

Misinterpretations of the “Cone of Uncertainty” in Florida during the 2004 Hurricane Season

BY KENNETH BROAD, ANTHONY LEISEROWITZ, JESSICA WEINKLE, AND MARISSA STEKETEE

Rigorous pretesting, including insights from social science, could improve hurricane forecast graphics aimed at the general public.

Societies' ability to cope with natural hazards such as hurricanes is mediated by many factors, including socioeconomic constraints (Diaz and Pulwarty 1997; Peacock et al. 1997), cultural preferences (Douglas and Wildavsky 1982; Hewitt 1983; Whitehead 2003), demographic patterns (Pielke and Landsea 1999; Pielke and Pielke 1997), technological and scientific advances (Rappaport and Simpson 2003), and the communication and subjective interpretation of probabilistic information (National Research Council 2003; Loewenstein et al. 2001; Kahneman et al. 1982; Murphy et al.

1980). This article focuses on media and public interpretations of the National Hurricane Center's (NHC's) “cone of uncertainty”¹ (“COU”), a hurricane forecast graphic that circulated widely in Florida during the active 2004 Atlantic hurricane season (1 June–30 November), and concludes with a broader discussion of hurricane forecast graphics from the perspective of risk communication theory.

The cone of uncertainty is only one piece of information that may be used in an individual's decision-making process; thus, no claims of direct causality regarding evacuation behavior or other public responses

¹ Although the image is officially referred to as the “Tropical Cyclone Track and Watches/Warning,” in interviews and by the media it has been given several different titles (to be discussed later). For the purpose of this paper we refer to it as the “NHC cone of uncertainty,” unless otherwise specified.

AFFILIATIONS: BROAD—Rosenstiel School of Marine and Atmospheric Science, and Center for Ecosystem Science and Policy, University of Miami, Miami, Florida, and Center for Research on Environmental Decisions, Columbia University, New York, New York; LEISEROWITZ—School of Forestry and Environmental Studies, Yale University, New Haven, Connecticut, and Center for Research on Environmental Decisions, Columbia University, New York, New York; WEINKLE—Center for Research on Environmental Decisions, Columbia University, New York, New York; STEKETEE—Rosenstiel School of Marine and Atmospheric Science, University of Miami,

Miami, Florida

CORRESPONDING AUTHOR: Kenneth Broad, University of Miami-RSMAS, 4600 Rickenbacker Causeway, Miami, FL 33149
E-mail: kbroad@rsmas.miami.edu

The abstract for this article can be found in this issue, following the table of contents.

DOI:10.1175/BAMS-88-5-651

In final form 18 January 2007
©2007 American Meteorological Society

are made in this article. Nonetheless, secondary evidence gleaned from other sources, including surveys of hurricane behavior, media reports, and in-depth interviews with hurricane forecasters, suggests that many members of the public pay close attention to this graphic, consider it as part of their decision-making process, and, at times, misinterpret it. The importance of this graphic was also identified by a comprehensive, multiagency study of behavioral responses, including evacuation actions, by officials and the general public in Florida during the 2004 hurricane season, conducted by the Federal Emergency Management Agency (FEMA), U.S. Army Corps of Engineers, and National Oceanic and Atmospheric Administration (NOAA). One of the three “most striking” findings of this study was that “too many people place undue confidence in the forecast track of the storm” (USACE 2005a, p. 12).

During the annual North Atlantic hurricane season, Florida is inundated with information regarding hurricane preparedness and updates on looming storms. NOAA’s NHC² relies heavily on the private sector to disseminate forecast information (Golden 1984). When a tropical cyclone threatens to make landfall, local television news stations often go into continuous coverage, alternating between forecast information, live footage of current weather conditions, and updates on government actions (e.g., evacuation orders, shelter locations, school closures, etc.).

The centerpiece of information used by both the NHC and the media to communicate hurricane risk to the public prior to landfall is the cone of uncertainty graphic (Fig. 1). This graphic has been coined “the

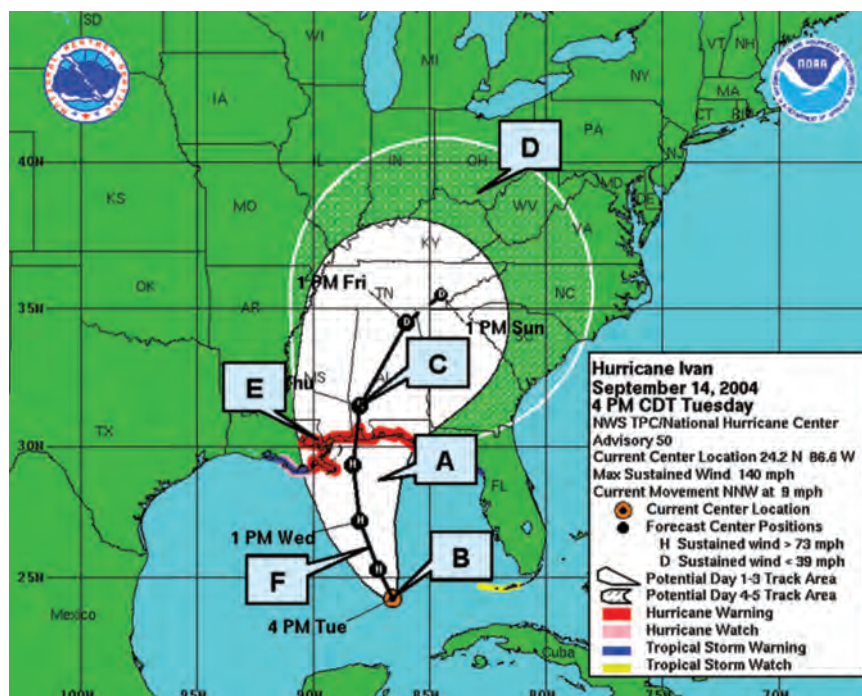


FIG. 1. “The cone of uncertainty.” A: Solid white area of cone indicates average forecast error out to 3 days, B: present location of storm’s center, C: forecasted location and intensity (i.e., H = Hurricane, S = tropical storm, D = depression) at a given time, D: nonwhite area of cone indicates average forecast error for days 4 and 5, E: coastlines under a watch/warning indicated by color-coded highlighting, and F: forecast track line, skinny black line (online at www.tpc.ncep.noaa.gov/archive/2004IVAN_graphics.shtml; modifications used to describe image made by authors).

cone” by the mass media (an abbreviation of a number of terms, including “cone of uncertainty,” “cone of probability,” “cone of error,” and the “cone of death”). Modified versions of the original NHC product have become familiar figures to most Floridians, and this iconic image is now firmly embedded in popular culture (Fig. 2). For example, one local news stations now offers the “cone on your phone” as an alternative way to access forecast information when a storm threatens South Florida (see information online at www.wsvn.com/eupdate/phonealerts.html).

The NHC cone of uncertainty includes the following several elements: the forecast track line, the white “cone” used to symbolize the 10-yr-averaged forecast error, colors used to designate hurricane watch and warning areas, and background elements, such as the legend, scale, and underlying map (e.g., of the southeast United States, the Gulf of Mexico, etc.).

The intention of the NHC cone of uncertainty, as described by the Tropical Cyclone Program Manager at the National Weather Service Headquarters, is “to provide information on any given tropical cyclone

² NHC is part of the National Center for Environmental Prediction (NCEP) and the Tropical Prediction Center of the National Oceanic and Atmospheric Administration’s National Weather Service (NWS).

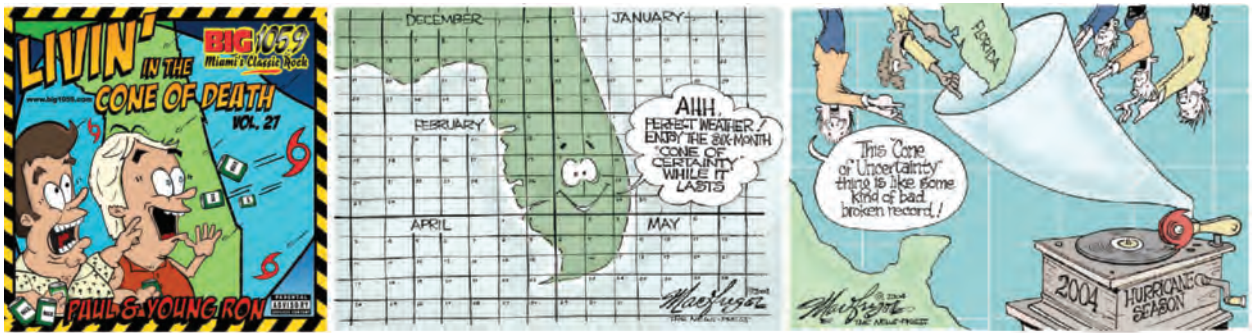


FIG. 2. Examples of the cone's use in popular culture (available online at www.big106.com; www.news-press.com).

so those potentially impacted can make timely and responsible decisions” (S. Kiser 2005, personal communication). Nonetheless, the 2004 hurricane season (in which four named storms struck Florida) demonstrated that hurricane-warning graphics, despite admirable attempts by the forecast community to make user-friendly products and to reach out to emergency managers and the media, are subject to misinterpretation by many members of the public. Based on interviews with key government officials and media figures, archival research of Florida newspapers, analysis of the 962 responses to a NWS request for comments on their cone of uncertainty graphic, surveys from the “2004 Hurricane Season Post Storm Assessment” of the National Hurricane Program, and the risk communication literature, this paper identifies several characteristics of the graphic that likely contribute to public misinterpretations. We suggest that NHC forecast providers both reevaluate their message (the cone) and more systematically identify the needs and predispositions of target audiences in order to design better information products.

