4.2 Public Reaction to National Weather Service Impact Based Warnings and the Effectiveness of Decision Support Services Provided During the June 12, 2014, Abilene, Texas Extreme Hail and Wind Event

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1. INTRODUCTION

A powerful, supercell thunderstorm with hail up to the size of softballs (>10 cm in diameter) and damaging winds impacted Abilene, Texas, during the Children's Art and Literacy Festival and parade on June 12, 2014. It caused several minor injuries. This storm produced widespread damage to vehicles, homes, and businesses, costing an estimated $400 million. More than 200 city vehicles sustained significant damage and Abilene Fire Station #4 was rendered uninhabitable. Giant hail of this magnitude is a rare phenomenon (Blair, et al., 2011), but is responsible for a disproportionate amount of damage.

In support of a larger National Weather Service (NWS) effort, the San Angelo Texas forecast office is part of an experiment to test Impact Based Warnings (IBW) that are designed to describe expected damage and how serious the weather threat will be "before it happens." Effectiveness of the IBW text warning that was issued for this event will be assessed by analyzing responses collected via a web-based survey that was designed to collect feedback from local residents who were affected by the damaging wind and hail.

A brief meteorological overview and analysis of radar signatures during the severe storm will be presented. Additionally, we will show an assessment of how effective impact based decision support tools and the integrated warning team (two elements of the National Weather Service Weather Ready Nation initiative) were to the warning process for this event.

2. ONLINE WEB SURVEY

A twenty-four question online survey, developed by Dr. Vankita Brown and Dr. Laura Myers, was assembled in association with WFO San Angelo, Texas. The main objectives were to learn the following: 1) how the public reacted to the warning; 2) how impact based wording contained in the Severe Thunderstorm Warnings was interpreted by the citizens who were in the path of the storm, and 3) how the NWS might improve its ability to warn citizens.

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3. HOW THE PUBLIC REACTED TO THE WARNINGS

Of the 324 respondents, 86% were impacted by the extreme hail event. Listed below are highlighted responses to some survey questions.

3.1 *Survey question # 3*

People rely on various sources of information when making a decision to prepare for hazardous weather events. Please indicate the sources that influenced your decisions on how to prepare BEFORE this severe thunderstorm event occurred.

1) Local television
2) Websites/social media
3) Wireless alerts/cell phones

3.2 *Survey question # 4*

How far in advance were you made aware that a severe thunderstorm would be possible for your area?

68% knew about the severe thunderstorm less than an hour before or did not know at all.

3.3 *Survey question # 5*

Based on the information you were given, what did you feel the threat(s) from the severe thunderstorm would be? (Please select all that apply) (Figure 1)

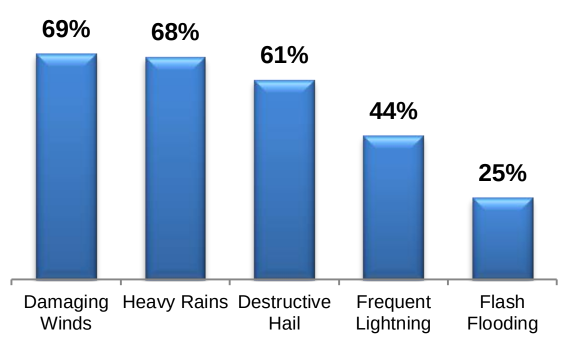

Figure 1. Main threats expected from the severe thunderstorm.

3.4 *Survey question #6*

What, if any, special preparations did you take in the days and hours before the severe thunderstorm event?

1) 62% did not take any significant special preparations but many did put their vehicle in their garage
2) 23% cancelled or adjusted scheduled plans, appointments, and/or activities
3) 15% increased communication with friends/relatives

3.5 *Survey question #7*

Did you receive warning of the severe weather prior to the severe weather event (Figure 2)?

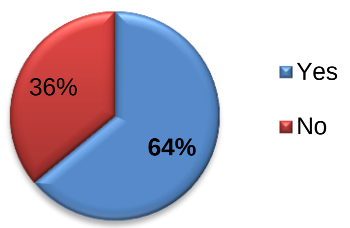

Figure 2. Percentage of those surveyed that received warning prior to the event.

3.6 *Survey question #8*

What actions did you take when you received the warning (Figure 3)?

