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Atmospheric Chemistry and Physics
Discussions

Interactive comment on "An investigation of how radiation may cause accelerated rates of tropical cyclogenesis and diurnal cycles of convective activity" *by* M. E. Nicholls

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1. Thank you for pointing out these older studies, which I think should be referenced in the manuscript.

2. This study examines the effect of radiation on the development of a tropical disturbance into a tropical cyclone, and so the evolution and the role of radiation are probably not too different than a typical cloud cluster, at least in the early stages. There is quite a significant initial circulation present for the cases simulated in this investigation, which has maximum winds of 8 m s-1 at a height of 4 km. With time the system developed a

considerably stronger mid-level circulation and denser stratiform layer prior to genesis than are likely to be found in the type of cloud clusters studied by Gray and Jacobson (1977). I don't think the fundamental process of "differential heating" proposed by Gray and Jacobson (1977) is likely to be different, but its magnitude and impact due to the presence of a strong mid-level circulation could be different. The second part of this comment brings up some important points. The way I am thinking of the difference between large scale cooling (or clear-sky cooling) and differential heating is to consider two extremes: First, if there is an idealized horizontally uniform atmosphere and horizontally uniform infrared cooling then clearly there is no differential radiative forcing. In this situation, which is easy to simulate in a model, the infrared cooling leads to an increase of relative humidity. At some point saturation might even occur in a layer and a cloud layer form. Tao et al. (1996) ran experiments for both the EMEX and PRE-STORM cases where they included 6h of longwave cooling to the initial sounding prior to triggering convection (Page 2641 of their paper). Results indicated that the increased relative humidity had a strong positive influence on surface rainfall production for both cases. Also, in this paper Experiment 22 that had horizontally uniform cooling prescribed beneath 10 km showed a much faster rate of development than the case without radiation. There is little doubt that the increase of humidity due to large scale cooling can enhance convection and the development of a cloud cluster. The second extreme is when there exists a thick symmetrical stratiform cloud canopy that results in large horizontal gradients in radiative forcing at night. This produces a secondary circulation, or a contribution to the secondary circulation produced primarily by latent heating in convective cells. The strength of this radiatively induced secondary circulation is weak when it begins. For instance, for the idealized simulation shown at 50 minutes shown in Fig. 1d the maximum inflow velocity is about 0.1 m s-1 at the surface. However, by 12 h shown in Fig. 2e it has increased to about 0.9 m s-1. For the full physics non-radiation case, at 24 h the inflow at the surface is about 1.5 m s-1 (not shown), which is due to both the convective upward mass flux in cells generating a system scale low level inflow and surface friction generating low level convergence.

Therefore, the inclusion of radiation can be expected to contribute a significant fraction to the low-level inflow. The contribution to the secondary circulation caused by the radiation will also influence the convective mass flux in the system core, since it is going to enhance the triggering of cells and reduce the detrimental effect of entrainment at mid levels as relative humidity is increased. Clear-sky longwave cooling is going to occur in the environment, so for this second extreme case it is not easy to clearly separate the effects due to large scale cooling from the effects due to differential radiative forcing. The clear sky cooling leads to an increase in humidity in the environment. Close to the stratiform canopy the compensating subsidence of the radiatively induced secondary circulation will counter this to some extent since drier air from aloft will be advected downwards. This compensating subsidence is strongest in the near-environment and propagates in a wave like manner. Another consideration is that because vertical velocity goes to zero at the surface the compensating subsidence has limited impact on the near-surface air. Now the environmental low-level air, which has higher relative humidity due to clear sky cooling, might help promote convective activity as it is converged into the forming TC circulation. However, I doubt that this is a dominant effect. I think if somehow there were no increase in humidity in the environment the deep sustained upward motion in the system core produced by the differential radiative forcing would still enhance convective activity. Moreover, there would still be low-level moisture convergence; the inflow air would just not be as cold, and therefore not as humid. It becomes even more difficult to separate the "differential radiative heating" mechanism and "large scale cooling" when there is scattered cloud cover produced by deep convection. I think the bottom line here is that the idealized experiments suggest that the contribution to the secondary circulation caused by horizontal gradients in radiative forcing when there is a dense cloud canopy present results in a significant impact on the convection. Therefore, it is important to understand the role of these circulations generated by differential heating, as proposed by Gray and Jacobson (1977), in order to obtain a complete picture of the effects of radiation on tropical cyclones.

3. The Harrington radiation scheme allows radiation to respond to variations in hy-

drometeor size spectra both for liquid and ice. So the microphysics and the radiation scheme do explicitly interact. The simulations in this study use a bulk two-moment microphysics scheme. There are limitations to using a bulk scheme as far as radiation interaction is concerned. For instance, a bin scheme allows the drop-ice distribution functions to evolve more freely than a bulk microphysical scheme. This increased accuracy however comes at much more computational expense (Harrington 1999).

4. The total hydrometeor mass was shifted earlier by about 6 hours for Experiment 17 that had steady cooling in the environment compared to Experiment 13 (radiation everywhere) and Experiment 15 (radiation only in the environment). Maybe the colors in the figure could be improved to be more distinctive. So even without the diurnal cycle of radiative forcing the simulation with steady environmental forcing still produced significant pulses in convective activity. However, they were not as large as the very significant pulse in activity that occurred at 46 hours for Experiments 13 and 15. This occurred shortly after daybreak and is almost certainly locked in with the radiative forcing. Nicholls and Montgomery (2013) also show oscillations of the total hydrometeor mass for a larger initial vortex case in Fig. 11 of that paper that look diurnal. The oscillations in Experiment 17 may have been associated with the spreading of cold downdraft air at the surface and the subsequent time for CAPE to recover.

5. I think the wording "a few days" may be a bit ambiguous in line 12 of page 6153 and should be changed to make the meaning clearer. What is meant that over the three-day period shown in Fig. 8 there is hardly any time lag between the temperature changes at mid levels in the unforced center and in the forced environment. I believe that there is only a small lag because the deep mode travels very fast and that any modulations of the environmental forcing consequently produce almost immediate effects within the unforced core.

6. I believe the outward propagating diurnal pulses described by Dunion are considerably slower moving (about 10 m s-1) than the two fastest moving thermally generated gravity wave modes discussed in this paper. Interestingly, there was some indication of

a ring of anomalously cold air forming at a radius of 200 km just below the tropopause for Experiment 13 (the radiation case) at 87 hours, probably associated with the peak in the total hydrometeor mass at 81 hours seen in Fig. 23b. However, it had a slow propagation speed of only 4-5 m s-1.

Adding experiment numbers to legends in Figures 23 and 25 is a good idea.

Interactive comment on Atmos. Chem. Phys. Discuss., 15, 6125, 2015.