CREATION AND COMMUNICATION OF HURRICANE RISK INFORMATION

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Working together and in collaboration with social scientists, NWS forecasters, emergency managers, and the media can improve the hurricane risk information that they convey to aid protective decision making.

K atrina, Rita, Ike, Irene—These and other hurricanes have caused substantial damage and loss of life in the United States during the past decade. In response to hurricane threats, some people who should evacuate their homes or take other protective action do not, often placing themselves at unnecessary risk, while others who are not at significant risk do evacuate, creating unnecessary congestion on roads and in shelters (Gladwin et al. 2009). Meteorologists and others often wonder why this happens. Hurricane forecasts have improved significantly in recent years; the average error in hurricane track forecasts has been reduced by 60% since 1990 (NOAA 2011b), and improving hurricane intensity forecasts is currently a major priority (Toepfer et al. 2011). Information about geographical areas at high risk from hurricanes is also improving, for example, through updated mapping, advances in storm surge modeling, and more precise determination of evacuation zones (Rappaport et al. 2009; Florida Division of Emergency Management 2011). Moreover, social science research is developing a growing understanding of the factors that contribute to people's hurricane preparation and evacuation decision making (Dow and Cutter 1998; Dash and Morrow 2001; Gladwin et al. 2001; Gladwin and Morrow 2005; Dash and Gladwin 2007; Zhang et al. 2007; Taylor et al. 2009; Lazo et al. 2010; Morss and Hayden 2010). Here we complement these efforts by examining the starting point of the warning and response process—that is, how information about forecasts, warnings, and recommended protective actions is created and communicated when a hurricane threatens. This understanding is critical because people's responses to hurricane risks are interconnected with the risk messages they receive. Yet few researchers have investigated this component of the process.

Although the hurricane forecast, warning, and response process involves many factors, we focus

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on three major groups that strongly influence how hurricane risk messages are created and conveyed: National Weather Service (NWS) forecasters at the National Hurricane Center (NHC) and local weather forecast offices (WFOs), local emergency managers (EMs), and local television and radio personnel. Together, we refer to these groups as the *hurricane warning system*. Our findings are based largely on an in-depth study of these groups in the Miami, Florida, area. This work is part of a larger project examining hurricane warning communication from several theoretical and methodological perspectives, including a parallel study in the Houston, Texas, area (Anthony et al. 2012) and work examining perceptions and responses to different hurricane risk messages by members of the public, including vulnerable populations (Lazrus et al. 2012).

By examining forecasters', emergency managers', and the media's roles, goals, and interactions, we aim to understand the processes that shape the messages underlying how people interpret and respond to hurricane risk. Building on this understanding, we identify strengths and challenges in how the hurricane warning system functions and how it serves the U.S. public in providing useful hurricane risk information, and we discuss opportunities for improving on current successes. Our goal is to help participants in the hurricane warning system improve how they interact with each other and how they generate and convey information, ultimately contributing to the broader goal of increasing societal resilience to hurricanes and related weather hazards (e.g., Subcommittee on Disaster Reduction 2005).

STUDY METHODOLOGY. This study employed a mixed-method, empirical approach. The primary source of data was in-depth, semistructured interviews with members of the three groups. The interviews included questions about interviewees' job roles and partnerships; their sources, uses, creation, and communication of information; their audiences; their views on the hurricane forecast and warning process; and related topics. Data were collected between April and September 2009 from three NHC forecasters, two Miami WFO forecasters, two Miami-area emergency managers, and nine meteorologists and other personnel from four television and four radio stations in the Miami area (including non-English language). The interviews were supplemented by observational sessions involving development of mock hurricane forecast products by a subset of

participants. The mock product development was based on a hypothetical hurricane threatening the Miami area, using a scenario provided by the NHC beginning four days prior to "landfall." Further information about the study methodology and data collection is available from the authors.

All observation sessions and interviews were digitally recorded and transcribed. The data were analyzed inductively to identify key themes, presented in this article. In developing the findings and recommendations, we also incorporated the authors' knowledge about NWS forecasters, emergency managers, the media, and the hurricane warning and response process from related work, as well as information from discussions with members of the project's Expert Advisory Group (which includes members of all of the groups studied). Based on this broader knowledge, we emphasize findings that we believe are broadly applicable. Nevertheless, because of the purposive sampling approach and geographic focus of the data collection, our results are not truly generalizable. To preserve anonymity, participants' quotations are identified only by their group type.

THE HURRICANE WARNING SYSTEM. Hurricane risk information is generated, communicated, and interpreted through complex interactions among a variety of actors, including NWS forecasters, private sector forecasters and vendors, multiple types of media and government agencies, nongovernment organizations, businesses, and members of the public. Within this larger process, we focus on three groups that have a primary influence on what risk information is created and communicated when a hurricane approaches the United States: NWS forecasters, local emergency managers, and local television and radio personnel. We selected these groups because they are key actors in the hydrometeorological[1] forecasting, public sector decision making, and media communication processes associated with landfalling hurricanes, respectively. Although each of these groups has a variety of concerns and responsibilities in general, here we analyze their roles within the hurricane warning system when a hurricane threatens.

