Technical Investigation of the May 22, 2011, Tornado in Joplin, MO

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NCST Advisory
Committee Meeting

Tornado Hazard Characteristics

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Objective #1

- Determine the tornado hazard characteristics and associated wind fields in the context of historical data

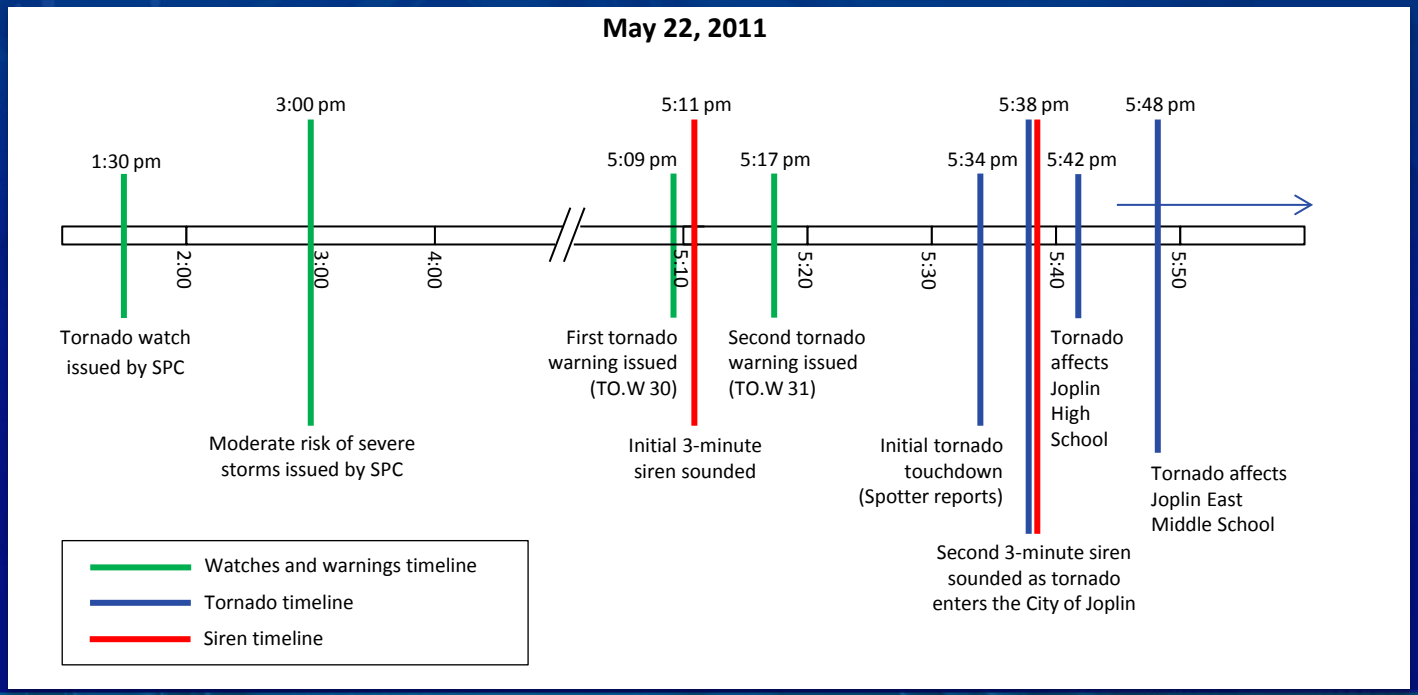
Presentation Outline

1. Objective Summary
2. Findings

1. Objective Summary

Summary: Meteorological Conditions

- Conditions favorable for the development of tornado-producing thunderstorms in the Joplin area were well forecast.
- Two tornado warnings issued that included all or part of Joplin. Tornado touched down at 5:34 CDT and was on ground for 15 minutes in Joplin.
- Radar was able to identify possible tornado, but the distance from the storm precluded detailed near-surface information



Summary: Near-Surface Wind Environment

- Indirect Method: EF-scale
  - Rated NIST-surveyed structures using EF-scale and compared with ratings of others
  - Variability in ratings increase with large structures

Table 2–2. Estimated wind speeds for NIST-surveyed structures using EF Scale.

