July 2020

The Perceived Usefulness of a Weather Radar Display by Tampa Bay Residents

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by

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A dissertation submitted in partial fulfillment
of the requirements of the degree of
Doctor of Philosophy in Geography and Environmental Science and Policy
School of Geosciences
College of Arts and Sciences
University of South Florida

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Date of Approval:
June 19, 2020

Keywords: risk perception, mixed methods, scenario, surveys, interviews

DEDICATION

I am forever grateful for the love and support of my parents Janet and Michael, my brother Jonathan, and my grandparents. Thank you for letting me travel great distances to study what I am passionate about. Robert, thank you for always believing in me and supporting my dreams.

ACKNOWLEDGMENTS

I would like to thank my advisor, Jennifer Collins for all of the opportunities you have provided for me during my time at USF, especially the hurricane surveying experiences, mentoring REU students, and presenting at conferences. Through these I gained valuable field research experience and improved my leadership skills. I also valued being an officer of the West Central Florida American Meteorological Society Chapter for the last five years.

Thank you to Robin Ersing, Rebecca Morss, Kamal Alsharif and Yujie Hu for serving on my committee. I appreciate your feedback and assistance through the PhD process. Thank you to Kevin Ash for your support and guidance. Thank you to the University of South Florida and the School of Geosciences for your support. Also, thank you to Richard Pollenz for believing in my abilities as a STEM Academy graduate mentor.

Thank you to all the Tampa Bay residents who were a part of this research, especially the 30 of you who took the time to be interviewed and who shared your passion for weather with me. This research would not have been possible without you.

This degree would not have been possible without my friends and fellow graduate students. A special thank you to Karena, Arsum, Faye, Emily, Charlie, Mitch, Glenn, Jen, Josh, Ashley, Saurav, Frank, Chloe, Amy, Leilani, Osen, and Lubana. Also, thank you David and Pat. Thank you to Marshay Forbes for your assistance with transcribing the qualitative interviews and to Meghan Cook for providing intercoder reliability. Phase two of this research was funded by the Tharp Fellowship.

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ABSTRACT

A weather radar display is a tool that provides spatially oriented, timely information about an impending weather event. While radar is frequently used by meteorologists, emergency managers, and pilots, this tool is now readily available for individuals to use on a variety of platforms including television, computer/laptop, smartphones and tablets. Most importantly, there are hundreds of mobile weather applications available as well as online sources that provide a weather radar display. However, little is known about how individuals use a weather radar display. Therefore, the purpose of this dissertation is to understand why radar is sought out as a tool and how useful it is perceived to be as a source of weather information.

This research uses a mixed methods approach to answer the many unknowns surrounding weather radar use. An online survey collected 510 responses from residents within seven counties within the Tampa Bay Area. Overall a weather radar display was found to be a very useful tool. Survey responses were analyzed to determine several factors that increased the overall usefulness of a radar display including age, wealth, and gender (female). Respondents who said that weather radar provided them with enough information for decision making, that trust radar data, that were more weather salient, and found the accuracy of the location of radar data to be greater were more likely to find a radar display to be a useful tool. Respondents reported locating a hazard watch or warning and the location of precipitation as being the most important information provided by a weather radar display. This survey also determined that a smartphone was used most often to view a radar display over television, computers, or tablets.

As smartphones were found to be used most often, the respondents' preferred mobile weather applications were evaluated. Mobile weather applications were also grouped by the type of information that was displayed first in the app and by how prominent the radar display was in each app. Findings showed that the average age of the user was significantly different between specific apps. More men than women used apps that solely served as a radar display or map focused display, while women preferred apps that delivered a forecast and/or current conditions first. Specific features of each mobile weather app were analyzed to discover what users liked most about their preferred mobile weather apps. Finally, a visual comparison of seven mobile weather apps showed several differences in layout, colors used to display reflectivity values, and legend types. This showed major differences for how each weather radar display looks, including the way reflectivity values are contoured and smoothed.

The second phase focusses on understanding the construal of situational risks and outcomes and applies several theories from social psychology and geography to address research objectives. Using radar involves interpreting space and time while simultaneously evaluating meteorological attributes (reflectivity etc.). Using six radar-based scenarios (three severe and three non-severe), 30 participants took part in semi-structured interviews in order to test how they perceived a radar display. Findings showed that participants found a radar display to be less useful during weather events where directionality was unclear or stationary. Radar was described most often as a tool used to anticipate what will occur in the near future. This study also reveals several possible misconceptions for what participants thought reflectivity values display such as inferring lightning or wind when 'red' or 'orange' reflectivity values were present. Time was also overestimated in most scenarios. Finally, the broader impacts, limitations, and future research are discussed.

CHAPTER ONE:

INTRODUCTION

Weather information is widely available and communicated across an array of media platforms. Radar (radio, detection, and ranging) is used to locate, track, and measure precipitation (Committee on Weather Radar Technology Beyond NEXRAD 2002). It is a tool used by the National Weather Service and has been in operation since World War II. Doppler radar is most commonly used by weather forecasters, pilots, and broadcast meteorologists among other professionals. However, the ways in which technology is used to access weather information have changed greatly over the past decade. The general public now has greater access to Doppler radar for personal use, though little has been published about their use of weather radar, or how useful they find radar as a source of information and as a decision-making tool. Therefore, the main purpose of this dissertation is to explore how a radar display is perceived and used as source of information and tool for decision making.

Radar History

The first weather radar network started in Panama, in April of 1944, during World War II. The research operations which took place at the Panama station contributed to several new findings included storm genesis characteristics, the effects of topography, and even the first lightning detection. The first radar system for use by meteorologists was the AN/CPS-9 Storm Detection Radar using an X-band wavelength. Weather radar can also be a tool used for detecting possible severe weather phenomenon. As early as the 1950's, a hook echo was first understood to be associated with a tornado. It was not until 1969 in Tampa, FL, that the first television station installed weather radar, as ground based radar systems had become more available (Whiton et al. 1998a). With the invention of the transistor, the Weather Bureau was able to phase out previous radar models that used vacuum tube technology, replacing them with the WSR-74C, a new generation of weather radar.

The current radar model used by the National Weather Service in the United States is the WSR-88D, an S-band system. There are many advantages to using this model, such as the ability to view echo patterns in a time-lapse sequence and computer aided interpretation of what the radar is displaying. The National Weather Service installed the first WSR-88D in Twin Lakes, OK and it took seven years to install all 158 stations (Whiton et al. 1998b). The WSR-88D upgraded to dual-polarization technology allowing for the use of a horizontal and vertical radar pulse to help differentiate between precipitation types. It can also be used to better estimate rainfall rates and the size of hail (Serafin and Wilson 2000; Kumjian 2013). While the current radar network is an integral part of weather forecasting, there have been some suggestions to improve common data errors such as gaps in coverage or beam blockage due to mountainous topography. One potential solution is to deploy a dense network of smaller radar systems (McLaughlin et al. 2009).

Technology and Risk Perception

Traditionally, broadcast meteorologists have used and explained radar on television. However, over the last several decades, technology has developed rapidly, allowing individuals to obtain weather information through a variety of different platforms including television, computers/tablets, and mobile devices. As of 2019, 81% of US adults own a smartphone, making it one of the most popular tech devices (Pew Research Center 2019). Age of the user plays an important role in their use of technology. It was reported that 75% of young adults (18-29 years) who did not have cable or satellite television had alternative ways of accessing content, most using online services (Horrigan and Duggan 2015). By not accessing cable or local television, a younger generation may not receive weather information from a broadcast meteorologist. Broadcasters do communicate through social media and mobile weather applications which may maintain them as a possible source of information.

There are a few articles, both peer-reviewed and published in the general media, about how people access, use, and perceive weather information (Demuth et al. 2009; Hickey 2015; Morss et al. 2008; Phan et al. 2018; Saunders et al. 2018; Stewart 2009; Stewart et al. 2012). However, some studies analyze how weather information was used and perceived before mobile weather applications became popular. Since the launch and adoption of smartphones, the way that weather information is accessed and used has drastically changed. With this shift in how technology is used to view weather information, it is important to discover why individuals seek out radar, how they use it as a tool, and how useful they find a radar display as a source of weather information. The perceived usefulness and ease of use greatly influences a user's acceptance of a technology (Davis et al. 1989). There are hundreds of meteorological and broadcast news websites as well as weather applications available for download, with a large range in features, layouts, and quality. As more traditional weather information sources such as newspaper, radio, and even traditional television broadcast news become less popular, it is vital that we understand how these newer internet and wireless sources are used.

This research answers many of the unknowns surrounding the general use of radar by studying Tampa Bay, FL, residents. It is important to understand what motivates individuals to use weather radar and to discover what factors lead to a greater perceived usefulness of radar as a source of information and decision aid. This research also explores the geographic elements of using a weather radar display as well as understanding how different meteorological events can affect the perceived usefulness of a radar display.

Frameworks

There are many theories and frameworks within the hazards and risk perception literature that explain how individuals behave before, during, and after hazardous events. Ashley & Strader (2016) define risk as the probability of a hazard or extreme event occurring. Risk perception is how one processes and interprets the risks involved for a particular event or activity (Slovic 1987; Wachinger and Renn 2010). Before being able to interpret risk, an individual has to first be aware of a potential risk. In the context of a risk from hazardous weather, awareness may come from a range of sources such as an official warning from the National Weather Service, a family or friend, or even environmental cues (Lindell and Perry 2012). The Risk Information Seeking and Processing Model takes into account both intrinsic and extrinsic factors as well as motivational factors to understand how people will make a decision about a potential risk (Dunwoody and Griffin 2015). Trust and confidence are also important factors in determining how risk is assessed (Earle 2010). These existing models and frameworks influenced the creation of the theoretical framework used by Saunders et al. (2018) to assess the perceived usefulness of the NWS website radar display.

Theoretical Framework

The working theoretical framework for this study guides the two phases of research outlined in this dissertation (Figure 1). Phase one of this research focuses on identifying specific intrinsic and extrinsic factors that may motivate an individual to seek out and use a radar display. This phase of the research also informs a radar user's perceived usefulness of a radar display.

Chapter two of this dissertation cites the framework used by Saunders et al. 2018. The second phase of this research analyzes the construal of situational risks and outcomes to discover how construal level theory, psychological distance, and geospatial thinking influence radar usefulness and what information is gathered from using a radar display (Lobben and Lawrence 2015; Trope and Liberman 2010). Therefore, construal level theory and psychological distance were integrated into the theoretical framework.

Methodological Framework

To carry out the research outlined, this study employs a mixed methods approach with the specific research framework set as an explanatory sequential mixed methods design (Creswell 2014). This design first uses quantitative data collection and analyses followed by qualitative data collection and analyses. This design was chosen for two reasons, first, to have the quantitative results help inform and prepare the qualitative protocol. The second being that qualitative research methods and analyses worked best to understand the construal of situational risks and outcomes, as they allowed for radar scenarios to be described in detail study participants. This method is also best used by researchers with strong quantitative backgrounds who are new to qualitative research methods (Creswell 2014). A mixed methods approach was the best fit for this research because it allowed for a complete and robust way to collect and analyze a broad dataset in order to answer all research questions and objectives.

Objectives

The scope and goals of this research fit well within the field of geography but also incorporate theories from psychology and the social sciences. There are several major themes connected to this study including risk/hazard perception, use of technology (radar and communication), as well as motivational and cognitive theories. Geospatial thinking and psychological distance are also incorporated as radar data are displayed over common map attributes. This identifies the importance of having geographic background in addition to meteorological knowledge. The overarching research question for this study is to discover why radar is sought out as a source of weather information and how useful it is deemed as a source of information and decision aid. This question is explored in greater detail using the following research outline:

Phase One

1. To identify what factors outlined in the conceptual framework influence the perceived usefulness of a radar display.
2. To examine characteristics of general radar use.
3. To discover radar user's preferences for mobile weather applications features.

Phase Two

4. To understand how the construal of situational risks and outcomes influence the perceived usefulness of a radar display.
5. To explore how radar users interpret distance, time, and meteorological attributes using hypothetical scenarios.

Structure of Dissertation

This dissertation includes three main manuscripts that are organized in order of how the research proceeded through the mixed methods design. Chapter 2 details the questions answered by phase one of this research: discovering the factors that influence the usefulness of a weather radar display. Chapter 3 provides an in-depth look at the specific mobile weather applications that respondents used most often from phase one. Chapter 4 explores the findings of phase two, which explore participants' construal of situational risks and outcomes when using a radar display. It also highlights the connections between distance, time and meteorological attributes through the use scenarios created from archived radar displays. Chapter 5 will serve to conclude the findings from phase one and two and provide context for the broader implications of this research.

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Figures

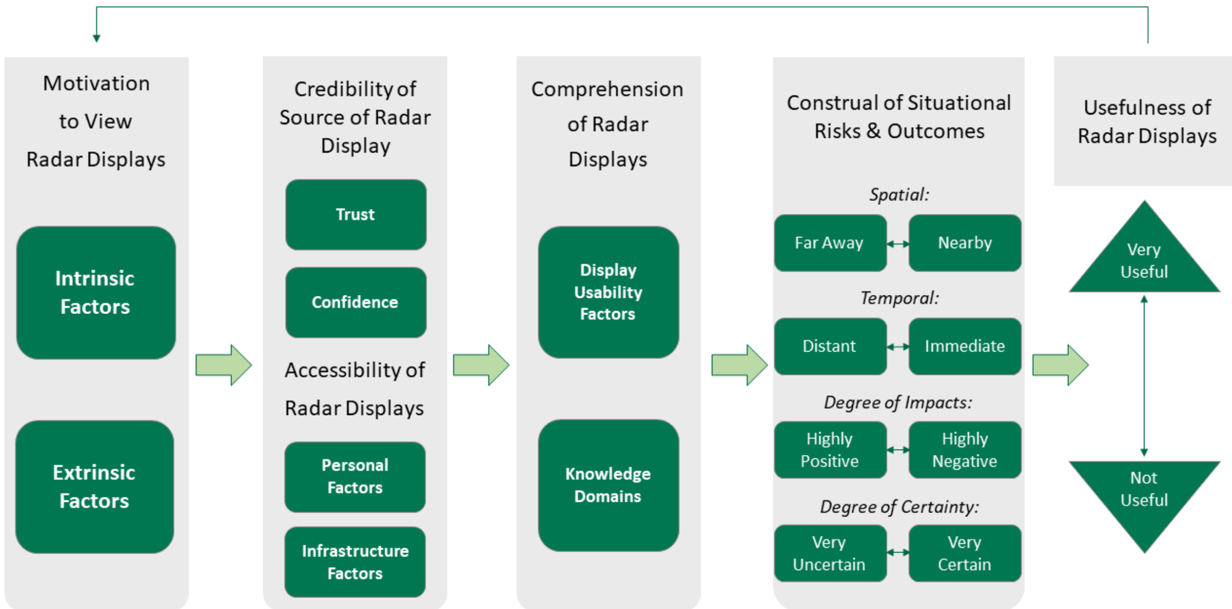

Figure 1.1. Full theoretical framework for the factors that may influence the perceived usefulness of a radar display.

CHAPTER TWO:

FACTORS INFLUENCING THE MOTIVATIONS & PERCEIVED USEFULNESS OF A WEATHER RADAR DISPLAY IN TAMPA BAY

Radar has been used for meteorological purposes since the 1940's and is a critical tool for forecasting the weather (Henson 2010). Meteorologists among other communities rely on this data to determine the location and intensity of precipitation, direction of winds, and can 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/tablet or download a radar application on a smartphone. However, little is known about what motivates a radar display to be used or how useful individuals find radar displays as a decision-making tool.

A weather radar display is a multifaceted tool; therefore, it is important to discern why individuals choose to view radar as a source of information about precipitation and storm events. In addition, it is essential to discover which factors lead to a higher perceived usefulness rating for radar displays because if specific factors, for example, demographics or trust for radar data, lead to an overall increase in the perceived usefulness rating, then those factors could be incorporated into current and future radar display products. By definition, useful means to be "capable of being put to use" or "of a valuable or productive kind" (*Merriam-Webster*). 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 study has several goals which include discovering what factors influence the perceived usefulness of weather radar displays as well as the motivation to use such displays. This study will also highlight what information is perceived as most important when viewing a radar display and what activities prompt Tampa Bay respondents to use a radar display.

To achieve these goals, a conceptual framework was used from Saunders et al. (2018) to determine which factors may influence the perceived usefulness of a radar display. Saunders et al. (2018) created this framework to assess the National Weather Service's (NWS) weather radar website display. 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. 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 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. Their 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.

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 suspected that depending on 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). 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). This study analyzes demographic data such as gender, age, education level, and household income to help identify how useful Tampa Bay Area respondents find a radar display. Intrinsic factors consider how often a radar display is used, 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).

Other factors that may determine the usefulness of a weather radar display are whether or not a respondent uses radar at their job and whether they consider themselves to be a weather enthusiast. These factors were included to help gain a better understanding of why a participant uses a radar display in addition to whether or not these factors would increase how useful radar was 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. There may also be specific activities that influence an individual to view a radar display more often. The type of media that is used to view radar may also affect a usefulness rating. Several devices can be used to view a radar display including televisions, tablets, computers, and smartphones. As of 2019, 81% of US 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?
- 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 a seven-county area that collectively makes up the Tampa Bay Area, including Hillsborough County, Pinellas County, Pasco County, Hernando County, Manatee County, northern Sarasota County, and western Polk County (See Figure 2.1). 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 hotspot for the United States is Orangetree, Florida which has a flash rate density (FRD) of 79 fl km^{-2} yr^{-1}. Another study that used cloud-to-ground lightning flash data and annual thunderstorm days found that the mean annual maximum lightning strikes for the US 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 in other places in the United States. The Tampa- St. Petersburg- Clearwater Area ranked fourth out of the top 25 counties for lightning fatalities in the US 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 electronic 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 as well as a few other local organizations, through websites and social media platforms such as Facebook, Instagram, and Twitter. Respondents were self-selecting and at least 18 years of age, lived within the Tampa Bay Area and were asked to indicate how frequently they used a weather radar display. Surveys were administered from March - April 2019. A total of 710 respondents completed the survey; however, after controlling for survey completion and the location of respondents only 510 respondents could be included in the data analyses.

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 2016 National Oceanic and Atmospheric Administration's customer satisfaction survey, using a ten-point scale. It was also asked in a later portion of this survey using a five-point Likert scale that included labels using the language "not at all useful" to "very useful". Two scales were used to gather the same type of information as a way to check for consistency among survey responses. The ten-point scale was used in the analysis (See Figure 2.2).

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 (See Table 2.1). 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, ordinal logistic regression using a cumulative logit link function was used. This type of regression is employed when modeling using 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 calculated to identify the factors that influenced Tampa Bay Area radar user's perceived usefulness ratings of radar displays. All non-binary 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 an individual with an array of important information about current conditions. To identify what information respondents found most important, respondents were asked to rate how important four specific pieces of information that could be obtained using radar using a five-point Likert scale ranging from not important to very important, without a neutral category. 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, etc. 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 comparisons was then conducted using the sign test to compare each of the four information choices separately. A Bonferroni correction was applied.

Respondents were asked how often they viewed a radar display. Also, they were 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 device's respondents used to view a weather radar display by gender.

This study was also interested in understanding specific activities that motivate a respondent to view a radar display. This question was asked in an open-ended format and was analyzed using NVivo 12, 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.

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 24 independent variables ranging from demographic variables to the intrinsic and extrinsic factors established in the conceptual framework (See Table 2.2). Women were more likely to rate a radar display to be more useful than men, as were respondents who were older and wealthier. 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 in addition to how often radar data is trusted by the user. Respondents with a higher weather salience score were more likely to rate a radar display as more useful. Finally, respondents who said that the information from a weather radar display provided them with enough information to make their own independent decisions about what they would do during a precipitation event using radar were more likely to find a weather radar display to be a useful decision-making tool. No extrinsic factors were found to be statistically significant. Questions were phrased in terms of how often environmental factors would influence the respondent to view a radar display which could have impacted how these questions were interpreted by a respondent.

Respondents were categorized into different groups of radar users such as those who had taken a meteorology course, considered themselves to be a weather enthusiast, and respondents who use radar at their job. Mann-Whitney U Tests were used to discover differences 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 = 11196, p = 0.004). In addition, there was also a positive significant difference when comparing respondents who had not taken a course to those who had taken a course online (self-taught) (U = 11773.5, 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 = 16520.5, 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 ($X^2(3) = 31.9$, p = < 0.001). (See Figure 2.3). From this test, locating a hazard watch or warning for a respondents 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" 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 Figure 2.4). Using a Spearman's Rho test, a correlation between age showed significant results for each device type. The strongest positive correlations with respect to age occurred with television (rs = 0.247, p = < 0.001), and tablets (rs = 0.254, p = < 0.001), followed by computer use (rs = 0.139, p = 0.005). Smartphone use had a significant negative correlation with age (rs = -0.185, p = < 0.001). To test for any differences between males and females for device type, Mann-Whitney U tests were conducted. Both computers (U = 24200.5, p = < 0.001) and tablets (U = 26897.5, 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. This survey question was open-ended allowing for a query to be conducted revealing the most common responses. Approximately 86% of respondents answered this question. Overall work was mentioned most often at (116) times. Specifically, "driving" or "commuting to work" or "work activities" were mentioned as well as "working outside" or doing "yard work". The next most common word was "outdoor" (90), in particular going to the "beach" (54), "walking" (36), and "boating" (33) were frequently mentioned.

