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2.1 COMMUNICATION DURING THE WARNING PROCESS: OBSERVATIONS OF PERFORMANCE

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1. INTRODUCTION

For years, the National Weather Service (NWS) has conducted "Service Assessments" (formerly called "Natural Disaster Survey Reports") following high-impact weather events, particularly those that resulted in multiple fatalities. These reports typically contain an event narrative including findings and recommendations for service improvement by the assessment team, usually composed of NWS management and support personnel not directly involved with the event plus additional subject matter experts. Though the service assessments are not performed by an independent organization, they do provide a set of data in evaluating performance.

Another way to examine issues related to performance is through a technique called root cause analysis (RCA). Beginning in 2004, the NWS Warning Decision Training Branch (WDTB) has trained most every NWS forecaster in the basics of conducting simple RCAs and has accumulated a database of thousands of RCA submissions while preserving the anonymity of the RCA. While there is no comprehensive or routine RCA process, they again provide a glimpse into one-time and recurring issues related to performance.

This manuscript summarizes a review of service assessments focused on communications issues and presents results from data mining of the RCA submissions. To motivate this study, this paper also includes additional observations of communications issues.

2. MOTIVATION

A definition of communication is "to transmit information, thought, or feeling so that it is **satisfactorily** received or understood" (Webster's New Collegiate Dictionary; emphasis added). To judge satisfaction implies some relationship exists between the parties involved in the communication. Sometimes forecasters may be placed in the position of simply broadcasting information without necessarily judging the clarity of their products for ease of understanding. For example, a particular Flash Flood Watch (Fig. 1) contains unclear verbiage regarding specific geographical references. The lack of clarity stems from trying to use multiple directional adjectives (for example, "eastern sections of central North Carolina") to describe various parts of the Raleigh County Warning Area (Fig. 2). Forecasters are often placed in the position of needing to describe a specific geographical area with general geographical and regional terms. Unfortunately, these regional terms are defined somewhat arbitrarily (and often through automation in the WarnGen software that forecasters use to compose short-fuse warnings), and the recipient of a product may not get a clear mental picture of the area under consideration. This issue occurs on various scales from sub-county regions inherent in storm-based (polygon) warnings, to sub-state areas to describe areas for a particular outlook, advisory, or watch. A clear challenge exists simply to satisfactorily describe regions and locales in a non-graphical and verbal way that

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RAINFALL AMOUNTS BETWEEN 3 AND 5 INCHES ARE EXPECTED ACROSS THE **WESTERN SECTIONS OF CENTRAL NORTH CAROLINA. ACROSS THE EASTERN SECTIONS OF CENTRAL NORTH CAROLINA**…GENERALLY EAST OF THE U.S. 1 CORRIDOR…RAINFALL AMOUNTS BETWEEN 4 AND 8 INCHES ARE EXPECTED WITH LOCALLY HIGHER AMOUNTS UP TO 10 INCHES POSSIBLE.

Figure 1. Excerpt of Flash Flood Watch issued by the Raleigh forecast office.

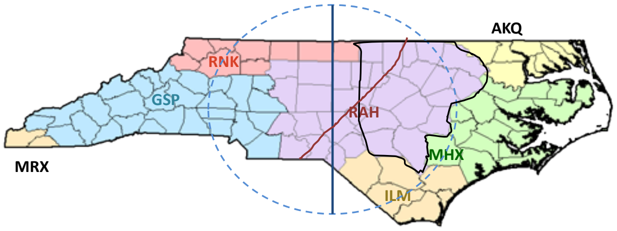


Figure 2. Illustration of challenges when crafting geographical descriptions. Shaded areas are county warning areas of NWS forecast offices that serve North Carolina. The Flash Flood Watch (Fig. 1) probably meant to describe the area outlined in black, and further delineated by Highway 1 (red line). Blue dashed circle illustrates a generic depiction of central North Carolina and the vertical line subdivides central North Carolina into eastern and western halves. An interpretation of the English description of "eastern sections of central North Carolina" could easily include counties in the forecast areas of RNK, MHX, and ILM, which is likely not the intent. The RAH office probably uses "central North Carolina" to describe their county warning area, thus representing a very specific area with a generic English description.

makes sense to local residents and also to people who may be travelling through the area. Local residents know local landmarks and can build mental maps based on landmarks and determine their position relative to them (Klockow 2011). Because travelers often don't know what county they are in, transportation terms may help. The flash flood watch in Figure 1 mentioned U.S. Highway 1, but perhaps the region under consideration could have been described using additional terms using highways as boundaries with mile markers or major town locations; for example, the portion of North Carolina east of Highway 1 and west of a line between Rocky Mount and Jacksonville. The assessment team for the 2008 Mother's Day weekend tornado in Oklahoma and Missouri noted a similar concern:

> "Because of differing views of relative location between those issuing the watches and warnings and those receiving them, verbal and written descriptions of locations at risk need to be carefully crafted and supplemented with graphics that depict the anticipated location as well as the uncertainty. NWS should work with communications experts to test various modes of presentation and dissemination of this kind of information" (NOAA 2009a).

One major issue for anyone receiving a watch, warning, advisory or statement product is just determining if the message applies to them based on geography (in other words, properly understanding the threat area of the warning). Once that occurs, then they can continue on to the other normal response steps (believing, personalizing, deciding, and confirming; Mileti and Sorenson 1990).

Another consideration in the communication of warnings is whether or not the recipient trusts the warning product (Mileti's "believing" or "confirming" stage). Does it make sense and fit with other information the recipient may already possess? As a consumer of weather information, the first author received a freeze warning (Fig. 3) and a heat advisory (Fig. 4) for separate events on a smart cell phone through the iNWS service (http://inws.wrh.noaa.gov). With this service, the NWS disseminates watch, warning, and advisory products, with links to auto-generated graphics, to government partners through text and email messages. Because of the variety of intermediate methods and services that retransmit warning products, forecasters usually do not know how their intended audiences perceive the warnings.

