Vaughn, C., K. Sherman-Morris, B. Gutter, and M. Brown, 2023: A change in the weather: Understanding public usage of weather apps. *J. Operational Meteor.*, **11** (11), 140-160, doi: https://doi.org/10.15191/nwajom.2023.1111.

Journal of Operational Meteorology
Article

A Change in the Weather: Understanding Public Usage of Weather Apps

COLE VAUGHN, KATHLEEN SHERMAN-MORRIS, BARRETT GUTTER, and MICHAEL BROWN
Mississippi State University, Mississippi State, Mississippi

(Manuscript received 14 July 2023; review completed 25 October 2023)

ABSTRACT

Weather information can now be accessed through a variety of different media. This study used a survey to determine if the weather app was the primary source for weather information in the United States and whether this was related to age and other personal characteristics. More than 75% of the sample reported using a weather app for general forecast information. In cases of severe weather, weather apps and websites were reported to be the top two primary sources. While younger demographics had more weather app users than older demographics, the weather app was still the most popular source among the older groups. The most popular apps were the pre-downloaded app on a phone, The Weather Channel's app, and the AccuWeather app. Participants who chose to use an app other than the pre-downloaded one reported higher self-perceived knowledge about, and interest in, weather. In addition, 80% of respondents reported getting severe weather notifications on their phone. The study's survey sample was heavily skewed toward a younger population and may not be generalizable to all socioeconomic demographics. Considering previous research, these results indicate a shift in the predominant forecast sources used by the public over the last 10–15 yr. Consequently, it has resulted in a widespread transfer of responsibility for interpreting and explaining the forecast. A majority of the public—untrained in meteorology—is now interpreting the forecast on their own without the help of a broadcast meteorologist as would be present in a television forecast, making the forecast open to misinterpretation and false expectation. This study calls for continued research to combat misinterpretation and to enhance weather apps and mobile notifications with more personalized information that can aid weather-related decision making to make weather apps a strong leader in forecast messaging.

1. Background

Prior to 2008, <10% of the mobile phone market had a smartphone, and this was even after the release of the Apple iPhone (https://www.comscore.com/Insights/Blog/US-Smartphone-Penetration-Surpassed-80-Percent-in-2016). By 2019, 81% of Americans owned a smartphone (https://www.pewresearch.org/internet/fact-sheet/mobile/#:~:text=Mobile%20phone%20ownership%20over%20time%20%20%20,%20%2081%25%20%2059%20more%20rows%20). This explosion of technology brought about many changes to the way most people live. Phone calls and text messages had already brought a new form of connectivity to the world prior to this time, but the smartphone changed the mobile phone into a small computer. With that change came (1) the ability to use the internet while on the go and (2) the invention of apps.

A smartphone app is software that accomplishes a task or provides information on the smartphone. For this work, a weather app is considered a smartphone application whereby a user can obtain up-to-date weather forecasts and information. Most smartphones come with a weather app already installed and ready for use before the consumer even buys and uses the phone. In just over a decade, a method for acquiring weather information went from virtually nonexistent to almost universal.

This research investigates the public's primary source for weather information during both routine and severe weather and looks to see if demographic characteristics have any effect on whether someone chooses to use a weather app as opposed to another source. It also seeks to understand which weather app most people use, when they use it, and whether their self-perceived weather knowledge and interest factor into

Corresponding author address: Cole Vaughn, Mississippi State University, Mississippi State. MS 39762
E-mail: cv441@msstate.edu

their weather app choice. Finally, this study examines the public's enabling of smartphone notifications as a way to be notified about weather information. The goal of this research is to understand whether a shift in weather forecast sources has occurred and what implications this shift could have on the communication of weather information and its interpretation by members of the public.

a. *Shift in weather forecast sources*

In the recent past, television was considered to be the primary way that the public received weather information (Lazo et al. 2009; Demuth et al. 2011). While these studies were published shortly after the invention of the smartphone, the massive expansion of smartphone usage had not yet occurred. Thus, the full effect of the smartphone on the weather forecast market had not yet been felt. Similarly, the subsequent rise in streaming services and decrease in subscription to traditional cable television services has changed what type of television people have access to and how they watch it (https://www.theguardian.com/tv-and-radio/2019/jul/24/young-people-uk-abandon-tv-news-almost-entirely-ofcom). This intrinsic change within the source also likely has had impacts on how people receive a weather forecast.

More recent studies seem to show a gradual change in how the public is receiving its weather forecasts. A study of college students found that an app was their primary way of getting weather forecast information (Phan et al. 2018), though these results may not have been representative of older populations. Older age groups are typically slower to adopt new technology (Charness and Bosman 1992). However, 80% of Americans have a smartphone (https://www.pewresearch.org/internet/fact-sheet/mobile/#:~:text=Mobile%20phone%20ownership%20over%20time%20%20%20,%20%2081%25%20%2059%20more%20rows%20), indicating that smartphones are being adopted by more than just college students. Consequently, it would be reasonable to assume smartphone weather apps also are being adopted by older demographics. This study expands weather app usage research to include participants in all age demographics.

While it is likely that many differences exist between smartphone usage in North America and eastern Asia, a study in Hong Kong found that those aged 45–64 preferred a smartphone as their source for weather information (Chan et al. 2017). However, smartphone usage does not indicate use of a weather app specifically. As of the late 2010s, Nunley and Sherman-Morris (2020) found that the weather app was strongly challenging television as the dominant medium for weather information. Combined with the overall decline in local television viewing (Nix-Crawford 2017), the previously mentioned studies would suggest that the weather app is becoming a popular, if not the most popular method by which the public receives weather information. Answering the question of which information medium is most commonly used is important to understand how to reach the greatest number of people with pertinent weather information and to provide a focus for where development and improvement of weather forecast media should occur.

While it is reasonable to assume that the weather app is potentially the most common way to get weather forecast information, other competing sources, especially television, still have significant support in severe weather (Sherman-Morris 2010; Perreault et al. 2014; Reuter and Spielhofer 2017; Silva et al. 2017; Stokes and Senkbeil 2017; Sherman-Morris et al. 2020b). For instance, television was cited as a source of information about tornado warning information by >40% in an online survey (Sherman-Morris et al. 2022) However, annual surveys of the public, conducted since 2017 by the Institute of Public Policy Research and Analysis at the University of Oklahoma, have shown a decline in the number of people learning about the issuance of tornado warnings on television along with a simultaneous increase in the number of people learning about tornado warnings via automated text messages or phone notifications (Silva et al. 2017, 2018, 2019; Krocak et al. 2020, 2021; Bitterman et al. 2022). By 2022, television as well as automated text messages and phone notifications were used by approximately the same number of people (Bitterman et al. 2022). Thus, a shift in sources even appears to be occurring in severe weather. Even if a person still considers the television to be their primary weather source, the weather app along with smartphone notifications can still play an important role in alerting the individual of the threat (Sherman-Morris 2010; Perreault et al. 2014; Jauernic and Van Den Broeke 2017; Silva et al. 2017).

b. *Weather app usage*

There are many different factors that affect app usage behavior. For example, app usage may directly or indirectly be influenced by the user's device type, personality, gender, age (van Deursen et al. 2015; Anshari et al. 2016), location, as well as time of day (Qiao et al. 2016). Usage may also be affected by the type of app being used. As mentioned previously, most smartphones come with weather apps pre-downloaded. However, Bryant et al. (2016) found that a slim majority of their respondents downloaded a different weather app. With hundreds of weather apps on the market, there are plenty of options for consumers to find exactly what they want. Consumers that download a weather app want more data (Phan et al. 2018) and have greater trust in it than those who use the pre-downloaded app (Bryant et al. 2017). Research also has shown that individuals who access specialty weather websites have a higher perceived knowledge about the weather (Nunley and Sherman-Morris 2020). It is not yet understood whether consumers who download their own app rate their weather knowledge or interest higher than those who use the pre-downloaded app.

