AVOIDING THE WINDSHIELD WIPER EFFECT: A SURVEY OF OPERATIONAL

METEOROLOGISTS ON THE UNCERTAINTY IN HURRICANE TRACK FORECASTS

AND COMMUNICATION

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Avoiding the Windshield Wiper Effect: A Survey of Operational

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ABSTRACT

The first line of defense for the threat of an oncoming hurricane are meteorologists. From their guidance, warnings are drafted and evacuation plans are made ready. This study explores uncertainty that operational meteorologists encounter with hurricane prediction, and more importantly, how meteorologists translate the uncertainty for the public. The study is based on a web survey of individual meteorologists, in cooperation with the National Weather Association (NWA). The survey received 254 responses with an estimated 18% response rate.

Specifically, the study focuses on three key areas: displaying uncertainty in hurricane track forecasts, perceived relationships between the public and the media and message characteristics on various platforms (e.g., television, web, and social media), and reliance on numerical weather prediction in the forecasting process. Results show that tracking graphics are varied between their use and usefulness and meteorologists think that they have a bigger role in information dissemination than previously thought.

ACKNOWLEDGEMENTS

DEDICATION

This thesis is dedicated to my parents Laura and Tupper Hyde who always encouraged and

supported me in efforts outside my comfort zone. This thesis is also dedicated to my future wife

Monica who supported me through all the troubles, long nights, and head on the keyboard

moments.

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CHAPTER 1: INTRODUCTION

Recent Events

Since 2005 the number of major hurricanes (category 3 or higher) hitting the United States has entered a so-called "drought". Hart, Chavas, and Guishard (2015) argue that while this occurrence is not necessarily unprecedented, it is uncommon. Despite the major hurricane drought, two storms have brought attention to the need to have clear communications in articulating uncertainty in hurricane track forecasting and messaging.

One of the most notable of these recent storms was Hurricane Sandy in October 2012. It made landfall in New Jersey as a transitioning extra-tropical hurricane. One forecaster at the National Weather Service -Weather Prediction Center division famously called it a "frankenstorm" due to its hybrid nature between an extra-tropical cyclone and a hurricane (Cisco, 2012). No matter what Sandy was, it best known in the meteorological and emergency management communities for forecasters' difficulty in forecasting its track. Due to the shifting track forecast, meteorologists attempted to explain the uncertainty of the forecast to the public in new ways. Terms such as "GFS"(Global Forecast System), "Euro"(European Center for Medium-Range Weather Forecasts), "Spaghetti Plot", and "phasing" had always existed in the meteorological community lexicon for many years, but with numerical models coming to a split decision on where to take the storm, meteorologists had to explain why there was so much uncertainty in the track forecast even as the storm closed in. Major news outlets began drawing battle lines between the numerical prediction models, namely between American based models, and models developed by Europeans. In the end, the European based model(s) "won", and correctly predicted the track of the storm before the American model counterparts picked up on the same pattern. In response to the outcry about American models "lacking", Congress

appropriated 25 million dollars to upgrade America's weather supercomputing power (Samenow, 2013). However, after the word was out, the general public had peeked behind the curtain of the meteorological world.

In 2015 another storm with the name of Joaquin was churning northeast of the Bahamas. Like Sandy, also developed in the midst of a complex weather pattern. Once again, the American models and the European models started splitting on Joaquin's predicted track. American models had it going into the coast while European model(s) had it going out to sea. The National Hurricane Center expressed low confidence in their forecast stating that:

> "...confidence in the details of the forecast after 72 hours remains low, since we have one normally excellent model that keeps Joaquin far away from the United States east coast. The range of possible outcomes is still large, and includes the possibility of a major hurricane landfall in the Carolinas." (Bevin, 2015)

As it turned out, the European model once again was victorious in its forecasting, and Joaquin eventually made its way out to sea. However, the media storm surrounded the initial build up to a potential landfall and then questioned why the American model(s) were inferior to the European(s) models once again. This prompted the National Hurricane Center to put out a tweet saying that "folks knocking US models might not know that over last 3 years, average tropical cyclone errors of GFS and ECMWF are virtually identical" (National Hurricane Center, 2015).

Significance and Rationale

These storms provided both a reminder and a lesson to both meteorologists and public officials. A hurricane does not need to be an Andrew, Katrina or a Rita to cause problems. A growing sentiment is to build collaboration and strengthen communication between both

meteorological and emergency management communities for the need of more collaboration and communication between the two disciplines. For example, the American Meteorological Society has an entire committee on emergency management. Their mission statement states that their goal is to:

> Develop approaches that engage the AMS weather, water, and climate enterprise with the broader emergency management community. This effort will help to expand collaboration, cooperation and mutual understanding between the enterprise and members of the emergency management community across federal, state, academic, private, and local interests (American Meterological Society, 2016).

Similarly, the International Association of Emergency Managers also has a caucus on climate and weather, one of whose goals is "to provide a conduit between emergency management practitioners and the weather and climate change communities" (International Assocation of Emergency Managers, 2016).

This need to understand each other is a mutual partnership between meteorologists and emergency managers. However, few studies have crossed the boundary to examine how each other works within this partnership. The meteorology community has already cross-examined emergency managers in regard to decision making and communications between parties (e.g., Baumgart, Bass, Philips, & Kloesel, 2006; Cavanaugh, Huffman, Dunn, & Fox, 2016). However, there are no published papers to date that take the opposite approach, emergency managers studying meteorologists. This study is groundbreaking in that this is the first time the emergency management discipline is exercising the element of emergency management's distributed function, in that many entities are inherently involved with emergency management, over to meteorologists at the intersection of hurricane forecasts and messaging.

There are three critical entities in an integrated warning system, operational

meteorologists, emergency management, and the media (Doswell III, Moller, & Brooks, 1999;

Cavanaugh, Huffman, Dunn, & Fox, 2016). In order to issue evacuations and warn the public

effectively, operational meteorologists must make accurate forecasts and communicate these

forecasts to the rest of the integrated warning system team in order to disrupt the least amount of

people as possible as well as save costs, which can be on the order up to one million dollars per

mile of evacuated coastline (Whitehead, 2003).

Operational meteorologists are persons with accredited degrees in meteorology whose job

is to make forecasts for a certain geographical area for the public or private entities on a daily

basis. In the public sector this may include governmental forecasters for federal entities, such as

the National Weather Service or forecasters in emergency management occupations. Operational

meteorologists may also include forecasters in the private sector whose clientele includes

businesses in environment, energy, logistics, and retail sectors. This also includes meteorologists

in media such as those in television, radio, print, and online media.

While a few studies have been performed internally amongst groups and organizations of

meteorologists on topics such as climate change (Stenhouse et al., 2014), very little literature has

examined meteorologists in regard to hurricane decision making and public awareness. However,

a vast body of literature has accumulated about the public's perception of hurricane risk, warning,

and evacuation (Huang, Lindell, & Prater, 2015). This situation provides an excellent

opportunity to explore how the perceptions of meteorologists on hurricane evaluation, warning,

and action differ from those of a non-weather savvy general public. Thus, this study is

comparatively powerful providing the platform to match research performed on the general

public versus the meteorologists who warn them. This comes at a critical time in the weather

community when meteorological models are becoming more numerous and their intricacies more complex. It is also important to remember that the concept of connectivity and the media has changed significantly during the past decade. For example, the popular social media site Facebook was only founded in 2004, and today it has over 1.65 billion users (Facebook, 2016). Another example is Twitter. Twitter was founded in 2006 after the last major hurricane struck the United States. Yet both of these entities are now a critical part in today's public life, and media have evolved significantly to take advantage of these new platforms and opportunities to spread messaging. How meteorologists take advantage of these new tools and others, has yet to be explored.

This study aims to explore how operational meteorologists view uncertainty in forecasting hurricanes and how this uncertainty translates into messaging. Specifically, the study examines hurricane track forecast preferences, perceived media - public relationships, and perceived message effectiveness on various platforms including television, web, and social media. The study will be focused on meteorologists who forecast for coastal areas along the Gulf of Mexico and east coast of the United States. Survey questions are designed to operate on a topic expert level so that nuances of difference of opinions can be evaluated.

CHAPTER 2: LITERATURE REVIEW

Hurricane Forecasting

The United States is no stranger to hurricanes. Hurricanes on average hit a coastline of the United States about 1.75 times each year with a major hurricane (Category 3 and above) hitting about 0.6 times per year (Landsea & Dorst, 2015). The earliest hurricanes that were recorded in the United States perhaps started as early as 1635 when the colonists of Plymouth and Boston recorded a strong hurricane that struck present-day Rhode Island with a 20 foot storm surge (Rosen & McDonald, 2014). The deadliest hurricane on record was the 1900 Galveston, Texas hurricane which killed upwards of 8000 persons on Galveston Island and surrounding areas (Frank N. L., 2003). This storm marked the turning point in hurricane forecasting and warning as several lessons were learned from the event.

Hurricanes and other natural disasters in history have long been considered acts of God, and seen as unavoidable. The shift in thinking from hurricanes being acts of God to events that can be predicted occurred as early as the 1890s (National Weather Service, n.d.) with the introduction of the United States Army signal corps, later translated into the United States Weather Bureau, the direct ancestor to today's National Weather Service (NWS). With the signal corp. introduction, along with the Galveston hurricane, much advancement was made in hurricane knowledge about tracking and the hazards they present.

These lessons included the fact that hurricanes are not regulated to the Caribbean Sea but they can, and do reach up into Gulf of Mexico and they have the potential to be very violent even up to the Gulf Coast region. Second, the conception of what a storm surge is shifted from the idea of a gradually building waves to the idea of a wind pushed "dome" of pushing of water of which large waves ride atop (Frank N. L., 2003).

As more hurricanes hit the shorelines of the United States, and more ships encountered them at sea, more information was gathered about how hurricanes work and function. The spread of meteorological instruments in the early 1900s along with faster communication methods such as the wireless telegraph and radio, widened meteorological knowledge about these events. A couple of the key events in the past century have been the catalysts for these knowledge leaps. Namely, the 1935 Labor Day Hurricane (Category 5, Florida Keys), the 1938 "Long Island Express" (a Category 3 hurricane into Long Island, NY with less than 6 hours warning because of it's extremely fast forward speed), Hurricane King of 1950 (Category 4, with landfall in downtown Miami, FL), and Hurricane Camille of 1969 (Category 5, Mississippi). The lessons learned from these events, coupled along with the use of aircraft measurements directly into storms and satellite data, helped reduce location and strength uncertainty in tracking tropical cyclones around the world (Landsea & Franklin, 2013).

Due to these advancements and the improved understanding of how hurricanes form, move, and the impacts they bring, meteorologists formed specialty centers to track them. When a tropical cyclone forms, the process of tracking the cyclone is the responsibility of the perspective Regional Specialized Meteorological Centers (RSMC's). There are a total of six RSMC's covering the world's oceans. These RSMC's are designated by the World Meteorological Organization (WMO), a specific semi-independent United Nations (UN) Agency, part of the United Nations Development Group (World Meteorological Organizaion, n.d.). The WMO, and its 185 member states also decide on the regional cyclone naming schema. This naming schema is language regionalized based on the RSMC and operates on a multi-year repeating list. A name from the list only is removed if a particular storm with that name has caused significant damage

and destruction to a member country. That country can petition the other member countries to have the name removed on its behalf (World Meteorological Organizaion, n.d.).

"[RSMC's] provide advisories and bulletins with up-to-date first level basic meteorological information on all tropical cyclones [in their jurisdiction]" (World Meteorological Organizaion, n.d.). These advisories include current information about the cyclone, a forecasted track, and any watches or warnings in effect. Issuing watches and warnings are not the responsibility of the RMSC. Watches and warnings for tropical cyclones are the responsibility of the impacted country(s). For example, if a hurricane was passing through the Caribbean islands, it would be the responsibility of each individual island's government to issue its own watches and warnings. These bulletins are then transmitted to the country's respective RSMC and then re-broadcast in the RMSC's bulletins.

For the Atlantic basin, the RSMC is the National Hurricane Center in Miami, Florida, and its area of responsibility covers the Eastern Pacific and the North and South Atlantic oceans which includes Western Africa, the Caribbean, Latin America, Canada, and the United States.

Hurricane Tracking and Forecasting Progress

Hurricane tracking has improved substantially in the past few decades, mainly due to the presence of geostationary and polar-orbiting satellites. No tropical cyclone in the world today can go an hour without being seen or scanned by satellites and its exact location measured.

Hurricane track prediction has also improved substantially in the past few decades, given the advancements of numerical modeling and observation based initialization techniques. For example, the amount of error in the track for a 24-hour lead time in the official National Hurricane Center forecast has dropped in half from the early 1990s to today. A 72 hour forecast has gone from an average of 300 nautical miles to just 100 nautical miles (Landsea & Franklin,

2013, p. 3586). The National Hurricane Center has become so confident in their ability to forecast hurricane tracks, that in 2001 they also started issuing day 4 (96hrs) and day 5 (120hrs) forecasts (Gross, 2004, p. 1). The National Hurricane Center keeps track of tacking errors over time since 1970. Since 1970 with the advances of hurricane tracking with satellite images and reconnaissance aircraft feeding data into more powerful numerical models, the error in tracking has gone down steadily. Since 1970, the forecast track area for 24,48, and 72 hours has gone down by nearly 60%. Day 4 and 5 forecasts which started in 2002 also have generally decreased in track error but not to the extent that shorter range outlooks have decreased (Figure 1).
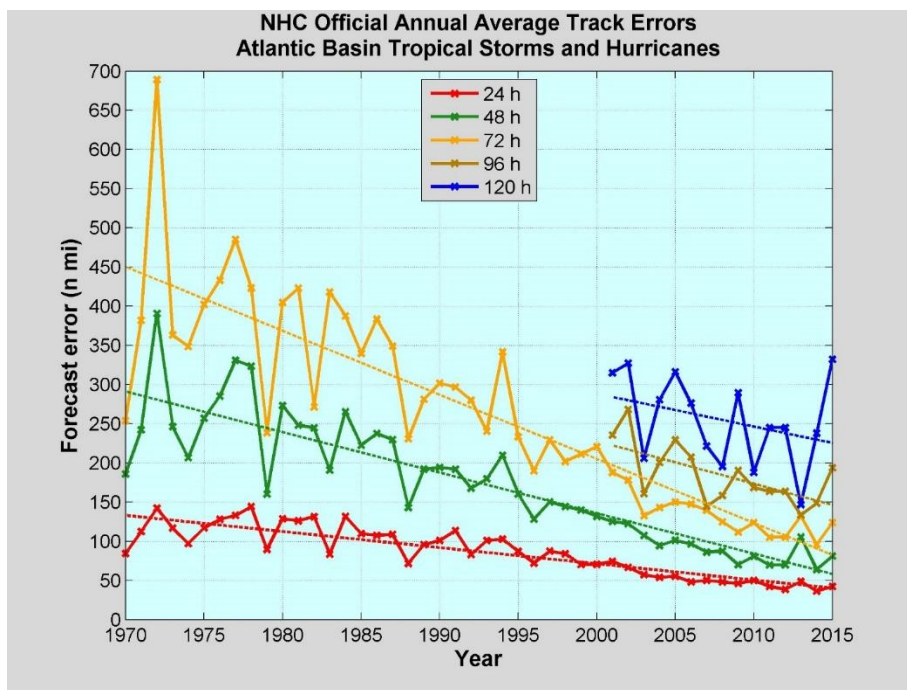
Figure 1. Distance Errors in Hurricane Track Forecasts from the National Hurricane Center for the Atlantic Basin as Plotted Over Time (National Hurricane Center, 2016).

However, hurricane strength continues to be the main problem in hurricane prediction (Marks, Shay, Barnes, & Black, 1998; Landsea & Franklin, 2013). Measuring the strength of a tropical cyclone still tends to pose a challenge occasionally while storms are at sea and being remotely observed. Strong and compact storms such as eastern Pacific's recent Hurricane Patricia

(2015) can rapidly intensify and result in large intensity "jumps" between satellite passes or aircraft observations (Kimberlain, Blake, & Cangialosi, 2016). When a hurricane intensifies, especially when it rapidly intensifies, the hurricane itself can change its "depth" in the atmosphere, this can cause different larger synoptic weather patterns to shift its course, which become headaches for forecasters and raise uncertainty for track forecasting. Official intensity forecast errors have remained relatively steady with little progress, except for some slight progress in the three to five-day range. Day 2-5 intensity forecasts continue to be off by about 15 to 20 knots (17mph to 23mph) on average. A 24 hour forecast remains at an error of about 10 knots (12 mph) (Landsea & Franklin, 2013). While a difference of 10 to 20 mph error on average sounds small, it can have drastic impacts for track and guidance as well.

Hurricane Preparedness and Evacuation

Since the time early 1900s various mitigation projects all over the country have been constructed. From beach and dune replenishment along sections of the east coast, to coastal wetlands rehabilitation and levees along the gulf coasts, mitigation measures help protect properties along our nation's shores from coastal flooding threats. Better building construction methods and building codes have also been developed that make resilience to minor disaster events easier to cope with and bounce back from (Lindell, Perry, Prater, & Nicholson, 2006). Counteracting these protection measures, coastal buildup of residents in vulnerable settings to hurricane hazards is increasingly becoming a major issue along the United States coastlines. From 1990 to 2005, there was a jump of 11 percent on average in population count in United States coastal areas from with a growth rate of about 1 percent per year; some counties in Florida have even jumped over 500% in the past half-century (Cutter, Johnson, Finch, & Berry, 2007, p. 11). Furthermore, there is some evidence to suggest that this population buildup may be persons

with social and economic demography's that are known to be more vulnerable in the case of a hurricane impact (Cutter et al., 2007, p. 13). However, while mitigation measures protect against loss of properties and resources, people themselves are still at risk against the storm. Thus other means, such as evacuation, are still needed to move persons out of harm's way.

When the greatest threat to American localities during the 1950s and 1960s was the threat of nuclear attack, civil defense agencies made or were given plans to evacuate their localities. However soon after they realized that they could also use the same plans to evacuate from other natural hazards including hurricanes (Quarantelli, 2000, p. 10). Case studies by academia soon followed with empirical studies starting as early as 1963 with Hurricane Carla and the Texas coastline, with additional studies in the 1970s and 1980s. From this many questions with relatively few, or at least conflicting, answers about the factors which influence evacuation decision making started to develop in the early 1990s. These factors included prior experiences, demographics, official warnings, and information sources (Baker, 1991; Dow & Cutter, 1998; Lindell, Lu, & Prater, 2005).

As researchers gained a better understanding of the factors that motivate people to evacuate, a growing realization soon became apparent that evacuation decision making is a complex process involving multiple information sources, risk perceptions, and personal experiences which control behavioral actions within the individual and the household. Dash and Gladwin (2007) noted that "for as much research as has been conducted on the issue of evacuation, our understanding of evacuation is extremely limited. Those expected to evacuate often do not, and those who should not evacuate (at least in the estimation of emergency managers) often do." (p. 72)

Many studies have examined the correlation between the demographics of people living in hurricane prone areas and those who evacuate in advance of a storm. Huang, Lindell, and Prater (2015) in a meta-analysis of 38 studies found that few demographic variables can explain how individual households make decisions to evacuate. However, they did find that official warnings, the knowledge of and/or presence of hurricane related risks (i.e., wind and water), and whether their peers were evacuating, all showed a strong and positive relationship to their decisions to evacuate.

What this tells us, is that perhaps it is not the demographics or socio-economical position that a person is in that determines whether or not that person will evacuate, but instead what messages they receive that drive one's decision to evacuate. This notion directly correlates into the widely used *Protection Action and Decision Model* proposed by Lindell and Perry (1992; 2004; 2012). Lindell and Perry (2012) state that those at risk from a hazard, in this case a hurricane, must answer a basic question; "Is there a real threat that I need to pay attention to?" There is a growing evidence body that suggests "a positive relationship between level of threat belief and disaster response across a wide range of disaster agents, including… hurricanes" (Lindell & Perry, 2012, p. 621). The key question to ask then becomes "who is informing them of the threat". Arguably, one of the main informers for an oncoming hurricane threat is the meteorologist.

