Should We Consider Polluting Hurricanes to Reduce Their Intensity?

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Abstract

An overview of simulations of hurricane response to African dust is presented. Those simulations suggest that under some conditions storm intensity might be reduced if large concentrations of small hygroscopic particles are present at the time the storms develop. Based on those results, it is proposed that seeding hurricanes with small hygroscopic particles can reduce hurricane intensity and damage, but future research is needed to determine the range of conditions under which such seeding may be effective and to determine whether such seeding is practically viable. Recommendations for a research program to further investigate the feasibility of such a procedure are provided.

1. INTRODUCTION

The first attempt at modifying a tropical cyclone or hurricane occurred during Project Cirrus in 1947. Because of the extensive damage produced by hurricanes, interest in developing an economical technique to modify hurricanes developed to a high level. For example Gentry (1974) stated: "For scientists concerned with weather modification, hurricanes are the largest and wildest game in the atmospheric preserve. Moreover, there are urgent reasons for 'hunting' and taming them." Therefore, in 1962, a joint project between the U.S. Weather Bureau and the U.S. Navy called Project STORMFURY was created. The original STORMFURY hypothesis was first advanced by Simpson et al. (1963) and Simpson and Malkus (1964). They proposed that the additional latent heat released by seeding the supercooled water present in the eyewall cloud would produce a hydrostatic pressure drop that would modestly reduce the surface pressure gradient and as a consequence the maximum wind speed.

The original hypothesis was subsequently modified following a series of numerical hurricane simulations (Gentry 1974). Those numerical experiments suggested that application of the individual cloud dynamic seeding hypothesis to towering cumuli immediately outward of the eyewall would cause enhanced vertical development of the towering cumuli and removal of low-level moisture from the boundary layer immediately beneath them. The loss of moisture outward from the eyewall would starve the clouds of moisture in the eyewall region, causing a shift in the eyewall convection outward to greater radii. Like ice skaters extending their arms, the storm should rotate slower and the winds diminish appreciably.

For nearly a decade STORMFURY performed seeding experiments in an attempt to reduce the intensity of hurricanes. Only a few storms were actually seeded, however, due to the fact the hurricanes are a relatively infrequent phenomena and the experiment was constrained to operate in a limited region of the north Atlantic well away from land. Some encouraging results were obtained from seeding Hurricane Debbie in 1969 with 30% and 15% reductions in wind speeds following seeding on two days separated by a no-seed day. This led to greatly expanded field programs for a few years but the program was eventually curtailed in the late 1970's with no definitive results. The conclusions of the project were summarized in Sheets (1981). However, as concluded by Willoughby et al. (1985) observations in hurricanes indicate that they contain too little supercooled liquid water and too much ice in the convective cores for seeding to be effective. In this paper we propose a new concept for hurricane intensity reduction based on recent simulations of the affects of African dust on simulated hurricane intensity as described by Zhang et al. (2007).

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2. BRIEF SUMMARY OF THE ZHANG ET AL. (2007) SIMULATIONS

The simulations reported by Zhang et al. (2007) are designed to examine the impact of desert dust particles in the Saharan air layer (SAL) on the intensity of tropical cyclones. Using satellite data, Dunion and Velden (2004) concluded that the SAL tends to suppress hurricane activity by introducing hot and dry air into the storm and by increasing vertical wind shear. They view the principal action of dust to directly warm the SAL by absorbing solar radiation (i.e., the so-called aerosol direct effect). Zhang et al., on the other hand, examine the indirect effects of dust acting as cloud condensation nuclei (CCN). Ongoing research is also examining the influence of giant CCN (GCCN) and ice nuclei (IN). A recent paper by van den Heever et al. (2006) summarized CCN, GCCN, and IN concentrations observed during the 2002 CRYSTAL-FACE field campaign during an African dust event as well as on non-dusty days. They found that African dust increases the concentrations of CCN, GCCN, and IN. Their simulations of Florida thunderstorms revealed that African dust alters the dynamics of Florida thunderstorms and rainfall appreciably.

