First, the authors would like to thank the referee for his or her careful review of our manuscript and his helpful and constructive comments. In the following I reply to each of the comments on behalf of all co-authors. The reviewer comments are given in black while our reply is provided in blue.

General comments: - Why have you used just NO2? MIPAS observed both NO and NO2 so the analysis could be done for NOx, instead of just NO2. Surely the conclusions made on impact on NOx and NOx-production rates would be more robust if total NOx was used?

We have added the following sentences at the end of chapter 2 which justify our decision not to use NO: "MIPAS also observes NO which would allow to analyze the mesospheric response to geomagnetic variability for NO_x ($NO+NO_2$) instead of NO_2 alone. However, sensitivity tests have shown that mesospheric NO retrieved during polar summer can be affected by a down-folded thermospheric signal of the same order as the expected local response to geomagnetic variability (1 ppbv).Thus, small variations of geomagnetic activity affecting thermospheric NO cannot be distinguished in the mesospheric NO-signal from the possible local impact on mesospheric NO. Since NO_2 is not affected as there is no thermospheric NO_2, we only use this gas for data analysis instead of NO_x."

- Why limit the study to solar minimum times? You are focusing on seasons when the dynamical impact (or indirect-NOx) is minimised so why not include the whole MIPAS time series? This would provide more data for the analysis leading to more robust conclusions - this would also be interesting for the wider audience.

For this kind of analysis, we need daily measurements with as little gaps as possible. Due to measurements gaps during 2004-2006, there is only one additional Northern spring/summer/autumn with sufficiently continuous data coverage: 2003. For reasons of consistency we do not use this year: First, there was a strong solar maximum. Second, in 2003, MIPAS observed with a different measurement mode than in 2006-2012, so there might be systematic differences.

Also, I debate weather 2011 could be considered solar minimum, what were the Lyman-alpha levels like, for example, in 2006 (Fig. 1)?

We agree. 2011 should be considered as "the beginning of solar maximum". We have added it to the text.

- I think the seasonal & latitude selection needs to be clarified. The abstract suggest that the study focuses on the spring/summer/autumn seasons, but the selected time periods include the southern hemisphere mid-winter. The potential effect of descending NOx rich air in the Antarctic polar vortex is said to be taken into account by restricting data to latitudes from 50S-80N, but in the upper stratosphere the Antarctic polar vortex can easily stretch to 50S and further equator wards so this does not necessarily exclude the downwelling NOx impact, particularly not in mid-winter. Why not just separate the NH and SH analysis so local seasons can be looked at completely separately? Also, it is simply not true that the magnetic latitudes are more difficult to determine in the SH. The data selection criteria do not seem to be robust and this needs to be addressed.

- In the abstract, we have added the word "Northern": "... Northern spring/summer/autumn hemisphere."
- We have removed the sentence "... because geomagnetic latitudes can be determined in the Northern Hemisphere more precisely than in the Southern Hemisphere"
- The intention of the latitude selection is to show that there is only an impact at the geom. latitudes of the radiations belts. We agree that the winter polar vortex can stretch to lower latitudes than 50S, so we analyze the Northern Hemisphere and the Southern Hemisphere separately as suggested by the referee. The Following have been added:
  - Title: "...from 2007–2012"

