Factors Influencing the Motivations and Perceived Usefulness of a Weather Radar Display in Tampa Bay

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ABSTRACT: Weather information is widely available across many media platforms, including televisions, computers, smartphones, and tablets. In addition to weather forecast information, people are seeking and using a variety of weather information sources that provide them with current conditions and include tools such as satellite images and weather radar displays. However, little is known about how individuals use and perceive information from weather radar displays, despite the existence of radar since the 1940s. This study is a novel exploration of how Tampa Bay area residents use radar and identifies several important factors that influence how useful radar is perceived to be as a decision-making tool. It also investigates what information radar users find most important when choosing to view a radar display, as well as what electronic sources are used most often to access weather radar. The final goal of this study is to identify which activities motivate a Tampa Bay resident to view weather radar. Data were collected using an online survey instrument. This study finds that survey respondents in the Tampa Bay area frequently view a weather radar display and find it to be a very useful tool. Respondents who reported greater accuracy for the location of precipitation on a radar display were more likely to rate the radar display as being more useful. The majority of respondents indicate they use a smartphone device to view radar most often and that participating in outdoor activities was an important motivator for using radar.

KEYWORDS: Social Science; Radars/Radar observations; Communications/decision making

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Radar has been used for meteorological purposes since the 1940s and is a critical tool for forecasting the weather (Henson 2010). Meteorologists, among other communities, rely on these data to determine the location and intensity of precipitation and the direction of winds, and to detect other objects such as migrating insects or debris from a tornado. With advancements in technology, weather radar displays are widely available and popular outside of the meteorological and emergency management communities. Any individual can view a radar display on a television, computer, or tablet or download a radar application on a smartphone. While there is a growing volume of articles, both peer-reviewed and published in the media, that focus on how people access, use, and perceive weather forecast information (Demuth et al. 2009; Hickey 2015; Morss et al. 2008; Phan et al. 2018; Saunders et al. 2018; Sherman-Morris and Lea 2016; Stewart 2009; Stewart et al. 2012), few include the use of weather radar displays. Therefore, little is known about what motivates someone to use a radar display or how useful individuals find a radar display as a decision-making tool. With a large variety of sources to choose from for weather information, it is important to discern why individuals choose to view radar as a source of information about precipitation and storm events.

To focus our study, a conceptual framework was used from Saunders et al. (2018) to determine which factors may influence the perceived usefulness of a radar display (see Fig. 1). Saunders et al. (2018) created this framework to assess the National Weather Service's weather radar website display. By definition, useful means to be "capable of being put to use" or "of a valuable or productive kind" (<https://unabridged.merriam-webster.com/collegiate/useful>). Therefore, usefulness in this context will refer to how weather radar is used for practical, decision-making purposes, as a source of information about precipitation. This framework was adapted from several previous studies and frameworks including Ryan and Deci's (2000) self-determination theory, Dunwoody and Griffin's (2015) risk information seeking and processing (RISP) conceptual model, and Earle's (2010) review using the consensus model of trust. Self-determination theory was included within this study's framework due to the importance of self-efficacy or having the confidence to control one's actions and motivations that would ultimately lead to a successful outcome (Ajzen 2002; Bandura 2012; Becker et al. 2012; Lindell and Perry 2012; Neuwirth et al. 2000; Wachinger et al. 2013). As people may experience motivation for a variety of reasons, several factors may impact the motivations an individual has to seek out information that ultimately will determine what actions are taken as a result of viewing that information. Dunwoody and Griffin's (2015) RISP model incorporates individual characteristics such as sociocultural factors and information gathering skills as well as whether or not an individual finds the information they collect to be sufficient and of quality. According to self-determination theory, individuals may be motivated by intrinsic and/or extrinsic factors that influence their competency, autonomy, and relatedness about a situation or topic (Ryan and Deci 2000).

Saunders et al. (2018) found that respondents who indicated that they were very familiar with the NWS products, as well as those who said they were more likely to take action based

Fig. 1. Conceptual framework. Reprinted from Saunders et al. (2018).

on NWS information, were more likely to find the NWS radar display to be useful. Lightning was also found to be the most important hazard regarding weather radar usefulness. That study was an important first step for investigating the usefulness of a weather radar display, but the data only reveal the usefulness of the NWS website radar display. Therefore, this study aims to gather data about radar displays more generally, incorporating radar displayed across multiple media types such as televisions, smartphones, and displays that can be accessed online via a computer or tablet.

Both intrinsic and extrinsic factors may affect radar use. Intrinsic factors include how often radar information is trusted, how accurate radar information is perceived to be, how confident a respondent is in making a decision with a radar display, and whether they consider a radar display to have enough information to make a decision about an impending weather event. Extrinsic factors include social cues, such as receiving a tornado warning or overhearing or talking with others about future weather conditions, that may motivate an individual to seek out additional information (Wood et al. 2017). Environmental cues, such as the possibility of experiencing weather phenomena like rain, a thunderstorm, or a hurricane, are also included and can be either visual or auditory, alerting an individual about a particular weather event (Dewitt et al. 2015; Lindell and Perry 2012). The frequency that a radar display is used could be considered as both an intrinsic and extrinsic factor. Having a greater frequency of use could indicate that an individual finds radar to be an important tool or of special interest. However, a greater frequency of use could also arise due to an external need for information.