The freeze warning left many questions because of the discontinuous nature of the warned area depicted in the graphic which was

Interactive NWS Alert Information

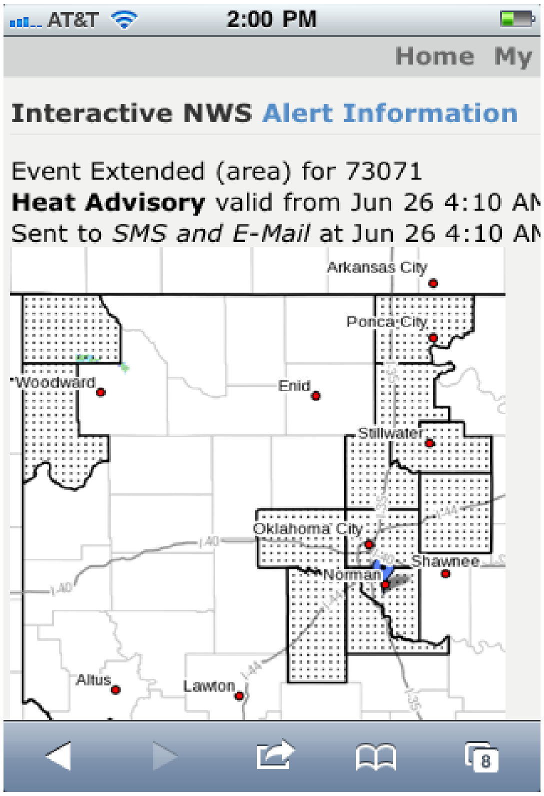
New Event for 73071

Freeze Warning valid from Nov 5 10 1:00 AM

Sent to *SMS and E-Mail* at Nov 4 10 1:36 PM C

Figure 3. Freeze warning issued by the Norman forecast office as depicted by the iNWS service.

an unusual configuration for a freeze warning. Were counties between Woodward, Enid, and Oklahoma City at risk of a freeze? Upon further investigation of the evolution of this warning event (Fig. 5), the freeze warning was an upgrade of a freeze watch (notated as "FZ.A.03") but also added counties in a previous freeze warning ("FZ.W.04") plus a few counties that bordered the southeast edge of the freeze watch, but not previously included in any freeze watch, warning, or advisory. The warning was segmented into two pieces (one for the counties under the watch and one for new counties not under the watch [depicted by Fig. 3] including the county with the placemark). Unfortunately, the iNWS graphic presented an incomplete picture of the hazard; perhaps simply depicting the entire hazard area would have been better than the potential disservice shown in Figure 3. A similar circumstance existed with the heat advisory, but at least the iNWS graphic stated that the advisory was extended in area, but the recipient still cannot easily determine the entire



Interactive NWS Alert Information

Event Extended (area) for 73071

Heat Advisory valid from Jun 26 4:10 AM

Sent to *SMS and E-Mail* at Jun 26 4:10 AM

Figure 4. Heat advisory issued by the Norman forecast office and disseminated by the iNWS service.

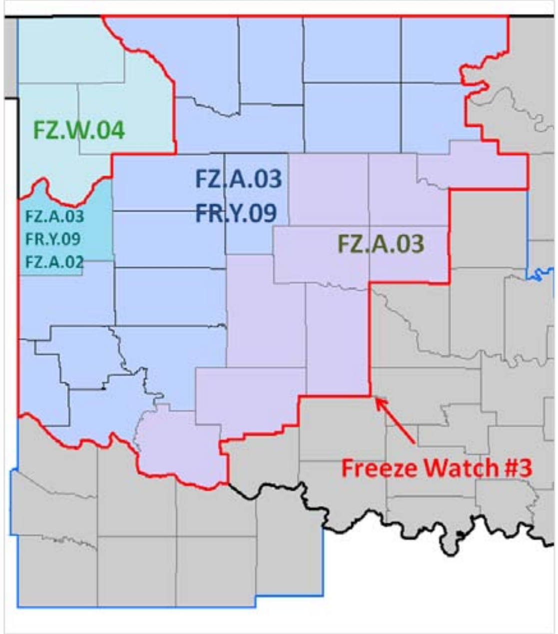


Figure 5. Evolution of freeze warning event.

advisory area. A mobile society needs the ability to easily and quickly understand the entire risk area; if the notification strategy represented by Figures 3 and 4 were applied a life threatening event, people likely would unwittingly put themselves at risk by traveling into hazardous areas unknown to them.

The process behind the depiction of the segmented areas in Figures 3 and 4 likely can be traced to formatting products for NOAA Weather Radio and teletype distribution where residents typically were notified for events (or changes to events) only for their immediate area. It is not clear how appropriate this strategy is for today's mobile population. The issues noted here are under the control of NWS software development and policy directive processes. Perhaps the entire watch, warning, advisory, statement paradigm should be revisited (Jacks 2011). Also, as new warning composition tools are under development (Ferree et al. 2011), alert products could be developed by considering their suitability for various dissemination systems rather than the one-size-fits-all/lowest common denominator approach used for decades. This suggestion is similar to Recommendation 5 of the Service Assessment for Southeast United States Floods of September 2009 (NOAA 2010; see Section 4.2 below). This approach may at least give the forecaster some ability to know how a particular alert product may be received and interpreted by a user, which is a shortcoming of the current system from a customer service perspective.

3. ROOT-CAUSE ANALYSIS

Root-cause analysis (RCA) is a technique designed to unveil causes for a particular incident and reveal relationships between these causes. A root cause is defined as a cause whose removal will change the event such that the incident will not recur. In the case of a RCA performed on a positive event (such as a successful warning), then the root causes may be interpreted as causes which were necessary for success. In nearly every event, multiple causes contribute to the outcome (either success or failure). For example, an RCA for a particular missed winter weather warning (Figure 6) could identify fourteen causes; some causes revealed other causes.

In 2004 and 2005, the WDTB included RCA as a part of the Advanced Warning Operations Course. Through this training course, most forecasters and local WFO (Weather Forecast

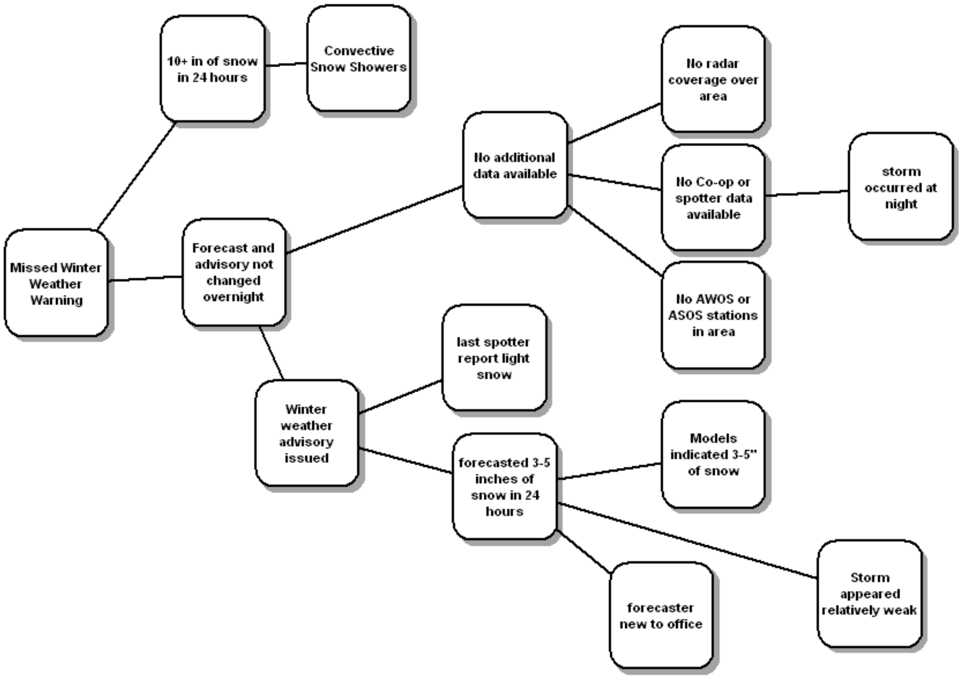


Figure 6. Sample Root Cause Analysis for a missed winter weather warning. Each box contains a contributing factor which was necessary for the winter weather warning to not be issued.