- Abstract: (i) "...from 2007 until 2012..." (ii) "Observations in the Northern and Southern Hemisphere..." (iii) "... in the Northern Hermisphere..." (iv) "Observations in the Southern Hemisphere do not have the same significance due to a worse sampling of geomagnetic storm occurances. Variabilities due to solar variation occur at the same altitudes at 60–70° S geomagnetic latitude but cannot be analyzed as in the Northern Hemisphere."
- 3 Data analysis: (i) "For the Northern Hemisphere, we did..." (ii) "Finally, we performed one SEA for the Southern Hemisphere (Sect. 3.4)."
- 3.1 Method: (i) "Figure 1 shows the daily zonal means of nighttime NO_2 VMR measured by MIPAS at $65 \pm 5°$ N and $65 \pm 5°$ S geomagnetic latitude, the Ap index, and solar Lyman-α flux in 2007–2012, i.e., during solar minimum (2007-2010) and during solar maximum (2011-2012), as a function of time." (ii) "On 23–30 January 2012 and 7–15 March 2012 two strong SPE occured producing NO_x the middle atmosphere (von Clarmann et al. 2013). Therefore, we do not use MIPAS data from 23 January 2012 on." (iii) Table 1 changed (appendix). (iv) "At the chosen time periods (Table 1), 659 daily means of MIPAS NO_2 VMR can be used in the Northern Hemisphere and 697 in the Southern Hemisphere. We restrict our analysis to geomagnetic latitudes from 0° to 80° of each hemisphere for the following reasons: first, with this restriction, downwelling of NO_x-rich upper atmospheric air of the other hemisphere in polar winter is excluded." (v) "...in the Northern Hemisphere..." (vi) "In the Northern Hemisphere, ..."
- 3.2 Northern Hemisphere: Different epoch types
- 3.3 Northern Hemisphere: Fit to the SEA
- 3.4 Southern Hemisphere: "We did the same analysis for the Southern Hemisphere at the time periods as described in Tab. 1. It turned out, that applying the criteria of the different epoch types to the whole data set led to no significant results. The reason for that is the sampling of the Ap Index. Ap events are generally lower during the periods of polar summer in the Southern Hemisphere used for the analysis, especially in the Southern summer 08/09 and 09/10. The Ap Index is so low during these periods that it has no significant effect on ΔNO_2, and other variations perturb the SEA. Therefore, these two periods are taken out of the analysis. There are 372 daily means of MIPAS measurements left. Applying epoch type 1 leads to 68 events.
  In Fig. 9, the SEA of epoch type 1 is shown for $65 \pm 5°$ S geomagnetic latitude and 50 km altitude. The maximum values around 0.1 ppb of ΔNO_2 are at day 1 and 2. But the peak is very broad. The other maxima are at day -26 and at day 25. The minima at day -13 and 13. A 27-day cycle is slighty identifiable, but the width of the peaks and the relative errors are larger than in the Northern Hemisphere. This is due to the lower number of used measurements and due to the worse sampling of the Ap Index in the periods. Thus, SEAs of the other epoch types and a correlation analysis lead to no significant result. In Fig. 10 the sensitivity of ΔNO_2 at day 1 is shown. Maximum values are 0.09 ppb at 48 and 50 km altitude. The altitudes with the highest sensitivity and the shape of the curve are similar to the Northern Hemisphere and confirm the results of Sect. 3.2 and 3.3. The maximal values are lower due to the reasons already mentioned."
- Conclusion: "Observations in the Southern Hemisphere are less significant due to a worse sampling of the Ap Index during the analyzed time periods. Nevertheless, they show a slight 27 day cycle and confirm that the altitudes of maximal sensitivity of NO_2 to solar variation are 48-50 km."
- Figures: The x-axis of the Figs. 3–6 changed to 0–75° N geom. latitude.

Specific comments: Abstract: - Last sentence: This is not the first study showing impact on trace gases, as you write in the introduction, effects on hydroxyl, down to 50km were discussed previously, e.g. by Andersson et al., 2012 who covered all seasons. Hydroxyl is a trace gas, so perhaps this should

be changed to NO2 instead.
- Same sentence: "local impact" could be interpreted as local in latitude and longitude, but the data used was averaged over all longitudes in the latitude band, I suggest changing the wording accordingly.

We have changed it to: "This is the first study showing the direct impact of electron precipitation on NO_x at those altitudes in the Northern spring/summer/autumn hemisphere"

Introduction: - Page 32328, line 20 "relativistic energies", It would be good to add the electron energy range in question here.

We have added: (∼1-4 MeV)

Chapter 2: - Page 32330, lines 21-23: This will not be clear to most readers, please clarify or provide a reference where this data selection method is explained.

We have added the reference: Funke, B. et al.: Composition changes after the "Halloween" solar proton event: the High Energy Particle Precipitation in the Atmosphere (HEPPA) model versus MIPAS data intercomparison study, ACP, 11, 9089–9139, 2011.