Other factors that may influence the usefulness of a weather radar display are whether or not a respondent uses radar at their job and if they consider themselves to be a weather enthusiast. We included these factors to help gain a better understanding of why a participant uses a radar display in addition to whether these factors would increase how useful radar is found as a tool. The idea to incorporate these factors came from a 2014 NWS customer satisfaction survey (Saunders et al. 2018). In addition, a weather salience score, which can be calculated using the Weather Salience Short Questionnaire created by Stewart et al. (2012), was included as weather salience relates to how important weather is to someone's daily life. This questionnaire was designed to measure how weather is psychologically significant in people's lives, which may relate to their use of weather information.

The type of media used to view radar may also affect a usefulness rating. Radar reflectivity can be displayed in different modes (base vs composite) and using different color ramps and "smoothing" effects, which may lead to a radar user having a preference for where they go to access a radar display. Several devices can be used to view a radar display, including televisions, tablets, computers, and smartphones. As of 2019, 81% of U.S. adults own a smartphone, making it one of the most popular tech devices (Pew Research Center 2019). Therefore, smartphone applications are also becoming a more mainstream source of weather information, especially among a younger demographic (Phan et al. 2018).

This study addresses the following questions using observations of the intrinsic and extrinsic factors, mentioned above, that may motivate members of the public to find radar to be a useful decision-making tool in addition to providing information about general radar use. To guide our research questions this study is divided into two sections: radar usefulness factors and general radar use.

Radar usefulness factors:

- Which factors outlined in the conceptual framework influence the perceived usefulness of a radar display?

Are there differences in weather radar usefulness ratings comparing

- respondents who use radar as part of their job,
- respondents who identify as being a weather enthusiast, or
- respondents who have taken a meteorology course?

General radar use:

- What information do radar users find most important when choosing to view a radar display?
- What electronic sources are used most often to view a radar display?
- What activities motivate a Tampa Bay resident to view a weather radar display?

Data and methods

Study area. The study area for this research incorporates an eight-county area that collectively makes up the Tampa Bay area, including Hillsborough County, Pinellas County, Pasco County, Hernando County, Manatee County, northern Sarasota County, Sumter County, and western Polk County (see Fig. 2). Florida is an ideal place to study the use of radar displays as there is abundant atmospheric moisture, unstable conditions, and several “lifting mechanisms” occurring during large sections of the year, making Florida a prime location for thunderstorm development (Collins et al. 2017). Albrecht et al. (2016) found that the lightning hot spot for the United States is Orangetree, Florida, which has a flash rate density (FRD) of 79 flashes per square kilometer per year. Another study that used cloud-to-ground lightning flash data and annual thunderstorm days found that the mean annual maximum lightning strikes for the United States occurred near Tampa (Koehler 2020). These statistics suggest that Florida residents are more likely to experience weather conditions that appear on Doppler radar more often compared to those living in other places of the United States. The Tampa–St. Petersburg–Clearwater area ranked fourth out of the top 25 counties for lightning fatalities

Fig. 2. Number of respondents per zip code from the seven-county study area of Tampa Bay.

in the United States and first when controlling for the size of a metropolitan area (Ashley and Gilson 2009). Florida is also home to other weather phenomena such as tropical cyclones, hail, and tornadoes. Florida was found to have a high frequency of tornado days per year (Brooks et al. 2003).

Survey data. Data were collected using an online survey instrument that was created using Qualtrics software and disseminated through the NWS Tampa Bay office, local broadcast meteorologists, the University of South Florida's research division, and a few other local organizations, through websites and social media platforms such as Facebook, Instagram, and Twitter. Respondents were self-selected and had to be at least 18 years of age and live within the Tampa Bay area. To participate in the survey, respondents also had to select that they use a weather radar display. Surveys were administered from March to April 2019. A total of 710 respondents took the survey; however, after controlling for survey completion and the location of respondents, only 513 respondents could be included in some of the data analyses, while the regression analysis incorporated survey responses from 420 respondents.

The survey asked respondents how useful they found a radar display as a source of information about precipitation. This question was asked in the same style as the 2014 National Oceanic and Atmospheric Administration's customer satisfaction survey, using a 10-point scale. The 10-point usefulness scale served as the dependent variable used in the analysis (see Fig. 3). Respondents were asked how frequently they use radar, possible weather conditions or scenarios that may prompt them to use radar more often, the amount of trust placed in radar, and what devices and apps they prefer, in addition to demographic questions (see the appendix).

