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Atmospheric Chemistry and Physics Discussions

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 referee questioned to what extent Hector-type thunderstorms are representative of tropical thunderstorms. It is indicated on P16727, L23-28 that Hector and other tropical island convection may create more powerful storms than are typically seen in the tropics and are not representative of tropical thunderstorms in general. The manuscript (P16727, L14-19) also states that lightning NO production in the Hector storm studied is similar to the mean of midlatitude and subtropical events, but the difference in wind speed between 850-200 mb is not as large, indicating that Hector thunderstorms are unique. The investigation of Hector thunderstorms points out the importance of investigating the development of convective cells in a variety of environmental conditions. As shown by Huntrieser et al. (2008, 2009, and 2011), wind shear is a useful parameter for assessing flash length and associated NOx production in different climate regimes. When ice mass, or volume, is not available (e.g. from radar), wind shear can be used as a proxy, since it relates to storm dynamics and updraft size. As lightning activity is physically more related to ice mass aloft, it is also associated with environmental shear, as storms grow larger under stronger shear. The referee also indicates that it is not clear how the Tiwi Islands play a role in driving lightning NOx production. The diurnal evolution of convective activity is described on P16712, L18-27, but more emphasis will be placed on describing the development of the strong low-level forcing of Hector thunderstorms to make it clear to the reader that it is the islands that influence the sea-breeze circulations and gust fronts.

The paper is in the process of being edited to remove portions that contain too much description and discussion, such as the portions of Sections 5.2 and 5.3 suggested by the referee. Also, the referee suggests combining Figures 16 and 17, which will be done to save on space.

Specific comments:

P16715, L4-6: 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 $\pm$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 $\pm$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

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not account for this possible enhancement, OH concentrations (from ozone photolysis) may be underestimated and therefore, the loss of NO_2 via reaction with OH is slower. In comparison to the lifetime of NO_x, 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 NO_x from using clear-sky conditions has only a minor effect on the amount of anvil NO_x. Use of clear-sky photolysis may also reduce the NO:NO_2 ratio compared with anvil conditions. However, we are concerned with NO_x in comparison with observations. Therefore, the partitioning between NO and NO_2 does not matter here. With large production of lightning NO and perhaps a greater fraction of NO_x as NO, we would also expect increased O_3 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.

P16716, L8: Defined CAPE (Convective Available Potential Energy).

P16716, L28-29: 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 evolution 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

P16723, L15-16: It sounds like the referee is asking how the directly observed and

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model-calculated NOx concentrations vary within the two different vertical layers (13.2 – 13.8 for observations and 12.0 – 12.7 for model), but this is not completely clear. If this is what the referee is asking, the comparison between the two vertical model layers and the observations are provided on P16723, L17 to P16724, L4 where we conclude that the "magnitude of the NOx peaks seen in the aircraft data are not reflected in the model results." This indicates that individual grid cells in the model contained smaller peaks in NOx than those in the observations.

P16724, L22: Changed Bierle to Beirle.

P16725, L9-11: Both of the OMI orbits (13:30 LT and 15:00 LT) were checked for a lightning NO2 signal, but none were found. Even if a signal did exist, the edge of the orbit lying above Darwin would be composed of larger pixels and not provide a very useful comparison against the model NO2 column values. Beirle et al. (2010) note that the lightning NO2 signal is seen for some active storms and not others.

Section 5.4: We couldn't perform this analysis without at least acknowledging (1) what was occurring with O3 during the simulation and what we noticed given (2) the sample size of our observations, (3) the location of the observations in relation to the storm cloud and (4) the lack of VOC's in the model. We determined the $\sim$4 ppbv loss of O3 based on a comparison of the vertical cross sections of modeled O3 with and without lightning (Figure 20). Simulations run with lightning produced larger NOx mixing ratios compared to when lightning was not turned on in the model (Figures 12 and 13). This suggests that lightning NOx had a role in O3 titration within the cloud. This effect has also been noted in previous research, such as Wang and Prinn (2000) and Ott et al. (2007). Hand calculations showed O3 loss due to NO was larger than 4 ppbv in the upper half of the anvil cloud, but processes included in the model, such as mixing within the cloud, were most likely responsible for lowering the amount of O3 loss. The referee also pointed out the importance of determining how much O3 is produced by a thunderstorm. Our simulation did not run past the end of the storm. Therefore, we do not know how much O3 was produced downwind as a result of this Hector storm.

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Therefore, we can only provide the start of an answer concerning the overall impact of this storm on O_3.

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