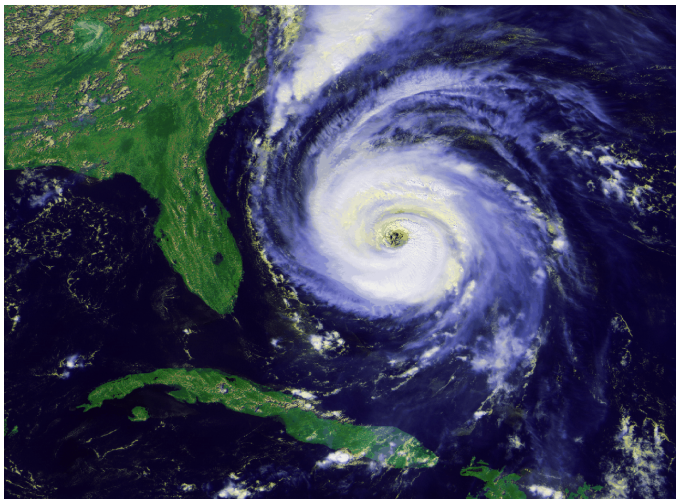
FINAL REPORT

Support for the Cone of Uncertainty Social and Behavioral Science Research Project

December 14, 2020

Eastern Research Group, Inc.,
Arlington, Virginia



Written under contract for the
NOAA's National Weather Service
www.weather.gov

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Introduction

The NOAA National Hurricane Center's (NHC's) tropical cyclone forecast track graphic, commonly referred to as the cone of uncertainty (and referred to in this report as the "Cone Graphic"), was introduced to the NHC website in 2002 (E. Rappaport, personal communication, October 24, 2018). The Cone Graphic (see sample in Figure 1) represents the probable track of the center of a tropical cyclone and is formed by enclosing the area swept out by a set of circles (not shown on the graphic) along the forecast track (at 12, 24, 36 hours, etc.). The size of each circle is set so that two-thirds of historical official forecast errors over a five-year sample fall within the circle. This means the size of the Cone Graphic is not dynamic on a storm-by-storm basis, or even a forecast-by-forecast basis, and reflects the amount of error (forecast vs. actual path) averaged for all events over the previous five years.

While the NHC and the Central Pacific Hurricane Center (CPHC) produce a suite of tropical cyclone graphics depicting different forecast parameters and information when a storm is active in the Atlantic or Eastern or Central Pacific Oceans, the Cone Graphic may be the most viewed product within this suite of products. The graphic's visual features have come under scrutiny over the years with studies and reports pointing to an array of misunderstandings that have important consequences on decision-making. The literature has largely focused on how non-experts interpret the Cone Graphic; less is known about the graphic's wider user base, particularly those industry sectors that can incur high economic impacts and losses due to hurricanes.

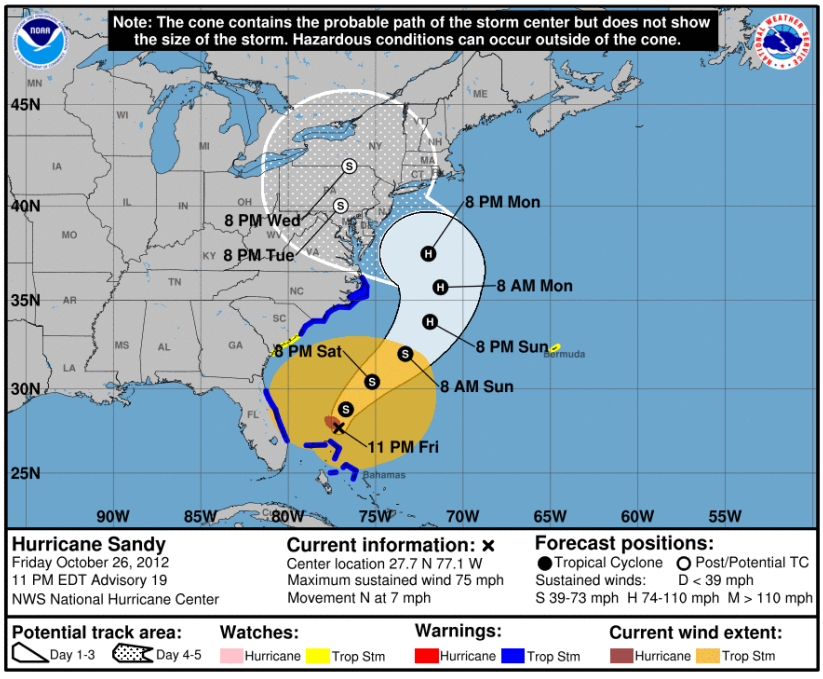

Figure 1. Tropical Cyclone Forecast Track Graphic Example

Research Project Overview

To better understand the studies already conducted on the Cone Graphic and to extend the research into less analyzed users of the graphic, Eastern Research Group, Inc. (ERG) conducted a two-year research project that examined the following questions:

- How do people interpret (or misinterpret) the Cone Graphic?
- How integral is the Cone Graphic to international partners' decision-making?
- How much do important economic sectors rely on the Cone Graphic for operational decision-making?
- Does the Cone Graphic meet these users' and stakeholders' needs?