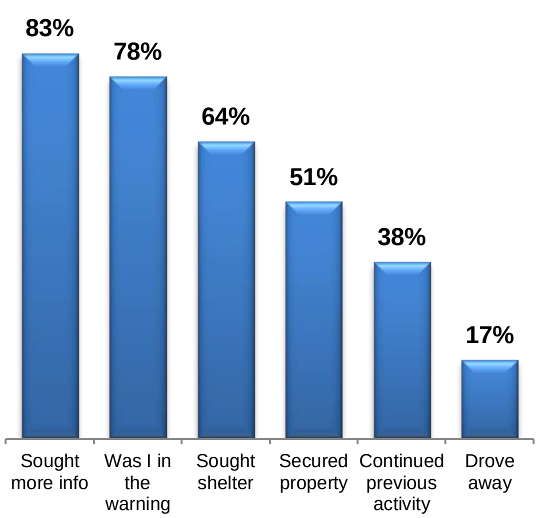

Figure 3. Actions taken when warning was received.

3.7 *Survey question #9*

Which of the following was the first action you took when you received the Severe Thunderstorm Warning (Figure 4)?

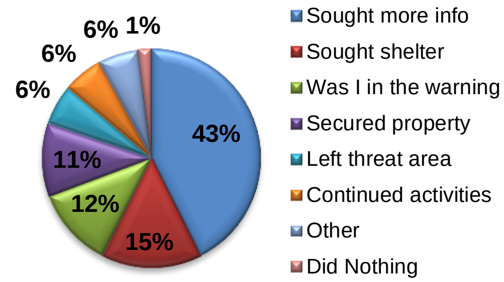

Figure 4. First action taken when warning was received.

3.8 *Survey question #10*

Did you seek shelter during the Severe Thunderstorm Warning? Sixty-four percent did seek shelter (Figure 5) during the warning.

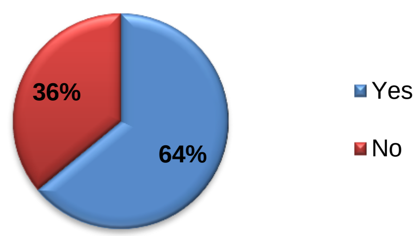

Figure 5. Respondents who sought shelter during the storm.

3.9 *Survey question #11*

What led to your decision to seek shelter during the Severe Thunderstorm Warning (Figure 6)? Seeing the threatening weather and the size of hail and/or wind speed mentioned in the warning drove them to seek shelter (Figure 6).

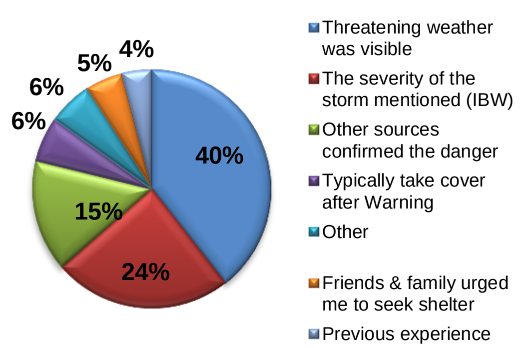

Figure 6. Reason decision was made to seek shelter.

4. METEOROLOGICAL ANALYSIS

The environment over West Central Texas was conducive for the development of organized convection during the afternoon hours of June 12, 2014. A slow-moving cold front was draped across West Central Texas running from south-central Oklahoma, southwest to near Sweetwater, TX, then south to a surface cyclone near Ozona, TX. A well-defined outflow boundary, resulting from earlier convection over north Texas extended from a surface low near Ozona, eastward into central Texas (Figure 7).

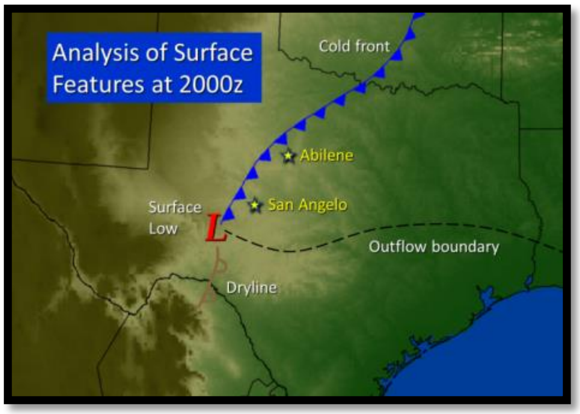

Figure 7. Surface features of the 12 June 2014 Abilene extreme hail event at 2000 UTC.

