May 03rd, 2016
NCST Advisory
Committee Meeting

Progress on Implementation of the Joplin Tornado Recommendations

Long Phan, *Leader, Structures Group,* NIST

Melissa Faletra, *Wind Engineer,* ARA Inc.

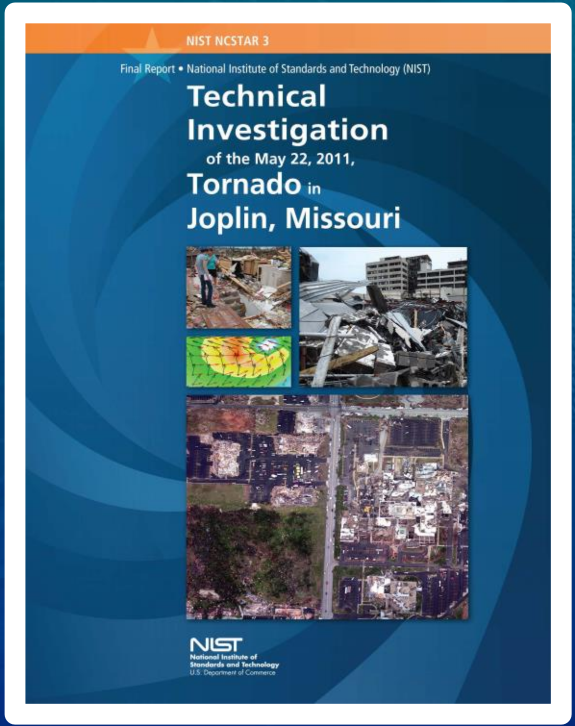
Marc Levitan, *Acting Director, NWIRP,* NIST

Erica Kuligowski, *Leader, WUI Fire Group,* NIST

Dave Jorgensen, *Chief, Warning R&D Div., NSSL,* NOAA

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

Joplin Recommendations



http://dx.doi.org/10.6028/NIST.NCSTAR.3

Sixteen recommendations calling for:

- Nationally accepted standards for tornado–resistant design and design methodologies
- Uniform national guidelines that enable communities to create safe and effective public sheltering strategies, tornado shelter standard for existing buildings, and installation of tornado shelters in new and existing buildings
- National codes and standards and uniform guidance for clear, consistent, recognizable, and accurate emergency communications and joint plans by emergency managers, the NWS, and the media to make sure that accurate and consistent emergency alert and warning information is communicated in a timely manner
- Research, technologies and strategies to advance tornado wind measurements, strengthen emergency communications, increase warning time, derive more accurate tornado hazard maps and improve public response

R #	JOPLIN TORNADO INVESTIGATION RECOMMENDATION SUMMARY	LEAD
1	Development and deployment of technology to measure tornado wind fields	NOAA
2	Archival of tornado event data	NWS
3	Development of tornado hazard maps	NIST
4	Improvement of EF Scale; means for continued improvement; adoption by NWS	NWS
5	Development of performance-based standards for tornado-resistant design	ASCE
6	Development of performance-based tornado design methodologies	NIST, FEMA
7	a) Development of tornado shelter standard for existing buildings; b) Installation of tornado shelters in more buildings in tornado-prone regions	ICC
8	Development of guidelines for public tornado sheltering strategies	FEMA
9	Development of guidelines for selection of best available refuge areas	FEMA
10	Prohibition of aggregate coverings or ballast in tornado-prone regions	ICC
11	Development of requirements for enclosures of egress systems in critical facilities	ICC, NFPA
12	a) Development of tornado vulnerability assessment guidelines for critical facilities; b) Performance of vulnerability assessments by critical facilities in tornado-prone	FEMA
13	Development of codes, standards, and guidance for emergency communications; Development of joint plan by emergency mgrs/media/NWS for consistent alerts	NFPA
14	Deployment of “push” technologies for transmission of emergency information	FEMA
15	Research to identify factors to enhance public perception of personal risk	NSF, NIST
16	Develop technology for real-time, spatially-resolved tornado threat information	NOAA

Summary of March 2015 Briefing

Briefed the committee on the following:

- New project for implementation of Joplin recommendations
- Implementation Plan/Strategy for implementing all 16 recommendations at the earliest possible date, based on code and standard development cycles
- Coordination with standards and codes development organizations (ASCE, ICC, NFPA) and other federal agencies (FEMA, NOAA, NRC, NSF)
- Conducting/coordinating research to enable development of technology for improved emergency communication, tornado hazard characterization, building performance in tornado, and public perception of risk and response in emergencies

Summary of March 2015 Briefing *(Cont'd)*

R #	RECOMMENDATION IMPLEMENTATION (red – in progress, black – in planning)	LEAD
1	Development and deployment of technology to measure tornado wind fields	NOAA
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16	Develop technology for real-time, spatially-resolved tornado threat information	NOAA

Progress Update Since Last Meeting

R #	RECOMMENDATION IMPLEMENTATION (Yellow highlighted – further progress since last mtg)	LEAD
1	Development and deployment of technology to measure tornado wind fields	NOAA
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3	Development of tornado hazard maps	NIST
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Progress Update Since Last Meeting *(cont'd)*

Recommendation 3 (NIST): NIST recommends that tornado hazard maps for use in the engineering design of buildings and infrastructure be developed considering spatially based estimates of the tornado hazard instead of point–based estimates.

- Existing tornado hazard maps do not account for biases and increased risk of strike on large spatial systems
- Contracted with ARA to develop *Tornado Hazard Maps for Building Design.* Presently 1.5 years into a four-year effort
- Progress to date:
  1. Reviewed the state-of-knowledge on tornado climatology, biases in tornado databases, and tornado risk assessment
  2. Conducted data analysis and sensitivity studies of factors affecting tornado data to inform tornado hazard maps development plan
  3. Quantified tornado risk metrics for pilot municipality (Joplin) and sensitivity analysis to guide prioritization of maps development
  4. Held stakeholder workshop to update key private sector, academic, and governmental stakeholders on progress of the tornado hazard maps development effort (September 2015)

ICC, FEMA 361

ANSI/ANS 2.3 (2011)
for Safety-Related Structures and Components of Nuclear Power Plants

* 3-second gust at 33 ft

NUREG/CR-4461

	124	122	120	118	116	114	112	110	108	106	104	102	100	98	96	94	92	90	88	86	84	82	80	78	76	74	72	70	68	66
47	0	144	130	158	142	91	103	159	168	164	198	180	199	186	186	183	213	195	169										191	
45	117	138	127	148	137	107	124	132	150	154	177	194	200	204	205	212	217	213	212	208	183	210						95	166	179
43	84	119	113	71	148	114	147	148	151	162	186	197	201	211	216	221	223	222	220	215	212	215		184	203	176	179	169	172	170
41	133	0	100	0	0	123	146	137	132	158	177	198	207	219	225	225	228	230	223	226	225	220	221	222	204	197	201	200		
39	152	151	130	148	83	146	125	142	123	120	177	191	210	223	229	230	225	227	227	226	225	215	202	203	200	202	172			
37		162	142	81	0	108	130	117	125	151	161	192	215	225	232	229	220	219	224	223	218	205	189	194	201	194				
35		159	134	140	0	138	142	124	112	136	163	194	217	229	235	228	226	227	226	229	219	200	208	206	193	195				
33			76	160	153	140	141	148	72	144	164	198	212	221	226	227	227	226	228	228	219	213	207	214	188					
31					135	140	142	148	145	151	161	187	200	207	214	222	221	223	224	219	215	210	195	193						
29		Region 1 -- 230 mph									123	182	183	200	208	211	211	204	211	205	203	198	199							
27		Region 2 -- 200 mph											203	186	196	173						212	198							
25		Region 3 --160 mph												181	192							227	191							
	124	122	120	118	116	114	112	110	108	106	104	102	100	98	96	94	92	90	88	86	84	82	80	78	76	74	72	70	68	66

R3: Tornado Hazard Maps Development

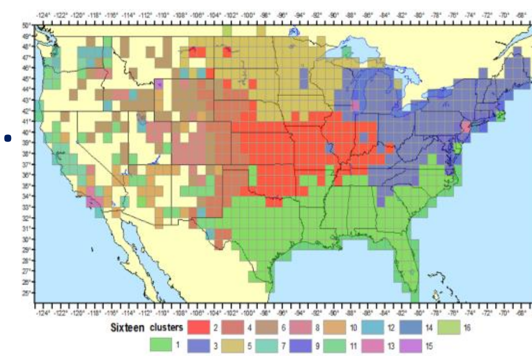
Melissa Faletra, *Wind Engineer*
Applied Research Associates

NCSTAC
Advisory Committee Meeting
May 3, 2016

TORNADO RISK MAPS FOR BUILDING DESIGN
NIST IDIQ CONTRACT SB1431-12-CQ-0014
Overview

EF DOD 4: Mean 97 mph

Applied Research Associates, Inc.
8537 Six Forks Rd, Suite 600
Raleigh, NC 27615



APPLIED RESEARCH ASSOCIATES, INC.
An Employee Owned Company

ARA Project Team and Tools

1. ARA Project Manager: Dr. L.A. Twisdale, Jr.
2. ARA Project Staff
   - Ms. Melissa Faletra (M.S. in M.E.)– Database Modeling/Analysis
   - Dr. Sudhan Banik – Windfield and Damage Modeling; TORDAM Code
   - Dr. Peter Vickery – Damage Modeling
   - Dr. Shahriar Quayyum – FE Modeling
   - Mr. Marsh Hardy (M.S. in Statistics) – Statistics
   - Other Engineers as needed and Ms. Lisa West – Administration
3. ARA Tools
   - TORRISK (Tornado hazard curves), TORDAM (tornado damage modeling), TORMIS (tornado missiles), and tornado data analysis tools
   - CLSPT (statistical cluster analysis for tornado regions),
   - HAZUS (hurricane modeling, building stock databases, damage modeling,…)

Tornado Hazard Modeling Process Overview

Approach

1. **Build on existing modeling and analysis tools**
2. **Probabilistic modeling, bias corrections**
3. **Develop engineering-damage-to-windspeed probabilistic models**
4. **Develop integrated tornado climatological model**
5. **Develop regional variations and iterate**
5. **Finalize PBD metrics and building/system spatial parameters**
6. **Produce regional tornado windspeed hazard curves and associated metrics**
7. **Develop tornado spatial variations/ smoothing for maps**

Data

Databases
- NWS
  - SPC
  - DAT
  - Storm Data
- HAZUS
- Census
- NLCD
- HUD
- •
- •
- •

Literature
- Individual Event Data
- Damage Maps
- Radar
- Models

Tornado Events
- Individual Historic
- New Data
- Field Surveys
  - Damage Model
  - Damage Indicators
  - Tornado Rating, PW, PL
- Validation

Modeling/Analytics

Components
- Reporting Trend
- Reporting Eras
- Population Bias
- F, EF Ratings
- Path Variable
- PLIV
- Region Dependencies
- Land Use-Land Cover
- Random Encounter
- Bias Corrections
- Correlations

Tornado Windfield
- Single Cell Vortex
- Probabilistic Parameters
  - Intensity
  - RMW
  - Translation Speed (V_t)
  - Vertical Profile
  - Core Slope
  - V_r/V_σ (Inflow)
  - Vz (Continuity)
  - Path Width, Path Length
- Scalable

Windspeed -to-Damage
- TORDAM
- Tornado Strike Simulations
- 3D Str. Load Model
- Probabilistic load/ Resistance
- Failure Mode Sequence
- WBD Loads
- Internal Pressure
- Progressive Failure
- Damage States

Climatology & Mapping

Tornado Climatology
- Occurrence Rates
- Tornado Days
- Point Probability
- Path Direction
- Elevation
- Land Fraction
- •
- •
- •

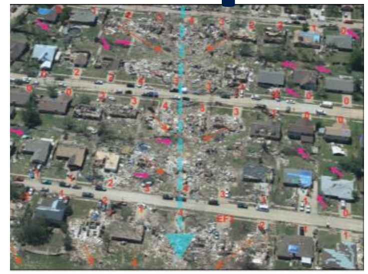
Geospatial Analysis
- Variables
- Cluster Analysis
- Statistical Significance

Regionalization
- Hazard Model
- Risk Metrics
  - Windspeed Exceedance Frequencies
  - Spatial Characteristics of Building Systems
  - WEF ~ 10^{-3} to 10^{-8} per year
  - Other Tornado Effects ?

Tornado Hazard Maps
- Spatial Smoothing for Contours
- Supporting Tables/Data

Damage vs.Windspeeds

- Tornado Intensity Ratings (max windspeed) are based on observed damage.
  - Fujita (F) Scale adopted in 1977, EF in 2007
  - The windspeeds associated with the damage scales are based on subjective estimates
  - There are significant uncertainties associated with damage intensity classification and potential biases in the windspeed estimation
  - Damage based classifications produce 2 major biases in the database: under-classifications from random encounters with DI and the use of default EF0 classifications for unknown
  - The tornado climatology development needs to be based on engineering estimates of windspeeds, validated as much as possible
- A significant task of this project is to develop engineering- based, probabilistic damage-to-windspeed relationships for the NIST/ASCE tornado windspeed maps.



EF DOD 4: Mean 97 mph

Hurricane Andrew: 155-165 mph

Project Schedule

Task	Year 1				Year 2				Year 3				Year 4			
	Oct. 2014 → Sept. 2015				Oct. 2014 → Sept. 2015				Oct. 2014 → Sept. 2015				Oct. 2014 → Sept. 2015			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1. Databases	SPC, DAT, Storm Data - Data Analysis				Census, HAZUS, Data Cleansing, EF0 Bias…				NLCD, HUD (HAZUS)							
2. Tornado Event Data & Field Work	PLIV				Radar (limited), Damage , EF, PL & PW Surveys				Damage, EF, PL & PW Surveys							
3. Tornado Windfield Parameters	TORMIS (TORRISK) minimal update				Additional updates, Rmax, …				Finalize Parameters							
4. Damage to Windspeed					Single family residential buildings (preliminary)				Additional Damage Indicators				Vali-dation			
5. Regionalization					Initial Testing				Preliminary Regions				Final Regions			
6. Tornado Hazard Simulations & Spatial Risk	Joplin, Initial Sensitivity Analysis				Initial Regional Windspeeds				Preliminary Regions & Map Metrics				Final Hazard Metrics			
7. Maps											Contours & Testing		Review Preliminary Maps		Final Maps	
8. Reports, Papers, Publications	Stakeholders Meeting				Conference & Journal Submittals				Conferences & Journal Publications				Conferences & Journal Publications			Final Report

NOTE: Year 3-4 Scope not finalized

Outline

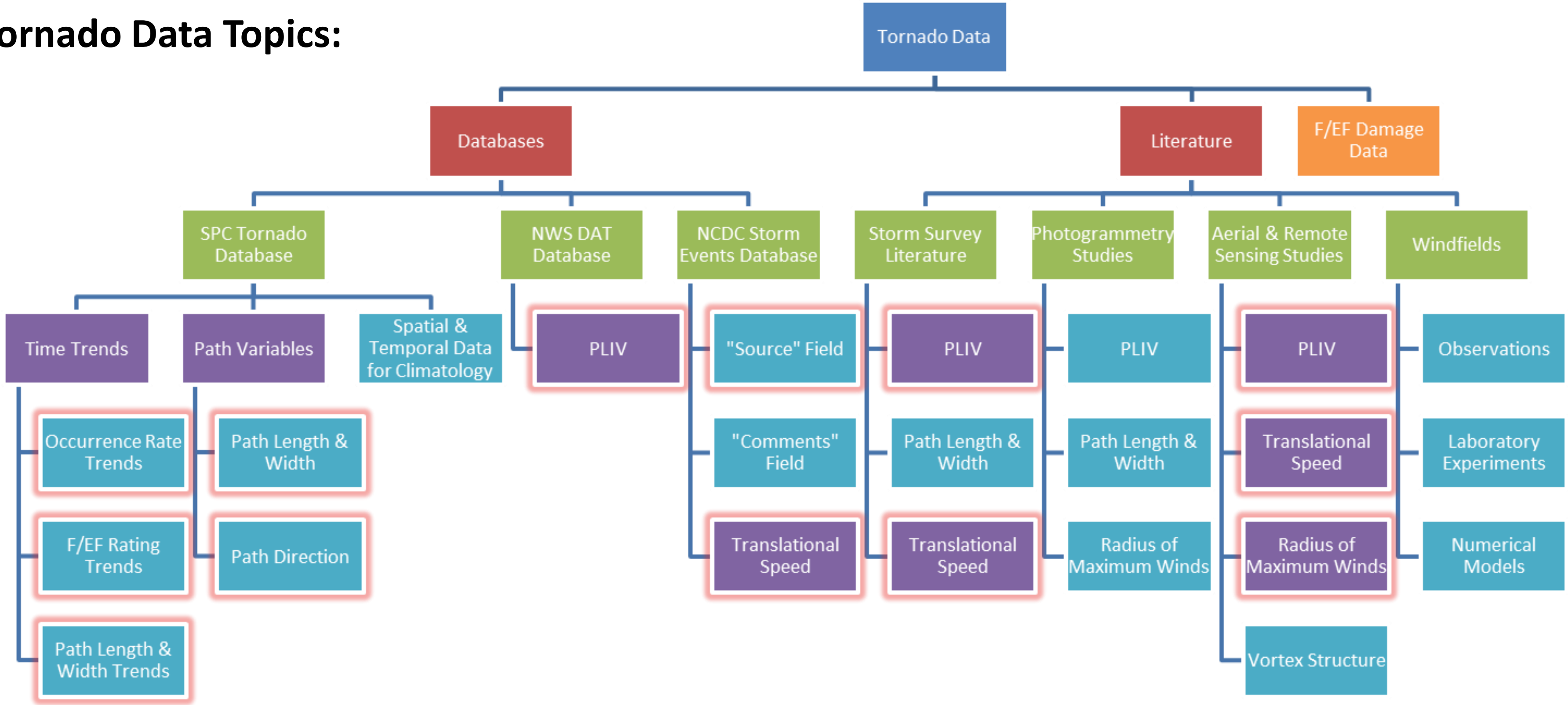
1. Tornado Data
2. Tornado Windfield Model
3. Year One Tornado Windspeed Sensitivity Analysis
4. Preliminary Probabilistic Analysis of F/EF Windspeeds
5. Preliminary Quantification of Population Bias in Tornado Data
6. Tornado Climatology Regionalization Progress
7. Summary

1. Tornado Data Overview

Tornado Data:

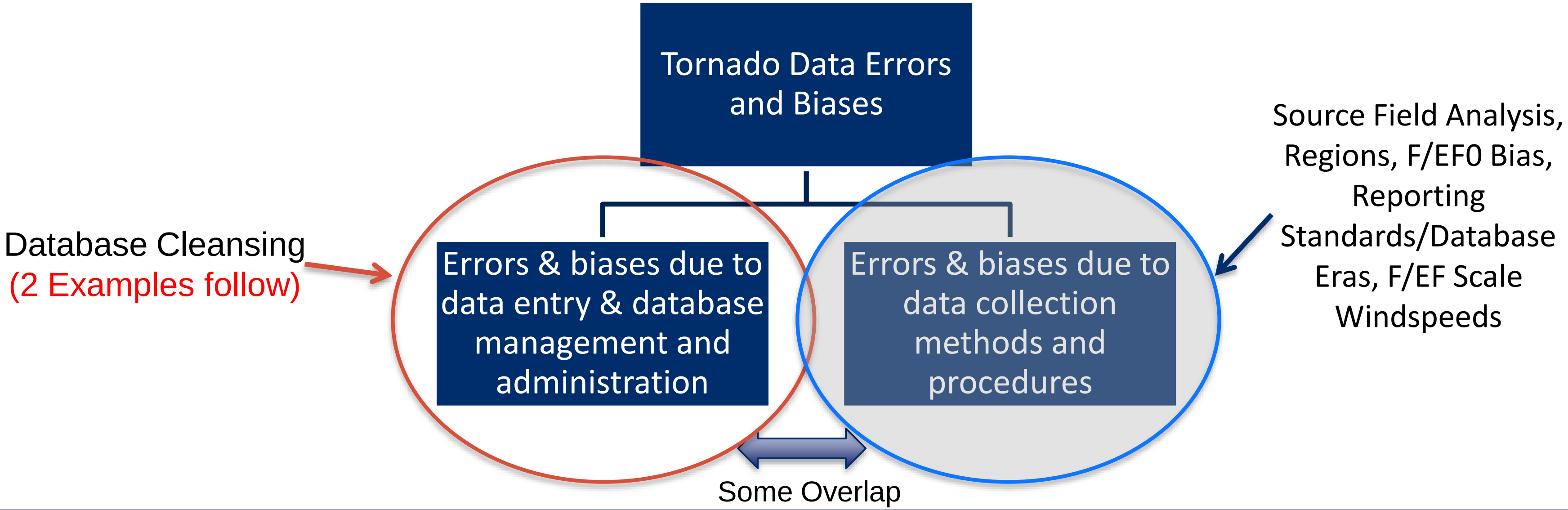
- Used to determine the tornado climatology and contains the inputs that drive the model
  - Source of information regarding the key parameters of path length, path width, intensity rating, number of reports, and location
- Has many issues including spatial and temporal biases, errors, and uncertainties
  - Cannot simply use the raw data
  - Must be aware of any data issues and adjust the data that we use in our models accordingly

Tornado Data Topics:



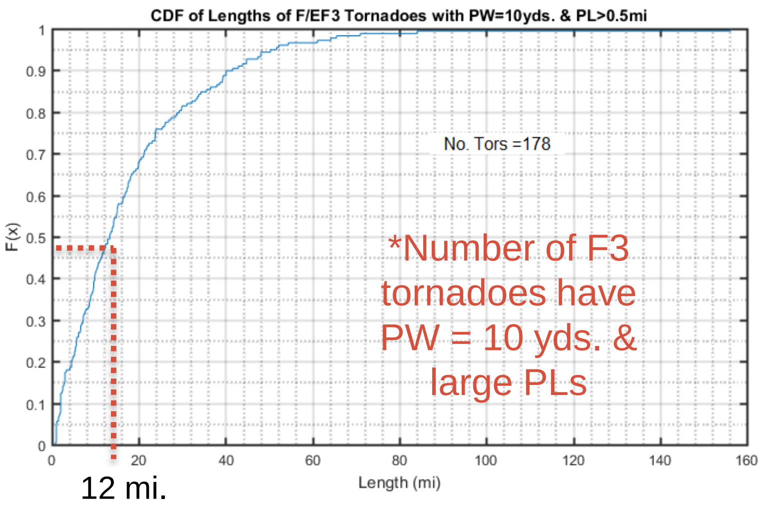
Database Cleansing

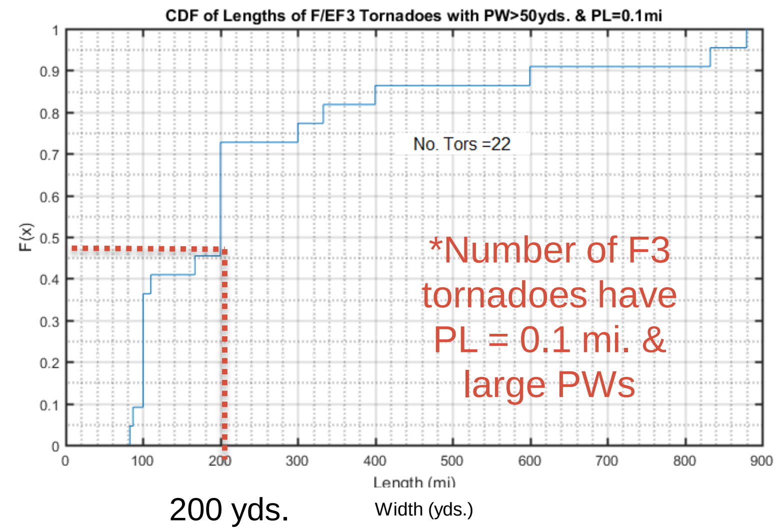
- Identify and understand errors and biases within the SPC database that are due to data entry and database maintenance
  - E.g. discrepancies, zero values, missing values, default values etc.
- Model and correct for these errors with approaches consistent with available level of effort
- Approach can be considered to include both component and system level analysis/modeling

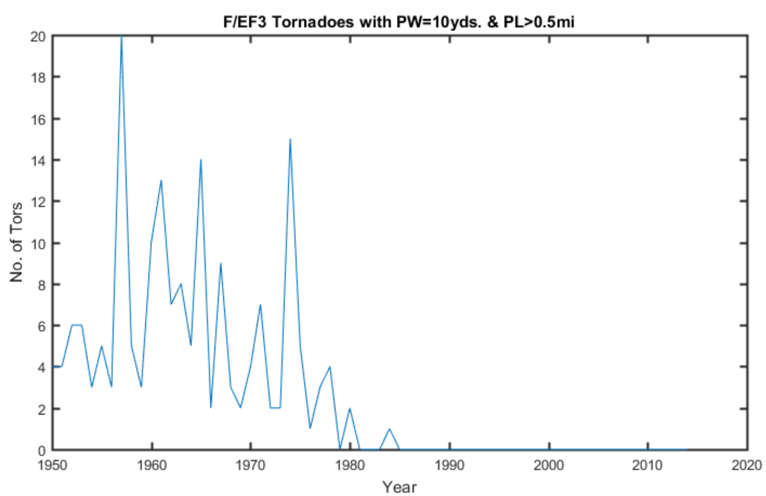


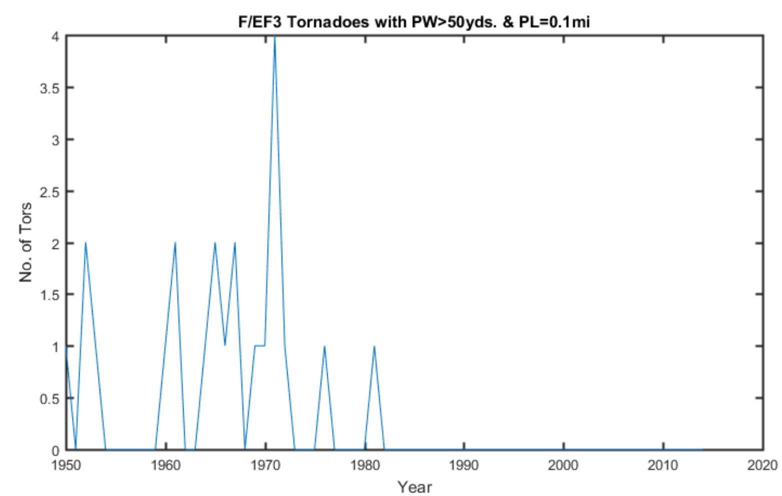
Unrealistically Small PW & PL : F3 Intensity

F/EF3









Units: PL – miles, PW – yards, Area – sq. miles

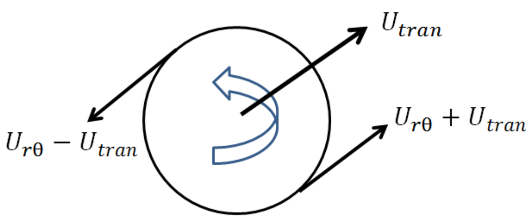
Table of F4-F5 Default PL & PW Corrections

Date	Location	Rating	SPC			Storm Events Database		Storm Data Pub.		Grazulis		ARA Updated		
			PW	PL	Area	PW	PL	PW	PL	PW	PL	PW	PL	Area
3/21/1952	Cross, Co., AR	4	880	0.1	0.05	880	0	NA	NA			880	TBD	NA
3/21/1952	Lonoke, AR	4	10	7.6	0.04	417*		NA	NA	800	70	417	7.6	1.80
5/1/1953	Choctaw Co., AL	4	100	0.1	0.01	100	0	NA	NA	200	10	100	10	0.57
6/27/1953	Adair Co., IA	5	100	0.1	0.01	100	0	NA	NA	200	10	100	10	0.57
5/10/1953	Wayne, IA	4	10	6.4	0.04	33	6.4	NA	NA	200	8	200	6.4	0.73
5/10/1953	Hancock, Cerro Gordo, IA	4	10	26.6	0.15			NA	NA	800	28	800	26.6	12.09
5/1/1954	Pottawatomie, Lincoln, Creek, OK	4	10	59.2	0.34	33	59.2	NA	NA	800	30	800	59.2	26.91
6/27/1955	Scottsbluff, Morrill, NE	4	10	26	0.15	33	26	NA	NA	400	11	400	26	5.91
7/7/1955	Lincoln/Lyon, MN	4	10	30	0.17	33	30	NA	NA	200	20	200	30	3.41
1/22/1957	Sequoyah, OK	4	880	0.1	0.05	880	0	NA	NA	50	5	880	5	2.50
12/19/1957	Columbia, Ouachita, AR	4	10	17.7	0.10	33	17.7	NA	NA	300	15	300	17.7	3.02
4/15/1958	Polk, Co., FL	4	300	0.1	0.02	300	0	NA	NA	300	5	300	5	0.85
5/4/1960	Pottawatomie, OK	4	10	8	0.05	33	8	?	?	400	6	400	8	1.82
5/5/1960	Sequoyah, OK	4	10	5.4	0.03	33	5.4	?	?	200	5	200	5.4	0.61
5/19/1960	KS	4	10	20.6	0.00	33	20.6	.5-3 mi**				TBD	20.6	NA
5/30/1961	NE	4	10	48.1	0.27	33	48.1	narrow	40***	400	45	400	48.1	10.93
6/29/1961	MT	4	10	15.9	0.09	33	15.9		15			TBD	15.9	NA
5/5/1964	Greeley, Boone, NE	4	10	51.2	0.29	33	51.2	narrow	60			TBD	51.2	NA
4/11/1965	St. Joseph, Elkhart, IN	4	10	21.2	0.12	33	21.2			400	22	400	21.2	4.82
4/11/1965	Branch, Hillsdale, Lenawee, Monroe, MI	4	10	80.5	0.46	1760*****	80.5	.5-1mi	70			1760	80.5	80.50
4/11/1965	Blackford, Wells, Adams, IN; Mercer, Van wert, OH	4	10	52.5	0.30	33	52.5			600	55	600	52.5	17.90
5/8/1965	Howard, NE	4	10	78.9	0.45	33	78.9	narrow	80	400	90	400	78.9	17.93
5/8/1965	Hall, Boone, Antelope, NE	4	10	125.7	0.71	33	125.7	narrow	120	400	85	400	125.7	28.57
6/10/1967	Blaine Co., OK	4	10	0.1	0.00	33	0			100	5	100	5	0.28
2/21/1971	Warren, Yazoo, Holmes, MS	4	10	65.2	0.37	33	65.2		69	800	70	800	65.2	29.64
4/19/1972	Carter, Murray, Garvin, OK	4	10	28.2	0.16	33	28.2	50	20-25	50	27	50	28.2	0.80
4/3/1974	Anderson, Franklin, Scott Co., KY	4	10	79.4	0.45	33	80			800	36	800	36	16.36
4/3/1974	Perry, Crawford, Harrison, Washington, Clark, Scott Co., IN	5	10	68	0.39	33	68	700	67	1000	62	700	68	27.05
4/3/1974	Hancock, Rush, Henry, IN	4	10	18.9	0.11	33	18.9	1000	21	800	20	1000	18.9	10.74
4/3/1974	Jeffereson, Oldham, KY	4	10	18.5	0.11	33	18.5			200	21	200	18.5	2.10
4/3/1974	Hardin, Nelson, Spencer, KY	4	10	37.9	0.22	33	37.9			400	42	400	37.9	8.61
4/3/1974	Green, Taylor, KY	4	10	20.2	0.11	33	20.2			800	29	800	20.2	9.18
4/3/1974	Cumberland, Clinton, Wayne, KY	4	10	38.4	0.22	33	38.4	440-1760	35	800	30	800	38.4	17.45
4/3/1974	Garrard, Madison, Clark, KY	4	10	31.9	0.18	33	31.9	133-400	22	300	35	300	31.9	5.44
4/3/1974	Wayne, McCreary, KY	4	10	16.1	0.09	33	16.1			500	26	500	16.1	4.57
6/18/1975	Custer, NE	4	10	15.2	0.09	33	15.2	100-500			15	300	15.2	2.59
6/3/1980	Allegheny, Westmoreland, Armstrong, PA	4	10	11.8	0.07	33	11.8		14		14	TBD	11.8	NA
4/27/1984	Waukesha, WI	4	10	6.5	0.04	10	6.5	100	6.5	100	6.5	100	6.5	0.37
Total (not including TBD tors)					6.04	Total (not including TBD tors)								356.62
Mean (not including TBD tors)					0.18	Mean (not including TBD tors)								10.81

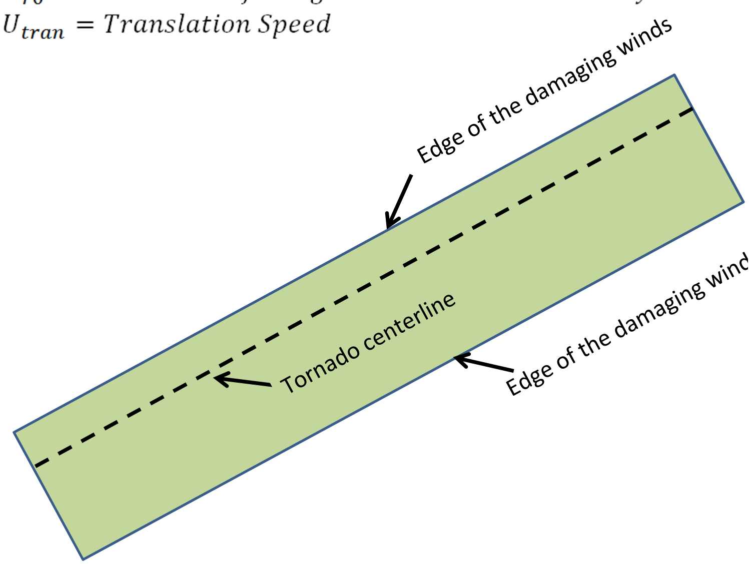
5,799% Increase in Total Area

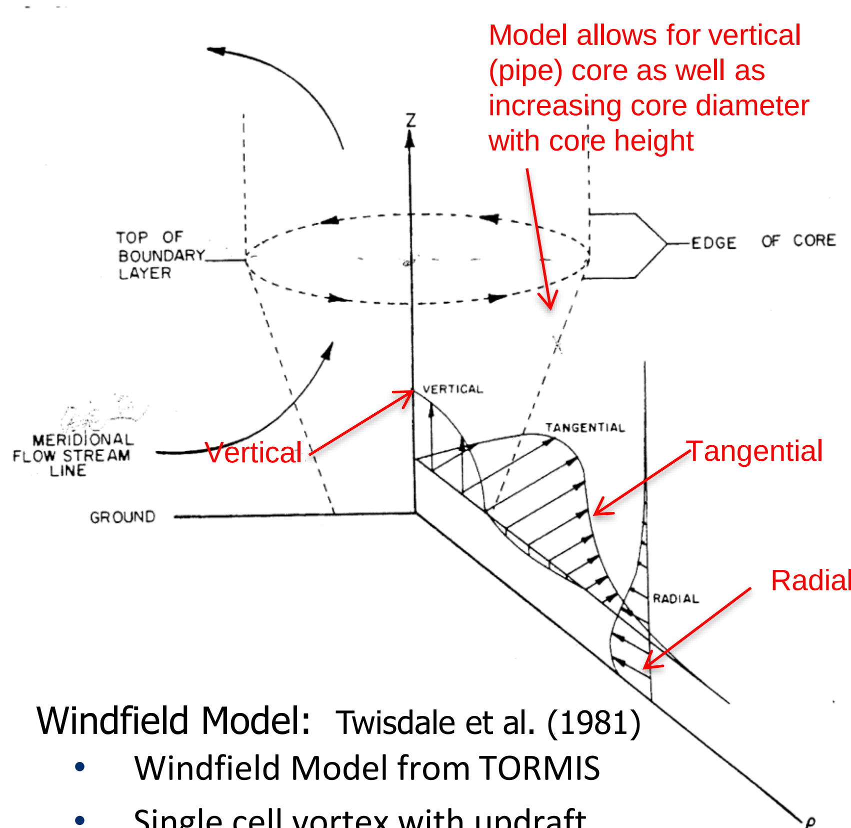
2. Tornado Windfield Model

Three dimensional windfield with radial and heightwise variation.



