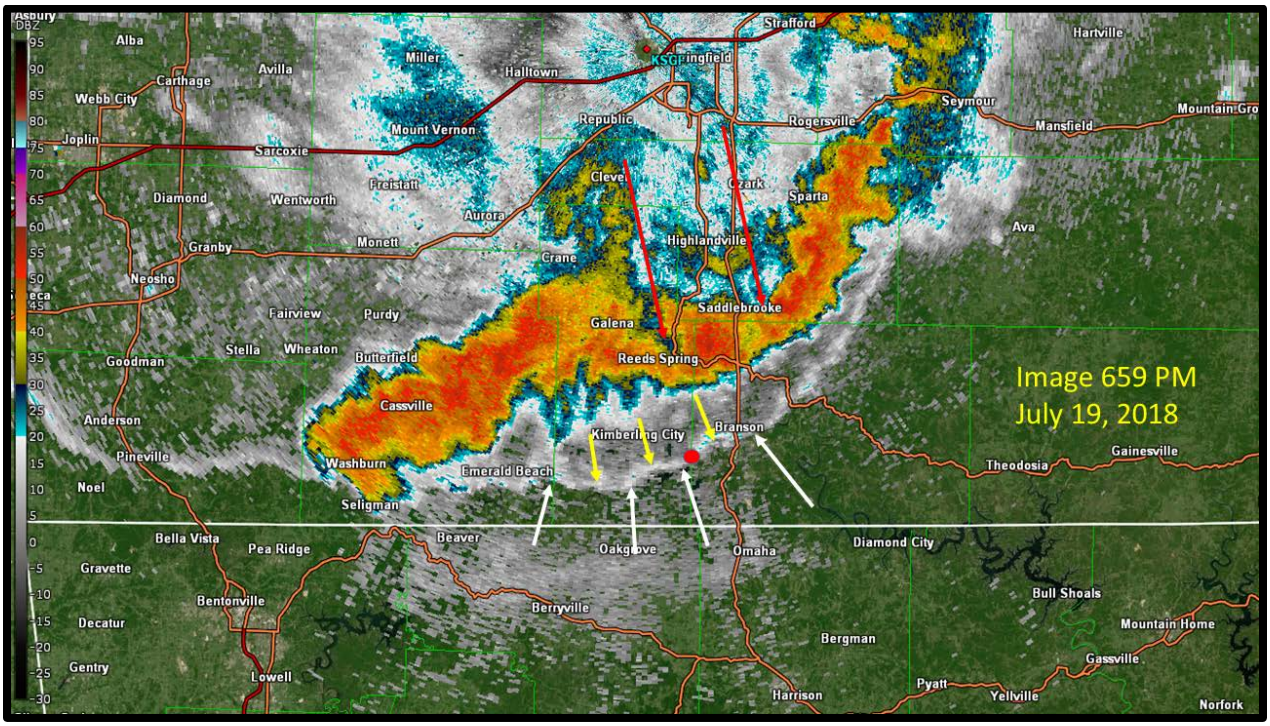
National Weather Service Central Region
Service Assessment

July 19, 2018 Table Rock Lake, Missouri Derecho



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service Central Region Headquarters
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Cover Photograph: Radar image of the derecho as damaging winds reach Table Rock Lake State Park at 6:59 pm July 19, 2018.

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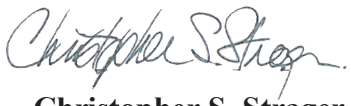
Preface

On July 19, 2018, a significant derecho event occurred over southern Missouri resulting in wind gusts over 70 mph over much of southwest Missouri and the Table Rock Lake region. Generating large media and public interest was the sinking of tourist boat DUKW "Stretch Duck 7" on Table Rock Lake at approximately 708 pm CDT on July 19, 2018. The "Stretch Duck 7", owned and operated by "Ride the Ducks Branson"/ Ripley Entertainment, Inc. had 29 passengers and two crew members aboard for a tour when wind and wave conditions deteriorated on Table Rock Lake. One crew member and 16 passengers died in the sinking.

Because of the rarity and historical significance of this event, a regional Service Assessment Team examined warning and forecast services provided by the National Weather Service.

Service Assessments provide a valuable contribution to ongoing efforts by the National Weather Service to improve the quality, timeliness, and value of our products and services. Findings and recommendations from this assessment will improve techniques, products, services, and information provided to our partners and the American public.



Christopher S. Strager
Director, Central Region

Executive Summary

On July 19, 2018, a significant derecho event occurred over southern Missouri resulting in wind gusts over 70 mph over much of southwest Missouri and the Table Rock Lake region. Generating large media and public interest was the sinking of tourist boat DUKW "Stretch Duck 7" on Table Rock Lake at approximately 708 pm CDT on July 19, 2018.

The National Transportation Safety Board (NTSB) initiated an investigation into the accident as the lead federal agency and named the NOAA/National Weather Service, United States Coast Guard (USCG), Missouri State Highway Patrol (MSHP) and Ripley Entertainment, Inc., as parties to the investigation. This Service Assessment is expected to serve as a companion piece to the forthcoming NTSB report on the accident.

Although the scope of the NWS Service Assessment was generally limited to evaluation of NWS products and services, the assessment was complicated by an inability to interview Ride the Ducks/Ripley Entertainment, Inc. personnel due to litigation concerns, lack of access to interviews and data from NTSB and USCG during their active investigations, and peripheral parties reluctant to participate in interviews due to litigation fears. For these reasons, the scope of the Service Assessment necessarily evolved from focus on the sinking of Stretch Duck 7 to learning how vulnerable outdoor populations receive, interpret, and act upon NWS weather information.

For this particular event, the USCG Investigative Service (with various state and local law enforcement entities) provided investigative information to the United States Department of Justice Attorney for the Western District of Missouri (DOJ) that was subsequently used in criminal indictments (June 20, 2019). Certain information contained therein was used to help construct a timeline of the events that occurred on Table Rock Lake, and to illustrate weather-related challenges faced by all vulnerable outdoor populations.

From a large-scale perspective, in the hours before the accident, publicly available weather information in the form of observations and NWS warnings were available to decision-makers of all types across the region. Importantly, Severe Thunderstorm Warning #243 was issued at 632 pm, roughly 28 minutes before the arrival of strong winds at the point of the accident. The large majority of the warnings issued by NWS Springfield on July 1, 2018, were timely and accurate, and product issuance and content mostly followed established NWS policy and guidance. There were 30 severe weather events in the NWS Springfield County Warning Area (CWA) on July 19, 2018, and 12 warnings were issued. Over 90% of the severe weather events were warned with 22-minute average lead-time to initial events. False alarms accounted for 33% of all warnings.

As is the purpose of Service Assessments, certain areas for potential improvement were indicated. Appendix 2 catalogs these along with all facts, findings, and recommendations. Specific highlights of areas for potential improvement include: 1) encouraging greater use of "pathcasts" in warning products to indicate important time of arrival information for locations in the path of severe thunderstorms; 2) judicious use of storm-based warning polygons that are more service-oriented and tailored for customer jurisdictions; and 3) a gradual phase-out of the Severe Weather Statement (SVS) as a warning follow-up device in favor of updates of the original PIL (e.g. SVR, TOR) to improve product visibility and public alerting protocols for warning upgrades.

The Service Assessment also includes an initial and limited sample evaluation of how core partners representing vulnerable outdoor populations (patrons of campgrounds, marinas, etc.) receive, interpret and respond to severe weather information. This evaluation also extended to traditional core partners such as media and emergency managers. Numerous interviews with groups representing outdoor recreational venues indicated an increasing reliance on smartphone technology to receive warning and weather information, and sometimes a tendency for self-interpretation of radar information. These findings support the need to continue pursuit of WEA alerts for Severe Thunderstorm Warnings.

Last, NWS Springfield was praised by all customers for their relationship-building with core partners and the Missouri State Park system. The office has a long-standing culture of partnerships with key constituents that has carried over to impact-based decision support services where trust is a cornerstone of success. As such, several Best Practices, Findings and Recommendations are addressed concerning educational outreach, training, and decision support functions for at-risk outdoor populations.

Service Assessment Report

Section 1: Introduction

Section 1.1 National Weather Service Mission

The National Oceanic and Atmospheric Administration (NOAA)/National Weather Service (NWS) provides weather, hydrologic, and climate forecasts and warnings for the United States, its territories, adjacent waters, and ocean areas for the protection of life and property and the enhancement of the national economy. NWS data and products form a national information database and infrastructure, which can be used by other governmental agencies, the private sector, the public, and the global community.

Section 1.2 Background

On July 19, 2018, a significant derecho event occurred over southern Missouri resulting in wind gusts over 70 mph over much of southwest Missouri and the Table Rock Lake region (Figure 1). Significant wind damage occurred in areas with vulnerable outdoor populations over water, in marinas, and in campgrounds largely adjacent to portions of Table Rock Lake.

Generating large media and public interest was the sinking of tourist boat DUKW "Stretch Duck 7" on Table Rock Lake at approximately 708 pm CDT on July 19, 2018. The "Stretch Duck 7" (SD7), owned and operated by Ripley Entertainment, Inc., had 29 passengers and two crewmembers aboard for a tour when wind and wave conditions deteriorated on Table Rock Lake. One crew member and 16 passengers died in the sinking.

SD7 was one in a collection of such boats referred to as "Duck Boats" that were used in a local tourist attraction operated as "Ride the Ducks Branson" (RTDB). The boat was an amphibious vehicle that took passengers on tourist excursions through Branson, MO, over land and in the adjacent waters of Table Rock Lake. The entry point into the water was just north of Table Rock State Park, which itself sustained damage from severe thunderstorm winds as the derecho passed through the general Branson region.

The United States Coast Guard (USCG) declared the accident a major marine casualty. The National Transportation Safety Board (NTSB) initiated an investigation into the accident as the lead federal agency and named the NOAA/NWS, USCG, Missouri State Highway Patrol (MSHP) and Ripley Entertainment, Inc., as parties to the investigation.

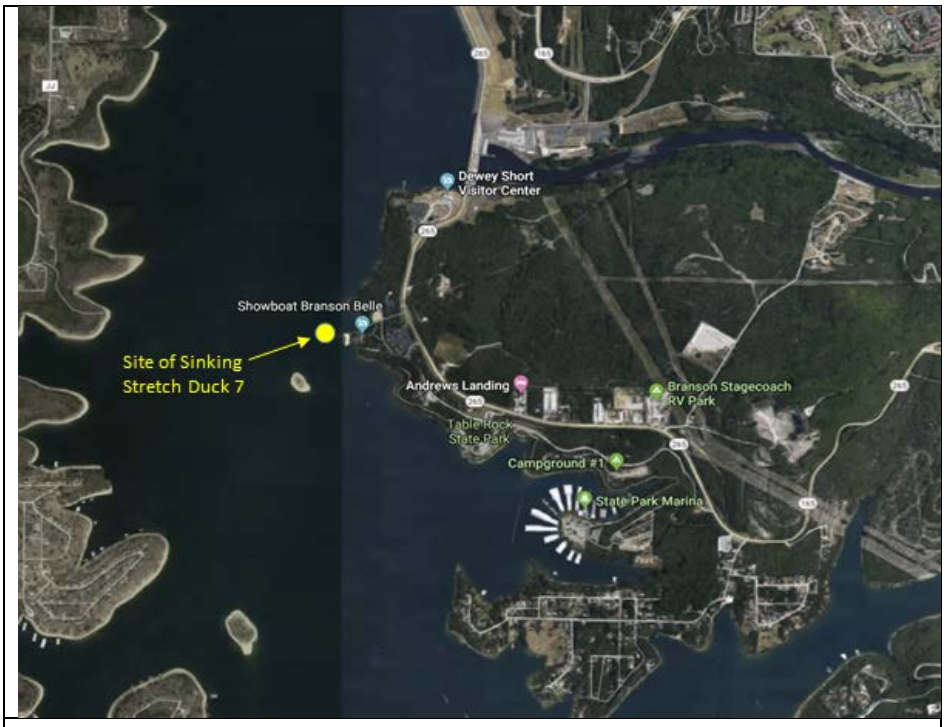


Figure 1: Map of region around Table Rock State Park, Table Rock Marina, Branson Belle Showboat Dock, and location of Stretch Duck 7 sinking.

Section 1.3 Purpose and Scope

The Central Region Service Assessment (SA) Team was charged with documenting and evaluating NWS services and operational procedures before and during the derecho event that affected Table Rock Lake in southern Missouri on July 19, 2018. For reasons more fully explained later in this section and Section 1.4, the scope of the SA quickly evolved from focus on the sinking of SD7 to seeking improvement of internal products and services, and learning how vulnerable outdoor populations receive, interpret, and act upon NWS weather information.

Threats from severe thunderstorm winds are generally under-appreciated in comparison to weak tornadoes, likely owing to perceptions linking most tornadoes with high-end tornado impacts. However, mortality rates for severe thunderstorm winds (as measured in deaths per event) are much higher than mortality rates from EF0 tornadoes, and roughly equivalent to mortality rates from EF0 and EF1 tornadoes combined[1]. In a bulk perspective, there were approximately 280 deaths from severe thunderstorm winds in a 10-year period from 2008 to 2018. Nearly 70% of those occurred to people caught in weather susceptible locations. In contrast, during the same time period, there were approximately 36 deaths from EF0 and EF1 tornadoes. These differences

[1] Source: NWS Verification Database

clearly demonstrate the need for additional attention on threats and warnings for severe thunderstorm winds from both NWS operational and user preparedness perspectives.

The scope and limitations of the SA are very important for this particular case. As mentioned, separate investigations were conducted by the NTSB, USCG, the Occupational Safety and Health Administration (OSHA), the Missouri State Highway Patrol, and local law enforcement agencies. Some of these investigations assessed potentially criminal conduct, while others addressed safety issues.