A warm, moist airmass was in place across the region ahead of the synoptic cold front. By mid-afternoon, dewpoints had climbed to near 21° C (70° F) across much of West Central Texas with surface temperatures of 30-32° C. Winds above 500 hPa were from the northwest across the southern and central Plains. Coincident with peak heating, a shortwave trough was moving southeast across the High Plains. Attendant synoptic scale ascent resulted in very steep mid-level lapse rates on the order of 8.0-8.5° C km^{-1}. These steep lapse rates contributed to high surface based instability, which enhanced the potential for very large hail.

Mesoanalysis data provided by the Storm Prediction Center (SPC)[1], based on the Rapid Refresh 2 (RAPv2), indicated 100 hPa MLCAPE values of 3000-4000 J kg^{-1} across West Central Texas (Figure 8). Modified Rapid Refresh (RAP) proximity soundings indicated that the combination of forcing for ascent and warming surface temperatures had essentially eroded the cap by 2100 UTC, allowing surface based parcels to realize the extant instability.

Boundary layer northeast winds on the cool (north) side of the outflow boundary (Figure 7) backed vertically to a west-northwest direction through 600 hPa, yielding effective bulk shear values near 20 m s^{-1} (40 kts). While on the lower end of the spectrum, this is sufficient for the development of supercells (Thompson, et al. 2007). Analysis of the 2100 UTC RAP point data from Abilene showed a relatively straight hodograph with slight counter-clockwise curvature, suggesting that splitting supercells would be a possibility, generally favoring a left moving, anticyclonic supercell (Weisman & Klemp, 1986). However, slightly farther south near Brady, TX, RAP point soundings indicated more of a veering vertical wind profile.

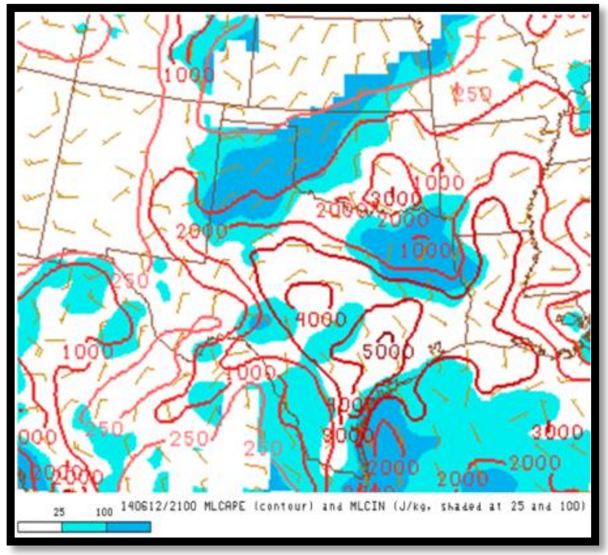

Figure 8. Storm Prediction Center Mesoanalsys (using the RAPv2) of 100 hPa Mean Layer Convective Available Potential Energy (MLCAPE) Values (J kg^{-1}) valid 12 June 2014 at 2100 UTC.

Given model resolution and the proximity to the cold front, the latter sounding is accepted as being more representative of the warm sector environment. The hodograph associated with this profile showed strong clockwise turning, especially in the lowest 3 km (see Figure 9). This particular hodograph would strongly

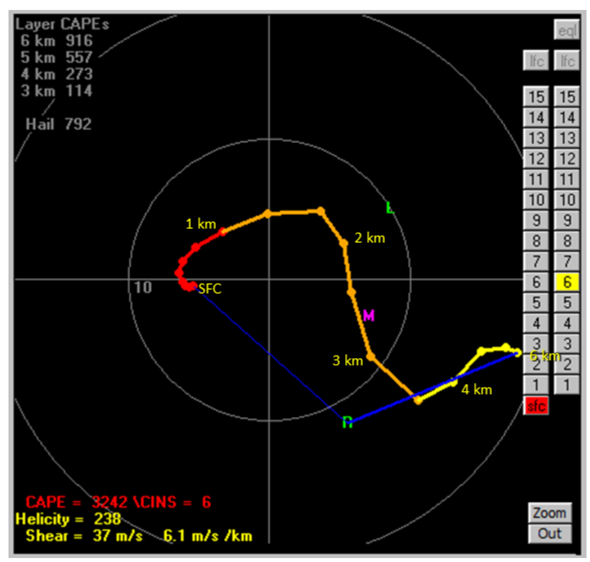

Figure 9. 2100 UTC Hodograph for Brady, TX, on 12 June 2014

favor a dominant, cyclonic, right-moving supercell, with a storm motion to the right of the mean flow. The

Internal Dynamics (ID) method, using for predicting supercell motion (Bunkers, et al., 2000), indicated that a right moving, cyclonic supercell would move from 330° at 6 m s^{-1} (12 kts). This is close to what was observed during the severe weather event.