In the first phase of the work, ERG conducted a comprehensive **literature review**, examining more than 50 studies and reports, to glean insights into interpretations, uses, and perceived strengths and weaknesses of the Cone Graphic by members of the public, public officials, and broadcasters. Next, ERG conducted **interviews** with international meteorologists who use and share the Cone Graphic. Finally, we conducted a web-based **survey** to gather insights into the interpretation and use of the Cone Graphic by decision-makers in four key industry sectors that can incur high economic impacts and losses due to tropical cyclones: 1) transportation, 2) marine, 3) tourism and recreation, and 4) energy and utilities. Table 1 summarizes the three phases of the research.

Table 1. Research Phases Overview

Approach	Purpose	Study Group	Final Report
Literature review	Understand interpretations of the Cone Graphic, implications for decision-making, and ideas for enhancements.	• Members of the public • Public officials, emergency managers (EMs) • Broadcasters	April 2019
Interviews	Understand how the Cone Graphic is used in decision-making and whether it serves operational and stakeholder communication needs.	• International meteorologists in Bermuda, Canada, Cuba, Jamaica, Mexico, and Netherlands	July 2020
Survey	Understand interpretation, use, and implications for decision-making by lesser-studied but economically significant sectors.	• Decision-makers in tourism/recreation, energy/utilities, marine, and transportation sectors	September 2020

Literature Review

As a first step in the research, ERG conducted a literature review of 56 government (mostly NWS service assessments) and academic works. These included social, behavioral, and economic science studies that examined misunderstandings of the Cone Graphic, implications on decision-making, and visualization concerns and alternatives. The literature revealed several types of misinterpretations with the Cone Graphic (see Table 2).

Table 2. Common Misinterpretations of the Cone Graphic

Problem	Implication
Misinterpreting the uncertainty cone as the swath of damage from the storm (i.e., an impact visualization).	• Believing a person is "safe" if located outside of the cone or having an exaggerated sense of *not* being safe if located inside the cone.
Misinterpreting the uncertainty cone as the actual size and or intensity of the hurricane.	• Believing the hurricane is growing in size or strength as it approaches land.
Anchoring to forecast track.	• Failing to recognize that landfall/impacts could occur at adjacent locations. • Loss of interest in a hurricane when a track shifts away from a person's location. • Failing to recognize that a storm's present track could change in the future.
Anchoring to storm intensity.	• Perceiving a higher intensity may occur even if the storm intensity is later downgraded.

The literature also showed that members of the public consult many different sources of information when making hurricane preparation and response decisions. While the Cone Graphic is the most well-known and pervasive (and sometimes the only) NOAA product they access, it may not have a major impact on their decision-making (Saunders and Senkbeil, 2017; Milch et al., 2018; Bostrom et al., 2018). Instead, the graphic may function as one factor (out of many) that elevates peoples' level of concern, but does not ultimately lead them to evacuate or prepare; in some cases, the graphic has even been shown to lower perceptions of personal risk. The research provides three main reasons for this:

1. The graphic can be confusing to people if they have limited graphic literacy or understanding of uncertainty principles. Because they don't really understand what they are seeing or have ambiguous feelings about what they are seeing, they aren't motivated to act (Heath and Tversky, 1991; Hogan Carr et al., 2016).
2. The graphic doesn't provide the types of information, such as storm size, calls-to-action, or potential impacts, that are most likely to influence people's response decisions. It also does not provide information on storm hazards such as rainfall and storm surge, and instead may reinforce the public's tendency to focus on wind (Bostrom et al., 2018; Milch et al., 2018; Saunders and Senkbeil, 2017; Meyer et al., 2014) due to its textual description of current wind speeds and graphical depiction of the storm's initial wind field.

3. Members of the public do not respond to hurricane threats based only on scientific and technical information. Instead, they are influenced by many factors, including past experiences, risk perceptions, emotions, attitudes and beliefs, and situational motivations and constraints (Lazo et al., 2015; Morss et al., 2016; Demuth et al. 2016).

Also documented in the literature are studies and experiments focusing on alternative visualizations of the Cone Graphic. The key goals of these studies have been to develop intuitive and accurate graphic displays without introducing potential biases or misinterpretations. Some researchers are also looking at ways to integrate additional storm attributes or use techniques such as interactivity and animation to better convey important temporal and spatial tropical cyclone storm information.

While some of these visualizations have shown promise in reducing common misunderstandings associated with the current graphic, they have, in some cases, introduced other issues. For example, one study considered four alternative ensemble visualizations (two static and two dynamic). Of the four visualizations, the animated icon display (second from right in Figure 2 below) was successful in eliminating a common misinterpretation with the current Cone Graphic: the tendency for people to confound the graphic with storm size. However, respondents mistakenly believed the icon animation was showing the passage of time.

