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Seeing Supercells as Heavy Rain Producers

Charles A. Doswell III
NOAA/National Severe Storms Laboratory, Norman, Oklahoma

1. INTRODUCTION

Supercell thunderstorms are well-known for their capability to produce severe local storm phenomena: large hail, strong convective wind gusts, and tornadoes (e.g. Browning 1964). The occurrence of supercell storms is related to the presence of substantial vertical wind shear in the pre-storm environment (Ludlam 1963; Weisman and Klemp 1982, Brooks et al. 1994).

It is the presence of wind shear that suggests supercell storms are unlikely candidates for the production of heavy precipitation, for two reasons. First, when vertical wind shears are large, the mean wind in the troposphere tends to be substantial. This tends to make storms move relatively rapidly, although on occasions, storm propagation effects can cancel much of the advective part of storm motion (see Chappell 1986). Second, it has been suggested (see Fankhauser 1971, 1988) that vertical wind shear contributes to reduced precipitation efficiency. Although the relationship between shear and precipitation efficiency is more empirical than it is based on rigorous physical reasons, there is clearly a tendency for supercell storms to be less efficient at converting water vapor to precipitation than some other types of storms. The consumption of some input water vapor to produce large hail is a factor in this efficiency, as well. Although large hail is certainly "precipitation," it is not typically a contributor to flooding problems.

Thus, there has been some tendency to neglect the impact of supercells as a contributor to flash flooding. Recently, however, there have been some developments that have begun to change that. With the recognition of the existence of a spectrum of supercell types (see Doswell and Burgess 1993), it became clear that at least some supercells were quite capable of prodigious rainfalls. Doswell (1994) called attention to the rainfall potential of high precipitation ("HP") supercells, but provided little direct evidence of it.

It has been recognized before that severe local storms and heavy precipitation events are not mutually exclusive (see, e.g., Schwartz et al 1990; Chappell and Rogers 1986). However, supercells and other non-supercellular forms of deep convection can coexist in close proximity; a rain event near a supercell could have come from a nearby non-supercell storm. Another possibility is that the

Corresponding author address: Dr. Charles A. Doswell III, Nat. Severe Storms Lab., 1313 Halley Circle, Norman, OK. E-mail: doswell@nssl.noaa.gov [*no longer valid*]

early stages of a convective event include supercells, but the event later evolves into a mesoscale convective system that is not supercellular at all. Thus, severe storms could occur early in a convective episode, but heavy rainfalls would be associated with subsequent, non-supercellular convection (see, e.g., Maddox 1983). It is not entirely obvious in a situation that produces both severe weather and heavy precipitation that it was supercells that produced, or contributed to, the flash flood events.

This study documents briefly a supercell storm that did, in fact, develop flash flood-producing heavy precipitation. After documenting this case, some additional evidence is presented to support the contention that instantaneous rainfall rates exceeding 100 mm hr^{-1} (and perhaps even exceeding 200 mm hr^{-1} on some occasions) may not be all that uncommon with supercells. A conceptual model of the processes by which this can occur is developed, and the potential for flash flooding is explored in light of what is typical supercell behavior.

2. THE DALLAS-FORT WORTH METROPLEX SUPERCELL OF 24 MAY 1986

This event, witnessed by the author in downtown Fort Worth during the heavy rainfall, was characterized by a number of reports of nontornadic severe weather: hail diameters up to 3 in (7.5 cm) and wind gusts up to 83 kt (41 m s^{-1}). Fourteen people were injured by the severe weather, mostly in a bowling alley roof collapse that was attributed to a combination of high winds and water loading. Two fatalities, however, were the result of urban flooding: a 30-year old woman and her 8-year old son drowned when they were swept from their car after driving into a flooded underpass.