The demographics of respondents in this study show that 55% self-identified as male, 44.3% female, and <1% as other. The average age of respondents was 48 years. Just over half, 55%, stated they had earned a bachelor's degree or higher. Overall, this dataset was not representative of the study area, as respondents are more likely to be white or male, and have a higher level of educational background (see Table 1). One unique variable that categorizes this dataset is that 78.7% of respondents identified as being a weather enthusiast, most likely as a result of respondents self-selecting to take this survey. Also, 81% of study respondents stated that they did not view a radar display as part of their job and 70.5% said they had not taken any meteorology courses either formally through a college or self-taught online. Therefore, this study population is not dominated by people exclusively based in meteorology focused jobs nor are they formally trained in meteorology as a discipline.

Statistical procedures: Radar usefulness factors. Both parametric and nonparametric statistical procedures were used in the analyses as many of the variables within this dataset are ordinal. All statistical analyses were completed using the Statistical Package for the Social Sciences (SPSS) version 25. The first part of this study aimed to understand what motivational factors influenced the perceived usefulness of a radar display; therefore, an ordinal logistic regression using a cumulative logit link function with a generalized linear model (GLM) methodology was used. This type of regression is employed when modeling with an ordinal dependent variable as well as for data that are not normally distributed or that are skewed (Agresti 2010; Nussbaum 2015). From this analysis, a proportional odds model was

Fig. 3. Respondent's weather radar usefulness ratings.

calculated to identify the factors that influenced Tampa Bay area radar user's perceived usefulness ratings of radar displays. Before modeling the data using ordinal logistic regression, a test of parallel lines was performed to ensure ordinal effect. The variables incorporated in this study passed the test of parallel lines with a p value of 0.988. All nonbinary variables were standardized to z scores to ensure odds ratios could be compared across all variables.

Weather radar usefulness ratings were compared among respondents who did and did not use radar for work purposes, for those who did and did not consider themselves to be a weather enthusiast, and those who did and did not take a meteorology course using Mann–Whitney U tests. Mann–Whitney U tests can be used to compare variables that are ordinal in nature.

Statistical procedures: General radar use. Weather radar displays provide a user with important information about meteorological phenomena such as locating precipitation, estimating precipitation intensity, showing the direction of storm motion, and estimating precipitation type. To identify what information respondents found most important, respondents were asked to rate the importance of four specific pieces of information that could be obtained using a radar display. Response choices were in the form of a five-point Likert scale ranging from not important to very important, without a neutral category (see the appendix). Respondents were asked to rate the importance of the following information including “finding the intensity of a precipitation event,” “finding out how long a precipitation event would occur,” “to locate a precipitation event,” and “to locate a hazard watch or warning for their area.” Respondents were also given an “other” category with the option to give their own response corresponding with the same importance rating scale. The choices selected for this survey were based on the kinds of information that can be observed when viewing reflectivity data, though more information can be observed using radar, especially with other tools such as velocity. A Friedman's test was used to determine which of these four choices was found most important when choosing to view a radar display. This test treated each possible answer choice as a repeated measure using the same sample group since all respondents answered for how important each action was to them. A follow-up pairwise comparison was then conducted using the sign test to compare each of the four information choices separately. A Bonferroni correction was applied.

Table 1. Demographic variables compared to the American Community Survey (ACS) 2018: 5-yr estimates data profiles for the Tampa Bay area. All values are percentages until otherwise indicated.

Demographic Variable	Sample Estimates	ACS Estimates
Gender		
Male	54.9	48.6
Female	44.3	51.3
Other	0.8	—
Median Age	48.0	46
Race		
White	90.4	83.4
Black African American	1.0	9.4
American Indian or Alaska Native	0.4	0.3
Asian	2.1	2.4
Native Hawaiian or Pacific Islander	0.2	0.1
Some other race alone	2.5	2
Two or more races	0.6	2.5
Missing	2.7	—
Hispanic or Latino	5.9	15.9
Highest Education Completed		
No high school degree	0.6	—
High school diploma or GED	9.0	31.4
Some college—no degree	22.0	21.2
Associates degree (2-yr)	13.3	9.5
Bachelor's degree (4-yr)	31.0	17.1
Graduate degree	23.7	9.8
Median Household Income	\$80,000–\$89,999	\$52,460
Commute by Driving	89.1	80.6

Respondents were asked how often they viewed a radar display. They were also asked how often they used several devices capable of displaying radar, including televisions, computers, smartphones, and tablets. Descriptive statistics were analyzed to find out how frequently each device was used. Using a Spearman's rho test, correlation between age and each device was examined. Mann–Whitney U tests compared each of the electronic devices respondents used to view a weather radar display by gender.

This study also sought to identify any specific activities that motivate a respondent to view a radar display. Respondents were asked in an open-ended format to describe what activities motivate them to use a radar display most often. These responses were analyzed using NVivo 12, a software built to analyze qualitative and mixed-methods data. Response frequencies were queried to identify which activities motivate a Tampa Bay radar user to use a weather radar display the most.

Results

Radar usefulness factors. Ordinal logistic regression was used to determine which factors influenced Tampa Bay radar users to find radar more useful. This model incorporated 26 independent variables ranging from demographic variables to the intrinsic and extrinsic factors established in the conceptual framework (see Table 2). Women were more likely to rate a radar display as more useful than men, as were respondents who were older, and those with a higher income. Respondents who found the location of precipitation displayed by radar to be more accurate were more likely to find a weather radar display to be more useful, as were respondents who indicated that they trusted radar data more often. Respondents with a higher weather salience score as well as respondents who said a weather radar display provides them with enough information to make their own decisions about what they would do during a precipitation event were more likely to find a weather radar display as a useful tool. Overhearing a conversation about current weather conditions was the only extrinsic factor found to be statistically significant.