$U_{r\theta}$ = vector sum of Tangential and Radial velocity
U_{tran} = Translation Speed





Windfield Model: Twisdale et al. (1981)

- Windfield Model from TORMIS
- Single cell vortex with updraft
- Vertical flow derived from continuity
- Probabilistic and Scalable to Width
- Used for damage modeling and windspeed exceedance calculations

Update to Tornado Path Length Intensity Variation Model

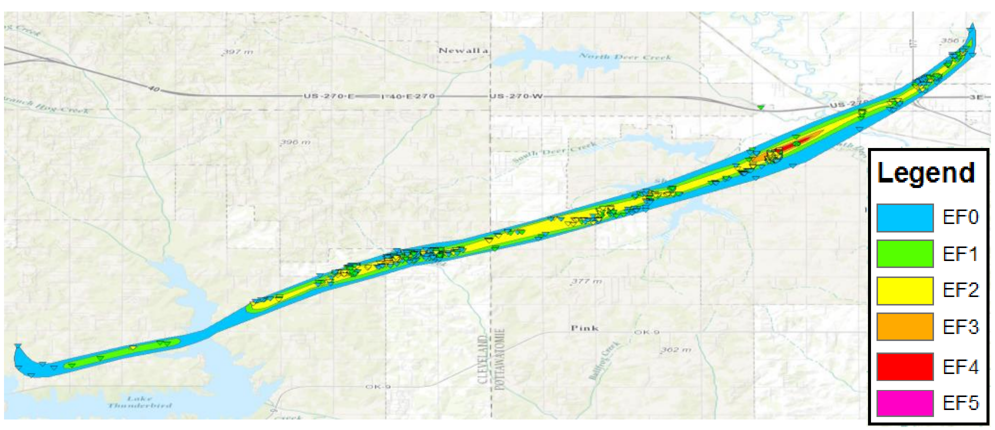
- A tornado’s intensity varies throughout its lifecycle, consisting of a formation stage, mature stage, and dissipation state
- This path length intensity variation (PLIV) is a critical input in tornado windspeed hazard analysis

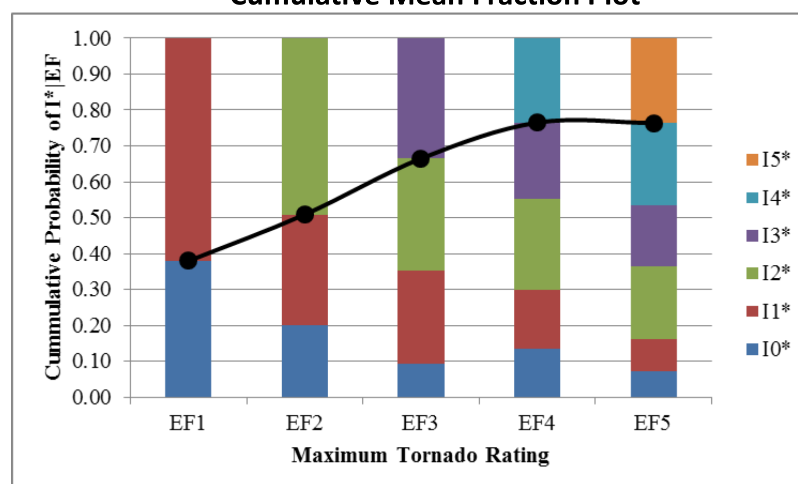
Year One:

- Collected and analyzed PLIV data to update our model for the creation of the tornado risk maps for building design
- There are a limited number of observations of PLIV for the entire tornado lifecycle - Hence, our year 1 effort focused on damage based PLIV data

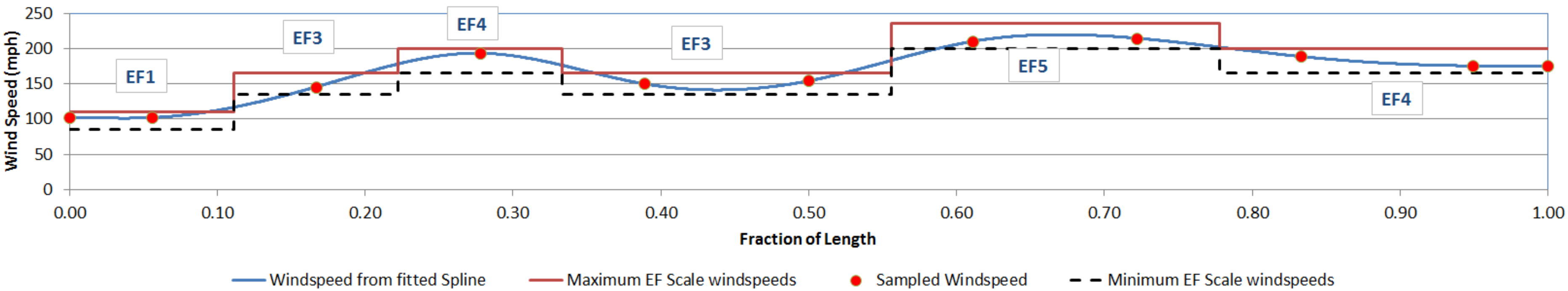
Example Results:

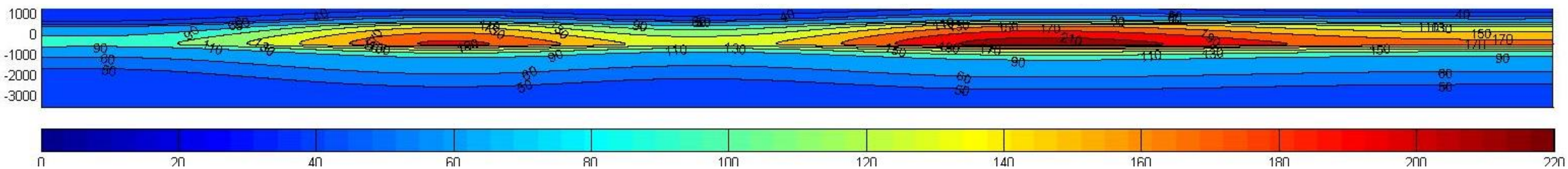
Cumulative Mean Fraction Plot





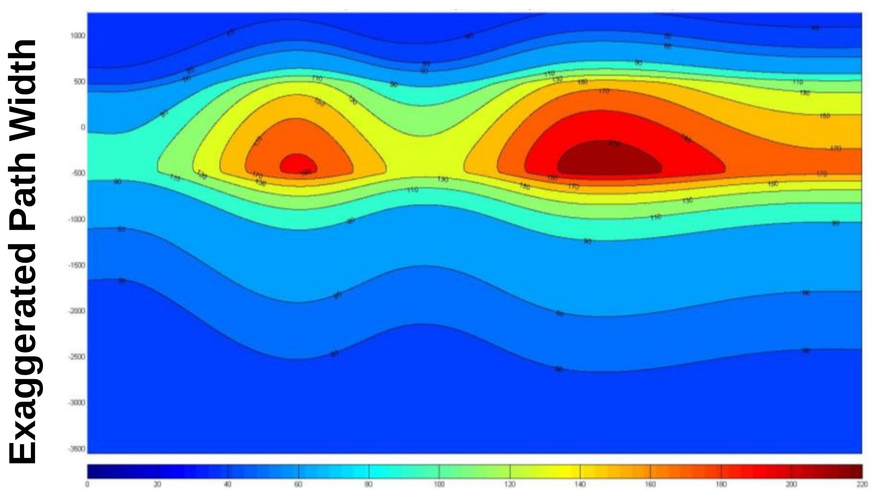
Simulated Wind Swath using PLIV





Maximum Horizontal Windspeed (mph)

Direction of Tornado

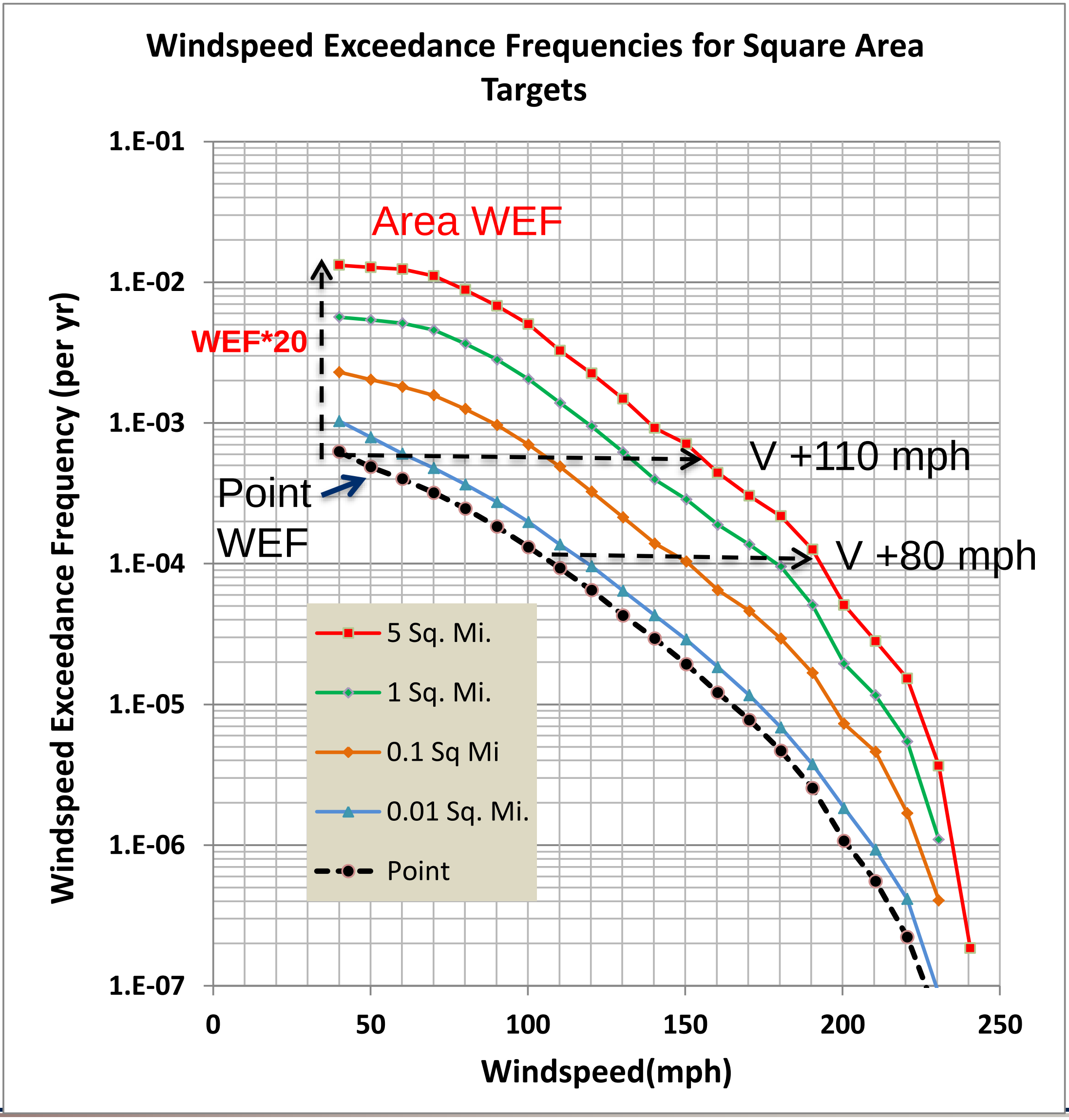


- Spline fitting of sampled windspeed at each EF-scale segment.
- Sampled windspeeds are assigned at the midpoint of each segment.

TORNADO RISK MAPS FOR BUILDING DESIGN. NIST IDIQ SB1431-12-CQ-0014.

3. Windspeed Exceedance Frequencies(WEF)

- Windspeed Exceedance Frequency plot quantifies the tornado windspeed hazard risk for a site
- Spatial Size of Target is a significant effect due to small path widths of typical tornadoes
- Due to small areas within tornadoes with the highest winds, the greatest WEF sensitivity occurs at high windspeeds.
- These curves are Year One Joplin hazard curves bases on EF scale windspeeds, capped at 234mph for these examples
- Used EF era path lengths and widths



200 MPH WEF Sensitivity Results (Year One)

Group	Calc	Model/Parameter	200 mph Windspeed Ex. Freq.			Ratio			Range
			Low	Base	High	Low	Base	High	H/Min
Occurrence	1	Random Unc. in Mean Occ Rate				0.96	1.00	1.04	1.08
	2	Intra-Annual (Seasonal) Variability	Est. : Occ, EF Dist, L,W			0.45	1.00	2.70	6.00
	3	Inter-Annual (Year to Year) Randomness, Polya				0.47	1.00	1.67	3.55
Path	4	Path Length and Width Models	1.05E-06	1.22E-06	1.50E-06	0.87	1.00	1.23	1.43
Windfield	5	PLIV	1.30E-06	1.22E-06	1.63E-06	1.07	1.00	1.34	1.34
	6	RMW	6.08E-07	1.22E-06	1.92E-06	0.50	1.00	1.58	3.15
	7	Translational Speed	1.10E-06	1.22E-06	1.68E-06	0.91	1.00	1.38	1.52
	8	Radial Inflow	9.72E-07	1.22E-06	1.58E-06	0.80	1.00	1.30	1.63
Damage Scale and Damage to Windspeed	9	F/EF Scale Distribution	7.53E-07	1.22E-06	3.90E-06	0.62	1.00	3.21	5.18
	10	Windspeed Given Damage	2.44E-06	1.22E-06	1.28E-05	2.01	1.00	10.54	10.54
	11	Dist. Of Windspeed Given Damage	6.79E-07	1.22E-06	1.61E-06	0.56	1.00	1.33	2.37
Statistics		Min				0.45	1.00	1.04	1.08
		Median				0.80	1.00	1.38	2.37
		Avg				0.84	1.00	2.48	3.44
		Max				2.01	1.00	10.54	10.54
		Product, Range of Product				0.05	1.00	987	20822
		Sq Rt Prod, Range of Sq Rt of Product				0.22	1	31	144

Analytically Determined

Relevant only to short term operational risk

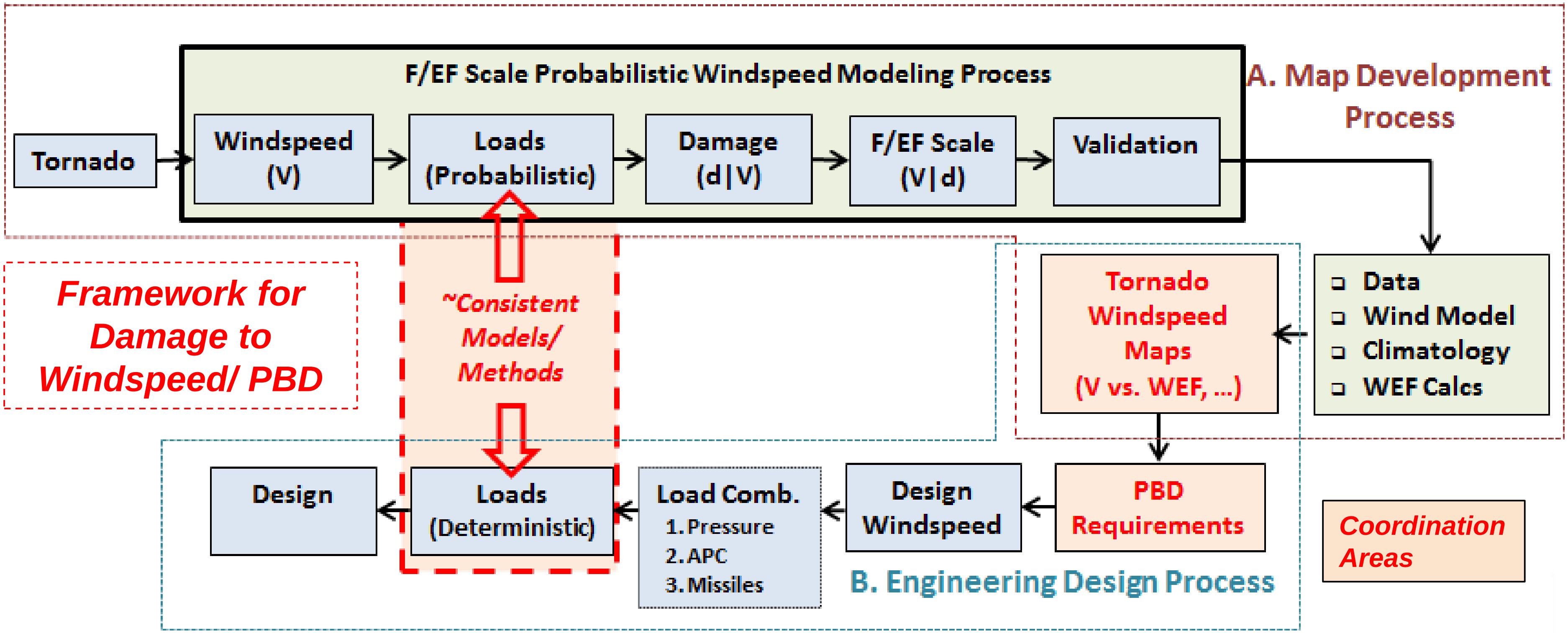
Relevance depends on structure lifetime

Under-estimated

Most Sensitive: Windspeed given damage, F/EF Dist, Windfield, Rmax, Inter-annual variability (within year risk)

Range > 1.50

4. Probabilistic Analysis of F/EF Windspeeds



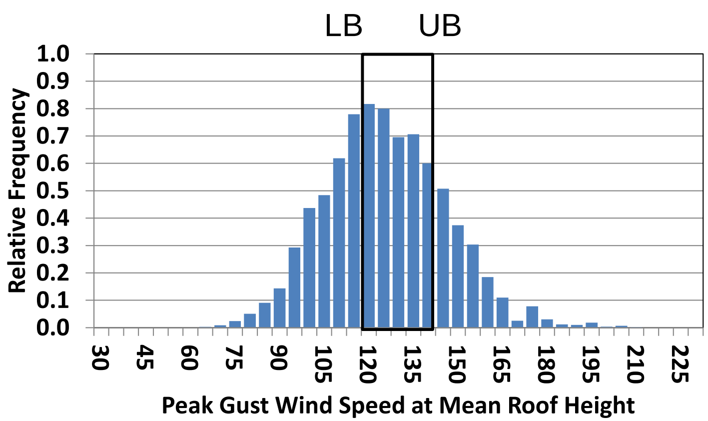
- Framework includes several coordination points: reference windspeed/profile, loads/load combinations, vertical winds and coefficients, PBD range of WEF, …
- Our plan is to produce tornado windspeed maps that can be used with to achieve PBD objectives with some confidence that the designs will perform to the developed windspeeds AND associated loads
- Probabilistic Modeling of F/EF Damage to develop a windspeed-based climatology is a key element of the project. (Key damage indicators only)

Probabilistic Modeling of DoD Windspeeds

- Develop probabilistic distributions of wind speeds for the most common DI's.
- Tornado damage model is based on the HAZUS methodology, and has been initiated under IR&D funding

DOD*	Damage description	Exp**	LB	UB
1	Threshold of visible damage	65	53	80
2	Loss of roof covering material (<20%), gutters and/or awning; loss of vinyl or metal siding	79	63	97
3	Broken glass in doors and windows	96	79	114
4	Uplift of roof deck and loss of significant roof covering material (>20%); collapse of chimney; garage doors collapse inward or outward; failure of porch or carport	97	81	116
5	Entire house shifts off foundation	121	103	141
6	Large sections of roof structure removed; most walls remain standing	122	104	142
7	Exterior walls collapsed	132	113	153
8	Most walls collapsed in bottom floor, except small interior rooms	152	127	178
9	All walls collapsed	170	142	198
10	Destruction of engineered and/or well constructed residence: slab swept clean	200	165	220