The evolution of hurricane forecasting and dissemination. Technological advancements in radar and weather reconnaissance aircraft have greatly improved hurricane forecasts (Rappaport and Simpson 2003). By 1954, 24-h forecasts of hurricane tracks were being made. By 1961, forecast ability extended to 48 h, and by 1964 72-h forecasts were being made (DeMaria and Gross 2003). Today, hurricane forecasting relies heavily on satellite data and imagery, especially outside the North Atlantic Ocean, where the use of aircraft reconnaissance is not as common (Willoughby 2003). Still and animated satellite images of hurricane tracks over ocean and land are prevalent features of televised hurricane forecasts.

The NOAA Environmental Visualization Program, part of the NOAA National Environmental Satellite Data and Information Service (NESDIS), provided

satellite images of hurricanes with overlaid forecast-track information for the first time in 1999. Although these new images were not official forecasts, all information in the images was scientifically accurate. Local and national news media quickly adopted and broadcasted these images to the public (T. Loomis 2005, personal communication).³ Some researchers have attributed reduced U.S. mortality from hurricanes “at least in part, from the visual impact of broadcast satellite information” (Willoughby 2003).

Hurricane-track forecasting continues to improve. As of 2005, NHC 3-day-track forecasts are now as accurate as 2-day forecasts were in the late 1980s (see information online at www.nhc.noaa.gov/verification/). By contrast, storm intensity remains hard to forecast, in part because relatively weak hurricanes can grow into major storms in just a few hours (Landsea and Lawrence 2004).

Hurricane forecasting, however, still retains subjective elements. Forecasters consider computer model output, current weather conditions, and their own individual experience in the process of constructing a forecast. In other words, forecasts are not solely the result of computer simulations; thus, “if you were to plot the model guidance and the official forecast on one chart, you would normally see they do not match . . .” (S. Kiser 2005, personal communication). Forecasters draw on an assortment of models, including statistical, trajectory, and dynamical models (J. Franklin 2005). Because of the improvements in three-dimensional dynamic models, NHC forecasts have improved substantially in the past 15 yr (J. Franklin 2005, personal communication). Forecasters

³ Although Loomis found it hard to believe that the Environmental Visualization Program was the first to produce such images, we were not able to find anyone at NHC that could recall if these images began elsewhere (T. Loomis 2005, personal communication; S. Kiser 2005, personal communication).

often average the results of several well-performing models. These “consensus” model averages are considered useful starting points and “on average outperform even the best-performing members of the consensus” (J. Franklin 2005, personal communication). If there is no particular reason to prefer one model within the consensus over the others, the consensus results are used in the construction of the forecast. After evaluating all information, including model output and individual analysis of current weather conditions, and drawing upon personal experience, the official hurricane forecast is ultimately made by a single person—the hurricane specialist on shift (J. Franklin 2005, personal communication).

A second subjective element is a self-imposed reluctance by the NHC to make drastic changes from one advisory to the next, that is, the so-called “windshield wiper effect,” for fear of sending mixed and contradictory signals to decision-making authorities (S. Kiser 2005, personal communication; J. Franklin 2005, personal communication). Franklin (2005) states, “It is far better to have a modest response lag than to jerk the forecast back and forth.” Forecasters are well aware that the naming of a hurricane and forecasting storm track and intensity initiates a host of responses from government agencies, emergency management organizations, and the private sector (Saffir 2003). The dramatic consequences of initiating hurricane warnings are increasingly evident as societal vulnerability to storm damage has greatly risen due to increasing U.S. coastal populations and coastal development (information online at www.magazine.noaa.gov/stories/mag167.htm). Thus, there are extensive socioeconomic implications for both false alarms and missed warnings. Also, because lives and property are at risk, forecasters prefer to err on the side of safety and are reluctant to cancel hurricane warnings, even after projections begin to indicate that a storm is likely to move away from land, so that they may be “as sure as we can [before] conveying a diminishing sense of threat” (J. Franklin 2005, personal communication).

Emergence of “the cone.” The NHC cone of uncertainty that included a track line first appeared in 2002. Prior to the cone of uncertainty, graphical warnings included a dark red circle in the center of an orange circle, representing winds of 74 mph or greater, a white line to represent the storm’s past track to date, red highlights to represent areas under hurricane warnings, yellow for hurricane watches, pink for tropical storm warnings, and light blue for tropical storm watches (see, e.g., information online

at www.nhc.noaa.gov/archive/2000/). While the NHC produced these images, accompanying text and a crude track chart was provided by the National Weather Service Headquarters. A change in senior-level management, technological advancements in computer graphics programs, and the increased use of e-mail with attachments at NWS led to the requirement for images with clearer depiction, more information, and ease of dissemination to NOAA Headquarters, the Department of Commerce, and the White House. Over time the requirements for the images outgrew the abilities of the National Weather Service Headquarters staff and responsibility was transferred to the NHC.

In 2002, the watch and warning graphic was further developed to include a white cone of uncertainty, intended to illustrate the potential geographic range of the track of the tropical cyclone center. However, the image retained the coastal highlights, indicating watches and warnings (Fig. 1, noted as E). The NHC COU (Fig. 1, noted as A and D) is constructed by connecting the outer boundaries of a series of concentric circles by a tangential line, which is why the cone’s end is rounded. Each circle represents a forecasting period (e.g., 36 h) and, critically, has a radius equal to the average error in all forecasted hurricane tracks over the previous 10 yr, in nautical miles (e.g., 128 nm). The cone’s vertex (Fig. 1, noted as B) represents the present location of the storm’s center and widens as the area of average error becomes larger. The solid white area depicts the forecast up to 3 days into the future (Fig. 1, noted as A). The hatched area was added in 2003 and represents a forecast average error for days 4 and 5 (Fig. 1, noted as D). In reality, the NHC’s COU accurately predicts the ultimate path of the tropical cyclone’s center about 2/3 of the time (J. Franklin 2005, personal communication). In other words, one out of three storm centers directly impact areas outside of the cone.

It is important to emphasize that the cone of uncertainty only forecasts the potential track of the center of any tropical cyclone (depression, storm, hurricane), and not the extent of the storm. Thus, the cone does not represent the size of the hurricane, its intensity, or the potential swath of destruction. The cone only illustrates where the eye of the hurricane may travel, based on the average error of track forecasts of all hurricanes over the previous decade; thus, all hurricanes in a given year (e.g., 2005) are illustrated with the exact same cone of uncertainty. The cone is not tailored to the size, severity, or previous behavior of each individual storm, which is perhaps the more intuitive, but incorrect, interpretation of the graphic, especially by the lay

public. Unfortunately, the NHC Web site, during the 2004 season, did not provide a detailed description of how the cone of uncertainty was made, although on the “frequently asked questions” page (online at www.aoml.noaa.gov/hrd/tcfaq/F7.html), the NHC described the characteristics of a storm in relation to the warning graphic associated with each time period (but again, not how the cone was constructed):

NHC forecast tracks of the center can be in error . . . This display shows an approximate representation of coastal areas under a hurricane warning (red), hurricane watch (pink), tropical storm warning (blue) and tropical storm watch (yellow). The orange circle indicates the current position of the center of the tropical cyclone. The black line and dots show the National Hurricane Center (NHC) forecast track of the center at the times indicated. The letter inside the dot indicates the NHC’s forecast intensity for that time.

It is also important to realize tropical cyclones are not a point. Their effects can span many hundreds of miles from the center. The area experiencing hurricane force (one-minute average wind speeds of at least 74 mph) and tropical storm force (one-minute average wind speeds of 39–73 mph) winds can extend well beyond the white areas shown enclosing the most likely track area of the center. The distribution of hurricane and tropical storm force winds in this tropical cyclone can be seen in the Cumulative Wind Distribution graphic displayed below.

The “track line” in particular has led to public confusion, misinterpretation and controversy (Fig. 1, noted as F). A series of black dots represent the forecasted position of the eye through time. The letters within the dots indicate the storm’s status (i.e., tropical storm or hurricane) and were added in 2004 (Fig. 1, noted as C). The dots are then connected by a black line, running through the center of the cone of uncertainty. The line represents the forecasted track of the storm’s center, and the times indicate the storms’ expected time of arrival at the specified geographic location. Overall, the cone of uncertainty has changed little since it was first introduced in 2002.

MEDIA AND PUBLIC INTERPRETATIONS.

Four diverse sources of convergent evidence allow us to infer media and public (mis)interpretations of the cone of uncertainty. These include 1) interviews with local and national television meteorologists about the cone, 2) a multiagency survey on the public response to Hurricane Charley (2004), 3) analysis of newspaper

articles discussing the cone, and 4) public comments on the cone of uncertainty and two proposed alternatives posted on the NHC Web site after the 2004 hurricane season.