Office) management staff received training on performing basic RCA and completed an assignment which was an RCA on an actual event of their choice. In later offerings of the course, additional forecasters (mostly interns) have also submitted RCA assignments.

For the training course assignments, WDTB assured the participants that the RCA submissions would be kept anonymous to protect the integrity of the analyses. As the assignments were graded, the contributing factors in the submissions were categorized into science, technology, and/or human factors (Fig. 7). Through this process, WDTB has accumulated a database of over 2,000 individual RCAs which were also classified according to event type (missed warning, successful warning, and so forth).

Looking at the 50 unwarned hail events reported through this RCA process, communication and teamwork failures were identified as a contributing factor most often (Fig. 8). These communications and teamwork issues could have been either internal to a local forecast office, between forecast offices, or between an office and its stakeholders. Human factors-related causes (65%) were attributed to these events more than science (24%) and technological failures (11%). Of the 144 human factors issues, fifty-two were communication/teamwork failures or lack of spotter reports. Thus, the subset of issues related to communications account for 36% of the human factors causes and for 16% of all causes.

The tabulations for missed tornado warnings, unwarned severe wind events, and unwarned flash flood events (Figs. 9-11, respectively)

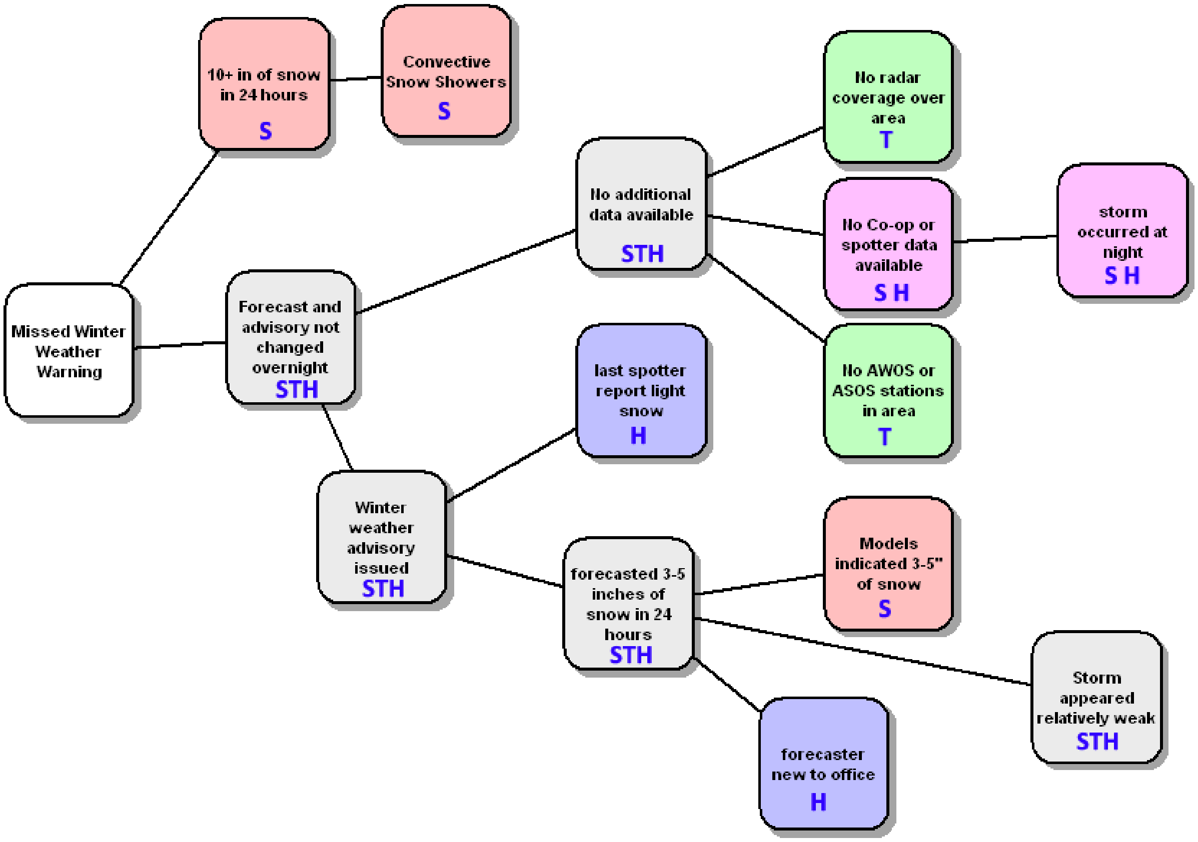


Figure 7. Same root cause analysis as in Fig. 6 but each contributing cause was categorized into Science (S), Technology (T), and/or Human Factors (H).

