**Laying the Cornerstone of Tornado Disaster Intervention:**

**Assessing Structural and Social Vulnerability Interdependence**

Cornerstone, tornado (like bc)

Structural vulnerability (multiple levels) on one side, social on the other

Tornado on the top

Blue background, white tornado, blue silhouette

White triangle

Blue tornado – structural is house (triangle recrangle) , social is couple of people

Cornerstone initiative t

Title: (“tornado disaster

intervention”)

**Goal: How we can evaluate a community’s vulnerability to tornados using two factors**

**NOFO Competition/Priority(ies) to be Addressed:** NOAA-OAR-WPO-2023-2007516 ->Vortex-USA-2: Understanding and reducing societal vulnerability to tornadoes.

**Date:** November 17, 2022

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**Budget Table:** In total, $1,189,038 is requested for 3 years. The breakdown is listed below.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| College | Year 1 | Year 2 | Year 3 | Total |
| Missouri S&T | $166,945 | $172,707 | $178,691 | $518,344 |
| Villanova University | $26,565 | $68,162 | $65,182 | $159,909 |
| Mississippi State University | $45,546 | $88,094 | $77,145 | $210,785 |
| University of South Carolina | $100,000 | $100,000 | $100,000 | $300,000 |
| Total | $339,056 | $428,963 | $421,018 | $1,189,038 |

**Laying the Cornerstone of Tornado Disaster Intervention:**

**Assessing Structural and Social Vulnerability Interdependence**

G. Yan (Missouri S&T), S. Strader (VU), K. Sherman-Morris (MSU), and Z. Li (USC)

**ABSTRACT**

The same tornado may result in a disaster in one community while causing only minor damage/loss to another due to their different levels of structural and social vulnerabilities. For example, a tornado can result in injuries or fatalities in a neighborhood with fragile housing occupied by vulnerable populations, while it may only barely impact the community in a neighborhood with sturdy houses and high human capital. Structural vulnerability reflects the fragility of buildings to tornadoes. Social vulnerability refers to those economic, demographic, and other societal factors that affect the ability of a person or community to prepare for and recover from a natural hazard or disaster. To reduce tornado vulnerability, this interdisciplinary team will conduct convergence research to lay the cornerstone of tornado disaster intervention through assessments of structural and social vulnerability interdependence and the public’s perception of tornado risk and protective actions (**Research Objective**). To achieve this goal, four research tasks are planned: 1) Develop advanced multi-layer neural networks (deep learning) to extract critical building attributes at a community level (**Task 1**); 2) Propose an innovative approach to develop tornado fragility and vulnerability curve(s) for any archetype of buildings and identify the current practice to alleviate structural vulnerability (**Task 2**); 3) Understand the interdependency of structural and social vulnerabilities and understand the worsening of tornado impact due to the overlapping structural/social vulnerabilities (**Task 3**); and 4) Understand the public’s perceptions of and responses to tornado threat and their ability to reduce structural vulnerability via mitigation decisions (**Task 4**). The proposed research will be piloted in three representative county warning areas throughout the country (Jackson, MS (JAN), Lincoln, IL (ILX), and Norman, OK (OUN)).

This project will yield gap-filling products that provide data/knowledge/evidence needed by stakeholders to make informed decisions on tornado disaster intervention. Products and deliverables include: 1) A new quantitative metric that combines structural and social vulnerabilities, which can be used by NWS weather forecast offices (WFOs) and local emergency managers (EMs) to measure the worsening of tornado impacts due to the overlapping structural/social vulnerabilities (**Task 3**); 2) Maps that display the combined structural/social vulnerability, which can be used by NWS WFOs and EMs to visualize spatial distribution of vulnerabilities (**Task 3**); 3) Understanding of the public’s risk perception and their mitigation decision-making to reduce structural vulnerability(**Task 4**); 4) Current practice identified to alleviate structural vulnerability (**Task 2**); 5) Animations of tornado impact on communities; 6) An innovative approach to develop tornado fragility and vulnerability curve(s) for any archetype of buildings (**Task 2**); and 7) A GeoSpatial tool to extract building attributes (**Task 1**). End-users include NWS WFOs, EMs, broadcast meteorologists, urban planners, policymakers, the public, etc.

The team has been engaging potential end-users throughout the proposal development stage and planned to continue to work alongside them during the project (e.g., developing a website and science education videos & holding Integrated Warning Team meeting) to ensure implementation of the research products. Research outcomes will improve NWS warning issuance decision-making process, enhance their risk communication with their core partners, help stakeholders make informed decisions on tornado resilience planning, emergency response and equitable recovery, and provide the public the information needed to take protective and mitigative actions. This project will address the program priority of “*VORTEX-USA-2: Understanding and reducing societal vulnerability to tornadoes*”.The total fund requested is $1,189,038.

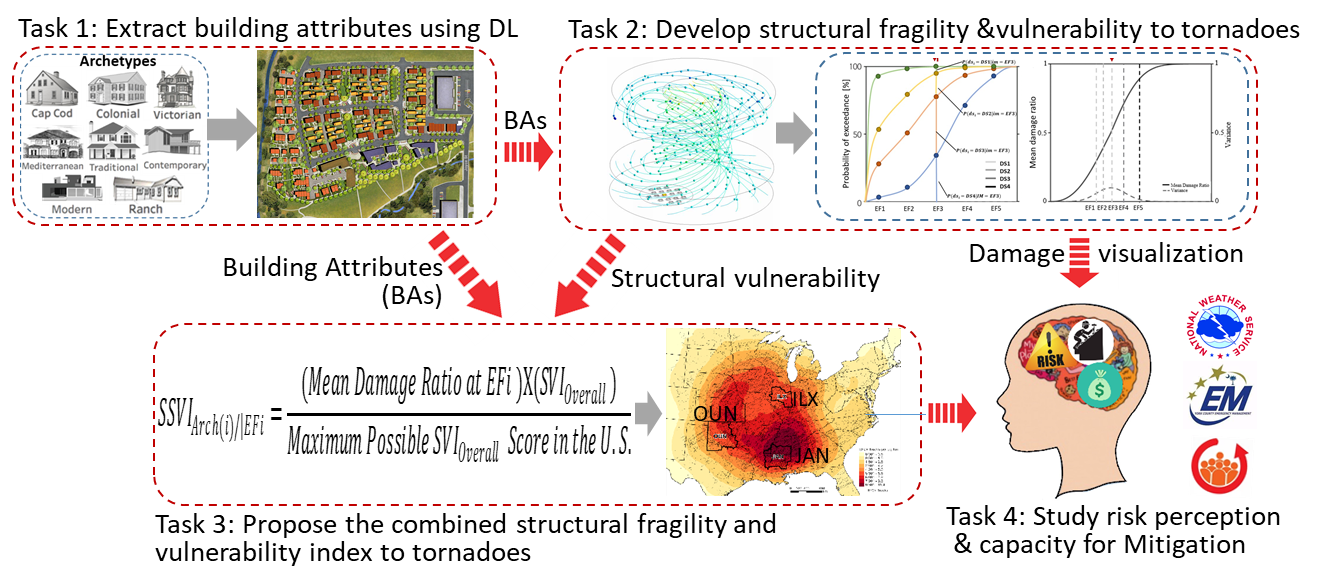
**Statement of Work**

**1. Problem/Opportunity Statement**

**1.1 Problem Statement, Scientific Objective, and Relevance to NOAA Science Priorities**

The same tornado may result in a disaster in one community while causing only minor damage/loss to another due to their different levels of structural and social vulnerability. Before developing proper disaster interventions to reduce societal vulnerability to tornadoes, our interdisciplinary team consisting of engineers, meteorologists, and social scientists will conduct convergence research to lay the cornerstone of tornado disaster intervention by assessing structural and social vulnerability interdependence and assessing the public’s perception of tornado risk and protective actions **(Primary Research Objective)**. The proposed research will address the following three **research questions** specified in the program priority of “*VORTEX-USA-2: Understanding and reducing societal vulnerability to tornadoes*”: *1) How do physical, social, and economic factors interact to contribute to harm, and which intersections in particular contribute to severity of impact at regional, local and household levels?* *2) What are … current practices that can be utilized to alleviate vulnerabilities and reduce harm from tornadoes in the Southeast and other regions? and 3) What are the factors and decisions that enhance individual survival of tornadoes?*

To address the above questions and achieve the stated research objective, for each pilot county warning areas (CWAs), an integrated research scheme has been planned, as illustrated in **Fig. 1**. PI Li will extract building attributes (**BAs**), including building archetypes, roof shape and story count, at a community level using advanced multi-layer neural networks from Google Street View images (**Task 1**); Based on the extracted **BAs**, PI Yan will determine structural fragility and vulnerability to tornadoes for each building archetype, and identify existing practices that alleviate structural vulnerabilities (**Task 2**); PI Strader will then reveal the disparity (or “pattern”) of structural vulnerability based on building archetypes and factors of social vulnerability, informing the inter-relationship between structural and social vulnerabilities (**Task 3**); To understand how the combined structural and social vulnerability metric relates to protective actions, PI Sherman-Morris will then share the information gained regarding building fragility/vulnerability with the public members of the CWAs, and understand their tornado risk perceptions, sheltering actions, perceived threats, and response costs that may motivate the public to implement mitigation measures (**Task 4**). The overarching goal is to obtain the data, knowledge, and evidence needed by stakeholders to make informed decisions on tornado disaster intervention, while improving the understanding of resources needed for the public to take protective actions.



**Fig. 1.** The integrated, interdisciplinary research proposed to address VORTEX-USA-2.

This project will be piloted in one CWA from each of the three representative regions in the country (OUN in Norman, OK of Central Plains; ILX in Lincoln, IL of Midwest and JAN in Jackson, MS of Southeast). Each of these CWAs was selected because they represent unique combinations of climatological tornado attributes, house archetypes, and social vulnerability. These factors all contribute to and influence tornado disaster potential for a given community [5].

**1.2 Research Motivation and Significance**

Prior research has illustrated the importance of examining social and physical vulnerability as it relates to tornado disasters [[[1]](#endnote-1),[[2]](#endnote-2),[[3]](#endnote-3),[[4]](#endnote-4),[[5]](#endnote-5)]. Relating vulnerability to tornado impact severity and disasters, most research to date has indicated the importance of housing construction quality or resilience [5,[[6]](#endnote-6)]. Specifically, 72% of tornado fatalities occur in housing structures [[[7]](#endnote-7)]. Highlighting the importance of structural integrity, manufactured homes often lack sufficient anchorage to the ground, which makes them more likely to fail during tornadic winds [[[8]](#endnote-8)]. In fact, residents are 15 to 20 times more likely to be killed in a manufactured home compared to a permanent home [[[9]](#endnote-9)]. However, the tornado-housing issue is not solely a manufactured housing problem. For instance, during the 27 April 2011 Southeast tornado outbreak, approximately 70% of the housing fatalities transpired in permanent homes [2,7]. This finding suggests that construction type and quality is a critical factor when it comes to resident survivability during significant (EF2+) and violent (EF4+) tornadoes.

In addition to structural quality, social vulnerability has also been proven to be an extremely important factor when it comes to tornado disasters. Research from [[[10]](#endnote-10)] and [7] have highlighted critical social, economic, and demographic characteristics that are often associated with greater hazard (e.g., tornado) impacts on populations. Socioeconomic variables, such as poverty, race, age, gender, etc., have all been illustrated to control tornado impact severity (cf. Table 1 in [7]). Structural and social vulnerability factors are often collocated in areas of elevated tornado mortality (i.e., Southeast U.S.). For example, a resident living in poverty is more likely to reside in a lower quality housing structure, such as a manufactured home [10]. Thus, these two vulnerability constituents are often commingled, increasing the likelihood of a tornado event producing a fatality. Understanding the relationships between housing type, structural vulnerability, and social vulnerability is critical to improving tornado survivability (**Task 3**).

