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Atmospheric Chemistry and Physics Discussions



# *Interactive comment on* "Variability of the nighttime OH layer and mesospheric ozone at high latitudes during northern winter: influence of meteorology" *by* A. Damiani et al.

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We thank Reviewer 1 for his/her helpful comments/suggestions. Below, first we show the comments of the reviewer and then we give our replies. We are submitting a revised manuscript that includes all changes as follows.

The new observations make important contributions to the body of knowledge needed to put together a comprehensive view of the interactions that took place during these years. The unique contributions from the present paper are 1) to show the variations of the distribution of OH and discuss its role in the chemistry of the Ox and HOx system, 2) to give quantitative determination of the cross-correlations of OH, T, and O3,



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and 3) to demonstrate the similarities in some aspects of the chemical response to the dynamical events of 2006 and 2009 to the chemical perturbations due to SPE events during 2005. The explanation of the composition anomalies that occurred during 2006 and 2009 is complicated because it involves transport, temperature dependent reaction rates, and reactive gases with chemical time scales that vary widely with altitude and can depend on the composition of other species. All of the aspects are discussed in the paper. However, it seems to me that the discussion makes the situation seem even more complicated than it already is. This can be addressed with some reorganization; suggestions are given in comments 3-4, below. The following comments address many aspects of the text of the paper. The figures are well-chosen to illustrate the phenomena under investigation.

REPLY: In the revised version we are reorganizing the text of the paper according to the reviewer's advice, with particular attention to the discussion section.

Comments: 1. The paragraph from p. 14586, l. 27 to p. 14586, l. 23 contains a lot of information but is so densely packed that it is not easy to read. Here are some suggestions. Split it into two paragraphs at l. 9.

REPLY: We have split the paragraph as suggested.

The sentence beginning "In Polar Regions..." contains a statement about variability that is contradicted by the results presented in the paper; perhaps this could be qualified to be less general or to encompass the range of variability observed.

REPLY: The sentence was referred to the OH variability in the middle/lower mesosphere, below the nighttime OH layer. In order to avoid misunderstanding we have deleted this sentence in the revised manuscript.

At l. 13, end the sentence after "odd-hydrogen" and, in the following sentence, be explicit about what is being transported. It seems to me that rather than "at mid latitudes", you mean "in the sunlit atmosphere".



ACPD
10, C7893–C7901, 2010

REPLY: We have reformulated the sentence pointing out that the mesospheric odd-hydrogen of the Polar Regions is mainly produced in the sunlit atmosphere, transported to the polar winter thermosphere, and then descends towards the upper mesosphere.

2. The mechanism for the impact of transport on OH* emission layer is not explained correctly (p. 14587; l. 14-16). The limiting contribution to the O3+H reaction is normally O3, not H. Here is a more accurate statement: When [O] decreases, the production of O3 falls off because it is generated through the reaction between O and O2; consequently, also the production of OH is reduced.

REPLY: In the revised manuscript we have stated clearly that the production of OH is proportional to [O] because O3 is generated through the reaction between O and O2. In order to move the layer toward lower altitudes a vigorous downward transport of Ox is required to maintain the abundance of O above its normal levels at anomalously low altitudes. As a result, the availability of O at lower altitudes leads to the descending O3 and consequently the descending OH.

3. The scenario of changes due to the SSW events and aftermath are described three times: in the introduction (p, 14588, l. 5 ff.), in the data analysis section, and in the discussion section. I suggest consolidate these. In the introduction, the brief description is hard to follow without the figures, which are only described later. You could just say that MLS data show changes in OH, ozone, etc. that are consistent with previous observations but that provide new information and details that can help fill in the picture of the dynamical-chemical processes acting during these periods. The rest of the detail could be moved to the appropriate parts of one of the later sections.

REPLY: We have moved to the discussion section the information on the scenario of changes due to the SSW events and we have made the introduction easier to read.

4. Also, I suggest that you should decide whether Section 3 should only present the observations or also discuss their implications for the processes involved. If the latter, then maybe it would be best to integrate the discussion in section 4 into section 3



ACPD

10, C7893–C7901, 2010



and not have a separate discussion section. Otherwise, you could move some of the discussion about the figures to the discussion section. My personal preference is to see the results discussed as they are presented but this is up to you.

REPLY: We have chosen to retain the discussion section and move some of the discussion about the figures of Section 3 to the discussion in Section 4.

