CORRESPONDENCE

Comments on "Downdrafts as Linkages in Dynamic Cumulus Seeding Effects"[1]

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The paper by Simpson (1980) addresses one of the most crucial research areas within the Florida Area Cumulus Experiment (FACE), namely, the mechanism of communication of the buoyancy pulse from the seeding level down to the boundary layer. Simpson hypothesizes that downdrafts may be the main communication mechanism from data assimilated from various research areas. Both observational and numerical models were used by Simpson to address this problem.

Recent research results within FACE indicate that another mechanism, namely the hydrostatic and nonhydrostatic pressure response within the boundary layer to developing convection overhead, may be equally as important as the downdraft mechanism. Findings from a case study analysis for 25 August 1975 show that as a convective system was in the rapid development stage, prior to the occurrence of downdrafts at the surface, the surface pressure decreased below the convection which increased the boundary-layer inflow into the storm. This rapid development was not just vertical development referred to by FACE scientists as Phase 1 development, but also horizontal development of the system (Fig. 1). As the three main convective towers A, B, and C were actively rising, with rise rates of $\sim$6–15 $\mathrm{ms^{-1}}$ (from photogrametric measurements, Fig. 2a), the surface pressure perturbation (Fig. 2b), derived by subtracting the station pressure from a 1 h running mean, decreased below the developing towers with a maximum pressure deficit of 0.35 hPa. This maximum deficit occurred at 1436 EDT during the rapid development of towers A and B, with the perturbation pressure remaining low after this time in response to the continued convective development. The surface convergence field responded to the pressure field with the grid-point maximum of convergence below the developing storm increasing from $6.8 \times 10^{-4}\ \mathrm{s^{-1}}$ at 1430 EDT to $1.5 \times 10^{-3}\ \mathrm{s^{-1}}$ at 1447 EDT (Fig. 2c). The maximum convergence occurred $\sim$10 min after the maximum pressure deficit. (Convergence was derived from an array of wind measuring stations within a mesonetwork with a station spacing of 6.4 km). This increased surface convergence appeared to initiate additional tower growth and development which transformed the convection into a long-lasting cumulonimbus system.

The increased cloud growth and development can be seen in the cloud mass calculations (Fig. 3).[2] The total mass of air occupied by the radar echo nearly quadruples between 1430 and 1450 EDT. This is accomplished not only by vertical growth of the towers but by horizontal expansion of the cloud as well. A chronology of the development of the cumulonimbus system provided in Fig. 4 shows that the development of towers A, B, and C and the broadening and additional tower growth all occur prior to the arrival of downdraft air on the surface which is indicated by the first occurrence of precipitation and divergence, at approximately 1448 EDT.

From this case study it appears that the rapid growth of the convective towers induced a surface low pressure by hydrostatic and/or nonhydrostatic means. The surface convergence increased in

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[1] A portion of this research was completed while the authors were at the National Hurricane Research Laboratory, NOAA, Coral Gables, FL 33146.

[2] The cloud mass was calculated for each 600 m layer throughout the cloud using the reflectivity data from one of the C-band Doppler radars operated within the mesonetwork and from the 1400 EDT field sounding which was taken in the near vicinity to the case study cloud. The reflectivity data, with a horizontal and vertical resolution of 600 m, was used to determine the cloud area for each layer and the sounding was used to determine the mean density for each layer.

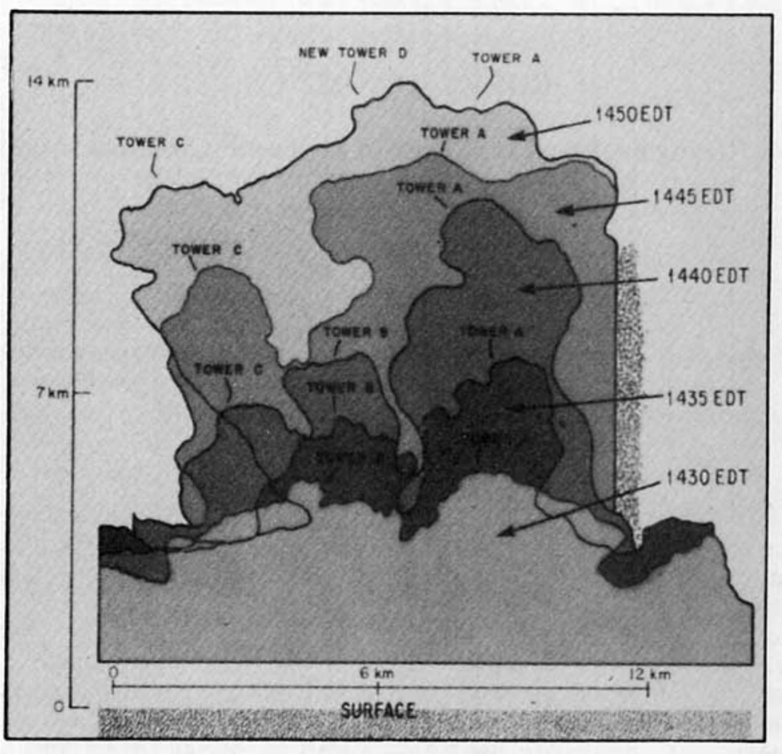

FIG. 1. Vertical and horizontal development of the case study convective system derived from time lapse photography from 1430 to 1450 EDT. (Note—right side of tower A is advected out of the field of view of the time-lapse camera.)

