Spatiotemporal Changes in Tornado Hazard Exposure:
The Case of the Expanding Bull's Eye Effect in Chicago, IL

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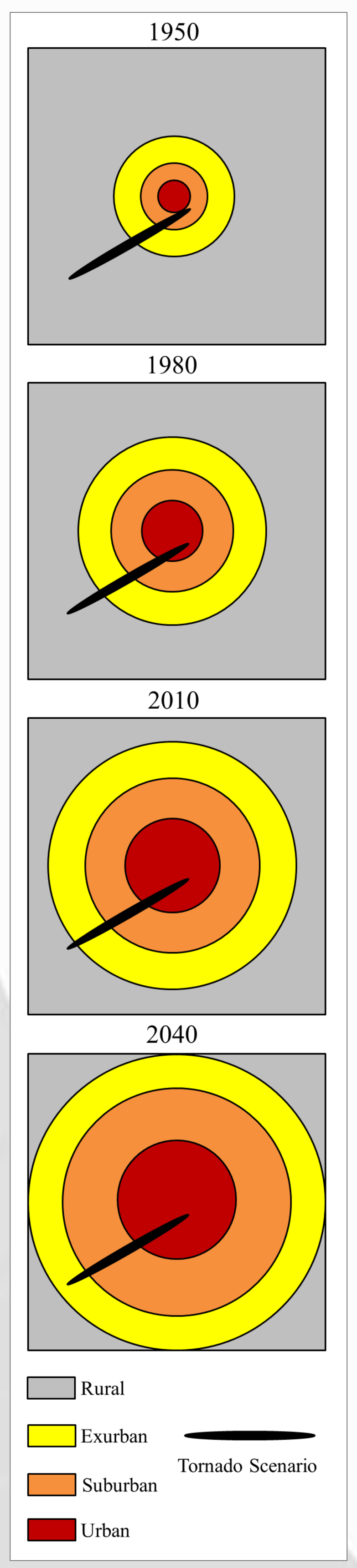
Introduction

Despite decades of improvement in activities aimed at reducing impacts from extreme events, the rapid increase in disaster losses and people affected suggests that swelling populations, development trends, and vulnerabilities are outpacing mitigation, leading to more events and amplified impacts. Due to data, computational, and methodological restrictions, research quantifying *changes* in human exposure to hazards has been relatively limited. We attempt to rectify this deficiency, advancing a framework for future work exploring how exposure and vulnerability contribute to disasters.

Methods

Our investigation employs historical demographic exposure data on a uniform grid to appraise how transformations in Chicago's land use have led to greater potential for tornado disasters. Chicago is an ideal example of the enormous growth that metropolitan regions have witnessed during the last century. The area is characterized by a dense urban core and has experienced extensive, spatially fragmented suburban growth, or sprawl … leading to an expanding bull's-eye effect (**Fig. 1**).



Expanding bull's-eye effect?

"Targets"—i.e., humans and their possessions—of geophysical hazards are enlarging as populations grow and spread. It is not solely the population magnitude that is important in creating disaster potential, it is how the population and built environment are distributed across the landscape that defines how the fundamental components of risk and vulnerability are realized in a disaster.

Fig. 1. A conceptual model of the "expanding bull's eye effect" for a hypothetical metropolitan region that is characterized by increasing development spreading from an urban core over time. A sample tornado scenario is overlaid to show how expanding development creates larger areas of potential impacts from hazards.

Macroscale Changes

The total population for our study area (**Fig. 2.B**) has increased from just over 7.2 million in 1970 to 8.8 million 2010, a 21% surge. The number of housing units during the 1970-2010 period swelled from 2.4 million to just over 3.5 million, an increase of nearly 47.4%. Thus, the built environment has increased at a faster rate than the number of people, with relatively high-density sprawl leading to the greatest change in the exposure landscape (**Table 1**). Any amplification in tornado losses from potential tornado disasters would be greater for insured or uninsured housing damages than human casualties.

Table 1. Percentage of each land use type in the 11-county Chicago region for 1990, 2000, and 2010.

	% of Total Area			% Change
Land-use Type	**1990**	**2000**	**2010**	**1990-2010**
Urban	4.5	4.8	5.0	0.6
Suburban	13.2	15.4	18.0	4.8
Exurban	24.0	23.9	23.9	-0.2
Rural	58.4	55.9	53.1	-5.2

Synthetic Tornadoes

We examined the path attributes of a portfolio of violent tornado events (**Fig. 2, Table 2**) and, thereafter, advance a structure for synthetic tornado hazard development based on observed damage indicators for a modern catastrophic event (Joplin EF5).

