# Summary of Progress on Implementation of Recommendations from the Joplin Tornado Investigation

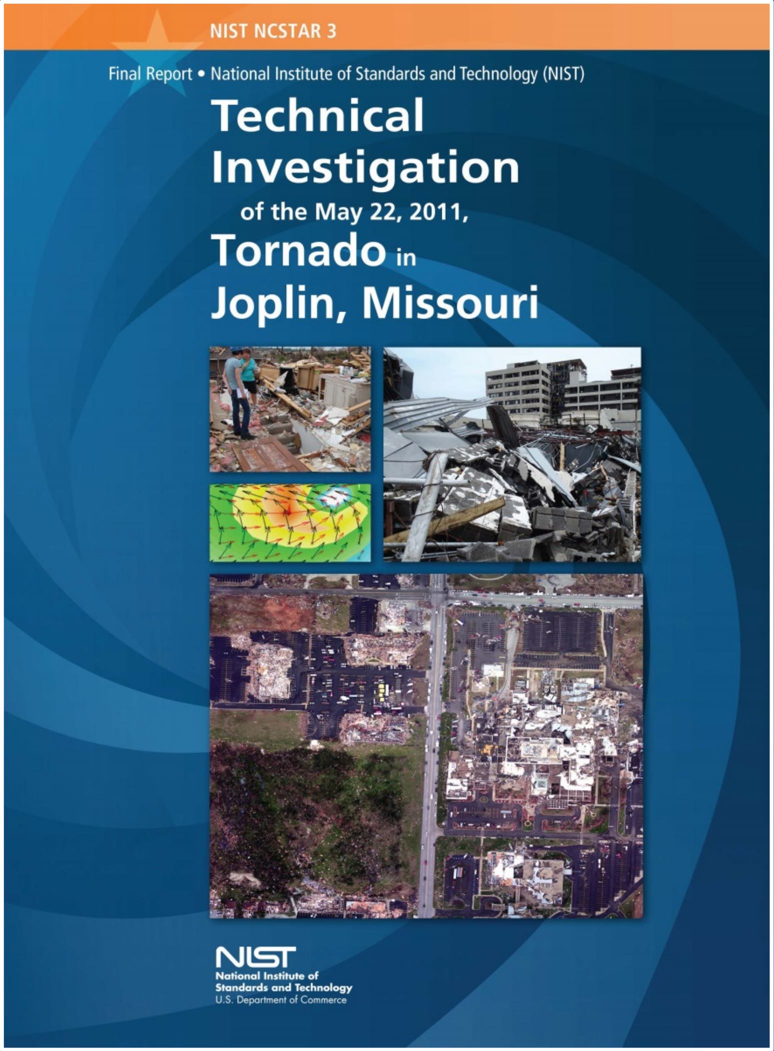
June 30, 2020
NCST Advisory Committee Meeting

NOTE – A summary of the recommendations are included in the following slides for context. The complete recommendations are available in the final report of the NIST Technical Investigation of the Joplin Tornado, at https://dx.doi.org/10.6028/NIST.NCSTAR.3

**Long Phan**
*Leader, Structures Group*

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

# NIST Joplin Tornado Investigation




The first tornado study to include storm characteristics, building performance, emergency communication and human behavior together - with assessment of the impact of each on fatalities

- **16 recommendations for improving:**
  - Tornado hazard characterization
  - Design and construction of buildings and shelters in tornado–prone regions
  - Emergency communications that warn of threats from tornadoes

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

# List of Joplin Recommendations

| Category | R # | RECOMMENDATION SUMMARY |
|---|---|---|
| Hazard Characteristics | 1 | Development and deployment of technology to measure tornado wind fields |
| | 2 | Archival of tornado event data |
| | 3 | Development of tornado hazard maps |
| | 4 | Improvement of EF Scale; means for continued improvement; adoption by NWS |
| Buildings, Shelters, Designated Safe Areas, and Lifelines | 5 | Development of performance-based standards for tornado-resistant design |
| | 6 | Development of performance-based tornado design methodologies |
| | 7 | a) Development of tornado shelter standard for existing buildings;<br>b) Installation of tornado shelters in more buildings in tornado-prone regions |
| | 8 | Development of guidelines for public tornado sheltering strategies |
| | 9 | Development of guidelines for selection of best available refuge areas |
| | 10 | Prohibition of aggregate roof coverings and ballast in tornado-prone regions |
| | 11 | Development of requirements for enclosures of egress systems in critical facilities |
| | 12 | a) Development of tornado vulnerability assessment guidelines for critical facilities;<br>b) Performance of vulnerability assessments by critical facilities in tornado-prone |
| Emergency Communication | 13 | Development of codes, standards, and guidance for emergency communications;<br>Development of joint plan by emergency managers/media/NWS for consistent alerts |
| | 14 | Deployment of "push" technologies for transmission of emergency information |
| | 15 | Research to identify factors to enhance public perception of personal risk |
| | 16 | Develop technology for real-time, spatially-resolved tornado threat information |