Risk Communication

When looking at the existing literature on hurricanes and their risks to people and property, the vast majority of the focus goes to looking at the public and their perceptions, reactions, and decisions that they make in order to protect life and property. Among the 49 hurricane evacuation decision making papers reviewed by Huang et al. (2015), none examined

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meteorologists, an important hurricane risk information predictor and disseminator. Additionally, only 25 of the 49 studied official warnings and only 15 of the 49 studied news media (Huang et al., 2015). This indicates a research void in the present literature about not only meteorologists and their role in risk communication for hurricanes but also via what channels the public accesses hurricane risk information fed from meteorological sources.

When faced with an incoming threat, the PADM tells us that people ask "[I]s there a real threat that I need to pay attention to?" in order to make a risk identification (Lindell & Perry (2012, p. 621). In a hurricane situation, a meteorologist can answer that question. Meteorologists are the interpreters between complex physical interactions in the atmosphere and the impacts of those felt on the ground.

The Protective Action Decision Model explains the way that people "'typically' make decisions about adopting actions to protect against environmental hazards" (Lindell & Perry, 2012, p. 617). It involves a three step process in which cues, messages, and other inputs come in different forms, then are "pre-processed" by the individual(s) that represent various personal characteristics, perceptions of the threat, and assessments of risk (Figure 2). From there a decision is made to take a certain action to protect themselves from the threat. Finally, that decision and subsequent action are manipulated by the "physical and social environment that can impede actions that they intended to take or that can facilitate actions that they did not intend to take" (Lindell & Perry, 2012, p. 624).

PADM is a standard model in the hurricane evacuation and decision making literature. It is important for this study to add to the growing body of literature by incorporating information sources, warning messaging, and channel access from the source of uncertainty in hurricane situations, the hurricane itself, and more specifically, the meteorologists who represent and

interpret it. These three characteristics are the first three elements in the flow of communication

to the end user as first described as the classical persuasion model which is now a staple

conceptual model of persuasive communication (Lasswell, 1948; Lindell & Perry, 2004, p. 14).

In transferring this model over to the concept of hurricane information and warning

dissemination, the operational meteorologist is critical as he/she is the source of information,

controlling what messages to portray about the threat and the channel in which to distribute the

information to.
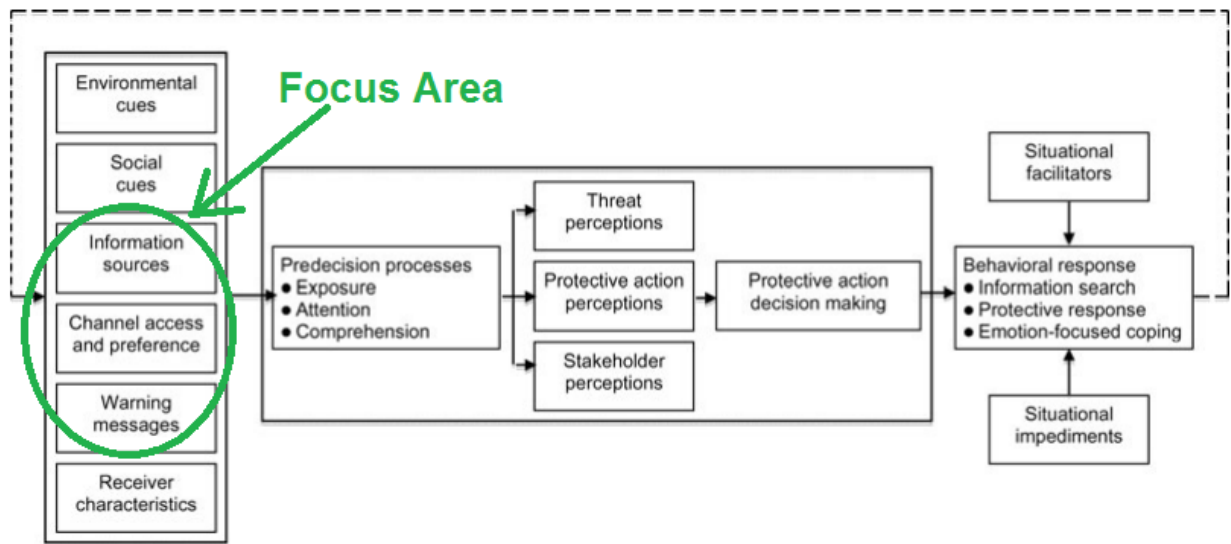
Figure 2. Protection Action Decision Model with Highlighted Focus Area of Research. (Lindell & Perry, 2012, p. 617).

Meteorologists as Information Sources

When a threat appears on the horizon, the first person that the media, government

entities, and the public in general turn to are subject matter experts that have intimate knowledge

of the threat on an everyday basis. For hurricanes they are operational meteorologists.

Operational meteorologists are representatives of an authority when placed in the context of a

meteorological threat. Their purpose is to convey the environmental threat and propose the

amount of risk the threat imposes to the audience. However, it is not proper to bundle all

operational meteorologists in the same frame. Not all operational meteorologists have contact

with the public for example, and not all of them work exclusively in a set geographical area.

Most importantly, not all operational meteorologists work with tropical weather exclusively. The

range at which an operational meteorologist is focusing on delivering products and information

to their constituents is based on the level of threat that the storm possesses. For example, a small

tropical depression in the middle Atlantic Ocean will only be the focus of meteorologists whose

sole job purpose is to make forecasts for the storm itself, such as the forecasters at the National

Hurricane Center. However, if the threat is a major hurricane in the middle of the Gulf of

Mexico, it is likely that every operational meteorologist who operates in the bordering Gulf

states and even beyond, including those from national organizations, will be busy making their

individual forecast duties ready for the pending event.

Likewise, it is not unreasonable to expect that the receivers of the information will be

different too, and thus their information sources will have different characteristics too. Therefore,

the operational meteorologists are also varied in their informational source concentrations and

materials. Operational meteorologists can work in both the private and public sectors. Private

sector operational meteorologists are often viewed as those who work on or for television or

radio networks, whereas other private sector meteorologists are concentrated in fields ranging

anywhere from legal consulting to energy production. There is only anecdotal evidence on the

number and diversity of occupational meteorologists in the private sector (Maibach et al., 2016),

but it appears that the ratio between meteorologists who work in the public light and ones who

do not is low. Operational meteorologists who work in the public sector are mainly located

within the National Oceanic and Atmospheric Administration (NOAA) with some meteorologists

working within state emergency management agencies or within FEMA, such as the Hurricane

Liaison Team (HLT).

Warning Messages

Dash and Gladwin (2007) note that "in understanding who evacuates and who does not...

warning message characteristics, such as its content, source, and frequency, have been an

important focus of research" (p. 69). In this respect, meteorologists have the responsibility to

give the first warning messages to their constituents about an oncoming meteorological threat.

Sorenson (2000) notes that warning messaging breaks down into four categories - prediction and

forecasting, warning integration, warning dissemination and the public's response to those

warnings. On the prediction and forecasting portion, Hurricane forecasting on average has made

significant progress in track forecasting (Figure 2). However, large impact events in complex

meteorological situations still plague numerical modeling capabilities. Such examples are

Hurricane Sandy of 2012, Hurricane Joaquin of 2015 and Hurricane Matthew of 2016. Sorenson

(2000) notes that warning integration and dissemination has had "major improvements" for the

hazard of hurricanes (p. 119). Evidence for these improvements are seen nearly every hurricane

season as official watches and warnings are displayed on every weather report. Further

integration into mobile applications means that it is very hard not to notice a watch or warning

posted for a locality when nearly every phone has a weather app. The public response to these

warnings has been shown throughout the literature to be highly correlated with making a

decision to take protective actions. According to Huang et al. (2015) over 90% of studies

reported significant correlations between official warnings and taking a protective action, in this

case, evacuation (p. 12).

Digging deeper in evaluating how effective warning dissemination and messaging is, Cova et al., (2016) establishes three key questions in determining the most effective methods of conveying protective action decisions. Who to target in the messages, what actions to take, and when should the message be disseminated. However, Cova et al. (2016) also notes that "[A]ddressing uncertainty in all aspects of an event that may affect who needs to take what action and when remains a relatively under researched topic" (p. 8). Additionally, Dow and Cutter (1998) noted that evacuation warnings are more effective when they are timely, personally relevant, and come from a credible source. One of the primary tasks of a meteorologist is to do exactly this. On-Air meteorologists have to have all of these qualities. For example, if a television meteorologist is not credible, station ratings would likely suffer. If a meteorologist for the private sector was not personally relevant, the business would unsubscribe from the service. Meteorologists interact with the public every day to make sure that information about the larger environment is understandable and their predictions can be put to action.

Channel Access and Preference for Decimation of Information

One key element in the role of the meteorologist in an oncoming hurricane situation is the communication of messages and products through their specific method of distribution. Some meteorologists who work in government have their message distributed through official channels, while others who work in broadcast may distribute through media, along with many other examples. At the end of this process, the questions that really matter are: 1) how does this information flow from the meteorological sources to the public, 2) how does the public perceive this information, 3) does it come from a knowledgeable source and 4) is the source trustworthy? The vast majority of hurricane impact literature to date has focused on these questions from the public perspective, noting credibility and trustworthiness of information sources.

On the topic of information credibility, Arlikatti, Lindell, and Prater (2007) note that credibility derives from two source characteristics: "Source credibility comprises expertise (knowledgeability about the situation) and trustworthiness (honesty and completeness of information communicated about the situation)" (p. 222). To this extent there has been no published literature to date about how meteorologists are perceived by the general public. However, proxy evidence from past hurricanes for figures that represent these characteristics do paint figures who have explicit knowledge about the situation at hand and media in general. For example, Huang et al., 2015 showed that "local officials are extremely important information sources" (p. 33) because of these characteristics. Similarly, local news media also scores high on credibility, especially during hurricanes, as was seen with Hurricane Andrew (Driscoll & Salwen, 1996, p. 295).

However, with the ever growing number of sources to get information from in modern times such as social media along with classic sources of television and print media, there is an ever growing number of intermediate sources that take the original message and redistribute it. Gladwin, Lazo, Morrow, Peacock, and Willoughby (2007) note that this makes "[T]he communication of hurricane warning today especially complex, involving multiple messages and sources" (p. 89). For example, Gladwin et al. (2007) also notes that "[P]rivate companies now issue their own forecasts and NHC advisories undergo interpretation and distribution through a gamut of public and private modalities. In general, repetition increases belief, but this effect also raises the possibility of conflicting messages" (p. 90).

The question for meteorologists then is two-fold. First, what are the important messages that members of the operational meteorologist community want to convey about uncertainty in times of a hurricane threat? Second, what platforms do they convey this information on?

Unfortunately, there has been hardly any literature on these subjects. The closest study that discusses these topics is from Demuth, Morrow, and Lazo (2009) in doing focus groups with 13 meteorologists about forecast uncertainty. Their study noted that:

> "First, broadcasters have varied perceptions with respect to what their audiences want, need, and can understand. Although they generally think the public already understands that uncertainty is implicit in forecast information, there are mixed viewpoints on how members of the public can benefit from additional information about forecast uncertainty." (p. 1617)

In any case, there is a broader need to bring in social science into the message and platform in disseminating hurricane information to end users (Demuth, Morrow, & Lazo, 2009, p. 1618; Morrow & Lazo, 2015; Demuth, Morss, Morrow, & Lazo, 2012; Broad, Leiserowitz, Weinkle, & Steketee, 2007; National Research Council, 2006).

Displaying Uncertainties in Hurricane Forecasts

There are many ways of displaying a measure of uncertainty in statistics. It could be in form of numerics of text, such as standard deviation or percentage, or in the form of a graph or plot, such as a standard bell curve. However, there are a limited number of ways to display uncertainty geographically. Especially, geographic uncertainty that is supposed to be easy to comprehend, understand, and ultimately provide guidance in the process to make a decision. Doswell (2016) notes that "[U]ncertainty is inevitable and probability is the language of uncertainty; by whatever verbiage we use to express it, we meteorologists need to communicate our uncertainty to our users such they accept the real capabilities of meteorological science as applied to the task of forecasting." These are the challenges that are posed to the meteorological community in issuing products for hurricane products. These products break down into four

types of geographical displays for conveying uncertainty information in hurricane forecasts: the cone of uncertainty, the probability plot, the spaghetti plot and the categorical plot.

Cone of Uncertainty

The Cone of Uncertainty is the primary method of displaying hurricane track, track uncertainty, and strength information by the National Hurricane Center (Zelinsky, 2016). The cone is made up of a series of concentric circles in which their radii increase for each progressive in forecast distance. An example of the cone of uncertainty can be seen in Figure 3. The forecast distance radii are set annually based on a past five-year forecast error sample. For example, for the 2016 hurricane season, the error (or radius) for a one-day forecast is 49 nautical miles (nmi), a three-day forecast is 115 nmi and a five-day forecast is 237nmi (National Hurricane Center, 2016). For each forecast distance circle, the methodology for determining the radius of the circle is designed so that there is approximately a 2/3 chance that the storm's center will fall inside of that circle at that given forecast time. This means then, when looking at the cone, there is a 2/3 chance that the storm's center will be inside the cone for any given forecast point, and 1/3 chance that it will lie outside of the cone. The circles' radii do not change for any given storm (National Hurricane Center, 2016). One way to visualize how this works is that if a storm stays in the same place, the cone will become a circle.

However, the cone of uncertainty has its perceived flaws. One of the main concerns as indicated by the National Academy of Sciences, is the property of the cone of uncertainty to be too deterministic in nature. "The existence of a central line in some of these forecast products (referring to the cone of uncertainty), indicating the most probable path, may detract from the effectiveness of the graphic" (National Research Council, 2006, p. 11). This particular issue came to the forefront in Hurricane Charlie in 2004 when the storm ran parallel to the Florida

Gulf coast and put many coastal areas in the cone. However, the centerline of the cone ran through Tampa while the storm actually made landfall about 40 miles to its south. A post-mortem report noted that:

> "Despite repeated warnings and targeted communication efforts by members of the forecast community, it appears that many people overly focused on the skinny black line (i.e., the track line). Some observed that the line did not pass through their locality and thus incorrectly assumed that they were safe, even if they were still within the cone, indicating that they did not understand that the actual track can vary anywhere within the cone. This suggests that the line actually subverts the key message of a graphic intended to convey uncertainty." (Broad, Leiserowitz, Weinkle, & Steketee, 2007, p. 663)

Wu, Lindell, and Prater (2015) also studied the cone of uncertainty with hypothetical landfall senarios and found that indeed participants focused more on areas towards the center of the cone as areas with the most risk, and the information gained by the cone graphic was more related to the future direction of the storm. This confirms previous studies noting that the public at large generally has trouble relating percieved probability to actual probability. The study also notes that it is important to determine how members of the general public interpret and use probability information and how that raw display of probability turns into how they convey that information as uncertainty to themselves, their family, and to others in their social circle or community.

In summary, the cone of uncertainty has traditionally been the most used and most often recognized hurricane and forecasting graphic. It is the main distribution product of the National Hurricane Center and it is directly copied or modified for distribution in media outlets around the country. Previous literature has concluded that while the public at large may have trouble with

uncertainty and probability, this question has never been posed to meteorologists, who directly

convey the graphic itself. Overall, although the cone of uncertainty is the main forecasting

graphic for hurricane forecasting, it is clear that it has drawbacks as it does not represent direct

probability, and thus is prone to errors in interpretation.
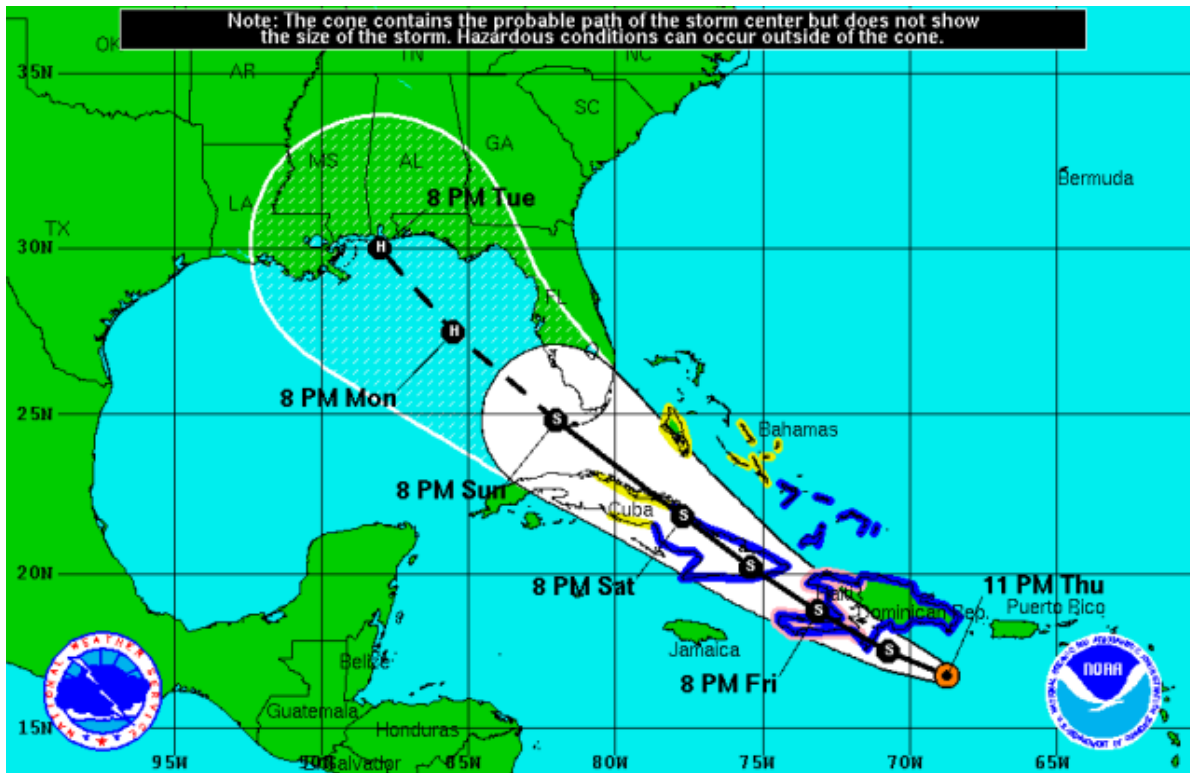
Figure 3. Cone of Uncertainty Plot from Hurricane Isaac (2012) (National Hurricane Center, 2012).

Windspeed Probability

The windspeed probability product (Figure 4) is a product distributed by the National Hurricane

Center as an alternative to the cone of uncertainty product. Its main advantage is that it explicitly

states the uncertainty as a measure of probability. It also focuses on tropical cyclone size and

intensity rather than the center of path.

> "The NHC has been issuing other products intended to convey the uncertainties in the
>
> track forecast. However, those products do not account for the uncertainties that also

exist in the forecast of the cyclone's intensity and size. However, the wind speed

probabilities products are about the weather.... That is, the wind speed probabilities

provide the chances of wind speeds equal to or exceeding familiar thresholds (for

example, tropical storm force and hurricane force) at individual locations. Therefore,

these probabilities likely have more direct meaning and impact to users."

(National Hurricane Center, 2014, p. 5)

In this way the National Hurricane Center believes that windspeed probability plots will

make it easier for decision makers to accurately calculate their odds of reaching a threshold for

which a decision will be made from. "In other words, these cumulative probabilities tell

decision-makers the chances that the event will happen at any point on the map within the time

period stated on each graphic" (National Hurricane Center, 2014, p. 3). However, these graphics

do not come without risks, primarily, how they display and express risk correctly. People

generally have difficulty in interpreting different levels of quantitative risk, and personal

experiences may warp an accurate depiction of the true probabilistic risk and unconsciously

involve biases that either under or overestimate the actual risk posed to them (National Research

Council, 2006).

