A Weather-Ready Nation for All? The Demographics of Severe Weather Understanding, Reception, and Response

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ABSTRACT: NOAA's National Weather Service (NWS) provides forecasts, warnings, and decision support to the public for the protection of life and property. The NWS Weather-Ready Nation model describes the process of applying weather information to achieve societal value. However, it is not clear how different racial and socioeconomic groups across the United States receive, understand, and act upon the weather information supplied under this model. There may be barriers that keep important, lifesaving information from the populations at the highest risk of severe weather impacts. This paper estimates the extent of racial and socioeconomic disparities in severe weather risk information reception, comprehension, response, and trust, as well as severe weather preparedness and risk perceptions in the United States. We use data from the University of Oklahoma's Severe Weather and Society Survey, which is annually completed by a sample of 3000 U.S. adults (age 18+) that is designed to match the characteristics of the U.S. population. We pool data over four years (2017–20) to provide reliable severe weather risk prevalence statistics for adults by race, ethnicity, and socioeconomic characteristics. As a robustness check, we supplement this information with data from the annual FEMA National Household Survey. We find that racial and socioeconomic groups receive, understand, trust, and act upon severe weather information differently. These findings suggest that NWS and their partners should adjust their communication strategies to ensure all populations receive and understand actionable severe weather information.

SIGNIFICANCE STATEMENT: It is crucial that severe weather risk communication is received, appropriately interpreted, and trusted by all communities—especially the most vulnerable. Past research has not explained how different racial and socioeconomic groups receive, understand, and act upon NWS forecasts and warnings. This study finds that racial and socioeconomic groups receive, understand, trust, and act upon severe weather information differently. Risk communication strategies should be adjusted to eliminate barriers that keep important, lifesaving information from vulnerable populations.

KEYWORDS: Climate services; Communications/decision-making; Decision support; Emergency preparedness; Societal impacts; Vulnerability

1. Introduction

In 2011, 550 people in the United States died because of tornadoes. In response, the National Oceanic and Atmospheric Administration (NOAA) held a national summit in Norman, Oklahoma, on 13 December 2011, with 175 participants from government, academia, industry, emergency management, the media, and nongovernmental organizations (Moore et al. 2012). The consensus that emerged was that all parties present needed to work together and better connect forecasts and warnings to decisions made by public safety officials, industries, and the public. This required a new level of relationship-building, education, and outreach before hazardous weather events, as well as new ways to communicate and deliver forecasts and warnings. NOAA created Weather-Ready Nation (WRN) as part of its National Weather Service (NWS) to answer this need.

The WRN vision is that communities across the nation should be ready, responsive, and resilient to hazardous weather and water events (Uccellini and Ten Hoeve 2019). This became the foundation of a new NWS strategy, which involves the NWS, America's weather industry, academia, nonprofit organizations, and federal, state, and local agencies involved in disaster response, working together to reduce the impact of extreme weather (Department of Commerce 2022). Over the last 10 years, NWS has made great strides in building relationships with core partners, including emergency managers, water resource managers, public safety officials, and the media.

NOAA recognizes that it cannot achieve a weather-ready nation alone. It takes the entire weather enterprise working together (academia, government, industry) to reach the diversity of sectors and publics in need of weather information. The Weather Research and Forecasting Innovation Act (Weather Act) of 2017 directs NOAA to use social and behavioral science to improve communication and delivery of preparedness, forecast, and warning information to the public, core partners, and vulnerable populations. Executive Order

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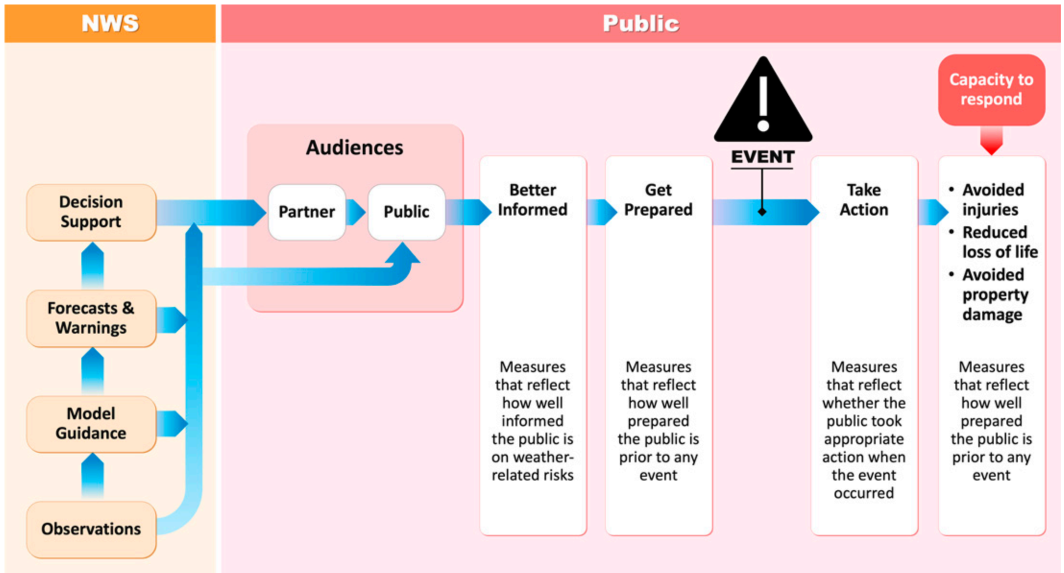

FIG. 1. The NWS Weather-Ready Nation logic model [the figure is adapted from Eastern Research Group (2016)].

13985, issued in 2021, goes further to mandate the federal government assess and improve the equity of government services (Executive Office of the President 2021).

The Weather-Ready Nation concept requires that the role of the NWS does not end at the provision of an observation, forecast, or warning. NWS provides Impact-Based Decision Support Services (IDSS; NWS 2020) before, during, and after extreme events (Uccellini and Ten Hoeve 2019). The Weather Act directed the NWS to increase IDSS to "state, local, and tribal emergency management agencies, and other agencies related to disaster management, to ensure a planned, coordinated, and effective preparedness and response effort." To fully meet the mission of protecting lives and property, the NWS must connect IDSSs to the needs of a wide array of decision-makers and must measure the societal outcomes that result from that interaction.

It is vital that different racial and socioeconomic groups across the United States receive, understand, and act on severe[1] weather information, and whether they do should shape policy decisions. Yet we know little about whether they do. This question is only becoming more urgent, as the nation experiences demographic shifts. According to the 2020 census, the Hispanic or Latinx population increased by more than 23% since 2010, making up more than 18% of the U.S. population. Accounting for a little more than 19 million, the Asian population is the fastest growing demographic group, growing more than 35% in the last decade, and is expected to reach more than 46 million by 2060 (U.S. Census Bureau 2021). Historically marginalized groups are disproportionately affected by climate change and its effects, including severe storms, hurricanes, flooding, and extreme heat (EPA 2021; Tripati et al. 2022).

Figure 1 presents a conceptual model used by NWS to depict how observations, forecasts, and warnings create societal value[2] as measured by avoided injuries, loss of life, and property damage caused by hazardous weather, adapted from Eastern Research Group (2016). The NWS observations, forecasts, and warnings rely on a complex system of observing infrastructure, numerical models, and computing resources. Trained meteorologists must analyze information and communicate it through multiple channels and to multiple audiences, from partners to the public, with varying levels of training and experience. As part of this process, NWS provides IDSS before, during, and after hazardous weather events (Uccellini and Ten Hoeve 2019). Before an event, these efforts improve understanding and comprehension of NWS products and services and help foster relationships between NWS personnel and local officials improving overall preparedness (Lazo et al. 2020). During the event, the NWS provides interpretative services by putting forecasts and warnings in historical context while helping government and community partners with real-time decision-making. Given the key role NWS partners play in a community's ability to respond appropriately to hazardous events, it is important that NWS cultivate partnerships that can reach all segments of society, including historically underserved or vulnerable populations. At the same time, NWS must also improve the effectiveness of its direct outreach and hazard communications to these communities.

The WRN logic model ties the entire weather value chain (observations, model guidance, forecasts and warnings, and

[1] We use the term "severe" to include both "extreme" and "severe" weather events, as compared with the typical meteorological definition, which only includes weather from mesoscale features such as thunderstorms or tornadoes.

[2] The weather enterprise contributes to these same societal outcomes through their own individual logic models, but for simplicity their contributions are not included.

decision support) to intermediate and long-term indicators of societal value (Fig. 1). Through decision support to partners and direct communication of forecasts and warnings to the public, the NWS aims to ensure the public's capacity to understand risks and respond appropriately in the face of extreme weather and water events (Fig. 1). The WRN logic model uses the following intermediate indicators to track this capacity:

- Better informed—Measures reflecting how well informed the public is about weather-related risks.
- Get prepared—Measures reflecting how well prepared the public is prior to any event.
- Take action—Measures reflecting whether or not the public took appropriate actions once an event occurs.

Individuals can take a range of actions in the face of an extreme event based on their socioeconomic status and personal level of risk, all of which can improve preparedness and response above a given baseline. To identify the actions and partnerships that will be most effective at targeting NWS efforts, we aim to identify which groups currently lack capacity to obtain, understand, and act on NWS information. Note that this logic model can be extended to the entire weather enterprise, since the weather enterprise is involved in all aspects of the weather value chain from observations to direct communication of forecasts to decision support. Many of the results presented in this paper are the result not just of NWS and NOAA efforts but of efforts of the enterprise as a whole. Over the years, the NWS has taken steps to build relationships with communities and community organizations at the local level that expand availability of NWS products and services to all Americans, regardless of their socioeconomic status or racial background. A network of NWS volunteers provides preparedness and forecast information in Spanish to offices across the country to use in their operations (Trujillo-Falcón et al. 2021). Local and national efforts are growing to provide services to the Deaf and Hard of Hearing Community (Saari et al. 2019; https://www.weather.gov/wrn/dhh-safety). The Flagstaff Weather Forecast Office developed a Navajo Nation weather dashboard on their website to provide IDSS specifically to this population (Panasiak et al. 2018; https://www.weather.gov/fgz/Dashboards). Another example involves the Metlakatla Indian Community in southeast Alaska, which experienced one of the worst drought periods in 2018/19 resulting in the loss of hydropower to the entire island impacting their electrical power generation, drinking water, fisheries, and forest health. The NWS Weather Forecast Office in Juneau, Alaska, provided weekly IDSS drought updates to the Mayor of Metlakatla for a full year, laying the groundwork for communication networks into tribal communities across southeast Alaska (https://www.weather.gov/media/wrn/NWS_Strategic_Plan_Status_Update_FY19-20.pdf). In addition, NWS local offices have built strong relationships with Pacific Island Nations, African American populations across the South, and urban homeless populations.

Yet, only recently has NWS begun to adapt its long-standing community engagement programs[3] to address equity more holistically (Department of Commerce 2022). For example, the NWS is in the process of establishing a cohesive Community Engagement Program (CEP) by restructuring existing programs to ensure historically underserved and socially vulnerable communities can access NWS data and services. Significant additional opportunities for progress on equity remain.

This paper examines how different racial and socioeconomic groups receive, understand, trust, and act upon severe weather information. This information may allow policy makers and weather services providers to address the barriers that keep preparedness, communication, and response information from certain vulnerable populations and better tailor their products and communication efforts.

Review of literature related to the equity of weather products and services

Inequality in information access may keep important, lifesaving information from certain populations that are more vulnerable to extreme weather and water events (Griego et al. 2020; Strader et al. 2021). Unequal environmental impacts have spurred a burgeoning climate justice literature that examines the interaction between extreme weather and water events and existing social and environmental inequalities (Smith and Wodajo 2022). Much of this literature focuses on recovery and support after hazardous weather (e.g., Emrich et al. 2019; McBride 2017; Méndez et al. 2020; Muñoz and Tate 2016; Thompson et al. 2017). The impacts of climate change are often unequal, disproportionately impacting populations who contributed least to the crisis (Watts et al. 2021). Racial and ethnic inequities have significant implications for the vulnerability and resiliency of communities to weather and water-related events (Herreros-Cantis et al. 2020; EPA 2021). Each of these vulnerable racial and ethnic groups have their own unique history, challenges, and opportunities associated with accessing, trusting, and acting on NWS information. To give a detailed account of each group is beyond the scope of this paper; however, we discuss several examples from the literature below.

In the United States, historic environmental racism practices such as redlining in relation to home loans, relegated many non-Whites to live in less desirable areas—including areas where industrial sites and highways have led to higher exposure to air pollutants, or to areas vulnerable to flooding. These areas also include urban core spaces or cities that are warmer due to urban heat islands that are created because of the proliferation of paved parking lots, asphalt roads, buildings, and the lack of green spaces. Most death from heatwaves occur in cities, and in their study of the 175 largest urbanized areas in the United States, Hsu et al. (2021) found that on average, non-White minorities live in a census tract with higher

[3] For example, the StormReady Communities Program, Skywarn Spotters Program, and the Weather-Ready Nation Ambassadors Program.

surface heat island intensity and are 2 times as likely to die from heatwaves and suffer heat-related illnesses.

People of color are also disproportionately exposed to extreme heat through their occupations. Noncitizen and Latinx migrants make up 50% and 75% of agricultural workers in the United States, respectively, and agricultural workers are 20 times as likely to die from heat-related illnesses as the average American worker (Castillo et al. 2021).

Inadequate language access is also a source of social vulnerability, leading to disproportionate damage and loss to populations with limited English proficiency in disaster (Xiang et al. 2021). This is critical, considering that more than 67 million people in the United States speak a language other than English at home (Zeigler and Camrota 2019). Post–Hurricane Katrina assessments have noted that many undocumented immigrants were unaware of the danger of Katrina and failed to evacuate in part because of limited English proficiency (Santos-Hernández 2006). In 2013, tornadoes in Oklahoma killed nine people from the Guatemalan community, and NWS acknowledges that a lack of warnings in Spanish may have contributed to their death. Trujillo-Falcón et al. (2022) surveyed a sample of U.S. English ($n = 1550$) and Spanish ($n = 1010$) speakers on their ability to accurately interpret the translations of weather watches and warnings in order to determine whether these translated products lead to linguistic disparities. In addition, they asked fluent Spanish speakers to evaluate the urgency of translations of weather watches and warnings. To enhance the impact of severe weather communications in multilingual environments, they recommend the NWS translate the meaning, not the words, of critical risk statements in weather products. In 2017, the Multimedia Assistance in Spanish (MAS) team was established in the southern region of the NWS and has since expanded to include Spanish-speaking staff from across the organization. This group assists with the Spanish translation of important communications. Additionally, the NWS has a second Spanish outreach team that translates fact sheets and preparedness materials. Both teams are composed of volunteers and have no dedicated resources. The NOAA service evaluations completed for Hurricanes Florence and Michael in 2018 recommend that translation resources were underutilized and that they should be used more effectively during significant weather events. In addition, the study suggests that these programs receive specific funding and be more officially structured (NWS 2020).

Maantay and Marko (2009) found that data aggregated by census tract can underestimate flood exposure for minority populations. Flooding risks are also more concentrated in metro areas, and those who live in the lowest lying areas and neighborhoods—without green space to absorb water—are often individuals with low wealth and who are non-White. Research has also identified several socioeconomic characteristics that are associated with challenges to extreme weather preparedness, communication, and response. For instance, Senkbeil et al. (2012) found that education, age, and race all influenced shelter-seeking behavior during severe storms. Phillips and Morrow (2007) identify several factors that influence weather warning reception including age, race and ethnicity, disability, occupation, immigration status, and the interaction of these factors. Schumann et al. (2018) developed a model of tornado warning reception that shows demographic variables and previous experience affect warning response. Social vulnerability data have helped to explain variances in death and property damage estimates due to flooding and tornadoes (Ashley et al. 2014; Ashley and Strader 2016; Strader and Ashley 2015; Tellman et al. 2020).

This study uses data from the University of Oklahoma's Severe Weather and Society Survey, which is an annual online survey that uses a sample of 3000 adults (age 18+) and is designed to match the demographic characteristics of the U.S. population as measured by the U.S. Census Bureau. The survey asks respondents numerous questions related to severe weather understanding, preparedness, comprehension, and response. For instance, Fig. 2 shows significant variation in respondents' perceived risk to severe weather segmented by race and ethnicity. Black respondents report they are more at risk than White respondents for extreme heatwaves (54% vs 45%), extreme rainstorms (46% vs 39%), floods (40% vs 26%), tornadoes (35% vs 25%), and hurricanes (34% vs 22%). Asian respondents report lower levels of perceived risk than White respondents for extreme heatwaves (37%) and extreme rainstorms (27%), but higher risk than White respondents for droughts (36%). Hispanics report significantly higher levels of perceived risk than non-Hispanics for every severe weather category but tornadoes.

Respondents were also asked to indicate their level of trust in severe weather information from various organizations and groups. Figure 3 shows that Black (72%) and Asian (67%) respondents have significantly lower levels of trust in the NWS than White respondents (77%). Similarly, Hispanics report significantly lower levels of trust in NWS (73%) than non-Hispanics (77%). However, Black and Hispanic respondents also report higher levels of trust in friends and family (41% and 37%, respectively) than White and non-Hispanics.

These microlevel data make it possible to examine how people perceive different weather hazards and how those perceptions vary across different regions with varying exposure levels, and they highlight the importance of understanding specific community characteristics for effective communication (Silva et al. 2019; Ripberger et al. 2019; Allan et al. 2020; Ripberger et al. 2020). We build on this foundation of research and offer actionable recommendations for NWS to improve service equity. As a robustness check, we also use recent data from FEMA's annual National Household Survey, finding similar results. Our analysis reveals important differences in how different demographic groups receive, understand, trust, and act upon severe weather information. Further study is needed to understand the roots of these issues (mechanisms) and how NWS and their local partners can most effectively address these differences.

