Middle atmospheric water vapor and ozone anomalies during the 2010 major sudden stratospheric warming

D. Scheiben, C. Straub, K. Hocke, P. Forkman, N. Kämpfer

ACPD Manuscript **ACP-2011-830**
Iteration: Revision

Response on the comments from Referee #1 on the manuscript acp-2011-830:

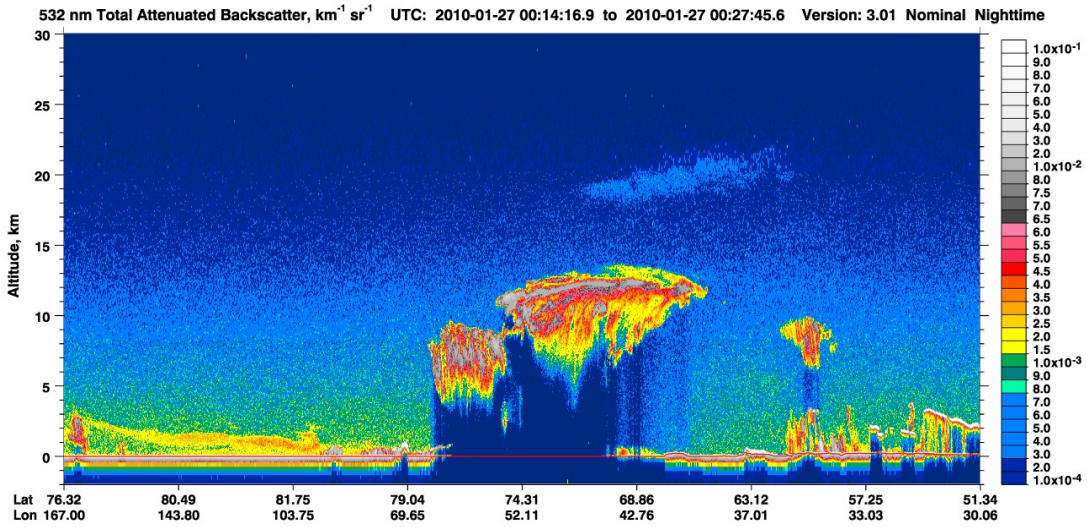
We appreciate the comments from the two anonymous Referees on our manuscript. Based on the comments from the two Referees, we have rewritten most parts of the paper and focus now on the potential of the network of ground-based instruments to capture and describe the relevant dynamical processes in the middle atmosphere during the sudden stratospheric warming (SSW) in January 2010. Additionally, since the focus of the paper changed, we changed its title to „Observations of middle atmospheric H_2O and O_3 during the 2010 major sudden stratospheric warming by a network of microwave radiometers".
In the following, we answer the comments from Referee #1 point-by-point. The comments from Referee #1 are given in *green and italic* font, our answer in black.

General comments:

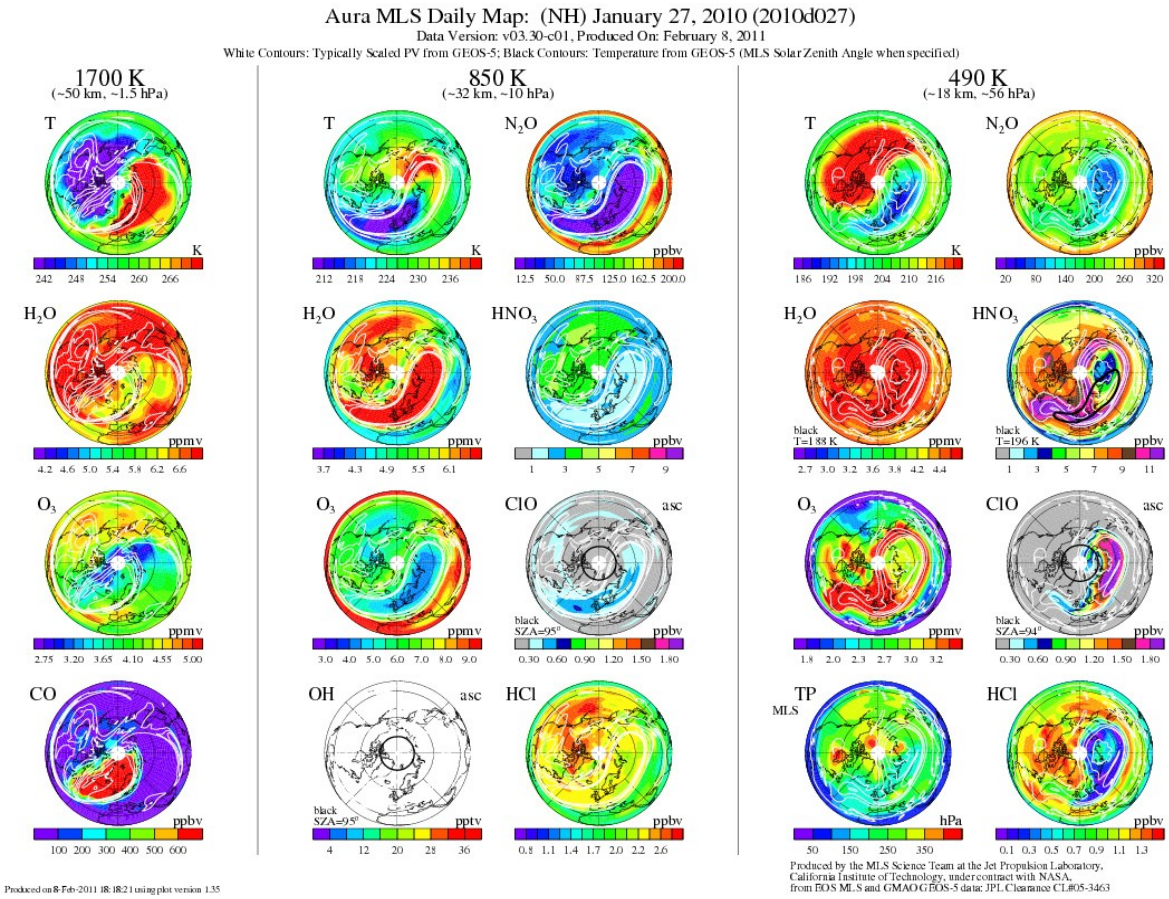
- *The major concern with this paper is that it is not clear what was learned from the ground-based measurements that could not be determined from the satellite observations. The way the paper is structured (showing a global view and then point measurements) is unfortunate. It perhaps would have made more sense to show the ground-based first and then explain the variability from the global observations of the large scale circulation. Still, even it that case, what was learnt from the ground-based observations? Unless this can be answered the scientific value of the paper is limited.*
  We have changed the main focus of our paper. Instead of trying to describe the SSW 2010 from a global perspective in terms of H2O and O3 changes, we now focus on the potential of a ground-based network of microwave radiometers and by how much such a network could be used to describe the dynamical processes during an SSW. First, the observations are interpreted by the relative position of the polar vortex with respect to the measurement sites. For this, we introduced a definition for the edge of the polar vortex which is valid from the lower stratosphere up to the upper mesosphere. Especially during an SSW, the shape and position of the polar vortex changes with altitude. Since commonly used definitions of the vortex edge are often based on PV, they can only be used in the stratosphere, because PV breaks down in the mesosphere and is not a vortex-centered coordinate anymore. The definition which we used now is based on geopotential height and maximum wind speed, obtained from the ECMWF analysis data and we show the validity of the definition by intercomparison with ECMWF PV in the stratosphere and trace species from satellite data in the mesosphere. In addition, we have applied the trajectory mapping method on the ground-based H2O observations to create synoptical maps of the northern hemispheric H2O distribution. The trajectory mapped data set, based on the H2O observations at the three measurement sites, has a broad geographical distribution and allows to determine the approximate development of the polar vortex in the stratosphere and the mesosphere during and after the SSW by using the ground-based H2O observations as a tracer. This is compared to the actual development of the polar vortex as determined by our definition of the vortex edge and shows good agreement. The investigation of the potential of a network of ground-based instruments in particularly important under the light of satellite missions that phase out in the near future without successor missions.
- *Figures 7 and 8 indicated the H2O measurements are very sparse at Sodankyla and Onsala. The light and dark color shading in these figures makes it difficult to discern when the ground-based systems were taking data. For Onsala, there is a change in H2O data source that is concurrent with a large increase - the reader is left to wonder if this is an instrument offset or the SSW. I would prefer to see timeseries plots showing both satellite and ground-based data at two heights (e.g. lower mesosphere and middle stratosphere).*
  The time series plots of the H2O and O3 observations have been changed (former Fig. 7 and 8). Since the focus of the paper has changed (see comment above), we now only show our ground-based observations in the time series plots, without mixing them with satellite data. Hence, there are now

