



# May 22, 2011 Joplin, MO Tornado Study

## Draft Study Plan and Research Overview

*Briefing for NCST Advisory Committee  
November 7, 2011*

*Marc L. Levitan*

*Joplin Tornado Study Team Leader  
Lead, National Windstorm Impact Reduction  
Program (NWIRP) Research and Development*

# Presentation Outline

- **Background and Draft Study Plan** – *Marc Levitan*
  - Rating Tornadoes – The Enhanced Fujita Scale
  - Joplin Tornado Overview
  - Preliminary Reconnaissance
  - National Construction Safety Team
  - Draft Technical Study Plan
- Tornado Hazard Characteristics – *Frank Lombardo*
- Emergency Communications and Public Response – *Erica Kuligowski*
- Building and Lifeline Performance – *Long Phan*

NOTE: The information contained in this presentation is preliminary and subject to change as additional data is collected and analysis is performed.



# Rating Tornadoes – The Enhanced Fujita (EF) Scale

- EF Number is assigned to a tornado based on observed damage
- Estimated wind speed ranges associated with EF Numbers

| EF Number | Wind Speed (mph) | % of US Tornadoes <sup>1</sup> |
|-----------|------------------|--------------------------------|
| 0         | 65-85            | 62.2                           |
| 1         | 86-110           | 26.5                           |
| 2         | 111-135          | 8.0                            |
| 3         | 136-165          | 2.6                            |
| 4         | 166-200          | 0.58                           |
| 5         | 200+             | 0.04                           |

<sup>1</sup>1991-2010, Data Source: NOAA

- Typical damage state with EF-scale rating:

**EF1**



**EF3**



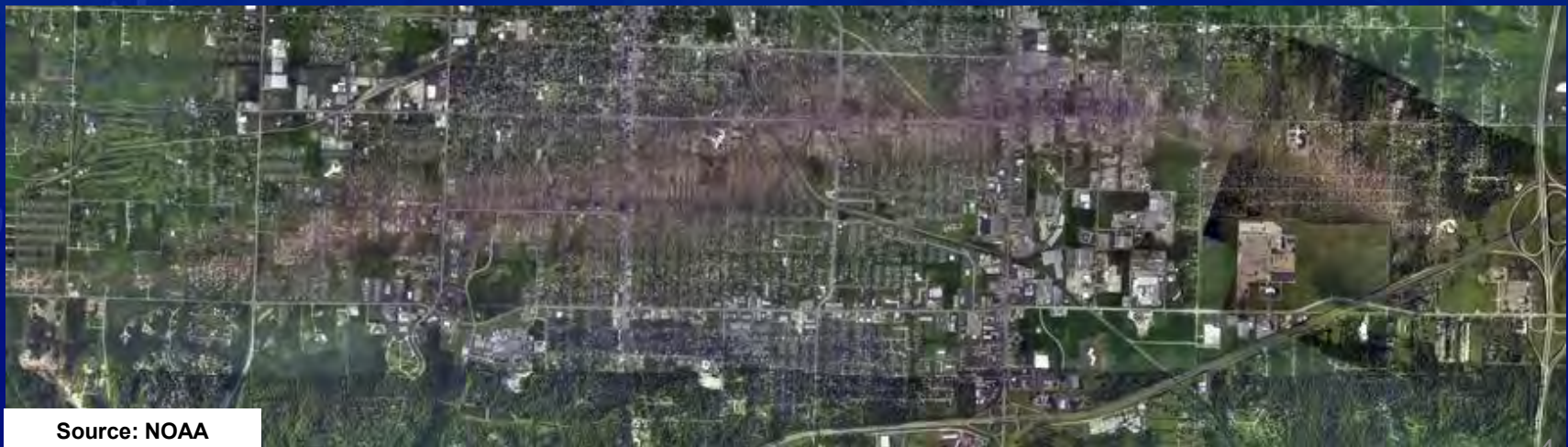
**EF5**



# Joplin Tornado Overview

- Touched down in Joplin beginning at 5:34 PM CDT, Sunday, May 22, 2011
- Enhanced Fujita Scale EF-5 tornado (highest category)
- Maximum estimated wind speeds: 200+ mph
- Path: up to 1 mile wide, 22.1 miles long (6 miles in Joplin)
- Track: generally West to East across Joplin (Newton and Jasper counties)
- $\approx$  8,000 structures damaged or destroyed ( $\approx$ 30% of Joplin)
- 162 fatalities, >1,000 injuries (Joplin Population: 49,024)

Sources: National Weather Service (NWS), Federal Emergency Management Agency (FEMA), City of Joplin



Source: NOAA





# Preliminary Reconnaissance

## Four person NIST team

- Departed from NIST afternoon of May 24, (< 48 hours following tornado)
- Returned May 28, 2011

## Objectives: Collect information and data on

- Tornado hazard
- Pattern, location, and cause of fatalities and injuries
- Tornado warning system, evacuation, emergency response, and occupant behavior
- Response of buildings, tornado shelters, and designated safe areas
- Damage to lifelines (natural gas, electrical distribution, etc.) and resulting fires

# Preliminary Reconnaissance - Data Collection Scope and Sources

- Warning Procedures/Emergency Operations
  - Director of Joplin/Jasper County Emergency Management Agency
  - NWS Incident Meteorologists
  - St. John's Medical Center, Director of Quality and Risk Management
  - St. John's Medical Center staff, Safety and Security
- Federal and State Tornado Mitigation and Response Efforts
  - FEMA Region VII Mitigation Division Director
  - MO State Emergency Management Agency (SEMA) Branch Chief, Logistics, Resources, Mitigation, and Floodplain Management Branch
  - SEMA Earthquake Program Manager
- Building Codes and Documents
  - City of Joplin Building Official and Code Enforcement Supervisor
- Fires and Lifelines
  - City of Joplin Fire Chief and Fire Marshall
  - Media Relations for Missouri Gas Energy
  - Engineering Manager of Missouri American Water
- Building and Infrastructure Performance
  - Observed and documented over 20 buildings and structures
- Behavioral Response
  - Interviewed 25 persons who experienced the tornado





# National Construction Safety Team

Based on analysis of the data collected and other criteria required by law and regulation, NIST Director Patrick Gallagher established a Team under the NCST Act on June 29, 2011, to proceed with a more comprehensive study of the impacts of the disaster.

- Team Members

- Four NIST Engineering Laboratory employees

- Dr. Marc Levitan: Study Team Leader,  
Wind Engineer, Leader of NIST NWIRP R&D
- Dr. Erica Kuligowski: Fire Protection Engineer and Sociologist
- Dr. Frank Lombardo: Wind Engineer and Meteorologist
- Dr. Long Phan: P.E., Structural Engineer,  
Experienced in wind disaster studies

- One National Oceanic and Atmospheric Administration (NOAA) employee

- Dr. David Jorgensen: Research Meteorologist and Chief,  
National Severe Storms Lab (NSSL)/Warning R&D Div.

# Draft Technical Study Plan

- Draft study plan available at
  - [http://www.nist.gov/el/disasterstudies/weather/joplin\\_tornado\\_2011.cfm](http://www.nist.gov/el/disasterstudies/weather/joplin_tornado_2011.cfm)
- Goals
  - To study the wind environment and technical conditions that caused fatalities and injuries in the May 22, 2011, Joplin, MO, tornado, the performance of emergency communications systems and public response, and the performance of residential, commercial, and critical buildings; designated safe areas in buildings; and lifelines.
  - To serve as the basis for:
    - Potential improvements to design and construction of buildings, designated safe areas, and lifeline facilities in tornado-prone regions;
    - Potential improvements to guidance for tornado warning systems and emergency response procedures;
    - Potential revisions to building, fire, and emergency communications codes, standards, and practices; and
    - Potential improvements to public safety.



