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Article

Understanding Emergency Manager Forecast Use in Severe Weather Events

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ABSTRACT

For Emergency Managers (EMs), preparations for severe weather have always relied on accurate, well-communicated National Weather Service (NWS) forecasts. As part of their constant work to improve these forecasts, the NWS has recently begun to develop impact-based products that share forecast uncertainty information with EMs, including the Probabilistic Hazard Information (PHI) tool. However, there is a lack of research investigating what forecast uncertainty information EMs understand, and what information needs exist in the current communication paradigm. This study used the Critical Incident Technique to identify themes from incidents involving weather forecast information that went well, or not so well, from the perspective of the EMs responding to them. In total, 11 EMs from a variety of locales east of the Rockies were interviewed—six of whom were county-level, two city, two state, and one from a school district. We found that EMs sought increased forecast detail as a potential event approached in time and built relational trust in the NWS through repeated interactions. EMs had difficulty preparing for events when they did not have details of the expected impacts, or the likelihood of those impacts, for their regions. In summary, EMs are already starting to work in an uncertainty-friendly frame and could be responsive to the impact details and increased forecaster relations proposed with the PHI tool.

1. Introduction

In recent years, paradigm-shifting technological advances have greatly increased forecast skill, changing the way forecasters produce weather information (National Research Council 2018). Unfortunately, these skill advances have not been matched by advances in the communication of these forecasts, including forecasts for severe convective weather events (Karstens et al. 2015). The current convective weather warning system has remained essentially unchanged for more than 50 years, save for county-based severe, flash flood, and tornado warnings being replaced by storm-based warnings in 2007 (Sutter and Erikson 2010). Disasters like the 2011 Joplin, Missouri, tornado and the 2013 El Reno, Oklahoma, tornado have revealed weaknesses in this system, such as communication breakdowns between the National Weather Service (NWS) and its core partners, resulting in significant societal costs (National Oceanographic and Atmospheric Administration (NOAA) 2011, NOAA 2014, National Institute of Standards and Technology 2014).

Seeking to improve forecast communication, NOAA has sought to develop improved decision support tools for their partners. One such example is the Prototype Probabilistic Hazard Information (PHI) tool being tested at the Hazardous Weather Testbed (HWT, Karstens et al. 2015). This tool is designed to provide partners with probabilistic guidance, as well as forecaster insights into current weather conditions.

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The first experiment with the Prototype PHI tool was conducted at the HWT in 2014 with NWS forecasters, with the goal of learning how forecasters might interact with a new tool and warning paradigm (Karstens et al. 2015). Though this first step in testing the Prototype PHI tool was insightful, it was quickly realized that future development efforts required forecast users to evaluate the tool in a more realistic environment (Karstens et al. 2018). The study described in this paper was initiated in late 2014 to investigate the current severe convective weather forecast information needs of Emergency Managers (EMs), the first partner group to be brought into the testbed in 2015.

The NWS is also increasingly providing enhanced forecast support through what is called Impact-Based Decision Support Services (IDSS, NOAA 2017). These services are defined as "the provision of relevant information and interpretative services to enable core partners' decisions when weather, water, or climate has a direct impact on the protection of lives and livelihoods" (NOAA 2017). Core partners include EMs along with other governmental safety entities (e.g., law enforcement, firefighters). The services offered to these partners range from episodic support during events (either onsite or through enhanced communication), to recurring support such as joint training, Integrated Warning Team meetings, and table-top exercises. Though IDSS has been implemented across the NWS for use with core partners, including EMs, effective IDSS policies and guidelines are still being developed with the input of social science researchers (NOAA 2017).

EMs themselves are the connective tissue of a disaster response, bringing together organizations from volunteer storm spotters to fire departments "to support our citizens and first responders to ensure...we work together to build, sustain and improve our capability to prepare for, protect against, respond to, recover from, and mitigate all hazards" [Federal Emergency Management Agency (FEMA 2016)]. Additionally, state and federal EMs are divided by their Emergency Support Functions (ESFs), which are based around different facets of crisis response and can be activated as needed (FEMA 2018). As part of a crisis response, EMs seek forecast information that allows them to anticipate, prepare, and respond to natural hazards, including the use of Doppler radar products, television news forecasts, and NWS products (League et al. 2010). Doppler radar also has been identified as especially important to EMs' interpretation of and response to weather threats (League et al. 2010).