NIST-Surveyed Structure	Damage Indicator (DI)*		Degree of Damage (DOD)**		Estimated Wind Speed (mph)		Estimated EF Number	
	NIST	Other	NIST	Other	NIST	Other	NIST	Other
Walmart	12	12[a,d]	6–7	6[a], 7[d]	140 ± 15	173[d]	3	4[a,d]
Home Depot	12	12[a]	6–7	7[a]	150 ± 15	N/A	3	4[a]
Franklin Technology Center	15	15[d]	9	9[d]	150 ± 15	153[d], 143[e]	3	3[d,e]
SJRMC (East/West Towers)	20	20[a,c]	7	10[a,c]	140 ± 15	148[c]	3	3[a,c]
Joplin East Middle School	16	16[d]	8–9	7[d]	140 ± 15	125[d], (137–164)[b]	3	2[a,d], 3[b]
Joplin High School	16	16[a,d]	8–9	11[a], 9[d]	140 ± 15	120[b], 139[d], 158[e]	3	2[b], 3[a,d,e]

*DI numbers: 12, large, isolated retail building; 15, elementary school (the Franklin Technology Center was not an elementary school but was a building of similar construction); 16, junior or senior high school; 20, institutional building.
**DOD numbers: see Texas Tech University 2006 (Available online at http://www.depts.ttu.edu/nwi/Pubs/FScale/EFScale.pdf).

a. FEMA 2012.
b. Miller and Coulbourne 2012. (Estimated wind speed values back-calculated)
c. Prevatt et al. 2012.
d. Marshall 2012.
e. Karstens et al. 2012.

Key: SJRMC, St. John's Regional Medical Center.

Summary: Near-Surface Wind Environment

- Indirect Method: EF-scale (cont.)
  - Random sample of 10 residential structures within each general damage class rated

Data Source: Pictometry®.
Used with permission.
Analysis by NIST

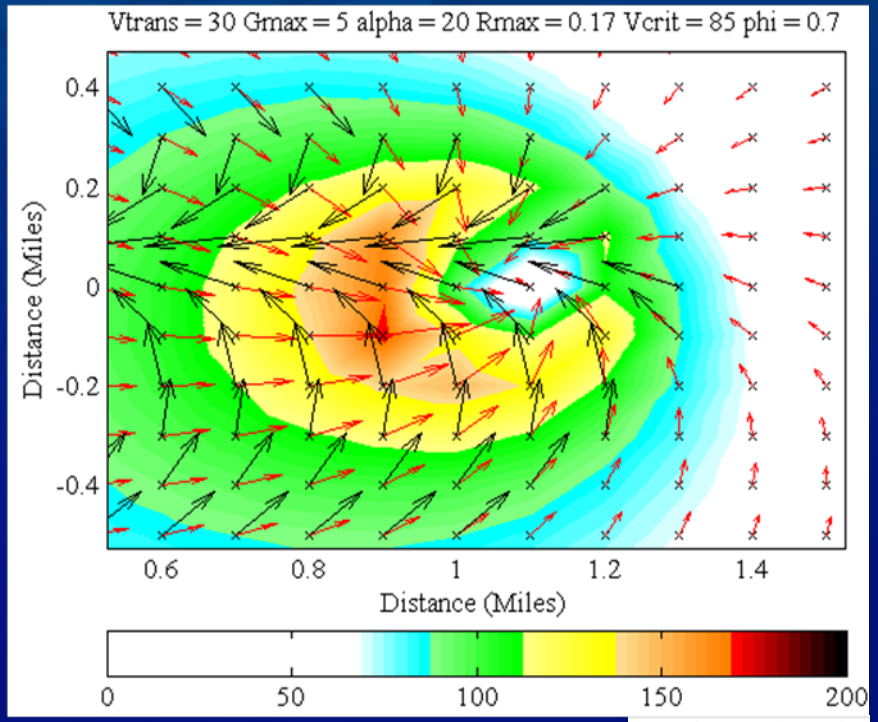
- Samples were assumed to be representative of the entire population of structures in the damage class.

Statistics	General Damage Classes			
	Light	Medium	Heavy/Totaled	Demolished
Mean wind speed – mph (m/s)	78 (34)	93 (42)	117 (52)	144 (64)
Standard Deviation – mph (m/s)	8 (3.6)	15 (6.7)	11 (4.9)	23 (10)
Range – mph (m/s)	65–85 (29-38)	85–120 (38-54)	95–130 (42 – 58)	110–175 (49-78)
Average EF Number	0	1	2	3
No. of Residential Structures[a]	3,498	732	1,119	2,062

a. Data source: Pictometry ® with permission. Analysis by NIST

Summary: Near-Surface Wind Environment

- Indirect Method: Tornado Wind Field Model (Rankine vortex)
  - Thousands of trees felled in Joplin
  - Initialize tornado wind field model in simulations to “re-create” observed tree fall
  - Grid system was created throughout Joplin and wind field model translated through it (250 ft or 80 m spacing)