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 showed to be significant including women and respondents who were older and wealthier. This differs from results found by Saunders et al. (2018) 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 any 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.

Respondent's weather salience scores showed to be another significant intrinsic factor in the regression model. Individuals with higher weather salience scores rated a weather radar display as being more useful. Therefore, radar users who are more connected to weather in their daily lives tend to find radar as more useful, however, in the model, frequency of radar display use was not found to be a significant factor, which went against our hypothesis. As a respondent's frequency of using a radar display may be dependent on the frequency of precipitation occurring, it may have been more difficult to answer this question. 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 the majority of respondents discovered this survey though a channel that distributes weather information such as the NWS Ruskin office or a local broadcast meteorologist. 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. Just as trust and belief that radar data are accurate; it is logical that if an individual feels like they have control over their decision making using a radar display that their perceived usefulness for a radar display would also increase.

General Radar Use

This study identified other noteworthy findings that relate to the overall use of a weather radar display. Respondents identified what information they found most important when viewing a radar display to be locating a hazard watch or warning for their area, followed by locating 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.

It was not surprising to find that smartphones were the most frequently used device type to view a radar display since the majority of US adults own them. It was also expected that there would be a negative correlation between age and using smartphones to view a radar display as younger people tend to adopt the latest trends in technology. Conversely, there was an even stronger positive correlation between age and respondents who use a television to view a radar display.

For the 86% of respondents who answered the open-ended question about the activities they do that would motivate them to view a radar display most often, the most common response related to some kind of work activity with the majority falling within 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 minutes (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 and 6.5% stating that they either worked from home or were retired. Being outside was the other most common response. As residents of Tampa can generally be outside for the majority of the year to take part in many outdoor sports and activities due to geographic location and fair-weather patterns, 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 and wealthier respondents 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, therefore, allowing 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.

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 wide spread power outage or cell service are lost.

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. However, this population is unique in that 78% of respondents identified as being a weather enthusiast. This study is novel as it captures the radar use and technology habits of those who are interested in the weather and who pay close attention to the weather consistently outside of the 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 explanation.

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Tables

Table 2.1. Demographic variables compared to the American Community Survey ACS 2018: 5-Year Estimates Data Profiles.

Demographic Variable	Sample Estimates	ACS Estimates
Gender		
Male	54.9	48.6
Female	44.3	51.3
Other	0.8	n/a
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	n/a
%Hispanic or Latino	5.9	15.9
Highest Education Completed		
No high school degree	0.6	n/a
Highschool diploma or GED	9.0	31.4
Some college - no degree	22.0	21.2
Associates degree (2-year)	13.3	9.5
Bachelor's degree (4-year)	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

Table 2.2. An Ordinal Logistic Regression - Likelihood Ratio χ^2: 188.296, 24 df, p value < 0.001, and N = 427.

Independent Variables	Coefficient	Wald chi-square	Odds ratio
Demographics			
Gender: Female	0.758	6.916***	2.134
Age	0.331	4.492**	1.393
Household Income	0.254	3.240*	1.289
Taken a Meteorology course	0.471	1.807	1.601
Years lived in Florida	0.176	1.141	1.192
Education	-0.061	0.179	0.941
Intrinsic Factors			
Accuracy of precipitation location	0.604	14.74***	1.830
Trust for radar data	0.628	12.025***	1.875
Weather salience score	0.485	9.027***	1.624
Enough info for decision making	0.330	4.273**	1.392
Average radar use per week	0.185	1.453	1.203
Confident making decisions with radar	0.089	0.352	1.093
Accuracy of precipitation intensity	-0.104	0.351	0.901
Weather enthusiast	0.372	1.297	1.450
Use radar at job	0.155	0.188	1.168
Extrinsic Factors			
Seeing lightning	-0.281	2.213	0.755
Receiving an official tornado warning	0.252	2.206	1.286
Receiving an official warning for a severe thunderstorm	0.234	1.715	1.264
Overhearing a conversation about current weather conditions	0.227	1.571	1.255
Seeing precipitation	0.197	1.546	1.218
Experiencing hail	-0.128	0.761	0.880
Seeing someone carrying an umbrella, or wearing a raincoat or rain	0.063	0.133	1.065
Viewing changing sky conditions	0.042	0.071	1.043
Experiencing hurricane conditions	0.024	0.041	1.024

* indicates p < 0.1, ** indicates p < 0.05, and *** indicates p < 0.01

Figures

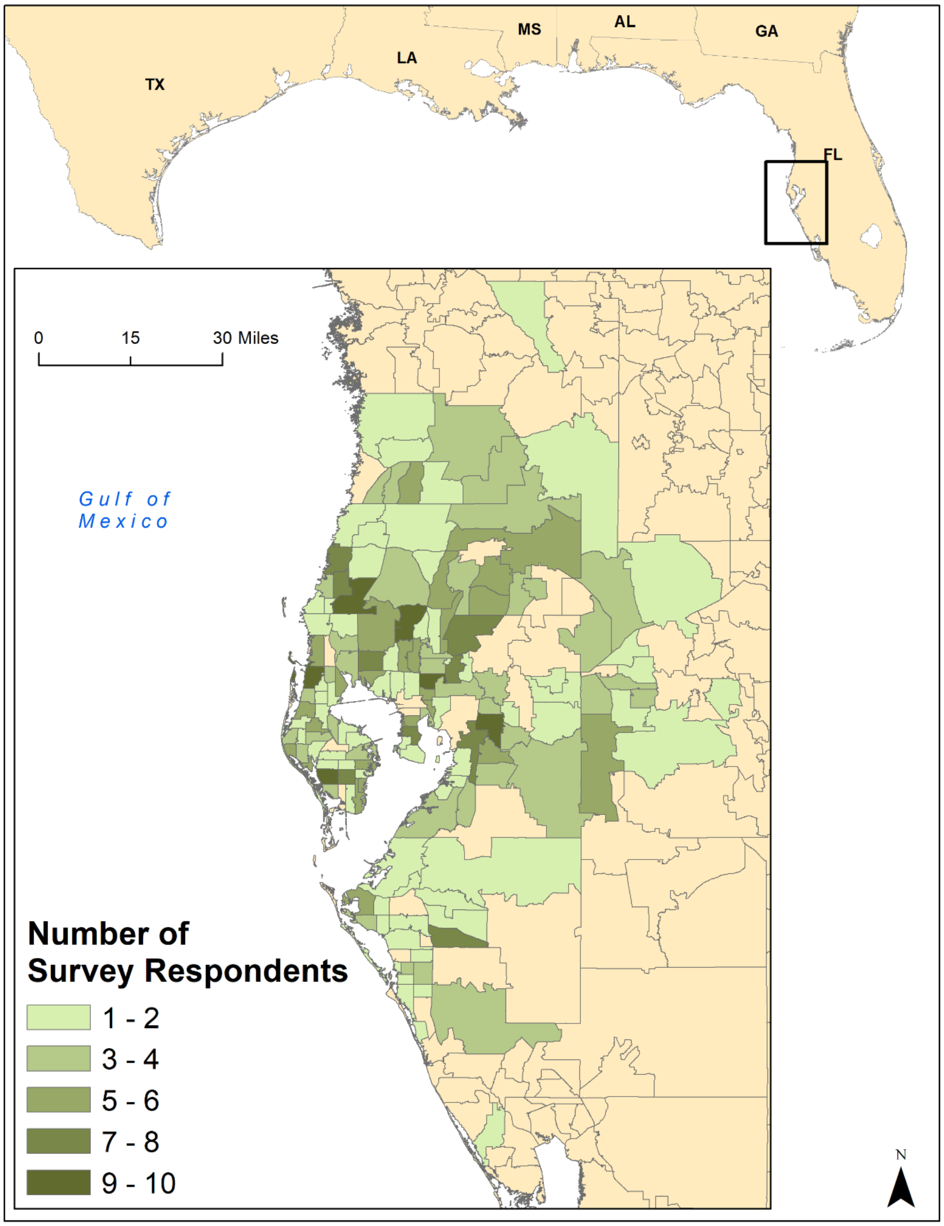

Figure 2.1. Number of respondents per zip codes from the seven-county study area of Tampa Bay.

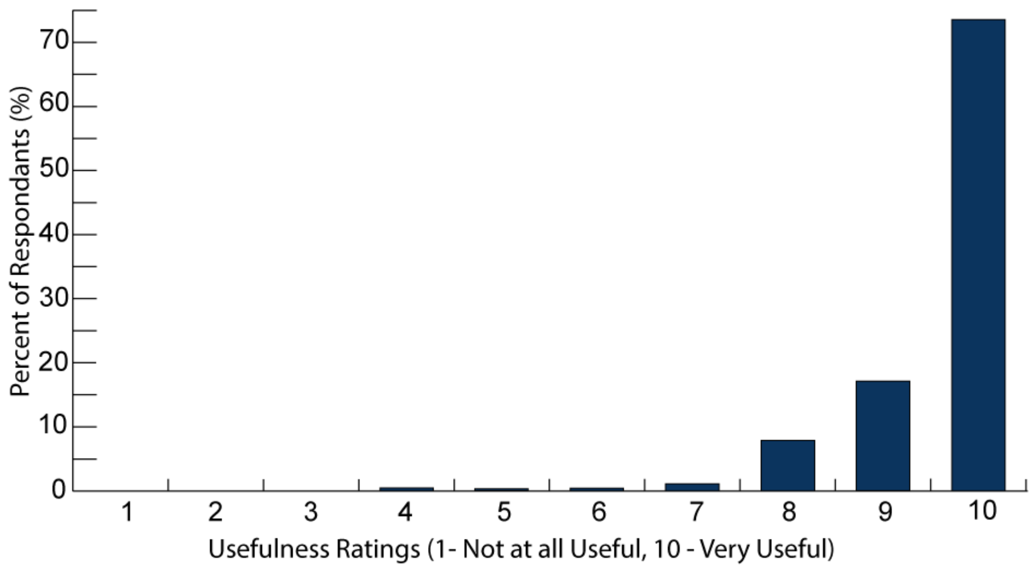

Figure 2.2. Respondent's weather radar usefulness ratings.

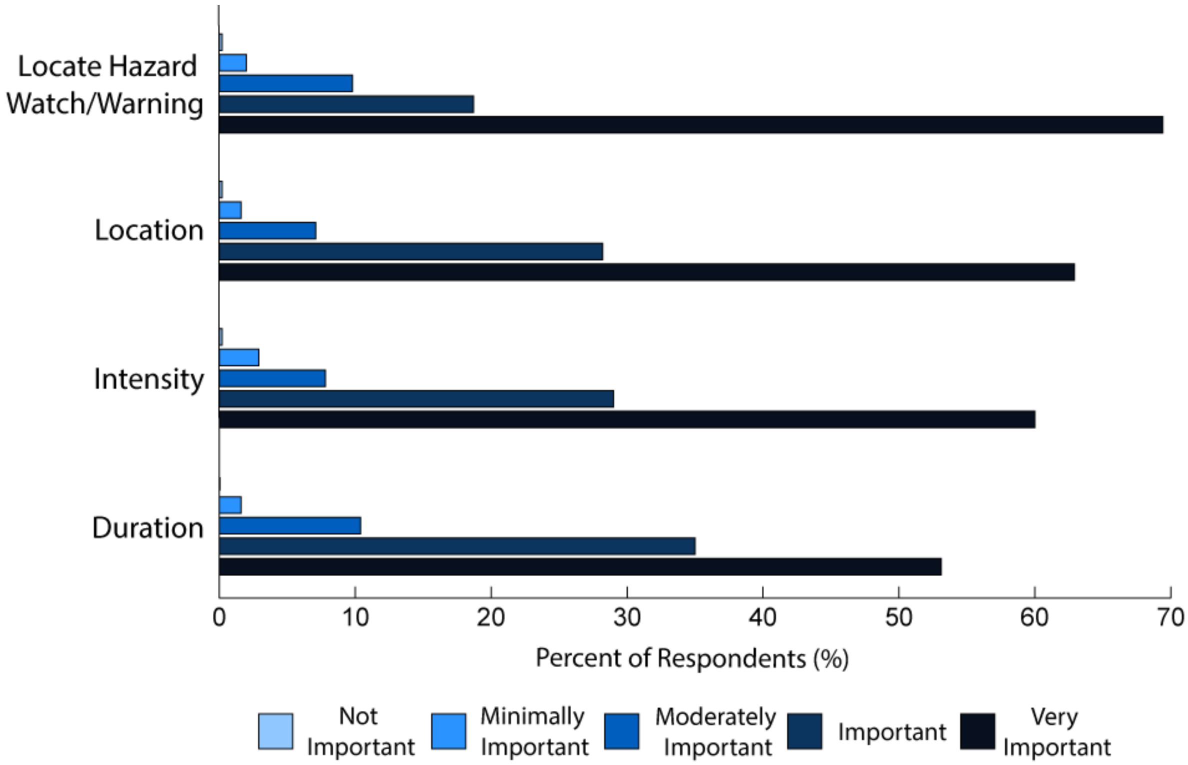

Figure 2.3. Results for how important respondents found different information that a radar display can provide.

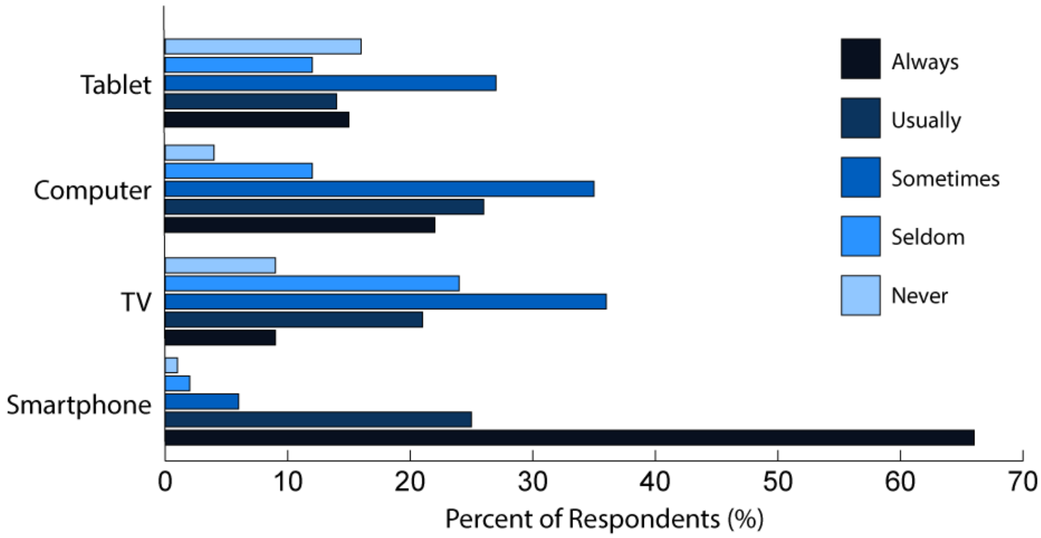

Figure 2.4. Percentage of respondent's frequency of radar use by device type.

CHAPTER THREE:

MOBILE WEATHER RADAR APPLICATIONS – USES, FEATURES, & PREFERENCES

Smartphones have quickly become one of the most popular tech devices since the release of the first Apple iPhone in 2007 and Google Android in 2009 (Islam and Want 2014). As of 2019, 81% of U.S. adults owned a smartphone, which has been on the rise since 2011 when ownership was closer to 35% (Pew Research Center 2019). A smartphone serves as both a communication device and a small computer that can be used to access the internet and mobile applications on the go. Therefore, the adoption of smartphone technology has changed how weather information is accessed by an ever-growing population. Embracing new technology is especially true for younger populations as smartphone ownership is even more mainstream with 96% of adults ages 18-29 and 92% of adults ages 30-49 owning a smartphone (Pew Research Center 2019). This adoption is evident in a few surveys such as Hickey (2015) from FiveThirtyEight who found that, out of eight methods for checking the weather, 23.2% of respondents used the default weather app that came with their phone, 20.6% watched local TV news, and 19.1% said they use a specific website or app. Paralleling the data from the Pew Research Group, Hickey found that only 8% of 18 to 29 year old respondents got their weather information from a local news broadcast while 29% of respondents 60 or older did. According to a recent study on how college students use mobile weather applications (MWA), 80.8% of college students used a weather app to check the weather forecast at least once a day while only 6.8% said they checked a forecast using a local television broadcast (Phan et al. 2018). This could indicate the beginning of a shift in how the next generations receive weather forecast information. It could also help predict how older populations are adapting. Age is one demographic variable that has been significant in influencing how people access, use, and perceive weather information (Demuth et al. 2011).

The ways in which people access weather information have changed since Lazo et al. (2009) published on the sources, uses, perceptions, and values of a weather forecast. They collected 1,465 survey responses in 2006, a year before the first iPhone launch. When respondents were asked about how often they used specific sources, 90% said they rarely or never used a mobile device to get a weather forecast and only 3% said they used a mobile device once or more per day. Instead 72% of respondents indicated they received their weather forecast one or more times a day from local TV, 40% from cable TV, 39% from radio, and 27% from newspapers. The authors conclude that this type of assessment should be performed on a regular basis to see how technology changes how we access weather information (Lazo et al. 2009). Therefore, one goal of this exploratory study is to provide new information on how technology is used to view a weather radar display.

Smartphone users can choose from hundreds of both free and paid MWAs. A weather radar display is one specific tool that is often integrated into MWAs, if not the primary purpose of an application. However, not all MWA radar displays are the same as there are differences in the data type displayed (base or composite radars), color ramps, legends, and other overlays such as lightning strikes or satellite imagery. Another important feature of an MWA is the use of location services and GPS to pinpoint a user's location which can be shown on a radar display. This may help a radar user to better assess spatial and temporal characteristics communicated by a radar display.

MWAs each contain their own compilation of features that range in customizability. Zabini (2016) looked at how the features of 39 of the most popular weather apps for the United States, United Kingdom, and Italy were communicating uncertainty of weather forecasts. They found several features about MWAs that failed to communicate the uncertainty that is an inherent part of a weather forecast to the public. Of the apps in their sample, about 67% (26 out of 39 apps) included an observation map, a feature that may be included in even more apps since 2016. Similar to Lazo et al. (2009), they conclude by noting that their study helped to track the changes in the ways that weather is communicated using mobile technologies. There have also been detailed reviews of MWAs, breaking down key features and the design/usability of the apps (Nagle 2014).

Mobile devices and MWAs have also become an important source for alerting and warning the public of hazardous weather events. However, many MWAs allow for the user to customize the alerts they would like to receive, including alerts for severe weather. One fear of using alerts is that if users are inundated with too much information the user could experience information fatigue (Yoder-Bontrager et al. 2017). Khamaj and Kang (2018) found that untrained users may take longer to perform tasks in MWAs that have a large number of settings and features that can be customized. In 2012, the Wireless Emergency Alert (WEA) system began to include imminent threat alerts pertaining to weather related hazards. One study investigated the effects of including a radar image along with a warning message from the NWS and from WEA's (Casteel and Downing, 2013). Surprisingly, they did not find many differences between the plain text warnings and the radar map with polygon warnings. Including a radar image within the WEA messaging also did not result in an increase in perceived risk or severity. Limitations include that the study sample was smaller and consisted of college students. It also only provided the user with a static image whereas an animation would provide users with more information and details about a weather event.

To date, little is known about how these MWAs with weather radar displays are used by the public and if users have any specific preferences for data types, features, or settings. There have been a few recent studies that address the general use of MWAs and the type of information users are looking for within an app, but none that focus specifically on radar displays. However, within these recent studies, a few have found that a radar or satellite display is a feature that users find important. For example, Phan et al. 2018 identified how important different mobile weather app features were to college students. Of their sample, 43.8% of respondents indicated that having satellite and radar features were very important or important while 29.9% indicated a neutral level of importance, with men finding these features to be more important than women. The two most important MWA features listed were an hourly forecast (87.4%) and the chance of precipitation (87.3%) (Phan et al. 2018). Again, this was a study specifically focused on college students and does not provide insight for how important older users find a radar display. Saunders et al. (2018) reviewed a national customer satisfaction survey from the National Weather Service (NWS) to find out how useful respondents found the NWS website radar display. Overall respondents found the radar display to be very useful especially among respondents in the Southern United States. Using a radar display more frequently, residing in an area with a higher lightning flash rate density, and an increased likelihood of taking action based on NWS information all had a positive relationship and were associated with higher perceived radar display usefulness ratings. However, this study could only make conclusions based on the use of the NWS website radar display, not MWAs.