When it comes to structural vulnerability, although fragility curves for civil structures under hurricane winds have been well developed [[[11]](#endnote-11),[[12]](#endnote-12),[[13]](#endnote-13),[[14]](#endnote-14),[[15]](#endnote-15),[[16]](#endnote-16)], fragility curves for tornadic winds have not been properly developed, despite few publications [[[17]](#endnote-17)]. Traditionally, a fragility curve can be established based on recorded historical wind records using Monte Carlo simulations. Because of the limited historical tornadic wind records, the chance to record sufficient years of near-ground tornadic wind speeds and then use traditional approaches to establish proper tornado fragility curves is very low, which still has a long way to go, if not impossible. To get around this, PI Yan will conduct tornado fragility analyses by taking advantage of existing HAZUS fragility curves (**Task 2**). To achieve this goal, a relationship between tornadic wind speed and straight-line wind speed will be created through high-fidelity CDF tornado-community interaction simulations. PI Yan has extensive experience in modeling tornado-community interactions [[[18]](#endnote-18),[[19]](#endnote-19),[[20]](#endnote-20),[[21]](#endnote-21),[[22]](#endnote-22),[[23]](#endnote-23)]. Recently, she has successfully combined CM1 (Cloud Model 1) [[[24]](#endnote-24),[[25]](#endnote-25),[[26]](#endnote-26)] and CFD (Computational Fluid Dynamics) to simulate tornado-community interaction at full-scale (**Fig. 2)**. She has applied this approach to reproduce the damage induced by 24 May 2011 El Reno, OK tornado outbreak [[[27]](#endnote-27)]. She is currently applying this approach to reproduce damage to the Amazon Facility (IL) and the Bowling Green (KY) community (**Fig. 3**) induced by the 2021 Midwest Tornado Outbreak.

|  |  |  |  |
| --- | --- | --- | --- |
| **Fig. 2** CM1-CFD  coupled simulation | An aerial view of a town  Description automatically generated with medium confidence |  |  |
| a) Observed damage  (EF-3) [[[28]](#endnote-28)] | b) Community layout of Bowling Green, KY | c) Translation of the simulated tornado |
| **Fig. 3** Simulation of tornado-community interaction using CM1+CFD | | |

To simulate tornado-community simulation, it is essential to obtain the **BAs** of buildings (i.e., archetype, roof type, and story count) in the community. Despite the publicly accessible datasets [[[29]](#endnote-29)] (e.g., property tax records in some states, Microsoft provides building footprints [[[30]](#endnote-30)], etc.), those critical **BAs** are still missing. To bridge the gap, PI Li aims to develop advanced multi-layer neural networks to accurately, quickly, and automatically extract these **BAs** from Google Street View imagery (**Task 1**). PI Li has extensive expertise and experience in developing cutting-edge deep learning (AI) algorithms to mine information from a variety of publicly available big data sources [[[31]](#endnote-31),[[32]](#endnote-32),[[33]](#endnote-33),[[34]](#endnote-34),[[35]](#endnote-35),[[36]](#endnote-36),[[37]](#endnote-37)]. In this project, he will improve these algorithms, and develop a tool with a set of new algorithms to extract the **BAs** of individual buildings in a community.

Once structural vulnerability has been assessed, Task 4 will examine its impact on risk perception and protective/mitigative actions. Research has indicated differences in preparedness and response to tornadoes based on housing type. For example, mobile or manufactured home residents have expressed lower levels of preparedness than residents of permanent homes [[[38]](#endnote-38),[[39]](#endnote-39)] and lower levels of efficacy (self or response) in sheltering [39,[[40]](#endnote-40)]. They are also more likely than residents of permanent homes to take shelter at another location [[[41]](#endnote-41)] but have also reported lower levels of actually sheltering in a safe location [38]. Perceptions of the safety of one’s home (regardless of housing type) are important in explaining response to hazards [[[42]](#endnote-42) [[43]](#endnote-43),[[44]](#endnote-44)]. While research has examined risk perception and response decision-making among mobile or manufactured residents to some extent, less is known about the influence of other structural housing factors on perception of risk and judgements about the efficacy of sheltering. Homes are often viewed as a place of refuge [[[45]](#endnote-45)]. Thus, it is important to understand what drives perceptions of safety beyond perceptions about severity of the threat, justifying the proposed research **Task 4**.

**2. Project Products/Outputs**

This project will yield the following the data/knowledge/evidence and models/tools needed by stakeholders to make informed decisions on tornado disaster intervention.

1) Quantitative metric of the combined structural and social vulnerabilities (called “SSVI”)(**Task 3**). This can be used by NWS WFOs and local EMs to measure the worsening of tornado impact due to the overlapping high structural/social vulnerabilities;(*Starting RL 1/Ending RL 3*)

2) Maps displaying combined structural/social vulnerability, with hotspots marked (**Task 3**), which can be used by NWS WFOs and EMs to visualize spatial distribution of vulnerabilities;

3) Qualitative understanding of the public’s risk perception and their mitigation decision- making to reduce structural vulnerability(**Task 4**); (*Starting RL 1-2/Ending RL 4*)

4) Current practice identified to cope with or alleviate structural vulnerability (**Task 2**);

5) An innovative approach to develop tornado fragility and vulnerability curve(s) for any archetype of buildings (**Task 2**); (*Starting RL 3/Ending RL 6)*

6) An advanced Geospatial tool to extract critical **BAs** of individual buildings using deep learning, and a geospatial database with the extracted **BAs** for three CWAs **(Task 1)**. The applied cutting-edge multi-layer neural networks are expected to increase classification accuracy and training efficiency. The new databasewill be the first dataset that covers all critical **BAs** for resilience planning; (*Starting RL 4/Ending RL 7*)

7) Animations and visual displays of community or building level tornado damage to demonstrate tornado impact (**Task 2**); (*Starting RL4/Ending RL 7*)

8) Short science videos for community education (the public and K-12 students), webinar recordings for professional education, and lecture recording for educational outreach to HBCUs.

9) A website to facilitate research findings dissemination and data sharing.

10) 6 journal papers and 20 conference papers.

This project is deemed successful if the above products are produced and delivered to different end-users for them to make informed decisions.

**3. Project Impact/Benefits/Outcomes**

The produced data/knowledge/evidence and the developed models/tools will benefit the NWS WFOs and their core partners (e.g., EMs, broadcast meteorologists), urban planners, policymakers, government officials at all levels, the public, etc. The team has been engaging the related stakeholders at the proposal development stage and planned to actively engage with them during the project (detailed in Section 6), to ensure the implementation of the project products. Meetings between the team and NWS WFO confirmed the value of this research (see the letters of support); their feedback has been taken to improve the proposed research from the operational perspective.

**1) To NWS WFOs.** a) This project will provide the NWS WFOs with the combined structural/social vulnerabilities of their CWA using an easy-to-understand index, which can clearly show the areas where high structural and social vulnerability overlap. Discussion between the team and NWS partners during the proposal development stage confirmed that this index will serve as a decision-support for their warning issuance, improving their warning decision-making process. For example, while an NWS WFO may delay issuing a warning to reduce the risk of false alarms, if the predicted tornado paths are forecasted to traverse areas with an overlap of high structural and high social vulnerabilities, they may decide to issue a warning more quickly. This index has a potential to enable NWS meteorologists to enhance their risk communication through tailoring their alert messages by including the failure probability of buildings and specific sheltering guidance. b) The obtained findings will complement existing outreach efforts by NWS Jackson through the CSTAR program, which centers on reducing vulnerabilities.

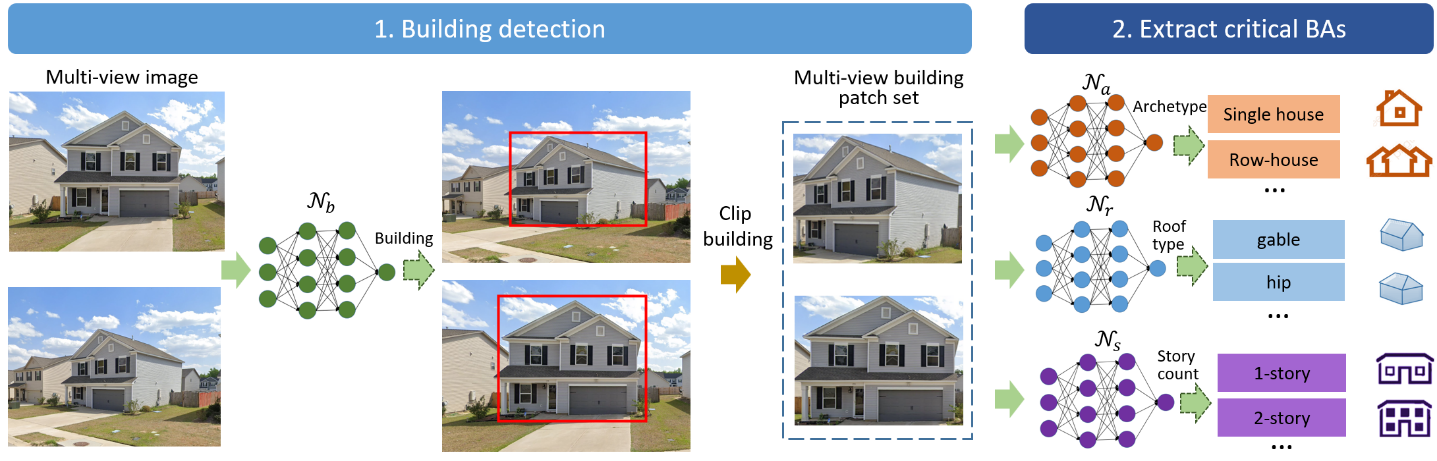
**2) To Integrated Warning Teams (IWTs), local EMs, urban planners, policymakers and decision-makers, and other local/state/federal government officials**. The developed index can be used by the above stakeholders to assess and even visualize the potential impact of future tornadoes on a region. Communities with compounding factors of high structural and social vulnerability can be easily identified and visualized, providing the information on populations where additional outreach is needed. The research products will provide these stakeholders with the needed information, to develop the related policies that increase tornado survivability for the most fatality-prone individuals and communities, and the related education and outreach activities that will be the most effective. This will provide “evidence” for the necessity to shift their priorities and resources onto tornado resilience, making communities more prepared for future tornadoes.

**3) To the public.** The obtained data/knowledge/evidence will provide the public the information to assist with taking protective and mitigative actions, including retrofitting their houses or building stronger houses, and timely responding to tornado warnings. Nationwide the innovative fragility analysis approach will address the NIST research needs on “evaluating the community-level disaster consequences,” and will advance tornado catastrophe modeling of IBHS.

**4. Proposed Methods and Activities**

**4.1 Task 1: Extracting Building Attributes (BAs) (Archetypes, Roof Types, and Story Count) Using Four Advanced Deep Learning (DL) Networks** (*Starting RL 4/Ending RL 7*; Led by Li; Supported by Yan and Strader)

Four cutting-edge multi-layer neural networks (, ) will be developed to extract critical **BAs** through the two-stage workflow. The workflow will take the Google Street View Images (GSVIs) and associated metadata (e.g., camera location and shooting direction) as the input, and extract the archetype, roof type, and story count of individual buildings, as illustrated in **Fig. 4**.



**Fig. 4** Two-stage workflow to extract critical **BAs** from GSVIs using four neural networks

At Stage 1, we will detect and clip buildings from GSVIs, and then create multi-view building patch sets for each building (two views in **Fig. 4**). We will then train an object detection neural network, , to detect individual buildings. At Stage 2, we will develop and train another three neural network models (, ), and feed multi-view building patch sets extracted at Stage 1 into (, ) to extract critical **BAs** of each building. denotes the building-archetype-classification neural network, while for roof type and for story count.

Specifically, we will build using YOLOv6 [[[46]](#endnote-46)] to detect buildings from GSVIs, and build , and using ResNet [[[47]](#endnote-47)] to conduct image classification to extract the critical **BAs** of individual buildings. The vanilla ResNet needs to be modified to fuse the features from multiple images. The late-fusion strategy [[[48]](#endnote-48)] will be adopted. The features from multi-view images will be averaged before passing through to the final module of the fully connected layers in ResNet.

**Creating the training datasets and training the four neural network models**. Four training datasets (, , , and ) will be created to train these four individual neural networks (, , , and ). is an object detection training dataset for buildings. Its samples are GSVIs, and the labels are building bounding boxes. To create the training dataset, we will use two methods: 1) convert the existing GSVI segmentation training datasets such as Mapillary Vistas 2.0 [[[49]](#endnote-49)] into an object training dataset, and 2) manually label (i.e., draw boxes enclosing the building) the randomly selected GSVIs from the study area. , , and are image classification training datasets for extracting the three **BAs**. Each training dataset will be created specifically for one attribute only. Similarly, we will convert the existing building information database and the associated GSVIs into training datasets or manually create them if necessary.