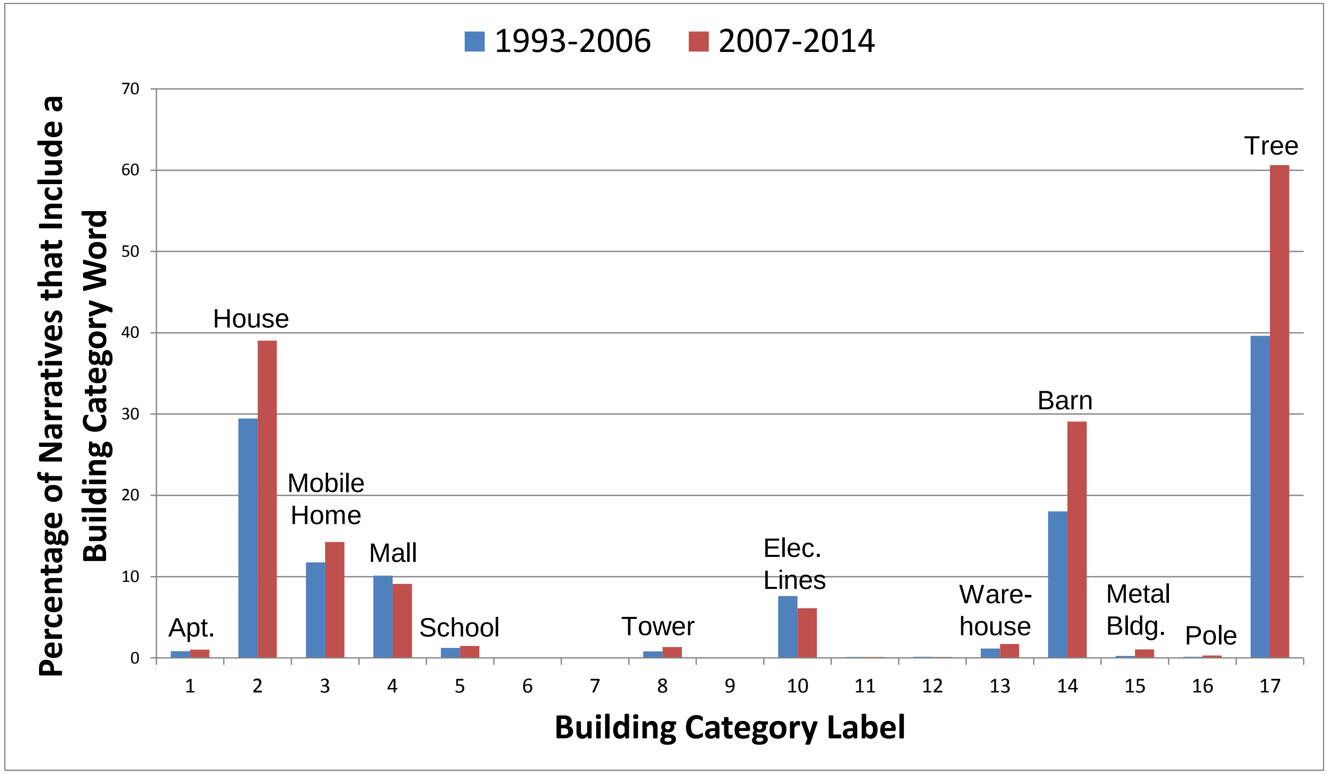
* DOD is degree of damage **Wind Speed values are in mph



SF House Damage Modeling in Year 2

Most Common Damage Indicators Used to Rate Tornadoes: F and EF Scale

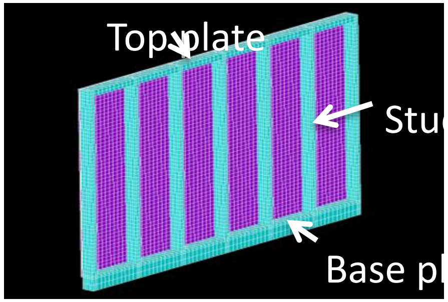
Label	Building Type Category
1	Apartment, condo, townhouse
2	House
3	Mobile home
4	mall, shopping center
5	school
6	low rise building
7	high rise building
8	Tower
9	University, Institutional building
10	electrical transmission lines
11	hotel
12	motel
13	warehouse, factory
14	barn, outbuilding
15	metal building
16	pole
17	tree



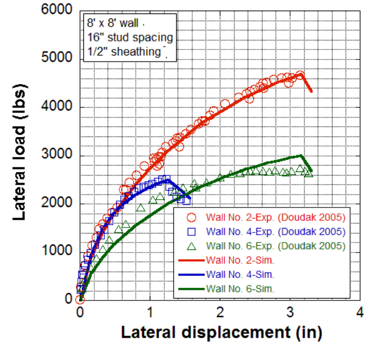
The most commonly used DI's to rate tornado damage intensity are similar for both the F-Scale era and the EF-Scale era

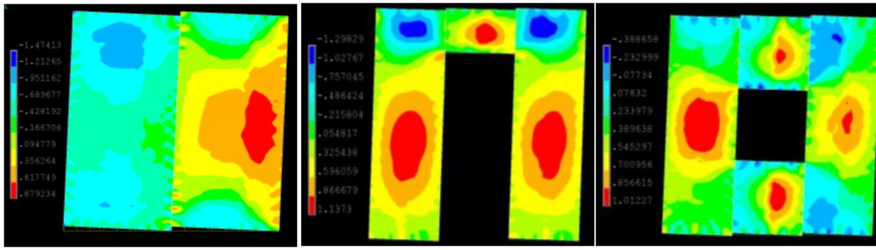
FE Modeling of Wood Frame Walls

- In year two, single family residential structures are being modeled for damage to windspeed relationships. ARA's HAZUS and HURLOSS wood frame models are being used as a starting point.
- FE models of wood stud wall failure are being developed for resistance models in ARA's TORDAM tool. In-plane shear and out-of-plane bending failure mechanisms are currently being studied.
- The models have been validated against experimental studies from literature
- The experimentally validated models were used to perform sensitivity analysis of racking and bending strength of wood walls
- Parametric models yielded very good correlation with FEM produced data and the data from the literature

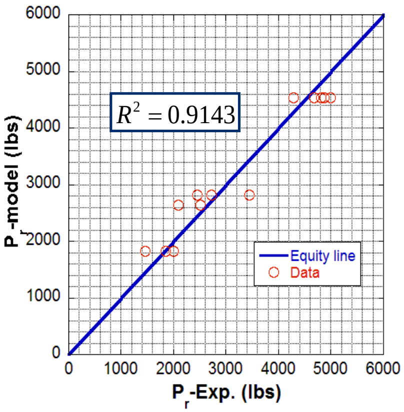


Racking

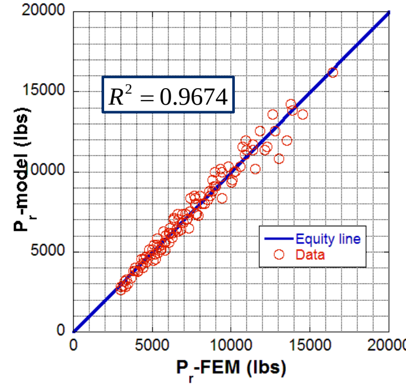




Model vs. Exp.

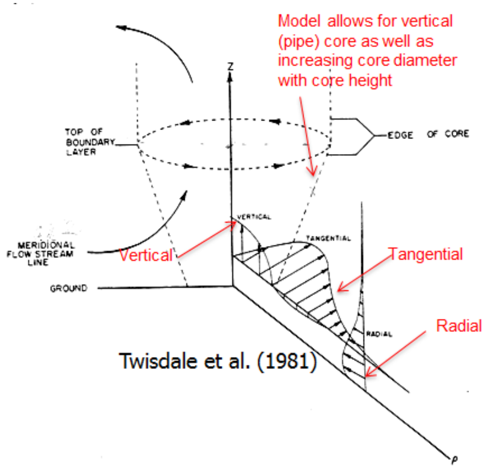


Model vs. FEM

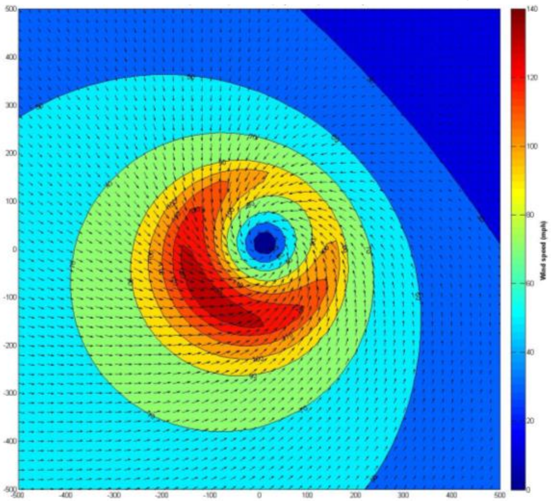


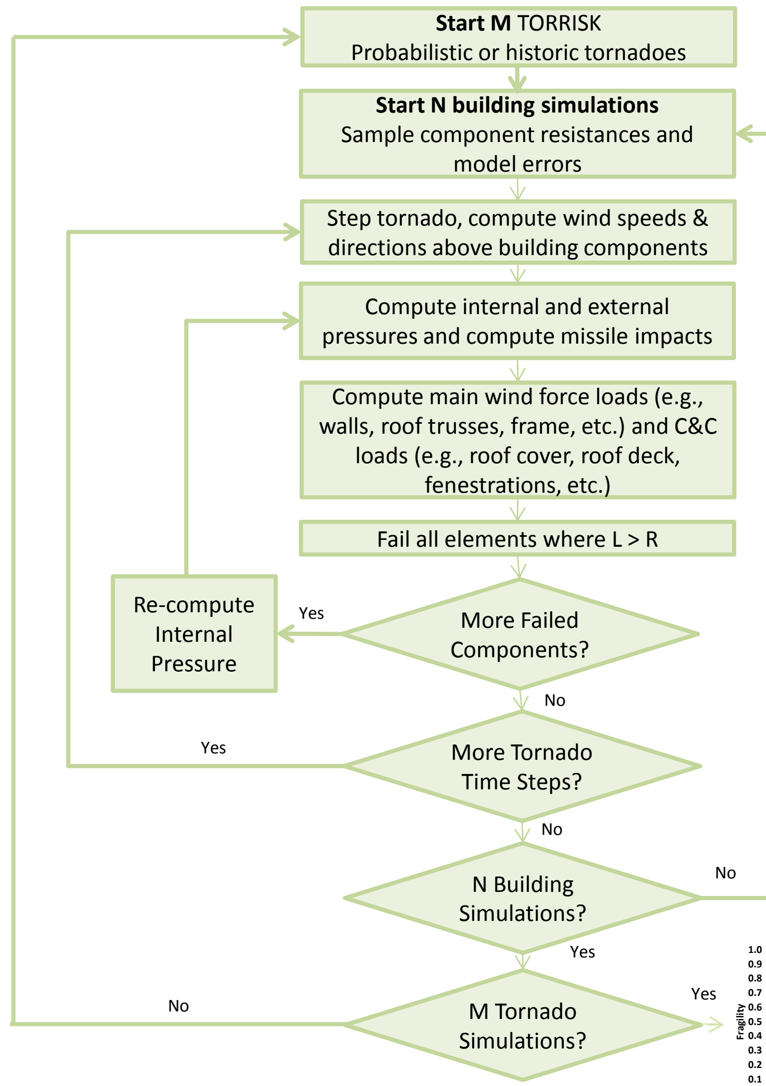
TORDAM 3-D Simulations

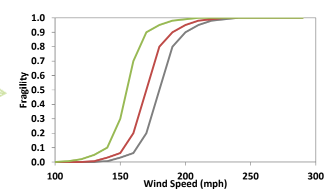
Tornado Windfield Model



Twisdale et al. (1981)





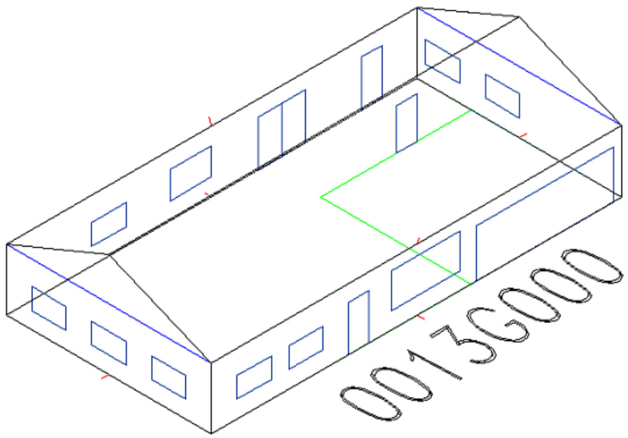


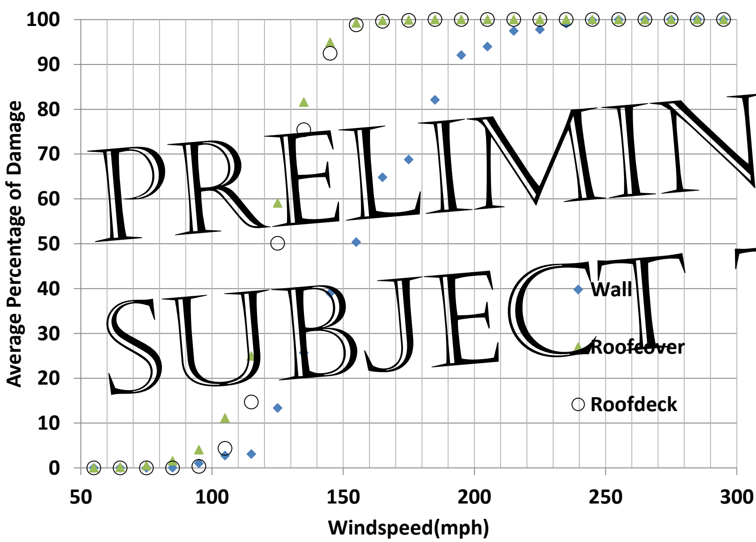
- **The 3D explicit model time-stepping approach captures:**
  - **Progressive failures**
  - **APC Loads**
  - **Tornado velocity profiles**
  - **Vertical winds**
  - **Rotational winds and directional effects.**
  - **Tornado size vs building size**
- **Straight wind analysis methods do not provide for accurate tornado windspeed estimation or damage modeling**

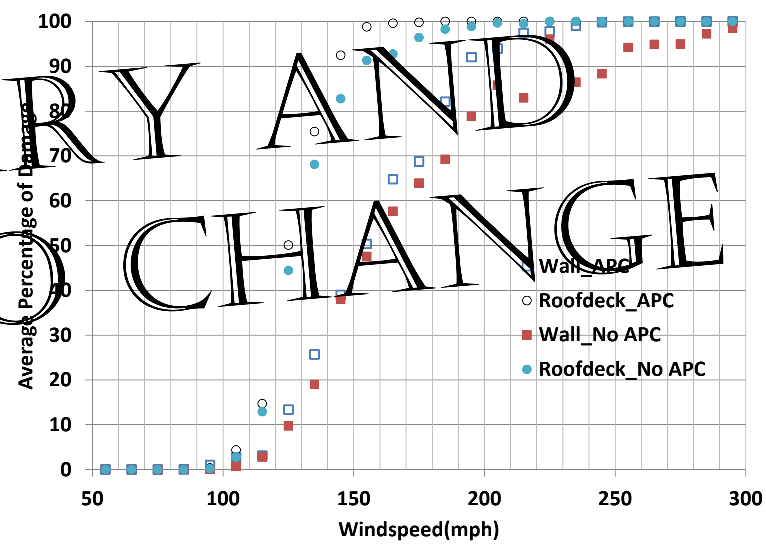
TORNADO RISK MAPS FOR BUILDING DESIGN. NIST IDIQ SB1431-12-CQ-0014.

Example Fragilities for Weak 1 Story Gable

- Roof slope of 4/12, 60ft long and 30ft wide
- Mean roof height:11.5 ft
- Roof to Wall connection: Toenail
- Wall to Foundation: Straight nail
- Roof deck to roof truss: 8d nail
- Roof cover: Asphalt (poor quality)
- Construction quality: Average
- TORDAM simulations: 1000 per EF scale, 5000 total
- Results are binned by peak winds at center of building
- APC load effects are noticeable; and significant for large buildings
- Initial results indicate large uncertainties in estimating tornado windspeeds and wind effects.