Smartphone users have an abundance of choices when it comes to choosing an MWA and the features they want most from an app, including the features and appearance of a weather radar display. This study explores which MWAs that include a radar display are preferred by Tampa Bay area respondents and for what reasons, addressing the following five research questions:

1. Which MWA with radar displays are used most often by survey respondents?
2. Are there associations between respondent demographics and preferred MWAs?
3. Do users of any specific MWA find a radar display to be more useful as a source of information about precipitation?
4. What features do respondents like most about their most used MWA weather radar display?
5. How do the most preferred MWAs radar displays differ in appearance? *(Ex. Color ramps, smoothing, layout, extra features)*

Methods

Survey

An electronic survey instrument developed in Qualtrics was administered in March and April of 2019 to collect data on the use of weather radar displays, among other topics. This survey was advertised on social media platforms such as Facebook, Instagram, and Twitter from accounts by the NWS Tampa Bay office, the University of South Florida's research group, local broadcast meteorologists, and a few local organizations. The goal was to find residents in the Tampa Bay area that use a weather radar display. To qualify to take the survey a respondent had to be 18 or older, live within the 7-county study area for Tampa Bay, and indicate that they use a weather radar display. This survey gathered information on the perceived usefulness and the motivations to use a weather radar display, which are the primary focus within Saunders (2020 submitted). Many other variables were collected including which MWAs with radar displays the respondent preferred to use and what features they liked the most about their preferred MWA with a radar display. The survey was taken by 710 individuals but after controlling for the study area and completion there were 510 respondents. Out of those there were 498 respondents who gave a response for which MWA they used to view a weather radar display; therefore, the analyses are focused on this sample.

In order to gather information on which MWAs respondents were using, apps from both Apple and Google Android app stores were searched to gather the top downloaded MWAs that had radar displays. Nine specific apps were included in the survey as the response choices for which applications respondents prefer most. Response choices also included a local news weather app that displays radar as well as a choice for “other”. Both of these choices allowed respondents to reply as an open-ended response. The nine apps included within the survey were AccuWeather, Dark Sky, MyRadar, Radar Express, RadarNow!, RadarScope, WeatherBug, The Weather Channel app, and Weather Underground. After reviewing responses, a new variable was created to include a few other apps that several respondents indicated they used from the “other” category, this included NOAA Weather Radar, Rainy Days, Storm Radar, and Windy. This new variable was used for analyses. In addition to which MWA respondents preferred, respondents were asked about the features they like the most about their preferred MWA for viewing a radar display. This open-ended question collected 421 responses regarding users preferred features.

Data Analyses

To further explore these data, MWAs were divided into five categories that grouped apps by their primary purpose and for how prominent the radar display was within each app. A similar grouping was done by Zabini (2016) in their analyses of app style. This “MWA type” variable was used for additional analyses alongside the variable with each named MWAs. These groups were created and classified by the authors. The first group, named "Radar Primary", consisted of apps where the primary purpose was to provide a radar display. When the app was opened it would immediately show a radar display. Therefore, the apps within this group did not contain forecast information. The second category grouped MWAs that provided either current conditions in text or graphic format or a forecast for the user's location when the app was first opened. In order to view radar, the user would need to navigate to a different part of the app, often located in a different tab. This multimodal group was designated as "Forecast Primary" as the primary purpose of this app was to deliver a forecast and current conditions but also contained other tools such as radar and satellite data. The third main category was named "Map Centric, Multi-Variable". These apps opened to a map view, but not necessarily a map that displayed radar reflectivity. This group consisted of apps that instead of a text or graphical forecast, allowed users to view multiple variables such as temperature, wind direction and speed, satellite imagery, pressure, waves etc., each as map layers with the ability to toggle them on and off. Users could also overlay these variables with radar reflectivity values. The next category was defined as, "No App". These respondents were a unique group that indicated they use their smartphone to access weather radar but did not use a specific MWA, instead they would use either a web browser and search for a radar display or would go specifically to the NWS weather radar website display. The final group included was "Other" and was left unchanged from the original survey question regarding which app a user preferred. This group was included to provide context for choices that did not fit within the defined groups. (See Figure 3.1.)

Both quantitative and qualitative methods were conducted to explain respondents' preferences for MWA use. All statistical analyses were completed using the Statistical Package for the Social Sciences (SPSS) version 25. Descriptive statistics were used to review each respondent's preferences regarding their choice of MWA. To test for independence between variables, contingency tables were used to compare specific user groups. Pearson Chi-square tests were performed to test the null hypothesis of having no association between genders, respondents who had and had not taken a Meteorology course, and respondents who did and did not consider themselves to be weather enthusiasts (Elliott and Woodward 2007). This study was very interested in understanding the MWA use by age, therefore, the mean age of respondents was compared for each MWA using an ANOVA with a Games-Howell post hoc test. This post hoc test was used due to not having homogeneity of variances between MWAs, this was discovered using a Levene's Test. The average age of respondents was about 47.8 years and the median was 47 years which was comparable to the median age for the study area of 46.2 years (U.S. Census Bureau 2019).

Survey respondents had also been asked to rate how useful they found a weather radar display as a source of information about precipitation on a scale from 1-10, similar to the useful measurement used by Saunders et al. (2018). In this study, contingency tables explored the distribution of how useful respondents found a radar display to be by their preferred MWA. Ordinal logistic regression was also used to calculate odds ratios for the preferred MWAs to see if any apps influenced the perceived usefulness of a weather radar display. Specifically, a Generalized Linear Model was used with a cumulative logit link function using RadarScope as the reference category (Agresti 2010).

Detailed information was collected in the form of an open-ended question on the specific features that respondents liked the most about their preferred MWA. These responses were analyzed using NVivo software. Responses were coded and queried into common features and themes. They were then sorted by each MWA and MWA type to determine if users had similar opinions for a particular MWA or MWA type. This also allowed for comparisons to be made between each MWA and MWA type, to see if different features were associated more with specific apps or app types.

Using an Android smartphone, screen captures were taken of several MWAs used by respondents during the same precipitation event in order to provide additional context and visual comparison for the MWAs radar displays used in this study. These images highlight several differences such as colors ramps, legends, the layout of the app, smoothing techniques applied to reflectivity values, and extra features available for some apps, similar to Zabini (2016). (See Figure 3.2)

Results

Compared to TV, computers, and tablets, respondents indicated that they use smartphones most often to view a weather radar display with 65.8% stating that they always use their smartphone. About half of respondents, 50.7%, were iPhone users, 47.7% were android and the other 1.6% specified other. The majority of these smartphone owners indicated that they do use an MWA to view a radar display with the exception of 4% of respondents who indicated that they use a web browser on their smartphone to view a radar display. Table 3.1 displays a list of preferred MWAs that respondents indicated they use to view a weather radar display. Just over a quarter of the sample prefer to use a local news weather application. The next most commonly preferred apps for this sample were MyRadar, The Weather Channel app, and RadarScope.

Overall, the study population had only 10.6% fewer female participants than male as 44.7% of respondents self-identified as female and 55.3% as male. When testing for association or independence between gender for which MWAs were preferred, a Pearson Chi-Square test highlighted that there was a significant relationship (χ^2 (17) = 59.05, p = < 0.001). There was also a relationship between gender and the MWA type variable (χ^2 (4) = 24.62, p = < 0.001). These contingency tables revealed that out of respondents who use apps within the "Radar Primary" group, 77.1% were male and 22.9% female. In contrast the "Forecast Primary" group was not as polarized with 52.6% of users being female and 47.4% male. Comparing the use of individual MWAs by gender revealed that 90% (45 out of 50) of RadarScope users were male.

The MWAs were then analyzed for relationships between respondents who had taken a meteorology course, either online (self-taught) or a college course and those who had not taken a course. Overall, the majority of respondents, 70.6%, had not had any meteorological instruction. That being said, there was a relationship between taking a meteorology course and a respondent's preferred MWA (χ^2 (17) = 77.42, p = < 0.001). Once again RadarScope users differed from other MWAs as 66% of users had studied meteorology. There was also a relationship between taking a meteorology course and MWA type (χ^2 (4) = 50.59, p = < 0.001). The "Radar Primary" type included more respondents who had taken a course than those who did not, while the "Forecast Primary" type, 80.3% of users had not taken a meteorology course.

Another contingency table was used to compare the relationship between gender and MWA type while controlling for respondents who had taken a meteorology course. (See Table 3.2.) Calculations include Pearson Chi-Square, Fisher's Exact Test, and an overall Mantel-Haenszel test of conditional independence. The Mantel-Haenszel test was statistically significant, χ^2 (1, N = 492) = 16.160, $p < 0.001$. This method revealed that for the "Radar Primary" group, though the proportion of men was slightly higher than women it was not statistically different. In fact, the observed counts almost exactly matched the expected counts. However, when looking at the "Forecast Primary" group, the proportion of men and women were statistically different using a Pearson Chi-Square, χ^2 (1) = 7.642, p = 0.006) and Fisher's Exact Test (p = 0.006) showing that 73.6% of men and 86.3% of women who had not taken a meteorology course used this type of MWA while 26.4% of men and 13.8% of women who had taken a meteorology course use an MWA from this group. This highlights the importance of considering meteorological knowledge in addition to gender when examining each MWA group. The "Map Centric, Multi-Variable" group was also statistically significant, (χ^2 (1) = 3.831, p = 0.05) and Fisher's Exact Test (p = 0.085) with 64.4% of men and 87% of women who had not taken a meteorology course and 35.6% of men and 13% of women who had taken a course use this type of MWA. Finally, the "No Apps" group was also statistically significant, (χ^2 (1) = 10.755, p = 0.001) and Fisher's Exact Test (p = 0.002), with 16.7% of men and 88.9 % of women having not taken a meteorology course and 83.3% of men and 11.1% of women who had taken a course.

The same type of contingency table was calculated using the weather enthusiast variable and gender. The Mantel-Haenszel test was significant, χ^2 (1) = 5.722, p = 0.017. However, only the "No App" group was significant, (χ^2 (1) = 5.619, p = 0.018) and Fisher's Exact Test (p = 0.046) with 8.3% of men and 55.6% of women not being a weather enthusiast and 91.7% of men and 44.4% of women identifying as being a weather enthusiast.

The last test for relationships was between respondents who did and did not self-identify as being a weather enthusiast across all MWAs and MWA types. Overall, the majority of respondents, 78.7%, did identify as being weather enthusiasts. A Pearson Chi-Square test found a significant relationship with a respondent's preferred MWA, χ^2 (17) = 38.93, p = 0.002. This contingency table revealed that all respondents who use RadarScope are weather enthusiasts. A significant relationship was also found between being a weather enthusiast and the variable MWA type, χ^2 (4) = 21.55, p = < 0.001. Once again, the "Radar Primary" group had far fewer non-weather enthusiasts as was expected with 97.1% of respondents identifying that they were enthusiasts.

Age

The mean age of respondents was compared across their preferred MWAs. A one-way ANOVA was performed to test if the average age of respondents was equal across all MWAs. A Games-Howell post hoc test was performed as the sample did not have sufficient homogeneity of variances. Using the Games-Howell post hoc test allowed for multiple comparisons of mean age to be made between each MWA. This ANOVA was found to be significant with the (Sum of Squares (17) = 7582.59, Mean Square = 446.04, $p = 0.001$). It was also found that respondents who use their local news weather app were on average about 9 years older than those who use RadarScope ($p = 0.008$) and almost 8 years older than respondents using Weather Underground ($p = 0.046$). Most other apps either had a similar average age or were not significantly different (See Figure 3.3) Eta and Partial Eta Squared values were also calculated in order to estimate the effect size for the ANOVA. Eta was found to be .289 and Partial Eta Squared was .083 meaning that the age has only a small to medium effect on determining a respondent's preferred MWA. Guidelines suggest that Eta Square values of .02 indicate a small effect, .13 a medium effect, and .26 a large effect.

Usefulness Rating

Overall, respondents found a radar display to be a useful tool and source of information about precipitation. However, contingency tables did show small variations in the distribution of how useful respondents found a radar display for the respondents preferred MWA. This table showed that 86% of respondents who use RadarScope as their main MWA for viewing a radar display rated the usefulness of radar as a 10 on the usefulness scale of 1-10 and 12% as a 9, totaling 98% of responses. In some cases, this was 15-17% more useful than other applications such as AccuWeather which had a combined 9 and 10 usefulness rating of 81.1% and Weather Underground's rating of 83.8%. Of respondents using their local news weather app, 83.1% rated usefulness as a 10 and 10% as a 9, totaling 93.1%. An Ordinal Logistic Regression with the reference category set as RadarScope was statistically significant, χ^2 (17) = 39.991, p = 0.001. This found that the majority of the other MWAs would have a decreased overall usefulness rating in comparison to RadarScope. Specifically, the significant MWAs included The Weather Channel, Weather Underground, AccuWeather, MyRadar, Dark Sky, Rainy Days and the "other" category. (See Table 3.3.) A second model was run using the "MWA type" variable but was not found to be statistically significant.

Features

Data were coded and queried by each MWA to look for similarities and differences for each preferred weather app and "MWA type" group using a crosstab query in NVivo. (See Table 3.4.) Coding these features revealed several themes about the MWAs and the reasons for why individuals decide to use a specific app (or not). The most commonly mentioned feature was the "accuracy" of the MWA. Not only was accuracy mentioned the most (72 times), it was also cited by respondents from almost every MWA, although, it was mentioned the most by respondents who use their local news weather app followed by MyRadar and RadarScope users. One MyRadar user stated, "I use about 7 different weather applications, I guess MyRadar is my go-to because it's pretty detailed and accurate."

The next most common feature referenced was how "easy" the app was to use. Respondents who primarily used an MWA within the "Forecast Primary" group mentioned the app being easy the most with 35 out of the 42 total references. These respondents often referred specifically to the app's layout or that it was a "user friendly" app, while almost all of the mentions from the "Radar Primary" group used the words "simplicity" or "simple" to describe the app.

"Data" was another theme that emerged from what features radar display users liked the most about their MWA, only this time the "Radar Primary" group had the most mentions (24 out of the 40). RadarScope users made up the largest portion of these references followed by users of Weather Underground. RadarScope users were also unique as they specifically mentioned that they liked the advanced features available to them with most citing the ability to show velocity and correlation coefficients within the display. RadarScope users also referenced "raw data" as a featured they liked most about the app, some referring to other apps as having "smoothing", for example one users stated that they liked seeing, "actual radar data not smoothed images".

Some radar displays offer a "nowcast" or "futurecast" which is an extrapolation of the precipitation forecast (model) into the future, usually ranging from one to six hours. This type of product has been used during TV broadcasts for the past decade and are now a component of many MWAs that include a radar display. "Futurecast" was the next most mentioned feature that respondents discussed (38 times). Those who use their local news weather app as well as the Weather Channel app mentioned a futurecast the most. Therefore, the "Forecast Primary" group had the majority of mentions with 34 out of the 38 references. Only 1 reference came from the "Radar Primary" group, specifically from a Radar Now! user.

Another theme that emerged was lightning. Lightning was mentioned most often by the "Forecast Primary" group (75.7%), where the local news weather apps and WeatherBug had the most individual mentions. Most references to lightning referred to either detection of lightning or having a lightning indicator within the app.

Appearance

The appearance of each MWAs radar display varies greatly in color ramps, the layout of the display, legend used, smoothing effects, warning polygon color and/or fill, and other variables or information overlays. These images were captured during the same precipitation event so that comparisons could be made between MWAs. The first feature to note are the color ramps that represent the reflectivity values (echo intensities). The National Weather Service has one color ramp with two scaling options, one to represent dBZ values that range from -28 to 28 in clear air mode and another scale to represent dBZ values that range from 5 to 75 in precipitation. The colors start with light blue to darker blue, then light green to darker green, yellow into a deepening orange, red, pink, purple and then finally 75 dBZ is white. In precipitation mode the number value of dBZ correlates to the intensity of the rainfall which is often expressed in inches per hour.

Looking through the color ramps of some of the MWAs in this study it is clear that most of these are not using the same color ramp as the NWS. Some MWAs include a legend that displays the color ramp used while others do not. Both the Weather Channel and WeatherBug have a legend that displays different colors depending on the type of precipitation, rain, mixed, and snow. For rain, The Weather Channel uses a green to red transition while WeatherBug has a color ramp similar to the NWS except for the top of the scale where the pink and purple are different and white is missing. Some of the MWAs do not have a scale or legend present in the image such as Weather Underground and Windy. Therefore, the maximum and minimum thresholds for precipitation intensity may be unclear and will vary by application.

There are also many differences in the overlays and extra features that can be displayed. During this precipitation event there was a severe-thunderstorm warning in place for the Tampa area. This is presented as an outlined polygon for RadarScope and the NWS Mobile App and a transparent polygon for Weather Underground and MyRadar. Other apps do not have the severe weather warnings in this image as they were not turned on at the time of the screen capture. Another example is how RadarScope is displaying lightning strike data, which is included in the pro version which requires a subscription. Other apps such as the Weather Channel give an optional overlay where storm cells can be tracked. Others give temperature bubbles for cities. Most apps have a timestamp either in a corner of the screen or on top of the play bar. The last feature to observe is that some apps have a "futurecast" option that will provide a radar like model of what is expected over the following few hours.

Discussion

When observing differences in MWA preferences between gender, it was found that men used MWAs that had a primary focus on a radar display more often compared to women. It was also found that those who had taken a meteorology course had the same preference. Therefore, a third contingency table was used to compare gender and meteorology education controlled by each MWA and MWA type. This highlighted that the relationship of gender and meteorology education is not the same across all MWAs. Accounting for both gender and having taken a meteorology course provides more details of the respondents who use each MWA type. This was evident as men and women were in similar proportion for those who had and had not taken a meteorology course for the "Radar Primary" group. But for the "Forecast Primary" group the proportions change. Overall, fewer women had taken a meteorology course than men.

The same analyses were performed comparing being a weather enthusiast and gender. Only the "No App" group users were statistically different. As the other groups were not significant this might suggest that having some meteorology education may impact a user's

MWA preferences more than being a weather enthusiast as it was found that 78% of this study population considered themselves to be a weather enthusiast.

There was only a small difference in the age distribution across the different MWAs and MWA type groups. In fact, the mean range was only 14 years and most MWAs had large standard deviations, meaning that most MWAs had a similar age range. The only significant findings were comparing the ages of local news weather app users to RadarScope and WeatherUndground users. Therefore, for this sample, age does not play as large a role in determining MWA usership or preferences. This was interesting as not many studies in the past have used age to look at usership, and this was the first for radar displays. However, when using this dataset to determine what factors influence the usefulness rating of a weather radar display, age was found to be a significant factor.

Overall, radar displays were perceived as very useful and only minor differences were discovered when comparing usefulness across the preferred MWAs. It is important to state that this usefulness rating was specifically asked in reference to a "radar display" in general. However, since the majority of respondents stated that they used their smartphones most often to view a radar display, it was of interest to see if there was any difference in usefulness ratings across the preferred MWAs. For the Ordinal Logistic Regression, RadarScope was chosen as the reference category since it had the higher percentage of users that found it to be most useful. Therefore, it was not surprising that the majority of the other applications saw a decrease in usefulness in comparison. The same model was run several times using a different reference category each time in order to understand the effect on the other MWAs in relation to the perceived usefulness.

Accuracy is an important aspect when conveying information in any capacity. Therefore, it was not surprising that accuracy was the most common feature mentioned by users about MWA radar displays. Often when mentioning accuracy, respondents were specifically referring to either the "intensity" or the "location" of the precipitation or weather events. Another survey question addressed these two attributes, asking participants to rate the accuracy of the intensity and the location of precipitation using a radar display. This prompted a comparison between the perceptions of these two additional attributes across the preferred MWAs. A contingency table revealed that 39% of local news weather app users, 45% of MyRadar users, and 64% of RadarScope users found the location of precipitation to be very accurate on a five-point Likert scale. Users rated the accuracy of intensity much lower across all MWAs in comparison to location. For intensity, most MWAs were rated as accurate instead of very accurate. One possible explanation for this decrease in perceived accuracy of intensity could be linked to the color ramps used to display rainfall intensity (reflectivity). Depending on the MWA or even broadcast TV provider the color ramps may be different. Also, since some maps use base reflectivity and others composite, it is possible for different reflectivity values to be displayed for the same weather event which could lead to differences in the perception of accuracy. Reflectivity is measured in dBZ or decibels of Z and different colors correspond to a dBZ value. Therefore, the interpretation of the color may not be as straightforward to some users as the rainbow color ramp is often used to display reflectivity values. Rainbow color ramps have been found to produce less accurate interpretations of rainfall intensity (Bryant et al. 2014).

Most of the MWAs were also found to be "easy to use" either having a user-friendly layout and interface or were found to be simple and clean. An MWA being categorized as easy to use would most likely lead to repeated use. It was interesting to find differences in the wording that respondents used to describe an app being “easy” depending on if the app was within the “Radar Primary” or “Forecast Primary” groups. An app’s layout or that it was a “user friendly” app was discussed more often about apps within the “Forecast Primary” group. “Ease of use” in general was also specified. Within the “Radar Primary” group, 4 out of the 5 mentions for “easy” described the radar display as “simple” or having “simplicity”. This may be in reference to the app being a designated radar app instead of a multipurpose app.