# Draft Technical Study Plan - Objectives

1. Determine the tornado hazard characteristics and associated wind fields in the context of historical data
2. Determine the pattern, location, and cause of fatalities and injuries, and associated emergency communications and public response
3. Determine the response of residential, commercial, and critical buildings, including the performance of designated safe areas
4. Determine the performance of lifelines as it relates to the continuity of operations of residential, commercial, and critical buildings
5. Identify, as specifically as possible, areas in current building, fire, and emergency communications codes, standards, and practices that warrant revision

# Draft Technical Study Plan - Technical Approach

1. Identification of Issues Requiring Technical Study
2. Data Collection
3. Analysis and Comparison of Designs, Codes and Practices for Buildings and Emergency Communications Systems
4. Technical Findings and Recommendations
5. Identification of Needs for Revisions to Codes, Standards, and Practices





# Draft Technical Study Plan - Expected Outcomes

- Findings and recommendations that provide the technical basis for:
  - Assessing tornado hazard probabilities at the local, regional, and national levels
  - Potentially improving emergency communications systems and public response to those communications
  - Potentially improving tornado-resilient design and construction of buildings and structures, including residential buildings, designated safe areas within buildings, and lifeline facilities as related to maintaining building operations

# Draft Technical Study Plan - Anticipated Impacts

- Improved resilience of buildings, infrastructure, and communities to tornadoes
  - specifically focused on life safety objectives and enhanced performance of buildings during tornadoes to better protect building occupants and property
- Enhanced emergency communications systems and lifeline performance in future disasters
- Inform future research for the development and dissemination of guidance and tools for
  - assessing and reducing vulnerabilities related to tornadoes
  - producing the technical basis for cost-effective changes in national codes, standards, and practices







# May 22, 2011 Joplin, MO Tornado Study

## Tornado Hazard Characteristics

*Briefing for NCST Advisory Committee  
November 7, 2011*

*Frank Lombardo*

*Study Task Leader*

*NRC Postdoctoral Research Associate, NWIRP*

*David Jorgensen*

*Study Task Leader*

*Research Meteorologist and Chief, NOAA/National  
Severe Storms Lab/Warning R&D Division*

# Primary Objective

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

# Presentation Outline

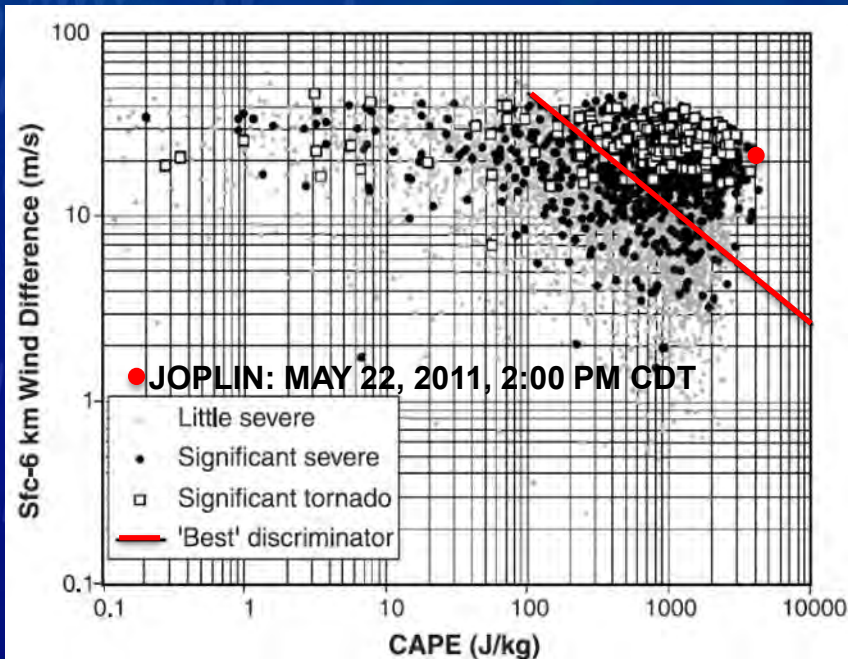
- Meteorological Conditions
- Near Surface Wind Environment
- Historical Context
- Tornado Climatology and Associated Risk
- Spatial Characteristics
- Enhanced Fujita Scale Assessment



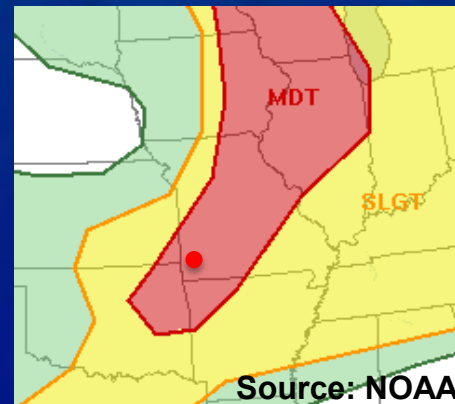
# Meteorological Conditions

- Severe Weather Outbreak Likely
  - Instability and wind shear were sufficient for severe weather
  - 1:30 PM CDT - Tornado Watch issued for Joplin and vicinity
  - 3:00 PM CDT - Moderate (MDT) risk of severe storms
  - 3:00 PM CDT - 10% probability of strong tornadoes (EF2 or greater) within 25 miles of Joplin
  - 5:34 PM CDT - Approximate tornado touchdown in Joplin

