Low-Level Winds in Tornadoes and Potential Catastrophic Tornado Impacts in Urban Areas

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In a stimulating presentation, Wurman et al. (2007, hereafter W2007) have produced an interesting estimate of the possible effects of violent tornadoes in urban areas by making models of the wind field based on mobile Doppler radar observations. As part of that effort, they have estimated death tolls associated with those modeled wind fields, arriving at estimates from 13,000 up to 63,000 in Chicago, Illinois. Given that the highest death toll in a tornado in U.S. history is 695 in the Tri-State tornado of 1925, and that the last death toll of greater than 100 was in 1953, the validity of these estimates is of some concern. We are certainly in favor of raising the level of awareness of the potential for large casualty figures in future tornadoes. The concentration of our population in urban areas, combined with urban sprawl, has increased the threat of large fatality figures if a large, violent, long-track tornado were to hit a major metropolitan area. Planning for such a catastrophic event requires an estimate of the potential impacts. We fear, however, that the enormity of the fatality estimates in W2007 might discourage emergency managers from planning for such an event, because they would simply be overwhelmed by such a disaster.

Two assumptions drive the fatality estimates in W2007. First, W2007 estimate that 10% of occupants within housing subjected to Fujita-scale F4 and greater winds would be killed. Second, W2007 assumes that the maximum intensity and areal extent of high winds are held constant over nearly the entire length of the storm path. Both of these assumptions are open to question and, we believe, represent significant overestimates of the likely high-end events. An examination of past tornado events suggests these are simply unrealistic values.

W2007's assumption that 10% of residents in the path of such a catastrophic tornado would be killed is inconsistent with estimates that can be derived from studies of deaths in F4 and F5 tornadoes (Table 1). We infer the percentage of residents killed using the national average household size of 2.7 persons (see 2005 census estimates online at www.census.gov/popest/states/NST-ann-est.html, and www.census.gov/prod/2006pubs/h150-05.pdf). The 3 May 1999 Oklahoma City, Oklahoma (OKC), and 8 April 1998 Birmingham, Alabama, F5 tornadoes struck metropolitan areas and provide the best-available evidence on fatality rates. The estimates in Table 1 are based on varying levels of damage to homes. The first, from D. A. Speheger (2007, personal communication), is based on a count of homes in the OKC tornado that suffered F4 or F5 damage as rated in the postevent damage survey. The fatality rate in such damaged homes in OKC was only 1.9%, and this estimate most closely approximates W2007's assumption that all residences in the hypothetical tornado face F4 or F5 winds. But, Speheger et al. (2002) found that only 13% of the total path area affected in the OKC tornado was associated with F4 or F5 damage levels, which is typical of the few F5 tornadoes whose paths have been surveyed reasonably thoroughly. Thus, the other estimates that include either destroyed homes or damaged or destroyed homes [i.e., the Oklahoma Department of Emergency Management, which counted destroyed housing, regardless of the F-scale

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Table 1. Estimates of the fatality rate in the 8 Apr 1998 Birmingham and 3 May 1999 Oklahoma City F5 tornadoes. (Oklahoma Department of Emergency Management information is online at www.srh.noaa.gov/oun/storms/1990503/tornado_facts.html.)

Source	Tornado	Type of damage	Fatalities	Homes affected	Fatalities per home	Fatality rate
D. A. Speheger (2007, personal communication)	Oklahoma City	F4/F5-rated damage	17	334	0.051	1.9%
Legates and Biddle (1998)	Birmingham	Destroyed homes	32	1,100	0.029	1.1%
Oklahoma Department of Emergency Management[1]	Oklahoma City	Destroyed homes	20	2253	0.009	0.3%
Daley et al. (2005)	Oklahoma City	Damaged or destroyed homes				0.1%

rating, and Daley et al. (2005), based on a survey of residents in damaged or destroyed housing in the path] more accurately reflect the distribution of damage in F5 tornadoes. These fatality rates range from 0.1% to 1%, which are one to two orders of magnitude less than those of W2007.

W2007 claim that the OKC tornado had an unusually long lead time and that greater local awareness of tornadoes led to a more effective warning response, and they imply that fatality rates would be higher in other cities like Chicago or Houston, Texas. On the lead time question, official lead times for the warnings for Oklahoma and Cleveland Counties were 13 and 32 min, which are at the median and in the 85th percentile, respectively, for all tornado warnings with positive lead times in the United States from 1986 to 2004 (Fig. 1). In addition, F4 and F5 tornadoes are typically relatively well warned, and the warning performance for these tornadoes has increased since the installation of the Weather Surveillance Radar-1988 Doppler (WSR-88D) radars (Simmons and Sutter 2005). The implied long lead time is based on the time that the tornado was on the ground and

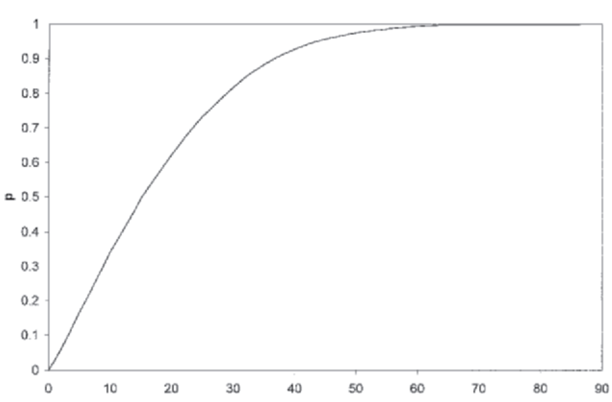

Fig. 1. Cumulative distribution of lead time for all tornadoes with warnings issued before the tornado occurred, 1986–2004.

