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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Annual variation and global distribution of strato-mesospheric carbon monoxide measured by ground-based Fourier Transform Infrared spectrometry" *by* V. Velazco et al.

V. Velazco et al.

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We would like to thank the reviewers for their constructive comments and suggestions.

Reply to Reviewer 1 Comments Response to Major Criticisms.

Referee Comment: On the study being poorly motivated, intention of the study, open scientific questions and the contribution of this study to solve them.

Response: The manuscript has been modified and we incorporated the follwing into the text: As motivation: Strato-mesospheric CO has been measured for the first time using ground based FTIR spectrometry by Kasai et al., (2005). However, they only presented

measurements for 2 years. This study supports the work of Kasai et al., (2005) but we present longer time series measurements from the northern and southern polar regions and the mid-latitudes. This allows us to have a better idea of the seasonal variation of strato-mesospheric CO and confirm that the current ground-based FTIR instruments and retrieval procedures are able to exploit the information on strato-mesospheric CO from existing spectra. Furthermore, current measurements provide very little evidence on the reversal of the accumulation of CO in the mesosphere brought about by the meridional circulation. By showing measurements from both the northern and southern hemispheres, we verified this reversal.

Referee Comment: The authors do not put their results in context to other studies. The results and conclusions sections do not mention any other publication of middle atmospheric CO. The discussion of the results should make clear what is verification of existing knowledge and what are new findings. Also, please discuss how your results compare to other studies, e.g. the ones mentioned in the introduction or from the list of additional references given later.

Response: The additional references were indeed helpful, thanks. We have included discussions of our results in context to other studies. However, because of the limited data and publications related to ground based measurements of strato-mesospheric CO, the comparison is also limited.

Referee Comment: The instrument section does not provide sufficient information about the used instruments and retrieval techniques. At a minimum you should add some information about the spectral range, spectral resolution and signal-to-noise. Also you should make clear that these instruments are Fourier Transform Spectrometers that they measure direct sunlight from the ground. Regarding the retrieval, you should mention that you use the optimal estimation technique and give some information about the used a priori constraint (a priori profiles and covariance). How many vertical levels have been used? Also, it would helpful to explicitly mention the microwindows and the interfering gases.

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Response: We have revised the instrument section and taken into account the comments above.

Referee Comment: Finally, the authors have to include error bars and an error discussion. Please provide errors for your retrieved CO columns and discuss the different error components. How large are the smoothing errors or the noise errors? What are the potential biases due to uncertainty in spectroscopy?

Response: We have included an error discussion on section 2.2, last paragraph in the revised version of the paper. For the strato-mesospheric CO partial columns above 24 km Kasai et al., (2005) reported an error of 15%. This error consists of random error terms including: measurement error of 5.2%, smoothing error of 8.2% and temperature error of 1%. The forward model error of 5% was has been treated as a systematic error. In comparison, the total column error was reported to be less than 5%. For this study, we estimate the partial column (18 km - top of atmosphere) errors to be between 8.3% and 9.3%.

Response to Specific Comments:

Referee Comment: p. 7123: Discussion of figure 1. For some cases, the kernel for the 18km to 85 km is not perfect... What is the cause for these differences? For which cases do you get a kernel close to unity? Please include such a case in Figure 1 as well.

Response: We have revised Figure 1 and included and example of the averaging kernel calculations for Poker Flat, Alaska which show kernels close to unity. Some of the factors that contribute most to the averaging kernels are: the optical path difference of the spectrometer, the solar zenith angle, the a-priori covariance matrix, the a-priori profile and the signal to noise ratio.

Referee Comment: p. 7124: Discussion of Figure2. Does each of the blue dots represent an individual measurement? What is the reason for the small amout of datapoints,

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e.g., there is only a single datapoint for spring 2004 from Ny Alesund.

Response: Each of the blue dots represent daily averaged measurements. The FTIR data are limited by the weather and personnel.