four plots showing O3 in Bern, H2O in Bern, H2O in Onsala and H2O in Sodankyla. Additionally, we indicate in the plots whether or not the polar vortex is located above the measurement site, depending on time and altitude. Showing the ground-based data only on two heights is not enough to show the variability in our observations, which is why we want to keep the color plots showing the data on pressure-time-coordinates. We explicitly do not show the satellite data time series since we focus on the potential of the network of ground-based instruments to describe the dynamical processed in the middle atmosphere.

- *Several times in the paper there is discussion of ozone loss caused by PSCs: "The low ozone concentrations are possibly due to polar stratospheric clouds (PSCs), i.e. PSCs activate catalytic ozone destruction cycles by heterogeneous reactions of chlorine reservoir compounds on the surface of the PSC particles. Such PSCs were observed over Northern Europe during the time of the major SSW", "In the lower stratosphere, ozone concentrations remained very low until 20 February due to the same effect as over Onsala, i.e. due to catalytic ozone destruction caused by PSCs.", "low ozone concentrations were measured in the lower polar stratosphere, i.e. Between 50 and 10 hPa, which are assumed to be linked to ozone depletion driven by heterogeneous reactions on PSCs."*
  This is speculation. No references are provided that indicated ozone chemical loss occurred during 2010. Did the temperatures get cold enough for PSC to form? It is also not clear the timing is correct - presumably sunlight is necessary to create active chlorine, and in January this may not be the case, depending on latitude. Since the authors have access to MLS data they could presumably look to see if HCl decreased and ClO increased during this winter, i.e., there was evidence of chlorine activation.
  Most explanations on the O3 anomalies were assumptions. However, a quick look at the publicly available images from CALIPSO (http://www-calipso.larc.nasa.gov/products/lidar/browse_images/) shows that on 27 January, 2010, there were PSCs in the near vicinity of Sodankylä (67°N/26°E).



Looking at the MLS data plots (http://mls.jpl.nasa.gov/plots/mls/mls_plot_locator.php) from 27 January, 2010, we can see that there also was Chlorine activation during the SSW in the lower stratosphere (plots on next page). Hence, our assumptions on chemical ozone loss were likely to be true. However, as the focus of the paper changed (see first comment), we have removed most of the discussion on the O3 chemistry. We want to demonstrate the potential of the ground-based instruments to describe middle atmospheric dynamical processed during the SSW, which we mainly do with the trajectory mapping of our ground-based H2O observations.



- *The trajectory analysis in Figure 5 is not particularly illuminating or convincing. The lines often cross making them hard to follow. In addtion, they do not show if the variations in temperature or water vapor come predominantly from horizontal or vertical advection.*
  We completely skipped this section. Again, the reason is the different focus of the revised manuscript. We do not want to explain the occurence of an SSW, but explain by how much the ground-based observations could contribute in understanding the dynamical processes during an SSW.

Specific comments:

- *32392/14: Is it necessary to define NDACC in the abstract?*
  We think that the abbreviation „NDACC“ is better known than the whole phrase „Network the Detection of Atmospheric Composition Change“. Therefore, we would like to keep the abbreviation in the abstract.
- *32393/10: Suggest 'The lack of solar radiative heating at the polar leads to a large ...'*
  Done
- *32393/14: Be consistent throughout the document regarding commas following e.g. and i.e. My preference is for a comma after e.g..*
  Done. We now use commas after e.g. and i.e..
- *32393/24: This should be zonal mean zonal wind*
  Done
- *32393/26: I think it should be yˆ-1 rather the yrˆ-1. I think 0.6 refers to major warmings, which should be defined here rather than 32395:5-9.*
  You are right, this should be y^-1. But we have removed this phrase and restructured this part of the introduction.
- *32394/18: You should probably explain how a "warming" can lead to the formation of PSC.*
  The formation of the PSC during the SSW in February 2008 were due to strong updraft and subsequent cooling of lower stratospheric air over England in the course of the polar vortex shift towards Europe. We have changed the sentence on the formation of those PSCs and added this

explanation. For more details, we refer to Flury et al. (2009, JGR).

