Biogeosciences
Discussions

# Interactive comment on "The imprint of surface fluxes and transport on variations in total column carbon dioxide" *by* G. Keppel-Aleks et al.

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Received and published: 28 September 2011

We thank the reviewer for her/his constructive suggestions for our paper. Below, we respond to each of the reviewer's comments.

*In this manuscript, the authors attempt to reveal the relationship between total column $CO_2$, and surface fluxes and transport using ground based total column $CO_2$ data from Total Carbon Column Observing Network (TCCON) observatories, and eddy covariance flux data, and free troposphere $[CO_2]$ data from aircraft. The total column $CO_2$ data were also used to compare with atmosphere transport modelling results and concluded that boreal growing season NEE (between 45–65° N) is underestimated by ~40% in CASA. I suggest the authors considering the following in revising this*

*manuscript.*
*(1) The section title of 3.1 is 'diurnal variations' of observed, and the authors claimed that they are small (during the summer growing season is 2 ppm) and influenced by a large spatial footprint. This may also a factor for the authors to 'use daily mean $CO_2$ model output" to compare with observed. However, the authors need to answer a question first: Can you quantify the diurnal variation of based on the measurements? Figure 4 does not provide enough information to do so as the observations only cover part of each day. From another angle, 2 ppm is also a significant variation to consider as it represents the total column, not the thin boundary-layer as 2 ppm change in the atmospheric $CO_2$ concentration means 1Pg C flux in the surface.*

(1) The reviewer asks whether we can quantify the diurnal variation in the column based on TCCON observations, and refers to Fig. 4, where we have plotted the data from one week at Park Falls. Due to the fact that we use a solar viewing instrument, we cannot make measurements over a full diurnal cycle, and data acquisition is limited to cloud-free conditions. We therefore consider 'diurnal variations' to mean the daytime drawdown. The maximum daytime variation, during the summer when we obtain measurements from early morning to evening, is 2 ppm – in fact a small change compared to the daytime variations in $CO_2$ observed at the surface. We will revise the text to more clearly reflect our meaning of diurnal variations.

The reviewer's point that a 2 ppm change in the total column is substantial since it integrates not just the thin boundary layer is well taken. In the subsequent comparison of column drawdown to eddy covariance observations obtained within two hours of solar noon, we show that the changes in the column are not due to local fluxes, as these would have to be quite large to reproduce the observed variations, but to larger scale effects.

*(2) In Fig.5, the authors compared the NEE calculated from drawdown in the total column and NEE inferred from eddy covariance measurements at Park Falls, Wisconsin. Clearly, the correlations at daily (a) and weekly (b) time steps are so poor*

*that it hardly to infer reliable fluxes from them. At the monthly (c) time steps the NEE calculated from drawdown in the total column overestimates the sink comparing with the NEE inferred from eddy covariance measurements (EC-NEE). This means using total column measurement may overestimate surface sink if EC-NEE is right. What is the implication of this relationship to your finding that 'boreal growing season NEE (between 45–65N) is underestimated by 40% in CASA'?*

(2) We agree with the reviewer that the diurnal comparison between drawdown in the column and the eddy covariance measurements is not particularly good. Indeed this is one of the points of the analysis and discussion. The column drawdown is influenced by substantially larger scale phenomena compared with the eddy covariance observations and we, therefore, cannot use column observations to infer local surface fluxes, as might be assumed a priori.