The underlying radar data may mean different things to different users. The majority of mainstream MWAs are generally using data collected from the same radar towers operated by the NWS, which has about 155 ground-based radars. However, some local news stations do have their own radar tower. Even when the data is the same, coming from the same radar, the outputs can be displayed differently. Some users may also expect or want a radar display to show reflectivity values in a specific way. For example, a user may want a mosaic view across a vast area while at the same time want the capability to zoom in at street level. Another user might want to be able to toggle between base and composite radar images and animations whiles others are not sure of the difference. “Data” as a feature and the capabilities and options that some MWAs have versus others, is a major dividing point between the type of MWAs that have a radar display. It was not surprising that most notably, RadarScope users mentioned these “data” differences the most. These users want the ability to view other products such as velocity while others would rather have wind direction or speed overlays. Specifically, WeatherUndground users mentioned the abilities to layer variables. They also found the crowdsourced data to be important, indicating that they wanted hyper local datapoints from personal weather stations that some other MWAs do not offer.

A “futurecast” was another popular feature that some respondents mentioned about the MWA they use most often. Overall, this feature was stated as helping with understanding the direction and speed of future precipitation events. A large portion of those that mentioned using a futurecast also discussed liking the ability to see what has already occurred or “past radar”. Having an animation is important but it’s really being able to view what has already occurred in addition to a model of what is expected next that some MWA users want in a radar display, especially those in the “Forecast Primary” group. This feature will be explored more in the next phase of this study.

Lightning is a hazard that can occur all year round for Tampa Bay residents so it was not surprising to see lightning detection as a feature that users like about their preferred MWA. Some respondents mention that they like to see where the strikes are occurring live as an overlay on the radar display while others noted their MWAs option to receive a lightning alert that the user sets for a particular distance from their location. This feature however is not available for every MWA with a radar display and is often a feature locked behind a premium subscription.

In this example, there are many differences between the features and appearance of each MWAs radar display. the colors used to display reflectivity values are not the same across all of the radar displays even when sourced by the same data. These color differences could lead to varied perceptions of precipitation intensity.

Conclusion

This study was part of a mixed methods approach to gather exploratory data about radar use and in the process has helped to advance the literature on how current technology is being used to access weather information using a radar display. For this study population we found that local news weather app users were on average 8-9 years older than RadarScope and Weather

Underground users but that overall age varied widely. Most apps had around the same age distribution and there were no significant differences when comparing the MWA type groups. Several interesting findings emerged regarding gender and meteorological education, such as, more men than women chose to use an MWA within the "Radar Primary" and "Map Centric, Multi-Variable" groups while women preferred the "Forecast Primary" group. For the number of respondents within each MWA type group, more "Radar Primary" group users had some meteorological education while both the "Forecast Primary" and "Map Centric, Multi-Variable" groups users had more respondents who had not taken a meteorology course.

This study population also included respondents who do not use an MWA but instead use their phone to search for weather radar using a web browser or used the NWS website radar. There were almost no differences between these users when looking at gender or meteorology education individually, however, when comparing these two variables accounting for MWA type there was a significant relationship where more men than women had taken a meteorology course. This "No App" group would be an interesting population to follow up with to better understand their reasoning for not using an MWA to view a radar display.

Our qualitative analysis revealed that "accuracy" and "data" were the two features liked the most about users preferred MWA with a radar display. "Accuracy" was mentioned across every MWA type group and highlighted differences between users' perceptions of accuracy for both the location and intensity of precipitation. This found that the location of precipitation was perceived as more accurate than intensity. Upon comparing the appearance of several MWAs that users prefer, there were noticeable differences in the colors used to display the reflectivity values. This could impact how the accuracy of intensity is perceived by users, especially if a user compares one or more MWAs. Users may associate specific colors to their own perceived rainfall intensities. Accuracy is a feature that will be analyzed in greater detail within the next phase of this research. “Data” was mentioned across all but one MWA type group and was discussed most often by the “Radar Primary” users. This group specifically highlighted both the accuracy of data as well as having access to advanced tools and multiple data sources as the features they liked most about their preferred radar display. Respondents also mentioned features such the “ease of use”, having a “futurecast”, and having access to “lightning” detection.

Future research should further investigate the perceptions of accuracy for both the location and intensity of precipitation regarding the differences between apps that display base vs composite values and for the color ramps used. It is also important to understand the perceptions of past and current radar displays as the capabilities of a futurecast improve.

One limitation for this study is that participants were self-selecting, therefore, the demographics are not representative of the greater Tampa Bay area. However, this sample did survey members of the general public ranging in age from 18 - 80 with an average of 48 years old. Therefore, this sample helped to get an idea of which MWAs with radar displays are being used by an older population.

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Tables

Table 3.1. A list of preferred mobile weather applications that respondents indicated they use to view a weather radar display most often.

Mobile Weather Applications	Frequency	Percent of Respondents
Local News Weather APP	130	26.1%
MyRadar	62	12.4%
Weather Channel	60	12.0%
RadarScope	50	10.0%
AccuWeather	39	7.8%
Weather Underground	37	7.4%
WeatherBug	37	7.4%
Other	22	4.4%
No APP - NWS Website	13	2.6%
NOAA Weather Radar	8	1.6%
Dark Sky	7	1.4%
Storm Radar	7	1.4%
No APP - web browser	7	1.4%
RadarNow!	6	1.2%
Weather APP Pre-installed other	5	1.0%
Radar Express	3	0.6%
Rainy Days	3	0.6%
Windy	2	0.4%
Total	498	100.0%

Table 3.2. A contingency table comparing the relationship between gender and mobile weather application type while controlling for respondents who had taken a meteorology course.

Type of Radar App				Taken Meteorology Course No	Taken Meteorology Course Yes	Total
"Radar Primary"	**Binary Gender**	**Male**	Count	22	32	54
			Expected Count	22.4	31.6	54.0
			% within Binary Gender	40.7%	59.3%	100.0%
		Female	Count	7	9	16
			Expected Count	6.6	9.4	16.0
			% within Binary Gender	43.8%	56.3%	100.0%
	Total		Count	29	41	70
			Expected Count	29.0	41.0	70.0
			% within Binary Gender	41.4%	58.6%	100.0%
"Forecast Primary"	**Binary Gender**	**Male**	Count	106	38	144
			Expected Count	115.6	28.4	144.0
			% within Binary Gender	73.6%	26.4%	100.0%
		Female	Count	138	22	160
			Expected Count	128.4	31.6	160.0
			% within Binary Gender	86.3%	13.8%	100.0%
	Total		Count	244	60	304
			Expected Count	244.0	60.0	304.0
			% within Binary Gender	80.3%	19.7%	100.0%
"Map Centric, Multi-Variable"	**Binary Gender**	**Male**	Count	29	16	45
			Expected Count	32.4	12.6	45.0
			% within Binary Gender	64.4%	35.6%	100.0%
		Female	Count	20	3	23
			Expected Count	16.6	6.4	23.0
			% within Binary Gender	87.0%	13.0%	100.0%
	Total		Count	49	19	68
			Expected Count	49.0	19.0	68.0
			% within Binary Gender	72.1%	27.9%	100.0%

Table 3.2 (Continued)

"No App"	**Binary Gender**	**Male**	Count	2	10	12
			Expected Count	5.7	6.3	12.0
			% within Binary Gender	16.7%	83.3%	100.0%
		Female	Count	8	1	9
			Expected Count	4.3	4.7	9.0
			% within Binary Gender	88.9%	11.1%	100.0%
	Total		Count	10	11	21
			Expected Count	10.0	11.0	21.0
			% within Binary Gender	47.6%	52.4%	100.0%
"Other"	**Binary Gender**	**Male**	Count	8	9	17
			Expected Count	10.0	7.0	17.0
			% within Binary Gender	47.1%	52.9%	100.0%
		Female	Count	9	3	12
			Expected Count	7.0	5.0	12.0
			% within Binary Gender	75.0%	25.0%	100.0%
	Total		Count	17	12	29
			Expected Count	17.0	12.0	29.0
			% within Binary Gender	58.6%	41.4%	100.0%
Total	**Binary Gender**	**Male**	Count	167	105	272
			Expected Count	192.9	79.1	272.0
			% within Binary Gender	61.4%	38.6%	100.0%
		Female	Count	182	38	220
			Expected Count	156.1	63.9	220.0
			% within Binary Gender	82.7%	17.3%	100.0%
	Total		Count	349	143	492
			Expected Count	349.0	143.0	492.0
			% within Binary Gender	70.9%	29.1%	100.0%

Table 3.3. An Ordinal Logistic Regression with the reference category set as RadarScope was statistically significant, χ^2 (17) = 39.991, p = 0.001.

Independent Variables	Coefficient	Wald chi-square	Odds ratio
Rainy Days	-4.030	16.219***	0.018
AccuWeather	-1.793	12.198***	0.166
Weather Underground	-1.279	5.840**	0.278
Dark Sky	-1.894	5.828**	0.150
The Weather Channel	-1.080	4.869**	0.340
Other	-1.195	3.817**	0.303
My Radar	-0.917	3.496*	0.400
Weather App Pre-installed	-1.653	2.634	0.192
No App Web Browser	-1.204	1.621	0.300
WeatherBug	-0.639	1.331	0.528
Windy	-1.517	1.297	0.219
Radar Express	-0.991	0.633	0.371
Local News Weather App	-0.275	0.345	0.760
No App NWS Website	-0.168	0.037	0.845
RadarNow!	-0.173	0.022	0.841
NOAA Weather Radar	0.146	0.016	1.157
Storm Radar	-0.001	0.000	0.999
RadarScope (Reference Category)	0.000		

Table 3.4. The Frequency (count) of features mentioned by participants for each “mobile weather application type” group.

Radar Display Features	"Forecast Primary"	"Radar Primary"	“Map Centric, Multi-Variable”	"No APP"	"Other"	**Total (499)**
Accuracy	44	12	14	1	1	72
Easy	35	5	1	0	1	42
Data	9	24	4	3	0	40
Futurecast	34	1	3	0	0	38
Lightning	25	4	3	1	0	33
Local	20	8	0	0	0	28
Forecast Info	20	2	1	1	0	24
Intensity	14	2	5	0	0	21
Direction and motion	17	3	0	0	0	20
Past radar	15	1	1	0	1	18
APP Speed	13	3	0	0	1	17
Total	246	65	32	6	4	353

Figures

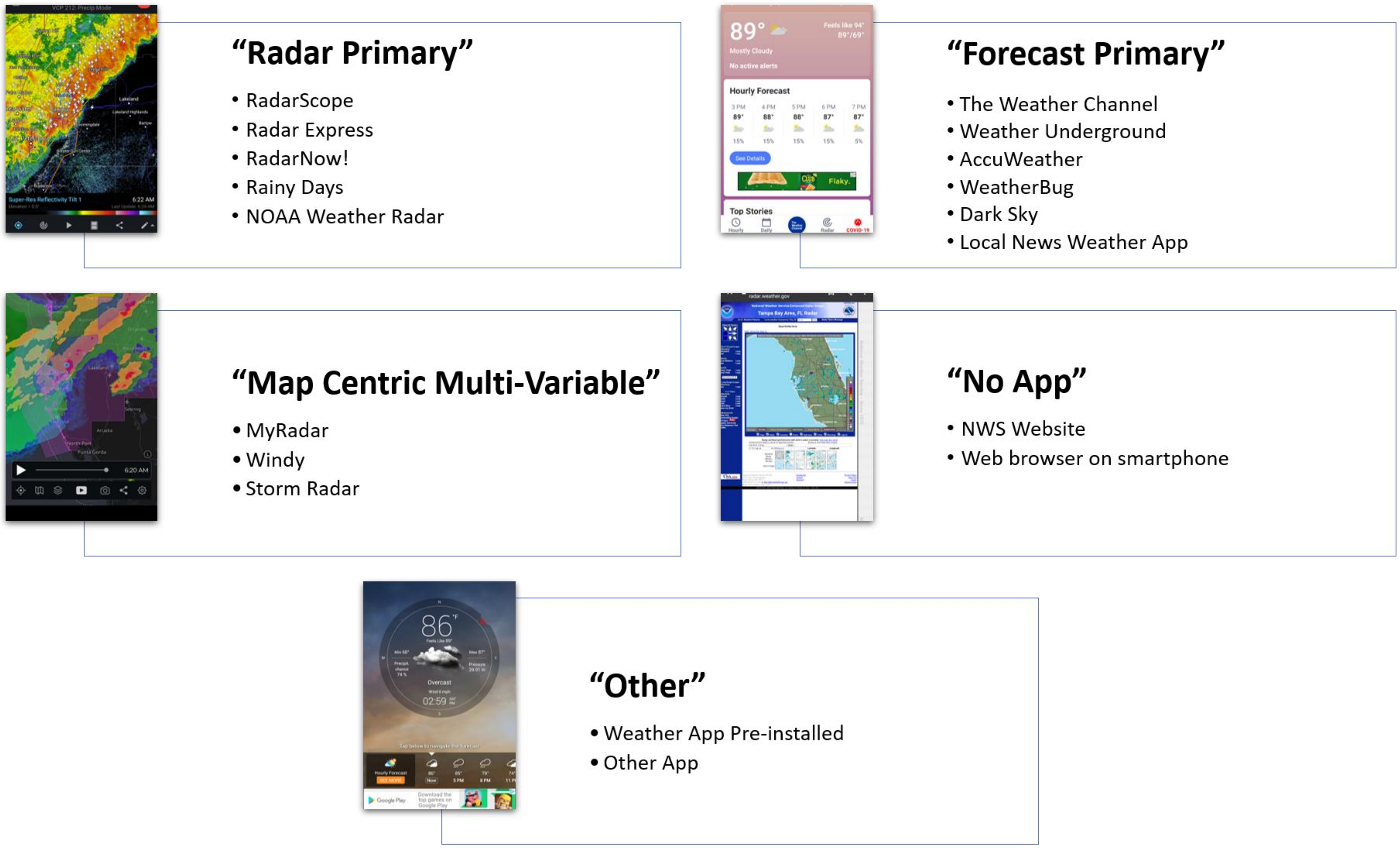

Figure 3.1. Mobile weather application "type" groups. Each preferred mobile weather application was grouped into an app type by their primary purpose and for how prominent the radar display was within each app.

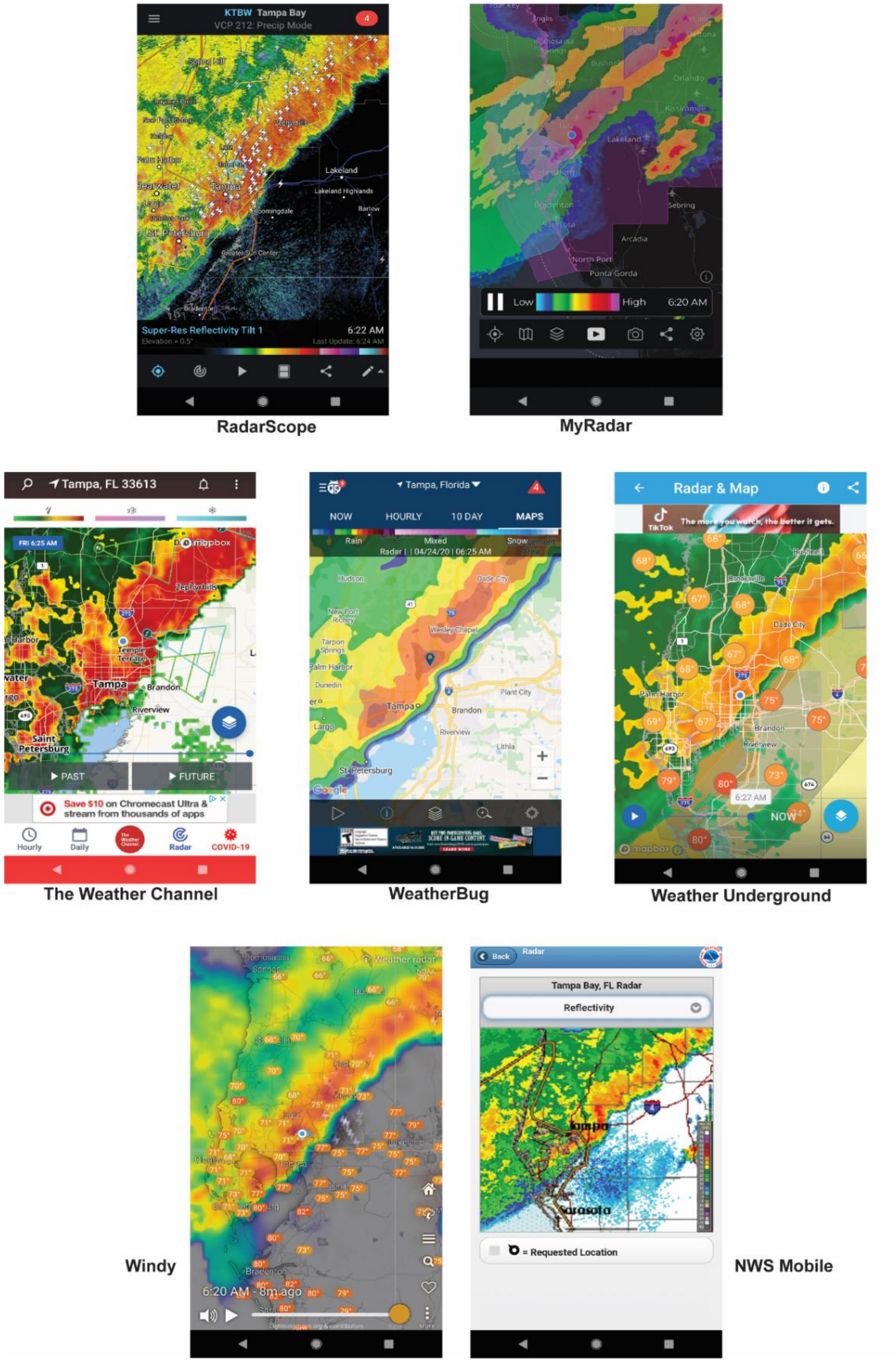

Figure 3.2. Screen captures of seven mobile weather application radar displays used by respondents.

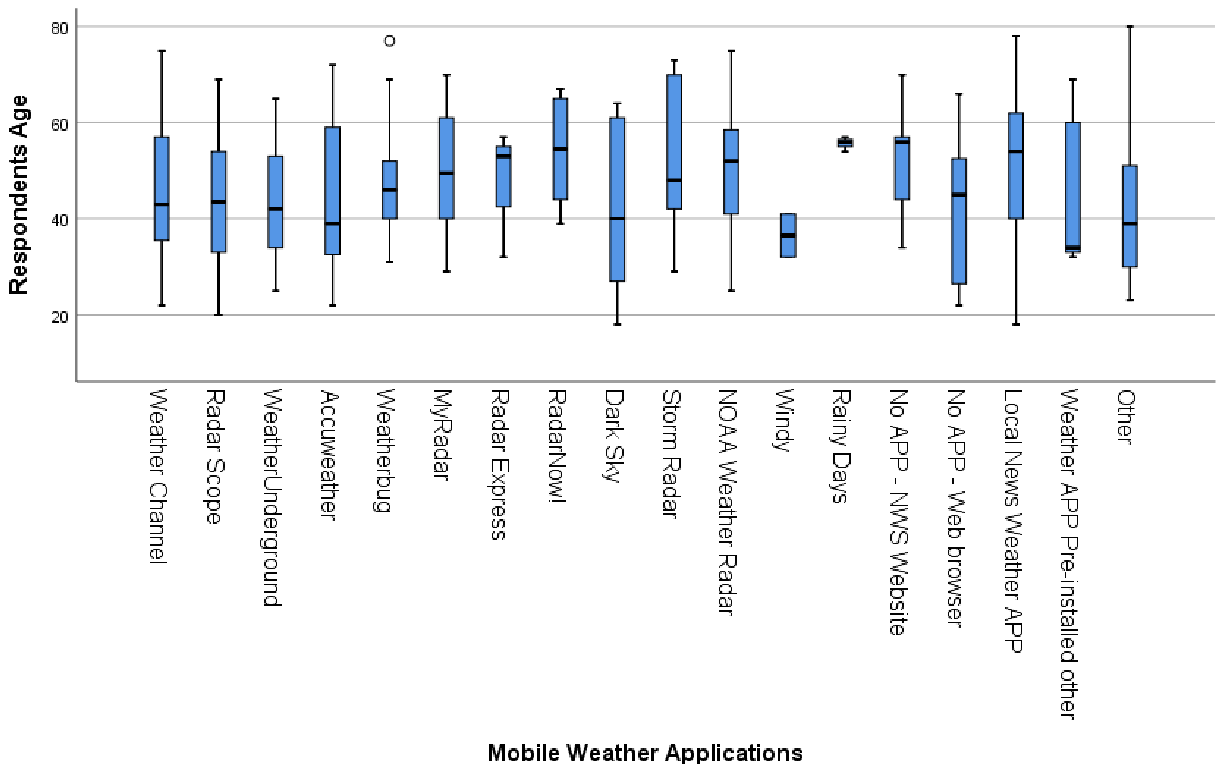

Figure 3.3. Respondents' age for each mobile weather application. The box represents the 1st and 3rd quartiles and the line within the box is the median. The whiskers extending from the box report the minimum and maximum value and a circle indicates an outlier.