Analysis of our data revealed that the three groups have different job roles and specialties (Figs. 1, 2). They also work in organizations with different priorities, constraints, and broader roles. Despite these differences, the groups interact within the hurricane warning system context to further overarching,

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[1] In this article, we use the term *hydrometeorological* to refer to meteorological and hydrological fields.
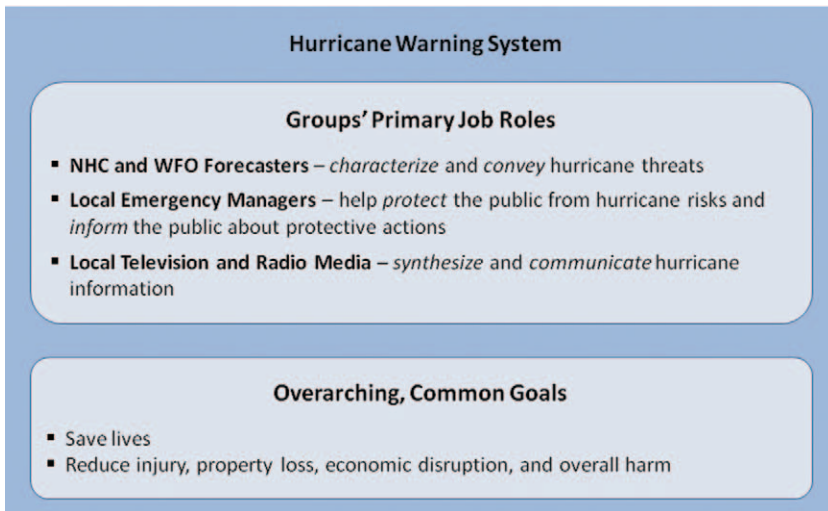
Fɪɢ. 1. Primary job roles of the three major groups in the hurricane warning system and their common goals.

common goals of saving lives and reducing harm when a hurricane threatens (Fig. 1). The groups' roles and interactions are guided by organizational procedures and public policy, but the hurricane warning system is largely informal. Many aspects of the structure in its current incarnation developed (and continue to develop) in an ad hoc manner over time, with each group's roles evolving in ways that complement the others' roles while maintaining its own specialty (Fig. 2) and orientation toward the overarching goals.

National Weather Service forecasters. The NHC is the national-level center in the NWS that specializes in tropical cyclones, including hurricanes. When a hurricane has formed or is forming, NHC forecasters' primary role is to characterize and convey the hydrometeorological threat that the storm poses at regional and larger scales (Fig. 2). They characterize the threat by applying their expertise to analyze and synthesize information from multiple sources (Lindell et al. 2007; Morss and Ralph 2007; Heinselman et al. 2012). They then convey this threat by regularly generating and issuing a suite of products, including textual forecasts,

track forecast cone graphics, wind speed probabilities, and tropical storm and hurricane watches and warnings. NHC forecasters described their role as the "quarterback . . . calling the signals based on the meteorology of what's going on." They "tell everybody where the storm is going to go, how strong it will be, how big it will be." In this way, NHC products serve as a starting point for the other groups in the hurricane warning system to do their jobs.

NWS forecasters at local WFO offices also characterize and convey hurricane threats but with an emphasis at regional and local scales[2] (Figs. 1, 2). When a hurricane threatens their area of responsibility, Miami WFO forecasters described their primary role as "taking the information [NHC puts] together and downscaling it to be digestible"
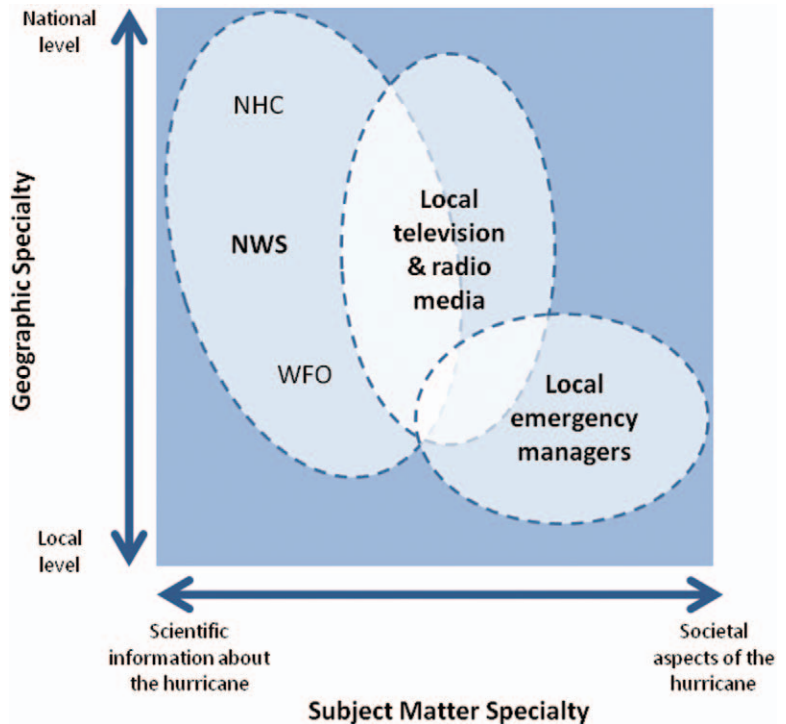

