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Double trouble: Examining public protective decision-making during concurrent tornado and flash flood threats in the U.S. Southeast

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ABSTRACT

Severe weather can often include multiple hazard threats, including simultaneous tornadoes and flash floods. These events, known as TORFF events or TORFFs, create a complex decision-making process for the people receiving warning protocols, as the recommended protective actions for the two hazards are contradictory—sheltering below ground during a tornado and moving to high ground during flash flooding events. Public response to TORFF events, which are warned for approximately 400 times per year, has yet to be examined. In the current study, we utilized structural equation modeling (SEM) to assess the factors and mechanisms of protective decision-making in members of the public ($N = 247$) who experienced concurrent tornado and flash flood threats on the 25 and 27 of March 2021 in the U.S. Southeast region. SEM analysis found direct and indirect relationships between hazard information sources, risk perception, and protective action for both hazards. In addition, results found that an increase in tornado risk perception led to a decrease in flash flood protective action. These results suggest that more public education and awareness on TORFF hazards is needed, along with dual protective guidance, particularly for socially vulnerable populations.

1. Introduction and background

On average (mean), tornado and flooding hazards have killed 156 people per year since 1990, making them the second (flooding) and third (tornado) deadliest types of weather events behind heat [1]. Approximately 400 times per year within the United States (U.S.), the National Weather Service (NWS) forecasters issue simultaneous tornado and flood warnings in a given area—events known as potential TORFFs [2]. Those that are then verified via local storm reports (LSRs) are considered verified TORFFs. Verified TORFFs are tornado and flash flood warnings that intersect each other in geographic space and time (within 30 min of one another; [2,3]. These dual warnings occur most frequently in south-central Missouri and the lower Mississippi River valley [2]; e.g., Fig. 1).

Potential TORFFs are considered to be challenging for members of the public receiving warning protocols, as the recommended protective actions for the two hazards are contradictory—sheltering below ground during a tornado and moving to high ground during flash flooding events [2,4]. TORFF events, therefore, can create confusion for the public about the level of danger for each threat and what protective action they are recommended to take. For example, in May 2013 a lethal tornado developed west of Oklahoma City, killing eight people. In addition, the storm caused extensive flooding and 12 people were killed from flash flooding when they

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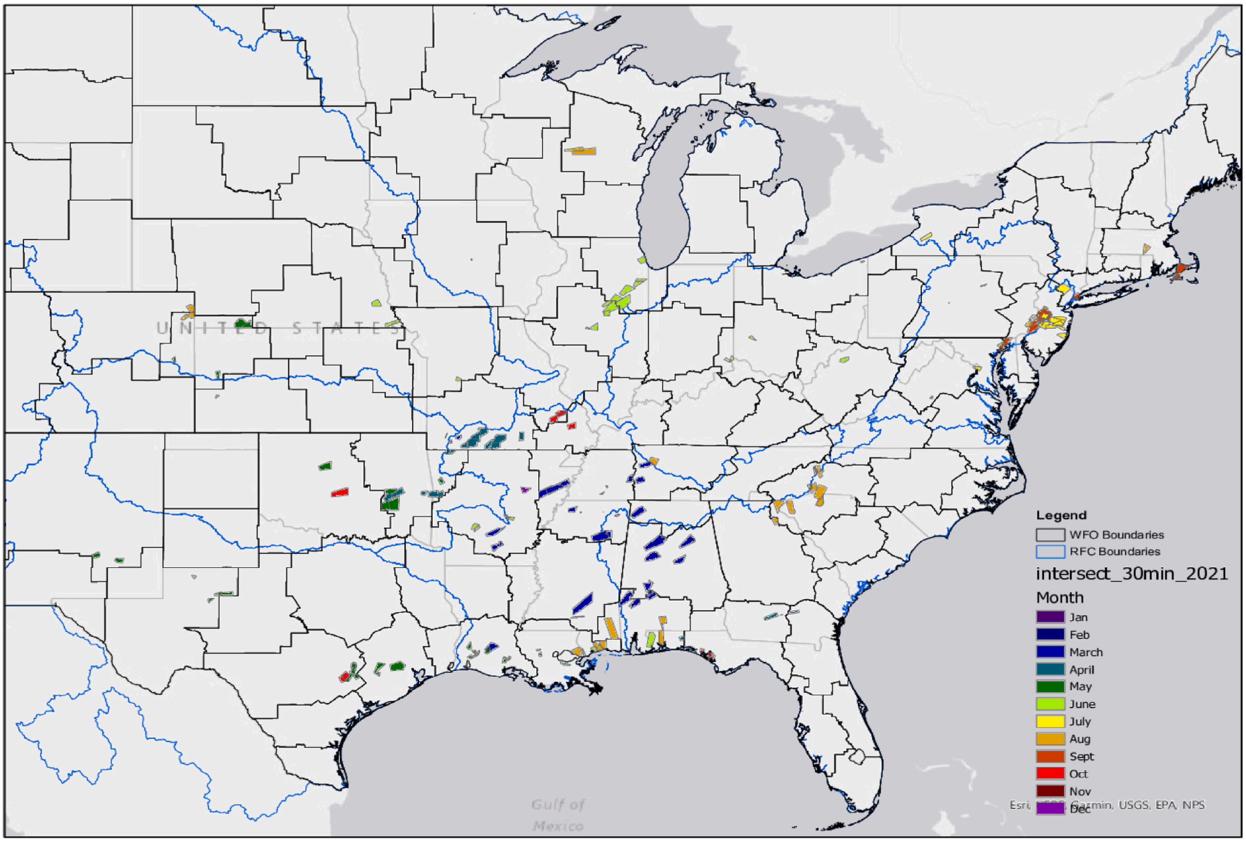

Fig. 1. Geographic distribution of overlapping tornado and flash flood warnings that occurred in the U.S. within 30 min of one another from January 1, 2021 – December 31, 2021. The shaded polygons correspond to the area that is common between both the tornado and flash flood warning (see Nielsen et al., 2015; Nielsen and Schumacher, 2021 for details)[1]. [1]Image downloaded from http://schumacher.atmos.colostate.edu/weather/TORFF_rt/.

took shelter from the tornado in a drainage ditch [5]. The NWS found that people were warned about the tornado, but many members of the public indicated they were not aware of simultaneous flash flood threats despite warnings being issued [5]. This event and other similar events (e.g., concurrent tornadoes and floods from Hurricane Harvey [6], highlight the life-threatening situations that TORFFs can produce.

Furthermore, when TORFF events occur, dimensions of social vulnerability may further compound protective decision-making as many people do not have access to the resources (i.e., basement, storm shelter, vehicle, etc.) necessary to respond safely to one or both hazards [7–11]. For instance, when tornado threats arise the NWS recommends that mobile/manufactured home residents flee their home for more sturdy shelter [11]. This presents an issue given many mobile/manufactured home residents evacuate their home in a vehicle, placing themselves at greater risk for flash flooding. Thus, a factor in TORFF response may be related to social vulnerability, which includes the various social conditions that create conditions of inequality that determine the resources that people have at their disposal to prepare for, cope with, and recover from the impacts of natural hazards (e.g., Refs. [12–18].

In the current study, we utilized structural equation modeling (SEM) to examine the factors and mechanisms influencing protective decision-making in members of the public ($N = 247$) who experienced simultaneous tornado and flash flood threats on 25 and March 27, 2021 in the U.S. Southeast region. The overall goal of this study is to contribute foundational knowledge about the factors involved in the protective decision-making process during multi-hazard risk perception, with a focus on TORFFs. We believe this understanding can guide future research by informing theoretical and methodological approaches to investigating protective decision-making in multi-hazard situations. It can also help guide studies of risk communication to enhance protective decision-making during TORFF warnings.

2. Literature review

Prior studies indicate the protective decisions people make are based upon a variety of factors, including knowledge and understanding of local risk and exposure, hazard information and warnings, perceptions of threat and forecast uncertainty, and resources to take protective action [7,14,19–26]. First and foremost, prior research suggests that individuals who do not receive hazard warning are less likely to take protective action [18,26,27]. Lack of hazard warning receipt has been found time and again by numerous studies to be an influential decision factor. Research has found there is not a single most effective information source for hazard warnings, but that hazard warnings disseminated by a variety of sources (e.g., TV, radio, outdoor warning sirens, word-of-mouth communication [28]; is the initial motivator in protective action if the receiver is able to understand the warning and know what protective action to take.