Chapter 3.1: - Page 32332, line 2-3: This is simply not true.

We have added to the sentence: "and the beginning of solar maximum" (see also general comments)

- Why the long time interval +-30 days? CIR, which are common during solar minimum times, are expected to repeat in the epoch analysis as events at +-27 and 0 days. You will end up counting several events in each epoch period, and counting them again as individual day = 0 events. This should be discussed.

We add following to the text: "It is possible that the same event can be counted in different epoches at, e.g., day -27, 0, and 27. But if some events are counted several times, they will be counted for the ΔAp, the ΔLy-α, and the ΔNO_2 epoches. So the same averaged epoches are compared."

- Why Delta Ap $>$ 3.5? How is this limit determined?

We add following: "The criterion is chosen in that way, that there are ∼100 different epoches to count."

Chapter 3.2: - Epoch type 1: What do you mean by "out-of-phase UV radiation having non-linear influence on deltaNO2"?

We reword the sentence: "They are triggered by high UV radiation averaged out in the ΔLy-α epoch of the figure. But due to non-linear influences of UV radiation on ΔNO_2, which are explained below, the observed small and not significant maxima can appear."

- Epoch type 2: Since you are using the Ap index the more accurate statement here would be that the NO2 enhancements are linked to the Ap peaks, not that they are cause by pure electron precipitation. After all, Ap is not a measure of electron precipitation, just used as a proxy for it, but also affected by protons. Last sentence: It looks like this peak is centred at day -15, which does not clearly correspond to the Lyman-alpha. Please clarify.

We reword the sentence: "Evidently, the averaged NO_2 enhancement is linked to the Δ Ap peaks, which are an indicator for enhanced particle precipitation."

- Epoch type 3: The correlation is also very good with Ap, based on Fig. 2.

We add the sentence: "Additionally, the correlation between Δ Ap and ΔNO_2 is also very good."

- Epoch type 4: "due to noisy Ap signal", the goal is to control for the Ap signal by restricting to DeltaAp $<$ 1, so I'm not sure I understand what is meant by noisy Ap signal?

Yes, the goal is to control the Δ Ap signal, mainly the 27-day period in the Δ Ap signal. This is achieved. A quiet Δ Ap signal cannot be achieved because one has to balance the number of epoches and the strength of the Δ Ap-criterion. So the Δ Ap signal remains noisy. We add the sentence: "The Δ Ap signal does not show a 27-day-period. Instead it is more noisy due to smaller N. The ΔNO_2 signal..."

- Figure 3: What happens if you include the total NOx, instead of just NO2 in the analysis? One would expect to see the correlation extending towards higher altitudes. I think this would be an important test.

The reviewer is right. This would be important. But due to the reason, we mentioned in the general comments, we do not use the NO data.

- Page: 32335, lines 13-15. Yes, this would be expected as you are looking at the in-situ (1 day, i.e. no delay from vertical transport point of view) instantaneous impact, for particle precipitation this should indeed be tied to the magnetic field. The high correlation extends to geomagnetic latitudes >70N, is this in line with the expected impact region of radiation belt electron precipitation?

Figure 4 is a contour plot via a 10°-grid with respect to geom. latitudes. At 75N, maximal values of r are < 0.3 (48 km altitude). So, high correlation does not extend to geomagnetic latitudes >75N. We add to/reword the text:

- "(10°×2 km grid)"
- "There is neither a significant correlation at lower geomagnetic latitudes nor at 75 ± 5° N."

- Figure 5: This makes me worry about the Ap index filtering criteria for the UV impact. How is the Ap criteria selected? What is the significance of the p-values for this type of correlation?

- The Ap index filtering criterion for the UV impact is balanced between a strong filter and the number of daily means (~ 400).
- We add following: "By this method, the precision p is determined indicating the significance level of a monotonic correlation between both variables. p does not determine the strength of the correlation or the sign of the monotonicity."

- Figure 6: Why is the UV correlation not at all symmetrical wrt the equator?

