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

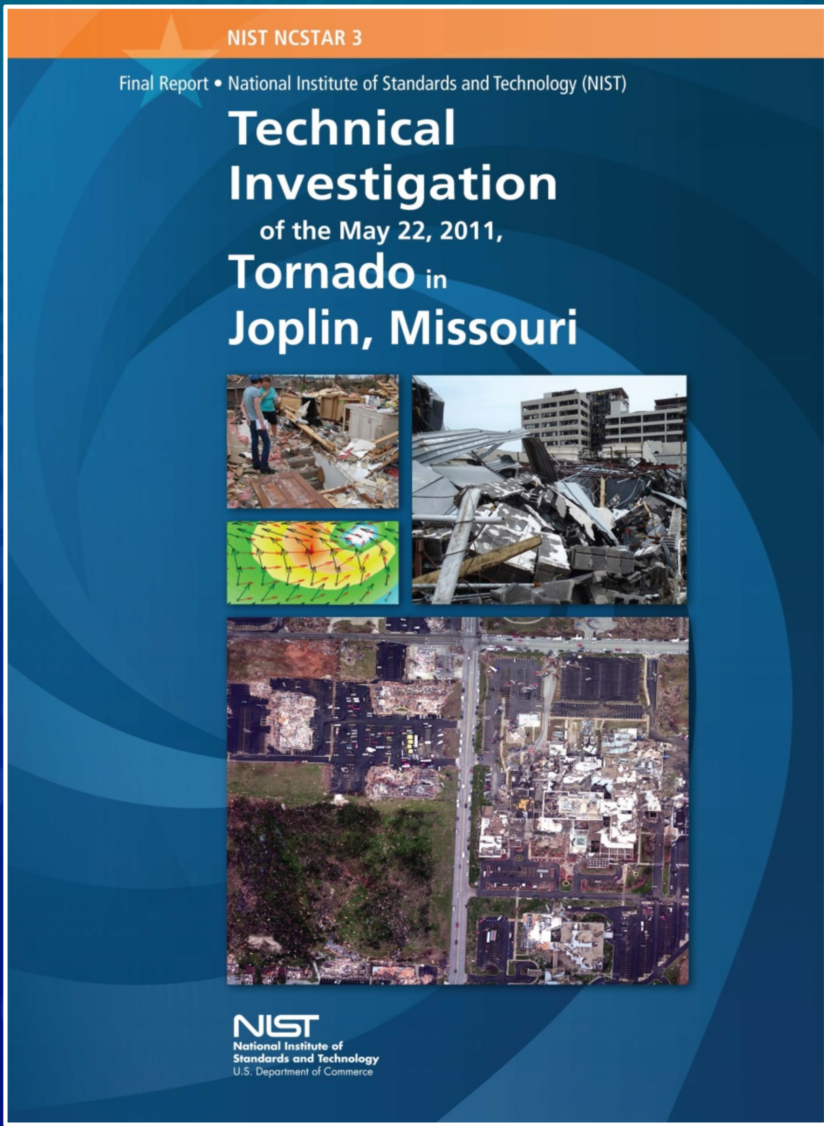
September 6, 2019
NCST Advisory
Committee Meeting

NOTE – Summaries 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



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

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

- **16 recommendations for improving:**
  - Tornado hazard characterization
  - How buildings and shelters are designed and constructed in tornado–prone regions
  - Emergency communications that warn of threats from tornadoes.

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; 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; b) Performance of vulnerability assessments by critical facilities in tornado-prone
Emergency Communication	13	Development of codes, standards, and guidance for emergency communications; Development of joint plan by emergency mgrs/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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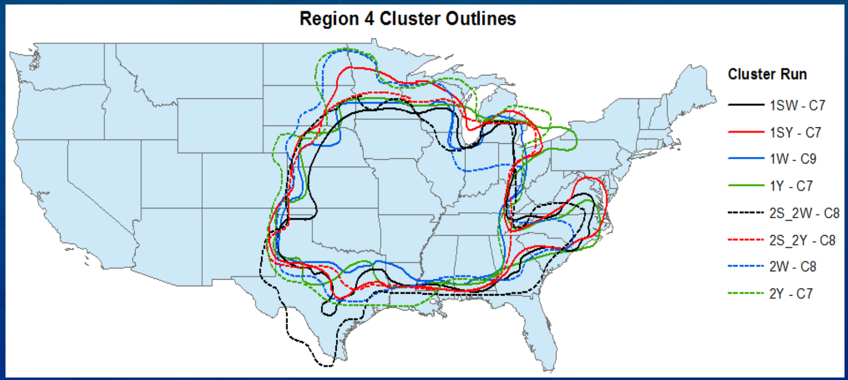
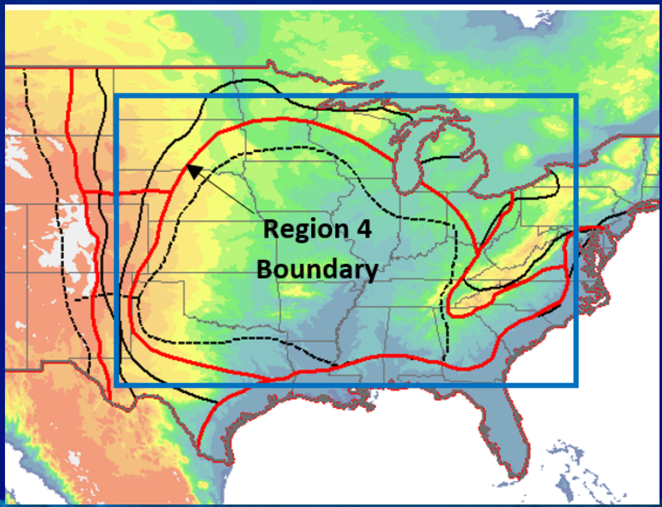
Highlights of Implementation Activities and Successes since 8/18 Meeting (1/5)

Nearing Completion of R3: Development of Tornado Hazard Maps

- Map development methodology has been completed
  - Incorporates variation of risk with size of the building or facility
  - Includes explicit treatment of epistemic (modeling) uncertainty
- Draft Tornado Hazard Maps have been produced
- 2nd Tornado Map Stakeholder Workshop held on May 14, 2019
  - Obtained valuable feedback being used to update the methodology and maps

Tornado Climatology Region Boundaries and Uncertainties





Highlights of Implementation Activities and Successes since 8/18 Meeting (2/5)

Awarded 4 grants totaling $2.24M under the NIST Disaster Resilience 2018 Notice Of Funding Opportunity[1], supporting development of sensors and methods to collect spatiotemporal data on windstorm phenomena, including surface-level winds and near ground velocity profiles in tornadoes, hurricanes, thunderstorms and other high wind events. **(R1)**

[1] https://www.nist.gov/el/disaster-resilience/disaster-resilience-federal-funding-opportunity-ffo

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NEWS

NIST Awards $6.6 Million for Research to Help Structures Better Withstand Earthquakes, Wind and Fire

August 08, 2019

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

NIST has awarded more than $6.6 million to study ways buildings can be made more resilient to hazards such as the 2011 Joplin tornado that destroyed this large store.