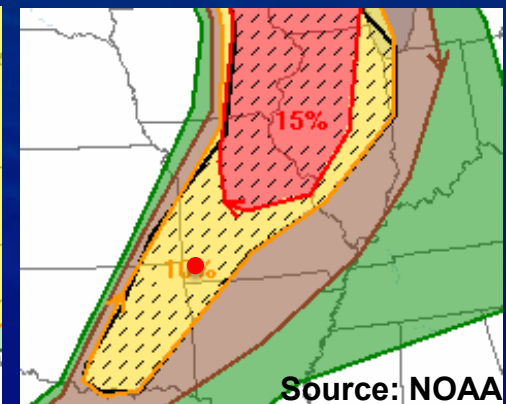
Source: NOAA



Categorical Severe Risk



Tornado Probabilities



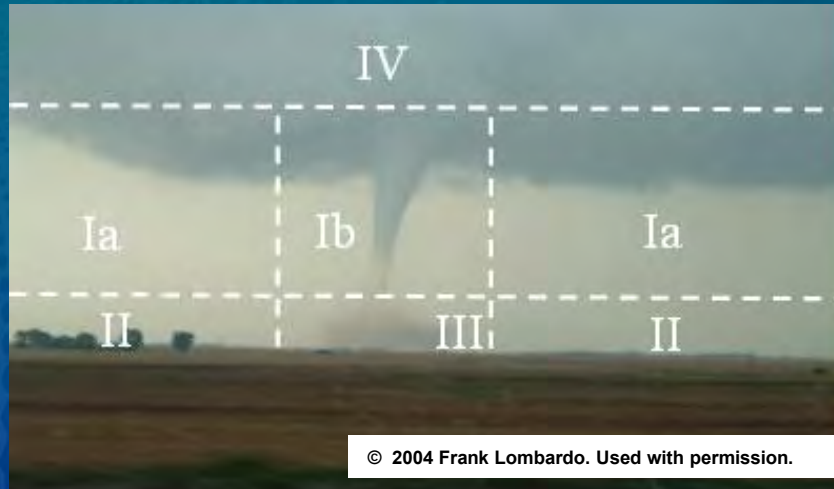
Source: NOAA  
Enhancements: NIST

CAPE: Convective Available Potential Energy



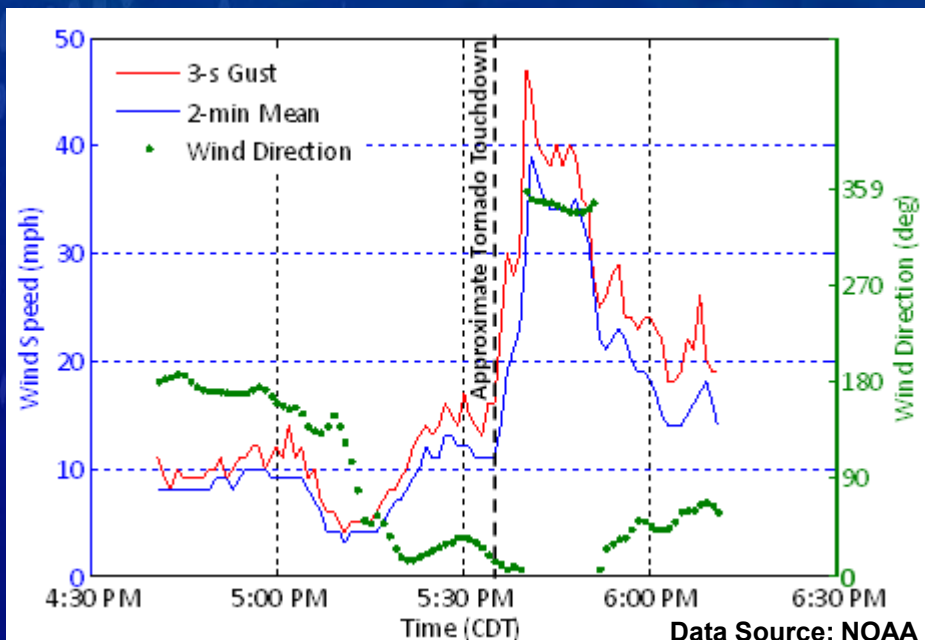
# Near Surface Wind Environment

- Tornado Flow Regions



- Ia. Outer Flow
- Ib. Core Flow
- II. Boundary Layer
- III. Corner Flow
- IV. Mesocyclone

- Direct Wind Speed Measurements



Joplin airport 10m anemometry data showing effects of tornado even though ~ 5-6 miles away! (Region II)

- Gusts ~50 mph
- Sustained ~40 mph
- Wind direction corroborates tornado position (south of airport)





# Near Surface Wind Environment – Indirect

- Observed Damage (Using EF-scale)
- Three data sources
  1. NIST rated from aerial photos and ground photos/videos
  2. Jasper County Geographic Information Services (GIS)
  3. US Army Corps of Engineers (USACE)



Aerial Photo Source: NOAA  
Enhancements: NIST

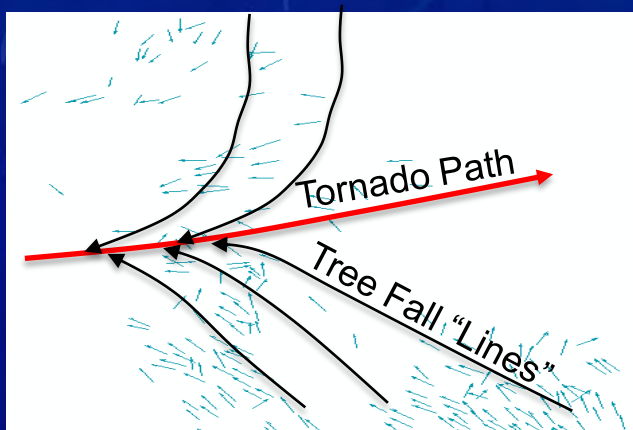


# Near Surface Wind Environment – Indirect

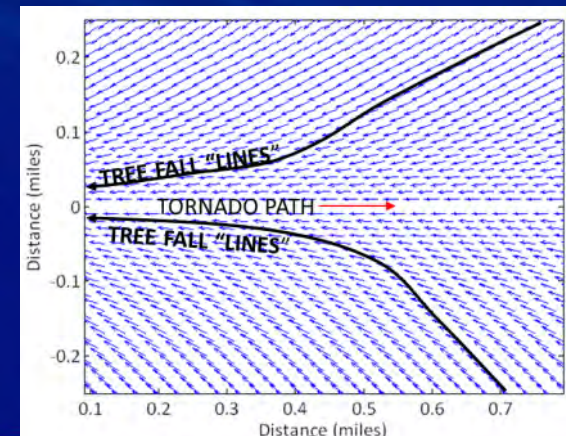
- Back calculations of wind speed from discrete structural failures
  - Lower and upper bounds on wind speed
  - Sign/Lightpost Failure
    - Used in other studies → obtained samples from Joplin Public Works



- Tree fall analysis
  - Recent work (Beck and Dotzek, 2010) incorporates both:
    - Wind Field and Tree Damage Model → estimate wind speed



← Actual and Modeled →  
tree fall patterns near  
St. Johns Hospital





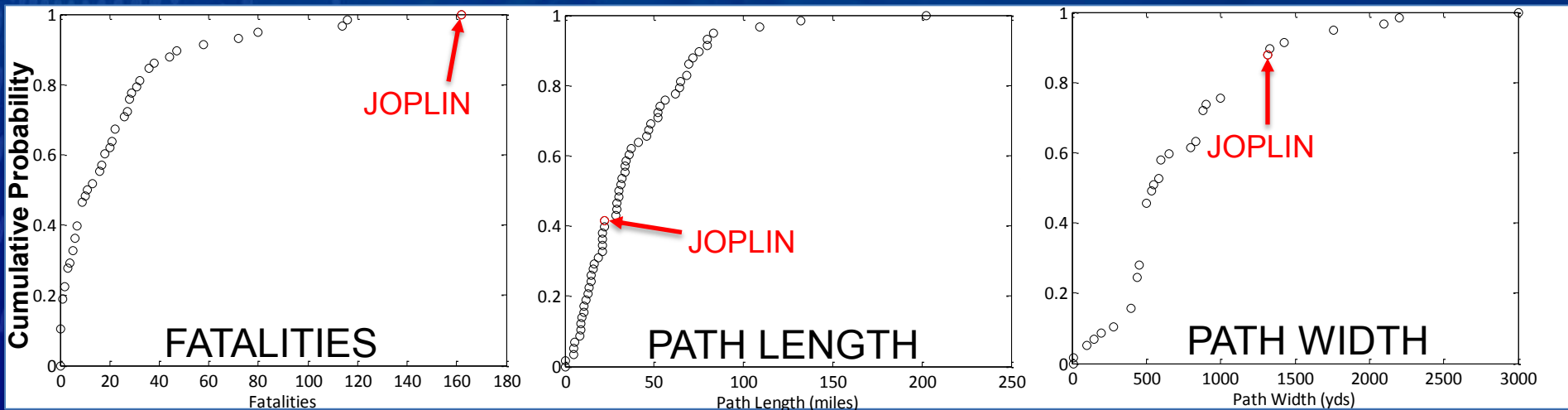
# Near Surface Wind Environment – Indirect

- Photogrammetry
  - Surveillance videos obtained from Joplin School District for
    - Joplin High School
    - Joplin East Middle School
  - Estimate object speeds (i.e., windborne debris) from surveillance videos given distances and frame rates
  - Done in previous tornado investigations
  - Distances available from site survey and aerial photos
  - Object Speed = Distance/Time Elapsed Between Frames
  - Inferred as lower bound on wind speed



# Historical Context of Joplin Tornado

- Local Tornadoic Events Prior to May 22, 2011 (Source: NOAA)
  - May 5, 1971 (F2) → 1 fatality, 60 injuries, \$2.5M
  - Three Nearby Significant Events (< 25 miles from Joplin)
    - April 3, 1956 (F4) → 118 injuries
    - May 4, 2003 (F3) → 17 fatalities, 116 injuries, \$95M
    - May 10, 2008 (EF4) → 43 fatalities, 710 injuries, \$122M
- US Tornadoic Events - 58 F5 or EF5 tornadoes in official record (NOAA)



