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WARNING DECISION MAKING PROCESS DURING THE 3 MAY 1999 TORNADO OUTBREAK

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1.0 INTRODUCTION

The largest tornado outbreak in Oklahoma history occurred during the afternoon and evening of 3 May 1999 when over 60 tornadoes tore through the state. The previous one-day record had been 26 tornadoes which occurred on 13 May 1983 and again on 4 October 1998. Several tornadoes early in the event were photographed and broadcast live by local television stations. The Bridge Creek-Moore-Oklahoma City-Midwest City tornado (hereafter called the Metro tornado) was also broadcast live nationwide. The widespread destruction which resulted from this tornado was accompanied by a relatively low death toll.

The extensive media coverage in part helped to create the impression that the events of 3 May were easily forecast and warned for, when in fact, the magnitude of the event was a significant surprise and the challenge to the warning operations was formidable. For example, while the Metro tornado was perhaps the most notorious that night, it was only one of 59 tornadoes to impact the Norman Forecast Office (OUN) County Warning Area (CWA) during a 10 hour period, the great majority of which were not covered live. At times, tornadoes were occurring at a rate of four per minute. This made for an especially challenging situation considering many of the tornadoes occurred after dark and after the damage from the Metro tornado had captured the focus of much of the local media.

This paper will discuss the decision making process as experienced at the NWS Norman Forecast Office. The decisions made and the reasoning behind them will be viewed in the light of topics discussed at the Operations Training Branch (OTB) Warning Decision Making (WDM)Workshops.

2.0 WARNING DECISION MAKING WORKSHOPS

Since 1997, the OTB has conducted WDM workshops which have been attended by a representative from every field forecast office in the NWS. The goal of these workshops is: "To evoke a better understanding of the elements of the warning process, which leads to better decision making, which leads to better service" (OTB,1999) Those elements include (but are not limited to): recent research findings, data interpretation and integration, impacts of software updates, user interface issues, situation awareness, decision making, and user interactions. Many of these elements are tied together as the workshop attendees participate in displaced real-time (DRT) scenarios utilizing workstations similar to those actually used by NWS field offices.

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3.0 WARNING METHODOLOGY

The warning methodology (1992 Quoetone and Huckabee; 1995 Andra, et al) referred to here is one that takes many aspects of the warning process and integrates them in a logical and functional way to arrive at an end result. The elements of the warning process include:

Anticipation: Mental and physical preparation for what is likely to occur.

Product selection: Radar data (or other data) which are used in the analysis of the current state of the environment.

Feature recognition: Conclusions based on knowledge of the data sources, their strengths, limitations, and the application of storm structure and mesoscale analysis.

Ground Truth: The influence of ground truth reports or the lack thereof.

Warning Generation/Dissemination: The act of formulating and disseminating a warning which elicits the proper response from the users.

Non-Meteorological factors: The impact of accomplishing the above in an environment in which people interact with technology in a dynamic manner, under time pressure, and with missing or ambiguous information.

3.1 The Decision to Warn

Ultimately the decision to warn (or not to warn) will be arrived at by weighing the value of each of these elements. While non-meteorological factors are not considered as input into the decision, their presence may determine how well that input is perceived and evaluated. The final outcome will be determined when the “warning scales” are tipped in the favor of a warning decision, based on a preconceived warning threshold and acceptable degree of uncertainty. This is similar to how a verdict is reached in a courtroom with the level of certainty ranging from a “preponderance of the evidence” to “beyond a reasonable doubt”. In both instances, the decision threshold is based not only on the data and how they are presented, but also on the experience and value system brought into the mix by the decision maker (Hammond, 1996). The decision threshold will often vary as the perceived threat and possible outcomes are considered.

4.0 WARNING METHODOLOGY ON 3 MAY

4.1 Anticipation

In the eyes of many forecasters, 3 May was to be the next in a series of severe weather days with the usual mixture of large hail, strong winds, and probably a few tornadoes. The ambiguity and uncertainty in what was expected was evident in the wording of both local forecast discussions and national guidance (Thompson and Edwards, 2000). Both indicated storms would develop primarily along a dryline in western

Oklahoma, especially overnight. While the highlighted threat risk increased throughout the day, the final wording before storm time focused on only isolated tornadoes in the evening with the main threat being large hail. The end result in the minds of most forecasters was that severe weather was likely, as was the possibility of a few tornadoes, mainly after dark. The first tornado watch was issued at 445pm, but did not include enhanced wording. This can be compared with the 26 April 1991 outbreak which drew heightened awareness and preparation from much of the weather community hours even days before the event occurred. The level of certainty was made evident to the public early on by the wording in the Public Severe Weather Outlook which highlighted the likelihood of an "outbreak of tornadoes and severe thunderstorms..." as early as 4am on April 26th (DOC, 1991).