5. It is not clear what features you are referring to as the "further mesospheric ozone variability" on p. 14592, l. 16.

REPLY: The other mesospheric ozone variability consists of the increased ozone abundance roughly during the SSWs clearly discernible at the altitude of the ozone minimum (0.01 hPa).

6. The discussion does not address or explain the reasons for the higher correlation coefficients during active years. Is this just a signal to noise issue or is there something more? Please comment.

REPLY: The correlation coefficients reported in Table 1 for the pressures 0.02 hPa, 0.01 hPa and 0.004 hPa mainly reflect the transport air motions in the different years. Both "quiet" years and "disturbed" years have an intrinsic anomaly which is stronger and longer lasting during "disturbed" years. The anomaly of "quiet" years is represented by the SSW-influenced days when we see low temperatures and a probable upward vertical motion in mesosphere. The anomaly of "disturbed" years is determined by the very high temperature and the strong vertical air descent during February 2006 and 2009. Therefore even if the correlation coefficients are similar in the two periods, the causes of such values are very different. For example, at 0.01 hPa we note a positive correlation in both "quiet" years and "disturbed" years, driven by high T and high OH abundance (due to OH layer descent) for "disturbed" years, whereas by low T and low OH abundance for "quiet" years. T and O3 at the same altitude are also driven by chemistry, due to short life of O3, so we have low T and high O3 during "quiet" years whereas high T and low O3 during "disturbed" years. Note that the high posi-



ACPD

10, C7893–C7901, 2010



tive correlation at 0.004 hPa during “disturbed” years is indicative of the thermospheric O3 descent. Finally as expected, the correlation between OH and O3 is negative at all altitudes in both “quiet” years and “disturbed” years but more intense during “disturbed” years. Note the roughly constant increase of the coefficients in “disturbed” years compared with “quiet” years at all selected pressures (see for example the regression between OH and O3). This means that the presence of some days of noisy ozone (only at 0.01 hPa) does not noticeably influence our results. In general the higher correlation values during “disturbed” years are mainly due to a larger number of anomalous days (i.e., characterized by very high temperature) compared with “quiet” years (i.e., characterized by low temperature induced by SSWs). We have inserted a new paragraph about the above discussion in Section 4 (page 6, right column) of the revised manuscript.

7. Reference to the “vortex core” during SSW (p. 14595, l. 25) does not mean much considering that sudden warmings are characterized by a major displacement and/or splitting of the polar vortex.

REPLY: We have removed this reference in the revised manuscript.

8. Without additional information, I think it is not possible to distinguish between a reduction in the downwelling and an actual upwelling (cf. p. 14596, l. 6; l. 16).

REPLY: In the revised manuscript we have pointed out that additional information is needed in order to distinguish between a reduction in the downwelling and an actual upwelling.

9. Please explain the negative values of ozone (p. 14598, l. 12) by, for example, adding a few sentences to Section 2.

REPLY: As explained in the data quality and description document of MLS data (Livesey et al., 2007), some of the MLS observations are "noisy" in nature. A consequence of this is that the abundances of the MLS retrieval components may have



ACPD
10, C7893–C7901, 2010





negative values because MLS measurements have a poor signal to noise ratio for individual profiles. In order to avoid introducing a high bias in calculating averages, it is necessary to retain these points. For ozone negative values occur at pressures lower than 0.02 hPa. In our case, despite the large amount of profiles utilized for the averages (about 250 in January and about 200 in February), some negative daily values persist but only at the altitude of the ozone minimum (0.01 hPa) and under anomalous circumstances which involve an increase of [OH] (i.e., during some days of February 2006 and 2009 when the OH layer descended to this altitude and doubled its concentration and during SEP events, when the solar protons led to high OH values in mesosphere). Therefore we believe that such low ozone abundances, with concentrations below the noise level of MLS, occur at least in part because the HOx catalytic cycles of O3 destruction are more efficient (in February 2006 and 2009 this is due to higher concentration of atomic oxygen than "quiet" years).

However, in addition, perhaps change the wording here to "ozone abundance is so low that the concentrations are below the noise level of MLS, resulting in a mix of positive and negative values : : :".

REPLY: In the revised manuscript we have changed the sentence as suggested.

