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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.

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We thank Reviewer #1 for the helpful comments to improve our manuscript.

General remarks: The paper reports and analyses in great detail airborne observations of LNOx (Lightning-produced NOx) made in the north of Australia (Darwin area) during a SCOUT field experiment. Here, the 19 Nov. 2005 case study focuses on the anvil outflow of the "Hector" system which has a daily occurrence over the Tiwi Islands. These observations are compared to those of a MCS sampled in the vicinity of Darwin and to those of a more continental subtropical multi-cell thunderstorm case. The study combines mostly NO, NOy, O3 and CO data collected by the Falcon aircraft of the DLR, a series of lightning strokes recorded by the portable LINET network and radar pictures to assist the interpretation of the results.

My first impression is that the paper is well-written but too long and contains too much superfluous details (Section 5.2 and 6.4) with lots of reference to figures and tables. This renders the narration of the paper difficult to follow and also dilutes the major interest of the paper which is to refine estimates of high LNOx production rates in tropical thunderstorms (results are well summarized in Table 4).

- The number of references to figures and tables has been reduced in Sect. 5.2. Furthermore, Sect. 6.4 has been shortened substantially and the main results concerning the anvil outflow depth are instead listed in a new table.

My second remark concerns the choice of the authors to select the observations of a "golden day" in a 1-2 month field campaign (November-December 2005). This is contradictory with the fact that LNOx concentration is highly variable (and poorly predictable) in anvil outflows. So it is frustrating that a larger statistics of LNOx production rate, taken from the whole campaign in the investigated tropical region, is not reported in the study.

- Unfortunately, a larger statistics on the LNOx production rate is not available in this case. The general focus of the airborne measurements during the SCOUT-O3 campaign was on the chemical composition and transport processes in the tropical tropopause layer (TTL), as mentioned in the introduction. The Falcon aircraft was equipped with a lidar instrument and mainly acted as a pathfinder for the surveys made by the Geophysica aircraft in the TTL. Therefore, only few Falcon flights were dedicated to the fresh outflow of LNOx from thunderstorms and this circumstance has been added to the introduction. The selected flight from 19 November was, besides a flight on 16 November, the only Falcon flight targeting the Hector outflow. However, on 16 November the Hector development was not as explosive and extended as on 19 November. The Hector system was comparatively short-lived and small, and the mean NOx mixing ratio in the outflow at 12 km was only 0.5-1.0 nmol mol-1. The outflow was only penetrated twice and it was also more aged with a NO/NOy ratio varying between 0.5-0.6. From the second phase of the ACTIVE campaign, a paper on lightning-produced NOx analysing a case from 22 January 2006 has been become available recently (Labrador et al., 2009). The reference to this paper and its results (mean NOx 0.7-1.0 nmol mol-1 in the Hector outflow) has been added to the introduction and to the reference list: Labrador, L., Vaughan, G., Heyes, W., Waddicor, D., Volz-Thomas, A., Pätz, H.-W., and Höller, H.: Lightning-produced NOx during the Northern Australian monsoon; results from the ACTIVE campaign, Atmos. Chem. Phys. Discuss., 9, 10647-10673, 2009.

The third point to outline is the similarity of the manuscript with a previous paper (referred HH08 in the manuscript) about the TROCCINOX campaign in Brazil as for instance, figure 3 and details of the method to get the LNOx production rate are repeated here.

- Figure 3 has been cut and the reader is referred to Fig. 3 in HH08 for the chart flow.

The central discussion of the paper concerns the estimate of the horizontal LNOx flux (F_LNOx in Eq. 1) and the LNOx production rate per stroke (R_LNOx in Eq. 2) from airborne measurements and from LINET data, respectively. The measured excess of NOx concentration (with an averaged nchi_LNOx value per anvil penetration) can be clearly depicted along the Falcon passes in Fig. 7. However the temporal and the vertical aspects of the NOx variability both sides of the penetrations are not well outlined (sections 6.4 and 6.5).

- Unfortunately, the Falcon aircraft flew through most anvils at constant level (see Table 4). Therefore, vertical profiles covering the whole anvil outflow are not available in most cases from the Falcon flights. However, in the new table added to Sect. 6.4 (estimate of mean anvil outflow depth) information on the vertical NO distribution has been added when available. NO measurements were not available from the ascent (instrument still warming-up) and not above 11.9 km for the Falcon. Therefore, other trace gases, as O3 and CO measured by the Geophysica, were found to be more suitable to estimate the vertical extent of the anvil outflow. Concerning the temporal variability of NO on both sides of the penetrations: In Sect. 5.2 (Flight summary) it was mentioned that

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the NO mixing ratios were distinctly enhanced by a few nmol mol-1 during the anvil penetrations compared to the background (<0.1 nmol mol-1 NO) before and after the penetration.

The discussion about the estimate of the mean depth of the anvil outflow is also difficult to follow. Why not considering the vertical shear (taken from aircraft and CPOL radar data) as a good indicator of the anvil boundaries?

- The discussion about the mean depth of the anvil outflow (Sect. 6.4) has been shortened substantially and replaced by a new table which also includes estimates based on the vertical shear from aircraft and the CPOL radar data.