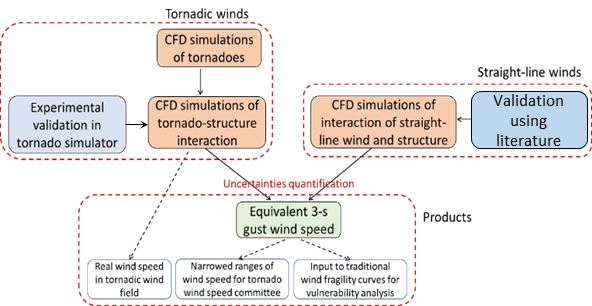
In , nine types of roofs [[[50]](#endnote-50)] will be extracted, including *gable, cross gable, simple hip, pyramid hip, cross hipped, mansard, saltbox, gambrel,* and *flat*. In , eight archetypes [[[51]](#endnote-51)] will be extracted, including *cap cod, colonial, contemporary, mediterranean, modern, ranch, traditional,* and *victorian*. The story counts in will contain 1, 1.5, 2, 2.5, 3, 3.5, and 4. The four neural network models, once trained, will be used to extract the critical **BAs** of individual buildings of the three CWAs. The format of the final output of this workflow will be a CSV (comma-separated values) file with each row for an individual building. The file will contain six columns (building ID, latitude of building, longitude of building, archetype, roof type, and story count).

**4.2 Task 2: Developing an Innovative Approach for Tornado Fragility/Vulnerability Analysis and Reducing Structural Vulnerability** (*Starting RL 3/Ending RL 6;* Led by Yan and supported by Li and Strader)

**4.2.1 Subtask 2.1 Developing an Innovative Approach to Establish Tornado Fragility Curves**

Structural fragility to synoptic winds can be evaluated using the fragility curves provided in HAZUS [[[52]](#endnote-52)]. The curves provide the probability of the civil structure exceeding a specified limit state as a function of intensity measure (IM) of a hazard [[[53]](#endnote-53)]. They consider the uncertainties from loading and resistance. This subtask will establish tornado fragility curves by innovatively taking advantage of these existing fragility curves related to synoptic winds. In these existing fragility curves, the horizontal axis represents IM, in terms of 3-second gust wind speeds in straight-line winds. To use these curves for tornado fragility analyses, the wind speed relationship between tornadic winds and straight-line winds needs to be established. To be specific, for each intensity of tornado, we need to determine the equivalent 3-s gust wind speeds in straight-line winds (“Vs” in the sequel) that can produce the same extent of damage. In this project, this will be achieved using CFD simulations of tornado-structure interaction and straight-line-wind-structure interaction (described below), with validation using experimental testing for representative cases (see **Fig. 5)**.

**Fig. 5** Flowchart to obtain equivalent straight-line wind speed Vs” for any intensity of tornado



**Performing high-fidelity numerical simulations of tornado-structure interaction through combining CM1 and CFD.** The extracted **BAs** enables the community-level modeling of tornado-structure interaction. For each community of interest, the extracted **BAs** will be assigned to each building, and then tornado-community interaction will be simulated. The one-way coupled CM1 and CFD approach will be applied to simulate the actions of different intensities of tornadoes on the pilot locations. CM1 is used to simulate tornadic supercells at 10m resolution using the atmospheric soundings collected adjacent to observed tornadic supercells [24,25,26] (see **Fig. 2**); CFD simulations (Large Eddy Simulation) will be used to simulate the near-ground tornado vortex with a finer resolution in a smaller cylindrical computational domain (see “CFD” in **Fig. 2**). CM1 supplies the initial conditions and time-dependent boundary conditions to CFD, driving it with the flow that reflects the variability of real-world tornadoes in time and space, addressing the shortcoming of previous chamber simulation approaches and enabling better turbulence modeling in tornadic wind fields.

**Conducting model calibration and validation in PI Yan’s large-scale laboratory tornado simulator.** The small-scaled community model will be built and tested in the tornado simulator. In order to match the tornadic winds produced in the lab with those produced in the coupled simulation, trial and error as well as micro-tuning will be conducted in the facility.

Once validated, besides getting the equivalent Vs, animations for visualizing structural fragility for representative cases before and after applying protective strategies will be developed. They can help the public easily understand the difference that protective actions can make.

**Simulating straight-line wind fields to obtain equivalent Vs***.* The same community will be placed into straight-line wind fields (CFD simulations). A rectangular computational domain is applied. The height, width and length of the flow field will be set up to meet the blockage rate, similar to what we apply in wind tunnel testing. Large Eddy Simulation (LES) is applied. The velocity profile applied at the velocity inlet will be governed by logarithmic law. The CFD simulation of straight-line-wind-structure interaction will be validated using existing literature. To determine the equivalent Vs, for any intensity of tornado, the key is to adjust the wind speed input to the straight-line wind CFD simulation until the damage to the civil structure in the straight-line wind field reaches the same extent of damage as the damage caused by tornadic winds. Then, the wind speed at the 10m height in the straight-line wind field will be used to calculate Vs, which will be input into traditional fragility curves to obtain data points for tornado fragility curves. To make the workload manageable, instead of matching damage, the wind effects (pressure and wind forces) acting on the structure will be compared and matched. In addition, in tornado simulation, it is noted that the wind effects on the building that is passed by the tornado center will be used for damage matching. This building is referred as “target building”.

**Establishing tornado fragility curves using an innovative approach.** DI2 defined in EF scales (One- and two-family resilience houses) [[[54]](#endnote-54)] is used as an example here to explain this approach. To be consistent with EF scale, specific DODs (Degree of Damage) for DI2 defined in EF Scales will be used to determine the IMs to be applied. The damage description of DoD 3, DoD 5, DoD 8, DoD 9, and DoD 10 will be used to simulate tornadoes at the rating of EF1, EF2, EF3, EF4 and EF5. For each IM, the input of the tornadic wind field will be adjusted to produce the damage described in the associated DOD. Then, based on the obtained wind effects on the “target building”, the equivalent Vs will be obtained from straight-line wind simulation.

|  |  |  |
| --- | --- | --- |
| C:\Users\yang\AppData\Local\Microsoft\Windows\INetCache\Content.Word\pdf curve_5.jpg | | |
| a) Traditional fragility curve | b) Tornado fragility curve | c) Vulnerability curve |
| **Fig. 6** Schematic diagram of developing tornado fragility curves from traditional fragility curves and developing vulnerability curve (DS-Damage State). | | |

For each IM, by plugging this equivalent Vs into the traditional HAZUS fragility curve, the failure probability of each damage state (e.g., four damage states) will be obtained, as illustrated by the four data points in **Fig. 6a)** on the vertical line associated with each Vs. By running it for another IM, the associated four points will be obtained for another intensity of tornado (on another vertical line). Then, as shown in **Fig. 6b)**, by curve fitting the obtained data points (from traditional fragility curves) associated with a specific DS, the tornado fragility curve will be obtained. This will be validated by the established tornado fragility curves using the traditional approach based on Monte Carlo Simulations.

**4.2.2 Subtask 2.2: Developing Structural Vulnerability Curve for Each Archetype**

For each archetype, after obtaining the fragility curves for four different damage states, the vulnerability will be evaluated using the following total probability relation [[[55]](#endnote-55)]. It represents the mean damage ratio for all damage states (1-4) under a certain tornado intensity *im* (EFi here).

(1)

where *n* (= 4) is the number of damage states considered; P(*dsi*|*im*) is the probability of a building sustaining a damage state *dsi* given an intensity measure *im*; *E*(*C*>c|*dsi*) is the complementary cumulative distribution of the cost (or loss) given *dsi*; *E*(*C*>*c*|*im*) is the complementary cumulative distribution of cost (or loss) given an intensity level *im*. From **Fig. 6b)** to **Fig. 6c)**, it illustrates how to obtain a vulnerability value from fragility values associated with all damage states for EF3.

**4.2.3 Subtask 2.3: Identifying Existing Practice for Reducing Structural Vulnerability**

To reduce structural vulnerability, the team identified FORTIFIED Standards of IBHS (Insurance Institute of Business and Home Safety) and will promote the implementation of FORTIFIED Standards in tornado-prone areas. “FORTIFIED Standards go beyond typical building codes to deliver superior performance during severe weather. FORTIFIED is a nationally recognized building method based on 20 years of scientific research and real-world testing by IBHS”.

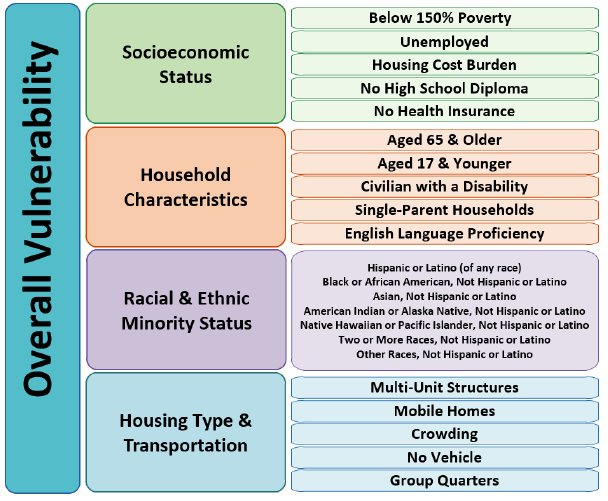
The team will also promote the implementation of updated building codes (**UBCs**) to alleviate structural vulnerabilities. According to FEMA Headquarter Building Science Branch, many counties and jurisdictions are still using older codes (prior to 2000), instead of **UBCs**. This project will run different simulation cases to demonstrate what difference the adoption of **UBCs** can make. The research findings will inform local codes decision-makers in reducing catastrophic risk of the society in tornado-prone areas. This will align with FEMA’s Building Code Strategy and the administration’s new National Initiative to Advance Building Codes [[[56]](#endnote-56)]. To ensure the research findings to be implemented by FEMA, the team has been collaborating with Dr. Shane Crawford of FEMA Headquarter Building Science Branch.

**4.3 Task 3:  Determining Regional Patterns and Relationships between Climatological Tornado Risk, Structural Vulnerability, and Social Vulnerability** (Starting RL 2/Ending RL 5; Led by Strader and supported by Yan and Li)

**4.3.1 Subtask 3.1: Conducting Spatial Analyses of Urban, Exurban, and Rural Sample CWA Climatological Tornado Risk, Housing Archetypes, and Social Vulnerability**

In this subtask, the data generated in Tasks 1 and 2 will be utilized to determine the geospatial relationships that exist between climatological tornado risk, housing archetypes, structure vulnerability, and social vulnerability in three pilot locations. First, measures of tornado frequency, magnitude or intensity, spatial dimensions (i.e., length and maximum width), etc. will be generated to provide a robust understanding of climatological tornado risk in each CWA domain. The Storm Prediction Center’s (SPC) SVRGIS tornado path data from 1950 to 2021 will be utilized to map tornado paths for the CWAs. Moreover, theoretical tornado damage footprints (i.e., maximum tornado width by tornado length) will only be assessed from post-1994 because of the change from mean tornado width to maximum tornado width reporting [1,4]. An emphasis will be placed on mapping significant tornadoes (EF2+) given historically they have represented ~99% of all tornado fatalities in the U.S. [2]. In all, these spatiotemporal analyses including measures such as mean annual tornado frequency, path length, path width, intensity, damage footprint area, etc. will reveal the climatological characteristics of tornadoes in the three selected CWAs, while informing Task 2 efforts about tornado frequency and intensity in the regions.

**Fig. 7** CDC SVI variables derived 2016-2020



Then, a geospatial examination of housing archetypes in each CWA will be conducted. The top *three* most common archetypes in each selected CWA will be mapped at the Census tract spatial scale. Based on Task 2 outcomes, information and data from the structural vulnerability curve generated for three most common CWA archetypes and at varying damage states will also be incorporated into the housing archetype analyses, providing additional spatial information pertaining to physical vulnerability. Specifically, archetype and structural vulnerability maps will be created for the three CWAs and EF2+ tornado events at the tract spatial scale. These examinations will provide NWS forecasters and IWT partners with a better understanding of their region’s common housing archetypes and likely probability of structural failure (potential property loss) given a specific tornado intensity striking the region. In addition to tract-level maps, hotspot and kernel density estimate maps of archetypes and vulnerability statistics by archetype will be provided for stakeholders.