CHAPTER FOUR:

CONSTRUAL OF SITUATIONAL RISK AND OUTCOMES – EXPLORING THE USE OF RADAR DISPLAYS

There are a variety of tools that are used to collect, interpret, and display weather information. Some require very little geographic knowledge such as a numeric or text forecast, while others such as a weather radar display, satellite imagery, or a hurricane forecast are built on a geographic foundation. This requires users to internalize and interpret distance and time in order to properly use these geographically based tools. Using these tools also requires the user to have knowledge of the attributes or meteorological data that are displayed over a map feature. This study focuses on how a weather radar display is a nexus for space, time, and attributes, where understanding one component is just as critical as the other two.

Distance is a variable that can be measured with units to provide a frame of reference. It can also be a perceived amount of space between two things, without a concrete metric. Similarly, time can be measured using exact measurements but can also be estimated. While distance and time are separate variables, they are often intertwined or used interchangeably. For example, estimating how far to the nearest grocery store could be done using miles or minutes depending on the context of the situation. For time, events might be referred to as occurring recently (close) or in the past (distant). Therefore, it is important to understand how distance and time are used in specific contexts.

Geospatial thinking can be used to help identify how and what information is interpreted from a radar display. Lobben and Lawrence (2015) argue that geospatial thinking skills involve all three primitives - space, time, and attributes. They demonstrate how their synthesized geospatial thinking model can be applied to future research, aiding in organizing ideas and the creation and testing of hypotheses. Radar data are displayed as both static images as well as rendered into animations that incorporate a dynamic attribute (reflectivity), over a dynamic timeframe, within a dynamic space. Lobben (2003) would describe this type of animation as a 'process animation' as each of the three components (attribute, time, and space) are dynamic. It has also been found that people think differently when they use maps in comparison to other geometric objects and evidence for this can be seen in the neural pathways using a functional magnetic resonance imaging (fMRI) scan (Lobben et al. 2014). Therefore, using a radar display requires the user to interpret meteorological data as it is displayed across a space that is moving forward time.

Distance can also be defined outside of a physical space and can be used to describe the mental construal. Construal level theory (CLT) is a general psychological theory explaining how an individual thinks about objects or events that are separate from their immediate, self-centered environment (Trope and Liberman 2010). Objects, people, and events that are psychologically close to an individual are thought about more concretely while psychologically distant objects, people, or events are more abstract. Within psychological distance, there are four subjective dimensions; spatial distance, temporal distance, social distance, and hypothetical (probabilistic) distance (Trope and Liberman 2010). Trope and Liberman (2010) demonstrate the connections and relatedness between these four psychological distances. They also explain how these are influenced by level of mental construal and can affect how people react and think about a future reality.

CLT has been applied within risk perception and communication research (Zwickle and Wilson 2014) and for research on climate change (Duan et al. 2017; McDonald et al. 2015). Simandan (2016) argues for the use of CLT and the use of psychological distance within the field of Geography to understand how humans use distance to view the world around them, both real and imagined (hypothesized). They argue that geographers have not "kept pace" with how distance is theorized within place and time-space concepts. CLT has not yet been used to study how meteorological phenomenon are construed.

Construal level theory and geospatial thinking were chosen to structure this research as they help explain how people might think about and react to near-future events. Ash (2015) proposed linking CLT and geospatial thinking for tornado preparedness research. CLT could evaluate an individual's perception of risk for meteorological phenomena, allowing them to hypothesize possible outcomes from viewing a radar display. This may include what type of precipitation is expected, the amount of precipitation they might receive, the timing of when they might expect a weather event, and if they will experience any weather hazards (lightning, flooding, tornado etc.). These theories can also link to risk perception theories for how people gather and respond to meteorological information. This relates to people's attitudes, risk sensitivity, and specific fears that play a role in the perception of risk (Sjöberg 2000). Brewer et al. (2007) who within health behaviors outlines three important risk perception dimensions which include perceived likelihood (the probability of an individual being harmed), perceived susceptibility (how the individual views their vulnerability), and perceived severity (the degree of harm potentially caused by the hazard). These dimensions are similar to the degree of impact and the degree of certainty, which are included within the construal of situational risk and outcomes section of the theoretical framework used in this study (See Figure 4.1).

A radar display inherently requires the use of spatial and temporal thinking. It also requires the user to be able to make assessments based on their meteorological knowledge, past experiences both using radar and from their previous weather experiences, as well as their spatial knowledge (familiarity of place). Radar can be used to judge or estimate time based on the location and movement of echoes in previous frames, thus providing a relative idea of how fast an 'event' is moving. This information is then used to extrapolate into the future for what may occur at the user's location. The temporal and spatial components must be combined with the knowledge of meteorological attributes in order for the user to approximate how far away a weather 'event' is from their location, how much time they have, and what they may experience.

While this study does not explicitly test for the comprehension of using a radar display it does explore aspects surrounding it. Radar users must have a way of interpreting what they view in a radar display and extrapolate those interpretations in order to make decisions. Radar users would need some level of meteorological knowledge to apply to what they are seeing using a radar display. They also must use a scale to interpret the intensity of precipitation. This is officially measured in decibels of Z (dBZ) but in many displays is represented only by a color scale without any numerical values (Bryant et al. 2014). Scale color ramps are also different across different radar displays. Users should have a general meteorological understanding of what to expect based on these scales (League et al. 2010; Wiggins 2014). In regard to severe weather situations, radar will display NWS warning products, therefore, it would be an advantage to the user if they are familiar with what the warnings represent and what to do if they are within an area with a warning (Lindell et al. 2016; Nagele and Trainor 2012).

Geographic literacy may also influence the use and understanding of a radar display. Bednarz and Bednarz (2008) argue that an increase in spatial thinking is necessary in order to maximize use of the technology currently available. They reported that many people use spatial thinking passively. Hegarty, Smallman, Stull, & Canham (2009) look at how Naïve cartography could have a negative effect on content understanding of a visual display. One example tested the animation component of a weather map. The authors note that while participants preferred an animation to a still image, other studies suggest that animations may lead to a lack of comprehension. In contrast, Drost et al. (2016) found that using an animation instead of a static image may provide more information allowing for better comprehension of the information. These concepts need further analysis.

The overarching goal of this study is to understand how the construal of situational risks and outcomes influence the perceived usefulness of a radar display. Using the greater Tampa Bay area as a case study, both CLT and geospatial thinking guide the qualitative methods used in this study in order to attain four objectives. The first is to discover the primary reasons for why people seek out information from a radar display and what information they want most from this medium. Second, to understand what information a user receives from viewing a radar display and how the information is described. Third, to determine what factors influence the perceived usefulness of a radar display. Finally, the last objective is to examine how time is estimated when viewing a radar display.

Methods

Study Participants

To find interview participants an advertisement was placed at the end of the weather radar survey (Chapter 2). A total of 59 survey respondents emailed the PI stating they were interested in being interviewed. These respondents were then contacted by the PI with an invitation to take a follow-up survey that helped the PI gain information about the volunteers.

There were 42 respondents who took the follow-up survey. Participants were queried by age, gender, and location in order to get a broad sample. Participants were then emailed to be scheduled for interviews. The majority of interviews were conducted at county libraries in the study area, while one interview took place at the Hillsborough County Emergency Communications offices and another was conducted at the University of South Florida Tampa Campus. There were 17 male and 13 female participants for a total of 30 people who were interviewed in this study. The average age of a participant was 50 with the youngest being 25 and the oldest being 73 years old. Interview length ranged from 31 – 96 minutes with an average of 53 minutes. All respondents were presented with a $10 gift card as compensation for their participation in the study.

Radar Scenarios

Scenarios were created using Gibson Ridge Analyst Software capable of displaying Level 3 radar data. Level 3 products are gathered from about 160 NOAA Next-Generation Radar (NEXRAD) Doppler radar stations. Archived radar data were downloaded from NOAA National Centers for Environmental Information and used to create six radar scenarios (National Centers for Environmental Information). Radar images were purposefully selected to vary the situational risks and outcomes observed in each scenario (distance, time, attributes). To select each scenario, the Storm Events Database was used to help search for specific events that impacted the Tampa Bay area, specifically at Curtis Hixon Park. This location was chosen for its central location and popularity in the Tampa Bay area. It is an open green space on the Tampa Riverwalk and has museums, restaurants, and shops nearby. Archived events were varied by their distance to the park (study location), their speed, the type of weather event (ex. frontal vs convective) and the degree of impacts expected at the park (severe or non-severe). The Iowa Mesonet archived text products were also used to verify the weather conditions for each of the scenarios including area forecast discussions, local storm reports, and specific products such as severe thunderstorm warnings, tornado warnings, and flood advisories/statements. Once all six events were chosen, two animations were created for each scenario: a short segment, consisting of the first 6 frames of the event and a longer segment showing the first 6 frames plus an additional 17-22 frames depending on the duration of the scenario. A dot was marked on the map to indicate where the participant was in each scenario (Curtis Hixon Park).

The Tampa Bay area receives on average around 46 inches of rainfall per year (NOAA). Residents and visitors also experience a fair number of severe weather events. To provide context on the frequency of severe weather warnings from January 2015 – May 2020, the National Weather Service Tampa Bay Ruskin Forecast Office has issued 103 tornado warnings, 265 severe-thunderstorm warnings, 264 flood warnings, 1,429 flood advisories, and 838 special marine warnings (Iowa Mesonet). The scenarios were divided into severe and non-severe events. Scenarios B, C, and F were severe and A, D, and E were non-severe; severe events are discussed first:

SEVERE SCENARIOS

Scenario B was a severe event in late April in the form of a squall line. Soundings for the day showed very unstable conditions with the possibility of rotation. There was a tornado watch in effect for the day and there was a severe thunderstorm warning issued during the frames selected for this scenario. Local storm reports stated wind gusts of 53 mph near the coast in Pinellas County as this came onshore. This squall line maintained its strength and structure as it crossed the study area which would experience heavy rain and wind followed by an hour or so of light rain.

Scenario C was a severe event in late March and was caused by a surface low near the panhandle with a cold front that approached from the Gulf of Mexico. This was described in the area forecast discussion as “TWO DISTINCT BOWING SEGMENTS ARE MOVING TOWARD SHORE WITH SOME CELLS SHOWING SIGNIFICANT ROTATION. THIS LINE WILL CONTINUE RAPIDLY SOUTHEAST AND LIKELY CAUSE DAMAGING WINDS...LARGE HAIL AND EVEN SOME TORNADOES.” There was a tornado watch in effect before this event would have taken place and there were two active tornado warnings (one for Curtis Hixon Park) and a few severe thunderstorm warnings to the south of the study location in the frames chosen for this scenario. Local storm reports indicated 61 mph winds at MacDill Air Force Base, an overturned tractor trailer on Interstate 275, 0.75-inch hail in Plant City and an unconfirmed tornado report with two overturned vehicles in Brandon. The Storm Prediction Center National Severe Weather Database Browser also indicated reports of several EF0 and EF1 tornadoes and wind gusts near the park and throughout the Tampa Bay area (See Figure 4.2). Therefore, it is possible that Curtis Hixon Park would have experiences very strong winds, upwards of 50+ mph, heavy rain, and lightning during the scenario. While there were no reported tornadoes in the park there would have still been a threat for the area as they were within the tornado warning.

Scenario F occurred in June and although there were no warnings in effect, there was a flood advisory that included most of South Tampa and downtown. In this scenario, training thunderstorms caused by a layer of cyclonic flow moved in over the Tampa Bay area and continued to grow over downtown. The radar animation begins with light to moderate rain in the area. This event was chosen as it started at the participants location in the park, giving no time. Local storm reports indicated 3.5-6 inches of rain fell within the timeframe of this event. This caused street flooding, forcing roads to be closed in South Tampa and other areas around Tampa Bay.

NON-SEVERE SCENARIOS

Scenario A was a non-severe event in December that was caused by a surface low in the eastern Gulf of Mexico that had a stationary warm front across the northern portions of FL. This produced a southerly flow of warm, moist air that began to develop showers and thunderstorms due to some mid-level instability. According to a local storm report, a lightning strike across from Raymond James Stadium sent eleven people to the hospital with one in critical condition. Lightning was the main hazard of concern for this event. Curtis Hixon Park would have experienced some moderate to heavy rain for only a brief time. The precipitation then continues to the northeast and the event clears at the park.

Scenario D was a non-severe event in late June that was initiated by the west coast sea breeze. This produced a few areas or clusters of convective summer thunderstorms. The area forecast discussion included possible hazards as gusty winds, heavy rainfall, and frequent lightning. Meteorologists also stated that funnel clouds and water spouts could not be ruled out due to "PLENTY OF OPPORTUNITIES FOR BOUNDARY COLLISIONS WITH CONVECTION." Local storm reports indicated a few small limbs broken and pea sized hail in Temple Terrace but nothing for South Tampa or Downtown. The park would have experienced some periods of moderate to heavy rain turning to light rain along with lightning, and gusty winds.

Scenario E was a non-severe event in late August with a surface low off the southeastern coast. This created a southeast flow that would eventually collide with the west coast sea breeze causing a line of thunderstorms to form just east of Interstate 275 and right over Curtis Hixon

Park. The area forecast discussion highlights the main concerns as locally heavy rainfall, gusty winds, and frequent lightning. Curtis Hixon Park would receive each of these hazards, the Tampa International Airport reported gusting winds of 43 mph. This scenario begins with no storms in the vicinity but an 'outflow boundary' can be seen within the radar image which will serve as an important feature for analysis.

Interview Protocol

The psychological distances (spatial, temporal, and hypothetical) were included within this framework to help assess the connectedness between distances. These components aided in the design of the study protocol and served as a guide for this portion of the research. Participants were first asked about their main reason for using a radar display and to think about a time they found most memorable using a radar display. In contrast, they were also asked whether they have ever had a time that they did not find a radar display to be useful. To set the scene, before starting each scenario, a participant was shown the Google street view image of Curtis Hixon Park in order to make sure participants were familiar with what their surroundings would be for each scenario. Participants were then guided through radar scenario's A-F.

Each short radar animation was accompanied by three questions. Each question used a 1-5 Likert scale to gather information such as how far the participant felt the (green) rain bands were from their location at the park (1 being far away – 5 being at their location) from the last frame, how certain they were that it would rain at the park based on the radar animation (1 being very uncertain – 5 being very certain), and then how much time they would have before any rain would begin at the park, if they thought it would rain (1 having no time – 5 having plenty of time). For time, participants were also asked how many minutes they felt they would have before it would begin to rain at the park. Participants were told the month that each scenario occurred, that each frame elapsed approximately 6 minutes and were shown the time clock in the animation.

Participants were then shown the full scenario animation. The first question asked how they thought their location at Curtis Hixon Park would be impacted by the event, first estimating the amount of rain they would expect to receive (1 experiencing light rain – 5 experiencing heavy rain). Questions were also asked about their concern for any hazards for the scenario at the park and why. Participants then described what they were seeing in the scenario as they looked at the radar display as well as what drew the most attention to them. In addition, they were asked what they would do during this scenario.

To sum up each scenario, participants were asked whether or not the radar animation provided them with enough information to make a decision about what to do in the scenario. Then on a 1-5 scale (1 strongly disagree – 5 strongly agree) if using a weather radar display helped them to feel confident when making a decision about a real time- precipitation event. The last question asked participants to rate on a 1-5 scale (1 not at all useful – 5 very useful) how useful they found the weather radar display. This process was repeated for scenarios (A-F).

After the scenarios, participants were asked several follow-up questions which included topics about zoom abilities and using 'futurecasts' and lightning indicators. They were also asked which scenario they would be most concerned for and why, about what prompts them to view a radar display, and what information they are seeking when they view radar.

Mixed Methods Analyses

Interviews were recorded and transcribed and all Likert scale and numeric responses were added to a spreadsheet so statistical analyses could be performed using SPSS 25 software (Bryman 2012; Elliott and Woodward 2007). Qualitative analyses were performed through code generation to look for themes by way of content analysis using NVivo 12 software (Denzin and Lincoln 2003; Gilbert 2001). All 30 interviews were coded by the PI. A second outside researcher coded a subsection of the interviews to provide intercoder reliability. Any divergences were discussed and modified until agreement was reached.

Findings

Objective 1: Primary Use and Information Seeking

The first objective was to discover the primary reasons for using a weather radar display and what information users wanted most from this tool. The first question participants were asked during their interview was “what is your main reason for using a weather radar display?” One participant was quoted stating:

> “Obviously, it's, it's a blueprint, of what kind of weather is on its way, short term maybe within a within two or three hours or less. And I watch it usually throughout the day and in the evening just to see what's happening around me and anticipate. kind of a junkie for it.”

The majority of participants indicated that they use radar to figure out, or anticipate what the short-term conditions are ‘going’ to be for their area. This was followed by those who indicated that they use it plan or prepare for their day. Radar was also said to be used to locate what is currently happening in the user’s area or to verify/validate changing conditions. Around 20% of participants directly mentioned wanting to know about severe weather, either a tropical cyclone or severe storms. While the majority of participants indicated they use a radar display either daily or several times a week, when asked to recall a most memorable time while using a radar display over 75% mentioned using it during a hurricane, especially hurricane Irma.

To follow up from the survey phase of this study, participants were asked about what information they are seeking when they view a radar display. In the survey, respondents chose from predetermined responses and ‘locating a hazard watch or warning for their area’ and ‘locating a weather event’ were found to be the two most important pieces of information. It was also found that the timing and direction of weather events were deemed very important. During the interviews, participants confirmed that they use a radar display to understand intensity of precipitation, to understand what will be happening for their area, and what direction precipitation or storms are moving in. To find out the direction that events were moving was mentioned often throughout the interviews as an important factor used for decision making as well as the inability to make a decision. In fact, lack of directionality was found to be one of the most common reasons why a participant found a radar display to be less useful during the scenarios.

Using radar was often brought up as participants discussed their daily routines. Many participants noted using weather radar as part of their morning routine, just to “look around” their area to check for precipitation or storms in the vicinity. Some participants also referenced using a forecast in addition to viewing the radar but in a way that did not differentiate between a forecast and radar. This topic brings awareness to the integration of a radar display into apps that serve as a multi-purpose tool (i.e. delivering a forecast, having a radar display, satellite imagery). A better example of this would be when participants discussed hurricanes, some mentioned the use of models (spaghetti plots), tropical forecasts, satellite images, and even upper air charts when they were asked about radar. This came across as though these data sources might be viewed more as “weather maps” but thought of similarly to or the same as a radar display.

Objective 2: Information/Hazards Conveyed

The purpose of this study was not to test participants on their meteorological knowledge but rather to serve as a first look into how users describe what they see when they view radar and what information they gather from the display. The majority of participants had no formal meteorological training. The participants who had training said they had either taken a meteorology course in college, a self-taught course online, or that they were Skywarn[1] trained. Overall the majority of participants came across as very knowledgeable about weather occurring in the Tampa Bay area and displayed experience with using a radar display.

For each scenario participants were asked to describe what they were seeing as they viewed each radar display. Participants did not focus on the same characteristics for every scenario and instead described the most pressing attributes, which varied by scenario. For scenario A, most participants described the location and or direction for where 'cells of rain' were moving. For Scenario B, the 'linear' or 'band' structure was highlighted the most followed by defining this event as either a strong/severe thunderstorm or a thunderstorm that most likely occurred due to a 'cold front'. There was a noticeable difference in how participants described scenario C compared to A and B. There were 23 participants who labeled this event as a strong or severe thunderstorm. Many focused on the size and structure of the storm with even a few mentioning the 'bowing' nature of this thunderstorm. Scenarios D, E, and F were all summertime events and had a larger range of descriptions. Most descriptions for scenario D and E were split evenly between the structure and intensification of the 'pop-ups' and the locations at which these were occurring. Just less than half of the participants noted that these events were most likely caused by either the East coast or West coast 'sea breeze'. For scenario F, most participants described how the precipitation continued to strengthen over the study area, growing in intensity.

[1] Skywarn is National Weather Service storm spotter program. Volunteers can enroll in a class to become a spotter.

This study also explored participant's perception of risk for potentially hazardous weather as they viewed each radar display. Scenarios were varied by severity/impacts and by the type of each event (convective or frontal) so that each scenario had the potential for different hazards. In general, the most mentioned hazard in every scenario was the potential for lightning. As Florida experiences the highest flash rate densities and maximum number of lightning strikes in the United States, this was understandable (Albrecht et al. 2016; Collins et al. 2017; Koehler 2020). The Tampa Bay area was also ranked fourth out of the top 25 metropolitan areas for lightning fatalities (Ashley and Gilson 2009). Each scenario displayed base reflectivity values and therefore did not include any form of lightning count or indication as some radar displays offer. When participants were asked why they were concerned about lightning there were a variety of reoccurring responses. The most common statement about lightning was that there is always the concern or threat of lightning because they live in Florida. An unexpected finding was that the majority of participants stated that they knew there was lightning when they would see 'red' or 'orange' reflectivity values:

> "Like if lightning would be possible, anytime I see like the reds and stuff, that's first thing I'm like, 'Oh, that's going to be heavier, there'll probably be more lightning and thunder associated with it'."