response to the low pressure, which resulted in increased convective growth and development prior to the development of downdrafts on the surface. This is one instance then in which vertical cloud growth and expansion occurred without the benefit of downdrafts, and additional case studies not discussed here appear to support these basic findings.

Results from numerical modeling efforts also appear to verify these findings, particularly the pressure responses below developing convection. Schlesinger (1980), analyzed the dynamics of an isolated convective storm embedded within vertical wind shear as simulated by a three-dimensional anelastic numerical model. He showed that updraft parcels are accelerated upward from below cloud base, first by pressure gradient forces and then by thermal buoyancy. He then decomposed the pressure force into three components, the hydrostatic, dynamic and drag-induced parts, and showed that the low pressure below the convection is induced by hydrostatic and dynamic effects. Tripoli and Cotton (1980) used a fully compressible, three-dimensional model to investigate convective storm variability within the Florida environment. They found that when they intensified the boundary-layer convergence below the cloud, the resulting stronger updraft and released latent heat produced surface pressure deficits which, if strong enough, diverted the boundary-layer flow and downdraft flow into the low-pressure region. This increased the surface convergence which fed back into the convection and developed a longer lasting storm. They also stated that in a low-shear environment, typical of Florida, the resultant convective activity and precipitation is dependent on the magnitude of the surface convergence.

A point that has not been mentioned is that the towers, illustrated in Fig. 1, which induced the surface low pressure in the case study were extensively seeded to induce a dynamic change in their updraft structure. We hypothesize in this comment that any additional acceleration and warming within the updraft that resulted from seeding caused larger surface pressure deficits than those that would have occurred naturally. Larger surface convergences induced by the larger amplitude pressure perturbations gave rise to more intense convective towers which then fed back to the boundary layer.

The hypothesized surface pressure response can be considered as a first-order response to seeding in that it basically occurs simultaneously with the microphysical changes induced by the seeding. The downdraft response discussed by Simpson is more a second-order response, in that additional entrain-