Highlights of Implementation Activities and Successes since 8/18 Meeting (3/5)

NIST Disaster Resilience Grant Awardees

- **Florida Institute of Technology ($421,000)**

  For a project to develop a wireless sensor network system and lidar experiments to characterize wind profiles near the ground and strong wind loads on nonstructural components of buildings (such as architectural details or electrical systems).

- **Texas Tech University ($582,000)**

  To deploy new 4D measurement and modeling techniques to advance understanding of windstorm characteristics and provide input and validation of numerical, experimental and empirical modeling efforts.

Highlights of Implementation Activities and Successes since 8/18 Meeting (4/5)

NIST Disaster Resilience Grant Awardees

- **The University of Illinois ($498,000)**

  To close fundamental knowledge gaps through the development and use of sensors to measure pressure, wind and wind load (the force wind exerts on a structure) characteristics in thunderstorm, tornado and tornado-like environments.

- **The University of Oklahoma ($738,000)**

  For the development of maps of damaging winds from integrated remote and on-site observations that provide high resolution in time and space.

Highlights of Implementation Activities and Successes since 8/18 Meeting (5/5)

- Main Committee balloting has begun on draft chapters of the new ASCE/SEI/AMS Standard on Wind Speed Estimation in Tornadoes and Other Windstorms **(R4 and R2)**
- Development of tornado load provisions (by NIST, ARA, and the ASCE 7 Tornado Task Committee) for the ASCE 7-22 Standard to accompany the new tornado wind speed maps is well under way (**R5 and R6**)
- A joint NIST/NOAA/FEMA workshop was held to identify the opportunities and challenges associated with planning, communications, and operations related to public tornado shelters (**R8, R13, and R16**)
- Guidance was published on short message templates for 280-character Twitter and 360-character Wireless Emergency Alert (WEA) messages (**R13**)
  - — 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.

engineering laboratory

Tornado Hazard Characteristics

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

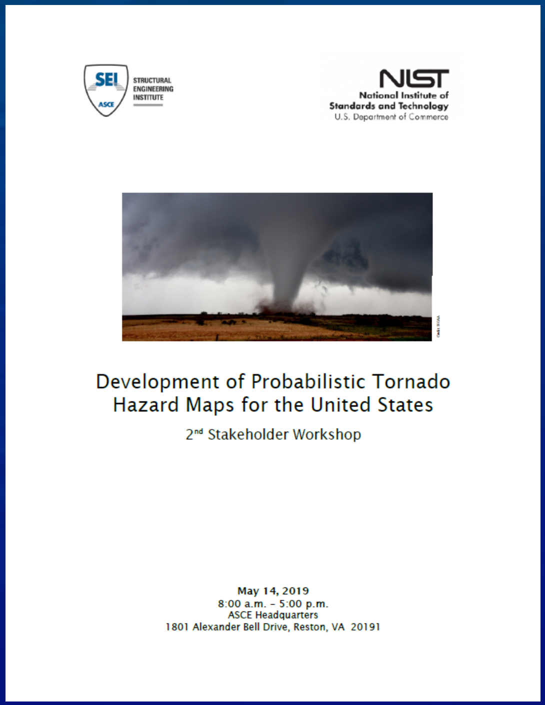
Marc Levitan, *Research Wind Engineer*
Structures Group

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

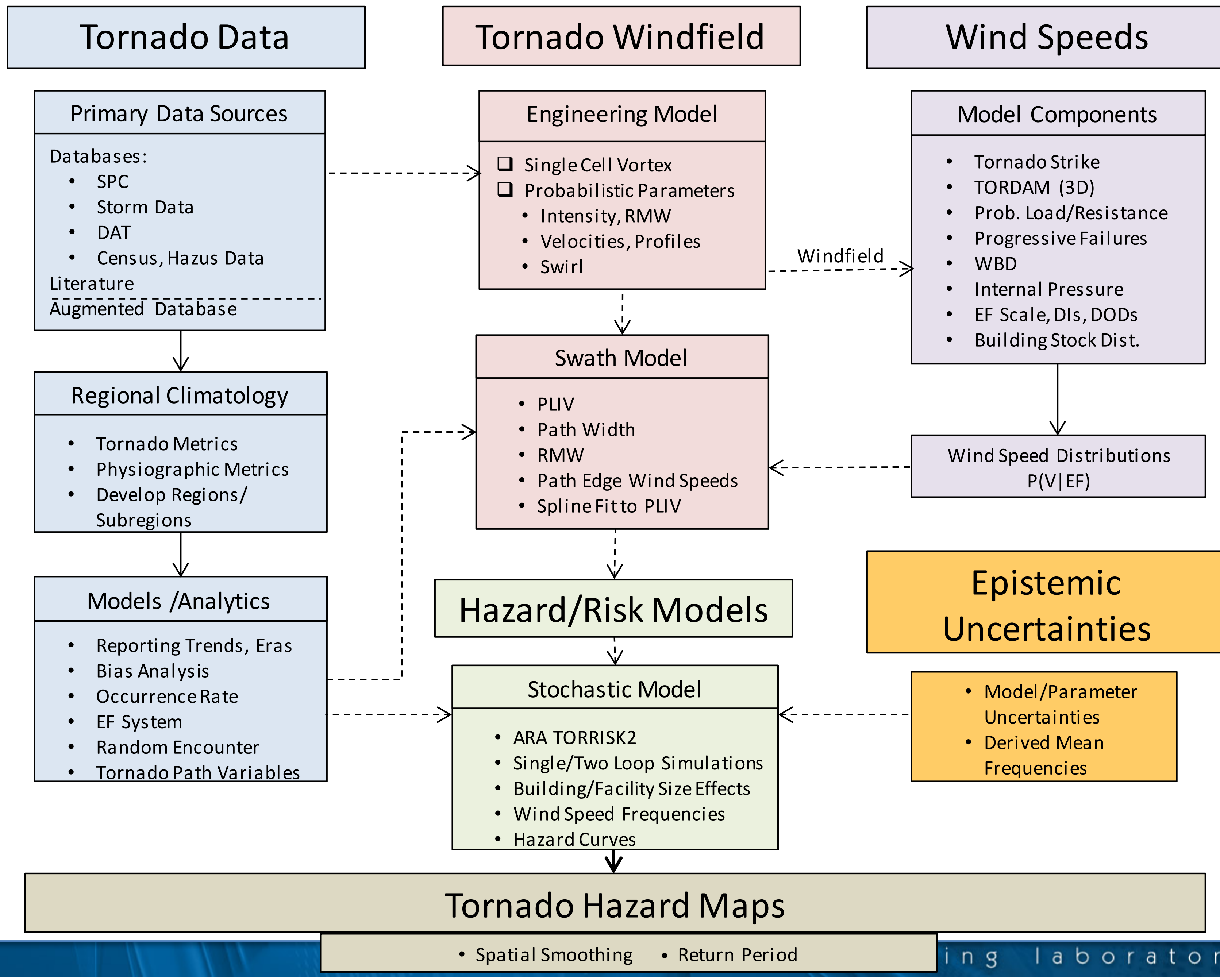
Progress – Tornado Hazard Maps

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.