Previous literature reveals that EMs look to the NWS to explain the details of forecast impacts—the what, when, and where of an event. Demuth et al.'s (2012) study of hurricane risk information reported that two EMs in the Miami area sought forecasts of the timing of tropical storm force winds, ahead of watch and warning issuance, to allow them to complete preparations before impacts arrive. Similarly, Morss and Ralph's (2007) study of West Coast heavy rain events interviewed two EMs and found that they used detailed rain forecasts several hours ahead of the beginning of the event to know what regions to prepare for flash floods. However, the information needs for these longer time scale events may not be the same as those for the severe convective weather forecasts upon which the Prototype PHI tool development was initially focused. Baumgart et al. (2008) and Lussenden's (2014) surveys of the kinds of forecast information sought by EMs for severe convective weather events identified that for 11 Oklahoma and 239 Upper Midwest EMs (respectively), timely tornado warnings and verification of reported impacts were highly valued by EMs. These studies suggested that impact details, such as location, duration, and intensity, for convective events gave EMs the insight they needed to prepare an effective response to weather hazards. They did not investigate the use of probabilistic information, like that in the Prototype PHI tool.

Indeed, the NWS has increasingly begun to communicate forecast uncertainty information for the what, where, and when impact details EMs seek. Products that include forecast uncertainty give forecast users the ability to determine their personal risk from the range of potential outcomes versus only having a single most likely outcome to work with. Joslyn and LeClerc's (2012) study of psychology student decision-making, for example, found that student decisions were more in line with ideal decision models when they were given uncertainty forecast information. This conclusion was further supported by Savelli and Joslyn (2013) when using a variety of visuals to communicate risk, though these studies with students may not reflect the real-world decision-making process of EMs. There is some evidence that suggests that EMs benefit from uncertainty information, in particular from information on the worst-case scenario of a given event (Morss and Ralph 2007). This was also found to be the case for flooding forecasts in a study of interviews with 17 EMs near rivers by Hoss and Fischbeck (2016) and by

Demuth et al. (2012) for two Miami EMs in tropical weather events. Similarly, Donner (2008) found that the 39 Oklahoma EMs they interviewed saw tornado forecasts as more uncertain than flooding forecasts, due to the more unpredictable and more rapidly evolving impacts of tornadoes. This suggests further work needs to be done to understand how to effectively communicate convective severe weather forecast uncertainty.

Both the communication of forecast information and use of IDSS would be less effective without the relationships EMs and the NWS have built. Without frequent, trust-building engagement from the NWS, novice EMs can be susceptible to errors in judgement of weather data (Baumgart et al. 2008). This was later corroborated by Lussenden (2014), who found that EMs learn to read cues from the forecasters they build relationships with that help them understand the forecasters' level of concern. This ability to read forecaster reactions gives EMs a way to better understand the threat relative to them posed by severe weather. Andrew and Carr's (2012) study of local government officials in the Dallas-Ft. Worth-Denton Metroplex has also found that bonding relationships between individual actors are critical to the success of regional planning activities. Bonding relationships with local partners were reported by forecasters at the NWS Brownsville and Corpus Christi Weather Forecast Offices (WFOs) to be a crucial part of preparation and response (Goldsmith et al. 2012). These findings align with those from Demuth et al. (2012), who found that trust between EMs and the NWS is an important part of the success of the relationship needed for an effective weather response and confirm the importance of the NWS's recurring IDSS activities.