A Tornado Watch was issued for most of West Central Texas, including the Abilene area, at 2105 UTC. In addition to the threat for tornadoes, the Storm Prediction Center (SPC) watch noted the potential for isolated very large hail and wind gusts up to 31 m s^{-1} (61 kts).

5. RADAR ANALYSIS

The initial thunderstorm developed around 2030 UTC near Stamford, TX, well to the north of the outflow boundary and in the vicinity of enhanced moisture convergence along the synoptic cold front. This storm rapidly intensified, developing a mid-level mesocyclone by 2115 UTC. The first Severe Thunderstorm Warning was issued for areas north of Interstate 20 at 2101 UTC. The mean 850-300 hPa wind was from the west-northwest (290°) at 10 m s^{-1} (20 kts), but this storm quickly deviated off the hodograph, moving to the southeast (330°) at 10 m s^{-1} (20 kts).

At 2200 UTC, the storm was crossing U.S. Highway 180 just to the east of Anson, approximately 30 km (19 mi) north of Abilene (Figure 10). Echo tops had increased to 18,500 m (60,700 ft) AGL by this time with radar reflectivity values exceeding 70 dBZ at a height of 8,015 m (26,300 ft) AGL.

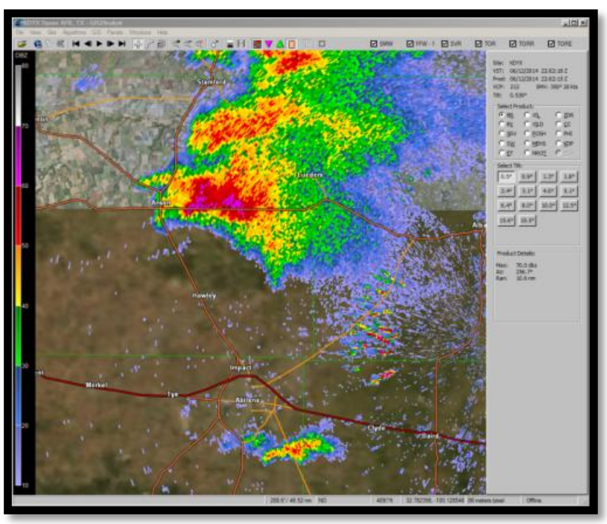

Figure 10. Radar reflectivity valid 12 June 2014 at 2200 UTC.

At 2221 UTC, a new Severe Thunderstorm Warning was issued for this storm that included the city of Abilene. This warning highlighted the potential for tennis ball size hail and wind gusts up to 31 m s^{-1} (61 kts) in Abilene around 2255 UTC. The experimental "impact based" wording stated:

"PEOPLE AND PETS OUTDOORS WILL BE INJURED. EXPECT HAIL DAMAGE TO ROOFS...SIDING...WINDOWS AND VEHICLES. EXPECT CONSIDERABLE TREE DAMAGE. WIND DAMAGE IS ALSO LIKELY TO MOBILE HOMES...ROOFS AND OUTBUILDINGS."

The extended lead time was critical given the intensity of this storm. Complicating matters further, Abilene was host to the Children's Literacy and Art Festival during the evening of June 12, 2014 with a parade scheduled to take place at approximately 2230 UTC. Several hundred adults and children were expected to be outdoors along the streets of downtown Abilene to watch this parade.