In addition to physical vulnerability, social vulnerability metrics using the Center for Disease Control (CDC) Social Vulnerability Index (SVI) will be assessed within each CWA at the Census tract spatial scale. The tract-level scale is being utilized because it is the finest spatial resolution the Census, American Community Survey (ACS), and therefore, SVI measures are made publicly available. The 2020 SVI data shown in **Fig. 7** will be used in this study. The variables under each SVI sub-category are combined using a summation method to provide a vulnerability metric for that specific category. Similarly, all sub-categories are summed to yield the overall SVI estimate at the tract scale. Measures of individual SVI variables, sub-categories, and the overall SVI will be plotted in each CWA to illustrate social vulnerability across the region of interest. The SVI analyses will improve NWS forecaster and IWT partners insight about the precise locations within CWAs that are most socially vulnerable to tornado hazards. Through maps and statistical tables, findings will be shared with interested stakeholders.

**4.3.2 Subtask 3.2: Determining Relationships between Structural and Social Vulnerability**

Based on the results provided in Task 1, Task 2, and Subtask 3.1, spatial analysis results will be combined to reveal the overall juxtaposition of the tornado disaster variables (i.e., housing archetypes, structural vulnerability, and social vulnerability). A structural and social vulnerability index (SSVI) will be created at the tract spatial scale for the three most common archetypes, using the mean damage ratio generated in Task 2 and the overall SVI measures for the selected CWAs.

(2)

where is derived from the structural vulnerability curves generated in Task 2 for a selected archetype (**Fig. 6c)**), representing the mean damage ratio for all damage states (0-4) under *EFi*. This physical vulnerability metric varies between 0 and 1 (**Fig. 6c)**), with higher values indicating a greater structural loss. SVIOverall represents the overall SVI measure, which is the sum of all SVI sub-category measures. SVIOverall varies between 0 and 15 across the U.S. at the tract scale, with higher values representing greater social vulnerability. The two physical and social vulnerability values are then multiplied together and divided by the maximum possible overall SVI score possible in the U.S. to scale the SSVI from 0 to 1. Greater SSVI values denote greater combinations of physical and social vulnerability, and therefore, higher damage and fatality potential.

SSVI results will then be presented through geospatial maps at the Census tract spatial scale for the three selected CWAs. In addition, descriptive statistics for the SSVI measure will also be provided in table format. Tornado risk, as determined by Subtask 3.1, will not be directly incorporated into the SSVI due to the fact a majority of Census tracts in the U.S. and selected CWAs have not experienced a tornado with the observed period of record. However, hot spot and kernel density estimation (KDE) representations of EF2+ tornado events will be geospatially compared to the SSVI values to reveal potential areas of overlap between high physical vulnerability, social vulnerability, and tornado risk.

The new SSVI can be used by stakeholders to identify “Communities in Need of Intervention” throughout the U.S. This will facilitate the development of new policies and practices that enhance tornado resilience for structurally and socially vulnerable communities. Findings generated from the SSVI and individual components of the SSVI will be used to create specific survey questions in Task 4 that target vulnerable residents and their housing structure knowledge.

**4.4 Task 4: Reducing Vulnerability through Understanding Tornado Risk Perception and Capacity for Mitigation** (Starting RL 2/Ending RL 4; Led by Sherman-Morris, supported by All)

**4.4.1 Subtask 4.1: Understanding Participants’ Perceived Safety Regarding Their Home and Protective Actions Currently Taken Prior to and During Tornado Warnings**

Prior research suggests that individuals will make decisions regarding their own safety during a tornado based on individual-level constraints and beliefs, such as threat perception and perceptions about recommended protective actions [[[57]](#endnote-57),[[58]](#endnote-58)]. To better understand how individually held beliefs will interact with other social and physical vulnerabilities, an online survey will be administered. A representative sample of at least 500 individuals will be collected by Qualtrics for each of the pilot locations. Respondents will be screened to approximate population characteristics with respect to age, education, gender, and race. Oversampling will be used in proportion to the percentage of non-white population for each CWA to acquire a racially representative sample.

The survey will ask participants to classify their home according to age, primary material of construction, number of stories, presence of any reinforcing materials, and other factors identified to be relevant in Tasks 2 and 3. Questions will be based on factors that predict protective motivations in protection motivation models [58], such as perceptions about the threat severity, participant’s susceptibility to the tornado threat, and perceptions about the efficacy of current or previous actions taken to make themselves safe during a tornado, such as sheltering in a bathroom or basement, evacuating their location to go somewhere safer, or doing nothing. Participants will be asked how safe they feel staying inside their home in the safest location they can identify during a tornado. Participants will also be asked to describe where they do or would shelter during a tornado. Most of the questions will be Likert-type questions to allow for statistical testing, but at least one open ended question will be used to ask the participant to elaborate on their beliefs about the safety of their home and/or shelter location during a tornado.

**4.4.2 Subtask 4.2: Determining How Structural Vulnerability Visualization Influences Risk Perception, Protective Decision Making, and the Desire to Mitigate Tornado Vulnerability through Structural Improvements**

Based on participants’ responses to questions about the home structure type, their home will be best classified according to one of several pre-identified building archetypes. Participants will be directed to a video showing typical damage to a home like theirs based on the predicted damage to that archetype structure in Task 2. They will respond again regarding their perceptions of safety staying inside their home. The survey questions will be worded similarly to earlier survey questions to allow for the effects of the visualization to be tested. Additional questions will gauge participants’ ability to make structural adjustments to their homes to make them safer during a tornado. They will be asked to rate the perceived costs of the adjustments as well as to rate the perceived efficacy and benefits of making them.

The survey will be able to test whether there are differences in or associations with perceived safety based on participant’s home archetype or based on specific characteristics of the home. For example, we would expect participants with homes constructed primarily of brick or stone to feel safer sheltering there than participants with mobile or manufactured home. However, would age of the home or number of stories play a role in perceived safety? Understanding these factors may help warning communicators message tornado threat in a way that might help overcome beliefs about the home that would make sheltering there more dangerous.

**5. Schedule (Key Milestones and Timeline) (i denotes Quarter i)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Milestones** | **Year 1** | | | | **Year 2** | | | | **Year 3** | | | |
| 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Task 1: Extract building attributes at a community level for three CWAs | Develop and train four neural network models using training datasets |  |  |  |  |  |  |  |  |  |  |  |  |
| Extract individual building |  |  |  |  |  |  |  |  |  |  |  |  |
| Extract BAs |  |  |  |  |  |  |  |  |  |  |  |  |
| Refine/calibrate models based on output |  |  |  |  |  |  |  |  |  |  |  |  |
| Task 2: Determine structural fragility and vulnerability,  and identify practice to reduce structural vulnerability | Simulate tornado-structure interaction (TSI) |  |  |  |  |  |  |  |  |  |  |  |  |
| Experimental validation of TSI |  |  |  |  |  |  |  |  |  |  |  |  |
| Develop visualization of TSI |  |  |  |  |  |  |  |  |  |  |  |  |
| Determine building fragility |  |  |  |  |  |  |  |  |  |  |  |  |
| Determine building vulnerability |  |  |  |  |  |  |  |  |  |  |  |  |
| Identify current practice to reduce structural vulnerability |  |  |  |  |  |  |  |  |  |  |  |  |
| Task 3: Measure social/structural vulnerability | SSVI social vulnerability analysis |  |  |  |  |  |  |  |  |  |  |  |  |
| SSVI structural vulnerability analysis |  |  |  |  |  |  |  |  |  |  |  |  |
| Deliverable preparation (maps and docs) |  |  |  |  |  |  |  |  |  |  |  |  |
| Task 4: Understand risk /mitigation perception | Survey development |  |  |  |  |  |  |  |  |  |  |  |  |
| Survey administration |  |  |  |  |  |  |  |  |  |  |  |  |
| Data analysis and manuscript preparation |  |  |  |  |  |  |  |  |  |  |  |  |
| Engagement with NWS and core partners, & other end users | |  |  |  |  |  |  |  |  |  |  |  |  |
| Educational outreach with all stakeholders | |  |  |  |  |  |  |  |  |  |  |  |  |

**6. Outreach and Education for Broader Impact**

1) Develop a public-facing website (tdintervention.com) to disseminate research findings/data to stakeholders and facilitate the data sharing among project team members as a data and code repository. A website called “**Tornado Disaster Intervention**” will be developed. A preliminary version of the website has been created as part of the team’s proposal development and made live already. To one type of end-user, the public, it provides information and resources about the mitigation strategies to make homes safer under tornadoes. This website may be linked to the website of the collaborative NWS WFOs, which will help further disseminate research findings directly through their websites, such as weather.gov/Jan (see a letter of support), as these websites are regularly visited by their core partners.

2) Hold an Integrated Warning Team (IWT) meeting near the conclusion of the project to share project products and demonstrate how they can use them to plan and implement tornado disaster intervention. This is an online meeting, with key stakeholders from the three study CWAs involved. The team will also provide information on the most vulnerable communities with high SSVI index, which are in need of intervention. The team will demonstrate the structural damage animations to participants and provide them YouTube links where they can use the visualizations to help communicate tornado risk in tornado awareness campaigns or other public safety events.

3) Conduct community engagement by developing science education videos. Short science videos for public and professional education will be developed by a professional film director of Missouri S&T. This is to ensure that complicated phenomena can be intuitively understood by people of any age and the public with any background, addressing social equity to a certain degree. Videos will be hosted on the project’s website and be shared with professional organizations that offer professional development (e.g., National Institute of Building Sciences-NIBS, FEMA, and Alliance of National and Community Resilience that PI Yan has been collaborating with).

4) Outreach and education activities that can leverage existing resources from participating universities and Co-PIs. a) Webinars will be held to empower researchers and practitioners to confront tornado hazards through NIBS’ webinar series (see a letter of support), to reach out through their network and membership. b) Results will be disseminated via journal article(s) and conference presentation(s). c) All the developed short science videos will be further disseminated to pre-college students through the Kummer STEM Education Center of Missouri S&T (see a letter of support) and will be shared during separate outreach programs conducted at three other participating universities, nurturing next generations of scientists and engineers. d) The results of this project will inform teaching of undergraduate and graduate courses that are taught by co-PIs.

**7. Diversity, Equity, Inclusion, Accessibility (DEIA)**

Strength lies in differences. This is a diverse, inclusive, and interdisciplinary research team with various expertise to engage in integrated and convergent research. Two of the four investigators are female, representing STEM. The LGBTQ group through the Spectrum organization of Missouri S&T (see a letter of support) will be actively recruited for research assistant positions, as well as women, persons with disabilities, and underrepresented minority students from all participating universities. For all the four universities, PI Yan will facilitate their hiring of graduate students from HBCUs through her connections with Florida A&M University (FAMU) and Hampton University (HU) (two HBCUs; see 2 letters of support) and other minority serving universities. The four Co-PIs will inform research into teaching at FAMU and HU through a Zoom lecture per semester per year on “Cornerstone of Disaster Intervention: Structural/Social Vulnerability Interdependency” in Years 2 and 3 through their graduate or senior seminars. The last (the 4th) lecture will be recorded, and the recorded lecture will be used after the project period.

The NAAHDRI organization with 100 research centers affiliated [[[59]](#endnote-59)] that PI Yan has been leading is striving to create and foster a diverse and inclusive environment for hazards and disaster research fields nationwide. The DEIA endeavor in this project will further the commitments of NAAHDRI to DEIA. PI Sherman-Morris completed a certificate program in multicultural mentoring in 2022. She will share her knowledge with the rest of the team and help to build an inclusive research environment for this project.

To benefit historically underrepresented and under-resourced groups, the pilot study areas were chosen to ensure the coverage of different demographics. In addition, when developing the website, the feedback on the user interface will be collected from a diverse group of stakeholders, especially those from vulnerable communities, which also provide the team an opportunity to gain local knowledge, facilitating the knowledge co-building and co-producing process. The team will share their research findings with the Association of Native Americans, through their contact from Zona Verde (see a letter of support), a company producing affordable, green and resilient houses for Native Americans that PI Yan has been providing knowledge on tornado resilience.

**8. Data Management Plan**

Task 3 data and derived information will be stored on PI Strader’s internal hard drives and network attached storage (NAS). Data and findings will be made available to all co-PIs during the project. Task 3 employed and derived data will be made available upon request by the general public one year after the completion of this project. The SVRGIS tornado data and CDC SVI data are currently publicly available. Task 3 data formats include, but are not limited to .csv and shapefile format.

