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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Evaluation of a new lightning-produced NO_x parameterization for cloud resolving models and its associated uncertainties" *by* C. Barthe and M. C. Barth

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We would like to thank the referees for their interest in our work and for the helpful comments. The response to the specific comments are below and our manuscript has been revised based on these comments. The referee's comment is italicized and our response is in normal font.

Specific Comments

The LNOx parameterization presented is based on three "unique characteristics"; including a vertical velocity threshold to select lightning-producing cells, a flash rate esti-

mate from the product of non-precipitation and precipitation ice mass fluxes, and a filamentary LNOx source location. The described relationships have already been found and published by other authors and not been developed by the authors of this paper (as you get the impression from the abstract and partly introduction). However, here for the first time these "unique characteristics" are combined in a meaningful way to improve the parameterization of lightning-produced NOx. This should be pointed out more clearly. It is mentioned that Ott et al. (2007) first applied a filamentary LNOx source location in their CRM. How does the LNOx parameterization in the Ott et al. CRM differs from the one described here? How are lightning-producing cells selected and the flash rate determined in their model (same or different methods)?

As far as we know, this is the first time that the lightning-producing convective cells are identified in a LNOx parameterization as well as the total lightning flash rate is deduced by the non-precipitation and non-precipitation ice mass flux product. Only the LNOx distribution in the cloud has been previously used and published.

The only similarity between the Ott et al. (2007) parameterization and our parameterization is the way NO molecules are distributed. In Ott et al. (2007), the NO molecules produced by lightning are produced in the northern and southern cells of the storm. "The areas in which lightning occurred in the northern and southern cells were estimated from plots of observed IC and CG flashes. Areas of approximately this size were centered 10 km downwind of the maximum updraft of the northern and southern cells in the model...". There is no mention of a convective cell identification algorithm that could be used, but rather a specific treatment for this particular storm. In their model, the flash rate is determined from observations.

We have revised the abstract to not mislead the reader.

In the introduction you present the different parameters that you investigate in your simulations as total flash rate, spatial flash distribution, LNOx production per flash and

ACPD

8, S4355–S4362, 2008

so on with references. Here some information about flash length, that you give in Sect. 5.4, should also be added.

Some information about flash length has been added in the introduction.

In Section 5.4 the flash length is discussed (Page 6625). Line 23-25: "The value of 21 km corresponds to the mean flash length simulated when a lognormal distribution for the flash length is used and when short duration flashes are taken into account. The aim of these sensitivity test is to investigate the impact of using a constant or a varying flash length." It is not surprising that both simulations give about the same result since on average both is the same. Instead, it would be important to vary the flash length and to consider the number of flashes with a certain flash length. Is the LNOx contribution from many short flashes ($<$ 1 km) more or less important than the contribution from a few long flashes (e.g. $>$ 30 km)? This would be a very important question to answer.

The reviewer is right: using a constant or a varying flash length is on average the same. But we think it is interesting to investigate if it is necessary to use a “sophisticated" flash length distribution in our LNOx parameterization.

We tested the impact of increasing the constant flash length to 34 km. We found by increasing the flash length value by 62% that the NO increased by 63%. Thus, it is a linear increase and is similar to changing the number of NO molecules produced per meter of flash.

Further, we analyzed the results from the REF simulation to determine the contribution to NO production from long and short flashes. If the same number of NO molecules are produced per meter of flash for all the flashes (as is the case in our simulations), the flashes $>$30 km are r esponsible for nearly 80% of the lightning-produced NO while these longer flashes were only $\sim$30% of the number of flashes. Flashes $<$1 km in length represented 46% of the total number of flashes, but produced only 2% of the lightning-generated NO. However, in our opinion, more observational and theoretical

ACPD

8, S4355–S4362, 2008

Interactive Comment

studies are needed to investigate the contribution of short flashes and spider lightning f or example, or to define (if possible) what a typical IC or CG flash is.

These remarks are now included in the manuscript.

Is it necessary to describe a lot of model chemistry (page 6612, upper half) when you write in line 22-23: "LNOx is transported only and does not undergo any chemical reactions."

The NO, NO_x profiles (Figure 2), distributions (Figures 4 and 5), and transects (Figures 6 and 7) show chemically reactive NO and NO_x, which is more appropriate to compare with observations. Because the first paragraph of p. 6612 is too detailed for a study focused on NO and NO_x, the description of the chemistry has been reduced.

Technical corrections

The suggested technical corrections by the reviewer have been included in the revised manuscript. Comments on some of the points are included here.

Page 6606, Line 27: "Wang and Prinn (2000) tested". What were the results?

Wang and Prinn (2000) did not conclude about the realism of the two estimates of NO_x production per flash. However, they stated that the run using the Franzblau and Popp (1989) values gives very high modeled NO_x mole fraction that is suspect. Further, Salzmann et al. (2008) pointed out that Franzblau and Popp (1989) is unrealistically high compared to other values reported in the literature (note that in the late 1990s there was not much more information available). This information has been added to the revised version of the manuscript.

Page 6607, Line 23 and line 25: "Two of the models" "The four other models". In line

ACPD

8, S4355–S4362, 2008

Interactive Comment

23 you wrote eight models (what about the other two models?).

In this intercomparison exercise, eight models participated, but only six of them had a LNOx parameterization.

Page 6609, line 6: "must exceed 15 m s-1". Who found that (references)? For the U.S.?

