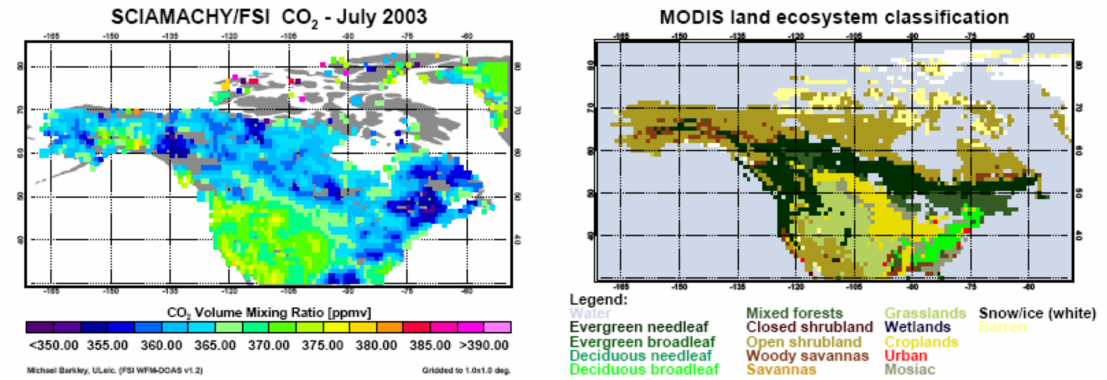


**Figure 3:** SCIAMACHY $CO_2$ observations (smoothed with a 3°×3° box car average) over North America for July 2003 (left panel) with a map of the land vegetation cover over this scene (right panel). The transition from low $CO_2$ VMRs along the Canadian Shield and the eastern coast to the higher values found over the mid-western US, corresponds to a change in vegetation type from evergreen needle leaf, mixed and deciduous broadleaf forests to land covered by crops and large grass plains. The vegetation map is taken from the Land Ecosystem Classification Product which is a static map generated from the official MODIS land ecosystem classification data set, MOD12Q1 for year 2000, day 289 data (October 15, 2000) (see http://modis-atmos.gsfc.nasa.gov/ECOSYSTEM/index.html).

## PRECISION AND ERRORS

It is important to give some assessment of the accuracy (bias) and precision of the $CO_2$ VMRs retrieved by the FSI algorithm. The mean retrieval (spectral fitting) errors over the selected scenes is <3%. These fit errors are predominantly affected by the signal to noise ratio of the spectra and thus are strongly influenced by the surface albedo. The standard deviation of the 'raw' (un-gridded) FSI $CO_2$ columns is ~3.0% which seems consistent with the mean retrieval errors. The mean of the standard deviations, of the retrieval errors over each scene, is consistently below 1% implying that FSI spectral fitting procedure is itself quite precise. The mean root mean square (RMS) error of the spectral fits is also extremely stable at 0.1-0.3%. Comparisons of the FSI retrievals to the FTIR and model data suggest a suggest that implies that a bias of -4% to the true $CO_2$ concentration is probably realistic (assuming both the FTIR and model data are correct) with the precision of monthly 1°×°1 gridded data close to 1.0%. There is a requirement to expand the validation of the data beyond one FTIR station.

## SUMMARY

Atmospheric $CO_2$ VMRs have been successfully retrieved from SCIAMACHY measurements in the NIR using the FSI retrieval algorithm with comparisons made to ground based FTIR data, model data, NOAA/ESRL observations and additionally to $CO_2$ retrieved by the AIRS instrument. From these comparisons, the overall precision and bias of the $CO_2$ columns retrieved by the FSI algorithm are estimated to be close to 1.0% and <4.0% respectively. It also must be re-stressed that at no stage whatsoever have scaling factors been applied to the FSI retrieved $CO_2$ VMRs as they have been in other studies. Whilst these results are encouraging they are still not of the desired quality for inverse modelling. It is hoped that further improvements to the retrieval algorithm, through better calibration of the SCIAMACHY data and by improving the quality of the input *a priori* data used in the creation of the reference spectra, will overcome this issue in the future

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