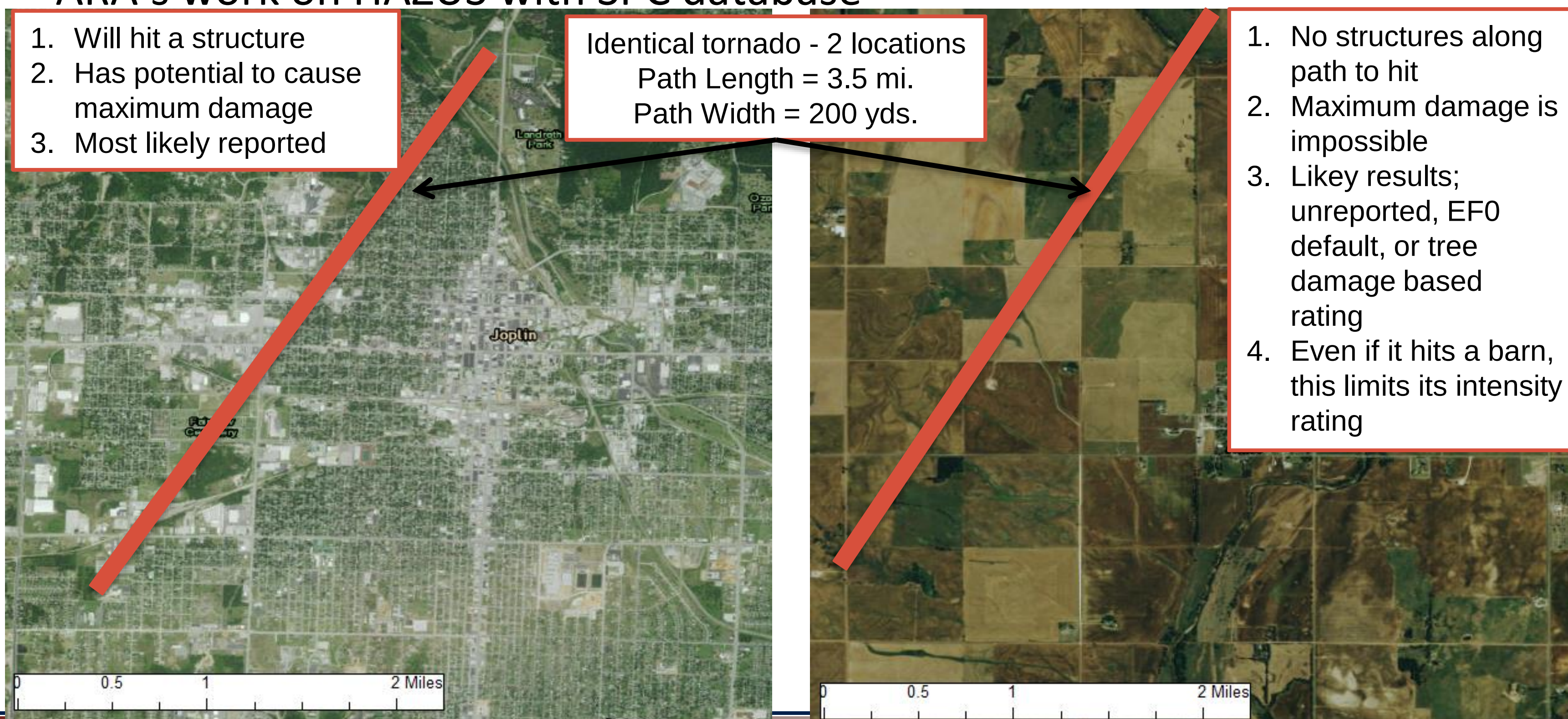






5. Population (Bldg. Den.) Bias in Tornado Data

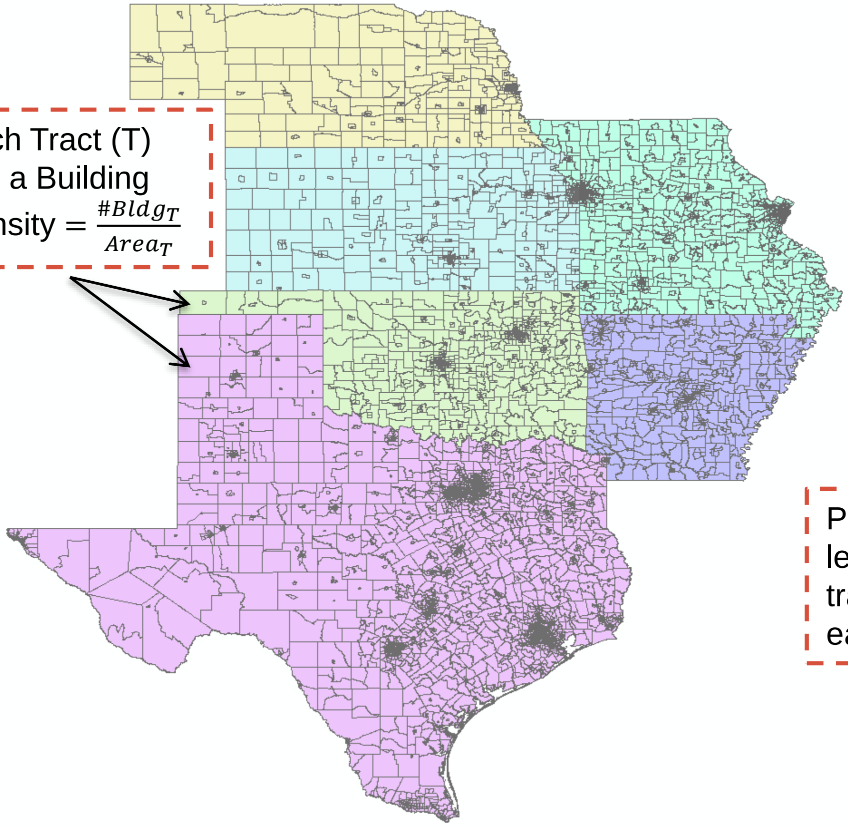
- Tornadoes are classified by damage
  - Tornadoes that produced no damage are not reported or are under-rated
- Our analysis approach is use a modeling approach with validation based on reported events vs building density
- Initial work underway using 2000 census and building information data from ARA's work on HAZUS with SPC database



Analysis Method for Initial Empirical Quantification of Building Density Bias

Analysis Region Census Tracts

Each Tract (T) has a Building Density = $\frac{\#Bldg_T}{Area_T}$

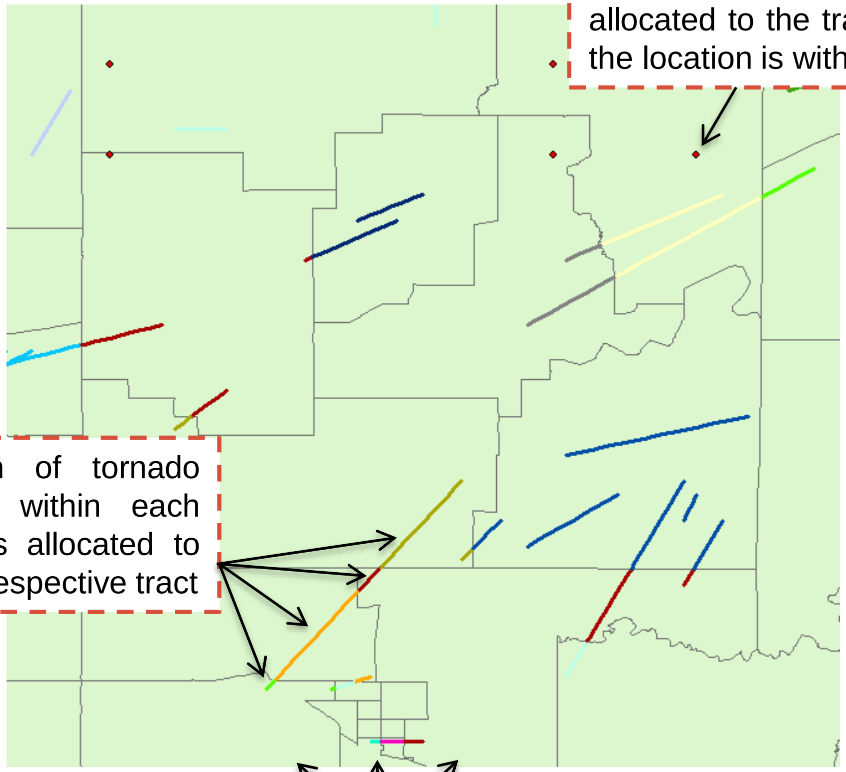


* Tracts from 2000 Census

* Tornadoes from 1995-2005

Allocation of Tornadoes to Census Tracts

Entire length of tor. w/ only 1 location allocated to the tract the location is within

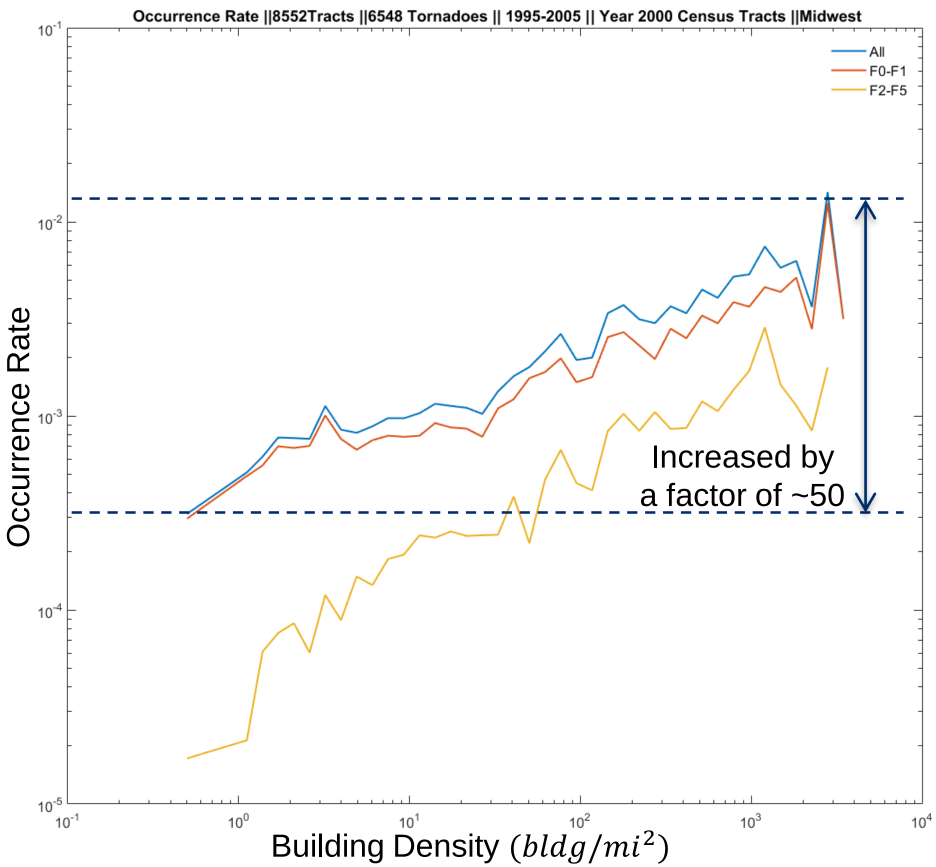


Portion of tornado length within each tract is allocated to each respective tract

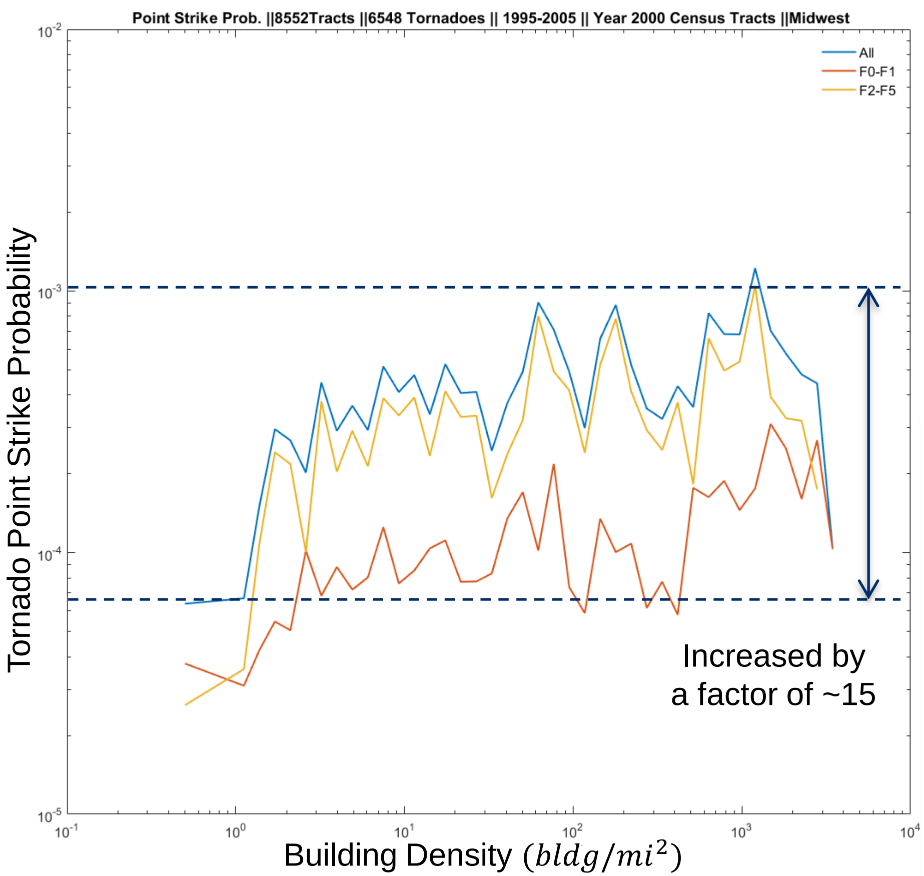
Tracts

Tornado Occurrence Rate & Point Probability Increase with Building Density

Tornado Occurrence Rate vs. Building Density (BD)



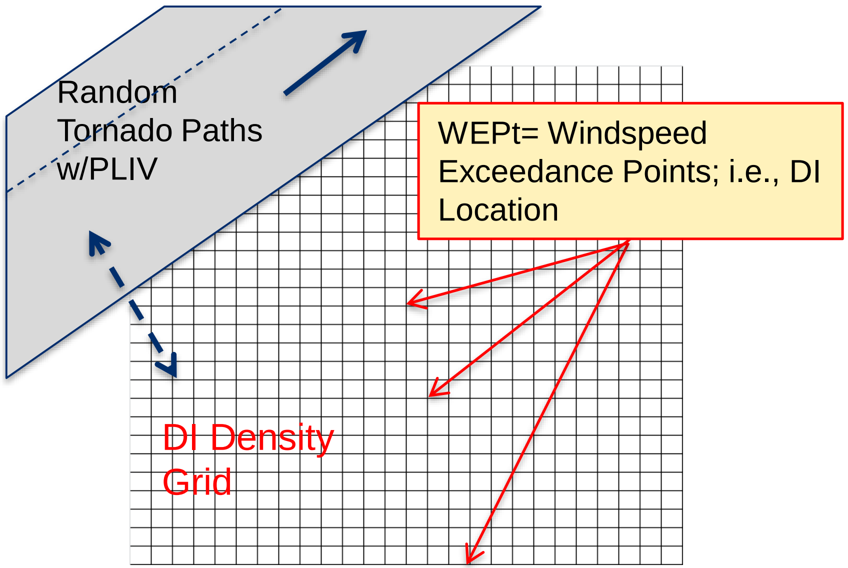
Tornado Point Strike Probability vs. Building Density



Significant BD bias in the database is noted even for the relatively modern period of 1995- 2005

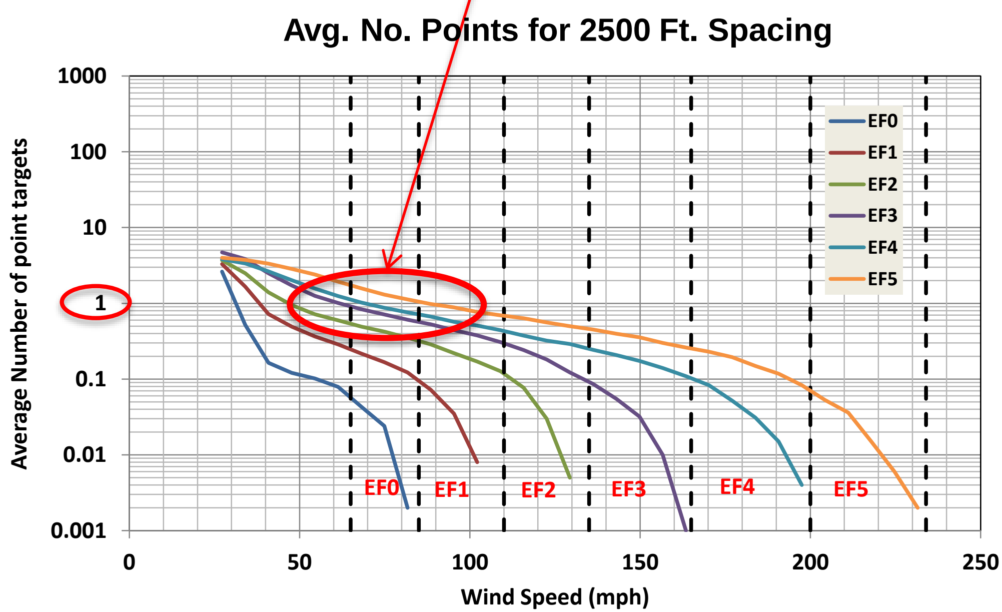
Modeling Approach for Quantification of Pop. Density Bias

1. Tornado- BD Simulations



2. Results for 2500 ft. BD Spacing

- Low EF Damage will Dominate the Ratings or NO DAMAGE will occur.



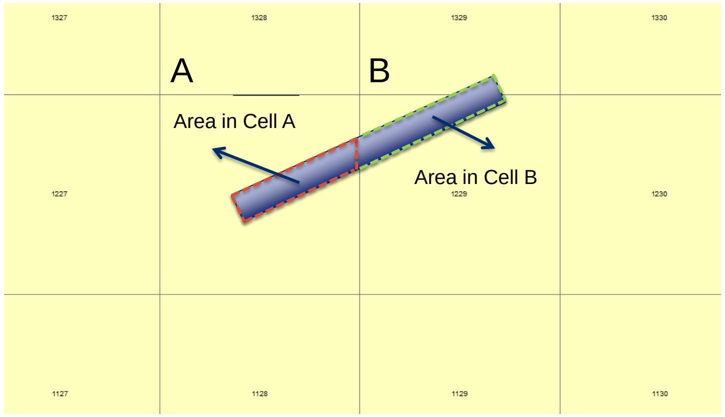
3. Results for 500 ft. Spacing

- Many EF0 will produce no damage
- Some EF1 will produce no damage
- Higher intensities have a good chance of being under-classified by 1-2 EF scales.

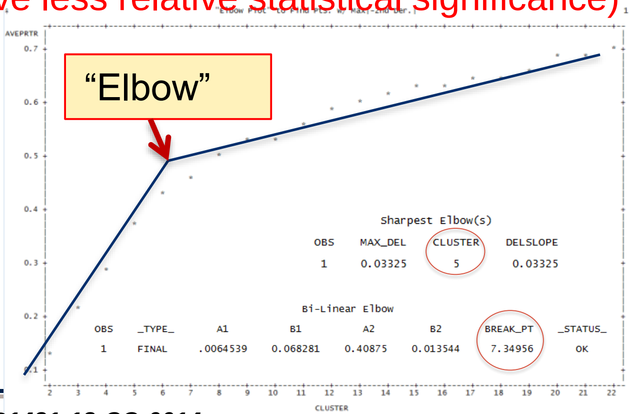
6. Regionalization Analysis Progress

- Starting from ARA's Nuclear Power Plant work on site specific risks
- Clustering process was semi-automated
- Can quickly produce plots that allow clustering results to be visualized
  - Ability to set the cell size used for regionalization
  - Sensitivity studies now practical and variable size cells
- Climatology metrics(inputs): Point Strike Prob., Occ. rates, Tor Direction, Tor Days per year, land/water fraction,….
- These metrics are computed for each cell and input to SAS Clustering algorithm (Exponential Maximum Likelihood clustering with stepwise discriminant analysis)

Tornados allocated to affected cells considering reported path length



Stepwise analysis "Elbow Plot" shows point of diminishing returns (additional clusters have less relative statistical significance)

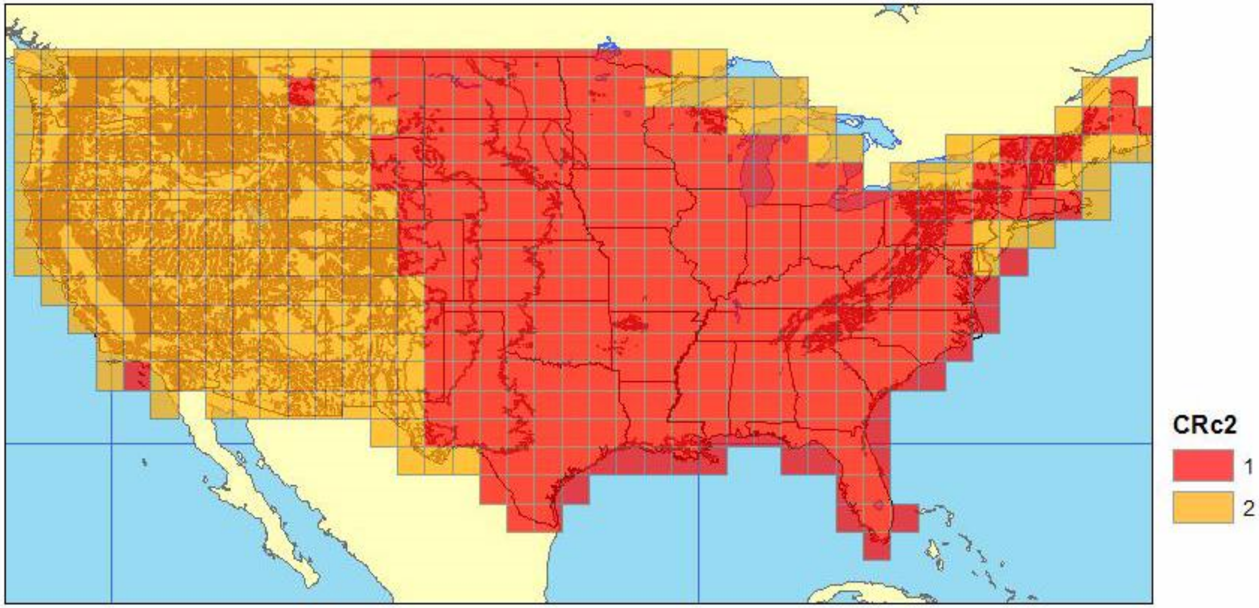


Initial Regionalization Testing in Year Two

- **Parametric Studies Include:**
  - Cell Size ($1°,\ 1.4°,\ 2°,\ and\ 3°$)
  - Variable Transformations (Log, equivalent normal,….)
  - Multiple combinations of climatological variables
  - Testing does not include final data cleansing
- **Example Clustering Results (1.4 °Cells)**
  - Variables and Transformations :

Run	TDpY_a	DirAv	OccM_a	OccS_a	PP_a	LndFr	ELMean	ELSD	Lat	Long
4C	Norm.		Ln	Ln	Ln	Norm.	Unadj.	Unadj.	Unadj.	Unadj.