Location and the broader social context will impact not only what type of app is used, but also if it is even being used at all. Qiao et al. (2016) described what types of apps are most often used in different locations. Entertainment and connectivity apps, such as YouTube and Facebook, are often used at home. Commuting may involve a mix of getting ready for the workday with emails, as well as entertainment similar to home. At work, communication apps and business or market-related apps are common, in addition to weather apps. Social media is often used when at an entertainment establishment or when relaxing. However, the social context is important to consider along with location (Shepard et al. 2010). If consumers are busy, traveling, shopping, or with a group of people, they may not use their phones as much, which in turn affects app usage (Oulasvirta et al. 2005). Even if the social context does not affect a consumer's app usage, it may affect their response to any information gleaned from the app (Bean et al. 2015). For example, if a severe weather alert pops up on the phone, the consumer may see it, but reacting to the message could be altered if the person is with friends, busy, or perhaps feels safe at home and does not take action—despite actually receiving the warning (Bean et al. 2015).

Time of day has also been shown to heavily influence what apps are used. Qiao et al. (2016) pointed out that each type of app has a distribution of daily usage that is similar from day to day, though usage tends to be different for different types of apps. Temporally, app usage transitions from news and information gathering early in the day to business and communication during the day to entertainment by the end of the day (Qiao et al. 2016). News and weather app usage have been found to typically occur in the morning (Böhmer et al. 2011).

Users also may find different features of an app more useful or relevant. Perceived value is mentioned by Kaasinen (2005, p. 73) as "the key features of the product that are appreciated by the users." Phan et al. (2018) found the hourly forecast, 5-day forecast, severe weather alerts, chance of rain, and current conditions are in the top five features of the app—indicating that the app is used for both general forecast information and severe weather. However, it is possible that the usage could be distinct between the two different situations in terms of usage session length, features used, and the frequency of usage.

c. Advantages of weather apps

Regardless of the weather app's ubiquity, this does not necessarily mean that most people will adopt the new technology. According to the Technology Acceptance Model, in order for technology to be adopted it needs to be considered easy to use and useful to the consumer (Davis 1989). The usefulness referred to by Davis is not the usefulness of the forecast, but rather of the new technological medium. For a weather app to be adopted, the consumer will have to consider the app both a useful way of getting the weather forecast and easy to use.

There are many reasons why the weather app is gaining so much traction, and many of these reasons make the app superior to television when considered in light of the Technology Acceptance Model. Weather apps contain location-based services that give a forecast for either your local town or even your specific geographic position system location. This was found to be attractive simply because it is more personalized to an individual (Kaasinen 2005). Television weather forecasts are generally given for a region or for the main towns of the region. When it comes to specificity of location and personalization, television cannot match the app. Convenience is another advantage for the weather app (Phan et al. 2018). Users can access the forecast at any time and virtually any location, instead of being confined to a certain time and place for a television forecast (Kaasinen 2005).

Weather apps also make use of notifications that take advantage of both convenience and location-based services so that instead of consumers even needing to seek out a forecast or weather information, the information comes to them (Zabini 2016; Sherman-Morris et al. 2020a). The notification can contain forecast information or a severe weather alert that pops up on the screen of their smartphone. Because the frequency and deployment of notifications can be controlled by app developers and app managers, this can be used to encourage app usage.

In times of crisis or urgent situations, "getting the right information to the right person at the right time" is invaluable (Hagar 2015, p. 10). With notifications, the weather app has the ability to target specific information to specific people at specific times in a way that television cannot. This makes the app a valuable tool when severe weather situations arise. However, if notifications are not enabled, some of the value of the app is lost. This research seeks to understand the public's enablement and reception of notifications. Five hypotheses were tested in this research, as follows:

H1: The weather app is the primary way the public gets general forecast information.

H2: The television is the primary way the public gets severe weather information.

H3: Lower age brackets will include more weather app users than higher age brackets.

H4: Individuals with a higher self-perceived weather knowledge will be more likely to use another app besides the pre-downloaded one.

H5: Individuals with a higher self-perceived weather interest will be more likely to use another app besides the pre-downloaded one.

2. Data and methods

A survey (refer to the appendix) was deployed in November 2021 asking participants about their weather app usage. This method has been used in numerous other studies for the purpose of understanding app and smartphone usage as well as for investigating weather information acquisition (Anshari et al. 2016; Bryant et al. 2016; Chan et al. 2017; Phan et al. 2018). The survey was open to more than just weather app users but attempted to obtain a representative sample of the public in order to gauge how many participants use the app versus those who use television or another means to get weather information. The survey asked participants to provide their demographic information—age, gender, race, ethnicity, education level, and urban/rural classification—in addition to rating their self-perceived weather knowledge and interest in weather. Participants were also asked about their smartphone ownership and usage. Additional questions asked participants about their specific weather app, their usage of it, and whether or not it is the pre-downloaded app that came on their phone.

The survey was published in Qualtrics and distributed via Prolific—a survey panel that includes individuals from all over the world who participate in surveys for compensation. The average time taken to complete the survey was <6 min and participants were compensated at a rate of about $0.20 min^{-1}. Recruitment requirements specified that the survey sample be nationally representative of the United States. Survey responses from 600 people had been collected within 16 h. The use of Prolific meant that participants had to be technologically savvy enough to operate a computer and to register as a participant with the company. This could have resulted in a more technologically savvy survey sample for this study as compared to the United States population, which may have resulted in greater acceptance of weather apps. There also was no indication of the income of participants, and this may limit the results' generalizability to a vulnerable audience. Prolific participants also have the option to choose which surveys they take. Prolific has a list of different surveys presented to each registered participant, and the participant then chooses which surveys—if any—they want to take. Thus, individuals may have chosen to participate in this study because it interested them. Consequently, the sample of people who have a higher interest in, or knowledge about, the weather may be greater than typical.

The Statistical Package for the Social Sciences (SPSS) was used for all statistical analyses, and all statistical tests used were nonparametric due to the data's non-normality. Hypotheses 1 and 2 were each based on a survey question asking about the participant's main source for weather information both in general and in times of severe weather, respectively. Confidence intervals were calculated for each source listed in the answer categories to these questions. The number of people answering in each category could then be compared between sources while still acknowledging possible variance by using a confidence interval. The sample size of the survey was not small (N = 600); however, the data for these questions were bootstrapped to increase confidence in the data. Bootstrapping is a statistical method that augments an original sample by creating a group of new samples of equal size to the original, called bootstrapped samples, with each new response in the bootstrapped samples having been randomly selected from the original sample's values (Efron and Tibshirani 1994). This method gives greater confidence that the sample distribution matches the population's distribution. When calculating confidence intervals, the number of bootstrapped samples or resamples typically is 1000 or more (Efron and Tibshirani 1994). The bootstrapped data were then used to create confidence intervals for each weather information source to compare which sources were most common.

Hypothesis 3 assessed whether age was related to choosing the weather app as the primary source for weather information. The hypothesis was evaluated using the Kruskal-Wallis (KW) test (McKight and Najab 2010a) that compared the mean ranks of age distribution along each weather information source for significant differences. When checking for relationships between other demographic characteristics of a nominal nature such as gender, race and ethnicity, education, and urban/rural living environment, a chi-squared test would typically be used to check for different distributions of demographics across different weather information sources. When conducting a chi-squared test, a table is created in this case using the categories of a specific demographics and the categories of weather information sources. The expected frequencies or expected distribution of the demographic categories along the weather information sources are calculated. In order for the chi-squared test to be valid, ≥80% of the cells in the table should have expected frequencies of ≥5. If they do not, as is often the case with small sample sizes or many categories in one or both variables, a Fisher's exact test is recommended in place of chi-squared (Kim 2017). The purpose and function of the test is the same as chi-squared. The demographic data of this study violated the expected frequencies assumption because of the large number of categories in both the weather information source variable and the demographic variables—resulting in the use of a Fisher's exact test to check for a relationship between demographic characteristics and weather information source used. SPSS introduced a Monte Carlo algorithm that estimates the p value of the Fisher's exact test by resampling similar to the bootstrapping method mentioned previously (Mehta and Patel 2010). The number of resamples created was 10 000 and the confidence level of the p value was set at 99.9%. While not exact, the Monte Carlo estimate is considered a reliable method of estimating the significance of a Fisher's exact test (Mehta and Patel 2010). Due to the number of categories in most variables, the Monte Carlo estimate was used for all Fisher's exact tests except the one involving gender.

Finally, hypotheses 4 and 5 were evaluated using a Mann-Whitney U test to check for a significant difference in the mean rank of weather knowledge and interest scores between those who use a pre-downloaded app and those who found their own app to download (McKight and Najab 2010b).