10. Please be more specific about the "low concentrations of atomic oxygen" (p. 14598, l. 21). At least above about 80 km, O has a long lifetime and has its highest abundance in the polar night due to downwelling. The destruction of ozone is also quite rapid (models calculate chemical timescales of minutes).

REPLY: This sentence referred to middle/lower mesosphere below the OH layer. We want to say that chemistry, in addition to transport, can contribute to reduce the ozone minimum, because in February 2006 and 2009 the catalytic cycles involving odd-hydrogen are more efficient due to the large availability of atomic oxygen (note also the higher OH abundance at this altitude). We have rephrased the sentence in the revised manuscript.



ACPD

10, C7893–C7901, 2010



11. Terms like middle mesosphere and upper mesosphere are not precise since both the stratopause and mesopause heights are highly variable. It would be better to give altitude and/or pressure ranges. This is especially the case for the present study because the focus in on a region that could be classified as either upper or middle mesosphere and is sometimes even below the elevated stratopause. For example, p. 14586, l. 14-15, but many other instances as well.

We have inserted more explicit altitude/pressure ranges in the revised manuscript and we have left these terms only if referred to general concepts.

12. The paper would be easier to read if words were spelled out rather than using abbreviations. The examples I had trouble following were PR, DY, and QY.

REPLY: We have removed these abbreviations in the revised manuscript.

13. Throughout, I suggest change "drop" to "descend" or "descent" when referring to layer position. "drop" is ambiguous because it is also used to indicate quantity; a drop in the OH layer could mean either a movement in its location or a decrease in its concentration.

REPLY: We have changed "drop" to "descent" in the revised paper.

Editorial suggestions

page line 14584 15 Give an approximate altitude range for the third ozone peak.

REPLY: We have stated that the nominal altitude of the third ozone peak is 72 km but it descends by about 5 km under anomalous conditions (i.e., February 2006 and 2009).

19-22 The sentence is unclear. Suggested revision: During these periods, there was an upward displacement of the OH layer coupled to changes in ozone and carbon monoxide. These perturbations were strongest during the SSW of January 2009; coincident upper mesospheric temperatures were the lowest recorded over the late winters of 2005–2009.



ACPD

10, C7893–C7901, 2010



REPLY: We have changed the text accordingly.

14586 6 Begin a new sentence at the parentheses: ": : : typical atmospheric conditions. (Slight hemispheric : : :"

REPLY: We have changed the text accordingly.

19 "main path" for what?

REPLY: The main OH production pathway.

14587 13-14 "transport at lower altitudes" Do you mean "transport to lower altitudes"?

REPLY: Yes we do, we have changed the sentence to "transport to lower altitudes".

Please say what altitudes.

REPLY: At least down to 80 km, since during 2004 and 2006 the layer of OH* descended by about 5-8 km (Winick et al., 2009). Other data (including the ones of the present paper) have shown that the Ox transport influences also the altitudes of the third ozone peak.

21 Do you mean "emission rate" rather than "production rate"?

REPLY: In Sonnemann et al., 2006 it is reported the OH excited production rate [cm-3/s]

14589 24 Begin a new sentence at the parentheses: ": : :results. (Experimental: : :"

REPLY: Agreed

14590 6 Figure 1 shows the time series, not the trend (which would be the derivative of the time series).

REPLY: Agreed, we have changed the term "trend" to "time series".

19 Suggest change "usually not affected by" to "below the usual position of".



ACPD

10, C7893–C7901, 2010

REPLY: Agreed

14591 1 “representative of the OH distribution inside the mesospheric polar vortex” This has not been demonstrated and cannot be without additional data. I suggest drop this sentence.

REPLY: Agreed, we have removed this sentence in the revised manuscript. 14592 4 Specify downward transport.

REPLY: Agreed

14594 23-24 Be more explicit; such as “the layer of ground state OH, normally situated about 5 km below the Meinel band emission layer”.

REPLY: We have changed the sentence as suggested.

14595 3-5 Suggest change “Although only some studies linked the temperature to the OH layer at 82 km because” to “Although there has been only limited observational evidence determining the link between the temperature and the OH layer at 82 km because”.

REPLY: Agreed

14596 29 Delete “enhanced” and replace “that is not coupled with large” with “but reduced”.

REPLY: Agreed

14597 10-11 Begin a new sentence at the parentheses: “: : : by CO. (See : : :”.

REPLY: Agreed

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