The fact that weekly and monthly averaged data show less scatter indicates that part of the difference between the measured changes during each day and measured daily eddy covariance flux is that the column is influenced substantially by transport, the effects of which are mitigated when measurements over several synoptic cycles are considered. More important for flux estimation, the fact that the slopes differ from unity, even after averaging, indicates that the drawdown in the column reflects a different footprint than the flux inferred from the eddy covariance observations, and that we shouldn't, in fact, expect the two observations to agree. The rest of the analysis in the companion paper (Keppel-Aleks et al., 2011) and in this paper suggest that the footprint of the column is significantly larger due to its sensitivity to the free troposphere, and we show in the companion paper that the column is particularly sensitive to boreal NEE. Therefore, we can use the seasonal cycle in the column to make robust inferences about hemispheric scale drawdown, whereas we could not use, for instance, the eddy covariance flux observations at Park Falls to do the same thing. We don't think the disagreement between the monthly averaged column drawdown and the monthly averaged eddy covariance data points to a problem with our conclusion that boreal growing season NEE is underestimated; rather we think it

C3309

points to the fact that column data can be used in novel ways to get at this large scale drawdown. In the revised text, we will make this point more clearly.

*(3) A daily version of AM2 was used in the study. 1) Daily AM2, however, cannot reproduce the $CO_2$ concentration at the time, and solar zenith angle (SVZ) that the observation is made. 2) The authors calculated the daily mean of the observed in order to match the daily AM2 output, but $\langle CO_2 \rangle$ is only observed in certain time of day. 3) Monthly mean solar zenith angles (SVZ) for TCCON sites are shown in Fig 8, and these mean SVZs were used to convert the daily mean $CO_2$ model output from AM2 into $\langle CO_2 \rangle$. As the relationship with SZA is nonlinear, using mean SZA could lead more uncertainties.*

(3-1) We agree with the reviewer that it would be better to use data output at shorter timescales than one day. We use daily data due to the high computational cost of outputting and analyzing data at higher temporal frequency. As a sensitivity study, we have run some shorter simulations (one year duration) with hourly output. Compared with using daily mean $CO_2$ data , the seasonal cycle amplitude differs by -0.1 to +0.2 ppm at the four northern hemisphere TCCON sites. We will incorporate this uncertainty into the revised paper.

(3-2) As application of the solar zenith angle dependent averaging kernel to the daily-average model output changes the value of the SCA and estimated meridional gradient by less than 0.2 ppm, applying the averaging kernel to higher frequency output and then averaging will have a small affect (well under 0.2 ppm) on the diagnostics of interest, since this is a second order correction. However, we will do a sensitivity estimate on the hourly data plus hourly averaging kernel to better quantify error on the model in the revisions.

*(4) Uncertainties of the observations, the model and the relationship obtained in this manuscript should be further concerned. As it is not easy to evaluate the uncertainty of the model (AM2), you may first quantify the influence of the observation*

C3310

*uncertainties. An uncertainty of 0.8 ppm, for example, in observation from one site could inversely bring how much uncertainty in surface flux in different regions is a critical question to answer.*

(4) In the companion paper, we analyze the effect of gross transport errors on the column by putting surface fluxes in the free troposphere to quantify the effect of vertical mixing error on the column diagnostics and by using zonally uniform fluxes to determine what $\langle CO_2 \rangle$ would look like if zonal mixing were instantaneous. In these simulations, the two diagnostics of SCA and estimated meridional gradient are largely unaffected. Therefore, we conclude that the column is much less sensitive to transport errors than are surface observations, in agreement with Yang et al., 2007.

With regard to observation error, the TCCON data used in the analysis have all been calibrated (Washenfelder et al., 2006; Wunch et al., 2010, Messerschmidt et al., 2011), with multiple calibration points being obtained over multiple years at most locations. We expect that any bias between the sites, or at a single site across a seasonal cycle, would be primarily attributable to retrieval bias associated with the solar zenith angle at which observations are obtained. To estimate the potential error due to varying solar zenith angle, we average TCCON data obtained only between 60-70° solar zenith angle. The SCA values change by at most 0.1 ppm at all sites. This suggests that the potential bias in our conclusions due to observation errors is small. We will expand discussion of the measurement error in the revised paper.