The UV correlation is not symmetric to the equator because different seasons are observed in the different hemispheres. The mechanism for this is not yet clear, but this is out of the scope of this paper. We do not mention it in the text, because due the general comment we now focus only on 0-80° of each hemisphere.

- Page 32336, lines 1-4: The meaning of this sentence is very difficult to understand, could you please clarify it.

We have reworded the sentence: "But since p is even higher, other effects have to be taken into account. Simultaneous variations in temperature, ozone, and NO-photolysis triggered by UV-radiation can affect ΔNO_2 as well. This can lead to a positive correlation at high latitudes and a negative correlation at lower latitudes."

Chapter 3.2: -Page 32337, lines 14 and 16: Do you mean NO2 lifetime here as only NO2 observations were used? The NOx lifetime should probably be different from the NO2 lifetime, particularly at the higher altitudes?

It was not mentioned explicitly, but we mean NO_x-lifetimes. So we have added to the text: "Since we analyze NO_2 at a fixed local times (and hence roughly constant NO_x-partitioning), retrieved NO_2-lifetimes correspond to NO_x-lifetimes."

- Figure 8: I'm not sure I understand this figure, it should be discussed in more detail.(Currently only mentioned on one line).

We have reworded the text: “In Fig. 8, the averaged epoches of epoch type 2 at 54, 50, and 46 km altitude are shown in black (top/middle/bottom, respectively). The fits to each of them are shown in red. These fits illustrate that the central peak and the peaks around the days ±27 can be explained by an Ap Index-dependent NO_x-production considering the altitude-dependent NO_x-lifetime.”

Typos: - Abstract, line 16: “at that altitudes” should be “at those altitudes”
We have changed it.

- Lyman-alpha with a hyphen. Across the text.
corrected

- Page 32336, line 13 and later, Should “pr” be in italics as on line 11, or should the italics be removed on line 11?
We decided to set “pr” in italics because it is a variable: pr.

Additionally, we have cited a paper in the Introduction, released in the meanwhile:
Sinnhuber, M., Funke, B., von Clarmann, T., López-Puertas, M., and Stiller, G. P.: Variability of NO_x in the polar middle atmosphere from October 2003 to March 2004: vertical transport versus local production by energetic particles, Atmos. Chem. Phys. Disc., 14, 1–29, doi:10.5194/acpd-14-1-2014, 2014.

Table 1: Time periods, for which MIPAS NO_2 data are used in the analysis. The periods left out for Figs. 9 and 10 are in parantheses.

Northern Hemisphere	Southern Hemisphere
21 Mar 2007 – 28 Oct 2007	13 Sep 2007 – 07 Apr 2008
05 Apr 2008 – 05 Oct 2008	(17 Sep 2008 – 15 Apr 2009)
28 Apr 2009 – 07 Oct 2009	(02 Sep 2009 – 30 Mar 2010)
20 Mar 2010 – 12 Oct 2010	10 Sep 2010 – 15 Apr 2011
24 Feb 2011 – 05 Oct 2011	10 Sep 2011 – 21 Jan 2012