- **2nd Tornado Mapping Stakeholder Workshop**
  - Jointly sponsored by NIST and ASCE/SEI
  - May 14, 2019, at ASCE HQ , prior to the ASCE 7-22 Wind Load Subcommittee meeting
  - Over 100 stakeholder participants
- **Goals**
  - Inform participants on the data, analysis, and methodology used in development of new probabilistic tornado hazard maps for engineering design
  - Present the draft maps and options for incorporation into ASCE 7-22
  - Obtain stakeholder feedback on the proposed tornado hazard maps and their implementation in ASCE 7-22
- **Outcomes**
  - Obtained valuable feedback that is being used to update the methodology and maps



Tornado Map Development Components/Process



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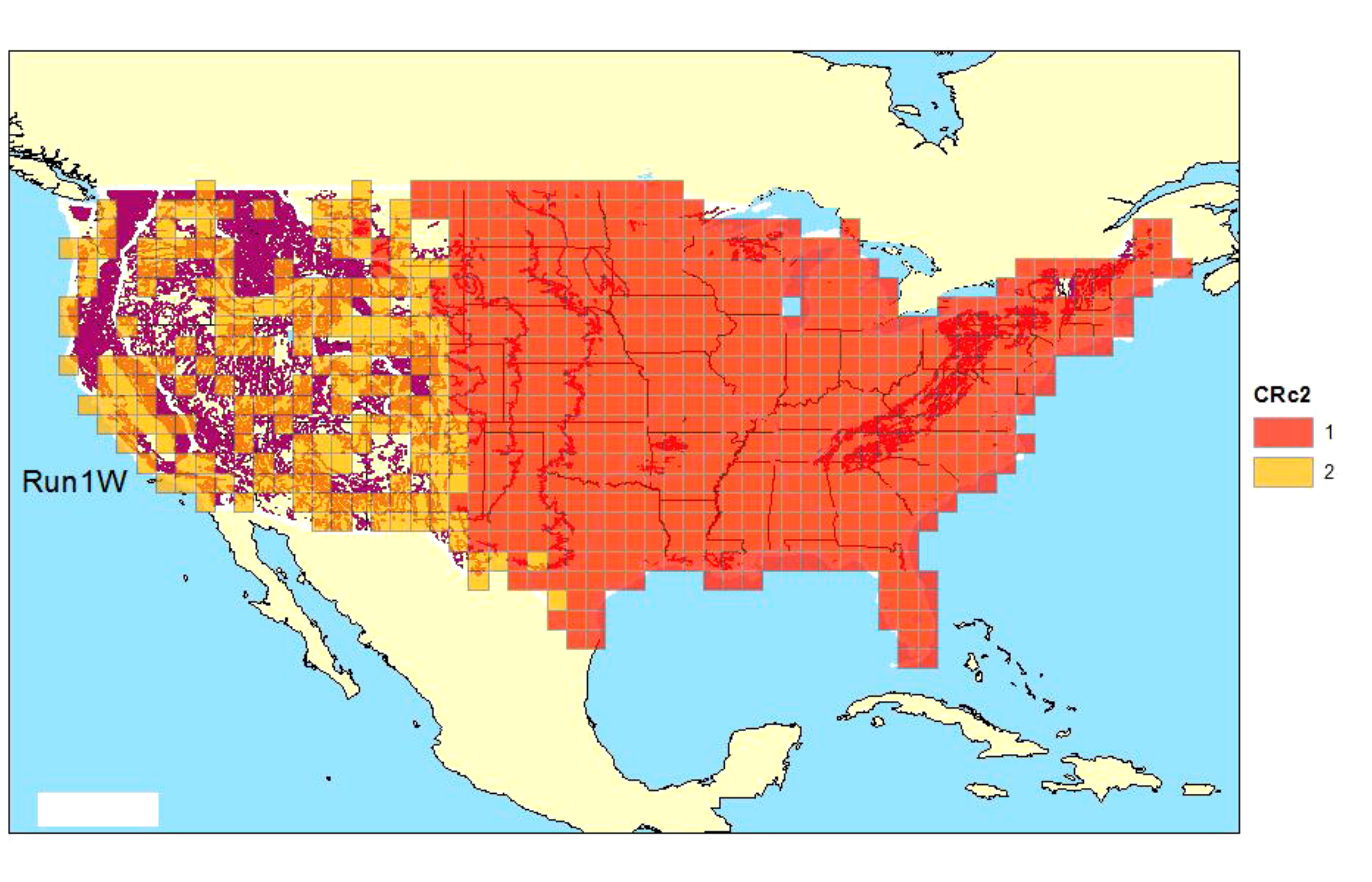
Tornado Climatology – Region Identification[1]