Second, people's appraisal of risk or risk perceptions play an important role in how they respond to warnings. Hazard risk perception, has long been studied, and includes the perceived probability or consequences that relate to a certain hazard and is an important motivator to consider protective action [22,27,29,30]. Risk perception may also be conceptualized as a mediating agent, as theorized by behavioral response models such as Protection Motivation Theory (PMT [31]; and the Protective Action Decision Model (PADM; [22]. Both models theorize that when individuals become aware of a hazard threat, it initiates appraisal of risk perception, which in turn affects a behavioral response. When individuals perceive the hazard threat as high, they consider taking protective actions, but if risk perception is low, they are less likely to consider protective action [32]. For example, in the PADM, Lindell and Perry [22] conceptualize the protective decision-making process as a multi-stage model that includes a casual chain of responses involving reception and attention to warnings and environmental cues; individual threat and coping perceptions; and a behavioral response that includes actions such as information search and protective response action (i.e., sheltering, evacuating).

Although prior research has examined protective decision-making during tornadoes [33]; Ash et al., 2014 [34–36]; and flash floods [37,38], these studies have focused on each hazard individually and research has yet to examine the process when these hazards co-occur. As mentioned previously, when tornadoes and flash flood hazards occur concurrently, TORFF events can create confusion for the public about what protective action they are recommended to take (e.g., shelter below ground for a tornado and move to higher group for a flash flood threat). Furthermore, the public may amplify one risk over another. From an NWS forecaster perspective, Henderson et al. [4], found that forecasters believe the public perceive tornadoes as more of a dangerous threat and that flash floods are often viewed as a nuisance, which indicates that tornado threats may take precedence over flash flood threats if they occur at the same time.

While recent research has examined TORFF events in conjunction to climatological conditions [2,39] and the operational challenges faced by NWS forecasters [4], research has yet to examine how members of the public actually respond to TORFF events. The current study addresses this gap and examined protective decision-making with a sample of 247 adults ($N = 247$) exposed to TORFF events on 25 and March 27, 2021 in the U.S. Southeast. Our study's research questions are as follows:

RQ1: During concurrent tornado and flash flood warnings, how does hazard information sources shape (a) tornado risk perception, and (b) flash flood risk perception?
RQ2: During concurrent tornado and flash flood warnings, how does tornado risk perception impact (a) tornado protective action, and (b) flash flood protective action?
RQ3: During concurrent tornado and flash flood warnings, how does flash flood risk perception impact (a) flash flood protective actions, and (b) tornado protective actions?

As previously stated, protective decisions are often based upon a variety of factors such as receiving hazard information and warning, perceptions of threat and forecast uncertainty, and their available resources to take protective action [7,14,22,24,25]. Therefore, we propose the following hypotheses:

H1. Access to more hazard-related information sources will be associated with (a) increased tornado risk perceptions and (b) increased flash flood risk perceptions.

H2. Having increased tornado risk perceptions will be associated with (a) more tornado protective actions, and (b) less flash flood protective actions.

H3. Having increased flash flood risk perceptions will be associated with (a) more flash flood protective actions, and (b) less tornado protective actions.

3. Study region

The U.S. Southeast is the most tornado disaster-prone region of the U.S [40–42]. In fact, tornado mortality in this region is driven by a combination of elevated climatological risk, higher population densities, and societal and environmental vulnerabilities (e.g., Refs. [13,17,42,43]. Specifically, the Southeast U.S. contains a high population and developed land density that increases tornado exposure, a greater number of mobile/manufactured homes that are less wind resistant to tornadic winds, a higher percentage of socially vulnerable populations (i.e., people without vehicles, people with disabilities, older adults, and people with limited English proficiency, etc.), and a larger number of nocturnal tornado events, each of which increases tornado casualty odds [40–42,44]. Research has also highlighted this area as being subject to higher flash flooding risk [13], especially during simultaneous tornadic events (i.e., TORFFs; [39].

In the current study we focus on two dates (25 and March 27, 2021) where TORFF events occurred in southeastern Arkansas, southern Tennessee, northern Mississippi, and northern Alabama (Fig. 2). These events were a part of two separate severe weather events that occurred on 25 and March 27, 2021. The March 25, 2021 TORFFs were a part of a Storm Prediction Center (SPC) high risk outlook, with a 30% significant tornado threat centered on northeastern Mississippi and northwestern Alabama. The Weather Prediction Center (WPC) issued a moderate (20–50% risk of rainfall exceeding flash flood guidance within 40 km of a point) and slight (10–20%) categorical outlook for this region as well. The tornado and flood warnings were issued during the mid-afternoon on March 25, 2021, with the primary storms of concern being the embedded supercells within a quasi-linear convective system (QLCS).

The March 27, 2021 TORFF events were a part of a SPC enhanced risk with a 10% chance of significant tornadoes centered on the Memphis, TN region. The WPC did issue a moderate excessive rainfall outlook for this day as well. The storm mode for the March 27,

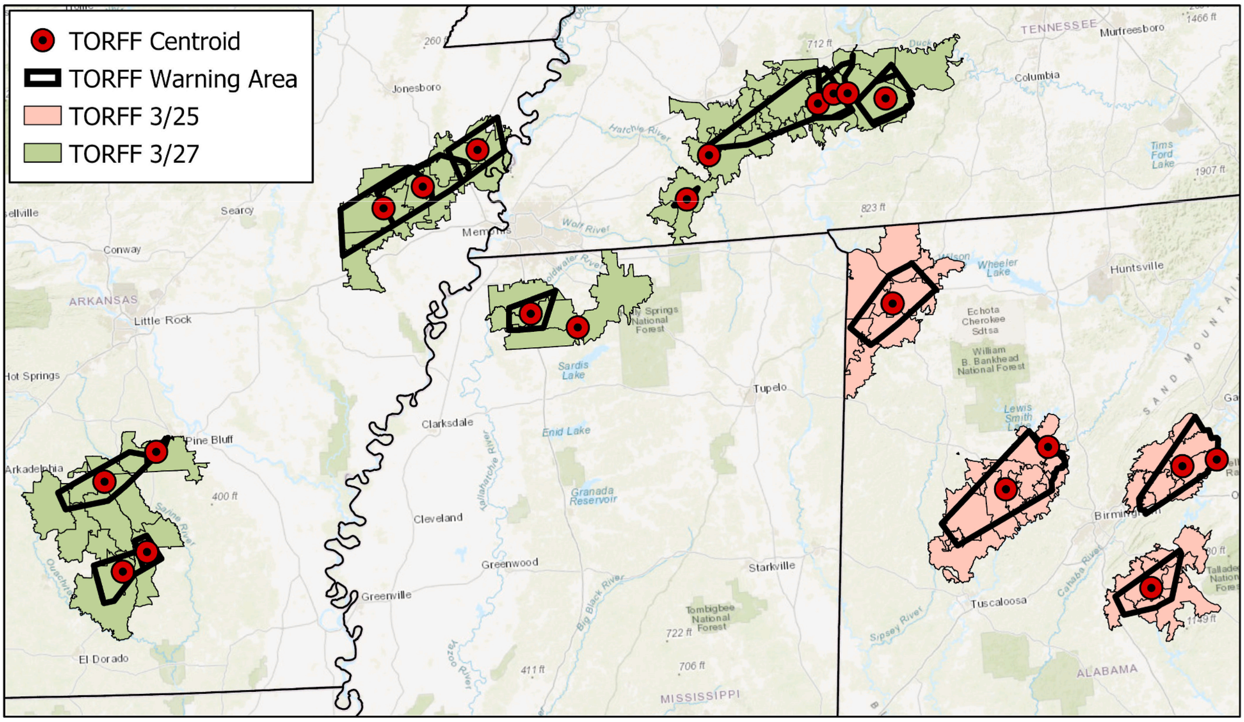

Fig. 2. TORFF events that occurred on 25 and March 27, 2021 across the Southeast U.S. The zip codes intersected by each TORFF event are also denoted.

2021 TORFFs was QLCS with embedded supercells. All tornado and flash flood warnings for this event were issued after 7 p.m. (CDT) as the sun was setting or after sunset. Local sunset time for Memphis on March 27, 2021 is 7:17 p.m. (CDT).