**8.a Type of data and information created**

Social: The project will generate the following types of data: maps, surveys and spreadsheets containing participant responses or community information..

Engineering: Data will be generated through numerical simulations and experimental testing. For numerical simulations, the Fluent Module of ANSYS and the Opensource code OpenFOAM, as well as the Mechanical Module of ANSYS, will be used to simulate tornadic wind fields and structural responses. The type of data created will include the simulation and analysis programming and codes, the generated data for wind fields (velocity and pressure), wind pressure on house surface, and structural responses. For each experimental test, the testing setup will be recorded; the velocity and the pressure distribution at representative locations in the wind field will be measured; and the pressure distribution on the structural surface will be measured.

Geospatial: All data employed herein is publicly available or derived from other portions of the research.

**8.b Expected schedule for data sharing**

Social: We will retain human subject data generated by the project for a period of at least 5 years. We plan to share any information learned with NOAA personnel, as well as the rest of the Integrated Warning Team..

Engineering: The expected schedule for data sharing is tiered. In Year 1, develop preliminary CFD models of tornadic wind field and tornadic wind effects on houses. In Year 2, CFD models and the proposed reinforce strategy will be validated and ready to share. In Year 3, the AI models will be shared.

Geospatial: Data will be stored on PI Strader’s network attached storage (NAS) and made available upon request one year after the completion of this project.

**8.c Standards for format and content**

Social: Copies of survey questions or other evaluation materials will be included in reports, publications as possible and will be made available electronically upon request. Copies of the publication will be made available upon request to those without access. All participants will be kept confidential. No data with direct identifiers will be made available except to the investigators or project evaluators who have the rights to this information through the IRB process. Results from the project will be shared with the academic community via journal articles and conference presentations.

**8.d Policies for stewardship and preservation**

Social: All human subject data will be kept for a minimum of 5 years after any interaction with the participants ceases as specified in the IRB protocol.

Social and Engineering: A secure database through the NSF DesignSafe CyberInfrastructure (CI) will be used for storage of the generated data. The DesignSafe CI maintain all uploaded data on storage resources at the Texas Advanced Computing Center. These resources are geographically replicated at different locations for security. The DesignSafe CI has stated its commitment towards the continuity of data preservation and has ensured preservation beyond the conclusion of the DesignSafe project.

**8.e Procedures for providing access**

Social: Data on project participants will be aggregated or anonymized before including in publications, reports or presentations unless we have specific written permission to use a participant’s name. Engineering: Projects published in DesignSafe are assigned a unique digital object identifier (DOI), which enables free public access. Data can also be accessed through our refereed journal papers, conference papers and presentations. Geospatial: All employed is publicly available.

**8.f Approximate total volume of data to be collected:**

Social: Survey data will total less than 500 MB.

Engineering: For each simulation case, it is expected to generate the engineering data with the approximate volume of 150 GB, with up to 20 T for the entire project. The storage space in DesignSafe is unlimited.

**8.g Ethics & Privacy**

The study will be reviewed and approved by the IRB at Mississippi State University. This includes documented informed consent. There will be no direct participant identifiers in the final retained data files. No identified data will be released to outside researchers, and only aggregate data will be shared, as appropriate, to maintain confidentiality.

**9. References**

**Note:** I heard from Southern Headquarters. They will help us locate an office (or more) in that region if we’re funded. They said Norman gets many requests and suggested Tulsa or Lubbock. I think it is too short in time to ask for a letter, but we could say this in the proposal. We should probably look at how we say which CWA’s we plan to work with. I can address this if you’d like.

CURRICULUM VITAE

**Guirong (Grace) Yan, Associate Professor**

A. Professional Preparation

|  |  |  |
| --- | --- | --- |
| Harbin Commercial University, China | Civil Engineering | Bachelor & 1998 |
| Harbin Institute of Technology, China | Structural Engineering | Master & 2002 |
| Harbin Institute of Technology, China | Engineering Mechanics | PhD & 2006 |
| Polytechnic University of Turin, Italy | Nonlinear System  Identification | Postdoc, Jun. 2007-May 2008 |
| Washington University in St. Louis | Structural Health Monitoring  and Vibration Control | Postdoc, Jun. 2008-Sept. 2009 |
| Purdue University | Wireless Sensor Networks | Postdoc, Oct. 2009-Feb. 2010 |

B. Appointments

**Associate Professor** (Sept. 2020-present)

Department of Civil, Architectural and Environmental Engineering, Missouri University of Science and Technology, Rolla, MO

**Assistant Professor** (Aug. 2014-2020)

Department of Civil, Architectural and Environmental Engineering, Missouri University of

Science and Technology (MS&T), Rolla, MO

**Assistant Professor** (Aug. 2012-Aug. 2014)

Department of Civil Engineering, The University of Texas at El Paso (UTEP), El Paso, TX

**Lecturer** (Feb. 2010-Aug. 2012)

School of Engineering, University of Western Sydney (UWS), Australia

C. Products

**Journal Papers**

1. Honerkamp, R., **Yan, G**., & Van De Lindt, J. (2022). Revealing Bluff-Body Aerodynamics on Low-Rise Buildings under Tornadic Winds Using Numerical Laboratory Tornado Simulator. ***ASCE Journal of Structural Engineering***, 148(3), 04021294.
2. Honerkamp, R., **Yan, G**.(2022). Influence of Turbulence Modeling on CFD Simulation Results of Tornado-Structure Interaction. ***Journal of Wind and Structures****,* 35(2): 131-146.
3. Honerkamp, R., **Yan, G**., Han, D., Feng, R., Li, Z., & Li, T. (2022). Tornado-Induced Structural Damage Based on Reconnaissance Surveys of the 2019 Jefferson City, Missouri, Tornado and Previous Tornadoes Notable Tornadoes. ***Journal of Natural Hazards Review***, 23(4), 05022008.
4. Zhao, Y., **Yan, G**., Feng, R., Kang, H., & Duan, Z. (2022). Influence of swirl ratio and radial Reynolds number on wind characteristics of multi-vortex tornadoes. ***Advances in Structural Engineering***, 13694332221119867.
5. Omar M. Nofal, John W. van de Lindt, Trung Q. Do, **Guirong Yan**, Sara Hamideh, Daniel T Cox, and Casey Dietrich (2021), “Methodology for Regional Multihazard Hurricane Damage and Risk Assessment,” ***ASCE Journal of Structural Engineering***. 147(11): 04021185.
6. Jian Yang, Yu Chen, Yanan Tang, **Guirong Yan** and Zhongdong Duan (2021), “A High-fidelity Parametric Model for Tropical Cyclone Boundary Layer Wind Field by Considering Effects of Land Cover and Terrain,” ***Atmosphere Research***, 260, 105701.
7. Guirong Yan and John van de Lindt (2021), “Living in Harmony with Natural Hazards by Being Prepared Psychologically, Physically, and Financially,” ***Journal of Wind Engineering***. May, 2021.
8. Yi Zhao, **Guirong Yan** and Ruoqiang Feng (2021), “Wind Flow Characteristics of Multi-Vortex Tornadoes,” ***Journal of Natural Hazard Review***, DOI: 10.1061/(ASCE)NH.1527-6996.0000462.
9. Jianxun Zhao, Guirong Yan, and Daoru Han (2021), “A Review of Approaches to Simulate Windborne Debris Dynamics in Wind Fields,” ***Journal of Wind Engineering and Industrial Aerodynamics***, Published online on March 30, 2021.
10. Stone, N. J., **Yan, G.**, Nah, F. F.-H., Sabharwal, C., Angle, K., Hatch, G., Rennels, S., Brown, V., & Schoor, G. (2021), “Virtual reality for hazard mitigation and community resilience: An interdisciplinary collaboration with community engagement to enhance risk awareness,” AIS Transactions on Human-Computer Interaction, 12(4). DOI: 10.17705/1thci.00134. Available at http://aisel.aisnet.org/thci/vol12/iss4/1
11. Ryan Honerkamp, **Guirong Yan** and Jeff Synder (2020), “A Review of the Characteristics of Tornadic Wind Fields through Observations and Simulations,” ***Journal of Wind Engineering and Industrial Aerodynamics***, (202): 104195. https://doi.org/10.1016/j.jweia.2020.104195
12. Zhi Li, Ryan Honerkamp, **Guirong Yan** and Ruoqiang Feng (2020), “Influence of a community of buildings on tornadic wind fields,” ***Journal of Wind and Structures***, 30(2): 165-180. DOI: http://dx.doi.org/10.12989/was.2020.30.2.165
13. Tiantian Li, **Guirong Yan**, Fangping Yuan and Genda Chen (2019), “Dynamic Responses on Large-Scale Dome Structures Induced by Tornado,” ***Journal of Wind Engineering and Industrial Aerodynamics***, (190): 293-308.
14. Fangping Yuan, **Guirong Yan**, Ryan Honerkamp, and Kakkattukuzhy M. Isaac, Ming Zhao and Xiaoyong Mao (2019), “Numerical Simulation of Laboratory Tornado Simulator that can Produce Translating Tornadoes,” ***Journal of Wind Engineering and Industrial Aerodynamics****,* (190): 200-217.
15. Tiantian Li, **Guirong Yan**, Ryan Honerkamp and Yi Zhao (2019), “Identification of Existing Stress in Existing Civil Structures for Accurate Assessment of Structural Behavior under Impending Extreme Winds,” ***Advances in Structural Engineering.*** 23(4): 702-712. https://doi.org/10.1177/1369433219879362
16. Tiantian Li, **Guirong Yan**, Ruoqiang Feng and Xiaoyong Mao(2019), “Investigation of the flow structure of single- and dual-celled tornadoes and their wind effects on a dome structure,”***Engineering Structures***. Available online 3 December 2019, 109999. https://doi.org/10.1016/j.engstruct.2019.109999

**Conference Papers**

1. Nofal, O. M., Lindt, J. W. van de, **Yan, G.**, Hamideh, S., and Dietrich, C. (2021), “Multi-Hazard Hurricane Vulnerability Model to Enable Resilience-Informed Decision.” Proceedings of International Structural Engineering and Construction (ISEC-11), S. El Baradei, A. Madian, A. Singh, and S. Yazdani, eds., Cairo, Egypt.
2. Ryan Honerkamp and **Guirong Yan** (2021), “Validation of CFD Model of Tornado Simulator Using Experiments Conducted on a Gable-roofed Structure.” *The 13th International Conference on Structural Safety and Reliability (ICOSSAR 2021)*, June 21-25, 2021, Shanghai, China.
3. Yi Zhao, **Guirong Yan** (2021), “Failure Modes of Low-rise Buildings under Multi-vortex Tornadoes.” *SEI and ASCE Structures Congress,* March 10-13, 2021 Seattle, WA, USA.
4. Yi Zhao, **Guirong Yan** (2021) “Size Effect on Wind Loads Induced by Multi-vortex Tornadoes on Low-rise Buildings.” *The 13th International Conference on Structural Safety and Reliability (ICOSSAR 2021)*, June 21-25, 2021, Shanghai, China.
5. Zhi Li, **Guirong Yan** (2021), “Proper Determination of Designing Tornadic Wind Loading on Civil Structures.” *SEI and ASCE Structures Congress,* March 10-13, 2021 Seattle, WA, USA.
6. Zhi Li and **Guirong Yan** (2021), “Investigation of Wind Effects on Bridges Induced by Tornadoes.” *The 13th International Conference on Structural Safety and Reliability (ICOSSAR 2021)*, June 21-25, 2021, Shanghai, China.
7. Ryan Honerkamp and **Guirong Yan** (2020), “Reveal bluff-body aerodynamics on low-rise buildings under tornadoes using “numerical” laboratory tornado simulator.” *9th International Colloquium on Bluff Body Aerodynamics and Applications (BBAAIX)*, July 20-23, 2020, Birmingham, UK.
8. Yi Zhao, **Guirong Yan** (2020). “Wind effects induced by multi-vortex tornadoes on a low-rise building.” *9th International Colloquium on Bluff Body Aerodynamics and Applications (BBAAIX)*, July 20-23, 2020, Birmingham, UK.
9. Ryan Honerkamp and **Guirong Yan** (2019), “Investigation of Structural Failure Modes Induced by Tornadoes through Post-event Surveys.” *The 9th International Conference on Structural Health Monitoring of Intelligent Infrastructure*, August 4-7, 2019, St. Louis, MO, USA

D. Synergistic Activities

1. Founded the Wind Hazard Mitigation (WHAM) Laboratory that houses a large-scale tornado simulator;
2. Developing the virtual reality animation CUBE Module to simulate tornado disasters. This is to promote the involvement of the community to build tornado-resilient communities together;
3. Delivered a TEDX talk titled as “Make Tornado Alley a Better Place to Live” on March 15, 2018. This talk was to encourage the entire community to be proactive in either reinforcing their houses or building more tornado-resistant houses, and to work together to achieve tornado-resilient communities;
4. Chairing Board of Directors of North American Alliance of Hazards and Disaster Research Institutes, with 99 hazards/disaster research centers/institutes affiliated;
5. Represented North America to organize the 5th GADRI (Global Alliance of Disaster Research Institutes) Global Summit: Engaging Science with Actions, held in August 2021;
6. Founded University Center for Hazard Mitigation and Community Resilience (HMCR), in which 35 faculty members from 12 departments are affiliated;
7. Outreached over 200 students from elementary schools in her WHAM lab using two small-scale tornado simulators through the “It’s A Girl Thing Camp” and “Introduce a Girl to Engineering” programs at MS&T;
8. Mentored Hispanic undergraduate and graduate students and involved Hispanic and BAA undergraduate students in her research.

