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Atmospheric Chemistry and Physics Discussions

Interactive comment on "A framework for comparing remotely sensed and in-situ CO_2 concentrations" *by* R. Macatangay et al.

R. Macatangay et al.

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We thank our reviewer for an evaluation of important points on our paper that we are pleased to respond to.

The major aspect pointed out was the optimization of the STILT model by the tower data before deriving the total column. In our view, an optimization of surface fluxes is an additional step, which is beyond the scope of this paper. Instead, we show that the STILT model using the greatly simplified biosphere (GSB) already agrees quite well with the tower observations (see added Table 3 in the revised manuscript). We then use the same model for the FTIR measurements.

The innovation of the approach is that it uses a model that represents the relevant scales of transport (using meteorological fields at 0.35 degrees and using surface fluxes at 10 km, STILT has higher resolution transport than any global tracer transport model), with the result that the model performs well in comparison to the in-situ observations. Another innovative part is that the framework allows the assessment of footprints, i.e. the surface areas that influence the measurements, a piece of information not usually available from forward simulations. This allows for illustrating differences between the information content of the different measurement devices such as tower, aircraft or ground based remote sensing.

The following addresses the individual aspects mentioned:

Point 1 (use of high resolution FTS and comparison to previous work): As pointed out in the paper, the FTS used is not optimal for CO2, hence the paper is predominantly methodological. However, the methodological points of view are essential especially with two carbon dioxide satellites set for launch at the end of this year. As formulated in the introduction of the paper, a clear relation between surface measurements and space-borne observations is needed and the FTS is the rational and favored measuring technique for the task.

Point 2 (justification of using balloon data from New Mexico for determining the total column over France): The coordinate transformation in page 1558 lines 1-9 takes care of this. See Washenfelder et al. 2006 for a similar procedure this time for Park Falls, Wisconsin. See also Waugh and Hall 2002 for an analysis of the mean age of the air in the stratosphere.

This is explained in the revised manuscript:

For the stratospheric part of the profile, in-situ balloon data from the Observations of the Middle Stratosphere (OMS) experiment performed in Fort Sumner, New Mexico (35°N, 104°W) on 17 September 2004 were utilized. Since the balloon measurements were not performed during the same period as CERES, the balloon profile was corrected for age using the annual increase rate of CO2. Since also the balloon measurements were not done in Biscarrosse, France, a coordinate transformation is necessary.

Measurements of potential temperature during the balloon flight were utilized. Since potential temperature is approximately a conserved quantity in the stratosphere. The potential temperature was then converted to altitude using the equation formulated by Knox (Knox, 1998) z = {[ln(theta/350)]/0.045}+13 (5)

where q is the potential temperature in Kelvin and z is the altitude in km. It was then converted back to pressure using NCEP altitude-pressure-temperature profiles for Biscarrosse, France during the specific aircraft overpass dates and the CO2 concentration values were then interpolated. Point 3 (FTS averaging kernel peaking near the tropopause): When integrating the CO2 profile to produce the total column, it is weighted by the pressure. Therefore, the lower most part of the troposphere gets the most weight.

Point 4 (how the uncertainty of the aircraft, model and balloon data have been combined to determine the overall uncertainty in the total column): An error propagation was performed when the profile was integrated to produce the total column.

This is now explained in the revisions:

The uncertainties in each level were squared, weighted with the square of the pressure, integrated and the square root of the integrated value was calculated.

Minor comments:

(referee) page 1550, line 6: what is meant by the global calibration scale?

(authors) This refers to the fact that the measurements are referred to the WMO standard for atmospheric CO2. This has been modified accordingly in the revised manuscript.

(referee) page 1550, line 25: water vapor is the most significant greenhouse gas not carbon dioxide.

(authors) The line has been rephrased to the most significant anthropogenic green-

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house gas.

(referee) page 1550, line 26: What is meant by absorption characteristics of CO_2. Is it spectroscopy? I would think that that is not a limiting factor for understanding the relationship between the carbon cycle and climate change.

(authors) For remote sensing, the accuracy of determining the absorption characteristics of CO_2 (i.e. determining the line strengths) is a vital factor as these are used in the retrieval process.

(referee) page 1553, line 4: What wavelength is used? The Planck function peaks around 500 nm. As far as I know there is no CO_2 line there.

(authors) The wavelength used is around 1607 nm (6220 cm-1) which is in the near-infrared. We agree that the near-infrared is not at the peak of the Planck function. The line therefore reads proximity to the solar Planck function maxima

(referee) page 1556, line 4: The O_2 VMR varies Please explain due to what. The way it is written now suggests that O_2 actually varied over that range, which I understand is not what is meant.

(authors) These are raw data therefore, no averaging has been performed. The variation comes from variations in the solar intensity during the measurements due to cloud cover (e.g. from clear day blue skies to whitish skies due to thin cirrus clouds) and due to the solar zenith angle dependence of O_2 (the O_2 lines in this wavenumber region come from dayglow emissions). See also section 3.4 (Effect of clouds on O_2 and CO_2 precision).

(referee) page 1556, line 23: I suppose that instead of minimum and maximum diurnal variations the most negative and positive deviations of the mean are meant (the minimum variation is clearly not the same as the most negative deviation)

(authors) Yes. It is now rephrased.