Referee Comment: Referee Comment: I feel that it is an overstatement to argue that model and measurements agrees very well for northern high-latitude. There is only a small number of data points from the Ny Alesund site and the comparison for the Kiruna site shows significant differences. For Arrival Heights, the authors claim that the winter maximum is higher in the model. However, the FTIR instrument does not provide any measurements in winter and the observed discrepancies could also be explained by a phase shift.

Response: We revised this statement in the re-written manuscript. Please see related answer below regarding the correlation plots.

Referee Comment: Bremen and Lauder comparison: What do you mean by lesser values over Lauder. Lesser than the observations or lesser than for Bremen?

Response: Thanks for pointing this out, this sentence was not constructed clearly, we changed it to: “In the mid-latitudes, the model predicts a slight enhancement of the strato-mesospheric CO columns during winter times over Bremen. The model predicts this enhancement to be less pronounced over Lauder.”

Referee Comment: Also you argue that the comparison with the model is very good for both places. I would argue that the model constantly overpredicts the Lauder observations and that it underpredicts the 2003 observations at Bremen. In summary, the comparison between model and measurement should be done more carefully and more quantitative, e.g. correlation plots would nicely reveal potential biases. Also without any information about errors, it is difficult to assess if the measured and the modeled results agree well or not.

Response: Thank you for the suggestion, we have taken this into account. We included

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corrrelation plots and revised the discussion on FTIR and model comparisons. Below is a summary:

Kiruna: Although the correlations of FTIR and model are quite good for high latitudes, where CO is mainly controlled by downward transport from the thermosphere, the correlation for Kiruna is slightly worse. For Kiruna, horizontal transport or the shearing of the polar vortex possibly play a role as well. These factors are not well taken into account in the model. We can tell this by the high strato-mesospheric CO values measured by the FTIR in contrast to the low values from the model. Sometimes, the model also predicts much higher values of strato-mesospheric CO compared to what the FTIR measures.

Arrival heights. The seemingly logarithmic distribution of the correlation plot for Arrival Heights may be due to the assumptions of 1: converting all the thermospheric CO2 into CO and 2: not using a real and smooth CO2 profile in the thermospehre. These lead to too much CO descending from the thermosphere during late fall, then levelling off in winter.

Bremen and Lauder Comparison: The correlation coefficients are not so good in mid-latitudes where downward transport of thermospheric CO is not the most significant contributing factor.

Referee Comment: p. 7125: From the average curves shown in Figure 4, the authors argue again that the maximum CO is larger in the Arctic compared to the Antarctic. Only Kiruna provides measurement of the peak CO values. For all other sites, measurements are only available for spring and fall and I do not believe that you can make this statement.

Response: We have modified this statement: “The average curves also indicate that, the partial column amounts above 18 km in spring in the Arctic (79°N) are generally slightly higher than in the Antarctic (78°S). Although the data points for the spring months are quite scarce, we speculate for now that this could be due to the subsidence

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being stronger above Ny Alesund around spring." In the conclusions, we stated: ...."On the other hand, the data from the average curves suggest that, partial column amounts in the Arctic spring are slightly higher than in the Antarctic spring. For now, we speculate that this could be due to the subsidence being stronger in the Arctic than in the Antarctic. However, we still could not say much for the periods with very scarce or no measurements. In winter, the intra-seasonal and inter-annual variability in of mesospheric CO alone is large, according to Forkmann et al., (2003). From two years of observations, they reported CO columns above 60 km in the winters (defined as Nov.-Mar.) of 2001-2002 to be twice larger than the previous year. We could not completely confirm this yet from the FTIR data due to lack of observations. Nevertheless, filling in this information gap for the future is another challenge for the FTIR."

Response to Technical Comments:

Referee Comment: p. 7119: The title is very misleading. The authors do not present a global distribution but only measurements at 6 different sites (e.g. no tropical site).

Response: We have changed the title to: Annual variation of strato-mesospheric carbon monoxide measured by ground-based Fourier transform infrared spectroscopy.