Fɪɢ. 2. Conceptual representation of the primary geographic and subject matter specialties of the groups in the hurricane warning system. Areas of overlap represent overlap in specialties, not necessarily interactions among the groups.

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[2] The Miami WFO's area of responsibility, for example, includes seven counties covering south Florida (excluding the Florida Keys).

for their users. They do so by assessing the hydrometeorological situation for their area of responsibility and the anticipated hydrometeorological and societal impacts. They convey this information through products such as textual hurricane local statements, hazard impact graphics, and warnings for hurricane-related hazards, such as inland winds, tornadoes, and flooding.

In deciding how to characterize and convey threats, NHC and WFO forecasters coordinate with each other and with other NWS entities (e.g., Hydrometeorological Prediction Center, Storm Prediction Center) through a regularly scheduled "hotline" call and other mechanisms. They provide forecast and warning information to emergency managers, the media, the public, and others through NWS products that are disseminated via multiple automated mechanisms as well as through formal briefings and informal discussions.

As a governmental agency, the NWS has a public service orientation; its mission is to provide forecasts and warnings for the protection of life and property and enhancement of the economy (NOAA 2011c). Thus, NHC and WFO forecasters characterize and convey hurricane threats with this broader goal in mind (Fig. 1). However, they cannot directly accomplish this broader goal on their own for several reasons. First, their primary emphasis is generating and providing forecast information that, at best, can only inform and promote the protective actions needed to save lives and reduce harm. Second, many audiences, excepting the media and emergency managers, do not directly receive information from NWS forecasters; much of the NWS information received by others (e.g., the public) is filtered through the private sector, especially radio and television, or through interpersonal sources (e.g., Taylor et al. 2009; Morss and Hayden 2010). Third, NWS forecasters' primary training is in meteorology, not in forecast communication or use, so the primary expertise they contribute is in the physical sciences. NHC and WFO forecasters must also work within their organizational constraints and policies, including guidelines on the allocation of responsibilities within the NWS, on the generation of forecast and warning products, and on their role relative to the private sector (NRC 2003; NOAA 2011a). Thus, NHC and WFO forecasters must partner with each other and with other groups in the hurricane warning system to fulfill their job roles in ways that support the overarching goals.

Local emergency managers. Local emergency managers described their primary role when a hurricane threatens as being "to protect the public" by informing people at risk and helping keep them out of harm's way (Fig. 1). This includes recommending, coordinating, and implementing preparedness and public safety activities (such as evacuations, sheltering, and closures) for their area of responsibility. It also includes working to "advise [people] what they should be doing and what the consequences are if they fail to do that," for instance, by recommending such activities as shuttering, gathering emergency supplies, and finding safe shelter. In other words, within the hurricane warning system, emergency managers work to translate hurricane threats into risk-reduction actions based on their assessment of a hurricane's potential societal impacts (Fig. 2). In doing so, they incorporate a variety of considerations beyond the hydrometeorological threat. Decisions about risk-reduction actions are made by several actors; for example, evacuation decisions typically are made by elected officials, and most protective actions are implemented by members of the public, businesses, and other governmental and nongovernmental actors. Emergency managers play a critical role by serving as primary translators of hydrometeorological information for these groups.

Like the NWS, local emergency managers are employed by governmental agencies and thus have a public service orientation. Emergency managers' role connects them more directly than the NWS's role to the broader goals of saving lives and reducing harm (Fig. 1). However, like NWS forecasters, they cannot accomplish their job role in support of these overarching goals without partnering with other groups. Emergency managers rely on the NWS to provide scientific expertise about the hydrometeorological threat posed by a hurricane and, in many cases, on private sector forecast services to amalgamate and provide enhanced forecast information. They also rely on the media to communicate information about the hurricane threat and recommended actions to the public and other audiences. And, again, emergency managers typically only recommend or facilitate protective action, so they must work to achieve their job role and goals within the constraints of their organizational and political environments.