Respondents were categorized into different groups of radar users such as those who had taken a meteorology course, those considered themselves to be a weather enthusiast, and those respondents who use radar at their job. Mann–Whitney U tests were used to discover differences in radar usefulness ratings between these different groups of radar users. When comparing respondents who had taken a college meteorology course to those who had not taken a meteorology course, there was a significant difference ($U = 11,196$, $p = 0.004$). In addition, there was also a significant difference when comparing respondents who had not taken a course to those who had taken a course online (self-taught) ($U = 11,773.5$, $p = 0.018$). However, there was no difference in the radar usefulness rating between those who had taken a college course and those who self-taught online. When comparing respondents who self-identified as being a weather enthusiast to those who did not, there was a significant difference ($U = 16,520.5$, $p < 0.001$). However, when comparing those who use weather radar at their job to those who do not, there was no significant difference.

General radar use. A Friedman's test revealed that respondents did not find all information that can be accessed via a radar display to be equally important, as it found the distributions to be different across the four information variables [$\chi^2(3) = 31.9$, $p < 0.001$] (see Fig. 4). From this test, locating a hazard watch or warning for a respondent's area had the greatest overall importance. As the Friedman's test was significant, follow-up pairwise comparisons were conducted using sign tests. After applying a Bonferroni correction, it was determined that participants found it most important to identify the location of a hazard watch or warning for their area when compared to each information variable except for locating precipitation in their area. The speed and direction of storms and precipitation events were the most common responses for the "other"

Table 2. An ordinal logistic regression–likelihood ratio χ^2 : 189.761, 26 df, p value < 0.001, and $N = 420$. Dependent variable was the respondent’s usefulness rating of a weather radar display on a scale of 1 to 10, where 1 means “Not at all useful” and 10 means “Very useful.” For p values, * indicates $p < 0.1$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$.

Independent Variables	Coefficient	Wald chi-square	Odds ratio
Demographics			
Gender: Female	0.829	7.969***	2.291
Age	0.317	4.211**	1.373
Household Income	0.264	3.268*	1.302
Taken a meteorology course	0.556	2.460	1.743
Years lived in Florida	0.195	1.394	1.216
Education	−0.056	0.145	−1.058
Intrinsic factors			
Accuracy of precipitation location	0.655	16.695***	1.925
Trust frequency for radar data	0.644	12.812***	1.904
Weather salience score	0.381	5.661**	1.464
Enough info for decision-making	0.349	4.615**	1.418
Frequency of use	0.194	1.659	1.214
Weather enthusiast	0.329	1.008	1.389
Accuracy of precipitation intensity	−0.140	0.618	−1.150
Confident making decisions with radar	0.100	0.444	1.105
Use radar at job	0.113	0.094	1.119
Extrinsic factors			
Overhearing a conversation about current weather conditions	0.288	2.728*	1.334
Experiencing rain	0.305	2.700	1.356
Receiving an official warning for a severe thunderstorm	0.234	1.850	1.264
Experiencing hail	−0.220	1.701	−1.246
Experiencing thunderstorm conditions	−0.181	0.880	−1.198
Experiencing a tornado	0.148	0.691	1.159
Receiving an official tornado warning	0.129	0.557	1.137
Experiencing lightning	0.092	0.291	1.096
Experiencing hurricane conditions	−0.031	0.063	−1.031
Viewing changing sky conditions	0.023	0.021	1.023
Seeing someone carrying an umbrella or wearing a raincoat or rain	−0.014	0.007	−1.014

Fig. 4. How important respondents found different information that a radar display can provide.

open-ended response category. Respondents who listed knowing the speed and direction of storm movement as important information rated this information as very important.

When comparing which devices were used most often to view a weather radar display, the majority of respondents indicated that a smartphone was their go-to choice over televisions, computers, and tablets, with about 91% stating they usually or always use a smartphone. Only 48% usually or always use a computer, 30% usually or always use a television, and 29% usually or always use a tablet (see Fig. 5). Using

a Spearman's rho (r_s) test, significant correlations were found between age and the frequency of use for each device type. The strongest positive correlations with respect to age occurred with television ($r_s = 0.247$, $p < 0.001$) and tablets ($r_s = 0.254$, $p < 0.001$), followed by computer use ($r_s = 0.139$, $p = 0.005$). Smartphone use had a significant negative correlation with age ($r_s = -0.185$, $p < 0.001$) suggesting that younger respondents were more likely to use their smartphone to view a weather radar display. To test for any differences

between males and females for device type, Mann–Whitney U tests were conducted. Both computers ($U = 24,200.5$, $p < 0.001$) and tablets ($U = 26,897.5$, $p = 0.013$) were significantly different with men having a greater mean rank for these devices. Mean ranks for televisions and smartphones were closer in range, with women having a slightly greater average.