Interviews with television meteorologists. Local television stations have become key intermediaries in the communication of hurricane risks. All major local television stations in Florida repeatedly broadcast their own modified versions of the NHC cone of uncertainty during the 2004 hurricane season. Drawing upon the official NHC forecast, individual stations often alter the color and style to match the station’s graphical formats and color schemes, but occasionally make more fundamental changes, including the removal of the hurricane forecast track line.

Television meteorologists in south Florida view hurricanes as their “Superbowl” moment, when public attention is focused upon them and their forecasts prior to a storm’s landfall. In our interviews, all of them stated that a critical responsibility during hurricanes is not only to provide an accurate forecast, but also to provide psychological support before the hurricane makes landfall. “It’s not just the forecast,” said B. Norcross (2005, personal communication), “the whole thing is an emergency message.” Many of these meteorologists have experienced multiple hurricanes and are key sources of information for the public. They also have a unique perspective on public understanding and reaction to hurricane forecasts, through both direct public feedback and viewer ratings.

We interviewed meteorologists from several local television stations: Bryan Norcross and Craig Setzer from the CBS affiliate WFOR, John Morales from Telemundo (an exclusively Spanish station), and Don Noe from the ABC affiliate WPLG. During “normal” weather forecasting, individual meteorologists typically develop their own forecasts and graphics. For hurricanes, however, many news stations rely on the official NHC forecast. They do, however, often modify the appearance of the NHC cone of uncertainty graphic. For example, WFOR in Miami uses the official NHC forecast and data to construct their own cone with the track line removed (B. Norcross 2005, personal communication). WFOR uses the NHC data to avoid confusing the public with conflicting forecasts (C. Setzer 2005, personal communication). B. Norcross (2005, personal communication) and D. Noe (2005, personal communication) each said that when on-air, they try to explain what the cone of uncertainty is and what it means in detail, while J. Morales (2005, personal communication) said he does not.

Morales said that while he uses the NHC forecast, he does not always agree with it. He argued that giving his own opinion and offering as much additional information as possible, even if it contradicts the NHC forecast, helps people make their own decisions. He only provides contradictory information, however, if he has very strong feelings based on his own experience. Similarly, during Hurricane Charley, meteorologists Jim Reif from ABC affiliate WJLA and Robert Van Winkle from NBC affiliate WBBH each notified their viewers of a wobble on the radar that seemed to indicate that the storm had veered from its forecasted track several hours before the NHC mentioned the change. Thus, these broadcasters went “out on a limb without the hurricane center,” said Reif (Boxleitner 2004).

Several of the meteorologists we interviewed have removed the forecasted track line from their station’s graphics. C. Setzer (2005, personal communication) expressed concern that the line conveys more certainty than actually exists. Even with the line removed, he and his colleagues consciously strive to emphasize the uncertainty in the image (C. Setzer 2005, personal communication). The Weather Channel, another important source of information for the public (USACE 2005b, p. 60), also removed the track line. One station, however, that does continue to include the track line from the NHC graphic is WPLG. Their alterations, done by a third-party graphic provider, include color coding to reveal the projected Saffir–Simpson category at a given time. The line is described on-air as the forecasted track line, followed by a description of the error associated on either side of the line. The exact wording varies by the meteorologist broadcasting at the time (D. Noe 2005, personal communication). A second broadcast that continues to use the track line is the national CBS Evening News. They explained they do not have their own staff meteorologists and therefore use the information directly from the NHC. The graphic image is changed slightly, however, to remain consistent with the program’s visual formats (News Desk, CBS Evening News 2005, personal communication). Finally, Morales at Telemundo also uses the graphic from NHC. The graphic is altered only for aesthetic purposes and accompanies his verbal commentary (J. Morales 2005, personal communication). Thus, communication of the official NHC cone of uncertainty to the public is mediated by the differing interpretations and strategies of local weather forecasters, who are often the primary source of hurricane warning information for the public. In essence, several different versions of the cone are currently being com-

municated to the public, with possibly significant consequences. It is outside the scope of this study to determine the relative effectiveness of the various modifications to and explanations of the NHC’s COU made by the media.

2004 Hurricane Charley. In 2004, Florida was struck by four hurricanes in just 2 months (Charley, Frances, Ivan, and Jeanne). The NHC cone of uncertainty graphic became the subject of controversy after Hurricane Charley, with some critics claiming that it confused the public because it “unduly focused the users of the graphic too much on the track forecast line” (S. Kiser 2005, personal communication). Hurricane Charley provided an illustrative example of how the cone of uncertainty graphic may lead some to misinterpret forecasts.

By 11 pm Wednesday, 11 August, most of Florida’s west coast was under a hurricane watch. By 5 pm the next day, hurricane warnings extended from the lower Florida Keys to north of Tampa Bay. Critically, however, the track line within the cone of uncertainty graphics issued by the National Hurricane Center between 5 am on Thursday, 12 August and 11 am on Friday, 13 August projected that the center of Hurricane Charley would pass directly over Tampa Bay. The track line within the cone of uncertainty graphic issued at 2 pm on Friday, 13 August, however, suddenly projected that the hurricane would pass instead over Charlotte County approximately 100 miles south of Tampa (Fig. 3). Hurricane Charley ultimately struck Punta Gorda, about 70 miles south of Tampa, at about 3:45 pm as a category 4 storm, with winds of 145 mph. Charlotte County, which contains one of the largest percentages of people older than 65 in the nation (Breed 2004), was devastated. Charley became one of the costliest storms in U.S. history, causing an estimated \$15 billion in damage (adjusted for inflation) (Blake et al. 2005).⁴

In the aftermath, it became evident that many people in Charlotte County had not evacuated. Some argued that the cone of uncertainty graphic had played a role. There are contrasting points of view on how the media provided information to the public based on the NHC forecast and/or cone of uncertainty graphic. For example, FOX4 News meteorologist Dave Roberts stated, “A lot of the folks here [in Charlotte County] weren’t taking it [Charley] seriously. It was supposedly this big problem for Tampa Bay.”

⁴ For a detailed description of the meteorological conditions and characteristics of Hurricane Charley and all other named Atlantic storms during 2004, see Franklin et al. (2006).

(Boxlietner 2004). WFOR News meteorologist Bryan Norcross argued that much of the television coverage on Florida's west coast inappropriately urged the public to pay attention to the forecasted track line, leaving those within the cone, but not on the line, vulnerable to wobble in the hurricane's path (B. Norcross 2005, personal communication). The NHC cone of uncertainty graphic was also criticized by some county officials. For example, John Wilson, head of emergency management for Lee County (also impacted by the storm), subsequently argued that the NHC should eliminate the track line because it caused confusion. For example, early forecasts showing the line shifting from Fort Myers (in Lee County) to Tampa Bay led some residents of Fort Myers to believe they were out of harm's way (Boxlietner 2004).

Yet, landfall probabilities along the entire southwest Florida coast, including Charlotte County, remained essentially the same all of Wednesday and Thursday (infor-

mation online at www.tpc.ncep.noaa.gov/archive/2004/CHARLEY.shtml). Charlotte County was also well within the area of the cone in the forecast graphics produced during this time, and National Hurricane Center forecasters repeatedly cautioned people that forecasts were imprecise. Afterward, in response to criticism about the Charley forecast, Max Mayfield, director of the NHC, defended the sudden change in the storm track just before Charley made landfall. He argued that there should have been no surprise:

The Charlotte Harbor area was within the hurricane warning area for 24 hours. *They were in the cone of uncertainty for four days.* [emphasis added] The strike probability at 5 a.m. on the morning of landfall—and landfall was about 4 p.m.—was 50 percent, and higher than that at 11 a.m. So they really shouldn't say they were surprised. For us, that was a very good forecast (Stone 2005).