3. Analysis

a. Survey sample

The sample included 600 people from across the United States. It had some variation from what would be considered nationally representative of the United States. The deviations can be seen in the results of the demographic related questions presented in Table 1. The only major differences between the survey demographics and the 2020 United States Census existed in race and ethnicity data, education attainment, and age distribution. There were fewer individuals who identified as White and Hispanic or Latino in the survey than in the census. The survey participants were more educated, with more respondents having a bachelor's degree or some college experience compared to census data. Another major discrepancy occurred in age distribution where the sample was significantly younger than the United States population.

Survey participants who provided a valid zip code (N = 554) were located in 41 of the 50 United States, as well as the District of Columbia (Fig. 1). New England was noticeably void of participants, along with Wyoming and North Dakota.

This survey contained questions about severe weather without providing a standard definition for severe. Thus, the inclusion of nonsevere, yet hazardous or extreme weather in a participant's perceived definition, was possible. However, of the people who provided their zip code, 430 (77.6%) of them were east of the continental divide where severe convective weather is often experienced during some season. An experience with traditionally defined severe weather does not indicate that a person would answer questions

Table 1. Comparison of survey sample demographics with 2020 United States Census demographics of ages 18+ for gender (https://www.census.gov/data/tables/2020/demo/age-and-sex/2020-age-sex-composition.html), race and ethnicity (https://www.census.gov/data/tables/time-series/demo/popest/2020s-national-detail.html), education level (https://www.census.gov/data/tables/2020/demo/educational-attainment/cps-detailed-tables.html), urban/rural living environment (https://www.census.gov/programs-surveys/geography/guidance/geo-areas/urban-rural/2020-ua-facts.html), and age (https://www.census.gov/data/tables/2020/demo/age-and-sex/2020-age-sex-composition.html).

	Demographic Characteristics	Survey Participants	2020 Census Data
Gender **N = 600**	Male	289 (48.2%)	48.5%
	Female	292 (48.7%)	51.5%
	Transgender Male	3 (0.5%)	-
	Transgender Female	1 (0.2%)	-
	Gender Variant/Non-Conforming	14 (2.3%)	-
	Prefer not to identify	1 (0.2%)	-
Race & Ethnicity* **N = 600**	White	424 (70.7%)	77.3%
	Black or African American	74 (12.3%)	13.0%
	Asian	39 (6.5%)	6.2%
	Hispanic or Latino	39 (6.5%)	16.6%
	Mixed race	19 (3.2%)	2.0%
	Middle Eastern or North African	3 (0.5%)	-
	American Indian or Alaska Native	1 (0.2%)	1.2%
	Other	1 (0.2%)	-
Education Level **N = 600**	Some High School	7 (1.2%)	6.5%
	High School Graduate	90 (15.0%)	27.8%
	Some College	189 (31.5%)	17.5%
	Associate's Degree	53 (8.8%)	10.1%
	Bachelor's Degree	176 (29.3%)	22.1%
	Advanced Degree	82 (13.7%)	12.7%
Urban/ Rural Living Area **N = 600**	Urban area	183 (30.5%)	Urban 80.0%
	Suburban area	320 (53.3%)	
	Rural small town	65 (10.8%)	Rural 20.0%
	Rural outside of town	29 (4.8%)	
	Not sure	3 (0.5%)	
Age **N = 600**	18–29	334 (55.7%)	20.7%
	30–39	147 (24.5%)	17.4%
	40–49	58 (9.7%)	15.7%
	50–59	46 (7.7%)	16.3%
	60+	15 (2.5%)	30.0%

*More than one choice was possible for race and ethnicity.

Figure 1. Each dot on the map represents the location of the survey participants who provided a zip code. *Click image for an external version.*

according to that definition, though the experience could help shape their perception of what severe weather is.

b. Primary weather information source

H1: The weather app is the primary way the public gets general forecast information.

This hypothesis was evaluated using a bootstrapped confidence interval (95%) and a 1000 resampling process. The results showed that between 74.0 and 80.5% of the sample used a weather app or widget to get their forecast (Table 2), far exceeding the next most common source—a website on the internet. Television did not even account for 10% of the sample. This led to the conclusion that the weather app (or widget) is the primary way that the public gets a weather forecast, a change from research published near 2010 that showed television as the primary source (Lazo et al. 2009; Demuth et al. 2011).

c. Weather information sources during severe weather

H2: The television is the primary way the public gets severe weather information.

Participants were asked to identify *all* of the sources they turn to during severe weather after having been alerted about it, providing the possibility of multiple responses. The hypothesis was evaluated by performing another 95% confidence interval with a 1000 resample bootstrap. The most common response was a website on the internet followed closely by a weather app (Table 3). Television was chosen more frequently as a source for severe weather information compared to general forecast information, though it was still a distant third source on the list. Interestingly, social media saw more popularity during severe weather potentially due to citizens looking for severe weather reports and pictures or messages from friends or family. These results do not lend credence to H2, and are thus at odds with recent research findings (Sherman-Morris 2010; Perreault et al. 2014; Reuter and Spielhofer 2017; Silva et al. 2017; Stokes and Senkbeil 2017; Sherman-Morris et al. 2020b). Thus, television may in fact not be the primary way that the public gets severe weather information. Attention also should be drawn to subtle differences in previous studies that seeked to understand the *most used* source for information (Silva et al. 2017, 2018, 2019; Phan et al. 2018; Krocak et al. 2020, 2021; Nunley and Sherman-Morris 2020; Bitterman et al. 2022) and the *most important* source for information (Sherman-Morris et al. 2020b), as these may not be the same.

d. Weather app user demographics

1) DEMOGRAPHICS PER WEATHER INFORMATION SOURCE

Several demographic characteristics were asked of participants in the survey including age, gender, race and ethnicity, education level, and urban/rural living environment. Because age was the only interval level variable, a KW test was performed to determine if there were any significant differences in the mean age of users of each type of weather information source.

H3: Lower age brackets will include more weather app users than higher age brackets.

The KW was significant and led to rejection of the null hypothesis that the ages were the same for all weather information sources ($H = 38.315$, $p < 0.001$). Following a significant KW test, SPSS includes the Dunn-Bonferroni post-hoc test that compares the means between only two of the categories out of the multiple included in the KW test. Thus, the specific weather information source categories that had significantly different age demographics than others were identified. When multiple post-hoc tests are run, the level of significance ($\alpha = 0.05$) must be divided by the number of tests performed to get a new, (lower) threshold level of significance. Because there were five different categories to compare, that meant 10 different post-hoc tests were run resulting in a threshold significance level

Table 2. Main source for getting weather forecast information.

What would you describe as your main source for getting a weather forecast?			
		95% Confidence Interval	
***N* = 600**	**Frequency**	**Lower**	**Upper**
Weather App or Widget	464	74.0%	80.5%
A Website on the Internet	87	11.7%	17.3%
Television	37	4.3%	8.2%
Social Media	7	0.3%	2.0%
Other	5	0.2%	1.0%
Radio	0	0.0%	0.0%

Table 3. Typical information sources during severe weather after the individual has been alerted of the threat.

After you have been initially alerted about severe weather, what source or sources do you typically go to next for more information? Check all that apply.			
		95% Confidence Interval	
***N* = 599**	**Frequency**	**Lower**	**Upper**
Weather App or Widget	305	46.8%	54.8%
A Website on the Internet	277	42.2%	50.0%
Television	137	19.5%	26.0%
Social Media	108	15.2%	21.2%
Other	18	1.7%	4.3%
Radio	6	0.3%	1.8%

of 0.005. These post-hoc tests determined that the only significant differences in the mean age of each source were between weather app or widget and a website as well as weather app or widget and television ($p = 0.003$, $p < 0.001$). The mean age for weather app or widget users was significantly lower than the mean age of television and website users (Table 4).

While there were weather app or widget users of all ages, the mean age (29.64) was lower than all other sources except social media (28.29). The survey data were divided into different age categories (18–30, 31–40, 41–50, 51–60, 61+), and the use of different sources was then compared. Overall, weather apps or widgets still dominated every age group. However, the percentage of people in each age group that used weather apps decreased with age.

The other demographic variables examined were nominal level, thus a Fisher's Exact test was used (Table 5). The results of the Fisher's Exact test for gender and weather information source were statistically significant ($N = 582$, $p < 0.001$). Websites and television were used by more males, and the weather app was used by slightly more females.