Tampa Bay radar users were also asked about which activities motivate them to view a radar display most often. Approximately 86% of respondents answered this open-ended question allowing for a query to be conducted revealing the most common responses. While, “work” was mentioned most often (116 times), not all of these references necessarily relate to a respondent's occupation (e.g., “working outside” or doing “yard work”). Specifically, “driving” or “commuting to work” or “work activities” were mentioned. Another common word was “outdoor” (90), specifically, going to the “beach” (54), “walking” (36), and “boating” (33) were frequently mentioned. Therefore, outdoor activities motivate radar users most often, when including “working outside” and “yard work” within the outdoor group.

Discussion

Radar usefulness factors. Using an ordinal logistic regression helped to provide insight into which factors influence Tampa Bay radar users' perceived usefulness of a weather radar display. Several demographic and intrinsic factors were shown to be significant including identifying as a women, respondents who were older, and those with a higher income. This differs from results found by Saunders et al. (2018), who found that women were less likely to find a radar display to be useful, but is similar to findings that indicate women are generally more active in gathering information about potential risks (Schumann et al. 2018; Stewart et al. 2012). Two of the most significant intrinsic factors were finding the location of precipitation on radar to be more accurate as well as trusting radar data more often. Both variables had a positive relationship with finding a radar display to be more useful. One major draw to using radar is that it provides the user with the location of precipitation and hazard information; therefore, it is logical that as the perceived accuracy of the location of precipitation viewed on radar increases, the perceived usefulness of the radar display also increases. The same relationship can be reasoned for the frequency of trust a radar user places in radar data.

Fig. 5. Percentage of respondent's frequency of radar use by device type.

Respondents' weather salience scores were another significant intrinsic factor in the regression model. Individuals with higher weather salience scores rated a weather radar display as being more useful. This finding aligns with Stewart et al. (2012), who found that weather salience was significantly related to the use of precipitation and temperature forecasts. Therefore, people who care more about how weather impacts their daily lives are more likely to rate a radar display as a useful tool. The frequency of using a radar display was not a significant predictor of radar usefulness in the model, which may be a result of how the question was asked.

Overall, this sample was unique in that 78% of respondents selected that they were a weather enthusiast. This is most likely explained by the fact that they self-selected to take this survey without any incentive and that most respondents discovered this survey through a channel that already distributes weather information, such as the NWS Ruskin office or a local broadcast meteorologist. Identifying as a weather enthusiast does appear to influence the perceived usefulness of a radar display when compared to non-enthusiasts; however, it does not have a significant effect in the overall regression model.

In general, other research into the use of weather information, broadly, has found that their respondents seek out weather information often and find value and importance in a weather forecast (Demuth et al. 2011; Lazo et al. 2009). While a radar display is a more specialized tool than a weather forecast, there are parallels in how useful they are found, but more could be studied about this specific population. Information sufficiency was an important factor that influenced the perceived usefulness rating of a weather radar display, as respondents who more frequently agreed that a weather radar display provided them with enough information about a precipitation event to make their own independent decisions about an event were more likely to find a radar display to be more useful. This finding aligns well with Dunwoody and Griffin's (2015) RISP model, in that needing information sufficiency and quality increase motivation. Just as having trust in or believing that radar data are accurate, it is logical that if an individual feels that they have more control over their decision-making while using a radar display, their perceived usefulness for a radar display would also increase. It was surprising that the only significant extrinsic variable was overhearing a conversation about current weather conditions, as we had anticipated that experiencing rain or receiving an official warning would have a significant relationship with the radar usefulness rating.

General radar use. This study identified other noteworthy findings that relate to the overall use of a weather radar display. Respondents identified that the information they found most important when viewing a radar display was to locate a hazard watch or warning for their area, as well as to locate precipitation for their area. Radar provides unique spatial data that would not otherwise be provided by a precipitation forecast using a percentage or hourly possible precipitation. It was also interesting that the majority of the open-ended responses noted that respondents use radar to find out storm characteristics such as speed and directionality. These two variables can be communicated in space and time, allowing radar to be the ideal source of information for these variables. One caveat to this finding is that the answer choices in the survey were predetermined, with the exception of the open-ended response, which could have introduced bias; therefore, the information users want most from a radar display could have been different if the questions were solely open-ended.

It was not surprising to find that smartphones were the most frequently used device type to view a radar display since the majority of U.S. adults own them. As expected, there was a negative correlation between age and using smartphones to view a radar display, as younger people tend to adopt the latest trends in technology. Thus, it is not surprising that there was an even stronger positive correlation between age and respondents who use a television to view a radar display. Smartphones also allow users to view a radar display anywhere they have a cell or Wi-Fi connection and often can show the user their exact location in relation

to the data being displayed. This again provides a unique spatial component that a standard weather forecast does not.