Local television and radio personnel. When a hurricane threatens, television and radio are the most common sources of hurricane information for the public (Piotrowski and Armstrong 1998; Zhang et al. 2007; Morss and Hayden 2010). In the context of the hurricane warning system, media personnel described their primary role as "storytellers" who synthesize hurricane forecast, preparedness, and response

information, and communicate it to their audiences (Figs. 1, 2). Although most television meteorologists use their own meteorological knowledge, they typically do not develop their own hurricane forecasts or warning products from raw meteorological data. Rather, they and radio broadcasters rely on their warning system partners—NWS forecasters and emergency managers—to provide them with hurricane risk information. The media also rely on private sector weather vendors to transmit and postprocess NWS data, produce value-added forecast information, and provide a platform for creating camera-ready graphics for television. The media say they then take the hurricane risk information they receive and focus on "boil[ing] it down into bullet points, into facts, into useful information" for their audiences. As one television meteorologist described, "Most people today . . . still get their information from TV and still rely on us to explain it to them, decipher the information, and communicate it."

NWS forecasters and emergency managers do provide information directly to the public, and venues such as the Internet are a growing source of hurricane risk information (Lee et al. 2009; Sherman-Morris et al. 2011). However, television and radio broadcasters remain the everyday faces and voices that serve as a primary conduit for weather warning information to the public (Sherman-Morris 2005; Demuth et al. 2009). Unlike the NWS and emergency managers, media organizations are in the private sector and thus have goals such as maintaining market share and generating profit. In pursuit of these goals, media producers and managers can influence aspects of hurricane coverage. The media aim to effectively communicate impending weather threats in part because doing so helps them retain audience trust and therefore market share. In addition, the media personnel we interviewed felt that, within the context of the hurricane warning system, they communicate threats in support of the altruistic goal of protecting their viewers and listeners (Fig. 1). As one television meteorologist said, "I don't care if somebody's watching me or . . . another station, as long as they're getting the message and preparing. To me, it's not about me, it's about safety and the message." Although the media personnel we interviewed indicated they often have flexibility in deciding when and how they communicate hurricane risks, they nevertheless face constraints from the media environment in which they work. They also cannot accomplish their roles or goals without their NWS and emergency management partners.

Groups in partnership: Beyond borders. Our analysis indicated that the partnerships within the hurricane warning system are generally successful, in that each group plays a unique and critical role and that, together, the groups make information about hurricane threats widely available (Taylor et al. 2009; Morss and Hayden 2010). As one NHC forecaster noted, "It's amazing when you sit down and look at everything that could go wrong, and yet 99-point-some percent of the time, the forecasts go out on time. The public is able to get it." Another NHC forecaster added, "The TV stations get it, the word goes out. It gets widely disseminated. That's something that's the biggest strength, the ability to rapidly disseminate that critical information." This information is then used by many public officials, members of the public, and others to make protective decisions.

One reason for these successes is the complementarity of roles within the hurricane warning system. The expertise and job functions required within the system are extensive; there is sufficient overlap to allow the groups to support each other's roles but enough differentiation that groups typically avoid unproductive duplication of effort. For example, NHC forecasters do not order people to evacuate, but they do aim to provide emergency managers and members of the public with the scientific information they need to make evacuation decisions because "they can't interpret the science like we can." Meanwhile, emergency managers know that "our mission is not to tell the world about the dynamics of the hurricane."

Another factor underlying the hurricane warning system's successes is that group members generally recognize and appreciate their interdependency and the importance of their partnerships. A member of the media explained, "I couldn't do my job without [the NHC and WFO] . . . With the hurricane, I don't have the tools, the data, and the knowledge that they do . . . so I rely on them almost 100% for info that I'm getting . . . I'm an extension of them to get out their hard work."

And, according to an NHC forecaster, "I think there's been a big push in the media lately, too, to take our information but expand on it and actually provide additional information that they can with either fancy graphics or things that we don't produce here. I think that's great. If they can find ways of getting people thinking and getting them to take action beyond what we can do, I think that's a good thing."

The emergency managers we interviewed spoke about their strong relationships with specific NWS and media partners, including personal connections that helped them contact WFO forecasters, in

particular, for specific information or clarification about the forecasts when needed. As one emergency manager noted, "If we're unclear, we'll call them up and talk to them . . . [I'm] not even kidding about having [WFO forecaster] on speed dial." In return, one WFO forecaster indicated, "As far as emergency managers, I'm becoming increasingly convinced that, more than users, they're really our partners." The partnerships are not flawless, and below we discuss challenges pertaining to certain aspects of the partnerships. Nevertheless, an important component of the partnerships' successes is the confidence that members of the groups have in each other based on the organizational trust and personal relationships they have built over time.