- *32394/22: Supply reference for NOx loss temperature dependence*
  The ozone loss due to the temperature dependence of the NOx cycle was modeled in the study of Flury et al. (2009), which is the reference.
- *32395/22: Be consistent and comply with journal style regarding Sect. and Section.*
  Done. ACP journal style rules are applied throughout the paper.
- *32396/8: Is OEM used elsewhere - if not, do not define the acronym*
  We removed the abbreviation „OEM“.
- *32396/27: MLS defined after it is first used.*
  „MLS“ is now defined before its first use.
- *32397/2: Not sure what you mean by 'in the frame'*
  MIAWARA-C is a campaign instrument. „in the frame“ means that MIAWARA-C was operating and contributing data within the LAPBIAT campaign during the first half of 2010. MIAWARA-C is not stationary in Sodankylä.
- *32397/3: Ref. for LAPBIAT?*
  As a reference for LAPBIAT, we can only provide their homepage: http://www.sgo.fi/lapbiat/
- *32397/10: What is the valid MLS range?*
  The valid range of the MLS data are now given for all the MLS data which are used in our study, that is 316 - 0.002 hPa for H2O v2.2, 261 - 0.001 hPa for temperature v3.3 and 100 - 0.0046 hPa for CO v3.3.
- *32397/19: Why are two sets of reanalysis data necessary? If they are different, then the discussion and figures should indicate which set is being shown. How good is the data in the mesosphere? I seem to recall a paper by Manney indicating reanalysis near the lid (80km) is in error during an SSW due to the handling of parameterized gravity waves.*
  By revising our paper, we now only use one ECMWF data set, which is the operational analysis (T1279, 91 levels from the surface to 0.01 hPa, extracted on 1.125x1.125 degrees horizontal resolution). We know that the data near the lid (0.01 hPa) has to be interpreted with care, especially during an SSW. However, the vortex edge definition that we use (see our answer to your general comments), which is based on ECMWF geopotential height and wind fields, shows good agreement with trace species from Aura MLS and with our ground-based observations, even in the mesosphere on 0.1 hPa.
- *32398/4: 'typical' is vague. Is it a zonal mean? Is it a monthly mean? In a winter without an SSW? How are in and out of the vortex determined?*
  The figure with the „typical“ profiles of H2O and O3 inside and outside of the vortex has been removed in the revised manuscript. However, the „typical“ profiles where daily mean Aura MLS H2O and O3 profiles in Bern and Sodankyla on 16 January, 2010, when Sodankyla was within and Bern outside of the vortex throughout the middle atmosphere.
- *32398/23: photodissociation or reaction with O(1D)*
  This part is skipped in the revised manuscript.
- *32399/13-18: Move to Introduction*
  This part was completely rearraned for the revised manuscript.
- *32400/5-14: The text should make clear this is satellite data*
  Since we changed the focus of the paper, the temperature time series (from Aura MLS) at the measurement locations are not shown anymore.
- *32401/24: "at this altitude" - which altitude?*
  This part was completely rewritten.
- *32402/21 "associated with the"*
  As above, this part was completely rewritten.
- *32403/12: PSCs have already been defined*
  This sentence is remove due to the completely rearranged structure of the paper.
- *32408: "Red (blue) colors correspond to relatively high (low) mixing ratios." This shorthand is often used but makes for difficult reading, and its usage should be eliminated. In this situation, however, it is unnecessary since there is a scale.*
  Done. That sentence was removed from the figure captions and/or within text, since there is always a scale showing high values being red and low values being blue.