- Figure suggests causative factors at play in addition to size of tornado





# Tornado Climatology and Associated Risk

Joplin Area Tornado Climatology (1950-2010)  
(25 mile radius)

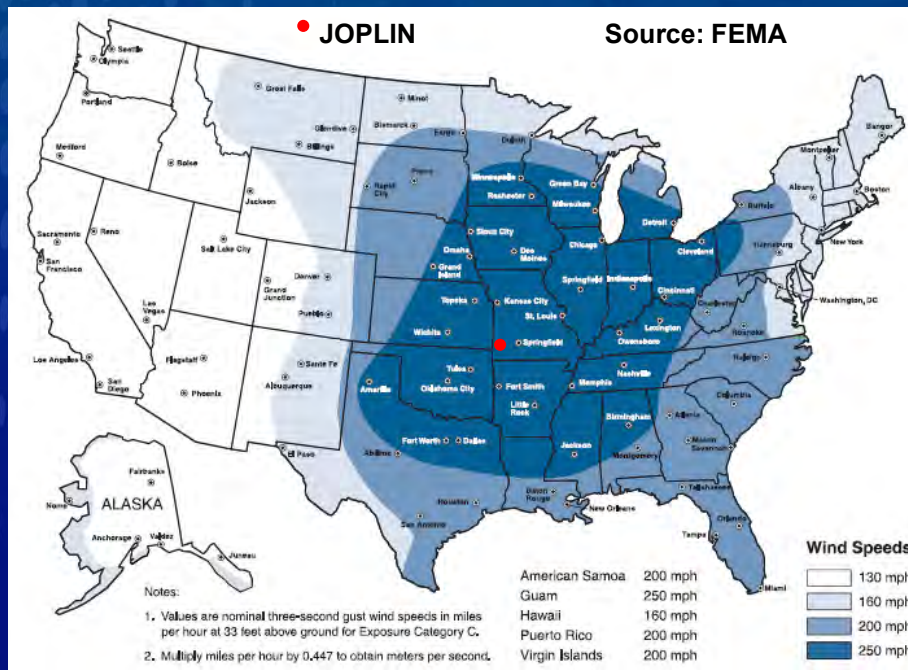
| (E)F Number      | Tornado Count | Fatalities | Injuries |
|------------------|---------------|------------|----------|
| 0                | 30            | 0          | 2        |
| 1                | 57            | 2          | 49       |
| 2                | 15            | 0          | 12       |
| 3                | 7             | 19         | 179      |
| 4                | 4             | 45         | 840      |
| Unknown          | 2             | 0          | 0        |
| Total            | 115           | 66         | 1082     |
| 5 (May 22, 2011) | 1             | 162        | 1000+    |

Data Source: NOAA



# Tornado Climatology and Associated Risk

- Tornado Hazards Specified in Standards and Guidelines
  - ANSI/ANS-2.3-2011 (for Nuclear Facilities)
  - ASCE/SEI 7-10 (Commentary) →  $10^{-5}$  annual probability (ANSI map)
  - ICC 500, FEMA 361 (for Storm Shelters, Safe Rooms)
  - Typically based on a “point” approach → design of a single structure



Tornado Safe Room  
Design Wind Speed  
Map (FEMA 361)

Consistent with Tornado  
Hazard Map in the  
ICC 500 Storm Shelter  
Standard

**ANSI:** American National Standards Organization; **ANS:** American Nuclear Society; **ASCE:** American Society of Civil Engineers; **SEI:** Structural Engineering Institute; **ICC:** International Code Council





# Spatial Characteristics of Joplin Tornado

- Tornado/Damage Path → Using ArcGIS, other sources
- Losses (Economic, Human, Physical)
  - Have locations of a majority of fatalities, structural damage, property info
  - Total estimated number of damaged and destroyed structures
    - 7,608 per Jasper County GIS
    - 8,369 per USACE
    - Majority are residential structures

Jasper County GIS Damage Estimate

|                     | Light | Medium | Totaled | Demolished |
|---------------------|-------|--------|---------|------------|
| <b>Residential</b>  | 3562  | 608    | 1010    | 2058       |
| <b>Commercial</b>   | 245   | 90     | 185     | 272        |
| <b>Agricultural</b> | 7     | 20     | 12      | 98         |
| <b>Excepted</b>     | 51    | 18     | 31      | 92         |

USACE Damage Estimate

|                    | Limited | Moderate | Extensive | Catastrophic |
|--------------------|---------|----------|-----------|--------------|
| <b>Residential</b> | 1381    | 1166     | 1192      | 1612         |
| <b>Commercial</b>  | 58      | 65       | 60        | 138          |
| <b>Industrial</b>  | 13      | 1        | 1         | 0            |
| <b>Unknown</b>     | 561     | 409      | 379       | 572          |

- Comprehensive characterization of all information described



# Enhanced Fujita Scale Assessment

- History
  - Fujita (F) Scale developed in 1971 → operational in late 1970's
  - Limited damage indicators and construction quality issues (Phan and Simiu, 1998)
    - Enhanced Fujita (EF) Scale proposed
      - 28 “DIs” → damage indicators (homes, trees, etc...)
      - Each DI has a number of “DODs” → Degrees of Damage
      - Each DOD has a range of wind speeds determined by expert elicitation (wind engineers, meteorologists)
      - NWS adopted in 2007
- NIST Preliminary Finding
  - Tornado rating procedure (i.e., Enhanced Fujita intensity scale) lacks adequate indicators for distinguishing intense tornadoes (observations used in the determination not included as indicators in EF scale)





# Next Steps

- Finalize analysis of meteorological conditions leading to and during the Joplin, MO, tornado
- Perform detailed analysis of direct and indirect wind speed estimates
- Assess the Joplin, MO, tornado in a climatological context. Probabilistic approaches to assess the tornado hazard at the local, regional, and national levels will be investigated.
- Evaluation of the overall spatial characteristics, including in a historical context.
- Assess rating tornadoes based on observed damage, using the EF scale. Implementation, directives and usage of the current EF scale and appropriateness and sufficiency of the existing damage indicators and degrees of damage will be studied.
- Identify issues and develop findings pertaining to tornado hazard characteristics
- Make recommendations, as warranted, for potential changes to building codes, standards, and practices to increase tornado resilience of buildings, lifelines, and communities