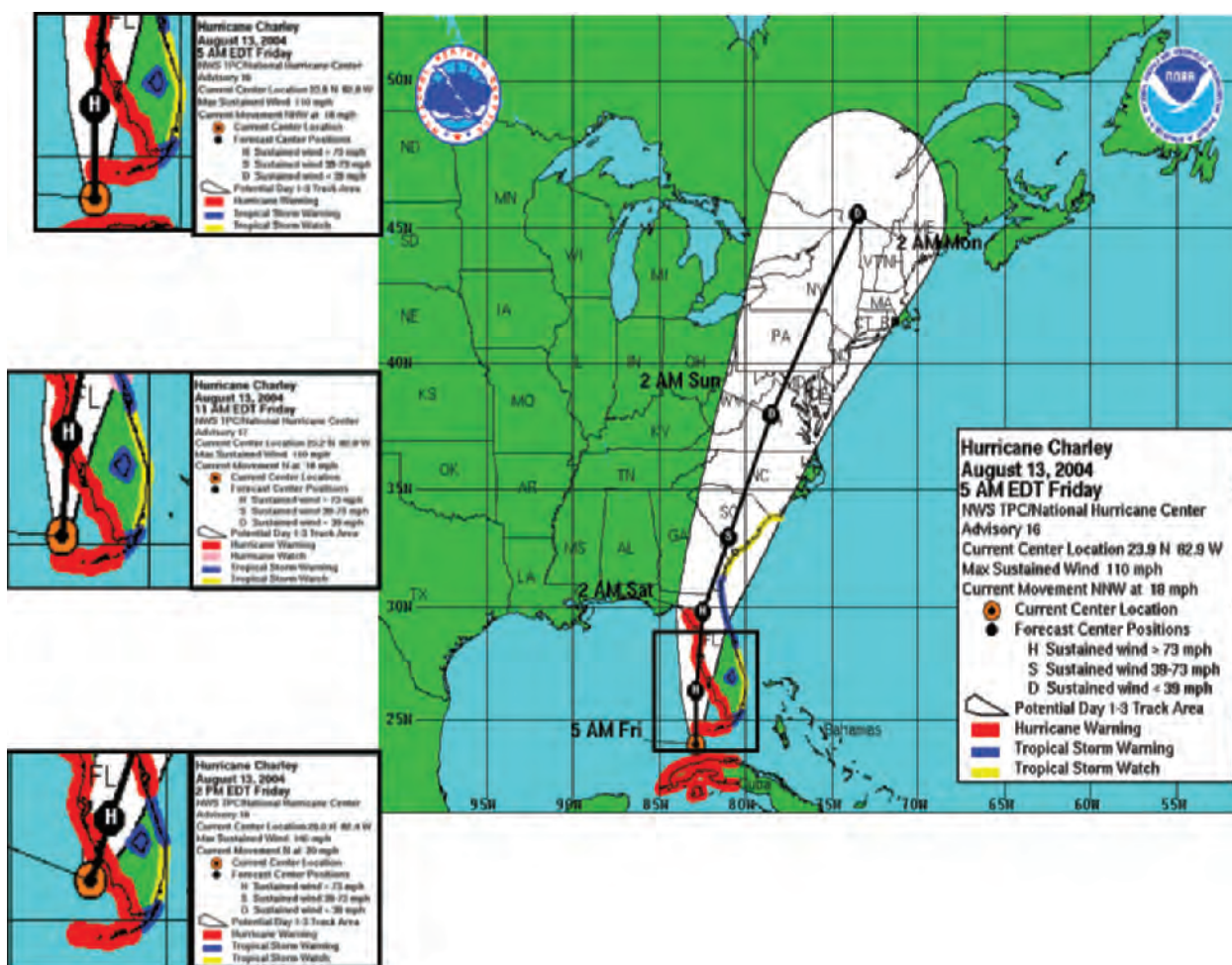


FIG. 3. Three consecutive forecasts for hurricane Charley. Many people were misled by the forecasted track line. Notice the sudden shift of the line toward the south (available online at www.tpc.ncep.noaa.gov/archive/2004/CHARLEY_graphics.shtml).

The key issue, however, was that the NHC track line for forecasts issued on 12 August and early on 13 August consistently went near Tampa.

A subsequent multiagency survey of public behavior during Hurricane Charley found that the majority (57%–68%) of respondents in all areas studied said the cone of uncertainty graphic was a “very important” factor in their evacuation decision (USACE 2005b, p. 38).⁵ Likewise, in an open-ended question, the forecasted track of the storm was one of the highest volunteered reasons for why individuals either did or did not evacuate, demonstrating that many Floridians were using some version of the cone of uncertainty graphic in their decision making.

The survey also found that people living within category 1 risk zones in Tampa Bay were significantly more likely to evacuate (53%) than people living in similar zones in southwest coastal Florida (including Charlotte County; 31%) (USACE 2005b, p. 4). The survey also found that Tampa Bay residents were more likely (68%) than residents in southwest coastal Florida (59%) to say that the forecast graphic was very important in their evacuation decision. By contrast, of those respondents from southwest coastal Florida who did not evacuate, roughly half said they “would have left had it appeared that Charley was going to hit their location directly.”

Misinterpretations of the cone of uncertainty were not limited to Hurricane Charley. One of the primary conclusions of the multiagency survey of behavior responses to *all* of the storms of the 2004 hurricane season was that “Many people believe the storm will miss them, placing too much faith in the storm forecast track” (USACE 2005c). Likewise, this study also concluded, based on interviews with Emergency Medical Associates (EMA) management personnel, that “Some EMA’s focused too much on the forecast track” (USACE 2005d).

Taken together, none of these results conclusively demonstrate that public misinterpretations of the cone of uncertainty graphic were a decisive influence on hurricane-related behavior. Protection and evacuation decisions and behavior are clearly the result of a complicated set of factors, including the forecasted storm track, storm strength, official evacuation notices, housing types, previous hurricane experience, access to transportation, fear of looters,

pet ownership, etc. Yet collectively, they do suggest that public misinterpretation of the graphic, such as the tendency to overfocus on the track line, may be common and may be an important factor in public decision making.

Newspaper analysis. Newspapers are another key source of information about hurricanes for the public. In order to examine newspaper interpretations of the cone of uncertainty, we gathered articles from 14 major Florida newspapers using LexisNexis and the Miami–Dade Public Library System databases. Searches were made for articles containing the phrases: “cone of uncertainty,” “cone of probability,” “cone of error,” “cone of terror,” “cone of possible tracks,” and “cone of death” for the period from 1 January 2004 to 16 August 2005.⁶ Table 1 shows the number of articles found in each paper and Fig. 4 shows a graphical representation of readership by each Florida paper.

KEY TERMS. A total of 101 articles were analyzed; “cone of uncertainty” and “cone of probability” were the most commonly used terms (Fig. 5). It is possible

TABLE 1. Number of articles between 1 Jan 2004 and 16 Aug 2005 mentioning “the cone.”

Newspaper title	Number of articles
<i>Daytona Beach News-Journal</i>	2
<i>Miami Herald</i>	8
<i>Orlando Sentinel</i>	10
<i>Palm Beach Post</i>	28
<i>Sarasota Herald-Tribune</i>	2
<i>St. Petersburg Times</i>	3
<i>The Tampa Tribune</i>	7
<i>Tallahassee Democrat</i>	4
<i>Palm Beach Daily News</i>	1
<i>News Press</i>	20
<i>Florida Today</i>	2
<i>Bradenton Herald</i>	2
<i>Jupiter Courier</i>	2
<i>South Florida Sun-Sentinel</i>	10
Total	101

⁵ It should be noted that although the report did assess public use of the cone of uncertainty and distinguished key elements of the graphic, it did not identify to whose version of the cone (e.g., NHC, particular media outlet, etc.) respondents were referring.

⁶ Again, newspaper articles usually did not identify to which version of the cone of uncertainty (e.g., NHC, particular media outlet, etc.) they were referring.

that some people may interpret the word “probability” (the chance that a given event will occur) incorrectly as “probable” (i.e., likely to happen; Jardine and Hrudey 1997). Thus, the word probability in the cone of probability may lead some to conclude that hurricane-track forecasts are more certain than they are in reality. The NHC does not use the term cone of probability, preferring instead cone of uncertainty. In fact, hurricane specialist James Franklin of the NHC was not familiar with the term cone of probability (J. Franklin 2005, personal communication). Yet, 38% of the articles analyzed used the cone of probability label. At a minimum, the use of different terms may lead to public confusion, and perhaps even significant misinterpretation. This, along with public interpretations of the graphic itself, is a critical need for future research.

TRACK LINE. Much of the controversy generated by Hurricane Charley centered on claims that the public was overconfident in and reliant upon the track line, that is, the “skinny black line” embedded in the white cone that depicts the forecasted track of the hurricane center. In the days and hours leading up to the landfall of Charley, multiple cone of uncertainty graphics had projected that the eye would hit Tampa. In the last hours, however, the storm veered from this track line and hit Punta Gorda and Charlotte County instead. This shift in the track line remained well within the cone of uncertainty, and yet as described above, many subsequently criticized the NHC’s graphics. After Hurricane Charley, there were a

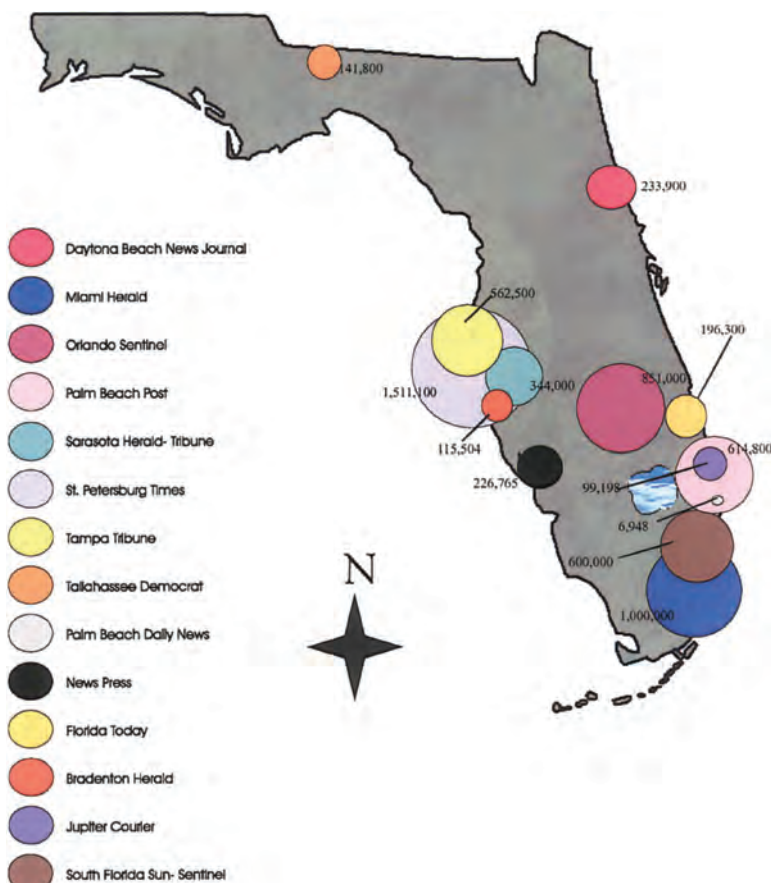


FIG. 4. Newspaper readership numbers. Circulation numbers were used for *Palm Beach Daily News* because readership numbers were not available.

number of articles that debated what should be done about the skinny black line that apparently had caused so much public confusion.