Based on the results of van den Heever et al. (2006), Zhang et al. (2007) anticipated that dust serving as CCN, GCCN, and IN would impact hurricane intensity as well. The model used by Zhang et al. (2007) was the Regional Atmospheric Modeling System (RAMS) version 4.3 as described by Cotton et al. (2003). It was initialized with an axis-symmetric mesoscale convective vortex using an algorithm developed by Montgomery et al. (2006). The microphysics used in the study was the two-moment bin-emulating bulk microphysics scheme described by Saleeby and Cotton (2004). This included explicit nucleation, transport, and sinks of dust serving as CCN, GCCN, and IN similar to van den Heever et al. (2006). RAMS was set up with three domains with the finest horizontal grid spacing at 2 km. A horizontally uniform sea surface temperature of 29^{o}C was imposed. The sounding used to initialize the model was the mean Atlantic hurricane season Jordan sounding, and there were no initial horizontal environmental winds. The simulations were carried out for a period of 72 hours.

The initial CCN concentration was varied from 100, 1000, to 2000 cm^{-3} between 1 and 5 km where dust is typically found. Figure 1 illustrates the initial dust profiles.

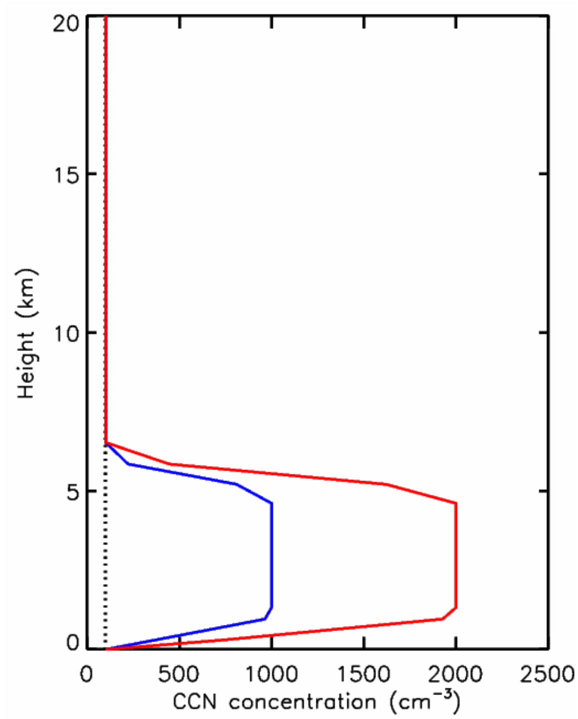

Figure 1. Vertical profiles of initial dust concentrations acting as CCN. Dashed curve is the clean profile, blue the profile for 1000 cm^{-3}, red is for 2000 cm^{-3}.

For full details of the simulation results the reader is referred to Zhang et al. (2007). Here we will focus on simulated minimum sea level pressure (SLP), and maximum surface wind speeds shown in Fig. 2. Note that as CCN concentrations increase, the SLP monotonically decreases with the difference between the heavily polluted case (2000 cm^{-3}) and clean case (100 cm^{-3}) almost 25 hPa and corresponding differences in maximum surface wind speeds almost 25 m s^{-1} or 50 knots! These differences would result in major reductions in storm damage. Note that the total precipitation reaching the ground during the 72 hours are 1.38, 1.46 and 1.44 $\times$ 10^{10} m^{3} for “Clean”, “Polluted” and “Double” cases, respectively. The difference between simulations is less than 5%.

Preliminary results for simulations in which GCCN and IN concentrations were varied similar to van den Heever et al. (2006) suggest much smaller maximum differences in minimum SLP for

GCCN (less than 15 hPa). Moreover, the storm intensity does not change monotonically with GCCN concentrations. If further simulations with varying vertical resolutions, meteorological conditions and other initial and boundary conditions confirm these trends, the results would suggest that application of standard hygroscopic seeding techniques to hurricanes might not be advisable. The simulations with varying IN concentrations had little consistent influence on simulated storm intensity. Note that these IN concentrations are not small as the observed IN concentrations in the dust event reported by DeMott et al. (2003) were the highest natural values ever measured with the continuous flow diffusion chamber (DeMott 2006, personal communication). Thus, contrary to the original STORMFURY hypothesis, ice nuclei seeding would have a small effect.