The remainder of this paper is organized as follows: in the next section, we discuss the data and methods used for our analyses; the results are then presented and discussed. We conclude with a discussion of our findings and how they can be used to ensure important, lifesaving information reaches every person in the United States.

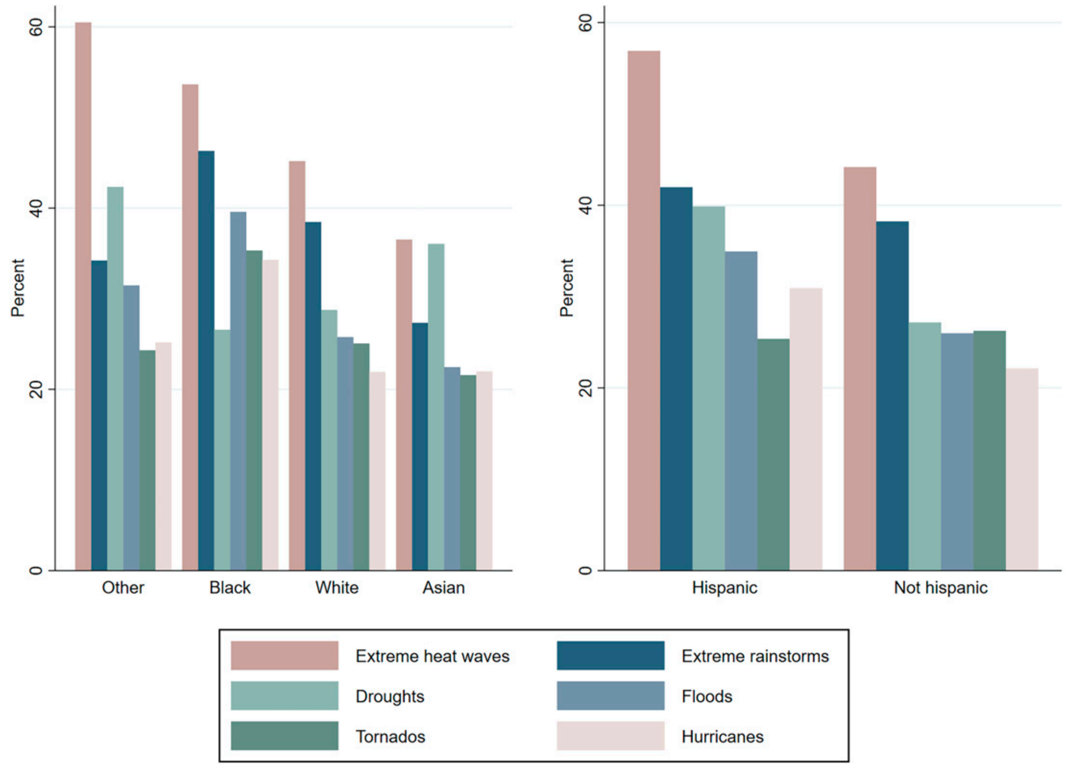

FIG. 2. Percentage of respondents that perceive severe weather risk for themselves and the people in their area, by race and ethnicity (data source: 2017–20 Severe Weather and Society Surveys).

2. Data and methods

To measure the public's capacity to respond to NWS information we use the 2017–20 waves of the Severe Weather and Society Survey (WX Survey) conducted by the University of Oklahoma, which is an annual online survey of adults. Respondent data are pooled over four years to ensure large enough sample sizes for reliable analyses of population groups. We supplement these data with FEMA's National Household Survey (NHS; FEMA 2021), for variables where questions from the NHS are similar to the WX Survey. The NHS tracks the American public's personal disaster preparedness, actions, attitudes, and motivations.

The WX Survey includes annual recurring questions that measure forecast and warning reception, comprehension, and response, and a rotating supplement that addresses important emerging topics in the weather community. The online questionnaire is completed each year by 3000 adults across the contiguous United States with a sample designed to match the demographic characteristics of the U.S. population. The internet survey company Qualtrics provides the sample of survey participants and uses a quota system to produce representative samples. The WX Survey provides consistent, transparent, and replicable measures that permit generalizable inference to the U.S. population (Ripberger et al. 2019).

The WX Survey is unique in its use of multiple questions that gauge reception, trust, comprehension, and response across different situations and events, which can decrease measurement error (Cohen et al. 1996; Ripberger et al. 2019). The first wave of the WX Survey in 2017 focused primarily on questions around tornado warning reception and response, but the survey has been expanded each year to include additional types of severe weather. While some WX Survey questions use a Likert scale—an ordered set of possible answers to each question—we construct binary versions of each dependent variable for simplicity in interpretation. While this allows us to present measures that are easily interpretable, some information is lost using this technique. As a sensitivity analysis, we explore the full-ordered responses in appendix D using multilevel ordered logistic models. The results are qualitatively similar to those using the binary measures.

a. Dependent variables

We use the intermediate capacity indicators from the WRN logic model to construct our dependent variables—namely, "better informed," "get prepared," and "take action"—to identify relevant survey questions from the dataset (see Table 1). See appendix A for a complete list of the survey questions associated with each WRN index.

b. Analysis samples

The survey began in 2017, focusing on tornado risk. As a result, there are typically larger sample sizes for the tornado-related

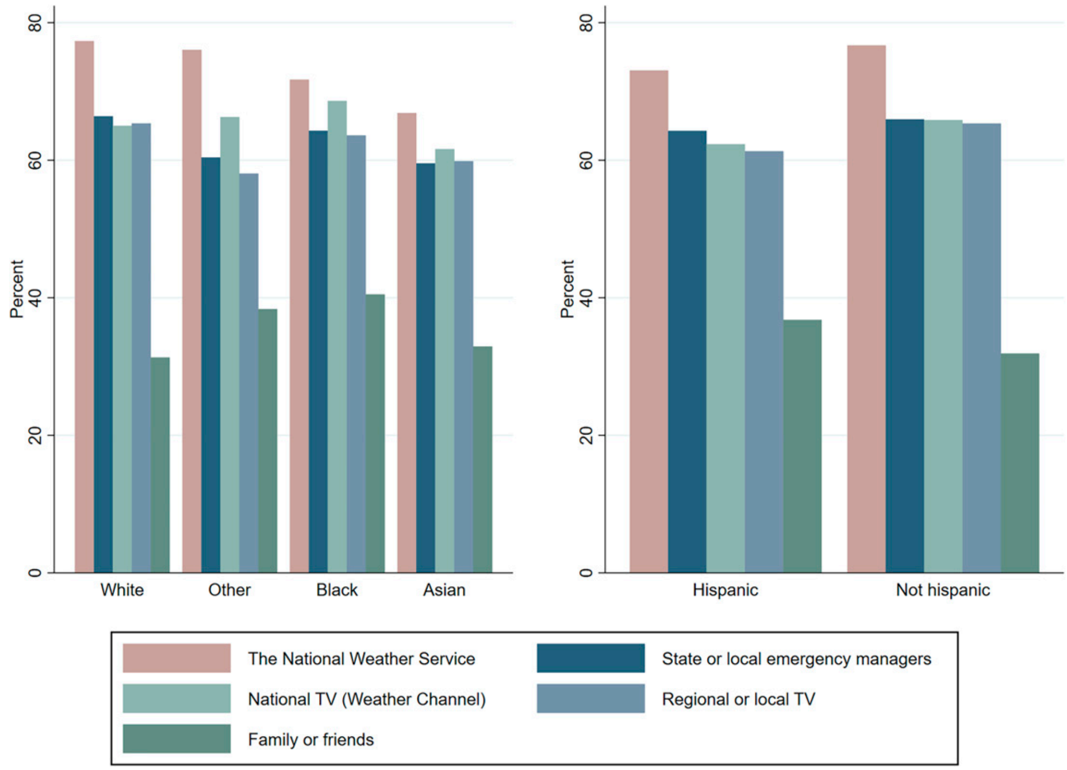

FIG. 3. Percentage of respondents that trust information about severe weather from various information sources, by race and ethnicity (data source: 2017–20 Severe Weather and Society Surveys).

measures. The objective comprehension, trust in information, and risk perception questions were asked in all four years, 2017–20. Tornado information reception, subjective risk comprehension, and weather response questions were asked in the years 2018–20, and weather information reception and risk perceptions were asked in 2019–20. To avoid comparing groups of respondents across different samples, we combined the samples of similarly themed survey questions: Severe weather information reception and tornado information reception responses are combined into a single sample, and the subjective comprehension and objective comprehension responses are combined into a single sample. We dropped observations for individuals who failed to provide valid information on one or more of the questions used to construct the dependent variables (i.e., dropped missing observations). Column 2 of Table 1 shows the original sample

TABLE 1. Analysis samples. Counts were calculated using sample-weighted individual-level data from the 2017–20 Severe Weather and Society Survey waves and the 2018–20 FEMA National Household Surveys.

Dependent variables	Survey years	Obs	Regression sample
Better informed			
Severe weather information reception			
Weather information reception	2019, 2020	5301	5082
Tornado information reception	2018, 2019, 2020	8735	5082
Severe weather information reception (FEMA)	2018, 2019, 2020	12 707	12 707
Severe weather comprehension			
Subjective comprehension	2018, 2019, 2020	8751	8320
Objective comprehension	2017, 2018, 2019, 2020	10 612	8320
Trust in weather sources	2017, 2018, 2019, 2020	10 574	10 341
Get prepared			
Severe weather preparedness	2019, 2020	5726	5612
Severe weather risk perceptions	2017, 2018, 2019, 2020	10 962	10 709
Severe weather preparedness (FEMA)	2018, 2019, 2020	12 957	12 957
Take action			
Severe weather response	2018, 2019, 2020	8328	8162

sizes for each group of measures. We pooled the 2017–20 WX Survey responses to ensure adequate sample sizes for analysis. We also dropped observations for individuals who failed to provide valid information on one or more of the questions used to construct the control variables. Column 3 shows our sample sizes for the regression analyses after dropping these missing values.[4]

c. *Better informed*

We study several different dimensions of "better informed," including the reception of information, comprehension of the information, and trust in the information.

1) SEVERE WEATHER INFORMATION RECEPTION

The WX Survey measures reception of information by trying to capture most circumstances surrounding severe weather information reception and encourages respondents to think about reception of information across multiple settings and times of day (Ripberger et al. 2019). We use two survey questions as the basis for our severe weather information reception measures: The first concerns the source of weather information and the frequency with which each source is used. The second asks specifically about the timeliness and reliability of tornado warning reception. We also examine similar questions from the FEMA NHS on preferred media sources and real-time warning reception (FEMA 2021).

2) SEVERE WEATHER SUBJECTIVE AND OBJECTIVE RISK COMPREHENSION

The WX Survey measures both subjective and objective comprehension of severe weather warnings. The *subjective* measure of severe weather warning comprehension uses multiple items that measure comprehension generally by asking participants if they recognize the difference between all types of watches and warnings, severe thunderstorm watches and warnings, and tornado watches and warnings. The survey also asks about respondents' understanding of maps and radar images, which are the principal tools that forecasters use when issuing tornado warnings (Ripberger et al. 2019). The *objective* comprehension measure uses test questions to gauge respondents' actual comprehension across multiple dimensions. The survey first asks about basic knowledge of the difference between tornado watches and warnings, but then goes into more detail, asking about average watch and warning lead times and the geography of watches and warnings. These dimensions are important because comprehension requires that severe weather warning recipients know what the risk is, where the risk is, and when to act if they want to reduce loss of life and property (Ripberger et al. 2019).

3) TRUST IN SEVERE WEATHER INFORMATION

We use one survey question that asks about the level of trust for different providers of weather information, including NWS, national television (TV), regional/local TV, state/local emergency managers, and family or friends.

d. *Get prepared*

1) SEVERE WEATHER PREPAREDNESS

The WX Survey contains several questions about preparedness, including questions about emergency supplies, plans for emergency situations and practices, or drills to respond to hazardous events. Similarly, the FEMA NHS has several questions about preparation, shelter options, emergency plans, supplies, and financial resources and respondents' confidence about their disaster preparedness.

2) SEVERE WEATHER RISK PERCEPTIONS

Last, we include questions related to respondents' self-rated risk for several types of hazardous weather events.

e. *Take action*

SEVERE WEATHER INFORMATION RESPONSE

The WX Survey measures tornado warning response by asking respondents to estimate how often they have taken protective action in response to past tornado warnings and how confident they are that they will take protective action in response to future tornado warnings in a variety of circumstances (Ripberger et al. 2019).

f. *Other control variables*

The WX Survey also collects information commonly considered determinants of severe weather information reception and response.[5] These variables capture demographic, socioeconomic, and geographic characteristics and are measured at the individual and household level. Specially, we include the following variables in our multivariate regression analyses:

- An indicator for whether the respondent is female.
- Age group of the respondent: 18–24 years (reference), 25–34, 35–44, 45–54, 55–64, and 64–100 years old.
- Indicators for whether the respondent is White (reference), Black, Asian, or other.
- An indicator for whether the respondent is Hispanic (ethnicity).
- Indicators for whether the respondent's highest education level is less than high school (reference), high school, some college, bachelor's degree, and postgraduate degree.
- Respondents' estimated total annual household income in quartiles: $0–$50,000 (reference), $50,000–$100,000, $100,000–$150,000, and $150,000 or more.
- Indicators for whether the respondent's current primary residence is located in an urban location in a densely populated area, suburban location in a neighborhood that is

[4] We do not apply survey weights for the regression analyses since we use the same control variables in each model that were used to calculate the sample weights.

[5] A description of the FEMA variables used is presented in appendix A.

TABLE 2. Severe weather information reception for linear fixed-effects models. One, two, and three asterisks indicate significance at the 0.10, 0.05, and 0.01 levels, respectively. Models were estimated using weighted individual-level data from the 2017–20 Severe Weather and Society Surveys. Standard errors are in parentheses. Reference categories are White, age group 18–24, less than high school education, less than $50,000 household income, and suburban location. Each model also includes CWA- and year-fixed effects.

Variables	Local TV	Cellphone applications	Nongovernment websites	Cable TV	Family, friends, or colleagues	Radio	Social media	Newspapers	Government websites
Female	−0.026** (0.013)	−0.012 (0.014)	−0.066*** (0.014)	−0.063*** (0.014)	0.036** (0.014)	−0.066*** (0.014)	0.014 (0.013)	−0.110*** (0.013)	−0.100*** (0.013)
Black	0.067*** (0.018)	0.043** (0.020)	−0.068*** (0.021)	0.089*** (0.021)	−0.013 (0.022)	0.034 (0.022)	0.009 (0.021)	0.050** (0.021)	0.041** (0.021)
Asian	−0.010 (0.028)	−0.024 (0.029)	−0.022 (0.030)	−0.089*** (0.031)	−0.060** (0.030)	−0.045 (0.031)	0.012 (0.029)	0.001 (0.030)	−0.048* (0.027)
Other	−0.023 (0.036)	0.022 (0.041)	0.022 (0.039)	−0.011 (0.040)	−0.019 (0.039)	−0.022 (0.041)	−0.003 (0.037)	0.023 (0.038)	0.002 (0.036)
Hispanic	0.046*** (0.018)	0.040** (0.019)	0.040** (0.019)	0.099*** (0.020)	0.042** (0.020)	0.064*** (0.020)	0.040** (0.020)	0.059*** (0.019)	0.059*** (0.019)
25–34	0.083*** (0.025)	0.040 (0.025)	0.046* (0.026)	0.034 (0.026)	−0.054** (0.025)	0.050* (0.026)	0.015 (0.026)	0.061** (0.024)	0.037 (0.025)
35–44	0.151*** (0.026)	0.064** (0.025)	0.025 (0.027)	0.084*** (0.027)	−0.065** (0.026)	0.061** (0.027)	−0.002 (0.027)	0.067*** (0.025)	0.042 (0.026)
45–54	0.170*** (0.026)	−0.010 (0.026)	−0.085*** (0.027)	−0.030 (0.027)	−0.205*** (0.026)	0.042 (0.028)	−0.226*** (0.027)	−0.040 (0.025)	−0.090*** (0.025)
55–64	0.211*** (0.025)	−0.101*** (0.027)	−0.118*** (0.027)	−0.035 (0.027)	−0.296*** (0.026)	−0.006 (0.027)	−0.361*** (0.025)	−0.054** (0.025)	−0.159*** (0.024)
65–102	0.284*** (0.024)	−0.215*** (0.026)	−0.169*** (0.027)	0.056** (0.027)	−0.371*** (0.025)	−0.078*** (0.027)	−0.391*** (0.025)	0.023 (0.025)	−0.212*** (0.023)
High school	0.137*** (0.049)	0.020 (0.050)	−0.006 (0.052)	−0.049 (0.050)	0.038 (0.048)	0.031 (0.051)	0.032 (0.049)	0.020 (0.043)	−0.014 (0.043)
Some college	0.128*** (0.049)	0.028 (0.049)	0.056 (0.051)	−0.032 (0.050)	0.073 (0.048)	0.057 (0.051)	−0.009 (0.049)	0.031 (0.043)	−0.013 (0.043)
Bachelor's degree	0.122** (0.049)	0.042 (0.049)	0.126** (0.051)	−0.062 (0.050)	0.057 (0.048)	0.110** (0.051)	−0.034 (0.049)	0.043 (0.043)	0.008 (0.043)
Postgraduate	0.140*** (0.049)	0.047 (0.049)	0.119** (0.051)	−0.039 (0.050)	0.071 (0.048)	0.122** (0.051)	0.024 (0.049)	0.065 (0.043)	0.062 (0.043)
$50,000–$100,000	0.037** (0.015)	0.073*** (0.017)	0.073*** (0.017)	0.079*** (0.017)	0.069*** (0.017)	0.090*** (0.017)	0.051*** (0.016)	0.084*** (0.016)	0.062*** (0.015)
$100,000–$150,000	0.040** (0.019)	0.086*** (0.021)	0.074*** (0.022)	0.063*** (0.022)	0.069*** (0.021)	0.082*** (0.022)	0.037* (0.020)	0.107*** (0.020)	0.086*** (0.020)
$150,000 or more	0.018 (0.023)	0.090*** (0.024)	0.139*** (0.024)	0.096*** (0.025)	0.117*** (0.024)	0.115*** (0.025)	0.049** (0.023)	0.165*** (0.024)	0.115*** (0.023)
Urban	0.047*** (0.014)	0.029* (0.016)	0.054*** (0.016)	0.050*** (0.016)	0.046*** (0.016)	0.069*** (0.016)	0.097*** (0.015)	0.125*** (0.016)	0.083*** (0.015)
Rural	−0.002 (0.018)	0.001 (0.020)	0.012 (0.020)	−0.016 (0.021)	−0.026 (0.020)	0.015 (0.021)	0.026 (0.018)	−0.011 (0.018)	0.006 (0.018)
CWA- and year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log likelihood	−2745.712	−3279.038	−3348.988	−3421.688	−3357.134	−3478.094	−2985.339	−3056.296	−2810.789
No. of obs	5082	5082	5082	5082	5082	5082	5082	5082	5082
R^2	0.083	0.088	0.102	0.089	0.119	0.077	0.198	0.121	0.151

TABLE 3. As in Table 2, but for tornado warning reception for linear fixed-effects models.