CURRICULUM VITAE

**Stephen M. Strader, Associate Professor**

**Professional preparation:**

Northern Illinois University DeKalb, IL Ph.D. 2016

Northern Illinois University DeKalb, IL M.S. 2012

Indiana University Bloomington, IN B.S. 2010

**Research and professional appointments:**

Asoc. Professor, Department of Geography & Environment, Villanova University, 2022-current

Assist. Professor, Department of Geography & Environment, Villanova University, 2016-2022

Instructor, Department of Geography, Northern Illinois University, 2012-2016

Research Assistant, Department of Geography, Northern Illinois University, 2014-2015

Teaching Assistant, Department of Geography Northern Illinois University, 2010-2012

**Relevant publications:**

**S. M. Strader,** W. Ashley, A. Haberlie, and K. Kaminski, 2022: Revisiting U.S. Nocturnal Tornado Vulnerability and its Influence on Tornado Impacts.*Weather, Climate, and Society*. DOI: 10.1175/WCAS-D-22-0020.1

**S. M. Strader,** A. Haberlie, and A. Loitz, 2021: Assessment of NWS County Warning Area Tornado Risk**,** Exposure, and Vulnerability. *Weather, Climate, and Society.* DOI: 10.1175/WCAS-D-20-0107.1

**S. M. Strader**, D. Roueche, and B. David, 2020: Unpacking Tornado Disasters: Illustrating the Southeast U.S. Tornado-Mobile and Manufactured Housing Problem Using the March 3, 2019 Beauregard-Smith Station, Alabama Tornado Event. *Natural Hazards Review*. DOI: 10.1061/(ASCE)NH.1527-6996.0000436

Ash, K., M. Egnoto, **S. Strader,** W. Ashley, D. Roueche, K. Klockow-McClain, D. Caplen, and M. Dickerson, 2020: Structural Forces: Perception and Vulnerability Factors for Tornado Sheltering Within Mobile and Manufactured Housing in Alabama and Mississippi, USA. *Weather, Climate, and Society.* 6(12), 453-472.

**Strader, S. M.,** K. Ash, E. Wagner, and C. Sherrod, 2019: Mobile home resident evacuation vulnerability and emergency medical service access during tornado events in the southeast United States. *International Journal of Disaster Risk Reduction*. DOI: 10.1016/j.ijdrr.2019.101210

**Strader, S. M.,** and W. Ashley, 2018: Fine-scale assessment of mobile home tornado vulnerability in the Central and Southeast U.S. *Weather, Climate, and Society*. DOI: 10.1175/WCAS-D-18-0060.1

**Strader, S. M.,** W. Ashley, T. Pingel, and A. Krmenec, 2018: How land use alters the tornado disaster landscape. DOI: 10.1016/j.apgeog.2018.03.005

**Strader, S. M.,** W. Ashley, T. Pingel, and A. Krmenec, 2017: Projected 21st century changes in tornado exposure, risk, and disaster potential. *Climatic Change*. DOI: 10.1007/s10584-017-1905-4

**Strader, S. M.,** W. Ashley, T. Pingel, and A. Krmenec, 2016: Observed and projected changes in United States Tornado Exposure. *Weather, Climate, and Society*. DOI: 10.1175/WCAS-D-16-0041.1

Ashley, W. S., and **S. M. Strader,** 2016: Recipe for disaster: How the dynamic ingredients of risk and exposure are changing the tornado disaster landscape. *Bulletin of the American Meteorological Society*. DOI 10.1175/ BAMS-D-15-00150.1

**Relevant presentations within the last three years:**

* 30th Severe and Local Storms Conference, American Meteorological Society, 2022, (Santa Fe, NM) – *Revisiting U.S. Nocturnal Tornado Vulnerability and its Influence on Tornado Impacts*
* 100th American Meteorological Society Annual Meeting 2020, (Boston, MA) - *Building Stronger: Bringing Together Geospatial, Social Scientific, and Engineering-Based Perspectives on Weak-Framed Housing in the Southeastern United States*
* 100th American Meteorological Society Annual Meeting 2020, (Boston, MA) - *Mobile Home Resident Evacuation Vulnerability during Tornado Events in the Southeast United States*
* National Weather Association Annual Meeting 2019 (Huntsville, AL) - *Illustrating the Southeast U.S. Tornado-Mobile Home Vulnerability Problem by Investigating Impacts during the March 3rd, 2019 Lee County, Alabama EF4 Tornado*
* National Weather Association Annual Meeting 2019 (Huntsville, AL) - *Mobile home resident evacuation vulnerability and emergency medical service access during tornado events in the southeast United States*
* Vortex-Southeast Annual Workshop 2019 (Huntsville, AL) - *Tornadoes and Mobile Homes: An Inter-science Approach to Reducing Vulnerabilities and Improving Capacities for the Southeast’s Most Susceptible Population*
* Delaware Valley Geographical Association 2019, Keynote Speaker, (Fort Washington, PA) - *Fine-Scale Assessment of Mobile Home-Tornado Vulnerability in the Central and Southeast U.S.*
* 99th American Meteorological Society Annual Meeting 2019, (Phoenix, AZ) - *Investigating Mobile Home Residents, Tornadic Weather, and Vulnerability: A review of survey data focused on social and physical resources and responses to tornadic information.*
* 99th American Meteorological Society Annual Meeting 2018, (Phoenix, AZ) - *Using Network and Near Analyses to Examine Mobile Home Resident Evacuation Potential and Emergency Medical Service Response during Tornado Events in the Southeast U.S.*
* Annual Pennsylvania Geographical Society Meeting 2018, (Villanova, PA) - *Using Network and Near Analyses to Examine Mobile Home Resident Evacuation Potential and Emergency Medical Service Response during Tornado Events in the Southeast U.S.*
* American Meteorological Society 29th Severe and Local Storms conf. 2018 (Stowe, VT) - *Using Network and Near Analyses to Examine Mobile Home Resident Evacuation Potential and Emergency Medical Service Response during Tornado Events in the Southeast U.S.*
* American Meteorological Society 29th Severe and Local Storms conf. 2018 (Stowe, VT) - *Fine-scale Assessment of Mobile Home Tornado Vulnerability in the Central and Southeast U.S.*
* American Meteorological Society 29th Severe and Local Storms conf. 2018 (Stowe, VT) - *How Land Use Alters the Tornado Disaster Landscape*
* American Association of Geographers Annual Meeting 2018, William Garrison Computational Geographer Symposium (New Orleans, LA) - *Observed and projected changes in United States Tornado Exposure*
* 98th American Meteorological Society Annual Meeting 2018, (Austin, TX) - *Fine-scale Assessment of Mobile Home Tornado Exposure in the Southeast U.S.*
* 98th American Meteorological Society Annual Meeting 2018, (Austin, TX) - *Projected 21st century changes in tornado exposure, risk, and disaster potential*.

**Synergistic activities:**

* Over the last decade years I have: a) taught and developed a number of courses relevant to geography, meteorology, climatology, hazards, and GIS; b) published several manuscripts related to tornado disasters and society; c) served on the AMS Board of Early Career Professionals and AMS Board of Societal Impacts; d) participated in over 100 media interviews and Op-Eds, including outlets such as the New York Times, USA Today, Wall Street Journal, NPR Science Friday, LA Times, Chicago Tribune, Philadelphia Inquirer, Forbes, Scientific American, Washington Post, Boston Globe, etc.
* Advised both undergraduate and graduate students so that they may develop a strong understanding of the severe hazardous weather and potential impacts on society. Advising includes aiding them in developing efficient workflow and data analysis strategies, the improvement of quantitative and qualitative reasoning, and developing unique, efficient, and creative solutions to problems.
* Employ a number of GIScience methods and analyses within the atmospheric and hazard sciences in projects focused on a) understanding how geophysical hazards interact with society across spatiotemporal domains; b) geospatial characteristics of severe weather hazards (e.g., tornadoes, wildland fires, flooding, etc.); c) mobile home resident evacuation vulnerability during tornado events. Results for these research topics are aimed at initiating a dialogue among researchers, policy makers, operational forecasters, emergency management officials, etc.
* Partake in scholarly activities with the ultimate goal of transferring knowledge and research results to other academic, research, and professional parties. For instance, delivered many presentations at national, regional, and local American Meteorological Society conferences, National Weather Association meetings, VORTEX-USA workshops, National Weather Service (NOAA) workshops, and local STEM outreach symposiums that highlight my research.

**Collaborators & other affiliations:**

*Collaborators and Co-editors:* K. Ash (UF), W. Ashley (NIU), S. Childs (CSU), B. DePodwin (AccuWeather), M. Egnoto (Air Force), K. Ellis (UTK), J. First (UTK), V. Gensini (NIU), A. Haberlie (NIU), A. Hill (CSU/CIRA), K. Hoogewind (CIWRO/NSSL), K. Klockow-McClain (OU-CIMMS), P. Kremer (Villanova), A. Krmenec (NIU), Z. Li (U of SC), D. Roueche (Auburn) T. Pingel (Virginia Tech), J. Rennie (NCICS), C. Sherrod (Fulbright Scholar; Villanova Law), R. Schumacher (CSU/CIRA), K. Sherman-Morris (MSU), V. Smith (Villanova), E. Wagner (ESRI), J. Walker (NIU), G. Yan (Missouri S&T).Total number of collaborators and co-editors: 17.

CURRICULUM VITAE

**Kathleen Sherman-Morris, Professor**

A. Professional Preparation

|  |  |  |
| --- | --- | --- |
| Mansfield University | Social Studies | B.S. Ed. 1997 |
| Mississippi State University | Geosciences | M.S. 1999 |
| Florida State University | Geography | Ph.D. 2006 |

B. Appointments

**Assistant Dean** (Jul. 2022 - Present)

Mississippi State University

**Interim Assistant Dean** (Jul. 2021 - Present)

Mississippi State University

**Professor** (Aug. 2019 - Present)

Mississippi State University

**Associate Professor** (Aug. 2013 – Jul. 2019)

Mississippi State University

**Assistant Professor** (Jan. 2007 - Jul. 2013)

Mississippi State University

**Instructor** (Jan. 2003 – Dec. 2006)

Mississippi State University

C. Products

**Journal Articles Most Closely Related to Proposed Project**

**Sherman-Morris, K**., Vaughn, C., Senkbeil, J., Wooten, S. (2022) The influence of demographic and place variables on personalized tornado risk area, Weather, Climate and Society. 14, 1261-1272

Senkbeil, J., **Sherman-Morris, K**., Skeeter, W., Vaughn, C. (2022) Tornado Radar Images and Tornado Paths: An Assessment of Public Knowledge in the Southeastern U.S. Bulletin of the American Meteorological Society https://doi.org/10.1175/BAMS-D-21-0204

**Sherman-Morris, K.**, Senkbeil, J., Vaughn, C. (2022) How close is close enough? A discussion of the distances relevant to personalizing tornado risk. Bulletin of the American Meteorological Society https://doi.org/10.1175/BAMS-D-21-0142.1

Croskery, C. **Sherman-Morris, K**., Brown, M. (2021) Learning from the COVID-19 Pandemic: When Public Health and Tornado Threats Converge. Weather, Climate and Society. https://doi.org/10.1175/WCAS-D-20-0141.1

Senkbeil, J., Griffin, D., **Sherman-Morris, K.,** Saari, J., Brothers, K. (2021) Improving Tornado Warning Communication for Deaf and Hard of Hearing Audiences. Journal of Operational Meteorology 9(2) 18-35

**Sherman-Morris, K.** Pechacek, T. Griffin, D, Senkbeil, J (2020) Tornado warning awareness, information needs and the barriers to protective action of individuals who are blind. International Journal of Disaster Risk Reduction. https://doi.org/10.1016/j.ijdrr.2020.101709

Nunley, C.L., and **Sherman-Morris, K**. (2020) What People Know About the Weather, Bulletin of the American Meteorological Society. Early online release: https://journals.ametsoc.org/doi/abs/10.1175/BAMS-D-19-0081.