Wind was the second most mentioned hazard for scenarios A, B, E, and F. Just as for lightning, participants noted that seeing 'red' and 'orange' reflectivity values equated to experiencing greater wind speeds. This was not stated as often as it was for lightning but was still noteworthy. One participant referred to this during scenario A:

> "Well in December, you don't get a lot of lightning. But I mean, when I see the red and orange cells pass over, I would be concerned that there could be some high winds or there

could be lightning that could typically show up when you have that much, that kind of weather pattern show up."

Throughout the scenarios, the colors representing reflectivity values were mentioned as being what drew the most attention to participants as color indicated the 'intensity'. However, for scenario D, E, and F more attention was given to the intensification and development of the event. Finding an association with color and the potential for other hazards besides rainfall intensity may be due to the use of a rainbow color scale, as red in this scale is often associated with danger. One participant expressed what drew the most attention to them as saying: "I always look for red, red's bad." Radar reflectivity is the measure of the strength of energy returned to the radar in decibels of Z (dBZ). Therefore, any associations of color with hazards other than rain or hail would come from previous experiences with using radar and experiencing hazardous weather events.

For both severe scenarios B and C, a lot of attention was given to the warnings and were noted as 'boxes' or 'outlines'. However, there was a lot of confusion as to what the 'boxes' represented. While all but three participants made mention of the warnings in scenario C, some were not sure if it was a tornado watch, tornado warning, or severe thunderstorm warning. Most concerning was that a few participants did not mention the warnings at all in their descriptions of the radar display and did not mention the possibility for a tornado when asked about potential hazards. In most apps and online products warnings are interactive. As warnings had not been a part of the original focus for this study, there was no way for participants to hover over or click on these warnings to gain more information. While part of this confusion was due to design, it is still worth mentioning the inability to recognize exact warnings. While the National Weather Service has set colors that they use for warnings, not all applications and media sources use these colors. The style of warning products may also vary, as some products use shading to represent a warning or watch for an area instead of an outline. There are also differences in the ability for users to turn warnings and watches off in the settings for certain applications. One participant highlights this uncertainty as she uses multiple products:

> "I'm trying to remember. I think yellow is watches and reds are warnings. And then it depends on if it's tornadic or thunderstorms, severe thunderstorm. I always have to check sometimes as I go to different products, I always need to verify which one's which."

Scenario C, which had a tornado warning in effect for Curtis Hixon Park had 12 participants mention the potential for a tornado (1 for a waterspout) and 18 who mentioned concern for high winds. This was concerning as it meant that less than half of those interviewed mentioned the possibility of a tornado during an event with an active tornado warning.

Other hazards participants reported were heavy rains and the potential for flooding. Scenario F was of particular interest for flooding hazards as up to 6 inches of rain fell around Tampa Bay during the event. However, more participants mentioned a concern for lightning (25 out of 30 participants) and wind (19 out of 30) than flooding (12 out of 30). This was surprising, especially because (9 out of 30) participants said they were concerned for flooding for scenario B.

In most cases participants listed hazards that were possible for the scenario. However, there were a few mentioned that would have had a low probability of occurring such as for scenario F, there were four participants who mentioned the possibility of a tornado or a waterspout. One participant who voiced concern for a possible tornado stated:

> "I might also think about problems with tornadoes if I saw it because the storm is definitely surrounding an area and then there's a spot in the middle that doesn't have

anything and I always feel when I see that that means odd wind patterns or you know, difference in what's going on in the air. Instability."

This most likely had to do with the direction the storms were moving (southwest to northeast), interpreting wind using reflectivity values, and the coverage of the 'red' reflectivity values. Overall, participants acknowledged the differences between scenarios and were able to articulate each event and their concerns.

Objective 3: Radar Usefulness

Participants were asked to rate the usefulness of the radar display after viewing each scenario. Initial we hypothesized that if the degree of impact (severity or duration) and the degree of certainty for being impacted by a precipitation or storm event were greater, then the radar display should be perceived as more useful. In the same way that the closer an event is to an individual, whether spatially or temporally, the radar display should be perceived as more useful. First, descriptive statistics were used to compare the usefulness ratings which discovered slight variation between the 6 scenarios. Scenarios B and C had the highest usefulness ratings with 90% of respondents rating the usefulness as very useful (5) on the five point scale for scenario B and 93% for scenario C. Scenarios D and E had the fewest number of five ratings in comparison to the other scenarios with 63% for D and 60% for E. What is most interesting is that D and E had much larger ranges in usefulness ratings. This prompted further exploration to uncover the reasons for decreased usefulness ratings.

It is possible that the severity of a weather event has a positive relationship with the usefulness of viewing a radar display as both severe scenarios (B and C) had the highest usefulness ratings, though higher usefulness ratings may also have to do with how certain a radar user is about whether or not they will experience a weather event. Therefore, the distance and the structure of a weather event help to influence the level of certainty participants had for each scenario. One interesting example of how meteorological knowledge increased the usefulness ratings occurred in scenario E. Participants were least certain about this event out of all the scenarios, however, there were five participants who were very certain that they would be impacted. This polarity lead to further investigation and it was discovered that before seeing the full scenario each of the five participants noted seeing either a 'gust front', 'sea breeze', or 'outflow boundary'. All five then indicated that the radar display provided them with enough information to make an independent decision and they all mentioned that they would either leave or most likely leave the park instead of sheltering in the vicinity. In contrast, most of those who indicated they were not certain that this would impact them mentioned that this event would have 'caught them off guard'. This prior knowledge and experience with viewing this type of event using a radar display helped them to anticipate what was possible at Curtis Hixon Park far better than those who did not. For scenario D, which displayed summertime convective thunderstorms, participants who indicated that the display was less useful, mostly said it was due to the uncertainty of where the storms were moving as they lacked direction,

> "I don't feel that I understood enough about what the storm was doing based on the information that I see, I didn't tell where it was moving. And there's no input about which direction the wind is blowing. Like, I felt like I needed more to be correct about what the storm was going to do."

Another participant echoed another common theme:

> "Well, but just like you'll watch the radar and you think like, 'Okay, so here's the radar loop, however long it is and it's been doing X' and then, so you extrapolate to, it's going

to keep doing X… and they don't. So no, in the summer with the summer storms, I don't believe it until it actually is raining."

This highlighted the importance of being able to estimate the amount of time a person had before they would be impacted by a weather event and whether they thought there was enough time to make a decision about what to do. Even though these storms were in the vicinity of the park, the usefulness ratings were lower due to not being about to make a decision about the direction the storms would move. This example expresses just how intricate the relationships of distance, time, and attributes are and how connected they can be.

Participants were also asked whether or not a radar display provided them with enough information to make a decision about what to do during the scenario, to which one participant stated: "Yes. Which doesn't mean it's the correct decision and only means I have the information to make it." This was a surprising comment that may speak to the human element and uncertainty within risk perception and decision making. Just because someone has enough information to make a decision, does not guarantee they will make the 'correct' decision at the 'correct' time. To some degree, whether or not they felt they were provided with enough information did have an effect on the usefulness rating. Many participants expressed that they use multiple radar displays as they prefer specific features from each application or source. Others mentioned that they would use multiple radars in order to verify what they were viewing.

Other information discussed with participants was about the use of other tools available within some radar displays such as lightning indicators and futurecasts. The majority of participants found a lightning indicator to be a useful tool. But there were a few that described it as messy or unnecessary. For example, it was mentioned that if you have already heard thunder then you know you are at risk for lightning, deeming the indicator as unnecessary. Another participant described why she does not find lightning detection as useful, stating:

> "I don't, I guess I don't understand the technology or the science behind when they pick a lightning strike. So, I don't know. Does that mean lightning hit the ground? Does that mean lightning in the clouds? I mean, I know they talk about strikes on the news. But I don't, I don't know. It's just I guess it's not important to me. I don't want to be electrocuted, and I would never trust that to look at and see like, 'Oh, no, there's no lightning anywhere in my neighborhood. So it's safe for me to go out.' Because I know that lightning could strike. Whereas like a watch box or rain or a little tornado indicator, that I feel like, I would pay attention to that."

She was not alone as another participant had similar thoughts:

> "Yeah, that would be useful to know sometimes [where lightning is]. And some of the apps I know they have [a] little lightning key markers on it. But it doesn't really tell you. Is that real time? Is it past? Is it... Do they predict this is where it's gonna occur? I mean, I know you can't predict where lightning is going to occur. But yeah, so sometimes it's knowing if it's like an actual, like lightning event storm or just a rain storm."

Again, while there were a few people that questioned how this information was collected and what the data represented, the majority found this tool to be useful.

Another tool available within some mobile weather applications and from most television stations is a 'futurecast'. A futurecast is a forecasted representation of what the precipitation may who over an area for a short window into the future, usually from one to six hours. For the respondents that answered about whether they use a futurecast and if they find them useful, only five participants said they found them to be useful. Eight participants used a futurecast but had reservations about the quality or accuracy of the forecast. This group described it as being useful to understand the flow of the weather pattern but did not trust the actual precipitation amounts or location that was forecasted. The remaining 12 participants that answered this question said that they not only did not use a futurecast but did not find it to be useful or accurate. Most in this group said that they preferred to extrapolate into the future using their own knowledge of meteorological patterns. The other five participants either did not answer this question or did not state whether they found it to be a useful tool.

At the end of each scenario participants were asked to rate how confident they were when using a weather radar display to make decisions about a real-time precipitation event. This rating often matched the usefulness rating for each scenario. Therefore, if the confidence decreased, often so did the usefulness rating. When asked why they felt less confident, it was more about the weather conditions and less about the radar display, for example one participant stated:

> "It's not the radar so much, it's less confidence in what Mother Nature is going to do. The radar's great. But what is Mother Nature up to? I prefer the storms that are in a high wind and you know, they're coming down here to there. It's those weird pop up ones and those weird stationary ones, they don't know what it's going to do. It's like a, it's like an erratic child or something."

Scenarios D and E had the lowest confidence ratings out of the six scenarios, which almost mirrored the usefulness ratings.

Participants also revealed information about what they did not like or find as useful for certain radar displays. This highlighted potential misunderstandings of what a radar display is actually showing. The biggest criticism was that there would be precipitation at their location but nothing displayed on radar or vice versa. This was often described as not being accurate. A 'lag' or delay in the update for radar images was another common complaint made by users followed by disliking 'noise' or 'ground clutter'. It was unclear if participants understood what was causing the delay or the ground clutter, however, this may be a misunderstanding for how radar collects and displays information. It is possible that some participants expect that radar data should show 'real time' information for what is currently happening instead of showing what has already happened. Some referred to false echoes or ground clutter as being a hindrance to the point that they would use a coverage from a different radar such as the Orlando market (Melbourne) radar in order to avoid these features. One such participant stated that:

> "In the winter, in the front situations it's obvious that I could ignore that, but like in the summer when I literally need to know is it raining on the place that I'm supposed to be at like right now, and there's all sorts of stuff, it's like what is any of this, you know..."

This participant owns a construction company and therefore relies on using radar to know when precipitation may be in the area. They noted that especially during the summer months this information could be the difference between keeping materials dry or delaying work. The complaints about delay or 'lag' and 'noise' suggest that some participants may not be as familiar with radar data and some of the data limitations.

Objective 4: Average Time Estimates

To gain perspective on temporal decision making, participants were asked how many minutes they thought they had before any rain would reach their area at Curtis Hixon Park. One sample student's *t*-tests were performed to determine how well participants' rain estimates matched the actual time for each scenario. As some participants gave a range of time for an estimate, the average times were calculated and analyses were run two ways, first, where the ranges were averaged and second, where only the lower bound was considered. Using either method, many participants overestimated the amount of time they had for scenarios A, C, and E. Using the averaged values first, the mean average time for scenario A (mean = 15.534, SD = 7.963, N = 29) was significantly different from the hypothesized value of 6 minutes, $t(28) = 6.448$, $p < 0.001$. The mean average time for scenario C (mean = 38.167, SD = 16.346, N = 30) was significantly different from the hypothesized value of 18 minutes, $t(29) = 6.757$, $p < 0.001$. The mean average time for scenario E (mean = 51.667, SD = 20.111, N = 30) was significantly different from the hypothesized value of 42 minutes, $t(29) = 2.633$, $p = 0.013$. This was the only scenario that was not significant at the 0.05 level when using the lower bound estimates method but was close with a (mean = 49.50, SD = 20.525, N = 30) and $t(29) = 2.001$, $p = 0.055$).

Scenario B was the only scenario that was underestimated where the mean average time (mean = 21.733, SD = 8.223, N = 30) was significantly different from the hypothesized value of 36 minutes, $t(29) = -9.502$, $p < 0.001$. Scenario F estimates matched the hypothesized mean as the scenario began with precipitation in the park. Scenario D was compared using two different hypothesized values. The first evaluated scenario D with the hypothesized value of 18 minutes which was the first light rain to reach the park, but was short lived. Using this estimate, the mean average time for scenario D was (mean = 27.407, SD = 15.834, N = 27) and $t(26) = 3.087$, $p = 0.005$. However due to the sporadic nature of this event, Curtis Hixon Park experienced a second and slightly heavier rain event around 60 minutes into the scenario. Using this estimate, the mean average time for scenario D was underestimated, $t(26) = -10.69$, $p < 0.001$.

Most participants overestimated the amount of time they would have before rain would begin at their location at the park after seeing the short animation for each scenario. In scenario A the mean difference was about 9.5 minutes over the actual time it would take for rain to begin at Curtis Hixon Park with most estimating around 15 minutes. For this scenario there was only one outlier of 45 minutes, even accounting for the outlier, the mean difference would be 8.5 minutes with a mean of 14.5 minutes. In scenario C, the mean difference was about 20 minutes. This scenario was interesting as 8 participants estimated 30 minutes and 7 estimated an hour, with only a few providing times in-between. This may be due to how far away the storm appeared to be from the last frame of the scenario in comparison to scenarios A and B. While this storm was farther away, it was moving at a higher rate of speed. Scenario E was an event that appeared at the first frame to be far to the east of the park and most participants indicated that they were very uncertain that they would receive any impact, however noting that August is an unpredictable month when thunderstorms can "pop-up". Therefore, it was not surprising that scenario E had the largest range of 102.5 minutes. It also had the largest standard deviation (20.8).

Scenario B was underestimated possibly due to the structure of the event, as some smaller pockets of reflectivity values appear slightly out ahead of the larger system. Difficulties in estimating speed may also be a factor for the underestimation. Scenario D, representing a convective or "pop-up" thunderstorm, was a difficult scenario to estimate time. This had the second largest range behind scenario E with the majority of participants estimating around a half hour. The summertime or "pop-up" storms were mentioned numerous times as being unpredictable and hard to estimate. While this scenario was analyzed for both the first and second rain events it should be noted that participants were asked to estimate based on the first chance of rain.

Conclusions

Uncertainty plays a key role in how people make decisions about impending weather events. A weather radar display is one tool that can be used to help address this uncertainty and provide users with useful spatial, temporal, and hypothetical information. The goal of this study was to highlight the information that is used and wanted most by radar users. It also shows the complexity and interconnectedness of meteorological data which are used to infer information and make decisions as they are construed over distance and time. This was done by incorporating construal level theory and the synthesized geospatial thinking model. Construal level theory and psychological distance was used to create the interview protocol and design the scenarios used in this study. To evaluate how distance and time are related, scenarios were designed with specific variations in spatial, temporal, and severity attributes in order to observe participants perceptions. The synthesized model of geospatial thinking served as a guide when interpreting participants responses to questions asked while viewing each scenario. Our findings showed that radar is used most often as a tool to anticipate what will happen in the near future. This requires users to interpret what radar is currently displaying and then extrapolate both spatially and temporally to conceptualize what meteorological attributes may occur in the near future. A notable finding is that radar is a tool used not only to infer information about precipitation but other meteorological hazards such as lightning, wind, and severe weather phenomena such as tornadoes and hail. Though some inferences made may go beyond what reflectivity values are intended for, such as associating that lightning or strong winds are present solely because 'red' and 'orange' values are displayed on the radar. There were also a few participants who overestimated some of the hazards they expected to receive at the study location. Overall participants were knowledgeable about what Florida weather is capable of and what they should expect during different times of the year. This seasonal knowledge played a role in how they described each radar scenario and as they explained how they know what hazards to anticipate. It would be of great interest to use a similar protocol in different states to see if a similar location-based knowledge exists for other regions.

Overall weather radar was found to be a very useful tool that provides enough information to the user to make a confident decision about what they should do. However, the usefulness rating decreased when the directionality of a precipitation or storm event was unclear, such as during a convective ‘pop-up’ thunderstorm event or during an afternoon sea breeze induced event which occur in the summer and fall months in Florida. Participants revealed valuable information about what they did not like or find as useful for certain radar displays. Radar data were described as inaccurate for two main reasons. First, if a participant was experiencing precipitation at their location but the precipitation was not displayed on radar or vice versa. Second, was a report of a ‘lag’ or delay in the update for radar images. This may represent a misunderstanding for how radar data is collected and displayed.

The average time that a participant had before any rain would begin in each scenario was most commonly overestimated. This directly highlights the difficulties of combining distance, time, and extrapolating attributes for meteorological events. Participants were more confident using a radar display during scenarios with a west to east flow pattern and less so during convective and sea breeze scenarios.

This study also confirms that participants are using more than one source or application to gather their weather information. Often this has to do with wanting specific features that only one application or source offers or that offers a feature better than a competitor. Especially for extra features such as a lightning indicator or wanting satellite images or hurricane tracking. This is an important finding that will supplement the findings from the radar survey about the use of mobile weather applications.

While the severe weather scenarios were intentionally included within this study, the weather warnings were not originally intended to be a focal point for analysis. The uncertainty surrounding these warnings as they are displayed on the radar will lead to future research. Additionally, it would be of interest to see if the proximity of a participant's home location to the park would have any connection to usefulness or change how participants make decisions about what to do for each scenario. The duration of events was not focused on within this study but would also be an area of interest for future work.

This research has a few limitations including that participants were asked to provide Likert scale responses for distance, certainty, confidence, and usefulness. Several participants gave some responses as a range which were then averaged for calculations. While responses were elaborated on, no true comparisons for distance were made in this study due to the subjectivity of the measurement. It is also possible that distances were too similar within each scenario. If done again, we would increase the distance for one of the scenarios. Finally, a laptop computer was used during the scenario portion of the interviews. This provided users with a larger screen which is easier for viewing. As some respondents said they did use a computer or television to view radar in addition to a smartphone this was not a large concern, however, for future research using a smartphone would be ideal.

Acknowledgments

The authors would like to first thank Meghan Cook for providing intercoder reliability for this study. Her expertise was a huge asset to ensuring the quality of data analyses. Thank you to Marshay Forbes for your assistance in transcribing the interviews, this was an enormous help to the PI for this study. The authors would also like to acknowledge the Tharp Fellowship for providing a research scholarship to support this portion of the study. Funds were used to pay for participant compensation in the form of $10 gift cards.

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Figures

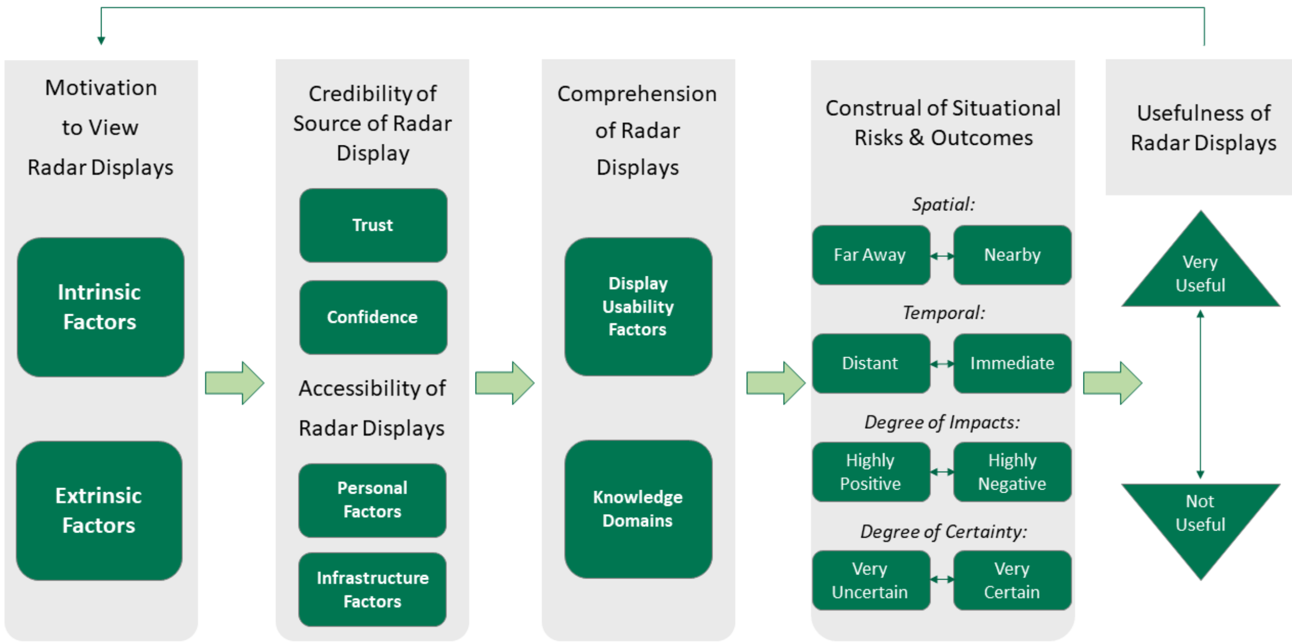

Figure 4.1. Full theoretical framework for the factors that may influence the perceived usefulness of a radar display.