# May 22, 2011 Joplin, MO Tornado Study

## Emergency Communications and Public Response

*Briefing for NCST Advisory Committee  
November 7, 2011*

*Erica D. Kuligowski*

*Study Task Leader*

*Fire Protection Engineer, Fire Research Division*



# Study Objective

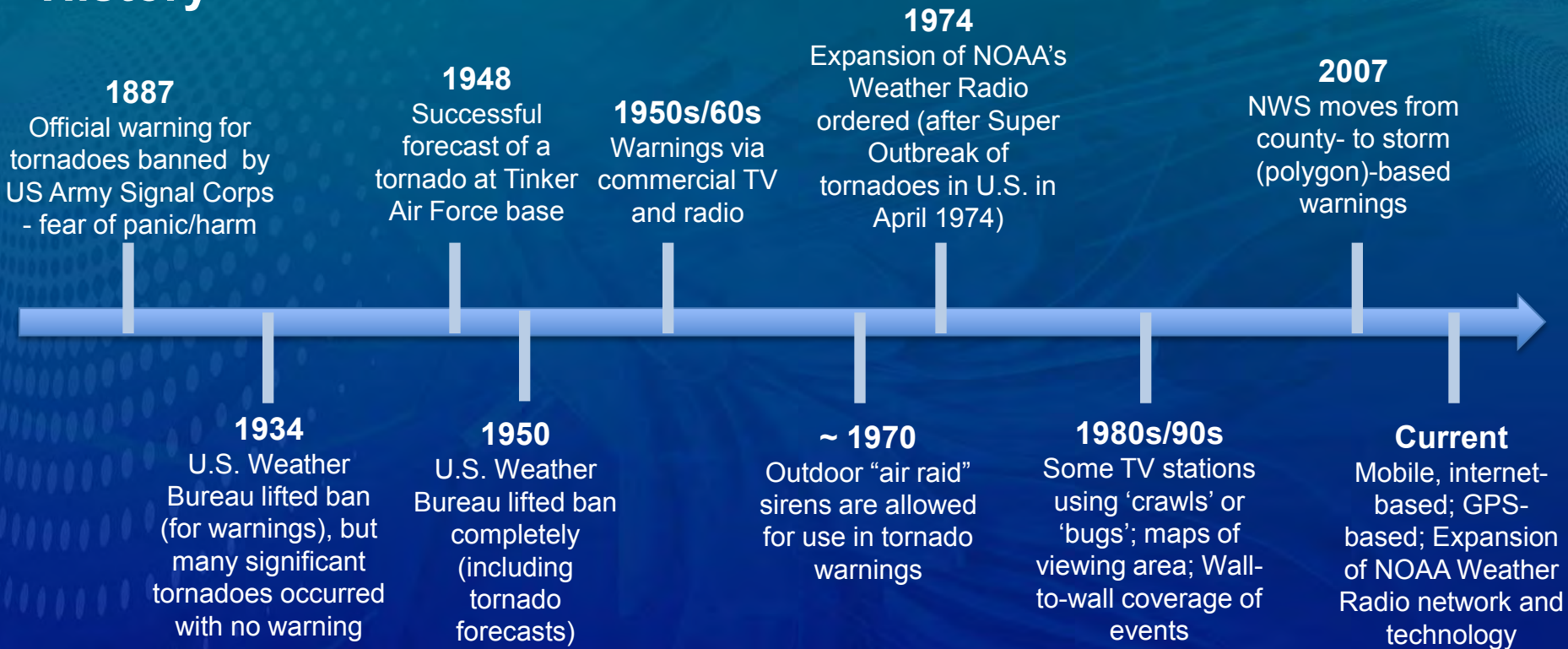
- Determine the pattern, location, and cause of fatalities and injuries, and associated emergency communications systems and public response

# Presentation Outline

- Warnings
- Public Response to U.S. Tornadoes
- Historical Context of Joplin Tornado—  
Joplin/Jasper County, MO
- May 22, 2011 Joplin, MO Tornado

# Warnings

## History



## Federal laws, codes, and standards

- No federal law requiring local broadcasters to provide tornado warnings
- FCC requires a broadcaster to operate in public interest (most TV/radio stations do provide severe weather info – varying degrees)





# Warnings (Cont.)

## Codes/Standards applicable to public alerting systems (FEMA 2006)

- Codes/Standards on the system itself – focus on the construction, performance and testing of the individual physical components of the system

|           |  |
|-----------|--|
| NFPA 72   | National Fire Alarm and Signaling Code, Chapter 24 on Emergency Communications Systems   |
| NFPA 1221 | Standard for the Installation, Maintenance, and Use of Emergency Services Communication Systems, Chapter 14 on Public Alerting Systems |
| UL 1971   | Standard for Signaling Devices for the Hearing Impaired  |

- Others focus primarily on sound and intelligibility levels (including how to measure each)

|            |  |
|------------|--|
| ANSI S1.13 | Measurement of Sound Pressure Levels in Air                                    |
| ANSI S1.26 | Method for the Calculation of Absorption of Sound by the Atmosphere            |
| ANSI S3.2  | Method for Measuring the Intelligibility of Speech over Communications Systems |
| ANSI S3.5  | Methods for the Calculation of the Speech Intelligibility Index (SII)          |
| ISO 9921   | Ergonomic Assessment of Speech Communication                                   |

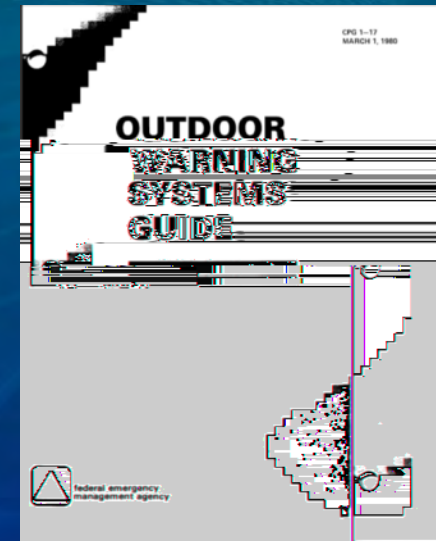
- Also standards devoted to the individual physical components of the systems

|         |  |
|---------|--|
| UL 1480 | Standard for Speakers for Fire Alarm, Emergency, and Commercial and Professional Use |
| UL 1989 | Standard for Standby Batteries   |



# Warnings (Cont.)

- Federal Guidance on outdoor warning systems (FEMA 1980, 2006)
  - **Guidance** on the use of these systems for two different hazards:
    - Attack signal
    - Alert signal
- Current practice in over 75 U.S. counties, cities and towns
  - Use of outdoor warning systems vary significantly among U.S. counties, cities, towns
  - Many communities (e.g., small towns and rural areas) do not have outdoor sirens



Source: FEMA





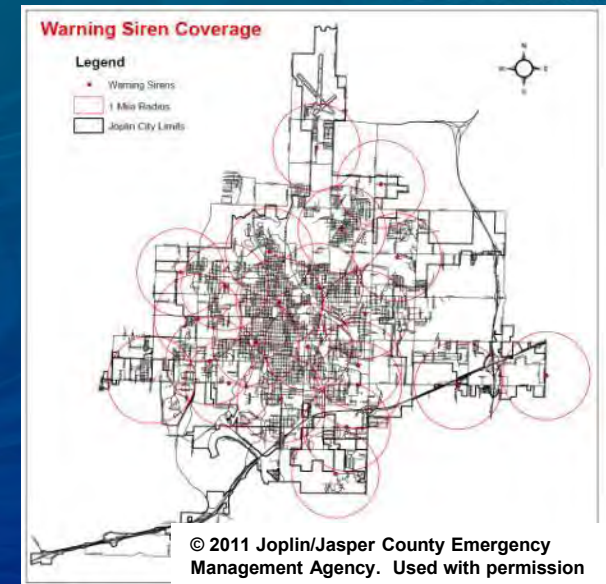
# Public Response to U.S. Tornadoes

- Factors that contribute to injuries and fatalities (Simmons and Sutter, 2011)
  - 4 major vulnerabilities for casualties:
    - Tornadoes that occur overnight
    - Tornadoes that occur during the fall/winter months
    - Living/located in a manufactured home
    - Location in the United States (Southeastern part of the US, specifically)
  - The influence of warning lead time



# Historical Context of Joplin Tornado

- Emergency communications systems
  - Outdoor warning sirens (Source: Joplin/Jasper County Emergency Management Agency)
    - 25 sirens in Joplin “zone,” all tied to the same system (if one activated, they all activated)
    - Tested weekly at 10:00 AM (CDT) on Mondays, sounded for 1 min only
  - Other channels (Source: Joplin/Jasper County Local Emergency Operations Plan)
    - Primary and local Emergency Alert System (EAS) TV and radio stations
    - Reverse 911
    - NOAA Weather Radios