While the probability plot has existed for the better part of a decade, it is not the preferred

method of showing uncertainty in forecasting due to its perceived difficulty in interpreting raw

numerical probabilities and other factors such as no time scale and track centerline.
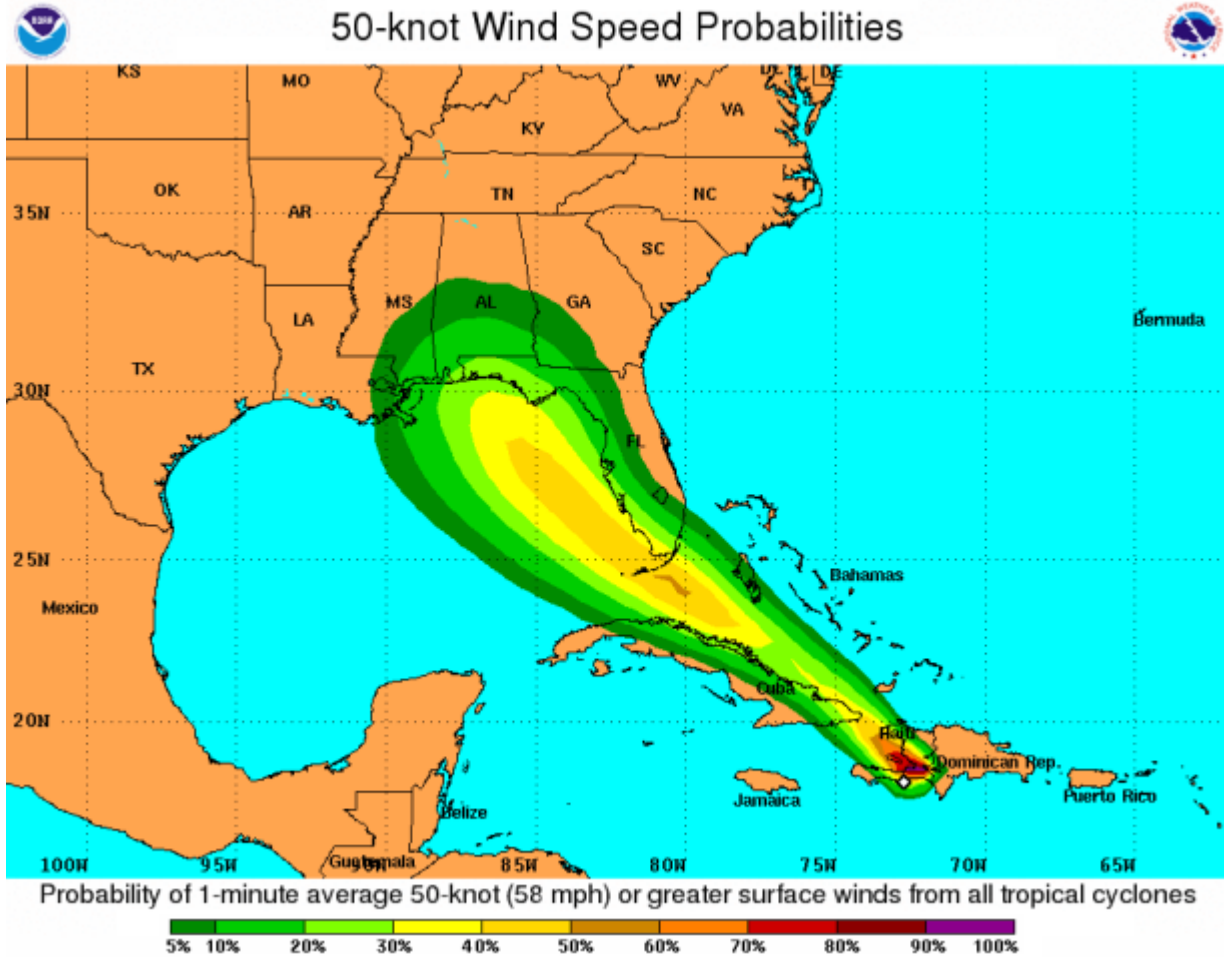
Figure 4. Probability Based Plot from Hurricane Isaac (2012) (National Hurricane Center, 2012).

Spaghetti Plot

The spaghetti plot (Figure 5) is fairly new on the tropical meteorological scene, only appearing in the past decade or so and sooner for public consumption. The rise in this product within the meteorological community and to the public in general is a result of the rise of ensemble systems in numerical weather modeling, used as a gauge of uncertainty in the track forecast. However, more recently it has become more widely used in meteorological sectors as well as the public through social media and traditional media channels as a portrayal of uncertainty of path or disagreement amongst the numerical modeling simulations. The common principle is that it shows uncertainty through deterministic solutions by taking the centerline

track of many numerical simulations and plotting them onto a map. The most common way to

achieve this is by using an ensemble forecast. Ensemble forecasts operate by taking an initial set

of conditions and altering those initial conditions slightly, denoting possible variations and errors

in observations. When this set of initial conditions is set forward in the model, the simulations

diverge to create a collection or ensemble of possible solutions. If the simulations diverge largely

from each other, there is little confidence in the forecast. If there is strong overlapping of

forecasts, the forecast can be interpreted as more certain (American Meteorological Society

Council, 2008).
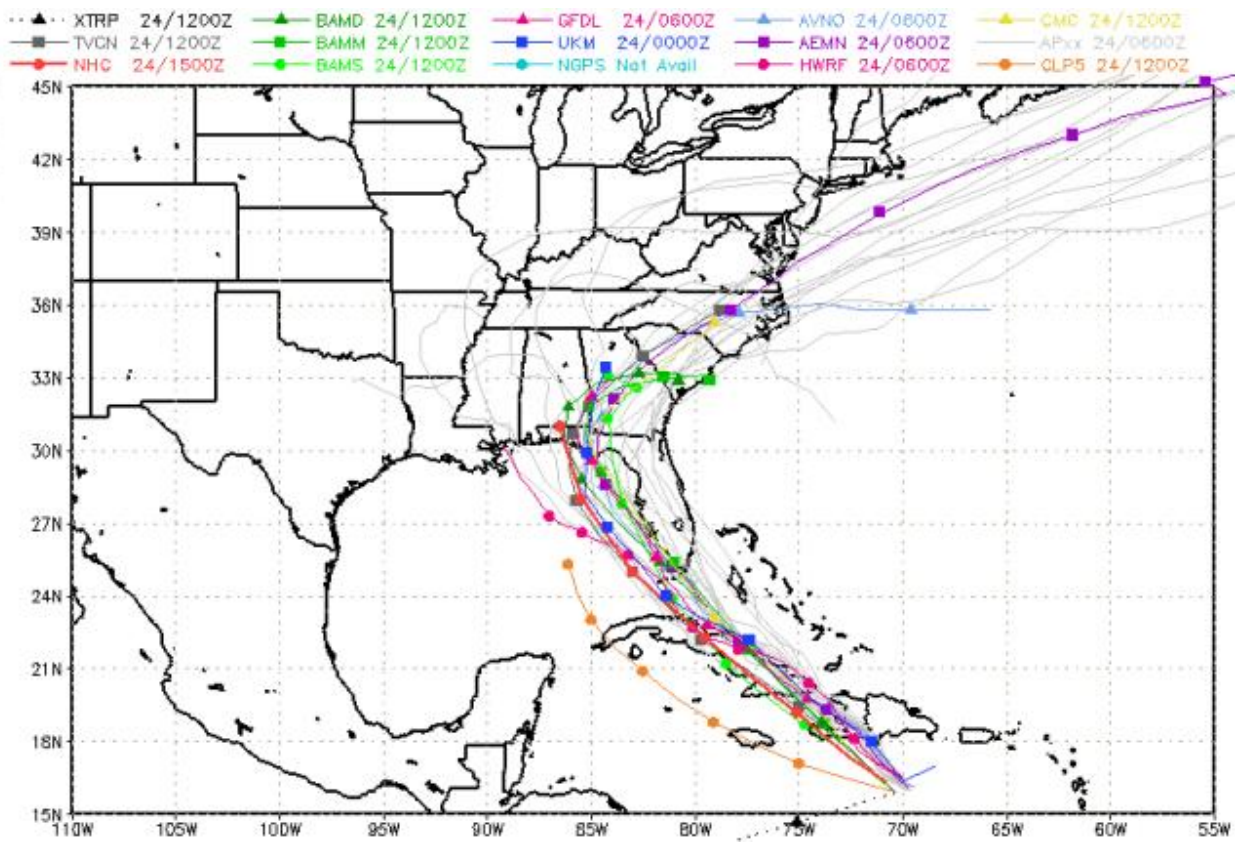
Figure 5. Spaghetti Model Based Plot from Hurricane Isaac (2012) (South Florida Water
Management District, 2012).

Categorical Risk Maps

Categorical risk maps are no strangers to the meteorological community, but they are rarely used in a hurricane or tropical cyclone setting. In the United States, categorical risk maps are usually associated with severe weather or flooding. The National Hurricane Center does not issue an official categorical based map, whereas other agencies, such as the Storm Prediction Center and the Weather Prediction Center, use the categorical risk map for threats of severe storms and heavy rainfall. The private sector and media has also been known to produce categorical risk maps as a way of informing end users of levels of actions to consider. The benefit of using categorical risk maps is that they can be labeled with descriptives, such as seen in Figure 6, or through a scalar, similar to a Likert scale.

Figure 6. Categorical Based Plot from The Weather Channel, LLC (The Weather Channel, 2012).

The four graphics explained and represented above a broad and comprehensive view at hurricane tracking graphics encompassing different methods of displaying quantitative uncertainty in a forecast. The cone of uncertainty represents a Boolean approach with a cutoff of

66th percentile. The probability plot represents a raw representation of probability and thus forecast certainty. The spaghetti plot takes the concept on ensembles and applies it to hurricane forecasting showing both potential scenarios and spread of forecast showing uncertainty. Finally, the categorical plot, while used extensively in other meteorological hazards has not generally been conducted on the hazard of hurricanes. All of these graphics have their strengths and weaknesses in perception of risk, understandability, and familiarity. The question is which one of these graphics best composes the true risk presented while also being easily interpreted.

Research Questions

In examining the need for a base in the literature for operational meteorologists in hurricane forecasting and risk communication, three areas were identified as areas that would expand the current understanding about how meteorologists think about risk and uncertainty, communicate these factors to the public and how the field is changing in the future.

RQ1: How do meteorologists perceive and use various hurricane tracking graphics? For example, do they prefer the traditional cone of uncertainty, or have the spread-of-ensembles-made probability and "spaghetti" based plots more acceptable to present?

While a majority of the literature on hurricane tracking and forecasting graphics have focused on the cone of uncertainty (Broad, Leiserowitz, Weinkle, & Steketee, 2007; National Research Council, 2006; Wu, Lindell, & Prater, 2015), and to an extent comparing the product to the other forms of tracking graphics (Radford, Senkbeil, & Rockman, 2013; Liu, Mirzargar, Kirby, Whitaker, & House, 2015; Mirzargar, Whitaker, & Kirby, 2014; Cox, House, & Lindell, 2013) , a major gap in the literature remains how meteorologists themselves use the graphics. The goal of this question is to gain better understanding about the persons who use these

graphics the most to provide the greater research body about their use in the field and the certainty, or lack thereof, that the authors put into these graphics.

RQ2: Meteorologists' communication to the public over media, including social media, regarding the content that should be included in those messages, and what types of information content meteorologists think they are responsible for proclaiming and distributing.

The PADM model tells us that information sources, channel access and preference, and warning messages have an important role in the decision making process. As detailed in the Risk Communication subsection of this chapter, meteorologists have an integral role to play in this process, especially when a weather hazard, such as hurricanes, is the threat. The goal of this question is to determine which information channels meteorologists prefer and trust, what massages they want to deliver through those channels.

RQ3: Meteorologists' opinion on the rise of numerical modeling products in the forecasting process and how they think these products help or hinder public understanding of hurricane track forecasts.

As numerical weather prediction (NWP) modeling grows in complexity and power every year as supercomputers become more and more powerful, so does the intricacies of the outputs / forecasts they produce. Oftentimes today NWP products are shown on the television, online, and in newspaper as graphics in order to better explain complexities or complications that meteorologists are encountering that raise the level of uncertainty in a forecast. In a hurricane context this often manifests itself as a "battle of the models" or "GFS vs. Euro", but has precedent in other areas of weather as well such as snowfall and severe weather. As this survey is the first quantitative survey of operational meteorologists conducted to date on this type of

subject, an important question is to ask their opinion on this issue and its repercussions onto the general public.

In summary, even though there has been vast improvement in the range of prediction for hurricanes, there still remains a large gap in conveying the forecast to decision makers and the public. The meteorologist is the source of relayed of information to those decision makers and the public in general. While a vast amount of hurricane evacuation literature has talked about the decision making process of evacuation and a standard model, the PADM, explains the process, surprisingly, there is a large literature gap to date about the sources of uncertainty in the evacuation decision making process. An essential part of the sources come from meteorologists who represent hurricane forecasts. Additionally, there is very little literature in both the meteorological and sociological world about meteorologists' opinions on forecasting displays of uncertainty, messaging content, media use, and general demographic information. The research being conducted with this survey is exploratory in nature as it is the first of its kind to explore meteorologists from this perspective, and will provide valuable information to the broader emergency management, meteorological and sociological communities.

CHAPTER 3: METHODOLOGY

This describes the methodologies in three sections. The first section is on the design of the survey and details of the questionnaire for meteorologists. The second section describes how the target population is sampled. The third section discusses constraints of the methodology and how some obstacles were overcome.

Survey Design

Since this is a new area of study for both emergency management and meteorology, there are few if any comparisons to other surveys to base a question layout on. Therefore, the survey is designed using Fowler's (2014) guidelines by, which provides an excellent baseline in designing questions.

The survey has four sections. The first section focuses on understanding the meteorologists' perceptions about hurricane tracking graphics. The second section is on the relationship between the meteorologist and the public on social media. The third section gauges the meteorologist's perceptions of numerical model reliance and how the rise of modeling products shown to the public impacts understanding. The fourth section gathers demographic data on the survey participants.

Section A: Perceptions About Hurricane Forecasting Graphics

Section A aims to gauge the survey taker's perceptions about different kinds of hurricane forecasting graphics. There are four hurricane track forecast graphics that are presented in the survey. Each of the graphics presented is taken from an actual storm system, Hurricane Isaac of 2012, at roughly the same forecast period. The forecast period is chosen so that the day five forecast is when the system was forecasted to make landfall. Each of the graphics is obtained through the National Hurricane Center graphics archive or a Google images search with specific

keywords linking the storm and the time of forecast. Each image is to be verified for the storm and time of product issuance to ensure that they are all created roughly at the same forecast time, or as close as possible, to each other. The reference storm and time is Hurricane Issac at the August 23, 2012 11pm National Hurricane Center Advisory, which also coincides with the 2012-08-24 00z numerical modeling runs. In order to conceal the storm's identity and prevent obvious recognition bias from skewing potential results, all text and graphics revealing the storm's identity were removed from the images.

In going in depth about the four graphics, we gauged an accurate representation of the possible formats in which uncertainty was displayed. As explained in the previous section, these differ from plain "black and white" delineations, percentages, potential solutions, and a categorical risk. The first graphic is the classic cone of uncertainty tracking map, with a "black and white" representation as keyed on earlier in the last section. This map was directly taken from the National Hurricane Center graphics archive (National Hurricane Center, 2012) and is an actual advisory as aforementioned. The second map is a probability map of 50 knot (58 mph) winds or higher for the next five days. This graphic again was taken from the National Hurricane Center's graphics archive (National Hurricane Center, 2012). The third graphic is a typical spaghetti plot consisting of numerical (dynamic) and statistical models, using an image and website that was popular at creating these kinds of graphics at the time. The image itself was obtained via archives at Google Images but was created at the time by the South Florida Water Management District (2012). The fourth and final graphic is a categorical based plot obtained again by the archives at Google Images but originally created by The Weather Company, LLC (2012).

Accompanying each of these sections were three questions in a revolving format for each of the four hurricane tracking graphics. Each graphic was separated by its own page on the survey distribution site so that there is no confusion on which graphic the question is referring to. The first question is a recognition test asking wither the respondent has ever seen the graphic before. Participants answer with a simple Yes or No answer. This question is a test for the prevalence of the graphic type in the meteorological community. An extra benefit in the case of the cone of uncertainty recognition test is a litmus test for phony results. If a respondent does not know about the cone of uncertainty, the basis of all official forecasts for decades, then the respondent is not qualified for the rest of the questions. The second question asks how often the meteorologist would use the graphic in a presentation to the public in a hurricane tracking situation. This is done by assigning a Likert scale ranging from "Never Use" = 1 to "Always Use" = 5. The third question asks whether the meteorologist believes that the graphical product is useful in communicating track uncertainty. This question also uses a Likert scale with "Not Useful at All =1" to "Very Useful" = 5.

These two questions together set up a dichotomy where the relationship between the two creates a correlation that determines which graphics meteorologists think are good for displaying uncertainty, but also think that they can't be understood by the public. Or the reverse, which graphics meteorologists think are good for the public but are poor for displaying uncertainty.

Finally, there are two miscellaneous questions which are in this section but are not part of the set of three questions. The first is a test of the level of understanding of a key part, and one of the key criticisms, of the cone of uncertainty which is that the cone of uncertainty does not change for each storm. The second question asks about the situation in which if the

meteorologists are a difficult forecasting situation with diverging prediction / forecast solutions, what kinds of products they would show to their constituents.

Section B: Perceptions about the Meteorologist / Public Relationship Communication

Section B determined what message content meteorologists want to convey to their audiences and through what media they want to distribute that information. Social media outlets have become a major influence on the amount and diversity of the public options in consuming information (Anderson & Caumont, 2014). We can safely assume that part of an operational meteorologist's job would be producing an output or product through their primary medium (e.g., television, print, radio etc.). Question 16 asked the meteorologist about which forms of social media they also distribute information on. To avoid bias, the top common social media platforms were named in alphabetical order. Questions 17 and 18 asked the meteorologists about how well they think information distributed via social media connects to the public. Question 17 asks about the strength of the connection between themselves and the public via social media, and question 18 about the extent to which they think that social media is an effective tool in disseminating hurricane information. Both Questions 17 and 18 are rated on a Likert scale from 1 to 5.

Questions 19, 20, and 21 focused on the kind of messaging that meteorologists distribute and what they think is the most important information to distribute. Question 19 asked the respondents to select the information they would disseminate if a hurricane is certain to hit their area. The options presented are designed to be scaled in terms of how far a meteorologist will venture out of their own duties and into the practice of emergency managers. Estimated landfall point, which is firmly in the realm of meteorology, is the first option. Strength and timing of impacts is the second. Third, preparedness advice which is bordering on a duty both historically

taken from meteorologists and emergency managers. Fourth is providing evacuation information, such as shelter locations. Fifth and finally, recommending evacuations, which is firmly in the practice of emergency management. Question 20 asks to what extent that the general public can understand the differences between watches and warnings for tropical systems using a Likert scale from "Cannot understand at all" = 1 to "Can understand completely" = 5. In Question 21, we ask the meteorologists what the most important information is to disseminate if a hurricane is forecasted to make a landfall. The four categories given are: 1) statistical information about the hurricane, such as windspeed and location; 2) hurricane tracking graphics, such as maps, and intensity charts; 3) text products, such as official advisories and warnings, and 4) information about evacuation, such as shelters and evacuation routes.

Finally, Question 22 asked the meteorologists how effective they think communication of the risk a hurricane poses to the public through various information sources, including national television networks, local media, local officials, and new age media such as from social media sources and internet only based sources. Each information source is rated on a Likert scale for effectiveness with "Least Effective" = 1 to "Most Effective" = 5. The goal of this question is to see which information source meteorologists think is most effective with such questions answered as local vs. national media and old media vs. new age media.