To compare social vulnerability of the Census tracts affected by the March 2021 TORFF to the larger U.S. geographic region, we employed the Center for Disease Control (CDC) Social Vulnerability Index (SVI) [45] Census tract-level data [46]. The SVI data comprises 15 different population measures (e.g., income, employment, age, race, language, mobile/manufactured homes) that are often linked [44] to increased hazard vulnerability and impacts. Specifically, the SVI tract data separates these measures into four distinct categories, socioeconomic status, household composition and disability, minority status and language, and housing type and transportation. Compared to the rest of the U.S., the Census tracts affected by the March 2021 TORFF events (Table 1) contained greater

Table 1
Social vulnerability estimates for study areas impacted by the 25 and March 27, 2021 TORFF events.

		Mean	Median	St. Dev.	Minimum	Maximum
	Population Density (ppl per sq.km)	77.5 (2043)	23.4 (834.1)	141.7 (4544)	1.58 (0.0)	679.1 (135,234)
	Housing Density (homes per sq.km)	36.6 (861)	10.5 (349)	72 (2079)	1.1 (0.0)	422.9 (98,903)
Socioeconomic Theme 1	% Below Poverty	17.1 (15.2)	16.5 (12.0)	7.7 (11.9)	2.2 (0.0)	41.5 (100.0)
	% Unemployed	6.9 (6.3)	6.5 (5.3)	3.7 (4.7)	0.7 (0.0)	18.1 (100.0)
	Income (per capita)	24,323 (32,279)	23,450 (28,554)	4978 (16,826)	15,183 (42)	42,239 (227,064)
	% No High School Diploma	17.1 (13.0)	17.3 (10.1)	5.4 (10.5)	3.9 (0.0)	30.1 (100.0)
Household Composition Theme 2	% Aged 65 or Older	18.1 (16.0)	18 (8.0)	3.4 (8.0)	9.3 (0.0)	26.9 (100.0)
	% Aged 17 or Younger	22.0 (22.1)	22.1 (22.2)	3.5 (6.7)	31.2 (0.0)	12.1 (87.6)
	% Civilian with a Disability	19.5 (13.3)	19.2 (12.5)	5 (5.9)	8.0 (0.0)	37.4 (100.0)
	% Single-Parent Households	7.8 (9.2)	7.2 (7.9)	3.8 (6.4)	1.0 (0.0)	21.9 (100.0)
Minority Status and Language Theme 3	% Minority	19.3 (38.3)	14.6 (29.6)	16.1 (30.0)	1.2 (0.0)	78.5 (100.0)
	% Speaks English "Less than Well"	0.55 (4.2)	0.1 (1.3)	0.96 (6.8)	0 (0.0)	5.7 (100.0)
Housing Type and Transportation Theme 4	% Multi-Unit Structures	1.6 (12.4)	0.2 (4.6)	4.2 (18.5)	0 (0.0)	40.9 (100.0)
	% Mobile/Manufactured Homes	23.0 (6.0)	22.8 (0.7)	12.1 (10.7)	0 (0.0)	47.3 (100.0)
	% Crowding	1.7 (3.6)	1.2 (1.8)	1.8 (5.2)	0 (0.0)	8.1 (100.0)
	% No Vehicle	5.8 (9.4)	4.1 (5.3)	5.3 (12.2)	0.4 (0.0)	37.2 (100.0)
	% Group Quarters	1.9 (2.4)	0 (0.2)	5.1 (8.2)	0 (0.0)	35.5 (100.0)

Note: The mean, median, standard deviation, minimum, and maximum of all tracts affected are presented. In parenthesis are the conterminous U.S. values for comparison.

mean percentages of persons in poverty (17.1%), those who were unemployed (6.9%), and individuals with no high school diploma (17.1%). This finding suggests that those affected by the TORFF events were more socioeconomically vulnerable. Focusing on the CDC SVI vulnerability Theme 2 (household composition), persons in the TORFF-affected tracts were also more likely to be aged 65 years or older (18.1%) or have a disability (19.5%). However, the percentages of households with minor populations (less than 17 years old) and single parents were less than the U.S. Only 19.3% of all persons impacted by the TORFF events were considered racial/ethnic minorities and 0.6% spoke English "less than well." The greatest difference between TORFF-affected tracts and the rest of the U.S. was found in the mean percentage of homes that are mobile/manufactured (23% vs. 6% for the conterminous United States). Prior research indicates that elevated mobile/manufactured housing density leads to greater probability of tornado fatalities [9,11,13,17,40,43,46,47]. As shown in Table 1, these TORFF events intersected populations where a variety of socioeconomic and demographic vulnerability factors could impact mortality and protective action-taking efficacy.

4. Methods

Data collection and participants. To investigate protective decision-making during TORFF warnings we survey 247 adults living in areas that were exposed to the March 2021 TORFF events detailed above. An online survey was conducted on individual hazard information sources, individual risk perceptions of tornadoes and flash floods, and tornado and flash flood protective actions taken, and demographic and socioeconomic variables. Data collection procedures with human subjects were approved by the [Identity Removed for Review] Institutional Review Board (IRB). The study sample included 312 adults (18 years or older) living in one of the counties affected by TORFF events on March 25 and 27, 2021 that occurred across the Southeast U.S. This sampling procedure increased the likelihood that respondents had a recent potential TORFF experience, though not all respondents were exposed to one or both warnings. Because the current study focused on protective decision-making during TORFF events, our analysis was limited to the 247 respondents ($N = 247$) that were within the warning polygons for both tornado and flash flood warnings. Data were collected during 15–20 April 2021 approximately three weeks following the TORFF events. Although we did not directly assess participant past TORFF experiences, participants may have had previous exposure to TORFF events according to prior research conducted by Nielsen [48]; Henderson et al. [4]; and the TORFF archive at Colorado State University (e.g., Fig. 1).

Participants were recruited via a Qualtrics Panel aggregator system which recruits participation from a pool of U.S. adults who have volunteered to be in online research via the company. The company is able to recruit participants in targeted areas and provides participants with compensation to participate in a research study. Potential respondents were invited via email with a secure URL from Qualtrics to review the study's purpose and access the survey questionnaire. All participants first read a consent form and were required to provide consent to participate in the study by selecting an "I agree to participate in the study" button. After consenting to the study, participants were directed to the online survey. Participants were compensated for their time with incentives through Qualtrics incentive program, which includes prize drawings and cash incentives.

The majority of participants were female (55.5%) and White (78.9%) followed by participants identifying as Black (16.6%), Hispanic (2.8%), and Asian American (1.2%). Nearly one-third (29.9%) of participants made less than $29,000 per year and 14.6% resided in a mobile/manufactured home. More than one-third (35.6%) of participants indicated their property was damaged by the severe weather events, 79.6% of participants indicated that at the time of the severe weather events they believed they or someone they knew could be killed or harmed and 87.6% of participants viewed damaged areas in their community. Less than half of participants (35.6%) indicated their property was damaged by the severe weather events, 79.6% of participants indicated that at the time of the severe weather events they believed they or someone they knew could be killed or harmed and 87.6% of participants viewed damaged areas in their community. See Table 2 for descriptive information for the survey.

In comparison to the larger Southeast U.S. geographic region for the study areas impacted by the TORFF events (see Table 1), more than half of the survey participants were found to have an income of $30,000 USD or higher in comparison to the regional mean income of $24,323 USD. Minority status for survey participants was 21% in comparison to the regional estimates at 19.3%. Estimates for mobile/manufactured home owners for the survey participants was lower at 14% in comparison to the study region at 23%.

4.1. Measures

Hazards information sources. Based on prior literature [27,28,49], hazard information sources were measured by creating an observed variable by asking participants the following question: "Which of the following were sources of information you used during the recent severe weather events in your area? (1) Television (e.g., TV news, emergency broadcast system announcements), (2) AM/FM commercial radio (e.g., weather forecasting radio sites), (3) News media websites, (4) Wireless emergency alerts (smart phone alerts), (5) Landline phone (e.g., reverse 911), (6) Outdoor warning sirens, (7) National Oceanic Atmospheric Administration (NOAA) weather radio, and (8) Family, friends, neighbors. Response options were *not at all* (0), *a little* (1), *somewhat* (2), or *a great deal* (3). The scores of all items were summed to reflect indexes of weather information sources and create an observed variable. The scores range from 0 to 24, with a higher score indicating access to more hazard information sources, the mean (M) = 12.41 and the standard deviation (SD) = 4.02. In the present sample, the reliability or internal consistency of the instrument is represented by the Cronbach's alpha value of 0.64. Cronbach's alpha utilizes inter-item correlations to determine if an instrument's items are measuring a specified domain/factor (Cronbach, 1951). Cronbach's alpha values above 0.60 are considered to be an acceptable index while values below 0.60 are considered to be low [50].