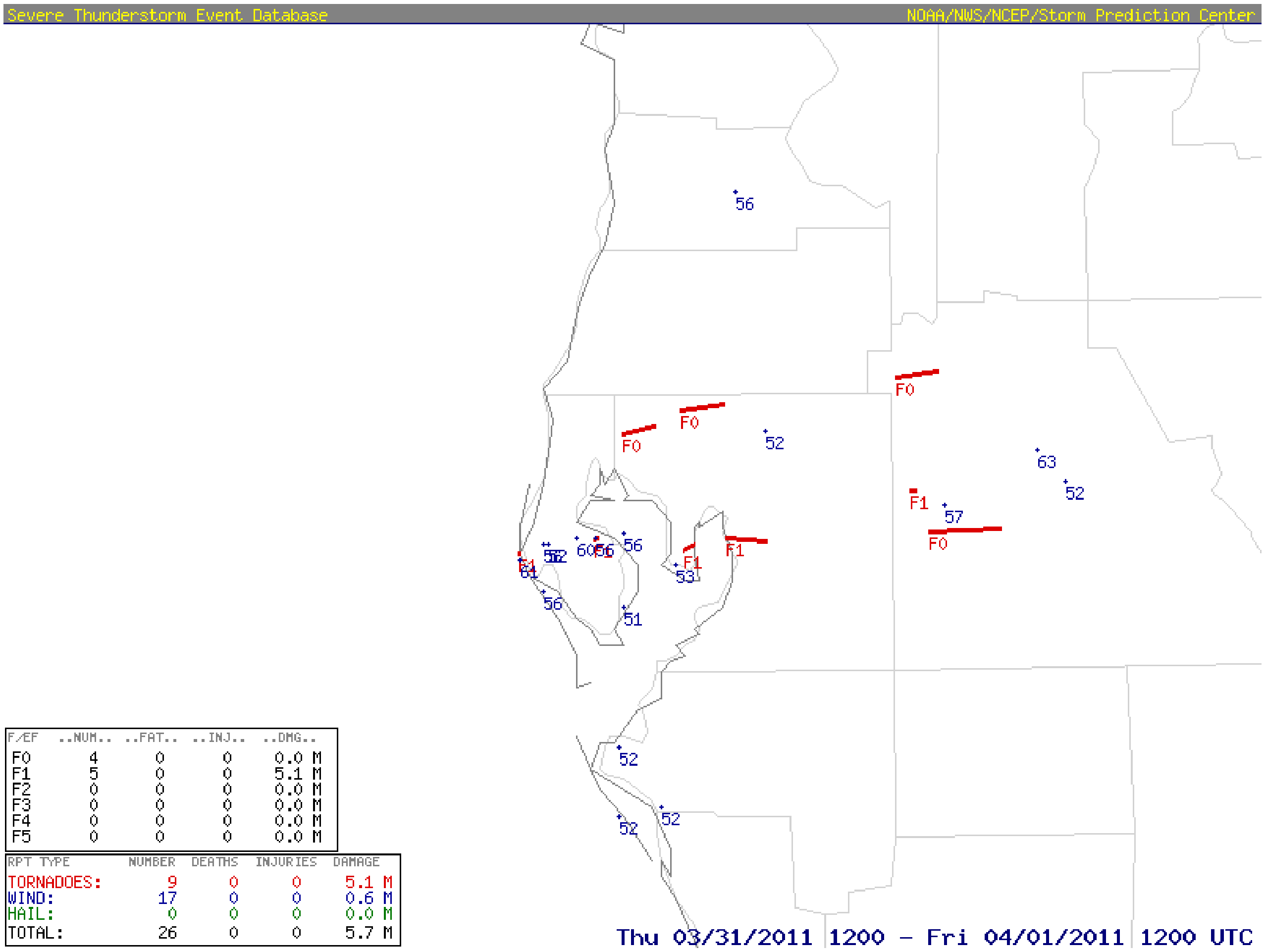

Figure 4.2. March 31, 2011 tornado paths by Enhanced Fujita rating and wind reports (knots). The amount of damage is reported for each hazard type in millions of US dollars.

CHAPTER FIVE:
CONCLUSIONS

The overarching objectives for this study were to discover why radar is sought out as a source of weather information and how useful it is deemed as a source of information and decision aid. This question is explored in greater detail using the following research outline:

Phase One:

1. To identify what factors outlined in the conceptual framework influence the perceived usefulness of a radar display.
2. To examine characteristics of general radar use.
3. To discover radar user's preferences for mobile weather applications features.

Phase Two:

4. To understand how the construal of situational risks and outcomes influence the perceived usefulness of a radar display.
5. To explore how radar users interpret distance, time, and meteorological attributes using hypothetical scenarios.

The primary findings are summarized by each chapter of this research.

Chapter Two: Factors Influencing the Motivations & Perceived Usefulness of a Weather Radar Display in Tampa Bay

Overall Tampa Bay respondents find a radar display to be a very useful tool and use it regularly. The most common reasons for use were to locate hazard watches and warnings for their area and to locate precipitation and storm events. Respondents who were older and wealthier were more likely to find a radar display as more useful. Women were also more likely to find a weather radar display more useful. Smartphones were used most often to view a radar display over television, computers/laptop, and tablets as a smartphone can be used while traveling and throughout the day. Participating and planning for outdoor activities was a main reason that motivated respondents to use a radar display. It was also found that respondents agreed that a radar display provided them with enough information for them to make their own decisions about a weather event and that they found radar to be an accurate source of information.

Chapter Three: Mobile Weather Radar Applications – Uses, Features, & Preferences

This chapter looked specifically at various mobile weather applications used by survey respondents. This study first set out to group mobile weather applications by type creating three main groups that were used for analysis. These were "Radar Primary", "Forecast Primary", and "Map Centric, Multi-Variable". There was also a group for those who did not use an app but still used their smartphones called "No App". Apps were then grouped into these categories based on the primary purpose of the app and how prominent a radar display was in each app. In respect to age, local news weather app users were on average 8-9 times older than RadarScope and Weather Underground. User's overall age varied greatly and when comparing mobile weather app type groups, there were no significant differences found.

More men than women chose to use a mobile weather app with the "Radar Primary" and Map Centric, Multi-Variable" groups, while women preferred apps within the "Forecast Primary" group. "Radar Primary" group users had more meteorological education than the other groups. This study also brought awareness to respondents who do not use a mobile weather application to view a radar display. These individuals instead use a web browser to search for a radar display. Within this group there were more men than women who had taken a meteorology course.

The qualitative analysis revealed that "accuracy" and "data" were two features that users liked the most about their preferred mobile weather application. Specifically, the location of precipitation was perceived to be more accurate than the intensity. "Data" was cited most by "Radar Primary" group users who mentioned that they like the capabilities and options that their mobile weather application offered in relation to data. Other features that respondents liked the most about the mobile weather application they use were the "ease of use", having a "futurecast" and having access to "lightning" data. A visual comparison of several mobile weather applications used by respondents showed noticeable differences in the color ramps used to display reflectivity values. This could be a reason for a decreased perception of accuracy for intensity, especially if respondents are using and comparing more than one MWA. These acts of comparison were confirmed in the next chapter.

Chapter Four: Construal of Situational Risk and Outcomes – Exploring the Use of Radar Displays

As in previous chapters, a weather radar display was found to be a very useful tool that provides enough information to make a user confident in their decision making. However, this qualitative analysis discovered that the usefulness rating decreases during precipitation events when the directionality of the event is unclear or stationary. Therefore, especially during summertime 'pop-up' thunderstorms or during events triggered from sea-breeze thunderstorms both the perceived usefulness of the radar display and the confidence an individual had when making a decision about what to do decreased. Using scenarios that varied in distance, time, and severity succeeded in highlighting what may cause the usefulness rating to decrease, where the survey metric in chapters 2 and 3 only gather the overall rating for usefulness.

Radar was used most often as a tool to anticipate what will happen in the near future based on current conditions. Radar was also used to infer information about precipitation as well as other meteorological hazards such as lightning, wind, and severe weather phenomena (tornadoes and hail). Though some inferences may go beyond what reflectivity values are intended for, such as correlating that because ‘red’ and ‘orange’ are displayed on the radar that there will be lightning or wind present. The colors used to display reflectivity values were mentioned often as what stood out the most to participants.

Participants most commonly overestimated how much time they would have before any rain would begin during each scenario, highlighting the difficulties of combining distance and time, while extrapolating attributes for meteorological events. This study also confirms that participants are using more than one source or mobile weather application to gather their weather information, including different radar displays. Reasons ranged from wanting specific features that only one application or source offered, or that was ‘better’ than a competitor. Other reasons for using more than one source was to verify or check that two radar displays were showing the same attributes for the same event. Participants also discussed extra features such as a lightning indicator or wanting satellite images or hurricane tracking abilities. This is an important finding that supplements the findings from the radar survey about how respondents use mobile weather applications. Participants were also divided on the usefulness of a ‘futurecast’ feature with many stating that it is unreliable. This disparity is important as this was not expressed in the survey, as the survey only asked respondents about the features they found useful.

Finally, participants discussed what they did not like or find useful about a weather radar display. Radar data were described as inaccurate for situations where a participant was experiencing precipitation at their location but the precipitation was not displayed on radar or vice versa. Other common reports were for a 'lag' or delay in the update for radar images and a dislike for ground clutter and 'noise' which may highlight a misunderstanding for how radar data is collected and displayed as well as data limitations.

Research Limitations

This research is limited from generalizing results as the survey data were not demographically representative of the Tampa Bay area. This was due to data collection methods as the sample was gathered using convenience sample from self-selecting participants. However, this sample was unique as 78% of survey respondents were weather enthusiasts. Interview participants were also found on a volunteer basis, limiting the generalizability. It would have been interesting to report more on the findings from the warnings in scenarios B and C from chapter 4 but since participants did not have same capabilities to view the warning as they would using a mobile weather application, participants' understanding of the warning were not able to be properly assessed. Interviewees were also asked what they would do for each scenario. However, results were not reported as the question should have been asked during the first round of questions rather than the second and was therefore not included as a major finding.

Future Research

There are several avenues for future research based on the findings from this dissertation. Since the survey population gathered were weather salient and the majority of respondents considered themselves to be weather enthusiasts, it would be of interest to compare with a study population who does not use weather radar or rarely uses a radar display. Using a survey sampling company to obtain a more representative sample for a study location will be used for future research, this method was not used in this research due to funding limitations. In person surveying could also be implemented.

Future research should address the uncertainty surrounding the warnings displayed on the radar in chapter 4. Additionally, it would be of interest to see if the proximity of a participant's home location to Curtis Hixon Park would have any connection to usefulness or change how participants make decisions about what to do for each scenario. Finally, the duration of events was not focused on within this study but would also be an area of interest for future work.

Contributions to the Literature

This dissertation contributes to several fields including geography, meteorology, and the social sciences. This research helps to address some of the needs published by the National Academy of Sciences in 2017, which include researching how people access and interpret weather information as well as assessing their level of interest for weather information. It also helps to understand how new technology affects how people access weather information and how that impacts their interpretations and preparedness for weather events. It updates and advances the literature connecting risk perception and the use of technology. As technology continues to advance it is important to understand how it is being used to communicate weather information to the public. The 3-4 research articles that will come from this dissertation will be some of the first to discuss the use of weather radar by the public.

This research identifies that with varying weather events situational risks can be evaluated using a radar display but that it does not necessarily aid in decision making for all weather events. The findings from this dissertation may help meteorologists to better understand what information people gain from viewing a radar display and how NWS messaging can improve as a result.

Some components of this research could also be used to help improve current mobile weather applications. It could aid in the design of new features that may help to mitigate the uncertainty for certain types of weather events, making it a better tool for users. The findings may also help to suggest a need for providing more information to users about what the radar display they are using.

APPENDICES

Appendix A: Weather Radar Motivation Survey

Start of Block: Qualifying Questions

Q1.3 A weather radar display in this study will include any format used to view weather radar, including a TV weather broadcast, website, or smartphone/tablet application. Weather radars are mainly used to detect precipitation and thunderstorm hazards. These radar displays may range in layout/design or color legends. Below are three different examples of various weather radar display formats available for use:

Q1.4 We are interested in how people use weather radar displays that can be viewed on television, internet websites, and mobile device applications. Which of the following answers best matches how often, on average, you viewed weather radar displays during the past year?

- ◯ Never (1)
- ◯ A few times per year (2)
- ◯ A few times per month (3)
- ◯ A few times per week (4)
- ◯ A few times per day (5)

Skip To: End of Survey If We are interested in how people use weather radar displays that can be viewed on television, inte... = Never

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Q1.5 How many times per week, on average, did you view weather radar displays in the last year?

- ◯ Less than once a week (1)
- ◯ 1-2 days per week (2)
- ◯ 3-4 days per week (3)
- ◯ 5-6 days per week (4)
- ◯ Daily (7 days per week) (5)

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Q1.6 How many years have you lived in the state of Florida?

____

End of Block: Qualifying Questions

Start of Block: Radar Use

Q2.1 On a weekly basis, how often do you check a weather forecast for your area during the following times of day?

	Never (4)	1-2 days per week (5)	3-4 days per week (6)	5-6 days per week (7)	Daily (7 days per week) (8)
Morning (4am - 11:59am) (1)	○	○	○	○	○
Afternoon/Evening (12pm - 7:59pm) (2)	○	○	○	○	○
Night (8pm - 3:59am) (3)	○	○	○	○	○

Q2.2 How ***valuable*** do you find a weather radar display as a source of information about precipitation?

○ Not at all Valuable (1)

○ Minimally Valuable (2)

○ Moderately Valuable (3)

○ Valuable (4)

○ Very Valuable (5)

Q2.3 How often do the following conditions prompt you to view a radar display?

	Never (1)	Seldom (2)	Sometimes (3)	Usually (4)	Always (5)
Viewing changing sky conditions (1)	○	○	○	○	○
Seeing lightning (2)	○	○	○	○	○
Hearing thunder (10)	○	○	○	○	○
Seeing precipitation (rain, snow, sleet, etc.) (3)	○	○	○	○	○
Receiving an official warning for a severe thunderstorm (4)	○	○	○	○	○
Receiving an official tornado warning (8)	○	○	○	○	○
Overhearing a conversation about current weather conditions (5)	○	○	○	○	○
Seeing someone carrying an umbrella, or wearing a raincoat or rain boots (6)	○	○	○	○	○
Other (Please specify) (7)	○	○	○	○	○

Q2.4 When viewing a weather radar display, how important is the following information to you?

	Not Important (6)	Minimally Important (7)	Moderately Important (8)	Important (9)	Very Important (10)
To find out the intensity of a precipitation event (1)	○	○	○	○	○
To find out how long a precipitation event will occur (2)	○	○	○	○	○
To locate a precipitation event (3)	○	○	○	○	○
To locate a hazard watch or warning for your area (4)	○	○	○	○	○
Other (Please specify) (5)	○	○	○	○	○

Q2.5 Are there any activities that influence you to view a weather radar display more often? (Examples: any specific recreation, leisure, or work activities)

____

____

____

____

____

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?

	Never (1)	Seldom (2)	Sometimes (3)	Usually (4)	Always (5)
Rain (1)	◯	◯	◯	◯	◯
Thunderstorm (8)	◯	◯	◯	◯	◯
Hurricane (4)	◯	◯	◯	◯	◯
Lightning (5)	◯	◯	◯	◯	◯
Tornado (6)	◯	◯	◯	◯	◯
Hail (7)	◯	◯	◯	◯	◯

Q2.7 How ***useful*** do you find a weather radar display as a source of information about precipitation?

◯ Not at all Useful (1)

◯ Minimally Useful (2)

◯ Moderately Useful (3)

◯ Useful (4)

◯ Very Useful (5)

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.

- 1 (1)
- 2 (4)
- 3 (5)
- 4 (6)
- 5 (7)
- 6 (8)
- 7 (9)
- 8 (10)
- 9 (11)
- 10 (12)

Q2.9 On average, how often do you trust the information displayed by a weather radar?

- Never trusted (1)
- Seldom trusted (2)
- Sometimes trusted (3)
- Usually trusted (4)
- Always trusted (5)

Q2.10 How accurate do you find the following information provided by weather radar?

	Not at all Accurate (18)	Minimally Accurate (19)	Moderately Accurate (20)	Accurate (21)	Very Accurate (22)
Intensity of precipitation (1)	◯	◯	◯	◯	◯
Location of precipitation (2)	◯	◯	◯	◯	◯

Q2.11 Do you view a radar display as a part of your job?

◯ Yes (1)

◯ No (2)

Display This Question:

If Do you view a radar display as a part of your job? = Yes

Q2.12 Please describe any situations where you have used radar as a part of your job.

____

____

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____

____

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 (for example - 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?

- Never (4)
- Seldom (5)
- Sometimes (7)
- Usually (8)
- Always (9)

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.

- Strongly disagree (51)
- Somewhat disagree (52)
- Neither agree nor disagree (53)
- Somewhat agree (54)
- Strongly agree (55)

End of Block: Radar Use

Start of Block: Accessibility of Radar Displays

Q3.1 Please rate how often you use the following electronic sources to view a weather radar display?

	Never (1)	Seldom (2)	Sometimes (3)	Usually (4)	Always (5)	Do not own this device (6)
TV (1)	○	○	○	○	○	○
Computer/Laptop (2)	○	○	○	○	○	○
Smartphone (3)	○	○	○	○	○	○
Tablet (4)	○	○	○	○	○	○
Other (Please specify) (5)	○	○	○	○	○	○

Q3.2 What type of smartphone do you use?

○ Apple iPhone (1)

○ Android (2)

○ Windows Phone (3)

○ Other (Please specify) (4) ____

○ Do not own (5)

Skip To: Q3.6 If What type of smartphone do you use? = Do not own

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Q3.3 If you use a smartphone to view a weather radar display, which application do you prefer?

- ◯ Weather Channel (1)
- ◯ RadarScope (2)
- ◯ WeatherUnderground (3)
- ◯ Accuweather (4)
- ◯ WeatherBug (5)
- ◯ MyRadar Weather Radar (6)
- ◯ Radar Express (7)
- ◯ RadarNow! (8)
- ◯ Dark Sky (13)
- ◯ Local news weather app (that has radar) (9) ____
- ◯ The weather app that was pre-installed on your phone (Please specify if it has a name) (12) ____
- ◯ Other (Please specify) (10) ____

Q3.4 What features do you like the most about your preferred smartphone application for viewing a weather radar display? Why?

____

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____

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____

Q3.5 How did you select the weather radar application you use?

- ◯ I downloaded the first radar application I found from an App store (1)
- ◯ I sought out a specific radar application (2)
- ◯ A friend or family member recommended an application for me to use (3)
- ◯ I use my favorite news station application (4)
- ◯ I use the weather app that was pre-installed on your phone (6)
- ◯ Other (Please specify) (5) ____

Q3.6 What is your primary mode of transportation to get to work or school?

- ◯ Automobile (Personal) (1)
- ◯ Automobile (Ride sharing service, ex. Uber, Lyft, taxi, etc.) (2)
- ◯ Public transportation (Bus, train, light rail, etc.) (3)
- ◯ Motorcycle (4)
- ◯ Bicycle (5)
- ◯ Walking (6)
- ◯ Other (Please specify) (7) ____

Q3.7 Has your home location in Florida experienced any significant weather events within the past 5 years?

- Yes (1)
- No (2)
- I have not lived in my home location in Florida for 5 years (4)

Display This Question:

If Has your home location in Florida experienced any significant weather events within the past 5 ye... = Yes

Q3.8 What type of significant weather event did your home location experience?

____

____

____

____

____

Q3.9 Do you consider yourself to be a weather enthusiast?

- Yes (1)
- No (3)

End of Block: Accessibility of Radar Displays

Start of Block: Weather Salience Metric

Q4.1 I take notice of changes that occur in the weather.

- ◯ Never (1)
- ◯ Seldom (2)
- ◯ Sometimes (3)
- ◯ Usually (4)
- ◯ Always (5)

Q4.2 I notice how the clouds look during various kinds of weather.

- ◯ Never (1)
- ◯ Seldom (2)
- ◯ Sometimes (3)
- ◯ Usually (4)
- ◯ Always (5)

Q4.3 I plan my daily routine around what the weather may bring.

