Answer to Referee # 1

Corinne Straub

March 15, 2012

Dear Referee, thank you for carefully reading our paper and for your helpful and constructive comments and suggestions. They will help to improve the article. All technical corrections have been applied and will not be discussed below. Reviewer comments are in bold face, replies in italic.

P. 32812, L. 8: Introduce acronym for ppmv.
Done.

P. 32812, L. 25: Quantify this agreement.
We added the following sentence: The average value of the SD-WACCM residual vertical wind is 325 m/d while the along trajectory vertical displacement is 335 m/d. The similar descent rates found indicate good agreement between the model and MIAWARA-C's measurements

P. 32813, L. 9: References should be provided to support the statements made.
We now cite the following book:
[2]

P. 32813, L. 16: Do you mean 'mesosphere' instead of 'atmosphere'?
Yes we do. We changed it.

P. 32813, L. 22: References should be provided to support the statements made.
We now cite the following paper:
[10]

P. 32814, L.8: References should be provided of the studies mentioned.
We now cite the following papers:
[4, 8, 14, 7]

P. 32814, L. 10: Does the vortex disappear completely? Or is it just very distorted during this period?
This is probably a too strong formulation. We changed this paragraph accordingly:
In the course of SSWs the stratospheric polar vortex is strongly distorted and

either shifted off the pole (vortex displacement event) or even split in two pieces (vortex split event), [3]. There has been a strong vortex displacement SSW in 2006 and a strong vortex split SSW in 2009. Both events were used to thoroughly study dynamics and transport processes during SSWs (e.g. [4, 8, 14, 7]). The weakening of the vortex transport barrier in the course of a SSW can lead to strong mixing of airmasses.

P. 32814, L. 23: Are there other studies regarding estimate of the descent rates in the USLM? If so, references should be made to them.
We changed the order of this section so all the studies estimating descent rates are together now (we moved [6] and [1] forward). In addition we added citations of [13] and [12]:
Fall descent rates for the upper stratosphere in both hemispheres have been modeled by [11] who obtained a value of approximately 260 m/d for the 1992/1993 Arctic vortex. In addition there have been studies investigating the fall descent rate in the Arctic/Antarctic middle atmosphere using ground based measurements. [6] determined fall descent rates of up to 300 m/d at 75 km altitude at 60° N using CO and H_2O data while [1] found Antarctic fall descent rates of 250 m/d at 60 ° S and 330 m/d at 80 ° S in the upper stratosphere using CO data.
There have only been few studies investigating USLM descent rates after SSWs. Using observations of Aura/MLS and Empirical Orthogonal Function analysis [10] determined descent rates of approximately 1500 m/d at 80 km decreasing linearly to 500 m/d at 60 km for the time after the 2006 and 2009 SSWs. [13] found mesosphere to stratosphere descent rates of approximately 700 m/d after the 2009 SSW using NO_x data from ACE/FTS and the FinROSE chemical transport model. After the SSW of February 2004 [12] estimated a descent rate of 150 m/d in the upper stratosphere from CH_4 and H_2O measurements of ACE/FTS.

P. 32816, L. 19: What are the errors in the MIAWARA-C data?
We added the following paragraph:
The uncertainty on MIAWARA-C's profiles is typical for ground based 22-GHz water vapor radiometers as shown in [15, 16]. The simulated accuracy (determined as the 2-σ systematic error arising from uncertainties in a priori temperature, in calibration and in spectroscopy) is below 16% at all altitudes, while the simulated precision (determined by propagation of 1-σ measurement noise) degrades from 5% at altitudes up to 50 km to 18% between 50 and 75 km.

P. 32817, L. 3: What are the errors in the Aura MLS data?
We added the following paragraph:
The vertical resolution of this retrieval version is 3-4 km in the stratosphere but degrades to approximately 12 km at 0.1 hPa and above. The single profile precision (1-σ random error estimated from the level 2 algorithms) is 4-9% in the stratosphere and degrades from 6 to 34% between 0.1 and 0.01 hPa. The accuracy (probable magnitude of 2-σ systematic error) is estimated to be 4 to 11% for the pressure range 68 to 0.01 hPa [9]. The Aura satellite is in a Sun-synchronous orbit passing through two local times at any given latitude. At the latitude of Sodankylä (67.4° N) Aura passes at approximately 02:30 and 12:00 local time. For this analysis zonal mean water vapor at 67° N is used in order

to complement MIAWARA-C's point measurements with zonal mean profiles. When using mean values of a number of profiles n it is assumed that the accuracy is the same as for a single profile while the 1-σ random uncertainty decreases by a factor $1/\sqrt{n}$.

P. 32819, L. 5: Provide a reference for ECMWF operational data.
We now cite the following website:
[5]

P. 32819, L. 7: Provide a reference supporting your statement regarding the inaccuracy of the wind fields.
We left away this sentence as it might be a bit too harsh. It was there because Alan Geer suggested to be cautious with mesospheric wind data. Since we already mention the limitations of ECMWF mesospheric data in the section about ECMWF (3.1) we believe that this sentence is unnecessary here.