Variables	Receive most tornado warnings	Receive tornado warnings as soon as they are issued	Receive all tornado warnings
Female	0.007 (0.014)	0.019 (0.014)	0.019 (0.015)
Black	−0.030 (0.021)	−0.025 (0.022)	0.008 (0.022)
Asian	−0.146*** (0.029)	−0.076** (0.030)	−0.068** (0.030)
Other	−0.071* (0.039)	−0.076* (0.041)	0.037 (0.041)
Hispanic	−0.006 (0.020)	0.013 (0.020)	0.019 (0.020)
25–34	0.085*** (0.026)	0.058** (0.026)	0.071*** (0.026)
35–44	0.121*** (0.027)	0.104*** (0.027)	0.107*** (0.027)
45–54	0.126*** (0.027)	0.058** (0.027)	0.069** (0.027)
55–64	0.144*** (0.026)	0.085*** (0.027)	0.068** (0.028)
65–102	0.133*** (0.026)	0.035 (0.026)	0.036 (0.027)
High school	0.031 (0.051)	0.056 (0.051)	0.060 (0.051)
Some college	0.035 (0.051)	0.059 (0.051)	0.070 (0.051)
Bachelor's degree	0.054 (0.051)	0.054 (0.051)	0.057 (0.051)
Postgraduate	0.073 (0.051)	0.058 (0.051)	0.075 (0.051)
\$50,000–\$100,000	0.038** (0.016)	0.014 (0.017)	0.033* (0.017)
\$100,000–\$150,000	0.037* (0.022)	0.007 (0.022)	0.036 (0.022)
\$150,000 or more	0.084*** (0.024)	0.077*** (0.025)	0.096*** (0.025)
Urban	0.017 (0.016)	0.063*** (0.017)	0.058*** (0.017)
Rural	−0.002 (0.019)	0.028 (0.020)	0.012 (0.020)
CWA- and year-fixed effects	Yes	Yes	Yes
Log likelihood	−3251.174	−3411.174	−3485.013
No. of obs	5082	5082	5082
R^2	0.117	0.091	0.076

near a densely populated area (reference), or a rural location in a sparsely populated area.

We also include NWS County Warning Area (CWA)-fixed and year-fixed effects in our multivariate regression analyses to control for any policy changes and regional climate shocks.

3. Econometric methods

For the regression analyses of severe weather information reception and response, we estimate a series of parsimonious linear fixed-effects models to adjust for differences in demographic, socioeconomic, and geographic characteristics of respondents.[6] The models for severe weather information reception and response are as follows:

$$Y = f(\text{race, ethnicity, gender, age, education, household income, rurality}), \quad (1)$$

where Y is the binary dependent variable. The control variables in the model include race, ethnicity, gender, age groups, education level, household income, and rural, suburban, or urban location. We are interested in how these demographic characteristics are correlated with an individual's ability to be informed, prepared, and take action in response to weather-related hazards. We also include NWS CWA- and time-fixed effects, respectively. These allow us to control for heterogeneity across survey years, underlying policy differences across NWS warning areas, and any regional climate and/or economic shocks that may influence peoples' survey responses. Last, as a sensitivity analysis to the linear fixed-effects models, we also run a series of multilevel ordered logistic models using the full-ordered WX Survey responses (i.e., Likert-scale variables; see appendix D).

To conserve space, the descriptive statistics are included in appendix B.[7] These statistics represent the most detailed nationally representative information on severe weather information reception and response across racial, ethnic, and socioeconomic groups to date, allowing for better targeting of NWS communication and services.

[6] We use linear probability models instead of probit or logistic models on the binary outcome variables to avoid the incidental parameters problem with the fixed effects. For example, the incidental parameters problem can cause fixed effects probit and logistic models to produce biased estimates and standard errors (i.e., in nonlinear models, as the number of groups increases towards infinity, the number of estimated parameters increases at the same rate, which may produce inconsistent estimates). As a robustness check, we present a series of ordered logistic models in appendix D, finding similar results with both methods.

[7] We use poststratification survey sample weights provided by Ripberger et al. (2019) for the descriptive statistics to address minor imbalances from the Qualtrics quota samples in the geographic and demographic attributes of respondents. The survey weights are constructed by dividing the proportion of the target population that shares the demographic characteristics of each respondent (the population proportion) by the proportion of the sample that shares these characteristics (Ripberger et al. 2019). All descriptive statistics in this report were estimated by applying the survey weights to responses by the surveyed individuals.

TABLE 4. As in Table 2, but for severe weather risk comprehension for linear fixed-effects models.

Variables	Subjective comprehension: Understand difference between watches and warnings	Subjective comprehension: Understand severe thunderstorm watches and warnings	Subjective comprehension: Understand tornado watches and warnings	Subjective comprehension: Understand maps	Subjective comprehension: Understand radar images	Objective comprehension: Tornado watch or warning correct	Objective comprehension: Tornado watch size correct	Objective comprehension: Tornado warning time correct	Objective comprehension: Tornado watch time correct
Female	−0.007 (0.009)	−0.053*** (0.010)	−0.065*** (0.011)	−0.093*** (0.010)	−0.141*** (0.010)	0.003 (0.009)	−0.030*** (0.011)	−0.001 (0.010)	0.003 (0.010)
Black	−0.084*** (0.015)	−0.075*** (0.016)	−0.037** (0.017)	−0.121*** (0.016)	−0.126*** (0.017)	−0.084*** (0.016)	−0.046*** (0.017)	−0.100*** (0.014)	−0.047*** (0.015)
Asian	−0.156*** (0.022)	−0.172*** (0.023)	−0.166*** (0.023)	−0.147*** (0.023)	−0.153*** (0.023)	−0.087*** (0.022)	−0.055** (0.024)	−0.138*** (0.017)	−0.047** (0.019)
Other	−0.102*** (0.028)	−0.062** (0.029)	−0.082*** (0.031)	−0.075*** (0.029)	−0.089*** (0.030)	−0.023 (0.028)	0.000 (0.031)	−0.065*** (0.024)	−0.040 (0.025)
Hispanic	−0.042*** (0.013)	−0.010 (0.014)	−0.001 (0.015)	−0.005 (0.014)	0.014 (0.015)	−0.018 (0.014)	−0.054*** (0.016)	−0.021 (0.013)	−0.025* (0.013)
25–34	0.023 (0.018)	0.026 (0.019)	0.077*** (0.020)	−0.025 (0.018)	0.044** (0.019)	0.003 (0.019)	−0.007 (0.021)	0.042*** (0.016)	0.016 (0.017)
35–44	0.060*** (0.018)	0.062*** (0.019)	0.103*** (0.020)	−0.023 (0.018)	0.040** (0.020)	−0.021 (0.019)	−0.003 (0.021)	0.084*** (0.017)	0.034* (0.018)
45–54	0.083*** (0.017)	0.031 (0.019)	0.046** (0.020)	−0.028 (0.018)	0.030 (0.020)	0.069*** (0.018)	0.054** (0.021)	0.166*** (0.017)	0.039** (0.018)
55–64	0.108*** (0.017)	0.019 (0.019)	0.044** (0.020)	−0.067*** (0.018)	−0.011 (0.020)	0.097*** (0.018)	0.067*** (0.021)	0.172*** (0.017)	0.088*** (0.018)
65–102	0.115*** (0.016)	0.023 (0.019)	0.034* (0.020)	−0.060*** (0.018)	−0.043** (0.020)	0.103*** (0.018)	0.053*** (0.020)	0.134*** (0.017)	0.090*** (0.018)
High school	0.068 (0.041)	0.045 (0.044)	0.045 (0.045)	0.024 (0.043)	0.009 (0.043)	0.046 (0.042)	−0.013 (0.045)	−0.071* (0.040)	0.057 (0.036)
Some college	0.103** (0.041)	0.073* (0.043)	0.038 (0.045)	0.067 (0.043)	0.035 (0.042)	0.092** (0.041)	0.041 (0.045)	−0.067* (0.040)	0.044 (0.036)
Bachelor's degree	0.110*** (0.041)	0.047 (0.043)	0.008 (0.045)	0.088** (0.042)	0.043 (0.042)	0.104** (0.041)	0.042 (0.045)	−0.054 (0.040)	0.052 (0.036)
Postgraduate	0.135*** (0.041)	0.058 (0.043)	0.044 (0.045)	0.084** (0.043)	0.047 (0.042)	0.080* (0.041)	0.057 (0.045)	−0.067* (0.040)	0.049 (0.036)
$50,000–$100,000	0.024** (0.010)	0.033*** (0.012)	0.061*** (0.013)	0.041*** (0.012)	0.056*** (0.012)	0.016 (0.011)	0.035*** (0.013)	−0.004 (0.012)	−0.000 (0.012)
$100,000 or more	0.014 (0.012)	0.057*** (0.013)	0.100*** (0.014)	0.080*** (0.013)	0.085*** (0.014)	0.011 (0.013)	0.038** (0.015)	0.001 (0.013)	0.012 (0.014)
Urban	−0.007 (0.010)	0.023* (0.012)	0.038*** (0.012)	0.005 (0.011)	0.011 (0.012)	−0.061*** (0.011)	−0.063*** (0.013)	−0.058*** (0.011)	−0.037*** (0.011)
Rural	0.011 (0.012)	0.011 (0.014)	0.024 (0.015)	0.011 (0.014)	0.043*** (0.015)	−0.008 (0.013)	−0.003 (0.016)	0.020 (0.015)	−0.017 (0.015)
CWA- and year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log likelihood	−3467.899	−4856.053	−5287.590	−4501.085	−5045.832	−4349.120	−5802.245	−4550.891	−4730.633
No. of obs	8320	8320	8320	8320	8320	8320	8320	8320	8320
R^2	0.069	0.064	0.093	0.070	0.090	0.063	0.052	0.103	0.048

TABLE 5. As in Table 2, but for trust in weather sources for linear fixed-effects models.

Variables	NWS	State or local emergency managers	National TV (Weather Channel)	Regional or local TV	Family or friends
Female	0.030*** (0.009)	0.026*** (0.010)	0.055*** (0.010)	0.020** (0.010)	−0.009 (0.009)
Black	−0.058*** (0.014)	−0.038** (0.015)	0.023 (0.014)	−0.024 (0.015)	0.029* (0.015)
Asian	−0.082*** (0.020)	−0.056*** (0.021)	−0.019 (0.020)	−0.026 (0.021)	0.005 (0.020)
Other	−0.020 (0.023)	−0.033 (0.025)	−0.009 (0.025)	−0.025 (0.025)	−0.001 (0.024)
Hispanic	−0.021* (0.012)	−0.009 (0.014)	−0.009 (0.014)	−0.003 (0.014)	0.025* (0.014)
25–34	0.009 (0.017)	−0.016 (0.018)	−0.025 (0.018)	0.001 (0.018)	0.027 (0.018)
35–44	0.058*** (0.017)	0.028 (0.018)	0.048** (0.018)	0.078*** (0.019)	0.063*** (0.019)
45–54	0.092*** (0.017)	0.038** (0.018)	0.051*** (0.018)	0.111*** (0.018)	−0.038** (0.018)
55–64	0.132*** (0.016)	0.076*** (0.018)	0.101*** (0.018)	0.168*** (0.018)	−0.056*** (0.018)
65–102	0.157*** (0.016)	0.077*** (0.018)	0.118*** (0.018)	0.160*** (0.018)	−0.106*** (0.017)
High school	0.017 (0.032)	−0.010 (0.034)	0.009 (0.034)	0.048 (0.034)	−0.004 (0.034)
Some college	0.052 (0.032)	0.031 (0.034)	0.026 (0.034)	0.052 (0.034)	−0.034 (0.034)
Bachelor's degree	0.092*** (0.032)	0.033 (0.035)	0.065* (0.034)	0.073** (0.035)	−0.052 (0.035)
Postgraduate	0.078** (0.032)	0.034 (0.035)	0.040 (0.034)	0.059* (0.035)	−0.045 (0.035)
$50,000–$100,000	0.017 (0.010)	0.023** (0.012)	0.021* (0.011)	0.033*** (0.011)	0.007 (0.011)
$100,000 or more	0.029** (0.012)	0.032** (0.013)	0.021* (0.013)	0.032** (0.013)	0.008 (0.013)
Urban	0.034*** (0.010)	0.046*** (0.011)	0.051*** (0.011)	0.047*** (0.011)	0.085*** (0.011)
Rural	−0.015 (0.012)	−0.019 (0.014)	−0.030** (0.014)	−0.015 (0.014)	0.012 (0.013)
CWA- and year-fixed effects	Yes	Yes	Yes	Yes	Yes
Log likelihood	−5568.572	−6823.375	−6783.930	−6768.931	−6566.547
No. of obs	10 341	10 341	10 341	10 341	10 341
R^2	0.049	0.029	0.044	0.052	0.049

4. Results

We find that several racial and socioeconomic characteristics are correlated with the probability of being informed, prepared, and able to take action during hazardous weather events. We do not attempt to account for potential endogeneity; therefore, causality cannot be inferred without strong assumptions. However, understanding these correlations is a first step in understanding the differences in severe weather information reception and response across differing populations in the United States.

a. Better informed

1) BEING INFORMED: SEVERE WEATHER INFORMATION RECEPTION

Table 2 shows that demographic characteristics have an effect on the source of weather information gathered by individuals. After controlling for other demographic, socioeconomic, and geographic characteristics, we find a statistically significant difference between Black respondents and their White counterparts: Black respondents are more likely to get weather information from local TV, cellular telephone (cellphone) applications, and cable TV (6.7, 4.3, and 8.9 percentage points, respectively). Black respondents are also 6.8 percentage points less likely than White respondents to get their weather information from nongovernment websites. Similarly, Asian respondents are 8.9 and 6.0 percentage points less likely than Whites to get their weather information from cable TV and friends and family, respectively. Black respondents are more likely than Whites to get weather information from newspapers and government websites. Similarly, Hispanics are more likely to get weather information from every source, when compared with non-Hispanics.

In checking the sensitivity of the WX Survey results, it is seen that the FEMA data similarly showed that Black and Hispanic respondents are more likely to get weather information from television and weather channels (see Table C1 in appendix C for results). FEMA data also showed that Black respondents are less likely than White respondents to get weather information from nongovernmental internet sources and social media. Overall, the FEMA results showed similar relationships to the WX Survey results.

Gender had a small but significant effect on the likely source of weather information. Women are less likely than men to get weather information from local TV, nongovernment websites, cable TV; but more likely than men to get their weather information from family, friends, or colleagues. Women are less likely than men to get weather information from radio, social media, and newspapers. Age correlates with likelihood of getting weather information from local and cable TV, and declining likelihood of getting weather information from websites (government and nongovernment), social media, and family or friends. Specifically, adults 65–100 years old are 39 percentage points less likely to get weather information from social media than those who are 18–24 years old. Other weather sources have a nonlinear relationship with age. For example, middle-aged respondents use cellphone applications and radio more than both 18–24-year-olds and adults from 65 to 100.

FEMA data similarly showed that women are more likely to get information from friends and family and social media,

TABLE 6. As in Table 2, but for severe weather risk perceptions for linear fixed-effects models.