The hurricane warning system's effectiveness is also enhanced by its flexibility. When a critical opportunity or need arises in a specific hurricane situation, individuals can go beyond their typical roles to serve the overarching goal. For example, although NHC forecasters' specialty is the science of tropical cyclone and hurricane forecasting, over time they have also become a trusted face in communicating about hurricane risk with the public (NOAA 2011d). Reflecting this, the media sometimes turn to the NHC as an on-camera source for hurricane information, including information about the local hurricane forecast and impacts generated by WFOs. As credible voices with the public, NHC forecasters and television meteorologists also aid emergency managers by advising protective actions. Similarly, leading up to Hurricanes Katrina and Ike, WFO forecasters concerned about life-threatening situations included in their hurricane local statements dramatic language warning of catastrophic damage and urging people at risk to take protective action (Morss and Hayden 2010). Although such extensions of roles can create tensions among warning system partners, in most cases they seem to be accepted by other groups in the hurricane warning system because of the overall sense of partnership in service of a common goal. Such role extensions can also allow groups to evolve and renegotiate their roles over time, as needs for information and opportunities change.

CHALLENGES IN COMMUNICATING HURRICANE RISK. Despite many successful aspects of partnerships within the hurricane warning system, our analysis revealed some issues. These can lead to challenges for NHC and WFO forecasters, emergency managers, and media in fulfilling their job roles and, more generally, in effectively communicating hurricane risk to achieve the broader goals of saving lives and reducing harm. The types of challenges we observe are common in interorganizational settings (e.g., Brown and Duguid 2001). Thus, our goal is not to be critical of the actors involved, but rather to identify opportunities for improvement.

NWS forecast products: Volume, complexity, content. Hurricane forecast information provided by the NWS is indispensable. However, it could be improved in several ways. One issue is the volume of information produced by the NWS—including the number of products, their length, and the detail included. For example, a member of the media noted that NHC and WFO forecast products can be so long that they're "unwieldy;" he has "to ferret through all of [the] stuff that gets mixed in together" to find out what information applies to which geographical areas. This problem is exacerbated when a hurricane is near or makes landfall and the NWS issues additional products for different associated hazards. Another member of the media observed, "As the hurricane's getting closer, we get advisories after advisories after advisories . . . So a hurricane watch becomes a hurricane warning. Then a flood watch is issued. Then a tornado watch is issued. Then an inland high wind watch is issued. It's a little bit too much, I think, sometimes."

This raises challenges for time-constrained emergency managers and media personnel who must sift through this detailed information and sort out what they and the public need to know. As a member of the media explained, "It gets to the point where it's like, all these watches, all these warnings, all this stuff . . . We know all of that is or likely is going to happen with a hurricane. So instead of getting bogged down in all of that stuff, the most important thing to do . . . [is] really giving people specific information on when this stuff might occur, when the worst of it could be. That's the kind of stuff we try to communicate."

Another issue with NHC and WFO information is that it can have an NWS-specific meaning that may confuse audiences outside the NWS. According to a member of the media, "A good example of what the problem is, and I don't know if it's political boundaries or Weather Service or what, but a hurricane warning only affects the coast, and then there's an inland hurricane wind warning. So all of a sudden you've got this demarcation, and people are like, is it a hurricane or not?"

Even an NHC forecaster, a producer of the information, noted that users can have difficulty interpreting their forecast products:

I think the biggest obstacle in communicating is, I don't think people really understand what [NWS products] mean. People, as in the public, and even sometimes the emergency managers, I'm not sure really understand when we put up a warning, what does that really mean? Because it doesn't mean that every place along the coast that's under the warning is going to experience hurricane-force winds. What it means is that hurricane-force winds will be experienced by someone within the warning area within 24 hours.

A related issue is the level of scientific and technical content of many NWS products. Because NHC and WFO forecasters' primary emphasis is on scientific accuracy and thorough characterization of hurricane threats from a hydrometeorological perspective, they tend to use technical language and provide meteorological detail. This can frustrate warning system partners who need more accessible information to fulfill their roles. As one member of the media explained:

Sometimes scientists speak like scientists and not like people. You know, some people don't know what low pressure means, what high pressure means, and some people don't know and don't care what millibars are. They don't care about all of the meteorological terms. They want to know three things: what does it mean to them, what does it mean to their family, and what do they need to do right now. And so don't speak like a meteorologist. Tell me what we need to know . . . I can't tell you in the middle of an emergency how many times we've looked at each other in the news room and said, "Well, that was no help whatsoever," because we couldn't get numbers, specifics, what the public needed to know at that moment.