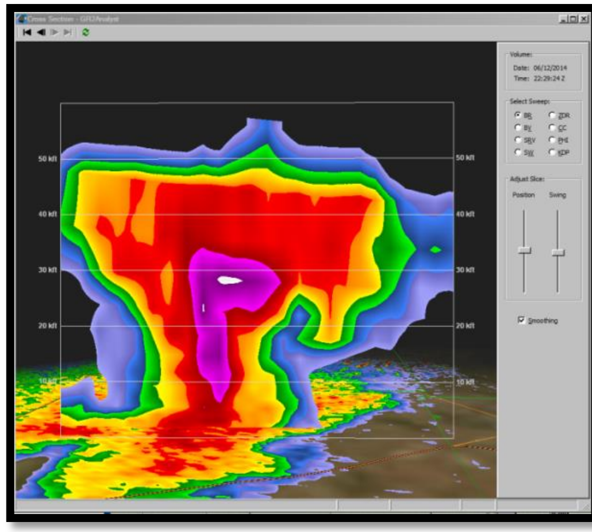

Figure 11. Bounded Weak Echo Region valid on 12 June 2014, at 2230 UTC about 15 miles north of Abilene, TX.

A bounded weak echo region (BWER) radar signature was evident approximately 15 miles north of Abilene on both the plan view and cross-section of the thunderstorm by 2230 UTC (Figure 11), indicating a very strong updraft and a high potential for large hail (Lemon & Doswell, 1979). A Severe Weather Statement (SVS) was issued at 2230 UTC, updating the storm's location and severity. Hail up to the size of baseballs (7.0 cm) was now expected with this storm, reaching Abilene by 2255 UTC. In addition, the low-level horizontal shear (VR-shear) had increased to near 13 m s^{-1} (25 kts) just before 2230z, concomitant with the development of a hook echo signature on the 0.5° reflectivity. This prompted the inclusion of a "Tornado Possible" tag in the severe weather statement.

The storm crossed the Jones-Taylor County line between 2235 and 2245 UTC, moving into the northern portion of Abilene. Radar reflectivity data continued to show an impressive BWER signature over the city with reflectivity values exceeding 60 dBZ reaching as high as 12,560 m (41,200 ft) AGL. A 3-D rendering of the storm's 60 dBZ isosurface continued to indicate a strong weak echo region (WER) over the city of Abilene (Figure

12), with the updraft showing no signs of weakening. Giant hail estimated at 11.4 cm (4.50 in) in diameter was reported by the National Severe Storms Lab's (NSSL) Severe Hazards Analysis and Verification Experiment (SHAVE, Ortega et al. 2009) on the north side of Abilene, near the community of Impact, at 2240 UTC. Analysis of radar data suggests that this hail was falling through the updraft, with most of the large hail still north of the area in the downdraft region of the storm. Large hail of 7.0 cm (2.75 in) in diameter and measured wind gusts of 26 m s^{-1} (50 kts) were observed at the KTXS-TV studio on the north side of Abilene at 2246 UTC. By 2257 UTC, baseball size hail was reported on the Abilene Christian University Campus, located on the northeast side of town. Hail up to 11.4 cm (4.5 in) in diameter was also falling 3 km (2 mi) southwest of Hamby in extreme northeast Taylor County.

A new Severe Thunderstorm Warning was issued for the Abilene area to replace the expiring warning at 2257 UTC. This warning called for softball size hail (10.8 cm or 4.25 in) and wind gusts of 36 m s^{-1} (70 kts). Given the persistent mesocyclone and favorable environment, the "Tornado Possible" tag was continued. The impact based wording at 2257 UTC read:

"YOU ARE IN A LIFE THREATENING SITUATION. FLYING DEBRIS MAY BE DEADLY TO THOSE CAUGHT WITHOUT SHELTER. MOBILE HOMES WILL BE HEAVILY DAMAGED OR DESTROYED. HOMES AND BUSINESSES WILL HAVE SUBSTANTIAL ROOF AND WINDOW DAMAGE. EXPECT EXTENSIVE TREE DAMAGE AND POWER OUTAGES."

Hail to the size of baseballs, and larger pounded the northern, central, and eastern portions of Abilene between 2255 UTC and 2310 UTC, including the downtown area where the parade had just ended. Fortunately, most patrons were able to take cover, but some did sustain minor head injuries due to the falling hail and were treated at Hendrick Medical Center in Abilene.

The Automated Surface Observing System (ASOS) located at Abilene Regional Airport (KABI) measured a wind gust of 27 m s^{-1} (52 kts) at 2309 UTC. However, these strong winds arrived just as the large hail began to fall. Hail of at least 5.1 cm (2 in) in diameter caused significant damage to several of the ASOS sensors. This knocked the ice free wind and present weather sensors offline. Actual wind speeds may have been stronger, but the equipment was unable to provide wind data after sustaining the damage.