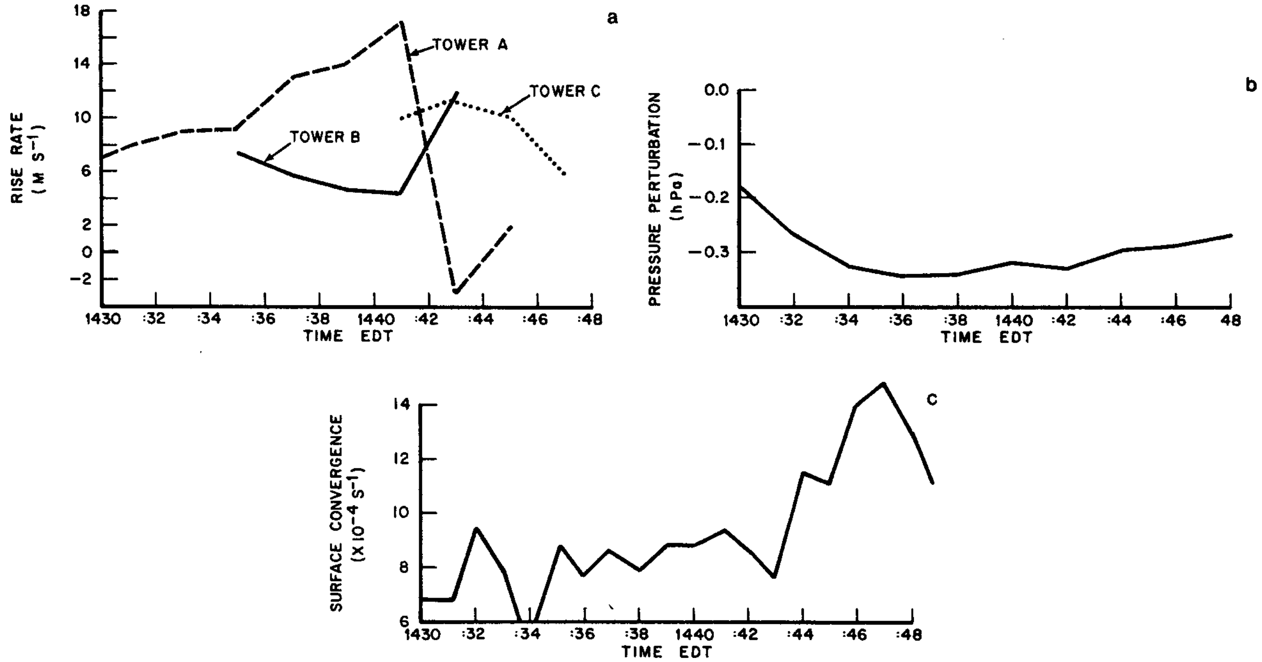

FIG. 2. Temporal changes in (a) rise rates of towers in the convective system from photogrametic measurements, (b) the maximum point surface pressure perturbation below the developing convective system, and (c) peak values of surface convergence below the developing convective system.

ment has to first occur through some depth below the seeding level. This may then enhance the downdraft which will after some minutes interact with the surface boundary layer. Convective growth can be further enhanced by this process as well as by the surface pressure response.

This area of research is crucial to understanding the response of convective clouds to seeding.

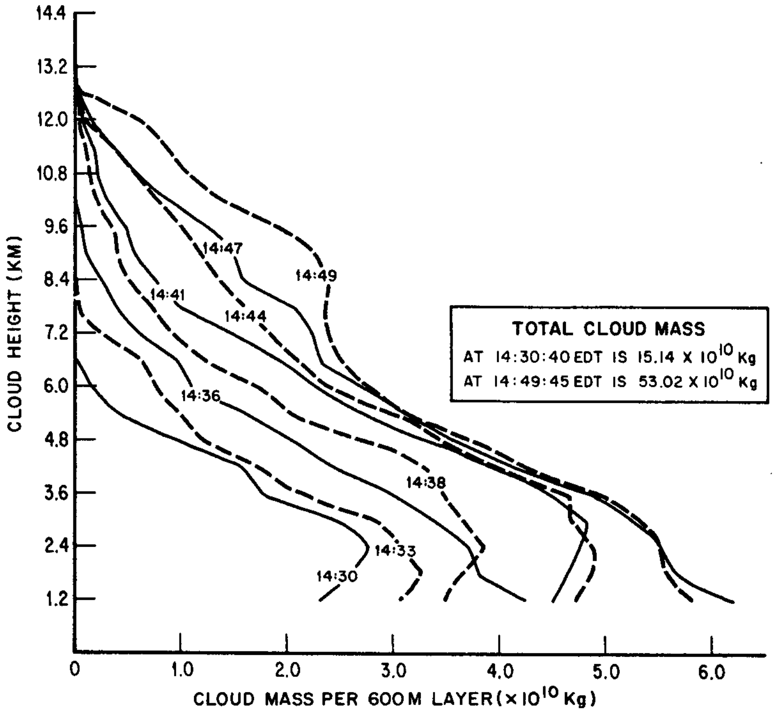

FIG. 3. Temporal changes in cloud mass with height per 600 m layers for the case study convective system up to the time of downdrafts on the surface.

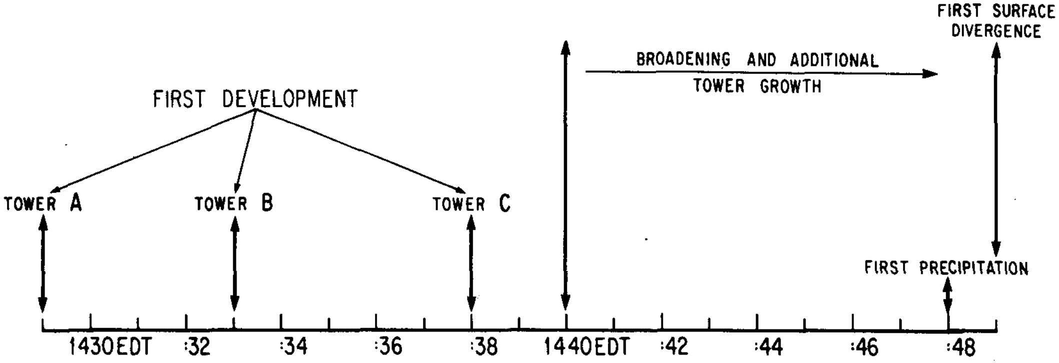

FIG. 4. Temporal changes in the case study convective system derived from time-lapse photography and surface mesonetwork measurements. (Note—the first occurrence of precipitation on the surface at 1448 EDT which is ~20 min after the first development within the convective system.)

Further case studies involving both observational analysis and numerical simulation are needed to address this problem. Future research programs such as the Cooperative Convective Precipitation Experiment (CCOPE), and the Cumulus Dynamics and Microphysics Program (CDMP), should lead to much greater insights into the interactions between developing convection and the boundary layer and the response of both, directly and indirectly, to seeding.

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