For the 86% of respondents who answered the open-ended question about which activities motivate them to view a radar display most often, the most common responses were being outdoors or relating to a “work” activity, primarily referring to driving or commuting to work. Tampa Bay area residents primarily commute to work via personal car and travel alone, with a mean travel time around 28 min (U.S. Census Bureau 2019). Therefore, knowing where precipitation or storm events might intersect their commute could be important, especially for streets in low-lying areas or for any traffic delays. The majority of respondents in the study, 89%, said they use a personal car to commute to work, while 6.5% stated that they either worked from home or were retired. Outdoor activities such as yard work, going to the beach, and boating were other common responses. Due to Tampa’s geographic location and temperate winters, Tampa Bay residents can generally be outside for the majority of the year to take part in many outdoor sports and activities; therefore, radar would be an important tool to have available in case of any precipitation or storm event.

Conclusions

Overall, this study finds that respondents find a radar display to be a very useful tool and that they use it regularly. Respondents report that locating a hazard watch or warning for their area, followed by locating precipitation and storm events, as being the most important information variables when viewing a radar display. Women, as well as older respondents and those with higher incomes, are more likely to find a radar display more useful. An overwhelming majority of respondents indicate that they use their smartphones to access a radar display, which allows radar to be accessed anywhere a wireless signal is received. This is especially important in Florida, as residents state that being outside and participating in outdoor activities motivate them to use a weather radar display most often. These findings could help in future smartphone application development, especially surrounding the trust for radar data and the perceived accuracy of precipitation on a radar display. Perhaps more background information could be provided to radar users within the application about what information is being displayed.

As technology continues to change the way people access weather information, it is also important to understand how people change their information viewing habits so that technology can evolve to best suit their needs. The gradual shift from accessing weather information using a television to using a smartphone is one example of this change. Other important messaging through smartphones includes the Wireless Emergency Alerts (WEA) system that will send an alert signal to anyone in a specific geographic location. This system became operational in 2012 and is being refined to improve the accuracy of alerts. In addition, lots of weather apps have optional alerts that can be turned on and off by the user that will give warnings about lightning, tornadoes, and hurricanes, among other hazards. While accessing weather information via smartphones provides users with flexibility and mobility, it may not always be reliable in cases where cell service is lost or unreliable.

A limitation of this study is that the sample collected was not demographically representative of the Tampa Bay area, most likely due to the way the survey was disseminated. Radar display usage may also be different in the Tampa Bay area compared to other geographic locations due to the type of weather events that occur. Our study is novel as it captures the radar use and technology habits of those who are interested in the weather and who consistently pay close attention to the weather, outside of the operational meteorology community. It was essential to gather data and information about a population of individuals who use radar often before examining people who do not use this information tool. There is still more to discover about people’s radar use, such as the types of decisions they make with radar data. Future research will also include surveying people who choose not to use a radar display as a source of weather

information. It would also be ideal to understand the preferences between the use of radar versus an hourly precipitation or percent chance of precipitation forecast. The differences between the weather enthusiast versus non-enthusiast populations is another theme for further exploration.

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Appendix: Survey Questions

Below are the survey questions that were considered for the analyses in this manuscript, with the exception of demographic questions. Response choices are included for each question. Roman numerals indicate questions that were asked in matrix form with the same response choices.

Q1.4 Which of the following answers best matches how often, on average, you viewed weather radar displays during the past year? (Response choices: *Never, A few times per year, A few times per month, A few times per week, A few times per day*)

Q1.6 How many years have you lived in the state of Florida? (Open-ended)

Q2.3 How often do the following conditions prompt you to view a radar display? (Response choices for each subquestion: *Never, Seldom, Sometimes, Usually, Always*)

- (i) Viewing changing sky conditions
- (ii) Seeing lightning
- (iii) Hearing thunder
- (iv) Seeing precipitation (rain, snow, sleet, etc.)
- (v) Receiving an official warning for a severe thunderstorm
- (vi) Receiving an official tornado warning
- (vii) Overhearing a conversation about current weather conditions
- (viii) Seeing someone carrying an umbrella, or wearing a raincoat or rain boots
- (ix) Other (Please specify)

Q2.4 When viewing a weather radar display, how important is the following information to you? (Response choices for each subquestion: *Not Important, Minimally Important, Moderately Important, Important, Very Important*)

- (i) To find out the intensity of a precipitation event
- (ii) To find out how long a precipitation event will occur
- (iii) To locate a precipitation event
- (iv) To locate a hazard watch or warning for your area
- (v) Other (Please specify)

Q2.5 Are there any activities that influence you to view a weather radar display more often? (Open-ended)

Q2.6 When the following weather conditions occur in your area, how often would each weather condition motivate you to view a weather radar display? (Response choices for each subquestion: *Never, Seldom, Sometimes, Usually, Always*)

- (i) Rain
- (ii) Thunderstorm
- (iii) Hurricane
- (iv) Lightning
- (v) Tornado
- (vi) Hail