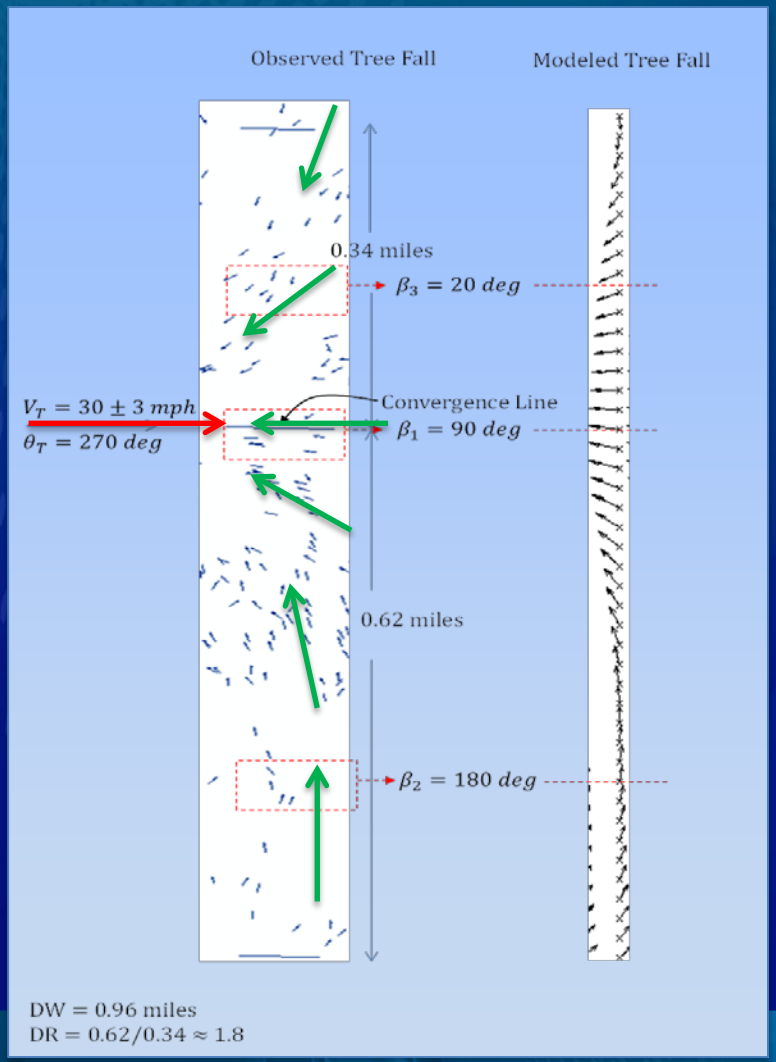
Summary: Near-Surface Wind Environment

- Indirect Method: Tornado Wind Field Model (cont.)
- Model Assumptions/Limitations:
  - Average critical tree fall wind speed (see range below) used due to relatively unknown variation in critical speed between tree types, urban v. rural, tree spacing, age, etc..
  - Rankine vortex (RV) is a simplification of flow fields – multiple vortices present in early stages and tornado wind speeds known to exhibit variations in time and space
  - Terrain corrections, debris effects not accounted for
  - Uniform profile assumed, no vertical wind speeds, representative of “3-second gust”
- Model Parameters:

Parameter	Initial Range	Description
V_T	30 ± 5 mph (radar, video)	Translation speed
θ_T	Damage centerline ± one grid point	Translation direction – fixed in model
α	0 – 90 deg (other studies)	Angle to determine wind components
φ	0.4 – 1.0 (other studies)	Decay exponent
G_{max}	3.0 – 6.0 (other studies)	Ratio of V_{RV} to V_T
RMW	Estimated damage width ± one grid point	Radius of maximum wind
V_{crit}	70 – 110 mph (EF-scale, studies)	Critical tree fall speed
$\hat{V}$	$(G_{max}+1)V_T$	Maximum wind speed – derived