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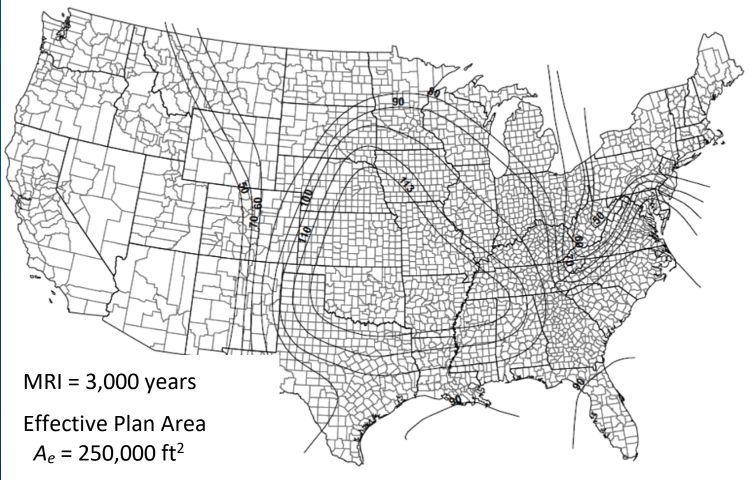
# Highlights of Implementation Activities and Successes since 9/19 Meeting (1/3)

## R3: Tornado Hazard Maps

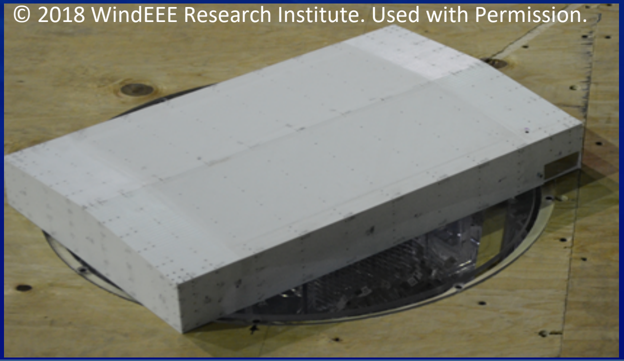
- **Tornado maps completed!**
- Submitted to ASCE 7 Wind Load Subcmte (WLSC)
- Technical Report and Tornado Database to be published in Q4/FY20




*Example tornado map, speeds in mph*

## R5/6: Performance-based standards/design methodologies for tornado resistant design

- **Tornado load design methodology completed!**
- **Proposed provisions for ASCE 7-22 completed!**
  - Provisions being balloted through ASCE 7 WLSC
  - Technical reports to be published in Q1/FY21:
    - Tornado load coefficients
    - Tornado load reliability / tornado map return period analysis




*Building model in tornado simulator. Tornado load coefficients were developed using data from a combination of experimental and computational models.*

# Highlights of Implementation Activities and Successes since 9/19 Meeting (2/3)

## R1: Development and deployment of technology to measure tornado wind fields

## R2: Archival of tornado event data

**NIST awarded grants[1] to 4 universities totaling $2.24M** in August 2019 under the Disaster Resilience Grant Research Program, supporting sensor development and field deployments to collect, analyze and disseminate spatiotemporal data on windstorm phenomena, including surface-level winds and near ground velocity profiles in tornadoes and other high wind events.

Year 1 Progress Briefings for these projects will be presented at the July 28-29

**VIRTUAL-2020 NIST Disaster Resilience Symposium**

For registration, see https://www.nist.gov/news-events/events/2020/07/virtual-2020-nist-disaster-resilience-symposium

[1] https://www.nist.gov/news-events/news/2019/08/nist-awards-66-million-research-help-structures-better-withstand

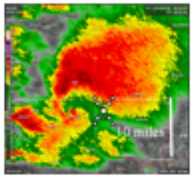
# Grant Projects Supporting R1 & R2 (1/4)

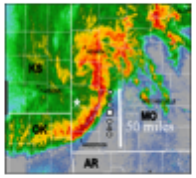
***Measurement of Near-Surface Pressure, Wind and Wind-Induced Load Characteristics using Novel Sensors in Thunderstorm, Tornado and Tornado-Like Environments***

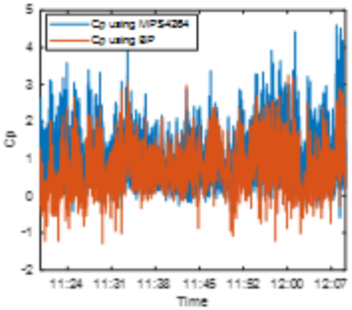
PI: Franklin T. Lombardo
NIST Award No: 70NANB19H057

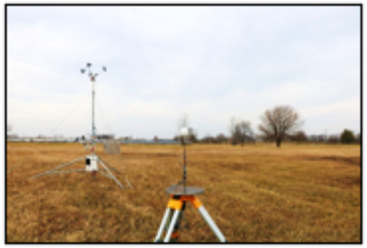
**_PRIMARY OBJECTIVES_**

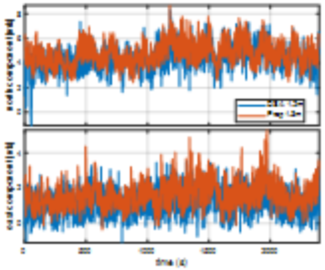
(1) Development, validation and production of low-cost sensors to measure wind and wind loading characteristics
(2) Rapid deployment and collection of unprecedented datasets
(3) Analysis and dissemination of these datasets