Animation of Sequential Cluster Formation - 1° Grid



Variables Include

Latitude, Longitude

Elevation

Std Dev Elevation

Land Fraction

Tornado Days/Yr

Path Length

Occurrence Rates
- All Intensities
- Moderate
- Strong

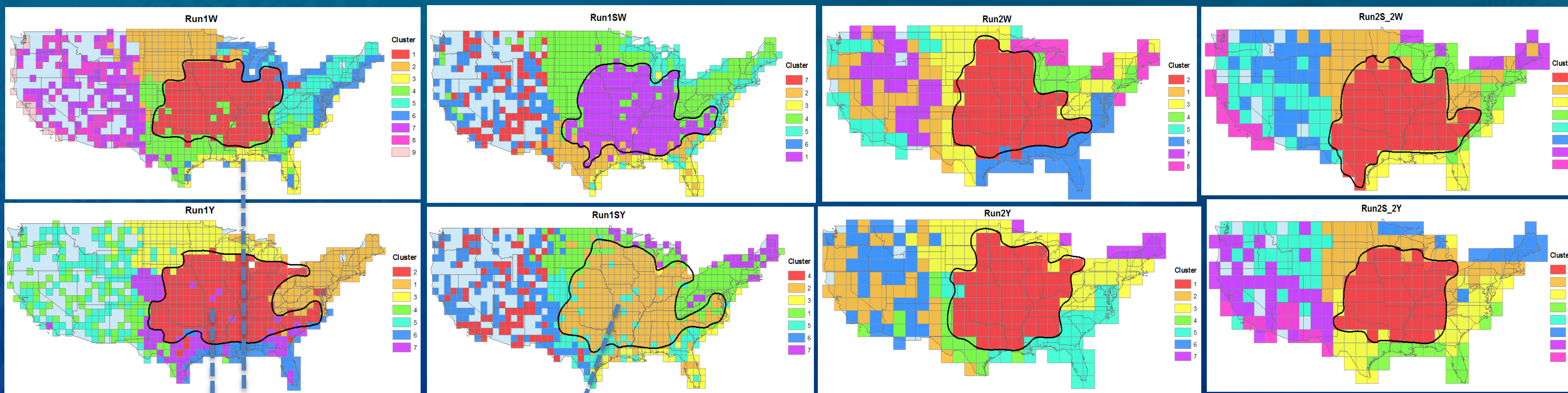
Point Strike Probability

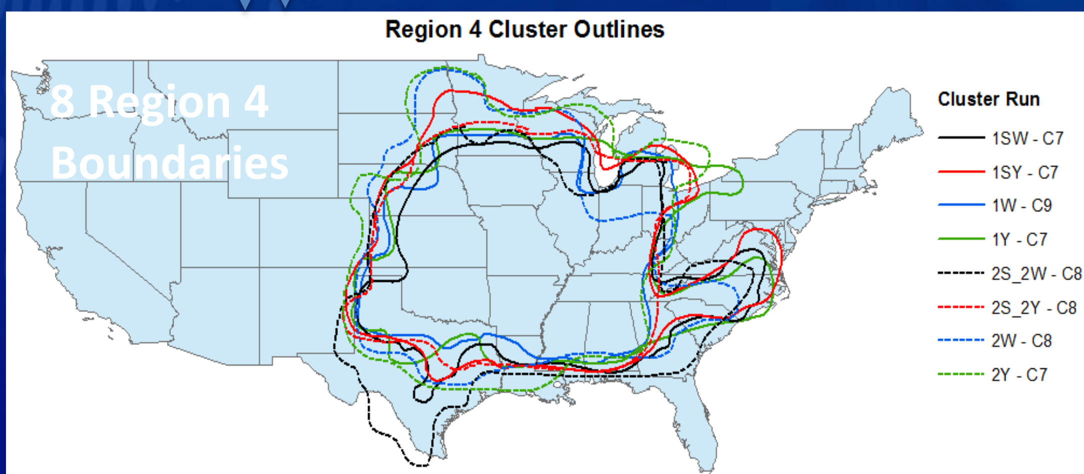
Also ran 2° grids and repeated 1° and 2° cluster analyses with grids shifted over half a grid cell

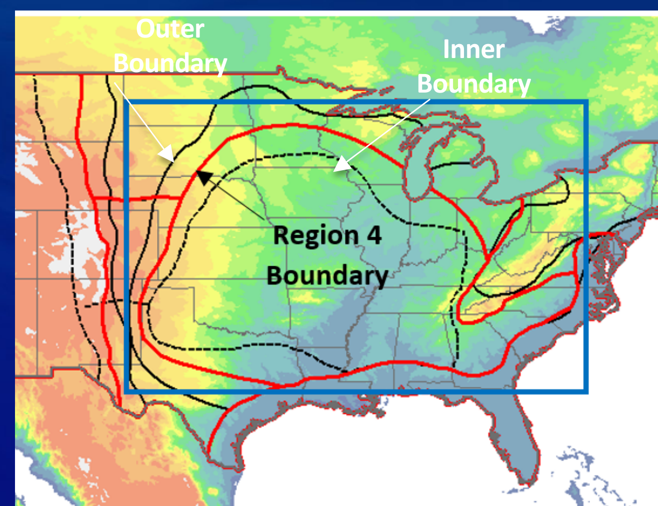
[1] Continuation of tornado regionalization presented to the NCSTAC on Aug. 30, 2018.
For data sources and analysis, see items 1-3 on slide 17 of last year's presentation, available at the link below.
https://www.nist.gov/sites/default/files/documents/2019/01/28/02_phan_levitan_kuligowski_ncstac_aug2018_joplin_recommendations_update_final.pdf

Region Boundaries and Uncertainties

8 Model Cluster Runs



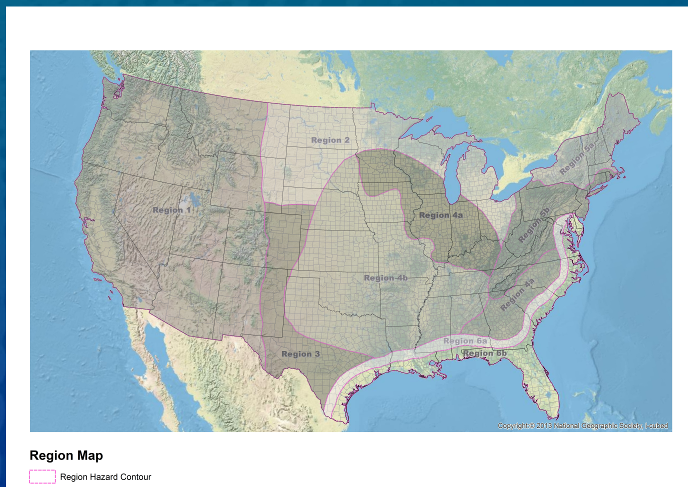




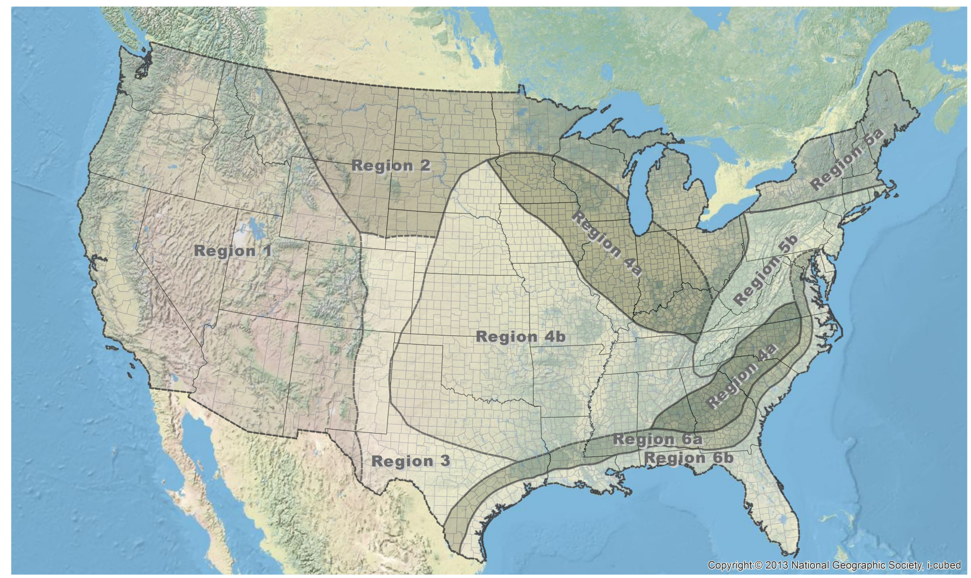
- The boundary contours are also used to quantify region boundary uncertainties through spatial smoothing, described on slide 18.