The Fisher's Exact test for race and ethnicity and weather information source was not significant ($N = 600$, $p = .371$). Despite a lack of significance, further investigation showed that Black or African American individuals were more likely to use television and White and Asian individuals were more likely to use a website than the other race and ethnicity categories. These two observations were not likely enough to make the whole test come back as significant.

Education levels "high school graduate" and "some high school" were combined in the Fisher's exact test between education level and weather information source due to similarities between the two categories and the small number of "some high school" respondents in this sample. The test result was not significant, indicating

Table 4. Mean age of individuals in each primary weather information source category.

Primary Weather Information Source *N* = 599	**Mean Age**
Weather App or Widget	29.64
A Website on the Internet	33.87
Television	40.51
Social Media	28.29
Other	44.60
Radio (N = 0)	N/A

no relationship between education level and source type (*N* = 597, *p* = .468).

Finally, the effect of urban/rural classification on weather information source was examined using a Fisher's exact test. The test showed no significance (*N* = 600, *p* = .378).

2) PARTICIPANT CHARACTERISTIC'S EFFECT ON TIME AND FREQUENCY OF APP USAGE

Characteristics of the participant and their smartphone were considered when evaluating at what time they used their app and how often they used it. When asking the time of day that participants used their app, most (66.5%) reported using it in either early or late morning (Table 6). To provide customers with accurate weather information when customers are most inclined to seek it out, app developers should ensure that the traditional forecast and any supplemental forecast videos or write-ups are updated by early morning. They also may wish to promote updated information from the previous day, as it may have been missed by many app users. App developers also could investigate ways in which to alert app users to significant forecast changes that are occurring at times of the day when app usage is lower—perhaps through a notification.

A KW test was run to test the relationship between age and the time of the day an individual uses their weather app. Early morning app users tended to be older than late morning app users (*H* = 19.443, *p* = 0.008, N = 563).

A Fisher's Exact test was used to test the relationship between weather app usage frequency and smartphone brand, smartphone reliance, gender, and time of day of app usage. Weather app usage frequency was found to have a significant relationship with smartphone brand, gender, and time of day of usage. Apple smartphone users are more likely to check their weather app multiple times per day compared to other brands' users (Table 7). Furthermore, females tended to use their weather app slightly more often than males (Table 7). Those who check their weather app in the early morning or late morning are more likely to check the app more frequently too as opposed to those who check it later in the day. This is a logical conclusion as those who check their app in the morning, early or late, consider weather information important enough to check it earlier in their day. Similarly, those who check a weather app frequently likely consider a weather forecast to be important information. Those who check the forecast late in the day or less frequently are more likely to put less importance or interest in that type of information.

e. Weather app notifications usage

The survey asked participants to choose from a list of all notifications that they had enabled (Table 8). This question intentionally refrained from asking what weather app notifications a person received, as there is likely to be confusion among participants as to whether a notification is coming from an app or if it is a Wireless Emergency Alert (WEA). With the unlikelihood of avoiding this confusion, this survey question was phrased to include any type of weather notification. In doing so, the researchers were able to see how many people were getting weather information pushed to them.

The most likely notification to be confused with WEA is a severe weather alert. Nearly 80% of the sample reported getting severe weather notifications on their smartphones (Table 8). Beyond that, the usage of notifications dropped off markedly. Approximately 25% of the sample got notifications about weather headlines and nearby rain. These two notifications are most likely coming from a weather app or potentially a news app and are not likely confused with WEA. There was still a small group of people (14.9%) that reported not getting any weather notifications on their phone. Thus, the utility of the smartphone as a weather-alert system is not absolute, as there are still some people who are not affected by WEA and weather app notifications.

Given the confusion surrounding severe weather alert notifications and what source is responsible for them, it is unclear whether a majority of weather app

Table 5. Fisher's exact test results and distribution of respondents by age bracket. (*) indicates significance.

Table	Demographic Characteristics	Weather App N (% of demographic characteristic using source)	Website	Television	Social Media	Radio	Other	Fisher Test Value	*p* value
Gender *N* = 582	Male	195 (67.5%)	62 (21.5%)	26 (9.0%)	4 (1.4%)	0 (0%)	2 (0.7%)	40.32	<.001*
	Female	253 (86.6%)	23 (7.9%)	11 (3.8%)	2 (0.7%)	0 (0%)	3 (1.0%)		
Race & Ethnicity *N* = 600	White	323 (76.2%)	67 (15.8%)	24 (5.7%)	5 (1.2%)	0 (0%)	5 (1.2%)	37.81	.371
	Black or African American	55 (74.3%)	7 (9.5%)	11 (14.9%)	1 (1.4%)	0 (0%)	0 (0%)		
	Asian	33 (84.6%)	6 (15.4%)	0 (0.0%)	0 (0%)	0 (0%)	0 (0%)		
	Hispanic or Latino	32 (82.1%)	4 (10.3%)	2 (5.1%)	1 (2.6%)	0 (0%)	0 (0%)		
	Mixed race	17 (89).5%)	2 (10.5%)	0 (0.0%)	0 (0%)	0 (0%)	0 (0%)		
	Middle Eastern or North African	3 (100.0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)		
	American Indian or Alaska Native	1 (100.0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)		
	Other	0 (0%)	1 (100.0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)		
Edu. Level *N* = 597	High School	74 (76.3%)	15 (15.5%)	6 (6.2%)	2 (2.1%)	0 (0%)	0 (0%)	14.48	.468
	Some College	147 (77.8%)	30 (15.9%)	10 (5.3%)	1 (0.5%)	0 (0%)	1 (0.5%)		
	Associate's Degree	37 (69.8%)	10 (18.9%)	5 (9.4%)	1 (1.9%)	0 (0%)	0 (0%)		
	Bachelor's Degree	143 (81.3%)	22 (12.5%)	8 (4.5%)	2 (1.1%)	0 (0%)	1 (0.6%)		
	Advanced Degree	60 (73.2%)	10 (12.2%)	8 (9.8%)	1 (1.2%)	0 (0%)	3 (3.7%)		
Urban/ Rural Living Area *N* = 600	Urban area	143 (78.1%)	27 (14.8%)	10 (5.5%)	3 (1.6%)	0 (0%)	0 (0%)	17.67	.365
	Suburban area	251 (78.4%)	45 (14.1%)	20 (6.3%)	2 (0.6%)	0 (0%)	2 (0.6%)		
	Rural small town	48 (73.8%)	9 (13.8%)	5 (7.7%)	1 (1.5%)	0 (0%)	2 (3.1%)		
	Rural outside of town	20 (69.0%)	5 (17.2%)	2 (6.9%)	1 (3.4%)	0 (0%)	1 (3.4%)		
	Not sure	2 (66.7%)	1 (33.3%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)		
Age *N* = 600	18–30	299 (83.5%)	40 (11.2%)	13 (3.6%)	4 (1.1%)	0 (0%)	2 (0.6%)	-	-
	31–40	99 (74.4%)	25 (18.8%)	6 (4.5%)	3 (2.3%)	0 (0%)	0 (0%)		
	41–50	36 (64.3%)	10 (17.9%)	8 (14.3%)	0 (0%)	0 (0%)	2 (3.6%)		
	51–60	23 (60.5%)	8 (21.1%)	7 (18.4%)	0 (0%)	0 (0%)	0 (0%)		
	61+	7 (46.7%)	4 (26.7%)	3 (20.0%)	0 (0%)	0 (0%)	1 (6.7%)		

users have their notifications turned on. When excluding severe weather notifications from the list, 41.3% of respondents said they got at least one of the other notifications on the list. However, it can be said that a large majority of weather app users do report receiving a notification of some kind on their smartphone regarding severe weather.

f. Weather knowledge and interest of weather app users

H4: Individuals with a higher self-perceived weather knowledge will be more likely to use another app besides the pre-downloaded one.

H5: Individuals with a higher self-perceived weather interest will be more likely to use another app besides the pre-downloaded one.

Table 6. The time of day participants reported using the weather app most frequently.