Section C: Numerical Model Reliance

Section C contained three questions about numerical model reliance. Numerical models are the backbone of the forecasting process. However, they are prone to significant errors that can impose significant uncertainty into location, timing, and impacts of hurricanes. This section aims to find whether meteorologists find that there is an over or under reliance on those models in the forecasting process, and whether the increasing use of showing these different models to

the public tends to create understanding or misunderstanding of hurricane tracking. Question 23 asks simply if the participant thinks that there is an over or under-reliance of numerical modeling in the forecasting process based on a Likert scale with 1 = "Not enough reliance" to 5 = "Too much reliance". Question 24 asks whether the distribution of these modeling products to the public facilitates understanding or misunderstanding to interpret uncertainty in a forecast product. This question also uses a Likert scale with 1 = "Facilitates misunderstanding" to 5 = "Facilitates understanding". Question 25, an open-ended question, follows onto this line of thinking by asking the meteorologists exactly why they think this is the case. Five coded responses are used to group the different answers: 1) "Facilitates Understanding: Helps the public see what I see"; 2) "Facilitates Understanding: Shows potential solutions to the threat"; 3) Facilitates Misunderstanding: Gives the public too many options to think about"; 4) "Facilitates Misunderstanding: Confuses the public about what is going on and what will happen"; and 5) "Facilitates Misunderstanding: Lacks a single concise answer to the public's question(s) about the threat".

Section D: Geography and Demography

Section D collected basic information about the respondents, including location, specific occupation sector, level of education, level of experience in tropical forecasting and experience with hurricanes. Question 26 contained an extensive list of service sectors in which operational meteorologists can operate, including public sector entities, such as NOAA and DHS, or private sector entities, such as media, energy, and transportation logistics. These answers were dummy-coded (0 = Not in sector, 1 = in sector), and in some instances combined to generalize larger sectors such as federal government, media, private sector, education, etc.

In order to identify locations in which the meteorologists are responding from there are many considerations including media markets, states, FEMA Regions, and zip codes. However, in Question 27 the decided method is to break the US hurricane vulnerable coastline down into six different sub regions, five along the coastlines (i.e., Western Gulf Coast, Eastern Gulf Coast, Atlantic Southeast, Atlantic Northeast) and one for the rest of the nation or worldwide. There are three reasons for this: 1) historically these regions have different experiences with hurricanes in regard to strength and timing; 2) the topography of the coastlines heighten or lower some impacts versus others; and 3) the extent and distributions of populations of these areas and the media coverage of them are different. To accompany this question, Question 28 asks a boolean whether the location that they just selected is the place that they live in. The rationale for this question is that many meteorologists work remotely, or work for companies that are headquartered in one location but forecast for another location. Conversely, if the respondent does live in the same area that one forecasts for, this tells us that one may have better local forecasting experience with hurricanes and thus his or her judgments on uncertainty in forecasting may vary from those who forecast remotely.

Questions 29, 30, and 31 focused on the demographic characteristics of the respondent. Question 29 asked the respondent how many years s/he has been tracking hurricanes in a professional setting with options of 0-5 years, 6-10 years, 11-20 years and 20+ years. These categories were treated as a nominal variable for quantitative analyses such as the correlation matrix. Question 30 asked the individual about their maximum educational degree attainment. This question was modeled after the 2015 American Metrological Society member survey (Maibach et al., 2016) with adjustments to simplify the amount of options presented. Namely, grouping many degrees under the Science, Technology, Math, and Science (STEM) moniker.

Thus there are eleven categories to choose from, bachelors in meteorology, STEM, or other and this is repeated for each level of attainment, master's and doctoral degree levels. The remaining options are for an associate's degree and other, where a user can specify such things as equivalent military training if applicable. This question will be re-coded into a nominal variable (ie., Associates = 1, Bachelors = 2 , Masters = 3 , Doctorate = 4) for the purpose of educational attainment level regardless of field for qualitative analysis. Finally, Question 31 asks the respondents gender.

Questions 32 through 34 asked what prior experience the respondents may have had with hurricanes in their work and life. Question 32 is an all-encompassing qualifier that asks if the respondent has ever forecasted for a hurricane before, which will give an estimate of the actual percentage of hurricane forecasters we reach. Question 33 asked if the respondent has have ever personally experienced a hurricane before, with a boolean "Yes" or "No" answer coded into 0 = No , 1 = Yes. Question 34 goes one step further and asks if the respondent has ever had to evacuate from a hurricane before, also with a boolean "Yes" or "No" answer. All boolean operators are coded as 0 (No) and 1(Yes) for all qualitative analyses. The reasoning for Question 33 and 34 is that it may be plausible that people who have personally experienced a hurricane before may have different opinions on forecast uncertainty as forecaster-participants of varying degrees than those who have never experienced one.

Survey Implementation

The web-based survey recruited operational meteorologists via three platforms, including E-mail, social media platforms, and a newsletter via a meteorological professional organization. Each provided a narrative of what the survey is about then provided a link to the online survey interface.

The distribution of the survey was implemented through a partnership with the National Weather Association (NWA) who helped to distribute two rounds of survey invitations to their member listserv via e-mail as well as to their social media accounts and monthly electronic newsletters during and after Hurricane Matthew (2016), due to the possibility of many of the NWA members were busy during Hurricane Matthew. The survey was hosted and conducted through surveymonkey.com.

Constraints and Obstacles

Survey Platform Constraints

The main constraint of the survey is that it was online only. However, in today's modern meteorological workplace, it is essential that an operational meteorologist has an internet connection to conduct business. Nearly all meteorological information today is transmitted over the Internet, from satellite images and radar to forecasting models and real-time observations. It was not expected that the method of an online only platform would limit the response rate for operational meteorologists in the workplace.

Otherwise, the SurveyMonkey platform allowed all necessary operations to take place in the design and implementation of the survey as originally outlined. No questions had to be altered or otherwise transformed to fit the hosting platform.

Potential Survey Biases

It is still possible that a keen forecaster would recognize the individual storm, namely Hurricane Isaac, based on the forecasting tracking graphics given. However, given the relatively low impact the storm had on the United States, the five years that have passed since the storm, and looking at the results of the survey, there is no indication that these proposed phenomena occurred and/or skewed the results.

Corrections to data before processing

A few corrections to the overall dataset were made before processing. In examining the list of responses to the NWA emails and other forms of communication, it is clear that some respondents responded twice. The vast majority of these instances is when respondents answered both the first and second round emails. In this instance, the most complete round was kept and the other discarded. When both rounds had the same amount of completion, then the first round was taken.

Data Analysis Methods

In processing the resulting data from the survey, the data were downloaded from the SurveyMonkey platform in a raw format that was inserted into the SPSS statistical software platform. From there the data were put into separate sections, mirroring the sections of the survey. For section A, descriptive statistics were used to determine the most popular answer for each of the rotating questions. Each of the rotating questions was then compared using a ranking of means for each forecasting graphic. Additionally, One-Way Repeated Measures ANOVA tests with post-hoc t-tests were conducted to determine the extent to which the difference in the forecasting graphics, if any, was causing the greatest amount of variance within the data. For sections B, C, and D, descriptive statistics were used to establish patterns in the data and an intercorrelation matrix was created to examine the correlations between studied variables. Since this survey is the first of its kind many of the analysis methods are exploratory in nature.

CHAPTER 4: RESULTS

This chapter includes descriptive statistics and quantitative tests to answer the following research questions (RQ) outlined in Chapter 2.

RQ1: How do meteorologists perceive and use various hurricane tracking graphics? For example, do they prefer the traditional cone of uncertainty, or have the spread-of-ensembles-made probability and "spaghetti" based plots more acceptable to present?

RQ2: Meteorologists' communication to the public over media, including social media, the content that should be included in those messages, and what types of information content meteorologists think they are responsible for proclaiming and distributing.

RQ3: Meteorologists' opinion on the rise of numerical modeling products in the forecasting process and how they think these products helps or hinders public understanding of hurricane track forecasts.

An intercorrelation matrix table is provided at the end of the chapter to support claims about relationships between some demographics of the surveyed meteorologists and their responses to RQ2 and RQ3.

Hurricane Tracking Graphics (RQ1)

RQ1 aims to distinguish the perceived differences between various hurricane tracking products used in hurricane forecasting. In testing each of the four tracking products as described in Chapter 2, three questions were asked that relate to recognition, use, and usefulness of the product. As shown in Figure 7, the overwhelming majority of the surveyed meteorologists recognized the cone of uncertainty (99.6% , $N = 255$), spaghetti plot (99.6%, $N = 252$), and wind speed probability graphic (97.6%, $N = 255$). It is only the categorical map that the recognition differs from the other three products with only 57.9% ($N = 252$). This is consistent with the

expectation as categorical based maps are not typically used as a hurricane graphic. These results confirm that the graphics that are being tested with this survey are with the correct demographic audience and that results of the use and usefulness of these hurricane tracking products are representative of the meteorologists who are familiar with them.
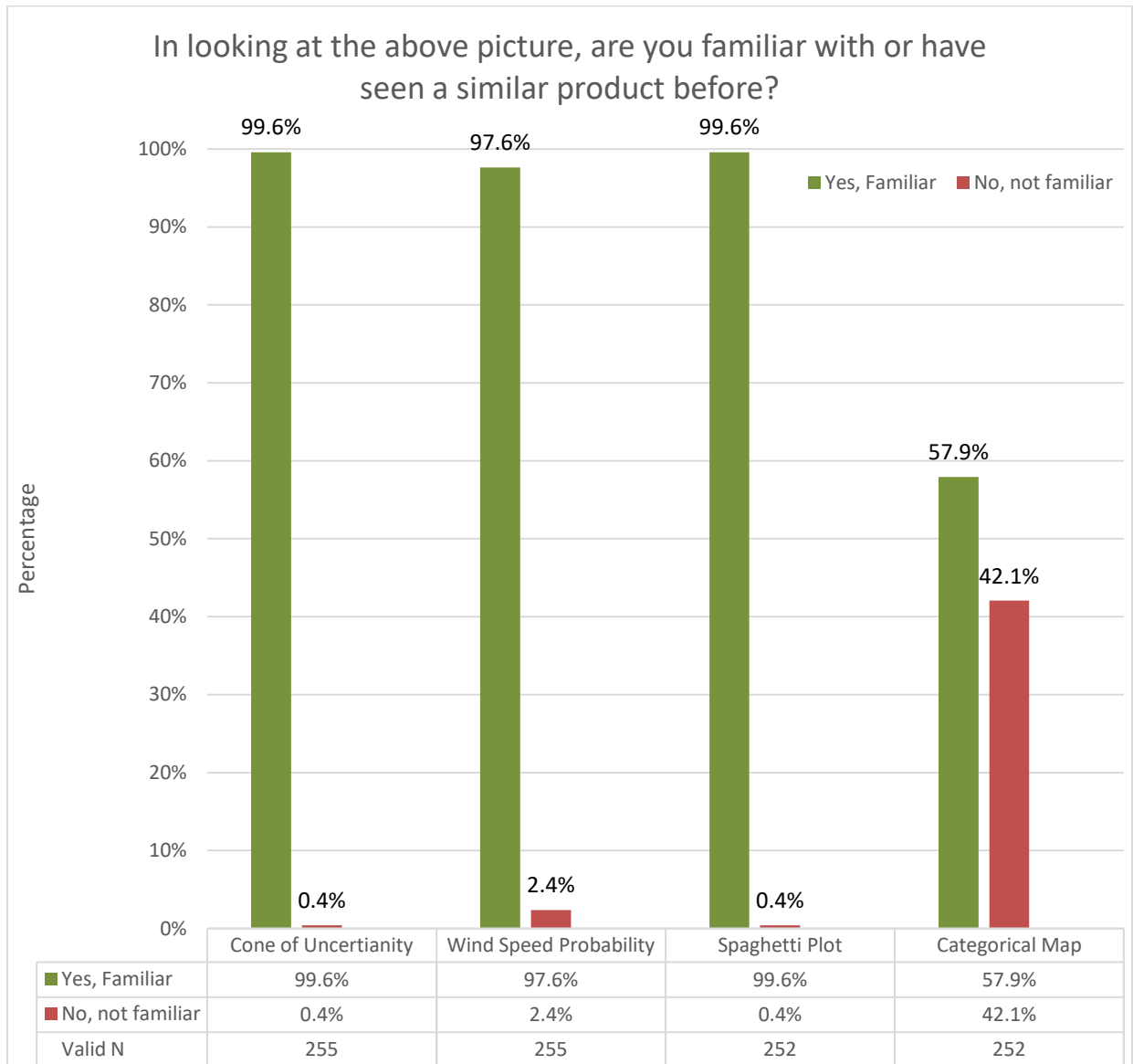

In looking at the above picture, are you familiar with or have seen a similar product before?

	Cone of Uncertianity	Wind Speed Probability	Spaghetti Plot	Categorical Map
Yes, Familiar	99.6%	97.6%	99.6%	57.9%
No, not familiar	0.4%	2.4%	0.4%	42.1%
Valid N	255	255	252	252

Figure 7. Familiarity With Each of the Four Tracking Products.

In looking at tracking graphic use in Figure 8, it shows that the cone of uncertainty is the most often used hurricane tracking graphic (mean, $M = 4.3$, $SD = 0.82$, $N = 255$). Every other

tracking graphic falls behind by at least a full point with wind speed probability ($M = 3.3$, $SD =$ 1.10 , $N = 255$), spaghetti plot ($M = 3.2$, $SD = 1.11$, $N = 252$), and categorical plot coming in at the lowest ($M = 2.7$, $SD = 1.20$, $N = 252$).

In looking at the distribution in Figure 8, the cone of uncertainty is heavily skewed to the left at a skewness of -1.46 ($SE = 0.15$), while the other graphics are near zero in skewness and near a normal distribution. Switching to Figure 9 and examining the 'usefulness' of the hurricane tracking graphics, again the cone of uncertainty has the highest mean ($M = 3.9$, $SD = 0.90$, $N = 255$). However, unlike the means of 'use', 'usefulness' means of the other three graphics are not far behind – wind speed probability ($M = 3.6$, $SD = 0.93$, $N = 253$), spaghetti plot ($M = 3.6$, $SD = 1.12$, $N = 253$), and categorical maps ($M = 3.0$, $SD = 1.19$, $N = 251$).

While it is clear that the cone of uncertainty is rated the highest in 'use' and 'usefulness', there is a strong disparity between how meteorologists use the four graphics and how useful they find them in forecasting hurricane tracks. In Table 3, a Paired Samples t-test was used between 'use' and 'usefulness'. The results show that the cone of uncertainty and the other three graphics are different between their use and usefulness at the $p < .001$ level. The cone of uncertainty is the only graphic without a positive mean difference ($M_{usefulness} - M_{use} = -.445$). This indicates that every graphic, other than the cone of uncertainty, has a perceived usefulness that is higher than its actual use.

The graphics are also different in their use and usefulness between the graphics themselves. Two One-Way Repeated Measures ANOVA tests were conducted to show the differences in use and usefulness between the four graphics. The result of the tests showed that all graphics were significantly different from each other in both use [$F(3, 762) = 127.38$, $p <$ .001] and usefulness [$F(3, 762) = 32.2$, $p < .001$] at the $p < 0.05$ level. Surprisingly, only the

probability plot and the spaghetti plot were found not to have significance within each other in terms of both use (Table 1) and usefulness (Table 2).

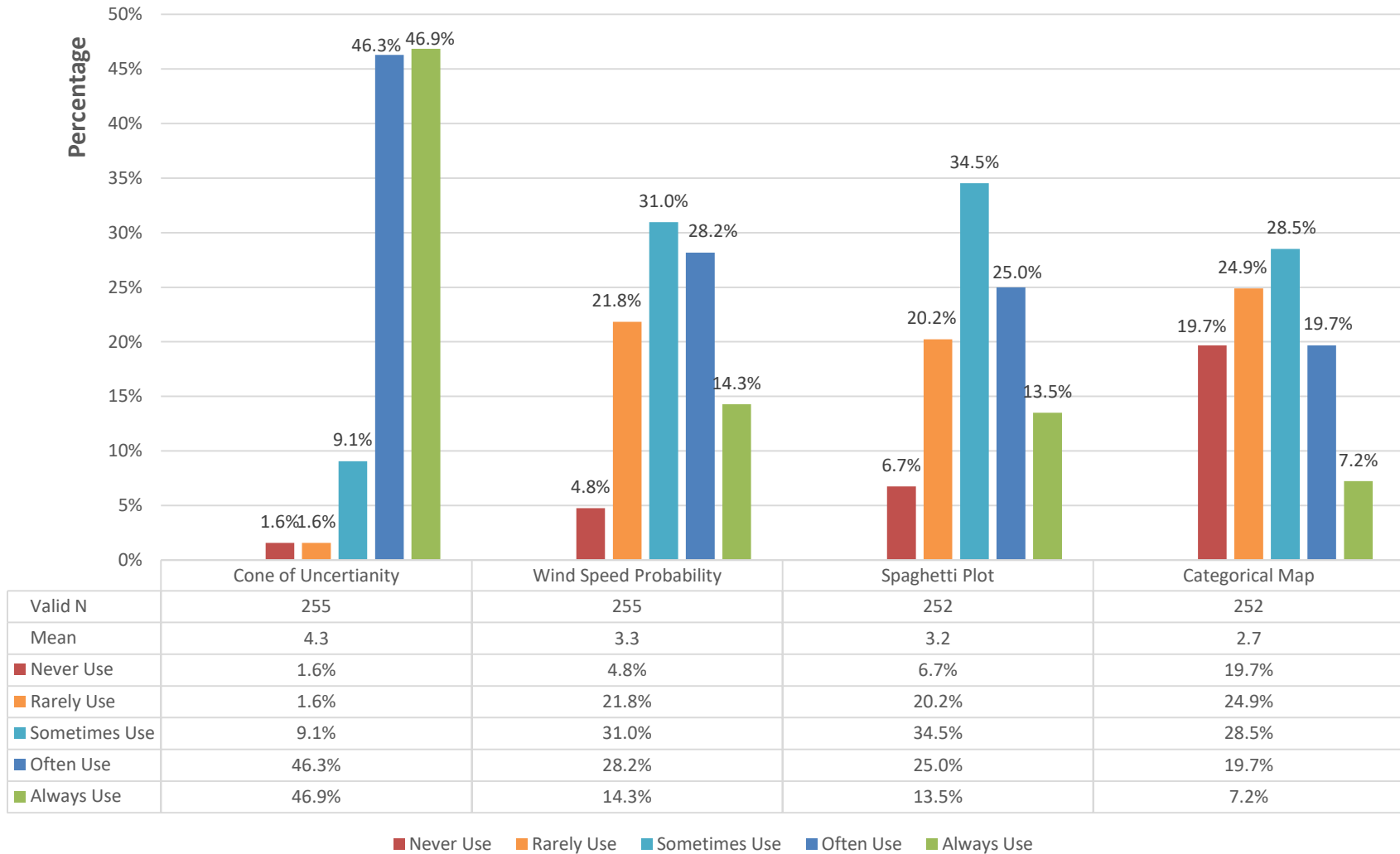## How often do you (or would you) show this product?

	Cone of Uncertianity	Wind Speed Probability	Spaghetti Plot	Categorical Map
Valid N	255	255	252	252
Mean	4.3	3.3	3.2	2.7
■ Never Use	1.6%	4.8%	6.7%	19.7%
■ Rarely Use	1.6%	21.8%	20.2%	24.9%
■ Sometimes Use	9.1%	31.0%	34.5%	28.5%
■ Often Use	46.3%	28.2%	25.0%	19.7%
■ Always Use	46.9%	14.3%	13.5%	7.2%

■ Never Use   ■ Rarely Use   ■ Sometimes Use   ■ Often Use   ■ Always Use

Figure 8. Distribution of Use of the Four Tracking Graphics.