Summary: Near-Surface Wind Environment

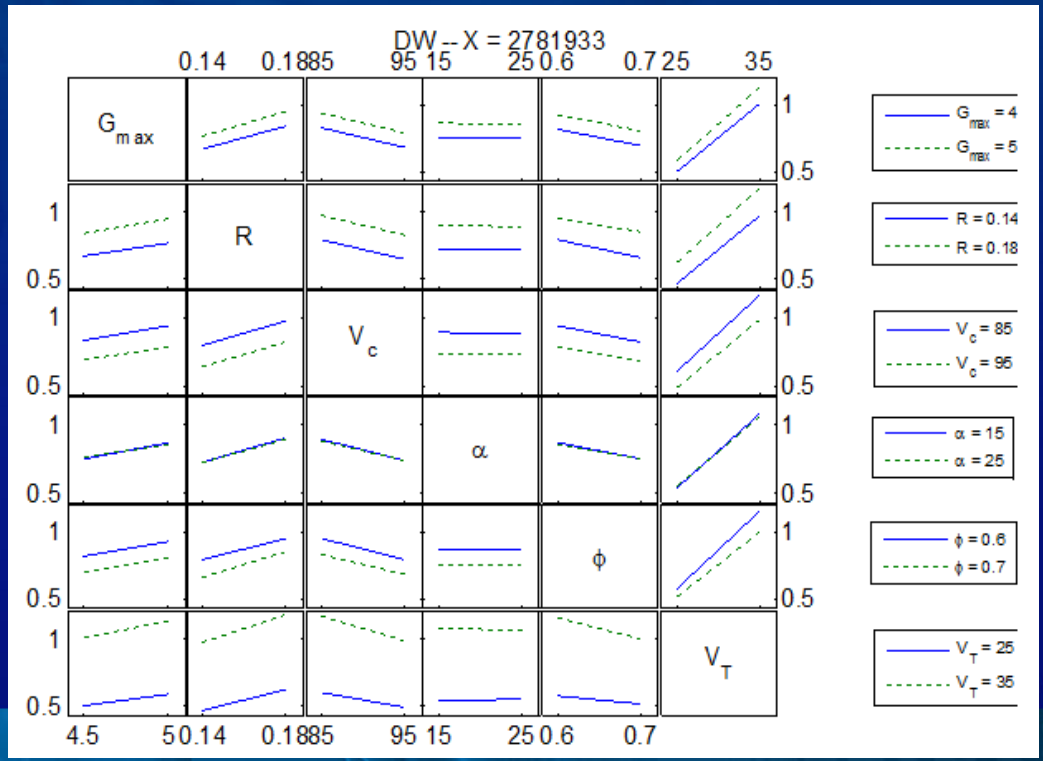
- Indirect Method: Tornado Wind Field Model (cont.)
  - Match to observed tree fall dimensions and directions
  - Used factorial design -- 3^6 (729) model runs using ranges on previous slide



Damage Width (DW): Width of tree fall

Damage Ratio (DR): Ratio of tree fall width on either side of "convergence line" (180 deg to V_T)

Tree Fall Direction (β): Distance from convergence line where tree fall directions were 90 and 180 degrees