Tornado risk perception. Based on prior research [30]; Liu et al., 2019) tornado risk perception was measured with six items assessing the degree to which the respondent perceives tornado hazard situations as a threat to create a latent variable. These questions included: "I think that tornadoes are likely to happen in my area", "I think that a tornado can cause major damage to

Table 2
Descriptive information on study participants (N = 247).

	N	%
Gender		
Male	107	43.3
Female	137	55.5
Race		
Black/African American/Afro-Caribbean	41	16.6
Asian American	3	1.2
Hispanic/Latino	7	2.8
White	195	78.9
Native Hawaiian or other Pacific Islander	1	0.4
Age		
18–25	40	16.2
26–35	41	16.6
36–45	57	23.1
46–55	37	15.0
56–65	30	12.1
66–74	33	13.4
75 and older	9	3.6
Income		
Less than $15,000	27	10.9
$15,000 to $29,999	47	19.0
$30,000 to $44,999	29	11.7
$45,000 to $59,999	35	14.2
$60,000 to $74,999	34	13.8
$75,000 to $104,999	29	11.7
$105,000 or more	46	18.6
Education		
Grade School	1	0.4
Some High School	10	4.0
High School Graduate	62	25.1
Some College	61	24.7
College Graduate	66	26.7
Advanced Degree	47	19.0
Housing Structure		
Mobile/Manufactured Home	36	14.6
One-family house detached from other buildings	149	60.3
One-family house attached to other buildings	25	10.1
A building with apartments	33	13.4
A boat, RV, van, etc.	4	1.6
Hazards Exposure on 3/25/21 or 3/27/21		
Had property damage	88	35.6
Had Injuries	67	27.1
Knew people who had damage to their property	158	63.9
At the time of the event, believed they or someone they knew could be killed or harmed	197	79.7
Viewed scenes of the aftermath (damaged areas, debris)	220	87.6

my home", "I think that a tornado can cause injury to me or other family members", "I think that tornadoes are unpredictable", "I think that tornadoes can pose great financial threat", and "Thinking about the possibility of a tornado makes me feel fearful or worried." Each item is scored on a 5-point Likert scale from 1 (*strongly disagree*) to 5 (*strongly agree*). In the present sample, the Cronbach's alpha value was 0.83 ($M = 24.47$, $SD = 4.98$).

Flash flood risk perception. Based on prior research [38,51] flash flood risk perceptions were measured with six items assessing the degree to which the respondent perceives flash flood hazard situations as a threat to create a latent variable. These questions included: "I think that flash floods are likely to happen in my area", "I think that a flash flood can cause major damage to my home", "I think that a flash flood can cause injury to me or other family members", "I think that a flash flood is unpredictable", "I think that flash floods can pose great financial threat", and "Thinking about the possibility of a flash flood makes me feel fearful or worried." Each item is scored on a 5-point Likert scale from 1 (*strongly disagree*) to 5 (*strongly agree*). In the present sample, the Cronbach's alpha value was 0.77 ($M = 21.26$, $SD = 5.14$).

Tornado protective actions. Based on prior research [52]; Ash, 2016) tornado protective actions were measured by the following four indicators related to TORFF warnings on March 25th or 27th, 2021 to create a latent variable: "I paid attention to the weather forecasts and warnings because I knew about the threat of tornadoes that day." "I searched for more information of forecasted timing and severity of the tornado threats (e.g., look to TV, social media, online, apps)." "I sought confirmation of the tornado threats (e.g., looked outsides, environmental cues)." "I took action to protect myself or my loved ones against the threat of tornadoes that day (e.g., sought shelter below ground or in an interior room, evacuated mobile/manufactured home)." Each item is scored on a 5-point

Likert scale from 1 (*strongly disagree*) to 5 (*strongly agree*). In the present sample, the Cronbach's alpha value was 0.75 (M = 9.76, SD = 2.24).

Flash flood protective actions. Based on prior research [38,51] flash flood protective actions were measured by the following four indicators related to TORFF warnings on March 25th or 27th, 2021 to create a latent variable: "I paid attention to the weather forecasts and warnings because I knew about the threat of flash floods that day." "I searched for more information of forecasted timing and severity of flash flood threats (e.g., look to TV, social media, online, apps)." "I sought confirmation of the flash flood threats (e.g., looked outsides, environmental cues)." "I took action to protect myself or my loved ones against the threat of flash flooding that day (e.g., went to higher ground, avoided flooded areas)." Each item is scored on a 5-point Likert scale from 1 (*strongly disagree*) to 5 (*strongly agree*). In the present sample, the Cronbach's alpha value was 0.82 (M = 8.50, SD = 2.59).

5. Statistical analysis

Structural Equation Modeling (SEM) was used to examine the protective decision-making process during overlapping tornado and flash flood warnings. SEM is a statistical method that combines confirmatory factor analysis and path analysis which provides important advantages for this analysis. First, SEM is able to estimate latent variables from indicators of the underlying constructs and accounts for measurement error. Second, SEM also allows for the simultaneous examination of direct and indirect relationships between multiple independent and dependent variables (e.g., hazard warning information, tornado and flash flood risk perception, tornado and flash flood protective action), allowing for a more accurate model of complex path structures between multiple variables [53].

Data analyses were completed using R statistical software and packages (R Development Core Team, 2011). SEM is able to estimate both the proportion of variance common to multiple indicators of a given construct and the structural relations among latent constructs while correcting for measurement error [53]. Following this two-step procedure recommended by Kline [53]; a confirmatory factor analysis (CFA) of the measurement structure first tested the relationships between latent variables and indicators to test the study's hypotheses. Confirmatory factor analysis (CFA) is a method for measuring latent variables based on the correlated variations of the dataset from their indicators. In the CFA, each parameter of the measurement model was estimated to produce a predicted variance-covariance matrix (e.g., Σ) that resembles the sample variance-covariance matrix (e.g., S). The objective in a CFA was to find a set of factor loadings that produce the predicted Σ matric using the input of S matrix [53].

Second, after establishing the measurement model, a structural model was estimated to examine the direct and indirect associations between the independent and dependent variables that are hypothesized to influence people's protective actions during dual hazards (e.g., hazard warning sources, risk perception, behavioral actions). In the structural model, unstandardized coefficients are model parameter estimates based on the analysis of raw data, while the standardized coefficient, or a beta value (β), indicating the size and direction of the effect of an independent variable on the dependent variable in a path model based on the analysis of standardized data [53]. To estimate the SEM models, the fixed factor method was used which sets the latent variance to one (e.g., $\psi = 1.0$) and a robust maximum likelihood estimation to ensure multivariate normality [53]. For missing data, a full information maximum likelihood estimation was implemented. The indirect effects between variables were further tested using Preacher and Hayes [54] procedure by inspecting the 95% confidence interval of 1000 bootstrapped resamples of the product of coefficients to ensure the confidence intervals do not include zero, and therefore the effect is considered statistically significant.

Guidelines for goodness of fit indices for estimated models (Little, 2013) included chi-square test (χ^2) which tests the hypothesis that there is a discrepancy between model-implied covariance matrix and the original covariance matrix, the root mean square error of approximation (RMSEA; values of 0.08 or less indicate adequate fit), standardized root mean square residual (SRMR; values of 0.08 or less indicate adequate fit), Tucker–Lewis Index (TLI; which should be equal to, or greater than values of 0.90), and comparative fit index (CFI; which should be equal to, or greater than values of 0.90). Modification indices were also inspected for high values indicating the possible need to remove an item or change the path of an indicator (Little, 2013).