One reason this occurs is that NWS forecasters' primary expertise and training is as physical scientists. Moreover, they work in an organization that focuses on precise scientific information and that evaluates forecasters' performance based on specific metrics that are often scientifically based. As a result, they do not want to omit important details about hydrometeorological threats, and they sometimes have difficulty explaining those threats in layperson's terms. Further, NWS forecasters work within an organizational structure that emphasizes timely issuance of a consistent, structured suite of products. This emphasis is beneficial because it helps product recipients know what to expect and design

their systems accordingly, and it helps the NWS serve audiences with limited communication technologies (e.g., mariners at sea). However, this structure creates inertia, leading the NWS to retain outdated or redundant forecast products and formats and to be slow to adopt new techniques and technologies for conveying information. An NHC forecaster explained:

I think by us latching onto these legacy text products so much, we're kind of limiting ourselves in what we can do . . . People are very visual, and they need more graphical-type products . . . I think we're very slow to react to changes in the population and the population's needs. I think right now, the structure of the forecast process doesn't really quickly allow for these types of things to be incorporated . . . [However], the process has worked now for decades, and there is some good stuff that has been instituted that needs to be kept, needs to be followed. It's just trying to find that balance for moving ahead in the modern age but keeping the legacy things that are good and have worked well.

Another challenge is that the NHC and WFO have multiple, diverse audiences; even with the suite of products NWS forecasters provide, it is not possible for them to serve all of their users' needs all of the time. Moreover, despite the partnerships described earlier, the NWS does not receive much direct feedback from many of the people who receive and use its information. Thus, NWS forecasters sometimes do not have a clear sense of who their audiences are for specific products and what information these audiences need and can use. Based on the limited feedback they do receive, however, NWS forecasters recognize some of the issues with their forecast information. As a WFO forecaster described:

From the insider in the agency, I consider [the NWS hurricane forecast and warning process] to be probably convoluted and complex, more than it needs to be. There's too much emphasis on products instead of thinking, what is essentially what we need to get out and finding the most efficient way to get it out . . . The media complains about this constantly, "Why do you guys have to issue so many different types of products?" All you have to do is look at our website in a tropical cyclone situation event. Oh, my God! I mean, it's unbelievable.

The NHC and WFO forecasters we interviewed want to do a better job of communicating hurricane risk to their warning system partners and to members

of the public, but they struggle with how to best do so given their knowledge, training, and institutional constraints.

Media information needs: Sooner, more, better. Given their role as communicators, the media want to present timely, aesthetically pleasing, and useful information to their audiences. Yet the media personnel we interviewed identified several ways in which the information they receive from NWS forecasters and emergency managers does not always meet their needs. One issue, discussed earlier, is that NWS products are sometimes too long and complex and contain content that is too technical for the media to easily translate into what members of the public need to know. This, along with the timing of NWS product issuance relative to television newscast timelines, squeezes the time broadcast meteorologists have to learn the latest forecast information and put together their weathercast.

Further, as a hurricane approaches, the media significantly increase the amount of time they devote to hurricane coverage, with television often covering the threat continuously (going "wall to wall"). During such times, media personnel crave updated information so they can tell an evolving story. They also want useful information so they can meet the needs of their listeners and viewers. An NHC forecaster noted:

> [The media] alway want the data sooner, quicker, they want insights. Can you whisper it in my ear? type of thing . . . They typically want more details, more specifics. They want more content. We tend to be very conservative, maybe rightfully so, on content, given the uncertainty. We don't want to hype things up, so they often want more content, more detail, more specifics, prettier pictures, things they can show on air, maybe things that are not appropriate to show on air.

This creates a tension between the media's pull for more updated, usable information sooner and the NWS's capabilities and desire to provide that information.

Television meteorologists want to use high-resolution visuals that convey key information simply and clearly to their audiences. Although the NHC and WFOs have started to generate more graphical products, these must still be adapted, often significantly, by the media before they can be used to communicate with the public. Some of the graphics produced by the NWS were critiqued by media personnel as being not very useful because they are too difficult to understand, are of insufficient quality, or do not convey needed information. Although media outlets will always want to modify NWS graphics somewhat to differentiate themselves from other sources, having more useable graphics and graphics-ready data from the NWS and from the vendors that supply NWS information to the media nevertheless would help television meteorologists communicate updated hurricane information in a more timely manner.

The media also want to provide useful information on preparedness and response. Yet the media personnel we interviewed sometimes had difficulty obtaining accurate, updated information from local emergency managers as a hurricane threat evolved. To obtain this information, some members of the media expressed interest in getting a formal product from emergency managers at regular time intervals, similar to those issued by the NHC and WFOs. One said he "think(s) emergency managers should create their own HLS [Hurricane Local Statement] product." Another requested a "fact sheet" or "public information statement": "You know, just bullet points . . . It'd be nice if I could just go to an email and print off, 'this is what people need to do. . .' Because right now, that message is getting buried in press conferences. I have to dig for it. I have to go to their website, and sometimes it's not updated."

As one member of the media explained, it is also important for public officials, including emergency managers, to go on air at critical times during a hurricane event and communicate directly with the public. "You don't want the meteorologist, even the chief meteorologist at the TV station, to tell people when to evacuate. It's not their call."