Of the articles reviewed, 42% stated that people should simply not focus on the line because the white cone is actually more important (Fig. 6). For example, Ben Nelson, state meteorologist for Florida, said, “There are lessons to be learned from every catastrophic event [i.e., Hurricane Charley], and the

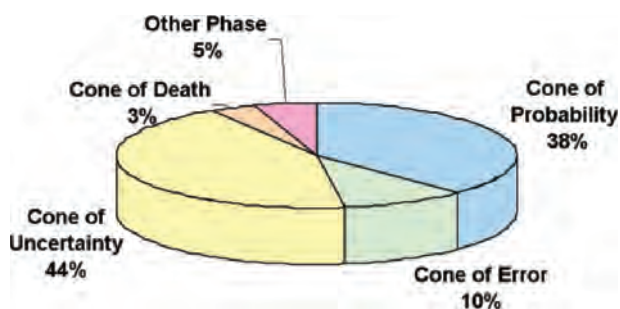


FIG. 5. Number of times a phrase used/total times a phrase is used.

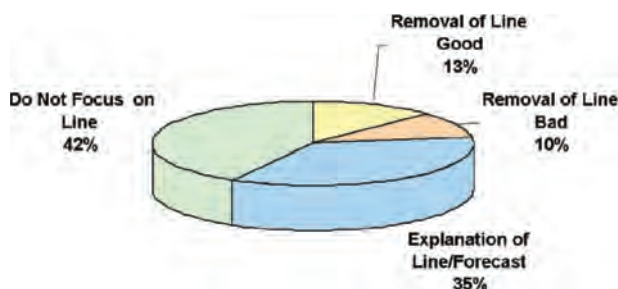


FIG. 6. Regarding “skinny black line.” Percentages are of total number of articles (i.e., one article may contain more than one category).

lesson we need to learn here is people cannot focus on that line the hurricane center provides” (Garcia and Bell 2004). Likewise, Max Mayfield of the NHC stated, “If you know what the black line means and how to use it, there’s no problem. But some people don’t know how to use it” (Kaye 2005). He also joked that he should have “Don’t focus on the skinny black line” engraved on his tombstone (Kaczor 2005).

Another 13% of articles argued that the line should simply be removed from all future uses of the graphic because people overfocus on the line. For example, one article quoted meteorologist Steve Jervis of NBC affiliate WFLA: “People just see it [the line], and their eyes go for right to it.” Likewise, Michele Baker, emergency management director of Pasco County stated, “sometimes because it’s there, people become fixated on it. I think the loss of the line is a good thing” (Johnson 2004).

By contrast, 10% of articles said that the line should be kept in future versions of the graphic. For example, the editors of *The Tampa Tribune* argued, “Unfortunately, some people want to change the National Hurricane Center’s ‘cone of uncertainty’ graphic to provide less information” (*The Tampa Tribune* 2005a). Another person (a flight instructor at Embry-Riddle and an avid forecast watcher) argued that the line is “a good thing, but people need to learn more about what it means” (Pulver 2004). In an interview, Max Mayfield said that FEMA also wanted to keep the line (Johnson 2004).

Finally, 35% of the articles tried to provide some explanation of what the line represents. Most explanations, however, were probably not very helpful. For example, “That’s the most likely forecast track, as established by the National Hurricane Center” and “The line shows the forecaster’s best prediction of a storm’s track. The swath, called the cone of probability, shows possible errors in the forecast” (Kleinberg 2004; *The Tampa Tribune* 2005b). These many articles provide additional circumstantial evidence, from the perspective of forecasters, meteorologists, evacuation officials, and journalists actively engaged with the public, that the cone of uncertainty graphic has produced some level of public confusion.

Public comment. In response to public and media criticism, the NWS requested public comments on the NHC cone of uncertainty graphic and two new alternatives using an online survey. Respondents were asked to vote for their preferred graphic among three options (Figs. 7a, 7b, 8a, 8b, 9a, 9b).

The call for comments was advertised by issuing a public information statement to the media, emergency

managers, private sector, etc. It was also advertised on the Tropical Prediction Center Web site. Finally, local NWS Weather Forecast Offices were asked to spread the invitation via their more direct contacts at the local level (S. Kiser 2005, personal communication). The NWS received 962 responses. Importantly, however, this was not a representative survey of the general population. It was conducted online; thus, participation was strongly biased toward those with Internet access and, perhaps more importantly, a preexisting interest in the NHC and its Web site. Thus, the survey was based on individuals self-motivated to take the survey, which likely produced a biased sample.⁷ Unfortunately, because of legal constraints, the NWS was unable to collect demographic information, making it impossible in the end to determine how representative the results are.

The survey used relatively vague, open-ended questions and did not ask respondents to explain their preferences. Also, some respondents clearly did not understand that the survey presented only three options, not six (Figs. 7–9). The source of their confusion was the survey itself, which pictured the three alternative graphics using two different storms—one that moved along a linear track and one with a more complex track that looped in a circle. For example, one respondent wrote, “I prefer Graphic 1a . . . Next best is 1b in my opinion,” even though 1a and 1b actually represented the same graphic. Another respondent stated, “Option 2A is the least confusion. The ‘b’ options are useful, but to the majority of people, they are JUST TOO cluttered and way too confusing looking.” Thus, it is clear that some respondents misinterpreted the graphics presented in the survey. Not only could the survey have been better constructed, but these responses provide further evidence that people have trouble interpreting the cone of uncertainty. Respondents’ preferences were grouped into the following five categories by the NHC: 1) option 1 (the original cone of uncertainty graphic, Fig. 7), 2) option 2 (Fig. 8), 3) option 3 (Fig. 9), 4) no preference, and 5) cannot determine (Table 2).

OPTION 1 (THE ORIGINAL CONE OF UNCERTAINTY GRAPHIC, FIG. 7). Of the three alternatives provided, a majority of respondents preferred option 1, representing the original cone of uncertainty. In their comments, several respondents mentioned a “margin of error” while another stated, “. . . I believe many people

⁷ However, the final decision on which graphic to use considered newspaper articles, personal contacts and other unsolicited comments sent in to the NWS (S. Kaiser 2006, personal communication).

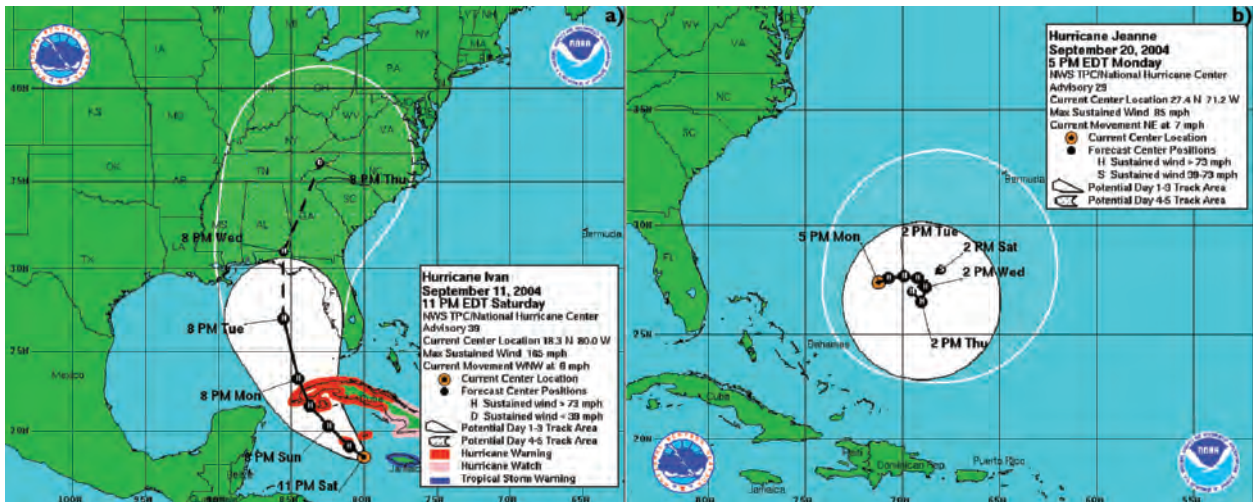


FIG. 7. Option 1 offered by NHC in the request for comments. Note that this is the originally used image (online at www.nhc.noaa.gov/graphicsprototypes.shtml).