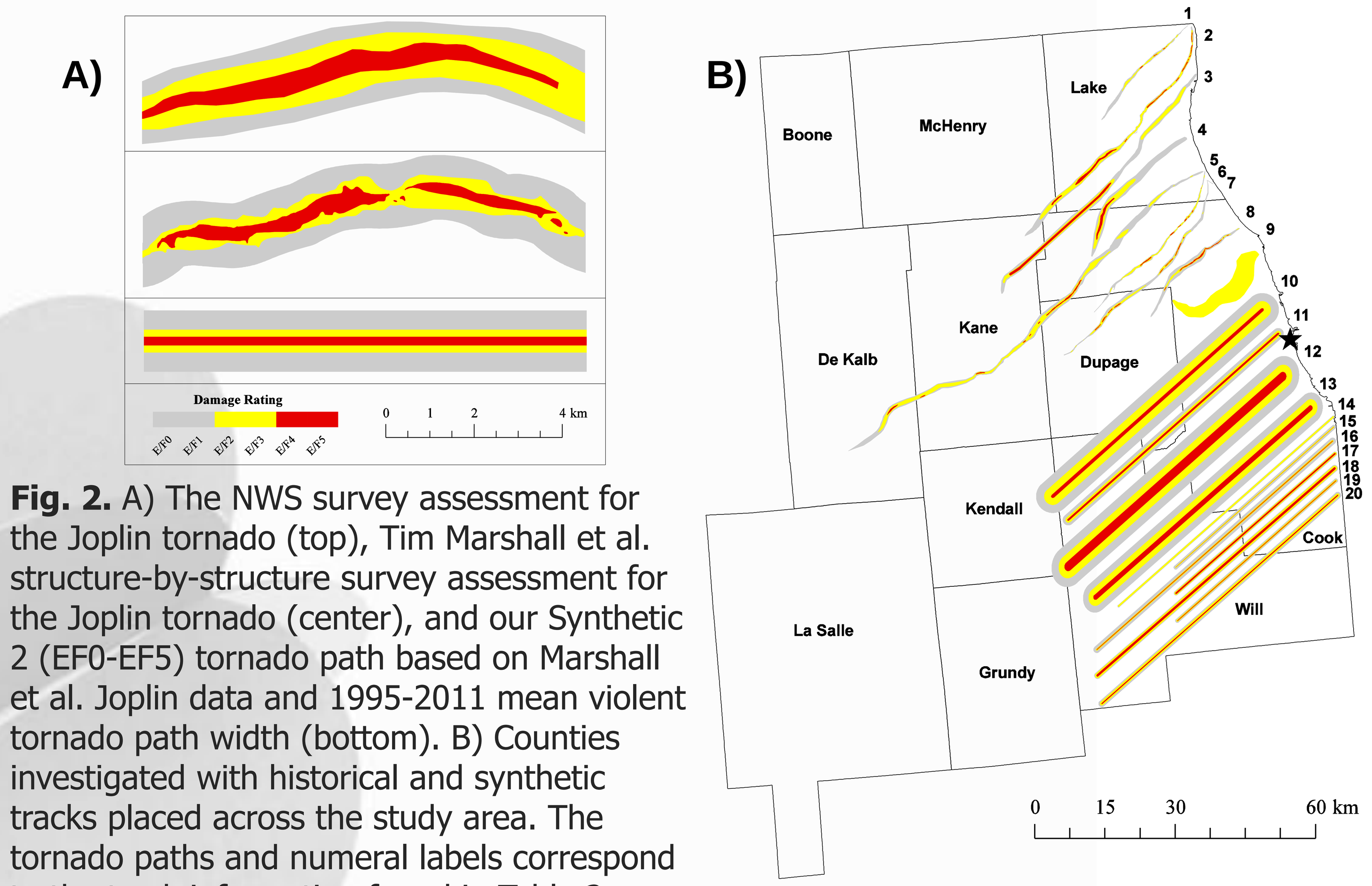


Fig. 2. A) The NWS survey assessment for the Joplin tornado (top), Tim Marshall et al. structure-by-structure survey assessment for the Joplin tornado (center), and our Synthetic 2 (EF0-EF5) tornado path based on Marshall et al. Joplin data and 1995-2011 mean violent tornado path width (bottom). B) Counties investigated with historical and synthetic tracks placed across the study area. The tornado paths and numeral labels correspond to the track information found in Table 2.