What time of day do you most frequently use your weather app? *N* = 563	Frequency	Percentage
Overnight (Midnight - 6am)	3	0.5%
Early Morning (6am - 9am)	232	38.7%
Late Morning (9am - Noon)	167	27.8%
Early Afternoon (Noon - 3pm)	47	7.8%
Late Afternoon (3pm - 6pm)	26	4.3%
Early Evening (6pm - 9pm)	24	4.0%
Late Evening (9pm - Midnight)	24	4.0%
Anytime you are bored	40	6.7%

To begin evaluating these hypotheses, questions were asked about the number of weather apps participants had, whether they had downloaded a weather app before, and which app they preferred—the pre-downloaded app or the one they downloaded. A large majority (74.1%) of people only have one weather app on their phone. Only a small majority (56.8%) stated that they had downloaded a weather app before, which would indicate that a sizable share of the population is using the weather app that came on their smartphone. Interestingly, >37.9% who had downloaded an app still preferred the pre-downloaded app instead of the one they chose to download. The most frequent apps chosen for download (Table 9) included The Weather Channel (47.5%), AccuWeather (31.8%), Weather Underground (10.7%), and local news station apps (9.7%).

The sample was then divided into two groups—those who had downloaded a weather app and those who had not—based on their previous indication. The survey then asked participants to rate their weather knowledge and weather interest on a Likert scale. The data from these two questions were recoded as 1–5 interval data. A mean score was then calculated for each recode for both groups of people—those who had downloaded an app and those who had not. Mann-Whitney U tests were then run to compare the means.

The mean self-assessed weather knowledge rating of those who had not downloaded a weather app (2.94, $N = 243$) was lower than that of people who had downloaded an app (3.17, $N = 318$). Mean weather interest was also lower for the group that had not downloaded an app (3.03, $N = 243$), in comparison to its counterpart (3.38, $N = 319$). The Mann-Whitney U test for weather knowledge led to the rejection of the null hypothesis and showed that those who download a weather app do have a higher self-assessed weather knowledge rating ($U = 4.128$, $p < 0.001$). Similarly, the Mann-Whitney U test rejected the null hypothesis for weather interest, indicating that those who download an app have a higher interest in weather than those who did not download a weather app ($U = 4.932$, $p < 0.001$).

4. Discussion and conclusions

a. A shift in forecast information sources

The results of this work indicate a massive shift in the source from which people get a weather forecast, building on the findings of Phan et al. (2018), Chan et al. (2017), and Nunley and Sherman-Morris (2020) who indicated a growth in weather app usage. In a 2006 survey, Lazo et al. (2009) found that >70% of people got a weather forecast from television at least once per day. Now, nearly 15 yr after that study was published, the weather app is the most popular (and primary) source for weather information among all age brackets. While this is especially true in lower age brackets—consistent with Phan et al.'s (2018) findings in a college-aged group of individuals—questions exist surrounding how far this truth extends into older age brackets. Yet the results of this research, though limited by the small number of people in older age brackets, indicate that weather apps are dominant even among older groups, though to a lesser extent.

Furthermore, websites and weather apps were the leading sources of information in severe weather situations. Interestingly, this conclusion differs from the findings of much of the literature focusing on weather information sources during severe weather. Several studies from 2017 found that television was the most common source used for alerting or information during a tornado warning (Silva et al. 2017; Stokes and Senkbeil 2017) and emergency situations (Reuter and Spielhofer 2017). Sherman-Morris et al. (2020b) found that local television was the most important source—though not necessarily most popular—for information during a hurricane. These studies still presented a strong indication that other sources were used, including digital sources, but they found television to be at the top. The 2022 survey from the Institute of Public Policy Research and Analysis indicated that, for tornado warnings, television and automated text messages and phone notifications were approximately tied as the top information resources followed by sirens and internet (Bitterman et al. 2022). Another study published in

Table 7. Fisher's exact test results testing for relationship between weather app usage frequency and smartphone reliance, gender, time of day of app usage, and smartphone brand.

		Weather app usage frequency N (% of participants who use it at this frequency who have characteristic to left)						
		Multiple times per day	Once per day	More than once per week, but not daily	Once per week	Less frequently than once per week	Never	Fisher Test Value (*p* value)
Smartphone Reliance (How easily one could function without a smartphone) *N* = (594)	Very Easily	18 (32.1%)	21 (37.5%)	6 (10.7%)	2 (3.6%)	4 (7.1%)	5 (8.9%)	24.52 (0.582)
	Easily	20 (21.5%)	35 (37.6%)	14 (15.1%)	8 (8.6%)	9 (9.7%)	7 (7.5%)	
	Somewhat Easily	41 (24.7%)	68 (41.0%)	31 (18.7%)	7 (4.2%)	10 (6.0%)	9 (5.4%)	
	Not Easily	59 (30.1%)	66 (33.7%)	43 (21.9%)	8 (4.1%)	11 (5.6%)	9 (4.6%)	
	Not at all Easily	25 (30.5%)	33 (40.2%)	16 (19.5%)	3 (3.7%)	3 (3.7%)	2 (2.4%)	
Gender *N* = (575)	Male	68 (23.9%)	105 (36.8%)	55 (19.3%)	15 (5.3%)	25 (8.8%)	17 (6.0%)	11.47 (0.042)*
	Female	92 (31.7%)	112 (38.6%)	52 (17.9%)	11 (3.8%)	10 (3.4%)	13 (4.5%)	
Time of day of weather app usage *N* = (562)	Early Morning (6–9am)	85 (36.6%)	93 (40.1%)	38 (16.4%)	6 (2.6%)	10 (4.3%)	-	66.75 (<.001)*
	Late Morning (9am-Noon)	37 (22.2%)	85 (50.9%)	33(19.8%)	9 (5.4%)	3 (1.8%)	-	
	Early Afternoon (Noon–3pm)	13 (27.7%)	10 (21.3%)	13 (27.7%)	3 (6.4%)	8 (17.0%)	-	
	Late Afternoon (3pm–6pm)	7 (28.0%)	7 (28.0%)	6 (24.0%)	3 (12.0%)	2 (8.0%)	-	
	Early Evening (6–9pm)	5 (20.8%)	9 (37.5%)	4 (16.7%)	1 (4.2%)	5 (20.8%)	-	
	Late Evening (9pm-Midnight)	5 (20.8%)	9 (37.5%)	5 (20.8%)	3 (12.5%)	2 (8.3%)	-	
	Overnight (Midnight–6am)	1 (33.3%)	2 (66.7%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	-	
	Anytime I'm bored	10 (25.0%)	8 (20.0%)	12 (30.0%)	3 (7.5%)	7 (17.5%)	-	
Smartphone Brand *N* = (594)	Apple	120 (33.1%)	141 (39.0%)	66 (18.2%)	15 (4.1%)	20 (5.5%)	-	23.39 (0.018)*
	Samsung	23 (18.7%)	57 (46.3%)	24 (19.5%)	10 (8.1%)	9 (7.3%)	-	
	Google	9 (29.0%)	8 (25.8%)	11 (35.5%)	2 (6.5%)	1 (3.2%)	-	
	Other	11 (23.9%)	17 (37.0%)	10 (21.7%)	1 (2.2%)	7 (15.2%)	-	

2022 identified television as the second-most common source for tornado warning information (Sherman-Morris et al. 2022). The current study indicates that television may be even further down the list than these other studies show.

The survey used in this study did not specify a type of severe weather situation, it simply asked for the most common source used to gather information during severe weather. The lack of specificity about the situation may have affected the results as the definition of severe weather is broad and may be interpreted differently from person to person. Participants' definition could go so far as to include tropical or winter weather. This could help explain the deviation of this study's conclusions when compared to the other literature. However, it is also possible that reliance on digital sources during severe weather situations has truly grown since the time of the previous research work.

Participants were able to pick multiple sources that they use in severe weather, as it is commonly recommended to have many sources by which to be alerted of hazardous weather (https://www.weather.gov/mob/Severe_Alert). Thus, those who predominantly use an app or website could have also indicated that they used television in addition to these sources, but most did not. One potential reason could be the lack of access. As streaming services have grown, access to local news and weather coverage has decreased as many—though not all—streaming services do not include access to local news stations who might provide severe weather

Table 8. Notifications the survey sample reported getting on their smartphone.