*(5) As the authors used observations from 5 TCCON sites, a pretty small observation set, and all the adjustments (Fig 12) are made seemingly to fit only observations at Park Falls, one of these sites. Considering this and the uncertainties from observation, modelling, it is still hard for readers to evaluate the conclusions from this manuscript.*

(5) Although the TCCON dataset is small, as the reviewer points out, this is a new network that provides a new type of data. We were careful only to use data that had been calibrated (precluding the use of some other column data from other sites). The

large footprint of the column that we establish both in this paper and the companion paper suggest that datasets from five sites will provide significant information about hemispheric scale exchange. We rely heavily on the Park Falls data site because it is the longest timeseries of column data available and because it is located at the center of the baroclinic zone. We can therefore robustly estimate the meridional gradient from synoptic variations (Keppel-Aleks et al., 2011). We do show in the paper that the column diagnostics from all the sites improve when we use enhanced boreal exchange (Tables 1–2, Fig. 9, Fig. 12).

Our conclusion that boreal NEE is underestimated is consistent with other published work (Yang et al., 2007; Schneising et al., 2011) as well as data assimilation of surface data (CarbonTracker). What makes our results unique is that we are able to exploit the large footprint of a new type of data to draw this conclusion in a relatively straightforward manner.

**References**

Keppel-Aleks, G., P. O. Wennberg, and T. Schneider: Sources of variations in total column carbon dioxide, Atmos. Chem. Phys., 11, 3581–3593, 2011.

Messerschmidt, J., M.C. Geibel, T. Blumenstock, H. Chen, N.M. Deutscher, A. Engel, D.G. Feist, C. Gerbig, M. Gisi, F. Hase, K. Katrynski, O. Kolle, J.V. Lavric, J. Notholt, M. Palm, M. Ramonet, M. Rettinger, M. Schmidt, R. Sussmann, G.C. Toon, F. Truong, T. Warneke, P.O. Wennberg, D. Wuch, and I. Xueref-Remy: Calibration of TCCON column-averaged $CO_2$: the first aircraft campaign over European TCCON sites, Atmos. Chem. Phys. Disc., 11, 14541-14582, 2011.

Schneising, O., M. Buchwitz, M. Reuter, J. Heymann, H. Bovensmann, and J. P. Burrows: Long-term analysis of carbon dioxide and methane column-averaged mole fractions retrieved from SCIAMACHY, Atmos. Chem. Phys., 11, 2863–2880, 2011.

Washenfelder, R. A., Toon, G. C., Blavier, J.-F., Yang, Z., Allen, N. T., Wennberg, P. O., Vay, S. A., Matross, D. M., and Daube, B. C.: Carbon dioxide column abundances at the Wisconsin Tall Tower site, J. Geophys. Res., 111, D22305, doi:10.1029/2006JD007154, 2006.

Wunch, D., Toon, G. C., Wennberg, P. O., Wofsy, S. C., Stephens, B. B., Fischer, M. L., Uchino, O., Abshire, J. B., Bernath, P., Biraud, S. C., Blavier, J. F. L., Boone, C., Bowman, K. P., Browell, E. V., Campos, T., Connor, B. J., Daube, B. C., Deutscher, N. M., Diao, M., Elkins, J. W., Gerbig, C., Gottlieb, E., Griffith, D. W. T., Hurst, D. F., Jimenez, R., Keppel-Aleks, G., Kort, E. A., Macatangay, R., Machida, T., Matsueda, H., Moore, F., Morino, I., Park, S., Robinson, J., Roehl, C. M., Sawa, Y., Sherlock, V., Sweeney, C., Tanaka, T., and Zondlo, M. A.: Calibration of the Total Carbon Column Observing Network using aircraft profile data, Atmos. Meas. Tech., 3, 1351–1362, 2010.

Yang, Z., Washenfelder, R. A., Keppel-Aleks, G., Krakauer, N. Y., Randerson, J. T., Tans, P. P., Sweeney, C., and Wennberg, P. O.: New constraints on Northern Hemisphere growing season net flux, Geophys. Res. Lett., 34, L12807, doi:10.1029/2007GL029742, 2007.

Interactive comment on Biogeosciences Discuss., 8, 7475, 2011.

C3313