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Interactive Comment

Interactive comment on "Summertime stratospheric processes at northern mid-latitudes: comparisons between MANTRA balloon measurements and the Canadian Middle Atmosphere Model" *by* S. M. L. Melo et al.

S. M. L. Melo et al.

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Reply to: Referee #2

We thank the referee for the time expended in review this paper and for the clear and constructive suggestions. We have revised the text and re-done part of the analysis as much as possible to address all the suggestions made by the referee. In modifying the paper following the reviewer suggestions we enhanced the analysis and sharpened the discussions making the paper much more substantial.

The referee comments are in italic and our response follows right after in normal fonts.

Overall: This is a relatively routine paper that compares model calculations (from the Canadian Middle Atmosphere Model) to a limited set of observations (balloon-borne measurements of ozone and temperature, plus a single profile each of long-lived gases CH_4, HCl, HNO_3 and N_2O). As such, it has some utility as a validation of the model. It does not really convey any new scientific results of note.

Specifics: The paper starts out with a fairly extensive introduction focused on the state of under-standing of lower stratospheric ozone, especially the observed trends in ozone at the mid-latitudes. While this is an appropriate context from which to motivate the observations and model calculations, it somewhat misleads the reader into thinking that he will learn something new about mid-latitude ozone trends.

The authors do point out and discuss an oddity in the ozone profiles measured during summer 1998 - the persistence of a low-ozone feature that may be a remnant of polar vortex air. However, given the relatively sparse data set and the inability of the model to reproduce this feature, they cannot really attribute the cause of the observation, nor explain how much it (and others like it) may contribute to mid-latitude ozone trends.

1 - The introductory section is written well. In the second paragraph, it would be more appropriate to cite primary sources (e.g., journal articles) rather than WMO 2006 for the rates of mid-latitude ozone loss.

R: We believe that reference to the WMO report is appropriated since it is easily accessible at the internet and can point the reader to the more specific literature. The WMO has the advantage of be a review rather than a single paper.

2 - At the end of paragraph three in this section, references should be cited.

R: We added: see for example Chiperfield and Jones, 1999; Millard et al, 2003; Durry and Hauchecorne, 2005; Berthet et al., 2006; WMO, 2007; and references therein.

3 - In section 3, description of the model is incomplete. The reader should be supplied with information about how the model is initialized and how it is run (e.g., time step,

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how chemical species are calculated, etc.)

R: In order to clarify this point we introduced the following text in Section 3: Details about how the chemical species are calculated can be found in de Grandpré et al. (1997). A slightly more recent version of CMAM (differing only in its dynamical aspects, which are not of great importance in the late summer midlatitude stratosphere) has been recently assessed in the model intercomparison of Eyring et al. (2006); more detailed comparisons of CMAM ozone with observations can be found in Tegtmeier and Shepherd (2007), Hegglin and Shepherd (2007), and Shepherd (2008). The CMAM data used here comprise years 28-48 from a timescale simulation representing conditions in the year 2000. Profiles are generated for the model grid point closest to Vanscoy, and at various solar zenith angles. For this run CMAM was sampled in approximately 10 minute increments, producing 144 profiles per model day.

4 - Section 4: In section 4.1, paragraph 2, the description of a model day is not clear. Perhaps this is because I don’t know how many profiles are calculated by the model on a daily basis - I just couldn’t understand here what was being averaged when.

R: We revised the text including more information on how the model is sampled and how a model day is build. In the first paragraph of Section 3, where the model is presented, we added the sentence: For this run CMAM was sampled in approximately 10 minute increments producing 144 profiles per model day. Then in Section 4 we introduce the text: A model day is calculated as the average of the 144 model profiles produced daily for ozone and temperature, for each year of the model run. Thus, for each measurement point there are at least 20 corresponding model points (one for each model year). .

5 - Later in the same paragraph, the authors comment that temperature points above 20 km fall below the 1:1 line in Figure 2, implying that the model is undercalculating the temperature. Why is this interesting ? What does it mean? Should the model be doing

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better than this? How do you know?

R: The text was extensively revised. We enhanced the analysis and sharpened up the discussions. For example, given the altitude resolution of the ozonesondes measurements is of the order of hundred of meters while the model vertical resolution is of the order of 1.5 km, the ozone and temperature measurements were smoothed to the model altitude resolution using a low pass band filter, making the comparisons model and measurements more appropriate. We also revised the separation in altitude ranges using slightly different limits. Data is now blocked as: from 10-15 km , where mixing of lower stratosphere with the upper trosposphere is expected, from 15-25 km where the ozone pick is located, and above 25 km. The figure 2 and the text were revised accordingly. We further elaborate on the possible causes of observed differences between model and measurements. The temperature plot in Figure 2 shows that points corresponding to altitudes above 25 km, therefore the upper stratosphere, tend to be consistently located below the 1:1 correlation line suggesting the model overestimate the temperatures at this altitude range. This suggested warm bias in CMAM is consistent with the warm bias in the global-mean temperature that indicates a radiative bias in the model (Pawson et al. 2000, Eyring et al., 2006). A caveat of our analysis is that measurements spread over a 8 year period (1998 to 2004), which may not enough to represent a climatology.