- Q2.8** Using a 1 to 10 scale, where 1 means “Not at all useful” and 10 means “Very useful,” please rate the usefulness of a weather radar display. (Response choices: *1–10 scale*)
- Q2.9** On average, how often do you trust the information displayed by a weather radar? (Response choices: *Never trusted, Seldom trusted, Sometimes trusted, Usually trusted, Always trusted*)
- Q2.10** How accurate do you find the following information provided by weather radar? (Response choices for subquestions: *Not at all Accurate, Minimally Accurate, Moderately Accurate, Accurate, Very Accurate*)
- (i) Intensity of precipitation
 - (ii) Location of precipitation
- Q2.11** Do you view a radar display as a part of your job? (Response choices: *Yes, No*)
- Q2.13** When a precipitation or severe weather event is occurring, or might occur, a person may need to make a decision that impacts their plans (e.g., you are attending an outdoor event and it begins to rain; or, you receive a tornado warning for your area). How often does a weather radar display provide you with enough information about a real time precipitation event to make your own, independent decisions about that event? (Response choices: *Never, Seldom, Sometimes, Usually, Always*)
- Q2.14** Choose whether you agree or disagree with the following statement: Using a weather radar display helps me to feel confident when making decisions about a real-time precipitation event. (Response choices: *Strongly disagree, Somewhat disagree, Neither agree nor disagree, Somewhat agree, Strongly agree*)
- Q3.1** Please rate how often you use the following electronic sources to view a weather radar display? (Response choices: *Never, Seldom, Sometimes, Usually, Always, Do not own this device*)
- (i) TV
 - (ii) Computer/laptop
 - (iii) Smartphone
 - (iv) Tablet
 - (v) Other (Please specify)
- Q3.9** Do you consider yourself to be a weather enthusiast? (Response choices: *Yes, No*)

Short Weather Salience Questionnaire (Stewart et al. 2012):

- Q4.1** I take notice of changes that occur in the weather. (Response choices: *Never, Seldom, Sometimes, Usually, Always*)
- Q4.2** I notice how the clouds look during various kinds of weather. (Response choices: *Never, Seldom, Sometimes, Usually, Always*)
- Q4.3** I plan my daily routine around what the weather may bring. (Response choices: *Never, Seldom, Sometimes, Usually, Always*)
- Q4.4** The weather or changes in the weather really do not matter to me. (Response choices: *Strongly disagree, Disagree, Neither, Agree, Strongly agree*)
- Q4.5** I am attached to the weather and climate of my hometown (or the place of where my family of origin lives or lived). (Response choices: *Strongly disagree, Disagree, Neither, Agree, Strongly agree*)
- Q4.6** It is important to me to live in a place that offers a variety of different weather conditions throughout the year. (Response choices: *Strongly disagree, Disagree, Neither, Agree, Strongly agree*)
- Q4.7** In the past I have wished for weather that would result in a weather-related holiday. (Response choices: *Never, Seldom, Sometimes, Usually, Always*)