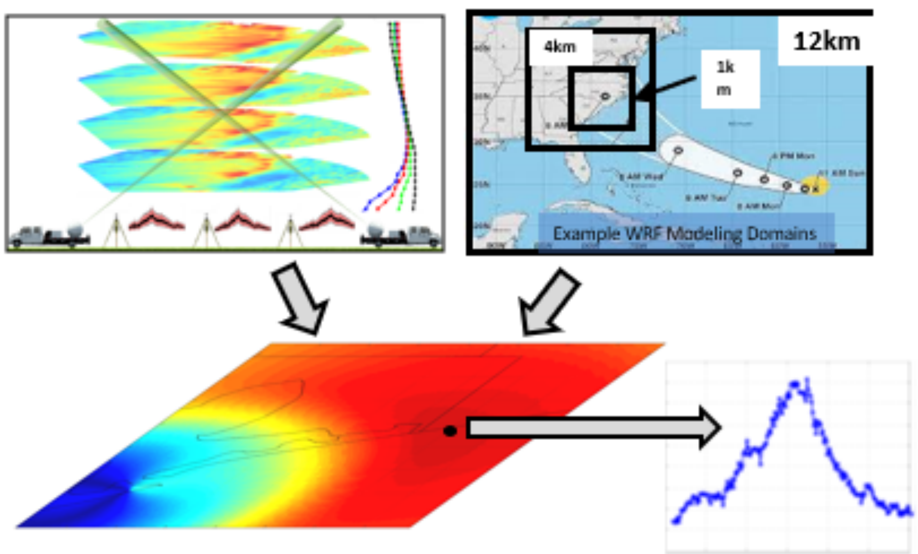
# Grant Projects Supporting R1 & R2 (2/4)

TEXAS TECH UNIVERSITY
National Wind Institute

## 4-D Measurement and Modeling of Engineering Relevant Windstorm Characteristics

PIs: John Schroeder, Brian Ancell, Brian Hirth
NIST Award #: 70NANB19H055

- Integrate research radar and StickNet measurements to produce four-dimensional wind fields of thunderstorms and hurricanes
- Develop and validate methods to extract engineering-relevant information from remotely sensed measurements
- Use high-resolution numerical weather prediction (NWP) formulate statistical relationships between regional atmospheric models and engineering-relevant winds
- Use radar-derived and NWP-derived information to bolster the creation of high resolution hurricane wind fields yielding accurate local wind records



# Grant Projects Supporting R1 & R2 (3/4)

## Spatiotemporal Maps of Damaging Winds from Integrated Remote and In Situ Observations (NIST 70NANB19H056)

Dr. Michael Biggerstaff (Univ. of OK) and Dr. Sean Waugh (NOAA/NSSL)

PROJECT GOALS

(i) develop high-spatiotemporal-resolution wind attribute maps over broad areas associated with land-falling hurricanes and large-scale thunderstorms

(ii) validate the wind maps using in situ observations

(iii) relate wind characteristics to storm features

Max surface winds during landfall of Hurricane Harvey

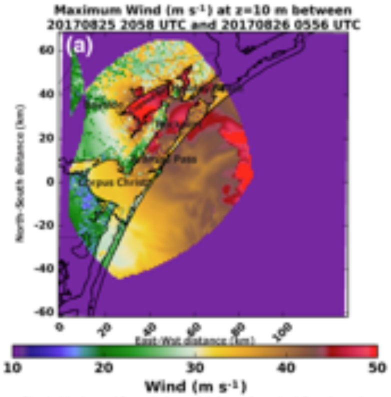



Fig. 1. Maximum 10-m wind speed defined from dual-Doppler radar analysis. Note SMART radar was off-line from 0141-0310 UTC.



# Grant Projects Supporting R1 & R2 (4/4)

FLORIDA TECH Wireless Sensor Network (WSN) System and LIDAR Experiments for the Characterization of Strong Wind Loads on Non-Structural components and Near-Surface Wind Profiles.

PI/co-PIs: Chelakara S. Subramanian, Jean-Paul Pinelli and Steven Lazarus

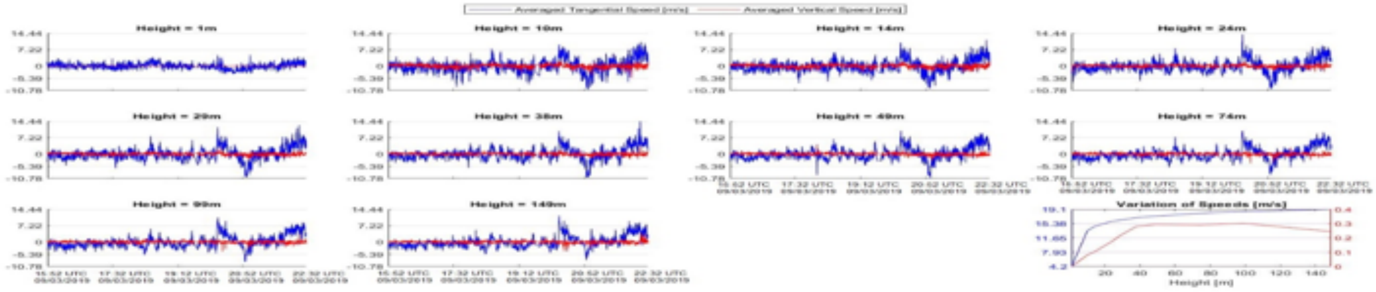
**NIST Award # 70NANB19H088**

Florida Institute of Technology

**The goal is to better understand the interaction of hurricane and other strong wind events with non-structural components of residential structures; and to characterize more accurately the near-surface wind profile for different terrain conditions in moderate to strong wind conditions.**

**The objectives are:**

1) to develop a new generation of a wireless pressure monitoring system
2) to deploy in large to full-scale tests at the Wall of Wind (WoW)
3) to measure wind pressures on different non-structural components, for different wind speeds and directions
4) to measure actual near-surface wind profiles for different terrain exposures with a LIDAR instrument
5) to analyze field and laboratory data to validate and improve current wind loads recommendations and models for pressure distributions on building components, wind profiles, and terrain roughness characterization.