6. Results

To examine protective decision-making during overlapping tornado and flashflood warnings, we used structural equation modeling (SEM) to examine the associations between the observed variable (hazard-related information sources) and latent variables (hazard risk perceptions and protective actions). We first conducted a confirmatory factor analysis of the measurement model to ensure the study's indicators represented the latent variables well (Table 3). The measurement model was found to exhibit acceptable fit with the data and the model fit statistics were: $\chi2(164) = 627.952$, $p < .01$, CFI = 0.91, TLI = 0.91, RMSEA = 0.06, SRMR = 0.08. Comparative fit index (CFI) and Tucker-Lewis index (TLI) values are above 0.90 (Little, 2013). Root mean square error of approximation (RMESA) is below the threshold of 0.8 and standardized root mean square residual (SRMR) is below 0.08 (Little, 2013). All factor loadings (λ) were found to be greater than 0.50 (0.51–0.88), suggesting that the measurement items are reliable [55]. Therefore, the latent constructs were found to be reflected by their corresponding items.

After establishing the measurement model, the structural model was estimated. In the structural model, the Flash Flood Risk → Tornado Protect ($\beta = 0.130$, $p = .189$) path was not found to be significant, thus a revised model was estimated that deleted or trimmed the nonsignificant path to find the most parsimonious model [56]. In addition, additional inspections such as residual matrix and modification indices were conducted [53]. Based on the inspections, correlated residual variances were included in the model for tornado risk item 2 and 3 and flash flood risk item 2 and 3. The revised structural model was found to achieve acceptable fit, model fit statistics included: $\chi2(181) = 528.140$, $p < .01$, CFI = 0.91, TLI = 0.90, RMSEA = 0.08, SRMR = 0.08.

Our first hypothesis (H1) predicted that access to more hazard-related information sources will be associated with (a) increased tornado risk perceptions and (b) increased flash flood risk perceptions. H1a was supported as results found that for the public, having

Table 3
Measurement model.

Latent Variables and Indicators	Factor Loading	Standard Error	R^2
Tornado Risk Perceptions			
TR1: I think that tornadoes are likely to happen in my area	0.680	0.062	0.463
TR2: I think that a tornado can cause major damage to my home	0.851	0.069	0.725
TR3: I think that a tornado can cause injury to me or other family members	0.885	0.063	0.783
TR4: I think that tornadoes are unpredictable	0.807	0.070	0.652
TR5: I think that tornadoes can pose great financial threat	0.775	0.084	0.601
TR6: Thinking about the possibility of a tornado makes me feel fearful or worried	0.543	0.080	0.294
Flash Flood Risk Perceptions			
FR1: I think that flash floods are likely to happen in my area	0.564	0.075	0.319
FR2: I think that a flash flood can cause major damage to my home	0.716	0.070	0.513
FR3: I think that a flash flood can cause injury to me or other family members	0.800	0.062	0.640
FR4: I think that a flash flood is unpredictable	0.676	0.070	0.457
FR5: I think that flash floods can pose great financial threat	0.687	0.083	0.472
FR6: Thinking about the possibility of a flash flood makes me feel fearful or worried	0.693	0.074	0.480
Tornado Protective Action			
TP1: I paid attention to the weather forecasts and warnings because I knew about the threat of tornadoes that day	0.699	0.065	0.489
TP2: I searched for more information of forecasted timing and severity of the tornado threats (e.g., look to TV, social media, online, apps)	0.704	0.063	0.495
TP3: I sought confirmation of the tornado threats (e.g., looked outsides, environmental cues)	0.530	0.058	0.281
TP4: I took action to protect myself or my loved ones against the threat of tornadoes that day (e.g., sought shelter below ground or in an interior room, evacuated mobile/manufactured home)	0.712	0.056	0.508
Flash Flood Protective Action			
FP1: I paid attention to the weather forecasts and warnings because I knew about the threat of flash floods that day	0.811	0.054	0.658
FP2: I searched for more information of forecasted timing and severity of flash flood threats (e.g., look to TV, social media, online, apps)	0.750	0.055	0.563
FP3: I sought confirmation of the flash flood threats (e.g., looked outsides, environmental cues)."	0.517	0.052	0.267
FP4: I took action to protect myself or my loved ones against the threat of flash flooding that day (e.g., went to higher ground, avoided flooded areas)	0.855	0.053	0.730

access to more hazard-related information sources increased respondents' tornado risk perception (β = 0.202, $p < .01$). H1b was also confirmed as results founds more hazard-related information sources increased flash flood risk perceptions (β = 0.434, $p < .001$). Next, our second hypothesis (H2) predicted that having increased tornado risk perceptions will be associated with (a) more tornado protective actions, and (b) less flash flood protective actions. H2a was confirmed as results found that tornado risk perception was found to increase tornado protective actions (β = 0.302, $p < .01$), and H2b was confirmed when tornado risk perception was found to decrease flash flood protective action (β = - 0.182, $p < .05$). Our third hypothesis (H3) predicted that having increased flash flood risk perceptions will be associated with (a) more flash flood protective actions, and (b) less tornado protective actions. Results found that H3a was confirmed as flash flood risk perception was found to increase flash flood protective actions (β = 0.315, $p < .01$), but H3b was not confirmed as flash flood risk perception did not have an effect on tornado protective actions. Finally, the indirect effects were tested and results found that hazard information sources were associated with greater tornado protective action, via the mediating pathway of tornado risk perception (β = 0.057, $p < .01$, [CI 95%: 0.020, 0.077]) based on the 95% confidence interval from 1000 bootstrapped resamples [54]. In addition, results found that hazard information sources were also associated with greater flash flood protective action via the mediating pathway of flash flood risk perception (β = 0.042, $p < .001$, [CI 95%: 0.025, 0.108]) based on the 95% confidence interval from 1000 bootstrapped resamples. See Table 4 and Fig. 3 for structural model results.

7. Discussion

While previous studies have highlighted the protective decision-making process during both tornadoes and flash flood events, this study examined the decision-making process when both threats occur. We examined the direct and indirect relationships between hazard information sources, risk perception, and protective action variables using structural equation modeling. Our results indicate several main findings.

First, we found that having multiple hazard information sources was directly associated with increased risk perception for both hazards, tornado and flash flood. Consistent with prior research [14,22,23,28] our finding highlights the central role of hazard warning and information sources in initiating the cognitive processes for protective decision-making. The current study sheds new light on the need to understanding how warning notifications motivate individual behavior through risk perception, particularly in multi-hazard situations. Results suggest that during TORFF events, public risk perception for both hazards was increased by receiving hazard information from multiple sources. However, it is worth noting that our hazard warning sources variable only measured the number of hazard warning sources and did not disaggregate forecast information or warning communication content related to each hazard threat.

Table 4
Structural Model.

Direct and Indirect Paths	Standard Estimate	Standard Error
Hazard Info Sources → Tornado Risk (R^2 = 0.08)	0.202**	0.016
Hazard Info Sources → Flash Flood Risk (R^2 = 0.19)	0.434***	0.019
Hazard Info Sources → Tornado Protect (R^2 = 0.30)	0.402***	0.025
Hazard Info Sources → Flash Flood Protect (R^2 = 0.39)	0.488***	0.024
Tornado Risk → Tornado Protect (R^2 = 0.30)	0.302**	0.104
Tornado Risk → Flash Flood Protect (R^2 = 0.39)	- 0.182*	0.102
Flash Flood Risk → Flash Flood Protect (R^2 = 0.39)	0.315**	0.120
Hazard Info Sources → Tornado Risk → Tornado Protect (R^2 = 0.30)	0.057** [CI: 0.020–0.077]	0.014
Hazard Info Sources → Flash Flood Risk → Flash Flood Protect (R^2 = 0.39)	0.042** [CI: 0.025–0.108]	0.019

Note: N = 247, Model Fit: $\chi2(181)$ = 528.140, $p < .01$, CFI = 0.91, TLI = 0.90, RMSEA = 0.08, SRMR = 0.08. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

