4th European Conference on Severe Storms 10 - 14 September 2007 - Trieste - ITALY

POSSIBILITIES AND LIMITATIONS OF CONCEPTS TO MODIFY HURRICANES BY CLOUD SEEDING WITH SUB-MICRON HYGROSCOPIC AEROSOLS

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(Dated: April 30, 2007)

I. INTRODUCTION

An experiment to reduce hurricane intensity by seeding its clouds with large concentrations of submicron cloud condensation nuclei was computer-simulated for hurricane Katrina. The seeding is aimed at suppressing the low-level warm rain. Evaporation of some of the extra unprecipitated cloud water cools and moistens the air below the freezing level and weakens the overall intensity of the TC as manifested by decreasing area covered by hurricane force winds. The cooling also drives the low level air closer to the center before it rises. This leads to contraction of the eye and a respective enhancement in the peak winds at the eyewall. The simulated effect on Katrina was decreasing almost to half the area covered by hurricane force winds while not changing much the peak winds at the smaller diameter eyewall. This is a shortened version of Rosenfeld et al. (2007)

II. CCN SEEDING FOR DELAYING RAINOUT

We hypothesize that an alternative approach for tropical cyclone (TC) mitigation may be the prevention of the early loss of cloud water by seeding the air that is ingested into the cloud bases with large concentrations (1000-2000 cm^{-3}) of small (0.1 to 0.2 μm diameter) cloud condensation nuclei (CCN). Such seeding is practical at the storm scale by dispersing hygroscopic smoke from 5 to 10 airplanes such as C-130 aircraft flying in the boundary layer just outside the TC spiral cloud bands so that the particles would be drawn into the storm by the low level convergence. This would delay the onset of precipitation until after the cloud water ascends to heights where freezing can occur. This additional latent heat of condensation and freezing should invigorate the convection at the TC periphery. Such a hypothesis is consistent with the observed suppressed raindrop formation in the lower parts of smoky clouds in the Amazon (Andreae et al., 2004). Simulations show that such delay of precipitation to greater heights indeed invigorates tropical convection (Khain et al., 2005; Van den Heever et al., 2006).

III. SIMULATED SEEDING EXPERIMENTS

The simulations in this study are aimed to test this hypothesis and gain physical insights to the way suppression of warm rain can weaken hurricanes. We used a two nested grid Weather Research Model (WRF) with 3 km resolution in its finest grid with the bulk-parameterization according to Thompson et al. (2004), and without two ways coupling to sea surface temperature. The evolution of hurricane Katrina during 27-29 Aug. 2005 was simulated. Results of several simulations have been compared. The natural or control run allowed for warm rain (WR) formation by drop-drop collisions. In two other runs the effect of small aerosols penetrating under natural conditions or as a result of cloud seeding with small CCN was simulated. Since small aerosols lead to the formation of a great number of small droplets with very low ability to form raindrops, the aerosol effects in "seeding" runs were parameterized by shutting off the drop-drop collisions. In the second simulation named "No Warm Rain" (NWR) the warm rain formation was shut off over the entire TC area. The NWR represents the “reference” simulation carried out under idealized conditions, which hardly can be realized in hurricanes, because wind driven sea spray particles serve as giant CCN (> 1 μm diameter) that initiate early rain even when large concentrations of small CCN exist (Woodcock, 1953) and overwhelm the seeding effect.

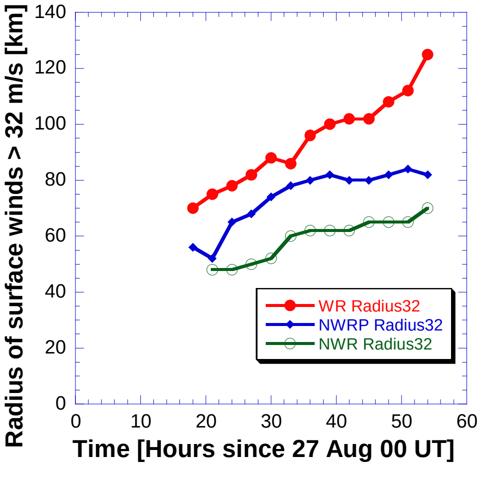

Figure 1: Suppression of warm rain causes low level cooling that causes weakening the storm as measured by area covered with hurricane force winds, more so for the greater extent of suppression of warm rain. WR is warm rain everywhere; NWRP is no warm rain in the periphery. NWR is no warm rain everywhere.