Referee Comment: p. 7120: Comparison with different model scenarios... -> Comparison with two model scenarios.

Response: Done

Referee Comment: p. 7121: ...Farmer et al. (1980); Zander et al., (1981)... change order of references

Response: Done

Referee Comment: p. 7122: ...(see also Rinsland et al.(1998). -> ...(see also Rinsland et al.(1998)).

Response: Done

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Referee Comment: p. 7122: ... developed by Hase (2000) -> Hase (2002)

Response: Done

Referee Comment: p. 7122: A detailed description and comparison of both retrievals are shown in .. -> A detailed description and comparison of both retrieval algorithms is shown in

Response: We changed this sentence to: An inter-comparison between SFIT2 and PROFFIT has shown excellent agreement of profiles and total column amounts. The averaging kernels are consistent and the results are compatible for independently chosen constraints (Hase, et al., 2004).

Referee Comment: p. 7123: ...extending from -85.3S to 85.3N... -> I assume that the model extents from -90S to 90N and the given values are centers of grid-points?

Response: Yes, this is true. We changed this sentence to: The model has a horizontal resolution of about 9.5° extending from pole to pole in 19 evenly spaced latitude bins

Referee Comment: p. 7124: ... Arrival heights station... -> Arrival Heights station

Response: Done, thanks.

Referee Comment: p. 7125: Note that Kiruna is often at the edge of the polar vortex. Do you mean the winterly polar vortex? If so, how does this affect the summer bulge ?

Response: Sorry, this sentence was not formulated clear enough. The winter polar vortex was meant here and we wanted to point this out as the possible explanation to the scattered data points around winter. The sentence was changed. At the moment, there is no clear explanation as to why the summer bulge over Kiruna is not seen in some years (for some years, it is present). We speculate that the averaging of the curves smoothes out the bulge, especially for Kiruna where data points are relatively much more frequent than in Poker Flat and Ny Alesund. We speculate that transport processes of CH4 are the major factors that determine the prominence of the summer

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bulge.

Referee Comment: p. 7126: The Lauder data do not show the very high values of strato-mesospheric CO.-> to what do you refer here ??

Response: We reformulated this sentence to: The steep gradients of strato-mesospheric CO seen in the polar regions are not evident in the FTIR data over Lauder (45° S)

Referee Comment: p. 7126: Figure 6 shows that the tropospheric CO does not influence the stratomesospheric CO. -> Isn't this already clear from the averaging kernel shown in Figure 1?

Response: We have changed this sentence to: ĎThis confirms that the columns below 18 km do not influence the columns above 18 km and that the retrieval could clearly separate both columns, as indicated by the averaging kernels.“

Referee Comment: p. 7128: Dupuy et al. reference: Strato.mesospheric... -> Strato-mesospheric...

Response: Done.

Referee Comment: p. 7130: Figure1 looks very stretched

Response: To visualize the kernels better, we set the x-axis from -0.2 to +1.2. Note also that Figure 1 was changed, we included the averaging kernels for Poker Flat (superimposed), as well as typical a-priori CO profiles (on an adjacent panel).

Referee Comment: p. 7132: Figure 3: Please increase the distance between the panels so that the x10Ĺ16 does not print on the next panel

Response: Done, we also solved this by indicating the multiplier on the y-axis.

Referee Comment: p. 7133: On my print-out, it looks like you have used different fonts in the legend. The larger number of data points make the thin line with symbols just

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look like a thick line. Maybe you want to use a consistent to display the data from the 4 different sites.

Response: Thanks for the suggestion, this Figure was improved.

Referee Comment: p. 7135: Figure 6: Please increase the distance between the panels so that the x10Ĺ18 does not print on the next panel

Response: Done, thanks. We also solved this by indicating the multiplier on the y-axis

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Interactive comment on Atmos. Chem. Phys. Discuss., 6, 7119, 2006.