The definitions of trust vary widely between disciplines, but the concept can be summarized as "the intentional and behavioral suspension of vulnerability by a trustor on the basis of positive expectations of a trustee" (Oomsels and Bouckaert 2014). EMs and other local officials are vulnerable to social (e.g., criticism) and economic costs if they either take action for a non-event (false alarm) or fail to activate for an impactful one. Thus, they defer their vulnerability when they choose to trust that forecasts and warnings from the NWS are accurate and directly actionable. In their seminal review of the sources of trust, Rosseau et al. (1998) described four dimensions of trust: deterrence-based, institution-based, calculus-based, and relation-based. The latter three dimensions are most important to understanding EM-NWS relationships (Oomsels & Bouckaert 2014). Institution-based trust is developed through in overarching cultural or legislative support systems that dissuade exploitation of trust (Rosseau et al. 1998). Calculus-based trust operates within a "trust but verify" framework, where the other party's actions are trusted but closely monitored for failures (Rosseau et al. 1998). Finally, relation-based trust is built over long periods of time through repeated interaction and based on positive expectations of the other party's intentions (Rosseau et al. 1998).

This study seeks to identify strengths and opportunities for EM-NWS interaction and communication through the Prototype PHI tool paradigm of conveying severe convective hazard near-warning and warning information. Interview-based studies have been done across a range of phenomenon, mostly with low numbers of participants and study foci that could limit applicability to our interests. Studies with greater numbers of participants, such as Lussenden (2014), have used surveys as their data collection tool, which may not collect data with the same detail that interviews can provide. By attempting to fill these knowledge gaps, this study seeks to aid in the construction of a more complete picture of EM needs in relation to weather information for severe convective weather events; it also provided a basis for tool development for the EM aspect of the Prototype PHI tool projects from 2015 through 2017.

2. Data and methods

a. Sample

Participants were purposively sampled to maximize variation in order to collect information-rich interviews from a wide variety of situations (Patton 2002), which was useful to our study because of restrictions on time and funding. We selected about half of our study participants from EMs in the Oklahoma area, and sought several EMs from other locations to attempt to check against regional bias and recruit outside EMs to the HWT. In the end, 11 EMs were selected based on their ESF type, jurisdiction size, local challenges, and distance from WSR-88D sites. Six EMs were county-level, two city, one state regional coordinator of 15 counties, one state public health official, and one school district were then selected for interviews (Table 1). These EMs were recruited from a wide range of locations across the contiguous United States east of the Rockies, with seven from the Central Plains, two from

Table 1. EM jurisdiction descriptions. The total number of collected critical incidents was 48.

EM Number	Jurisdiction	# of Critical Incidents
1	Urban County	**5**
2	Rural County	**2**
3	Rural County	**3**
4	Regional Coordinator (15 Counties)	**6**
5	Rural County	**5**
6	Small City	**6**
7	City	**5**
8	ESF-8 State Level Coordinator	**5**
9	Rural County	**4**
10	City School System	**3**
11	County	**4**

the Upper Midwest, one from the Deep South, and one from the foothills of the eastern Rockies (Fig. 1). The participants faced several different forecast challenges: three were in areas with poor radar coverage, three had sensitive facilities in their jurisdiction (oil refinery, oil and gas production, and a hazardous waste dump), one was near the boundary between four NWS county warning areas, one was on the eastern edge of a NWS county warning area, two were located in floodplains, two had high traffic highways and/or railroads, and for the school district EM, every building in their jurisdiction was defined as a critical structure.

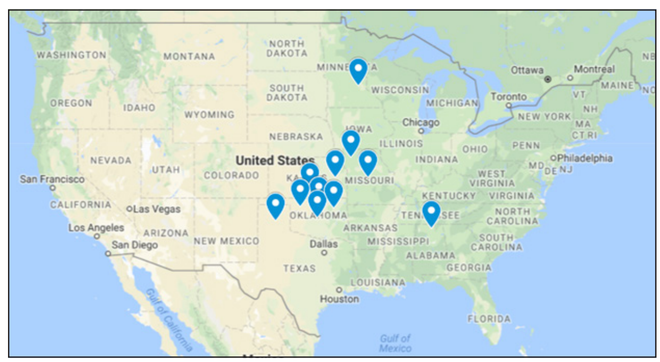

Figure 1. Locations of each of the 11 EMs interviewed for this study. *Click image for an external version; this applies to all figures hereafter.*