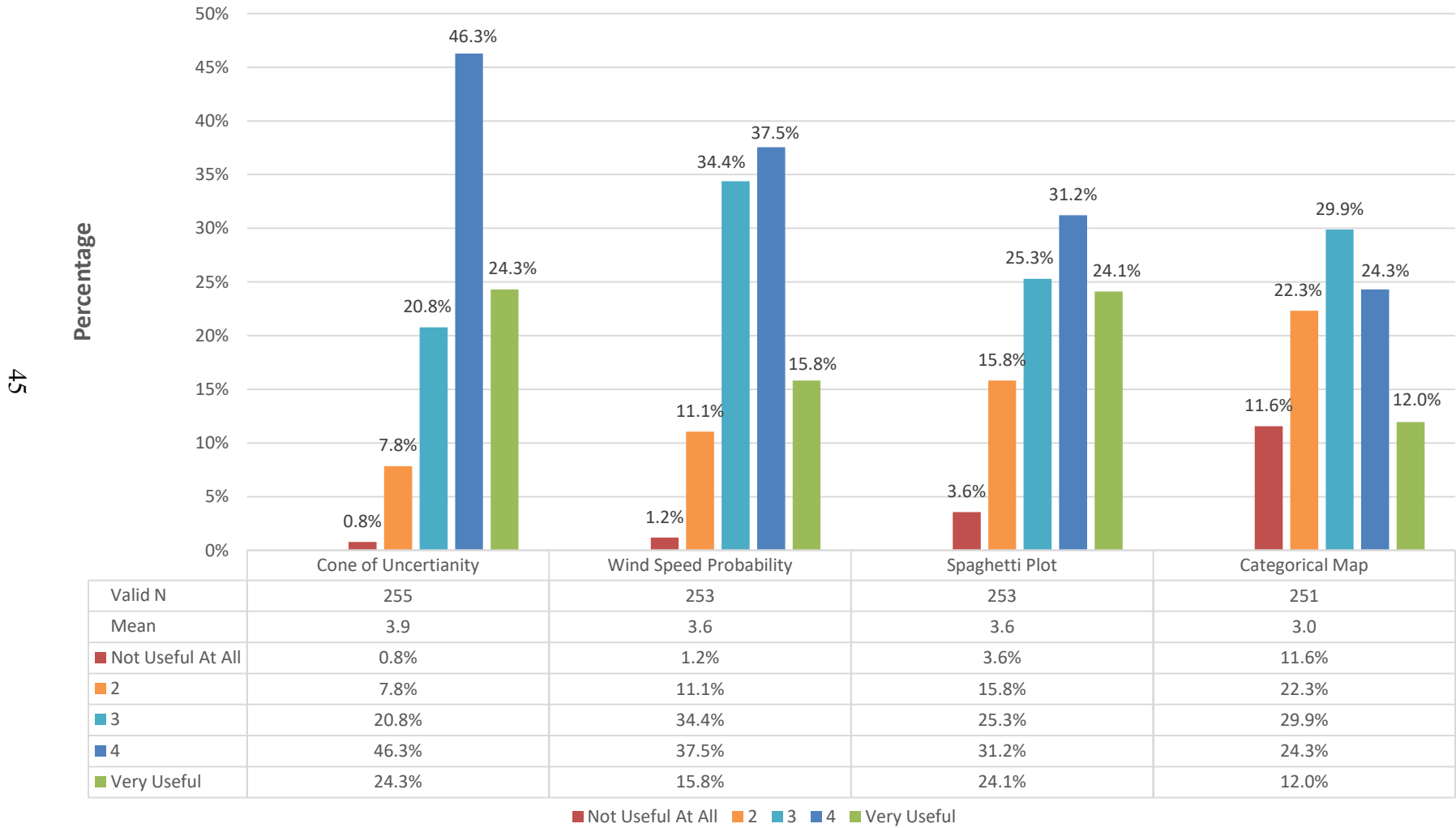# Perception of Usefulness of the Product in Communicating Track Uncertianty

	Cone of Uncertianty	Wind Speed Probability	Spaghetti Plot	Categorical Map
Valid N	255	253	253	251
Mean	3.9	3.6	3.6	3.0
■ Not Useful At All	0.8%	1.2%	3.6%	11.6%
■ 2	7.8%	11.1%	15.8%	22.3%
■ 3	20.8%	34.4%	25.3%	29.9%
■ 4	46.3%	37.5%	31.2%	24.3%
■ Very Useful	24.3%	15.8%	24.1%	12.0%

Figure 9. Distribution of Usefulness of the Four Tracking Graphics.

Table 1
Pairwise Comparisons Between Graphics In Use

(I) Use	(J) Use	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
Cone	Prob.	1.045*	.072	.000	.903	1.186
	Spag.	1.117*	.074	.000	.972	1.262
	Categ.	1.601*	.079	.000	1.446	1.755
Prob.	Cone	-1.045*	.072	.000	-1.186	-.903
	Spag.	.072	.096	.451	-.116	.260
	Categ.	.556*	.082	.000	.394	.718
Spag.	Cone	-1.117*	.074	.000	-1.262	-.972
	Prob.	-.072	.096	.451	-.260	.116
	Categ.	.484*	.101	.000	.286	.682
Categ.	Cone	-1.601*	.079	.000	-1.755	-1.446
	Prob.	-.556*	.082	.000	-.718	-.394
	Spag.	-.484*	.101	.000	-.682	-.286

*. The mean difference is significant at the .05 level.

Table 2
Pairwise Comparisons Between Graphics In Usefulness

(I) Usefulness	(J) Usefulness	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
Cone	Prob.	.298*	.072	.000	.156	.439
	Spag.	.290*	.078	.000	.135	.444
	Categ.	.827*	.087	.000	.656	.998
Prob.	Cone	-.298*	.072	.000	-.439	-.156
	Spag.	-.008	.089	.929	-.184	.168
	Categ.	.529*	.084	.000	.364	.695
Spag.	Cone	-.290*	.078	.000	-.444	-.135
	Prob.	.008	.089	.929	-.168	.184
	Categ.	.537*	.101	.000	.338	.736
Categ.	Cone	-.827*	.087	.000	-.998	-.656
	Prob.	-.529*	.084	.000	-.695	-.364
	Spag.	-.537*	.101	.000	-.736	-.338

*. The mean difference is significant at the .05 level.

Table 3

Mean Differences between Use and Usefulness in the Four Tracking Graphics

Paired Samples t-Test

		Mean Differences							
					95% Confidence Interval of the Difference				Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	
Cone	Usefulness - Use	-.445	1.046	.066	-.574	-.316	-6.779	253	.000
Probability	Usefulness - Use	.308	.980	.062	.186	.430	4.968	249	.000
Spaghetti	Usefulness - Use	.389	.982	.062	.267	.511	6.289	251	.000
Categorical	Usefulness - Use	.331	.865	.055	.222	.439	6.018	247	.000

Meteorologists / Public Communication (RQ2)

In Figure 10 below, meteorologists rated how effective they felt communicating risk to the public over various platforms is to gauge where their trust in various communication platforms lies. Local TV stations ($M = 4.4$), National Weather Service (NWS) entities ($M = 4.2$), and local officials ($M = 3.7$) were rated the top three of the list. Social media ($M = 3.2$) was aligned closely with national TV networks ($M = 3.3$) and local radio stations ($M = 3.2$). Newspapers ($M = 2.4$) and digital media outlets ($M = 2.2$) were ranked lowest in terms of effectiveness.
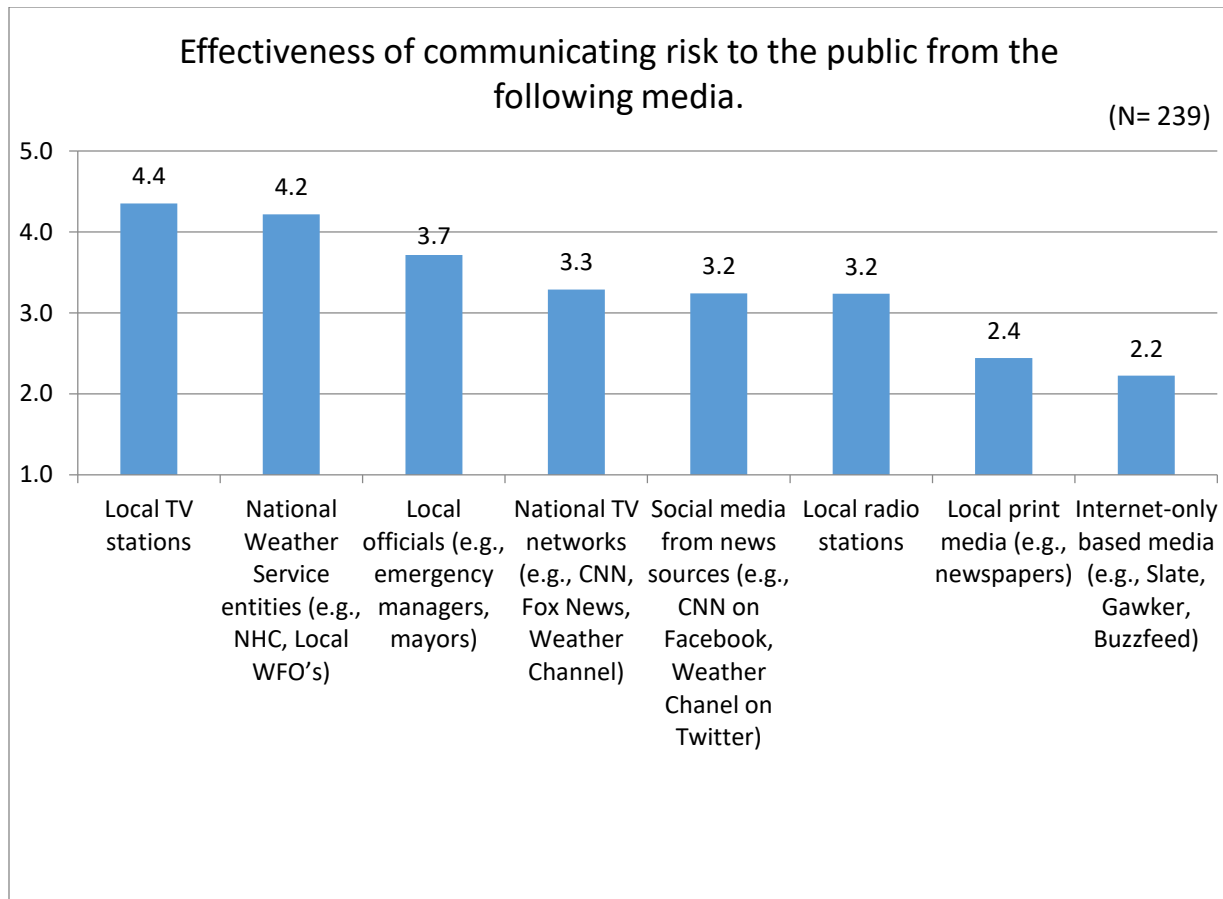
Figure 10. Perceived Effectiveness of Various Communication Platforms.

Given that a general sense of the most effective platforms has been established, the next question becomes as "[W]hat would meteorologists show and tell their audience if a hurricane was to make landfall?" Figure 11 depicts what meteorologists would show their audience in the event of a hurricane approaching their coastline. The results show that meteorologists believe that the most important information to disseminate to the public is hurricane tracking graphics (55.2%). This is important as it leads credence to the importance of RQ1. Interestingly though is evacuation information coming in the second place as this information is most often distributed by emergency management officials but not meteorologists. To explore this further, Figure 12 shows what meteorologists would tell their audiences in the event of a hurricane landfall.
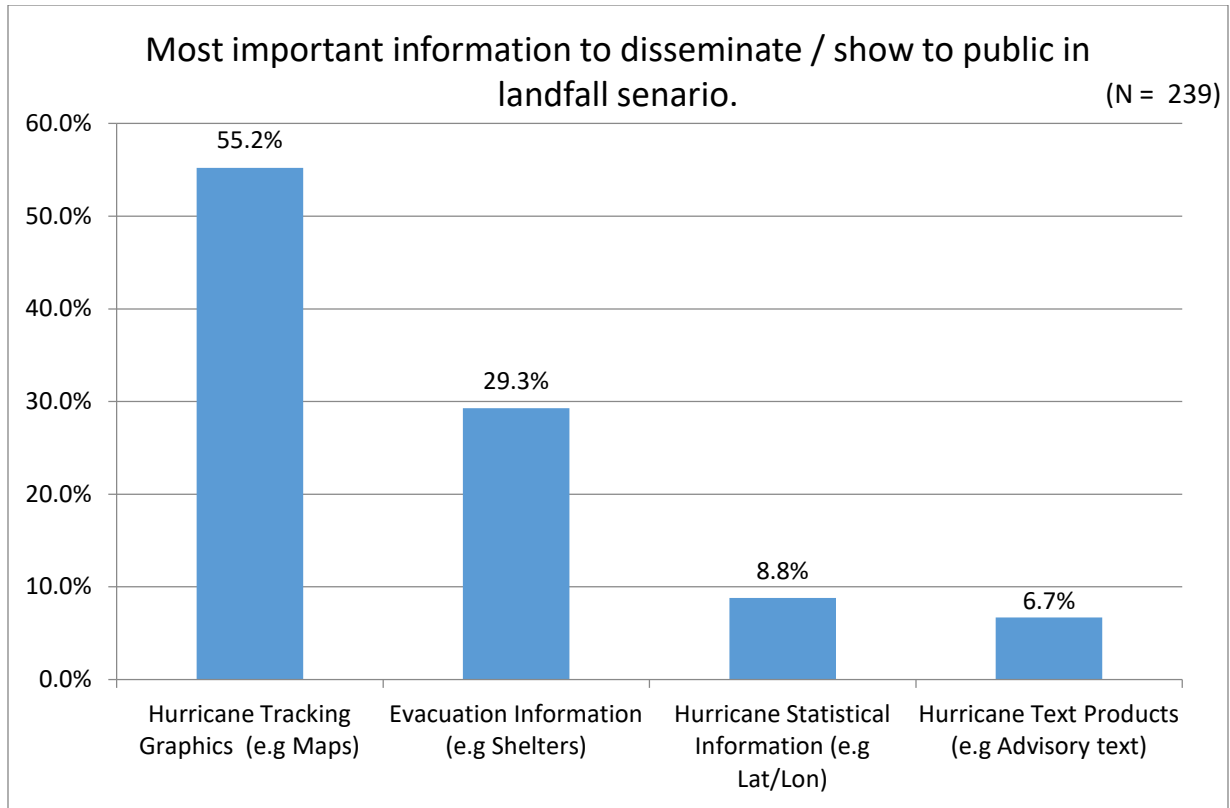
Figure 11. Most Important Information to Disseminate to Audience.
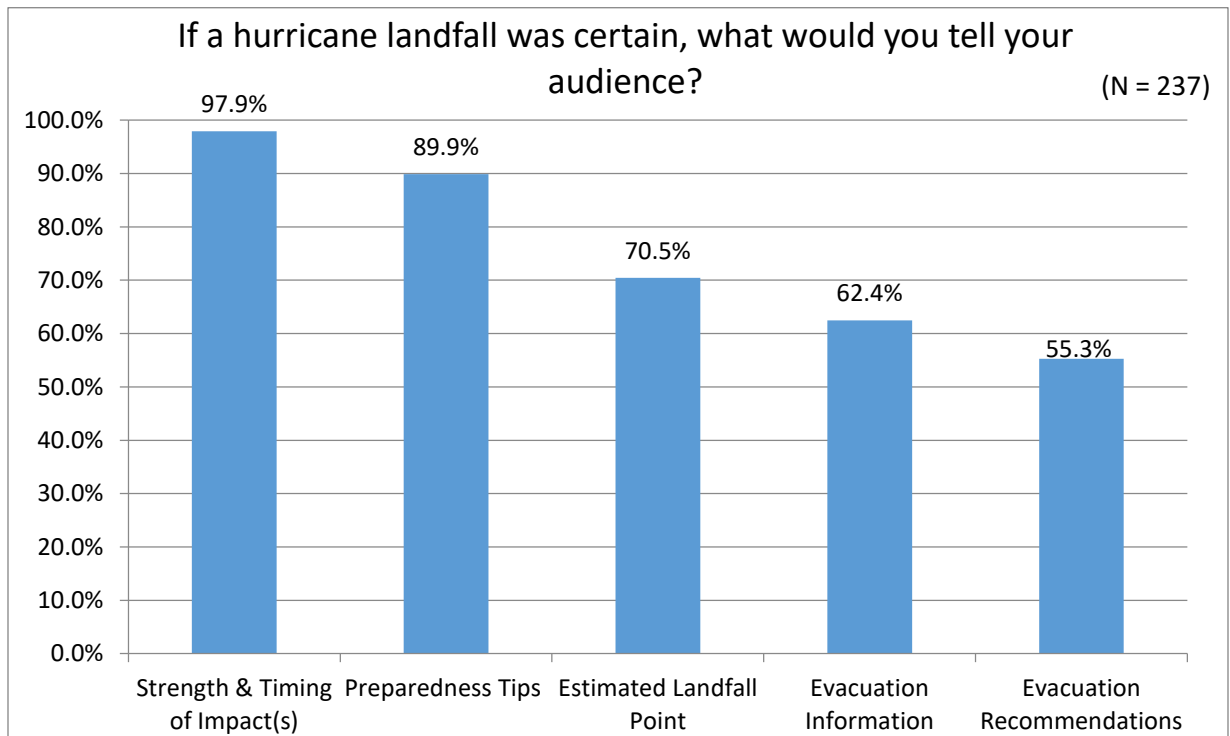
Figure 12. Messages Meteorologists Would Tell the Public if Hurricane Landfall Was Certain.

Figure 12 above shows that the highest preference on what messages meteorologists would tell their audience traditionally falls in the purview of meteorology such as strength and timing of impacts (97.9%). Preparedness tips (89.9%), such as securing loose belongings, also traditionally fall within this area. Most importantly shown in this figure, however, is the evacuation information (62.4%) and recommendations (55.3%). Over half of the surveyed meteorologists said that they would convey this information in the event of a landfall. A follow-up open-ended question in the survey indicated evacuation recommendations included that the respondent thinks that it is important to tell their audience that people should move from one location to another.