# Historical Context of Joplin Tornado

- Procedures for tornadoes  
(Source: Joplin/Jasper County Local Emergency Operations Plan)
  - Communication
    - Warning systems are sounded only after...
      - Communications Operator has been notified that a tornado has been sighted
      - Tornado warning is issued by the NWS for Jasper, Newton or Cherokee County
      - Sustained winds are 75 mph or higher
    - Sounded for 3 minutes continuously, once, no “all clear”
  - Protective Actions
    - The burden of heeding warnings - individual communities and citizens
    - No guaranteed safe place during a tornado
    - Some locations are better than others



SOURCE: FEMA



# May 22, 2011 Joplin, MO Tornado

- Emergency Communications Timeline Prior to Tornado Touchdown
  - 26 minutes - First siren sounded
    - Source: Joplin/Jasper County Emergency Management Agency
  - 17 minutes – NWS Tornado Warning
    - Included parts of the City of Joplin (Source: NWS)
  - Second siren sounded (time not logged)
    - Not usual procedure to sound second siren (Source: Joplin/Jasper County Emergency Management Agency)
- *"So...what other factors, if any, influenced the behavior and fate of individuals, and what did they do in response?"*





# May 22, 2011 Joplin, MO Tornado

## NIST Interview Recruitment Strategies and Methods

- Tornado survivors, families/friends of victims, building managers/owners
- Recruitment of survivors and families/friends of victims for interviews
  - Over 100 eyewitness media accounts
  - NIST Tech Beat article (10/14/11)
  - NIST flyer
  - Contacts in Joplin – radio stations, newspapers, public information officer, local emergency managers, faith-based organizations, chamber of commerce
  - In-person and phone interviews



# May 22, 2011 Joplin, MO Tornado

## NIST Interview Recruitment Strategies and Methods

- Interview methods (2 phases)
  - Convenience sample to generate specific knowledge about a particular event;
  - Data collection will cease when the Team deems the topics of interest as saturated
  - Phase 1: Respondents will be asked to describe their experiences from the time when they first became aware that something was wrong until the moment when they responded to the disaster
  - Phase 2: Unstructured, follow-up or clarification questions about important topics





# Preliminary Findings – Interviews

- Survivors' Behavior (n≈70)
  - Not everyone heard sirens
  - People did not react until perceiving danger
  - Residents delayed taking protection; some did not take shelter
- Findings from NWS Service Assessment Study (NWS, 2011)
  - Initial siren given little credibility; confirmation was key
  - Residents were desensitized to the warnings
  - Information/warnings provided via multiple means or channels



# May 22, 2011 Joplin, MO Tornado

## Fatalities and Injuries Analysis

- 162 fatalities
- Locations of death vary: residences, businesses, outdoors, and vehicles
- Other information on fatalities: date of birth, date of death, home address
- Factors of interest (to obtain):
  - Cause of death
  - Exact location found
  - Experiences of the deceased during the event

| Preliminary Locations of Deceased  | # of Victims |
|------------------------------------|--------------|
| Academy Sports Store               | 1            |
| AT&T store                         | 1            |
| Elks Lodge                         | 5            |
| Full Gospel Church                 | 7            |
| Greenbriar Nursing Home            | 21           |
| Harmony Heights Baptist Church     | 3            |
| Home Depot                         | 8            |
| Meadows Healthcare Facility        | 2            |
| Outside (6 in vehicles)            | 14           |
| Pizza Hut                          | 5            |
| Residences - apartments            | 11           |
| Residences - single family home    | 54           |
| Stained Glass Theater              | 2            |
| St. John Regional Medical Center   | 15           |
| Unknown                            | 9            |
| Walmart                            | 3            |
| Officer killed in the line of duty | 1            |





# Next Steps

- Complete interviews on the response of individuals (survivors and victims) to the Joplin, MO tornado
- Determine how situation awareness, decision-making, and the environment, including the tornado effects and physical location of the individual, influenced the performance of protective action (e.g., sheltering in place), injuries, and survival
- Compare data on public response from previous tornadoes to the Joplin, MO tornado
- Compare local community procedures and codes/standards on public alerting to practices in Joplin, MO
- Make recommendations, as warranted, for potential changes to emergency communications and building and fire codes, standards, and practices to improve life safety in tornado disasters





# May 22, 2011 Joplin, MO Tornado Study

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

*Briefing for NCST Advisory Committee  
November 7, 2011*

*Long Phan  
Study Task Leader  
Research Structural Engineer, NWIRP*



# Primary Objectives

- Determine the response of residential, commercial, and critical buildings, including the performance of designated safe areas
- Determine the performance of lifelines as it relates to the continuity of operations of residential, commercial, and critical buildings

## Presentation Outline

- Wind Design Context for Tornadoes
- Joplin City Building Code History
- Overview of Damage and Structures Surveyed
- Performance of Facilities
  - Buildings
  - Designated Safe Areas
  - Lifelines
- Preliminary Findings
- Next Steps

# Wind Design Context for Tornadoes

- Current national codes, standards, and practices:
  - Seek to achieve life safety for hazards considered in design
  - Do not require conventional buildings and other structures to withstand tornadoes
  - Design criteria specifically for tornado shelters and safe rooms are addressed, however, use of tornado shelters or safe rooms is not mandatory
- Trade-offs between risks and costs are made during the model building codes and standards development process and during adoption and enforcement at the state or local level





# Joplin City Building Code History

- City of Joplin has long history of code adoptions, dating back to 1877.

| Code Adopted (Date) <sup>1</sup> | Relevant Amendments <sup>1</sup>   | Required Increased Wind Loads for Critical Facilities <sup>2</sup> |
|----------------------------------|--|--|
| 1961 BOCA/NBC (7/1961)           |  | TBD  |
| 1965 BOCA/NBC (10/1966)          |  | TBD  |
| 1970 BOCA/NBC (3/1970)           |  | TBD  |
| 1978 BOCA/NBC (5/1980)           |  | Yes  |
| 1984 BOCA/NBC (7/1984)           |  | Yes  |
| 1990 BOCA/NBC (11/1990)          | Ord. 93-6 (snow and wind loads)  | Yes  |
| 1996 BOCA/NBC (7/1997)           |  | Yes  |
| 2000 IBC, IRC (3/2003)           |  | Yes  |
| 2006 IBC, IRC, IFC (5/2008)      | Ord. 08-068 (snow and wind loads, roofing and exterior finish materials) | Yes  |

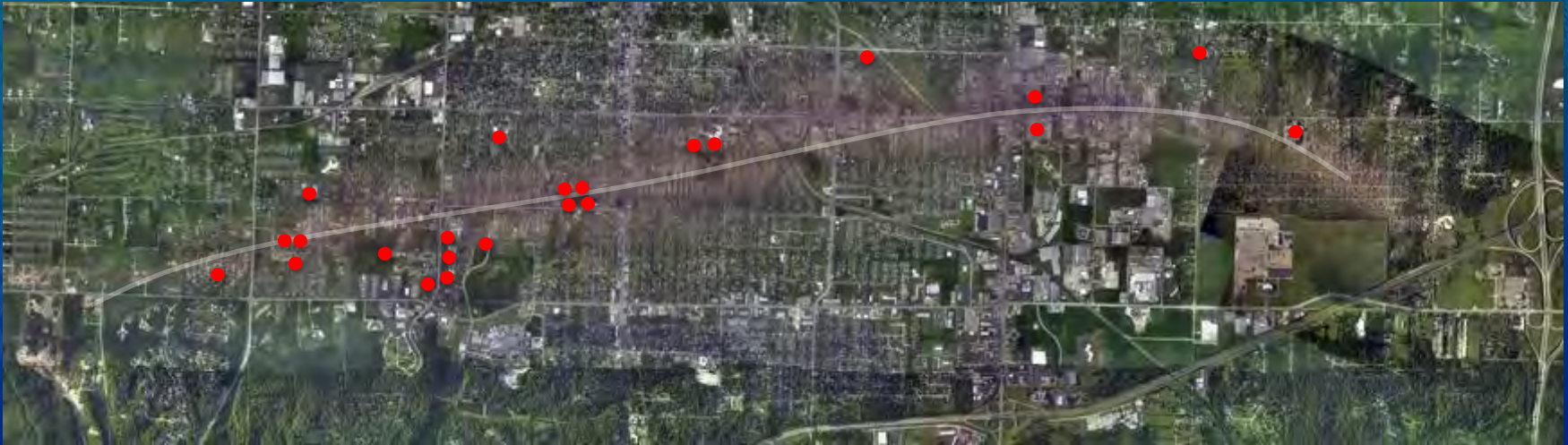
<sup>1</sup> Data Source: Building and Code Enforcement, City of Joplin