American Eagle Flight 3195 from KABI to Dallas-Ft. Worth (DFW) had boarded just prior to the arrival of this storm, despite the presence of the strongly worded Severe Thunderstorm Warning. The storm struck the airport shortly after the plane departed from the gate, slamming the aircraft with large hail and strong winds for more than 7 minutes. The plane was forced to return to the gate and de-plane passengers due to the significant hail damage it sustained. Skylights were broken inside the terminal and many cars were damaged in the parking lot.

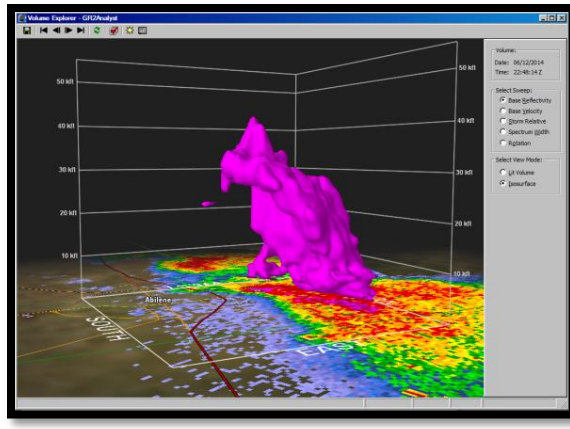

Figure 12. Weak Echo Region valid 12 June 2014 at 2248 UTC.

This storm began to weaken as it moved south of Abilene, merging with another storm that affected the western portion of the city. Following this merger, hail sizes diminished, but the low-level storm structure became more organized. Increasing low-level rotation and spotter reports of a rotating wall cloud near Potosi prompted the issuance of a Tornado Warning (TOR). However, this warning did not include the Abilene area and no tornado was observed or confirmed via a storm damage survey. Ironically, because Severe Thunderstorm Warnings do not trigger the Wireless Emergency Alerts (WEA), the issuance of this Tornado Warning prompted the first WEA of the severe weather event.

Figure 13. Hail up to the size of a DVD!

5.1 Storm Impacts

The storm continued to move to the south, leaving significant damage in its wake. Hail up to 12 cm (4.75") in diameter (Figure 13) was reported across portions of Abilene with wind speeds measured as high as 27 m s^{-1} (52 kts). Forty-six of the Abilene Police Department's vehicles were damaged, some severely enough to require towing. Widespread damage to roofs, windows, and vehicles was reported across the northern, central and eastern portions of Abilene, especially on the northeast side of town, including Hendrick Medical Center, Abilene Christian University, and Hardin-Simmons University. Total damage across the city was estimated at $400 million.

The initial warning for the city of Abilene was issued at 2221 UTC, providing residents on the north side of Abilene with 19 minutes of lead time. Farther south in the downtown area, hail was reported between 2250 and 2305 UTC, resulting in a lead time in excess of 30 minutes. Direct communication was made with Abilene Emergency Management officials, advising of the potential for hail up to the size of baseballs and damaging winds across the central and eastern portions of the city. Impact based wording was able to accurately portray a picture of the damage that occurred during this extreme hail event.

6. EFFECTIVENESS OF DECISION SUPPORT SERVICES and THE INTEGRATED WARNING TEAM

Independent of the online survey, WFO San Angelo met with their Integrated Warning Team (IWT) to evaluate their decision support services before and during this high impact event. The Integrated Warning Team and impact based decision support services (IDSS) are two key components of The Weather Ready Nation ® (WRN). The IWT (Doswell et al 1999 and Demuth et al 2007) is the name given to the partnership between the National Weather Service, emergency management, the broadcast media and other organizations. Members of the media and emergency managers are also known as the "core partners" of the NWS. NWS San Angelo routinely coordinates closely with their IWT members that serve Abilene and surrounding communities. The SKYWARN® amateur radio net controller, Texas Department of Public Safety District Coordinator, the Texas Forest Service, and the Texas Department of Transportation are also included in this IWT. The IWT has met numerous times since early 2002 to strengthen its partnership and promote hazardous weather awareness to Abilene residents. The team has also participated in the annual Abilene SKYWARN ® training class to build an even stronger relationship with the storm spotters and the community of Abilene.

During this high impact hail event, the NWS and emergency management relayed valuable ground truth reports through NWSchat and amateur radio to the Abilene TV media. NWSchat has become quite useful as a tool for IWT communications as it keeps channels of communications open when these groups are not in the same room during severe weather events (Johnson et al 2013). The local Abilene media said they rely heavily on NWSchat for real time reports and for storm updates. Below is a timeline of critical remote decision support services that were provided prior and during this event.