Social Media

Figure 13 breaks down the question of social media being an effective information dissemination tool. The answer to this question is mixed, with a mean of 3.6 out of 5 on a Likert scale. Even though the average rating is 3.6, the graph is left skewed denoting a propensity for meteorologists to believe that social media is an effective tool. In Figure 14, meteorologists were presented with many choices of social media platforms. Facebook and Twitter are by far the top choices in social media platforms used by meteorologists with over two-thirds usage. Other social media platforms indicate at around 10% of use or lower.
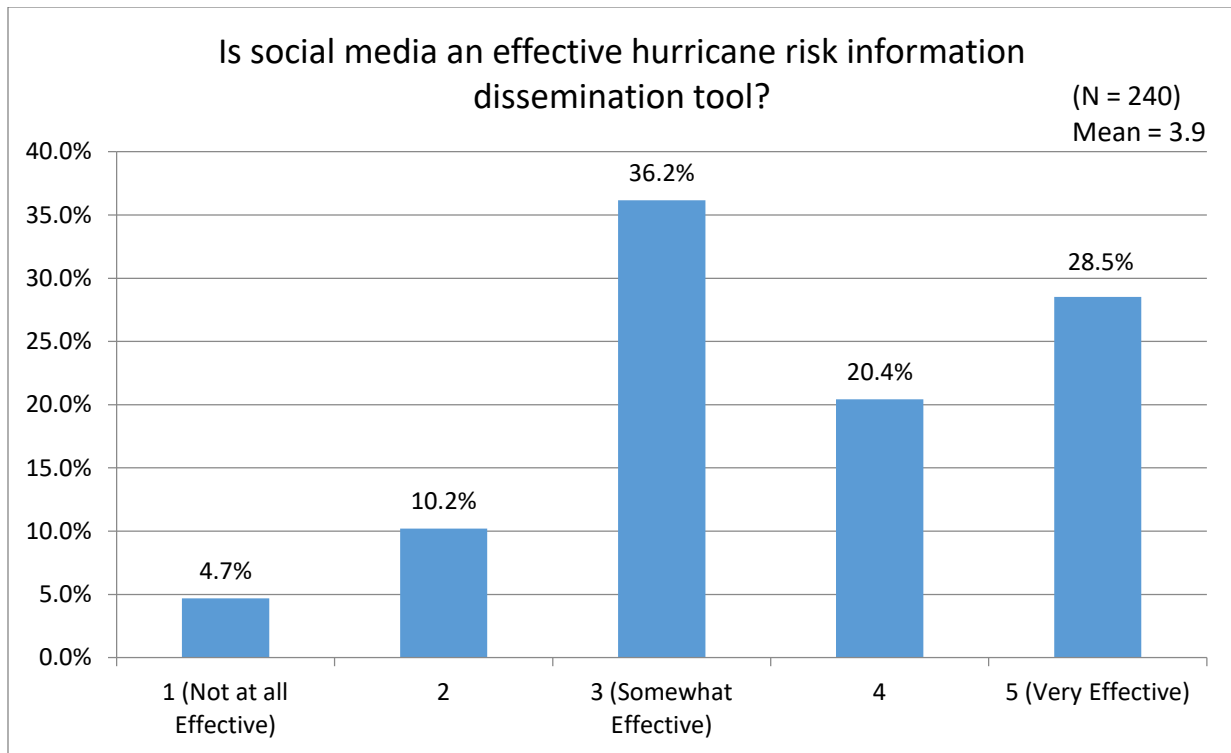
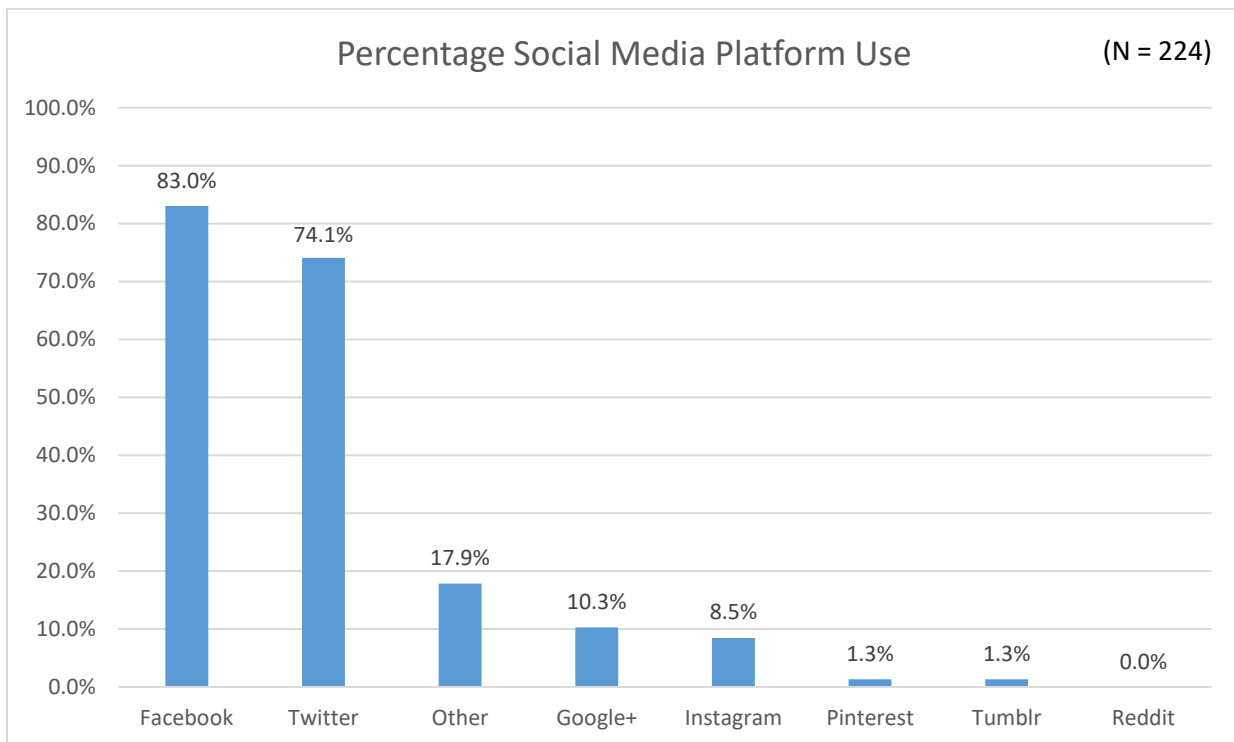*Figure 13.* Distribution of Likert Responses for Effectiveness of Social Media.

Figure 14. Social Media Platform Use.

Numerical Model Reliance (RQ3)

RQ3 is focused on two main questions about numerical weather prediction (NWP). The first question is whether meteorologists think that there is an over or under reliance in numerical models in today's forecasting process, whose answer is presented in Figure 15. In breaking down the individual 5-point Likert scale responses for this question, it is evident that the responses skew to the left with a mean of 3.7. Interestingly, the "Not Enough Reliance" category received zero responses.
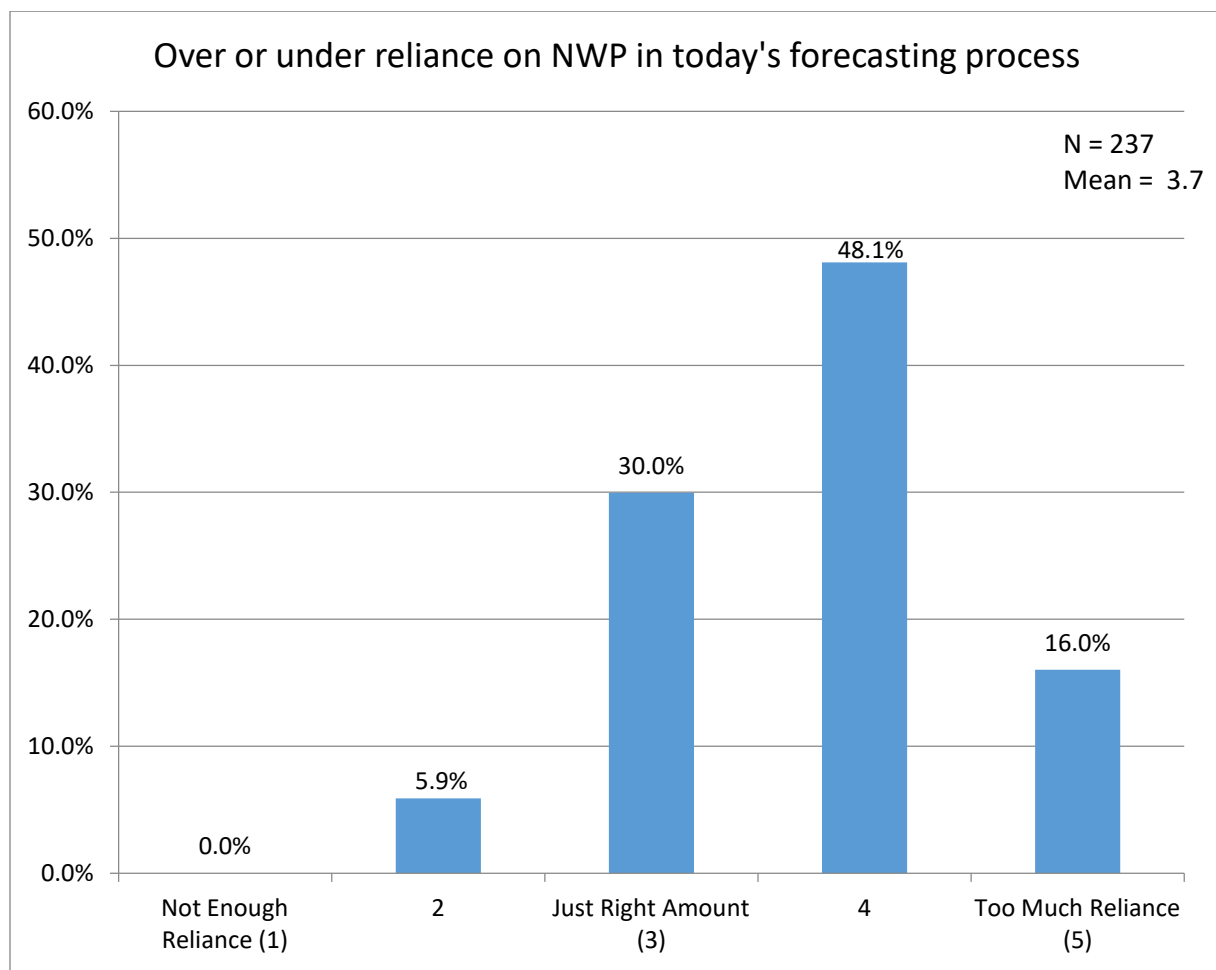
Figure 15. Reliance of NWP in Forecasting Process.

The second question asks the meteorologists whether showing NWP products to the public helps or hinders the public's overall ability to understand uncertainty in forecasts (see

Figure 16). With a mean of 2.6 and a standard deviation of 1.08, the results are normally

distributed but skewed right. Only 2.1% of all meteorologists surveyed indicated that it facilities
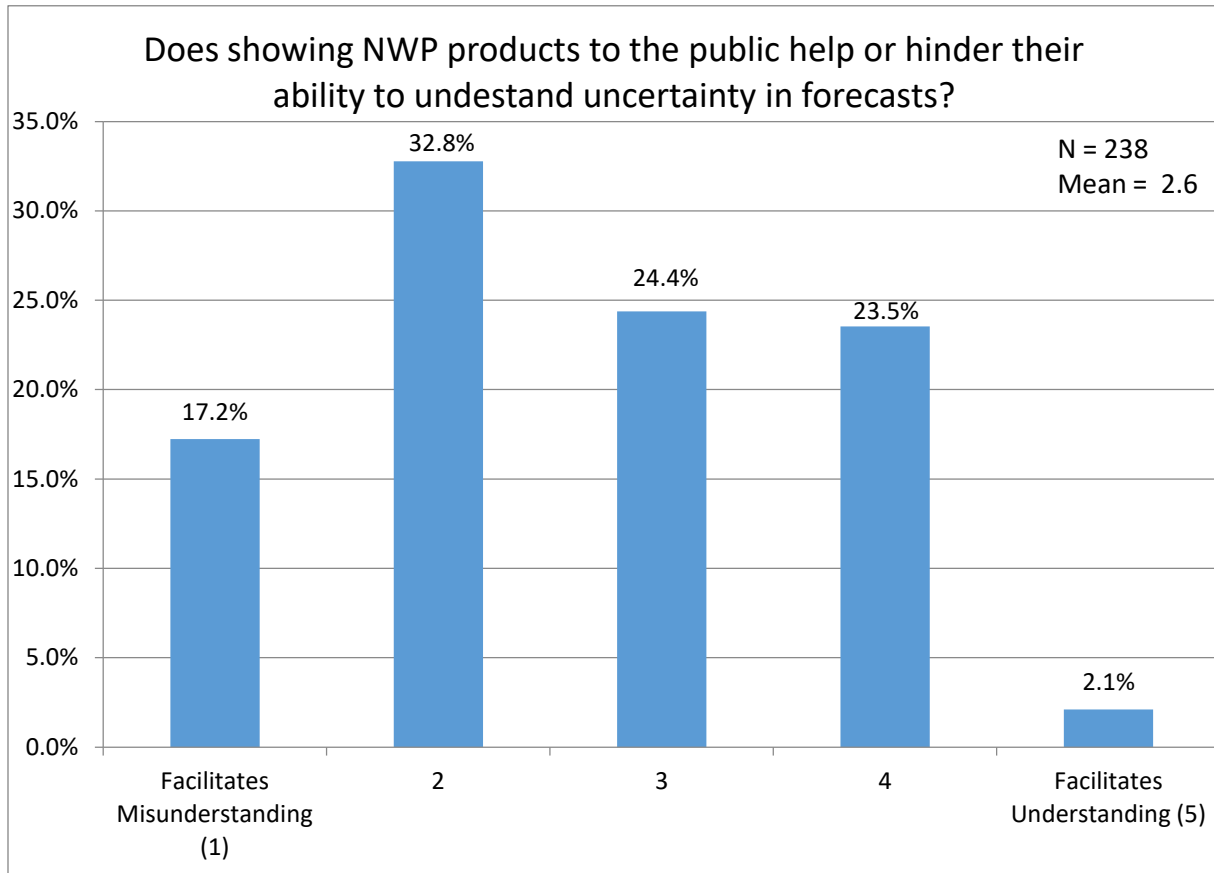
understanding.

Figure 16. Meteorologists Perception of NWP Products Being Shown to the Public.

Demographics

While not part of a formal research question, the collected demographics correlate with

some research question elements. Demographic information on survey respondents was collected

for common variables such as gender, education, working sector, years of experience and

location.

The self-selected gender of the survey respondents was predominately male (82.5%)

which is within 1% of the ratio that Maibach, et al. (2016) found. Educational attainment,

regardless of field, was found to follow the educational attainment curve with bachelor's degrees

representing the majority of responses (49.6%) followed by master's (39.0%) and doctoral (8.8%). Other forms of education such as certificates, military trained, or trained by mentor represented 2.6% of responses (*N*= 228). The field of the highest degree of attainment was dominated by meteorology degrees (75.4%), followed by STEM (11.4%) and others (12.7%) (*N* = 228).

In exploring the professional careers of the respondents, 59 % of respondents indicated that they had over 10 years of experience in tracking hurricanes. 36.7% indicated that they had over 20 years. Only 24.0% of respondents indicated that they had under 5 years of experience (*N* = 229). The majority of respondents indicated that they worked either in federal government (35.7%) or in media (35.3%). Other non-media private sector occupations made up 24.7% of respondents while education sector made up 17.9%. Other sectors combined made up for 8.5%. Some respondents (22.1%) indicated that they worked in more than one sector (*N* = 235)

Respondents also were asked to identify their location (Figure 17). 68.1% of respondents said they hailed from coastal states that are hurricane prone along the Gulf of Mexico and Atlantic coasts (*N* = 216). This compares favorably to question 28 which found that 62.4% of respondents forecast for the same place in which they live.
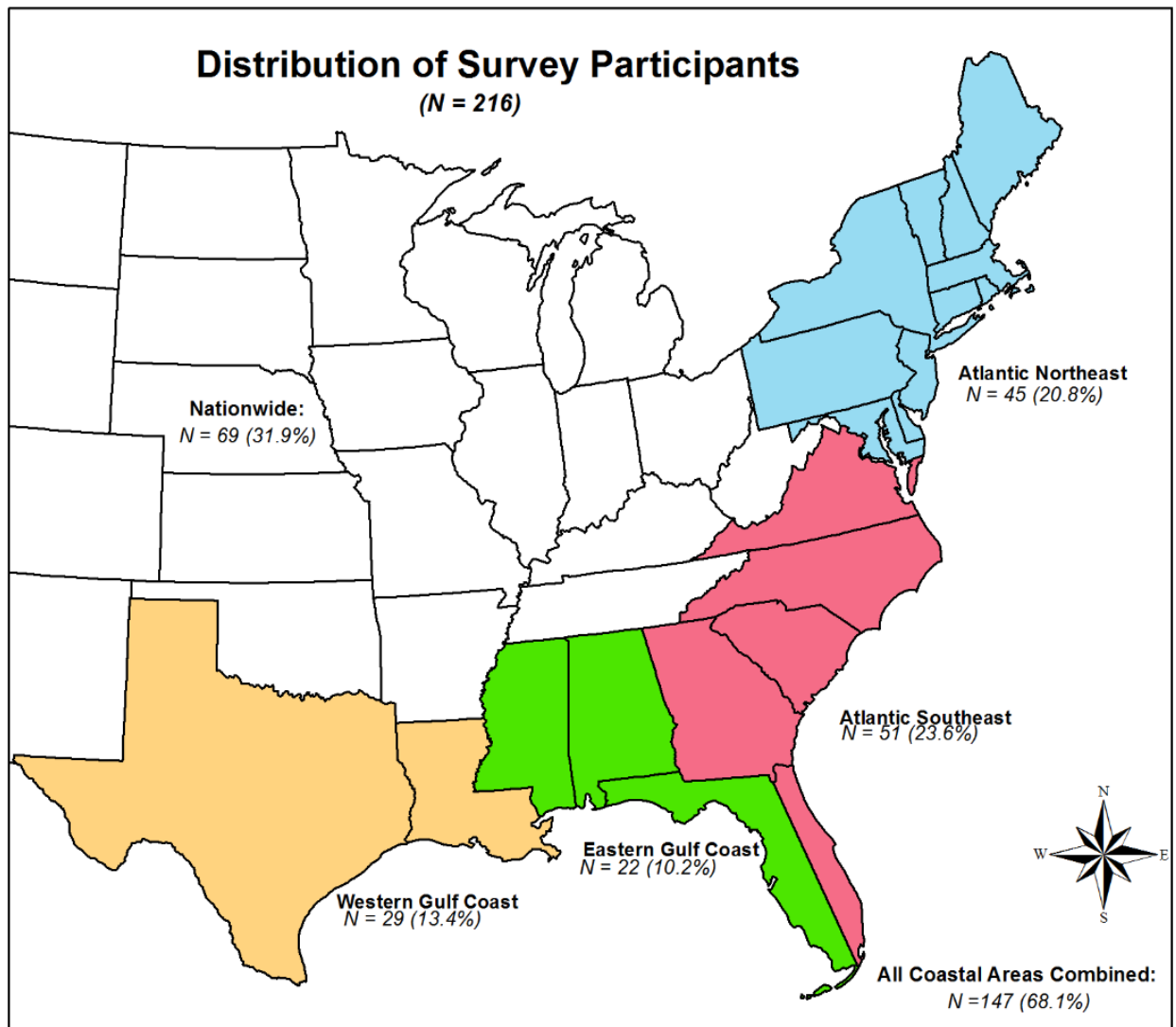
Figure 17. Geographic Distribution of Survey Participants.

To examine the possible correlations between demographic variables and the main

research questions an intercorrelation matrix is was also run and is provided on the following

page. The intercorrelation was run between 28 variables encompassing the major research

questions and demographic factors including: tracking graphic use and usefulness, social media

perceptions about use and effectiveness, messaging characteristics, numerical weather prediction

(NWP) reliance, and work and experience characteristics. Of the 378 correlations 105 (27.8%)

were significant at least to the $p < 0.05$ level. 17.7% of all correlations were significant to the $p < 0.01$ level. Discussion of some of the correlation matrix results is provided in the next chapter.