Which notifications do you get on your smartphone about the weather? (Check all that apply.)			
		95% Confidence Interval	
***N* = 563**	**Frequency**	**Lower**	**Upper**
Severe Weather	450	76.9%	83.1%
Rain is close to you	148	22.7%	30.4%
Weather headlines	141	21.5%	28.6%
Lightning is close to you	99	14.7%	20.8%
Other	24	2.7%	6.0%
None	84	11.9%	17.9%

Table 6. The time of day participants reported using the weather app most frequently.

From the list of weather apps below, please select any of the apps that you use regularly? (Check all that apply.) *N* = 318		
	Frequency	**Percentage**
The Weather Channel	151	47.5%
AccuWeather	101	31.8%
Local News Station's Weather App	31	9.7%
WeatherBug	29	9.1%
Weather Underground	34	10.7%
Other	73	23.0%

coverage. While many news stations offer streaming news coverage on their website or app, that would require that the individual stop using their smartphone for other purposes and instead dedicate themselves to watching the streaming television coverage on their smartphone. Thus, a lack of access to television services and the inconvenience of having to give up usage of their smartphone may make individuals less likely to use television in hazardous weather.

Another factor that could have led to a disproportionate amount of people using digital sources in severe weather could be the survey's sample that was recruited completely online. This could result in more people using online forecast sources than would be typical as well as a younger demographic. However, four studies mentioned above also used online survey methods (Reuter and Spielhofer 2017; Silva et al. 2017; Stokes and Senkbeil 2017; Sherman-Morris et al. 2020b), and only Silva et al. (2017) indicated that their sample was representative of the United States population by age. Stokes and Senkbeil (2017) as well as Reuter and Spielhofer (2017) had younger samples similar to this study. In light of this comparison, there does appear to be evidence of a change in forecast source even in severe weather. More research will be needed to better understand the generalizability of this conclusion.

The results of this study show a clear shift in the sources the public is turning to in both non-hazardous and severe weather situations. This shift in sources has much deeper implications than people simply taking advantage of a new technology for their weather forecast. There has now been a sweeping transfer of responsibility for interpreting and explaining the forecast. On television, a meteorologist does this with expertise and training on how to communicate with a public audience with limited education in meteorology. Now, using a weather app or website, that same public is doing the interpreting of the forecast on their own. Websites or newspaper forecasts have necessitated this for years. But as of 2006, these were not very popular sources for a forecast or were complemented by a television forecast as well (Lazo et al. 2009)—at least providing an opportunity for a meteorologist to help formulate the forecast interpretation in the mind of the consumer. While videos and livestreams can provide this same opportunity on weather apps, the apps' great utility and convenience is a readily displayed forecast that a consumer can view without having to wait for or watch a video presentation of it.

The public is also likely to be less informed about the "weather story" when using an app. On television, a forecaster provides a story-telling narrative that often involves explaining the "why" behind the forecast. Broadcast meteorologists use maps, pictures, videos, and animations to go in-depth as to what is influencing the forecast. Their forecast is able to provide great detail which can help consumers grasp things like uncertainty in the forecast, providing a greater understanding of the weather story. A weather app provides little more than strict data regarding the upcoming weather. A shift toward using the weather app as a forecast source also likely indicates a shift toward a lesser understanding of the weather story.

These findings present a call for continued research into public interpretation of weather information, especially on digital platforms. Without proper interpretation, unrealized false expectations are likely to occur, leading to disappointment, potential decline in forecast trust, and potential grave consequences in severe weather situations. Additionally, research should be conducted to find ways to enhance a weather apps' ability to communicate the weather story. For severe weather information especially, warning and efficacy messaging should be heavily vetted to ensure proper interpretation by the public. News stations often produce non-stop coverage in severe weather situations, providing the latest and often highly detailed information on the threat. Are weather apps and websites given the same ability to provide non-stop, detailed information? At the very least, news stations should enable streaming of on-air coverage during severe weather in the app.

Enhancing the need for this research is the findings on the age demographics of weather app users. As younger generations age and gradually replace older generations, their source for weather information—predominately apps—is also likely to replace other sources that find greater usage among older generations. While the occurrence of this is unproven, the possibility of its occurrence should be acknowledged and prepared for. Assuming technological advancements do not create a new weather forecast source of higher demand in the future, weather app popularity is likely to continue to grow.

Furthermore, with older generations having relied on television forecasts in the past, they have had greater exposure to broadcast meteorologists explaining the why behind the forecast. Their past exposure to "the weather story" and its associated terminology could help in their self-interpretation of a forecast from an app, whereas the younger generation has grown up in a time with lessening exposure to the detailed insights from broadcast meteorologists. Nunley and Sherman-Morris (2020) showed that older people have a greater self-reported weather knowledge and Ripberger et al. (2019) showed older people have a higher comprehension of tornado warning information. This calls for research into communication techniques for weather apps targeted to an audience that is growing less educated about meteorology and weather forecasts.

b. *Different apps being used*

Similar to Bryant et al. (2016), a slight majority of this survey sample downloaded a different weather app than the pre-downloaded one on their phone. Interestingly, this group was not very diverse in the apps they chose as large percentages chose either The Weather Channel or AccuWeather. Thus, for most people getting a weather forecast from an app, it is coming from only a handful of companies. These companies should work with both internal and external researchers to ensure the presentation and communication of forecast information in the app is most efficient and effective at reaching and being comprehended by the public. With all weather apps coming from the private sector, concerns could be raised about the commercialization of weather apps, where companies are focused more on having cool features or unreasonably long forecast ranges (15+ days), and less on pursuing accuracy and effective communication. The National Weather Service (NWS) has avoided competing with the private sector in the weather app arena, though perhaps this should be reevaluated because having an app coming from a publicly funded entity could enable a focus on proper forecast communication and less on profit and revenue. In addition to indirect support provided by this study for a NWS app, other research has consistently indicated that the NWS garnered the highest level of complete trust for severe weather information from the public in comparison to other sources such as television stations or emergency managers (Silva et al. 2017, 2018, 2019; Krocak et al. 2020, 2021; Bitterman et al. 2022).

Individuals who downloaded an app other than the pre-downloaded one also rated their weather knowledge and interest higher than those using a pre-downloaded app, which expands the findings of Nunley and Sherman-Morris (2020) into weather apps in addition to websites. This finding creates two consequences. First, if the self-perceived weather knowledge and interest are realistic, this means individuals who use the pre-downloaded weather app will be less knowledgeable about and less interested in the weather. The apps that come pre-downloaded on smartphones should be tested to evaluate their success at informing a less weather savvy public about the upcoming weather. Second, if people who download and use an app other than the pre-downloaded app have a higher self-rated weather knowledge and interest, they could be overconfident in their understanding of weather—a concern presented by Nunley and Sherman-Morris (2020). The findings of this study echo the calls for future research presented by Nunley and Sherman-Morris (2020) into how self-perceived weather knowledge and interest impact decision making in severe weather and how weather apps can be utilized to account for individuals who are both highly and weakly familiar with weather information.

c. Notifications

Severe weather alerts were found to be widely used, though it was unclear if these alerts originated from an app or WEA. Due to the uncertainty, it was not concluded that most app users have notifications turned on. Additional research into this will be important to truly understand the acceptance of notifications. However, with 80% of people reportedly getting severe weather notifications on their phones, WEAs—and app notifications—should continually be evaluated to ensure they include messaging comprehendible by the public and that points the public to further information. This finding could also be concerning in that the public may become overreliant on their smartphone to alert them about a potential weather threat. WEA is not currently used for all types of severe weather, but does the public know that? Or do they expect to be alerted regardless? Mobile internet service is not available for many rural areas of the country. Thus, some people will not be able to get WEAs in areas lacking service. While the technology is effective at getting information out quickly to a targeted audience, it does not reach everyone.

Finally, with the widespread acceptance of both weather apps and mobile notifications in severe weather, more could be done to personalize these apps to the consumer. Personalization is a high strength of the weather app as a medium, and thus personalization of the forecast and severe weather information should be maximized. When a severe weather threat becomes personalized to an individual—they feel it could affect them personally—they are more likely to take a protective action (Mileti and Peek 2000). However, severe weather warnings are still presented with limited personalization. They are currently narrowed down by time and area (a polygon). However, there is little detail as to the variance of threat and risk by area and time within the polygon. Some of these challenges are being addressed by the Forecasting a Continuum of Environmental Threats project (Rothfusz et al. 2018) and Threats-in-Motion project (Stumpf and Gerard 2021), but incorporating weather apps and smartphone notifications into these efforts will prove helpful at reaching a large audience with the severe weather information personalized to the individual.