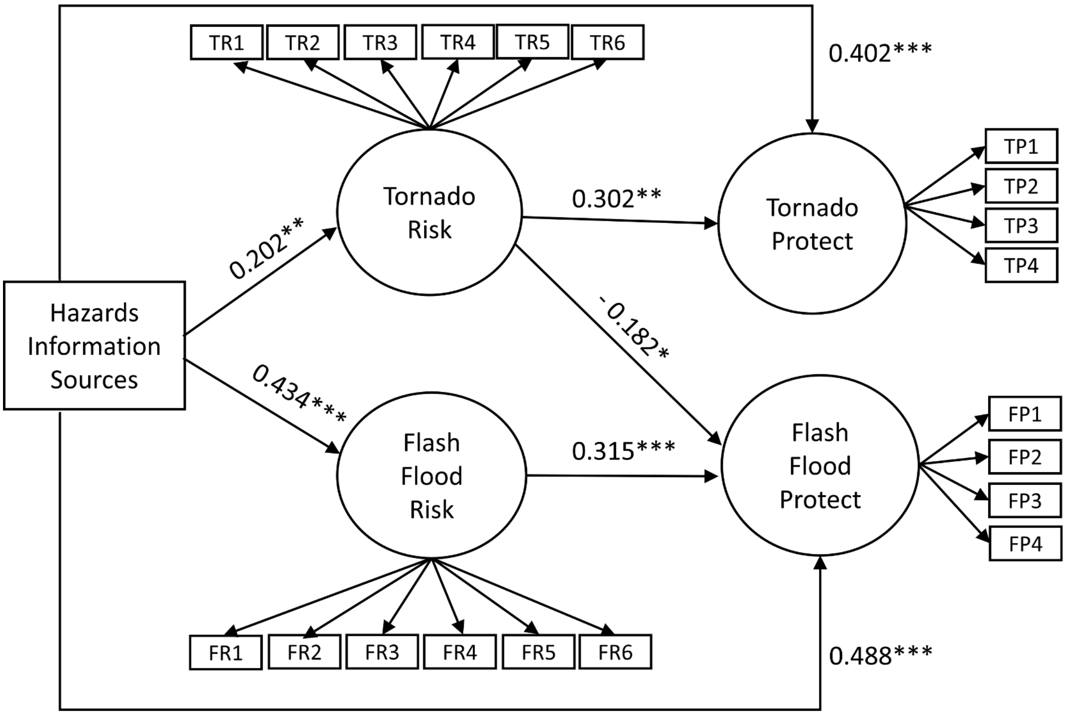

Fig. 3. Diagram of Structural Model. N = 247, Model Fit: $\chi2(181)$ = 528.140, $p < .01$, CFI = 0.91, TLI = 0.90, RMSEA = 0.08, SRMR = 0.08. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

We also found that risk perceptions played both a direct and mediating link for increased protective actions for both threats (e.g., looking for more information, sought confirmation, sheltered below ground, avoided flooded areas). This finding confirms the perceived probability or consequences that relate to hazards is direct motivator for protective action [22,27,30]. In addition, our findings indicate that risk perception is a mediating agent in a multi-stage model, as theorized by behavioral response models [22,31]. As our SEM model shows, after individuals become aware of hazard threats, it initiates appraisal of risk, which in turn affects a behavioral response. Risk perception, therefore, was found to provide a mediating mechanism that connects hazard warning information to a behavioral response of protective action against hazards.

Furthermore, our findings highlight the complexity of decision-making when tornadoes and flash flood threaten concurrently. As our results indicate, even when people are aware of both threats, deciding what protective actions to take can be complex and may lead to prioritizing protective action for one threat over the other. Specifically, our findings indicated that while tornado risk perception increased tornado protective action, it decreased protective action for flash flood events. In addition, we found that flash flood risk perception did not have an effect on tornado protective action. This finding is consistent with prior research by Henderson et al. [4], which found NWS forecasters believe the public perceives tornadoes as more dangerous than flash floods, and therefore they are more likely to attend to tornado warnings than flashflood warning. Thus, during TORFF situations, tornado risk perceptions may play an amplified role in how people assess both threats and make decisions to take protective action. Furthermore, these results highlight that risk perceptions in other compound hazard context could lead to interacting risk situations, where one threat (i.e., tornadoes) is perceived as greater than the other, and one hazard could reduce protective action for another hazard [57]. For example, in a qualitative study with mobile/manufactured home residents in the Southeast on their tornado protective decision-making, Ash (2016) found respondents indicated that one hazard (i.e., lightning) could affect protective action decision-making for a second hazard (tornadoes) when a portion of respondents noted they routinely unplug electronics during thunderstorms to protect property from an electrical surge caused by lightning. Local television stations are still the most widely used source for weather hazard information in the USA, and therefore if the television is unplugged, one is less likely to receive an urgent bulletin about a tornado in their area and fail to enact a sheltering plan (Ash, 2016). Our results, along with these examples, further highlight how in multi-hazard situations one hazard threat could be perceived as greater and reduce protective actions for another hazard.

In addition, our findings highlight that social vulnerability may further compound protective decision-making. Although TORFF events can occur anywhere across the U.S., these events presented a unique issue as they occurred in a region of the U.S. with a high percentage of homes that are mobile/manufactured [17]. Thus, the consequences of dual warning messaging as it relates to population protective actions are heightened in this region. Prior research has illustrated that the elevated mobile/manufactured housing density leads to greater probability of tornado fatalities [13,40]; Schmidlin et al., 2009 [43,46,47]; Simmons & Sutter 2011; [11]. Therefore, when tornado threats arise, NOAA, NWS, and Federal Emergency Management Association (FEMA) recommend that residents flee their home for more sturdy shelter [11] which presents an issue given most residents will evacuate their home in a vehicle, and could place themselves at greater risk for flash flooding. Complicating the issue even further, the Southeast is home to the greatest frequency of nocturnal tornado events [13,58,59] which makes driving during heavy rains after dark even more dangerous. However, it is important to note that while we were able to compare the social vulnerability characteristics of our study area to our survey demographics, our sample size and geographic scope limited the ability to examine SEM relationships between social vulnerability indicators and the survey variables. Future research should be conducted with a larger sample size to examine potential relationships between social vulnerability indicators and protective decision-making (e.g., spatially explicit SEM).

In total, TORFF events can create complex weather scenarios with conflicting safety protocols that can create uncertainty and confusion for protective decisions, particularly among socially vulnerable populations. In terms of implications, we recommend more public education and awareness on TORFF hazards is needed, especially within high TORFF risk areas in the U.S. Southeast. Information on the frequency of TORFF events that occur every year, along with guidance on how the public might assess their potential for compounding risk given their location (e.g., located near a flood plain) and shelter vulnerabilities (e.g., residing in a mobile/manufactured home), could help increase public awareness and protective actions for both threats. For example, public outreach initiatives and educational materials (e.g., handouts, website information) could be developed for individuals living in TORFF-prone communities to increase public awareness and motivate safety planning for when both extreme winds and flash flooding occur. Preparedness and warning information should include socially vulnerable populations. For instance, safety planning for mobile/manufactured home residents can include preparing tornado evacuation plans that are routed to avoid flood-prone areas. Likewise, during TORFF warning situations, forecasters and emergency management should provide specific guidance on what residents should do to seek protection from both tornadoes and flash flood threats (e.g., evacuate from mobile/manufactured homes; do not drive through flooded road; do not shelter in roadside ditches or storm drainage systems; see Ref. [4]. However, as our findings indicate, deciding what protective actions to take can be complex and often nuanced to each individual situation.

Our findings also identify several additional areas for future research. First, more in-depth investigation into how diverse populations perceive, interpret and respond to TORFF warnings is needed. More specifically, future studies should employ qualitative methods for providing further context into lived experiences (Bica et al., 2021) and protective decision-making process that occurs during dual hazards. Second, our results suggest it is important to understand how multiple risk perceptions (e.g., tornado and flash flood) interact to affect protective actions. However, while this study focused on cognitive risk perceptions (e.g., perceived likelihood of threat, severity of impacts), other research suggests it is also important to investigate people's perceived efficacy or coping appraisal, as these can also have influence on decision-making [22,60]. Furthermore, our study highlights the importance of effectively communicating multi-hazard risk and uncertainties and the need for protective guidance that considers how the public can respond to multi-hazard threats [61]. Future research is needed to test how to effectively communicate multi-hazard risk and uncertainties related to TORFF events in locally relevant ways [62]. This knowledge can then be used to improve overlapping tornado and flashflood alerts with the goal of helping people prepare for and evaluate risk combinations and decide what to do given the dynamic, uncertain nature of multi-hazard threats [63]. The global COVID-19 pandemic has shown the urgent need for research that considers the interactions of multi-hazard risk between natural hazards and pandemics (e.g., seeking refuge at a mass shelter vs. social distancing) along with compounding social vulnerabilities. Understanding the protective decision-making process within multi-hazard risk situations is essential for reducing deaths and injuries and for developing mitigation and resilience-building strategies for the future.