Variables	At risk for extreme heatwaves	At risk for extreme rainstorms	At risk for droughts	At risk for floods	At risk for hurricanes	At risk for tornadoes
Female	0.048*** (0.009)	0.022** (0.009)	0.016** (0.008)	0.013 (0.008)	−0.024*** (0.007)	−0.002 (0.008)
Black	0.051*** (0.015)	0.035** (0.015)	0.014 (0.013)	0.072*** (0.014)	0.053*** (0.013)	0.046*** (0.014)
Asian	−0.095*** (0.020)	−0.068*** (0.019)	−0.042** (0.018)	−0.014 (0.018)	0.032* (0.017)	0.009 (0.018)
Other	0.068*** (0.023)	0.014 (0.023)	0.016 (0.022)	0.026 (0.022)	0.048*** (0.019)	0.033 (0.021)
Hispanic	0.013 (0.014)	0.029** (0.013)	−0.003 (0.013)	0.043*** (0.013)	0.025** (0.011)	0.019 (0.012)
25–34	0.073*** (0.017)	0.022 (0.018)	0.054*** (0.015)	0.024 (0.017)	0.046*** (0.015)	0.053*** (0.016)
35–44	0.072*** (0.018)	0.022 (0.018)	0.093*** (0.016)	0.039** (0.017)	0.054*** (0.015)	0.070*** (0.016)
45–54	0.073*** (0.018)	0.010 (0.018)	0.069*** (0.015)	−0.068*** (0.017)	−0.034** (0.014)	−0.004 (0.016)
55–64	0.067*** (0.017)	−0.018 (0.018)	0.062*** (0.015)	−0.074*** (0.016)	−0.025* (0.014)	−0.010 (0.016)
65–102	−0.009 (0.017)	−0.095*** (0.017)	0.008 (0.015)	−0.155*** (0.016)	−0.053*** (0.013)	−0.056*** (0.015)
High school	−0.002 (0.034)	0.022 (0.033)	0.035 (0.028)	0.006 (0.030)	0.002 (0.027)	0.043 (0.029)
Some college	0.010 (0.034)	0.012 (0.033)	0.025 (0.028)	0.011 (0.030)	−0.024 (0.027)	0.017 (0.029)
Bachelor's degree	0.005 (0.034)	0.020 (0.033)	0.037 (0.028)	0.019 (0.030)	−0.010 (0.028)	0.014 (0.029)
Postgraduate	−0.003 (0.034)	0.033 (0.033)	0.048* (0.028)	0.038 (0.030)	0.004 (0.028)	0.044 (0.029)
$50,000–$100,000	−0.002 (0.011)	0.013 (0.011)	0.018* (0.010)	−0.013 (0.010)	0.021** (0.008)	0.018* (0.010)
$100,000 or more	−0.021* (0.013)	−0.003 (0.013)	0.028** (0.011)	−0.010 (0.011)	0.036*** (0.010)	0.038*** (0.011)
Urban	0.029*** (0.011)	0.017 (0.011)	0.024** (0.010)	0.056*** (0.010)	0.057*** (0.009)	0.046*** (0.010)
Rural	−0.022* (0.013)	−0.002 (0.014)	0.023** (0.012)	−0.010 (0.012)	−0.003 (0.010)	0.012 (0.012)
CWA- and year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Log likelihood	−6856.117	−7011.954	−5621.711	−5930.168	−4090.620	−5542.611
No. of obs	10 718	10 718	10 718	10 718	10 718	10 718
R^2	0.155	0.088	0.208	0.104	0.304	0.154

and less likely from the internet and radio (Table C1 in appendix C). FEMA data also showed that respondents are more likely with age to get their information from television and newspapers, and less likely from social media and the internet.

Gathering weather information from all sources increases monotonically with household income—that is, the richer you are, the more likely you are to gather weather information from every source. Urbanites were also more likely to use every source than suburbanites.

2) Being informed: Tornado warning reception

After controlling for other characteristics, there are no statistical differences between Black and Hispanic respondents from White and non-Hispanic respondents, respectively, in terms of receiving timely tornado warnings (Table 3). However, Asian and other respondents are 14.6% and 7.1% less likely to receive most tornado warnings than White respondents.

Respondents are more likely to receive tornado warnings as they age and with additional income. And while we cannot distinguish differences between suburban and rural areas from zero, urban respondents are 6.3 and 5.8 percentage points more likely than suburban residents to receive tornado warnings as soon as they are issued and receive all tornado warnings, respectively.

Black, Asian, and Hispanic respondents also rated themselves less likely than White and non-Hispanic respondents, respectively, to receive real-time tornado alerts and warnings in the FEMA survey data (Table C2 in appendix C). The FEMA data also showed a similar age effect, where tornado warning reception increases with age.

3) Being informed: Severe weather subjective and objective risk comprehension

People must not only receive weather warnings, but also understand those warnings, to be considered informed. The next set of results (Table 4) explores what the data tell us about how demographic characteristics correlate with weather warning comprehension. Black respondents are less likely than White respondents to report that they understand the differences between watches and warnings, understand severe thunderstorm watches and warnings, understand tornado watches and warnings, understand maps, and understand radar images, respectively. Similarly, Asian respondents are less likely than Whites to think they understand each of the subjective comprehension measures. Hispanic respondents are 4.2 percentage points less likely to feel they understand the differences between watches and warnings than non-Hispanics.

Women are much less confident than men in their ability to understand severe thunderstorm watches and warnings, tornado watches and warnings, maps, and radar images. Older respondents have more confidence in their ability to understand the differences between tornado watches and warnings than younger respondents, but their subjective understanding of maps and radar images is lower than younger respondents'.

Subjective comprehension of each risk category increases with household income. Urban respondents have higher subjective comprehension of severe thunderstorm watches and warnings and tornado watches and warnings than suburban

TABLE 7. As in Table 2, but for severe weather preparedness for linear fixed-effects models.

Variables	Small supply kit	Specific plan	Disaster supply kit	Specific meeting place	Practiced or drilled plan
Female	−0.019 (0.013)	−0.020 (0.013)	−0.031** (0.013)	−0.022* (0.012)	−0.032*** (0.012)
Black	−0.018 (0.021)	0.029 (0.021)	0.015 (0.020)	0.042** (0.020)	0.044** (0.020)
Asian	−0.069** (0.028)	−0.078*** (0.026)	−0.037 (0.028)	−0.082*** (0.024)	−0.054** (0.024)
Other	0.028 (0.038)	0.021 (0.037)	0.019 (0.038)	0.047 (0.036)	0.006 (0.034)
Hispanic	0.041** (0.019)	0.050*** (0.019)	0.064*** (0.019)	0.036* (0.018)	0.014 (0.018)
25–34	0.005 (0.025)	−0.014 (0.024)	0.041* (0.024)	−0.030 (0.024)	−0.006 (0.024)
35–44	0.039 (0.026)	0.042* (0.026)	0.093*** (0.025)	0.013 (0.025)	0.003 (0.025)
45–54	−0.021 (0.025)	−0.046* (0.025)	0.016 (0.024)	−0.084*** (0.024)	−0.091*** (0.023)
55–64	0.009 (0.025)	−0.041* (0.025)	0.028 (0.025)	−0.085*** (0.024)	−0.136*** (0.023)
65–102	−0.062** (0.024)	−0.070*** (0.024)	−0.019 (0.024)	−0.149*** (0.023)	−0.148*** (0.022)
High school	−0.009 (0.047)	−0.039 (0.047)	0.051 (0.043)	0.067* (0.040)	−0.015 (0.041)
Some college	0.016 (0.047)	−0.023 (0.046)	0.067 (0.043)	0.057 (0.039)	−0.009 (0.041)
Bachelor's degree	0.031 (0.047)	−0.055 (0.047)	0.068 (0.043)	0.043 (0.039)	−0.018 (0.041)
Postgraduate	0.058 (0.047)	0.009 (0.047)	0.082* (0.043)	0.089** (0.040)	0.041 (0.041)
$50,000–$100,000	0.052*** (0.016)	0.054*** (0.015)	0.047*** (0.015)	0.029** (0.014)	0.041*** (0.014)
$100,000 or more	0.042** (0.018)	0.086*** (0.018)	0.048*** (0.017)	0.082*** (0.017)	0.050*** (0.016)
Urban	0.036** (0.015)	0.036** (0.015)	0.044*** (0.015)	0.040*** (0.014)	0.051*** (0.014)
Rural	0.025 (0.019)	0.009 (0.018)	0.029 (0.018)	0.004 (0.017)	0.019 (0.017)
CWA- and year-fixed effects	Yes	Yes	Yes	Yes	Yes
Log likelihood	−3699.005	−3572.782	−3526.420	−3227.700	−3051.978
No. of obs	5612	5612	5612	5612	5612
R^2	0.063	0.055	0.077	0.067	0.079

respondents; rural respondents have higher subjective comprehension than suburban respondents of radar images.

The WX Survey also tested respondents' *objective* comprehension, by asking questions about the ability to correctly interpret the definitions of tornado watches and warnings. Relative to Whites, Black respondents are less likely to correctly interpret the tornado watch or warning experiment, tornado watch size experiment, tornado warning time experiment, and tornado watch time experiment. Asian respondents are also less likely than Whites to answer each of

TABLE 8. As in Table 2, but for tornado warning response for linear fixed-effects models.

Variables	Take protective action	If you are at work or school	If you are with a small group	If you are with a large group	If you are at a store	If you are in a car	If you are sleeping
Female	0.027** (0.011)	−0.002 (0.008)	0.010 (0.009)	0.007 (0.009)	−0.007 (0.010)	−0.034*** (0.010)	0.001 (0.011)
Black	0.009 (0.018)	−0.007 (0.013)	−0.000 (0.013)	−0.001 (0.013)	0.019 (0.014)	0.022 (0.015)	0.039** (0.017)
Asian	−0.008 (0.024)	−0.036* (0.019)	−0.046** (0.019)	−0.034* (0.019)	−0.080*** (0.022)	−0.115*** (0.023)	−0.094*** (0.024)
Other	−0.093*** (0.031)	−0.006 (0.025)	−0.016 (0.025)	−0.016 (0.026)	−0.050* (0.028)	−0.043 (0.029)	−0.041 (0.032)
Hispanic	0.021 (0.016)	−0.011 (0.012)	0.005 (0.012)	0.009 (0.012)	−0.005 (0.014)	0.004 (0.014)	0.035** (0.016)
25–34	0.069*** (0.021)	0.066*** (0.017)	0.067*** (0.016)	0.055*** (0.017)	0.056*** (0.018)	0.035* (0.019)	0.089*** (0.021)
35–44	0.122*** (0.022)	0.076*** (0.017)	0.079*** (0.017)	0.088*** (0.017)	0.082*** (0.019)	0.057*** (0.019)	0.109*** (0.021)
45–54	0.024 (0.022)	0.090*** (0.017)	0.075*** (0.017)	0.072*** (0.017)	0.059*** (0.019)	0.048** (0.019)	0.036* (0.022)
55–64	0.038* (0.022)	0.072*** (0.017)	0.064*** (0.017)	0.065*** (0.018)	0.050*** (0.019)	0.036* (0.019)	0.017 (0.021)
65–102	0.031 (0.021)	0.055*** (0.016)	0.049*** (0.016)	0.048*** (0.017)	0.048*** (0.018)	0.026 (0.019)	−0.019 (0.021)
High school	0.040 (0.044)	0.046 (0.039)	0.068* (0.038)	0.016 (0.037)	0.101** (0.042)	0.085** (0.042)	0.037 (0.044)
Some college	0.004 (0.044)	0.069* (0.038)	0.068* (0.038)	0.026 (0.037)	0.086** (0.042)	0.079* (0.042)	−0.003 (0.044)
Bachelor's degree	0.018 (0.044)	0.082** (0.038)	0.072* (0.038)	0.041 (0.037)	0.103** (0.042)	0.078* (0.042)	−0.022 (0.044)
Postgraduate	0.041 (0.044)	0.071* (0.038)	0.067* (0.038)	0.024 (0.037)	0.098** (0.042)	0.081* (0.042)	−0.008 (0.044)
$50,000–$100,000	0.030** (0.014)	0.027*** (0.010)	0.015 (0.010)	0.009 (0.011)	0.002 (0.012)	0.024** (0.012)	0.040*** (0.014)
$100,000 or more	0.053*** (0.015)	0.040*** (0.011)	0.013 (0.011)	0.002 (0.012)	0.008 (0.013)	0.016 (0.013)	0.069*** (0.015)
Urban	0.029** (0.013)	0.017* (0.010)	0.008 (0.010)	0.009 (0.010)	0.024** (0.011)	0.024** (0.011)	0.044*** (0.013)
Rural	0.026 (0.017)	−0.007 (0.012)	−0.014 (0.012)	−0.012 (0.013)	−0.004 (0.014)	0.004 (0.014)	−0.001 (0.017)
CWA- and year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log likelihood	−5754.182	−3206.629	−3257.057	−3658.059	−4400.177	−4546.641	−5718.510
No. of obs	8162	8162	8162	8162	8162	8162	8162
R^2	0.038	0.035	0.025	0.023	0.027	0.031	0.040

TABLE A1. Dependent and explanatory variables. Data are from the 2017–20 Severe Weather and Society Surveys.

WRN model category	Binary dependent variables	Survey question and description
Better informed		
	Severe weather information reception	
	Weather information reception (WX-Survey)	
	Local TV	How frequently do you get information about the weather from each of the following sources?
	Cellphone applications	Possible answers: a) never, b) less than once per week, c) about once per week, d) several times per week, e) about once per day, or f) several times per day; we construct a series of binary variables that equal 1 if the respondent reported "at least once per week" or more frequently for each question
	Nongovernment websites	
	Cable TV	
	Family, friends, or colleagues	
	Radio	
	Government websites	
	Social media	
	Newspapers	
	Tornado information reception (WX-Survey)	
	You receive most tornado warnings	Please tell us how strongly you agree with the following statements about tornado warnings: 1) you receive most tornado warnings, 2) you receive tornado warnings as soon as they are issued, and 3) you receive all tornado warnings
	You receive tornado warnings as soon as they are issued	
	You receive all tornado warnings	
		Possible answers: a) strongly disagree, b) disagree, c) neither disagree nor agree, d) agree, or e) strongly agree; we construct a series of binary variables that equal 1 if the respondent reported agree or strongly agree to each of the questions
	Severe weather information reception (FEMA NHS)	
	TV, TV news, weather channels	How did you get the information that you read, saw, or heard about getting better prepared for a disaster?
	Internet	Possible answers for each question: a) yes or b) no; we construct a series of binary variables that equal 1 if the respondent reported yes to each of the questions
	Newspapers	
	Conversation with others	
	Brochure, pamphlet, flyers	
	Provided by employer, at work	
	Public service announcement	
	Commercial on TV/radio	
	Utility company or other business	
	An event or training	
	Social media	
	Real-time alerts and warnings	
	Information about how to prepare	
	Severe weather comprehension	
	Subjective risk comprehension (WX-Survey)	Now we have some questions about the NWS, an agency of the United States government that issues weather forecasts and different kinds of alerts to the public about hazardous weather, including severe weather watches and warnings
	Do you understand the difference between watches and warnings?	1. In general, do you understand the difference between watches and warnings?
	Do you understand severe thunderstorm watches and warnings?	2. Do you understand severe thunderstorm watches and warnings?
	Do you understand tornado watches and warnings?	3. Do you understand tornado watches and warnings?
	Do you understand maps?	4. Do you understand maps?
	Do you understand radar images?	5. Do you understand radar images?
		Possible answers: a) definitely no, b) probably no, c) not sure, d) probably yes, or e) definitely yes; we construct a series of binary variables that is equal to 1 if the respondent reported probably or definitely yes to each of the questions

TABLE A1. (*Continued*)

WRN model category	Binary dependent variables	Survey question and description
	Objective risk comprehension (WX-Survey)	
	Tornado watch or warning experiment	1. The next few test questions focus on severe thunderstorms and tornadoes—they may be relatively rare in your area, but severe thunderstorms and tornadoes can happen in every state; to the best of your knowledge, is the following alert considered a tornado watch or a warning?
	Tornado watch size experiment	a. This alert is issued when severe thunderstorms and tornadoes are possible in and near the area; it does not mean that they will occur, it only means they are possible
	Tornado warning time experiment	b. This alert is used when a tornado is imminent; when this alert is issued, seek safe shelter immediately
	Tornado watch time experiment	2. If the National Weather Service issues a tornado warning for your area, how much time do you have before the tornado arrives? a. You indicated that there is less than 1 hour between when tornado warnings are issued and when tornadoes arrive; to the best of your knowledge, how many minutes are there between when tornado warnings are issued and when tornadoes arrive? 3. If the National Weather Service issues a tornado watch for your area, how much time do you have before the tornado arrives? a. You indicated that there is 1 to 24 hours between when tornado watches are issued and when tornadoes arrive; to the best of your knowledge, how many hours are there between when tornado watches are issued and when tornadoes arrive? We construct four binary variables that equal 1 if the respondent got each of the test questions correct
	Trust in weather information sources measures (WX-Survey)	
	The National Weather Service Regional or local TV	Extreme weather can be dangerous and technically complex, so getting information you can trust is important; please indicate your level of trust in information about extreme weather from each of the following organizations and groups
	National TV (Weather Channel) State or local emergency managers Family or friends	Possible answers: a) no trust, b) low trust, c) moderate trust, d) high trust, or e) complete trust; we construct a binary variable that is equal to 1 if the respondent reported high trust or complete trust
Get prepared		
	Severe weather preparedness (WX-Survey)	We construct a series of binary variables that equal 1 if the respondent reported yes for the following questions:
	Prepared a small kit with emergency supplies	In the last year, have you prepared a small kit with emergency supplies that you keep at home, in your car or where you work to take with you if you had to leave quickly?
	Made a specific plan	In the last year, have you made a specific plan for how you and your family would communicate in an emergency situation if you were separated?
	Prepared a disaster supply kit	In the last year, have you prepared a disaster supply kit with emergency supplies like water, food and medicine that is kept in a designated place in your home?
	Established a specific meeting place	In the last year, have you established a specific meeting place to reunite in the event you and your family cannot return home or are evacuated?
	Practiced or drilled on what to do in an emergency	In the last year, have you practiced or drilled on what to do in an emergency at home?
	Subjective risk perceptions (WX-Survey)	
	At risk for extreme heatwaves	Thinking about all four seasons (winter, summer, spring, and fall), how do you rate the risk of the following extreme weather events to you and the people in your area?
	At risk for extreme rainstorms At risk for droughts At risk for floods	1) at risk for extreme heatwaves, 2) at risk for extreme rainstorms, 3) at risk for droughts, 4) at risk for floods, 5) at risk for hurricanes, and 6) at risk for tornadoes