The motivation for the third simulation named No Warm Rain at the Periphery (NWRP) was to test whether the rain acceleration effect of the sea spray in the areas with strong winds would still leave some room for reduction of storm intensity when the small CCN are added in regions where sea spray is not a major consideration. Consequently, the shutting off of warm rain was performed only at the TC periphery, where the surface wind was smaller than 22 ms^{-1}. This threshold is near the lower bound of Beaufort 9 wind, which is defined at sea by "spray may affect visibility".

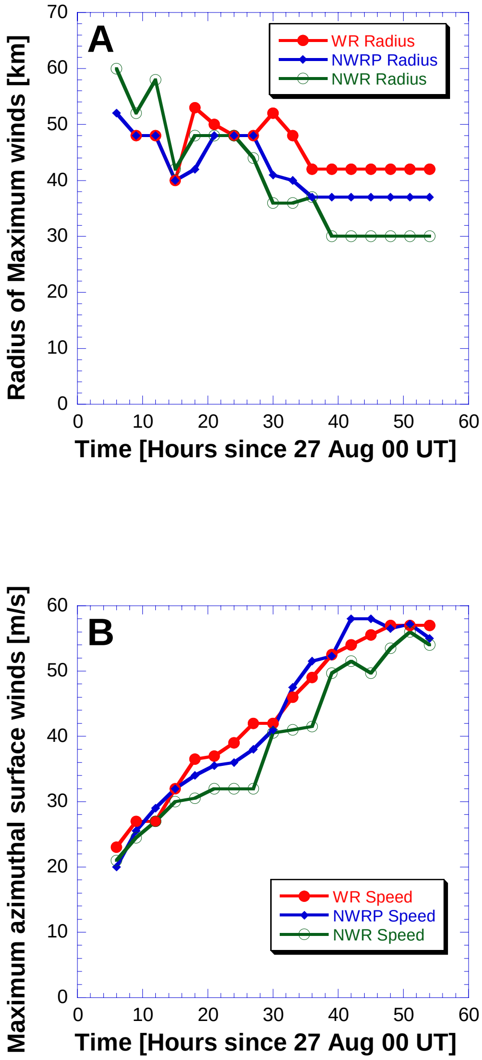

Figure 2: Suppression of warm rain causes low level cooling that causes less buoyant air that converges closer to the storm center before ascending and forming the eyewall. Panel A shows the smaller radius of the eye for greater extent of suppression of warm rain. Panel B shows that the peak azimuthal winds at the NWRP are similar to the WR due to the smaller eye. For the NWR case the overall reduction of the hurricane intensity dominates the intensification effect due to the contracting of the eye.

IV. INTERPRETATION OF THE RESULTS

The initial result of suppression of warm rain is warming at the upper levels due to the added release of latent heat of freezing and enhancing the updrafts aloft, coupled with low level melting and evaporative cooling. However, about 12 hours after the initial "seeding" (i.e., suppression of warm rain), the upper level warming became limited to a shallow layer above the freezing level and the enhanced updrafts aloft vanish in the NWRP and NWR runs. Yet, the low level cooling remains at least as strong. The enhanced low level relative humidity implies that this low level cooling occurs due to greater low level evaporation of cloud water that was not precipitated. This means a net loss of condensation latent heating, which leads to less buoyant lower tropospheric air and weakening the overall intensity of the hurricane (Fig. 1). The potential temperature does not change in the process of evaporation of cloud water. Therefore, this cooler air can still rise in deep convection, especially when initially forced upward at the eye wall. Based on these considerations, it is suggested here that the continuous cooling at the TC periphery, especially in the TC lowest 3 km, leads to compaction of the TC circulation which can be attributed to the lesser tendency of the more stable low level air to rise before reaching the circulation center (see Fig. 2A). This idea is also supported by the simulation results of Nong and Emanuel (2003), who showed that low level air with enhanced buoyancy tends to rise before reaching the eyewall and initiate the process of an eyewall replacement with a larger eye.

V. CONCLUSIONS

In the simulated case the wind speed was decreased by seeding during the whole period of simulations at radial distances r >40 km (i.e over the huge area exterior to the eye wall). The low level cooling causes also a contraction of the eye and hence the relative intensification of the eyewall winds, occasionally even matching or exceeding the peak wind intensity of the control simulation (see Fig. 2). Storm surge is caused by the mean wind over large areas and not by the maximum wind over very small zones. Therefore, even in the cases when peak winds at the eyewall are not reduced, if the seeding leads to a decrease of wind speed over most of the area of hurricane-force winds and decreasing its areal extent (see Fig. 1), it would be an important result.

VI. ACKNOWLEDGEMENTS

This study was supported by the European Community–New and Emerging Science and Technologies [Contract No. 12444 (NEST)–ANTISTORM].

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