EMERGENCY MANAGEMENT DECISION-MAKING DURING SEVERE WEATHER

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The Collaborative Adaptive Sensing of the Atmosphere (CASA) project will provide its end users with new weather radar data with finer spatial and temporal resolution than existing WSR-88D data. It is not clear what impact this new information will have on emergency managers. This work introduces a descriptive decision-making model of emergency management during the four severe weather phases: Pre-Storm, Severe Weather Watch, Severe Weather Warning, and Severe Weather Event. The initial model describes EMs' use of information and their decisions made. Eleven emergency managers participated in three questionnaires and two part-task simulated weather scenarios based on archived weather data. This work then refines the Severe Weather Warning phase of the model by validating the entries and adding data concerning the role of the information and precursors to decisions made and actions taken. The scenarios also highlight problems that EMs have with interpreting velocity data and with integrating data from multiple radar sources. These results will impact CASA system visualization design and training.

INTRODUCTION

Emergency managers (EMs) have a critical role in alerting the public of approaching severe weather and in deploying and protecting storm spotters (those who make visual observations of the atmosphere). EMs alert the public by calling hospitals or schools, interrupting local television programming, and communicating with first responders and storm spotters. Some jurisdictions maintain local storm sirens for which an EM may be solely or jointly responsible for sounding in cases of severe weather. Many EMs are also responsible for telling mobile storm spotters where to look for tornados based on their interpretation of the weather situation.

Emergency management information use and decision-making behaviors during severe weather have not been well-documented. Haddow and Bullock (2003), for example, discuss general approaches to risk assessment and communications during hazards, but their work is not specific to severe weather such as thunderstorms and tornado events. Thus an area important to understand is how EMs use weather information to make assessments and how they make decisions based on these assessments. It is clear that EMs actively monitor a range of products, but when the threat worsens, EMs are typically glued to the existing radar products (Morris et al., 2002). Since the mid 1990's, the weather community has used a network of 158 WSR-88Ds (Weather Surveillance Radar, 1988, Doppler) across the United States and its territories to observe the atmosphere (National Weather Service (NWS), 2004).

The Oklahoma Climatological Survey (OCS) currently provides training and decision support tools to EMs in Oklahoma in order to help them assess the weather so that the EMs may make better weather assessments and decisions. Weather information available in the OK-FIRST program (OCS, 2004) includes current and forecast data. Low resolution geographic information, such as county borders, highways, and major rivers, is also available. EMs, of course, can also gather information during severe weather from other sources, such as the media, internet sites, and the storm spotters.

Current WSR-88D technology has limited the ability of EMs to access information that would be helpful during severe storms and tornados. Although these radars have afforded significant improvements in weather detection and prediction, the lowest kilometers, where hazardous weather can cause its greatest impact, are still extremely under-sampled. The Collaborative Adaptive Sensing of the Atmosphere (CASA) project (McLaughlin et al., 2006) is developing radars that sense lower to the ground, more frequently, with shorter ranges, and with higher spatial resolution. In addition, CASA's radars will be controlled adaptively so they scan where the weather is as opposed to operating in a sit and spin mode. However, it is not clear what impact the new radar data will have on the decision-making behaviors of potential users of this weather information, such as emergency managers.

This research therefore focuses on characterizing OK-FIRST trained EM information use and decision-making behaviors during severe weather in order to identify potential impacts that CASA data may have on EM decision-making. Based on interviews with OCS researchers, NWS meteorologists, and OK-FIRST instructors, we developed an initial descriptive decision-making model of EM information use and decision-making (Figure 1). The model consists of four severe weather phases: Pre-Storm, Severe Weather Watch (issued by the Storm Prediction Center (SPC)), Severe Weather Warning (issued by local NWS Forecast Office), and Severe Weather Event. This research uses both questionnaires and part-task scenarios to make refinements to the severe weather warning phase of the decision-making model.

METHODS

Participants

Four CASA radars covering a 100x100 km test bed area in Oklahoma will be operational in late 2006. At the time of this study, twenty OK-FIRST trained EMs worked in this area. Eight of these volunteered to participate in this study. Three OK-FIRST trained EMs near the CASA test bed also volunteered.