Many decisions, ranging from staffing levels to equipment readiness, were made in the forecast office on May 3rd based on the anticipation of a night of severe weather. However, at this point in the event, no *unusual* plans were being made.

4.2 Product selection and data interpretation

Ideally, a warning forecaster spends most of the time viewing and interpreting data. Critical to this task is knowledge of the strengths and limitations of the data sets, as well as the limitations of the equipment displaying the data. This requires proper advance configuration of the radar viewing workstation (AWIPS -Advanced Weather Interactive Processing System) and the proper settings for operating the radar itself. The AWIPS workstations were configured prior to 3 May with procedure macros to permit quick display of numerous radar, satellite, and mesoscale products in a logical and cohesive sequence. This preliminary work was critical to allowing the warning forecaster to focus on the data, rather than the process of accessing the data. Tools and procedures used included those which help assess the three-dimensional velocity and reflectivity structure of storms. Other procedures allowed for a quick view of the mesoscale features apparent in satellite and surface data, and their likely impact.

Reflectivity and storm relative mean radial velocity data from multiple elevation angles were the primary products used by the warning forecasters. Volumetric algorithm products, such as those from the Tornado Detection Algorithm (TDA) and Mesocyclone Algorithm (MESO), were also available (Zittel and Conway, 2000) and were used in a "safety net" fashion. The Warning Decision Support System (WDSS) was used for supporting evidence and provided additional threat confirmation through high resolution velocity images.

Choosing the products is only part of the challenge in real-time storm interrogation. The other challenge lies in interpreting the images. Sampling limitations, including gaps left by discreet elevation cuts in the Volume Coverage Pattern, the so called "cone-of-silence" directly over the radar site, radar horizon, viewing angle, aspect ratio, range folding, and velocity dealiasing can hamper interpretation. To mitigate many of these limitations, forecast offices will usually access more than one radar when viewing a particular storm (Sohl, et al 1996). In fact, this practice can be imperative when significant data voids are noted from the primary radar. During the events of 3 May, two radars which covered parts of the OUN CWA were out of service (Wichita, KS and Tulsa, OK.) This made examination of storms in the OUN CWA covered by these radars more challenging.

4.3 Spotter Reports

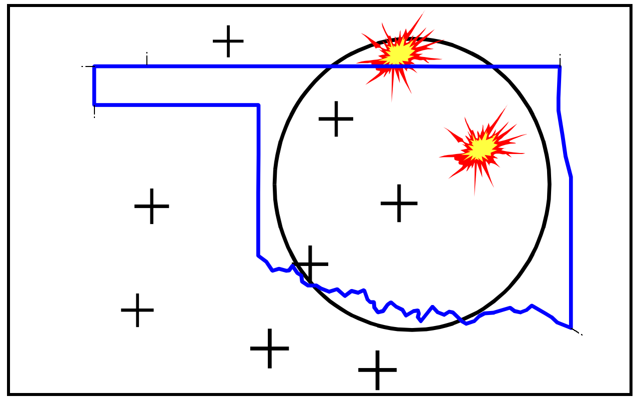

Figure 1. Radars available to the OUN Forecast Office (center of 125 nm range ring). The Tulsa and Wichita radars are indicated as out of commission.

Spotter reports can play a critical role in the warning process. During the outbreak, numerous private and government sponsored chase groups were on the roads, including all three major metro television networks. The OUN office also uses an amateur radio network to solicit reports from trained spotters in the field. This practice was especially beneficial as much of the local TV coverage was focused on the Metro storm. With up to four tornadic supercells occurring at once, intense efforts were undertaken to glean reports on the remaining tornadic (and non-tornadic) storms in the CWA. One staff member was devoted solely to soliciting, collecting, and sorting numerous reports from dime size hail to half-mile wide tornadoes. Getting this information into warnings and statements in real-time adds much more credibility and validity for the end users, increasing the likelihood of the proper response. Ensuring the right information got to the appropriate warning forecaster was therefore critical and, for a while a full time job. The Metro storm posed a particular challenge as it moved into the more populated areas, whereupon many spotter reports turned exclusively to damage reports. It was ultimately necessary to request that spotters refrain from giving damage reports in order to focus on information regarding the current tornado location which was critical for subsequent warnings.

