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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Unusually low ozone, HCl, and HNO_3 column measurements at Eureka, Canada during winter/spring 2011" *by* R. Lindenmaier et al.

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We thank the referee for his/her comments, which have helped improve the manuscript. In our reply below, the referee's comments are also included.

General comments: The authors present measurements of ozone, HCl, ClONO2, HNO3 and HF in the polar vortex of winter 20010/11. Since the site Eureka was frequently below the polar vortex a nice data set has been recorded showing chlorine activation as well as ozone depletion in that winter. These data are compared with data from previous winters. Furthermore, data have been compared with SLIMCAT

model data. Using these model calculations for passive ozone ozone loss has been quantified for winter 2010/11. The subject is fully appropriate for publication in ACP. I recommend publication after minor revisions.

Specific comments:

Chapter 1 Intro:

The Solomon et al., 1986 paper is cited on page 1055 and 1056, but is missing in the reference list. In contrast, Solomon et al 1990 & 1999 are listed, but not cited.

The Solomon et al. (1990) and (1999) papers were removed from the reference list and the Solomon et al. (1986) paper was added instead:

Solomon, S., R. R. Garcia, F. S. Rowland, D. J. and Wuebbles: On the depletion of Antarctic ozone, Nature, 321, 755–758, 1986.

Chapter 2 Measurements:

What's the solar elevation angle at Eureka on February, 23?

On February 24, spectra were acquired at solar zenith angles between 89° and 90°. We have added information on the SZA range on the first and last days of the 125HR measurements in the first sentence of Section 3.3. Note that we have changed the date to February 24, as this was the first date of useful 125HR measurements.

Is the spectroscopic error included in the error estimate as given in Table 1? Please list the error sources included in the error estimate. A total error of 4.5% for ClONO2 seems to be quite optimistic, except for large column amounts at the polar edge.

Yes, the uncertainties in the line intensity and air-broadened half width were considered for the 125HR, as discussed in Section 2.1. The error sources are all listed in the same section: "In addition to smoothing error and measurement error, forward model parameter errors have been calculated as described by Rodgers (2000) using a perturbation method and our best estimate of the uncertainties in temperature, line intensity, air-broadened half width, and solar zenith angle. Interference errors, as described by Rodgers and Connor (2003) have been calculated to account for uncertainties in retrieval parameters (i.e., wavelength shift, instrument line shape, background slope and curvature, and phase error) and in the interfering gases simultaneously retrieved. "

We added this sentence to the text in Section 2.1:

"The total error was calculated by adding all these errors in quadrature."

From our error analysis, the total error for ClONO2 during the spring is 4.5% averaged over the period from February 24 to April 6. This error increases significantly as the ClONO2 amount decreases and the atmospheric path length also decreases, reaching values larger than 50% in summer.

For the DA8 (Section 2.2), the line parameters were not included in the error calculation, as discussed by Fast et al. (2011).

We added this sentence to the text in Section 2.2:

"The total error was calculated considering the instrumental error, errors arising from the retrieval algorithm and from the chosen microwindow, uncertainties introduced by the a priori VMR profile, uncertainties due to temperature and solar zenith angle, spectral signal-to-noise ratio and spectral fitting."

Chapter 3 & 4:

How do the Q diagnostics differ from the more frequently used equivalent latitude method introduced by Nash et al., 1996?

Nash et al. (1996) define the vortex edge to be the location of the highest Ertel's potential vorticity (Epv) gradient constrained by the proximity of a strong westerly jet. They multiplied the values of the peaks in the Epv distribution with associated nearby peaks in the wind distribution and chose the largest resultant value in the Epv gradient distribution as the true vortex peak. The equivalent latitude of this resultant value indicates

the vortex edge "center". The vortex boundary region is defined to be located between the local maximum convex and concave curvature in the Epv curve that surrounds the vortex edge.

The Q-diagnostic is another method for determining the vortex edge, by characterizing the cyclonic and anti-cyclonic structures (Harvey et al., 2002). Q is a scalar measure of the relative contribution of strain and rotation in the wind field. Q is positive (negative) where strain (rotation) dominates the flow. Q is negative inside the center of the vortex and becomes positive toward the edge with large gradients near the polar night jet (Harvey et al., 2002). This vortex edge definition agrees well with the algorithm by Nash et al. (1996) (Singleton et al., 2007). It is most effective at identifying vortex edges when the circulation is strong and shear zones are well defined (as was the case in 2011). The Q diagnostic method is described in Section 2.1.

Nash, E. R., Newman, P. A., Rosenfield, J. E., and Schoeberl, M. R.: An objective determination of the polar vortex using Ertel's potential vorticity, J. Geophys. Res., 101(D5), 9471−9478, 1996.

Figs. 5 and 6 show data of different winters. While for 2011 polar vortex is indicated for other winters it is not. When comparing 2011 data with data from different winters it is not clear whether the data are taken inside the vortex or not. However, open and full symbols are already used to distinguish between BOMEM and Bruker spectra. Please provide additional information or omit outside vortex data.