Phase	Description of Phase	Information Sources	Decisions/Actions
Pre-Storm	SPC predicts potential of severe weather; no watches or warnings issued	Convective Outlooks from SPC Hazardous Weather Outlooks from local NWS office Media	Determine likelihood of severe weather occurring within the local area Determine whether or not to contact spotters and first responders
Severe Weather Watch	SPC has issued a severe weather watch for the local area	Oklahoma Mesonet surface observations WSR-88D data	Decide where and when to deploy spotters Determine when/if to notify other first responders
Severe Weather Warning	Local NWS office has issued a severe weather warning for the local area	Warning Decision Updates from NWS WSR-88D data Spotter reports Media	Determine likely location of severe weather within the local area Communicate with NWS about spotter reports Communicate with first responders Decide whether or not to sound siren (warn public) Decide whether or not to interrupt cable television
Severe Weather Event	Tornado touchdown observed by spotters, the media, or others	Warning Decision Updates from NWS WSR-88D data Spotter reports Media	Track where storm is going to protect first responders and to predict damage Communicate with first responders to determine event response Decide when to turn off sirens

Figure 1. Initial OK-FIRST Trained Emergency Manager Descriptive Decision-Making Model.

Participants' experience in the field of emergency management ranged from 1 to 33 years (median 8 years).

Apparatus

Two Part-Task Simulated Weather Scenarios. The archived weather data used in the two scenarios were from a severe weather event on May 29, 2001 in Tulia, TX. The participants in this study do not monitor data from this area and were not familiar with the event. The first scenario included current information sources: WSR-88D data from a radar located 60 nautical miles north of Tulia and text

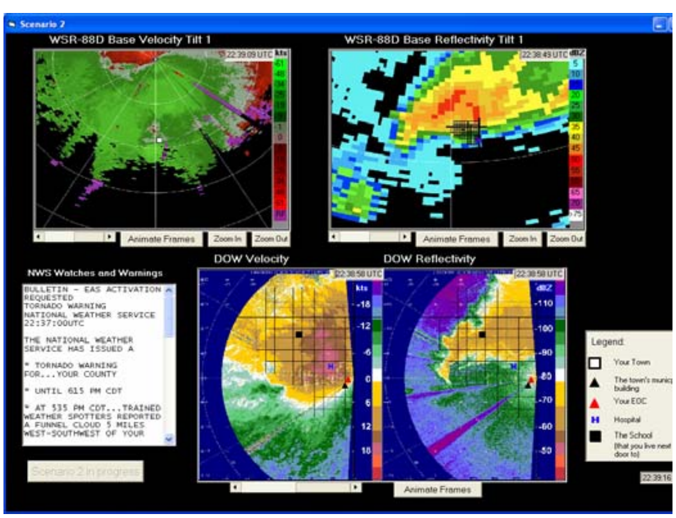

Figure 2. Screen shot taken 7 seconds into Scenario 2.

warnings issued by the local NWS Forecast Office. The second scenario also incorporated data from the Doppler on Wheels (DOW) project (Center for Severe Weather Research, 2006) because CASA data were not yet available. DOW data are similar in both spatial and temporal resolution to CASA data. The DOW radar was located 10 nautical miles east of Tulia. All radar images in the scenarios incorporated basic geographic data, including the location of the jurisdiction, municipal building, emergency operations center, hospital, and school. These features correspond to the level of spatial resolution that CASA radars will be capable of sensing.

The two part-task weather scenarios were presented via a tool developed for this study (Baumgart and Bass, 2006). It displays archived weather products at specific times during the scenarios. It also supports zooming and animation of successive weather products. WSR-88D data is displayed in the top two panes and DOW data (when included) in the bottom center (Figure 2). The NWS text product is shown in the bottom left and a legend in the bottom right.

Questionnaires. Three questionnaires were used in this study: All Phase Questionnaire, Post-Scenario 1 Questionnaire, and Post-Scenario 2 Questionnaire. The purpose of the All Phase Questionnaire was to probe participants' experiences and techniques employed during each phase of the decision-making process. It consisted of fifty questions divided into sections for each phase. Each section probed the information used (perceived value on a 5-point scale, frequency of use, and information hoping to obtain) and decisions and/or actions typically made during each phase. The Post-Scenario Questionnaires were targeted at the weather assessments and associated actions taken during each part-task scenario. They also collected the participants' perceived benefits and use of the geographic information and the effect that the CASA-like data had on their decisions during Scenario 2. See Baumgart (2006) for more detail.

Procedure

The volunteers participated in one of three scheduled sessions in October 2005. For observation, at least one analyst was paired with each participant. After signing a consent form and receiving an introduction, a participant completed Scenario 1 and the Post-Scenario 1 Questionnaire. Before Scenario 2, the participants received DOW interpretation training by an OK-FIRST instructor. Then each completed Scenario 2 and the Post-Scenario 2 Questionnaire. Both scenarios were audio-recorded. To increase workload, the All Phase Questionnaire served as a secondary task during both Scenarios 1 and 2. A debriefing occurred after Scenario 2.

Data Collection and Analysis

In addition to collecting responses from the three questionnaires, audio recordings from the part-task scenarios were transcribed. Two dependent variables were derived from each transcript (Table 1). The hope was that the two variables would provide additional insight into how EMs assess the weather and integrate information from multiple sources.