<sup>2</sup> Based on Model Code adopted

BOCA/NBC: National Building Code, IBC: International Building Code, IRC: International Residential Code, IFC: International Fire Code



# Overview of Damage and Structures Surveyed



Aerial Photo Source: NOAA  
Enhancements: NIST

- NIST surveyed 20+ non-residential (critical<sup>1</sup>, commercial, industrial) and numerous residential structures
  - Representative construction types, with typical damage
  - Spatially distributed throughout damage area

<sup>1</sup> For example, hospitals, fire stations, schools





# Overview of Damage and Structures Surveyed (Cont'd)

| Category                     | Name                       | Construction Type  | Use          | Year      | Damage Condition     | Fatalities/Injuries |
|------------------------------|----------------------------|--------------------|--------------|-----------|----------------------|---------------------|
| <b>Critical</b>              | St. John's Hospital        | RC, Steel, CMU     | Hospital     | 1965-1985 | Envelope/Collapse    | 15/TBD              |
|                              | Fire Station               | Wood Frame         | Fire         | TBD       | Roof                 | 0/0                 |
|                              | Police Station             | Wood Frame         | Police       | TBD       | Minor Exterior       | 0/0                 |
|                              | Joplin High School         | RC, Steel, CMU     | School       | TBD       | Collapse             | 0/0                 |
|                              | Joplin East Middle School  | Tilt-up Wall, CMU  | School       | 2009      | Collapse             | 0/0                 |
|                              | St. Mary's School          | CMU                | School       | TBD       | Collapse             | TBD/TBD             |
| <b>High Occupancy</b>        | Home Depot                 | Tilt-up Wall       | Retail       | 2000      | Collapse             | 8/TBD               |
|                              | Wal-Mart                   | CMU                | Retail       | TBD       | Partial Collapse     | 3/TBD               |
|                              | St. Paul's Church          | Steel Frame        | Church       | TBD       | Roof/Envelope        | TBD/TBD             |
| <b>Commercial</b>            | Ramesh Shaw Eye Center     | Steel Frame        | Office       | TBD       | Roof/Envelope        | TBD/TBD             |
|                              | W. Meredith Eye Center     | Steel Frame        | Office       | TBD       | Roof/Envelope        | TBD/TBD             |
|                              | 4-Story RC Office Building | RC Frame           | Office       | TBD       | Envelope             | TBD/TBD             |
| <b>Residential</b>           | Mercy Village              | Wood Frame         | Apartment    | TBD       | Envelope             | TBD/TBD             |
|                              | Greenbriar                 | Wood Frame         | Nursing Home | TBD       | Collapse             | 21/TBD              |
|                              | Single family              | Wood Frame         | Residence    | TBD       | Envelope to collapse | TBD/TBD             |
| <b>Designated Safe Areas</b> | Wal-Mart's                 | TBD                |              | TBD       | TBD                  | TBD/TBD             |
|                              | St. John's                 | Interior           |              |           | TBD                  | TBD/TBD             |
|                              | In-Residence               | RC room, Steel Box |              | TBD       | Intact               | TBD/TBD             |
| <b>Lifelines</b>             | Power                      | Open Frame         | Substation   | TBD       | Collapse             | 0/0                 |
|                              | Water Treatment Plant      | Brick              | Storage      | 1898      | Collapse             | 0/0                 |

RC: Reinforced Concrete; CMU: Concrete Masonry Unit

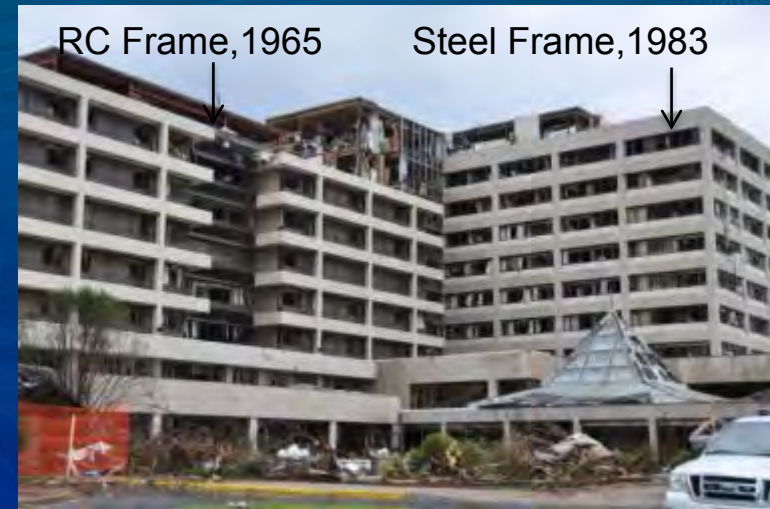


# Performance of Facilities

## Buildings

### Critical/High Occupancy: Hospital

- **Main Buildings** (RC, Steel Frame): Extensive damage to envelope (glazing; roof blow-off) and interior; No observed damage to Main Wind Force Resisting System (MWFRS); Loss of function
- **Ancillary Buildings** (CMU): Collapsed or substantially damaged
- **Performance Issues:**
  - Building envelope/Loss of function
  - Collapse/damage of ancillary buildings
  - Life safety, continuity of vital service not achieved



Generator Plant



Chiller Plant



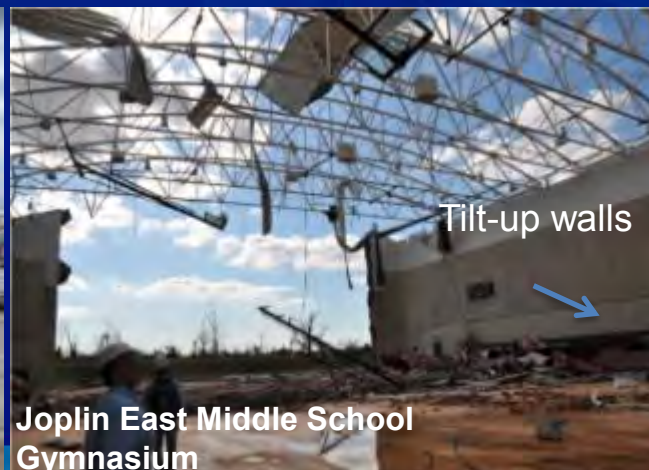


# Performance of Facilities (Cont'd)

## Buildings (Cont'd)

### Critical/High Occupancy: Schools, "Big Box" Stores

- Tilt-up Wall, CMU Wall with Long-Span Joist Roof: Partial or complete loss of roofing system; Failure of roof-to-wall connections; Collapse of walls
- Performance Issues:
  - Load Path Continuity
  - Robustness