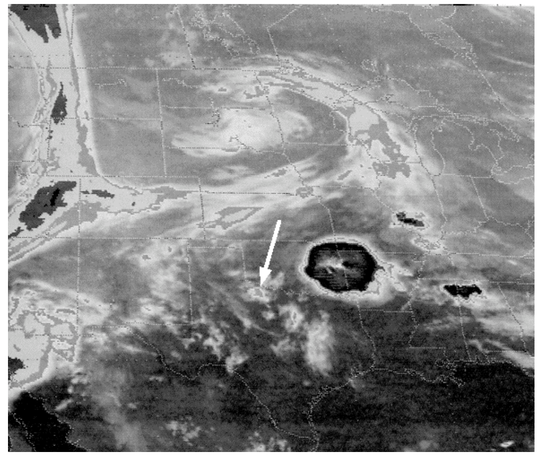

Fig. 1. Initial stages of development of convection (arrow) in western North Texas, as seen in an enhanced infrared satellite image at 1001 UTC on 24 May 1986.

The initial convective developments that were to evolve into the supercell began about 1000 UTC in western North Texas (Fig. 1) as a mesoscale convective system (MCS) moved through eastern Oklahoma.

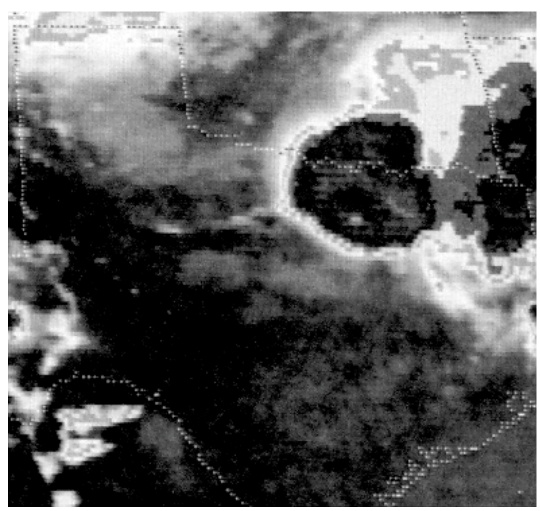

Fig. 2. Developing convection in central North Texas, as in Fig. 1, except at 2001 UTC..

These initial developments moved east-southeastward without much change until about 1400 UTC, when they began to expand rapidly, evolving into another MCS by about 1800 UTC in central and eastern North Texas

The supercell storm developed west of this second MCS and by 2000 UTC was already showing substantial growth (Fig. 2). This event occurred prior to the implementation of the WSR-88D radar system; all that is available are tracings of the contoured reflectivity from the previous system (WSR-57) radar, located at Stephenville, TX. The radar tracings show clear evidence of rotation at 1932 UTC (Fig. 3) as the storm approached downtown Forth Worth.

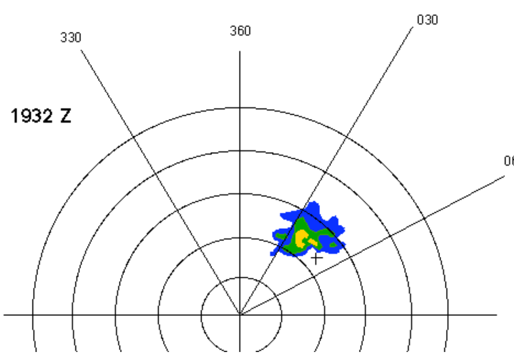

Fig. 3. Radar reflectivity contour tracings from the WSR-57 radar at Stephenville, TX. The location of downtown Fort Worth is indicated by the "+" sign. Reflectivity contours are for Video Integrator and Processor (VIP) levels 2 and higher, at unit VIP-level increments.

After the storm passed Fort Worth, the reflectivity increased slightly and the structure continued to show supercellular characteristics (Fig. 4).