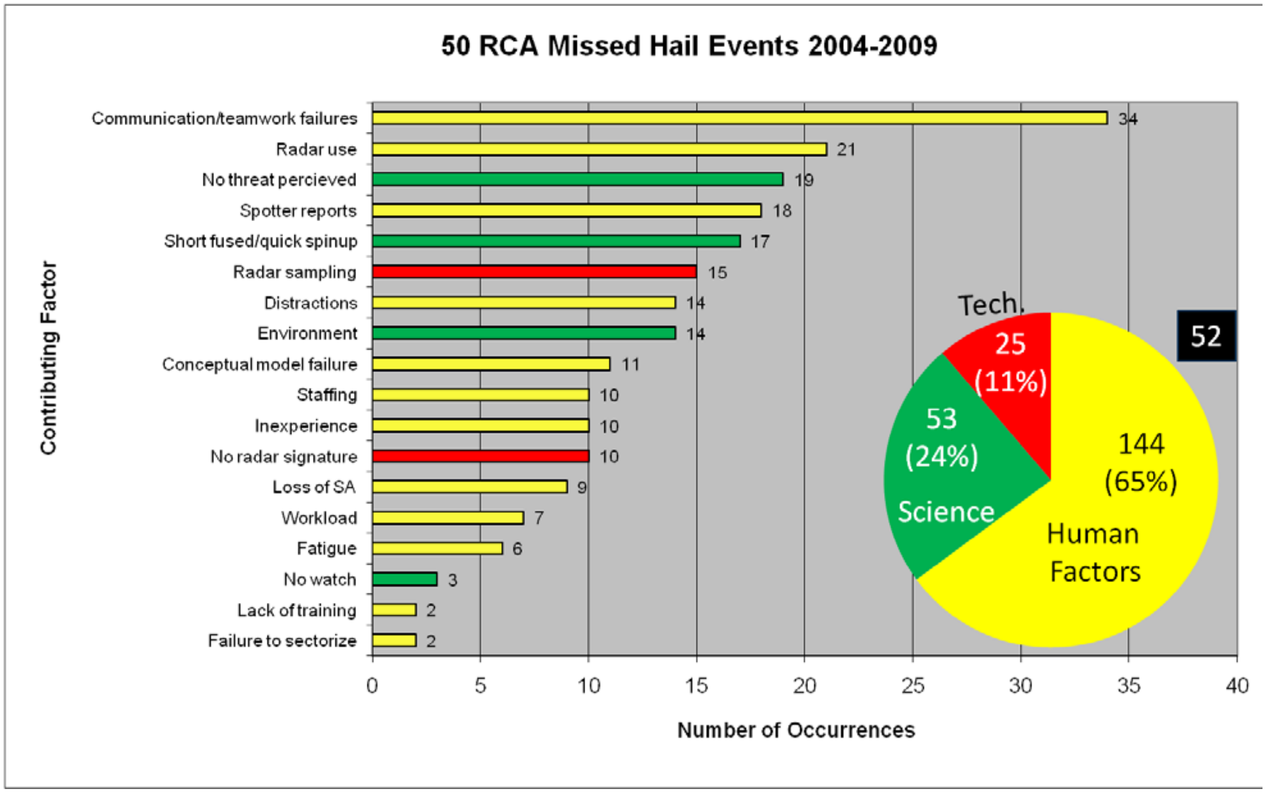


Figure 8. Analysis of 50 RCA submissions of missed hail events. Fifty-two of the contributing factors were related to communications: either teamwork/communications failures or spotter reports.

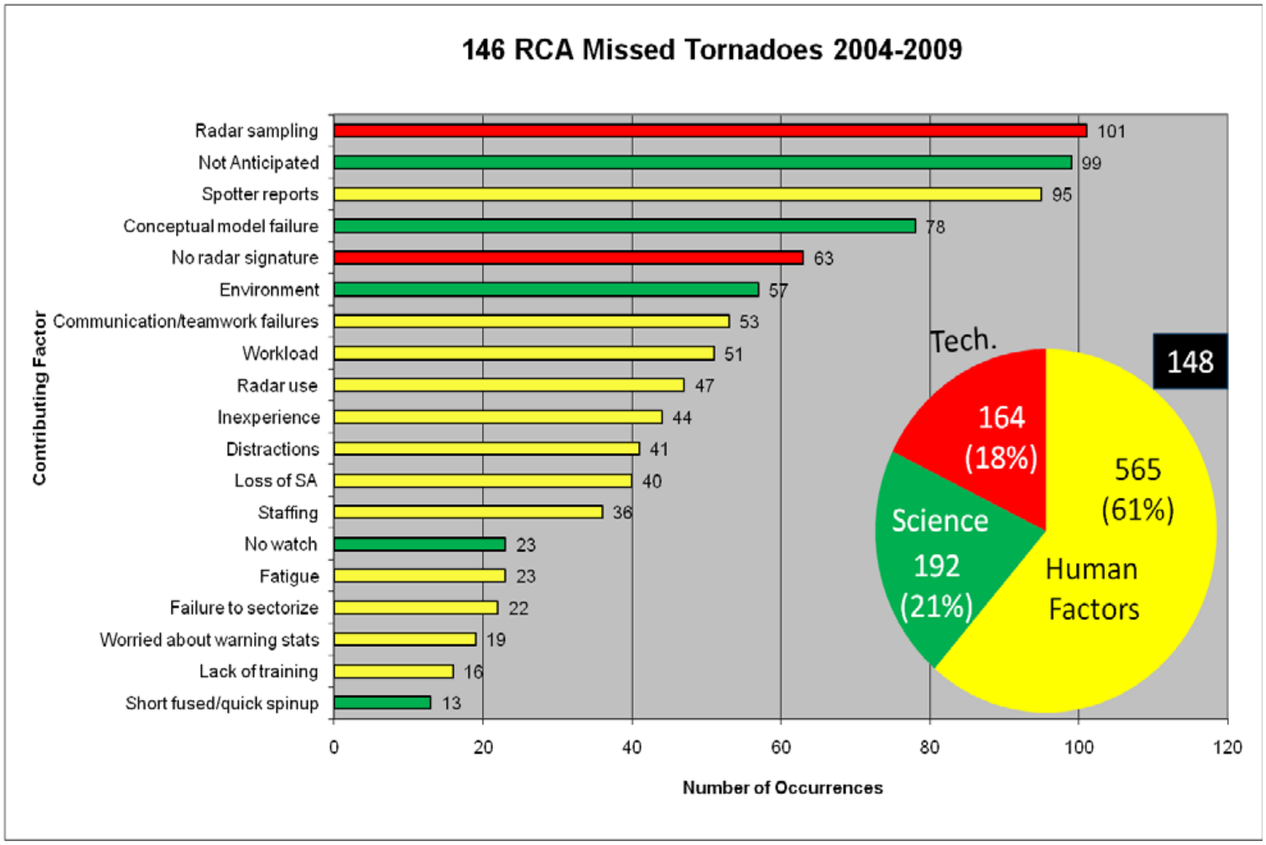


Figure 9. As in Figure 8, except for 146 missed tornado warnings.