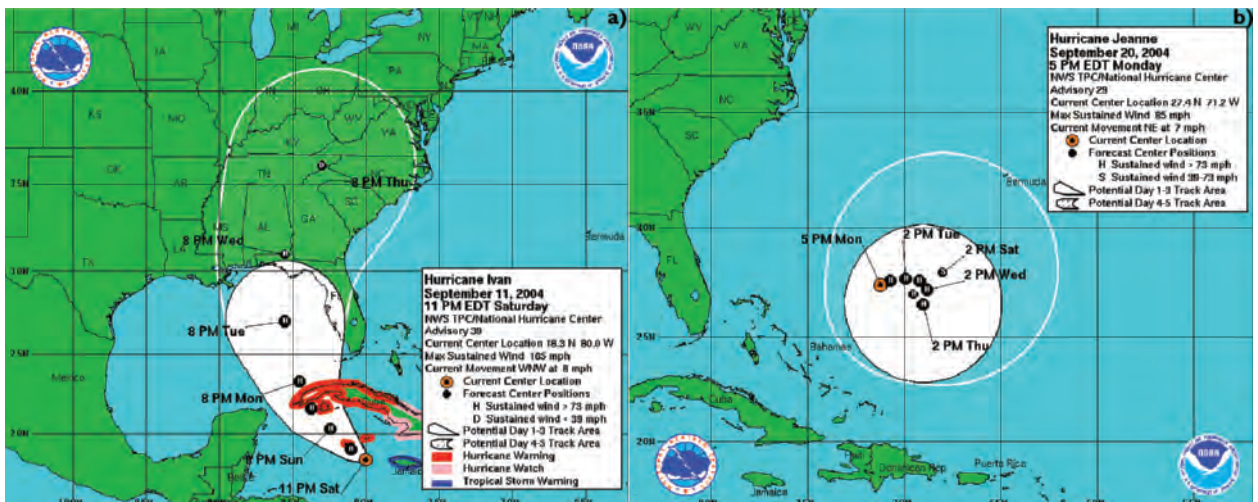


FIG. 8. Option 2 offered by NHC in the request for comments (online at www.nhc.noaa.gov/graphicsprototypes.shtml).

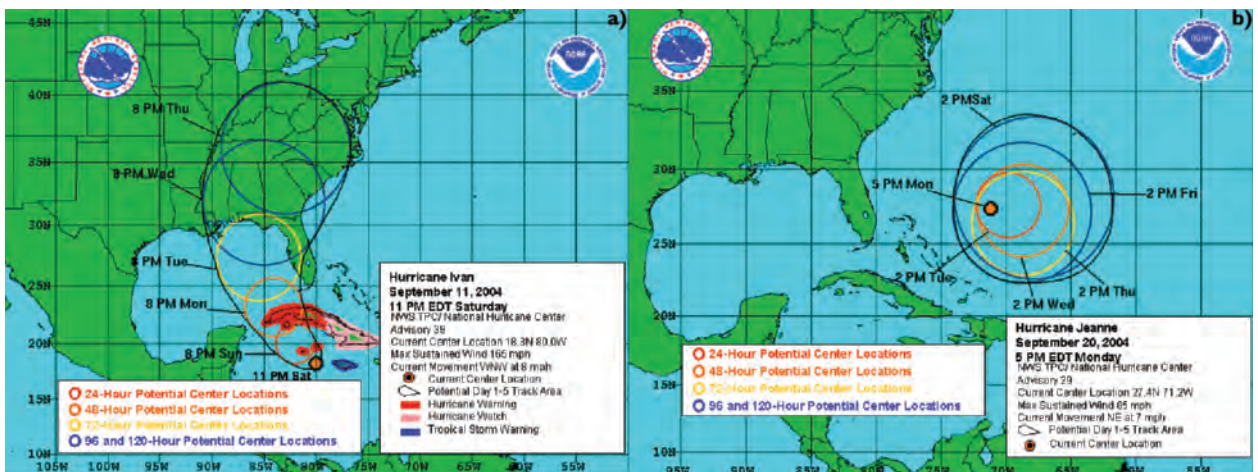


FIG. 9. Option 3 offered by NHC in the request for comments (online at www.nhc.noaa.gov/graphicsprototypes.shtml).

(including myself) focused too much on the ‘center line’ of the forecasts.” These comments imply that some respondents had correctly understood what the cone of uncertainty was supposed to symbolize. Other comments, however, indicate that many continued to misinterpret this graphic: “Stay with graphic 1. This shows the past and forecasted track of the storm.” In fact, the graphic depicts only the present location and forecasted track of the storm, it does not depict the past track. Other respondents argued that because they were now accustomed to the original image they did not want it changed. For example, “Those of us that have lived in the path of these storms are familiar with, and used to, the way you have been clearly warning us and informing us. Please do not let a few people, who may not have been paying attention, cause you to change your system unless you believe . . . know . . . that you have a better system.”

OPTION 2 (FIG. 8). Option 2 (Fig. 8) merely removed the connecting track line, while leaving the dated black dots representing projected future locations of the storm center. Option 2 was the least preferred graphic. Of those who did prefer this version, many argued that even though they liked the original image (Fig. 7), they saw the need to remove the line that had been the source of so much confusion. Thus, they felt option 2 served this need . . . “I think that the Hurricane Center should keep the graphics the way they are, but if you are wanting to change the graphics because there seems to be too much focus on the storm track and not the cone then I would go with the graphic #2 [Fig. 8]. It is something that people are already familiar with and without the line maybe there would be less focus on the track line.”

Similarly, one respondent wrote, I prefer the second, or Graphic #2 [Fig. 8], because it makes everything perfectly clear. It gives the impression that everyone in the area depicted is vulnerable, and must prepare. You are not distracted by the line in the first

graphic or those confusing circles in graphic number 3 [Fig. 9]. By contrast, one respondent complained that “[I] mentally connected the dots and made a track in my mind; that negates the changes you made with Graphic 2.”

OPTION 3 (FIG. 9). The graphic receiving the second most votes was option 3, which provided neither a skinny black line nor dated points, but instead a series of concentric circles. One respondent stated, “The third option—colored circles—is clearly the best. One of the stations used this option for its own broadcasts, and it seemed to be much less confusing, as it eliminates the urge to ‘believe’ the line is THE track.” Similarly, another respondent commented, “I think that the third chat [chart] would help the most. for [sic] the first one it looks like only hte peole [sic] on the line are in danger. but [sic] on the third it looks like everyone in that area hass [sic] a chance of getting hit by the hurricane.” Another respondent argued that “Tracking Chart 3a [Fig. 9a] and 3b [Fig. 9b] on your website is the least likely to be misinterpreted by the media, public and emergency agencies.”

Some respondents, however, still seemed to misunderstand the graphic. One said they liked option 3 best because it illustrated “the area that it [the storm] is effecting [sic].” In fact none of the graphics represent the potentially affected area or swath of destruction—they only depict the potential track of the eye, not the impact zone. Many respondents also did not understand that option 3 and option 1 (the original graphic) provided much of the same information. For example, “I think graphic 3 [Fig. 9] would be the most effective because it gives more possible locations and more choices of where it could move.” “I prefer Alternative #3. I think that it gives people in those potential areas more time to prepare their home for the oncoming storm.” “I think Graphic 3 [Fig. 9] is the best choice since it shows more possibilities.” Interestingly, some respondents apparently experienced visual illusions, believing that Options 2 and 3 depicted a bigger cone of uncertainty: “Graphic 2 [Fig. 8] & 3 [Fig. 9] are too confusing and hard to follow. It gives a bigger cone of uncertainty . . .” “In graphic #3 [Fig. 9], big circles do no one any good and leaves too big of an area of probability and the general public would not follow your forecast as close.” In fact, none of these comments were accurate. All three graphics depicted cones of exactly the same size.

Last, some respondents believed that option 3 offered more information than the other images. While the third image does provide a separate colored circle representing each particular time period, this

TABLE 2. Preferences of respondents to the NHC request for comments as coded by NWS reviewers.	
Preference	Number of respondents
Option 1 (Fig. 7)	540
Option 2 (Fig. 8)	121
Option 3 (Fig. 9)	201
No preference	33
Cannot determine	67
Total	962

graphic actually provides less information because the skinny black line and dated points have been removed. It is possible that the mere addition of more circles gave the (wrong) impression that this version provides more information.