The SA team limited its scope to issues directly related to public NWS products and services as outlined in NWS Directives; including impact-based decision support services (IDSS) for core government partners. Specifically, the SA focused on how NWS meteorologists evaluated and communicated weather risk, and how NWS partners and others used NWS weather risk information to serve constituents that are particularly vulnerable to weather and water hazards. Groups that were interviewed included emergency managers, television media, law enforcement, and public and privately-owned marinas/campgrounds and their patrons. Those patrons may directly or indirectly include boaters and recreational watercraft users on inland lakes, swimmers/beachgoers, and campground residents.

The expected outcomes of the SA include, a) identification of best practices in operations and services; b) identification of potential improvements to operational services, and c) recommendations of operational and service enhancements with regard to:

1. **NWS Forecasts, Products, Warnings, and Services;** the quality and effectiveness (i.e., timeliness, accuracy, specificity, clarity, consistency) of NWS forecasts, other products, watches and warnings.
2. **Messaging and Communication;** the quality and effectiveness (i.e., timeliness, accuracy, specificity, clarity, consistency) of NWS messages via usual dissemination channels, webpages, social media, etc.

The SA does not examine probable cause of the SD7 sinking, nor does it address issues related to amphibious vehicles and RTDB operations. These concerns fall under the purview of other federal, state, and local investigations.

Section 1.4 Coordination with NTSB, U.S. Coast Guard, Missouri State Highway Patrol, and U.S. Department of Commerce/NOAA General Counsels

The NWS assessment of events on Table Rock Lake on July 19, 2018, was complicated by investigations at other government agencies, and by the potential for civil and criminal litigation against the owners/operators of SD7/RTDB. Although the scope of the NWS SA was primarily

limited to evaluation of NWS products and services, the SA was still inhibited by 1) inability to interview Ripley Entertainment, Inc. personnel due to litigation concerns, 2) lack of access to interviews and other data from NTSB and USCG during their active investigations, and 3) peripheral parties reluctance to participate in interviews due to litigation fears. As a transportation sector accident, NTSB was assigned the lead federal role in the accident investigation, including the evaluation of weather impacts. The USCG subsequently convened a formal Marine Board of Investigation (MBI) and was named an "equal partner" with the NTSB.

NTSB investigations determine the probable cause of an accident and make safety recommendations based on their findings and contributing factors. The NTSB does not have regulatory or enforcement authority and does not find fault or liability. The USCG, however, is a regulatory agency and their investigations examine potential liability in marine accidents. The USCG can subsequently refer matters for administrative, civil, or criminal action. For this particular event, the USCG Investigative Service (with various state and local law enforcement entities) provided investigative information to the U.S. Department of Justice Attorney for the Western District of Missouri (DOJ) that was subsequently used in criminal indictments (June 20, 2019)[2]. The NWS SA team had no contact with DOJ during the course of this assessment.

Facts and findings from NTSB and USCG are confidential during the course of an investigation to preserve the integrity of those investigations and to protect the victims and their families. NWS cannot have access to this information until the information is publicly released by the respective agency. If the NWS is party to the NTSB investigation, certain individuals will have access to critical information throughout its course. However, this information cannot be released, even to other members of the SA team or NWS leadership without specific consent from the NTSB Investigator in Charge. Once NTSB (or other agencies) release factual information publicly, information that is pertinent to the NWS can be included in the SA. This resulted in a longer than usual assessment process.

For the purpose of this SA, NOAA and Department of Commerce General Counsel advised against NWS interviews of those that were potentially involved in, or targets of, civil or criminal litigation. This kept the NWS from unintentionally becoming witness to any subsequent litigation that might occur as a result of probable cause and liability found by any of the previous mentioned parties. As a result, it was advantageous to have the NWS Forensic Services Program Manager (FSPM) as a member of the SA Team to act as liaison to other federal agencies and DOC and NOAA General Counsels. Although the FSPM had access to confidential NTSB and USCG facts and findings, a federal-level Non-Disclosure Agreement was required which prevented the sharing of this information with the rest of the SA Team until public release.

[2] https://www.justice.gov/usao-wdmo/pr/two-more-ripley-employees-indicted-misconduct-negligence-resulting-17-deaths-table-rock

Nonetheless, the FSPM was able to coordinate with NTSB and USCG to forward the SA Team's questions for possible inclusion in other investigations and maintain awareness into the progress of other investigations. This eventually allowed for the SA team to progress in other areas and focus more generally on impacts of severe thunderstorms on vulnerable outdoor populations. Having the FSPM act as a liaison with General Counsel was also helpful in understanding and navigating through possible legal ramifications of the subsequent report.

Best Practice #1: To facilitate external coordination, the NWS Forensic Services Program Manager (FSPM) should be appointed to NWS Service Assessment Teams whenever liaisons may be needed to other investigative federal/state agencies and to DOC and/or NOAA General Counsel.

Section 1.5 Stretch Duck 7 Marine Accident

The sinking of SD7 occurred during a severe thunderstorm, but the details of the actual sinking remained largely unavailable to the SA team during the assessment process. The NWS SA was interested in how the operators of SD7 utilized publicly available weather information prior to the accident, but only as it pertained to general public safety. Of the many questions considered, the following were emphasized for understanding what information was important and how that information was used. The NWS FSPM shared the following with NTSB so they could gather information which could be shared with NWS at the end of their investigation:

- Did SD7/RTDB know there was a NWS Severe Thunderstorm Warning in effect for the area before going into the water?
- Did SD7/RTDB have advance weather information from upstream NWS warnings and reports, and understand that the leading edge of the high winds was ahead of the line of thunderstorms?
- Did SD7/RTDB conduct a self-diagnosis of radar information that may not have accurately recognize the gust front on radar ahead of the main line of storms - possibly resulting in a miscalculation in the arrival of high winds?
- Was there awareness that winds in excess of 60 mph were likely for the area through the length of the NWS warning? If so, was there an advance belief that once the thunderstorms arrived, conditions would not be as severe as predicted?
- Did the owner/operators of SD7/RTDB contract with a private weather information provider to receive weather information (including information from NWS sources)?

To conduct the assessment, the SA team utilized publicly known information - which includes the content of weather observations, NWS products and services, text portions of the audio and video recording on-board SD7 as available through NTSB, and video evidence from shoreline observers as available through various media. Additionally, on June 20, 2019, the DOJ released numerous investigative findings and allegations as part of a criminal indictment related to the

sinking of SD7. Certain relevant, factual information contained therein is used to help construct a timeline of the event. As such, the event timeline is as follows (as obtained from NTSB[3], DOJ[4] and NWS). All times are CDT unless otherwise noted:

1. At 1120 am, the NWS Storm Prediction Center issued Severe Thunderstorm Watch #283 for the Branson and Table Rock Lake area. At 1129 am, an e-mail notification of the Watch was sent to RTDB from RTDB's weather monitoring subscription service. The Watch was in effect at the time SD7 entered the water. (source NWS, DOJ)
2. At 507 pm, NWS Springfield issued Severe Thunderstorm Warning (SVR) #240 for portions of west central Missouri upstream from Table Rock Lake. The warning was in effect until 600 pm and used a "locations impacted" list containing 20 locations in the path of the storm. (source NWS)
3. At 528 pm, NWS Springfield issued a Severe Weather Statement (SVS) follow-up for SVR #240 and used a "locations impacted" list containing locations in the path of the storm. (source NWS)
4. At 545 pm, NWS Springfield issued Severe Thunderstorm Warning (SVR) #241 for areas northwest of (and including) Springfield/Branson Airport. This warning was in effect until 630 pm and included a "pathcast" with estimated times of arrival. Significant, widespread tree and other damage occurred within this warning polygon. (source NWS)
5. Prior to 600 pm, the RTDB General Manager reviewed radar information from RTDB's weather monitoring subscription service and made a self-assessment on timing of the derecho approaching from the north (northwest). (source DOJ)
6. At 607 pm, NWS Springfield issued Severe Thunderstorm Warning (SVR) #242 for the areas immediately north (upstream) of Branson and Table Rock Lake. This warning was in effect until 645 pm and did not use a "pathcast' option, but did use a "locations impacted" list. (source NWS)
7. At 615 pm, NWS Springfield issued a Severe Weather Statement (SVS) follow-up to SVR #242. The SVS included an upgrade in maximum winds expected to 70 mph. (source NWS)
8. At 623 pm, wind gusts were measured at 74 mph at the Springfield/Branson Airport. There were numerous reports of high winds and damage in the Springfield area, and extensive media coverage of the event occurred - including live television and social media. (source NWS)
9. From 625 pm to 627 pm, the RTDB Supervisor and SD7 Captain reviewed radar information from RTDB's weather monitoring subscription service. (source DOJ)
10. From 628 pm to 629 pm, the Captain of SD7 was told to take the water portion of the tour first by an individual that briefly stepped onto the rear of SD7, and the Captain made a

[3] https://www.ntsb.gov/news/press-releases/Pages/nr20180727.aspx

[4] United States Department of Justice Case 3:18-cr-0543-MDH Document 21 https://www.justice.gov/usao-wdmo/press-release/file/1175946/download

verbal reference to looking at weather radar as passengers were boarding at the RTDB land facility. (source NTSB, DOJ)

11. At 632 pm, NWS Springfield issued Severe Thunderstorm Warning #243 for the Branson area and the Table Rock Lake areas near Branson. An e-mail notification of SVR #243 was sent to RTDB by its weather monitoring subscription service. This warning was issued 28 minutes prior to the event and 36 minutes prior to the accident. SVR #243 used a "locations impacted" list, which included Branson, Table Rock Lake, Table Rock State Park and Silver Dollar City. Each of these locations contained vulnerable outdoor populations at the time. SVR #243 did not include a "pathcast" with times of arrival. SVR #243 conveyed gust front movement southeast at 50 mph and wind gusts in excess of 60 mph - possibly damaging trees, siding, and roofs. (source NWS, DOJ)
12. At 633 pm, SD7 left the RTDB facility to travel to Table Rock Lake. (source (DOJ)
13. At 646 pm, an e-mail lightning alert for the area was sent to RTDB from its weather monitoring subscription service. (Source DOJ).
14. At 655 pm, the Branson West (KFWB) AWOS observation north of Table Rock Lake reported a wind gust of 52 mph. As an AWOS site, observations only report at 20-minute intervals. It is unknown (outside of radar estimates) when the gust front first arrived at KFWB nor the peak magnitude of those winds. (source NWS)
15. At 655 pm, SD7 entered the water. The water appeared calm at the time. (source NTSB)
16. At 700 pm, winds began to increase and whitecaps appeared on Table Rock Lake (source NTSB).
17. At 701 pm, the Captain of SD7 made a comment on the increasing storm conditions (source NTSB).
18. At 702 pm, NWS Springfield issued a follow-up Severe Weather Statement (SVS) for SVR #243 for the Table Rock State Park and Branson areas. This SVS upgraded expected wind speeds to 70 mph and listed Table Rock State Park and Table Rock Lake as "locations impacted" in the text product. Around this time, an e-mail notification of the ongoing warning and upgrade of wind gusts to 70 mph was sent to RTDB from its weather monitoring subscription service. (source NWS, DOJ)
19. From 703 pm to 705 pm, the Captain of SD7 made two hand-held radio calls. (source NTSB)
20. Around 707 pm, an anemometer from a nearby vessel recorded a wind gust of 73 mph. (source DOJ)
21. Around 708 pm, the voice and video recording on SD7 ends (source NTSB). Video evidence shows SD7 struggling into the wind and the short-period wave train before being swamped (not capsized) by wind-driven waves coming over the bow (source, various media). Estimated winds at the time of the accident were likely near 70 mph (source DOJ) with significant wave heights potentially as high as 4 feet (source NWS)[5].

[5] Significant waves are defined as the average of the highest one-third of observed waves in a given period.

Section 2 Pre-Event and Warning Services

Section 2.1 Event Overview

The event overview section provides background information for the evaluation of severe weather watches and warnings on July 19, 2018. A more detailed description of the event meteorology is in Appendix 1 of this report.

The large-scale pattern featured an upper level trough over the western Great Lakes, which was moving slowly to the east, with an upper level ridge centered over the Rocky Mountain region (Figure 2). This pattern placed the Missouri Valley region under deep northwest flow aloft. A 70-75 knot, 500-mb jet streak approaching the base of the trough, moved over Missouri during the afternoon increasing the flow aloft and contributing to strengthening deep layer shear.

At 700 am CDT (all times are CDT unless otherwise noted), a surface low was centered near the Minnesota-South Dakota border with a trailing cold front stretching through Nebraska and a warm front extending into Missouri (Figure 3). By mid-day, the cold front would move into far northwest Missouri and northeast Kansas aiding the development of thunderstorms in this region. Southern Missouri was deep into the warm sector. A very moist airmass was in place across the region with a plume of high precipitable water values stretching from the Gulf Coast into the Northern Plains. By afternoon, precipitable water values would be around 1.75 inches across southern Missouri and northern Arkansas (not shown).

Figure 4 is a 6-hour forecast of surface-based Convective Available Potential Energy (CAPE) from the NAM model valid at 100 pm on July 19, 2018. Values of 3000-4500 Joules/kilogram (J/kg) indicated an extremely unstable airmass supportive of severe thunderstorm development. Strong environmental shear and steep mid-level lapse rate (not shown) were supportive of severe thunderstorms, including the development of a Quasi-Linear Convective System (QLCS).

Storms initially developed around 1100 am just ahead of the cold front in north central Kansas. Over the next hour the storms began to increase in coverage and the first severe wind event occurred just before noon. By 100 pm the storms had formed into a cohesive line, which was producing widespread wind gusts in excess of 58 mph as the storms moved east and southeast.

By mid-afternoon the line was a mature bow echo (Figure 5) as it approached the Missouri border with increasing speeds from 30 mph to 45 mph and having produced dozens of severe wind reports. There were also several isolated thunderstorms ahead of the thunderstorm cluster. The cluster then began organizing into a serial derecho with bowing segments over eastern Kansas and southwest Missouri that continued through the remainder of the afternoon and into the early evening hours. There were several upstream reports of winds greater than 80 mph with a peak gust of 90 mph reported in Kansas.