4.4 Warning Generation and Dissemination

The graphical warning generation software (WARNGEN) provided with AWIPS proved extremely beneficial during this event. Radar data on multiple workstations allowed for "sectored" warning operations (OTB,1999), something which would have been difficult with the previous radar display. At times, warnings were generated at four different workstations and disseminated for NOAA Weather Radio (NWR) broadcast on 8 different transmitters across the CWA. During a ten hour period, 116 county warnings (154 products total) were transmitted, averaging about one product every 3.9 minutes. This volume of traffic was made manageable on the NWR by the Console Replacement System (CRS) which allowed for timely and efficient automated transmission of most products and warnings. However, the system was not without challenges and required a dedicated staff member to monitor and intervene on several occasions when warnings were either missed or not tone alerted, or to reboot the software during occasional lockups.

4.5 Non-Meteorological Factors

It can be easy to forget during drills, case studies, and post event evaluations that many things which impact the effectiveness of a warning event have nothing to do with science, meteorology, or skill. These factors which include stress, fatigue, and equipment managing, can be challenging to train on, yet can make or break an office's ability to perform their mission. The stress factor on 3 May, while not initially an issue, became considerable just prior to the Metro tornado and continued throughout the night (actually for several days after the event as well). Stress and fatigue became of concern when after the impact of the Metro storm became apparent, there were still another seven labor intensive hours of severe weather to be worked. In fact, it was during the later part of the night that several additional communities were devastated including Stroud and the town of Mulhall, which was struck twice by tornadoes after sunset. Staff were personally impacted as well when the Metro storm took a path toward the northern part of Norman, including the forecast office. Surrounding offices were called to prepare them for backup operations should the trend continue. A deviation to the north resulted in the storm missing the northern part of town (within 6 miles of OUN) and ultimately taking the storm across Moore.

The view out the west windows of the forecast office was dramatic and had an impact of its own on stress levels. With the passing storm came occasional yet extremely intense cloud-to-ground lighting and ear splitting thunder, as well as power flashes off to the northwest. The expectation of death and destruction was significant and weighed heavily amongst the staff. Many personnel had family and friends in the path of the tornado. This included the warning forecaster in charge of the Metro storm who was ultimately relieved of duty to help in the recovery efforts in his family's neighborhood. Remaining focused on the numerous other storms which were simultaneously occurring, and for the next several hours after the Metro storm passed, became a constant struggle as damage reports and television images relayed the devastation just down the road.

Another challenging factor included equipment malfunctions which were at best annoying, and at worst significant. At various points during the evening many pieces of equipment were impacted: workstations locked up, radar ingest required reset, surrounding radars malfunctioned, and phones lines were jammed. Tulsa's inoperative radar, coupled with the loss of reliable phone service, meant that unusual measures were required for the OUN staff to get radar information to the Tulsa office for warning purposes. Any one of these issues, if not handled properly or accounted for, could have made the difference between a warning heeded, and a tornado missed.

5.0 SITUATION AWARENESS

The concept of situation awareness (SA) was introduced in the WDM workshops in 1997, but has been incorporated into the training of many other disciplines for the last several years. These areas include aviation, military warfare, emergency room medicine, and nuclear power plant management.

The WDM workshops focus on the definition of the three levels of SA as presented by Endsley (1988): 1) the perception of the elements in the environment, 2) the comprehension of their meaning, and 3) the projection of their status in the near future. When studying the environments of those who use SA in their training, many similarities between these disciplines and the warning environment were noted. These similarities include: people working with technology, a situation which can unfold in many ways, events where not all information is known, use of a team environment, time pressure, and lives at stake (Orasanu and Connolly, 1993). SA was first introduced into the aviation community when studies looked at why well trained, experienced pilots with state of the art equipment still faced accident rates which remained basically unchanged. Examples of events in which SA errors have been cited as a part of the ultimate disastrous outcome include the 1995 crash of an American Airlines jet into a mountain near Cali, Columbia (NTSB, 1996) and the USS Vincennes downing of an Iranian Commercial Airliner in 1988(Cannon-Bowers and Salas 1998).

Examples in the meteorological world could include numerous events which have been characterized by the downgrade of a tornado warning (or allowing it to expire), followed by the occurrence a damaging tornado which strikes a population center. In these instances, all cues seem to point to the action being correct (top decreases, reflectivity loses its structure, mesocylone shrinks or disappears). However, these cues are also characteristics of another possibility, namely the collapse phase of a cyclic tornadic supercell where tornadoes are most likely (Lemon and Doswell, 1979).