- ◯ Never (1)
- ◯ Seldom (2)
- ◯ Sometimes (3)
- ◯ Usually (4)
- ◯ Always (5)

Q4.4 The weather or changes in the weather really do not matter to me.

- ◯ Strongly disagree (1)
- ◯ Disagree (2)
- ◯ Neither (3)
- ◯ Agree (4)
- ◯ Strongly agree (5)

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).

- ◯ Strongly disagree (1)
- ◯ Disagree (2)
- ◯ Neither (3)
- ◯ Agree (4)
- ◯ Strongly agree (5)

Q4.6 It is important to me to live in a place that offers a variety of different weather conditions throughout the year.

- ◯ Strongly disagree (1)
- ◯ Disagree (2)
- ◯ Neither (3)
- ◯ Agree (4)
- ◯ Strongly agree (5)

Q4.7 In the past I have wished for weather that would result in a weather-related holiday.

- ◯ Never (1)
- ◯ Seldom (2)
- ◯ Sometimes (3)
- ◯ Usually (4)
- ◯ Always (5)

End of Block: Weather Salience Metric

Start of Block: Participant Information

*

Q5.1 What is your ZIP code?

____

Q5.2 What city do you live in?

____

*

Q5.3 What is your age?

____

Q5.4 What is your gender?

- ◯ Male (1)
- ◯ Female (2)
- ◯ Other (Please specify) (3) ____

Q5.5 What is the highest level of school you have completed or the highest degree you have received?

- ◯ Less than high school degree (1)
- ◯ High school graduate (high school diploma or equivalent including GED) (2)
- ◯ Some college but no degree (3)
- ◯ Associate degree in college (2-year) (4)
- ◯ Bachelor's degree in college (4-year) (5)
- ◯ Master's degree (6)
- ◯ Doctoral degree (7)
- ◯ Professional degree (JD, MD) (8)

Q5.6 Have you taken any meteorology courses or online weather training programs?

- Yes, a college course (4)
- Yes, self taught online (6)
- No (5)

Q5.7 What is your race? (Choose one or more options)

- White (1)
- Black or African American (2)
- American Indian or Alaska Native (3)
- Asian (4)
- Native Hawaiian or Pacific Islander (5)
- Other (Please specify) (6) ____________________

Q5.8 Are you of Hispanic, Latino or Spanish origin?

- ◯ Yes, Mexican, Mexican American, Chicano (2)
- ◯ Yes, Puerto Rican (3)
- ◯ Yes, Cuban (4)
- ◯ Yes, another Hispanic, Latino, or Spanish origin - (Please specify) (5)
____
- ◯ No, not of Hispanic, Latino, or Spanish origin (1)

Q5.9 Which statement best describes your current employment status?

- ◯ Working (paid employee) (1)
- ◯ Working (self-employed) (2)
- ◯ Not working (temporary layoff from a job) (3)
- ◯ Not working (looking for work) (4)
- ◯ Not working (retired) (5)
- ◯ Not working (disabled) (6)
- ◯ Not working (other) (7) ____
- ◯ Prefer not to answer (8)

Display This Question:

If Which statement best describes your current employment status? = Working (paid employee)

And Which statement best describes your current employment status? = Working (self-employed)

Q5.10 Where are you employed?

- ◯ PRIVATE-FOR-PROFIT company, business or individual, for wages, salary or commissions (1)
- ◯ PRIVATE-NOT-FOR-PROFIT, tax-exempt, or charitable organization (2)
- ◯ Local GOVERNMENT employee (city, county, etc.) (3)
- ◯ State GOVERNMENT employee; 5-Federal GOVERNMENT employee (4)
- ◯ Federal GOVERNMENT employee (5)
- ◯ SELF-EMPLOYED in own NOT INCORPORATED business, professional practice, or farm (6)
- ◯ SELF-EMPLOYED in own INCORPORATED business, professional practice, or farm (7)
- ◯ Working WITHOUT PAY in family business or farm (8)

Q5.11 What is your occupation?

____

____

____

____

____

Q5.12 What was your entire household income last year before taxes?

- Less than $10,000 (1)
- $10,000 - $19,999 (2)
- $20,000 - $29,999 (3)
- $30,000 - $39,999 (4)
- $40,000 - $49,999 (5)
- $50,000 - $59,999 (6)
- $60,000 - $69,999 (7)
- $70,000 - $79,999 (8)
- $80,000 - $89,999 (9)
- $90,000 - $99,999 (10)
- $100,000 - $149,999 (11)
- $150,000 or more (12)

Q5.13 Where did you hear about this survey?

- National Weather Service (1)
- Local broadcast news (2)
- Other (4) ____

End of Block: Participant Information

Start of Block: End of Survey

Q6.1
Thank you for completing this survey which is part one of a weather radar study.

The second part of this study will consist of in-person interviews to understand how people make decisions viewing a radar display on a smartphone device. Each interview will take between 35 - 45 minutes and each participant will receive a gift card for participating. Interviews will be conducted in a public space. Interviews will take place during late spring, early summer 2019.

If you are interested in taking part in the second phase of this study or would like more information about part 2, please email the Principal Investigator, Michelle Saunders at msaunders1@mail.usf.edu.

End of Block: End of Survey

Appendix B: Interview Protocol

Scenario Structuring

Degree of Certainty

- Ask how certain participants are that the event will impact them

Degree of Impacts

- Vary the severity/impacts of the event
  A. One multi-cell line or cluster thunderstorm (non-severe) **12/21/2014 16:10 UTC**
  B. One multi-cell line thunderstorm (severe with Severe Thunderstorm Warning) **4/19/19 1:00pm**
  C. One multi-cell line thunderstorm (severe with Tornado Warning) **3/31/11 10 am 2UTC**
  D. Airmass pop-up thunderstorm (non-severe) **6/26/13 4pm**
  E. One sea breeze thunderstorm (East to West) (non-severe) **8/28/18 19:12 Z 3:12pm**
  F. One training thunderstorm (non-severe) produced flooding **6/10/15 17:51 1:51pm**

Temporal

- Vary the speed of the event
  - One fast moving/one slow moving
- Duration of event (How long will the precipitation event impact your area?)

Spatial

- Vary the distance from participants location and event
  - One close to River Walk/one off-shore

Interview Questions and Schedule

A. Introduce myself and the study
B. Choose the persons pseudonym
C. Introductory questions

Grand-touring questions

1. What is your main reason for using a weather radar display?
2. When was the last time you used a radar display?
3. I'd like you to think back to a time that you used a radar display that was memorable to you. Can you tell me about the event? (Where were you? What activities were you doing?)
   a. What type of weather event?
   b. Did you find the radar display useful during this particular event?
4. Can you describe (Have you had) a time when you did not find a radar display useful?

D. Scenarios

Statement before scenarios are shown:

"Not all precipitation or storm events are the same in size, duration, or intensity. Therefore, we are interested in trying to understand how different storm events impact how useful you find radar to be as a decision-making tool. I am going to walk you through six different scenarios, each involving a different precipitation/storm event. Each animation is made up of radar images that show reflectivity values. Each scenario takes place in the Tampa Bay area. I am first going to ask you to rank different aspects of each precipitation event using a 1-5 scale. I am then going to ask you to generally describe what you are viewing during each scenario. It's important to remember that there are no correct answers or responses during this interview. We are instead interested in how you personally think about and use radar images and animations. For each of the six scenarios you will be located at **(the red dot) Curtis Hixon Riverfront Park along the Tampa Riverwalk**." **(Show base map of Tampa Bay with participant location clearly marked) X on screen**

Google Street View (Curtis Hixon Riverfront Park): https://www.google.com/maps/@27.9489703,-82.4623488,3a,75y,225.38h,90.24t/data=!3m8!1e1!3m6!1sAF1QipPj4fVnIhlU4q_f5nxSew7ylkkTfY7CDZDlpSIm!2e10!3e11!6shttps:%2F%2Flh5.googleusercontent.com%2Fp%2FAF1QipPj4fVnIhlU4q_f5nxSew7ylkkTfY7CDZDlpSIm%3Dw203-h100-k-no-pi-0-ya32.89386-ro-0-fo100!7i8704!8i4352

START SCENARIOS

"I am now going to show you the first radar scenario." (Play short animation)

1. In terms of distance between your location in this scenario and the precipitation event, how far away do you think the precipitation event is from your location at Curtis Hixon Park?
    - On a scale of 1-5 where 1 is far away and 5 is at your location, how would rate this event?
2. How certain are you that this particular event will impact you at your location in this scenario?
    - On a scale of 1-5 where 1 is very uncertain and 5 is very certain?
3. How much time do you think you would have before the rain would reach your location at Curtis Hixon Park?
    - On a scale of 1-5 where 1 is no time and 5 is plenty of time, how much time would you have.
    - How much time in minutes would you estimate you have before the rain begins?

~Play entire scenario~

4. How do you think your location at Curtis Hixon Park will be impacted by this event?
    - On a scale of 1-5 where 1 is light rain and 5 is heavy rain, what do you expect to receive at Curtis Hixon Park during this scenario?
    - Are there any hazards you would be concerned about?
5. Can you please describe to me what you are seeing in this scenario (anything that comes to your mind)?
6. What draws the most attention to you during this event as you look at the radar display?

7. If this scenario were real and you were viewing this radar animation, what would you do during this particular event? (Would you move from your location, maybe inside?)
8. Do the images in this animation provide you with enough information about a real-time precipitation event to make your own, independent decisions about the event?
9. For this particular scenario, on a scale of 1-5 where 1 is strongly disagree and 5 is strongly agree, do 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.
10. For this particular scenario, using a 1 to 5 scale, where 1 means "Not at all useful" and 5 means "Very Useful," please rate the usefulness of this weather radar display.

Repeat questions for each scenario.

- **Wrap-up Question: Out of the six scenarios which one would you find to be the most concerning and why?**

Zoom level of map?/ Lightning detector/indicator

E. Follow-up Questions

- **"In addition to the scenarios there are several questions from the motivation survey I would like to follow up on (FQ = Follow-up Question):"**

FQ 2.3: What usually prompts you to view a radar display?

Q2.3 How often do the following conditions prompt you to view a radar display?

Viewing changing sky conditions (1)

Seeing lightning (2)

Hearing thunder (3)

Seeing precipitation (rain, snow, sleet, etc.) (4)

Receiving an official warning for a severe thunderstorm (5)

Receiving an official tornado warning (6)

Overhearing a conversation about current weather conditions (7)

Seeing someone carrying an umbrella, or wearing a raincoat or rain boots (8)

Other (Please specify) (9)

Family and friends

FQ 2.4: What information are you seeking when you view a radar display?

Q2.4 When viewing a weather radar display, how important is the following information to you?

To find out the intensity of a precipitation event (1)

To find out how long a precipitation event will occur (2)

To locate a precipitation event (3)

To locate a hazard watch or warning for your area (4)

Other (Please specify) (5)

FQ 2.10: In the survey we asked about the accuracy of radar data both for intensity and precipitation. How would you describe accuracy in this context?

Q2.10 How accurate do you find the following information provided by weather radar?

Intensity of precipitation (1)

Location of precipitation (2)

- "That concludes my questions for you about weather radar. Do you have any questions for me?"
- "Thank you so much for volunteering to participate in my research, this really is not possible without you!"

Present each participant with a gift card at the end of the interview.

Appendix C: Institutional Review Board Approval Letters

USF
UNIVERSITY OF
SOUTH FLORIDA

RESEARCH INTEGRITY AND COMPLIANCE
Institutional Review Boards, FWA No. 00001669
12901 Bruce B. Downs Blvd., MDC035 • Tampa, FL 33612-4799
(813) 974-5638 • FAX (813) 974-7091

2/27/2019

Michelle Saunders
School of Geosciences
4007 Ashford Green Place Unit # 203
Tampa, FL 33613

RE: **Exempt Certification**
IRB#: Pro00038910
Title: Understanding Tampa Bay Residents' Perceived Value of a Weather Radar Display

Dear Ms. Saunders:

On 2/27/2019, the Institutional Review Board (IRB) determined that your research meets criteria for exemption from the federal regulations as outlined by 45 CFR 46.104(d):

(2) Research that only includes interactions involving educational tests(cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior (including visual or auditory recording) if at least one of the following criteria is met:(i) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the
subjects; (ii) Any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation; or (iii) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a limited IRB review to make the determination required by 45 CFR 46.111(a)(7).

As the principal investigator for this study, it is your responsibility to ensure that this research is conducted as outlined in your application and consistent with the ethical principles outlined in the Belmont Report and with USF HRPP policies and procedures.

Please note, as per USF HRPP Policy, once the exempt determination is made, the application is closed in ARC. This does not limit your ability to conduct the research. Any proposed or anticipated change to the study design that was previously declared exempt from IRB oversight must be submitted to the IRB as a new study prior to initiation of the change. However, administrative changes, including changes in research personnel, do not warrant an Amendment or new application.

We appreciate your dedication to the ethical conduct of human subjects research at the University of South Florida and your continued commitment to human research protections. If you have any questions regarding this matter, please call 813-974-5638.

Sincerely,

Kristen Salomon, Ph.D.,
Chairperson USF Institutional
Review Board

RESEARCH INTEGRITY AND COMPLIANCE
Institutional Review Boards, FWA No. 00001669
12901 Bruce B. Downs Blvd., MDC035 • Tampa, FL 33612-4799
(813) 974-5638 • FAX (813) 974-7091

7/1/2019

Michelle Saunders
School of Geosciences
4007 Ashford Green Place
Unit #203
Tampa, FL 33613

RE: **Exempt Certification**
IRB#: Pro00041097
Title: Understanding Tampa Bay Residents' Perceived Value of a Weather Radar Display

Dear Ms. Saunders:

On 6/30/2019, the Institutional Review Board (IRB) determined that your research meets criteria for exemption from the federal regulations as outlined by 45 CFR 46.104(d):

(2) Research that only includes interactions involving educational tests(cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior (including visual or auditory recording) if at least one of the following criteria is met:(i) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the
subjects; (ii) Any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation; or (iii) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a limited IRB review to make the determination required by 45 CFR 46.111(a)(7).

As a reminder, please contact USF IT at help@usf.edu to set up your Box.com study folder before storing data on the cloud. You will need to include the name of the Principal Investigator (folder owner), study title, data to be stored, and a list of IRB-approved study team members in your email to USF IT. For additional information, please see section 12.2 of USF HRPP Policy.

As the principal investigator for this study, it is your responsibility to ensure that this research is conducted as outlined in your application and consistent with the ethical principles outlined in the Belmont Report and with USF HRPP policies and procedures.

Please note, as per USF HRPP Policy, once the exempt determination is made, the application is closed in ARC. This does not limit your ability to conduct the research. Any proposed or anticipated change to the study design that was previously declared exempt from IRB oversight must be submitted to the IRB as a new study prior to initiation of the change. However, administrative changes, including changes in research personnel, do not warrant an Amendment or new application.

We appreciate your dedication to the ethical conduct of human subjects research at the University of South Florida and your continued commitment to human research protections. If you have any questions regarding this matter, please call 813-974-5638.

Sincerely,

Melissa Sloan, PhD, Vice
Chairperson USF Institutional
Review Board

Appendix D: Fair Use Worksheet

USF Fair Use Worksheet

The fair use exception was added to the Copyright Act of 1976 as section 107 and was based on a history of judicial decisions that recognized that unauthorized use of copyrighted materials were "fair uses." The distinction between fair use and infringement may be unclear and not easily defined. There is no specific number of words, lines, or notes that may safely be taken without permission. This worksheet is offered as a tool to help you determine if your use of copyrighted content is likely to be considered to be a "fair use."

Before you begin your fair use determination, ask yourself the following questions:

1. Is the work no longer protected by copyright?
    a. Is it in the public domain?
    b. Did I retain my copyright ownership over a work I created when signing my publication contract?
2. Is there a specific exception in copyright law that covers my use?
    a. Does my use fit within Section 108 of copyright law: 'Reproduction by libraries and archives?'
    b. Does my use fit within Section 110 (1) of copyright law: 'performance or display of works in face to face classrooms?'
    c. Does my use fit within Section 110 (2) of copyright law: 'performance or display of works in online classrooms (also known as the TEACH Act)?' *see TEACH Act checklist*
3. Is there a license that covers my use?
    a. Is the work issued under a Creative Commons license and can I comply with the license terms?
    b. Do I have access to the material through library licensed content? *Ask your librarian*

If your answer to the above questions was no, then you should proceed with your fair use evaluation. Section 107 also sets out four factors to be considered in determining whether or not a particular use is fair:

1. The purpose and character of the use, including whether such use is of commercial nature or is for nonprofit educational purposes
2. The nature of the copyrighted work
3. The amount and substantiality of the portion used in relation to the copyrighted work as a whole
4. The effect of the use upon the potential market for, or value of, the copyrighted work

None of these factors are independently determinative of whether or not a use is likely to be considered fair use. In evaluating your use, you should evaluate the totality of the circumstances and consider all of the factors together. The Fair Use Worksheet will help you balance these factors to determine if your use of copyrighted material weighs in favor of 'fair use.' While valuable for your own documentation the Worksheet is not intended as legal advice, which can be provided only by USF General Counsel.

INSTRUCTIONS

Check all boxes that apply, and keep a copy of this form for your records. If you have questions, please contact the USF General Counsel or your USF Tampa Library Copyright Librarian.

Name: Michelle Saunders Date: 6/19/20

Class or Project: The Perceived Usefulness of a Weather Radar Display by Tampa Bay Residents

Title of Copyrighted Work: Figure 3.2. Screen captures of seven mobile weather application radar displays used by respondents.

PURPOSE AND CHARACTER OF THE USE

Likely Supports Fair Use	Likely Does Not Support Fair Use
☐ Educational	☐ Commercial
☐ Teaching (including multiple copies for classroom use)	☐ Entertainment
■ Research or Scholarship	☐ Bad-faith behavior
■ Criticism, Parody, News Reporting or Comment	☐ Denying credit to original author
☐ Transformative Use (your new work relies on and adds new expression, meaning, or message to the original work)	☐ Non-transformative or exact copy
☐ Restricted Access (to students or other appropriate group)	■ Made accessible on Web or to public
☐ Nonprofit	■ Profit-generating use

Overall, the purpose and character of your use ■supports fair use or ☐does not support fair use.

NATURE OF THE COPYRIGHTED MATERIAL

Likely Supports Fair Use	Likely Does Not Support Fair Use
■ Factual or nonfiction	☐ Creative or fiction
■ Important to favored educational objectives	☐ Consumable (workbooks, tests)
■ Published work	☐ Unpublished

Overall, the nature of the copyrighted material ■supports fair use or ☐does not support fair use.

AMOUNT AND SUBSTANTIALITY OF MATERIAL USED IN RELATION TO WHOLE

Likely Supports Fair Use	Likely Does Not Support Fair Use
■ Small amount (using only the amount necessary to accomplish the purpose)	☐ Large portion or whole work
☐ Amount is important to favored socially beneficial objective (i.e. educational objectives)	☐ Portion used is qualitatively substantial (i.e. it is the 'heart of the work')
■Lower quality from original (ex. Lower resolution or bitrate photos, video, and audio)	☐Similar or exact quality of original work

Overall, the amount and substantiality of material used in relation to the whole ■ supports fair use or ☐ does not support fair use.

EFFECT ON THE MARKET FOR ORIGINAL

Likely Supports Fair Use	Likely Does Not Support Fair Use
■ No significant effect on the market or potential market for the original ■ No similar product marketed by the copyright holder ■ You own a lawfully acquired copy of the material ☐ The copyright holder is unidentifiable ■ Lack of licensing mechanism for the material	☐ Replaces sale of copyrighted work ☐ Significantly impairs market or potential market for the work ☐ Numerous copies or repeated, long-term use ■ Made accessible on Web or to public ☐ Affordable and reasonably available permissions or licensing

Overall, the effect on the market for the original ■ supports fair use or ☐ does not support fair use.

CONCLUSION

The combined purpose and character of the use, nature of the copyrighted material, amount and substantiality of material used in relation to the whole and the effect on the market for the original

■ likely supports fair use or ☐ likely does not support fair use.

Note: Should your use of copyrighted material not support fair use, you may still be able to locate and request permissions from the copyright holder. For help on this, please feel free to contact your Copyright Librarian.

This worksheet has been adapted from:

Cornell University's Checklist for Conducting A Fair use Analysis Before Using Copyrighted Materials: https://copyright.cornell.edu/policies/docs/Fair_Use_Checklist.pdf

Crews, Kenneth D. (2008) Fair use Checklist. Columbia University Libraries Copyright Advisory Office. http://copyright.columbia.edu/copyright/files/2009/10/fairusechecklist.pdf

Smith, Kevin; Macklin, Lisa A.; Gilliland, Anne. A Framework for Analyzing any Copyright Problem. Retrieved from: https://d396qusza40orc.cloudfront.net/cfel/Reading%20Docs/A%20Framework%20for%20Analyzing%20any%20Copyright%20Problem.pdf

LeEtta Schmidt, lmschmidt@usf.edu and Drew Smith dsmith@usf.edu

Reviewed by USF General Counsel 08/11/2015