Gutter, B., **Sherman-Morris, K**., Brown, M. (2018) Influence of severe weather watches on daily activities. Weather, Climate and Society. 10(4) 613-623

**Sherman-Morris, K**., Lea, A. (2016). An Exploratory Study of the Influence of Severe Weather Radar Broadcasts. Journal of Operational Meteorology. 4(8): 108-122. DOI http://dx.doi.org/10.15191/nwajom.2016.0408

**Sherman-Morris, K.,** Antonelli, K., Williams, C. (2015). Measuring the effectiveness of the graphical communication of hurricane storm surge threat. Weather, Climate and Society 7(1): 69-82

**Sherman-Morris, K**. (2013) The public response to weather hazards: 25 years of research. Geography Compass 7(10): 669-685.

**Sherman-Morris, K**. and M. E. Brown (2012) Experiences of Smithville, Mississippi Residents with the 27 April 2011 Tornado, National Weather Digest. 36: 93-101

**Sherman-Morris, K**. (2010) Tornado Warning Dissemination and Response at a University Campus. Natural Hazards. 52(3): 623-638

**Sherman-Morris, K.,** (2005) Tornadoes, Television and Trust—A Closer Look at the Influence of the Local Weathercaster during Severe Weather. Environmental Hazards. 6(4) 201-210

**Other Significant Publications**

**Sherman-Morris, K.,** Lussenden, H., Kent, A., and MacDonald, C. (2018) Perceptions about Social Science among NWS Warning Coordination Meteorologists Weather, Climate and Society. 10(4) 597–612

**Sherman-Morris , K**., Houston, B, and Subedi, J (2018) On the Need for Hazards and Disaster Theory Developed through Interdisciplinary Research Risk Analysis. https://doi.org/10.1111/risa.13223

**Sherman-Morris, K**, and Martinez I. D. (2017) Optimistic Bias and the Consistency of Hurricane Track Forecasts, Natural Hazards. 88(3) 1523-1543

Strawderman. L., Carruth, D.W., **Sherman-Morris, K**., Menard, P. Warkentin, M., and McNeal, K. (2018) Individual Transportation Decisions under Conditions of Risk and Uncertainty Natural Hazards. 92(2), 927-942. https://doi.org/10.1007/s11069-018-3232-0

**Sherman-Morris, K.**, C. L. Wax, and M. E. Brown. (2012) Mississippi Weather and Climate. Jackson, MS: University Press of Mississippi

D. Synergistic Activities

1. President National Weather Association: As a director, president-elect, and president of the NWA, I have the ability to interact with operational meteorologists from around the country to discuss issues that are relevant to the operational community.
2. Weather and Society Integrated Studies Fellow: Participated in summer program designed to incorporate social science theory and methodology into improving the creation and delivery of meteorological information to the public and other user communities. Goals of the program included fostering relationships between public and private sectors of meteorological and social science communities and recognizing the importance of incorporating stakeholders at various aspects of a research project.
3. Enhancing Diversity in the Geosciences: As PI or Co-PI in the NSF OEDG program, I mentored an undergraduate research project, conducted workshops for teachers, ran a summer camp for middle school students, organized a capacity building workshop for project personnel and partners, administered multiple surveys about attitudes toward science and geoscience career knowledge.

CURRICULUM VITAE

**Zhenlong Li**

A. Professional Preparation

Wuhan University, China Geographic Information Systems Bachelor & 2006

George Mason University, VA Earth System Science Master & 2010

George Mason University, VA Earth Systems and Geoinformation Sciences PhD & 2015

B. Appointments

**Associate Professor** (2020 – present)

Department of Geography, University of South Carolina, Columbia, SC, USA

**Assistant Professor** (2015 – 2020)

Department of Geography, University of South Carolina, Columbia, SC, USA

**Director** (2015 – 2020)

Geoinformation & Big Data Research Laboratory at USC

**Faculty Member** (2015 – present)

Hazards & Vulnerability Research Institute; Faculty Associate, South Carolina SmartState Center for Healthcare Quality

**Graduate Research and Teaching Assistant** (Sep 2012 – May 2015)

George Mason University

**Manager and Chief GIS Engineer** (Aug 2011 - Aug 2012)

Department of Research and Development, SeaSky Geomatics Technology Inc., China

**GIS Engineer** (Jun 2010 - Aug 2011)

Heilongjiang Bureau of Surveying and Mapping, China

**Visiting Research Scholar** (Aug 2007 – Jun 2010)

Center of Intelligent Spatial Computing for Water/Energy Science, George Mason University

**GIS Developer** (Aug 2006 – Aug 2007)

Heilongjiang Bureau of Surveying and Mapping, China

C. Products

**Journal Papers**

1. Ning, H., **Li, Z.**, Ye, X., Wang, S., Wang, W., & Huang, X. (2021). Exploring the vertical dimension of street view image based on deep learning: a case study on lowest floor elevation estimation. ***International Journal of Geographical Information Science***, 1-26.
2. Lyu T., Hair N., Yell N., **Li Z.,** Qiao S., Liang C., Li X., (2021), Temporal Geospatial Analysis of COVID-19 Pre-infection Determinants of Risk in South Carolina, ***International Journal of Environmental Research and Public Health***, 18(18), 9673.
3. Kupfer, J. A., **Li, Z.,** Ning, H., & Huang, X. (2021). Using Mobile Device Data to Track the Effects of the COVID-19 Pandemic on Spatiotemporal Patterns of National Park Visitation. ***Sustainability***, 13(16), 9366.
4. **Li Z.,** Huang X., Hu T., Ning H., Ye X., Huang B., Li X., (2021), ODT FLOW: A Scalable Platform for Extracting, Analyzing, and Sharing Multi-source Multi-scale Human Mobility, ***Plos one***, *16*(8), e0255259.
5. Hu T., Wang S., She B., Zhang M., Huang X., Cui Y., …, **Li Z.,** (2021) Human Mobility Data in the COVID-19 Pandemic: Characteristics, Applications, and Challenges, ***International Journal of Digital Earth***
6. **Li Z.,** Huang X., Ye X., Jiang Y., Martin Y., Ning H., Hodgson M., Li X., (2021), Measuring Global Multi-Scale Place Connectivity using Geotagged Social Media Data, ***Nature Scientific Reports****,* *2102.03991*.
7. Hu, T., Wang, S., Luo, W., Yan, Y., Zhang, M., Huang, X., … & **Li, Z.** (2021). Revealing public opinion towards COVID-19 vaccines using Twitter data in the United States: a spatiotemporal perspective, ***Journal of Medical Internet Research***,
8. Jiang, Y., Guo, D., **Li, Z.** Hodgson, M., (2021) A novel big data approach to measure and visualize urban accessibility. ***Computational Urban Science****,* 1, 10 (2021).
9. Martín, Y., **Li, Z.** Ge, Y., Huang, X. (2021) Introducing Twitter Daily Estimates of Residents and Non-Residents at the County Level. ***Social Sciences***,
10. Jiang Y., Huang X., **Li Z.** (2021) Spatiotemporal patterns of human mobility and its association with land use types during COVID-19 in New York City, ***ISPRS International Journal of Geo-Information***, *10*(5), 344.
11. Jiang Y., **Li Z.,** Cutter S., (2021) Social Distance Integrated Gravity Model for Evacuation Destination Choice, ***International Journal of Digital Earth***, 1-15.
12. Ye X., Wang W., Zhang X., **Li Z.,** Yu D., Du J., Chen Z., (2021), Reconstructing spatial information diffusion networks with heterogeneous agents and text contents, ***Transactions in GIS***, 25: 1764-1673.
13. Zeng C., Zhang J., **Li Z.**, Sun X., Olatosi B., Weissman S., Li X., (2021) Spatial-temporal relationship between population mobility and COVID-19 outbreaks in South Carolina: A time series forecasting analysis, ***Journal of Medical Internet Research***, 23(4):e27045,
14. **Li Z.,** Qiao S., Jiang Y., Li X., (2021), Building a Social media-based HIV Risk Behavior Index to Inform the Prediction of HIV New Diagnosis: A Feasibility Study, ***AIDS***, 35 (Suppl 1):S91–S99.
15. Zeng C., Zhang J., Sun X., **Li Z.,** Weissman S., Olatosi B., Li X., (2021), County-level predictors of retention in care status among people living with HIV in South Carolina from 2010 to 2016: A data-driven approach, ***AIDS***, 35(Suppl 1): S53-S64
16. Huang, X., **Li, Z.,** Jiang, Y., Ye, X., Deng, C., Zhang, J., & Li, X. (2021). The characteristics of multi-source mobility datasets and how they reveal the luxury nature of social distancing in the US during the COVID-19 pandemic. ***International Journal of Digital Earth***, *14*(4), 424-442. (Web of Science Highly Cited)
17. Xu D., Huang X., Mango J., Li X., **Li Z.**, (2021), Simulating multi-exit evacuation using deep reinforcement learning, ***Transactions in GIS***, *25*(3), 1542-1564.
18. Qiao S., **Li Z.,** Weissman S., Li X., Olatosi B., Davis C., Mansaray A., (2021), Disparity in HIV service interruption in the outbreak of COVID-19: A mixed-method study in South Carolina, ***AIDS and Behavior***, *25*(1), 49-57.
19. **Li Z.**, Li X., Porter D., Zhang J., Jiang Y., Olatosi B., Weissman S., (2020) Monitoring the Spatial Spread of COVID-19 and Effectiveness of Control Measures Through Human Movement Data: Proposal for a Predictive Model Using Big Data Analytics, ***JMIR Research Protocols***, *9*(12), e24432.
20. Huang X., **Li Z.,** Lu J., Wang S., Wei H., Chen B., (2020) Time-series clustering for home dwell time during COVID-19: what can we learn from it? ***ISPRS International Journal of Geo-Information***, *9*(11), 675.
21. Huang X., **Li Z.**, Jiang Y., Li X., Porter D., (2020) Twitter reveals human mobility dynamics during the COVID-19 pandemic, ***PloS One***, *15*(11), e0241957. (Web of Science Highly Cited)
22. Ning H., **Li Z.**, Wang C., Yang L., (2020), Choosing an appropriate training set size when using existing data to train neural networks for land cover segmentation, ***Annals of GIS***, *26*(4), 329-342.
23. Yang C., Sha D., Liu S., Li Y., Lan H., Guan W., Hu T., **Li Z.,** Zhang Z., Thompson J., Wang Z., Wong D., Ruan S., Yu M., Richardson D., et al., (2020) Taking the pulse of COVID-19: A spatiotemporal perspective. ***International Journal of Digital Earth***, *13*(10), 1186-1211. (Web of Science Highly Cited)
24. **Li Z.,** Tang W., Huang Q., Shook E., Guan Q., (2020), Introduction to Big Data Computing for Geospatial Applications, ISPRS ***International Journal of Geo-Information***, 9(8), 487.
25. Huang X., Wang C., **Li Z.,** Ning H., Kim H. (2020), A 100m population grid in the CONUS by disaggregating census data with open-source Microsoft building footprints, ***Big Earth Data***, *5*(1), 112-133.
26. Xu D., Huang X., **Li Z.,** Li X., (2020). Local Motion Simulation using Deep Reinforcement Learning, ***Transactions in GIS***, *24*(3), 756-779.
27. Ning H., **Li Z.**,Hodgson M., Wang C., (2020). Prototyping A Social Media Flooding Photo Screening System Based on Deep Learning, ***ISPRS International Journal of Geo-Informatio***, 9(2), 104.
28. Martín, Y., Cutter, S. L., **Li Z.**, Emrich, C. T., & Mitchell, J. T. (2020). Using geotagged tweets to track population movements to and from Puerto Rico after Hurricane Maria. ***Population and Environment***, *42*(1), 4-27.
29. Hu L., **Li Z.**, Ye X., (2020) Delineating and Modelling Activity Space Using Geotagged Social Media Data, ***Cartography and Geographic Information Science***, 47(3).
30. Pham E., Emrich C., **Li Z.**, Mitchem J., Cutter S., (2020) Evacuation Departure Timing during Hurricane Matthew, ***Weather, Climate, and Society***, *12*(2), 235-248.
31. Martín Y., Cutter S.L., **Li Z.**, (2020) Bridging social media and survey data for the evacuation assessment of hurricanes, ***Natural Hazard Review***, 21(2).
32. Ning, H., Huang, X., **Li, Z.**, Wang, C., & Xiang, D. (2020). Detecting new building construction in urban areas based on images of small unmanned aerial system. ***Papers in Applied Geography***, *6*(1), 56-71.
33. Huang X., **Li Z.**, Wang C., Ning H. (2020), Identifying disaster related social media for rapid response: a visual-textual fused CNN architecture, ***International Journal of Digital Earth***, 13(9).

