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Atmospheric Chemistry and Physics Discussions

Interactive comment on "NO_x production by lightning in Hector: first airborne measurements during SCOUT-O3/ACTIVE" *by* H. Huntrieser et al.

H. Huntrieser et al.

Heidi.Huntrieser@dlr.de

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We thank Reviewer #2 for the helpful comments to improve our manuscript.

General remarks: The submitted manuscript details measurements of lightning, chemical species (CO, O3, NO, NOy), and meteorological parameters obtained during the Scout-O3/ACTIVE campaign of 2005 with a focus on the Hector thunderstorm observed on 19 November. Analysis of several other thunderstorms is also included. The authors use a variety of airborne observations to estimate production per lightning flash in these storms and then use extrapolation to estimate the global lightning NOx source per year. In addition, several theories regarding differences in production per flash in different thunderstorms are presented. The analysis presented is well done and the topic very important and relevant to ACP readers. However, the paper is very long

and needs to be more cohesively organized. At times the analysis can be difficult to follow in one reading, although after a second reading, most of the methods and ideas are sound. For this reason, I recommend publishing with revisions. I have outlined some suggestions below which could be used to shorten the paper – the authors need not follow these precisely as long as a shorter and clearer presentation is achieved in the revision process.

- The manuscript has been shortened at several places to achieve a clearer presentation. Details are given below and in the answer to Referee #1.

Specific remarks: 1. Section 1 (Introduction) is reasonably concise. I would recommend significantly shortening Sections 2 and 3 (on Hector and other field projects conducted in the area) and adding these to the Introduction. While a large portion of the background on Hector is relevant to the later LNOx analysis, much of Section 3 could be removed with only the most relevant results highlighted. If the results of some of these campaigns are particularly relevant to the results, they could be introduced in later sections as necessary.

- Sect. 3 was cut and replaced by a table which include some of the relevant information. Furthermore, some important parts were moved to the introduction.

2. Section 4 is well written and fairly concise. I think it would be useful to include a few more details on the LINET system in Section 4.3 on p. 14373. Some relevant material is contained in Section 7.1 which would be more helpful if introduced earlier in the paper. Also, the method used to estimate LNOx (Section 4.4) needs to be moved so that it introduces the section on these estimates (Section 6).

- More details on the LINET system concerning the detection efficiency of IC and CG strokes, and the "flash component" length have been added to Sect. 4.3 (partly from Sect. 7.1). The following sentences have been added: "Also the possibility to discriminate between IC and CG strokes decreases with increasing distance from the LINET detection centre. Within the centre region, more than 80% of all strokes can be clearly defined as IC or CG strokes. About 100 km outside the centre region, this fraction decreases down to 30%. At a distance of 200 km from the centre region, no discrimination between IC and CG strokes is possible anymore." "The strokes registered by LINET are VLF/LF sources along a flash. It is however not known, which parts of the flash emit these sources. To obtain some information about the flash length, a small set of single strokes were therefore combined to a "flash component", see Sect. 6.1. A "flash component" is defined as a part of the whole flash and is composed of several strokes (on average 3, however sometimes up to 10) within a certain time period (<1 s) and within a small area (<35 km). The average time period of a flash component was 0.3 s. The distance between the position of the first and last stroke registered within a flash is defined as the length of the "flash component"." Furthermore, Sect. 4.4 has been moved to Sect. 6.

3. Much of Section 5.1 (General meteorological situation) could be removed including Figure 4. Section 5.2 (which provides a lengthy summary of the 19 November flight) could also be reduced in length. For instance, I'm not sure that Figure 6 is necessary because the flight locations and proximity to lightning are more strongly related to the analysis and are given in Figure 9. Some of the sequencing of figures is also difficult to follow. For example, figures 8 and 9 are introduced and discussed before NO and NOy mixing ratios presented in Figure 7. Though interesting, I would suggest cutting the paragraph on CN on p. 14381-2.

- Figure 4 has been removed and the number of references to figures and tables has been reduced in Sect. 5.2, as also suggested by Referee #1. However, Sect. 5.1 and Fig. 6 were left since to our opinion value information would otherwise get lost. The presentation order of Figs. 7, 8 and 9 has now been changed. The short paragraph on CN was also left, since these measurements in the outflow are rare, as already mentioned in the manuscript.

4. Section 6.3 on the contribution of BL-NOx to anvil NOx could likely be reduced in length, especially since the BL was found to fairly clean, and therefore, a minor factor

in determining anvil mixing ratios.

- Section 6.3 (first paragraph) was slightly reduced in length.

5. The estimate of anvil outflow depth (Section 6.4) is somewhat hard to follow and very long. The authors seem to use two terms – main anvil outflow and anvil outflow which have different definitions. This can be unclear and I am not sure how precisely the narrow range of main anvil outflow altitudes can be identified using these methods. I would suggest using a single range and term to describe it. For example, on p. 14390, the range of 10.4-11.8 km for anvil outflow is used on line 14, and on line 16, the range for main anvil outflow of 10.5-11 km is used. Section 6.5 is also hard to follow and I wonder if it is necessary or could be incorporated into other sections. Sections 6.6 and 6.7 are comparatively concise and easy to follow.