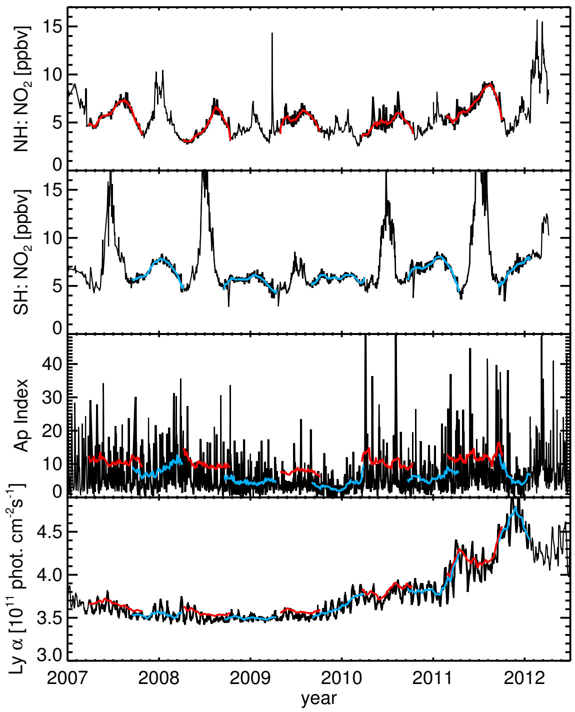

Figure 1: First panel: Daily means of nighttime NO_2 VMR in ppb at $65 \pm 5\,^\circ$ N geomagnetic latitude and 50 km altitude in 2007–2012. Second panel: The same for $65 \pm 5\,^\circ$ S geomagnetic latitude. The red/blue curve shows the 27 day running mean of the curve for the days listed in Table 1. Third panel: Daily means of the Ap index in 2007–2012. The blue curve shows the 27 day running mean of the curve for the days listed in the SH column in Table 1. The red curve shows the same for the days listed in the NH column, shifted by 3.5 for the days defining the threshold of an Δ Ap-event. Fourth panel: Solar Lyman-α in 2007–2012. The blue curve shows the 27 day running mean of the curve for the days listed in the SH column in Table 1. The red curve shows the same for the days listed in the NH column, shifted by 0.05 photons $cm^{-2}\,s^{-1}$ defining the threshold of an Δ Lyman-α-event.

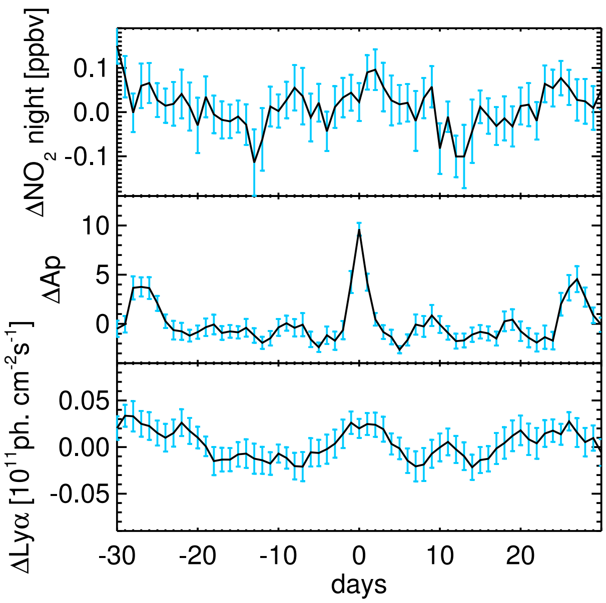

Figure 9: Epoch type 1 SEA of $\Delta\,NO_2$ at $65 \pm 5°$ S geomagnetic latitude and 50 km altitude. The blue error bars show the 1σ range.

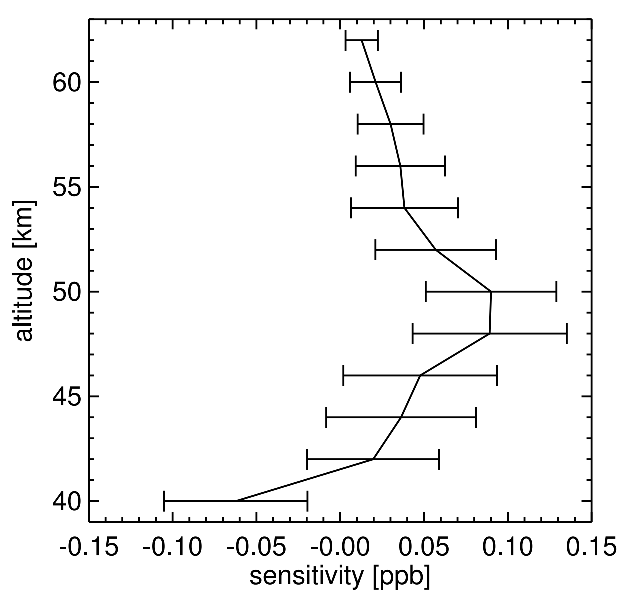

Figure 10: Altitude dependent sensintivity of $\Delta\,NO_2$ on the conditions of epoch type 1 at $65 \pm 5°$ S geomagnetic latitude.