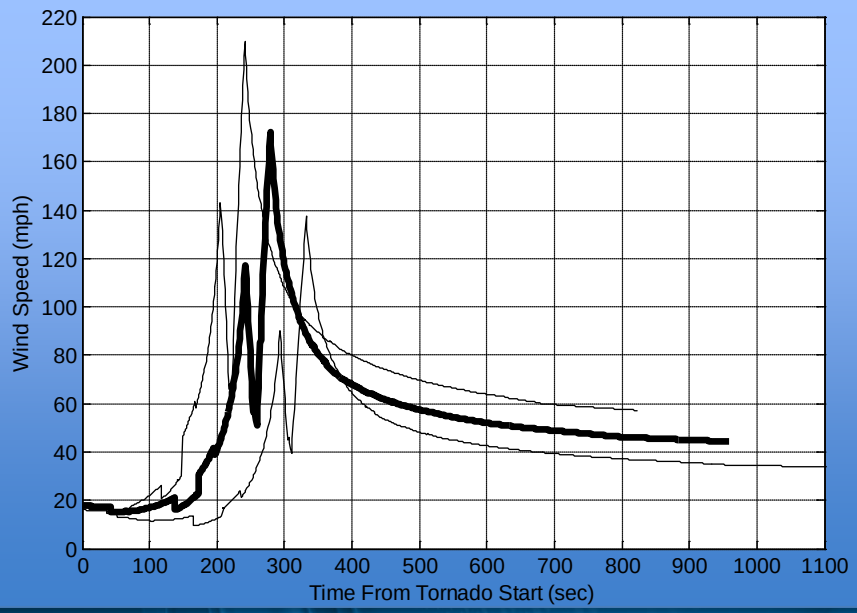


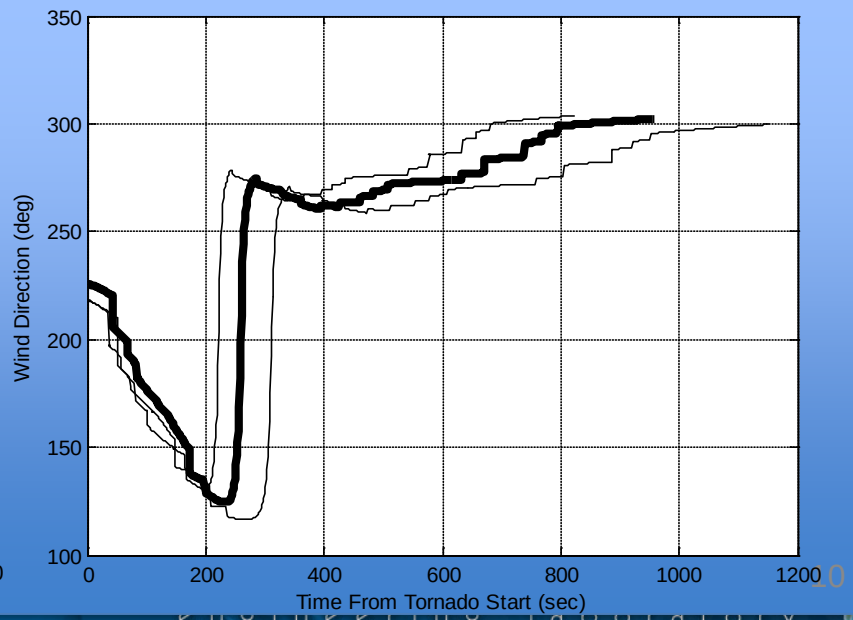
Summary: Near-Surface Wind Environment

- Indirect Method: Tornado Wind Field Model (cont.)
  - Ranges of parameters narrowed, used for final uncertainty

Mile Point (X)	Radius of Maximum Wind (RMW) (miles)	Phi	G_{max}	Alpha (degrees)	V_T (mph)
1.22	0.12–0.14	0.6–0.7	4.5–5.0	15–25	25-35
2.10	0.14–0.18	0.6–0.7	4.5–5.0	15–25	25-35
2.68	0.14–0.18	0.6–0.7	4.5–5.0	15–25	25-35
3.14	0.14–0.18	0.6–0.7	4.5–5.0	15–25	25-35
3.69	0.14–0.18	0.6–0.7	4.5–5.0	15–25	25-35
5.18	0.14–0.18	0.6–0.7	4.5–5.0	15–25	25-35
6.01	0.14–0.18	0.6–0.7	4.5–5.0	15–25	25-35
6.47	0.14–0.18	0.6–0.7	4.5–5.0	15–25	25-35
6.77	0.14–0.18	0.6–0.7	4.5–5.0	15–25	25-35

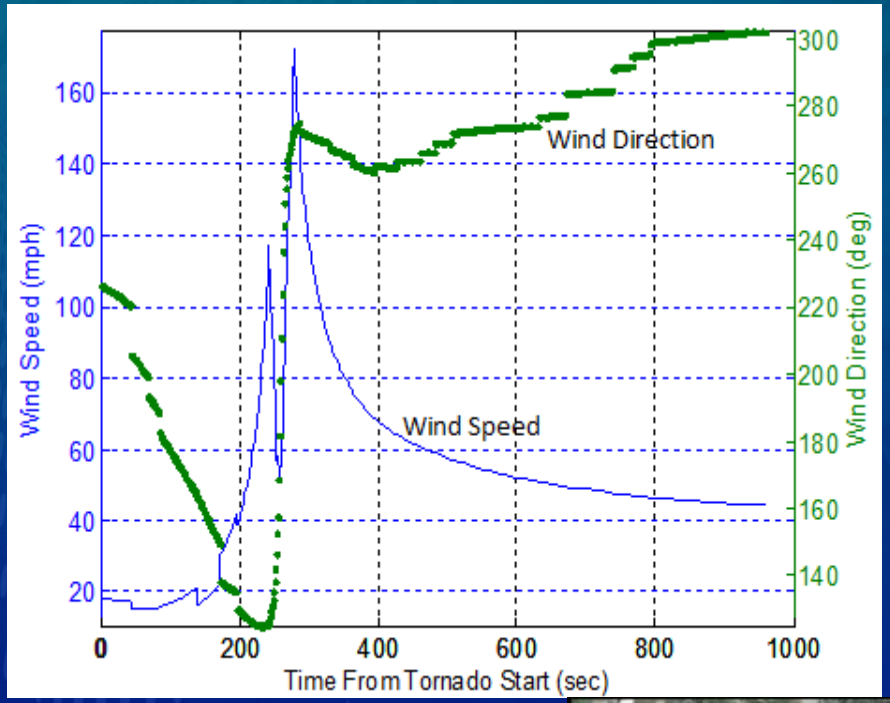
  - Estimated maximum wind speed 175 ± 35 mph; ~80% of uncertainty due to V_T