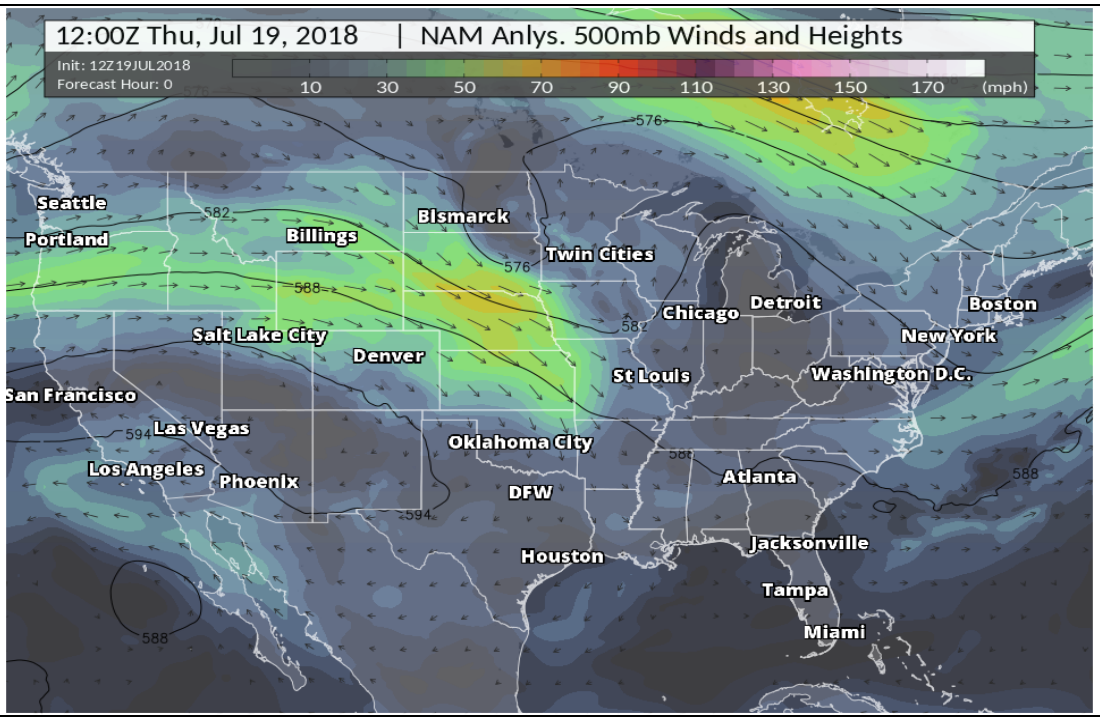


Figure 2: 500 millibar (mb) NAM analysis valid at 700 AM CDT, July 19, 2018. Thin black lines are height (m) contours and shading is wind speed (MPH). Arrows indicate wind direction and speed with longer arrows indicating stronger winds.

Wind gusts of this magnitude require a higher degree of situational and temporal awareness to prepare for impactful weather events - especially for those in vulnerable outdoor populations such as in campgrounds, marinas, outdoor parks, etc. Equally, it requires awareness by meteorologists concerning lead-time and event magnitude thresholds that are necessary for effective decision-making by core partners and the public.

Table 1 contains a list of those organizations and individuals interviewed as part of this Service Assessment. For the purposes of this report, they are loosely organized into two categories, 1) traditional core partners such as emergency management, law enforcement, and media; and 2) non-traditional partners and private entities, such as campground or marina operators that have responsibility for vulnerable outdoor patrons. This list also includes numerous interviews with individual patrons located at campgrounds or marinas.

Several NWS Springfield staff were interviewed but don't belong to either category. Most interviews (including patrons) were done with small groups of two or more individuals, providing additional perspectives on how NWS information was used. Nonetheless, this assessment represents a limited sample that requires expansion going forward.

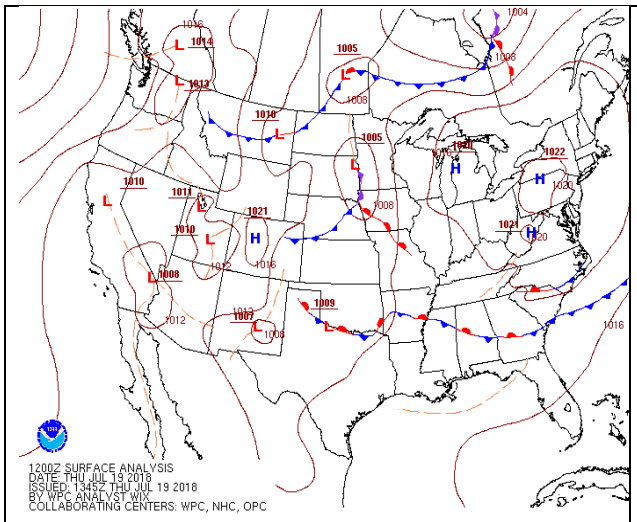


Figure 3 - Surface map valid at 700 am, July 19, 2018.

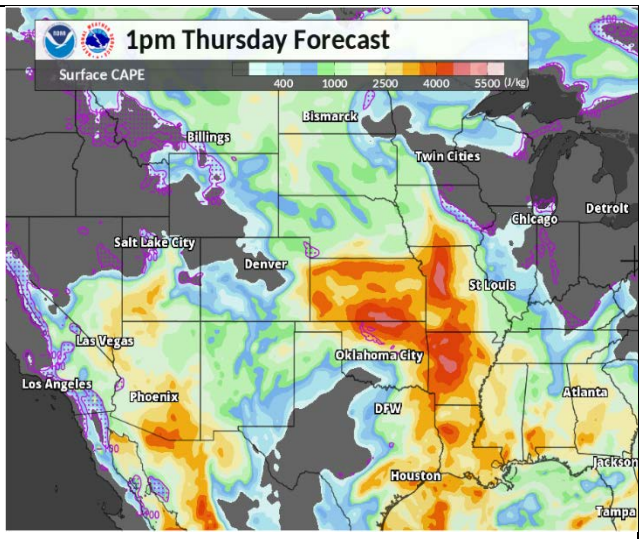


Figure 4: 6-hr forecast of NAM surface-based CAPE valid at 100 pm on July 19, 2018.

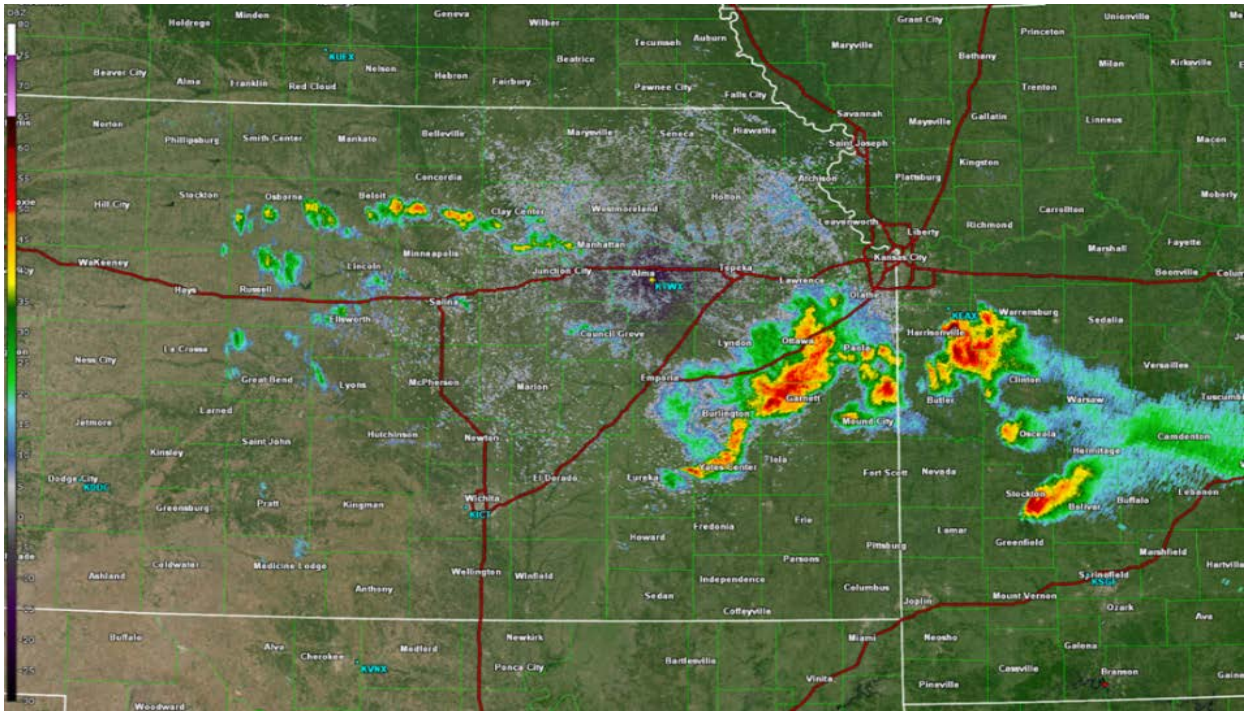


Figure 5 - Base Reflectivity at 405 pm from the Topeka, KS WSR-88D (KTWX).

Traditional Core Partners	Non-Traditional Core Partners/Private Entities
Taney County Emergency Management (gov)	Table Rock State Park operator (gov)
Stone County Emergency Management (gov)	Indian Point Marina Operator (private)
Branson MO Emergency Management (gov)	Table Rock SP Marina operator (gov contractor)
KTYV Springfield MO (media)	US Army Corp Campgrounds Supervisor (gov)
KOZL Springfield MO (media)	Bay City MI State Park (gov) patrons
KRBK	Starved Rock IL State Park (gov) patrons
MO State Highway Patrol Communications (gov)	Stockton MO State Park/Marina operator (gov)
	Boysen WY State Park Supervisor (gov)
Other Interviews	Lakeview (MO) Campground Operator (private)
NWS Springfield Forecast Staff/SOO/WCM	MO State Highway Patrol Marine Division (gov)

Table 1- List of organizations/individuals interviewed as part of Service Assessment

Section 2.2: Pre-Event Forecasts and Services

This section evaluates longer-fused, pre-event products and services provided by NWS Springfield and the Storm Prediction Center (SPC) in Norman, OK.

Initial SPC Convective Outlooks for Day 3 (not shown) and Day 2 (Figure 6a) valid July 19, 2018, placed southwest Missouri in an area of General Thunder with Marginal Risks for severe weather concentrated further north and ranging across eastern Nebraska, eastern South Dakota, Iowa, southern Minnesota, northern Missouri, into far southwest Wisconsin and northwest Illinois.

Forecast trends for southern Missouri severe weather first began to increase with the SPC Day 2 Convective Outlook and Discussion from 1230 pm on July 18 (text box #1) and the NWS Springfield Area Forecast Discussion (AFD) from 315 pm on July 18. While the Table Rock Lake area remained under General Thunder risk, the Marginal Risk area expanded southward to very near southwest Missouri and a Slight Risk area first appeared over southeast Iowa, northeast Missouri, and western Illinois. NWS Springfield Hazardous Weather Outlooks roughly mirrored the SPC progression during this time with cursory mention of a minimal severe weather threat for Day 2 (July 19).

1. SPC Day 2 Outlook Update 1230 PM CDT 07/18 - Excerpt

Further south down the Mississippi Valley, a more conditional severe risk will be present. Any early day thunderstorm cluster that survives may rejuvenate across portions of southern MO/northern AR during the afternoon. Later-day storms that initiate further north may also merge into a cluster that moves southeastward into this region. Some damaging wind risk would be possible in either scenario, with some marginal hail risk associated with any more discrete convection that may develop.

While the Day 3 and Day 2 SPC Outlooks under-forecast the southwest Missouri severe thunderstorm threat for July 19, the Day 1 Convective Outlooks (as shown in Figures 6b-d) indicated gradual convergence toward a solution of increased threats for the region. This trend was reflected in the early morning NWS Springfield Area Forecast Discussion (AFD) issued at 130 am Thursday July 19 (text box #2). The 759 am SPC Day 1 Outlook expanded a Slight Risk area southwestward to include all of central Missouri, impinging slightly on southwest Missouri (text box #3).

2. WFO Springfield MO - Area Forecast Discussion 130 AM CDT 07/19 - Excerpt

Thunderstorm chances this afternoon (Thursday) are a tough call with multiple possible triggers. The two main mechanisms appear to be: 1) Any remaining outflow boundaries from morning storms; 2) Storms firing in the Kansas City metro/I-70 corridor with an incoming short-wave trough. There seems to be loose agreement in both of these scenarios playing out from convection-allowing-models (CAMs).

While some areas may get worked over by morning convection, it does appear that most of the area will become highly unstable this afternoon with MLCAPE values of 2500-3500 J/kg. There will also be anomalously strong westerlies in place across northern and central Missouri as an upper level speed max punches into the region.

Inspection of RAP forecast soundings indicates that supercell structures (possibly splitting) are in play this afternoon and this evening across central Missouri. Thus, large hail would a concern if this panned out. High 0-3 km theta-e differentials(30-35 Kelvin) will also support strong cold pool conglomeration and a damaging wind threat with storms that congeal into line segments and move southeast across the region. At this point, we are going to advertise a limited severe weather risk given the questions on triggering mechanisms and scenarios. It is quite possible that the severe risk may be increased later today.