TABLE A1. (*Continued*)

WRN model category	Binary dependent variables	Survey question and description
	At risk for hurricanes	Possible answers: a) no risk, b) low risk, c) moderate risk, d) high risk, or e) extreme risk; we construct a series of binary variables that equal 1 if the respondent reported high or extreme risk to each of the questions
	At risk for tornados	
	Severe weather preparedness (FEMA)	We construct a series of binary variables that equal 1 if the respondent reported yes for the following questions:
	Did you take any steps to prepare	After receiving the information about how to get better prepared, did you take any steps to prepare for a disaster?
	Developed and discussed an emergency plan	Has your household developed and discussed an emergency plan that includes instructions for household members about where to go and what to do in the event of a local disaster?
	Plan includes information about where to shelter	Does your plan include information about where to shelter or a safe place you can stay in the event of a disaster?
	Enough supplies set aside in your home	Do you have enough supplies set aside in your home to get you through three days or more without power or running water and without transportation?
	Do you have money set aside for emergency	Do you have money set aside for emergency?
	Do you have copies of critical documents	Do you have copies of critical documents, such as identification, insurance, and banking information, stored in a fireproof/waterproof location or stored electronically?
	Have you practiced what to do in a disaster	In the past year, have you practiced what to do in a disaster by participating in a disaster preparedness exercise or drill at home?
	Rely on public transportation or the local authorities	In the event of a disaster that required you to leave your area, would you need to rely on public transportation or the local authorities for transportation in order to leave?
	Confident that you can prepare for a disaster	How confident are you that you can take the steps to prepare for a disaster in your area? Would you say you are (read a–e)? Possible answers: a) not at all confident, b) slightly confident, c) somewhat confident, d) moderately confident, or e) extremely confident; we construct a series of binary variables that equal 1 if the respondent reported somewhat confident, moderately confident, or extremely confident.
Take action		
	Severe weather response (WX-Survey)	
	Always take protective action	Please tell us how strongly you agree with the following statements about tornado warnings: 1) always take protective action, 2) take protective action if you are at work or school, 3) take protective action if you are with a small group, 4) take protective action if you are with a large group, 5) take protective action if you are at the store, 6) take protective action if you are driving, and 7) take protective action if you are sleeping
	Take protective action if you are at work or school	
	Take protective action if you are with a small group	
	Take protective action if you are with a large group	Possible answers: a) strongly disagree, b) disagree, c) neither disagree nor agree, d) agree, or e) strongly agree; we construct a series of binary variables that equal 1 if the respondent reported agree or strongly agree to each question
	Take protective action if you are at the store	
	Take protective action if you are driving	
	Take protective action if you are sleeping	
Control variables		
	Female	A dummy variable that is 1 if the individual is female
	Race	A set of dummy variables that represent whether the individual is White, Black, Native, Asian, or other; Native is composed of American Indian or Alaska Native and Native Hawaiian or Pacific Islander
	Ethnicity	A binary variable that is 1 if the individual is Hispanic

TABLE A1. (*Continued*)

WRN model category	Binary dependent variables	Survey question and description
	Age group	A set of dummy variables that represent whether the individual is 18–24, 25–34, 35–44, 45–54, 55–64, or 65–102
	Education	A set of dummy variables that represent whether the individual has less than high school, high school, some college, bachelor's degree, or postgraduate degree
	Household income	A set of dummy variables that represent whether the individual's household income is 0–$50,000, $50,000–$100,000, $100,000–$150,000, or $150,000 or more
	Rurality	A set of dummy variables that represent whether the individual is located in urban, suburban, or rural areas

the objective comprehension questions correctly. Similarly, Hispanic respondents are less likely to understand the tornado watch size and tornado watch time experiments correctly[8] than non-Hispanics. These findings align generally with respondents' self-reported comprehension of these concepts.

Women are 3 percentage points less likely to answer the objective tornado watch size question correctly but are largely indistinguishable from men in the objective comprehension of severe weather watches and warnings. Objective comprehension also generally increases with age. Household income plays a limited role in determining objective comprehension, although the likelihood of answering the tornado watch size experiment correctly generally increases with income. Geographic location, however, plays a large role in determining objective comprehension. Urban respondents have much lower objective comprehension of all tornado watch and warning experiments, relative to suburban respondents.

4) BEING INFORMED: TRUST IN SEVERE WEATHER INFORMATION

The final aspect of the "being informed" component of the WRN logic model is trust in severe weather information. After controlling for other characteristics, Black respondents are 5.8 and 3.8 percentage points less likely than White respondents to trust the NWS and local emergency managers, respectively (Table 5). However, they are 2.9 percentage points more likely than Whites to trust in family, friends, and colleagues. Similarly, Hispanics are 2.1 percentage points less likely to trust the NWS but 2.5 percentage points more likely to trust in family, friends, and colleagues (although this result is weakly significant at the 10% level). Asian respondents also have lower trust in weather information from the NWS and local emergency managers than White respondents.

Women trust every weather information source more than men, except for family or friends where the difference is statistically insignificant. Similarly, respondents are more likely with age, in comparison with 18–24-year-old adults, to trust every weather source except for family and friends. Trust in family or friends as a source of weather information has a nonlinear relationship with age, increasing at middle age, and decreasing with old age. Trust increases with household income, although not at an increasing rate. Relative to those in suburban areas, individuals located in urban areas have significantly more trust in every type of weather information source.

5) BEING INFORMED: SUMMARY

Overall, we find large differences in being informed about severe weather by demographic and socioeconomic status. For example, while Black and Hispanic respondents are more likely than Whites to get weather information from government websites, they are far less trusting in the NWS and local emergency managers. Black and Hispanic respondents tend to trust their friends and family for their severe weather information. Women are also more likely than men to gather weather information from friends and family and less from official sources but have greater trust than men in all sources of weather information, except for friends and family. Wealthier respondents are more likely to gather and trust weather information. While we do not see much difference in the reception of tornado warnings across Black and Hispanic respondents, Asian respondents report much lower probabilities of receiving tornado warnings, than do White respondents.

We also find large differences in subjective and objective comprehension of severe weather risk information across demographics and socioeconomic status. Black and Hispanic respondents report lower subjective comprehension (i.e., believe they understand tornado and severe thunderstorm watches and warnings) and objective comprehension (i.e., answered correctly to the tornado watch or warning experimental questions). Women reported lower subjective comprehension of severe weather information but are largely indistinguishable from men in the objective comprehension of severe weather watches and warnings. Finally, both subjective and objective comprehension of severe weather watches and warnings increase with household income.

[8] It is important to be clear about what we mean by "correctly." Respondents were given an objective test question, so there was technically a correct answer. However, we do not mean to imply that respondents themselves are correct or incorrect. The responsibility for determining the right answer does not lie solely with participants or members of the public. Rather, the onus is on the NWS to ensure that severe weather information is comprehensible across different backgrounds, cultures, languages, and lived experiences.

TABLE B1. Severe weather information reception descriptive statistics. One, two, and three asterisks indicate significance at the 0.10, 0.05, and 0.01 levels, respectively. Means were calculated using sample-weighted individual-level data from the 2017–20 Severe Weather and Society Surveys. Standard deviations are in parentheses. Asterisks indicate whether the difference in means for the specific race category is statistically significantly different from White and non-Hispanic, respectively.

		Race					Ethnicity	
Variables	Total sample	White	Black	Native	Asian	Other	Not Hispanic	Hispanic
Severe weather information reception								
Local TV	0.750 (0.433)	0.744 (0.437)	0.831*** (0.375)	0.707 (0.457)	0.685 (0.465)	0.576 (0.499)	0.749 (0.434)	0.754 (0.431)
Cellphone applications	0.624 (0.485)	0.610 (0.488)	0.711*** (0.454)	0.622 (0.487)	0.629 (0.484)	0.646 (0.483)	0.604 (0.489)	0.731*** (0.444)
Nongovernment websites	0.563 (0.496)	0.566 (0.496)	0.523 (0.500)	0.673 (0.471)	0.598 (0.491)	0.592 (0.496)	0.552 (0.497)	0.621*** (0.486)
Cable TV	0.551 (0.497)	0.539 (0.499)	0.657*** (0.475)	0.531 (0.501)	0.468*** (0.500)	0.588 (0.497)	0.536 (0.499)	0.632*** (0.483)
Family, friends, or colleagues	0.530 (0.499)	0.526 (0.499)	0.574*** (0.495)	0.520 (0.502)	0.488 (0.501)	0.461 (0.503)	0.514 (0.500)	0.613*** (0.487)
Radio	0.520 (0.500)	0.515 (0.500)	0.568** (0.496)	0.496 (0.502)	0.510 (0.501)	0.408 (0.496)	0.509 (0.500)	0.578*** (0.494)
Government websites	0.450 (0.498)	0.443 (0.497)	0.501*** (0.500)	0.536 (0.501)	0.449 (0.498)	0.432 (0.500)	0.431 (0.495)	0.553*** (0.497)
Social media	0.386 (0.487)	0.372 (0.483)	0.472*** (0.500)	0.369 (0.485)	0.392 (0.489)	0.411 (0.497)	0.364 (0.481)	0.502*** (0.500)
Newspapers	0.333 (0.471)	0.325 (0.469)	0.379*** (0.485)	0.405 (0.493)	0.352 (0.478)	0.294 (0.460)	0.318 (0.466)	0.412*** (0.492)
Tornado warning reception								
Receive most tornado warnings	0.606 (0.489)	0.616 (0.486)	0.637 (0.481)	0.322*** (0.469)	0.378*** (0.486)	0.503 (0.505)	0.619 (0.486)	0.532*** (0.499)
Receive tornado warnings as soon as they are issued	0.554 (0.497)	0.559 (0.497)	0.586 (0.493)	0.334*** (0.474)	0.407*** (0.492)	0.491 (0.505)	0.561 (0.496)	0.517 (0.500)
Receive all tornado warnings	0.513 (0.500)	0.508 (0.500)	0.585 (0.493)	0.409 (0.494)	0.397*** (0.490)	0.613* (0.492)	0.516 (0.500)	0.496 (0.500)
No. of obs	5186	4035	665	114	319	53	4334	852

TABLE B2. Similar to Table B1, but for FEMA severe weather information reception descriptive statistics. Means were calculated using sample-weighted individual-level data from the 2018–20 FEMA National Household Surveys.

		Race				Ethnicity	
Variables	Total sample	White	Black	Asian	Other	Not Hispanic	Hispanic
TV, TV news, weather channels	0.442 (0.497)	0.431 (0.495)	0.545*** (0.498)	0.358*** (0.481)	0.426 (0.495)	0.440 (0.496)	0.461*** (0.499)
Internet	0.198 (0.399)	0.196 (0.397)	0.199*** (0.399)	0.183** (0.388)	0.236 (0.425)	0.199 (0.399)	0.193*** (0.395)
Newspaper	0.0499 (0.218)	0.0522 (0.223)	0.0362* (0.187)	0.0243 (0.154)	0.0500 (0.218)	0.0513 (0.221)	0.0376*** (0.190)
Conversation with others	0.0275 (0.164)	0.0259 (0.159)	0.0292 (0.168)	0.0553 (0.229)	0.0400* (0.196)	0.0279 (0.165)	0.0242 (0.154)
Brochure/pamphlet/flyers	0.0554 (0.229)	0.0588 (0.235)	0.0446 (0.207)	0.0142 (0.119)	0.0392 (0.194)	0.0579 (0.234)	0.0341 (0.182)
Provided by employer/at work	0.0536 (0.225)	0.0549 (0.228)	0.0440 (0.205)	0.0842 (0.279)	0.0419 (0.201)	0.0511 (0.220)	0.0743 (0.262)
Public service announcement or notice from local government	0.0489 (0.216)	0.0485 (0.215)	0.0434 (0.204)	0.0704* (0.257)	0.0598* (0.237)	0.0492 (0.216)	0.0467 (0.211)
Commercial on TV/radio	0.0416 (0.200)	0.0438 (0.205)	0.0166* (0.128)	0.0968 (0.297)	0.0388 (0.193)	0.0393 (0.194)	0.0613** (0.240)
Utility company or other business	0.0134 (0.115)	0.0149 (0.121)	0.00912 (0.0952)	0.0105 (0.102)	0.000406 (0.0202)	0.0149 (0.121)	0.00126 (0.0355)
An event or training on disaster preparedness	0.0260 (0.159)	0.0263 (0.160)	0.0123 (0.110)	0.0720 (0.259)	0.0336 (0.180)	0.0264 (0.160)	0.0232 (0.151)
Social media	0.0436 (0.204)	0.0474 (0.213)	0.0212 (0.144)	0.0310 (0.174)	0.0342 (0.182)	0.0436 (0.204)	0.0433 (0.204)
No. of obs	5186	4988	597	157	6041	5226	815

TABLE B3. As in Table B2, but for additional FEMA severe weather information reception descriptive statistics.

		Race				Ethnicity	
Variables	Total sample	White	Black	Asian	Other	Not Hispanic	Hispanic
Real-time alerts and warnings	0.815 (0.389)	0.826 (0.379)	0.807*** (0.395)	0.696*** (0.461)	0.727*** (0.446)	0.827 (0.378)	0.724*** (0.447)
Information about how to prepare	0.439 (0.496)	0.454 (0.498)	0.377*** (0.485)	0.297*** (0.457)	0.431** (0.496)	0.447 (0.497)	0.383** (0.486)
No. of obs	12 707	10 058	1528	431	690	10 867	1840

A well-informed public is a key component of the NWS WRN strategy. Without an understanding of core weather information, the public will not assess risk appropriately and may not prepare and respond in their best self-interest. NWS should take into account this population-specific information when building outreach and education materials. Future studies should investigate the factors contributing to these differences and explore strategies to close gaps across different demographic groups.

b. Get prepared

A second intermediate indicator in the WRN logic model is how well prepared the public is prior to an event. We examined two survey questions that provide indicators of the level of preparedness among survey respondents.

1) GET PREPARED: SEVERE WEATHER RISK PERCEPTIONS

Risk perceptions are an important driver of individual actions to prepare for hazardous events (Guillot et al. 2020; Keul et al 2018; Levac et al. 2012). Thus, we first examined respondents' self-assessed risk for several types of hazardous weather events (Table 6).

After controlling for other characteristics, Black respondents are more likely than White respondents to rate their risk highly, and the risk of others in their area, for extreme heatwaves, rainstorms, floods, hurricanes, and tornadoes (5.1, 3.5, 7.2, 5.3, and 4.6 percentage points more likely, respectively). Similarly, Hispanics rate their risk higher than non-Hispanics for extreme rainstorms, floods, and hurricanes. Relative to White respondents, however, Asian respondents are 9.5, 6.8, and 4.2 percentage points less likely to rate their risk high for extreme heatwaves, extreme rainstorms, and droughts, respectively.

Women are more likely than men to rate their risk high for extreme heatwaves, rainstorms, and droughts. However, women are 2.4 percentage points less likely than men to rate their risk high for hurricanes. Respondents are more likely with age, relative to 18–24-year-old adults, to consider themselves at high risk for extreme heatwaves and droughts, but less likely for extreme rainstorms and floods. Other types of severe weather risk have nonlinear relationships with age. For example, middle-aged respondents are more likely to rate their risk high for hurricanes and tornadoes than are 18–24-year-olds, but both decrease significantly in old age.

Last, self-rated risk for droughts, hurricanes, and tornadoes rises with household income. That is, the richer you are, the more likely you are to consider yourself more at risk for these severe weather types. Respondents in urban areas are more likely than suburban respondents to consider themselves at high risk for every severe weather category except for extreme rainstorms, while rural individuals consider themselves less at risk than suburban respondents for extreme heatwaves, but more at risk for drought.

2) GET PREPARED: SEVERE WEATHER PREPAREDNESS

The WX Survey contains questions about concrete actions taken by respondents to prepare for severe weather events, including planning, supply kits, and practicing for an event. Black respondents are 4.2 and 4.4 percentage points more likely than White respondents to have a specific meeting place and have practiced or drilled a plan in case of a disaster, respectively (Table 7). Similarly, Hispanics are more likely to be prepared in each category than non-Hispanics, except for practicing a disaster plan. However, Asian respondents are less likely than White respondents to be prepared for each category of preparedness, except for having a disaster supply kit, which is negative but statistically insignificant. These results are unsurprising given that the self-rated risk of these groups from exposure to hazardous weather is generally higher than White respondents.

The FEMA survey results similarly showed that Black, Asian, and Hispanic respondents are more likely than White and non-Hispanic respondents, respectively, to take steps to prepare for severe weather (Table C3 in appendix C). Similarly, Black respondents are more likely to have practiced what to do during a disaster.

According to the WX Survey, women are less likely than men to have a disaster supply kit and a specific meeting place as well as to have practiced a disaster plan. Generally, severe weather preparedness is highest among middle-aged respondents and decreases among older and younger respondents. Severe weather preparedness increases with household income, and at an increasing rate. Also, relative to those in suburban areas, individuals located in urban areas report they are significantly more prepared.

Similar results are shown in the FEMA data, with female respondents being less likely to have supplies set aside or to report confidence in their disaster preparedness (Table C3 in appendix C). Additionally, the FEMA data suggest that the types of preparedness actions taken can vary widely across age groups.

3) GET PREPARED: SUMMARY

Overall, we find differences in severe weather risk perceptions and preparedness by demographic and socioeconomic

TABLE B4. As in Table B1, but for severe weather subjective and objective risk comprehension descriptive statistics.