The bottom panel in Fig. 5 shows the evolution of the sPV for each year as described in Section 3.3, thus providing information on whether the data were recorded inside or outside the vortex. The color coding is the same as that used for the trace gases, to emphasize the five cold years. For the following figures, we kept only the shading to highlight the measurements in 2011 that were made on the edge or outside the vortex.

When comparing data of different winters did you consider a trend of the species? Maybe you can add a statement on the trends of the species studied, and whether detrending of the data is needed in this context or not.

We did not consider trends of the species during the comparison. Total column trends in the Arctic based on FTIR data for all species except HNO3 (based on model results for NOy) are 0.9% for O3, -0.9% for HCl, -0.6% for HF, -0.2% for HNO3, and -4.6% for ClONO2 (Vigouroux et al., 2002; SPARC CCMVal, 2010; Kohlhepp et al., 2011). Due to the highly variable meteorological conditions of the Arctic atmosphere, a detrending of the data would not make too much difference in the final result, given that the magnitudes of the trends are much smaller than the changes of dynamical or chemical origin. We therefore assumed that all the changes occurred either because of dynamical effects or because of chemical reactions. We added the following sentence to Section 3.4:

"Note that we neglected species trends in our comparisons, as they are very small compared to the changes of dynamical or chemical origin (e.g., see Vigouroux et al., 2002; SPARC CCMVal, 2010; Kohlhepp et al., 2011)."

SPARC CCMVal, 2010: SPARC report on the evaluation of chemistry-climate models. V. Eyring, T. G. Shepherd, and D. W. Waugh, Eds., SPARC Rep. 5, WCRP-132, WMO/TD-1526.

Kohlhepp, R., Ruhnke, R., Chipperfield, M. P., De Mazière, M., Notholt, J., Barthlott, S., Batchelor, R. L., Blatherwick, R. D., Blumenstock, Th., Coffey, M. T., Duchatelet, P., Fast, H., Feng, W., Goldman, A., Griffith, D. W. T., Hamann, K., Hannigan, J. W., Hase, F., Jones, N. B., Kagawa, A., Kaiser, I., Kasai, Y., Kirner, O., Kouker, W., Lindenmaier, R., Mahieu, E., Mittermeier, R. L., Monge-Sanz, B., Murata, I., Nakajima, H., Morino, I., Palm, M., Paton-Walsh, C., Reddmann, Th., Rettinger, M., Rinsland, C. P., Rozanov, E., Schneider, M., Senten, C., Sinnhuber, B.-M., Smale, D., Strong, K., Sussmann, R., Taylor, J. R., Vanhaelewyn, G., Warneke, T., Whaley, C., Wiehle, M., and Wood, S.W.: abundances, Atmos. Chem. Phys. Discuss., 11, 32085-32160, doi:10.5194/acpd-11-32085-2011, 2011.

'However, in 2011, the conversion of active chlorine back into these two reservoirs was simultaneous, differing from the usual repartitioning.': There are just 2 data points (day 86 & 87) which support this statement of Antarctic type of recovery. Slimcat model shows rapid recovery in HCl and ClONO2 around day 80. Unfortunately there are no FTIR observations during this period to compare with.

Let us compare the evolution of HCl and ClONO2 during 1997, 2007 and 2011. It is clearly seen that during 2007, for example, when the instrument sampled inside the vortex (days 67 to 84), the chlorine level was much higher than in other years, indicating that active chlorine was converted back to this reservoir. For the same days, the HCl total columns were smaller than in other years, and recovered later. For 1997, the measurements were made inside the vortex for all days shown in the plot. We can see how the ClONO2 total columns slowly increase, but faster than the HCl total columns. In 2011, the total columns of both species increase simultaneously (on days 95 and 96 the instrument sampled again inside the vortex). The patterns of recovery in MLS HCl and ClO (Manney et al., 2011) are also consistent with the more Antarctic-like patterns we see at Eureka.

Last but not least, there is a nice result which is not yet discussed in the paper: Assuming a standard ratio O3/HF of 4000 a column ozone loss of 37.5% ((2500-4000)/4000) is calculated. This is in good agreement with the 35% value as obtained by the more sophisticated method applied in this study: FTIR measurement minus Slimcat passive ozone. Therefore, the simple O3/HF method without applying model calculations, just using the measured data, gives a good estimate of column ozone loss. I would like to encourage the authors to add a short paragraph on this topic.

We thank the reviewer for this suggestion. The following text was added to Section 3.4:

"For a quick estimate of the chemical ozone depletion, we can assume a standard O3/HF ratio of 4500 on the edge and inside the polar vortex (e.g., Mellqvist et al., 2002). Using this value, a column loss of 34% can be calculated from ((4500-2977)/4500), where 2977 is the mean O3/HF value for 2011 measurements inside the vortex. Since this approach is oversimplified and has not been validated, a more rigorous method is needed to confirm this result."

Interactive comment on Atmos. Chem. Phys. Discuss., 12, 1053, 2012.