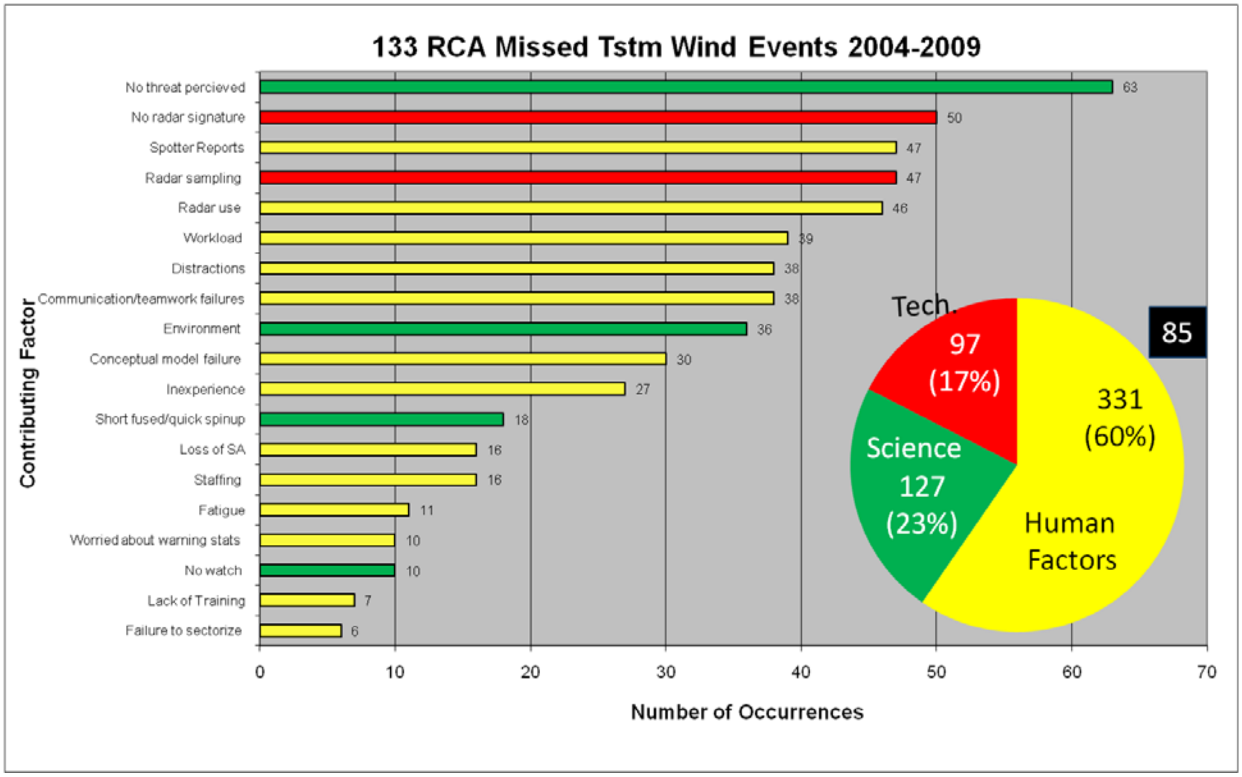


Figure 10. As in Figure 8, except for 133 missed severe thunderstorm wind events.

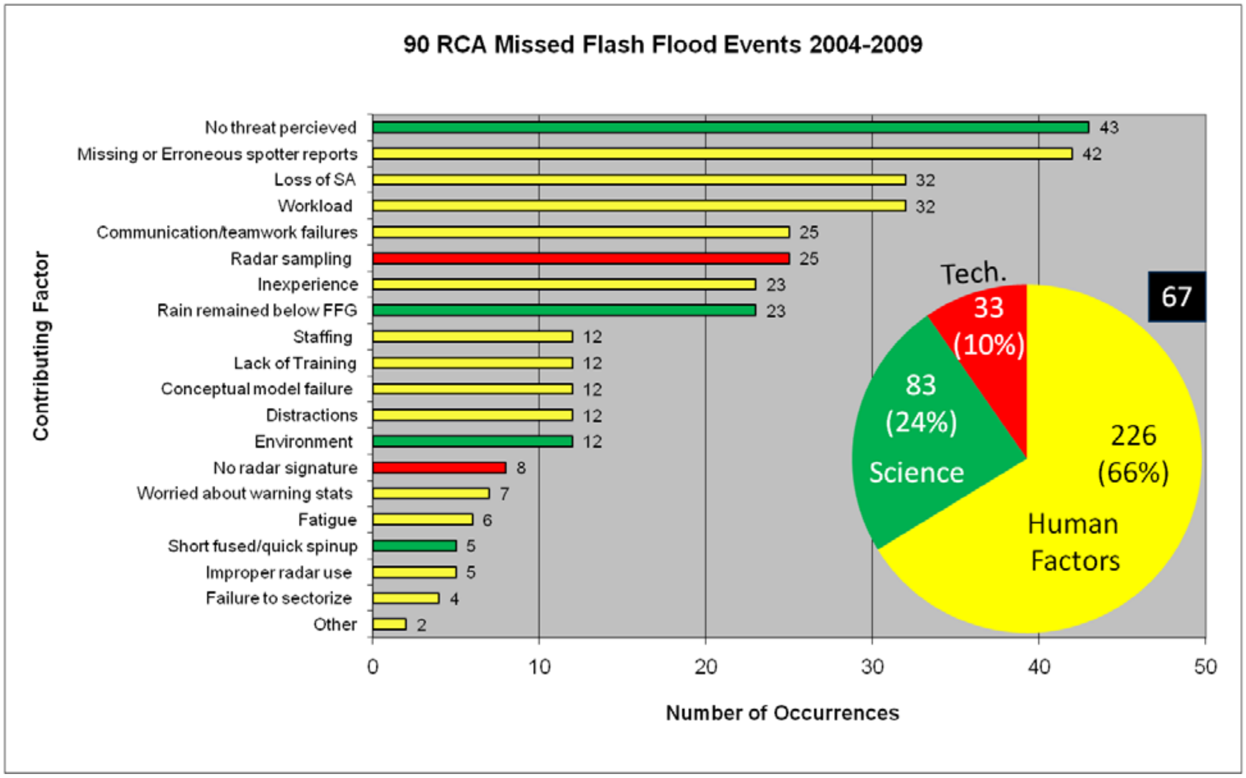


Figure 11. As in Figure 8, except for 90 missed flash flood warning events.

revealed similar patterns though communications and teamwork failures did not rank as the number one cause in the tornado, severe wind, and flash flood events. Summarizing all four of these hazards, nearly two-thirds of all causes were related to human factors and 28% of the human factors causes were attributed to communications failures and spotter reports. Therefore, an effective process to address and solve communications issues would, in theory, reduce the number of missed warnings.

Fewer submissions were received on positive events like lead time on tornado warnings (Fig. 12). Even so, a large percentage (55%) of factors enabling a positive outcome was related to human factors, and 26% of the human factors were related to communication/coordination or spotters. Hence, this analysis seems to present a similar pattern of the contribution of communications towards successful events as to a lack of communications towards missed warning events.