		Race					Ethnicity	
Variables	Total sample	White	Black	Native	Asian	Other	Not Hispanic	Hispanic
Subjective risk comprehension								
Understand difference between watches and warnings	0.823 (0.381)	0.842 (0.365)	0.775*** (0.418)	0.676*** (0.470)	0.671*** (0.470)	0.709*** (0.456)	0.835 (0.372)	0.760*** (0.427)
Understand severe thunderstorm watches and warnings	0.720 (0.449)	0.740 (0.439)	0.688*** (0.463)	0.719 (0.451)	0.514*** (0.500)	0.552*** (0.499)	0.730 (0.444)	0.661* (0.474)
Understand tornado watches and warnings	0.639 (0.480)	0.653 (0.476)	0.643 (0.479)	0.640 (0.482)	0.452*** (0.498)	0.457*** (0.500)	0.651 (0.477)	0.574** (0.495)
Understand maps	0.755 (0.430)	0.779 (0.415)	0.659*** (0.474)	0.782 (0.414)	0.627*** (0.484)	0.634*** (0.483)	0.757 (0.429)	0.741** (0.438)
Understand radar images	0.680 (0.467)	0.707 (0.455)	0.582*** (0.493)	0.612** (0.489)	0.526*** (0.500)	0.506*** (0.502)	0.681 (0.466)	0.673 (0.469)
Objective risk comprehension								
Tornado watch or warning expt	0.766 (0.424)	0.786 (0.410)	0.685*** (0.465)	0.664 (0.474)	0.647*** (0.478)	0.712 (0.455)	0.774 (0.418)	0.718*** (0.450)
Tornado watch size expt	0.463 (0.499)	0.475 (0.499)	0.407*** (0.492)	0.413 (0.494)	0.425*** (0.495)	0.414 (0.494)	0.480 (0.500)	0.370*** (0.483)
Tornado warning time expt	0.269 (0.443)	0.294 (0.456)	0.172*** (0.377)	0.218 (0.415)	0.117*** (0.321)	0.139*** (0.347)	0.282 (0.450)	0.192*** (0.394)
Tornado watch time expt	0.248 (0.432)	0.259 (0.438)	0.229*** (0.420)	0.193 (0.396)	0.156*** (0.364)	0.139 (0.347)	0.259 (0.438)	0.188*** (0.391)
No. of obs	8486	6613	1069	135	517	152	7110	1376

TABLE B5. As in Table B1, but for severe weather information response descriptive statistics.

		Race					Ethnicity	
Variables	Total sample	White	Black	Native	Asian	Other	Not Hispanic	Hispanic
Tornado warning response								
Always take protective action	0.475 (0.499)	0.476 (0.499)	0.493 (0.500)	0.443* (0.498)	0.464 (0.499)	0.337*** (0.474)	0.473 (0.499)	0.489* (0.500)
Take protective action if you are at work or school	0.846 (0.361)	0.849 (0.358)	0.842 (0.365)	0.845 (0.363)	0.827** (0.379)	0.752* (0.433)	0.846 (0.361)	0.846 (0.361)
Take protective action if you are with a small group	0.845 (0.362)	0.845 (0.362)	0.864 (0.343)	0.805 (0.398)	0.810*** (0.393)	0.797 (0.404)	0.842 (0.365)	0.859 (0.348)
Take protective action if you are with a large group	0.824 (0.381)	0.824 (0.381)	0.841 (0.366)	0.785 (0.412)	0.800** (0.400)	0.784 (0.413)	0.822 (0.382)	0.833 (0.373)
Take protective action if you are at the store	0.775 (0.418)	0.777 (0.416)	0.796 (0.403)	0.760 (0.429)	0.726*** (0.446)	0.666*** (0.473)	0.774 (0.418)	0.779 (0.415)
Take protective action if you are driving	0.760 (0.427)	0.761 (0.426)	0.789 (0.409)	0.682 (0.467)	0.680*** (0.467)	0.738* (0.441)	0.760 (0.427)	0.763 (0.426)
Take protective action if you are sleeping	0.548 (0.498)	0.545 (0.498)	0.588*** (0.492)	0.520 (0.501)	0.499*** (0.500)	0.521 (0.501)	0.541 (0.498)	0.585*** (0.493)
No. of obs	8328	6463	1073	139	507	146	6972	1356

TABLE B6. As in Table B1, but for trust in severe weather information descriptive statistics.

Variables	Total sample	Race					Ethnicity	
		White	Black	Native	Asian	Other	Not Hispanic	Hispanic
Trust the National Weather Service	0.762 (0.426)	0.774 (0.418)	0.720^{***} (0.449)	0.622^{***} (0.486)	0.672^{***} (0.470)	0.770 (0.421)	0.768 (0.422)	0.733^{***} (0.443)
Trust state or local emergency managers	0.658 (0.474)	0.664 (0.472)	0.649^{***} (0.478)	0.588^{***} (0.494)	0.600^{***} (0.490)	0.604 (0.490)	0.661 (0.473)	0.643 (0.479)
Trust national TV (Weather Channel)	0.653 (0.476)	0.650 (0.477)	0.689^{*} (0.463)	0.511^{***} (0.501)	0.615 (0.487)	0.674 (0.470)	0.658 (0.474)	0.626 (0.484)
Trust regional or local TV	0.649 (0.477)	0.655 (0.475)	0.641^{**} (0.480)	0.473^{***} (0.501)	0.600^{***} (0.490)	0.589^{*} (0.493)	0.655 (0.475)	0.617 (0.486)
Trust in family or friends	0.328 (0.470)	0.314 (0.464)	0.410^{***} (0.492)	0.286 (0.453)	0.329 (0.470)	0.392 (0.489)	0.320 (0.467)	0.370^{***} (0.483)
No. of obs	10 558	8074	1386	177	652	273	8836	1722

TABLE B7. As in Table B1, but for severe weather preparedness descriptive statistics.

Variables	Total sample	Race					Ethnicity	
		White	Black	Native	Asian	Other	Not Hispanic	Hispanic
Prepared a small kit with emergency supplies	0.362 (0.481)	0.361 (0.480)	0.374 (0.484)	0.399 (0.491)	0.348 (0.477)	0.331 (0.474)	0.350 (0.477)	0.428^{***} (0.495)
Made a specific plan	0.334 (0.472)	0.328 (0.469)	0.394^{***} (0.489)	0.317 (0.467)	0.269^{***} (0.444)	0.403 (0.494)	0.319 (0.466)	0.416^{***} (0.493)
Prepared a disaster supply kit	0.321 (0.467)	0.317 (0.465)	0.356 (0.479)	0.421 (0.496)	0.311 (0.464)	0.256^{*} (0.440)	0.306 (0.461)	0.404^{***} (0.491)
Established a specific meeting place	0.267 (0.443)	0.262 (0.440)	0.322^{***} (0.467)	0.423^{**} (0.496)	0.223^{**} (0.417)	0.213 (0.413)	0.257 (0.437)	0.326^{***} (0.469)
Practiced or drilled on what to do in an emergency	0.257 (0.437)	0.248 (0.432)	0.334^{***} (0.472)	0.218 (0.415)	0.231 (0.422)	0.211 (0.411)	0.244 (0.430)	0.329^{***} (0.470)
No. of obs	5726	4452	730	129	350	65	4795	931

TABLE B8. As in Table B2, but for FEMA severe weather preparedness descriptive statistics.

Variables	Total sample	Race: White	Race: Black	Race: Asian	Race: Other	Ethnicity: Not Hispanic	Ethnicity: Hispanic
Did you take any steps to prepare	0.496 (0.500)	0.488 (0.500)	0.495** (0.500)	0.512*** (0.501)	0.612** (0.488)	0.484 (0.500)	0.600*** (0.490)
Developed and discussed an emergency plan	0.491 (0.500)	0.508 (0.500)	0.437*** (0.496)	0.372*** (0.484)	0.428 (0.495)	0.505 (0.500)	0.393*** (0.489)
Information about where to shelter	0.802 (0.398)	0.803 (0.398)	0.799 (0.401)	0.750 (0.434)	0.823 (0.382)	0.805 (0.396)	0.774*** (0.418)
Enough supplies set aside in your home	0.812 (0.391)	0.830 (0.375)	0.748*** (0.434)	0.710*** (0.454)	0.734 (0.442)	0.829 (0.377)	0.690*** (0.462)
Money set aside for emergency	0.693 (0.461)	0.719 (0.449)	0.598*** (0.491)	0.660*** (0.474)	0.546*** (0.498)	0.717 (0.450)	0.522*** (0.500)
Copies of critical documents	0.696 (0.460)	0.712 (0.453)	0.634*** (0.482)	0.682*** (0.466)	0.605 (0.489)	0.713 (0.452)	0.571*** (0.495)
Practiced what to do in a disaster	0.217 (0.412)	0.207 (0.405)	0.247*** (0.431)	0.200 (0.401)	0.293*** (0.456)	0.219 (0.413)	0.203 (0.403)
Confident take the steps to prepare	0.912 (0.283)	0.921 (0.269)	0.900*** (0.301)	0.853*** (0.355)	0.835** (0.372)	0.919 (0.272)	0.859*** (0.348)
Rely on public transportation or the local authorities	0.195 (0.396)	0.157 (0.364)	0.326*** (0.469)	0.303*** (0.460)	0.387*** (0.487)	0.168 (0.374)	0.384*** (0.487)
No. of obs	12 616	9985	1519	428	686	10 783	1833

TABLE B9. As in Table B1, but for subjective severe weather risk perceptions descriptive statistics.

Variables	Total sample	Race: White	Race: Black	Race: Native	Race: Asian	Race: Other	Ethnicity: Not Hispanic	Ethnicity: Hispanic
At risk for extreme heatwaves	0.461 (0.499)	0.452 (0.498)	0.536*** (0.499)	0.579* (0.495)	0.365*** (0.482)	0.607*** (0.489)	0.442 (0.497)	0.569*** (0.495)
At risk for extreme rainstorms	0.388 (0.487)	0.385 (0.487)	0.463*** (0.499)	0.375 (0.485)	0.273*** (0.446)	0.339 (0.474)	0.382 (0.486)	0.420*** (0.494)
At risk for droughts	0.291 (0.454)	0.287 (0.453)	0.266 (0.442)	0.388 (0.489)	0.360** (0.480)	0.426** (0.495)	0.272 (0.445)	0.399*** (0.490)
At risk for floods	0.274 (0.446)	0.258 (0.437)	0.396*** (0.489)	0.369 (0.484)	0.225 (0.418)	0.310 (0.463)	0.260 (0.438)	0.349*** (0.477)
At risk for tornados	0.261 (0.439)	0.250 (0.433)	0.353*** (0.478)	0.309 (0.464)	0.216 (0.412)	0.237 (0.426)	0.263 (0.440)	0.254 (0.435)
At risk for hurricanes	0.235 (0.424)	0.219 (0.414)	0.343*** (0.475)	0.380 (0.487)	0.220 (0.414)	0.241 (0.428)	0.221 (0.415)	0.309*** (0.462)
No. of obs	10 944	8378	1431	188	669	283	9156	1788

TABLE C1. FEMA severe weather information reception for linear fixed-effects models. One, two, and three asterisks indicate significance at the 0.10, 0.05, and 0.01 levels, respectively. Models were estimated using weighted individual-level data from the 2018–20 FEMA National Household Survey. Standard errors are in parentheses. Reference categories are White, age group 18–24, and less than high school education. Each model also includes FEMA region- and year-fixed effects.

Variables	TV, TV news, weather channels	Internet	Newspapers	Conversation with others	Brochure, Pamphlet, flyers	Provided by employer, at work	Public service announcement	Commercial on TV/radio	Utility company or other business	An event or training	Social media
Female	0.023*	−0.042***	0.007	0.008**	0.002	−0.006	0.008	−0.018***	−0.002	0.003	0.018***
	(0.012)	(0.010)	(0.006)	(0.004)	(0.006)	(0.006)	(0.005)	(0.006)	(0.003)	(0.004)	(0.005)
Black	0.105***	−0.064***	−0.008	0.006	−0.011	0.007	0.004	−0.009	−0.003	−0.010*	−0.016**
	(0.020)	(0.015)	(0.009)	(0.007)	(0.009)	(0.010)	(0.009)	(0.008)	(0.004)	(0.006)	(0.008)
Asian	−0.032	0.020	0.008	0.003	−0.006	0.007	0.019	−0.005	−0.007	0.008	−0.015
	(0.038)	(0.036)	(0.018)	(0.014)	(0.017)	(0.021)	(0.020)	(0.021)	(0.007)	(0.016)	(0.019)
Other	0.011	−0.010	0.010	0.012	−0.019	0.011	0.013	−0.015	−0.009**	0.003	−0.007
	(0.029)	(0.023)	(0.014)	(0.012)	(0.012)	(0.015)	(0.014)	(0.014)	(0.004)	(0.012)	(0.013)
Hispanic	0.081***	−0.063***	−0.014*	−0.006	0.004	−0.008	−0.007	0.019*	−0.001	0.007	−0.011
	(0.019)	(0.015)	(0.008)	(0.006)	(0.009)	(0.009)	(0.009)	(0.010)	(0.004)	(0.007)	(0.008)
25–34	0.101***	−0.068**	−0.001	−0.017	0.004	0.048***	−0.013	0.006	0.004	−0.041**	−0.024
	(0.031)	(0.031)	(0.010)	(0.013)	(0.015)	(0.017)	(0.016)	(0.016)	(0.006)	(0.016)	(0.021)
35–44	0.116***	−0.030	−0.009	−0.021*	0.008	0.017	−0.006	0.018	0.008	−0.046***	−0.053***
	(0.030)	(0.031)	(0.010)	(0.013)	(0.014)	(0.015)	(0.016)	(0.016)	(0.006)	(0.015)	(0.020)
45–54	0.182***	−0.116***	0.012	−0.011	−0.001	0.035**	−0.021	0.025	0.001	−0.034**	−0.072***
	(0.029)	(0.029)	(0.010)	(0.013)	(0.014)	(0.015)	(0.015)	(0.015)	(0.005)	(0.016)	(0.019)
55–64	0.252***	−0.125***	0.043***	−0.025**	0.002	−0.009	−0.023	0.004	0.009	−0.039**	−0.089***
	(0.028)	(0.028)	(0.011)	(0.012)	(0.013)	(0.014)	(0.015)	(0.014)	(0.006)	(0.015)	(0.019)
65–100	0.345***	−0.193***	0.075***	−0.020	0.015	−0.027**	−0.023	−0.016	0.002	−0.053***	−0.105***
	(0.027)	(0.027)	(0.011)	(0.012)	(0.013)	(0.013)	(0.014)	(0.014)	(0.005)	(0.015)	(0.019)
High school	−0.129***	0.030	0.034***	−0.011	0.009	0.020*	0.007	0.024	0.009	0.002	0.005
	(0.034)	(0.022)	(0.011)	(0.014)	(0.013)	(0.011)	(0.015)	(0.015)	(0.006)	(0.012)	(0.014)
Some college	−0.202***	0.078***	0.041***	−0.016	0.034***	0.033***	−0.004	0.021	0.000	0.001	0.013
	(0.033)	(0.021)	(0.011)	(0.014)	(0.013)	(0.011)	(0.014)	(0.014)	(0.005)	(0.012)	(0.013)
Bachelor's degree	−0.243***	0.087***	0.045***	−0.005	0.028**	0.043***	0.012	0.019	0.005	0.005	0.003
	(0.033)	(0.021)	(0.010)	(0.014)	(0.013)	(0.011)	(0.014)	(0.014)	(0.005)	(0.012)	(0.013)
Postgraduate	−0.277***	0.110***	0.069***	−0.018	0.034**	0.032***	0.008	0.027*	0.003	0.005	0.006
	(0.034)	(0.023)	(0.012)	(0.014)	(0.013)	(0.011)	(0.015)	(0.014)	(0.006)	(0.012)	(0.013)
FEMA region- and year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log likelihood	−4041.284	−2815.444	76.352	2788.640	581.976	581.346	1196.303	707.185	5185.227	2648.021	1329.668
No. of obs	6055	6055	6055	6055	6055	6055	6055	6055	6055	6055	6055
R^2	0.100	0.051	0.027	0.009	0.005	0.020	0.007	0.022	0.006	0.015	0.028

TABLE C2. As in Table C1, but for additional FEMA severe weather information reception for linear fixed-effects models.

Variables	Real-time alerts and warnings	Information about how to prepare
Female	−0.021*** (0.007)	0.023*** (0.009)
Black	−0.031*** (0.010)	−0.103*** (0.014)
Asian	−0.132*** (0.023)	−0.114*** (0.024)
Other	−0.023 (0.017)	−0.020 (0.020)
Hispanic	−0.087*** (0.011)	0.010 (0.013)
25–34	0.010 (0.017)	0.055*** (0.020)
35–44	0.047*** (0.017)	0.122*** (0.020)
45–54	0.084*** (0.016)	0.161*** (0.019)
55–64	0.083*** (0.015)	0.172*** (0.018)
65–100	0.049*** (0.015)	0.167*** (0.018)
High school	0.058*** (0.021)	0.045* (0.023)
Some college	0.112*** (0.020)	0.134*** (0.022)
Bachelor's degree	0.124*** (0.020)	0.169*** (0.022)
Postgraduate	0.129*** (0.020)	0.214*** (0.023)
FEMA region- and year-fixed effects	Yes	Yes
Log likelihood	−5388.258	−8932.678
No. of obs	12 788	12 788
R^2	0.041	0.052

status. For example, Black and Hispanic respondents are more likely than Whites to highly rate their risk for severe weather events. Correspondingly, these groups also report to be more prepared (e.g., have a specific meeting place and practiced or drilled a plan in case of a disaster) than White respondents. Women are generally more likely than men to rate their risk for extreme weather highly, but they are less likely to have a disaster supply kit or a specific meeting place or to have practiced or drilled a plan in the event of a disaster. In general, we find the richer a respondent is, the more likely they are to consider themselves at risk for severe weather events and to be more prepared.

c. Take action

The final indicator of a population's capacity to respond to NWS-provided information is whether members of the community take action in response to this information. The WX Survey asked respondents whether they take protective actions in response to tornado warnings and the situations in which they take those protective actions.