6 - In paragraph 4, the authors describe the histograms plotted in Figure 3. I am not sure what significance they draw from these comparisons. How important might sub-grid-scale variability be in explaining these differences?

R: The statistic analysis was strengthened. In order to make the text more clear, we added two more figures in this section. The text was revised accordingly.

MANTRA measurements are further compared to the CMAM statistically. In this analysis we used model daily averaged ozone profiles from 9 August to September 11. The ozone and temperature model daily averaged profiles from 19 years model run are averaged to build the CMAM mean and determine the CMAM standard deviation (1 s). Since the observation period span over a about a month, we fitted and then extracted a linear trend for each altitude to account for seasonal variations. Examples of the magnitude of the linear trend are shown in Figure 3 where ozone and temperature at a given altitude (15 and 24 km chosen arbitrarily) are plotted as a function of the day (from August 9 to September 11) producing one curve for each model year. As this figure illustrates, the linear trend becomes important in both the ozone and the temperature above about 20 km altitude.

After removing the linear trend, the CMAM daily averaged profiles for the 19 model years are used together to build the CMAM mean profile and the CMAM standard deviation for each altitude. Figure 4 and 5 show the MANTRA ozone and temperature profiles (after removing the linear trend) together with the CMAM mean profiles. The error bars in the CMAM mean profiles represent the standard deviation (1 ). Also shown in the same figures are the ozone and temperature anomalies (MANTRA – CMAM mean) and the anomalies divided by the CMAM standard deviation ((MANTRA-CMAM mean)/CMAM mean). We see the larger variability for ozone below about 15 km where missing of air from stratosphere and troposphere are expected, and at the peak region (from 20 to 25 km). As discussed in more details below, it is important to keep in mind that above about 25 km altitude factors such as loss of air pump efficiency, instrument temperature changes, slow secondary reactions and sensing solution evaporation render the sonde measurements less reliable (World Climate Research Programme, 1998). From Figure 5 it is clear the suggestion of a warm bias in the model above about 25 km. Large variability is observed in the temperature profiles below 15 km, as expected.

The differences between the model and the measurements as described above ((MANTRA–CMAM mean)/CMAM std) are shown in Figure 6 as histograms. The histograms are shown as frequency of occurrence (number of occurrence divided by the total number of points). On the left side of Figure 6 the histograms (for ozone

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and for temperature) are constructed using the full altitude range. On the right side of the Figure the histograms are constructed for different altitude ranges. It is interesting to notice that the largest differences between model and measurement happens for altitudes above about 25 km with the model underestimating ozone by about 6.6 s (s represents the model standard deviation) and overestimating the temperature by about 3 s. Note that this analysis is limited to 35 km, the maximum altitude common to all the measurements used.

7 - Why start the altitude bin at 10 km? Where is that in relation to the tropopause? Couldn’t the values in this bin be affected by strat-trop exchange processes that are not represented in the model?

R: The data used to build the histograms (now shown in Figure 6) start now at 6 km altitude.

8 - The same general questions apply to the description of Figure 4 in paragraph 6. What is the significance of the model’s differing performance over different altitude ranges? Wouldn’t altitudes between 10 and 15 km be more of tropospheric character? How well are the chemical and dynamical processes of the UTLS known and/or represented in the model?

R: Indeed. As we discussed above, we modified the choice of altitude range as 6-15 km where mixing between tropospheric and stratospheric air are more likely to take place; 15-25 km, including the ozone peak; and above 25 km, or the upper stratosphere.

9 - In section 4.2: With regard to Figure 5, what do the error bars on the DU-FTS data represent? Accuracy? Precision? at what statistical significance?

R: The error bars in the balloon FTS measurements are explained in detail in Section 2.1: they are estimated from uncertainties in the RADCO inputs (the pressure, temperature profile and the line parameters) and in the sensitivity of the quality of fit to variations in the retrieved mixing ratio (i.e., the mixing ratio in the tangent layer).

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10 - In paragraph 2 of this section, some results from an earlier version of CMAM are shown to illustrate the importance of vertical diffusivity. Are there any other significant differences between the two version of the model?

R: In order to clarify this point we added the text: Note that the diffusion coefficient and the slight reduced vertical resolution are the sole changes between CMAM-WMO and CMAM-V7 that might have first-order effects on the constituents profiles.

11 - Toward the end of section 4.2, there is a discussion of the HCl observations and model results, including climatological data from the UARS HALOE instrument. The authors seem to be searching for a reason why the model is wrong here, rather than looking at potential errors in the two measurements. They should look at some comparisons of DU-FTS HCl with other HCl measurements and also at the HCl validation work done for HALOE data.

