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Atmospheric Chemistry and Physics Discussions

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Interactive Comment

Interactive comment on "Cloud-resolving chemistry simulation of a Hector thunderstorm" *by* K. A. Cummings et al.

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We would like to thank the referee for taking the time to review our paper and for providing beneficial questions and comments. Below we've addressed both general and specific comments provided by the referee.

The description of lightning NOx production by regions, such as midlatitude, subtropical, and tropical, is indicated by the referee as problematic, since it does not express the variability thunderstorms may have within a given region. The research conducted by May and Ballinger (2007) will be used to explore and explain to the reader how thunderstorms that develop over the same area (e.g., tropical northern Australia) cannot be lumped into one specific category of convection.

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Interactive Discussion

Discussion Paper

The question is posed as to whether or not the 10% decrease in moles NO per flash results in NO concentrations that follow a simple linear function. A quick comparison of the average in-cloud NOx in each model layer plotted in Figure 18 for both NO scenarios shows that a 10% decrease in NO production per flash yields about a 10% decrease in mean NOx mixing ratios in the cloud. Thus, this relationship appears to be linear. There is slight spreading in NOx concentrations at the primary and secondary peaks in the vertical profiles, but the shape of the vertical profiles are generally the same for both scenarios. This analysis can be added to the paper for additional information regarding the sensitivity of the simulation to a 10% change in source strength.

The referee indicates that it is unclear as to whether evaluating the model at the true altitude of the measurements would lead to an over or underestimation of NOx and how that would affect the conclusion that 500 moles NO per flash is the best estimate. The simulation showed that by using a tracer species like CO there was a small overestimate of CO at anvil altitudes. This indicates that vertical transport in the model has small errors and that it might not be necessarily correct to focus only on the same altitude to compare observed and modeled trace gases (P16721, L6-11). The referee also points out the confusion that is introduced by discussing the slight differences in the CO mixing ratio statistics for each lightning NO production scenario. Per the referee's suggestion, the results will be discussed for only one of the lightning NOx scenarios (500 moles per flash).

The referee indicated that Section 5.3.2 on NO2 column values is not very convincing and has little relevance in the context of the study. The reason for including an analysis on NO2 column amounts in the paper is to inform the NO2 satellite retrieval community of the NO2 column amounts that might be expected in the outflow from a highly electrified, high NOx production storm. Beirle et al. (2010) note that there is still much uncertainty in observing LNO2 from space, as the LNO2 signal from some thunderstorms is observed by satellites, while other storms show no signal at all. Beirle et al. (2010) mentions the importance of investigating LNO2 signals with satellite observations to identify regional differences in thunderstorm contribution to NO2. We pointed out (P16724, L23) that the LNO2 columns reported in the manuscript represent the maximum values that might be expected for this Hector storm. If NO were enhanced due to enhanced NO2 photolysis in the upper portion of the cloud, the computed LNO2 columns would be slightly smaller. The comparison of background NO2 column values between this study and previous studies, will be removed, per the referee's suggestion, as it provides little in the way of a meaningful conclusion. In addition, the maximum partial NO2 column amounts observed by OMI during the TC4 field campaign (∼45x1014 molecules cm-2) will also be added to P16726, L2 for a better comparison between this study and that of Bucsela et al. (2010).

Specific comments:

P16704, L3: Changed Vaughn to Vaughan.

P16710, L18: The authors agree that the terminology of "tropical thunderstorm" may be confusing to the reader at times. In previous research this term has been used to characterize the air mass a storm developed in, not the geographical location. May and Ballinger (2007) will be referenced in order to make it clear to the reader that Hector storms cannot simply be classified as tropical convection. The findings from May and Ballinger (2007) regarding the difference in convective cells during the monsoon and break/build-up periods in Darwin, Australia, will also be incorporated into the paper as additional support for why a greater variety of thunderstorm types and environmental conditions need to be investigated.

P16710, L19: This sentence was meant to imply that a greater variety of regions would provide a greater variety of storm types and environmental conditions. The sentence will be reworded to make this intention clearer.