1) TAKE ACTION: SEVERE WEATHER INFORMATION RESPONSE

Black and Hispanic respondents are more likely, than White and non-Hispanic respondents, respectively, to take protective action after receiving a tornado warning by means of a siren or other means that woke them when they were sleeping (Table 8). Asian respondents are significantly less likely than White respondents to take protective action in each of the scenarios after receiving a tornado warning.

Women are 2.7 percentage points more likely to take protective action than men but are 3.4 percentage points less likely to take protective action specifically when in a car. In general, respondents are more likely with age, relative to 18–24-year-old adults, to take protective action when receiving a tornado warning in each scenario. Respondents are also more likely to take protective action as household income rises. Urban respondents are 2.9 percentage points more likely to take protective action than suburban respondents, and more likely to take protective action than suburban respondents when at work, at the store, in the car, and when sleeping.

Similarly, the FEMA survey had questions about reliance on public transportation; non-White respondents are roughly 15 percentage points more likely to be reliant on public transportation in the event of an emergency (Table C3 in appendix C).

2) TAKE ACTION: SUMMARY

We found differences in severe weather risk information response by demographic and socioeconomic status. For example, Black and Hispanic respondents are more likely to take protective action after receiving a tornado warning while sleeping than are White and non-Hispanic respondents. By contrast, Asian respondents are generally less likely than White respondents to take protective action after receiving a tornado warning. We find that women are more likely than men to take protective action and that protective actions increase with household income.

Understanding why certain groups are more likely to take protective action is an important component of achieving the NWS WRN vision. Ignorance of appropriate measures, a lack of means such as access to adequate shelter, or insufficient time between warning reception and arrival of the hazardous event could all drive lack of action (Potter et al 2018; Kox and Thieken 2017; Weyrich et al. 2020). Improving knowledge of these barriers can help NWS tailor hazard communication and strike the appropriate balance between timely communication that risks false positives and more accurate forecasts that may not leave time for effective response to warnings.

5. Discussion and conclusions

We set out to examine racial and socioeconomic differences in the intermediate indicators of the NWS Weather-Ready Nation model; namely, that populations who receive NWS-provided observations, forecasts, and warnings are informed, prepared, and able to take action. Using nationally representative data on U.S. individuals from the 2017–20 Severe Weather and Society Surveys and the 2018–20 FEMA National Household Surveys, we conducted regression analysis to estimate the associations between racial and socioeconomic characteristics and survey questions linked with the factors identified in the WRN model. Prior to the collection and analysis of these microlevel datasets, the NWS could not estimate these intermediate indicators and as a result, could not know if its preparedness, education, outreach, and decision support activities were having the intended outcomes. We find evidence that these services and activities do not reach all groups equally.

TABLE C3. As in Table C1, but for FEMA severe weather preparedness and trust for linear fixed-effects models. Reference categories here are White, age group 18–24, less than high school education, less than $50,000 household income, and suburban location.

Variables	Did you take any steps to prepare	Developed and discussed an emergency plan	Plan include information about where to shelter	Enough supplies set aside in your home	Do you have money set aside for emergency	Do you have copies of critical documents	Have you practiced what to do in a disaster	Confident that you can prepare for a disaster	Rely on public transportation or the local authorities
Female	0.013 (0.012)	0.018** (0.009)	−0.024** (0.010)	−0.048*** (0.007)	−0.080*** (0.008)	−0.073*** (0.008)	−0.003 (0.007)	−0.028*** (0.005)	0.032*** (0.007)
Black	0.061*** (0.020)	−0.059*** (0.014)	−0.019 (0.016)	−0.080*** (0.012)	−0.123*** (0.013)	−0.064*** (0.013)	0.044*** (0.012)	−0.029*** (0.008)	0.160*** (0.012)
Asian	0.062* (0.037)	−0.085*** (0.025)	−0.036 (0.035)	−0.111*** (0.023)	−0.091*** (0.023)	−0.067*** (0.024)	0.005 (0.020)	−0.124*** (0.020)	0.165*** (0.022)
Other	0.074*** (0.028)	0.028 (0.020)	0.038* (0.022)	0.012 (0.016)	−0.052*** (0.020)	0.007 (0.019)	0.085*** (0.019)	−0.018 (0.014)	0.048*** (0.018)
Hispanic	0.134*** (0.018)	−0.048*** (0.014)	−0.040** (0.016)	−0.070*** (0.012)	−0.099*** (0.013)	−0.104*** (0.013)	0.001 (0.011)	−0.044*** (0.009)	0.175*** (0.012)
25–34	0.043 (0.033)	−0.005 (0.020)	0.005 (0.024)	−0.031* (0.018)	−0.046** (0.018)	−0.065*** (0.019)	−0.005 (0.016)	−0.003 (0.013)	−0.000 (0.016)
35–44	0.079** (0.032)	0.077*** (0.020)	0.004 (0.024)	0.022 (0.017)	−0.037** (0.018)	−0.041** (0.018)	0.031* (0.017)	0.025** (0.012)	−0.008 (0.015)
45–54	0.084*** (0.031)	0.085*** (0.020)	−0.013 (0.023)	0.071*** (0.016)	−0.050*** (0.018)	−0.028 (0.018)	0.014 (0.016)	0.020* (0.012)	0.019 (0.015)
55–64	0.104*** (0.030)	0.095*** (0.019)	−0.028 (0.023)	0.076*** (0.016)	−0.045*** (0.017)	−0.052*** (0.017)	−0.003 (0.015)	0.037*** (0.011)	0.015 (0.014)
65–100	0.091*** (0.029)	0.072*** (0.018)	−0.050** (0.022)	0.101*** (0.015)	−0.008 (0.016)	−0.058*** (0.017)	−0.014 (0.015)	0.014 (0.011)	0.062*** (0.014)
High school	0.031 (0.037)	0.080*** (0.023)	0.030 (0.032)	0.025 (0.020)	0.171*** (0.023)	0.085*** (0.023)	−0.006 (0.020)	0.074*** (0.018)	−0.173*** (0.022)
Some college	0.053 (0.035)	0.132*** (0.023)	0.028 (0.031)	0.051*** (0.019)	0.265*** (0.022)	0.128*** (0.022)	0.012 (0.019)	0.092*** (0.017)	−0.241*** (0.021)
Bachelor's degree	0.022 (0.035)	0.117*** (0.023)	0.038 (0.031)	0.045** (0.019)	0.354*** (0.022)	0.179*** (0.022)	−0.023 (0.019)	0.096*** (0.017)	−0.268*** (0.021)
Postgraduate	0.033 (0.036)	0.132*** (0.023)	0.053* (0.031)	0.024 (0.020)	0.378*** (0.022)	0.175*** (0.023)	−0.037* (0.020)	0.109*** (0.017)	−0.284*** (0.022)
FEMA region and year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log likelihood	−4613.794	−8983.624	−3277.525	−5595.570	−7032.386	−7795.539	−6370.805	−1386.716	−5059.346
No. of obs	6603	12 688	6522	12 666	12 612	12 678	12 697	12 661	12 449
R^2	0.034	0.033	0.020	0.038	0.085	0.034	0.010	0.028	0.104

TABLE D1. Severe weather information reception for multilevel ordinal fixed-effects models. One, two, and three asterisks indicate significance at the 0.10, 0.05, and 0.01 levels, respectively. Models were estimated using weighted individual-level data from the 2017–20 Severe Weather and Society Surveys. Standard errors are in parentheses. Reference categories are White, age group 18–24, less than high school education, less than $50,000 household income, and urban location. Each model also includes CWA- and year-fixed effects.

Variables	Local TV	Cellphone applications	Nongovernment websites	Cable TV	Family, friends, or colleagues	Radio	Social media	Newspapers	Government websites
Female	−0.027** (0.013)	−0.012 (0.014)	−0.066*** (0.014)	−0.063*** (0.014)	0.036** (0.014)	−0.066*** (0.014)	0.014 (0.013)	−0.111*** (0.013)	−0.101*** (0.013)
Black	0.067*** (0.018)	0.043** (0.020)	−0.068*** (0.021)	0.089*** (0.021)	−0.014 (0.022)	0.034 (0.022)	0.008 (0.021)	0.050** (0.021)	0.041** (0.021)
Asian	0.003 (0.065)	−0.038 (0.073)	0.077 (0.067)	−0.018 (0.070)	−0.098 (0.069)	−0.063 (0.069)	−0.058 (0.063)	0.107 (0.068)	0.078 (0.064)
Other	−0.010 (0.028)	−0.025 (0.029)	−0.022 (0.030)	−0.089*** (0.031)	−0.060** (0.030)	−0.045 (0.031)	0.012 (0.029)	0.001 (0.030)	−0.048* (0.027)
Hispanic	0.047*** (0.018)	0.039** (0.019)	0.040** (0.019)	0.099*** (0.020)	0.042** (0.020)	0.064*** (0.020)	0.040** (0.020)	0.061*** (0.019)	0.060*** (0.019)
25–34	0.083*** (0.025)	0.041* (0.025)	0.045* (0.026)	0.034 (0.026)	−0.053** (0.025)	0.051* (0.027)	0.016 (0.026)	0.060** (0.024)	0.036 (0.025)
35–44	0.150*** (0.026)	0.065** (0.025)	0.025 (0.027)	0.084*** (0.027)	−0.064** (0.026)	0.062** (0.027)	−0.001 (0.027)	0.066*** (0.025)	0.041 (0.026)
45–54	0.170*** (0.026)	−0.009 (0.026)	−0.086*** (0.027)	−0.030 (0.028)	−0.203*** (0.026)	0.044 (0.028)	−0.225*** (0.027)	−0.041* (0.025)	−0.092*** (0.025)
55–64	0.210*** (0.025)	−0.100*** (0.027)	−0.119*** (0.027)	−0.035 (0.027)	−0.295*** (0.026)	−0.005 (0.027)	−0.360*** (0.025)	−0.056** (0.025)	−0.160*** (0.024)
65–102	0.284*** (0.024)	−0.215*** (0.026)	−0.169*** (0.027)	0.056** (0.027)	−0.370*** (0.025)	−0.078*** (0.027)	−0.390*** (0.025)	0.023 (0.025)	−0.213*** (0.023)
High school	0.137*** (0.049)	0.019 (0.050)	−0.005 (0.052)	−0.049 (0.050)	0.037 (0.049)	0.030 (0.051)	0.031 (0.049)	0.021 (0.043)	−0.014 (0.043)
Some college	0.127*** (0.049)	0.027 (0.049)	0.056 (0.051)	−0.032 (0.050)	0.072 (0.048)	0.056 (0.051)	−0.010 (0.049)	0.031 (0.043)	−0.013 (0.042)
Bachelor's degree	0.122** (0.049)	0.041 (0.049)	0.127** (0.051)	−0.062 (0.050)	0.056 (0.048)	0.108** (0.051)	−0.036 (0.049)	0.044 (0.043)	0.008 (0.043)
Postgraduate	0.140*** (0.049)	0.046 (0.050)	0.120** (0.051)	−0.039 (0.050)	0.069 (0.048)	0.120** (0.051)	0.023 (0.049)	0.066 (0.043)	0.063 (0.043)
$50,000–$100,000	0.036** (0.015)	0.073*** (0.017)	0.073*** (0.017)	0.078*** (0.017)	0.068*** (0.017)	0.090*** (0.017)	0.051*** (0.016)	0.084*** (0.016)	0.062*** (0.015)
$100,000–$150,000	0.039** (0.019)	0.086*** (0.021)	0.074*** (0.022)	0.063*** (0.022)	0.069*** (0.021)	0.081*** (0.022)	0.037* (0.020)	0.107*** (0.020)	0.086*** (0.020)
$150,000 or more	0.017 (0.023)	0.090*** (0.024)	0.140*** (0.024)	0.096*** (0.025)	0.116*** (0.024)	0.114*** (0.025)	0.048** (0.023)	0.165*** (0.024)	0.115*** (0.023)
Urban	−0.047*** (0.014)	−0.029* (0.016)	−0.053*** (0.016)	−0.050*** (0.016)	−0.047*** (0.016)	−0.070*** (0.017)	−0.097*** (0.015)	−0.125*** (0.016)	−0.083*** (0.015)
Rural	−0.049** (0.020)	−0.028 (0.022)	−0.041* (0.022)	−0.066*** (0.023)	−0.072*** (0.022)	−0.054** (0.023)	−0.071*** (0.021)	−0.136*** (0.021)	−0.077*** (0.020)
CWA- and year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log likelihood	−2744.801	−3278.978	−3348.980	−3421.675	−3356.850	−3477.416	−2985.284	−3055.467	−2810.231
No. of obs	5082	5082	5082	5082	5082	5082	5082	5082	5082
R^2	0.083	0.088	0.102	0.089	0.119	0.077	0.198	0.121	0.151

TABLE D2. As in Table D1, but for tornado warning reception for multilevel ordinal fixed-effects models.

Variables	Receive most tornado warnings	Receive tornado warnings as soon as they are issued	Receive all tornado warnings
Female	0.008 (0.014)	0.020 (0.014)	0.020 (0.015)
Black	−0.030 (0.021)	−0.025 (0.022)	0.008 (0.022)
Asian	−0.181*** (0.065)	−0.122* (0.069)	−0.076 (0.066)
Other	−0.146*** (0.029)	−0.076** (0.030)	−0.068** (0.030)
Hispanic	−0.008 (0.020)	0.012 (0.020)	0.016 (0.020)
25–34	0.087*** (0.026)	0.058** (0.026)	0.072*** (0.026)
35–44	0.123*** (0.027)	0.105*** (0.027)	0.108*** (0.027)
45–54	0.128*** (0.027)	0.059** (0.027)	0.070** (0.027)
55–64	0.146*** (0.026)	0.085*** (0.027)	0.070** (0.028)
65–102	0.134*** (0.026)	0.035 (0.026)	0.037 (0.027)
High school	0.031 (0.051)	0.057 (0.051)	0.060 (0.051)
Some college	0.036 (0.051)	0.060 (0.051)	0.072 (0.050)
Bachelor's degree	0.053 (0.051)	0.054 (0.051)	0.057 (0.051)
Postgraduate	0.072 (0.051)	0.058 (0.051)	0.075 (0.051)
$50,000–$100,000	0.038** (0.016)	0.014 (0.017)	0.034* (0.017)
$100,000–$150,000	0.037* (0.022)	0.007 (0.022)	0.037* (0.022)
$150,000 or more	0.084*** (0.024)	0.077*** (0.025)	0.097*** (0.026)
Urban	−0.018 (0.016)	−0.063*** (0.017)	−0.058*** (0.017)
Rural	−0.019 (0.021)	−0.035 (0.022)	−0.046** (0.023)
CWA- and year-fixed effects	Yes	Yes	Yes
Log likelihood	−3249.307	−3410.283	−3481.422
No. of obs	5082	5082	5082
R^2	0.118	0.092	0.077

Our analyses have several limitations that should be noted. First, it is important to emphasize that this paper does not establish causal relationships. Our models do not fully correct for unobservable characteristics of respondents. Future research should seek to better understand the barriers faced by different populations in becoming informed, prepared, and taking action in the face of hazardous weather events, and the root causes of differences across these populations. Second, while the Severe Weather and Society Surveys and FEMA National Household Surveys provide useful information, they are still limited in their ability to capture information on racial and ethnic minorities, and we consider this analysis only a first step in measuring inequality for these populations. For example, due to limited sample sizes in our data there are fewer Black, Asian, and "other" race individuals in our sample. Thus, the estimates for these minority groups may be inherently less reliable (i.e., more variance within the group). This is also a problem in much larger surveys. For example, the U.S. Census Bureau has also acknowledged statistically significant undercounts for many minority groups in the 2020 decennial census (U.S. Census Bureau 2022). Additionally, the populations we look at in this paper are not necessarily homogeneous among themselves, and in many cases an even finer-scale analysis would be more appropriate (e.g., Trujillo-Falcón et al. 2021). Future work should incorporate the full range of tools available to social scientists; surveys need to be supplemented with field work, qualitative interviews, and community-driven perspectives. For example, using qualitative field studies to talk to vulnerable populations, social scientists (see Méndez et al. 2020) and have uncovered various vulnerabilities not addressed in survey data.

Third, the data used in our study are based on self-reported information and because of this, there may be measurement error in the data. If this is a nonclassical measurement error, then our estimates of the associations between racial and socioeconomic characteristics and severe weather reception and response may be biased. For example, Hispanics are more likely than other Americans to show acquiescence bias and are also more likely to give responses they perceive as socially desirable in response to sensitive questions (Brown 2015). Such patterns could help explain some of our findings (e.g., Hispanics claiming they are more prepared). Finally, while we use NWS CWA- and time-fixed effects in the model, we were unable to control for several characteristics related to severe weather due to data limitations, such as recent exposure to relevant hazards (Dow and Cutter 2000; Senkbeil et al. 2012; Schumann et al. 2018), respondents' living situation (Donner 2007; Ashley et al. 2008), urban characteristics, such as housing and street density (Pardowitz 2018), and amenities that coincide with environmental hazards (Maldonado et al. 2016). Future research should consider a broader range of factors that contribute to an informed and prepared public.

We find important statistically significant differences across racial and socioeconomic groups for a wide range of outcome measures. Low income, minority, and other vulnerable populations report more perceived exposure to weather related hazards. At the same time, these populations report lower levels of trust in NWS and are less likely to seek information about hazardous weather from government sources. Many of these subgroups had lower subjective and objective comprehension of severe weather warnings. However, Black and Hispanic respondents are more likely to have a plan for how to

TABLE D3. As in Table D1, but for severe weather risk comprehension for multilevel ordinal fixed-effects models.