R: Good point. The measurements presented here are done using an FTS that has a rather strong heritage as it has participated in several balloon and ground-based campaigns (Fogau, 2006). The data processing is well established not representing any particular challenging. The fact that CH4 and N2O measurements seems consistent between themselves for most of the altitude range give us confidence in the data processing approach. Indeed, as noted in the description of the instrument, the DU-FTS did not performed at its best and this is the justification for the rather larger error bars assigned to the measurements. However, we do not expect that measurements errors alone could explain the observed differences. HALOE version 19 data is now available to the public at the HALOE data portal (http://haloedata.larc.nasa.gov/download/index.php). Individual profiles for the location close to Vanscoy on days close to August 24 1998 became available with the new retrieval code used to generate Version 19. Those measurements show structures in the HCl profiles that in somehow resemble the structure observed in MANTRA HCl profile. Recently Huret et al. (2006) reported on the SPIRALE measurements made from a balloon on October 2, 2002 at mid-latitude. SPIRALE N2O and CH4 profiles show

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structures similar to the MANTRA 1998 profiles. We revised the text to include this discussion. In section 4 we added a figure (Figure 9) with the MANTRA N2O, CH4 and HCl profiles to make it easier the visualization of the co-location of the observed features as per N2O and CH4. In this same section, another figure (Figure 10) was added showing the MANTRA HCl together with individual HALOE HCl profiles for August 28, 1998 close to Vanscoy in latitude and covering all the longitude range. HALOE individual profiles show structures that in somehow resemble the MANTRA measurements but with smaller amplitudes. Therefore, it is our understanding that possible instrument and retrieval errors alone can not explain the HCl profile observed during the MANTRA 1998 campaign.

12 - Section 5: Much of this section discusses the extent of agreement between observations and model calculations of ozone profiles. Of considerable interest is the persistent layer of depleted ozone observed in 1998. The authors cite a number of studies to build a case that this observation could be the remnant of a polar vortex filament, but do not go the extra step to determine whether the time-scales required are consistent. For example, they note (at the end of the third paragraph from the end) that the photochemical life-time of ozone at altitudes of 20-28 km is of order 100 days or more. Yet certainly this timescale varies with season (one would expect it to be much shorter in high latitude summer). Moreover, how much of an ozone loss could persist from the break-up of the polar vortex (at the end of March) and the observation time period 5 months later?

R: We agree with the view that our analysis while suggestive is not conclusive. The text in this section was revised to broaden the possibilities as per mechanisms responsible for the observed features in the chemical species. As we discuss in the paper, a climate-transport model using winds and temperature from re-analysis would be required for attribution. However, the measurements in this paper still have the value to add to the growing evidence that the summertime stratosphere can be more disturbed then normally anticipated. The text was revised to lighten the focus on one particular

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mechanism.

13 - Could the depleted HCl in this altitude range as observed by the DU-FTS instrument be a vortext remnant as well?

R: This is indeed a very good question and a difficult one. While the version 19 of HALOE retrieval suggests that structures in HCl profile as seen during the MANTRA campaign in 1998 are plausible, we do not have elements to attribute this feature to a given mechanism. Indeed as discussed in Dufour et al. (Atmos. Chem. Phys., 6, 2355-2366, 2006) HCl recover may happen rather slow given the conversion of ClONO2 in HCl is slow and the partitioning between the two species will depend on the HNO3 abundance. However, our dataset is insufficient to access this hypothesis. MANTRA is a single profile and HALOE is also a relatively sparse dataset not including much as per high latitude measurements. We believe that the revised version of the paper includes a much clear discussion on this issue.

14 - In the penultimate paragraph, there is a description of polar vortex strength and temperatures in 1997 and 1998 that seems inconsistent. Typically colder temperatures are associated with a more stable polar vortex and more significant ozone loss. This paragraph seems to say the opposite.

R: The text in Section 5 was strongly revised. For example this part was removed.

15 - Figures: Figure 2 - It would be more useful to expand the scale on the temperature plot - all of the data are clustered over ranges of 10-15 degrees while both axes span 40-50 degrees.

R: It was not clear for me what the reviewer mean here. However, the axes on Figure 2 were revised.

16 - Figure 4 - The text says that in each plot the Sonde yyyy data are averages of all sondes launched that year, yet the plot shows fuzzy profiles which would seem to represent ranges. Which is it?

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R: The standard deviation is show as horizontal bars at each altitude in the MANTRA ozone and temperature mean profiles. A sentence was added tot the legend (now Figure 7) to clarify this point.

17 - Figure 6 - There should be errorbars plotted for both measurements (i.e., in both directions on the MANTRA observations).

R: Agreed! Changed.

All technical errors were corrected.

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