As a hurricane approaches landfall, NWS forecasters and emergency managers are extremely busy and are working under their own organizational and political constraints. Nevertheless, since the media are a key disseminator of hurricane information to the public, it is important for them to have information from NWS forecasters and emergency managers that is as accurate, updated, and accessible as possible given situational uncertainty, competing demands, and other constraints.

Information for emergency management decisions: Time sensitive under uncertainty. As a hurricane approaches, emergency managers make protective decisions using criteria partly based on the hydrometeorological threat, but not necessarily the specific information provided by NWS forecasters. This can lead to potential gaps when emergency managers must map the NWS information they receive onto what they

need for their decisions, often under significant time pressure and uncertainty. For example, NHC and WFO forecasters consider watches and warnings to be one of their most important products for triggering protective decisions. The emergency managers we interviewed, however, said that "we don't use watches and warnings as any of our triggers" because they must start preparations much earlier. The emergency managers do like to know in advance if and when watches and warnings will be issued, but primarily so they can anticipate decisions by businesses and other groups who do use watches and warnings as decision criteria.

Emergency managers interviewed instead emphasized their need to know when tropical-storm-force winds will arrive because they do not want major preparation activities to be occurring during those potentially dangerous conditions. Working backward from the expected arrival of tropical-storm-force winds, emergency managers use timelines to implement preparation measures. Currently, this key criterion must be calculated from other hurricane forecast information using software tools such as HURREVAC (2012). Thus, it would be useful for the NHC or WFOs to explicitly "include [the arrival] as another milestone," say emergency managers. Some forecasters know how important the arrival information is to emergency managers' decision making and try to provide it. However, it has yet to be formally included in NWS products.

Another area of mismatch is the provision and use of uncertainty information. NWS forecasters convey uncertainty as part of scientifically characterizing the hurricane threat, and they view this information as being useful to particular audiences in certain ways. For example, an NHC forecaster explained:

> This [wind speed probability product] is mainly meant for EMs, I think, because a lot of the general public won't really know—let's say their area is under a 10% chance of extreme hurricane force winds—they may not really know what that means, what they should do with that information. So it's really up to the EMs to take that information, give it to their public officials, and then they can say, "Based on this information, this is what we recommend that you do."

Emergency managers account for hurricane forecast uncertainty in their decisions—but not necessarily in the way NWS forecasters expect. Instead, given their focus on protecting the public, they often take a conservative approach to ensure they

are ready for a worst-case scenario (Morss 2010). As described by one emergency manager, "We say, 'When [the hurricane] comes straight nonstop and it intensifies,' that's how we plan for the uncertainty." The other emergency manager explained, "The arrival for me is more important than probabilities because I have to assume the worst-case scenario."

When emergency managers do not use the scientific uncertainty information conveyed in specific forecast products, forecasters sometimes misconstrue this as emergency managers not wanting any uncertainty information or not understanding forecast uncertainty. This view was expressed, for example, by an NHC forecaster: "[Emergency managers] typically don't like probabilistic. They usually get frustrated and don't want to mess with it." Yet planning for the worst-case scenario is a way of considering uncertainty. Thus, the primary issue appears to be a disconnect between how emergency managers currently account for uncertainty in their decisions and what uncertainty information the NWS provides. Underlying this mismatch are differences in how scientists and practitioners think about and treat uncertainty (e.g., Morss et al. 2005; Demeritt et al. 2007). Given the influence of emergency management recommendations on lives and life safety, addressing these information gaps is an important challenge.

FINDINGS AND RECOMMENDATIONS.
Based on our analysis, we identified several opportunities for improving how NWS forecasters, local emergency managers, and local television and radio personnel interact with each other to create and communicate hurricane risk information.

- Strengthen warning system partnerships through regular interactions to improve understanding of each other's priorities, constraints, and information capabilities and needs.

The success of the hurricane warning system relies on successful partnerships among NWS forecasters, emergency managers, and the media. Each group has its own job role and specialty, and no group can accomplish its role or achieve its goals without its partners. Members of each group are familiar with their own priorities, pressures, capabilities, and policies, but they typically only have a partial appreciation of others' priorities. Improving understanding of each other's work environments, needs, and goals can help the groups work together better to improve communication of hurricane risk information. We hope that this analysis is one step in that direction. Another

important step is for groups to regularly meet in person to discuss opportunities and needs for improved interactions and information exchange. We enthusiastically support current efforts that bring together diverse actors (e.g., the annual National Hurricane Conference), but we recommend that the groups also pursue locally oriented approaches. These could follow the Integrated Warning Team workshop model that brings together NWS forecasters, emergency managers, media, other warning system partners, and social science researchers within a geographic area (Dix and Fieux 2011; Rogers and Frazier 2011).

- Ensure that mechanisms for exchanging critical information are formalized, yet retain opportunities for flexibility in interactions.