NWS Springfield issued an updated Weather Story graphic at 850 am reflecting the expansion of the Slight Risk area. The expansion was still on the fringe of the eventual derecho path which was covered in totality by the previous Marginal Risk area. SPC Mesoscale Discussion (MD)

#1082 (text box #4) was issued at 958 am indicating an increasing, although not imminent, threat of severe thunderstorms for southwest Missouri and a 40% probability of a Watch issuance for late morning and early afternoon (Figure 7a). The MD #1082 also highlighted several key factors that were leading to an increased threat of bowing clusters and supercells. This information was disseminated via a Hazardous Weather Outlook (HWO) prior to 11 am and prior to the initial round of Severe Thunderstorm Warnings at 1058 am in the northern portion of the NWS Springfield County Warning Area (CWA). This appeared to prompt the issuance of Severe Thunderstorm Watch #283 (Figure 7b) for southwest Missouri at 1120 am (valid until 900 pm). Further expansion of the Slight Risk area occurred in the SPC Day 1, 1158 am Outlook to cover all of southwest Missouri.

From interviews with traditional core partners in southwest Missouri, the pre-watch messaging from NWS Springfield and SPC did not seem to significantly raise interest in the increasing severe thunderstorm threat developing to the north. For the three groups of local emergency managers in the Branson/Table Rock Lake area and the three groups of media from the Springfield, MO area, most noted the primary risk signals that raised awareness of increasing severe weather potential were the issuance of Severe Thunderstorm Watch #283 at 1120 am, and/or the initial issuance of Severe Thunderstorm Warnings in the areas to the north and northwest. Local media groups were more likely to be situationally aware of the increasing threat ahead of watch issuance, but mostly through their own procedures and forecasts rather than the use of WFO or SPC products.

3. SPC Day 1 Outlook 759 AM CDT 7/19 - Excerpt

Clustered or QLCS modes may develop and move southeastward along and southwest of the warm front this evening, offering a lowering threat for hail but better-organized wind potential. At this time, specific foci/location/timing for upscale growth appears too uncertain to highlight a smaller corridor of greater wind probabilities, but one may be justifiable in subsequent updates as influential mesoscale factors become more apparent.

Non-traditional core partners and private entities representing vulnerable outdoor populations had similar views of severe thunderstorm outlook products and Severe Thunderstorm Watches prior to severe thunderstorms. For these groups there was minor use of WFO or SPC severe weather outlook products for situational awareness. Instead, Severe Thunderstorm Watch #283 was generally the first indication of the need to follow the weather more closely. Managers at the two state parks (Table Rock and Stockton), the two marinas (Table Rock State Park and Indian Point), and the MSHP marine and communication units appeared more weather-aware in the "watch phase" than the private Lakeview campground and U.S. Army Corps of Engineers (USACE). Some in these groups also seemed more inclined to monitor severe weather through Severe Thunderstorm Warning issuances and local storm reports subsequent to the watch.

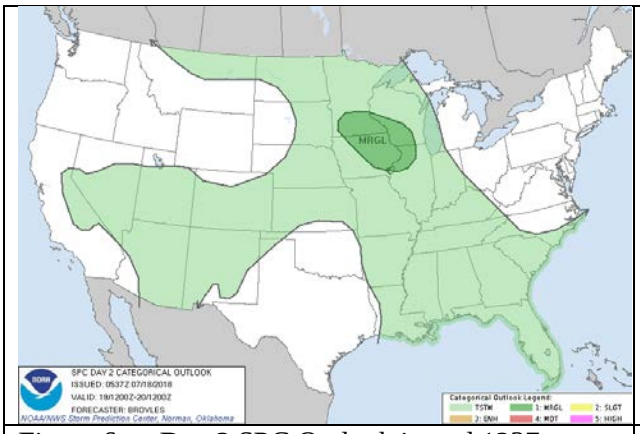


Figure 6a – Day 2 SPC Outlook issued 1237 am July 18, 2018

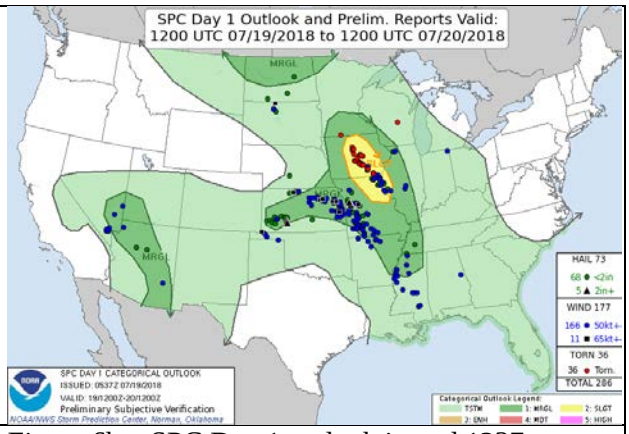


Figure 6b – SPC Day 1 outlook issued 1237 am July 19, 2018 with preliminary verification reports.

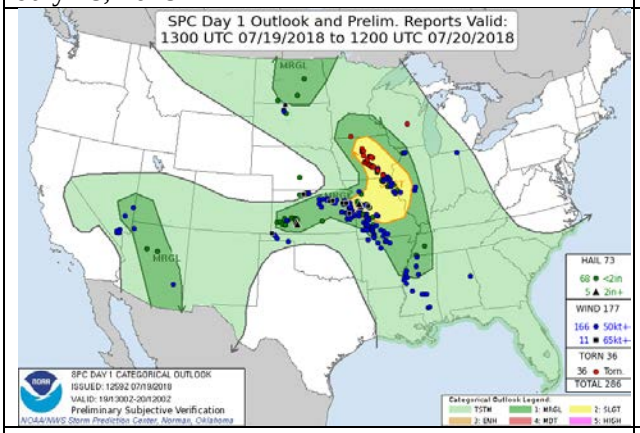


Figure 6c – SPC Day 1 outlook issued 759 am July 19, 2018 with preliminary verification reports.

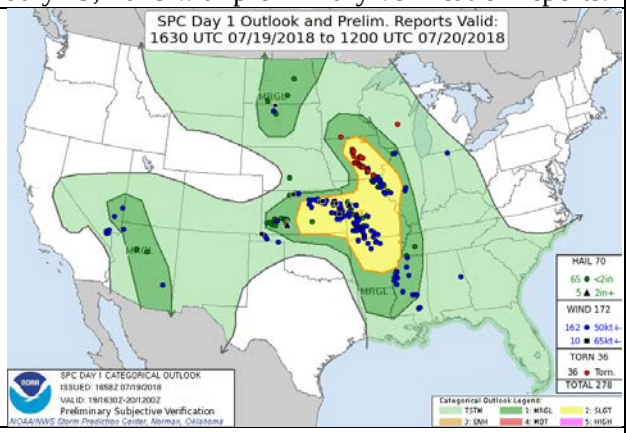


Figure 6d – SPC Day 1 outlook issued 1159 am July 19, 2018 with preliminary verification reports.

4. Mesoscale Discussion #1082 958 AM CDT – Excerpt

Clusters of thunderstorms may pose a risk of isolated severe gusts and large hail this morning. Through early afternoon, this threat may further increase, possibly warranting watch issuance.

Low-level stratus across parts of the state is slowing destabilization this morning, with current surface temperatures in the 70s to lower 80s. In turn, a rapid increase in severe potential is not currently anticipated. However, with further dissipation of these clouds and enhanced insolation, an increasingly unstable boundary layer should combine with steep mid-level lapse rates to promote fairly robust MLCAPE by afternoon across western/southern Missouri. If storm propagation can maintain some western component into this buoyancy corridor through the afternoon, a greater severe threat may be realized, with a mixture of supercells and bowing clusters possible,given considerable mid/upper northwesterlies. These cells would likely be capable of large hail, damaging winds, and perhaps a tornado. While this potential (and related watch issuance) does not appear imminent, it may materialize by early/mid afternoon. Regardless, if trends warrant, a watch could be issued sooner.

The length of Severe Thunderstorm Watch #283 (over 9 hours) was not strongly noted as a major concern by forecasters at NWS Springfield, nor by partner groups. However, a couple of on-duty NWS Springfield staff and Springfield area media did mention the potential challenge of maintaining an adequate information flow over a lengthy watch period. Despite the need for more advance lead-time and perhaps lower impact thresholds among outdoor populations in campgrounds, marinas, and outdoor parks, there was not extensive advance notification of the severe weather threat beyond the normal watch and warning processes. Between Severe Thunderstorm Watch issuance at 1120 am and 300 pm (when stronger convection began to impact southwest and south-central Missouri) there were two Facebook Live™[6] broadcasts and three Weather Story/Graphical Nowcasts from NWS Springfield. These products were well-received by key partners and Facebook Live™ views were as high as 4,500 users. However, these products presented only generic information on timing and potential severity in the "pre-warning" phase of this event. Furthermore, examination of NWSChat logs and social media posts showed several external inquiries concerning specific arrival and intensity of thunderstorms for specific locations. Some of the media partners indicated that they use live streaming technology routinely to warn the public of impending weather hazards.

Finding #1: Given the length of Severe Thunderstorm Watch #283, there were information gaps concerning timing of severe thunderstorm threats for the southern portions of the watch area which could have been used for additional decision support for vulnerable outdoor populations.

Recommendation #1: Forecast offices should be cognizant of the need for advance information on timing and severity of weather events for vulnerable outdoor populations. This information should take the form of social media posts for the general public, and more specific decision support for government-sector core partners (e.g. state parks, etc.).

Section 2.3 Warning Operations

The bulk of the warning phase for south central and southwest Missouri for July 19th was ushered in by a well-written SPC Mesoscale Discussion issued at 216 pm (Figure 7c and text box 5). This discussion accurately anticipated intensification of ongoing convection as it approached far southern Missouri, and provided a solid basis for subsequent warnings.

Ahead of the organizing derecho was an isolated strong thunderstorm (Figure 8) which was covered by Severe Thunderstorm Warning (SVR) #236 issued at 323 pm. This cell would produce significant winds (estimated as high as 80 mph) and damage to Stockton State Park and Marina before rapidly dissipating ahead of the main organizing derecho (Figure 9 and Figure 10). This essentially marked the beginning of the "warning phase" of the unfolding derecho event for southern and southwest Missouri.

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[6] Facebook Live™ Video #1 https://www.facebook.com/NWSSpringfield/videos/2160909847253437/

Facebook Live™ Video#2 https://www.facebook.com/NWSSpringfield/videos/2160997067244715/

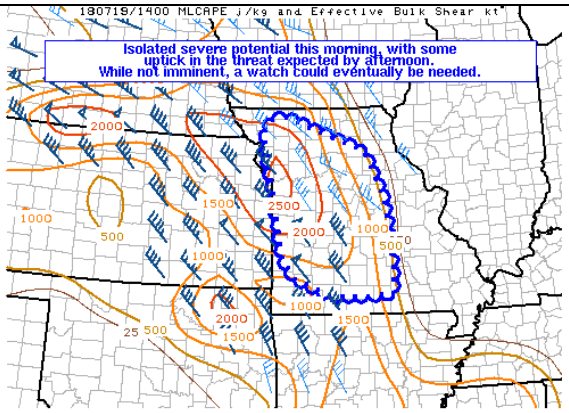

Figure 7a – SPC MCD #1082 issued 958 am July 19, 2018

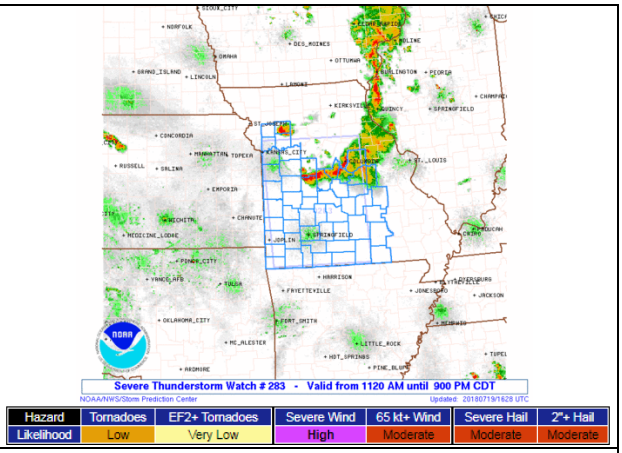

Figure 7b – Severe Thunderstorm Watch #283 graphic issued 1120 am July 19, 2018

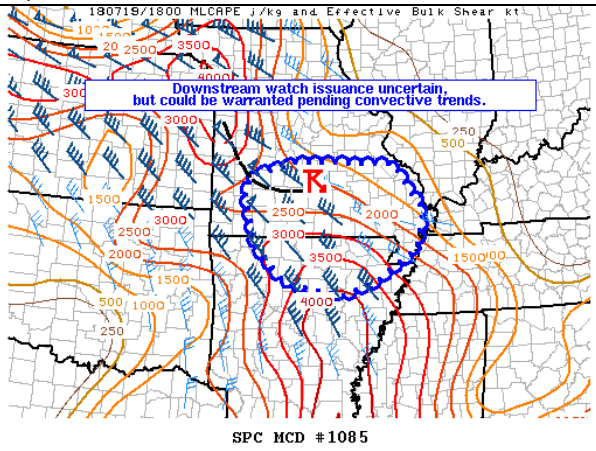

Figure 7c – SPC MCD #1085 issued 216 pm July 19, 2018

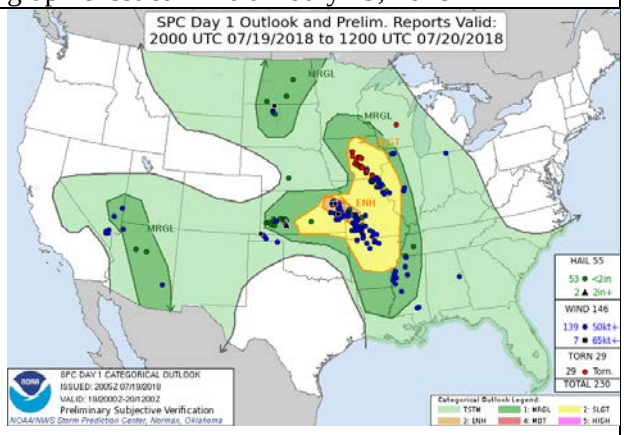

Figure 7d – SPC Day 1 outlook issued 3 pm July 19, 2018 with preliminary verification reports.