b. Interview design

Each interview followed LaDue et al.'s (2010) implementation of the Critical Incident Technique, which was based off the guidelines set in Dunn and Hamilton (1986). Most data were collected through phone calls, though a few in-person interviews were collected and followed a set structure. First the interviewer built rapport, then asked the participant to discuss incidents illustrating severe weather events where they 1) had the information they needed, or 2) when information was needed but not available. In closing the interview, participants were asked what severe weather information they would like to have in an ideal world. As the initial goal of this study was to prepare for the 2015 Hazardous Weather Testbed Prototype PHI Study (Karstens et al. 2018), interview guidelines were focused on seeking experiences with summertime severe convection. However, EMs did report critical incidents for a variety of weather besides convective events (see Table 2). Interviews were then analyzed using inductive thematic coding (Boyatzis 1998). Coding was done by hand, and codes were organized using the online Google Docs program.

c. Assumptions and limitations

There were several potential limitations to this study approach. First, most interviews were conducted during the winter season, when summertime events may not be recalled as clearly. This study assumes that EMs correctly remember the details of decisions made during their reported critical incidents, and that they knew the impacts to others in their jurisdictions (e.g., law enforcement, fire, public works). Our funding constraints dictated that we draw heavily from Oklahoma, from which we sought variation in jurisdiction size and ESF type. However, EMs from other regions were brought in to reduce any overall Oklahoma bias. Finally, our 48 incidents (Table 1) did not reach the recommended 100 incidents by Dunn and Hamilton (1986). Although the findings of this study are inclusive of the 11 purposively sampled EMs interviewed, they may not capture the full range of EM experiences.

3. Results

The events the EMs reported were mostly centered on tornadoes and convective wind, but winter storms, floods, fires, and extreme temperature events were also mentioned by the participants (Table 2). From these critical incident reports, four key themes were found across the interviews using the thematic coding technique. First, EMs looked to their local NWS WFOs as events approached to give them details about the event, narrowing their focus in time and space as the threat neared. Second, the participants described how trust in their NWS forecasters developed over time through decision support during events, which was most effective when a human forecaster was on hand for input. Third, all of the EMs described using uncertainty information—some explicitly expressed in NWS products and some not—to identify when thresholds for response action were reached. Finally, EMs also experienced a lack of uncertainty information that might have been helpful to identify when thresholds were passed.

a. Seeking greater detail as events approach

The information needs of the EMs changed throughout the event cycle, starting days in advance of a forecast impact. All 11 EMs mentioned seeking a "heads up" from the NWS as soon as potential severe weather entered the forecast, which they then used to begin preparations for a response to that threat. For example, EM1 mentioned how once they learned of potential severe weather, they would start looking at the NWS Storm Prediction Center (SPC) forecasts to gain a greater understanding of the threat. The SPC was also mentioned by EM4, who explained that "the Storm Prediction Center's items are up front—that's where we start first, with the convective outlook." Meanwhile, EM8 reported how their Warning Coordination Meteorologist (WCM) has "a personal email that he sends out, just FYI there's possibly some weather coming next week that you might want to pay attention to." This early warning allows EMs to begin their preparations for responding to the potential impacts of the forecast storms, as EM9 described:

> We're watching several days ahead and keeping up with what [NWS says]… I always make sure that my gas tank is always topped off, and then I send out those emails that I get from the National Weather Service… Basically, I'm trying to push that information out to everybody.

EM7 reported using this "heads up" to begin preparations several days before storms arrive, such as coordinating with their fire department to increase staffing for expected impact days. EM10, along with EM2 and EM11, reported repackaging NWS weather forecasts to better meet the perceived needs of their partners on a weekly basis. Though the repackaging of weather information varied from simplifying the forecast information to highlighting information on timing and impact details, the intent for all the EMs was to make an easily shared document for partners to use for briefing and decision-making. Overall, we found that these EMs are preparing for "something that hasn't happened yet… trying to push information to the cities to let them know what's coming." (EM11).