The smaller numbers of science and technology factors as compared to human factors in missed events may be related to several issues. First, more attention has likely been paid to the science and technology factors. Meteorologists probably prefer to work on science and technological issues due to their education and training. It is also well known that more research funding is available to tackle science and technological issues. Second, human factors issues may be more difficult to solve than science and technological problems due to frequent changes both in the composition of the team itself and in individual team members. In this context, "team" can refer to a given shift at a forecast office and also to the integrated warning team composed of emergency managers, broadcast media and NWS forecasters (Morris et al. 2008). Team compositions change due to shift schedules in that subsequent events probably involve different sets of forecasters working with stakeholders like emergency managers. Significant attrition also exists among some stakeholder groups. Consequently, developing continuing relationships between all on-duty forecasters and stakeholders becomes a challenging exercise. Moreover, each person involved in a team is a dynamic human being subject to all sorts of emotional, physical, and even spiritual issues, all of which can impact team performance. Unfortunately, few studies

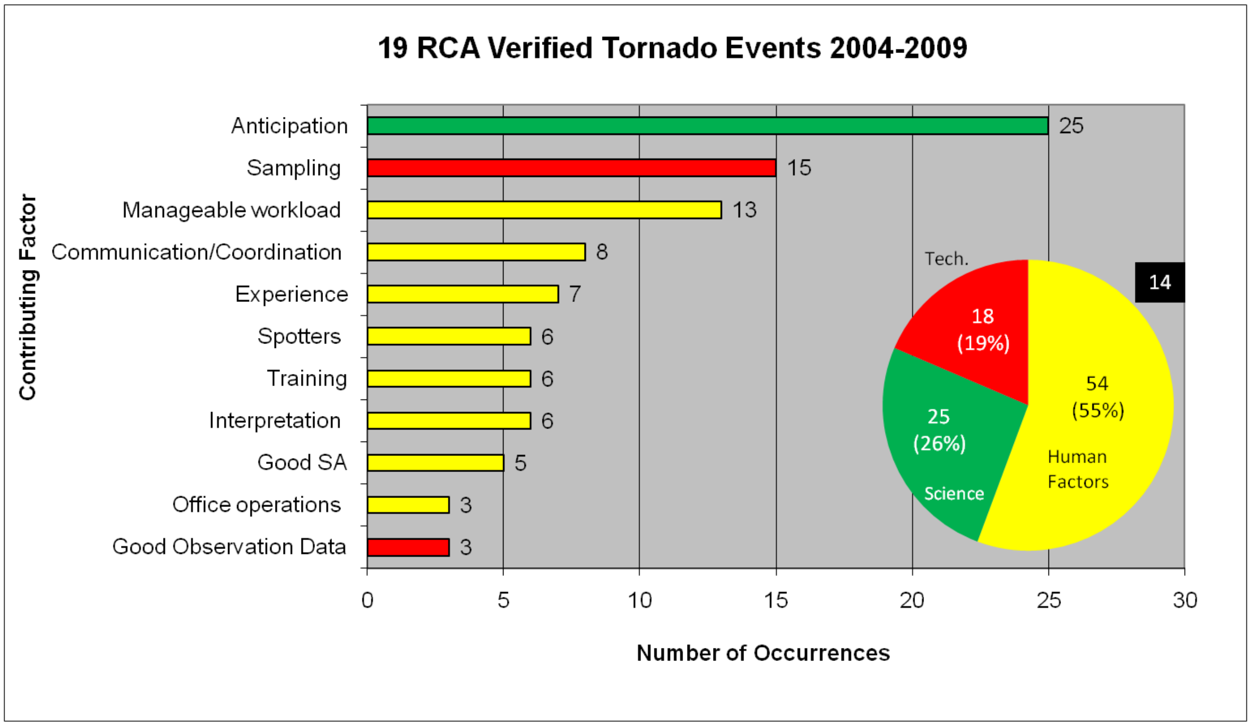


Figure 12. Analysis of RCA submissions on 19 tornado warning events with positive lead times.

have examined interactions among forecasters in an office and between forecasters and their stakeholders. Rather, many of the social- and human-factors studies that have been conducted (e.g., Mileti and Sorenson 1990, Baumgart et al. 2008, Spinney et al. 2011) tend to focus on customer needs and behavior to some extent.

While this analysis utilized thousands of individual RCA submissions, some caveats and issues exist with performing and analyzing RCAs in the NWS. First, there is no organized effort to conduct RCAs on a comprehensive basis, despite the fact that nearly every forecaster has received training on RCAs. While WDTB has collected more than 2,000 individual RCAs, many orders of magnitudes more forecast and warning decisions are made annually that are not subject to analysis, so the current sample size is small. Without an ongoing program to conduct RCAs routinely, there is no way to know when these results become outdated. Additionally, it is extremely difficult to capture impacts of changes in technology, new science, or process and human factors unless RCAs are included as part of a normal workflow and resources are dedicated to the collection and analysis of RCA submissions.

4. SERVICE ASSESSMENTS

A review of service assessments has revealed that some communication-related issues among NWS forecast offices and between the NWS and its stakeholders have been observed for decades. While the process the NWS utilizes to conduct these assessments could be improved, the time history of the assessments does provide a historical perspective to examine communications issues within the NWS and its stakeholders.

4.1 Communication with Partners and Stakeholders

Following the Shadyside, OH flash flood event of 14 June 1990 that resulted in 26 fatalities, the service assessment team found that

> "very little real-time information on flooding or heavy rains was relayed to the NWS by local officials which ultimately resulted in no flash flood warning being issued. The NWS did not learn about the Shadyside flood until four hours after the peak of the flood" (NOAA 1991).

Despite a multi-billion dollar modernization effort and nearly two decades of additional experience, the service assessment team that investigated the Southeast United States Floods of September 2009 (NOAA 2010) had three similar findings:

- "The lack of real-time feedback to WFO Peachtree City contributed to NWS forecasters, the media, and residents underestimating the magnitude of flash flooding."
- "Despite WFO Peachtree City outreach efforts and table-top exercise participations where communications with the NWS offices was stressed, EMs [emergency managers] generally were unaware of the NWS need for real-time feedback information during a major flood event."
- "…forecasters had little time to solicit feedback from affected counties. The efforts made to calls to 911 centers were unproductive: 'We're too busy to talk to you.' Direct contact with the EMs … would be a better way to obtain information."

In addition to flood events, assessment teams also have noted the need for improved communications with partners during tornado outbreaks:

- "The NWS should continue to work aggressively with emergency managers and others in law enforcement for timely receipt of severe weather information" (Recommendation from Southeastern United States Palm Sunday Tornado Outbreak of March 27, 1994; NOAA 1994).
- "WCMs [Warning Coordination Meteorologists] should work with local emergency management personnel to develop new or enhanced mass communications systems" (Recommend-

ation from Central Florida Tornado Outbreak of February 22-23, 1998; NOAA 1988a).

- “It is recommended that NWSFO EWX [NWS forecast office in Austin/San Antonio] work with emergency management officials to seek alternative and more efficient methods to confirm receipt of warnings. NWS should intensify efforts on both a local and state level to explore alternative methods of communicating critical weather products to emergency management officials” (Recommendation from the Central Texas Tornadoes of May 27, 1997; NOAA 1988b).
- “Some media partners prefer more definitive tornado warnings and SVSs” (Finding from Super Tuesday Tornado Outbreak of February 5-6, 2008; NOAA 2009a). [The process of understanding media preferences requires communication with them prior to and following events.]
- “The NWS should communicate with EMs and other key decision makers to highlight unusual or fast-changing situations involving extreme weather events” (Recommendation from Mother’s Day Weekend Tornado in Oklahoma and Missouri, May 10, 2008; NOAA 2009b).