Final Region/Subregion Boundaries

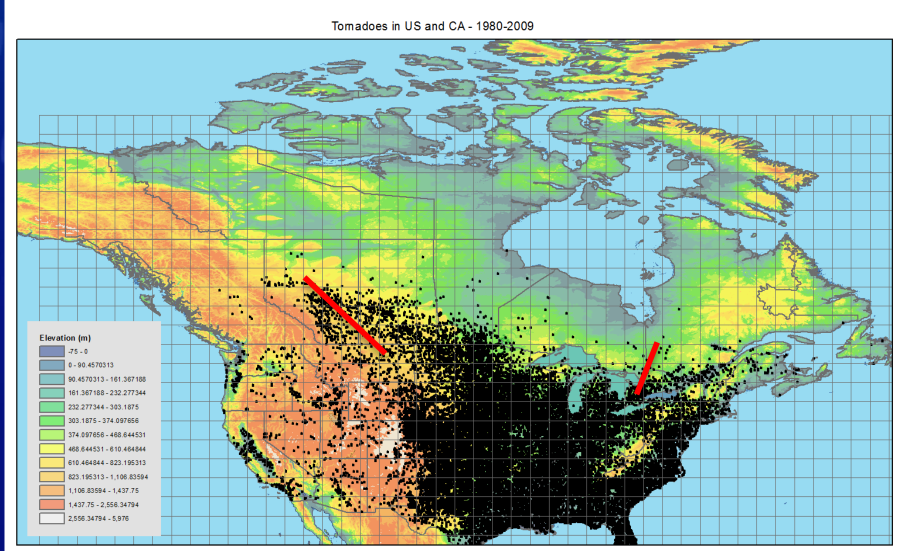
Hazard Regions from Cluster Analysis and Sub-region analysis



Final Climatology Regions for Tornado Maps



Additional Data on Tornadoes in Canada



Final regional boundaries determined using regions from cluster analysis with modifications, including

- Smoothing of certain boundaries to improve map contouring near multi-region intersections
- Adjusted Region 1-2 boundary in Montana-Wyoming to follow tornado trends in combined US-Canadian tornado maps and land elevation

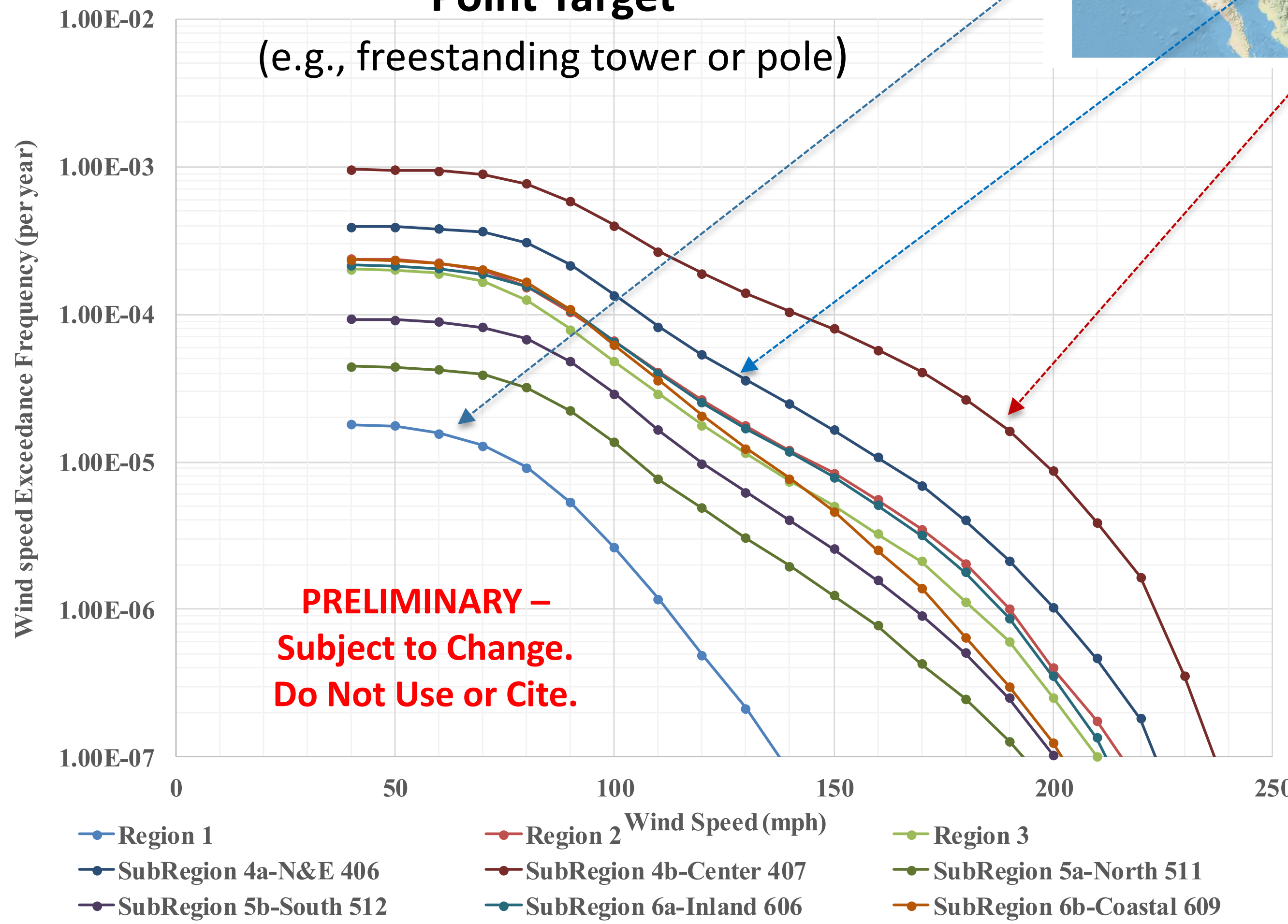
Data Sources: NOAA and Environment Canada