As an event approached in time, EMs would shift their focus towards identifying more exact spatial and temporal details of the forecast weather conditions from NWS (Fig. 2). EM11 mentioned an event where the NWS contacted them the day of an evening festival to explain that forecast evening thunderstorms would be more isolated in nature, allowing the EM to decide to keep the festival running while preparing for potential evacuations. When the NWS does not immediately provide information like in EM11's case, the EMs reported checking tools like Doppler radar before reaching out to their NWS WFO seeking additional

Table 2. Types of events EMs in the study reported, displaying the number of EMs that reported each type of event at least once.

Number of Recalled Events							
Event Type	**Tornado**	**Wind**	**Winter Storm**	**Hail**	**Flooding**	**Fire**	**Heat/Cold**
# of EMs	**10**	**8**	**6**	**5**	**3**	**2**	**2**

information. Eight of the EMs interviewed reported using radar as a situational awareness tool, though they would consult the NWS with questions based on their radar analysis. When they notice storms approaching on radar, EM2 mentioned they would "start chatting or get on the phone with [my local NWS] and ask them if they're going to put a warning out / what is coming towards us / what is going on / what are you thinking?" EM5 asked similar questions to their NWS when a squall line was forecast for their area to help them plan for a local high school event. Detailed information, when available, allowed the EMs we interviewed to put the previous days' preparations into action to protect the people in their jurisdictions.

b. Building relationships between NWS and EMs

The EMs we interviewed all shared a deep trust for the NWS and enjoyed a strong relationship with their local WFOs. This bond was built over time through consistent and effective decision support from NWS meteorologists. EM6 described one such trust building interaction, where before a storm "[the NWS] called me and said you might want to think about sounding your sirens!...It showed they were really paying attention." This feeling was shared by EM3, who mentioned that accurate NWS forecasts helped them build trust with the members of the public they served. Trust building events could happen in a variety of circumstances for these EMs, as EM5 recalled a day when they and their local WCM were away from their region when a dangerous storm approached EM5's main town. The WCM told the EM they were in for a rough afternoon considering "what's coming towards your county [he's being humorous]…but there's a very serious undertone to it…and that's the relationship we have." This interaction gave EM5 a deeper understanding and greater confidence in the NWS forecast, which gave them the ability to take mitigating action well in advance of the storm's arrival.

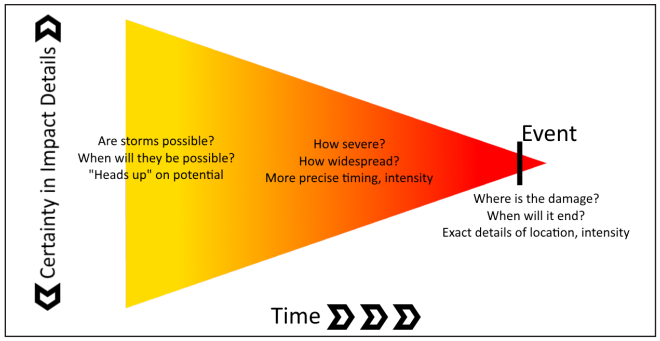

Figure 2. EMs understand that certainty in the details of a potential weather impact increases with time and ask questions that seek greater detail as a potential impact draws closer to fill information gaps between forecast product issuances. Note that certainty in the details of a weather impact do not reach zero as the event occurs. Certainty is only achieved after details of impacts are verified, sometimes well after the event occurs (graphic not to scale).