LIDAR 20-sec average horizontal (blue) and vertical (red) wind speed (m/s) variations with height for Hurricane Dorian. The right insert is the 10-min average wind profile.

# Highlights of Implementation Activities and Successes since 9/19 Meeting (3/3)

## R13: Development of codes, standards, and guidance for emergency communications; and development of joint plan by emergency managers/media/NWS for consistent alerts

**New Publication:**

**Field research to application: a study of human response to the 2011, Joplin tornado and its impact on alerts and warnings in the USA**

By Erica Kuligowski, *Natural Hazards* (2020)

https://doi.org/10.1007/s11069-020-03945-6

# Body of Work Supporting R13

## Developed guidance for communities on the creation and provision of public alerts via outdoor siren (warning) systems and social media (incl. mobile alerts)

- Stakeholder workshops on 1) siren policies and procedures and 2) short message alerting
- Publications, including:

NIST Technical Note 1950

**Outdoor Siren Systems: A review of technology, usage, and public response during emergencies**

Erica D. Kuligowski
Katrina Wakeman

This publication is available free of charge from:
https://doi.org/10.6028/NIST.TN.1950

NIST Technical Note 1982

**A Review of Public Response to Short Message Alerts under Imminent Threat**

Erica D. Kuligowski
Jessica Doermann

This publication is available free of charge from:
https://doi.org/10.6028/NIST.TN.1982

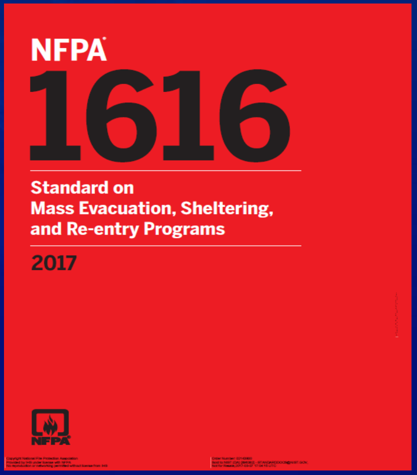
NIST Technical Note 2008

**Alerting under Imminent Threat: Guidance on alerts issued by outdoor siren and short message alerting systems**

Erica D. Kuligowski
Amanda Kimball

This publication is available free of charge from:
https://doi.org/10.6028/NIST.TN.2008

J. Sutton, E. Kuligowski, **Alerts and warnings on short messaging channels: guidance from an expert panel process**, *Nat. Hazards Rev*. 20 (2019). https://doi.org/10.1061/(ASCE)NH.1527-6996.0000324






## Impacts on Standards

**NFPA 1600 — Standard on Continuity, Emergency, and Crisis Management**

- Annex K: Emergency Communications: Public Alerts and Warnings in Disaster Response

**NFPA 1616 —Standard on Mass Evacuation, Sheltering, and Re-entry Programs**

- Annex K: Emergency Communication: Public Alerts and Warnings
- Annex L: Social Media Planning

# Tornado Hazard Characteristics

# Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines

Marc Levitan, *Research Wind Engineer*
Structures Group

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# Progress – Improvement of the EF Scale

## R4: Standardize the Enhanced Fujita (EF) scale and improve through addition of scientific/quantifiable damage indicators, particularly those that better distinguish between the most intense tornado events

## ASCE/SEI/AMS Standard on Wind Speed Estimation in Tornadoes and Other Windstorms *(NIST and NOAA co-chair this standards committee)*

- Complete drafts of chapters for all methods in the standard
- 1st Main Committee (MC) ballots on the following method chapters have been completed to date in FY20
  - Radar
  - **EF Scale**
  - Forensic Eng.
  - Treefall Pattern
- Chapters for remaining 2 methods are in Subcommittee review prior to MC ballot
  - In Situ
  - Remote Sensing Condition Assessment

*Summary of input requirements for each treefall-based wind speed estimation method*

| Input Requirement | Damage Severity Method | Treefall Pattern Methods | |
|---|---|---|---|
| | Godfrey–Peterson | Lombardo | Karstens |
| Treefall Pattern | | ✓ | ✓ |
| Damage Path Attributes | | ✓ | ✓ |
| Tornado Translation Speed | | ✓ | ✓ |
| Aerial Imagery | ✓ | ✓ | ✓ |
| Ground Assessment | ✓ | | |
| Tree Species Composition and Size Distribution | ✓ | | |
| Critical Treefall Wind Speed | | ✓ | |
| Critical Tree Population Wind Speed Distribution | | | ✓ |

# Progress – Tornado Hazard Maps (1/2)

**R3: Development of tornado hazard maps for use in the engineering design of buildings and infrastructure, considering spatially based estimates of the tornado hazard instead of point–based estimates.**

**Production of all 56 tornado hazard maps has been completed, incorporating the significant effects of target size**

## Maps Produced

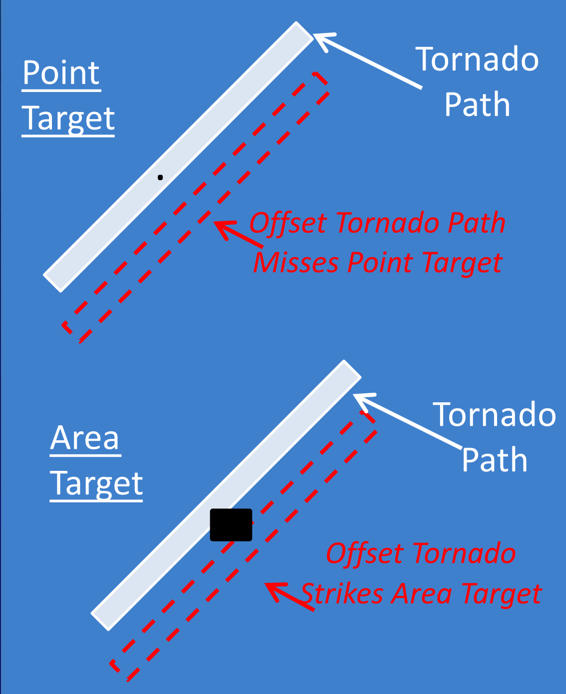
A. Target Sizes, $ft^2$ (Square targets)

