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Interactive Comment

Interactive comment on "The impact of model grid zooming on tracer transport in the 1999/2000 Arctic polar vortex" *by* M. M. P. van den Broek et al.

M. M. P. van den Broek et al.

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We would like to thank the referees for examining this paper and for their thorough and useful comments. All points raised by the referees have been addressed below, including changes and additions to the paper, with reference to the referee comments.

Anonymous referee #1

1) The referee raises the important point of the incomplete coverage of the polar region by HALOE. This did not escape our attention. However, finding a 'better' initialization is not trivial, since satellite observations of HF and CH4 do not have a full global coverage while other measurements are more sparse. Although equivalent latitude is indeed a useful coordinate to study transport characteristics, it would not be of much help for this problem, since no observations at all are available north of 73.9 degrees latitude. We have added this description to paragraph 2.2. To address this issue we have performed

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a sensitivity calculation by using a different initialization. The initial field has October 20 1999 as the starting date and uses the results of a multi-year full chemistry run by the ARPROBUS climate model [WMO, 1999]. The results indicate a strong impact of the initial field on the tracer distributions. They are discussed in paragraph 3.6. and in the discussion and conclusions (paragraph 4).

2) We agree with the referee that a 6° by 9° resolution does not represent the vortex well, but this kind of coarse resolution is still being used, e.g. in climate models [Pawson et al., 2000]. We also agree that the model results are more consistent with one another than with the data. The apparent lack of improvement when increasing the horizontal resolution is one of the main conclusions of this study and we have now stated this more clearly in paragraph 4.

3) Either a coarse vertical resolution, the advection scheme or the ECMWF mass fluxes could contribute to the model-measurements discrepancies shown in Figure 7a. The differences between model and observations thus may depend on the vertical resolution, as the referee suggests, although recent modeling studies show negligible impact when the vertical resolution is increased [e.g. Considine et al., 2003]. In the near future a model run with increased vertical resolution will be carried out and submitted for publication, using all 60 layers of the ECMWF model. This is also mentioned in the discussion/conclusions section.

4) The model does indeed poorly represent vortex tracers, but we feel that the comparison with the observed descent rates in Figure 7 can help in analyzing when these discrepancies occur and how they are caused. We have re-arranged the first part of paragraph 3.5 and added some lines to put this more clearly. We agree that the layer below 450 K is the most important regarding ozone depletion and we have emphasized this in paragraph 3.5. In paragraph 3.5 we stated that the downward advection could be causing the difference with the observations. We have added the emphasis in paragraph 3.5 that by tracer isopleth comparisons such as in Figure 7 there is still no separation between horizontal and vertical transport. So both can attribute to

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the model discrepancies. To calculate a vortex average descent rate, many observed and/or modeled vortex profiles were needed, The limited available observations make it not possible to make a distinction based on proximity to the vortex edge. See also our answers to referee #2 on this matter.

Anonymous referee #2

General comments: - The referee states that only 5 observed profiles are used inside the polar vortex. Two MkIV inner vortex balloon-borne profiles of both HF and CH4 were used (Figure 5) and another inner vortex TDLAS profile (balloon-borne) of CH4 (Figure 4). Besides those profiles, two TDLAS CH4 profiles at the edge of the vortex (Figure 4) and two HALOE HF profiles, also situated at the vortex edge, were used (Figure 6). As far as we know, these are the only inner vortex profile measurements of HF and CH4 that were carried out during this winter. Mid-latitude HF HALOE observations were already presented in Figure 3. Nevertheless, we have added several comparisons with mid-latitude HALOE CH4 profiles (Figure 9).

- We agree with the referee that correlation studies have proven to be very useful. We have discussed this point internally. However, there are unfortunately too little observations available for a good correlation study. From the present model comparison with observations, some of the regions and times where the discrepancies occur can be identified. The differences occur mainly in the inner vortex and vortex edge regions, from early December, which is the start of the vortex formation, onward (see Figure 4, 5 and 6). In addition, mid-latitude profiles also show a discrepancy at the end of the winter (see Figure 3), and whereas early winter profiles show a discrepancy at higher altitudes ($>$ 50 hPa), later profiles are deviated throughout the stratosphere (see Figure 5).

- The referee has pointed out an important subject. We have performed a sensitivity study on the initialization fields (paragraph 3.6). Since referee #1 also mentioned the initialization of the model run, we would like to refer here to our reply to referee #1.