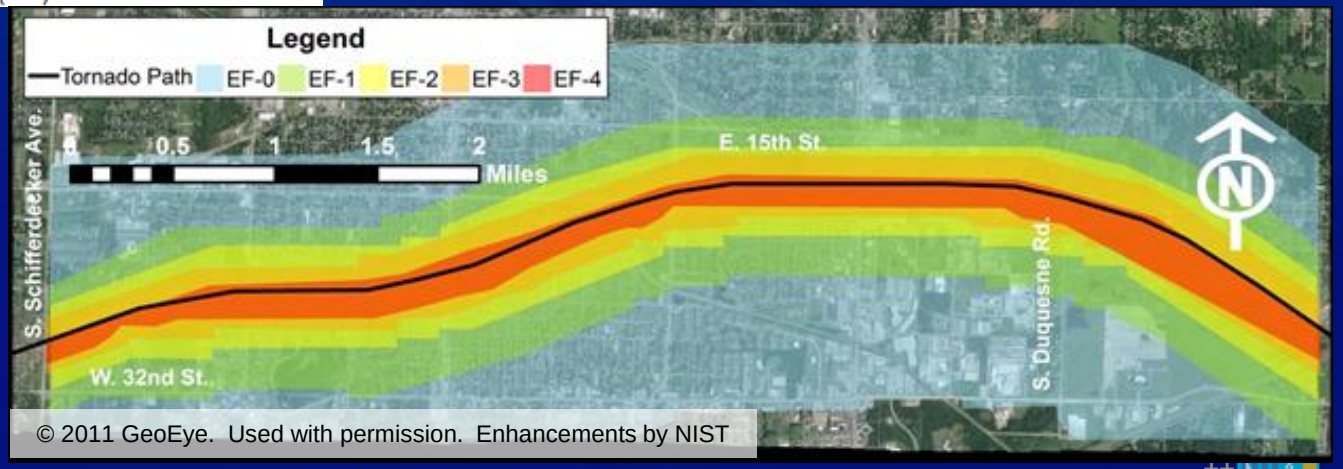
Summary: Near-Surface Wind Environment

- Grid-based simulation – time histories and spatial estimations



Left: Estimated wind speed and direction time history for a specific grid-point

Below: Estimated maximum wind speed associated with EF-number in Joplin



Summary: U.S. Tornado Hazard

- Current "point-based" (tornado-area based) analysis – low probability of occurrence – precludes use in codes and standards
- Risk underestimated for large structures (Twisdale and Dunn, 1983)