5. Mesoscale Discussion #1085 216 pm CDT - Excerpt

A secondary zone of potential convective development may offer a greater, although still uncertain, severe threat over far southern Missouri into northern Arkansas through this evening. Visible satellite displays towering cumulus along an outflow boundary extending westward from the aforementioned system. Ahead of this boundary, rich boundary-layer moisture, ample heating, and more robust mid-level kinematic/thermodynamic conditions are yielding a higher conditional threat. Deeper convection along this boundary would likely become severe…

From 500 pm to 615 pm the upstream derecho accelerated toward the Springfield area with rear inflow becoming strongly evident on base reflectivity data displays (Figure 10 and Figure 11). Figure 12 shows how quickly a bowing segment closed in on the Springfield area by 615 pm.

The advancing derecho would produce widespread severe and damaging winds well upstream of Springfield, and then throughout the city before moving south toward the Branson and Table Rock Lake areas. The nearby Springfield/Branson Airport recorded a peak wind gust of 74 mph at 623 pm. The primary progression of warnings during this time covered SVR #240, SVR #241, and SVR #242 as depicted in Figures 10-13. At 632 pm NWS Springfield issued SVR #243 covering the Branson area, Silver Dollar City, Table Rock Lake, Table Rock State Park and Marina, and numerous other locations with vulnerable outdoor populations (Figure 13). In all, there were 201 reports of severe thunderstorm winds or wind damage associated with this event across Kansas, Missouri and Arkansas (in the Preliminary Storm Reports from the Storm Prediction Center).

The most interesting, and perhaps most impactful characteristic of this derecho was a cold pool-dominated outflow that far outraced the main reflectivity core, and produced initial severe wind gusts in essentially precipitation-free air. In general, the gust front boundary and the onset of severe winds were 5-10 nm ahead of the primary convective updrafts – and high winds likely preceded the heavy rainfall (and thunder/lightning) by as much as 15 minutes.

Another unusual aspect of the event was the duration of extreme winds. As the outflow raced ahead of the main convective updrafts it resulted in a situation where winds greater than 50 mph continued episodically over time periods greater than 30 minutes in some areas. When a bowing segment went through the city of Springfield, there were numerous wind gusts over 50 mph between 615 pm and 645 pm. Just north of Table Rock Lake at the Branson West AWOS, winds gusting to 52 mph were measured at 655 pm. Similarly, when the derecho traversed the Table Rock Lake area there was considerable distance between the leading edge of the gust front and the backside of the convective towers, which resulted in a prolonged period of high winds. This likely contributed to a more sustained period of relatively high waves on the lake (see Appendix 1).

The large majority of the warnings issued by NWS Springfield on July 19 were timely and accurate, and product issuance and content mostly followed established NWS policy and guidance. There were 30 severe weather events in the NWS Springfield County Warning Area (CWA) on July 19, 2018, and 12 warnings issued. The SVR Probability of Detection (POD) for severe thunderstorm events was 0.92, the warning False Alarm Ratio (FAR) was 0.33, Critical Success Index (CSI) was 0.63, and average warning lead-time to initial events was 22 minutes.

The warning phase period evaluated for this portion of the event started with SVR #236 at 323 pm and continued until the time of the sinking of SD7 around 708 pm. This included 8 Severe Thunderstorm Warnings, 13 Severe Weather Statements (SVS), and 26 Local Storm Reports (LSR). For the purpose of this report, the team reviewed five Severe Thunderstorm Warnings as noted in Figures 8-15 (SVR #236, SVR #240, SVR #241, SVR #242, SVR #243); with emphasis on Severe Thunderstorm Warning #243 covering Table Rock Lake and the Branson area (Figures 13-15).

There were some challenging aspects to warning operations and products, most of which are covered in the sections that follow. In a high-instability environment with increasing shear favorable for bowing segments, forecasters were challenged to focus on changing forward propagation speeds where segments were, at times, accelerating (or decelerating) southeast and southward. At one point, starting before 5 pm, forward speeds at the apex of one bowing segment had increased to around 50 mph, and then surged to near 65 mph as it approached Springfield between 545 pm and 600 pm.

The trends in forward propagation speed of the derecho were reflected in products starting with SVR#240 at 506 pm and continuing sequentially through SVR #243 up to the time of the sinking of SD7. While trends were generally reflected in products, updated specifics in storm movement were sometimes lacking.

Beginning with SVR #240 issued at 506 pm (valid until 600 pm), storm movement was listed at 50 mph and also measured at 50 mph from 502 pm to 517 pm. However, the follow-up Severe Weather Statement (SVS) at 528 pm incorrectly lowered the movement to 40 mph, while the actual measured storm speed was sustained at 52 mph from 517 pm to 543 pm. For SVR #241 issued at 545 pm immediately downstream (Figure 11), the initial movement listed was then upgraded to 55 mph. However, this warning did not receive a SVS follow-up statement, and thus carried the 55 mph speed through the duration of the warning until 630 pm. This was mostly accurate for the southwestern portion of the polygon. But, a significant acceleration from a bowing segment in the north and northeast portion of SVR #241 was not communicated when the movement increased to 65 mph between 543pm and 600 pm (see Section 2.3-1).

Shortly thereafter, SVR #242 was issued at 607 pm and accurately upgraded the storm speed to 65 mph as the bow moved into the city of Springfield. The follow-up SVS at 615 pm, continued the 65 mph speed of movement through 645 pm. Around 630 pm, the southwest flank of the gust front began to decelerate as movement took on a more southerly component toward Table Rock Lake. The estimated speed of movement from 618 pm to 631 pm was 58 mph.

For SVR #243 issued at 632 pm, speed of movement in the warning was noted at 50 mph, which was slightly slower than the 58 mph measured. This discrepancy could have been partially a result of using a straight two-point polyline to mark the location of the spatially non-linear gust front (see Section 2.3-1). From that point through SVR #243, south to southeastward movement of the gust front slowed to slightly less than 50 mph between 632 pm and 646 pm and continued until reaching the site of the SD7 sinking around 700 pm. The first follow-up SVS for SVR#243 was issued at 702 pm and contained an estimated movement of 30 mph.

While overall trends in forward speeds of the gust front were generally captured in warnings and statements throughout the event, there were a couple missed opportunities to keep information fresh and more detailed through the use of additional follow-up SVS products. This also has implications for the use of “pathcasts” in warnings as discussed in Section 2.3-1.

Maximum wind gusts tagged in several SVRs and SVSs were generally under-predicted. All Severe Thunderstorm Warnings issued by NWS Springfield during the afternoon of July 19 noted maximum wind gusts of 60 mph (except SVR #244 at 645 pm which had a maximum wind

speed of 70 mph). In three instances there was an upgrade via SVS to 70 mph. These were during SVR #238 from 418 pm to 438 pm, during SVR #242 from 615 pm to 645 pm, and during SVR #243 after 702 pm. There was upstream observational evidence, both from surface reports and radar base velocity estimates, to suggest maximum wind gusts from 70 mph to 80 mph could have been more confidently employed in several SVRs or SVSs.

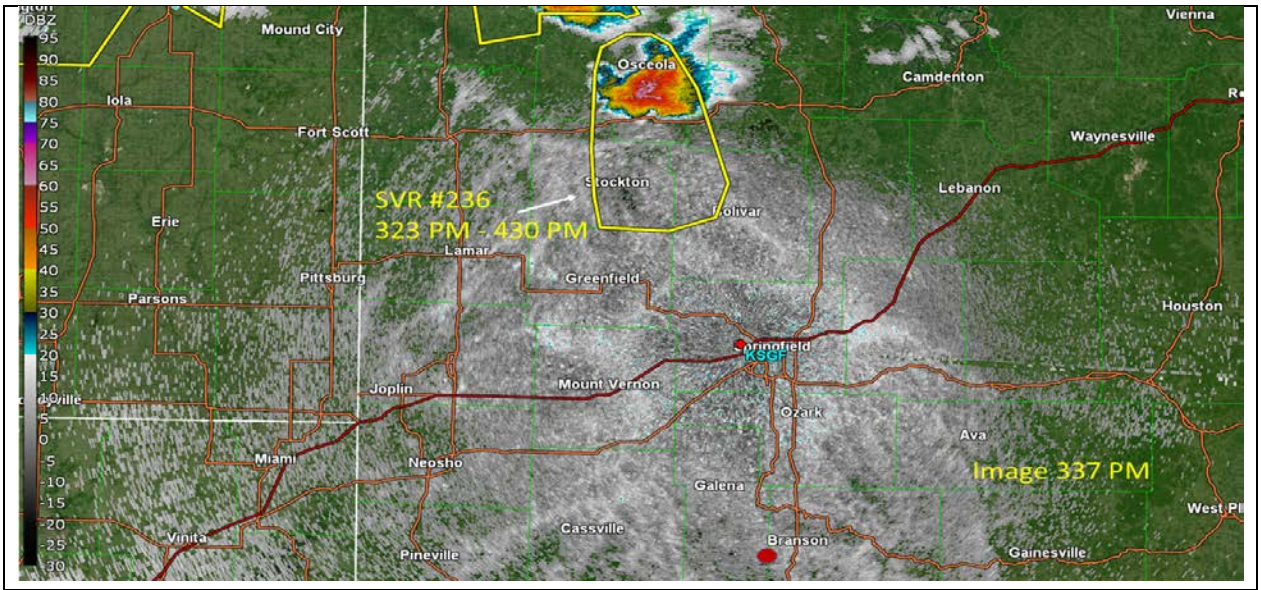

Figure 8 - 0.5 degree reflectivity image from Springfield WSR-88D at 337 pm. Yellow polygons are NWS Severe Thunderstorm Warnings. Small red circle in the lower center part of the image marks the location of the Table Rock Lake State Park.

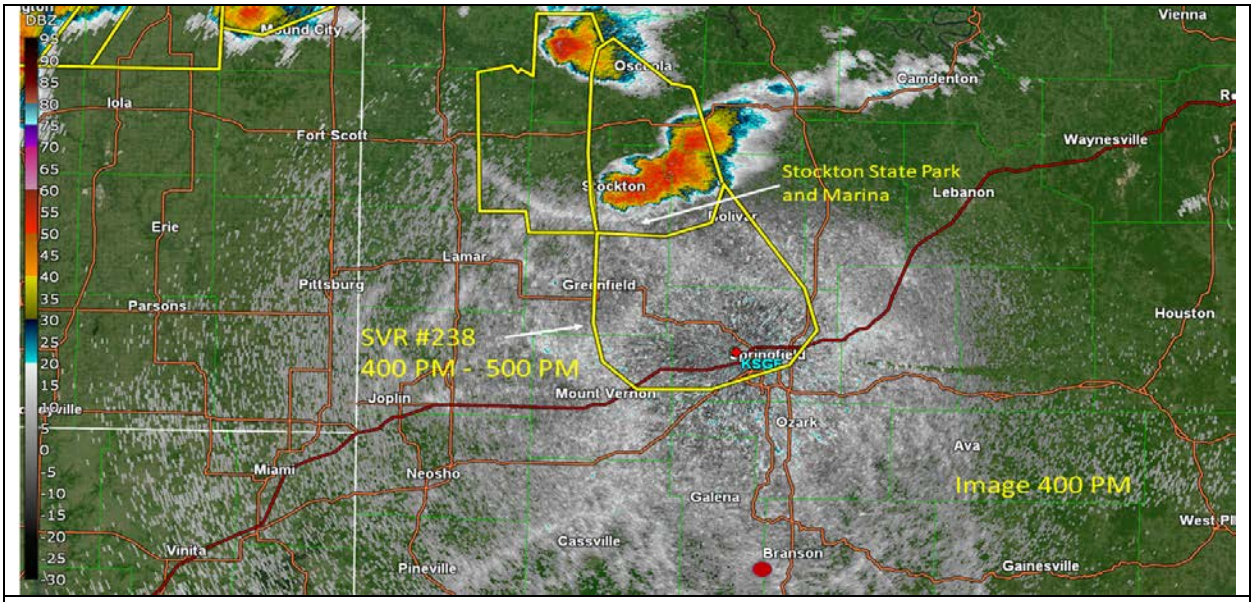

Figure 9 - 0.5 degree reflectivity image from Springfield WSR-88D at 400 pm. Yellow polygons are NWS Severe Thunderstorm Warnings. Small red circle in the lower center part of the image marks the location of the Table Rock Lake State Park.