D. Synergistic Activities

1. Founded the Geoinformation and Big Data Research Laboratory that houses a big data computing cluster with 15 computer servers dedicated for geospatial big data and AI research.
2. Chair, Cyberinfrastructure Specialty Group, Association of American Geographers (2018- present); Co-Chair of the Cloud Computing Group of Federation of Earth Science Information Partners (ESIP) (2018-2019)
3. Leading Guest Editor for four special issues: “Social Sensing and Big Data Computing for Disaster Management” in the International Journal of Digital Earth “Big Data Computing for Geospatial Applications” in the ISPRS International Journal of Geo-Information; and the “Big Earth Data Analytics” on the Big Earth Data journal; and “Harnessing Geospatial Big Data for Infectious Diseases” in the International Journal of Applied Earth Observation and Geoinformation

CURRICULUM VITAE

**Gregory J. Stumpf**

A. Professional Preparation

|  |  |  |
| --- | --- | --- |
| SUNY Oswego NY | Meteorology (Honors) | Bachelor & 1986 |
| Colorado State University | Atmospheric Science | Master & 1988 |

B. Appointments

**Meteorologist Research Associate IV** (Oct 2019-present)

National Weather Service (NWS) Meteorological Development Laboratory (MDL) and Cooperative Institute for Research in the Atmosphere (CIRA), Colorado State University, Fort Collins, CO.

**Meteorologist Senior Research Associate** (2004 – Oct. 2019)

National Weather Service (NWS) Meteorological Development Laboratory (MDL) and Cooperative Institute for Mesoscale Meteorological Studies (CIMMS), University of Oklahoma, Norman, Oklahoma.

**Group Manager** (1997-2004)

National Severe Storms Laboratory (NSSL) Severe Weather Warning Applications and Technology Transfer (SWAT) Group

**Meteorologist Research Associate** (1989-2004)

National Severe Storms Laboratory (NSSL) and Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma, Norman, Oklahoma

C. Products

**Journal Papers**

1. **Stumpf, G. J.**, & Gerard, A. E. (2021). National Weather Service Severe Weather Warnings as Threats-in-Motion. ***Weather and Forecasting***, *36*(2), 627-643.
2. Rothfusz, L. P., Schneider, R., Novak, D., Klockow-McClain, K., Gerard, A. E., Karstens, C., ... & Smith, T. M. (2018). FACETs: A proposed next-generation paradigm for high-impact weather forecasting. ***Bulletin of the American Meteorological Society***, *99*(10), 2025-2043.
3. Smith, T. M., Lakshmanan, V., **Stumpf, G. J.**, Ortega, K. L., Hondl, K., Cooper, K., ... & Brogden, J. (2016). Multi-Radar Multi-Sensor (MRMS) severe weather and aviation products: Initial operating capabilities. ***Bulletin of the American Meteorological Society***, *97*(9), 1617-1630.
4. Karstens, C. D., **Stumpf, G.**, Ling, C., Hua, L., Kingfield, D., Smith, T. M., ... & Rothfusz, L. P. (2015). Evaluation of a probabilistic forecasting methodology for severe convective weather in the 2014 Hazardous Weather Testbed. ***Weather and Forecasting***, *30*(6), 1551-1570.
5. Lakshmanan, V., Smith, T., **Stumpf, G.**, & Hondl, K. (2007). The warning decision support system–integrated information. ***Weather and Forecasting***, *22*(3), 596-612.

**Conference Papers**

1. **Stumpf, G. J. (2019), “A Second Look at the Threats-in-Motion (TIM) Concept for Severe Convective Weather Warnings.”** *44th Annual Meeting of the Nat. Wea. Assoc*., Huntsville, AL.
2. **Stumpf, G. J.,** T. L. Hansen, A. Bates, C. Golden, Y. Guo, J. James, J. G. LaDue, C. Ling, K. L. Manross, T. Meyer (2018), “Three Years of Hazard Services – Probabilistic Hazard Information (HS-PHI) Experiments at the NOAA Hazardous Weather Testbed.” *29th Conf. on Severe Local Storms*, Amer. Meteor. Soc., Stowe, VT.
3. **Stumpf G. J.,** C. D. Karstens, and L. P. Rothfusz (2015), “New Verification Techniques for FACETs: What Do False Alarm Area and Lead Time Really Mean in the Realm of Probabilistic Hazard Information?” *40th Annual Meeting of the Nat. Wea. Assoc.,* Oklahoma City, OK.
4. **Stumpf, G. J.,** C. D. Karstens and L. P. Rothfusz (2015) “Probabilistic Hazard Information (PHI): Highlighting the benefits via new verification techniques for FACETs.” *3rd Conf. on Weather Warnings and Communication*. Raleigh, NC, Amer. Meteor. Soc., 5.7 (manuscript available).
5. **Stumpf, G. J.,** and L. P. Rothfusz (2013) “A Next-Generation Warning Concept of Threats-In-Motion (TIM): Highlighting the Benefits via New Verification Techniques.” *37th Annual Meeting of the Nat. Wea. Assoc*., Madison, WI.

D. Synergistic Activities

1. Board Of Directors, National Weather Association, 2016-2018
2. Member: American Meteorological Society, National Weather Association
3. **The National Weather Association Larry R. Johnson Special Award** (2016), for research, development, and delivery of severe weather applications within the Multi-Radar, Multi-Sensor system, which has been successfully transitioned into NWS operations, providing critical tools for NWS forecasts and warnings.
4. **The National Weather Association Larry R. Johnson Special Award** (2015) — The Hazardous Weather Testbed – The Cooperative Institute for Mesoscale Meteorological Studies (CIMMS), NOAA/NWS Storm Prediction Center, Weather Forecast Office Oklahoma City/Norman, National Severe Storms Laboratory (NSSL).
5. **National Oceanic and Atmospheric Administration Silver Medal for Scientific and Engineering Achievement** (2015), for the successful transition of the Multi-Radar / Multi-Sensor system into National Weather Service Operations.
6. **National Oceanic and Atmospheric Administration Technology Transfer Award** (2013), for leading the development of an on-demand, near real-time, web-based tool for tracking severe weather and hail swaths across the continental U.S.

CURRENT & PENDING SUPPORT

**Guirong (Grace) Yan**, Ph.D., Associate Professor

Support Type: Pending

Project/Proposal Title: **Laying the Cornerstone of Tornado Disaster Intervention by Investigating Interdependency between Structural Vulnerability and Social Vulnerability** (this proposal)

Source of Support: NOAA Location of Project: Missouri University of Science and Technology

Total Award Amount: **$518,344** Total Award Period Covered: 08/01/2023 - 07/31/2026

Person Months Per Year Committed to the Project: 2 mos. each year

Support Type: Current

Project/Proposal Title: **Achieving Greater Tornado Resilience through Informed Decision-Making About Reinforcing the Anchorage of Mobile Homes**

Source of Support: NOAA Location of Project: Missouri University of Science and Technology

Total Award Amount: **$400,000** Total Award Period Covered: 09/01/2020 - 08/31/2022

Person Months Per Year Committed to the Project: 0 mo. each year

Support Type: Pending

Project/Proposal Title: **Improve Risk Communication of Probabilistic Forecasts through Dual-coding and Negative Framing via AI**

Source of Support: NOAA Location of Project: Missouri University of Science and Technology

Total Award Amount: **$500,000** Total Award Period Covered: 08/01/2023 - 07/31/2026

Person Months Per Year Committed to the Project: 1 mo. each year

Support Type: Current

Project/Proposal Title: **Investigation of Wind Effects on Bridges Induced by Tornadoes for Tornado-Resistance Design-Phase II**

Source of Support: Mid-America Transportation Center. USDOT Location of Project: Missouri University of Science and Technology

Total Award Amount: **$67,000** Total Award Period Covered: 05/01/2022 - 04/30/2023

Person Months Per Year Committed to the Project: 0 mo.

Support Type: Current

Project/Proposal Title: **Understanding of Bridge Vulnerability to Climate Change Enables Pro-active Adaptation Measures**

Source of Support: Mid-America Transportation Center. USDOT. Location of Project: Missouri University of Science and Technology

Total Award Amount: **$85,000** Total Award Period Covered: 01/01/2021 - 06/30/2022

Person Months Per Year Committed to the Project: 0 mo. each year

CURRENT & PENDING SUPPORT

**Stephen Strader**, Ph.D., Associate Professor

**Currently Under Funding**

* **Title:** Faster, Clearer, Stronger Communication and Action: Building IWT and Vulnerable Resident Connections to Improve Severe Weather Literacy and Outcomes (NA21OAR4590265)
* **Place of Performance:** Villanova University
* **Agency:** NOAA Broad Agency Announcement
* **Funding Start and End:** 9/2021 – 8/2024
* **Investigator Months:** 1 (2022); 1 (2023); 1 (2024); Total 3 Months
* **Total Dollar and Duration:** $176,225 (3 years)

**Pending Support**

* **Title:** In-Situ Collaborative Experiment for the Collection of Hail in the Plains (ICECHIP)
* **Place of Performance:** Villanova University
* **Agency:** National Science Foundation
* **Funding Start and End:** 9/2023 – 8/2026
* **Investigator Months:** 1.5 (2022); 1.5 (2023); 1 (2024); Total 4 Months
* **Total Dollar and Duration:** $183,164 (3 years)
* **Title:** Laying the Cornerstone of Tornado Disaster Intervention by Investigating Interdependency between Structural Vulnerability and Social Vulnerability
* **Place of Performance:** Villanova University
* **Agency:** NOAA VORTEX-USA
* **Funding Start and End:** 8/2023 – 7/2026
* **Investigator Months:** 0.5 (2022); 1 (2023); 1 (2024); Total 2.5 Months
* **Total Dollar and Duration:** $159,909 (3 years)
* **Title:** Tornado Forecasts of Opportunity: Deep Learning for Extended-Range Predictions
* **Place of Performance:** Villanova University
* **Agency:** NOAA VORTEX-USA
* **Funding Start and End:** 8/2023 – 7/2026
* **Investigator Months:** 0 (2022); 0.5 (2023); 1 (2024); Total 1.5 Months
* **Total Dollar and Duration:** $72,652 (3 years)

CURRENT & PENDING SUPPORT

**Kathleen Sherman-Morris**,Ph.D., Professor

Support Type: Pending

Project/Proposal Title: **Laying the Cornerstone of Tornado Disaster Intervention by Investigating Interdependency between Structural Vulnerability and Social Vulnerability** (this proposal)

Source of Support: NOAA Location of Project: Mississippi State University

Total Award Amount: **$210,785** Total Award Period Covered: 08/01/2023 - 07/31/2026

Person Months Per Year Committed to the Project: .7 mos. each year

CURRENT & PENDING SUPPORT

**Zhenlong Li**,Ph.D., Professor

Support Type: Pending

Project/Proposal Title: **Laying the Cornerstone of Tornado Disaster Intervention by Investigating Interdependency between Structural Vulnerability and Social Vulnerability** (this proposal)

Source of Support: NOAA Location of Project: Missouri University of Science and Technology

Total Award Amount: **$300,000** Total Award Period Covered: 08/01/2023 - 07/31/2026

Person Months Per Year Committed to the Project: 2 mos. each year

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