8. Conclusion

Traditionally, disaster planning and communication has focused on specific, singular events. In the current study we examined the direct and indirect effects between hazard warning sources, risk perceptions, and protective actions during concurrent tornado and flash flood threats using SEM. We found that hazard warning sources had a direct effect on increased risk perceptions (both tornado and flash flood) and an indirect effect on increased protective actions (both tornado and flash flood) through risk perceptions. Results also found that while risk perceptions of tornado threats led to prioritizing protective actions for tornadoes, they decreased protective actions for flash flood events. These results highlight that more public education and awareness on TORFF hazards is needed, along with dual protective guidance, particularly for socially vulnerable populations. Increasing multi-hazard education and awareness is essential for reducing vulnerability and enhancing public protective actions.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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References

[1] NWS, Weather related fatality and injury statistics, Available online at: https://www.weather.gov/hazstat/, 2020.
[2] E.R. Nielsen, G.R. Herman, R.C. Tournay, J.M. Peters, R.S. Schumacher, Double impact: when both tornadoes and flash floods threaten the same place at the same time, Weather Forecast. 30 (6) (2015) 1673–1693 Retrieved Feb 14, 2022, from. https://journals.ametsoc.org/view/journals/wefo/30/6/waf-d-15-0084_1.xml.
[3] E. Nielsen, R. Schumacher, Overlapping tornado and flash flood warnings for the US, in: Compound Wind and Water Hazards Embedded in Landfalling Hurricanes and Continental Convection, DesignSafe-CI, 2021, https://doi.org/10.17603/ds2-1vwk-rp47.
[4] J. Henderson, E.R. Nielsen, G.R. Herman, R.S. Schumacher, A hazard multiple: overlapping tornado and flash flood warnings in a national weather service forecast office in the southeastern United States, Weather Forecast. 35 (4) (2020) 1459–1481 Retrieved Feb 14, 2022, from. https://journals.ametsoc.org/view/journals/wefo/35/4/wafD190216.xml.
[5] NWS, May 2013 Oklahoma tornadoes and flash flooding, Available online at: https://www.weather.gov/media/publications/assessments/13oklahoma_tornadoes.pdf, 2014.
[6] NWS, August/september 2017 Hurricane Harvey, Available online at: https://www.weather.gov/media/publications/assessments/harvey6-18.pdf, 2018.
[7] K.D. Ash, M.J. Egnoto, S.M. Strader, W.S. Ashley, D.B. Roueche, K.E. Klockow-McClain, D. Caplen, M. Dickerson, Structural forces: perception and vulnerability factors for tornado sheltering within mobile and manufactured housing in Alabama and Mississippi, Weather, Climate Soc. 12 (3) (2020) 453–472, https://doi.org/10.1175/WCAS-D-19-0088.1.
[8] E. Gruntfest, J. Handmer (Eds.), Coping with Flash Floods, vol. 77, Springer Science & Business Media, 2001.
[9] T.W. Schmidlin, B. Hammer, J. Knabe, Tornado shelters in mobile home parks in the United States, J. Am. Soc. Prof. Emerg. Plann. 8 (2001) 1–15 Available online at: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.476.1644&rep=rep1&type=pdf.
[10] M. Špitalar, J.J. Gourley, C. Lutoff, P.E. Kirstetter, M. Brilly, N. Carr, Analysis of flash flood parameters and human impacts in the US from 2006 to 2012, J. Hydrol. 519 (2014) 863–870, https://doi.org/10.1016/j.jhydrol.2014.07.004.
[11] S.M. Strader, K. Ash, E. Wagner, C. Sherrod, Mobile home resident evacuation vulnerability and emergency medical service access during tornado events in the Southeast United States, Int. J. Disaster Risk Reduc. 38 (2019) 101210, https://doi.org/10.1016/j.ijdrr.2019.101210.
[12] B. Wisner, P. Blaikie, T. Cannon, I. Davis, At Risk: Natural Hazards, People's Vulnerability and Disasters, second ed., Routledge, London, 2004.
[13] S.T. Ashley, W.S. Ashley, Flood fatalities in the United States, J. Appl. Meteorol. Climatol. 47 (2008) 805–818, https://doi.org/10.1175/2007JAMC1611.1.
[14] R.E. Morss, J.K. Lazo, J.L. Demuth, Examining the use of weather forecasts in decision scenarios: results from a US survey with implications for uncertainty communication, Met. Apps 17 (2010) 149–162, https://doi.org/10.1002/met.196.
[15] B.K. Paul, Environmental Hazards and Disasters: Contexts, Perspectives and Management, John Wiley & Sons, 2011.
[16] K. Tierney, The Social Roots of Risk: Producing Disasters, Promoting Resilience, Stanford University Press, Stanford, 2014.
[17] S.M. Strader, W.S. Ashley, Finescale Assessment of mobile home tornado vulnerability in the central and Southeast United States, Weather, Climate Soc. 10 (4) (2018) 797–812 Retrieved Feb 14, 2022, from. https://journals.ametsoc.org/view/journals/wcas/10/4/wcas-d-18-0060_1.xml.
[18] J.M. First, K. Ellis, M.L. Held, F. Glass, Identifying risk and resilience factors impacting mental health among Black and latinx adults following nocturnal tornadoes in the U.S. Southeast, Int. J. Environ. Res. Publ. Health 18 (16) (2021) 8609, https://doi.org/10.3390/ijerph18168609.
[19] D.S. Mileti, P.W. O'Brien, Warnings during disaster: normalizing communicated risk, Soc. Probl. 39 (1992) 40–56.
[20] B. Fischhoff, Risk perception and communication unplugged: twenty years of Process 1, Risk Anal. 15 (2) (1995) 137–145, https://doi.org/10.1111/j.1539-6924.1995.tb00308.x.
[21] W.G. Peacock, S.D. Brody, W. Highfield, Hurricane risk perceptions among Florida's single family homeowners, Landsc. Urban Plann. 73 (2005) 120–135.
[22] M.K. Lindell, R.W. Perry, The protective action decision model: theoretical modifications and additional evidence, Risk Anal. 32 (2012) 616–632, https://doi.org/10.1111/j.1539-6924.2011.01647.x.
[23] Sherman-Morris, The public response to hazardous weather events: 25 Years of research, Geogr. Compass 7 (10) (2013) 669–685, https://doi.org/10.1111/gec3.12076.
[24] J.T. Ripberger, C.L. Silva, H.C. Jenkins-Smith, M. James, The influence of consequence-based messages on public responses to tornado warnings, Bull. Am. Meteorol. Soc. 96 (2015) 57–590, https://doi.org/10.1175/BAMS-D-13-00213.1.
[25] C.W. Trumbo, L. Peek, M.A. Meyer, H.L. Marlatt, E. Gruntfest, B.D. McNoldy, W.H. Schubert, A cognitive-affective scale for Hurricane risk perception, Risk Anal. 36 (2016) 2233–2246, https://doi.org/10.1111/risa.12575.
[26] J.E. Walters, L.R. Mason, K. Ellis, B. Winchester, Staying safe in a tornado: a qualitative inquiry into public knowledge, access, and response to tornado warnings, Weather Forecast. 35 (1) (2020) 67–81 Retrieved Feb 14, 2022, from. https://journals.ametsoc.org/view/journals/wefo/35/1/waf-d-19-0090.1.xml.
[27] L.R. Mason, K.N. Ellis, B. Winchester, S. Schexnayder, Tornado warnings at night, Weather, Climate Soc. 10 (3) (2018) 561–568. https://www.jstor.org/stable/26492319.
[28] B.F. Liu, J.D. Fraustino, Y. Jin, How disaster information form, source, type, and prior disaster exposure affect public outcomes: jumping on the social media bandwagon? J. Appl. Commun. Res. 43 (1) (2015) 44–65, https://doi.org/10.1080/00909882.2014.982685.
[29] S. Hoekstra, K. Klockow, R. Riley, J. Brotzge, H. Brooks, S. Erickson, A preliminary look at the social perspective of warn-on-forecast: preferred tornado warning lead time and the general public's perceptions of weather risks, Weather, Climate Soc. 3 (2) (2011) 128–140, https://doi.org/10.1175/2011WCAS1076.1.
[30] J.C. Senkbeil, D.A. Scott, P. Guinazu-Walker, M.S. Rockman, Ethnic and racial differences in tornado hazard perception, preparedness, and shelter lead time in tuscaloosa, Prof. Geogr. 66 (4) (2014) 610–620, https://doi.org/10.1080/00330124.2013.826562.
[31] R.W. Rogers, A protection motivation theory of fear appeals and attitude Change 1, J. Psychol. 91 (1) (1975) 93–114, https://doi.org/10.1080/00223980.1975.9915803.
[32] M. Bockarjova, L. Steg, Can Protection Motivation Theory predict pro-environmental behavior? Explaining the adoption of electric vehicles in The Netherlands, Global Environ. Change-hum. Pol. Dimens. 28 (2014) 276–288.

