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Interactive Comment

Interactive comment on "Regional lightning $\mathrm{NO_x}$ sources during the TROCCINOX experiment" *by* C. Mari et al.

C. Mari et al.

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First, we would like to thank the referee for his very constructive interactions and remarks. *(Note: the modification or addition to the initial text are given in italic)*

1 Different approaches for simulating lightning NOx:

We fully agree with both referees that the vertical placement of flashes and the production rates of lightning-NOx per flash are key issues. The sensitivity of the simulation to these parameters is, however, not discussed in this paper. The aim of the paper is indeed different. Our proposed approach is to use the model in its standard version, the same that was used for the forecast of lightning-NOx during the TROCCINOX field campaign in 2004 (http://mesonh.aero.obs-mip.fr/mesonh/troccinox/). Our objective was then to test whether this approach (no-apriori vertical placement) is reasonable or not compared to the measurements. We find that this parameterized approach gives realistic results, we then derive a budget of the convective terms and make a first attempt toward global source estimation. The sensitivity tests with the different proposed approaches are certainly crucial and could be done in a separate paper. However, the exercise has its own limit. As stated by the referee 2, the choice of different flashes rates and production rates can lead to similar results as the numbers can compensate each other. In order to really increase our understanding of the lightning NOx source, and subsequently improve the representation of this source in the models, the comparison with explicit electrical schemes based on explicit microphysics is promising (see for example Zhang et al. (2003) or Barthe et al. (2006)).

2 Lightning flashes measurements

Unfortunately, the measurements of flashes count were not available for this study. As far as we know, simultaneous measurements of lightning NOx and intracloud flashes are rare. Such measurements were made during the EULINOX and STERAO campaigns with the ONERA experimental set (with 50 to 100% uncertainty of the flash count).

3 Extrapolation method

The proposed extrapolation method takes into account the ratio between the horizontal domain size to the size of the continental southern America. We acknowledge that this calculation deserves further explanations. First it is important to note that the model

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domain size is 100 x 100 x 30 x 30 = $9\text{x}10^6\text{km}^2$ and not 100x100x30 = $3\text{x}10^5\text{km}^2$ as stated by the referee. Thus the ratio between the simulated domain and the southern America continent is 9/18 = 1/2 not 1/60. More precisely, the area of the America continent in the southern hemisphere is about $15\text{x}10^6\text{km}^2$, which gives a ratio of 9/15 = 0.6. According to Figure 6 b, the simulated domain concentrates most of the lightning activity of the 90S-Eq, 180W-30W region in DJF and MAM (certainly more than 60 %). So the size ratio should be weighted at a maximum by a factor of 1.6. Thus the two numbers compensate which means that we can assume the number of flashes in the simulated domain to be equal to the number of flashes in the larger domain in early March. Our initial choice was not to complicate too much the calculation on the paper. The corresponding paragraph has been modified as follow: *“ From Christian et al. (2003), a rough estimate of the relative lightning activity occurring over southern America can be derived. From the annual cycle of the global flash rate, it can be estimated that lightning activity in March represents about 8% of the annual global activity (Fig 7a of the cited paper). From Figs 7 and 8 of the cited paper, it can be estimated that lightning activity over the southern America (defined between 90S-Eq and 180W-30W) in March is about 18% of the global activity. The model domain size is about 9/15 of the whole southern America but concentrates more than 60% of the lightning activity (see Fig 6 of the cited paper). Thus the size correction factor is close to 1. ” (...) “ Following the hypothesis rated above, the extrapolation gives a global entrainment rate (...) ”*

The referee proposes an optional method for the extrapolation of the regional LiNOx source based on the regional flash rates compared to global flash rates. The domain integrated number of IC flashes, resp. CG, during the 66 hours period is $2\text{x}10^7$ flashes, resp. $4\text{x}10^6$ flashes. The total domain integrated number of flashes (IC+CG) during the 66h period is thus $2.4\text{x}10^7$ .The division by the size of the domain ($9\text{x}10^6\text{km}^2$) gives 0.04 fl/h/km^2 (0.03 fl/h/km^2 for the IC flashes). These numbers are above the average values found for this region and this period in Christian et al. (2003). It means that the model overestimate the lightning activity over the region which is coherent with

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the overestimation of the LiNOx source values in Tg(N)/year. This also shows the limitation of the exercise: both the production of NO per flash and the domain integrated number of flashes can be high and lead to realistic simulated NOx mixing ratios along the aircraft route. In order to estimate the uncertainties on the different parameters, simultaneous measurements of flashes and NOx are required together with explicit simulations of lightning and microphysics.