1. Geometrical Point (no area)
2. 2,000 (45’ x 45’)
3. 10,000 (100’ x 100’)
4. 40,000 (200’ x 200’)
5. 100,000 (316’ x 316’)
6. 250,000 (500’ x 500’)
7. 1,000,000 (1,000’ x 1,000’)
8. 4,000,000 (2,000’ x 2,000’)

B. Return Periods (Years)

1. 300
2. 700
3. 1,700
4. 3,000
5. 10,000
6. 100,000
7. 1,000,000
8. 10,000,000

## Target Size Effects



# Progress – Tornado Hazard Maps (2/2)

## Completed Mapping Methodology

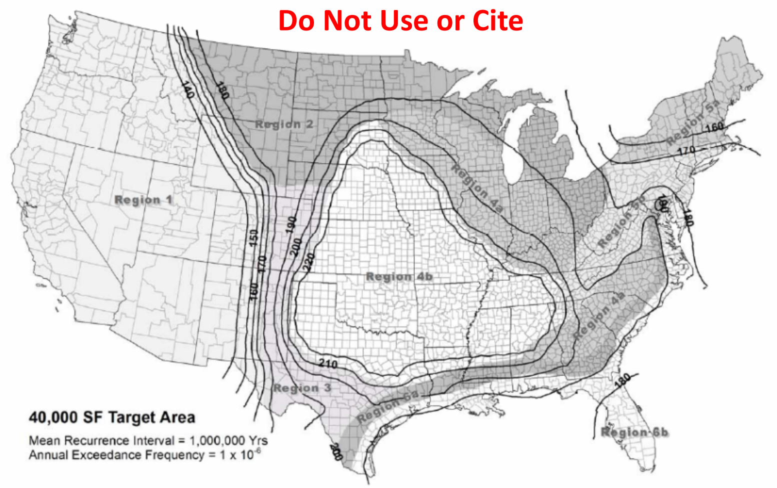
- **Preliminary Maps**
  - Maps as of 9/19 NCSTAC meeting (see slides 11-19 from that meeting[1])
- **Final Maps**
  - Added interior 'plateau' isotach

    The automated procedures used to create the preliminary maps resulted in isotachs at 10 mph increments, thus truncating the peaks in the center of the country.

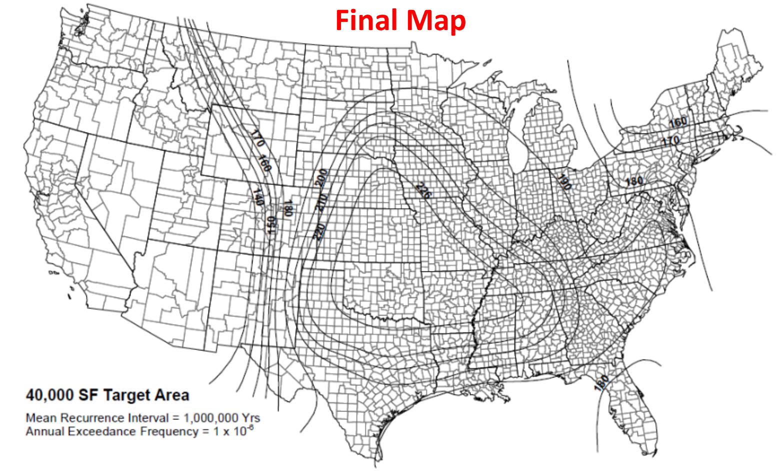
    The truncation interfered with interpolation between different target sizes at same return period.
  - Added smoothing of all isotachs using Polynomial Approximation with Exponential Kernel (PAEK) method
  - Updated formatting
  - Hand-cleanups