Finally, I don't find the discussion about the role of the wind shear (section 7.2) very relevant because basically the production of LNOx depends on the capability of thunderstorms to become electrified by non-inductive charge separation process, so something which is physically loosely related to the wind shear.

- It is correct that the production of LNOx depends on the number of flashes in the storm. However, the length of the flashes is also important for the production of LNOx (Wang et al., JGR, 1998). Here we suggest that the wind shear observed in different electrified storms may influence the lengths of flashes and not the number of the flashes (Sect. 7.1). It is known that the wind shear impacts the type of thunderstorm that will develop (Sect. 7.2).

I recommend the manuscript for publication in ACP but with substantial revisions. I suggest the authors to shorten their manuscript, to add results taken from other flights during the whole campaign (if they are available) and to concentrate on the difference between previous estimates of LNOx in tropical areas; e.g. those taken during the TROCCINOX experiment.

- As discussed in detail above and below, the manuscript has been shortened substantially without loosing important information. In addition, on recommendation of Referee

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#2, parts of Sect. 3 (Past field campaigns) were replaced by a table and incorporated into the introduction and Fig. 4 was cut. Moreover, no further measurements have been added since no other suitable Falcon flights are available as discussed above. All results from SCOUT-O3/ACTIVE have already been discussed and compared to results from the TROCCINOX experiment in large detail (Sect. 6-7).

Specific questions and remarks:

1. Section 4.3 (pp. 14373-14374): It is difficult to assess the accuracy of the detection of the IC strokes by the LINET network. Is there any indication that this detection was efficient enough at the scale of the network? How high is the IC/CG ratio in the Hector case?

- The following sentences were added to Sect. 4.3: "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 following sentences were added to Sect. 6.2 (Contribution from observed LINET strokes to measured anvil-NOx and resulting stroke rates): "The IC/CG ratio in the well-developed Hector system was 1.1 and much lower compared to thunderstorm 1a with an IC/CG ratio of 7.3. These ratios are within the range given by Kuleshov et al. (2006) for Australia (0.75-7.7)."

2. Section 6.2 (p. 14384): The references to Skamarock et al. (2003) and Fehr et al.(2004) are not relevant in the context of the present discussion about the dispersion of the LNOx because the model they used contains no explicit lightning flash scheme to produce the LNOx.

- These references have been replaced by Barthe et al. (2007) who used a model with

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an explicit electrical scheme to simulate LNOx.

3. Section 7.1 (pp. 14399-14400): The way the length of a "flash component" is estimated is obscure. It's difficult to figure out which information taken from the LINET network is used. The authors need to give more details. Moreover I find that a mean flash length of a few kilometers (Fig. 20) is very low compared to the large horizontal extension of the investigated storms. The authors should comment this point.

- The following sentences were added to Sect. 7.1, where a detailed definition of the "flash component" is already given: "The distance between the position of the first and last stroke registered within a flash is defined as the length of the "flash component". However, these estimated lengths are much shorter than the total flash lengths in reality, because LINET only registers VLF/LF sources along some parts of the flash and not along the complete flash channel." In future field studies, it would be important to compare measurements with LINET and three-dimensional lightning location systems that determine the total flash length more precisely (e.g. the French ONERA VHF interferometric mapper or the New Mexico Tech Lightning Mapping Array, LMA) to learn more about which parts of the flash are observed by LINET.

4. Section 7.2 (pp. 14401-14402): The discussion about the vertical wind shear is not very useful when restricted to the length of the lightning flashes because lightning flashes are very complex end products of tropical convective clouds. The vertical wind shear is a fundamental environmental component in the development of the deep convection itself, without consideration of lightning characteristics. Modifying the vertical wind shear leads to so many changes in the dynamics, in the microphysics and finally in the cloud electrical state that it is not realistic to interpret with geometrical arguments the sensitivity of the flash length to the wind shear.

- It is correct that the structure of lightning flashes is very complex and individual for every storm. However, it is known that the charged layers in thunderstorms may stretch especially far away in storms related with elevated wind shear, as already described in detail in this section. Both observations of the pathway of VHF lightning sources (e.g. Carey et al., 2005; Dotzek et al., 2005; Ely et al., 2008) and well-known conceptual models of thunderstorms (e.g. Stolzenburg et al., 1994; Wiens et al., 2005) have shown this. This means that the conditions for generating longer flashes are preferable given in storms related with elevated wind shear compared to short-lived tropical storms developing in a low-shear environment. I do not expect to find a one-to-one agreement between the wind shear and the flash length, but I expect to see some differences in the horizontal flash lengths between typical low-shear tropical storms and storms developing in more moderate shear conditions. Besides the wind shear, it is also suggested that other parameters as the horizontal dimension of the anvil outflow and the cell organisation within the thunderstorm system are important factors that may impact the horizontal flash length among many other parameters (mentioned in Sect. 8). In future, analyses of data from the new generation of three-dimensional lightning mapping systems will give more information on typical flash lengths in different types of storms (e.g. Coleman et al., 2008; Kuhlman et al., 2009).

5. Summary (p14406): Huntemann et al. (2009) should be omitted as it is not a published reference.

- Has been cut.

6. I couldn't get a good print of Fig. 16 (letters and numbers are missing) but I could visualize the whole pdf file.

- The problem is probably connected to the used printer. A complete printout of Fig. 16 was possible on all of our printers.

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 14361, 2009.