[33] D.M. Schultz, E.C. Gruntfest, M.H. Hayden, C.C. Benight, S. Drobot, L.R. Barnes, Decision making by Austin, Texas, residents in hypothetical tornado scenarios, Weather, Climate Soc. 2 (3) (2010) 249–254.

[34] K.D. Ash, A qualitative study of mobile home resident perspectives on tornadoes and tornado protective actions in South Carolina, USA, Geojournal 82 (3) (2017) 533–552. http://www.jstor.org/stable/26164350.

[35] S.M. Miran, C. Ling, A. Gerard, L. Rothfusz, The effect of providing probabilistic information about a tornado threat on people's protective actions, Nat. Hazards 94 (2) (2018) 743–758, https://doi.org/10.1007/s11069-018-3418-5.

[36] J.C. Senkbeil, K.N. Ellis, J.R. Reed, The influence of tornado activity, impact, memory, and sentiment on tornado perception accuracy among college students, Atmosphere 10 (12) (2019), https://doi.org/10.3390/atmos10120732.

[37] Renato Miceli, Igor Sotgiu, Michele Settanni, Disaster preparedness and perception of flood risk: a study in an alpine valley in Italy, J. Environ. Psychol. 28 (2) (2007) 164–173.

[38] R.E. Morss, J.L. Demuth, A. Bostrom, J.K. Lazo, H. Lazrus, Flash flood risks and warning decisions: a mental models study of forecasters, public officials, and media broadcasters in Boulder, Colorado, Risk Anal. 35 (11) (2015) 2009–2028, https://doi.org/10.1111/risa.12403.

[39] D. Burow, K. Ellis, L. Tran, Simultaneous and collocated tornado and flash flood (TORFF) warnings associated with tropical cyclones in the contiguous United States, Int. J. Climatol. 41 (2021) 4253–4264, https://doi.org/10.1002/joc.7071.

[40] W.S. Ashley, Spatial and temporal analysis of tornado fatalities in the United States: 1880–2005, Weather Forecast. 22 (2007) 1214–1228, https://doi.org/10.1175/2007WAF2007004.1.

[41] P.G. Dixon, A.E. Mercer, J. Choi, J.S. Allen, Tornado risk analysis: is dixie alley an extension of tornado alley? Bull. Am. Meteorol. Soc. 92 (4) (2011) 433–441 Retrieved Feb 14, 2022, from. https://journals.ametsoc.org/view/journals/bams/92/4/2010bams3102_1.xml.

[42] W.S. Ashley, S.M. Strader, Recipe for disaster: how the dynamic ingredients of risk and exposure are changing the tornado disaster landscape, Bull. Am. Meteorol. Soc. 97 (5) (2016) 767–786 Retrieved Feb 14, 2022, from. https://journals.ametsoc.org/view/journals/bams/97/5/bams-d-15-00150.1.xml.

[43] D. Sutter, K.M. Simmons, Tornado fatalities and mobile homes in the United States, Nat. Hazards 53 (1) (2010) 125–137, https://doi.org/10.1007/s11069-009-9416-x.

[44] S.L. Cutter, B.J. Boruff, W.L. Shirley, Social vulnerability to environmental hazards, Soc. Sci. Q. 84 (2003) 242–261.

[45] CDC Social Vulnerability Index, Available online at: https://www.atsdr.cdc.gov/placeandhealth/svi/documentation/SVI_documentation_2018.html.

[46] Barry E. Flanagan, Edward W. Gregory, Elaine J. Hallisey, Janet L. Heitgerd, Brian Lewis, A social vulnerability index for disaster management, J. Homel. Secur. Emerg. Manag. 8 (3) (2011), https://doi.org/10.2202/1547-7355.1792.

[47] C.T. Emrich, S.L. Cutter, Social vulnerability to climate-sensitive hazards in the southern United States, Weather, Climate Soc. 3 (3) (2011) 193–208, https://doi.org/10.1175/2011WCAS1092.1.

[48] Nielsen, Insights into Extreme Short-Term Precipitation Associated with Supercells and Mesovortices, ProQuest Dissertations Publishing, 2019.

[49] J.L. Demuth, R.E. Morss, J.K. Lazo, D.C. Hilderbrand, Improving effectiveness of weather risk communication on the NWS point-and-click web page, Weather Forecast. 28 (3) (2013) 711–726, https://doi.org/10.1175/WAF-D-12-00118.1.

[50] J. Pallant, SPSS Survival Manual - a Step by Step Guide to Data Analysis Using SPSS for Windows (Version 10), Buckingham Open University Press, 2001.

[51] H. Lazrus, R.E. Morss, J.L. Demuth, J.K. Lazo, A. Bostrom, Know what to do if you encounter a flash flood": mental models analysis for improving flash flood risk communication and public decision making, Risk Anal. 36 (2) (2016) 411–427, https://doi.org/10.1111/risa.12480.

[52] D.E. Nagele, J.E. Trainor, Geographic specificity, tornadoes, and protective action, Weather, Climate Soc. 4 (2) (2012) 145–155, https://doi.org/10.1175/WCAS-D-11-00047.1.

[53] R.B. Kline, Principles and Practice of Structural Equation Modeling, Guilford publications, 2015.

[54] K.J. Preacher, A.F. Hayes, Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models, Behav. Res. Methods 40 (3) (2008) 879–891, https://doi.org/10.3758/BRM.40.3.879.

[55] J. Hair, Multivariate Data Analysis: A Global Perspective, seventh ed., Prentice Hall, Upper Saddle River, 2009.

[56] D.L. Streiner, Building a better model: an introduction to structural equation modelling, Can. J. Psychiatr. 51 (5) (2006) 317–324, https://doi.org/10.1177/070674370605100507.

[57] R.W. Perry, M.K. Lindell, Volcanic risk perception and adjustment in a multi-hazard environment, J. Volcanol. Geoth. Res. 172 (3) (2008) 170–178, https://doi.org/10.1016/j.jvolgeores.2007.12.006.

[58] R.C. Bunker, A.E. Cohen, J.A. Hart, A.E. Gerard, K.E. Klockow-McClain, D.P. Nowicki, Examination of the predictability of nocturnal tornado events in the southeastern United States, Weather Forecast. 34 (2) (2019) 467–479, https://doi.org/10.1175/WAF-D-18-0162.1.

[59] K. Ellis, L.R. Mason, K. Hurley, In the dark: public perceptions of and national weather service forecaster considerations for nocturnal tornadoes in Tennessee, Bull. Am. Meteorol. Soc. 101 (10) (2020) E1677–E1684, https://doi.org/10.1175/BAMS-D-19-0245.1.

[60] T. Terpstra, Emotions, trust, and perceived risk: affective and cognitive routes to flood preparedness behavior, Risk Anal.: Off. Publ. Soc. Risk Anal. 31 (10) (2011) 1658–1675, https://doi.org/10.1111/j.1539-6924.2011.01616.x.

[61] I. Aguirre-Ayerbe, M. Merino, S.L. Aye, R. Dissanayake, F. Shadiya, C.M. Lopez, An evaluation of availability and adequacy of Multi-Hazard Early Warning Systems in Asian countries: a baseline study, Int. J. Disaster Risk Reduc. 49 (2020) 101749, https://doi.org/10.1016/j.ijdrr.2020.101749.

[62] J. Sutton, L. Fischer, M.M. Wood, Tornado warning guidance and graphics: implications of the inclusion of protective action information on perceptions and efficacy, Weather, Climate Soc. 13 (4) (2021) 1003–1014, https://doi.org/10.1175/WCAS-D-21-0097.1.

[63] S. De Angeli, B.D. Malamud, L. Rossi, F.E. Taylor, E. Trasforini, R. Rudari, A multi-hazard framework for spatial-temporal impact analysis, Int. J. Disaster Risk Reduc. (2022) 102829, https://doi.org/10.1016/j.ijdrr.2022.102829.