There are not many studies investigating a possible updraft velocity threshold for cloud electrification. The Zipser and Lutz (1994) study compared maximum reflectivities with reflectivity lapse rates from storms observed in the central US, oceanic storms near Darwin, Australia, and continental storms near Darwin, Australia. The midlatitude, continental convection always had higher reflectivities implying higher vertical velocities than the tropical oceanic storms. From their study, the midlatitude continental storms should almost always exceed the vertical velocity threshold, while the tropical continental storms straddle the threshold value and the tropical oceanic storms were usually weaker than the threshold vertical velocity value. As seen in Barth et al. (2007), the maximum updraft velocity tends to be overestimated by the models. That is why the initial threshold of Zipser and Lutz (1994) (10-12 m s^{-1}) has been slighlty increased.

Line 7-8: Can U.S. updraft velocities be compared to Australia?

As stated above, Zipser and Lutz (1994) examined US storms as well. The tropical continental convection proved to be the most sensitive to their threshold parameter. Nevertheless, the updraft velocity threshold is only used to find which convective cells in the domain could produce lightning activity. In each individual convective cell, the ice mass flux product is then computed to know how many flashes are produced per cell. In this simulation of the 10 July storm, the lightning activity starts $\sim$ 10 min after "potentially electrified cells" are detected. During the simulation, some of the convective cells match the updraft velocity condition but do not produce lightning since

ACPD

8, S4355–S4362, 2008

their ice mass flux product is too low.

Page 6610, line 8: "(radius 4 km". Reference or how determined?)

We did not find in the literature any dedicated study on the extent of the region where an individual lightning flash propagate. In Ott et al. (2007), the flash length is estimated to be 21.5, 27.9, and 31.4 km from Théry et al. (2000). These values are slightly higher than the mean flash length used in our study which explain why we chose 4 km instead of 5 km in Ott et al. (2007) who estimated the 5 km horizontal extent from the available interferometer data.

Page 6608, Line 20-22: "The flash length – constant or to have a lognormal distribution". Give some range and values as mentioned above.

In this section, our objective is to give some general statements about the LNOx parameterization. The detailed values of the flash length values are given in Section 4.1 for the control experiment and in the following sections for the sensitivity a nalyses.

Page 6617, Line 8: "multicell and transition stage". Why not supercell stage?

Only transects across the anvil during the multicell and the transition stages have been plotted since no data are available for the supercell stage Therefore no comparison between model output and observations is possible at this stage of the storm.

Page, 6617 Line 29: "efficiently transported in the mid- and upper troposphere". Any quantification of the BL-NOx transport to the upper troposphere?

An analysis of the simulated storm (and observations) showed that about 45% of the air in the anvil was entrained (Barth et al., 2007a). We added this information to the paragraph.

ACPD

8, S4355–S4362, 2008

Page 6618, line 1-2: Why reduced?

The chemistry is responsible for reducing BL NOx from 600 pptv to 350 pptv. It has been added in the text.

Page 6627, Line 10: I do not agree for Fig. 7.

The reviewer is correct. At 10 km, NO_SDF is sometimes $>$ REF, while at 50 km NO_SDF $<$ REF. And there are definite differences. It has been modified in the revised manuscript.

Page 6628, line 25: Fig. 7 (right middle panel): Why are the simulated values at the beginning much higher than the observations?

The high NO mixing ratios that the reviewer cites are a result of the placement of the lightning-produced NO source in the sensitivity simulations. Because the NO is placed within the 20 dBZ or everywhere in the cloud, the NO is spread out over a wider region. Note also, that the NO 10 km downwind of the convective cores (left middle panel, Fig. 7) does not have peaks associated with specific convective cells, but instead has plateau-shaped, elevated values (to only 400-800 pmol mol^{-1}). These same values occur (with a similar shape) 50 km downwind of the convective cores (right middle panel, Fig. 7). To summarize, the high NO mixing ratios on the SW side of the transect (Fig 7 - right column) are due to the uniform distribution of the LNOx source in the cloud or the 20 dBZ contour.

Line 3-4: Are the values correct and from where are the values?

The values are correct except for b_{10}. For simulation PROD_CG_2, the a and b factors

ACPD

8, S4355–S4362, 2008

Interactive Comment

used for IC flashes are multiplied by 2 (a_2 = 2 $\times$ 1.7 10^{21} = 3.4 10^{21}, and b_2 = 2 $\times$ 6.5 10^{16} = 13.0 10^{16}). For PROD_CG_10, the a and b factors used for IC flashes are multiplied by 10 (a_{10} = 10 $\times$ 1.7 10^{21} = 1.7 10^{22}, and b_{10} = 10 $\times$ 6.5 10^{16} = 6.5 10^{17}). The value for b_{10} has been corrected.

Page 6633, line 5-8: I do not agree that the LNOx parameterization is not very sensitive to the lightning flash length. Here you would have to add that you investigated the influence of different distributions of the lightning flash length (constant or lognormal).

The reviewer is right. We have investigated the sensitivity of the LNOx source to the flash length distribution and not to the flash length itself. This is corrected in the new manuscript.

Page 6642, Table 2, column 3: What does the three numbers in brackets mean?

In Table 2, column 3, the three numbers in brackets represent the NO peak values for the three different stages (multicell/transition/supercell) of the storm. It is now written in the caption.

Page 6649, Fig. 6-8: The two blue colors used are hard to distinguish. Use cyan blue of pink instead.

There is only one blue color, the other one is purple. We tried to replace purple by pink but it looks like red. So it was decided to keep both the blue and purple colors.