PRELIMINARY Map presented at 9/19 NCSTAC meeting

Do Not Use or Cite



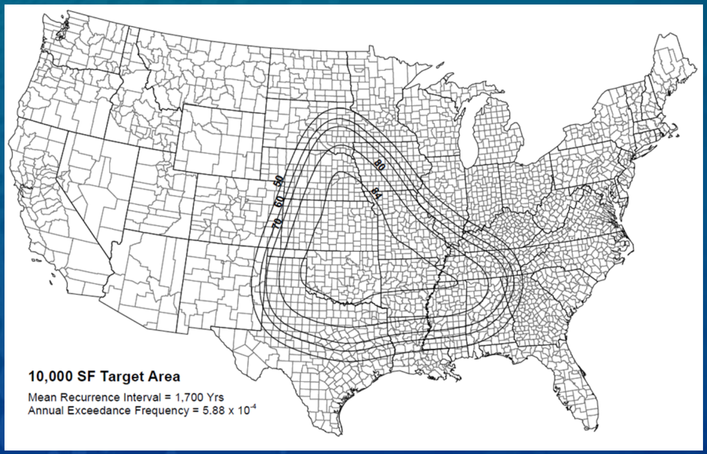

Final Map

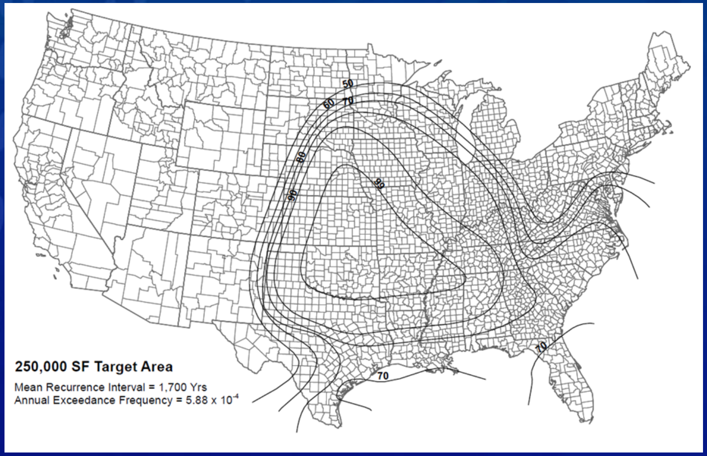



[1] https://www.nist.gov/system/files/documents/2019/09/19/02_phan_levitan_ncstac_sept2019_joplin_recommendations_update_final.pdf

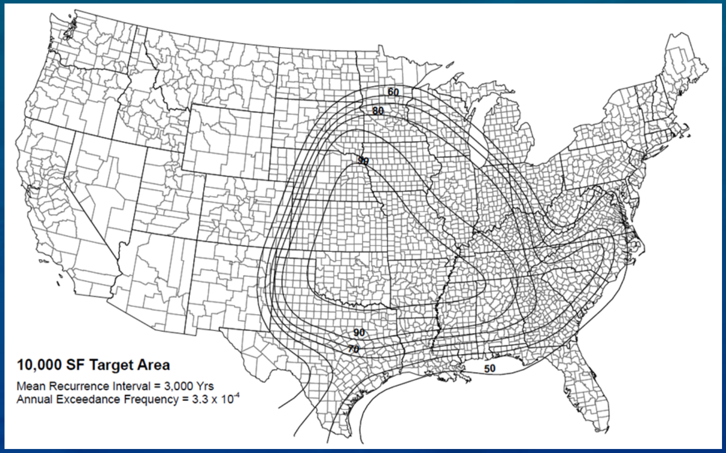
# Tornado Hazard Map Examples

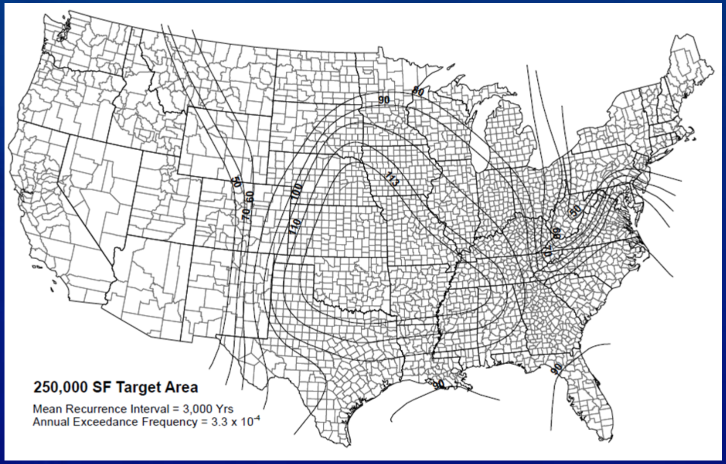
## Risk Category III




## Risk Category IV




- Tornado speeds are 3-s peak gusts at 33 ft height
- Linear interpolation between maps using the logarithm of the effective plan area sizes is permitted
- Tornado speeds less than those shown in ASCE 7-16 Chapter 26 may still produce loads that control the wind load design, due to differences in other load coefficients for tornadoes (e.g., $K_{zT}$, $K_{dT}$, $GC_{piT}$ and others)

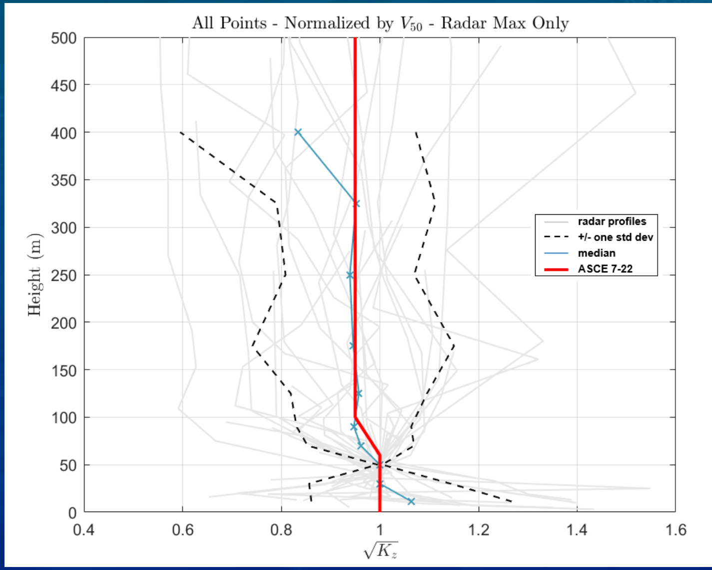
# Progress – Tornado Load Design (1/2)