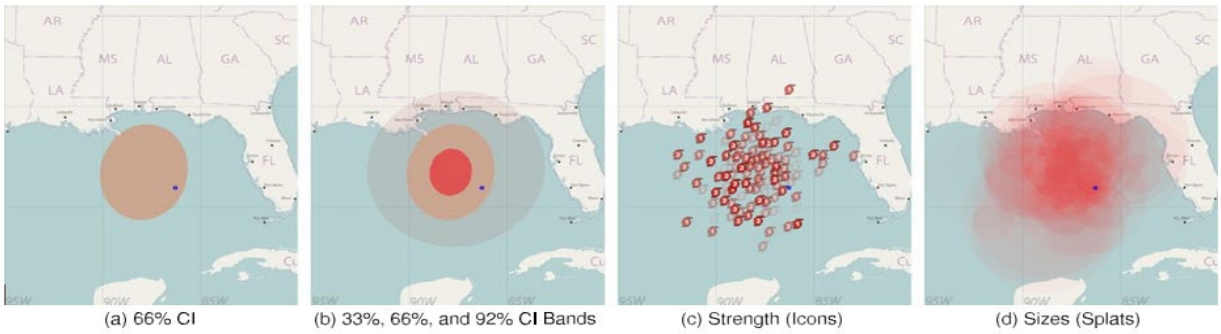

Figure 2. Cognitive Experiment of Four Ensemble Visualizations

Source: Liu, L., Boone, A.P., Ruginski, I.T., Padilla, L., Hegarty, M., Creem-Regehr, S.H., Thompson, W.B., Yuksel, C., and House, D.H. (2017). Uncertainty Visualization by Representative Sampling from Prediction Ensembles. *IEEE Transactions on Visualization and Computer Graphics*, 23(9): 2165–2178. https://doi.org/10.1109/TVCG.2016.2607204

Debate About the Center Track Line

The center track line on the Cone Graphic has been a somewhat controversial feature over the years. An NWS service assessment of Hurricane Charley in 2004 found that "Many people focused on the specific forecast track which showed the center of Hurricane Charley making landfall near Tampa rather than considering the cone of uncertainty which indicated areas of possible landfalls on either side of the predicted path" (NOAA, 2006). The assessment recommended that the NWS increase education on hurricane tracks and the uncertainty in forecasts and to find ways to better communicate the uncertainty and risk.

In 2009, the NHC removed the center line from the default view on its website (viewers can toggle to see the line). As recently as 2017, however, the NWS service assessment of Hurricane Matthew found that "Significant confusion continues regarding the official NHC tropical cyclone track forecast. NWS partners and the public alike continue to focus on the 'skinny black line'."

There is evidence that people do realize that hurricanes might not always follow the forecast track or fall within the uncertainty cone (Wu et al., 2014). One study even found that the track line might *help* preparedness decisions. In an experiment where participants used a ''virtual living room'' to search for information from simulated television and radio broadcasts, newspaper articles, internet sources, and peers as a hurricane approached, participants who viewed forecast graphics with the track line had higher preparation levels than those who saw only uncertainty cones, and this was true even for people living far from the predicted center path (Meyer et al., 2013).

Interviews with International Meteorologists

The NHC is responsible for issuing tropical cyclone products not only in the United States, but across the Atlantic and Eastern and Central Pacific basins. The meteorological services that serve these areas use these products to inform their decisions—particularly for issuing watches, warnings, and other communications to governments, emergency managers (EMs), the general public, and other stakeholders. As such, this portion of the research sought to understand how integral the Cone is to international partners' decision-making, as well as whether the graphic serves their operational and stakeholder communication needs.

To obtain these insights, ERG interviewed 12 representatives from six international meteorological services in Bermuda, Canada, Cuba, Jamaica, Mexico, and the Netherlands (serving Bonaire, Saba, and St. Eustatius). In addition to background questions about their general responsibilities and information sources related to hurricanes, interviewees were asked to describe the following:

- The Cone Graphic's role/importance in making decisions.
- Strengths and weaknesses of the Cone.
- Stakeholders' understanding of the Cone.
- Opinions on the Cone's current visualization and recommendations for changes.

The international meteorologists all use the Cone Graphic as part of their decision-making in concert with other types of information and understand its strengths and limitations (see Table 3 on the next page). However, as in the United States, this understanding does not always extend to stakeholders or members of the public. Even so, the graphic is very familiar to members of the public in these nations and territories. When it appears, the graphic serves as a signal that a tropical cyclone has developed and could become a threat. To help avoid misinterpretation of the graphic, all of the meteorological services provide context and interpretation around the graphic.

As for making improvements or changes to the current graphic, the international meteorologists were all enthusiastic about NHC producing a dynamic cone given the current state of modeling and the advancements that have been made. They were also interested in seeing the graphic convey additional information that they seek for forecasting purposes (e.g., wind speeds, timing of tropical storm force winds, storm maximum intensity and uncertainty in intensity and timing, multiple hazard parameters), but only if NHC can do so in a way that does not add more clutter or make the graphic cognitively overwhelming.

They suggested that given how highly visible the graphic is among members of the public, call-to-action statements and impact information could be most useful for a public-facing graphic along with information about hazard(s) of most concern. It would also be important to provide text to help readers understand what the graphic is showing and how to read the graphic.

There was a difference of opinion on having an NHC-produced 7-day track. Some felt the forecast is too uncertain 7 days out, and such a graphic could result in a “cry wolf” situation. In addition, having an earlier track would generate more work for some of the meteorological services (that are already stretched thin) and potentially start the spread of misinformation sooner. Others said they would welcome a 7-day graphic because of the preparations that need to be made far in advance of a storm.