Table 2. Tornado attributes from observed violent events (1-9), Wurman et al. (2007, *BAMS*) synthetics (10-14), and our synthetics (15-20), which are based on mean length (km) and width (m) information gathered from all U.S. violent tornadoes from 1995 to 2011 that contained information on those elements. Area (km^2) swept out by each tornado's reported violent class is provided.

Path	Date	Path length	Max width	F/EF 4+ area	Total area
Observed tornado event					
(1) Plainfield, IL	8/28/1990	26.4	548	0.14	11.72
(2) Bridgecreek-Moore, OK	5/3/1999	61	1609	6.38	49.50
(3) Mulhall, OK	5/3/1999	63	1609	12.64	67.41
(4) Joplin, MO (NWS)	5/22/2011	35	1463	3.56	45.70
(5) El Reno, OK	5/24/2011	101	1609	2.97	99.14
(6) Washington-Goldsby, OK	5/24/2011	37	805	0.70	13.08
(7) Chickasha-Newcastle, OK	5/24/2011	53	805	1.12	27.15
(8) Newcastle-Moore, OK	5/20/2013	27	1737	1.50	23.30
(9) El Reno, OK	5/30/2013	26	4184	-	73.06
Wurman et al. (2007, *BAMS*) synthetics					
(10) Mulhall, OK	5/3/1999	60	7050	45.87	462.03
(11) Bridgecreek/Moore, OK	5/3/1999	60	2315	30.56	143.11
(12) Hybrid	-	60	8800	109.58	523.76
(13) Hybrid Reduced	-	60	6580	61.80	385.45
(14) Small	-	60	548	-	30.38
Ashley et al. synthetics					
(15) Synthetic 1	-	45.21	873	5.81	40.09
(16) Synthetic 2	-	67.3	1390	13.78	95.06
(17) Synthetic 3	-	45.21	873	11.92	40.09
(18) Synthetic 4	-	67.3	1390	28.23	95.06
(19) Synthetic 5	-	45.21	873	8.04	40.09
(20) Synthetic 6	-	67.3	1390	19.05	95.06

Changes in Tornado Exposure

- We superimpose 5 full-length tornado paths based on our Synthetic 2 (represented in Fig. 2.A, bottom panel) across the study area, with the paths spaced north-to-south, 15-20 km apart (**Table 3, Fig. 3**). Further analyses in extended abstract overlaid hypothetical tornado events atop varying development morphologies.
- Results show that the number of people and their housing continues to geographically expand, confirming that more people and their possessions are potential targets for tornadoes.
- Differing development types (see extended abstract) lead to varying exposure rates that contribute to the unevenness of potential weather-related disasters across the region. For instance, a sprawl type of suburban development has led to the greatest change in hazard exposure setting. Conversely, while population loss along the periphery of the urban core has decreased the number of people potentially affected, those that remain may be highly vulnerable due to greater sensitivity/susceptibility and lower adaptive capacity caused by poverty.