This research provided a necessary step forward for the interests of weather communication by better understanding the public's new habits for learning about the weather. As technology has advanced, the most common source that the public turns to for weather information has changed. With this change comes different considerations for forecasters to evaluate how to best communicate the forecast and what information is needed most by forecast users. This should encourage an investment into making weather apps strong, reliable vehicles by which to communicate weather information in an effective, comprehendible, and personal way to the public.

Acknowledgments. Thank you to Dr. Philip Poe for his guidance and advice on this research and to the Mississippi State University Department of Geosciences for funding the survey. Thank you to Ethan Carr from the Cooperative Institute for Research in Environmental Sciences (CIRES) at the University of Colorado Boulder and NOAA's Global Systems Laboratory for his assistance with the GIS product in this paper.

APPENDIX — Survey Questions

What would you describe as your main source for getting a weather forecast?			
		95% Confidence Interval	
***N* = 600**	**Frequency**	**Lower**	**Upper**
Weather App or Widget	464	74.0%	80.5%
A Website on the Internet	87	11.7%	17.3%
Television	37	4.3%	8.2%
Social Media	7	0.3%	2.0%
Other	5	0.2%	1.0%
Radio	0	0.0%	0.0%

Which source is typically the first source to alert you that severe weather is occurring near you?			
		95% Confidence Interval	
***N* = 600**	**Frequency**	**Lower**	**Upper**
Weather App Notification	261	39.2%	47.3%
Mobile Phone Emergency Alert	166	23.7%	31.5%
Television	48	6.0%	10.2%
Friends or Family	47	5.7%	10.2%
A website on the internet	33	3.8%	7.3%
Social Media	24	2.5%	5.7%
Other	7	0.3%	2.2%
Tornado Siren	5	0.2%	1.7%
NOAA Weather Radio	5	0.2%	1.7%
Radio	4	0.2%	1.3%

After you have been alerted about the severe weather by (pipe above answer), what source or sources do you typically go to next for more information? Check all that apply.			
		95% Confidence Interval	
***N* = 599**	**Frequency**	**Lower**	**Upper**
A Website on the Internet	305	46.8%	54.8%
Weather App or Widget	277	42.2%	50.0%
Television	137	19.5%	26.0%
Social Media	108	15.2%	21.2%
Radio	18	1.7%	4.3%
Other	6	0.3%	1.8%

APPENDIX — Survey Questions

Do you have a smartphone?
N = 600

	Frequency	Percentage
Yes	595	99.2%
No	5	0.8%

How often do you use a weather app?
N = 594

	Frequency	Percentage
Multiple times per day	163	27.2%
Once per day	223	37.2%
More than once per week, but not daily	111	18.5%
Once per week	28	4.7%
Less frequently than once per week	37	6.2%
Never	32	5.3%

How many weather apps do you have on your phone?
N = 557

	Frequency	Percentage
0	3	0.5%
1	413	74.1%
2	119	21.4%
3	19	3.4%
4	3	0.5%

What time of day do you most frequently use your weather app?
N = 563

	Frequency	Percentage
Overnight (Midnight - 6am)	3	0.5%
Early Morning (6am - 9am)	232	38.7%
Late Morning (9am - Noon)	167	27.8%
Early Afternoon (Noon - 3pm)	47	7.8%
Late Afternoon (3pm - 6pm)	26	4.3%
Early Evening (6pm - 9pm)	24	4.0%
Late Evening (9pm - Midnight)	24	4.0%
Anytime you are bored	40	6.7%

Most smartphones come with a weather app already on them. However, some people choose to download a different weather app onto their smartphone. Have you ever downloaded a weather app?
N = 562

	Frequency	Percentage
Yes	319	56.8%
No	243	43.2%

Do you prefer to use the weather app you downloaded or the one that came on your phone?
N = 319

	Frequency	Percentage
The weather app I downloaded	198	62.1%
The weather app that came on my phone	121	37.9%

From the list of weather apps below, please select any of the apps that you use regularly? (Check all that apply.)
N = 318

	Frequency	Percentage
The Weather Channel	151	47.5%
AccuWeather	101	31.8%
Local News Station's Weather App	31	9.7%
WeatherBug	29	9.1%
Weather Underground	34	10.7%
Other	73	23.0%
Late Evening (9pm - Midnight)	24	4.0%

APPENDIX — Survey Questions

Which notifications do you get on your smartphone about the weather? (Check all that apply.)

		95% Confidence Interval	
***N* = 563**	**Frequency**	**Lower**	**Upper**
Severe Weather	450	76.9%	83.1%
Rain is close to you	148	22.7%	30.4%
Weather headlines	141	21.5%	28.6%
Lightning is close to you	99	14.7%	20.8%
Other	24	2.7%	6.0%
None	84	11.9%	17.9%

What brand is your smartphone?
N = 595

	Frequency
Apple	375
Samsung	137
Google	32
Other	51

How easily could you function without your smartphone for a day?
N = 594

	Frequency
Very Easily	56
Easily	93
Somewhat Easily	167
Not Easily	196
Not at all Easily	82

How would you describe your knowledge about the weather?
N = 599

	Frequency
Very High	14
High	101
Moderate	396
Poor	82
Very Poor	6

How would you describe your interest in the weather?
N = 600

	Frequency
Very High	44
High	163
Moderate	286
Poor	96
Very Poor	11

APPENDIX — Survey Questions

How would you describe your gender?
- Female
- Male
- Transgender female
- Transgender male
- Gender variant/Non-conforming
- Prefer not to identify

How would you describe your race or ethnicity? (Check all that apply.)
- White
- Hispanic or Latino
- Black or African American
- Asian
- American Indian or Alaska Native
- Native Hawaiian or Pacific Islander
- Middle Eastern or North African
- Mixed race
- Other

What is your highest level of education?
- Some High School
- High School Graduate
- Some College
- Associate's Degree
- Bachelor's Degree
- Advanced Degree

How would you classify the area in which you live?
- White
- Hispanic or Latino
- Black or African American
- Asian
- American Indian or Alaska Native
- Native Hawaiian or Pacific Islander
- Middle Eastern or North African
- Mixed race
- Other

REFERENCES

Anshari, M., Y. Alas, G. Hardaker, J. H. Jaidin, M. Smith, and A. D. Ahad, 2016: Smartphone habit and behavior in Brunei: Personalization, gender, and generation gap. *Comput. Human Behav*., **64**, 719–727, Crossref.

Bean, H., J. Sutton, B. F. Liu, S. Madden, M. W. Wood, and D. S. Mileti, 2015: The study of mobile public warning messages: A research review and agenda. *Rev. of Commun*., **15**, 60–80, Crossref.

Bitterman, A., M. Krocak, J. Ripberger, C. Silva, H. Jenkins-Smith, S. Ernst, and S. Stormer, 2022: Maintaining the series: Public reception, understanding, and responses to severe weather forecasts and warnings in the contiguous United States. University of Oklahoma Institute for Public Policy Research and Analysis, 34 pp., Crossref.

Böhmer, M., B. Hecht, J. Schöning, A. Krüger, and G. Bauer, 2011: Falling asleep with Angry Birds, Facebook and Kindle: A large-scale study on mobile application usage. *Proc. 13th Int. Conf. Human Comput. Interact. with Mobile Devices and Services*, New York, NY, Association for Computing Machinery, 47–56, Crossref.

Bryant, M. J., W. J. Smart, and S. J. Wilde, 2016: Swipe right with a chance of rain: Weather app usage on smartphones. Adv. Business-Related Sci. Res. J., 7, 80–89. [Available online at https://www.researchgate.net/profile/William-Smart-2/publication/317000237_Swipe_Right_with_a_Chance_of_Rain_Weather_App_Usage_on_Smartphones/links/591d90acaca272d31bcd9301/Swipe-Right-with-a-Chance-of-Rain-Weather-App-Usage-on-Smartphones.pdf.]

____, S. J. Wilde, and W. J. Smart, 2017: Taking the weather with you: User acceptance, trust, and value of weather apps on smartphones. *Int. J. Soc. Humanistic Comput*., **2**, 247–260, Crossref.