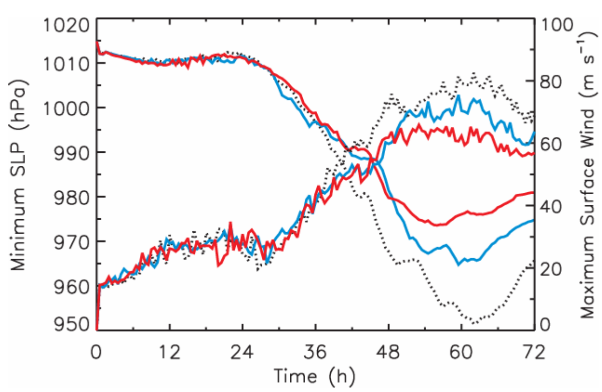

Figure 2. Simulated storm minimum sea level pressure and maximum surface wind speed for the clean (dotted), 1000 cm^{-3} (blue) and 2000 cm^{-3} (red) CCN initial profiles.

3. PROPOSED METHOD FOR SEEDING HURRICANES TO REDUCE STORM INTENSITY

The results of this modeling study suggests that seeding with small hygroscopic particles, probably less than 0.1 μm in diameter, might result in significant reduction in storm intensity, with concomitant reductions in storm wind damage and storm surge damage. Some important questions are: 1) Can a method of producing high volumes of CCN that can be delivered by aircraft such as a P-3 or C-130 be developed? (2) Can pyrotechnic hygroscopic seeding devices such as used by Mather et al. (1996) be modified to produce primarily small CCN particles rather than the larger sizes intended in hygroscopic seeding experiments? (3) Or, can some other type of high volume small hygroscopic seeding generator be developed? (4) Can multiple large aircraft produce a large enough volume pollution plume for long enough duration to cause significant reduction in storm intensity? (5) Will simulations of actual storms yield as strong a response to varying CCN concentrations as found in some of these idealized simulations, or will non-monotonic changes in storm intensity with increasing CCN concentrations be seen?

It should be noted that the Zhang et al. simulations were designed to simulate the response of a tropical cyclone to dust that is widespread through a layer in which a developing storm is embedded. This is quite different from localized insertion of seeding material in a storm when the storm is approaching land-fall in its mature stage. We expect that the response would be less in the case of an actual airborne seeding operation in part, because a much reduced volume of material would be seeded in the storm. Moreover, during the process of developing the Zhang et al simulations, the particular response to aerosols was quite sensitive to model configurations, in particular, the vertical grid spacing. Thus, a more complete ensemble of simulations of this type is needed with other investigators using other models and for different storm systems. Nonetheless, these simulations suggest that a hurricane is sufficiently sensitive to varying small CCN concentrations that more extensive investigations are warranted.

4. RECOMMENDATIONS

Based on these limited simulations, it is recommended that a federally funded research program be established to investigate the potential for decreasing hurricane wind damage through the application of small aerosol hygroscopic seeding. Such a program should include:

- The development of generators or flares which produce high volumes of small hygroscopic aerosol.
- Additional simulations in which actual aircraft flights are emulated releasing small CCN into idealized storms.
- Further seeding simulations for actual storms like Katrina.

- As noted in the above, simulations by independent modeling groups using different models and different model setups and different initial conditions and cases are strongly advised.
- Exploratory physical field experiments in which small-aerosol CCN seeding is performed in hurricanes well-removed from land-fall to examine if the predicted changes in precipitation, vertical velocity, along with storm intensity can be actually achieved. This proposed research could be done as a focused sub-program within the context of the proposed National Hurricane Initiative (NSB, 2007).

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