With repeated interactions of this kind, EMs build strong relationships with the forecasters that give them their forecasts. Eight of the EMs in this study directly mentioned a preference towards talking to a forecaster versus using an automated product. For example, EM7 reported that by knowing forecasters they could learn their triggers, whereas EM8 explained that "[EMs] understand nobody's perfect, and we don't expect perfection. We want humanity, right?" Knowing forecasters at the WFOs let EMs like EM6 communicate with them more confidently. The EMs also enjoyed receiving on-site support from forecasters, as they could ask the forecaster questions about model output and forecast changes and receive an immediate answer (EM11). EM5 summarized this need for personal interactions with forecasters well when they explained that "I would rather talk to any human than have a computer push something out to me! I can bounce back with, why are you seeing this, what are you seeing that's different…and I can get a good answer from just about anybody I ever ask."

c. Identifying response thresholds with uncertainty information

The communication of uncertainty information, which focuses on a range of outcomes and probabilities of impacts, was reported by nine out of the 11 EMs in this study. EM10 preferred using an experimental graphic from their local NWS that displayed risk level for individual hazard types several days into the future. EM5 also mentioned using probabilities to understand the spatial extent of a tornado threat in advance, describing how:

> "[NWS forecasters] put bullseyes out that kind of tells you here's the highest probability area, doesn't say it's going to happen… this is saying this is where the system is going to create the highest potential for tornadic activity."

Information regarding forecast confidence was also reported by EM11, who mentioned their NWS office sending out "low-confidence, high-confidence" statements through email regarding severe weather forecasts, whereas EM2 reported asking the NWS for confidence statements on forecasts. Additionally, four of the EMs in this study mentioned utilizing confidence information from third-party sources like The Weather Channel. EM1 recalled how "[before the tornado outbreak], the TOR:CON Index was at something like a nine or a ten. We were really, really high that day, and a lot of people were able to relate to that." The forecast confidence details conveyed by these uncertainty-based products are valued by the EMs we interviewed and play a role in the way they evaluate the threat a weather event poses.

Uncertainty information helped these EMs identify when threat levels passed either their institutional or personal thresholds for when to begin preparatory actions (Fig. 3). These thresholds were important to EM8, who at the time had state health personnel conducting checks on potential Ebola cases across their state. They were not sure whether a potential snow event would be significant, but the possibility of unsafe roads convinced them to ask their personnel to prepare a 4-wheel drive capable vehicle just in case. EM1 also applied uncertainty information to decision-making thresholds when a tornado watch was issued near their area. They noticed a pair of discrete thunderstorms heading into their region and stayed behind at their Emergency Operations Center (EOC) to watch them,

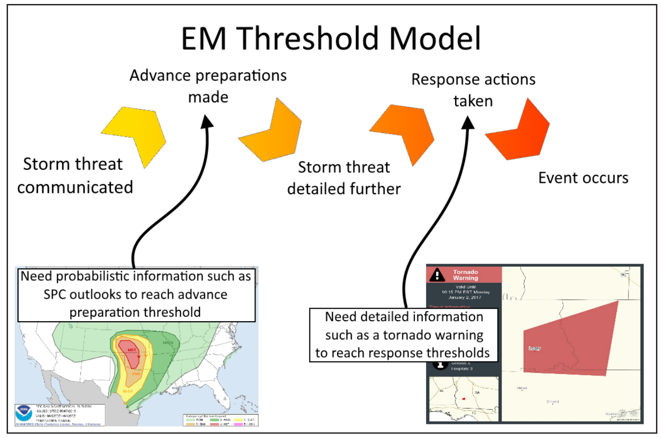

Figure 3. The typical threshold path that EMs in this study followed from their first notification of an event to the arrival of impacts.

partly because they were on-call in the event of a storm but also because of the proximity of the tornado watch. This information crossed a personal response threshold for the EM, causing them to hesitate before heading home and placing them in a better position to respond to the tornado that formed from one of those two storms. Others like EM7, reported regularly checking forecast severe weather risk levels when deciding to activate their EOC on potential storm days. As part of the weather forecast the NWS gave them before their evening festival, EM11 was told that there was "Moderate to high confidence, that [isolated supercells] will affect the metro…between 7 and 9 pm." This level of confidence played a role in the EM's decision to prepare protective actions for fair-goers without cancelling the event entirely, as it crossed the EM's threshold for response. Cautionary thresholds such as these were described by 8 of the 11 EMs we interviewed and were critical in helping EMs to make response decisions, as EM4 summarized:

> "I can get the forecaster's confidence on if he or she believes that storm's going to hold together, and potentially maintain the same severe potential, and that hour and a half's going to give me enough time to get my four or five thousand people that may be at a special event or even a couple hundred people at a high school prom, it's going to give me time to get them out of those areas."

d. Gaps in current warning information

Although EMs are using uncertainty-based information to meet response thresholds, the current warning system can suffer from gaps in impact and uncertainty information. One example of an impact information gap was shared by EM11, where after several days of heavy rain had saturated the ground, a strong but unwarned squall line impacted their area. Though the storm produced winds below severe criteria, it downed a significant number of trees over a wide area due to the saturated soils. Because the NWS told EM11 the storm would be sub-severe, and neither the EM, nor the NWS, had considered the potential for exacerbated impacts due to soil saturation, the EM did not make the preparations they needed to for a response to extensive wind damage. In other cases, such as one mentioned by EM6, the information gap was probabilistic in nature. They were surprised when a microburst struck and "I had the spotters out, but I don't think any kind of warning was ever issued...I just never heard anything about [the possibility of] microbursts." These impact and probabilistic information gaps can result in EMs being caught off guard by weather events, reducing their ability to respond to the impacts that result.

The information gaps reported by the EMs were most common for events where threat levels were below but close to warning thresholds, such as during an unusual hailstorm experienced by EM7. A slow-moving, high-precipitation supercell moved close to their city and over a major highway, dropping small hail that piled up to depths of several inches. As severe storms were expected that day, the EM had activated their EOC, though they were managing a helicopter crash that occurred south of their region as the storm approached. After informing the EM that the storm would not directly impact their city, the NWS did not issue a warning for it because the hail size from the storm was below severe limits. However, the storm's slow movement caused this hail to accumulate, making travel impossible. Without any warning details or additional communication from the NWS, EM7 did not have the information they needed to anticipate that the sub-severe hail would have significant impacts on road conditions, especially because the helicopter crash was occupying their attention. Because of this impact information gap, EM7 was caught off guard when reports of stranded motorists arrived and was forced to respond retroactively.

There were some circumstances where both uncertainty and impact communication gaps occurred simultaneously, such as for EM9 during an unexpectedly heavy snowstorm. They only had been an EM for a short time, and though amounts near the forecast snow total did fall, "it seemed like that storm was a lot worse than what had been predicted...if we had known that it was gonna be as bad as it was, maybe we could have positioned some supplies." This inexperienced EM did not understand what kinds of impacts that significant amount of snow could have and may not have internalized the range of snow totals forecast for this storm. The EM was thus less prepared for the storm's impacts than they would have preferred, hampering recovery efforts.

4. Discussion

EMs use lead time to make decisions well before watches or warnings are issued and are monitoring the forecast days in advance of a possible impactful weather event. This information is critical to the threshold decision making process that these EMs followed in advance of a storm event. Several days out the EMs were more focused on identifying days they needed to pay attention to, so that they could notify their responders or local officials and begin the process of preparing resources for potential impacts. Upon reaching the day of an event these EMs' needs changed, as they sought to identify the what, where, and when of potential storms. This constantly increasing certainty in impact details can be thought of as a cone, narrowing until a point where the exact impact a weather event has is known (though this may not occur until after the impact has happened, Fig. 2). Though EMs understand that certainty increases constantly, the timed-product nature of forecasts results in information gaps that EMs fill by contacting forecasters. The EMs in this study also tended to use Doppler radar to help set their expectations for potential impacts, which they would use to generate gap-filling questions for their NWS forecasters. These themes of increasing certainty as an event approaches, and use of Doppler products as well as NWS feedback, are similar to those found by Baumgart et al. (2008), Demuth et al. (2012), League et al. (2010), and Morss and Ralph (2007), though these studies had smaller samples of participants over more regionally focused areas.

Additionally, the relationships that EMs formed with local NWS forecasters improved their ability to deal with a severe weather event. This could be seen in the interviews as a desire for meaningful, back-and-forth relationships and conversations with local NWS forecasters. Morss and Ralph (2007) mentioned such conversations as an area for further study, specifically how these relationships affect EM decision making.