Table 3. Strengths and Limitations of the Cone Graphic Identified by International Meteorologists

Strengths	Limitations
• Is very familiar to audiences. • Provides the first view (especially more than 72 hours out) of a tropical cyclone's potential to make landfall. • Gives users an idea of the possible movements of a storm and allows them to become more confident in the track as lead times get shorter. • Provides an effective high-level overview of a storm system, including likely track, watches, warnings, and timing intervals.	• Does not explain impacts. • Some individuals or entities may rely too heavily on the Cone Graphic for decision-making. • Shows uncertainty in track, but not uncertainty in intensity and limited information on uncertainty in timing. • Does not provide information on storm size or storm hazards such as rainfall and storm surge. • Is based on historical performance, meaning users are stuck with a 5-year historical Cone even if models are well in agreement on the path of an event. • Is not understood by the general public and requires explanation. • Can prompt alarm when the cone appears over a person's location or complacency if it does not. • Can be misleading when the center track line is shown because people can assume if they are not on the line, they are safe.

Recommendations for Enhancements

In response to the perceived limitations or weaknesses in the current visualization, the international meteorologists recommended the following enhancements:

- Create a dynamic cone that becomes larger or smaller depending on low or high confidence.
- Rather than relying on historical tracks from the past 5 years, look at ensembles and trim the cone based on higher confidence.
- As feasible, create a multilayered, interactive graphic that uses different colors to show impacts, wind speeds, and other storm hazards (e.g., storm surge, rainfall) in addition to the track.
- Create an interactive visualization that would enable users to focus on areas of interest.
- Include text to explain elements of the graphic and/or provide additional information and key messages (e.g., what to pay attention to at that time, the top hazard of concern at that time, a call to action).
- Overlay the graphic with satellite imagery so users can see the storm extent.
- Show uncertainty in storm intensity and more information on storm timing.

Some of the meteorological services repackage the Cone Graphic for distribution to stakeholders with additional types of information (e.g., additional forecast parameters, threats, potential impacts, calls to action). For example, Bermuda produces a visualization that also depicts the fringing tropical storm force winds. Cuba provides radar and satellite imagery along with the storm track to depict live movement to government partners and the public while Mexico's Civil Protection System issues a bulletin that focuses mostly on the hazards and impacts of tropical cyclones rather than just the storm track. Many of the international meteorologists also stressed the importance of explaining the Cone Graphic in simple and colloquial language when sharing it with members of the public.

Sector-Based Survey

The final stage of the research centered on decision-makers in four important economic sectors (energy/utilities, tourism/recreation, marine, and transportation) that can be at significant risk during a hurricane. The survey gathered information on respondents' use and familiarity with the Cone Graphic and other NWS products and forecast parameters. It also evaluated their ability to accurately interpret the graphic and gauged the effectiveness of different graphic features (e.g., center track line, colors, legend), and their suggestions to enhance the graphic (see Table 4 for a summary of key survey topics and their purpose).

Table 4. Key Survey Topics and Purpose

Topic	Purpose
Organizational past experience with hurricanes.	Extent of damage and/or adverse effects that organizations have experienced from past hurricanes.
Use of information resources and tools.	Identify whether NOAA products are embedded in respondents' decision-making and, if so, how deeply they are embedded.
Types of forecast parameters needed (e.g., storm track, storm intensity, storm size).	Understand what forecast parameters are essential to respondents' decision-making and how the Cone Graphic fits into these needs.
Importance of the Cone Graphic to decision-making.	Understand how the graphic is used in respondents' activities, operations, and decision-making and how reliant they are on the graphic.
Interpretation of the Cone Graphic.	Determine if respondents are accurately interpreting the graphic and its features.
Feedback on ease of use and clarity of the Cone Graphic.	Understand if refinements to the Cone Graphic would be beneficial.
Suggestions for enhancing the content or design of the Cone Graphic.	Understand the types of refinements to the graphic that would be most desirable to organizations.

Survey Methods

To distribute the survey, NWS Weather Forecast Offices (WFOs) sent the survey link to their lists of partners. The survey link was also sent directly to individuals on specialized lists provided by the NWS and shared with the Office of the Federal Coordinator of Meteorology.

Overall, the survey received a total of 808 clicks from emails that were sent out; 152 individuals exited the survey without answering a question, and another 147 respondents were screened out based on the in-scope criteria. This resulted in a total usable sample size of 509 respondents. Despite this large number, however, the number of respondents declined over the course of the survey as some respondents opted out at later points in the survey. Each individual question was analyzed based on the number of respondents available for that question.

The survey analysis included simple tabulations of responses, as well as "score" calculations for questions that involved an ordered scale (e.g., level of agreement, extent, likeliness). In some cases, ordered logistic regression was used to estimate odds ratios to determine if responses were statistically significant. For certain questions, the analysis also considered whether those who experienced extensive impacts from a prior storm responded differently than those who had not experienced impacts.

Survey Respondents

At the outset of the survey, respondents were asked to choose among a set of 19 (overlapping) geographic areas in which their organization worked. Table 5 shows the distribution of the respondents across the four in-scope sectors and the two ocean-level regions.