  - Bi-Linear Break Point: 8.17



Variables:

TDpY: Tornado Days per Year

DirAv: Average Tornado Path Direction

OccM: Occurrence Rate F2-F3

OccS: Occurrence Rate F4-F5

PP: Point Strike Probability

LndFr: Land Fraction

ELMean: Mean Elevation

ELSD: Standard Deviation of Elevation

Lat: Latitude

Long: Longitude

"_a": Allocated path length

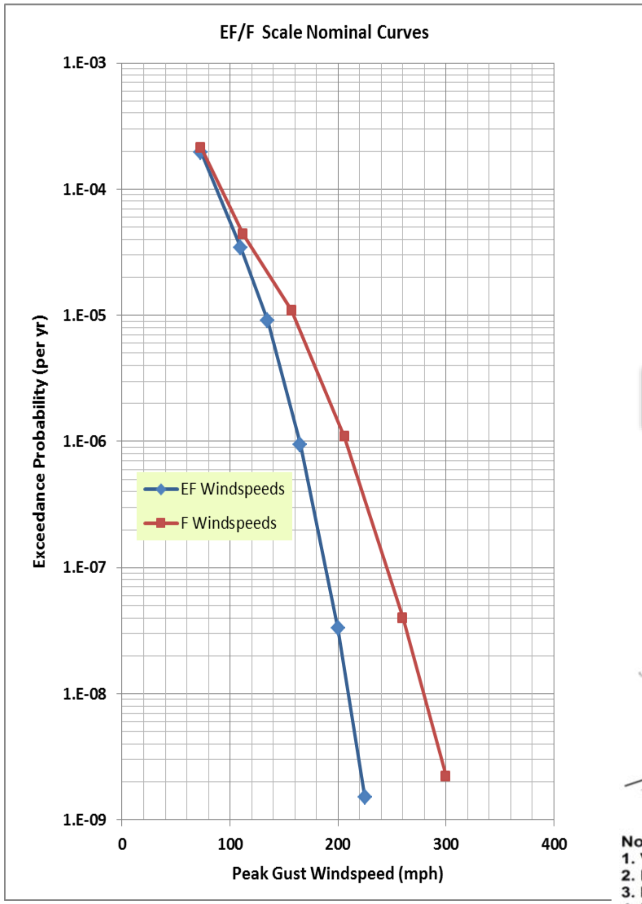
Transformed Variables

Unadj.: Unadjusted Values

Norm.: Normalized Values

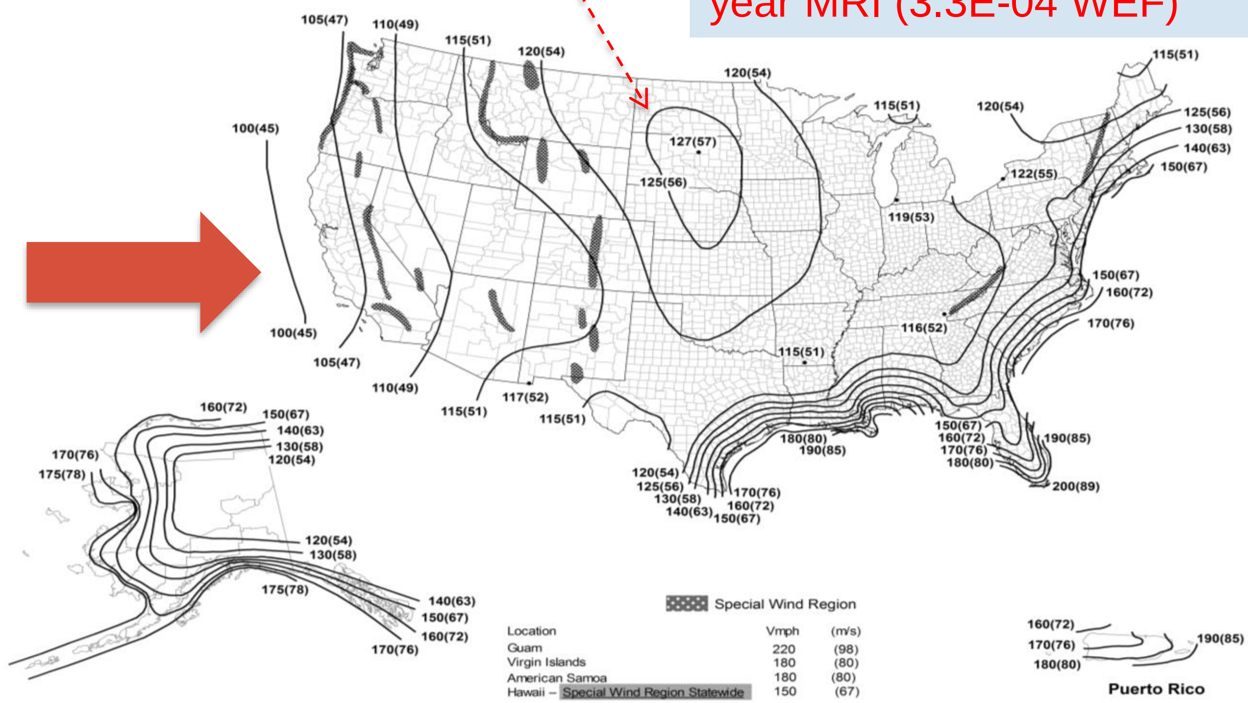
Ln: Natural Log of Values

Development of Final Maps from Modeling Results



125 mph contour

Example: ASCE straight windspeed map for 3000 year MRI (3.3E-04 WEF)

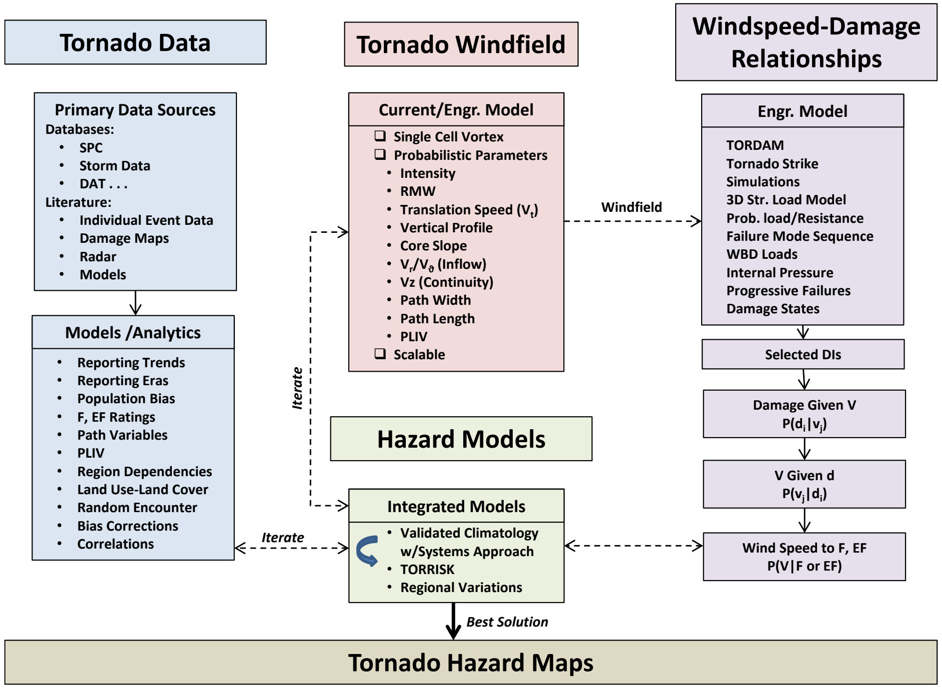


Notes:
1. Values are nominal design 3-second gust wind speeds in miles per hour (m/s) at 33 ft (10m) above ground for Exposure C category.
2. Linear interpolation is permitted between contours. Point values are provided to aid with interpolation.
3. Islands, coastal areas, and land boundaries outside the last contour shall use the last wind speed contour.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.
5. Wind speeds correspond to approximately a 1.6% probability of exceedance in 50 years (Annual Exceedance Probability = 0.00033, MRI = 3000 Years).
6. Location-specific basic wind speeds shall be permitted to be determined using www.atcouncil.org/windspeed

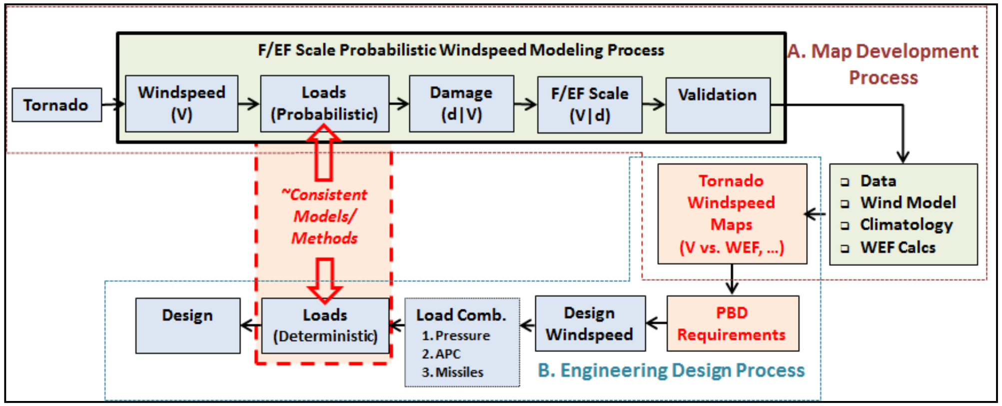
7. Project Summary

- Tornado hazard analysis is a complicated, iterative process, with many components.
- There are many biases/ limitations of the raw, damage-based tornado datasets.
- Our approach includes both component and "system" analysis methods.
- A consistent 3D modeling approach is being used for tornado hazard and damage-to-windspeed calculations.
- New field work is needed to support and validate tornado hazard and damage to windspeed modeling.

Integrated System Framework



Windspeed Map- PBD Framework



Standards, Code, and Guidance Development

Marc Levitan, *Acting Director*
National Windstorm Impact Reduction Program
NIST

Update on Standards, Code, and Guidance Development

Work in progress
Completed

- **Existing Standards**
  - ASCE/SEI 7-22, Minimum Design Loads for Buildings and Structures
  - ICC 500-2019, Standard for Design and Construction of Storm Shelters
- **New Standards**
  - ASCE/SEI Standard for Estimation of Wind Speeds in Tornadoes
  - NFPA 1616, Standard for Mass Evacuation and Sheltering
- **Building Codes**
  - 2018 International Building Code (IBC)
  - 2018 International Existing Building Code (IEBC)
- **Guidelines**
  - FEMA P-431, Tornado Protection: Selection Refuge Areas in Buildings
  - FEMA P-320, Taking Shelter from the Storm: Building a Safe Room for Your Home or Small Business, 4th ed. (December 2014)
  - FEMA P-361, Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms, 3rd ed. (March 2015)
  - ICC 500-2014 Commentary on the Standard for Design and Construction of Storm Shelters (January 2016)

Context – Building Codes and Standards

National model building codes, standards, and practices seek to achieve life safety for the hazards considered in design.

Tornado hazards are not currently considered in the design of buildings, except for safety–related structures in nuclear power plants, storm shelters, and safe rooms.

Development of Performance-Based Standard for Tornado-Resistant Design

Recommendation 5 (ASCE): NIST recommends that nationally accepted performance–based standards for the tornado–resistant design of buildings and infrastructure be developed in model codes and adopted in local regulations to ensure the resiliency of communities to tornado hazards. The standards should encompass tornado hazard characterization, performance objectives, and evaluation tools. The standards shall require that critical buildings and infrastructure such as hospitals and emergency operations centers are designed so as to remain operational in the event of a tornado.

- **Target Standard : ASCE 7-22**

Implementation of Performance-Based Design (PBD)

Continued working with ASCE Technical Committee on PBD for Extreme Winds (ad-hoc)

- Committee is creating a PBD framework for extreme wind hazards, including tornadoes, intended for inclusion in ASCE 7-22.
- Developing performance objectives and building performance levels for different wind hazards and risk categories of buildings
  - hurricanes, tornadoes, other windstorms
  - structural, cladding, and other building systems

Implementation of Performance-Based Design (cont'd)

Additional requirements to implement PBD for tornadoes

- New tornado hazard maps (R3)
- New tornado wind load design methods (R6)
  - variation of wind speed with height and terrain
  - pressure coefficients
  - atmospheric pressure change (APC)
  - missiles

To create more accurate tornado hazard maps in the future

- Better tornado wind / climate data needed (R4 / R2)

Improving Tornado Wind Speed & Climate Data

Recommendation 4 (NWS): NIST recommends that new damage indicators (DIs) be developed for the Enhanced Fujita tornado intensity scale to better distinguish between the most intense tornado events. Methodologies used in the development of new DIs and associated degrees of damage (DODs) should be, to the extent possible, scientific in nature and quantifiable. As new information becomes available, a committee comprised of public and private entities should be formed with the ability to propose, accept, and implement changes to the EF Scale. The improved EF Scale should be adopted by NWS.

Recommendation 2 (NWS): NIST recommends that information gathered and generated from tornado events (such as the Joplin tornado) should be stored in publicly available and easily accessible databases to aid in the improvement of tornado hazard characterization.

Background – Estimating Wind Speed from Damage using the EF Scale

- Degree of Damage (DoD) assigned to a Damage Indicator (DI) (e.g. house, school)
- Estimated wind speed associated with each DoD

2. ONE-AND TWO-FAMILY RESIDENCES (FR12)
(1000 – 5000 sq. ft.)

Typical Construction

- Asphalt shingles, tile, slate or metal roof covering
- Flat, gable, hip, mansard or mono-sloped roof or combinations thereof
- Plywood/OSB or wood plank roof deck
- Prefabricated wood trusses or wood joist and rafter construction
- Brick veneer, wood panels, stucco, EIFS, vinyl or metal siding
- Wood or metal stud walls, concrete blocks or insulating-concrete panels
- Attached single or double garage

DOD*	Damage description	EXP	LB	UB
1	Threshold of visible damage	65	53	80
2	Loss of roof covering material (<20%), gutters and/or awning; loss of vinyl or metal siding	79	63	97
3	Broken glass in doors and windows	96	79	114
4	Uplift of roof deck and loss of significant roof covering material (>20%); collapse of chimney; garage doors collapse inward; failure of porch or carport	97	81	116
5	Entire house shifts off foundation	121	103	141
6	Large sections of roof structure removed; most walls remain standing	122	104	142
7	Exterior walls collapsed	132	113	153
8	Most walls collapsed, except small interior rooms	152	127	178
9	All walls	170	142	198
10	Destruction of engineered and/or well constructed residence; slab swept clean	200	165	220

* DOD is degree of damage

Source: NOAA. http://www.spc.noaa.gov/efscale/2.html

Background - Rating Tornadoes: The Enhanced Fujita (EF) Scale

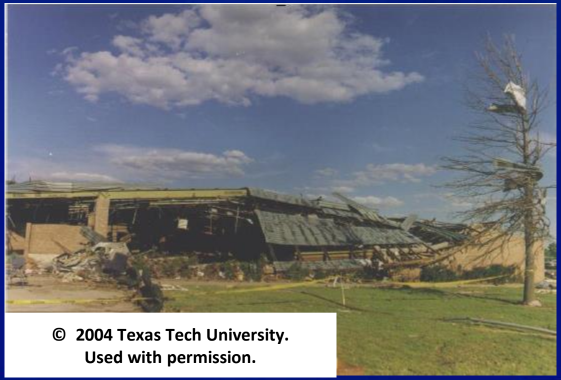
- EF Number is then assigned to a tornado based on estimated wind speed
- Wind speed ranges associated with EF Numbers

EF Number	Wind Speed (mph)
0	65-85
1	86-110
2	111-135
3	136-165
4	166-200
5	200+

- Typical damage state with EF-scale rating:

EF1

EF3



EF5

ASCE Standard on Wind Speed Estimation in Tornadoes

- Standards committee co-chaired by NWS and NIST staff
  - 93 members
  - mainly meteorologists, wind engineers, structural engineers
- Scope of new standard includes wind speed estimation by
  - EF Scale
  - Radar and In-situ Measurements
  - Forensic Engineering
  - Treefall Patterns
  - Remote Sensing
- Scope also includes requirements for data and metadata
- Intended for adoption by NWS

ASCE Standard on Wind Speed Estimation in Tornadoes (cont'd)

Source: NOAA

EF Scale Improvements

- Better guidance for existing DIs to provide more consistent wind speed estimates
- Development of new engineering-based DIs

Example- Jersey Barriers

- New DI based on wind tunnel tests to determine speeds required for overturning

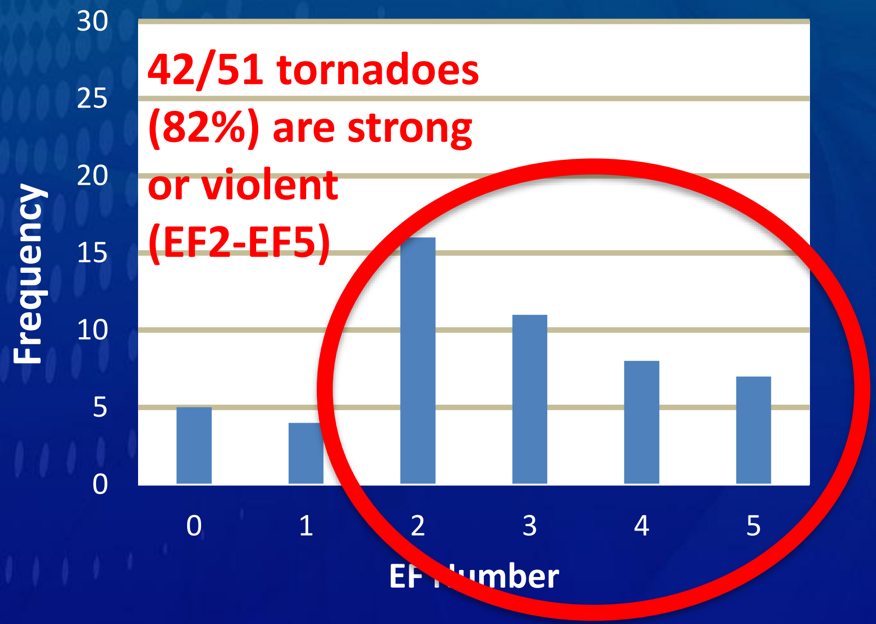
Key Limitation – EF Scale is damage based. The tornado has to hit something in order to get an estimated wind speed.