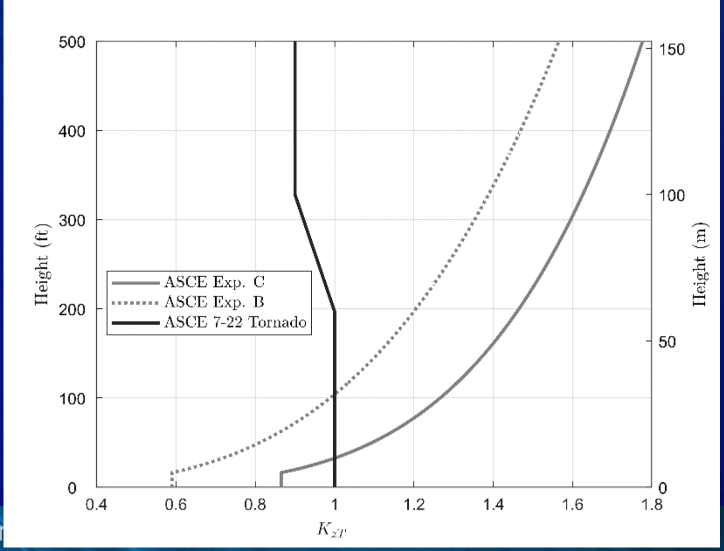
## R6: Develop risk–balanced, performance–based tornado design methodologies

### ASCE 7-22 *Tornado Task Committee*

*(NIST chairs this committee)*

- **Developed New Tornado Load Methodology**
- **Completed drafts for all tornado provisions and chapters of the standard** (completely new)
  - 1: General
  - 2: Load Combinations
  - 26: Wind Loads
  - 26: Appendix: Long MRI Wind Hazard Maps
  - 32: Tornado Loads
  - 32: Appendix: Long MRI Tornado Hazard Maps
- **All 23 ballot items passed the Wind Load Subcommittee on 1st round (Jan. 2020)**
- Worked closely with mobile radar community to analyze radar-measured tornado wind speeds and develop tornado velocity profile for ASCE 7-22, consistent with assumptions used in development of tornado hazard maps



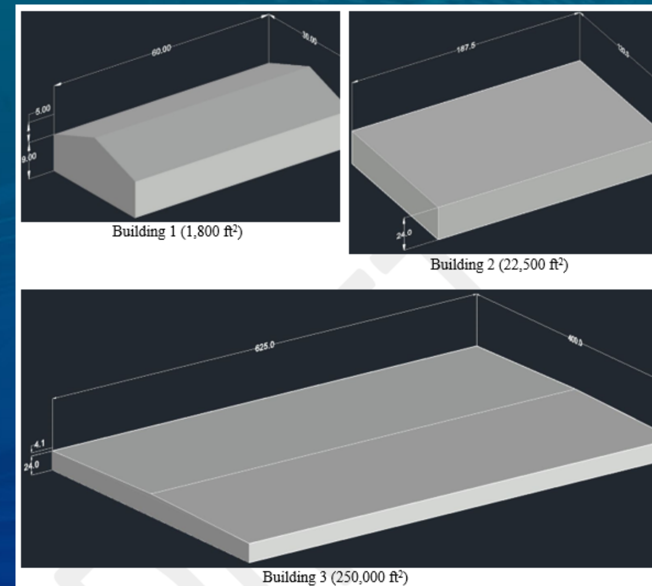
# Progress– Tornado Load Design (2/2)

- Developed New and Modified Wind Load Coefficients for Tornadoes
  - Tornado Velocity Pressure Exposure Coefficient $\mathbf{K_{zT}}$ (see previous slide)
  - Tornado Directionality Factor $\mathbf{K_{dT}}$, for MWFRS, C&C
  - Internal Pressure Coefficient $\mathbf{GC_{piT}}$, including effects of atmospheric pressure change
  - Tornado Pressure Coefficient Adjustment Factor for Vertical Winds $\mathbf{K_{vT}}$, for MWFRS and C&C

- Incorporated multiple requirements to differentiate tornado load provisions for ‘Risk Category IV and other facilities intended to remain operational’, in support of performance-based design

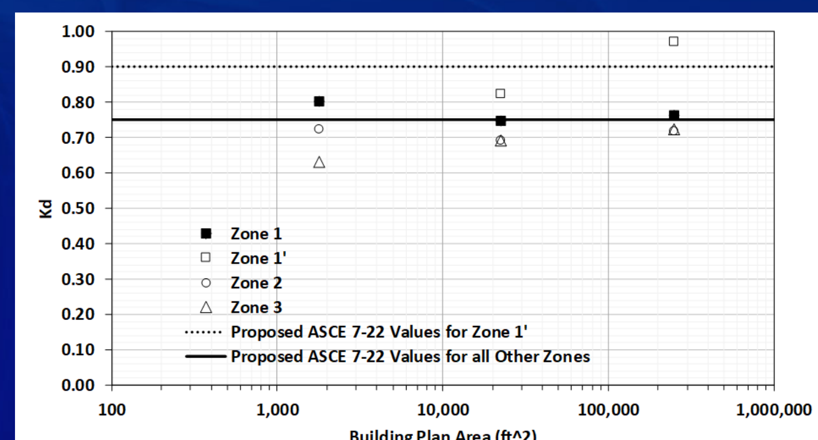
- Created and led Tornado Load Reliability Working Group, to identify tornado map return periods that provide reasonable consistency with the reliability delivered by ASCE 7-16 MWFRS wind load provisions
  - Collaboration between ASCE 7 Load Combinations Subcommittee and ASCE 7 Wind Load Subcommittee

- Developed tornado load combinations for Chapter 2






*Dimensions and plan areas for the three buildings used for $K_{dT}$ and $K_{vT}$ modeling.*