	Subjective comprehension					Objective comprehension			
Variables	Understand difference between watches and warnings	Understand severe thunderstorm watches and warnings	Understand tornado watches and warnings	Understand maps	Understand radar images	Tornado watch or warning correct	Tornado watch size correct	Tornado warning time correct	Tornado watch time correct
Female	−0.007 (0.009)	−0.053*** (0.010)	−0.065*** (0.011)	−0.093*** (0.010)	−0.141*** (0.010)	0.003 (0.009)	−0.030*** (0.011)	−0.001 (0.010)	0.003 (0.010)
Black	−0.084*** (0.015)	−0.075*** (0.016)	−0.037** (0.017)	−0.121*** (0.016)	−0.126*** (0.017)	−0.084*** (0.016)	−0.046*** (0.017)	−0.100*** (0.014)	−0.047*** (0.015)
Asian	−0.156*** (0.022)	−0.172*** (0.023)	−0.166*** (0.023)	−0.147*** (0.023)	−0.153*** (0.023)	−0.087*** (0.022)	−0.055** (0.024)	−0.138*** (0.017)	−0.047** (0.019)
Other	−0.102*** (0.028)	−0.062** (0.029)	−0.082*** (0.031)	−0.075*** (0.029)	−0.089*** (0.030)	−0.023 (0.028)	0.000 (0.031)	−0.065*** (0.024)	−0.040 (0.025)
Hispanic	−0.042*** (0.013)	−0.010 (0.014)	−0.001 (0.015)	−0.005 (0.014)	0.014 (0.015)	−0.018 (0.014)	−0.054*** (0.016)	−0.021 (0.013)	−0.025* (0.013)
25–34	0.023 (0.018)	0.026 (0.019)	0.077*** (0.020)	−0.025 (0.018)	0.044** (0.019)	0.003 (0.019)	−0.007 (0.021)	0.042*** (0.016)	0.016 (0.017)
35–44	0.060*** (0.018)	0.062*** (0.019)	0.103*** (0.020)	−0.023 (0.018)	0.040** (0.020)	−0.021 (0.019)	−0.003 (0.021)	0.084*** (0.017)	0.034* (0.018)
45–54	0.083*** (0.017)	0.031 (0.019)	0.046** (0.020)	−0.028 (0.018)	0.030 (0.020)	0.069*** (0.018)	0.054** (0.021)	0.166*** (0.017)	0.039** (0.018)
55–64	0.108*** (0.017)	0.019 (0.019)	0.044** (0.020)	−0.067*** (0.018)	−0.011 (0.020)	0.097*** (0.018)	0.067*** (0.021)	0.172*** (0.017)	0.088*** (0.018)
65–102	0.115*** (0.016)	0.023 (0.019)	0.034* (0.020)	−0.060*** (0.018)	−0.043** (0.020)	0.103*** (0.018)	0.053*** (0.020)	0.134*** (0.017)	0.090*** (0.018)
High school	0.068 (0.041)	0.045 (0.044)	0.045 (0.045)	0.024 (0.043)	0.009 (0.043)	0.046 (0.042)	−0.013 (0.045)	−0.071* (0.040)	0.057 (0.036)
Some college	0.103** (0.041)	0.073* (0.043)	0.038 (0.045)	0.067 (0.043)	0.035 (0.042)	0.092** (0.041)	0.041 (0.045)	−0.067* (0.040)	0.044 (0.036)
Bachelor's degree	0.110*** (0.041)	0.047 (0.043)	0.008 (0.045)	0.088** (0.042)	0.043 (0.042)	0.104** (0.041)	0.042 (0.045)	−0.054 (0.040)	0.052 (0.036)
Postgraduate	0.135*** (0.041)	0.058 (0.043)	0.044 (0.045)	0.084** (0.043)	0.047 (0.042)	0.080* (0.041)	0.057 (0.045)	−0.067* (0.040)	0.049 (0.036)
\$50,000–\$100,000	0.024** (0.010)	0.033*** (0.012)	0.061*** (0.013)	0.041*** (0.012)	0.056*** (0.012)	0.016 (0.011)	0.035*** (0.013)	−0.004 (0.012)	−0.000 (0.012)
\$100,000 or more	0.014 (0.012)	0.057*** (0.013)	0.100*** (0.014)	0.080*** (0.013)	0.085*** (0.014)	0.011 (0.013)	0.038** (0.015)	0.001 (0.013)	0.012 (0.014)
Urban	−0.007 (0.010)	0.023* (0.012)	0.038*** (0.012)	0.005 (0.011)	0.011 (0.012)	−0.061*** (0.011)	−0.063*** (0.013)	−0.058*** (0.011)	−0.037*** (0.011)
Rural	0.011 (0.012)	0.011 (0.014)	0.024 (0.015)	0.011 (0.014)	0.043*** (0.015)	−0.008 (0.013)	−0.003 (0.016)	0.020 (0.015)	−0.017 (0.015)
CWA- and year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log likelihood	−3467.899	−4856.053	−5287.590	−4501.085	−5045.832	−4349.120	−5802.245	−4550.891	−4730.633
No. of obs	8320	8320	8320	8320	8320	8320	8320	8320	8320
R^2	0.069	0.064	0.093	0.070	0.090	0.063	0.052	0.103	0.048

TABLE D4. As in Table D1, but for tornado warning response for multilevel ordinal probability model estimates.

Variables	Take protective action	If you are at work or school	If you are with a small group	If you are with a large group	If you are at a store	If you are in a car	If you are sleeping
Black	0.009 (0.018)	−0.007 (0.013)	0.000 (0.013)	−0.000 (0.013)	0.019 (0.014)	0.023 (0.015)	0.039** (0.017)
Native	−0.064 (0.045)	0.035 (0.033)	−0.003 (0.034)	−0.020 (0.036)	−0.006 (0.039)	−0.024 (0.041)	−0.042 (0.044)
Asian	−0.008 (0.024)	−0.036* (0.019)	−0.046** (0.019)	−0.034* (0.019)	−0.080*** (0.022)	−0.115*** (0.023)	−0.094*** (0.024)
Other	−0.120*** (0.042)	−0.042 (0.034)	−0.027 (0.034)	−0.012 (0.035)	−0.090** (0.040)	−0.059 (0.038)	−0.039 (0.044)
Hispanic	0.022 (0.016)	−0.010 (0.012)	0.006 (0.012)	0.009 (0.012)	−0.003 (0.014)	0.005 (0.014)	0.035** (0.016)
CWA- and year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Log likelihood	−5753.618	−3203.395	−3255.408	−3656.895	−4398.694	−4541.018	−5718.034
No. of obs	8162	8162	8162	8162	8162	8162	8162
R^2	0.038	0.035	0.025	0.023	0.027	0.032	0.040

react in the event of hazardous weather, potentially reflecting their perceived or actual increased exposure (Hoffman et al. 2020) as well as the disparities in postdisaster-recovery resources (Emrich et al. 2019; McBride 2017; Méndez et al. 2020; Muñoz and Tate 2016; Nelson and Molloy 2021).

The results indicate a disconnect between the "better informed" and "get prepared" indicators in the WRN model. While Black and Hispanic respondents report that they are more prepared, they also report that they are less informed than White respondents and also trust government sources of weather information less. According to the FEMA survey, Black respondents felt they received less information about how to prepare than White respondents. This is consistent with findings in Senkbeil et al. (2014). This poses a challenge to government agencies such as the NWS or FEMA, since minority communities' efforts to prepare may be more vital given their higher exposure to hazards (Zanocco et al 2022; Sharpe and Wolkin 2022). But at the same time these efforts may not be as informed as they could be.

The value of improving weather forecasting is integrally linked to the use of forecasts to improve societal outcomes. The societal benefits of NWS investments will increase with understanding of user needs. To be most effective, this understanding must be precise, shareable, and systematically collected. Shareability of information about user needs requires that it be documented and archived instead of being distributed across the memories of individual NWS employees. Instead of relying on interactions at conferences, during emergencies, and unplanned user meetings, the NWS should systematically collect the information needed to meet user needs, ensuring that the information is appropriately representative and varies when needed to account for differences among users and geographies (i.e., ad hoc data collection is not likely to be representative of the population). Documentation and archiving of this information is important because it can then be studied and shared and used to inform the efficacy of existing or new products, services, and partnerships. The process should include a feedback loop to indicate when meeting a specific user need will require a low versus high level of effort, or when it is impossible to meet a need. The Severe Weather Society Survey and the FEMA Household Survey are excellent sources of information for this purpose. We advocate that these sources continue to be collected periodically so researchers and other key decision-makers (e.g., emergency managers) can have tools to better understand how these groups respond to different hazards. We are also excited to see efforts to expand the Severe Weather Society Survey to include other weather phenomena (e.g., tropical weather or flooding), create a Spanish language version (Krocak et al. 2022), and to survey core partners in addition to the general public.

Our findings suggest that there is considerable heterogeneity in severe weather reception, preparedness, and response by race and ethnicity and by socioeconomic status. To address

TABLE D5. As in Table D1, but for trust in weather sources for multilevel ordinal probability model estimates.

Variables	The NWS	State or local emergency managers	National TV (Weather Channel)	Regional or local TV	Family or friends
Black	−0.058*** (0.014)	−0.038** (0.015)	0.023 (0.014)	−0.024 (0.015)	0.030* (0.014)
Native	−0.063* (0.036)	−0.064 (0.035)	−0.076** (0.034)	−0.068* (0.033)	−0.03 (0.027)
Asian	−0.082*** (0.020)	−0.056*** (0.019)	−0.018 (0.018)	−0.026 (0.018)	0.006 (0.017)
Other	0.007 (0.030)	−0.013 (0.029)	0.035 (0.028)	0.003 (0.028)	0.018 (0.025)
Hispanic	−0.021* (0.014)	−0.009 (0.014)	−0.01 (0.013)	−0.004 (0.013)	0.025* (0.011)
Controls	Yes	Yes	Yes	Yes	Yes
CWA- and year-fixed effects	Yes	Yes	Yes	Yes	Yes
Log likelihood	−6603.775	−6759.922	−5419.421	−5744.233	−3959.163
No. of obs	10 341	10 341	10 341	10 341	10 341
R^2	0.157	0.090	0.210	0.106	0.304

TABLE D6. As in Table D1, but for severe weather preparedness for multilevel ordinal probability model estimates.

Variables	Small supply kit	Specific plan	Disaster supply kit	Specific meeting place	Practiced or drilled plan
Black	−0.017 (0.021)	0.029 (0.021)	0.016 (0.020)	0.042** (0.020)	0.044** (0.020)
Native	0.075 (0.046)	0.007 (0.044)	0.066 (0.047)	0.101** (0.044)	0.007 (0.041)
Asian	−0.069** (0.028)	−0.078*** (0.026)	−0.037 (0.028)	−0.082*** (0.024)	−0.054** (0.024)
Other	−0.065 (0.060)	0.050 (0.062)	−0.072 (0.056)	−0.058 (0.056)	0.005 (0.058)
Hispanic	0.043** (0.019)	0.050*** (0.019)	0.066*** (0.019)	0.037** (0.018)	0.014 (0.018)
Controls	Yes	Yes	Yes	Yes	Yes
CWA- and year-fixed effects	Yes	Yes	Yes	Yes	Yes
Log likelihood	−3696.823	−3572.509	−3523.369	−3224.712	−3051.830
No. of obs	5612	5612	5612	5612	5612
R^2	0.063	0.055	0.078	0.068	0.079

these important issues, NWS must continue to move towards a customer centric service delivery model that focuses on expanding relationships and partnerships across the weather enterprise and with historically underserved and vulnerable communities across the nation. History, culture, and hazard vulnerabilities are unique for each community. NWS must recognize that differences in knowledge about hazards and trust in the NWS will impact efforts to reach these communities, and identify the possible barriers that keep preparedness, communication, and response information from certain populations vulnerable to severe weather conditions. Nevertheless, because extreme weather risk is a product of hazard, vulnerability, and exposure, NWS must make a shift towards serving more diverse and vulnerable populations to build a WRN. NWS's place-based service delivery organizational structure can facilitate this transformation, but a culture shift in NWS operations is also needed to allow for more innovative, community-based solutions. This culture shift, for example, may include a new emphasis on a community engagement model that seeks to build the required trust between communities and NWS needed to facilitate the reception of and response to risk messages. This model would center on the lived experiences and local knowledge of communities moving the engagement beyond transactional to transformative whereby existing community networks and resilience are strengthened. Public health models have employed similar approaches including community-based health prevention and intervention methods (Galer-Unti and Tappe 2019) that leverage existing relationships and partners to create community advisory councils to inform strategies and initiatives, and other models to train trusted individuals and community organizations to serve as extended informational networks (New York Academy of Medicine 2010). Likewise, the cultural shift could also include the exploration of new strategic partnerships across the weather enterprise (including industry, academia, nonprofits, etc.) to enhance NWS's service delivery model to meet growing demand and provide local, culturally appropriate decision support. Meeting the needs identified in this study may also require NOAA and the NWS to invest more resources in bringing members of underserved populations into the weather enterprise at all levels. Finally, NWS must invest more in social science research and applications to better connect forecasts to decisions. This could include the establishment of an organizational function within NOAA that would conduct longitudinal social science surveys as well as near-real-time assessments during extreme events, utilizing a variety of data sources.

It is our hope that this research can help the NWS to understand some of the complexities that inform people's ability to receive, comprehend, and prepare for severe weather, and the

TABLE D7. As in Table D1, but for severe weather risk perceptions for multilevel ordinal probability model estimates.

Variables	At risk for extreme heatwaves	At risk for extreme rainstorms	At risk for droughts	At risk for floods	At risk for hurricanes	At risk for tornados
Black	0.019 (0.021)	0.013 (0.021)	0.028 (0.020)	0.043** (0.020)	0.050*** (0.019)	0.072*** (0.020)
Native	0.037 (0.044)	−0.025 (0.043)	−0.026 (0.039)	−0.021 (0.038)	0.035 (0.032)	0.031 (0.038)
Asian	−0.126*** (0.027)	−0.089*** (0.025)	−0.039 (0.026)	−0.051** (0.024)	−0.002 (0.022)	−0.015 (0.024)
Other	0.068 (0.063)	−0.046 (0.060)	0.050 (0.061)	0.081 (0.059)	0.049 (0.057)	0.110* (0.057)
Hispanic	−0.013 (0.019)	0.033* (0.019)	−0.007 (0.018)	0.042** (0.018)	0.049*** (0.016)	0.029* (0.017)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
CWA- and year-fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Log likelihood	−3620.512	−3659.288	−3038.431	−3195.337	−2229.770	−2936.625
No. of obs	5612	5612	5612	5612	5612	5612
R^2	0.138	0.092	0.170	0.118	0.293	0.159

need to develop the right partnerships with other public, private, and nonprofit organizations to build capacity and address these challenges. NOAA should work to ensure that everyone in the United States, especially the most vulnerable, are more resilient to the socioeconomic consequences of severe weather and other climate-related hazards. Using social science research to enhance information and service delivery will help NOAA to meet its goals and save lives.

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Data availability statement. Data and more results from this research are available online (https://dataverse.harvard.edu/dataverse/wxsurvey).

APPENDIX A

Variable Description

See Table A1 for a complete list of the survey questions associated with each WRN index.

APPENDIX B

Regression Sample Descriptive Statistics

The descriptive statistics are included in Tables B1–B9.

APPENDIX C

Sensitivity Analyses: FEMA National Household Survey

We examine the sensitivity of the WX Survey results using FEMA data (Tables C1–C3). Overall, the associations for the FEMA NHS results and the WX Survey results were comparable.

APPENDIX D

Sensitivity Analyses: Multilevel Ordered Logistic Models

The WX Survey contains natural hierarchical or clustered data. The first level consists of individual- and household-level characteristics of the respondent. The second level represents information from the CWA where the respondent lives (e.g., regional unemployment rate). Ignoring the importance of this clustering (individuals within CWAs) may render invalid many traditional regression analysis assumptions (Goldstein 2011). For example, because of this clustering, the assumption that observations are independent and identically distributed may be violated. Hence, multilevel models are commonly used for clustered data in econometric analysis (Gelman and Hill 2007; Smith et al. 2017).

In order to utilize the full information provided by the Likert-scale questions and address these clustering concerns we use a series of multilevel ordered logistic models as follows:

$$\Pr(y_{ij} > k|X_{ij}, k, u_j) = H(X_{ij}\beta + z_{ij}u_j - k_k), \tag{D1}$$

where $H()$ is the logistic cumulative distribution function. The measures of severe weather reception and response are for individuals i in NWS County Warning Area j; y_{ij}, is an ordered categorical response, following the Likert-scale convention of low to high, and k denotes the corresponding set of cut-points. Respondents in this framework are clustered in CWAs, with u_j representing the set of CWA random intercepts. X_j contains all the explanatory variables at the individual level, including race and ethnicity, and the explanatory variables at the CWA level (i.e., unemployment rate and percentage that do not speak English well). The model also controls for heterogeneity across survey years by using year fixed effects. We assume the errors are distributed independently of each other and distributed as Gaussian with means of zero and variances of σ_i^2 and σ_{ij}^2.

The ordered response model estimates the probability that score S_{ij} is less than k_1 to obtain the probability that the severe weather measure is in category 1. The probability that S_{ij} is between k_1 and k_2 will in turn give the probability that the severe weather measure is in category 2; similarly, for the remaining the severe weather categorical responses. S_{ij} is defined as $S_{ij} = X_{ij}\beta + z_{ij}u_j + e_{ij}$. For the binary dependent variables, we use multilevel logistic regression. The results of our sensitivity analysis, which are found to be robust across model specifications, are presented in Tables D1–D7.

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