Comparison of Tornado Wind Speeds Estimated by Mobile Radar and Damage

Sample Size = 51 Tornadoes*

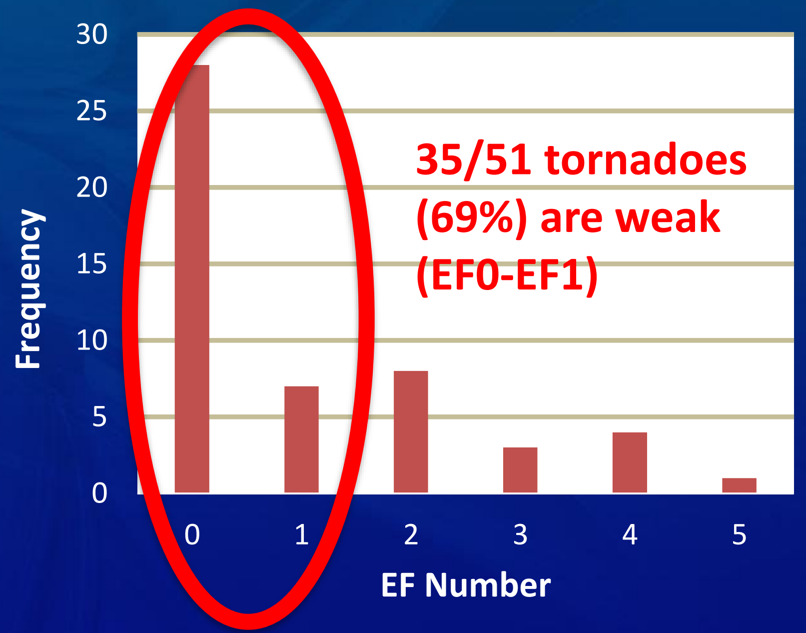
EF Numbers from Mobile Radar Measurements

Observations below 500 m AGL (above ground level)



EF Numbers for the Same 51 Tornadoes Reported in NOAA OneTor Database

From ground surveys of damage using EF Scale

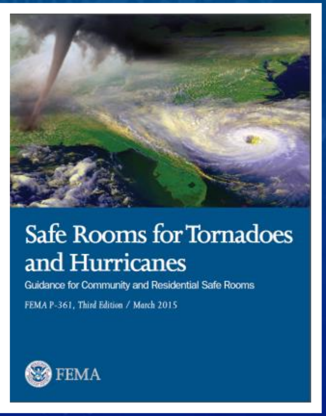


Mobile radar indicates much stronger winds than implied by damage

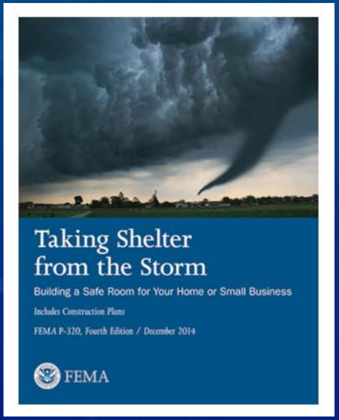
*Data Source: A Mobile Radar Based Climatology of Supercell Tornado Structures and Dynamics, by Alexander, Curtis R., Ph.D., The University of Oklahoma, 2010.

Sheltering Strategies

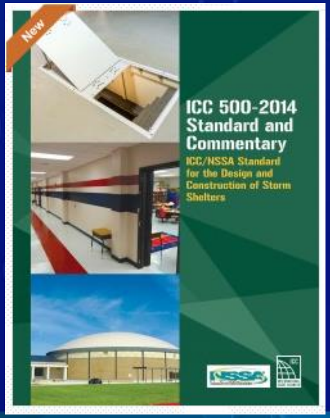
Recommendation 8 (FEMA): NIST recommends the development and implementation of uniform national guidelines that enable communities to create safe and effective public sheltering strategies. The guidelines should address planning for siting, designing, installing, and operating public tornado shelters within the community.



Source: FEMA.



Source: FEMA.



- NIST developed significant new guidance material that was incorporated into two FEMA Safe Room publications (FEMA P-320, 4th ed., and FEMA P-361, 3rd ed)
- NIST led development of *Chapter 3: Structural Design Criteria* in the ICC 500 Commentary
- Proposed shelter safety requirements and guidance for new **NFPA 1616 Standard for Mass Evacuation and Sheltering**

NFPA 1616 Proposed Annex: Best Practices for Shelter Facility Selection

General

- Minimum Recommendations for Selection of Existing Buildings
- Minimum Recommendations for Construction of New Sheltering Facilities
- Considerations for Shelter Exposure to the Hazard Event

Risk and Condition Assessments

- Pre-event Risk Assessment
- During-event Risk Assessment
- During-event Condition Assessment
- Post-event Condition Assessment
- Additional Assessment and Selection Considerations
  - Tornado
  - Hurricane
  - Tsunami
  - Snow and Winter Storms
  - Flood
  - Earthquake

Status

- Inclusion of changes to standard and proposed annex approved in Committee meeting on March 31, 2016
- Out for Letter Ballot now
- Anticipated publication of the standard is late 2016

Code Changes –Shelters

Recommendation 7 (ICC): NIST recommends that: (a) a tornado shelter standard specific for existing buildings be developed and referenced in model building codes; and (b) tornado shelters be installed in new and existing multi–family residential buildings, mercantile buildings, schools and buildings with assembly occupancies located in tornado hazard areas identified in the performance–based standards required by Recommendation 5.

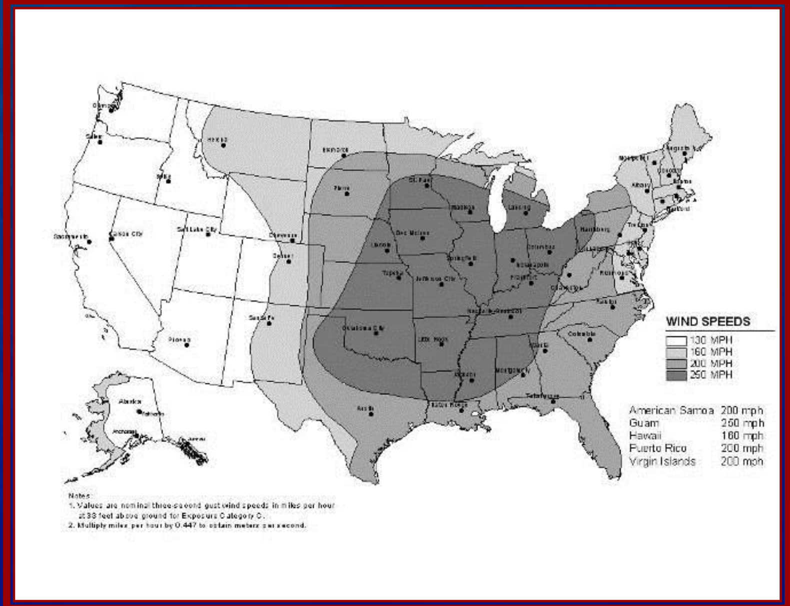
7(b): NIST-developed code changes were approved for the 2018 IBC and IEBC

- Developed in coordination with the Building Code Advisory Committee (BCAC) and FEMA
- Expand requirements for incorporation of ICC 500 storm shelters at both new and existing schools, including assembly spaces associated with schools

Code Changes, Shelters (cont'd)

- **Parallel requirements for**
  - New buildings on existing school campuses (IBC)
  - Additions to buildings on existing school campuses (IEBC)
- **Require ICC 500 shelters large enough to protect the population of the school, provided the new construction is of sufficient size**
- **Applies to**
  - Group E occupancies
  - Indoor assembly spaces associated with the Group E occupancy, e.g., theaters, auditoriums, gymnasiums w/bleachers

New IBC/IEBC shelter requirements apply in the 250 mph tornado wind speed zone (dark grey)



Code Changes –Roof Aggregate

Recommendation 11 (ICC): NIST recommends that aggregate used as surfacing for roof coverings and aggregate, gravel, or stone used as ballast be prohibited on buildings of any height located in a tornado–prone region.

Code change proposal for 2018 IBC

- Developed in coordination with the BCAC, with input from FEMA
- Status: Pending

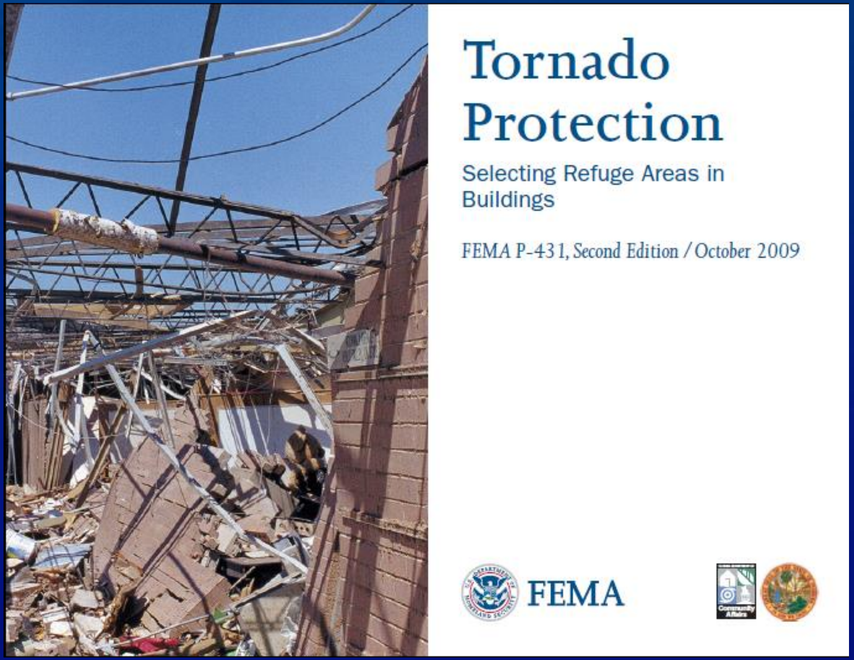
Guidance – Best Available Refuge Areas

Recommendation 9 (FEMA): NIST recommends that uniform guidelines be developed and implemented nationwide for conducting assessment of tornado risk to buildings and designating best available tornado refuge areas as an interim measure within buildings until permanent measures fully consistent with Recommendations 5 and 7 are implemented.

Working with FEMA to update

FEMA P-431 Tornado Protection: Selecting Refuge Area in Buildings

- Current version deals almost exclusively with schools
- The revised version will
  - have a new, engineering–based selection methodology
  - cover a much broader array of building occupancies and types
- Phase I of project completed 4/30/16



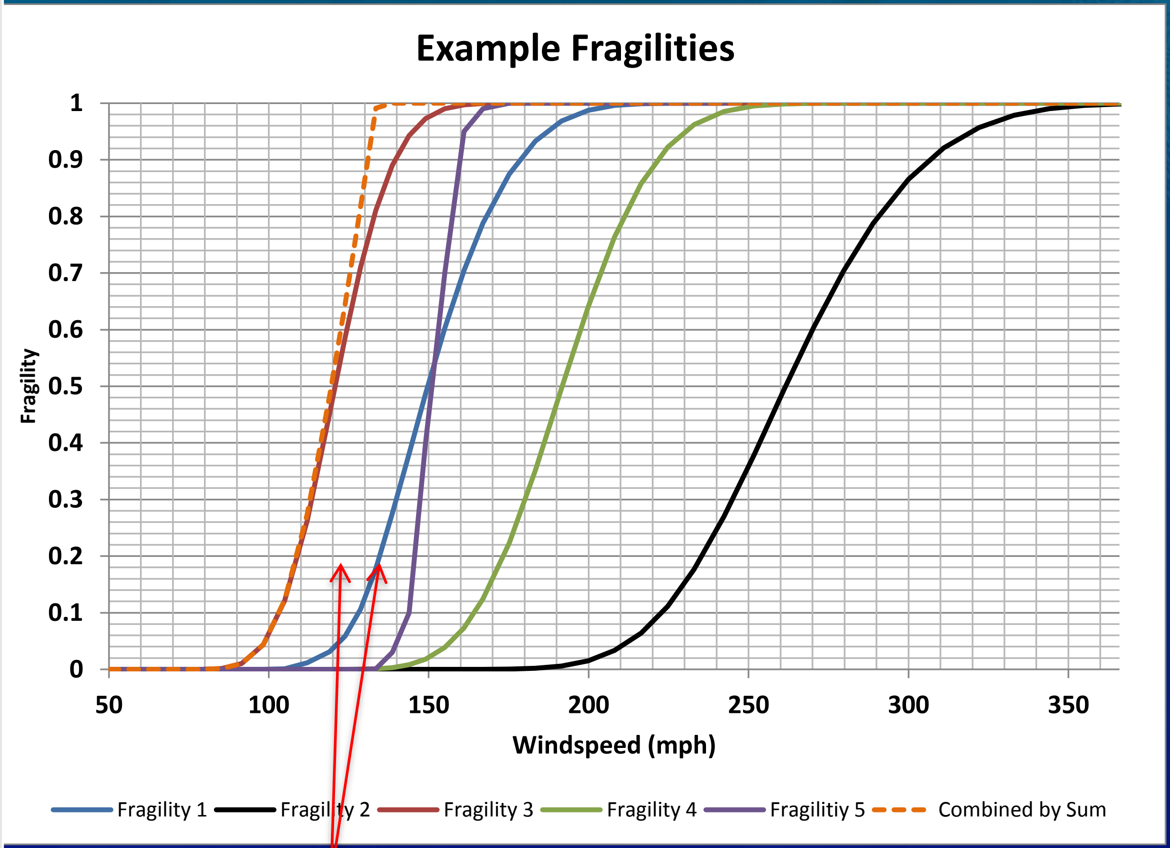
Source: FEMA.

Best Available Refuge Area Methodology

- Allow the evaluation of various building types within the same site or campus
- Provide a consistent manner of conducting the structural assessment
- Provide a validated approach for the structural assessment
- Leverage the latest available modeling and forensic research
- Utilize 13 Building Types (based on ASCE 41)
- Incorporate quantitative and qualitative factors that are evaluated for each candidate refuge area to support the Design Professional's final determination of relative ranking

Application of Fragility Functions

- Quantify Probability of Failure
- Phase I Refuge Area (RA) Fragilities
    - Collapse of wall and roof…
    - Frame and Missiles (future Phase)
- Fragilities for multiple failure modes are aggregated to produce the refuge area fragility
- The position and slope of the fragilities provide the fundamental engineering information to assess relative safety of candidate areas
- Use of fragilities facilitates engineering analysis of components and the MWFRS.
- Loads are based on ASCE 7 information and tornado modeling research



Slope indicates relative uncertainty; for example, drawing available, lack of redundancy, ….

Phase I Project Scope – ARA

- Develop a engineering-based methodology analysis framework and validation approach to support a Design Professional's evaluation of a *Best Available Tornado Refuge Area*

- The Methodology encompasses 5 Building Types in Phase I:
  1. Reinforced Masonry (RM)
  2. Unreinforced Masonry (URM)
  3. Tilt-Up (PC1)
  4. Steel Frames (S1)
  5. Steel Frames with Masonry Infill (S5)

- Damage modeling validation for two building types

- Modeling of roof and wall system failures

- Investigation of methods to capture the engineering-based methodology into a "job-aid" to aid the Design Professional in selecting the Refuge Area

R13:
Emergency Communications

Erica Kuligowski, *Leader*
Wildland-Urban Interface Fire Group
NIST

New Project: “Development of Guidance for Community-wide Public Alerts in Emergencies”

- 2-year project to: Develop guidance for communities on the creation and provision of public alerts – via outdoor siren (warning) systems and social media (including mobile alerts)
- The guidance document will…
  - Focus on alerting strategies for relevant hazard and threat scenarios in communities in the U.S.
  - Provide technical foundation for NFPA 1616 on alerting requirements
- Success: Development of a guidance document on alerting strategies that NFPA 1616 can use as a basis for annexes for the standard.