Hazard Curves

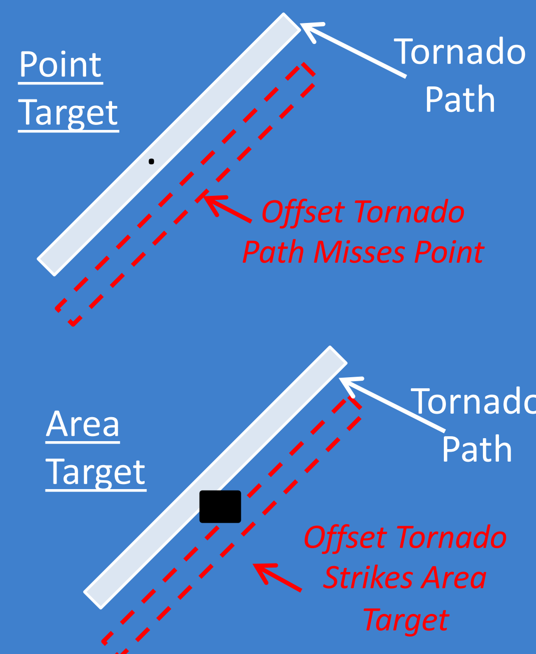
Windspeed Exceedance Frequencies (WEFs) are then developed for each region and subregion, for a range of target sizes

Point Target

(e.g., freestanding tower or pole)



Target Size Effects

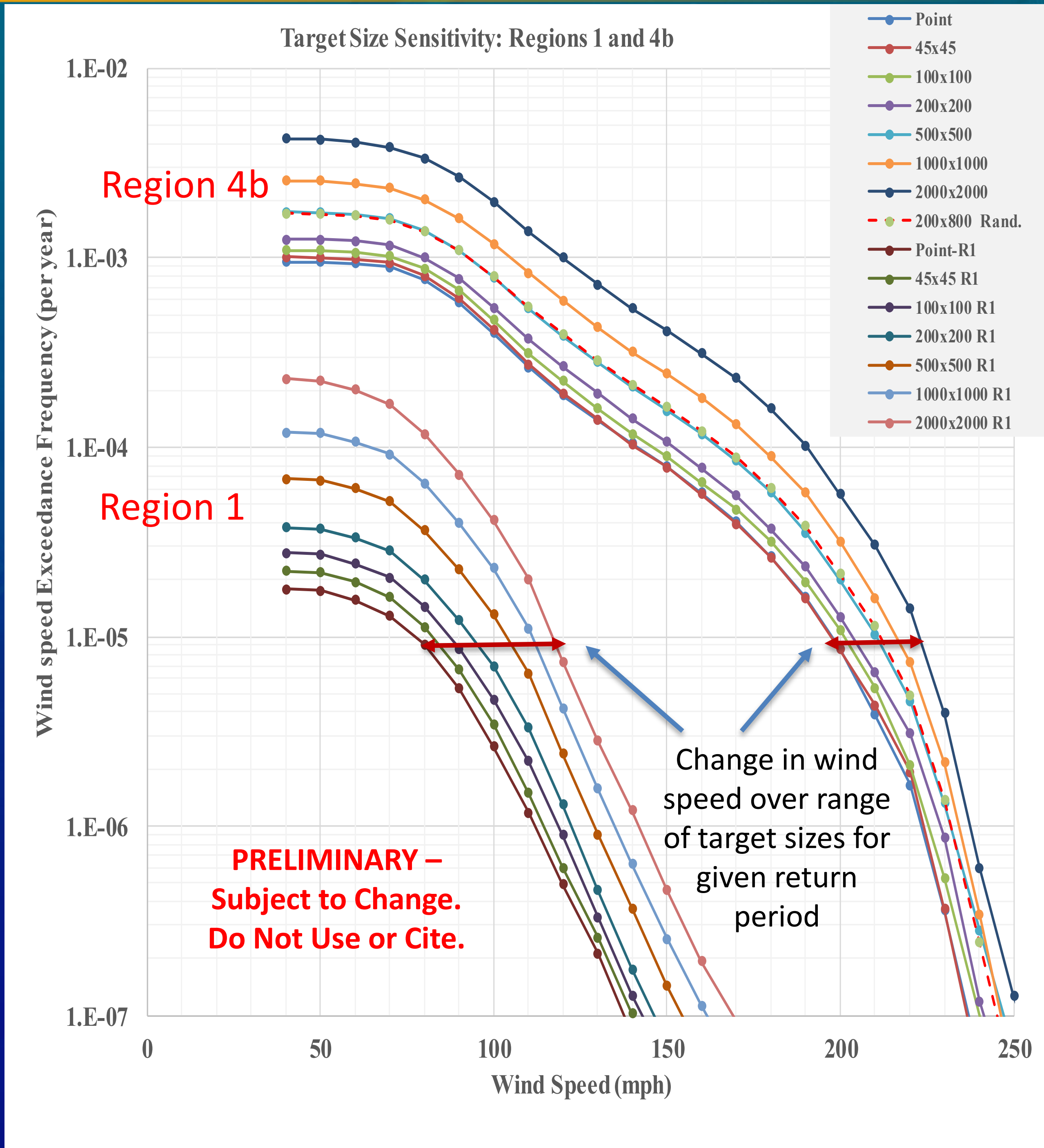


Target Size Sensitivity

- Region 1 shows more sensitivity than region 4b, due to smaller tornadoes
- For square targets, there is virtually no change for random orientation of target
- Targets w/plan aspect ratio >>1 have somewhat increased wind speeds over square targets with same target area.

Target Sizes

Plan Size (ft)	Area (ft^2)
Point	-
45x45	2K
100x100	10K
200x200	40K
500x500	250K
1000x1000	1M
2000x2000	4M



Map Development Process

1. A six step process is used to develop maps.
2. The grid wind speeds for a given Return Period and Target Size were smoothed using Gaussian smoothing.
3. The Kriging was performed in ArcGIS with default parameters, similar to the current ASCE 7 non-tornadic maps.

1. Hazard Curve WEFs (Given Target Size)

2. Interpolate Windspeeds to Return Periods

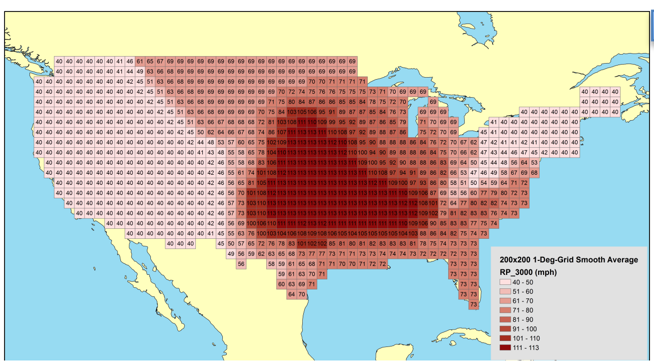
3. Input Windspeeds to Region/Subregion Grid Cells