Table 5. Distribution of Respondents Across In-Scope Sectors and Atlantic and Pacific Regions

Graphic Assignment	Tourism and Recreation	Energy and Utilities	Marine	Transportation	All Sectors
Atlantic	144	91	225	167	449
Pacific	17	8	6	15	42
Total	161	99	231	182	491

Note: Respondents could select more than one sector. Thus, the totals in the "all sectors" column will be less than the sum across the four sectors in the rows.

The survey respondents were largely experienced decision-makers with nearly two-thirds (64 percent) having more than 20 years of experience, and another one-fourth (25 percent) having 11 to 20 years of experience. Almost half (48 percent) identified themselves as experts, and 38 percent identified themselves as proficient. Less than 2 percent identified as an advanced beginner, and none were novices. Seventy-five percent of respondents were either the primary decision-maker or part of a group of top decision-makers in their organization.

Key Survey Findings

Conclusions associated with the key survey topics are described below.

Organizational Past Experience with Hurricanes and Impacts

A total of 410 respondents (85 percent) indicated they were impacted by at least one hurricane between 2017 and 2019, and a majority in each sector also indicated being impacted (see Table 6). As for the extent of these impacts (see Table 7), large numbers of respondents indicated they either had no impacts from any of the storms (167 respondents) or extensive impacts from at least one storm (187 respondents).

Irma, Harvey, Dorian, Michael, Maria, and Florence were associated with the largest impacts (see Table 8). Irma was clearly the most impactful storm across all sectors.

Table 6. Respondents Impacted by One or More Hurricanes Between 2017 and 2019

Response	Tourism and Recreation	Energy and Utilities	Marine	Transportation	All Sectors
Impacted	134	81	197	158	410
Not impacted	23	17	30	23	74
Total	157	98	227	181	484

Table 7. Maximum Reported Impact Across Hurricanes

Maximum Reported Impact	Tourism	Energy	Marine	Transportation	All Sectors
None	49	30	84	57	167
Little, if any	14	12	11	16	41
Moderate	24	26	36	42	89
Extensive	70	30	96	66	187
Total	157	98	227	181	484

Table 8. Impact Ratings of 17 Storms, All Sectors

Hurricane	All Sectors	
	N	Score
Irma	288	64.0
Harvey	256	41.4
Michael	238	35.9
Dorian	240	35.0
Maria	234	29.3
Florence	231	26.3
Nate	226	17.3
Barry	214	17.0
Alberto	219	16.0
Jose	221	14.3
Gordon	219	13.5
Lane	222	11.6
Olivia	220	10.5
Hector	218	10.4
Imelda	211	10.4
Mangkhut	213	7.5
Gita	211	6.2

Use of Resources and Tools

The survey asked respondents about the extent to which they use 14 NWS hurricane products. Across all four sectors, the "Tropical Cyclone Track and Error Cone Graphic" tended to be the most used, although in the energy/utilities sector, the "Time of Arrival of Tropical-Storm-Force Winds Graphics" was used slightly more. Overall, all 14 graphics are used at rates above the mid-point of the scale (50) as depicted in Table 9.

Table 9. Use of NWS Hurricane Products, All Sectors

Information Source	All Sectors		
	N	Score	Not Familiar
Tropical Cyclone Track and Error Cone Graphic	340	92.6	8
Time of Arrival of Tropical-Storm-Force Winds Graphic	341	90.1	7
Wind Speed Probability Products	342	88.6	6
2-Day and 5-Day Tropical Weather Outlooks	341	89.8	7
Storm Surge Watch and Warning Graphic	324	84.4	24
Wind (hurricane, typhoon, or tropical storm) Watch and Warning Graphics	320	79.6	28
Tropical Cyclone Danger Graphic	314	75.8	34
Forecast/Advisory Text Product	314	74.3	34
Tropical Cyclone Local Watch/Warning VTEC Text Product	327	71.7	21
Tropical Cyclone Discussion Text Product	301	69.2	47
Public Advisory Text Product	315	69.1	33
Key Messages Graphic	296	66.2	52
Hurricane Threats and Impacts Graphics	290	65.9	58
Hurricane Local Statement Text Product	285	64.2	63

The survey also indicated that respondents across all sectors in both the Atlantic and Pacific Regions are very familiar with the Cone Graphic (see Table 10). Large percentages have seen the graphic at the NHC/CPHC web sites (94 percent) and on local/national news (81.6 percent).

Table 10. Familiarity with Cone Graphic, Atlantic and Pacific Regions Combined

Sector	N	Not at All Familiar	Slightly Familiar	Moderately Familiar	Very Familiar	Extremely Familiar	Score
Energy and Utilities	72	0	0	2	23	47	90.6
Marine	158	0	1	5	52	100	89.7
Tourism and Recreation	113	1	2	2	43	65	87.4
Transportation	134	0	3	7	49	75	86.6

Forecast Parameters Needed for Decision-Making

The survey asked respondents to identify the forecast parameters that they consider in their decision-making. Of the 18 parameters provided, storm track, storm intensity, storm size, time of onset of sustained tropical-storm-force winds, and sustained wind speed at a specific location all were cited by more than 300 respondents (see Figure 3).