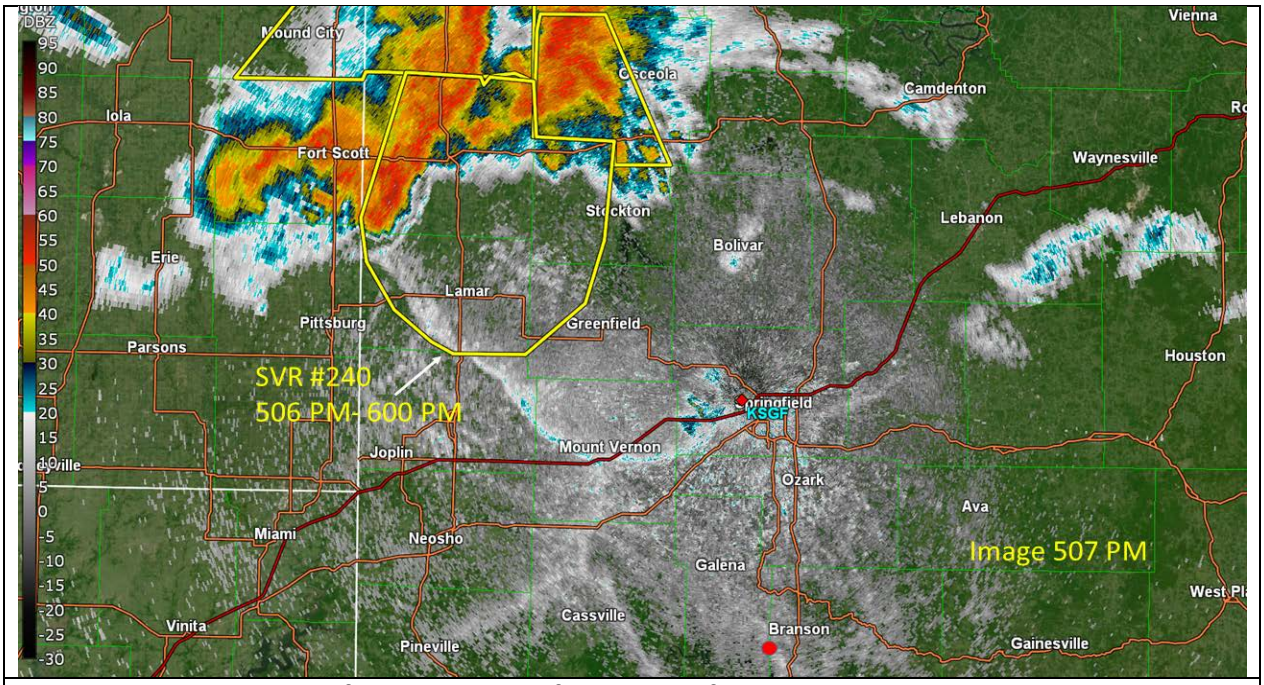

Figure 10 – 0.5 degree reflectivity image from Springfield WSR-88D at 507 PM. Yellow polygons are NWS Severe Thunderstorm Warnings. Small red circle in the lower center part of the image marks the location of the Table Rock Lake State Park.

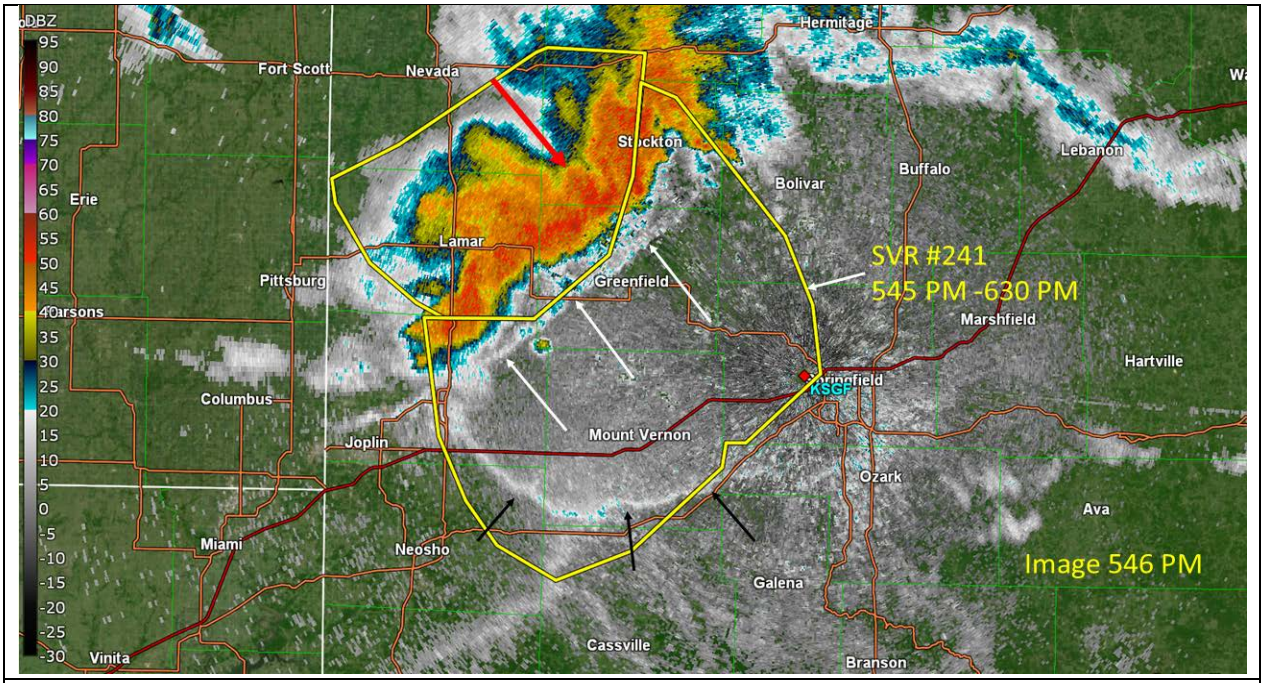

Figure 11 - 0.5 degree reflectivity image from Springfield WSR-88D at 546 pm. White arrows show the leading edge of the outflow associated with the derecho and black arrows identify location of remnant outflow from earlier convection. Red arrow is location of rear inflow.

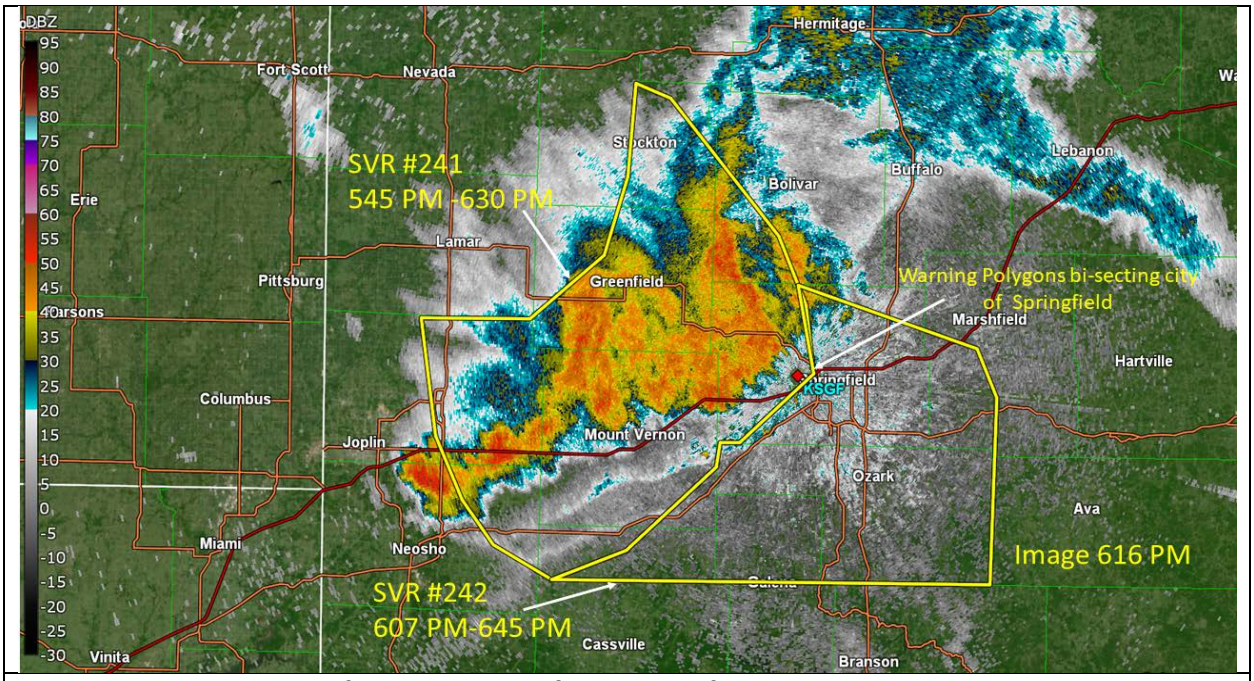

Figure 12 – 0.5 degree reflectivity image from Springfield WSR-88D at 616 pm. Yellow polygons are NWS Severe Thunderstorm Warnings.

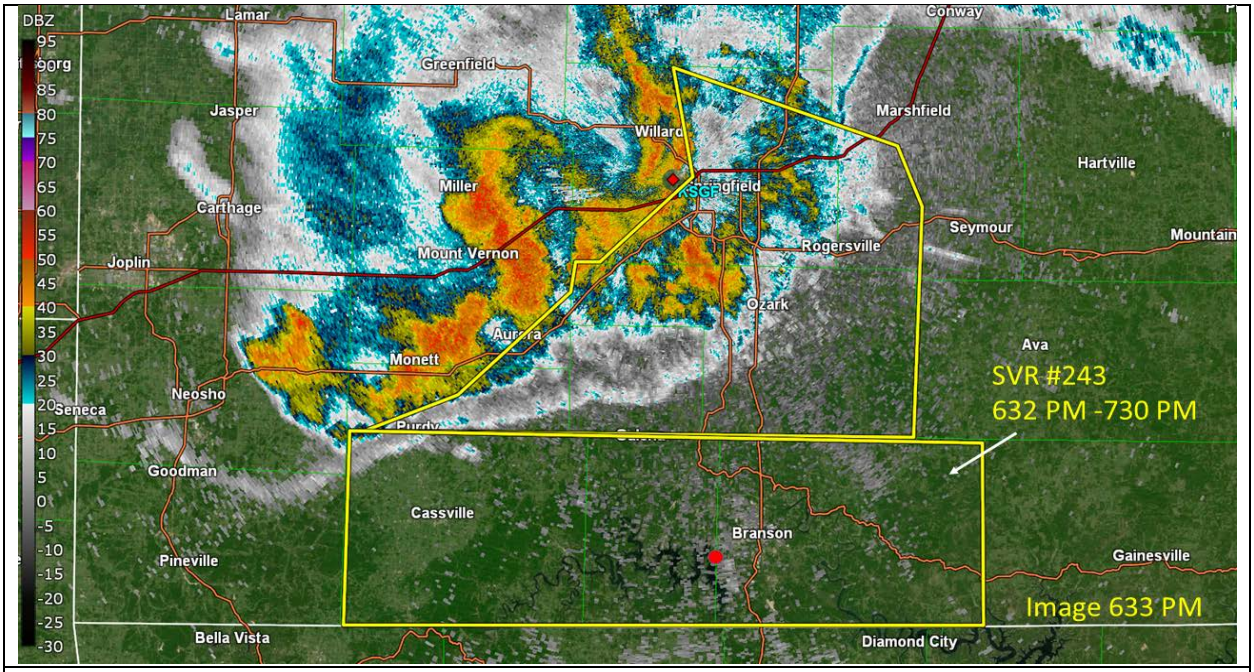

Figure 13 – 0.5 degree reflectivity image from Springfield WSR-88D at 633 pm. Yellow polygons are NWS Severe Thunderstorm Warnings. Small red circle in the lower center part of the image marks location of Table Rock Lake State Park.

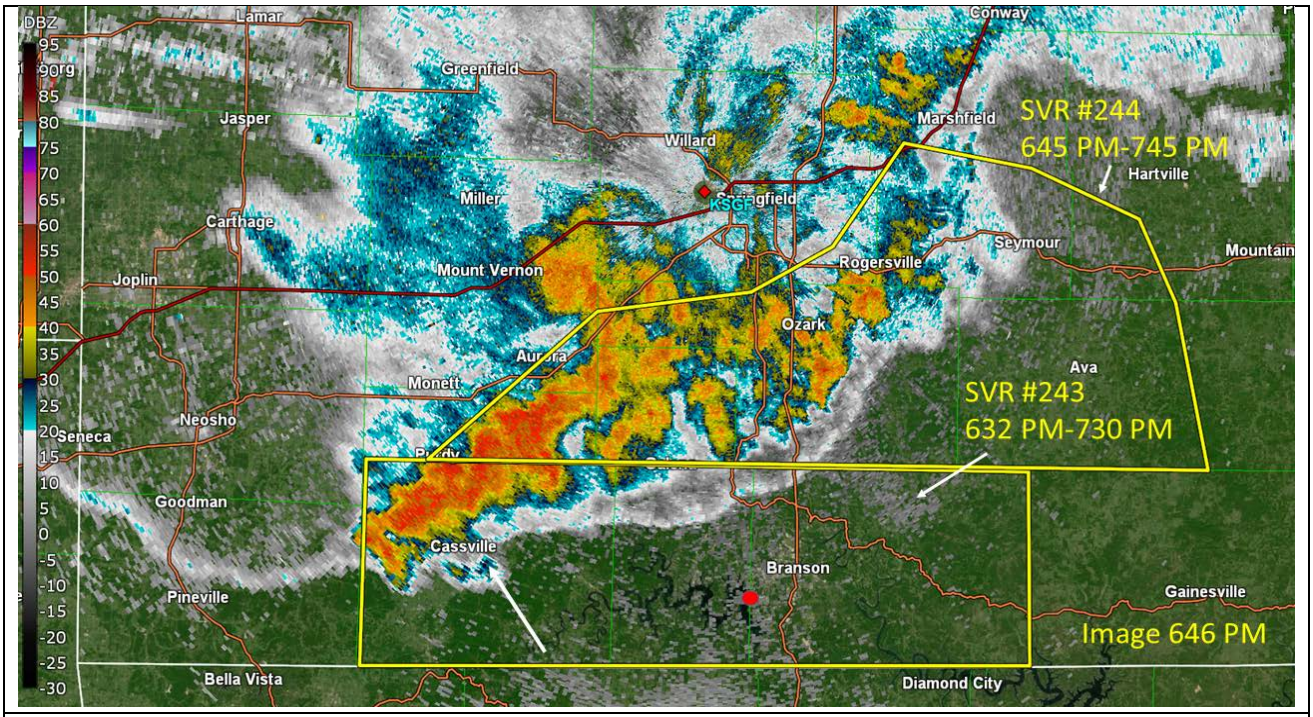

Figure 14 - 0.5 degree reflectivity image from Springfield WSR-88D at 646 pm. Yellow polygons are NWS Severe Thunderstorm Warnings.White arrow in lower left denotes location where outflow and updraft interface are nearly coincident.