CONCLUSIONS. Hurricane forecasters have made impressive strides in both forecast accuracy and lead time, and, to a lesser extent, the ability to forecast storm characteristics, such as precipitation, spatial extent, storm surge, and wind speeds. The NHC cone of uncertainty represents the state of the art in forecast products. The image has been widely adopted and disseminated to the public by the media, in part because it is a graphic and thus telegenic (Lundgren and McMakin 1998). Yet the cone of uncertainty is a complicated figure, containing multiple messages represented by multiple graphical elements. Some of these elements, namely, the track line and the cone, have been blamed by some for having contributed (to an unspecified degree) to some public confusion during the 2004 hurricane season. 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. Likewise, many people apparently focused on the skinny black line and assumed that only areas along the line were actually at threat, ignoring both the size and severity of the hurricane. The line itself, however, says nothing about how strong or large a storm is. Finally, many people focused on the boundaries of the cone and assumed that if they were outside of the boundaries they would not be impacted. Again, the boundaries only represent a range of uncertainty about the track of the eye. The cone does not provide any direct information about impact risk. Further, the cone itself accurately predicts the ultimate path of the hurricane center only about 2/3 of the time (J. Franklin 2005, personal communication).

At best, the line and cone provide only proxy information about potential hurricane damage, which is probably the information in which people are most interested. The most intense sustained winds in a hurricane are usually found near the eye; thus, in

that limited sense, it does suggest who is most at risk. Again, however, the line says nothing about how big the eye or this particular hurricane is.

By now, public officials and NHC forecasters are keenly aware of peoples' tendency to overly focus on the track line. In fact, several of the media outlets in our study now remove the track line when they reproduce the image for public consumption. Yet, two main arguments are made for keeping the line in the graphic. First, some respondents to the NHC survey said they preferred the original image containing the track line because they were now used to it. While true, the responses also indicate that some of these same people continue to misunderstand what the graphic actually depicts. Also, as described earlier, the solicitation for comments was conducted in manner that very likely resulted in a biased sample. Further, misunderstanding of the image by this group is especially troublesome because this sample (i.e., people interested in the National Hurricane Center Web site) ought to be less susceptible to misinterpretation than the general public.

A second argument for continuing to use the original graphic is made by some meteorologists who claim they have a responsibility to provide all the information that they have available. These proponents of "more information is better" argue that the skinny black line does provide additional information that people can use to make decisions. By itself, however, this is an insufficient argument. More information packed into a graphic is often confusing (Tufte 1983), and when people misunderstand the information, it can lead to flawed decision making: "Poorly designed or produced visuals are worse than no visual at all" (Hager and Scheiber 1997). In this case, one element—the track line—appears to be commonly misinterpreted and potentially subverts the message about uncertainty that the graphic is intended to convey.

We have only begun to understand how the diverse audiences in Florida actually interpret the cone of uncertainty. The above analysis focused on the 2004 Atlantic hurricane season. The subsequent very active 2005 season has further increased public attention on hurricanes, and a flurry of popular press publications dealing with storms has become available. As an example of the continuing misinterpretation, we quote from a book written to help boat owners understand and prepare for storms:

A quick way to get a feel for the storm's progress is to look at the forecasted path on the site's map. [NHC Web site]. The anticipated storm path will be shown as a cone (which actually looks more like a wedge)

projected forward 3 days, with a different-colored cone projecting out 5 days. In both the 3- and 5-day projections, the wider cone of possibility shows the area the entire storm is expected to cover, and the narrower cone shows the area of highest wind and greater severity. The whole cone of possibility shows the geographical area the storm might impact. This cone of possible strike locations gives you some idea of the potential changes in direction the storm might take using current data (Burr 2006, 50–51).

This example is noteworthy and worrisome because the misinterpretations that we identify above continue to manifest in publications that are intended for educational purposes. The quote illustrates that, more broadly, even when people understand that the cone depicts uncertainty, they may still be confused about what specific event is being depicted (Fischhoff 1994).

The challenge of producing a graphic that minimizes misinterpretation raises the difficult question of what to include or exclude in a graphic. Mass media communication products (like the cone) are usually aimed at a broad, general audience with widely ranging education levels, languages, and cultural barriers. Graphics should therefore attract attention and convey a single key point in a simple, uncluttered style (Lundgren and McMakin 1998). The cone of uncertainty graphic produced by the NHC arguably provides too many different pieces of information, including the projected track line, the cone of uncertainty, areas under a hurricane watch, areas under a tropical storm warning, different sustained wind speeds, and the distinction between potential track areas for days 1–3 versus 4–5. 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.

Likewise, there is no perfect “one size fits all” image. No one presentation format or piece of information will be interpreted in the same way by all people. Many other factors influence risk perception and decision making, including the nature of the risk; the trustworthiness and credibility of the messenger; the knowledge, values, and worldviews of the recipient; etc. (Slovic 1999). Thus, the utility of any single risk communication product must be evaluated within the individual, social, and institutional contexts of the recipient. What to include and not include should in part be a function of who

the intended audience is and their ability to handle different sorts of information (Doswell 2004). Thus, those developing risk communication products, like the cone of uncertainty, should consider the following questions: who is the intended audience and what information do they want and need (which they may not realize they need yet)? How relevant is this information, and does it provide enough detail for people to assess the risk to themselves, their property, or their communities (Fischhoff 1994)? For example, some individuals and areas are more vulnerable to storm surge (coastlines), others to wind speed (trailer parks), while others are more vulnerable to the loss of electricity (e.g., those who rely on refrigerated medication). Merely knowing the likelihood that a hurricane might strike a particular area does not provide the more specific information people need to consider when assessing the risks and choosing a course of action. Of course there are many other sources of hurricane information in addition to forecast graphics. Nonetheless, they should ideally be coordinated in order not to contradict each other. [e.g., people ignoring evacuation orders because of their strategic (from a self-serving psychological point of view) interpretation of uncertainty in a forecast graphic].

Given budget limitations, it may be unrealistic to expect agencies to tailor-make different products for different audiences ranging from ethnic subgroups, to local emergency managers, to the elderly. A first step might be to produce a relatively simple graphic to communicate the most vital information using the elements most likely to be correctly interpreted by the widest possible audience. A subsequent step might be to design more sophisticated versions of the simple graphic, containing additional information for emergency managers, FEMA officials, etc. Because the NHC already has close relations with these emergency management groups (see, e.g., www.hurricanemeeting.com), they have the opportunity to explain complex graphics in more depth. Nonetheless, the optimal design of these products is an empirical research question requiring controlled experiments testing alternative products.

Hurricane warning imagery continues to evolve in response to societal needs. Experimental graphics, such as the wind speed probability graphic, to be made operational in 2006 are currently being developed and have been offered to the public via the NHC Web site (Fig. 10). In addition, some news stations have already begun to adopt and adapt these new graphics (e.g., aesthetically and by adding or subtracting information).

More broadly, uncertainty is a difficult concept to communicate. “Many people are unfamiliar with uncertainty in risk assessment and in science in general, making the job of the risk communicators all the more challenging” (Lundgren and McMakin 1998). As a whole, research has found that increased uncertainty leads to greater perceived risk (Slovic et al. 1986). The current cone of uncertainty, however, while explicitly providing information about uncertainty, does so using graphic elements that seem paradoxically to lead many to perceive *lower* risk, as experienced with Hurricane Charley. The skinny black line and the outlines of the cone itself apparently led many to overestimate the certainty of the projected track; therefore, if they did not live within the vicinity of the track line, or alternatively lived just outside the boundaries of the cone, they incorrectly concluded that they were not at risk. Ironically, a graphic intended to convey uncertainty may have had the opposite effect, at least with some members of the public.

The communication of hurricane risk is an essential function of both the government and private sector. Decision makers at all levels, from individuals to institutions, now rely, at least in part, on these messages to make critical decisions about hurricane preparedness and evacuation. The cone of uncertainty has quickly become a central figure in the communication of hurricane risks. Yet we still know relatively little about how audiences actually interpret, evaluate, or utilize this key graphic. Social science methods and approaches should be integrated into the design, development, and evaluation of hurricane risk communications, which are so vital for the well being of the public.

ACKNOWLEDGMENTS. The authors would like to express their sincere gratitude to Scott Kiser of the National Weather Service Tropical Cyclone Program; to the personnel at the NHC and NOAA/AOML for their generosity in providing data and opinions; to Amy Clement, Jennifer Marlon, and Elke Weber for comments on earlier drafts; and to three anonymous reviewers. Funding was provided by the NSF SES-0345840 through the Center for Research on Environmental Decisions (CRED) at Columbia

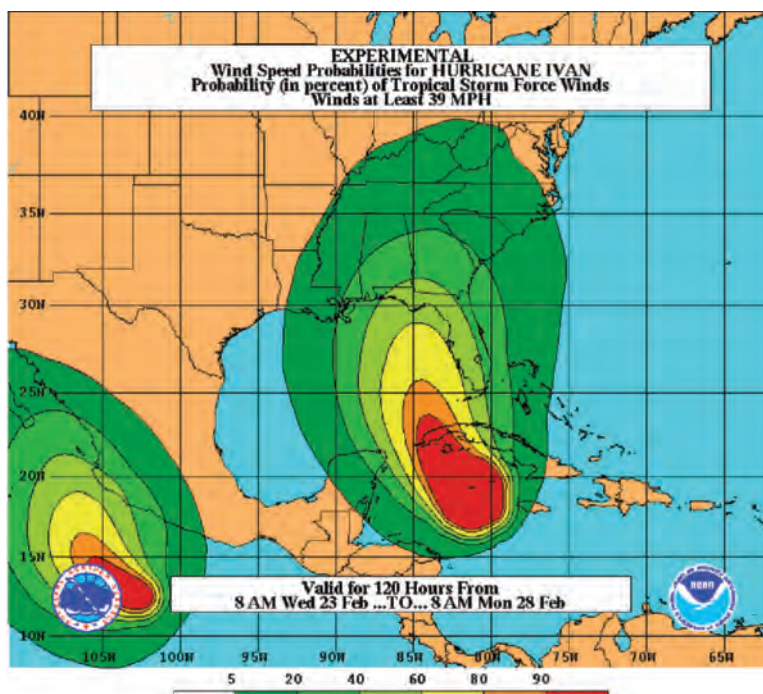


FIG. 10. Probability of the extent of hurricane- or tropical storm-force winds for Hurricane Ivan in 2004 (online at www.nhc.noaa.gov/feedback-pws-graphics2.shtml).