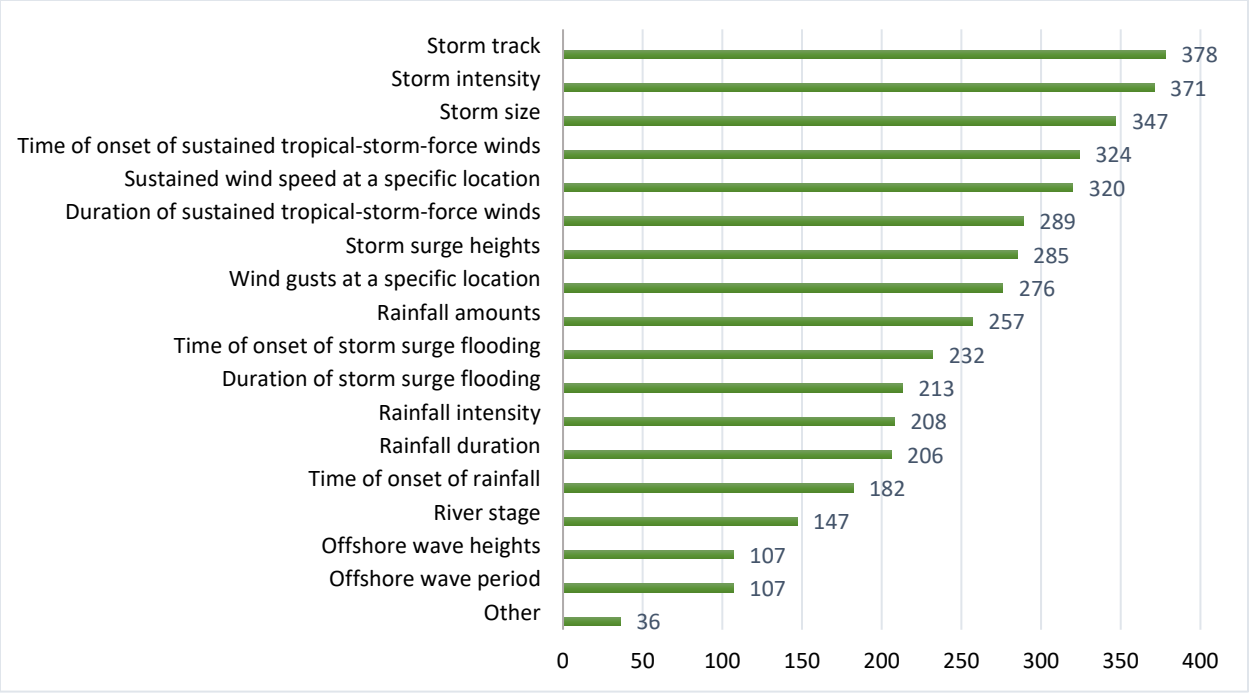

Figure 3. Forecast Parameters

Importance of the Cone Graphic on Decision-Making

The Cone Graphic is important to all sectors' activities, operations, and decision-making. The graphic was rated as particularly important to decision-making for the tourism/recreation and marine sectors. Across all sectors, respondents rated "spaghetti" (ensemble) graphics as less important than the Cone Graphic in their importance to decision-making.

Interpretation of the Cone Graphic

The survey showed misunderstandings across all sectors about certain aspects of the graphic, including believing that cone size depends on the degree of uncertainty in the track forecast for a particular storm (which it does not).

There were also misconceptions that the graphic depicts:

- Areas that could experience strong winds[1]
- When strong winds are likely to arrive

[1] The cone of uncertainty itself does not show areas that could experience strong winds. The NHC/CPHC Cone Graphic, which includes the cone of uncertainty along with other features, does display coastal Hurricane and Tropical Storm Watches and Warnings (which relate to coastal areas that could experience strong winds), but the graphic does not currently include inland or marine Watches and Warnings. Thus, not all areas at risk of strong winds are depicted. In addition, some users (e.g., broadcast meteorologist) often present the cone of uncertainty by itself without displaying concurrent coastal watches and warnings.

- All the possible tracks for a storm.

Ease of Use and Clarity of the Cone Graphic

The survey asked respondents to assess the information content of the Cone Graphic on a five-point agreement scale ("Strongly disagree," "Disagree," "Neither agree nor disagree," "Agree," and "Strongly agree"). Respondents tended to agree that the graphic is effective in showing where the storm is likely to go and in helping to decide when and whether to prepare. There were differences in opinion (some statistically significant) [2] about some aspects of the graphic by sector and storm experience (see Table 11 and text boxes on next two pages).

