

Answer to Rev.2 questions:

It's great to see more data added, supporting a much wider precipitation event. Indeed one of the main remaining comments I have is the mixing of the global signals with the emphasis on very localised effects and small precipitation area. It is challenging for the reader to separate between the global responses and the local emphasis. The clarification in the reviewer responses was very helpful in this regard, but the issue remains the manuscript. For example, the POES data is presented in a very local sense (limited lat and long rage), VLF captures wider area, MIPAS and MLS provide a more global view but discussed in context of local impact (the extreme statistics reflect the impact totally elsewhere and not over Moscow), models are used to evaluate local impact, but HAMMONIA in a global sense (including transport). I may just require a careful, small revision of the text to guide the reader. Perhaps using sub-headings to structure the contents in this regard?

We thank the referee for the consideration of the manuscript and useful suggestions that helped to improve the manuscript. Following the reviewers' suggestion, we have changed most of the section headers to make the structure of the paper clearer regarding local (over Moscow), regional (broader region centered around Moscow) and hemispheric impacts. We have also added suggested information in the text of the paper, see response to comments below. All the changes in the text of the paper are highlighted by blue fonts.

The reason for enquiry about solar x-ray flux relates to solar flare activity, which should be excluded as a potential driver for the x-ray observations presented. My understanding is that solar flares can reach well below 90 km altitudes. See: Thomson, N. R., C. J. Rodger, and M. A. Clilverd (2005), Large solar flares and their ionospheric D region enhancements, *J. Geophys. Res.*, 110, A06306, doi:10.1029/2005JA011008

From my checking, there do not appear to be any large flares on 14 Dec 2009

Yes, we also could not find any solar flares class M and X during December 2009 and was no any solar flare during 14 Dec 2009.

We have added in section 2.3:

While solar flares and their ionospheric D-region enhancements are known to reach well below 90 km altitude (Thomson et al., 2005), no M- or X-class flares occurred in December 2009, and there was no flare on December 14, 2009.

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MIPAS HNO₃: Thank you for clarifying the purpose of the use of HNO₃. This is an important point, please also explain this in the manuscript text.

We have added:

As HNO₃ is a longer-lived reservoir for NO_x and HO_x, formation of HNO₃ can prolong ozone loss, and also enhance the stratospheric impact by downward transport in polar winter (indirect effect). Here we take into account HNO₃ mainly because it is formed very efficiently by ion chemistry reactions, and is therefore a good tracer for particle precipitation impacts.

In the revised MIPAS maps CO has been added as a tracer. However, this is not yet described in the revised version in section 3.2 or the figure caption. Does the vortex really extend to Sahara? This contradicts the statement on lines 265-266

Please note that the extension of the vortex in the mid-mesosphere (70 km) as shown here can be different to the stratospheric vortex, and this does not mean that the stratospheric vortex below 45 km extends so far South. The reference in lines 265-266 refers to the vortex in the HAMMONIA model, not to the observations.

We've added the description to the figure caption, and added the following text at the end of section 3.2:

...or fast horizontal transport "within the mesospheric polar vortex. The latter possibility is investigated in Fig. 5 c by including MIPAS CO observations with vmrs > 1.5 ppmv in 70 km altitude as tracers of vortex air, indicating highest NO values at the edge of the area of enhanced CO."

We've added "in the model" to the sentence in (formerly) lines 265-266 for clarification

Section 4 heading change "ozone layer" -> "mesospheric ozone". Ozone layer as a term refers to the primary ozone maximum in the stratosphere.

Done

Please revise "rhombi" -> "diamond"

Done

Line 13: "nitric" -> "nitrogen"

Done

Line 21: This new sentence needs revising, and a reference.

Sentence changes from:

Mid-latitude electron precipitation has received proper observation-only recently. Comprehensive measurements of precipitation from a slot between the outer and inner radiation belts at L~2-4 have been made on the Van Allen Probes (e.g. Su et al., 2017; Foster et al., 2016).

to:

Comprehensive measurements of mid-latitude electron precipitation from a slot between the outer and inner radiation belts at L~2-4 have been made on the Van Allen Probes (e.g. Su et al., 2017; Foster et al., 2016).

Line 91: "captured" -> "trapped"

Done

Lines 314-315: This sentence seems to be missing something, please revise

Sentence changes from:

The predicted ozone losses are largest in the range 68-90 km, but this is not covered by MIPAS data, which in the nominal limb mode only scan up to 68 km. MLS data are available, but noisier and would have to be averaged over a larger area. The large ozone losses are restricted to a small area but not for the zonal averages.

to:

The predicted ozone losses are largest in the range 68-90 km around Moscow region during and after the EEP event.