Table 1. Dependent variables not from questionnaires.

Dependent Variable	Examples
Cross validation between information sources	Using spotter reports to confirm radar data, using media to confirm radar data, comparing velocity to reflectivity
Weather assessments	Location of the storm, intensity of wind shear, reflectivity values, presence of hook echo structure (tornado indication)

To refine the initial model, phase specific criteria were used for validating an information source (from the initial decision-making model) and for adding an information source. The criteria for the Pre-Storm and Severe Weather Watch phases were:

- The median perceived value of the information source was 4 or 5 (valuable or very valuable) in the All Phase Questionnaire.
- Five or more EMs reported using the information source at least once per day in the All Phase Questionnaire.

The criteria for the Severe Weather Warning and Severe Weather Event phases were:

- The information source was used by at least two EMs during either Scenario 1 or Scenario 2.

The actual decisions made during Scenario 1 were used to refine the Severe Weather Warning and Severe Weather Event phases of the model. Decision-making data from Scenario 2 were not used because of the potential influence of the new DOW data on EM decision-making behavior. Conditions leading to specific decisions during each severe weather phase were compiled from the questionnaires and comments made during the part-task scenarios.

RESULTS

Decision-Making Model

Figure 3 and Figure 4 show the updated EM descriptive decision-making model during a Severe Weather Warning. The white background cells contain information validated from the initial model and the gray background cells contain information that was added based on the analysis of the EM data.

Figure 3 focuses on information sources used. The model now includes details concerning perceived value and what particular data element the information source provides. The median perceived value of communicating with fire, police departments and the NWS and Vertically Integrated Liquid were not included in the All Phase Questionnaire as indicated by the "N/A".

OK-FIRST trained EMs use several sources of information to identify particular weather features that may indicate the potential for a tornado or other damaging weather. They have the ability to understand the raw data in the weather products (such as reflectivity). They also can identify weather features in the imagery (such as the V-notch, a radar reflectivity signature in the downwind part of a thunderstorm echo seen on supercells and thought to be a sign of diverging flow around the main storm updraft (and hence a very strong updraft)). They can also make higher level assessments related to storm and tornado development and movement.

The only information source not validated from the initial descriptive decision-making model was "Warning Decision Updates" (short technical explanations of the reasoning behind NWS warnings) during the Severe Weather Watch and Severe Weather Warning phases. No EMs requested or mentioned this source during either Scenario 1 or Scenario 2. However, most EMs used the NWS text product provided and five EMs in Scenario 1 and two EMs in Scenario 2 mentioned that they would directly communicate with the NWS during severe weather by phone, radio, or teletype. Furthermore, one EM mentioned using NOAA Weather Radio to hear messages and warnings from the NWS.

Not all information currently available to EMs during severe weather was provided during the scenarios. This may have affected which information sources were requested as the sources were not available and they knew they could not use certain sources of information to make their assessments. For example, Composite Reflectivity and Storm Relative Velocity both received median value scores of five ("very valuable") during the Severe Weather Event phases; however, during Scenario 1 only three EMs requested Composite Reflectivity and two requested Storm Relative Velocity. No EMs requested either source during Scenario 2.

PHASE	Information Source	Median Value (1-5)	Information Sought by Accessing the Source
Severe Weather Warning Local NWS office has issued a severe weather warning for the county.	Spotter Reports	5	Ground truth and constant updates of wind speeds, circulation, storm tops, hail, rainfall; verify radar interpretation
	Storm Relative Velocity	5	Movement, intensity, structure, and speed of storm; areas of wind shear; actual wind speed and direction inside storm
	WSR-88D Reflectivity	5	Current location, size, structure, movement, and intensity of storm; rear-flanking downdraft; V-notch and hook echo structures (indications of tornado potential); big picture (looking for storms moving into jurisdiction); indication of hail
	WSR-88D Velocity	5	Current location, structure, movement, intensity and speed of storm; presence and direction of wind shear
	Composite Reflectivity	4	Current location, size, movement, and intensity of storm; inflow (to feed potential tornado); wind shear; hail
	Mesonet	4	Wind speed and direction; rainfall; temperature; pressure; location of fronts and dry lines; data regarding flood prone areas
	TV reports	4	Ground truth; second opinion; location of storm; forecasts
	Communication with fire/police depts.	N/A	Exact location of storm
	Communication with NWS	N/A	Look for watches and warnings; help with radar interpretation; help with deciding whether or not to sound sirens
	Vertically Integrated Liquid	N/A	Indication of hail size

Figure 3. Updated Descriptive Decision-Making Model during a Severe Weather Warning – Information Sources Used.