4. Gaussian Smoothing

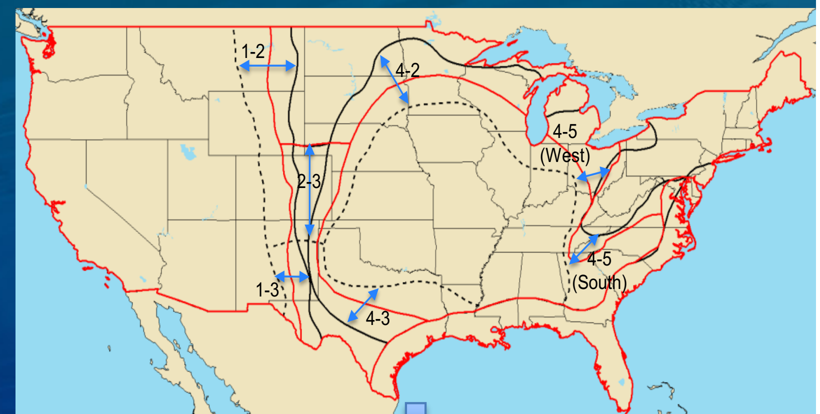
5. ArcGIS Kriging

6. Hand Adjustments for Final Maps

Example Grid After Smoothing



Regional Boundary Uncertainties



Region Boundary	Mean Distance (mi)	Approx. Number of 1 Deg. Cell Widths
Region 1- Region 2	166	2.8
Region 1 – Region 3	125	2.1
Region 2 - Region 3	416	6.9
Region 4 – Region 2	217	3.6
Region 4 – Region 3	130	2.2
Region 4 – Region 5 (West of Appalachians)	85	1.4
Region 4 – Region 5 (South and East of Appalachians)	177	3.0
Overall Mean	**188**	**3.1**

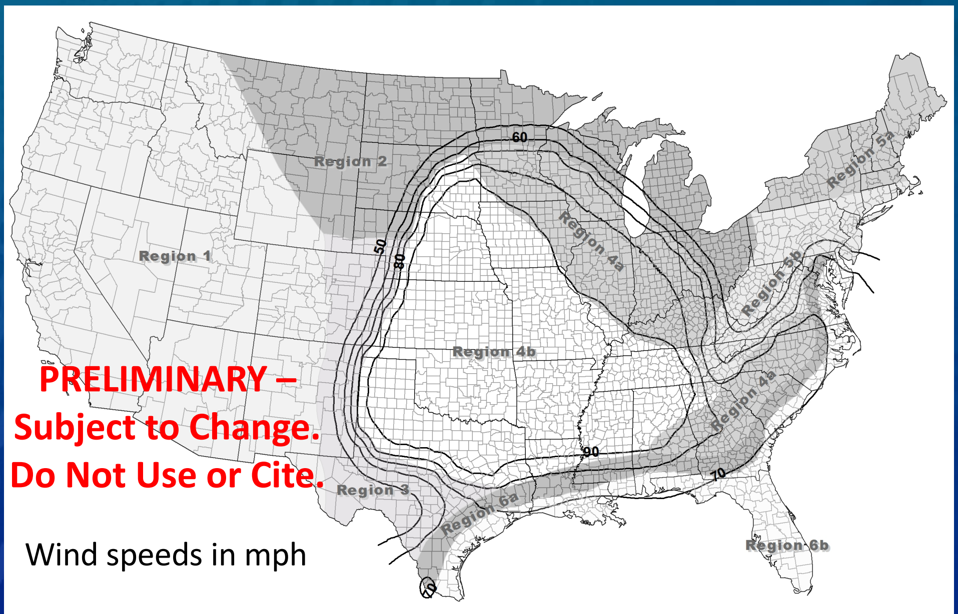
Gaussian Smoothing Weights.

0.0099	0.0239	0.0320	0.0239	0.0099
0.0239	0.0575	0.0770	0.0575	0.0239
0.0320	0.0770	0.1031	0.0770	0.0320
0.0239	0.0575	0.0770	0.0575	0.0239
0.0099	0.0239	0.0320	0.0239	0.0099

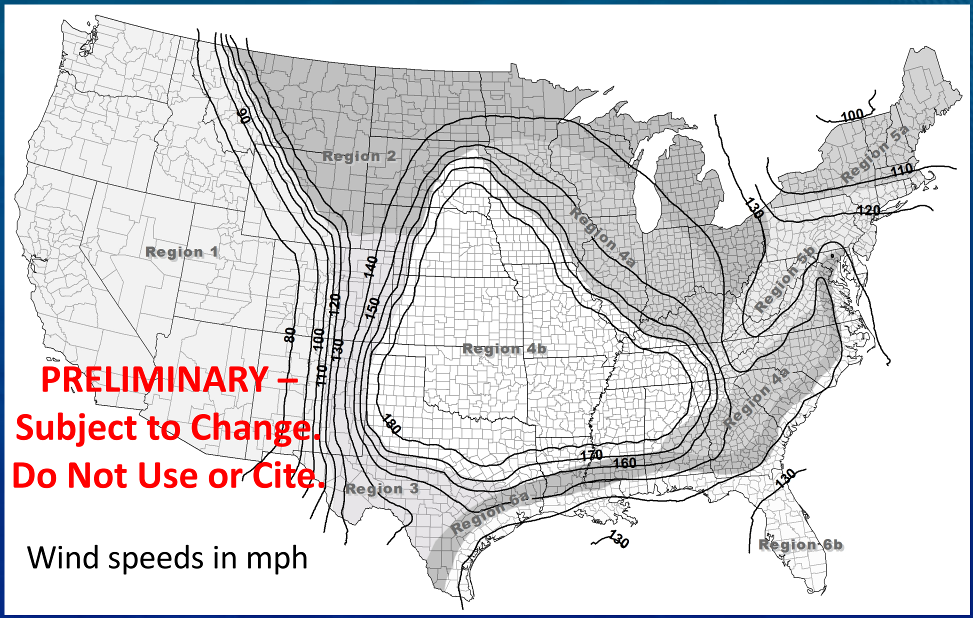
Map Examples

Target Size – 200 x 200 ft (40K ft²)

3,000 Year Return Period



100,000 Year Return Period



Notes

- Isotachs (i.e., contours) drawn in 10 mph increments
- Wind speeds less than those shown in ASCE 7 may still produce loads that control the wind load design, due to differences in other wind load coefficients for tornadoes (e.g., K_z, K_d, GC_p), which are still under development

Next Steps

- Continue working with the ASCE 7 Tornado Task Committee and Wind Load Subcommittee to refine maps and cartography for application in ASCE 7-22

Progress - Tornado Databases

R2: Improve publicly available tornado databases

During the last year continued working with multiple NOAA offices to improve tornado data collection and archiving, including:

- **NWS Storm Prediction Center (SPC)** on tornado database structure and data collection procedure improvements, including to the NWS Damage Assessment Toolkit
    - Most recent meeting at SPC on March 6, 2019

- **NWS Performance Branch (PB)** to improve the Storm Events Database
    - The NWS Storm Data Program has recently begun a major revision to its underlying software to move from a purely text-based system to one that can accommodate geospatial information, imagery, and other data formats
    - The new system will document much more information about each tornado and how/why it received a certain rating
    - Many of the changes are a direct result of significant engagement from NIST and the committee developing the ASCE/SEI/AMS Standard for Wind Speed Estimation in Tornadoes and Other Windstorms (see R4)