Table 11. Factors Assessing the Content of the Cone Graphic, by Sector

Factor	Tourism and Recreation		Energy and Utilities		Marine		Transportation	
	N	Odds Ratio	N	Odds Ratio	N	Odds Ratio	N	Odds Ratio
It provides *all* the information needed for preparation decisions	111	1.42	67	2.50***	156	1.32	131	1.42
It shows where the storm is likely to go	111	1.05	67	1.26	156	1.07	131	0.73
It covers the area of all possible tracks for a storm	110	1.58**	67	1.09	156	0.98	129	1.17
It is easy to understand the different symbols and labels on the map	111	1.69**	67	1.31	156	0.91	131	1.27
It is hard to understand the legend	111	0.77	67	0.90	156	1.51*	131	1.09
It is useful in deciding when and whether to prepare	111	1.44	67	2.04**	156	1.34	131	1.20
I do not get all of the information I need from this graphic	110	0.86	66	0.49**	155	0.93	130	0.99
It provides too much information	111	0.79	67	0.70	155	1.20	131	0.89

* Significant at the 10 percent level; ** significant at the five percent level; *** significant at the one percent level

[2] The statistical significance of an odds ratio is judged by comparing the value to 1.0; values that are significantly different than 1.0 are considered statistically significant. Lower levels of significance are associated with stronger results; that is, a result that is significant at the 1 percent level indicates that we are 99 percent confident that the estimated value is larger (or smaller) than 1.0 (i.e., the value 1.0 is within a 99 percent confidence interval around the estimated value).

SECTOR-SPECIFIC FINDING: ENERGY/UTILITIES

The energy/utility sector may be relying too heavily on the Cone Graphic for decision-making. These entities were 2.5 times more likely than the other sectors to say that they get ***all*** the information they need from the graphic and more than 2 times more likely than the other sectors to agree that the graphic helps them decide when and whether to prepare.

SECTOR-SPECIFIC FINDINGS: MARINE

Compared to other sectors, those in the marine sector tended to find the legend hard to understand (this finding was statistically significant) and the symbols hard to understand (not statistically significant). In response to a question asking for suggestions on ways to enhance the graphic, several commenters mentioned they preferred the Mariner 1-2-3 Rule graphic.

SECTOR-SPECIFIC FINDINGS: TOURISM/RECREATION

While the tourism/recreation sector misunderstood certain aspects of the graphic (for example, tending to believe that it shows all the possible tracks of a storm), it also rated the graphic effective, easy to understand, and important to decision-making. Compared to the other sectors, the tourism/recreation sector was more likely to agree that the symbols and labels on the map are easy to understand (statistically significant). They disagreed more than the other sectors with the statement (inversely worded) that it is hard to understand the legend (but this finding was not statistically significant).

Assessment of Graphic Features

Respondents rated most of the graphic features of the visualization in the moderately high range (score > 50, but < 80) as depicted in Table 12. Those that had experienced extensive impacts in a prior storm were much less likely to rate the uncertainty cone or the center track line as being effective. The disclaimer was rated highly but 77 respondents also had no opinion about it.

Table 12. Assessment of Graphic Features

Graphic Feature	All Sectors			Odds Ratio Comparing Those With…	
	N	Score	No opinion	Prior Storm Experience with Impacts	No Storm Experience with Impacts
Labels	320	65.0	5	0.98	1.07
Colors	319	63.3	6	0.94	0.98
Cone	323	61.8	2	0.64*	1.17
Center track line	312	72.0	13	0.52**	0.94
Disclaimer	248	88.3	77	0.81	1.26
Forecast position symbols	315	69.0	10	1.24	0.96

* Significant at the 10 percent level; ** significant at the five percent level, *** significant at the one percent level

Storm Experience Matters

In some instances, the survey revealed differences between those who had prior experience with a storm with extensive impacts versus those that lacked this experience. These differences related to how they used the graphic in decision-making, as well as their assessments of the graphic.

Those with prior storm experience were:

- Less likely to agree that the Cone Graphic provided all the information they needed for preparation decisions.
- Less likely to agree that the graphic shows where the storm is likely to go.
- Less likely to rate the actual uncertainty cone feature or the center track line effective.
- More likely to understand that impacts can occur outside of the cone.
- More inclined to agree that locations adjacent to the cone could experience impacts in addition to a location inside the cone.

Ideas for Enhancing the Graphic

Respondents provided ideas for enhancing the graphic in response to an open-ended question in the survey. Many respondents liked the Cone Graphic the way it is and/or had no suggestions for improving it. Some suggested simplifying it or modernizing its look, while others suggested adding more types of information to the graphic. However, there was also a recognition that a single graphic cannot depict everything and that other sources of information are available to get these additional parameters.

In addition, there were suggestions to:

- Break the graphic into two or three separate graphics.
- Make the graphic interactive.
- Provide the capability of layering information and toggling on or off layers of interest.
- Depict other storm hazards (e.g., rainfall, storm surge, tornadoes), or direct a user to other sources to find this information.

Summary of Cross-Cutting Research Themes

Across all three phases of the research, some common themes emerged, as described below.

Misinterpretations

Misinterpretations of the Cone Graphic by non-experts are well documented in the literature, and the international meteorologists also felt the graphic was largely misunderstood by the public. However, the sector-based survey conducted in this research showed that professionals with many years of experience also have some misunderstandings about the graphic. These findings signify there may be confusion about how the Cone Graphic is derived and what it represents.

Ubiquity and Familiarity

All of the international meteorologists reported using the graphic and sharing it with their partners and members of the public. They also indicated that their partners and members of the public are very familiar with the graphic. The survey also showed that respondents in the sectors studied were very familiar with the Cone Graphic.

Even though there are misunderstandings about the Cone Graphic, the literature suggests that it is the most well-known and pervasive (and sometimes the only) NOAA hurricane product that members of the public access (Bostrom et al., 2018; Bostrom et al., 2016). This may be because people are more likely to seek hurricane information from television, radio, social media, and internet sources and well as their own social networks (King, 2018; Bostrom et al., 2018: Bostrom et al., 2016; Morss and Hayden 2010).