Demuth et.al. (2012) also mentioned the importance of close relationships between EMs and the NWS in the context of hurricanes, which is echoed by our participants for severe convective weather events. This rapport between EMs and their NWS forecasters was mentioned in all 11 interviews and affected the EMs' understanding of the risks storms present to them. The EMs in this study picked up on habits and perceptual cues presented by forecasters that allowed them to better identify threat levels based on the known trigger levels of their meteorologists, similar to the findings of Lussenden (2014). Future research should seek to determine the ideal conditions for the growth of this rapport.

The role of the forecaster was also highlighted by the EMs, who reported that the decision support and outreach that NWS forecasters provided during severe weather events was useful to their preparations. This emphasis on relationships and direct human input suggests that these EMs seek to build relation-based trust with NWS forecasters. Calculus-based trust would take the form of trusting forecasts, whereas institution-based trust would take the form of trust in the NWS organization, neither of which the EMs in this study focused on in depth. Future work should seek to expand upon the findings of Rosseau et al. (1998) and Oomsels and Bouckaert (2014) and investigate if more frequent opportunities for forecasters to interact with their EM partners can build relation-based trust. Understanding the building blocks of relation-based trust, and trust's interaction with products like the Prototype PHI tool and IDSS, may be able to help improve the communication of convective hazard information.

The decision-making process these EMs followed also played a role in how EMs responded to different types of weather information. EMs in this study prepared in stages as they passed risk thresholds, preparing for impacts through a series of smaller-scale decisions that sum to a complete response. This series of action triggers is similar to those reported by Savelli and Joslyn (2013) and Morss and Ralph (2007). However, risk thresholds are not met unless EMs are able to refine the details of a potential impact as the event nears in time. This information was most useful to the EMs in a form that captures the uncertainty inherent in the forecast situation and explains the potential impacts from an event in detail. By understanding the severity of potential outcomes, and which outcomes are most likely, EMs may be able to more efficiently prepare supplies and respond to evolving events.

The EMs in this study also suggested that the most significant issues occur for them when they are not granted detailed information on forecast impacts. The negative stories the participants shared all have a common element: the impact and uncertainty information gaps inherent in the current forecast paradigm reduced the EMs' ability to understand, prepare, and respond to an event before ground truth is obtained. EMs act based off the information they have on hand, and missing information can prevent action from occurring until an impact has already occurred. Though it is possible that IDSS or PHI products could work to fill some of these information gaps, studies of the effectiveness of new forecast services at addressing information gaps have not been completed at this time.

5. Conclusions

This study examined 48 critical incidents described by EMs purposefully sampled from varied regions of the United States and discovered the critical elements of NWS communication that these selected EMs rely on during severe weather events. EMs were sampled from a variety of regions to identify a generalized model of NWS/EM interactions, though further research should seek to refine the findings of this study to the local level and identify the unique characteristics of different regions. Key knowledge gaps identified by Morss and Ralph (2007) and Lussenden (2014) were addressed, as a large pool of stories of extreme convective weather events was collected from a geographically varied interviewee pool. Second, EMs in this study reported the importance of trust and conversation between themselves and their local forecasters, which supported the conclusions of previous studies of EM/NWS interactions. This trust also appears to be relation-based in nature, suggesting frequent forecaster interaction with EMs can build stronger relationships between the two. Uncertainty-based forecasts, such as worst-case scenarios mentioned in Demuth et al. (2012), were found to be part of the EM decision making process ahead of storms, as uncertainty information allows EMs to more accurately define whether their decision thresholds have been reached. This suggests that the findings of Donner (2008) are correct and that EMs do understand that there is uncertainty within convective weather forecasts. In conclusion, if IDSS and the Prototype PHI tool can help bridge the information gaps that occur in the current warning paradigm, EMs may be receptive to the use of these products in a range of situations. These findings should continue to be tested in live simulation of weather events with EMs, such as at the HWT.

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