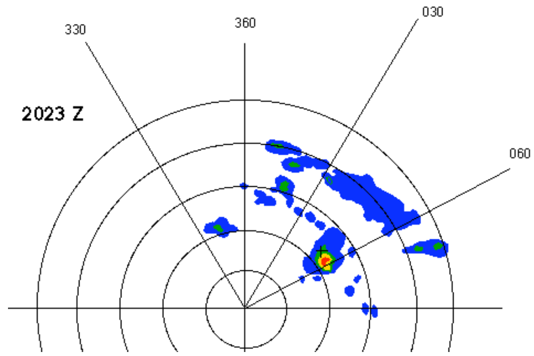

Fig. 4. As in Fig. 3, except at 2023 UTC.

The radar reflectivity indicated pretty clearly that this was an HP supercell (see Moller et al. 1990); the mesocyclone is wrapped up in high reflectivities, showing evidence of "spiral bands" in Fig. 3 and a "kidney bean" shape in Fig. 4. The observed rainfall peak was on the order of 100 mm (4 in) in "less than an hour" according to the *Storm Data* report. This caused considerable urban flash flooding of streets and underpasses, producing the two fatalities already noted.

3. HIGH PRECIPITATION RATES FROM SUPERCELLS

Other cases could be cited; e.g., the famous tornado outbreak near Grand Island, NE on 03 June 1980. This event also included a much less well-known flash flood. However, there are other ways to assess the precipitation potential from severe thunderstorms.

3.1 Numerical simulations

Numerical cloud models have contributed substantially to our understanding of supercell storms (e.g., Weisman and

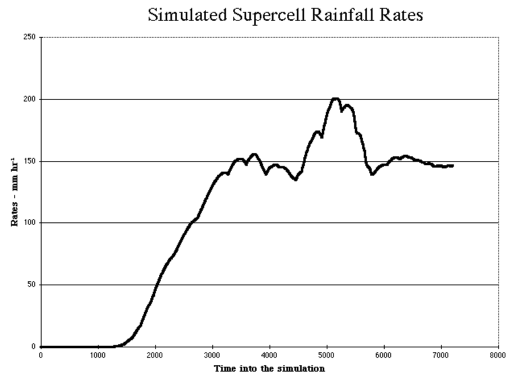

Fig. 5. Instantaneous precipitation rate in a simulated supercell storm as a function of time into the simulation.

Klemp 1986). A project is currently underway to explore precipitation production in supercells specifically, in idealized environments, with instantaneous precipitation rates being monitored (Fig. 5). Once the storm begins, it develops into a quasisteady supercell, with precipitation rates averaging about 150 mm hr^{-1}, and a brief peak of 200 mm hr^{-1}. The peak accumulation at the surface, however, is 48 mm. As noted in Doswell et al. (1996), the accumulated precipitation at any point is proportional to the product of the average rate times the duration of the precipitation. Thus, storm motion becomes an important issue in determining the total precipitation.

Further, another aspect of supercells that the simulations can be used to explore is the efficiency of rainfall production. In the simulations done so far, it has become clear that an increase in shear certainly does have the effect of reducing the efficiency, if the efficiency is defined as the ratio of total precipitation divided by the water mass involved in the convection.

The simulations show, however, that the reduction in efficiency associated with increasing shear is more than compensated for by increases in updraft size and duration. Supercells tend to have large, persistent, and strong updrafts. This promotes a high rainfall rate, in spite of relatively low efficiency; as noted in Doswell et al. (1996), the precipitation rate is proportional to the product of updraft speed, water vapor content of the ascending air, and efficiency of conversion of that water vapor to precipitation. Since supercells tend to occur in environments with high low-level moisture content and develop strong updrafts, the simulations suggest the net result for many supercells is that they produce high rainfall rates in spite of being relatively inefficient. The HP class of supercells may even be fairly efficient in some cases.