P. 32819, L. 8: Mention here for how long the backward trajectories are run.
Done. It's 3 days.

P. 32820, L. 3: Provide a reference for the statement made.
We removed this sentence from here and added a section about the quality of the SD-WACCM and ECMWF mesospheric data which includes references.

P. 32822, L. 22: Why is this expected?
Because of the winter polar descent associated with the stratospheric and mesospheric circulation. However, we leave the '(as expected)' away as it is unnecessary to mention.

P. 32823, L. 6: Are you taking account of the different spatial resolutions (e.g. in the vertical) when making this 'direct' comparison? If not, you should. Same for P. 32824, L. 1, and following.
We are not for two reasons. On one hand the vertical resolution of MLS version 2.2 and MIAWARA-C are comparable in the mesosphere (almost the same, approximately 12 km, at altitudes above 0.1 hPa). On the other hand this paper is not meant to provide a comparison between MLS and MIAWARA-C, but instead we want to show that we observe similar effects in the data of both instruments.

P. 32827, L. 7: Provide a reference to support the statement made.
We now cite the following paper:
[10]

P. 32829, L. 1: Quantify the 'good agreement'.
We added a plot (right panel) to Fig. 12 (here Fig. 1) and changed the altitudes displayed in the left panel so they match the upper and lower limit covered by the 5.2 ppmv water vapor isopleth. In addition we changed the text as follows: The vertical motion from the TEM wind fields is given by either the residual vertical wind w^* or the vertical displacement along the TEM trajectories. The information content of w^* and the along trajectory altitude change is slightly different; w^* indicates vertical displacement at a fixed latitude while the TEM

trajectories follow the latitude change of the bulk motion of air masses. The vertical motion along the backward trajectories is calculated by taking the difference between the along trajectory altitudes on day 0 and day -3.

Assessment of errors in the atmospheric circulation of the WACCM model is

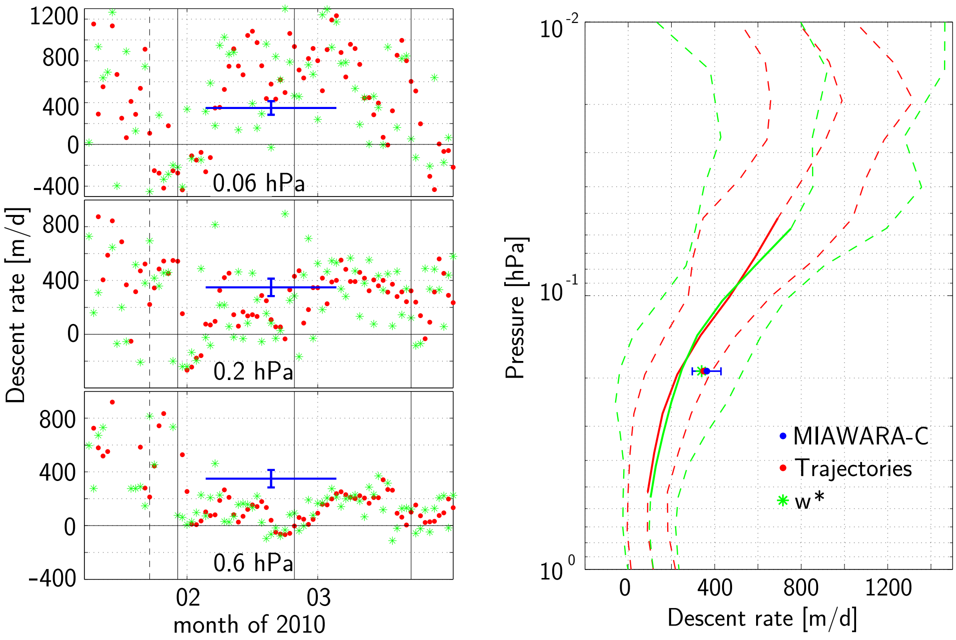

Figure 1: Descent (or during the SSW ascent) rates at 67° N and over Sodankylä determined from TEM trajectories (red), w* (green) and MIAWARA-C water vapor measurements (blue horizontal lines in the left panel and blue dot in the right panel).
Left panel: Daily vertical motion at the indicated altitude levels; positive values indicate descent, negative values ascent. The vertical lines indicate the following dates (from the left): 24 January (wind reversal mesosphere), 30 January (maximum temperature at 60° N and 10 hPa), 24 February (end of the time of enhanced meridional mixing) and 21 March (equinox).
Right panel: Mean value and standard deviation of daily descent rates between 5 February and 5 March. The solid part of the red and green curve indicates the altitude range covered by the 5.2 water vapor isopleth. The green asterisk, red and blue dots are the mean descent rates in that range found from TEM vertical wind and trajectories and determined from MIAWARA-C's measurements, respectively.

subject to current research. Validation of the polar descent rate with direct measurements of the atmospheric wind field is difficult as wind measurements suffer under large uncertainties in the order of 0.1 to 1 m/s (9 to 90 km/d) as shown in [17]. For that reason no errors are provided for the descent rates determined from WACCM data.