assumes that residents of Cleveland and Oklahoma Counties inferred that the tornado would remain on the ground long enough to strike their communities. The relationship between official lead times and what individuals in the warning area perceive as their lead time is certainly complex. But, it is likely that any tornado producing the damage paths assumed by W2007 would be on the ground for an hour or more, allowing residents to infer a substantial lead time. It seems difficult to justify the statement that the OKC tornado had radically different lead times than those of other violent tornadoes. With regard to awareness, the public in Oklahoma City may indeed have a high level of tornado awareness, but very few of the housing units in the path of the OKC F5 tornado had either below-ground or in-residence shelters. Thus, there are factors that imply that Oklahoma City residents might have a higher probability of being killed in a tornado in addition to factors leading to a lower probability thereof. It seems unreasonable for us to assume a significantly higher death rate than around 1% in destroyed housing.

Although much of the focus in W2007 is on the Chicago area, other metropolitan areas are discussed. In particular, the tornado history of Saint Louis, Missouri, provides valuable evidence on urban tornado fatalities. Three historical tornadoes are of interest in this regard (see Grazulis 1993 for details). The most recent, an F5 tornado starting at 0140 LT 10 February 1959, killed 21 people. On 29 September 1927, an F3 [possibly F4, according to Grazulis (1993)] tornado killed 79 people. The most devastating storm, of F4 force, on 27 May 1896 killed 255 people, with 138 of them on the Missouri side of the Mississippi River. Beatty (2002) used the detailed damage descriptions of Curzon (1896) to map the damage path. On the Missouri side of the river, he shows an area of F4 damage larger than the 3-km area indicated in the smallest hypothetical tornado (labeled SM, in

W2007). The death estimate in W2007 for the SM tornado in Saint Louis is 1,600. Given the decline in the population of Saint Louis since 1896, the complete lack of a warning system in 1896 and 1927, and the relatively primitive system in 1959, combined with a tornado in the middle of the night, the W2007 estimate seems excessively large. In comparison with the 1959 event, it is almost two orders of magnitude larger. In comparison with 1896, it is more than an order of magnitude larger, compared to an era with no warnings and a larger population.

An event based on maintaining the maximum intensity of the Bridge Creek tornado throughout the track across Oklahoma City gives an estimated death toll of 3,300, which is two orders of magnitude larger than what occurred. The high estimate compared to the observed event results from the combination of a 10% death rate in destroyed houses and the extremely large area of F4 and higher coverage.

In summary, combining an estimated 1%, rather than a 10%, death rate due to destroyed housing and a lower fraction of area of the highest winds leads to estimated catastrophic death tolls approaching two orders of magnitude lower than that estimated by W2007. Note that more plausible estimated death tolls of 130–630 are still extremely large by modern standards. The last death toll greater than 42 in a single tornado was in 1971. The only years with annual totals greater than 94 since 1974 were 1984 (122) and 1998 (132), and there were 623 deaths in total from 1997 to 2006. A toll of 630 would represent more than two deaths per million people in the United States, a higher rate than that prior to the Tri-State tornado in 1925 (Brooks and Doswell 2002). Thus, even estimates that are two orders of magnitude lower are still catastrophic, but far more realistic.

Catastrophic event analysis allows emergency managers and other public officials to plan and prepare in advance. Clearly, even more extreme casualty events than W2007 can be imagined, for example, either a long-track violent tornado traveling along an urban interstate highway at rush hour with tens of thousands of automobiles in the path, or a tornado hitting the Indianapolis Motor Speedway with over quarter of a million people in attendance during the Indianapolis 500 race. But, "realistic high-end events" might be of greater value to emergency planners than estimates of unrealistically large death tolls. In addition to the death tolls, the simulated tornadoes in W2007 would generate staggering injury totals. If half of the remaining population in the tornado paths were injured, W2007's tornadoes could result in hospital admission counts of 55,000–285,000. Given that there are fewer than 660,000 hospital beds in the entire United States (Halpern et al. 2006), emergency managers may conclude that planning for a catastrophic urban tornado is hopeless. Emergency managers might find that planning for more realistic high-end events is worthwhile. Recreating historical events in metropolitan areas, including shifting the paths around the region (e.g., similar to Rae and Stefkovich 2000; information online at www.nctcog.org/weather/study/), could be a useful exercise in this regard. Beatty (2002) did this when estimating potential property damage in Saint Louis. Historical tornadoes in other large cities prone to tornadoes, such as Kansas City, Kansas, Omaha, Nebraska, Chicago, and Louisville, Kentucky, could be used in a similar way. A fatality event two orders of magnitude smaller than that of W2007 would result in 130–630 fatalities and 2,000–10,000 hospital admissions, based on the finding in Brown et al. (2002) of 15 injuries requiring hospital admission to each death in the Oklahoma City tornado. Such planning in the Oklahoma City area was put into place in both the 1999 tornado and in the Murrah Federal Building bombing in 1995.

We applaud the efforts of W2007 to estimate potential damage from tornadoes in urban areas, but believe that the combination of an unrealistically high death rate due to destroyed homes and the area covered by the highest winds lead to extreme overestimates of the real potential. Fatality estimates even two full orders of magnitude lower suggest the possibility of a future tornado exceeding the number of fatalities from the 1925 Tri-State tornado, a prospect that is sobering enough.

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