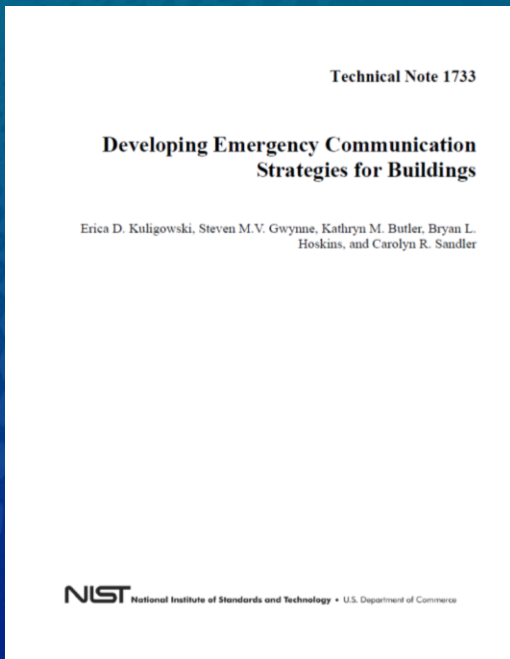
Elements of an Community-Wide Emergency Communication System – Alerts and Warnings

- Examples of technology (or channels):
  - Outdoor sirens
  - Television
  - Radio
  - NOAA Weather Radio
  - Internet (websites), email
  - Cell phone/mobile devices
  - Visual displays (e.g., airport, subway systems)
  - Social media (Facebook, Twitter)
- Examples of sources (or message providers)
  - Emergency managers/ local government
  - Weather-related federal agencies (e.g., NOAA/NWS)
  - Media
  - Federal/state governments
  - Community leaders
    - Business owners
    - Health care providers
    - Education
    - Transportation agencies

NIST Public Alerts Project Collaboration

- NFPA 1616 Technical Committee
  - Annex K Emergency Communication: Public Alerts and Warnings
  - Annex L Social Media Planning
- Fire Protection Research Foundation (FPRF) – Project Panel
  - Department of Homeland Security (S&T)
  - NOAA/National Weather Service
  - U.S. Department of Veterans Affairs
  - Local (and State) emergency management and response community
  - Siren/alarm manufacturers
  - Research community (social dimensions of disasters)
  - NFPA 1616 Chair

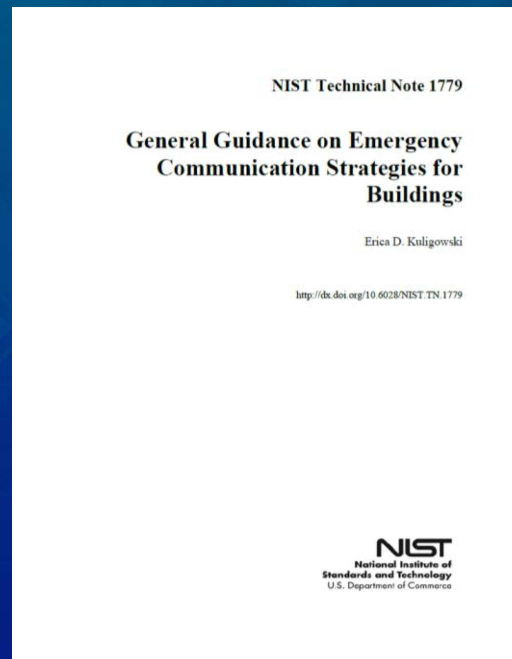
Previous Collaboration: NIST, FPRF, and NFPA 72 (National Fire Alarm and Signaling Code)


Technical Note 1733

Developing Emergency Communication Strategies for Buildings

Erica D. Kuligowski, Steven M.V. Gwynne, Kathryn M. Butler, Bryan L. Hoskins, and Carolyn R. Sandler

NIST National Institute of Standards and Technology • U.S. Department of Commerce

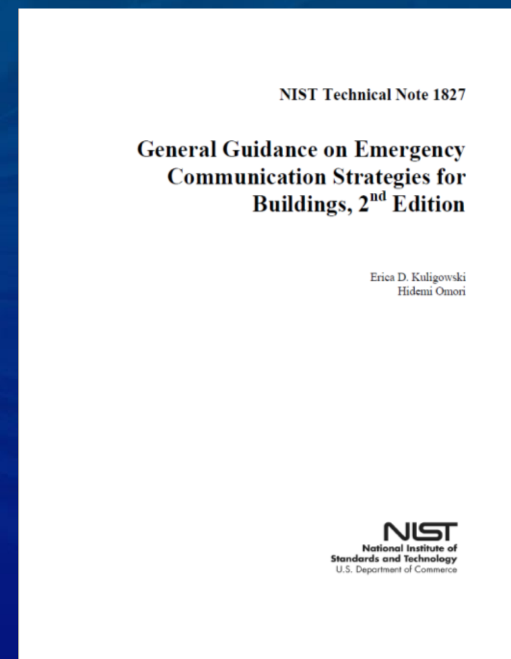

NIST Technical Note 1779

General Guidance on Emergency Communication Strategies for Buildings

Erica D. Kuligowski

http://dx.doi.org/10.6028/NIST.TN.1779

NIST National Institute of Standards and Technology U.S. Department of Commerce


NIST Technical Note 1827

General Guidance on Emergency Communication Strategies for Buildings, 2nd Edition

Erica D. Kuligowski
Hidemi Omori

NIST National Institute of Standards and Technology U.S. Department of Commerce

Acknowledgements

The Science and Technology Directorate of the U.S. Department of Homeland Security sponsored the production of this material under Interagency Agreement HSHQDC-07-X-00723 with the National Institute of Standards and Technology (NIST)

Fire Protection Research Foundation's Technical Panel and Industry Project Sponsors

Public Alerts Project: Technical Approach

- Year 1 – Interim guidance document outlining the usage, activation procedures and sounds/sounding patterns for community-wide public siren (warning) systems
  1. What are the current siren technologies and their capabilities/limitations in alerting?
  2. How do people, of all ages, abilities, and other important demographics, respond to alerting sounds and patterns?
  3. What are the current methods that leading communities have adopted to standardize neighboring siren systems?

Public Alerts Project: Technical Approach, cont.

- Year 2 – Guidance document outlining alerting strategies
  1. What are the current social media available to alert the public in emergencies, including their capabilities/limitations in alerting; how are they being used?
  2. What research exists related to public response to emergency-based social media alerts, including Facebook, Twitter, and Instagram?
  3. Develop guidance on the most effective usage of mobile devices and social media tools to alert the public of an emergency.

Progress to Date…

- Reviewed 30 different outdoor siren (warning) systems available for community use from 5 different siren manufacturers
- Reviewed FEMA Guidance for sirens, including:
  - FEMA CPG 1_17 (1980)
  - FEMA Outdoor Warning Systems, Technical Bulletin 2.0 (2006)
- Purpose – understand the capabilities of current systems and the ways in which they differ
- Collected and reviewed current siren policies, including:
  - North Central Texas
  - Association of Minnesota Emergency Managers
  - Southwest Missouri Emergency Support Organization

Next Steps

- Summer (SURF) student begins May 23, to complete the following:
  - —Review literature on how people, of all ages, abilities, and other important demographics, respond to alerting sounds and patterns
  - —Collect additional siren policies developed by communities
- Plan and organize a workshop in Summer 2016
  - —Invite community leadership (EMs/officials) involved in regional siren policy development
    - What are the current siren policies in U.S. Midwest communities?
    - What are the benefits/limitations of standardized siren procedures (national, regional)? How can NIST play a role?
- Provide biannual updates to FPRF project panel and NFPA 1616

R16:
NOAA Grid-Based Threat Communication: Forecasting a Continuum of Environmental Threats (FACETS)

Dave Jorgensen, *Research Meteorologist and Chief*
National Severe Storms Laboratory/R&D Division
NOAA

Progress Update

Recommendation 16 (NOAA): *NIST recommends that technology be developed to provide tornado threat information to emergency managers, policy officials, and the media on a spatially resolved real–time basis to supplement the currently deployed official binary warn/no warn system*.

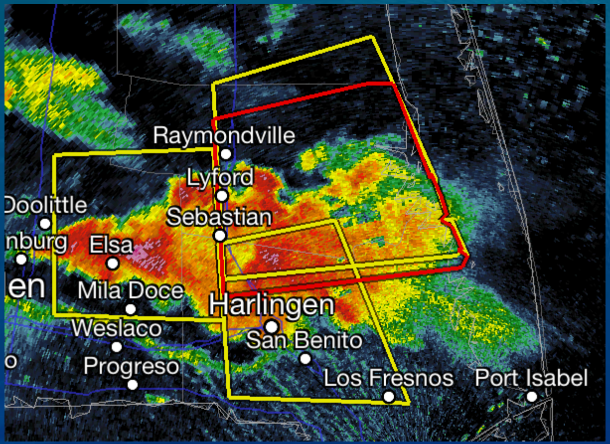
NOAA's National Severe Storms Lab (NSSL) is actively exploring and developing a new grid-based threat communication paradigm, called

Forecasting a Continuum of Environmental Threats (FACETs)

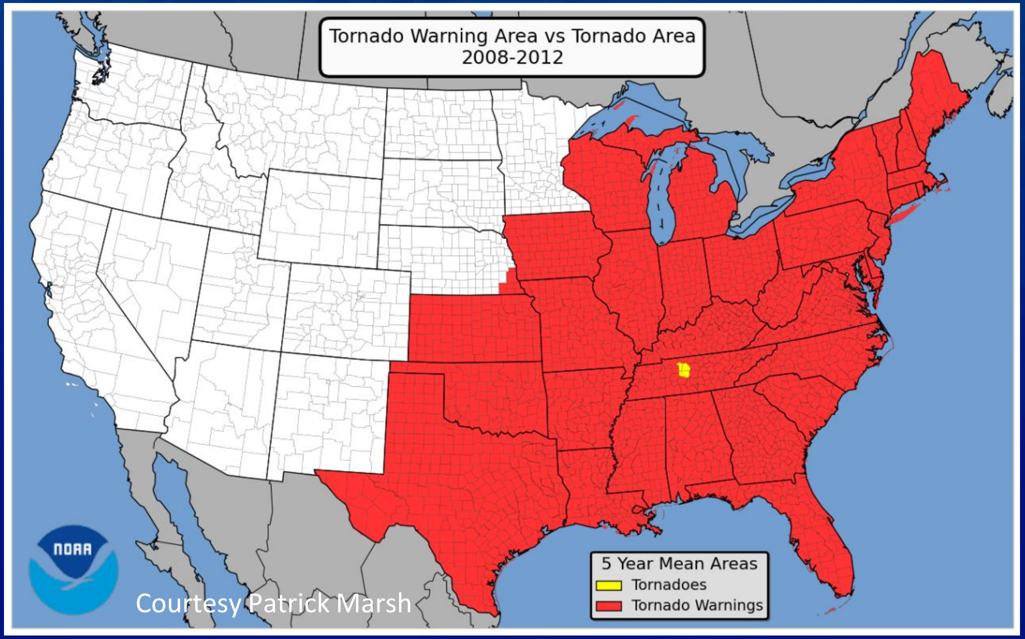
- FACETs is a new, all-hazard watch/warning paradigm (grid-based, probabilistic threats) redesigned with social/behavioral science infused
- Multi-year exploration/development effort. FY 15 tasks completed:
  - Completed first iteration of probabilistic hazard grids and tools
  - Limited tests with NWS forecasters in Hazardous Weather Testbed
  - 12 years of NWS radar data analyzed and cleaned up in preparation for statistical based methods for warnings.
- See http://www.nssl.noaa.gov/projects/facets/

The Current Tornado Warning System

- Warning polygons are messy!
- Inherently “binary” (on/off; in/out)
- Huge false alarm rate.
- 1950s Teletype-era paradigm.



Source: NOAA



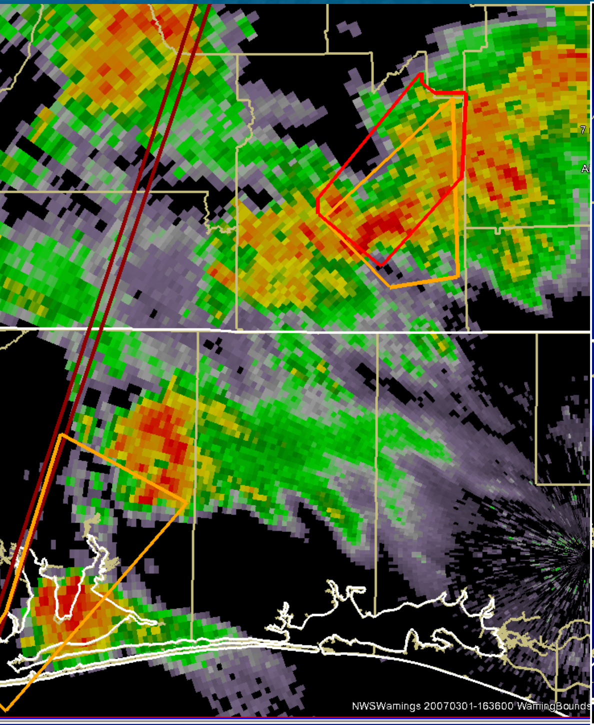
Source: NOAA

FACETs Is...

- Optimized for user-specific decision-making through comprehensive integration of social/behavioral/economic sciences.

FACETS Tornado Warning Timeline (est)

Present	5-10 years?	>10-20 years?



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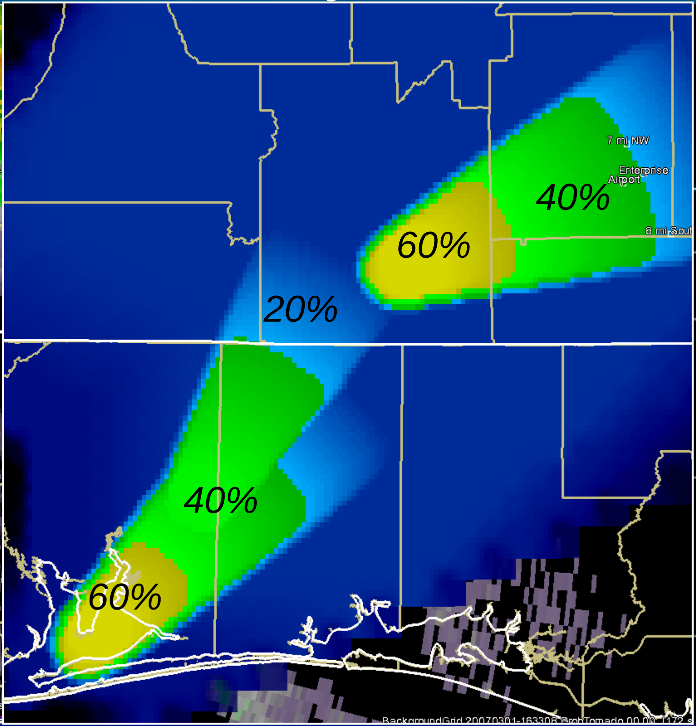

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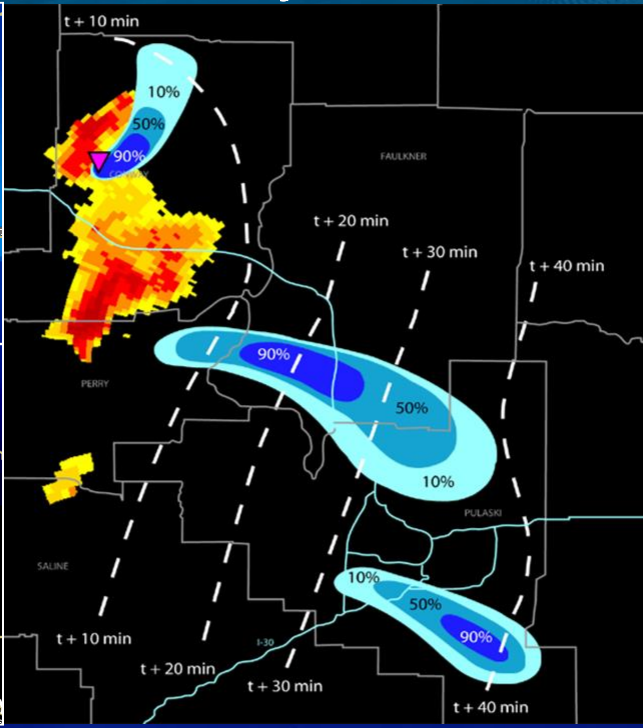


Source: NOAA

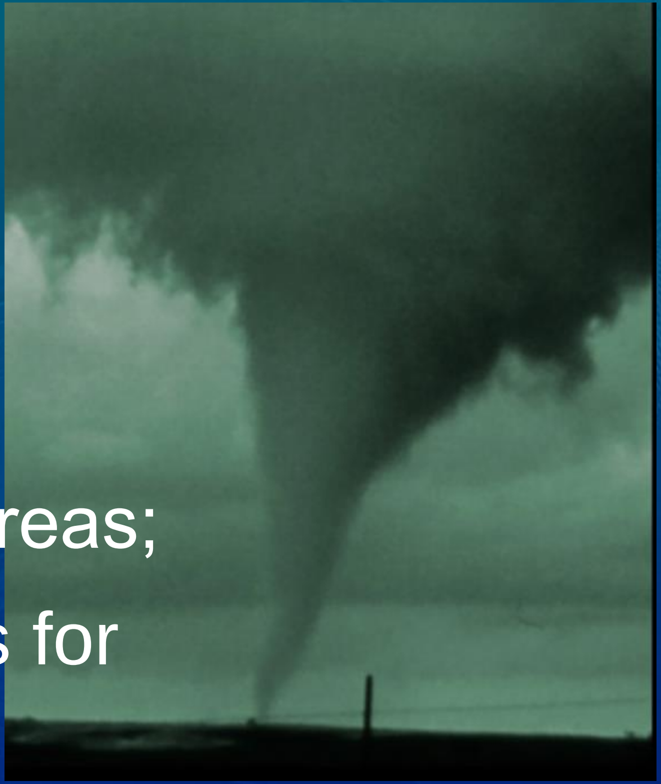
Polygons or county based warnings updated ~15 min

Probabilistic guidance from climatology and human “estimation” updated ~15 min

Probabilistic guidance using numerical model ensembles and updated continuously

Expected Benefits

- A fully-integrated continuum of weather threat information;
- Reduction in size of "warned" areas;
- Considerable new opportunities for America's Weather Industry;
- More useful, actionable, and recipient-specific information.
- A Weather-Ready Nation.

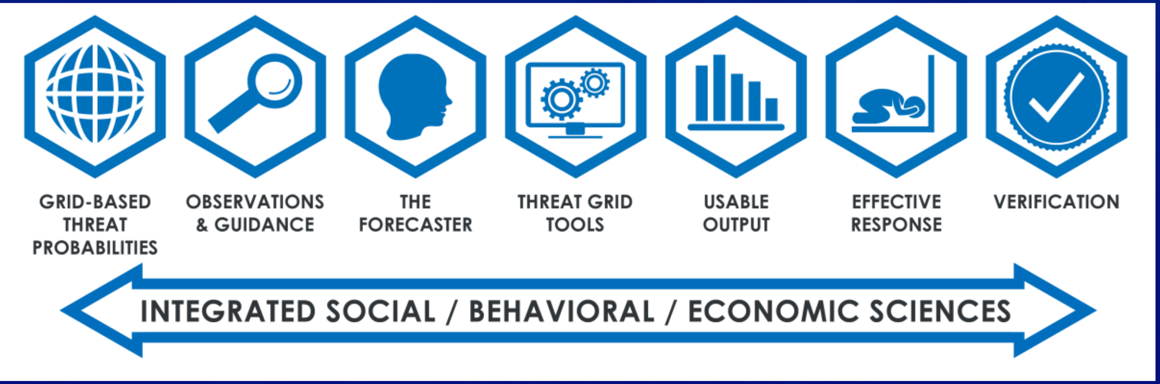


Source: NOAA

Source: NOAA

Summary

- FACETs: An over-arching vision to modernize NOAA's hazardous weather forecasting paradigm.
  - —A "master plan" exists – but much work to do! (e.g., transition from "binary" to "probabilistic" warnings.
  - —NWS and Weather Industry on board (part of WRN).
  - —Improved protection of life, property and economic vitality.
  - —Steep learning curve as we transition from binary to probabilistic warnings.
  - —Suitable for other than tornado hazards (e.g., heavy rain, flash floods, hail, strong winds)



Source: NOAA

Progress on Implementation of the Joplin Tornado Recommendations

May 03rd, 2016
NCST Advisory
Committee Meeting

Questions?

National Institute of Standards and Technology
U.S. Department of Commerce