The events corresponding to these last two excerpts occurred following the implementation of more direct communications technology between NWS forecasters and integrated warning team members enabled by NWSChat and its prototype predecessor IEMChat. Thus a *means* of communication between forecasters and partners was available. Evidently effective communications requires more knowledge of *what* to communicate and *when.* Perhaps recurrence of communications problems stem from a lack of routine communication among stakeholders prior to events through context-specific exercises, which would be necessary to determine the preferences of both media and emergency management partners. As noted in the Southeast US floods assessment, even a table-top exercise among specific emergency management partners did not have the intended effect. The assessment team for the “Record Floods of Greater Nashville Including Flooding in Middle Tennessee and Western Kentucky, May 1-4, 2010” service assessment noted that

> “limited interactions among OHRFC [Ohio River Forecast Center], USACE [US Army Corps of Engineers], and USGS [United States Geological Survey] prior to this historic flood contributed to a lack of understanding of each agency’s operational procedures, forecast processes, and critical data needs. This led to a breakdown in effective interagency communication” (NOAA 2011).

4.2. Internal NWS Coordination

Several assessments between 2008 and 2010 have highlighted the need for improvement in communication and coordination between neighboring forecast offices and between national and regional centers and local forecast offices.

- “There was no coordination between WFO Nashville and WFO Louisville on the Allen County tornado warning” (Finding from the Super Tuesday outbreak; NOAA 2009b).
- “NWS should require regions to develop severe weather coordination procedures between neighboring offices” (Recommendation from the Super Tuesday outbreak; NOAA 2009b).
- “When a severe weather event is moving from one CWA [county warning area] to another, the appropriate WFOs should contact each other to ensure a full and complete exchange of relevant information” (Recommendation from the Mother’s Day weekend tornado; NOAA 2009a).
- “To increase communication between field offices and HPC [Hydrometeorological Prediction Center] before and during significant hydrological events, field offices should request or HPC should initiate, HPC hosted conference calls with affected WFOs and RFCs” (Recommendation from the Nashville floods; NOAA 2011).

It is interesting to note that while the Super Tuesday assessment team recommended that

NWS regional headquarters develop procedures to facilitate better communications among their WFOs, both the Super Tuesday and Mother's Day events involved interactions between WFOs located in different NWS regions. The Mother's Day event involved forecast offices at Tulsa, OK and Springfield, MO in the NWS southern and central regions, respectively, while the Nashville and Louisville offices highlighted in the Super Tuesday recommendation also are in the southern and central regions, respectively. Hence, implementation of these procedures and any associated training exercises or drills should involve cross-region interactions.

4.3. End-User and Customer Perceptions

In the service assessment of the Nashville Floods of May 2010, the narrative included several statements that are related to whether or not customers and end-users satisfactorily understood the threat. Of course, citizens may receive information directly from the NWS or, most often, through one or more intermediaries.

- "Residents interviewed in the neighborhoods of Greater Nashville impacted by flooding said they could not relate forecast stages on the Cumberland River to the threat at their homes and they all perceived they had 'no warning.'"
- "Local TV meteorologists and Nashville OEM [Office of Emergency Management] stated the numerous flood warnings and products were confusing and made people 'numb' to warnings".

The assessment team apparently recognized the recurrence of communications issues by noting:

> "This fact further validates Recommendation 5 from the Southeast United States Floods, September 18-23, 2009, Service Assessment, as well as a similar Recommendation from the Big Thompson Canyon Flash Flood July 31-August 1, 1976".

These two recommendations and a finding from Big Thompson are reprinted below:

- "A review of the current suite of NWS flash flood and flood products should be conducted. The review should consider:
    1. How best to handle flash flooding that is expected to last more than 6 hours beyond the causative event, taking into account public perceptions of the severity of flash flooding vs. areal flooding;
    2. The best use of Flash Flood Emergency as a flash flood statement, as a separate flash flood product, or as a new emergency product that could be used for any type of weather emergency; and
    3. Changes to the text watch/warning product paradigm to serve customers more effectively, including possible separate "public" and "emergency professional" products, and products in a concise format for Smartphones" (Recommendation from NOAA 2010).
- "The warnings and statements issued by WSFO Denver on July 31 were worded in accordance with existing procedures and standards, but evidently did not convey to users the needed sense of urgency. The State Director of Disaster Emergency Services commented along these lines and said he felt the wording of watches and warnings is "too bland and stereotyped." News media representatives said much the same thing. They felt the NWS must somehow help them establish the appropriate urgency of such message (Finding from NOAA 1976).
- NWS should review its directives in regard to the wording of severe thunderstorm and flash flood watches and warnings. The degree of seriousness and urgency of the situation should be conveyed by the warnings" (Recommendation from NOAA 1976).

The assessment team also noted:

> "Customers and partners in the OHX [Nashville WFO] service area, including local officials, EMs, private entities, and the public, were aware of the significant storm potential over the

> weekend, but did not perceive the attendant risk of extreme flooding."

The Nashville flood event revealed that the *exact same* efforts of communication can result in awareness of *significant storm potential* and perceptions of *no warning* or *over-warning*. Customers can also perceive a lack of urgency in warnings whether the warnings are created manually (as in 1976) or by using some automated software tools.

5. DISCUSSION AND RECOMMENDATIONS FOR IMPROVEMENT

The nature of the forecast and warning problem in the United States is that it is inherently a distributed and collaborative decision-making process (Doswell et al. 1999). Within the NWS, national centers collaborate with one or more local weather forecast offices. Similarly, the watersheds for the 13 river forecast centers (RFCs) encompass multiple WFOs. Besides communicating with WFOs, actions of the regional and local offices of USGS and USACE can have considerable impact on river forecasts, and RFCs need to interact with those stakeholders. In the short-fuse warning process, WFOs should routinely interact with various integrated warning team partners including emergency managers and broadcast media outlets. In longer-fuse events, more core government partners (transportation, environmental quality, health, agriculture, and other local agencies) can become involved. Regardless of the parties involved, this short review of service assessments revealed that collaboration, communication, and coordination issues have recurred over at least the past two decades. Sometimes the issues are internal to the NWS, but often they involve the NWS and its core partners.