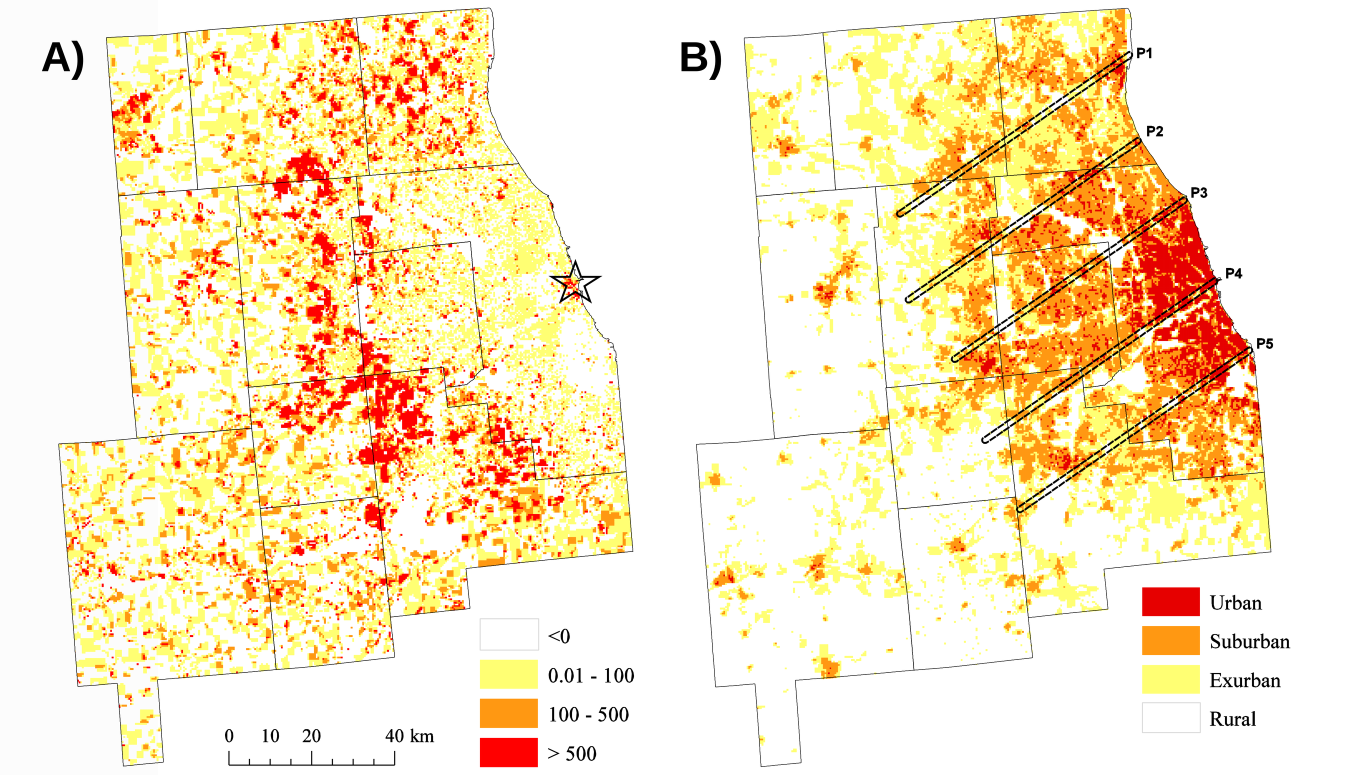


Fig. 3. The A) percentage change in population from 1990 to 2010 for each 0.16 km^2 grid cell, which was the resolution of our demographic grid. Chicago CBD, or "the Loop", is denoted by a star. The B) 2010 land-use classification, with 5 full-length scenario (Synthetic 2) paths placed across the developed core of the study area (cf. Table 3).

		Population Affected				Housing Units Affected			
Position	**Year**	**EF2-EF5**	**EF4-EF5**	**EF0-EF5**	**1990-2010 % Change**	**EF2-EF5**	**EF4-EF5**	**EF0-EF5**	**1990-2010 % Change**
1	**1990**	14,155	5,451	35,947		5,554	2,138	13,921	
	2000	19,953	7,612	52,418		7,167	2,715	18,906	
	2010	22,292	8,591	56,327	56.7%	8,206	3,160	20,741	49.0%
2	**1990**	24,790	9,600	63,458		9,731	3,764	24,393	
	2000	25,780	9,786	69,923		10,022	3,802	26,765	
	2010	28,269	10,916	74,920	18.1%	11,355	4,396	29,646	21.5%
3	**1990**	38,935	14,867	104,961		14,975	5,700	40,335	
	2000	43,592	16,743	115,892		16,734	6,450	43,853	
	2010	46,300	17,841	120,828	15.1%	18,013	6,938	46,744	15.9%
4	**1990**	57,214	21,772	161,378		22,881	8,505	65,782	
	2000	66,676	25,130	185,859		25,779	9,477	75,043	
	2010	73,022	27,292	205,771	27.5%	32,009	11,599	95,139	44.6%
5	**1990**	37,411	14,240	102,587		12,857	4,932	34,798	
	2000	39,278	15,090	105,294		14,048	5,399	37,413	
	2010	35,461	13,624	95,105	-7.3%	13,999	5,373	37,334	7.3%

Table 3. Number of people and housing units affected and affiliated 1990-2010 percent changes of total impacted for 5 simulated tracks of tornadoes across Chicago region based on the S2 scenario (cf. Figure 3.B).

Conclusions

While climate change may amplify the risk of certain hazards, the root cause of escalating disasters is not necessarily event frequency, or risk, related. Rather, our research confirms that the upward trend in disasters is predicated on increasing exposure and vulnerability of populations. Communities need to understand how local exposure landscapes have transformed spatiotemporally and how those changes may influence the tasks of warning, rescue, and recovery should a catastrophic scenario come to fruition.