Section 2.3: Chemel et al. (2009) will be added as an additional example of a numerical simulation that investigated a Hector thunderstorm during the same SCOUT-O3/ACTIVE field campaign. The information provided in this section will focus on the

ACPD

12, C8132–C8137, 2012

contribution of simulated water vapor from a Hector thunderstorm in the upper troposphere and lower stratosphere.

Section 3: The Hector simulation indicated that the IC flashes were distributed within a broad height range from 12-17 km, with a peak around 13.5 km, which is where the upper mode isotherm (-60°C) is located in the model. Based on LINET observations during the 2005/2006 lightning season, the mean altitude of IC flashes was 12.2 km, which is slightly lower in altitude compared to the placement of the upper mode isotherm in our simulation, but still within the broad height range that IC flashes were distributed. A more in depth analysis of the vertical placement of IC flashes during the 16 November 2005 Hector storm (including detailed LINET analysis) is beyond the scope of this paper.

P16718, L7: For model initialization, an idealized sounding was used where the boundary layer winds were adjusted, so convection would start in the desired location in the simulation. It is possible that this adjustment caused the simulated storm to begin two hours earlier than observed, but despite the difference in storm onset the general features of Hector were still captured by the simulation. The question was also posed as to whether the simple treatment of the surface as being a sensible heat source of 40% of solar flux was appropriate or a cause for the difference in storm initiation. It is possible that the percentage of solar flux was too large and sped up the onset of the storm, but as stated above, the general features of Hector were still captured by the simulation. We focused on sensible rather than latent heat flux, or a combination of the two, based on research conducted by Crook (2001) who tested the sensitivity of convective strength to sensible and latent heat fluxes and found that convective strength is “more sensitive to the sensible heat flux than the latent heat flux.” This is mentioned on P16712, L15-16).

Section 5.1, discussion of Figure 8: Differences in anvil structure can be incorporated into the discussion of Figure 8 with reference to how ice mass concentrations are calculated in the WRF-AqChem model (P16718, L23 to P16719,L1) and discussion of

ACPD

12, C8132–C8137, 2012

hydrometeor sedimentation from work by Chemel et al. (2009).

P16720, L13-14: Changed Tables 2 and 3 to Tables 3 and 4.

P16722, L23: The TUV code does not account for overhead cloudiness. We don't believe that employing a cloud perturbation to the photolysis rates will reduce uncertainty in these rates within the cloud. Clear sky values of j(NO2) are uncertain within ±20% (JPL, 2011). Mie scattering characteristics of ice crystals in the upper portion of the cloud greatly depend on their sizes and shapes, which the model does not predict in detail. Any cloud perturbation employed would only be empirical, and would likely increase the uncertainty above ±20%. The effects of using clear-sky only conditions on photolysis rates, and the resulting chemistry of importance, are likely to be fairly minor in this Hector storm simulation. With the presence of anvil clouds, photolysis rates may be enhanced by multiple reflections off the ice crystals. But since we do not account for this possible enhancement, OH concentrations (from ozone photolysis) may be underestimated and therefore, the loss of NO2 via reaction with OH is slower. In comparison to the lifetime of NOx, which is on the order of several days in the upper troposphere, the length of a thunderstorm is only several hours, so the slowing of the loss of NOx from using clear-sky conditions has only a minor effect on the amount of anvil NOx. Use of clear-sky photolysis may also reduce the NO:NO2 ratio compared with anvil conditions. However, we are concerned with NOx in comparison with observations. Therefore, the partitioning between NO and NO2 does not matter here. With large production of lightning NO and perhaps a greater fraction of NOx as NO, we would also expect increased O3 loss via titration by NO (Figure 20). However, we showed the titration losses to be small (<4 ppbv), and we would expect the possible increase in titration due to enhanced photolysis rates to be even smaller.

Figure 6: Figure 6 has been adjusted to include continental outlines and flight tracks during anvil crossings.

Figure 14: The continental outlines and wind arrows will be made thicker and bolder,

ACPD

12, C8132–C8137, 2012

so they are more visible.

Interactive comment on Atmos. Chem. Phys. Discuss., 12, 16701, 2012.

ACPD

12, C8132–C8137, 2012

Interactive Comment