1) At approximately 3PM CDT, NWS San Angelo sent an email notification to the IWT alerting them of the severe weather potential and the need for storm spotter activation.

2) The NWS gave detailed information on NWSchat at 522 PM CDT, mentioning the time of the storm's arrival into Abilene.

3) At 526 PM CDT, the NWS contacted the Abilene Emergency Manager by telephone to notify him the storm would bring large hail to the north, east and central part of the city.

Just prior to the phone call, the emergency management staff thought the storm was going to miss the city. This phone call gave the emergency manager confidence and adequate time to activate CodeRED ®, enabling local government officials to record, send and track personalized messages to thousands of resident's cell phones and telephones in minutes. According to this online survey, cell or smart phones were the third highest warning source that influenced the respondents decision to prepare before and during this severe thunderstorm warning.

The emergency manager stated his appreciation for the email notification and the phone call as it increased his confidence to activate Code Red ®. Emergency management and the SKYWARN amateur radio net controllers also said, "The email notifications gave them good situational awareness because there are times when they may be distracted with other duties or emergencies and are unable to monitor weather."

7. CONCLUSION

7.1 How The Public Reacted

The online survey provided understanding of how the public reacted to a warning with a slightly above average lead time (a minimum of 19 minutes) of an extreme hail event in Abilene, Texas. Sixty-four percent of the respondents (Figure 2) received the warning; thirty-six percent of the respondents did not receive the warning (the city of Abilene does not have outdoor sirens). The survey indicated that the top three warning sources were 1) television, 2) websites/social media and 3) cell phones. Abilene does use Code Red® to warn their citizens who sign up to receive warnings through their telephone or cell phone.

Three useful results received from the survey that we can use to improve severe weather warning performance are:

1) Respondents preferred to seek out additional information upon receiving the warning (Figure 4),
2) They wanted to know if the storm would impact their location (Figure 3), and
3) They wanted to verify the threat visually.

By making sure the IWT partners are providing a consistent message, these three concerns can be minimized.

Based on respondent information, they felt the top three threats from a "severe thunderstorm" were:

1) damaging winds,
2) heavy rain,
3) destructive hail,

With flooding and lightning also in the damage mix. Therefore, it appears that confusion remains as to what a Severe Thunderstorm Warning really will cause. However, impact based wording appeared to help with this confusion for citizens in the storm's path, because sixty-eight percent of the respondents were satisfied with the way the warning portrayed the threats and the impacts. It is hoped that as the IBW process grows within the NWS, confusion over what specific weather element will cause damage (e.g. flood, hail, wind, etc.) will diminish and eventually be eradicated!

Some of these findings are consistent with research that upon receiving a warning or threat, people, tend to seek additional information before taking protective action (Lindell & Perry, 2004 and Hammer & Schmidlin 2002). Prior to taking action, people want to know if there is a real and impending risk they should pay attention to. The need for additional information is based on the belief of recipients that they do not have adequate information to make a decision. Unfortunately, waiting to see and seeking more information cuts their reaction time. Finally, 40% of the respondents desired to look outside to see if they were in the path (Figure 6), before taking shelter.

Previous research suggests that as part of risk assessment, people will sometimes seek confirmation of a threat via environmental cues such as searching for physical evidence (Aguirre, et al.,1991 and Legate & Biddle, 1999). This threat confirmation often involves a visual confirmation of cloud formation, high winds, or a tornado. Additionally, the magnificence of such a weather phenomenon as a tornado makes a sighting appealing. Thus, people are tempted to bear witness to it. However, once people obtain visual confirmation of a tornado, the time frame to take shelter becomes limited and some people perish while attempting to take action. The good news is that sixty-four percent of those surveyed did seek shelter (Figure 5). Finally, survey question #19.2 asked; "Based on your understanding of the National Weather Service's Severe Thunderstorm Warnings, how likely are you to take protective action?" Eighty-one percent of respondents are likely to take protective action based on their understanding of the NWS Severe Thunderstorm Warnings (Figure 14).