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- Even though the filaments visible in the TDLAS balloon-borne observations are a feature of horizontal transport processes, the vertical resolution of the model (as well as, for instance, of the MkIV remote measurements) is too poor to resolve them. However, the higher resolution runs do show more filamentary structure, as can be seen in the latitudinal comparison with the HALOE observations (figure 6). In the near future, we will perform a 60 layer run as we have stated more clearly in the manuscript in paragraph 4.

- We have emphasized more clearly now that the comparisons of diabatic descent do not separate between horizontal and vertical transport. Therefore, excessive mixing may not only be caused by the coarseness of the horizontal resolution, but also by the vertical resolution, the type of advection scheme or the quality of the wind fields. We added this to the text (paragraph 3.4), to restrict the term 'excessive mixing'.

- We find this suggestion very useful and have added a figure (4b), since some profiles measured at the vortex edge are used in figure 4a. We focussed on the vortex edge around the balloon-borne observation above Kiruna of February 13 2000, to clearly show the gradient differences. In figure 4b we show the results of the Gl23 run (3° by 2° resolution) and the Gl96 (9° by 6° resolution) run. The gradients across the vortex edge are visible in both runs, although the gradient is less pronounced in the coarse model run. However, the gradient is smaller than the differences between model and observations. The analysis and discussion of this figure have been added to paragraph 3.2.

Specific comments: 2.1, line 11 We used the ECMWF forecast data and not the analysis data, because the forecast data are less noisy.

2.2 line 17 The constraints at the top were taken from Randel et al. [1998] and originate from a monthly averaged, zonally averaged UARS data. The effect of using these constraints was tested by van Aalst et al. [2003], who show that ignoring the production of HF has no effect on this timescale, whereas the photochemical destruction of CH4 has a small effect at altitudes above 10 hPa.

3.1 line 22 The mean difference between HALOE HF and correlative balloon underflight measurements is $<$7% in the altitude range of 5 hPa to 50 hPa [Russell et al., 1996]. We have added this clarification to paragraph 3.1.

3.1 line 6 The paper mentions two reasons for the discrepancy at the end of winter, between HALOE and modeled mid-latitude profiles. First, it is mentioned that mixing of mid-latitude air with vortex air may cause the difference. Second, it is suggested that chemical production of HF may play a role. The latter suggestion has been addressed, but the first point is discussed throughout the paper. We have reversed the two items, which makes more sense.

3.1 fig 3. The referee asks for a discussion of the horizontal HF and CH4 gradients of two model runs with different zooming options. We decided to include this discussion addressing Figure 4, because Kiruna, the observation location in this figure is sometimes situated at the edge of the vortex. It is further outlined in one of the next point.

3.4 fig 6. The referee suggests that the strong discrepancy between HALOE and modeled HF in the altitude region between 10 and 1 hPa in Figure 6 should be discussed more thoroughly. In paragraph 3.1 the same discrepancy is visible in Figure 3 in late winter and a short discussion is included there. In paragraph 3.4, we have now made a note of this discrepancy and the previous discussion in paragraph 3.1.

3.5 line 24. The number of profiles used for the descent calculations differs per date (determined by the vortex size) and per model run. The coarsest model run (Gl96) could logically provide the least number of inner vortex profiles. For the December 1 1999 vortex 12 profiles were used. The Gl96_NH32, Gl23 and Gl23_NP11 runs used a factor of 6, 6 and 54 more profiles for the descent rate calculations. The inner vortex profiles were selected by looking at the steepest PV gradients from the ECMWF forecasts, combined with the strongest wind fields, between 100 and 10 hPa. The

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statement "at all altitudes" has been replaced in the text of paragraph 3.5.

4 line 8-10 We meant to say here that perhaps the neglect of the climate impact of ozone depletion in the dynamical calculations of the ECMWF could give an underestimation in the downward transport. However, we agree with the referee that this is quite speculative, therefore this remark has been removed.

Minor comments: - Section 1: This sentence has been rephrased. In the Hall et al. [1999] study several 2D models were used and a number of 3D CTMs. - Section 2.1: ECMWF has been rewritten - Section 2.1: Description of the layer definition has been improved - Section 2.1: Tiedtke [1989] has been added to the reference list - Section 3.2: a reference for the estimated error of the TDLAS CH4 measurements is Garcelon et al. [2002] - Section 3.5: end date for descent rates has been improved - Section 3.5: Reference for N2O results [Greenblatt et al., 2002] has been added - References: references of Bregman et al. [now 2003] and v. Aalst et al. [2003] are updated. - Figure 4: dates are corrected in caption, CH4 is written in capital letters.

Interactive comment on Atmos. Chem. Phys. Discuss., 3, 2261, 2003.