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Revised manuscript:

Quantiles were used to quantitatively assess the diurnal variations, specifically quartiles and the central 90%ile. Using quartiles, for O_2, the first quartile is at -0.2110%, the median is at 0.0007%, the third quartile is at 0.2072%, the interquartile range is 0.4182% and the quartile deviation is 0.2091%. The most negative O_2 diurnal variation is -1.6128% and the most positive O_2 diurnal variation is 1.7793%. For CO_2, the first quartile is at -0.2046%, the median is at 0.0038%, the third quartile is at 0.2098%, the interquartile range is 0.4144% and the quartile deviation is 0.2072%. The most negative CO_2 diurnal variation is -1.2337% and the most positive CO_2 diurnal variation is 1.2826. This means that approximately 50% of the measured data have diurnal variations between ś0.21% for both O_2 and CO_2. Using the central 90%ile, for O_2, the 5%ile is at -0.5596%, the 95%ile is at 0.5558%, the 95%ile-5%ile range is 1.1154% and the central 90%ile deviation is 0.5577%. For CO_2, the 5%ile is at -0.5349%, the 95%ile is at 0.5181%, the 95%ile-5%ile range is 1.0530% and the central 90%ile deviation is 0.5265%. Approximately 90% of the measured data have diurnal variations between ś0.56% for both O_2 and CO_2. This is depicted in Fig. 6. The outliers in the diurnal variations result from influences of clouds (Warneke et al., 2006).

(referee) page 1557, line 1-10: Some more explanation is needed of what these values are supposed to represent. They seem to have been used in figure 9 to represent the uncertainty of the FTS.

(authors) The important values are the quartile and the 90%ile deviations as they represent that 50% and 90% of the data, respectively, fall in the mentioned ranges. The uncertainties used for the FTS in Figure 9 though are actually standard deviations of the FTS data that fall within the definition of the instances (see Table 1) since the time frame of the instances do not last for the whole day.

(referee) However, some of the variation represents signal and not error (for CO_2 I mean). In this respect the use of diurnal variation is dangerous, as it is usually associ-

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ated with the diurnal cycle of CO2, whereas - as confirmed by fig. 5 - this variation is dominated by noise.

(authors) The diurnal variation represents the upperlimit of the precision (the worst case scenario).

(referee) I was surprised that the relative variation of the CO2 mixing ratio is lower than that of O2. This is unexpected since the CO2 column averaged mixing ratio is derived by O2 normalization and therefore carries the combined uncertainty of the O2 and CO2 FTS measurements. This should be explained.

(authors) O2 normalization also minimizes systematic errors common to both O2 and CO2 (covariance between errors in O2 and CO2), hence O2 normalization reduces the CO2 variation.

(referee) page 1557, line 18: How can Domina and the FTS measure the same air-mass?

(authors) This has been restated to the Dimona and the FTS measured simultaneously within the 50 km radius from the FTIR station.

(referee) page 1558, line 1-9: First pressure is converted into vertical elevation and then converted in pressure again. The reason for this procedure should be explained.

(authors) Since the balloon measurements were not done in Biscarrosse, France a coordinate transformation is necessary. The potential temperature measured from the balloon data is approximately a conserved quantity in the stratosphere. This is then converted into altitude using equation (5). From this, NCEP altitude-pressure-temperature profiles for the specific instances were used to interpolate the strato-spheric CO2. This is now explained in the revisions.

(referee) page 1558, line 10: It is unclear how the 0.75 ppm has been derived. This should be explained.

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(authors) This is now explained in the revised manuscript:

The 0.75 ppm uncertainty comes from the 0.5 year uncertainty in the mean age of the air in the stratosphere. An 0.5 year uncertainty in the stratosphere translates into approximately 0.75 ppm uncertainty in the carbon dioxide concentration when one considers the 1.4 ppm year-1 annual increase rate of CO2.

(referee) page 1558, line 25: Looking at the right panel of Fig 8 I see much more variation in the vertical profile then can possibly be explained by the averaging kernel. Actually the averaging kernel only expresses the sensitivity to the total column and has no relation with the number of degrees of freedom at which the vertical profile is resolved. Nevertheless it is clear that to resolve the vertical profile like in the right panel requires much more vertical resolution than an FTS could provide. This should be explained.

(authors) There seems to be a misunderstanding. The figure on the right panel of Figure 8 are from the combined data set (aircraft, model and balloon) simulated or weighted by the FTS averaging kernel and not profile retrievals from the FTS measurements. The term simulated is synonymous with weighted in this case. The reason for using simulated is to be consistent with terms stated in Rodgers et al., 2003 where the method is described.

Quoting from the Rodgers et al., 2003 paper:

We find that the effect of different averaging kernels can be reduced if the retrieval or the derived quantity of one instrument is simulated using the retrieval of the other. The effect of the remote sounder could be simulated using the direct measurement, and compared with the actual remote measurement, either as the original measurements or as the retrieval.

Technical Corrections:

(referee) page 1550, line 1: The sentence becomes much easier to read when has

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been developed is placed after A framework.

(authors) This is now corrected.

Revised Manuscript:

A framework has been developed that allows validating CO2 column averaged volume mixing ratios (VMRs) retrieved from ground-based solar absorption measurements using Fourier transform infrared spectrometry (FTS) against measurements made in-situ (such as from aircrafts and tall towers).

(referee) page 1551, line 10: This makes please explain what is meant by This.

(authors) This is now revised to The limited spatial coverage and the proximity to local sources and sinks makes model estimates

Revised Manuscript:

The limited spatial coverage and the proximity to local sources and sinks makes model estimates susceptible to transport errors, such as errors in vertical transport processes (moist convection and turbulent mixing in the boundary layer), especially for continental regions (Washenfelder et al. 2006; Gerbig et al. 2007).

(referee) page 1554, line 1: what is meant by the combined dataset?

(authors) This is now revised to The overall precision of the combined CO2 dataset (the fast open path LICOR 7500, the slower closed path LICOR 6262 and the flask samples) at 1 Hz is 0.5 ppm.

Interactive comment on Atmos. Chem. Phys. Discuss., 8, 1549, 2008.