University and by the University of Miami’s Abbes Center for Ecosystem Science and Policy. Any errors are the sole responsibility of the authors.

REFERENCES

- Blake, E. S., J. D. Jarell, M. Mayfield, E. N. Rappaport, and C. W. Landsea, cited 2005: The deadliest, costliest, and most intense United States tropical cyclones from 1851 to 2004 (and other frequently requested hurricane facts). NOAA/NWS Tech. Memo. NWS TPC-4, 51 pp. [Available online at www.nhc.noaa.gov/pastcost2.shtml]
- Boxleitner, G., 2004: Hurricane Charley. *The News-Press*, 29 August, final edition, National section, 1A.
- Breed, A. G., 2004: Government, citizens mobilize to care for Charley’s most vulnerable victims- elderly. *The Associated Press*, 18 August, Domestic News section.
- Burr, W. M., 2006: *Stormproof Your Boat: The Complete Guide to Battening Down When Storms Threaten*. McGraw-Hill, 152 pp.
- DeMarie, M., and J. M. Gross, 2003: Evolution of prediction models. *Hurricane! Coping with Disaster*, R. Simpson, Ed., Amer. Geophys. Union, 103–126.
- Diaz, H. F., and R. S. Pulwarty, Eds., 1997: *Hurricanes: Climate and Socioeconomic Impacts*. Springer-Verlag, 292 pp.

- Doswell, C. A., III, 2004: Weather forecasting by humans—Heuristics and decision making. *Forecaster's Forum*, **19**, 1115–1126.
- Douglas, M., and A. Wildavsky, 1982: *Risk and Culture: An Essay on the Selection of Technological and Environmental Dangers*. University of California Press, 221 pp.
- Fischhoff, B., 1994: What forecasts (seem to) mean. *Int. J. Forecasting*, **10**, 387–403.
- Franklin, J. L., R. J. Pasch, and L. A. Avila, 2006: Atlantic hurricane season of 2004. *Mon. Wea. Rev.*, **134**, 981–1025.
- Garcia, J., and M. Bell, 2004: Storm's lesson: Listen, grasp. *The Orlando Sentinel*, 15 August, special section, p. A.8.
- Golden, J. H., 1984: On the role of the private sector in disseminating hurricane forecasts and warnings. *Bull. Amer. Meteor. Soc.*, **65**, 972–980.
- Hager, P. J., and H. J. Scheiber, 1997: *Designing and Delivering Scientific, Technical, and Managerial Presentations*. John Wiley and Sons, 345 pp.
- Hewitt, K., 1983: *Interpretations of Calamity*. Allen and Unwin, 304 pp.
- Jardine, C. J., and S. E. Hrudey, 1997: Mixed messages in risk communication. *Risk Analysis*, **17**, 489–498.
- Johnson, N., 2004: Hurricane forecast maps may lose direct-hit line. *Tampa Tribune*, 22 October, final edition, National/World section, p.1.
- Kaczor, B., 2005: Weather officials keep “skinny line” for hurricane tracking. *Associated Press*, 23 March, State and Regional section.
- Kahneman, D., P. Slovic, and A. Tversky, 1982: *Judgment under Uncertainty: Heuristics and Biases*. Cambridge University Press, 555 pp.
- Kaye, K., 2005: Black hurricane line to stay: Public favors way Weather Service charts storm paths. *South Florida Sun-Sentinel*, 24 March, Broward Metro edition, Local section, p. 5B.
- Kleinberg, E., 2004: 2004 season one for history books. *The Palm Beach Post*, 26 September, final edition, Local section, p. 3B.
- Landsea, C., and M. Lawrence, cited 2004: Subject: F6) How accurate are the forecasts from the National Hurricane Center? Atlantic Oceanographic and Meteorological Laboratory. [Available online at www.aoml.noaa.gov/hrd/tcfaq/F6.html.]
- Loewenstein, G. F., E. U. Weber, C. K. Hsee, and N. Welch, 2001: Risk as feelings. *Psychol. Bull.*, **127**, 267–286.
- Lundgren, R. E., and A. H. McMakin, 1998: *Risk Communication: A Handbook for Communicating Environmental, Safety and Health Risks*. Batetelle Press, 473 pp.
- Murphy, A. H., S. Lichtenstein, B. Fischhoff, and R. L. Winkler, 1980: Misinterpretations of precipitation probability forecasts. *Bull. Amer. Meteor. Soc.*, **61**, 695–701.
- National Research Council, 2003: *Communicating Uncertainties in Weather and Climate Information: A Workshop Summary*. National Academy Press, 68 pp.
- Peacock, W. G., B. H. Morrow, and H. Gladwin, 1997: *Hurricane Andrew: Ethnicity, Gender and the Sociology of Disasters*. Routledge, 157 pp.
- Pielke, R. A., Jr., and R. A. Pielke Sr., 1997: Vulnerability to hurricanes along the U.S. Atlantic and Gulf coasts: Considerations for the use of long-term forecasts. *Hurricanes: Climate and Socioeconomic Impacts*. H. Diaz and R. Pulwarty, Eds., Springer-Verlag, 147–184.
- , and C. N. Landsea, 1999: La Niña, El Niño, and Atlantic hurricane damages in the United States. *Bull. Amer. Meteor. Soc.*, **80**, 2027–2033.
- Pulver, D. V., 2004: Hurricanes 2004: A look back at our mean season; Fine-tuning in works for 5-day forecasts. *Daytona Beach News Journal*, 28 November, final edition, sec. A, p. 1A.
- Rappaport, E. N., and R. H. Simpson, 2003: Impact of technologies from two World Wars. *Hurricane! Coping with Disaster*, R. Simpson, Ed., Amer. Geophys. Union, 39–61.
- Saffir, H. S., 2003: Communicating damage potentials and minimizing hurricane damage. *Hurricane! Coping with Disaster*, R. Simpson, Ed., Amer. Geophys. Union, 155–164.
- Schleifstein, M., 2005: Hurricane warnings not heeded, study says: Florida evacuation order misunderstood. *The Times-Picayune*, 24 March, National section, p. 1.
- Slovic, P., 1999: Trust, emotion, sex, politics and science: Surveying the risk-assessment battlefield. *Risk Anal.*, **19**, 689–701.
- , B. Fischhoff, and S. Lichtenstein, Ed., 1986: The psychometric study of risk perception risk evaluation and management. *Risk Evaluation and Measurement*, V. T. Corello, J. Menkes, and J. Mumpower, Eds., Plenum, 3–24.
- Stone, S., 2005: Weather watcher sees need for improvement. *The Virginian-Pilot*, 28 March, Local section, p. B1.
- The Tampa Tribune*, 2005a: Don't erase that hurricane forecast line. 22 January, final edition, Nation/World section, p. 12.
- , 2005b: Relax. 25 May, final edition, special section, p. 2.
- Tufte, E., 1983: *The Visual Display of Quantitative Information*. Graphics Press, 197 pp.

- USACE, cited 2005a: Executive summary of the 2004 hurricane season post storm assessment of the National Hurricane Program study products. 22 pp. [Available online at http://chps.sam.usace.army.mil/ushesdata/Assessments/2004Storms/2004_hurricane_season_page.htm.]
- , cited 2005b: Hurricane Charley Behavioral Analysis. 85 pp. [Available online at http://chps.sam.usace.army.mil/ushesdata/Assessments/2004Storms/2004_hurricane_season_page.htm.]
- , cited 2005c: Main findings of the behavioral study. [Available online at <http://chps.sam.usace.army.mil/ushesdata/Assessments/2004Storms/PPShow/Slide32.html>.]
- , cited 2005d: County interview issues & concerns. [Available online at <http://chps.sam.usace.army.mil/ushesdata/Assessments/2004Storms/PPShow/Slide40.htm>.]
- Whitehead, J. C., 2003: One million dollars per mile? The opportunity costs of Hurricane evacuation. *Ocean Coastal Manage.*, **46**, 1069–1083.
- Willoughby, H. E., 2003: A century of progress in tracking and warning: Improvements in observations, models, and forecasts. *Hurricane! Coping with Disaster*, R. Simpson, Ed., Amer. Geophys. Union, 205–216.