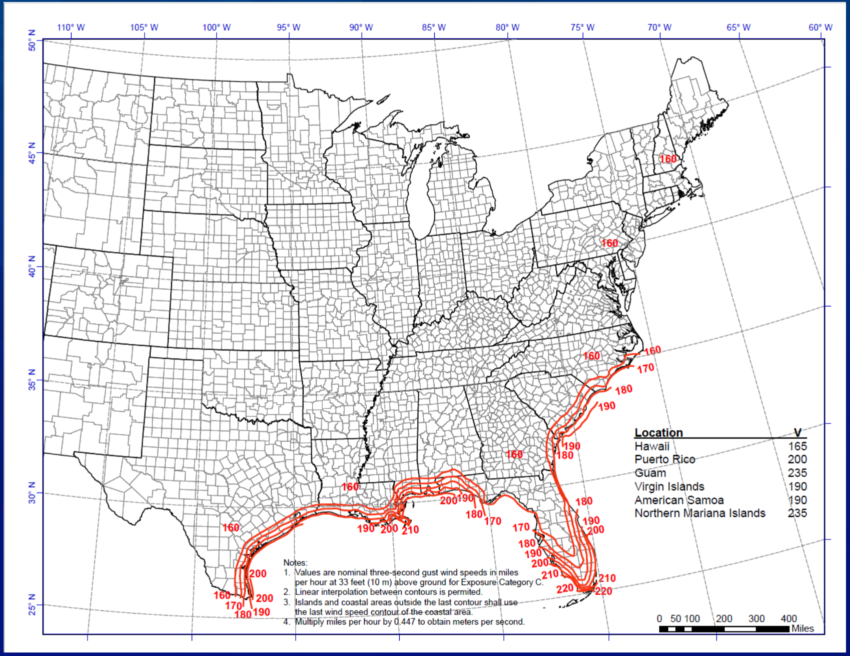

*$K_{dT}$ as a function of roof zone and building plan area for tornado-induced C&C loads*

# Progress – Tornado Shelter Standard

## R7a: Development of tornado shelter standard for existing buildings

**ICC 500-2020: ICC/NSSA *Standard on Design and Construction of Storm Shelters*** *(NIST chairs this standards committee)*

- 1st Public Comment Ballot - Oct 2019
- <u>NIST-led proposals include</u>
  - Expansion of scope to include shelters in existing buildings
  - Treatment of design and construction issues specific to installation of shelters in existing buildings
  - New 10,000-year MRI hurricane shelter design wind speed map
  - New provisions for impact loads due to laydown hazards and falling debris hazards
  - New load combinations provisions



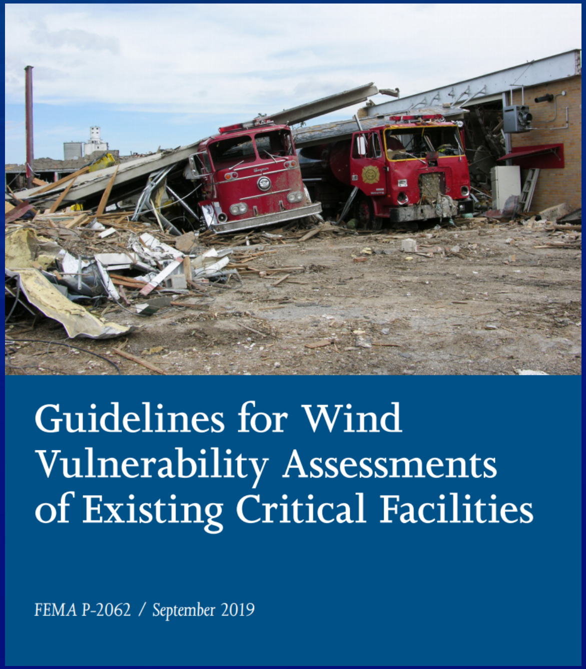
# Progress – Tornado Vulnerability Assessment

## R12a: Development of tornado vulnerability assessment guidelines for critical facilities

**New Publication**

**FEMA P-2062: Guidelines for Wind Vulnerability Assessments of Existing Critical Facilities**

- Methods to assess vulnerability of critical facilities to
  - wind pressure
  - wind-borne debris
  - wind-driven rain
- Guidelines apply to critical facilities "both within and outside hurricane-prone regions and to critical facilities in tornado-prone regions"
- NIST contributed to the development of these guidelines




Source: FEMA

# Implementation Progress to Date

**Legend**

- Published code/std/guidance
- Significant activities/progress
- In planning/modest progress

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| | 4 | Improvement of EF Scale; means for continued improvement; adoption by NWS | |
| Buildings, Shelters, Designated Safe Areas, and Lifelines | 5 | Development of performance-based standards for tornado-resistant design | |
| | 6 | Development of performance-based tornado design methodologies | Tornado load design method completed in FY20 |
| | 7 | a) Development of tornado shelter standard for existing buildings;<br>b) Installation of tornado shelters in more buildings in tornado-prone regions | On schedule for completion in Q1FY21 |
| | 8 | Development of guidelines for public tornado sheltering strategies | |
| | 9 | Development of guidelines for selection of best available refuge areas | |
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| | 16 | Develop technology for real-time, spatially-resolved tornado threat information | |

# Progress on Implementation of Joplin Tornado Recommendations

June 30, 2020
NCST Advisory Committee Meeting

## QUESTIONS?

**Please 'raise your hand' using the Blue Jeans Participant window and unmute your audio and video**


**Long Phan**
*Leader, Structures Group*

**Marc Levitan**
*Research Wind Engineer, Structures Group*


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