Decisions Made /Actions Taken	Conditions that Lead to Decisions/Actions
Alert first responders (fire or police departments, EMTs, etc.) that the NWS has issued a severe weather warning	Immediate response if a warning is issued by the NWS; want to advise them of what is going on (prepare for response)
Alert organizations (park officials, sports arenas, schools, etc.) that the NWS has issued a severe weather warning	Immediate response if a warning is issued by the NWS (depending on time of day and schedule of events
Alert other EMs that the NWS has issued a severe weather warning	Standard action to regularly communicate during a warning, especially when needing clarification or additional information
Alert spotters that the NWS has issued a severe weather warning	Immediate response if a warning is issued by the NWS; want spotters to look for a wall cloud
Communicate with the NWS	Get their opinions on the data and help with interpretation; give them spotter information
Contact local radio stations	Want to be sure they are broadcasting the warnings
Initiate a cable television override	When sirens are sounded in jurisdiction
Determine likely location of severe weather in the county	Immediate response if a warning is issued by the NWS
Open storm shelters	No information provided
Sound sirens	Immediate response if a tornado warning is issued by the NWS or the NWS specifically requests them to do so during other severe weather warnings; also sound for a high wind event or flooding potential

Figure 4. Updated Descriptive Decision-Making Model during a Severe Weather Warning – Decisions Made and/or Actions Taken.

Figure 4 focuses on the decisions made and/or actions taken during a Severe Weather Warning and now includes details concerning the conditions that typically lead to these decisions or actions during the warning. In addition to actions already included in the initial model, it is clear that communications including collaborative cross-checking play a major role in emergency management. OK-FIRST trained EMs' collaborate with several organizations to alert the public of severe weather, including local radio stations, schools, and EMs from other jurisdictions. These communications also involve confirming radar data interpretation.

Cross Validation between Information Sources

During Scenario 1, the median number of cross validations was 2 (range 0-4) and during Scenario 2 the median number of cross validations was 4 (range 2-11). There was a trend for the EMs to make more cross validations between information sources when CASA-like data were available (z = 1.851, N-Ties = 9, p = 0.064, two-tailed). Based on the scenario transcripts, this trend is a result of the EMs spending time making cross validations between WSR-88D and CASA-like data during Scenario 2.

Weather Assessments

The number of weather assessments made between Scenario 1 (range 3-19) and Scenario 2 (range 3-18) were not significantly different. However, this may have been due to the EMs' first exposure to the new data. In addition, many of the participants were aware that despite having already been trained to interpret velocity data, they could not accurately make assessments from this source (even with the WSR-88D). One EM mentioned difficulty understanding the velocity color palette and another had difficulty understanding the scale (thinking that negative values indicate very slow moving winds when negative values represent movement away from the radar). Additionally, one EM who used the WSR-88D Velocity was actually interpreting the data incorrectly (thinking that green pixels represented rainfall when green pixels represent movement toward the radar).

Many EMs did not understand the relationship between radar location and velocity data. The WSR-88Ds can only sense movement toward or away from the radar. When there were no high velocity values, many EMs thought there was no movement or wind shear at all. During Scenario 2, it was also unclear to some that because the DOW radar was located east of the storm and the WSR-88D was located north of the storm, the two systems were collecting different velocity data.

Because of the differences in the radars' locations and ranges, there arises a difference in the altitude in which the radars sample the same latitude and longitude. This results in the radars observing different reflectivity and velocity data due to the changing vertical structure of severe storms. Six EMs noticed this difference during Scenario 2. However, none of them understood what was causing it.

DISCUSSION

The questionnaires and part-task scenarios were effective in helping to refine the EM descriptive decision-making model. With respect to information sources, the initial model was mostly validated with and without CASA-like sources. With respect to decisions and/or actions during a Severe Weather Warning, more actions were added that involved collaboration and communication with other organizations. Many of the decisions during a Severe Weather Warning are made immediately based on the issuance of the NWS warning.

When CASA-like data were used in Scenario 2, the number of cross validations made between information sources increased. This could have been a result of the novel data; however, more cross validation of information could potentially help EMs make faster, more accurate, and more confident decisions.

One issue that requires further study is the workload introduced with interpreting and integrating the new data as well as the potential for loss of the big picture. As mentioned, the EMs were having problems figuring out what area was sampled. It is clear that EMs need more training and that future effort should investigate visualizations that ensure it is easier for the EMs to understand what part of the atmosphere is being sampled.

During the scenarios, the analysts noticed that the EMs became engrossed with the new finely detailed radar imagery. This may have been due to the novelty of the new data. However, future effort should investigate visualizations and procedures that ensure that the EMs maintain the big picture and do not spend too much time watching the fine-grained weather data.

ACKNOWLEDGEMENTS

This work was supported in part by the Engineering Research Centers Program of the National Science Foundation under NSF Award Number 0313747. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect those of the National Science Foundation. The authors thank the emergency managers who volunteered for this study.

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