The descent rates from the TEM winds are displayed in Fig. 1 together with the value determined from MIAWARA-C's measurements. The left panel displays daily values at three different altitudes (0.6, 0.2 and 0.06 hPa) within the range

covered by the 5.2 ppmv water vapor isopleth. The mean descent rate determined from water vapor, shown as blue horizontal line, is an altitude average and therefore shown on all three pressure levels.
The right panel shows the profiles of the temporal mean of descent rates with standard deviation, w^* in green and along trajectory altitude change in red, for the time period in which the water vapor data has been considered for the linear fit (5 February to 5 March). The plot shows that the values of the two profiles are comparable. The descent rates from the TEM wind fields increase from approximately 80 m/d at 0.6 hPa to approximately 700 m/d at 0.06 hPa. The linear fit to the 5.2 ppmv isopleth provides a mean descent rate for the covered altitude range which is shown as blue dot in right panel of Fig. 1. In order to make the descent rates determined from the TEM wind fields comparable to those from water vapor the mean value is taken over the same altitude range. This results in 335 m/d for the along trajectory altitude change (red dot) and in 325 m/d for w^* being in good agreement with the 350±40 m/d found from MIAWARA-C's measurements.
The lower mesospheric descent rates determined are slightly smaller than the values of 500 to 700 m/d [10] and [13] found after the 2009 SSW. In addition, the upper stratospheric descent rates in 2010 are slightly smaller than those of [12] who determined values of 150 m/d after the SSW 2004. The smaller descent rates after the 2010 compared to the two other years could indicate that the vortex recovery was weaker after the 2010 SSW than after the 2004 and 2009 SSW's.

P. 32829, L. 4: Explain why this is consistent with what is shown in Fig. 2.
This sentence has been left away.

P. 32830, L. 6: Provide more details of what is being mentioned: examples of consistency; examples of the exchange processes.
This sentence has been changed to:
There is a good qualitative agreement between polar descent as observed in MIAWARA-C's water vapor and the vertical component of the 67° N TEM trajectories (shown in Fig. 11). The similar mean descent rates indicate that the dynamics in the SD-WACCM model is consistent with the H_2O observations.

P. 32819, L. 16: This phrase should be rewritten as it does not make sense.
This sentence has been changed to:
For each trajectory point (each altitude and day) the MLS profiles within ±1° in latitude, ±10° in longitude and ±0.5 d in time are searched. This search results in one or two profiles per trajectory point. The H_2O VMR values at the altitude closest to the trajectory point are then averaged (if there is more than one profile) and used for the analysis.

P. 32842, Fig. 8: Lines are difficult to distinguish on the right-hand panels. Please consider changing the plotting style.
We changed this figure and now only display MIAWARA-C's measurements and the along trajectory water vapor VMR's from 3 days before.

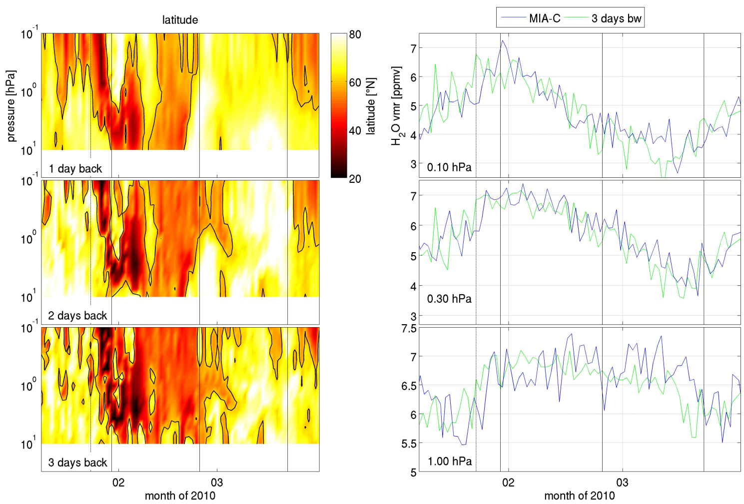

Figure 2: Geographical origin (latitude) of measured air mass determined using Lagrangian trajectory calculations. Left panel: Latitude of the air 1, 2 and 3 days before MIAWARA-C samples it over Sodankylä. White/yellow indicates polar latitudes and orange/red middle and subtropical latitudes. The black contour marks 60° N. Right panel: Water vapor VMR along the trajectories at stratopause altitude and 2 mesospheric pressure levels. Curves are H_2O VMR on the day of the measurement (blue) and 3 days earlier at the location found by the trajectories (green).
The vertical lines indicate the following dates (from the left): 24 January (wind reversal mesosphere), 30 January (maximum temperature at 60° N and 10 hPa), 24 February (end of the time of enhanced meridional mixing) and 21 March (equinox).

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