- The discussion about the mean depth of the anvil outflow (Sect. 6.4) has been shortened substantially (as also recommended by Referee #1) and replaced by a new table which includes estimates based on the temperature, trace gases, vertical shear from aircraft and the CPOL radar data. It has been added that the main anvil outflow is where the outflow accumulates and the maximum outflow takes place. Section 6.5 was left as it is, since it compares the mean anvil outflow depth with findings from other campaigns and discusses if the selected anvil were penetrated in a comparable and representative way.

6. Lastly, the theories presented in Section 7 are very interesting but I wonder if they might be better explored in a separate short paper. Some of these concepts could be introduced briefly and qualitatively in Section 8 (Summary and conclusions) but investigated in more depth, possibly with the addition of some model simulations, in another manuscript.

- Section 7 was left as it is, since we think that it is important to discuss possible explanations for our observations. As mentioned in Sect. 8 (Summary and conclusions) these hypotheses can first be investigated in detail during future field campaigns or in model simulations.

Paragraphs 1 and 2, p. 14388 – How is the value of 0.13 nmol/mol BL-NOx calculated? Over what altitudes is this applicable (BL, anvil, etc.)? I think the justification given in this section that the BL-NOx contribution to anvil NOx should be fairly small is convincing, but a sentence of two added to describe this calculation in more detail would be helpful.

- It was already described in this section and shown in Fig. 10 how this extrapolation was done and for which altitude, however "down to 1 km" has been added: "On 19 November, the Falcon measurements indicate that the NOx mixing ratio between 5 and 3 km altitude increased from 0.03 to 0.08 nmol mol-1 (Fig. 10)…. Due to the constant CO mixing ratios on average, we use the NOx gradient between 5 and 3 km to estimate NOx in 1 km (BL). The extrapolation down to 1 km is indicated in Fig. 10. It is assumed that the NOx mixing ratio between 5 and 3 km is increasing due to the decreasing age of NOx emissions observed towards the BL. With this method a value of 0.13 nmol mol-1 BL-NOx in 1 km is determined."

Lines 6-10, p. 14390 – Why are the Geophysica wind measurements discussed instead of measurements taken from the Falcon? Is it because these data better indicate the outflow level? I notice a similar vertical pattern evident in the Falcon data though the peak at 10.5 km is much smaller. It might be good to mention this.

- As mentioned in the manuscript already, the Falcon penetrated this thunderstorm at a constant level of 10.7 km (see Table 4 and Fig. 7b). The ascent of the Geophysica from Darwin was performed in the anvil outflow of this thunderstorm (Sect. 5.2). Therefore, more information on the vertical distribution of the anvil outflow is available from the Geophysica (Fig. 13).

Figure 13c and d. Its hard to see the changes in gradient noted. Would it be possible to make this more evident, either by changing the scale on the plots or by indicating where on the profiles these changes occur?

- The change in the gradient is hard to observe in the temperature profile, but better visible in the potential temperature profile (Fig. 13d). The figure size will be increased in the final publication and these altitudes are also listed in a new table.

Technical corrections and comments: Throughout manuscript - Change the phrase 'in large detail' to 'in detail'

- Done.

Throughout manuscript – Remove italics. The points emphasized by italics have generally been made in the text and the italics are not necessary.

- Done in most cases.

Line 23, p. 14364 – Change disproportional to disproportionately

- Done.

Line 3, p. 14365 – Add a few words: ': : :(TROCCINOX) conducted during: : :'

- Done.

Line 8, p. 14370 – This needs to be clarified. In previous sections there is discussion of production of LNOx per flash being weaker in the tropics than in the midlatitude storms due to differences in flash length and shear. I believe that the production indicated in this sentence is due to the concentration of flash rates – is that correct? If so, perhaps the sentence could be changed to ': : :estimate LNOx production rates in the tropics, where lightning flashes occur most frequently' or something of this nature.

- Done.

Lines 22-23, p. 14375 – I think it would be best to remove the sentence beginning 'Up to now: : :' Though the method laid out is certainly reasonable, it is still impossible to know these parameters exactly.

- Done.

Table 3, Table 4 – I think there is an inconsistency between the data given for flight segment 191105_1a_I. In Table 3, the mean stroke rate is given as 0.091 while in Table 4, it is 0.114.

- The correct value is 0.114 (changed in Table 3).

Line 13-14, p. 14387 – Change ': : :was similar low or even lower: : :' to ': : : was as low or even lower than on 16 November : : :'

- Done.

Lines 3-4, p. 14390 – Reaction with fresh lightning NO emissions could also reduce ozone mixing ratios – may want to mention that this could be contributing factor.

- It was added to the manuscript that the reaction with fresh lightning NO emissions may also reduce the ozone mixing ratios. However, in this case, we are quite convinced that the large O3 decrease from 70 to 50 nmol mol-1 in the anvil outflow is mainly due to rapid transport of ozone-poor air masses from the BL (also down to 50 nmol mol-1 observed) and not due to reaction with fresh lightning-NO emissions. Previous thunderstorm simulations with a cloud-resolved model by Ott et al. (JGR, 2007) indicate that the decrease in O3 due to reaction with lightning-NO emissions is more in the range of 5 nmol mol-1 within the lifetime of the storm. In Sect. 6 it was described that the observed O3 and CO mixing ratios in the fresh anvil outflow typically "mirror" the conditions in the BL due to rapid upward transport (Huntrieser et al., 2002) and this is probably the main effect observed in this case.

Line 17, p. 14399 – Insert space between 'more' and 'PLNOx'

- Done.

Line 24, p. 14399 – Change 'closer area' to 'small area'

- Done.