Chan, E. Y. Y., Z. Huang, C. K. M. Mark, and C. Guo, 2017: Weather information acquisition and health significance during extreme cold weather in a subtropical city: A cross-sectional survey in Hong Kong. *Int. J. Disaster Risk Sci*., **8**, 134–144, Crossref.

Charness, N., and E. A. Bosman, 1992: *The handbook of aging and cognition*, F.I.M. Craik and T.A. Salthouse, Eds., Lawrence Erlbaum, 495–551.

Davis, F. D., 1989: Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quart*., **13**, 319–340, Crossref.

Demuth, J. L., J. K. Lazo, and R.E. Morss, 2011: Exploring variations in people's sources, uses, and perceptions of weather forecasts. *Wea. Climate Soc*., **3**, 177–192, Crossref.

Efron, B., and R. J. Tibshirani, 1994: *An Introduction to the Bootstrap*. Chapman and Hall/CRC, 456 pp., Crossref.

Hagar, C., 2015: Crisis informatics. *Encyclopedia of Information Science and Technology, Third Edition*, M. Khosrow-Pour, Ed. IGI Global, 1350–1358, Crossref.

Jauernic, S. T., and M. S. Van Den Broeke, 2017: Tornado warning response and perceptions among undergraduates in Nebraska. *Wea. Climate Soc*., **9**, 125–139, Crossref.

Kaasinen, E., 2005: User acceptance of mobile services: Value, ease of use, trust and ease of adoption. M. S. Thesis, Tampere University of Technology, 222 pp. [Available online at https://publications.vtt.fi/pdf/publications/2005/P566.pdf.]

Kim, H. Y., 2017: Statistical notes for clinical researchers: Chi-squared test and Fisher's exact test. *Restor. Dent. Endod*., **42**, 152–155, Crossref.

Krocak, M., J. Ripberger, C. Silva, H. Jenkins-Smith, S. Ernst, A. Bell, and J. Allen, 2020: Measuring change: Public reception, understanding, and responses to severe weather forecasts and warnings in the contiguous United States. University of Oklahoma Center for Risk and Crisis Management, 31 pp., Crossref.

____, ____, ____, ____, A. Gaviria-Pabón, A. Forney, and A. Bitterman, 2021: Continuing the series: Public reception, understanding, and responses to severe weather forecasts and warnings in the contiguous United States. University of Oklahoma Center for Risk and Crisis Management, 33 pp., Crossref.

Lazo, J. K., R. E. Morss, and J. L. Demuth, 2009: 300 billion served: Sources, perceptions, uses, and values of weather forecasts. *Bull. Amer. Meteor. Soc*., **90**, 785–798, Crossref.

McKight, P. E., and J. Najab, 2010a: Kruskal-Wallis test. *Corsini Encyc. Psych*., 1–1, Crossref.

____, and ____, 2010b: Mann-Whitney U Test. *Corsini Encyc. Psych*., 1–1, Crossref.

Mehta, C. R., and N. R. Patel, 2010: IBM SPSS exact tests. Armonk, NY, IBM Corporation, 236 pp. [Available online at https://www.sussex.ac.uk/its/pdfs/SPSS_Exact_Tests_19.pdf.]

Mileti, D. S., L. and Peek, 2000: The social psychology of public response to warnings of a nuclear power plant accident. *J. Hazard. Mater*., **75**, 181–194, Crossref.

Nix-Crawford, B., 2017: The trust factor between meteorologists and viewers and the effects on local television audience retention. M.S. Thesis, College of Media Arts and Design, Drexel University, 82 pp.

Nunley, C., and K. Sherman-Morris, 2020: What people know about the weather. *Bull. Amer. Meteor. Soc*., **101**, E1225–E1240, Crossref.

Oulasvirta, A., S. Tamminen, V. Roto, and J. Kuorelahti, 2005: Interaction in 4-second bursts: The fragmented nature of attentional resources in mobile HCI. *Proc. SIGCHI Conf. Human Factors in Comput. Syst*., Portland, OR, Association for Computing Machinery, 919–928, Crossref.

Perreault, M. F., J. B. Houston, and L. Wilkins, 2014: Does scary matter?: Testing the effectiveness of new National Weather Service tornado warning messages. *Commun. Stud*., **65**, 484–499, Crossref.

Phan, M. D., B. E. Montz, S. Curtis, and T. M. Rickenbach, 2018: Weather on the go: An assessment of smartphone mobile weather application use among college students. *Bull. Amer. Meteor. Soc*., **99**, 2245–2257, Crossref.

Qiao, Y., X. Zhao, J. Yang, and J. Liu, 2016: Mobile big-data-driven rating framework: Measuring the relationship between human mobility and app usage behavior. *IEEE Network*, **30**, 14–21, Crossref.

Reuter, C., and T. Spielhofer, 2017: Towards social resilience: A quantitative and qualitative survey on citizens' perception of social media in emergencies in Europe. *Technol. Forecast. Social Change*, **121**, 168–180, Crossref.

Ripberger, J. T., M. J. Krocak, W. W. Wehde, J. N. Allan, C. Silva, and H. Jenkins-Smith, 2019: Measuring tornado warning reception, comprehension, and response in the United States. *Wea. Climate Soc*., **11**, 863–880, Crossref.

Rothfusz, L. P., R. Schneider, D. Novak, K. Klockow-McClain, A. E. Gerard, C. Karstens, G. J. Stumpf, and T. M. Smith, 2018: FACETs: A proposed next-generation paradigm for high-impact weather forecasting. *Bull. Amer. Meteor. Soc*., **99**, 2025–2043, Crossref.

Shepard, C., A. Rahmati, C. Tossell, L. Zhong, and P. Kortum, 2010: LiveLab: Measuring wireless networks and smartphone users in the field. ACM SIGMETRICS *Perform. Eval. Rev*., **38**, 15–20, Crossref.

Sherman-Morris, K., 2010: Tornado warning dissemination and response at a university campus. *Nat. Hazards*, **52**, 623–638, Crossref.

____, T. Pechacek, D. J. Griffin, and J. Senkbeil, 2020a: Tornado warning awareness, information needs and the barriers to protective action of individuals who are blind. *Int. J. Disaster Risk Reduct*., **50**, 101709, Crossref.

____, P. S. Poe, C. Nunley, and J. A. Morris, 2020b: Perceived risk, protective actions and the parasocial relationship with the local weathercaster: A case study of Hurricane Irma. *Southeast. Geogr*., **60**, 23–47, Crossref.

____, C. Vaughn, J. C. Senkbeil, and S. Wooten, 2022: The influence of demographic and place variables on personalized tornado risk area, *Wea. Climate Soc*. **14**, 1261–1272, Crossref.

Silva, C. L., J. T. Ripberger, H. C. Jenkins-Smith, and M. Krocak, M., 2017: Establishing a baseline: Public reception, understanding, and responses to severe weather forecasts and warnings in the contiguous United States. University of Oklahoma Center for Risk and Crisis Management, 30 pp. [Available online at http://risk.ou.edu/downloads/news/WX17-Reference-Report.pdf.]

____, ____, ____, ____, and W. Wehde, 2018: Refining the baseline: Public reception, understanding, and responses to severe weather forecasts and warnings in the contiguous United States. University of Oklahoma Center for Risk and Crisis Management, 29 pp., Crossref.

____, ____, ____, ____, S. Ernst, and A. Bell, 2019: Continuing the baseline: Public reception, understanding, and responses to severe weather forecasts and warnings in the contiguous United States. University of Oklahoma Center for Risk and Crisis Management, 33 pp., Crossref.

Stokes, C., and J. C. Senkbeil, 2017: Facebook and Twitter, communication and shelter, and the 2011 Tuscaloosa tornado. *Disasters*, **41**, 194–208, Crossref.

Stumpf, G. J., and A. E. Gerard, 2021: National Weather Service severe weather warnings as threats-in-motion. *Wea. Forecasting*, **36**, 627–643, Crossref.

van Deursen, A. J. A. M., C. L. Bolle, S. M. Hegner, and P. A. M. Kommers, 2015: Modeling habitual and addictive smartphone behavior: The role of smartphone usage types, emotional intelligence, social stress, self-regulation, age, and gender. *Comput. in Human Behav*., **45**, 411–420, Crossref.

Zabini, F., 2016: Mobile weather apps or the illusion of certainty. *Meteor. Appl*., **23**, 663–670, Crossref.