Therefore, members of the public may not be aware of other types of NOAA forecast products. The NWS, NHC/CPHC, and WFOs create many products that provide information to support decision-making needs, but members of the public may not know about them or be able to understand them. For example, Bostrom et al. (2016) estimated that during Sandy, “the NHC and WFOs issued over 500 different forecast, warning, and advisory products; the NHC alone issued 12 different communication product types and over 300 graphical products.” Yet despite the availability of this NOAA information (which was augmented by an abundance of hurricane information from broadcasters and public officials), members of the public still failed to receive key information about their storm surge risk (Bostrom et al., 2016).

Value to Decision-Making

The research showed that the Cone Graphic is valuable (even critical) to decision-making for international forecasters and the sector professionals that responded to the survey. At the same time, they recognize that the graphic is just one piece of valuable information among many other resources. Professionals consult many different sources of information at different times when making hurricane preparation and response decisions.

For members of the public, hurricane graphics are just one piece of risk information they may consider across a continuum of decision-making, and these graphics may not be as influential on their decision-making as other factors, such as past hurricane experience and risk perceptions (Saunders and Senkbeil, 2017; Lazo et al, 2015).

Messaging

Across all the research, there were criticisms that the Cone Graphic is a complicated figure that attempts to provide too many messages represented by too many graphical elements. Broad et al. (2007) concluded that "Few members of the general public are likely to study this image at length to absorb all of these different messages, even assuming they can understand them in the first place. Such a density of information also makes a distortion of the message by key intermediary communicators, such as the media, more likely." The survey found that respondents tended to agree that the graphic provides too much information. The international meteorologists noted that the graphic requires explanation for public audiences, with some of them packaging it with additional imagery or messaging to provide more context. At the same time that some of the international meteorologists (and some of the survey respondents as well) voiced a desire to see additional parameters on the graphic for forecasting purposes, they were well aware that adding more information could make it overwhelming to interpret.

Conclusions and Next Steps

Visualizations are powerful tools for explaining technical data and scientific processes. They can effectively compress and convey data in an understandable and memorable way. They can often provide insights that people may not glean from written text alone. With interactive functionalities, they can enable a user to be an active participant in learning—not just a viewer. But visualizations cannot fully deliver these benefits if viewers misunderstand or misinterpret them.

Multiple Audiences with Different Needs

A key challenge with the Cone Graphic is that it is widely disseminated/reproduced across so many types of media. As a result, it is used by both sophisticated partners and members of the public. These different audiences have different levels of technical acuity, training, and experience—as well as different ways they access or view the graphic. For example, members of the public are most likely to see a version of the Cone Graphic on a television broadcast, website, or social media platform whereas many professionals access NOAA information online, and many EMs see the graphic as part of a briefing.

Also, different audiences have different needs for the graphic. While members of the public may simply be using the graphic to monitor the situation, EMs and decision-makers are using the graphic (with other information) to make critical planning and preparedness decisions. Also, the tasks that different users are completing *change* as a hurricane approaches land—so the needs may be very different 7 days in advance compared to 2 days out. A key consideration is whether a single graphic can address the needs, tasks, and access methods of all its different users.

Information Depicted

One of the drawbacks of the Cone Graphic is that it does not provide all of the information that is important to decision-making—such as the storm size, intensity, confidence in the forecast track, where the worst weather will be, what the potential impacts might be, and what hazards (rainfall, tornadoes, storm surge, wind) to be concerned about. If the Cone Graphic continues to be the only or primary hurricane product the public sees before a storm, NOAA might consider adding more of these types of

data to the graphic. This could help the public more easily relate the forecast to their personal risk and increase their protective decision-making.

However, the research also indicated that it would be challenging to visually present all this information in one static graphic, which could potentially overwhelm the end user and cause them to misinterpret/miss key information—especially since there are already perceptions that the current graphic is trying to convey too many messages.

Ways Forward

There are many possible ways forward—or combination of approaches—from no change to minor change to a complete rethinking of the current visualization (see Figure 4):

- **Education:** Continue building on efforts to provide education on the visualization, such as a recent NHC video explaining the graphic.
- **Cosmetic changes:** Consider ways to enhance the current visualization (e.g., modernize the look, declutter the legend, reduce the number of elements included, provide more explanatory context).
- **More major changes:** Build on the work the NHC has already done with making the graphic interactive on its website. Test this version of the graphic (or other prototypes) with user groups to determine if this kind of approach meets their needs. Throughout the research, there were repeated suggestions to use technological advances and the mainstreaming of more visual techniques (e.g., simulations, virtual reality, interactive displays) to develop and test alternative cone visualizations.
- **A new visualization:** Consider a new visualization all together to address the fundamental misinterpretations documented in the literature—and the desires expressed for additional types of information that would better inform decision-making.

It should be noted that any kind of change can provoke rejection or opposition, particularly with a product that is so well-known. Therefore, going forward, it is suggested that the NWS test any potential changes or prototypes with user groups and consider implementing any changes, particularly major ones, incrementally.

Figure 4. Spectrum of Change Possible

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