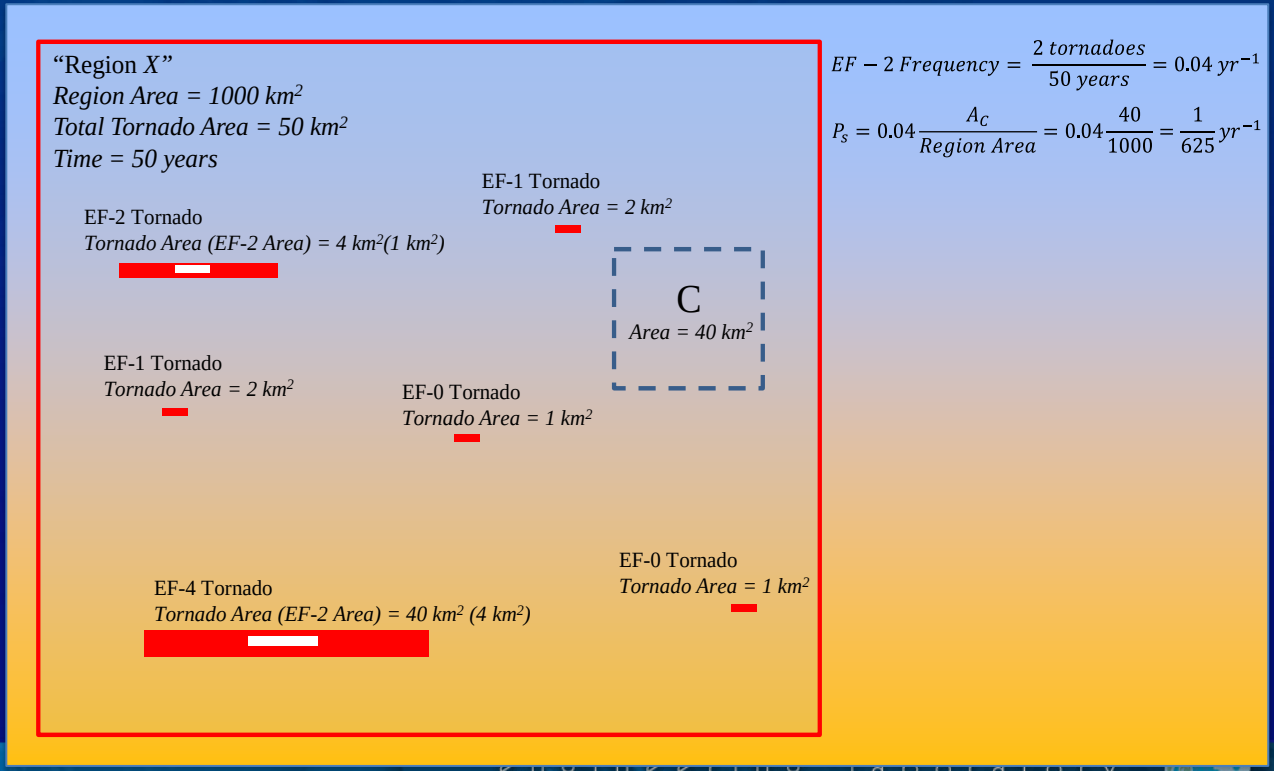
$$P = \frac{Total\ Tornado\ Area}{Region\ Area\ x\ Time} = \frac{50}{1000\ x\ 50} = \frac{1}{1000\ yr} = 0.001\ yr^{-1}$$

$$P_{EF-2} = \frac{P\ x\ EF-2\ Area}{Total\ Tornado\ Area} = \frac{0.001\ (5)}{50} = \frac{1}{10000\ yr} = 0.0001\ yr^{-1}$$

Summary: U.S. Tornado Hazard (Cont.)

- Observations in Joplin:
  - 28% ≥ EF-3 damage for residential structures – 12% in NRC (2007) for rated EF-5
  - 43% ≥ EF-2 damage for residential structures – 24% in NRC (2007) for rated EF-5
  - Similar observations in other tornadoes striking populated areas; could underestimate risk for these areas

- "Spatially-based" analysis
  - Forego tornado areal distribution; use a community-based area
  - Account for tornado frequency



Summary: U.S. Tornado Hazard (Cont.)