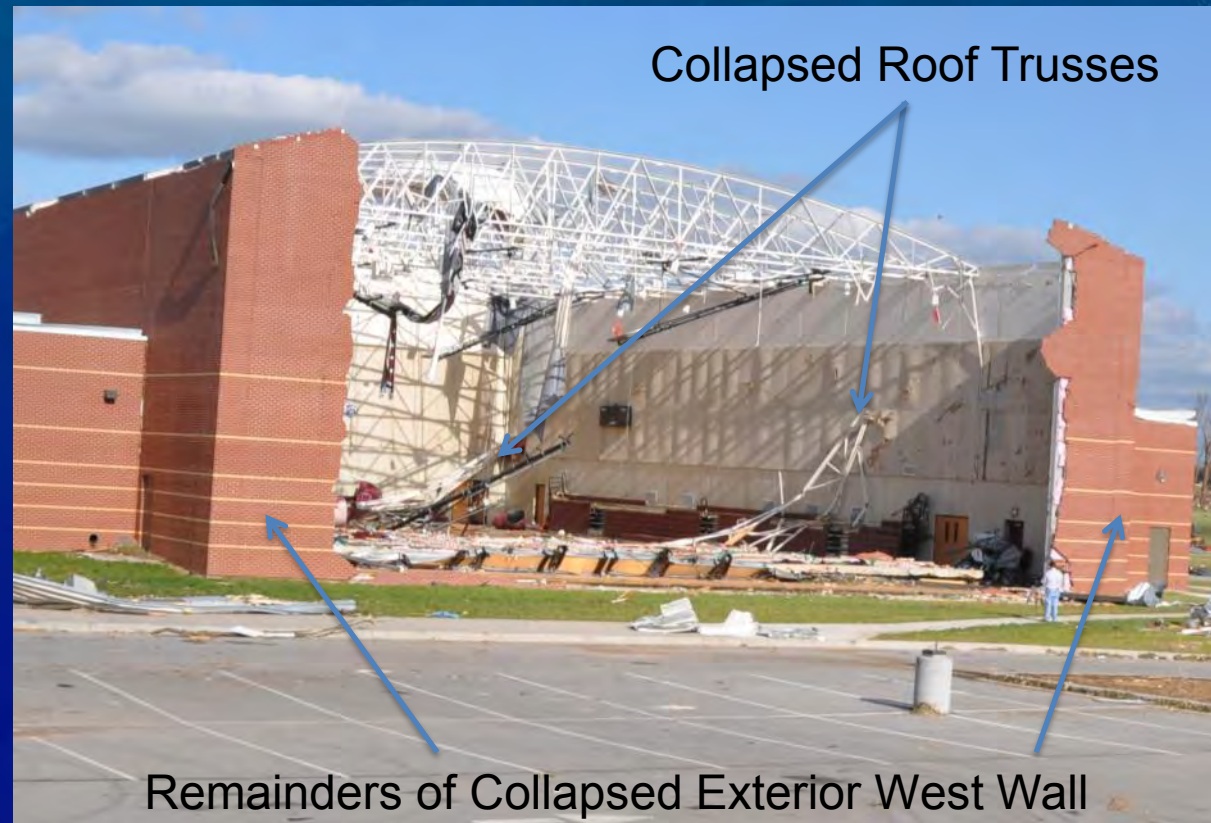
# Performance of Facilities (Cont'd)

## Buildings (Cont'd)

### Critical/High Occupancy: Joplin East Middle School

Analysis of Video from Joplin School District Shows Damage Sequence at Joplin East Middle School's Gymnasium

- Loss of steel roof deck
- Collapse of roof trusses (loss of roof-to-wall connection)





# Performance of Facilities (Cont'd)

## Buildings (Cont'd)

### Commercial

- **RC Frame:** Extensive damage to envelope; No observed damage to MWFRS; Loss of function
- **Light Steel Frame:** Loss of roofing system and building envelope; Damage to structural frame varied from none to moderate, but no collapse
- **Performance Issues:**
  - Building envelope/Loss of function

4-Story RC Frame Professional Building



Ramesh Shaw Eye Surgeon Building



William Meredith Eye Center



# Performance of Facilities (Cont'd)

## Buildings (Cont'd)

### Residential

- Wood Frame Single and Multi-Family:
  - Both older (late 1980's) and newer (early 2000's) construction sustained similar damage
  - Damage typically ranged from damage to roof and exterior walls to complete collapse.
- Performance Issues:
  - Building envelope
  - Collapse





# Performance of Facilities (Cont'd)

## Designated Safe Areas

- **Definitions**

- **Designated Safe Areas:** Spaces within buildings that have been identified by owners or operators to provide shelter for occupants.
  - **Best Available Refuge Areas:** Safest areas in buildings based on FEMA P-431.
  - **Storm Shelters:** Building, structure or portion(s) thereof, constructed in accordance with ICC 500-2008, *Standard for the Design and Construction of Storm Shelters*, and designated for use during a severe wind storm event such as a hurricane or tornado.
  - **Safe Rooms:** Building, structure or portion(s) thereof designed to meet FEMA 320 (residential or small business) or FEMA 361 (community) safe room guidelines
- No known community storm shelters or community safe rooms in Joplin  
(Sources: Joplin/Jasper County Emergency Management Agency and FEMA)
  - Uncommon for buildings in Joplin to have basements  
(Source: City of Joplin Building and Code Enforcement)
  - In-residence shelters (concrete room in basement and steel box on grade) and designated safe area at Wal-Mart



# Performance of Facilities (Cont'd)

## Lifelines

- **Power:** (Source: Empire District Electric)
  - 1 power substation destroyed (supporting steel frame collapsed), 2 damaged. 20,000 without power.
  - Approx. 3,900 poles damaged; 100 miles of line downed; 31 circuits off
  - 10 transmission lines out of service; 135 transmission structures affected; 30 fiber lines cut
- **Water Treatment Plant:** (Source: Missouri American Water Engineering)
  - Unreinforced brick storage building (1898) collapsed
  - Plant remained operational on back-up power
- **High Pressure Gas Valve** (Source: St. John's Hospital)
  - Major leak adjacent to area used to triage tornado victims
  - Not shut off for some time
- **Water:** (Source: Joplin Fire Department)
  - Numerous small leaks due to broken pipes in damaged buildings
  - Unable to use fire hydrants in some areas due to low pressure





# Preliminary Findings

- Performance of Buildings and Designated Safe Areas
  - The high level of fatalities indicates that life safety was not achieved; there is no such expectation in current model codes or standards
  - A large number of residential and non-residential buildings sustained complete loss of function
  - Critical and high-occupancy buildings did not perform better than those of similar construction type in lower risk categories with regard to loss of function or damage
  - Reinforced concrete and steel frame buildings suffered total loss of function and major damage to the envelope and the interior, but the structural frame remained largely intact
  - Most other buildings, including tilt-up wall construction, metal buildings, concrete and brick masonry, and wood-frame, suffered partial or complete collapse
- Performance of Lifelines
  - Utility-related fires did not play a prominent role in fatalities, injuries, or property damage
  - Loss of power affected functionality of hospital
  - Residential water leaks presented potential negative effect on fire fighting effectiveness
  - High pressure gas leak at hospital presented potential hazardous condition



# Next Steps

- Continue analyzing field performance data. Establish environmental conditions affecting facilities. Develop failure hypothesis for buildings of interest.
- Obtain design and actual performance information, including drawings and available videos. Compare designs with field observations to assess consistency between design and actual construction. Refine failure hypothesis.
- Review design/performance of designated safe areas within buildings, including shelters, safe rooms, and areas of buildings used for refuge from the tornado.
- Review/evaluate appropriate model building code and standards requirements for building envelopes and main wind force resistance systems. Assess performance based on observed damage relative to code requirements.
- Identify issues and develop findings pertaining to performance of buildings, designated safe areas, and lifelines.
- Make recommendations, as warranted, for potential changes to building codes, standards, and practices to increase tornado resilience of buildings, lifelines, and communities.





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# May 22, 2011 Joplin, MO Tornado Study

## Study Plan and Research Overview

*Briefing for NCST Advisory Committee*

*November 7, 2011*

# Questions/Discussion