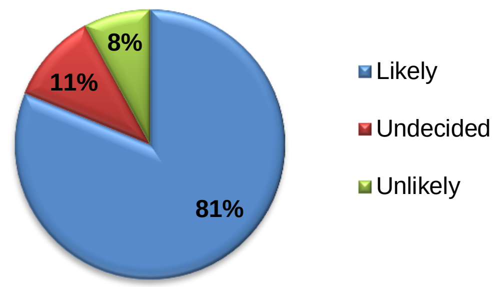

Figure 14. Percent of respondents likely to take action based on their understanding of the NWS Severe Thunderstorm Warnings.

The survey respondents who did not seek shelter reported they did receive the warning and believed it. Some reasons for not seeking shelter included the following: thought severe thunderstorms are not serious; there are too many warnings; they didn't receive the warning because they were at work or on the road; and some said they were already in the safety of their home and shelter was not necessary. Only 36% received their information directly from the NWS or the NOAA weather radio. Approximately 72% of the respondents were satisfied to very satisfied with overall information and services provided by the NWS during the event (survey question #15.7). Based on survey question #19 (Figure 14), 81% of the respondents were likely to take protection action from a Severe Thunderstorm Warning. 41% of the respondents were likely to take protective action for a severe thunderstorm watch, (hinting at a possible misunderstanding of the NWS definition of a "watch.")

7.2 Effectiveness of Decision Support Services and the IWT

After post storm meetings with our core partners, we strongly believe NWS decision support services and a working IWT were essential to the success of this high impact event. Issuing a warning alone may not have prompted activation of Code Red ® as quickly nor would have given trained spotters time to activate. Media using NWSchat can also more quickly see and respond to hazard threat tags and damage reports. As a result, the high impact based warnings were consistently disseminated through TV, social media, Code Red ®, NOAA All Hazards Weather Radio, and radio, giving opportunities for Abilene residents to receive this crucial warning.

7.3 Did the Impact Based Warning Make a Difference?

WFO San Angelo continues to participate in a National Impact Based Warning (IBW) test in 2015. One of the goals is to include impact based wording that quickly conveys the pending storm impacts to recipients, so that action is quickly taken to protect life and property. Special tags are included for hail size and wind speed at the bottom of these warnings. Based on this survey, the impact based wording contained in a Severe Thunderstorm Warning did make a difference to citizens who were in the storm's path. Sixty-eight percent of the respondents were satisfied with the way the warning portrayed the threats and the impacts (Survey Question #15.6 and Figure 15) although we do not have a baseline survey for Non-Impact Based Warning to compare to.

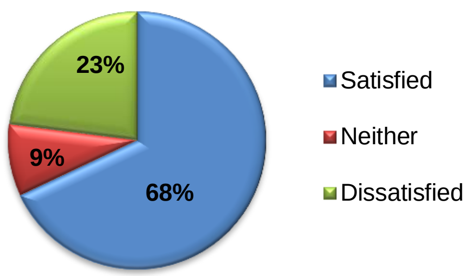

Figure 15. Degree in which information or services received explained the severe thunderstorm threat and expected impacts.

7.4 How Can NWS Improve Its Ability to Warn

1) Attempt to increase the number of citizens who will receive a NWS high impact Severe Thunderstorm Warning by enhancing warning dissemination to everyone, anytime, anywhere. The NWS could potentially push a high impact type Severe Thunderstorm Warning through the Wireless Emergency Alert System when hail or wind tags reach a certain criteria. The NWS should encourage the use of smart phone apps that use geo-location technology.

2) Remove confusion from the Severe Thunderstorm Warning title. Title NWS warnings with clear and basic weather terms, not titles that need to be defined like "Severe Thunderstorm Warning." Instead use terms people understand like "Destructive Hail and/or Strong Wind Warning."

3) Continue to find better ways to use impact based wording to paint a clear picture of personal impacts that prompt quick action.

8. ACKNOWLEDGEMENTS

A special thanks to the University of Alabama for hosting this online survey. A special thanks to our local media and emergency partners and other organizations in Abilene, namely, KRBC-TV, KTAB-TV, KTXS-TV and KXVA-TV, radio stations, the city of Abilene, the Texas Office of Emergency Management, the Abilene Reporter News, and the Abilene Chamber of Commerce, who posted this survey on their social media sites. The authors extend a special thanks to the warning team at WFO San Angelo and Skywarn volunteers for providing excellent service during this catastrophic severe weather event.

9. REFERENCES

If you would like to see the survey, please go to the following link:

http://www.srh.noaa.gov/images/sjt/Abilene_survey.pdf

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