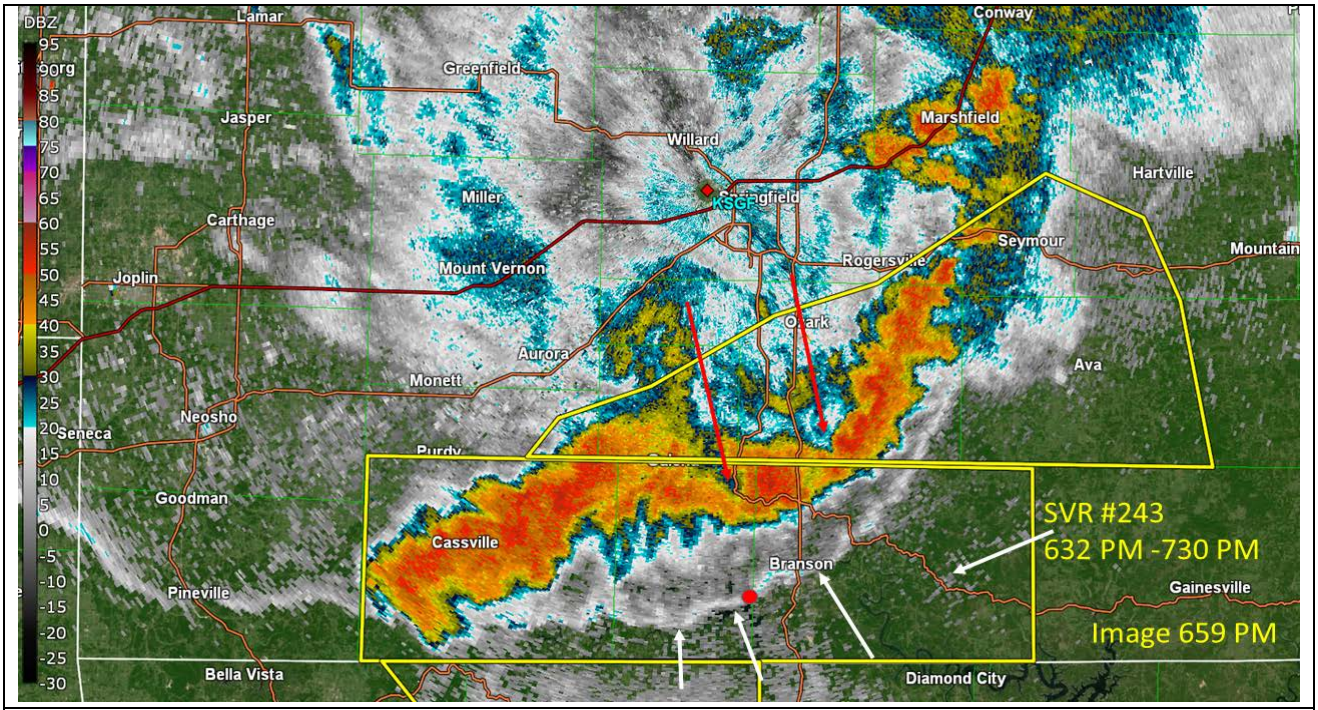

Figure 15 - 0.5 degree reflectivity image from Springfield WSR-88D at 659 pm. Red arrows indicate rear inflow notches and white arrows show the leading edge of the outflow.

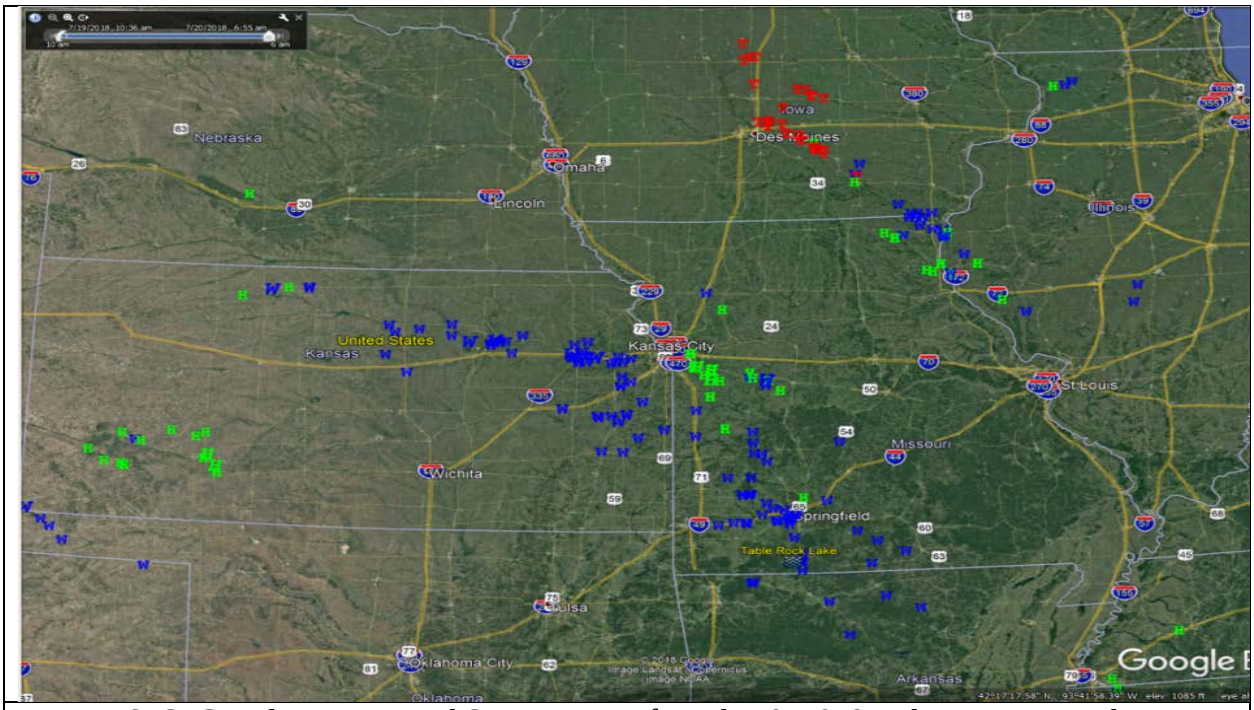

Figure 16- SPC Preliminary Local Storm Report for July 19, 2018. Blue Ws are wind reports, Green Hs are hail reports, and Red Ts are tornado reports.

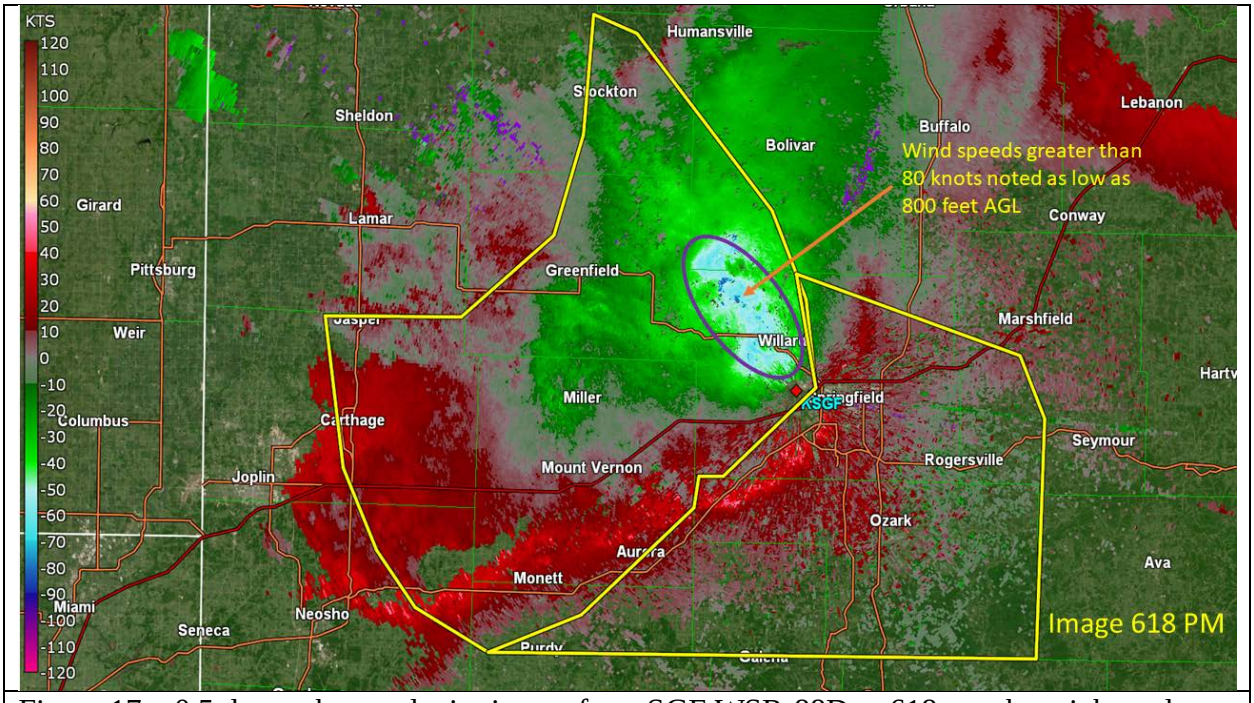

Figure 17 – 0.5 degree base velocity image from SGF WSR-88D at 618 pm show inbound velocities as high as 80 knots at 800 feet AGL.

Estimated storm movements, time of arrival, and maximum wind speeds in SVRs have important implications for event messaging. Those who have patrons or a constituency of vulnerable outdoor populations, such as campground and/or marina managers, expressed in interviews the importance of these factors for helping to ensure safety.

In circumstances that may require extra time or urgency for sheltering actions, key messaging in social media, graphics, and warnings may help vulnerable outdoor populations understand that typical visual or audible cues may be inadequate. Using this event as an example, statements could have been helpful for communicating that fast moving storms may arrive quickly or damaging winds are expected to arrive well in advance of thunderstorms. Accomplishing this type of messaging requires a high level of situational awareness and pre-event planning for unusual scenarios.

Section 2.3-1 "Pathcasts" and "Locations Impacted" in Severe Weather Warnings

The most immediate issues following the July 19, 2018, derecho event concerned the communication of where and when to expect hazardous severe weather. For this event, the presence of the severe gust front far ahead of the heaviest precipitation was a potential complicating factor for communicating the imminent threat of severe thunderstorm winds.

NWS Springfield recognized early that a strong cold pool-forced gust front was producing severe weather well in advance of the reflectivity cores. That gust front was well-depicted on radar which lent itself generally to more timely and accurate downstream warnings. NWS Springfield incorporated this information into WarnGen[7] operations and in the basis statements of all Severe Thunderstorm Warnings and Severe Weather Statements (i.e. the location of the line at the time of product issuance).

With one exception (SVR #241), the option of using a stand-alone "locations impacted" list in warnings was employed rather than a "pathcast" containing times of arrival for key locations.

NWS Policy[8] allows the option of choosing a "locations impacted" list or a "pathcast" in severe weather warnings and statements (note the "pathcast" option, when used, is always followed by a shorter "other locations impacted" statement). The choice is left to forecaster discretion with basis in local office policy.

[7] Software used by NWS forecasters to generate short-fused warning products

[8] https://www.nws.noaa.gov/directives/sym/pd01005011curr.pdf

There are positives and negatives associated with the use of both "pathcasts" and "locations impacted". There is also debate internally and externally concerning the best approach. For example, the NWS Mother's Day Weekend Tornado in Oklahoma and Missouri, May 10, 2008 Service Assessment[9] found issues with the use of a "pathcast" in a tornado event in that the warning "pathcast" was not well-aligned with the actual path of the tornado. The misalignment resulted in some confusion among the emergency management community over the polygon threat area. This eventually led to a recommendation which discouraged, but did not ban, the use of "pathcasts' in NWS warnings. As such, forecasters in general tend to favor the use of a "locations impacted" list in their warnings and statements. This is seen in practice at NWS Springfield and was confirmed in staff interviews.

6. SVR #243 "Locations Impacted" list… excerpt

* Locations impacted include...

Branson...	**Lake Taneycomo...**
Table Rock Lake...	Bull Shoals Lake...
Roaring River State Park...	**Table Rock State Park**...
Hollister...	Cassville...
Silver Dollar City...	Kimberling City...
Forsyth...	Merriam Woods...
Shell Knob...	Kissee Mills...
Purdy...	Reeds Spring...
Seligman...	Rockaway Beach...
Exeter...	Wheaton...

Many, but not all, of those forecasters interviewed expressed some concern with the general accuracy of "pathcasts" and the potential negative impact of slight variance in arrival times. Alternately, external core partners, such as emergency managers and media, were less concerned with degrees of precision and recognized there were inherent "arrival windows" associated with "pathcasts". Some media are well-accustomed to "pathcasts" with their own display software.

Stating locations to be impacted or arrival times within the text of a warning can be important for effectively communicating short-fused hazard risk to vulnerable outdoor populations. Furthermore, locations may include outdoor venues, highway markers, state and county parks, public lakes, beaches, etc. In the case of SVR #243, Table Rock Lake and Table Rock State Park were included in the "locations impacted" list (text box #6).

Best Practice #2: NWS Springfield has been proactive in adding geographical reference points to their AWIPS WarnGenLoc file to include state parks, lakes, beaches, etc. This has improved the ability to effectively message short-fused hazard threats to vulnerable outdoor populations in these venues. These geographic references can be used in both "locations impacted" lists and "pathcasts".

To further evaluate the practice of using "pathcasts" and "locations impacted" in the warning text, the SA team interviewed traditional and non-traditional core partners and users. These included campground managers at Table Rock State Park, Stockton State Park, the U.S. Army

[9] https://www.weather.gov/media/publications/assessments/mothers_day09.pdf

Corps of Engineers Visitor Center near Table Rock State Park, Lakeview Campground (private ownership) near Branson, Table Rock State Park Marina (state park contractor), Indian Point Marina (private ownership), and the Missouri State Highway Patrol Marine Unit (Table 1 and Figure 16). Also interviewed were local emergency managers in the Branson/Table Rock Lake area and the media from the Springfield market area. Because of sample size, findings are considered specific to this case with potential for general applicability.