5.1 The Impact of Situation Awareness on 3 May

Good situation awareness allows one to consider several possible scenarios which can produce the same set of symptoms, and can prevent one from becoming fixated on the first or easiest explanation. This could have been the case as the Metro storm, still not the killer tornado at this point, was moving into the southwest portions of Bridge Creek and Moore. As it moved into the population center, staff braced for the expected influx of calls from the public and emergency officials which ***always*** accompanies a storm moving over a population center. The calls never came. One explanation for this could have been that the tornado had lifted, or that it had looked worse than it actually was. Forecasters could have considered the possibility that the next action might then be to either downgrade the warning or at least back off on the heightened wording. Fortunately another possible explanation was considered and when phones were checked, it was discovered that no calls outgoing or incoming were possible. The less likely yet actual explanation for the lack of communication was not because of a lack of damage, but because of failure in the phone system. With the live national coverage the storm was getting, a plethora of incoming calls from around the country to check on family and friends in the affected area had rendered both conventional and cellular phones useless.

Situation awareness also played a critical role in elevating the event from "just another tornado day" for the Oklahoma City metro area (two of which had occurred during the previous 11 months) to an event of catastrophic proportions which required unparalleled public response. This awareness had to become evident in the minds of forecasters who then had to make attempts to convey that same awareness in the minds of the public. A key factor in accomplishing this heightened level of awareness was the use of live TV images. Second hand reports, while critical, could not convey the near 100 percent certainty of this event, nor could they portray the magnitude of the impending disaster. Thus, recognizing this once in a lifetime (we hope) event, *as it was unfolding*, became the key factor in the situation awareness of the staff, which led to unprecedented actions in the form of forecast products whose wording was exceptionally strong.

Headlines such as “tornado emergency”, which was conveyed in a Severe Weather Statement issued at 6:57 p.m. CDT, had never before been seen by the tornado-frequented metro residents and many took note. Neighbors called neighbors, people fled in cars, crowds at large events were moved en masse to safety, and citizens left homes to crawl down manholes. This type of wording was especially critical for those listeners who were not able to get visual confirmation via TV. The relatively low loss of life was due in large part to the proper and sometimes unusual actions taken by most in the path of the storm.

5.2 SA and the Role of Warning Coordinator

Some offices will choose to have a position devoted to overseeing events, ensuring no aspect is overlooked, similar to the incident commander role that is often established at disaster sites. The benefit of having this position is that there is at least one person responsible for maintaining overall situation awareness. This position can be assigned to one person, who has no specific other tasks, or as on 3 May, can be a shared task among 2 or 3 staff (the latter will be sufficient as long as the office is adept at communicating and coordinating activities). Some decisions that came out of this role on 3 May included: going to generator power, notifying surrounding offices of possible backup, assigning/re-evaluating warning sectors among the staff, ensuring all products were communicated to outside users, and ultimately, initial planning and coordinating for damage surveys and press conferences.

6.0 CONCLUSIONS AND LESSONS LEARNED

The events of 3 May 1999 were not only meteorologically significant, but elicited an unprecedented response from the many people affected. Effective communication of the threat to all in the paths of the tornadoes was critical to the NWS mission of saving lives and property. It was not just important to give information on 3 May, ***it was even more important to get a response...the proper response....from those in the storm’s path***.

Several elements were key to communicating the threat, namely:

- Training and experience which allowed forecasters to apply physically-based conceptual models and identify which storms posed a tornadic threat.

- Advanced workstations (AWIPS and WDSS) configured to allow quick access to important radar data and rapid dissemination of warning messages.

- Strategies such as “sectored” warning operations, extensive interaction with the amateur radio network, and integration of local television reports allowed forecasters to develop the awareness necessary to recognize and convey the extreme danger.

- Extensive coverage of the tornadoes by news media, especially the local network television affiliates, greatly heightened the office’s as well as the public’s awareness of the impending disaster.

As with every warning episode, there are things that can be learned or improved upon. For one, the reliance on public telephones, especially between other NWS agencies and offices, could have been a disaster when phone service was interrupted. While there were workarounds, they were less than efficient. In the public sector, dealing with the perception that underpasses offer safe refuge will be a challenge. Indeed, some people left relatively safe structures to seek refuge at underpasses, where two were killed and many more injured. Also, with so many successfully fleeing their homes, others may feel that this is the course of action to take the next time a tornado threatens, and without long lead times, there may be more people injured or killed in traffic jams fleeing the tornado than that incurred by those who seek shelter in the safest part of their house.

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