Table 4

Correlation Matrix

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Cone_Use	1																											
Cone_Useful	2	.271**																										
Prob._Use	3	.302**	0.011																									
Prob._Useful	4	.137*	.211**	.531**																								
Spag._Use	5	.281**	.156*	0.033	-0.038																							
Spag._Useful	6	.129*	.249**	-0.040	0.032	.611**																						
Cat._Use	7	.260**	0.070	.336**	.239**	0.017	-0.013																					
Cat._Useful	8	.166**	.133*	.135*	.199**	-0.026	0.015	.737**																				
Facbook_Use	9	-0.010	-0.002	-0.058	-0.055	0.086	0.074	0.097	0.097																			
Twitter_Use	10	-0.039	-0.118	-0.004	-0.067	0.023	-0.056	0.004	0.073	.222**																		
SM_Connect	11	0.097	-0.024	.141*	0.046	0.065	-0.052	0.051	0.015	0.044	.208**																	
SM_Effective	12	.199**	0.109	.148*	0.097	.173**	0.114	.219**	.204**	.255**	.204**	.304**																
Tell_Impacts	13	0.121	0.037	0.060	-0.038	-0.025	-0.003	0.017	0.010	0.095	-0.019	0.026	-0.051															
Tell_Evacuation	14	0.062	.213**	0.090	0.076	0.018	0.038	0.087	0.095	0.028	-0.103	0.069	-0.003	0.045														
Show_Tracking	15	0.043	0.110	-0.088	-0.044	0.113	0.099	-0.014	-0.056	-0.008	-0.068	-0.074	.129*	0.045	-0.080													
Effective_NWS	16	.132*	.180**	.154*	.188**	-.131*	0.014	0.045	-0.024	0.012	-.130*	0.110	0.048	0.004	.161*	-0.041												
Effective_LocalTV	17	0.075	.134*	0.055	-0.021	0.041	0.021	0.065	0.076	0.065	0.072	0.116	.217**	-0.009	0.021	0.068	.176**											
Effective_Officals	18	.148*	0.116	.182**	.206**	-0.065	-0.098	0.090	0.063	0.026	-0.061	0.039	0.044	-0.039	-0.066	-0.011	.378**	.179**										
NWP_Overeliance	19	-0.031	-0.050	-.134*	-.238**	0.049	0.029	-0.115	-0.116	-0.033	0.078	0.121	0.004	0.061	0.068	0.031	-0.079	-0.101	-.284**									
NWP_SharePublic	20	0.102	.162*	.137*	.179**	.245**	.304**	0.065	0.061	0.040	-.134*	-0.058	0.102	-0.024	0.102	-0.041	0.031	0.090	0.050	.263**								
Work_NOAA	21	-0.114	-0.059	0.113	0.082	-.263**	-.310**	-0.039	-0.036	0.056	.191**	-0.048	-0.072	0.093	-0.119	-0.031	0.040	-0.116	.236**	-.182**	-0.118							
Work_TV	22	.145*	0.063	-0.115	-.141*	.219**	0.115	0.090	0.102	.208**	.233**	.246**	.220**	-0.038	0.052	0.090	0.035	.351**	-0.057	0.078	0.076	-.374**						
Work_Location	23	0.078	.151*	0.074	0.098	-0.073	-0.075	0.002	0.053	0.029	.133*	.254**	0.100	-0.035	0.076	-0.018	0.049	.184**	-0.070	0.038	-0.078	0.028	.195**					
Years_Experience	24	0.097	0.056	0.063	-0.023	-0.041	-0.115	0.020	-0.008	-0.111	-0.051	.125*	-0.075	0.016	0.036	-0.079	0.012	-.158*	0.040	0.057	0.029	0.045	0.064	0.080				
Education_Level	25	-0.054	0.062	0.071	0.083	-0.062	-0.061	-0.099	-0.091	-.135*	-.205**	-.144*	-.193**	-0.013	-0.009	0.050	0.031	-0.019	0.018	-.128*	0.090	0.036	-.211**	-.173**	-0.002			
Gender (+ = Female)	26	-0.023	0.042	0.047	.135*	0.030	.146*	0.110	.133*	0.110	0.083	-0.058	.143*	-0.087	-0.026	-.182**	0.054	0.071	0.043	-.215**	0.098	0.074	-0.010	0.028	-.268**	0.022		
Fcast_Hurricane	27	0.085	-0.010	0.014	-0.009	.124*	-0.023	0.072	0.057	-0.015	0.045	.175**	0.042	0.105	0.041	-0.040	-0.071	-0.026	-0.100	176**	0.029	-0.090	166**	0.097	312**	195**	218**	
XP_Hurricane	28	0.028	-0.034	0.036	-0.076	0.052	0.003	0.078	0.049	-.155*	-0.024	.154*	0.008	0.077	0.014	-0.052	0.026	0.061	-0.047	0.071	-0.040	-.151*	.157*	0.111	351**	0.003	-.139*	-.189*

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Note: Variables 1-8 are related to tracking graphic use and usefulness (RQ1). Variables 9-12 are related to Social Media (SM), 13-15: messaging characteristics, 16-18: communication effectiveness of various sources (RQ2). 18-20 are related to NWP reliance and sharing graphics to the public (RQ3). Variables 21-28 are demographic variables including job sector (21-22), forecasting remotely (23), years of experience (24), highest education attainment (25), and previous hurricane forecasting experience (27-28).

CHAPTER 5: DISCUSSION AND IMPLICATIONS FOR FUTURE RESEARCH

This survey is the first comprehensive study of operational meteorologists and their

perceptions on hurricane forecasting in regard to tracking graphics, communication platforms,

messaging characteristics, and numerical model reliance. Thus far, prior literature has explored

how the messaging from the meteorologists has been received from a public perspective.

Including to what effect different kinds of tracking graphics communicate risk information to the

public (Broad, Leiserowitz, Weinkle, & Steketee, 2007; Wu, Lindell, & Prater, 2015; Cox,

House, & Lindell, 2013; Radford, Senkbeil, & Rockman, 2013; Liu, Mirzargar, Kirby, Whitaker,

& House, 2015), and communication messaging to the public (Demuth, Morss, Morrow, & Lazo,

2012; National Research Council, 2006; Dow & Cutter, 1998; Huang, Lindell, & Prater, 2015).

However, no studies to date have explored the opposite side of the coin in asking the message

source what they believe is valuable in terms of graphics and messaging.

Discussion RQ 1: Hurricane Tracking Graphics

The aim of RQ 1 is to explore how meteorologists perceive and use various hurricane

tracking graphics. While prior research has shown that the public has trouble in identifying the

perceived risk versus the actual risk presented by the cone of uncertainty and other graphics

(Ruginski, et al., 2016; Wu, Lindell, & Prater, 2015; Broad, Leiserowitz, Weinkle, & Steketee,

2007; Cox, House, & Lindell, 2013; Liu, Mirzargar, Kirby, Whitaker, & House, 2015), actual

research about use of the product from stakeholders is surprisingly vacant (Morrow & Lazo,

2015, p. 42).

In the survey, meteorologists were presented with four different kinds of tracking

graphics to rate their use and usefulness. All four graphics were found to be significantly

different from each other both in use [$F(3, 762) = 127.38$, $p < .001$] and usefulness [$F(3, 762) =$

32.2, $p < .001$] at the $p < 0.05$ level in a One-Way Repeated Measures ANOVA test. The

highest-ranking graphic in terms of 'use' and 'usefulness' was the cone of uncertainty (Fig. 8,

Fig. 9). 'Use' of the cone of uncertainty was rated with a mean of 4.3 out of 5 in a highly left-

skewed distribution of -1.46 ($SE = 0.15$). This result is a full point above the next highest, the

wind speed probability ($M = 3.3$). 'Usefulness' of the cone of uncertainty was also the highest

rating but not to the extent that use was. In fact, in the Paired Samples t-Test (Table 3), there is a

high level of significance for the cone of uncertainty product in the difference between these two

($M_{usefulness} - M_{use} = -.445$, $t = -6.779$, $p < .001$), compared to the other graphics. This strongly

indicates that even though meteorologists show the cone of uncertainty often, their perception of

its usefulness is less certain. This result could have multiple interpretations. Perhaps the

meteorologists think that the cone of uncertainty is traditional and are wary to stray from that.

Perhaps since the cone of uncertainty is the most widely distributed graphic, and since it is the

"main" graphic used by the National Hurricane Center (Zelinsky, 2016), they think that it is wise

to also do so.

On the opposite hand, the other three graphics have the opposite result with their mean

usefulness higher than their use (Fig. 8, Fig. 9). All to a significance of $p < .001$ in Paired

Samples t-Test. This implies that while meteorologists do not often use the probability plot ($M =$

3.3), spaghetti plot ($M = 3.2$), or categorical plot ($M = 2.7$) to the same extent that they use the

cone of uncertainty ($M = 4.3$). There is good agreement that they perceive their usefulness higher

than they actually use the graphics (Table 3).

In determining if there is a difference in use and usefulness between the graphics a paired

samples t-test was conducted as a post-hoc test along with the One-Way Repeated Measures

ANOVA. The results show that every graphic is significantly different from each other in both

terms of use (Table 1) and usefulness (Table 2) except for the probability and spaghetti plots. To confirm that the probability and spaghetti plots are not significantly different from each other, a t-test was conducted for the mean difference of use versus usefulness between these two graphics. The results found that they are not similar to each other with $p > 0.1$. ($M_{probability(usefulness-use)} - M_{spaghetti\ (usefulness-use)} = -0.081, t = 0.925, p = 0.355$). The reasoning for the probability and spaghetti plots being similar to each other while the other graphics are dissimilar is not clear and is was not further explored in this study. Future studies should explore why these two methods of showing probability were not found to be different from each other in this way.

Lastly, the categorical plot ranked lowest amongst the four plots in terms of use *(M = 2.7)* and usefulness (*M* = 3.0). The One-Way Repeated Measures ANOVA showed with significant differences in comparison between the other four graphics in terms of both use and usefulness (Table 1, Table 2). This indicates that while this type of map may be useful in some situations, for example as it is currently used in severe weather (Storm Prediction Center, 2017),meteorologists who forecast for hurricanes it perhaps is not best for hurricane tracking and impact guidance.

Discussion RQ 2: Meteorologists and Public Communication

The purpose of RQ2 is to analyze communication platforms and messaging of meteorologists and what the meteorologists think that they are responsible for distributing when confronting with an incoming hurricane event. Meteorologists as media sources has been accepted as an important information source and part of a larger integrated warning team (Cavanaugh, Huffman, Dunn, & Fox, 2016; Morrow & Lazo, 2015; Demuth, Morrow, & Lazo, 2009). Many studies have explored what the public response to various warning messages in both hurricanes (Morss, et al., 2015; Morrow B. H., Lazo, Rhome, & Feyen, 2015) and other

hazards (Dash & Gladwin, 2007; Huang, Lindell, & Prater, 2015). At a time when trust in media is in flux, it is important to understand where the most effective media platform for communicating risk is. In the purview of this study, knowing which platforms meteorologists believe are most effective is equally worth exploring. The results show that a mix of local vs. non-local media and timing of news cycles are main contributors to effectiveness of hurricane risk communication. Fast and local sources such as local TV stations were ranked the highest ($M = 4.4$), while slower and more broad sources such as Internet-only based media ranked the lowest ($M = 2.2$) (Fig. 10). Governmental sources ($M_{NWS\ Entities} = 4.2$, $M_{Local\ Officials} = 3.7$) could also be considered more effective as they ranked higher than the mean of all sources ($M = 3.32$). These results are similar to a recent study on channel preference for hurricane evacuation information by DeYoung, Wachtendorf, Farmer, & Penta (2016). Their results showed that television, radio and internet connections were highest rated while newspapers came last (p.280).

In regard to social media being an effective form of communication for hurricane risk information, it was found that there is good consensus ($M = 3.9$, $SD = 0.96$) that social media can be an effective platform for distributing hurricane risk information. However, the effectiveness of social media still has its doubters with 14.9% of respondents rating the effectiveness of social media below "Somewhat Effective" (Fig.12). The intercorrelation matrix (Table 4) shows the strongest proponents of social media's effectiveness are those working in television ($r = .220$, $p < .01$). Female meteorologists also have a positive correlation for believing social media is effective ($r = .143$, $p < .05$) . A significant negative correlation was found to exist between the perceived effectiveness of social media and highest attained education level ($r = -.193$, $p < .01$). Similar correlations, a positive correlation for females and a negative correlation for age, was reported in a massive study of social media account content. (Schwartz, et al., 2013).

Social media platforms used by meteorologists were also examined. Facebook and

Twitter were the top platforms used by meteorologists with a steep drop off for other platforms

such as photo-sharing or blogging sites (Fig. 14). Facebook use ($r = .208$, $p < .01$) and Twitter

use ($r = .233$, $p < .01$) also were highly correlated with meteorologists who worked in television.

One surprising finding however was that even though both Facebook and Twitter users from the

surveyed meteorologists thought that social media is an effective tool for communication

($r_{Facebook} = .04$, $p = .48$) ($r_{Twitter} = .208$, $p < .01$) only Twitter users had a strong correlation with

users who thought that they had a strong connection to their audience ($r = .208$, $p < .01$). This

finding contradicts an intriguing finding by Ke, Ahn, and Sugimoto, (2017) who found that

meteorologists on Twitter are generally self-contained within their own discipline, and rarely

interacting with other disciplines (p. 11). However, this analysis did not study their connection to

general users, only with other scientists.

Just as important as the platform for distributing information is the content of the

information. For analyzing this, we asked the meteorologists two main questions: 1) in the event

of a hurricane, what is the most important information to show to your audience (Q21); and 2)

what would you tell your audience(Q19)? For the first question, 55.2% of the meteorologists

indicated hurricane-tracking graphics as the most important information.

This finding becomes even more complex however when the data were analyzed about

the second question (Q19). While the more traditional meteorological messaging was ranked the

highest, such as strength and timing of impacts and preparedness tips, 62.4% of surveyed

meteorologists said that they would tell their audience about evacuation information, a topic

more traditionally spoken to from official sources or from a newsroom. Historically, through

observation and through literature, the role of the meteorologists and their associated entities has

been focused on providing warning information (Gladwin, Lazo, Morrow, Peacock, & Willoughby, 2007). The job of disseminating evacuation information is taken by emergency management officials, such as a Public Information Officer (PIO). A PIOs duty, according to the Federal Emergency Management Agency's (FEMA) Basic Guidance for Public Information Officers, is to "develop and releasing information about the incident to the news media…"(p.2), including information about "evacuation routes, alert systems, and other public safety information, to be coordinated and communicated to diverse audiences in a timely, consistent manner (Federal Emergency Management Agency, 2007, p. 4). FEMA also provides specific training and recommendations for PIO's to communicate to various platforms of media including television, radio, print, and social media (Federal Emergency Management Agency, 2013). However, none of the recommendations specifically includes meteorologists. Meteorologists may have access to this information like the rest of the media, but to have meteorologists indicate that they believe they are also partly responsible for distributing this kind of information is an unexpected finding. This study finds that a majority of meteorologists believe that they also have a role in evacuation information dissemination (62.4%)(Fig. 12). This indicates that the current literature body has potentially let a significant evacuation information source go undetected.

The most surprising finding, however, is that 55.3% of surveyed meteorologists would actually make evacuation recommendations (i.e., People in X location should move to Y location) to their audience (Fig. 12). Only a few prior examples of this behavior have been documented. Perhaps the most notable was an incident in the Oklahoma City metro are when a local television meteorologist told viewers to "get in your car and drive south" to get out of a path of a tornado (Mersereau, 2014). This information was against the advice of local officials

and the National Weather Service, which indicated that people should stay in their homes in a safe room or below ground level (Farley, 2013). The event was highly contentious as it crossed a perceived boundary that was seen as typically reserved for people with the official capacity to make those calls, such as emergency management officials. This phenomenon would benefit from further research to determine if the data are true and if so, to determine the motivations for such actions.
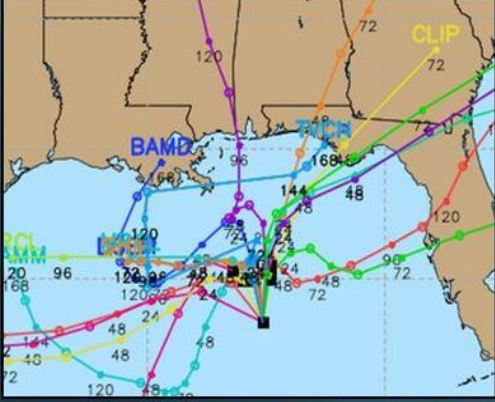
Discussion RQ 3: Numerical Model Reliance

This research question stems from the fact that as digital and social media grow in use, so does the number of people accessing or seeing weather products online or on television. In addition, computationally powerful supercomputers and the science behind them have advanced such to the point that some simulations have started to realistically depict reality with precision. Numerical weather prediction modeling is no different. When both of these factors are combined, more precise, but not always necessarily accurate, weather graphics have become easier to obtain and subsequently to be shared. It is feared among some in the meteorological community that without a meteorological interpreter to these graphics they could be misconstrued (Breslin, 2016). A prime example in the tropical weather and hurricane realm is the use of spaghetti plots. Graphics of these simulated hurricane tracks end up being spread among the public who sees the graphic without interpretation. The issue is so prevalent that the National Weather Service forecast office in New Orleans, Louisiana took to social media in before the hurricane season of 2016. The message was to warn of the "Dangers of Spaghetti Plots" dissuading the use of model graphics for the public without interpretation from a meteorologist (Fig. 18).

Figure 18. NWS WFO New Orleans warning of the "Dangers of Spaghetti Plots" (National Weather Service Forecast Office New Oreleans, 2016).

For this reason and others like it, this research question and its associated section in the survey has also been the subject of numerous comments and opinions written to the authors.

There are three main sub-questions, which this research question aims to answer. First, do meteorologists think that today's numerical weather prediction models are weighted too heavily in making a forecast? Second, do meteorologists think that the public seeing these model graphics hurt their ability to understand the inherent uncertainty in a forecast? Third, are these two questions correlated?

In regard to the first question, the data show that there is substantial attitude in the meteorological community that there is an overreliance on numerical weather prediction, with an

average of 3.7 of 5 with a slightly left-skewed distribution of -0.22 ($SE = 0.16$) towards over-reliance (Fig. 15). While this survey did not probe into the reasoning for this opinion, it provides an interesting finding into which future research could explore further.

The second question has unclear findings. While the mean was 2.6 of 5, leaning towards these model graphics facilitating misunderstanding, the standard deviation was near 1 ($SD = 1.08$) and the skewness near zero (.12) ($SE = 0.16$). There was, however, a dramatic drop-off between Likert ratings of 4 and 5 with only 2.1% of all meteorologists surveyed indicating the model graphics facilitate understanding (Figure 16). This means that while overall, meteorologists perceive model products being shown to the public as a slightly negative thing (facilitating misunderstanding), some of them hold out that it could be potentially useful.

In looking at the correlation between these two questions, a significant negative correlation ($t = -.263, p < .01$) between these two variables was observed. This implies that meteorologists who believe that there is too much reliance in numerical weather prediction models also believe that having the public exposed to these graphics facilitates misunderstanding of uncertainty in forecasts.

Limitations

There are several limitations in considering the results from this survey. First, the survey polled only one group of operational meteorologists (tropical meteorologists) belonging to only one professional organization (National Weather Association). Operational meteorologists that exist outside of this organization may think differently about the questions discussed in this study than meteorologists who did complete the survey.

Another consideration is the fact that all survey participants were self-selected. The distribution method, which the National Weather Association offered, could not be

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geographically constrained. The survey however, through self-selection, has an approximately

85% tropical forecaster rate and approximately 68% of respondents hail from coastal states that

have been hit by hurricanes (Fig. 17). However, as mentioned in the methodology, some

forecasters who forecast for hurricanes may live in a non-coastal state and forecast remotely.

Finally, the graphics presented as part of RQ1 are graphics that have been seen and used

only in the past half-decade. In 2017, the National Hurricane Center will release new types of

graphics that are derivatives on the cone of uncertainty and the probability plot (National

Weather Service Headquarters, 2017). It should be considered that these graphics are

independent of the ones considered in this study.

Future Research

As mentioned before, this survey is the first of its kind to survey meteorologists and their

perceptions to hurricane graphics, communications, and forecasting. Some of the ideas and

findings can be further explored by other researchers in two ways. First is to compare these

results with similar questions from the public. Second is to see if meteorologists think the same

about different kinds of weather phenomena, such as winter storms and tornadoes.

In thinking about how this survey could be translated to a public audience, all three

research questions could be adapted so that the responses from the public could provide

comparative power to the data obtained about meteorologists. For example, which graphics does

the public remember seeing and how useful do they find the graphics? Which media and social

media platforms do they trust when it comes to weather information? Do they remember seeing

model graphics on television or online and do they believe that they are useful?

While this study focused on hurricane threats, other threats such as winter storms and

severe thunderstorms also pose significant graphical, messaging, and numerical prediction

dilemmas. For example, winter storms have very tight boundaries between little snow or ice and a lot of snow. In nor'easters, these boundaries often cross major metropolitan areas. Due to these factors, graphics depicting snow and ice can differ spatially and temporally given discrepancies in modeling and forecaster preference. How these uncertainties pan out in communications from the meteorologist to the public has yet to be explored and should be an ongoing topic for research and discussion amongst social scientists with interests in meteorology.