References

- Agresti, A., 2010: *Analysis of Ordinal Categorical Data*. 2nd ed. John Wiley & Sons, Inc., 405 pp.
- Ajzen, I., 2002: Perceived behavioral control, self-efficacy, locus of control, and the theory of planned behavior. *J. Appl. Soc. Psychol.*, **32**, 665–683, <https://doi.org/10.1111/j.1559-1816.2002.tb00236.x>.
- Albrecht, R. I., S. J. Goodman, D. E. Buechler, R. J. Blakeslee, and H. J. Christian, 2016: Where are the lightning hotspots on earth? *Bull. Amer. Meteor. Soc.*, **97**, 2051–2068, <https://doi.org/10.1175/BAMS-D-14-00193.1>.
- Ashley, W. S., and C. W. Gilson, 2009: A reassessment of U.S. lightning mortality. *Bull. Amer. Meteor. Soc.*, **90**, 1501–1518, <https://doi.org/10.1175/2009BAMS2765.1>.
- Bandura, A., 2012: On the functional properties of perceived self-efficacy revisited. *J. Manage.*, **38**, 9–44, <https://doi.org/10.1177/0149206311410606>.
- Becker, J. S., D. Paton, D. M. Johnston, and K. R. Ronan, 2012: A model of household preparedness for earthquakes: How individuals make meaning of earthquake information and how this influences preparedness. *Nat. Hazards*, **64**, 107–137, <https://doi.org/10.1007/s11069-012-0238-x>.
- Brooks, H. E., C. Doswell, and M. P. Kay, 2003: Climatological estimates of local daily tornado probability for the United States. *Wea. Forecasting*, **18**, 626–640, [https://doi.org/10.1175/1520-0434\(2003\)018<0626:CEOLDT>2.0.CO;2](https://doi.org/10.1175/1520-0434(2003)018<0626:CEOLDT>2.0.CO;2).
- Collins, J. M., R. V. Rohli, and C. H. Paxton, 2017: *Florida Weather and Climate: More than Just Sunshine*. University Press of Florida, 264 pp.
- Demuth, J. L., B. H. Morrow, and J. K. Lazo, 2009: Weather forecast uncertainty information an exploratory study with broadcast meteorologists. *Bull. Amer. Meteor. Soc.*, **90**, 1614–1618, <https://doi.org/10.1175/2009BAMS2787.1>.
- , 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, <https://doi.org/10.1175/2011WCAS1061.1>.
- Dewitt, B., B. Fischhoff, A. Davis, and S. B. Broomell, 2015: Environmental risk perception from visual cues: The psychophysics of tornado risk perception. *Environ. Res. Lett.*, **10**, 124009, <https://doi.org/10.1088/1748-9326/10/12/124009>.
- Dunwoody, S., and R. J. Griffin, 2015: Risk information seeking and processing model. *SAGE Handbook of Risk Communication*, Sage Publications Inc., 102–116.
- Earle, T. C., 2010: Trust in risk management: A model-based review of empirical research. *Risk Anal.*, **30**, 541–574, <https://doi.org/10.1111/j.1539-6924.2010.01398.x>.
- Henson, R., 2010: *Weather on the Air: A History of Broadcast Meteorology*. American Meteorological Society, 241 pp.
- Hickey, W., 2015: Where people go to check the weather. Five Thirty Eight, <https://fivethirtyeight.com/features/weather-forecast-news-app-habits/>.
- Koehler, T. L., 2020: Cloud-to-ground lightning flash density and thunderstorm day distributions over the contiguous United States derived from NLDN measurements: 1993–2018. *Mon. Wea. Rev.*, **148**, 313–332, <https://doi.org/10.1175/MWR-D-19-0211.1>.
- Lazo, J. K., R. E. Morss, and J. L. Demuth, 2009: 300 billion served. *Bull. Amer. Meteor. Soc.*, **90**, 785–798, <https://doi.org/10.1175/2008BAMS2604.1>.
- Lindell, M. K., and R. W. Perry, 2012: The protective action decision model: Theoretical modifications and additional evidence. *Risk Anal.*, **32**, 616–632, <https://doi.org/10.1111/j.1539-6924.2011.01647.x>.
- Morss, R. E., J. L. Demuth, and J. K. Lazo, 2008: Communicating uncertainty in weather forecasts: A survey of the U.S. public. *Wea. Forecasting*, **23**, 974–991, <https://doi.org/10.1175/2008WAF2007088.1>.
- Neuwirth, K., S. Dunwoody, and R. J. Griffin, 2000: Protection motivation and risk communication. *Risk Anal.*, **20**, 721–734, <https://doi.org/10.1111/0272-4332.205065>.
- Nussbaum, E. M., 2015: Basic nonparametric tests for ordinal data. *Categorical and Nonparametric Data Analysis: Choosing the Best Statistical Technique*, Routledge, 129–163.
- Pew Research Center, 2019: Demographics of mobile device ownership and adoption in the United States. Pew Research Center, accessed 4 March 2020, www.pewresearch.org/internet/fact-sheet/mobile/.
- 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, <https://doi.org/10.1175/BAMS-D-18-0020.1>.
- Ryan, R. M., and E. L. Deci, 2000: Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *Amer. Psychol.*, **55**, 68–78, <https://doi.org/10.1037/0003-066X.55.1.68>.
- Saunders, M. E., K. D. Ash, and J. M. Collins, 2018: Usefulness of the United States National Weather Service radar display as rated by website users. *Wea. Climate Soc.*, **10**, 673–691, <https://doi.org/10.1175/WCAS-D-17-0108.1>.
- Schumann, R. L., K. D. Ash, and G. C. Bowser, 2018: Tornado warning perception and response: Integrating the roles of visual design, demographics, and hazard experience. *Risk Anal.*, **38**, 311–332, <https://doi.org/10.1111/risa.12837>.
- Sherman-Morris, K., and A. M. Lea, 2016: An Exploratory Study of the Influence of Severe Weather Radar Broadcasts. *J. Oper. Meteor.*, **4**, 108–122.
- Stewart, A. E., 2009: Minding the weather. *Bull. Amer. Meteor. Soc.*, **90**, 1833–1841, <https://doi.org/10.1175/2009BAMS2794.1>.
- , J. K. Lazo, R. E. Morss, and J. L. Demuth, 2012: The relationship of weather salience with the perceptions and uses of weather information in a nationwide sample of the United States. *Wea. Climate Soc.*, **4**, 172–189, <https://doi.org/10.1175/WCAS-D-11-00033.1>.
- U.S. Census Bureau, 2019: U.S. Census Bureau QuickFacts: Pinellas County, Florida; Hillsborough County, Florida; Pasco, Florida, accessed 8 April 2020, www.census.gov/quickfacts/fact/table/hernandocountyflorida,pascocountyflorida,pinellascountyflorida,hillsboroughcountyflorida,tampacityflorida/PST045219.
- Wachinger, G., O. Renn, C. Begg, and C. Kuhlicke, 2013: The risk perception paradox-implications for governance and communication of natural hazards. *Risk Anal.*, **33**, 1049–1065, <https://doi.org/10.1111/j.1539-6924.2012.01942.x>.
- Wood, M. M., D. S. Mileti, H. Bean, B. F. Liu, J. Sutton, and S. Madden, 2017: Milling and public warnings. *Environ. Behav.*, **50**, 535–566, <https://doi.org/10.1177/0013916517709561>.