3.2 Radar observations

Rainfall rates from rain gauges tend to have a serious sampling problem in association with convective rain events. The spacing between rain gauges, even in such relatively dense networks as the Oklahoma Mesonet (see Brock et al. 1995), is not capable of resolving the details of the precipitation distribution. Thus, it is clear that radar must be the basis for any high-resolution precipitation observations. This paper is not the forum for a discussion of the various methods for estimating precipitation from radars. The reader should consult Rhyzhkov and Zrnic (1995) for more details.

Consider the following example of a supercell storm within range of the NSSL polarimetric radar (operated in the vicinity of Cimmaron, OK). The storm in question occurred on 25 May 1994; using the polarimetric capability of the radar, it is possible to estimate precipitation from the specific differential phase parameter (KDP—see Ryzhkov and Zrnic 1995). Observe the relationship between this polarimetrically-determined rainfall rate and the inferred rate using the reflectivity, because reflectivity is strongly influenced by the presence of hail in supercells, whereas KDP is not. Thus, the distribution of rainfall in a supercell may not coincide with the cores of high reflectivity; this is apparent in Fig. 6. It should be noted that the peak rainfall rates in this case were on the order of 130 mm hr^{-1}, which is consistent with the simulations and the observations. It has been shown (e.g., Ryzhkov and Zrnic 1995) that KDP precipitation estimates are an improvement over those from reflectivity.

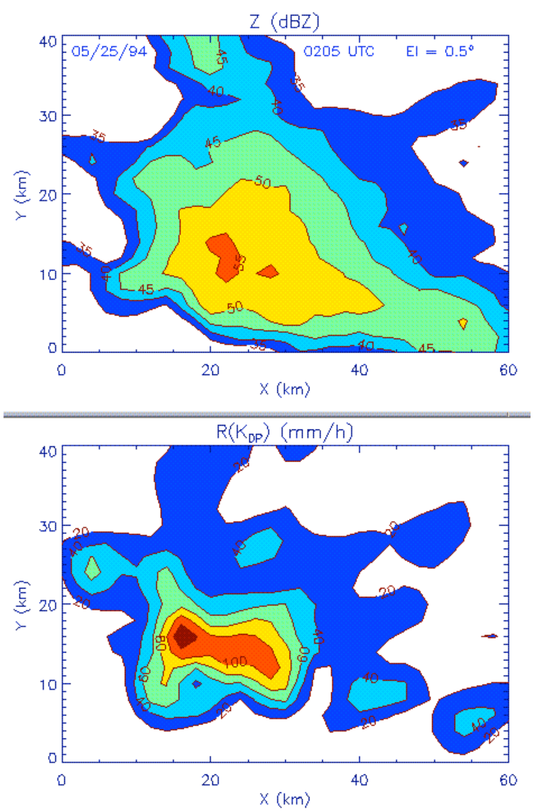

Fig. 6. Reflectivity (top) in dBZ, and instantaneous rainfall rate (bottom) in mm hr^{-1} inferred from KDP for the 25 May 1994 case.

4. DISCUSSION

Hopefully, this brief presentation helps to develop a greater awareness of the potential importance of supercell storms as heavy precipitation producers. Supercells occur in environments that seem to inhibit precipitation efficiency and that tend to promote sufficiently rapid storm movement that they are not often associated with excessive point rainfall accumulations.

Nevertheless, they can produce instantaneous rainfall rates that are well beyond the typical rates, even for convective storms. This can be significant in certain hydrological settings (e.g., where antecedent precipitation has inhibited infiltration, or in urban settings where infiltration is typically small, irrespective of antecedent precipitation). A rainfall rate exceeding 100 mm hr^{-1}, even for as short a duration as 15 min, can have serious consequences in vulnerable situations.

The fact that supercells typically are best known for other forms of severe weather than heavy rain can mean that forecasters and the public fail to recognize the dangers associated with the rainfall produced by supercells. If the primary threat is perceived to be limited to hail, wind, and/or tornadoes, a flash flood can catch forecasters and citizens unprepared, clearly a situation to be avoided.

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