The total number of IC flashes, resp. CG flashes, over the simulated domain during the 66h period is $2\text{x}10^7$*, resp.* $4\text{x}10^6$*. The total number of flashes (IC+CG) is thus equal to 0.04 fl/h/*km^2 *which is higher than the average flash rates during March over this region. This hypothesis may contribute to an overestimation of the global LiNOx (...)*

All technical corrections were made according to the referee's advices.

4 Abstract:

The typical lifetime of $\mathrm{NO_x}$ *increases from a few hours in the planetary boundary layer to a few days in the upper troposphere, where it can take part in the formation of* $\mathrm{HNO_3}, \mathrm{HNO_4}$ *and PAN which act as* $\mathrm{NO_x}$ *reservoirs.*

5 Introduction:

The LiNOx source is expected to dominate the southern hemispheric NOx budget in the upper troposphere even at the lower end of the current estimates. *The typical lifetime of* $\mathrm{NO_x}$ *increases from a few hours in the planetary boundary layer to a few days in the upper troposphere, where it can take part in the formation of* $\mathrm{HNO_3}, \mathrm{HNO_4}$ *and PAN which act as* $\mathrm{NO_x}$ *reservoirs.*

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6 Model description:

The typical lifetime of $\mathrm{NO_x}$ *increases from a few hours in the planetary boundary layer to a few days in the upper troposphere, where it can take part in the formation of* $\mathrm{HNO_3}, \mathrm{HNO_4}$ *and PAN which act as* $\mathrm{NO_x}$ *reservoirs.*

The initial and large-scale mixing ratios for chemistry and the meteorological initial and boundary conditions are provided by the MOCAGE (MOdele de Chimie Atmospherique de Grande Echelle) model (Josse et al., 2004; Massart et al., 2005).

A growing electrical field then results from the organization of dipolar, tripolar or even more complex charge structures at storm scale (Rust and MacGorman, 2002; Rust and Marshall, 1996; Stolzenburg, 2002; Barthe et al., 2005).

The model top is at 27 km.

7 Aircraft observations and model analysis

The figure 8 was intentionally limited to 4 ppbv on the y-axis to avoid the NO and NOy time series to be squeezed and therefore unreadable.

Observed NO mixing ratios reached very high values ($>$ *15 ppbv). In Figure* **??***, although the model reproduces the two maxima of convection activity at the beginning and the end of the flight, it cannot capture the very high mixing ratios of NO and* $\mathrm{NO_y}$ *observed during these two periods.*

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8 Regional lightning NOx budget

Unfortunately, there was no flight from the Brasilian Bandeirante in the boundary layer during the simulated period. Observations from this low level aircraft prior to the simulated period show low levels of NO in the boundary layer. Efficient vertical transport from the boundary layer is thus unlikely in this region during the studied period (no surface sources). In addition, from the modeling point of view, the simulated profiles in Fig 10 show that the entrainment below the cloud base is weak. So the NO mixing ratios in the modeled outflow are mainly constrained by lightning rather than transport from the boundary layer.

We would not expect a large difference if NOx instead of NO is transported as the NO-NO2 cycling is rapid and the timestep of the model for the chemistry is short (30s) This work represents a first attempt to deduce a global scale LiNOx budget from a regional scale simulation. To reduce the uncertainties, the parameterized approach has to be compared with explicit electrical schemes at cloud scale (Zhang et al., 2003; Barthe et al., 2006). Further work is needed to reconciliate the different approaches and provide a proper way to extrapolate storm and regional NO_x budgets to global scale.

9 Conclusion:

Exceptions are the very high levels of NO_x *observed in the anvils during flight 10 and which horizontal and temporal scales can not be resolved by the model.*

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10 Figures:

Fig 3: caption changed

Fig 6: Following the recommendation of referee 2, the unit of the total number of simulated intracloud lightning in Fig 6 (bottom) is now in flashes/h/km2. Note that these figures are valid for the inner model domain only.

Fig 10: caption changed

Fig 11: caption changed

11 References:

Barthe, C., JP. Pinty, C. Mari, Lightning-produced NOx in an explicit scheme: a STERAO case study; accepted to JGR, 2006.

Zhang et al., Numerical modeling of lightning-produced NOx using an explicit lightning scheme: 1. Two-dimensional simulation as a proof of concept, JGR, 108(D18), 224, 2003.

Interactive comment on Atmos. Chem. Phys. Discuss., 6, 5197, 2006.