During hurricane events, partners need information from each other, but everyone is busy and dealing with competing demands. Strong partnerships and personal relationships among group members can facilitate exchange of key information in these situations. However, relying on these informal mechanisms for information exchange is insufficient if some partners do not receive important information in a timely manner. For example, media personnel identified a need for more regular, updated information from emergency managers during hurricane threats. Thus, we recommend that the groups institutionalize formal mechanisms for exchanging critical information, following the examples of the hotline calls among NWS personnel and the briefings between NWS forecasters and emergency managers. In doing so, we recognize the importance of maintaining flexibility in intergroup interactions, given that each hurricane presents a unique situation.

- Focus on improving communication to audiences by using knowledge from risk communication and other social sciences to develop and test hurricane risk messages.

Given their specialties and job roles within the larger hurricane warning and response process, the groups we studied have limited direct ability to achieve their broader goal of saving lives and reducing harm. NWS forecasters, in particular, often feel frustrated and disheartened when they provide accurate hurricane forecasts and people nevertheless suffer harm. Meteorologists have a tendency to address such communication gaps by trying to educate their audiences about the scientific meaning of information. But often two-way interactions among information

providers and recipients are needed, to learn what information people want and can use in the decisions that matter to them (Fischhoff 1994; Vogel et al. 2007; Morss et al. 2008). In other words, although providing scientifically accurate information is important, communicating *the science* of hurricane threats is not the same as communicating *what people need to know* to effectively respond to hurricane risks (e.g., Weigold 2001). Thus, we recommend that NWS forecasters and warning system partners not dwell on what they cannot do and focus instead on what they can do: improve how they communicate about weather threats to enhance understanding of risks and motivate action to the extent possible.

NWS forecasters, emergency managers, and media personnel can improve how they convey hurricane risk messages through awareness and application of risk communication knowledge and best practices (Fischhoff 1995; Bier 2001; Lundgren and McMakin 2009; Heath and O'Hair 2009). More specifically, most NWS products are based on incomplete perceptions of audience needs rather than on sufficient research and user-oriented product development (e.g., Broad et al. 2007). Thus, to improve communication of hurricane threats, we recommend that the NWS and warning system partners collaborate with social scientists, including experts in communication, psychology, sociology, economics, anthropology, human geography, and other relevant areas, to 1) improve knowledge about how audiences interpret and use hurricane forecast and warning information and 2) apply this knowledge to rigorously design and test hurricane risk messages with intended audiences.

- Evaluate, test, and improve the NWS product suite through collaborations among warning system partners and with social scientists.

We identified several challenges with the volume, complexity, and content of NWS products that are important to address. If the media, emergency managers, and others do not get or cannot easily extract needed information from the suite of NWS products, then they cannot effectively communicate or respond to impending hurricane threats. Examples of this include 1) the need identified by the emergency managers interviewed for information about the timing of arrival of tropical-storm-force winds and 2) the challenge encountered by media personnel interviewed to quickly find updated information about the threat for a given area. Two-way dialogues through meetings between NWS personnel and their partners, as recommended above, can help bridge

these gaps. Yet such conversations are not sufficient; more formal mechanisms are also needed to help emergency managers and media personnel articulate their information needs and to connect these to what NWS forecasters can reasonably provide. Thus, we recommend that the NWS systematically evaluate its full hurricane-related product suite, especially before adding more products or more information to existing products.

Such evaluations should apply formal methods to examine the usability of current NWS products, identify opportunities for streamlining NWS products, and investigate ways to provide hurricane risk information that NWS's primary partners want and is appropriate given the NWS's roles relative to private sector forecasting entities. Doing so will require NWS working with emergency managers, the media, the private sector, and other warning system partners as well as with social scientists. Because the hurricane warning system environment is continually evolving, the NWS will need to implement such evaluations at regular intervals. We also recommend that the NWS work with the media and its vendors to provide graphics or data that can more readily be translated into visuals for communicating with the public.

This research focuses on hurricanes and is based largely on data from a specific geographic region. The specifics of the partnerships and the challenges of communicating hurricane risk may vary in different geographic areas based on, for instance, hurricane experience, governmental structure, demographics, and culture. Nevertheless, we believe our findings and recommendations can serve as a starting point for improving the creation and communication of hurricane messages in all areas and about weather risks more broadly. Addressing these types of issues is particularly important given that changes in technology and communication channels—especially the explosion in the use of the Internet, smartphones, and social media—are rapidly changing how people access and interpret hazardous weather information. NWS forecasters, emergency managers, and media personnel who create and communicate weather risk information must be proactive in adapting to this increasingly fragmented communication environment. To do so, we recommend that meteorologists and others interested in communicating weather-related risk reframe concerns that "people don't understand our information" into action to address the question, "how can we work together to best communicate in a way that people understand and can use?" Doing so is essential to achieving the overarching goals of saving lives and reducing harm.

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