5.1 The Potential Role of Simulations

Despite the distributed and collaborative nature of the forecast and warning process, most training in the NWS is focused on individual forecasters. For example, forecasters are directed to complete two simulations prior to every significant weather season (for most forecasters this translates to 4 simulations per year). These simulations use the Weather Event Simulator (WES; Magsig and Page 2002, Morris et al. 2011) and mostly focus on application of science and technology concepts learned through local or regional training programs and often through distance learning modules. Most of these distance learning modules are also focused on the individual forecasters. Depending on how a WES simulation is designed and facilitated, it can also address some human factors issues such as workload management, situation awareness, critical thinking, and stress management. Though the WES was described as a system where forecasters can "train as they fight", the description is valid in so much that forecasters work by themselves. Most WES simulations are completed by forecasters in isolation, but occasionally a group of forecasters use the WES in a case-review mode where they examine weather data from a science or decision-making perspective in a conference room. The simulator was not designed to easily handle exercises that are distributed and collaborative in nature, though plans call for the development of collaborative simulation exercises that can be applied throughout the NWS enterprise.

In the future, a distributed and collaborative simulation system needs to be deployed across the NWS enterprise that can also involve partners. Such a system can be possible because the national centers, RFCs, and WFOs will all transition to workstations based on AWIPS-II (Tuell et al. 2009). Research and experience in adult learning (Knowles et al. 1998) states that learning is effective and transferable to the job when the learning activity occurs in a realistic context. Hence the simulation system should involve real software and hardware tools and the actual partners whenever possible to increase the fidelity of these virtual reality simulations. In addition, involving partners in regular simulations and drills would require some integration of NWS training and outreach programs and an increased priority on both.

The concept of a distributed and collaborative simulation system applied to the Nashville Flood event is illustrated by Figure 13. This system should be capable of multiple types of simulations. First, an "intra-office" simulation would consist of an exercise where all players are local to one forecast office. This type of simulation would either use an event that was entirely in one county warning area and required sectorized warning operations, or use an event that spanned multiple warning areas and local office forecasters played the roles of forecasters from multiple forecast offices. Second, an "inter-office" simulation would exercise and drill communications between neighboring forecast offices (for example, Nashville and Paducah). Such a simulation could also be expanded to include additional parts of the NWS enterprise (national centers and river forecast centers, represented by HPC, SPC [Storm Prediction Center], and OHRFC in Figure 13). Finally, a full "inter-agency" exercise could also involve core government partners (represented by USGS and USACE) and integrated warning team partners (represented by an EOC [Emergency Operations Center] and a television station).

The drills designed for a distributed and collaborative simulation system should have objectives focused on the human factors identified as weaknesses (such as communication and coordination). These objectives could be determined using RCAs. If such a system involved actual partners that can work through a sample event prior to an actual event, the exercise would reveal shortcomings that can be fixed proactively, similar to the exercises and drills that emergency managers routinely conduct as part of their preparedness activities. As such, the simulations should be facilitated, debriefed, and evaluated to compile sets of actionable recommendations for improvements. In addition, because it is undesirable for forecasters to lose proficiency on existing skills, the current training regimen on science, technology, and human factors must also be maintained.

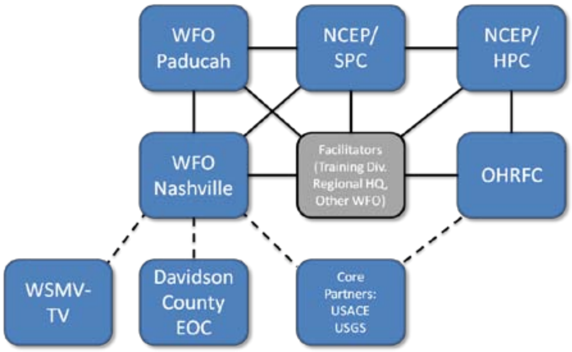


Figure 13. Illustration of the distributed simulation concept applied to the Nashville Floods.

Another kind of simulation called an "integrated warning team simulation" can also aid in identifying and correcting communications issues. In this type of simulation, various partners that comprise the integrated warning team switch roles while working through a weather event and being guided by experts (Morris et al. 2008, Nemunaitis-Monroe et al. 2011). This cross-training approach of "walking a mile in someone else's shoes" has been identified as a way to increase team situation awareness (Bolstad et al. 2005). Some role-playing in the simulations illustrated by Figure 13 would also improve teamwork and reveal potential areas for correction.

5.2 Service Assessments and Other Studies

The NWS has no independent and formalized process to conduct service assessments and evaluations. Because assessment teams often are formed in an ad-hoc manner, the recommendations sometimes are not actionable and are limited to the expertise and vision of particular teams rather than a comprehensive assessment organization or process. The lack of independence in the assessment process can limit the types of recommendations proposed. Recent service assessments, however, have begun to include more social science components. It is also unclear if the NWS has enough resources to adequately and completely address recommendations in service assessments and to verify if any remediation actually has the intended effect.

When other social science studies are conducted that involve the warning process, it is not clear if studies are repeated with enough frequency and in different geographical areas to determine if previous results are generalizable or whether the results are valid only for the particular region or population studied. In other words, both NWS forecasters and policy makers need better and clearer guidance on the formulation of their products that would aid in clear communication of hazards and on the role automation plays in this communication process.

There appears to be a lack of consistency in the product suite of watches, warnings, advisories, and statements issued by the NWS. Some warnings can be upgraded, expanded and extended; severe thunderstorm warnings and tornado warnings cannot. Some warnings are updated by reissuing a warning product; others are updated by issuing a statement (severe weather statements and flash flood statements). Sometimes events are warned (thunderstorms or winter storms), sometimes hazards are warned (freezes and flash floods), and sometimes a mix. For example, thunderstorms may produce five life-threatening hazards (wind, hail, tornadoes, lightning, and flash flooding). In the U.S., two hazards from thunderstorms are warned for explicitly and separately (tornadoes and flash floods), two are implicitly part of a severe thunderstorm warning (hail and wind), and one is not warned at all (lightning). It is not clear how well "power-users" (i.e., integrated warning team members and other core partners) of the NWS understand the subtleties of the organization of the product suite, much less uninformed users of the public. Moreover, it is also not clear if users and warning team partners actually routinely receive the complete stream of information from a local forecast office. Perhaps some customers receive the initial warning products but not the updated follow-up information. Hopefully social scientists will pursue examining the efficacy of the NWS product suite for partners and for end-users.

Many of the social science studies conducted so far have concentrated on the receipt and use of the products after they leave the forecast office. Few have examined the role of the forecaster. Depending on the event, a warning forecaster has a number of workload issues:

- Correctly applying the appropriate conceptual models to the observational data
- Understand and deal with technological limitations and the impacts on observations and workflow
- Maintain situation awareness
- Effectively communicate with and support partners
- Work on multiple storms and different types of long-fuse and short-fuse events.

Recommendations from communications studies need to account for the forecaster workflow. In some events, just the communication with partners requires a forecaster's full attention, so staffing issues in a forecast office also become a concern.

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