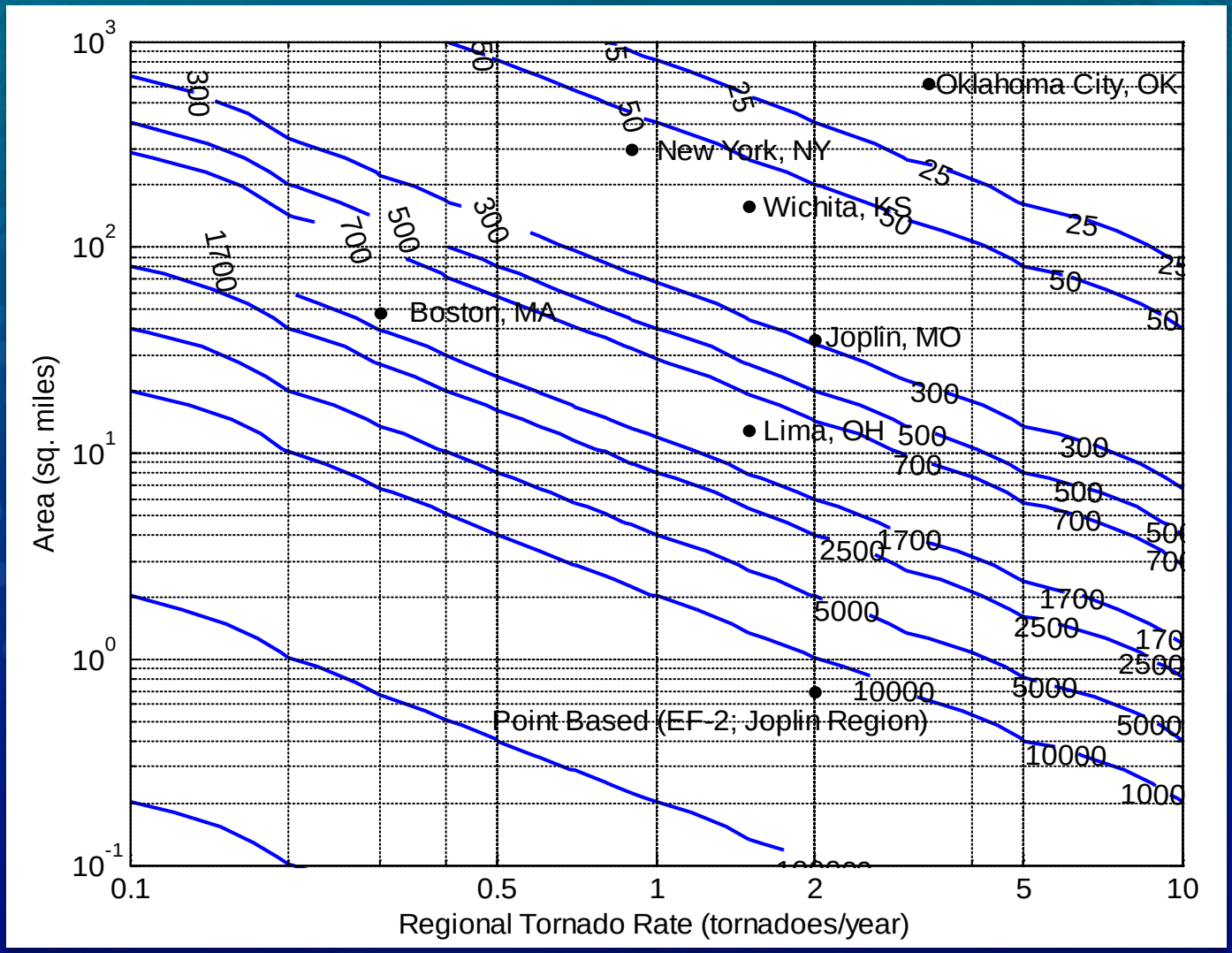


Figure: Mean recurrence interval of tornado rated EF-2 or greater striking any portion of a given city

2. Findings Related to Tornado Hazard Characteristics

Findings – Measurements of the Near-Surface Wind Field in Tornadoes(< 20 m)

- F1: Current radar technology is incapable of determining tornado occurrence and intensity at heights above ground that are relevant to structural engineering design. Closest radar to Joplin was 60 miles (100 km away)

- F2: Reliable measurements of tornadic wind speeds, especially in the most intense tornadoes are lacking or non-existent.

Findings – Measurements of the Near-Surface Wind Field in Tornadoes(< 20 m)

- F3: NIST estimated the maximum wind speeds in the Joplin tornado to be 175 mph with an upper bound of 210 mph. Existing indirect methods have considerable uncertainty in estimating wind speeds for structural design.

- F4: The spatial extent of damaging winds in the Joplin tornado were significantly greater than those expected. For example, EF-3 or greater wind speeds in the Joplin tornado were estimated to account for approximately twice the area than was expected for an EF–5 rated tornado.

Findings – Assessment of Tornado Climatology, Hazard and Risk for Structural Design

- F5: The risk from tornadoes is underestimated using point-based methodology. Actual damage for Joplin and other communities affected by damaging tornadoes were greater than predicted in the point-based methodology.

- F6: In tornadoes rated higher than EF-3, large amount of damaged area experiences wind speeds lower than EF-3. In Joplin, approximately 40 percent of the fatalities and as much as 90 percent of the tornado area were associated with EF–3 or lower wind speeds.

Findings – Limitations of the Enhanced Fujita Scale

- F7: The Enhanced Fujita scale lacks adequate damage indicators (DIs) and corresponding degrees of damage (DODs) for distinguishing among the most intense tornado events. The lack of DIs and DODs and overall nature of the EF-scale results in subjective, non-quantitative assessment of tornado damage.