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)*

- Subcommittees have begun balloting chapters through the Main Committee
- NIST proposed a major improvement to the EF-Scale methodology, including guidance and wind speed estimates for Damage Indicators (DIs) based on
  - Typical resistance
  - Stronger than typical resistance
  - Weaker than typical resistance
- Additional EF Scale methodology improvements include
  - Explicit consideration of uncertainty
  - Existing DIs being updated
  - Several new DIs being developed, for example

DI # – Center Pivot Irrigation Systems (CPIS)

DoD	Damage description	Estimated Wind Speed (mph)[1]		
		Weaker than Typical Resistance	Typical Resistance	Stronger than Typical Resistance
1	Threshold of visible damage. One span damaged or overturned. Remainder of CPIS intact.	**65**	**75**	**85**
2	Multiple spans overturned or flipped on side - one time	**75**	**85**	**95**
3	Multiple spans overturned several times, rolled or twisted.	**80**	**95**	**110**
4	1 or more spans separated from system. Pivot point is severely damaged or separated. Entire unit tumbles.	**>80**	**>95**	**>110**

[1]Actual wind speeds are estimated to be ±20% of the values of this table.

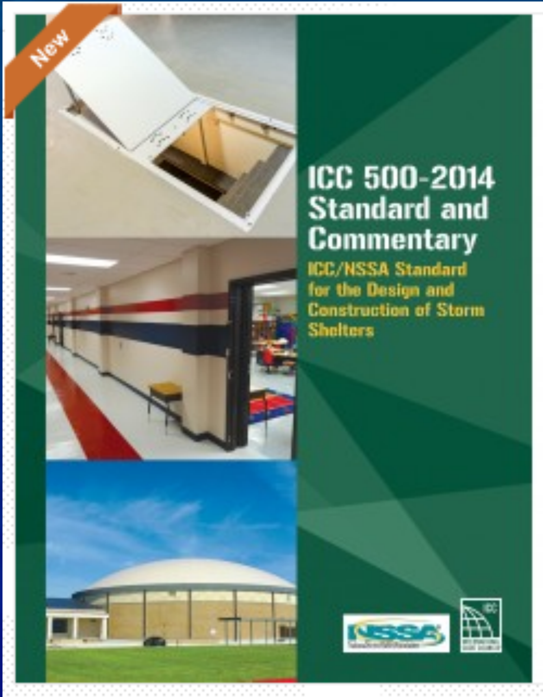
PRELIMINARY—Subject to change. Do not use or cite.

SOURCE: ASCE/SEI/AMS Committee on Wind Speed Estimation in Tornadoes. Used with Permission.

Progress – Tornado Shelter Standard

R7a: Development of tornado shelter standard for existing buildings

- **NIST is chairing the IS/STM Committee developing the 2020 ICC/NSSA Storm Shelter Standard**
- **<u>NIST successfully proposed expansion of scope to include construction of shelters within existing buildings</u>**
- **Other relevant ICC 500 proposals this cycle include**
  - Evaluation of existing slabs on grade to verify the ability to resist storm shelter loads
  - Applicability of current flood elevation criteria to installation of tornado shelters within existing buildings
- **Timeline: the revised standard is scheduled for completion by December 2020, to be incorporated into the 2021 I-Codes**



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Progress – Public Tornado Sheltering Strategies (1/2)

R8: Development and implementation of uniform national guidelines that enable communities to create safe, effective public sheltering strategies

Held Workshop on Public Tornado Sheltering

Venue

- National Tornado Summit
- March 4, 2019 in Oklahoma City

Workshop Goals

- Raise awareness of major changes taking place with the rapid expansion of public-use shelters
- Identify unique challenges posed by public tornado shelters across the many stakeholder communities
- Lay the foundation for a future workshop and subsequent development of guidance and best practices, which is needed for optimal planning and operations of public tornado shelters

Workshop Partners

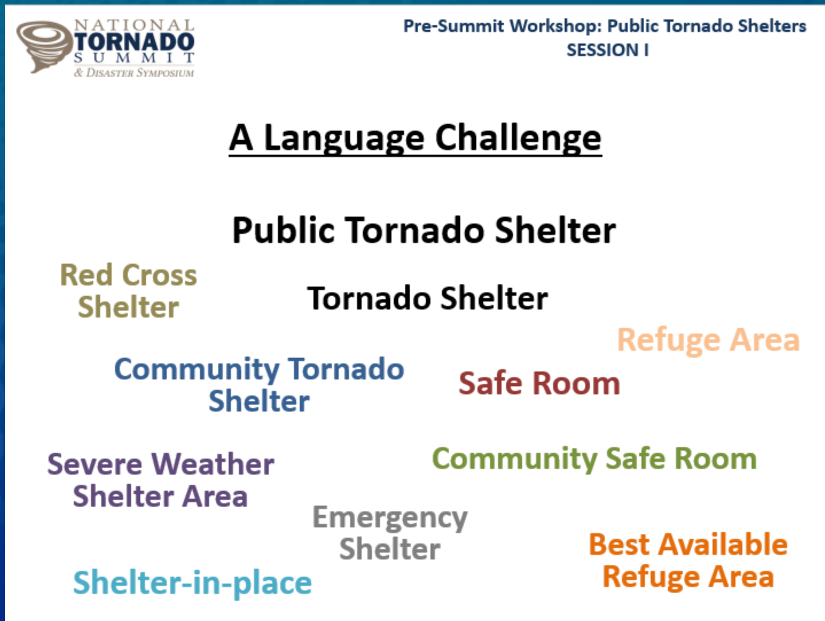
- FEMA, NOAA (NSSL and SPC), U. of Oklahoma, City of Birmingham AL, Industry

NATIONAL TORNADO SUMMIT & DISASTER SYMPOSIUM
MARCH 4 – 6, 2019
COX CONVENTION CENTER
OKLAHOMA CITY

Pre-Summit Workshop

Public Tornado Shelters:
Opportunities and Challenges for Improving Tornado Safety

Progress – Public Tornado Sheltering Strategies (2/2)



Workshop Focus Areas

- A Changing Paradigm – the Proliferation of Public Tornado Shelters Brings New Challenges
- Communications Challenges
- Operations Challenges
- Improving Tornado Safety - Opportunities and Best Practices

Workshop presentations available at
https://tornadosummit.org/archive/2019/detailed_agenda.php

Workshop Outcomes

- Based on positive results, NOAA and FEMA have agreed to work with NIST and industry partners on developing followup workshop(s)
- Emergency Communications was identified as a critical aspect of shelter operations, so this effort will also support implementation of R13 and R16, and make use of the results of work on R13 through R16.

Implementation Progress to Date

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

Progress on Implementation of Joplin Tornado Recommendations

September 6, 2019
NCST Advisory Committee Meeting

QUESTIONS?

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