Conclusion

This study examined how meteorologists view uncertainty in forecasting hurricanes using graphics and how this uncertainty translates graphic use and perceived usefulness. Which platforms in traditional media and social media are perceived to be most effective in transmitting risk information, the messaging that is being transmitted by meteorologists on these platforms, and how the rise of numerical weather prediction is influencing the forecasting process and how the public understands uncertainty.

The results show that the cone of uncertainty is the most used graphic by meteorologists, while there are potentially doubts about its usefulness. Other graphics, such as probability based plots and spaghetti plots, are less frequently used, but show signs of potential usefulness. Information sources that are perceived to be most effective tend to be local and rapid cycle news sources. However, the content of these messages distributed by meteorologists is surprisingly broad, encompassing both the realm of traditional forecasting but also messages that are in the domain of public officials, such as emergency management. Meteorologists' perceived reliance on numerical weather prediction (NWP) shows that the use of NWP and the extent that NWP graphics being shown to the public is too high. They overall believed it facilitates

misunderstanding of uncertainty to the public. However, there is evidence that if NWP used correctly, it could be a useful tool.

This investigative and groundbreaking work leaves more questions than answers at this stage. Nonetheless, it provides a baseline for other studies to compare surveys done on the public to their prime information sources during hurricanes – the meteorologists. It also opens up a new pathway for social science researchers interested in meteorology to study both hurricanes and other forms of extreme weather to examine if these findings are generalizable across other types of meteorological hazards.

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APPENDIX. SURVEY OF METEOROLOGISTS ABOUT PERCEPTIONS OF

HURRICANE FORECASTING
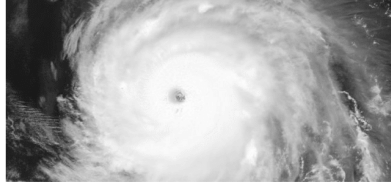
Survey of Meteorologists about Perceptions of Hurricane Forecasting

INFORMED CONSENT DECLARATION

The Department of Emergency Management at North Dakota State University is conducting an online survey of meteorologists and their perceptions about hurricane forecast uncertainty as well as relationships with the public in times of a hurricane threat. This survey is part of a National Science Foundation Grant #1520338 (Hazard SEES: Bridging Information, Uncertainty, and Decision-Making in Hurricanes Using an Interdisciplinary Perspective). This online survey is the first of its kind and is designed to ask meteorologists about their perceptions on different kinds of hurricane forecasting graphics, social media use, and numerical model reliance. Your expertise in this topic area will make this survey the best it can be to create an accurate gauge of the hurricane forecasting community.

The personal benefits for your participation include a better self-evaluation of hurricane forecast methods and how you are connected to the public through mainstream and social media. Your participation is voluntary. You can discontinue your participation at any time. You will not be penalized in any way for withdrawing from participation.

Information about you will be kept confidential to the extent permitted or required by law. People who have access to your information include the Principal Investigator and research personnel in the three participating universities - North Dakota State University, Virginia Polytechnic Institute and State University, and Purdue University. Representatives of regulatory agencies, such as Institutional Review Board offices in these three universities may access your records to make sure the study is being run correctly and that information is collected properly.

There are no foreseeable psychological or physical risks or discomfort as a result of your participation in this research study. Your responses to the questionnaires will be stored securely in the Department of Emergency Management at North Dakota State University.

If you have any questions about this study, you may contact the Principal Investigator, Dr. Yue Ge, 701-231-6687, yue.ge@ndsu.edu, or, you may contact the Research Assistant, Mr. James Hyde, 443-841-6030, james.hyde@ndsu.edu.

This research study has been reviewed and approved by the Institutional Review Board at all three participating universities. For research-related problems or questions regarding subjects' rights, you can contact the Institutional Review Board at ndsu.irb@ndsu.edu or 1.855.800.6717.

Please indicate that you have read and understood the explanation provided to you, that you have had all your questions answered to your satisfaction, and that you are voluntarily agreeing to participate in this study by e-signing below.
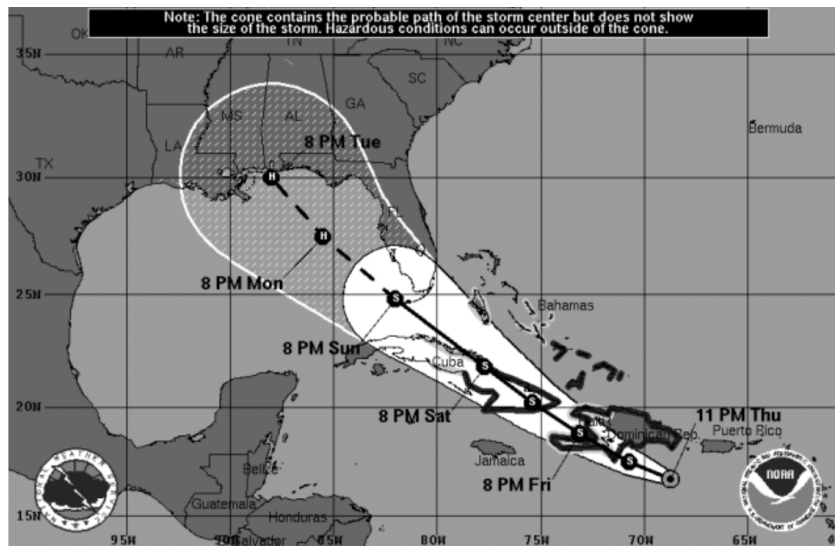
* 1. Signature

Name [   ]
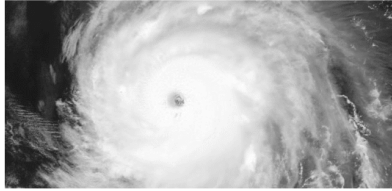
1

Survey of Meteorologists about Perceptions of Hurricane Forecasting

Section A: Perceptions about Hurricane Forecasting

Cone of Uncertainty

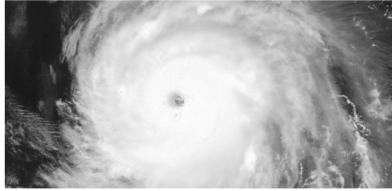2. In looking at the above picture, are you familiar with or have seen a similar product before?

◯ Yes, I have seen this kind of product before.

◯ No, I have not seen this kind of product before.

3. How often do you (or would you) use/show the cone of uncertainty, or similar cone product, in your forecasts to a non-meteorological audience in a hurricane tracking situation?

Never Use	Rarely use	Sometimes use	Often use	Always use
◯	◯	◯	◯	◯

4. In rating your perception of usefulness of the cone of uncertainty product in communicating track uncertainty, how would you rate the cone of uncertainty product on a scale from 1 to 5, with 1 being not useful at all, and 5 being very useful?

Not useful at all (1)	2	3	4	Very useful (5)
◯	◯	◯	◯	◯

5. Is the "cone of uncertainty" used by the National Hurricane Center a fixed size for all storms in a given season?

◯ Yes, it's a fixed size for each forecast point.

◯ No, it changes in radius for each storm.

◯ I'm not sure.
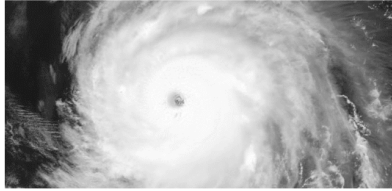
Survey of Meteorologists about Perceptions of Hurricane Forecasting

Section A: Perceptions about Hurricane Forecasting

Probability Based
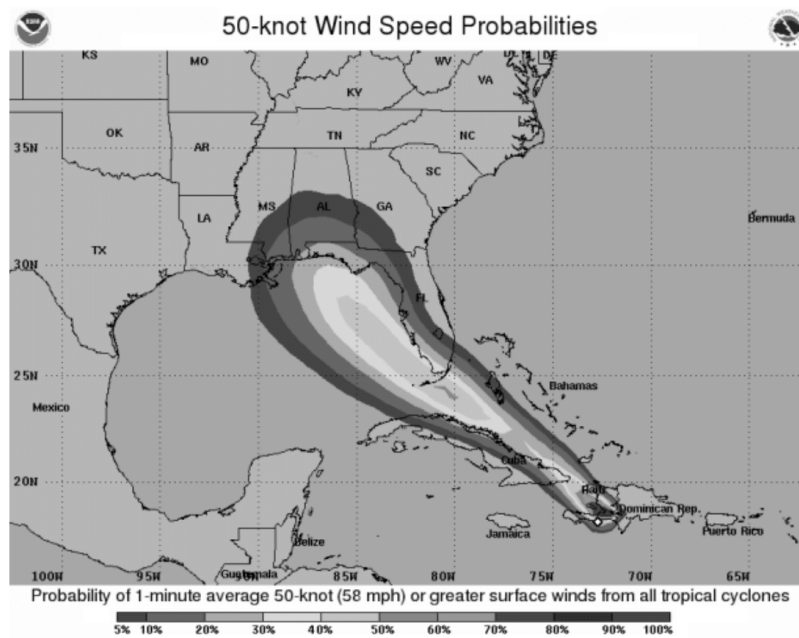
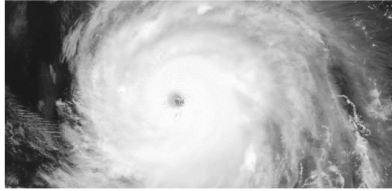6. In looking at the above picture, are you familiar with or have seen a similar product before?

○ Yes, I have seen this kind of product before.

○ No, I have not seen this kind of product before.

4

7. How often do you (or would you) use/show a probability based product in your forecasts to a non-meteorological audience in a hurricane tracking situation?

Never Use	Rarely use	Sometimes use	Often use	Always use
○	○	○	○	○

8. In rating your perception of usefulness of a probability based product in communicating track uncertainty, how would you rate a probability based product on a scale from 1 to 5, with 1 being not useful at all, and 5 being very useful?

Not useful at all (1)	2	3	4	Very useful (5)
○	○	○	○	○

5

Survey of Meteorologists about Perceptions of Hurricane Forecasting

Section A: Perceptions about Hurricane Forecasting

Spaghetti Based
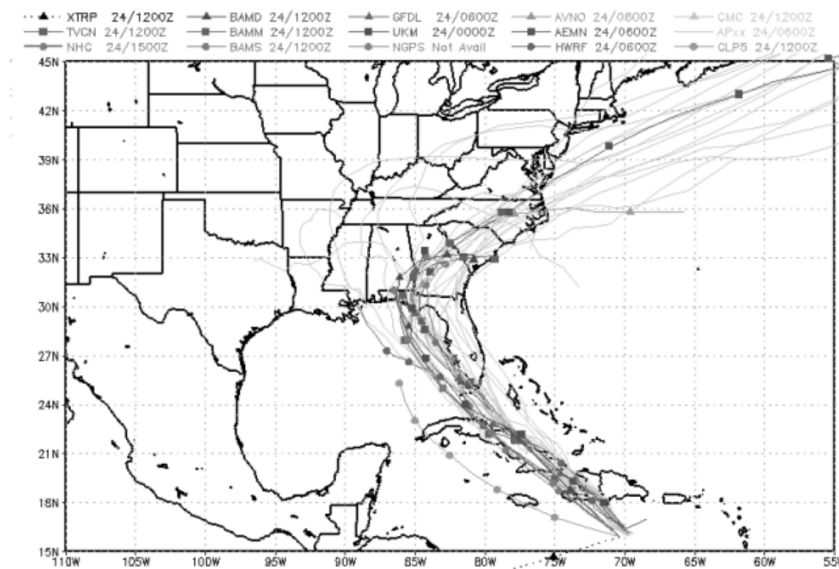
9. In looking at the above picture, are you familiar with or have seen a similar product before?

○ Yes, I have seen this kind of product before.

○ No, I have not seen this kind of product before.

10. How often do you (or would you) use/show a spaghetti plot or similar product in your forecasts to a non-meteorological audience in a hurricane tracking situation?

| Never Use	Rarely use	Sometimes use	Often use	Always use
○	○	○	○	○

6

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11. In rating your perception of usefulness of a spaghetti model(s) product in communicating track uncertainty, how would you rate a spaghetti model(s) product on a scale from 1 to 5, with 1 being not useful at all, and 5 being very useful?

Not useful at all (1)	2	3	4	Very useful (5)
○	○	○	○	○

Survey of Meteorologists about Perceptions of Hurricane Forecasting

Section A: Perceptions about Hurricane Forecasting

Categorical Based

12. In looking at the above picture, are you familiar with or have seen a similar product before?

◯ Yes, I have seen this kind of product before.

◯ No, I have not seen this kind of product before.

13. How often do you (or would you) use/show a scaled impact based product or similar product in your forecasts to a non-meteorological audience in a hurricane tracking situation?

Never Use	Rarely Use	Sometimes Use	Often Use	Always Use
◯	◯	◯	◯	◯

8

14. In rating your perception of usefulness of a scaled impact based product in communicating track uncertainty, how would you rate a scaled impact product on a scale from 1 to 5, with 1 being not useful at all, and 5 being very useful?

Not Useful at All (1)	2	3	4	Very Useful (5)
○	○	○	○	○

15. In a scenario in which the hurricane you are forecasting for has a high degree of uncertainty in its future track (e.g., Hurricane Sandy, 2012, or Hurricane Joaquin, 2015). Which of the following would you show your consumers? (Check all that apply).

☐ Your (or your entities') own forecast.

☐ The NHC official forecast track.

☐ A range of potential scenarios.

☐ Say, that "we're not sure" and to "keep an eye on it".

☐ Would not show any future track, just current information.
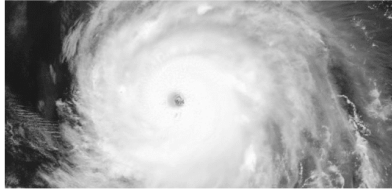
Survey of Meteorologists about Perceptions of Hurricane Forecasting

Section B: Perceptions about the Meteorologist / Public Relationship

16. Which of the following social media have you used in communicating hurricane forecasts? (Check all that apply)

☐ Facebook

☐ Google+ / Google Hangout

☐ Instagram

☐ Pinterest

☐ Twitter

☐ Tumblr

☐ Reddit

☐ Other (please specify)

[   ]

17. How would you rate your connection between your audience and yourself in regards to answering questions about hurricane forecasts? (e.g., social media, public outreach)

Not Connected (1)		Somewhat Connected (3)		Very Connected (5)
○	○	○	○	○

18. To what extent do you agree that social media are effective tools in disseminating hurricane risk information?

Not at All Effective (1)		Somewhat Effective (3)		Very Effective (5)
○	○	○	○	○

19. In a scenario in which a hurricane landfall is certain to happen in your forecast area, which of the following would you tell your audience? (Select all that apply)

☐ Estimated landfall point.

☐ Strength and timing of impact(s).

☐ Preparedness tips (e.g., secure loose belongings, stay in interior room).

☐ Evacuation information (e.g., for those in A, there is a shelter in B available).

☐ Evacuation recommendations (e.g., people in X location should move to Y location).

20. To what extent do you believe the public can understand watch / warning meanings when it comes to tropical systems?

Cannot understand at all (1)				Can understand completely (5)
○	○	○	○	○

21. Which of the following forecast contents is most important to disseminate to the public in a land-falling hurricane scenario? (Select one)

○ Hurricane statistical information (e.g., windspeeds, location, forward speed and heading)

○ Hurricane tracking graphics (e.g., maps, intensity charts etc.)

○ Hurricane text product (e.g., an advisory, forecast discussion, watch/warning locations)

○ Evacuation information (Shelters, evacuation routes, etc.)

22. Rate how effective you think the hurricane forecasting community is at communicating risk to the public using the following media. (With 1 being the least effective and 5 being the most effective)

	Least Effective (1)	2	3	4	Most Effective (5)
National TV networks (e.g., CNN, Fox News, Weather Channel)	○	○	○	○	○
National Weather Service entities (e.g., NHC, Local WFO's)	○	○	○	○	○
Local TV stations	○	○	○	○	○
Local radio stations	○	○	○	○	○
Local print media (e.g., newspapers)	○	○	○	○	○
Local officials (e.g., emergency managers, mayors)	○	○	○	○	○
Internet-only based media (e.g., Slate, Gawker, Buzzfeed)	○	○	○	○	○
Social media from news sources (e.g., CNN on Facebook, Weather Chanel on Twitter)	○	○	○	○	○

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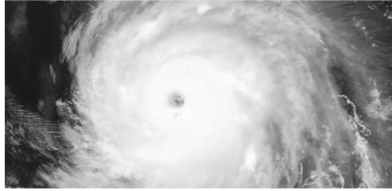
Survey of Meteorologists about Perceptions of Hurricane Forecasting

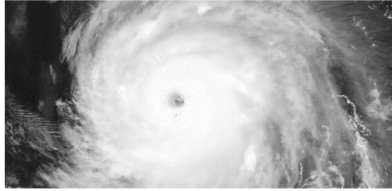Section C: Numerical Model Reliance

23. In your opinion, to what degree is there an over/under reliance on numerical forecast models in today's forecasting process?

Not Enough Reliance (1)	2	Just the Right Amount (3)	4	Too Much Reliance (5)
○	○	○	○	○

24. In your opinion, to what degree does the rise of model products being shown to the public at large (via print, TV, social media, etc.) helps or hinders the public to understand uncertainty in a forecast?

Facilitates Misunderstanding (1)	2	3	4	Facilitates Understanding (5)
○	○	○	○	○

25. In a sentence or two, explain the main reason why you think so? (Optional)

Section D: Geography and Demography

26. Please indicate in which sector you work in. Check all that apply.

- [ ] Federal: NOAA
- [ ] Federal: DHS
- [ ] Federal: DOD (e.g., Air Force, Navy, Army, Coast Guard)
- [ ] Federal: DOE
- [ ] Federal: EPA
- [ ] State Level: Emergency Management
- [ ] State Level: Natural Resources
- [ ] Other (please specify)

- [ ] Education: University
- [ ] Education: Research Group
- [ ] Consulting
- [ ] Energy: Oil / Gas Production
- [ ] Energy: Trading / Futures
- [ ] Insurance / Re-Insurance
- [ ] Media: Television

- [ ] Media: Radio
- [ ] Media: Print
- [ ] Media: Print
- [ ] Media: Online Only
- [ ] Legal
- [ ] Transportation and Logistics
- [ ] Retail

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27. Using the map above, please indicate in which coastal region you primarily forecast for.

○ Western Gulf Coast

○ Eastern Gulf Coast

○ Atlantic Southeast

○ Atlantic Northeast

○ Nationwide and/or Worldwide
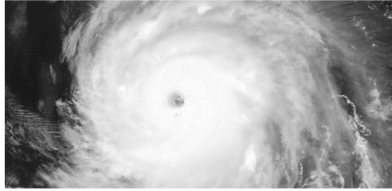
Survey of Meteorologists about Perceptions of Hurricane Forecasting

Section D: Geography and Demography

28. Does your place of work differ from the location in which you forecast for?

◯ Yes

◯ No

29. How many years have you been tracking hurricanes in a professional setting?

◯ 0-5 years

◯ 6-10 years

◯ 11-20 years

◯ 20+ years

30. Please select the highest educational degree in which you hold.

[⬍]

[   ]

31. What is your gender?

◯ Male

◯ Female

32. Have you ever forecasted for a hurricane before?

◯ Yes

◯ No

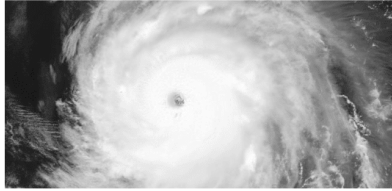33. Have you ever personally experienced a hurricane before?

◯ Yes

◯ No

34. Have you, or your household, ever had to evacuate from a hurricane before?

◯ Yes

◯ No

Survey of Meteorologists about Perceptions of Hurricane Forecasting

Survey Complete!

Thank you for participating in our survey! **Please share the link to the survey with your colleagues so that they may have the opportunity to complete it as well.** If you have any questions about this study, you may contact the Principal Investigator, Dr. Yue Ge, 701-231-6687, yue.ge@ndsu.edu, or, you may contact the Research Assistant, Mr. James Hyde, 443-841-6030, james.hyde@ndsu.edu.