All interviews indicated awareness of the Severe Thunderstorm Warnings for the Springfield, Table Rock Lake and Branson areas on July 19, 2018. The majority that were interviewed were not surprised by the winds gusting ahead of the main line of thunderstorms, and had a basic understanding that strong winds can occur ahead of thunderstorms. Traditional core partners in particular are equipped with knowledge/technology to identify and follow such signatures.

Non-traditional core partners and private entities representing outdoor populations were found to often use radar imagery via smartphone applications (app/s) and/or websites to determine where thunderstorms are located relative to their location. Those that access NWS text warnings may use the "pathcast" within a warning, if available, to help make a determination for time of arrival. If no "pathcast" is available, some users indicated they seek that information from television broadcasts, a smartphone app, website calculations, or use other means to view radar information and make their own rough estimates. To illustrate from July 19, 2018, just prior to the 600 pm Duck Boat tour the RTDB staff reviewed weather radar and attempted an assessment of the expected timing of the derecho (source DOJ). Additionally, from 625 pm to 627 pm, the RTDB staff also reviewed radar information just prior to SD7 leaving for the scheduled 630 pm tour. It is not known if a self-assessment of storm timing was made at this time.

NWS has an opportunity to address these concerns in products and services by appropriately providing the best information the agency can with respect to time of arrival for weather hazards. Many of those interviewed, especially those that keep a high awareness of weather information, generally had prescribed actions to take well before impactful weather was expected to affect their location. This "need to know in advance" can be an important aspect of risk response for these user groups.

Finding #2: Respondents to interviews indicated that a majority of core partners and their constituents, including those representing vulnerable outdoor populations, expressed a desire for arrival times of impending significant weather to assist in proper risk assessments and safety decisions. In the absence of information on arrival times, some in these populations may seek this information from additional sources or make their own estimate of arrival time.

Recommendation #2: To more completely inform core partners, NWS offices are encouraged to more frequently use the WarnGen "pathcast" options along with an "other locations impacted" list - especially for situations with relatively steady-state storm behavior.

Finding #3: In situations where "pathcasts" are deemed inappropriate or there is low confidence in accuracy, many core partners suggested organizing the "locations impacted" list to match the chronological progression of locations in the warning.

Recommendation #3: The NWS should re-program WarnGen to organize the sequence of "other locations impacted" in a chronological list per the storm's progression.

While many cases can be effectively covered with a "pathcast" option and an "other locations impacted" list, there are situations that may better lend themselves to a stand-alone "locations impacted" option. These include certain multicell or pulse type severe thunderstorms that may present more uncertainty or non-linear variability in storm movements.

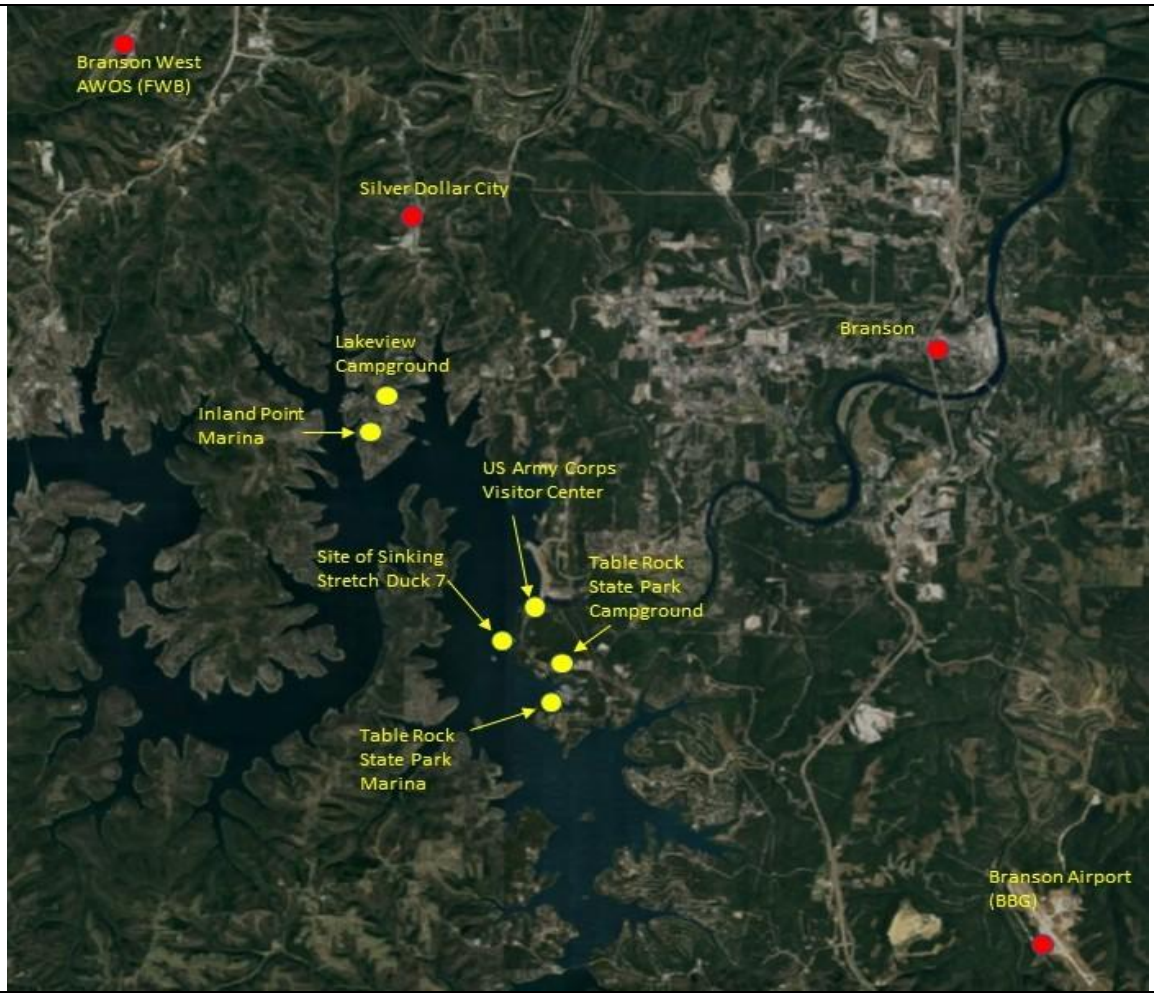

Figure 18: Map of pertinent locations around Table Rock Lake. Not shown – Stockton SP, MO State Highway Patrol Marine and Communication Units.

However, in the particular case of July 19, 2018, where a fairly well-defined, fast-moving serial derecho was impacting a large area, employing "pathcasts" with appropriately drawn polygons can often be the choice. A certain amount of care is required to execute an accurate "pathcast" in

any situation, and this should be incorporated into WFO training and practice plans. The July 19, 2018, case provides some examples of situational attention that could have aided decision-making via the "pathcast" options.

As mentioned, the increasing forward speed of the bowing line segment in SVR #241 was not communicated using a follow-up SVS for that warning. Because movement quickly increased from 55 mph to 65 mph after SVR #241 was issued at 545 pm, there was an immediate negative impact on the "pathcast" employed in that part of the original warning. This resulted in some downstream arrival times in the northeast portion of that polygon warning to be as much as 10 minutes late. This is a case where a timely SVS follow-up 10 minutes into the warning could have provided an accurate update to the time of arrivals listed in the warning "pathcast".

In SVR #243, the opposite issue exists. The actual movement of the gust front was southeast (veering slightly to toward the south) at approximately 58 mph when the warning was issued at 632 pm. Movement then slowed to roughly 47 mph by the time the gust front reached the site of the SD7 accident at 700 pm. This particular warning did not utilize a "pathcast" in real time, nor was there a follow-up SVS to the warning until after the gust front passed the site of the SD7 accident. For this example, the SA Team decided to reconstruct the warning process to view the "pathcast" option.

Following are three examples of how a "pathcast" may have been constructed with SVR #243. The first utilizes a polyline with two endpoints/vertices to designate the location of the gust front. Note the polyline in Figure 19 (identical to the two vertex polyline used in real-time) roughly coincides with the leading edge of the gust front but is not a perfect match because of the shape of the gust front. This lack of a match may have also contributed to an initially slower than actual movement noted in the SVR #243 warning text (50 mph versus 58 mph).

In the warning text excerpt associated with the first example (text box #7), there are only three locations listed in the "pathcast", and an additional ten locations in the "other locations impacted" section. Key locations such as Branson, Table Rock State Park, and Silver Dollar City are omitted from the mock-up warning. This is because WarnGen keys on the polyline vertices when calculating arrival times. Thus, unfortunately, only locations near the endpoints of the polyline are listed in the "pathcast" while important locations in the middle of the polygon centered on the calculated path are omitted.

In the second example (Figure 20), the polyline contains three vertices (including the endpoints) and is a better fit for the radar fine line. The movement of the gust front at the outset of the warning is correctly set to 58 mph. The warning text excerpt (text box #8), in contrast to the first example, lists eighteen locations in the "pathcast" and an additional 10 in the "other locations impacted" section. This is the result of adding a single vertex point in the middle of the polyline, capturing a much greater number of affected locations in the "pathcast". Because the forward propagation speed of the gust front has slowed to less than 50 mph by 645 pm, the "pathcast" arrival times are about 5 minutes too soon for the Table Rock State Park location. This is another

example of where a follow-up statement about 15 minutes into the warning could have provided important updated information on gust front arrival times. To illustrate, a mock-up of a Severe Weather Statement follow-up at 645 pm was created with WarnGen and is shown in Figure 21 and text box #9. Even with the decelerating gust front, the computed arrival times in this example are nearly an exact match with the observed arrival times at the point of the SD7 accident - up to 15 minutes in advance.

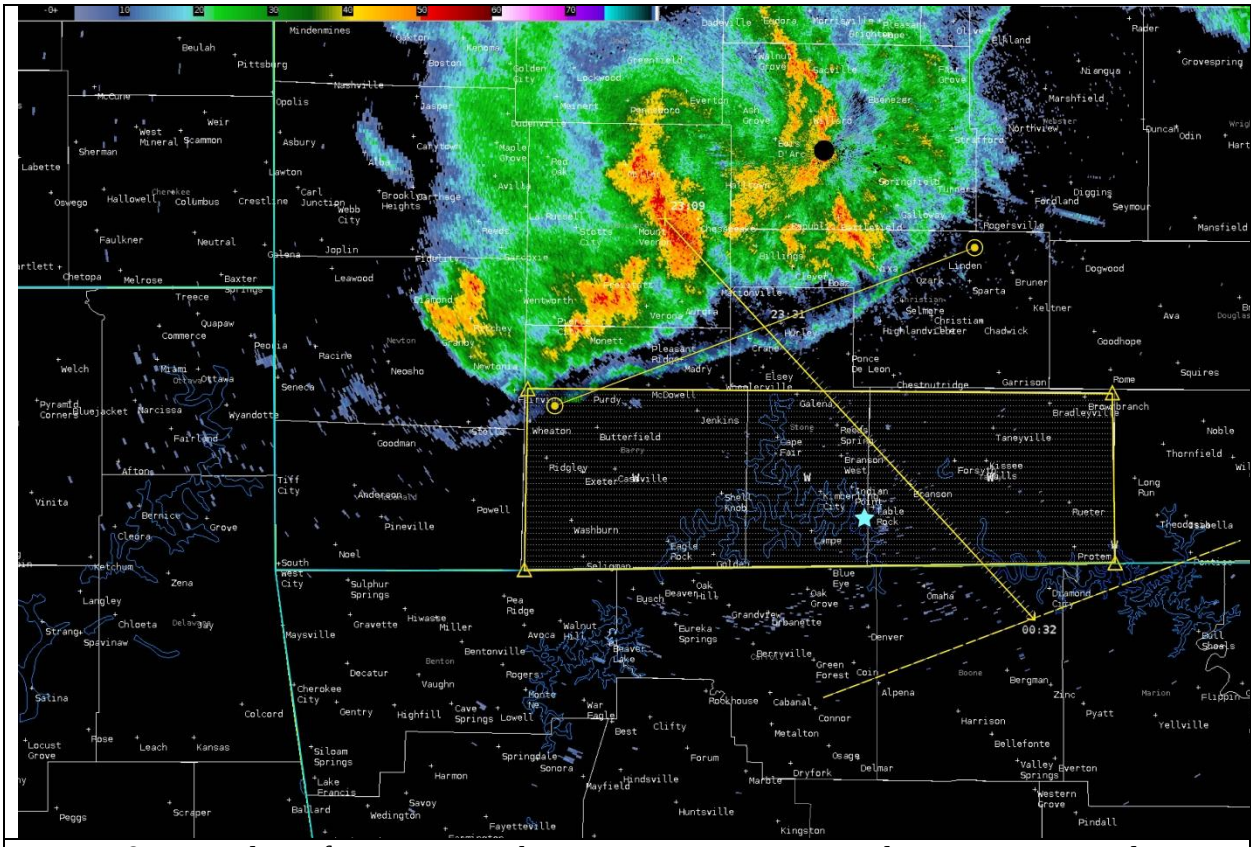

Figure 19: Example 1 of Warngen mock-up using exact vertices and storm motion used in real-time for SVR #243

7. Mock-up of Warngen pathcast option for SVR#243 for the 2 vertex polyline used by WFO SGF -Excerpt

* THIS IS A TEST MESSAGE. Severe thunderstorms will be near...

Washburn around 640 PM CDT.
Roaring River State Park around 645 PM CDT.
Table Rock Lake around 700 PM CDT.

Other locations impacted by these severe thunderstorms include

Emerald Beach, Powersite, Kirbyville, Protem, Chain-O-Lakes, Ridgley, Golden, Kissee Mills, Shell Knob and Cape Fair.

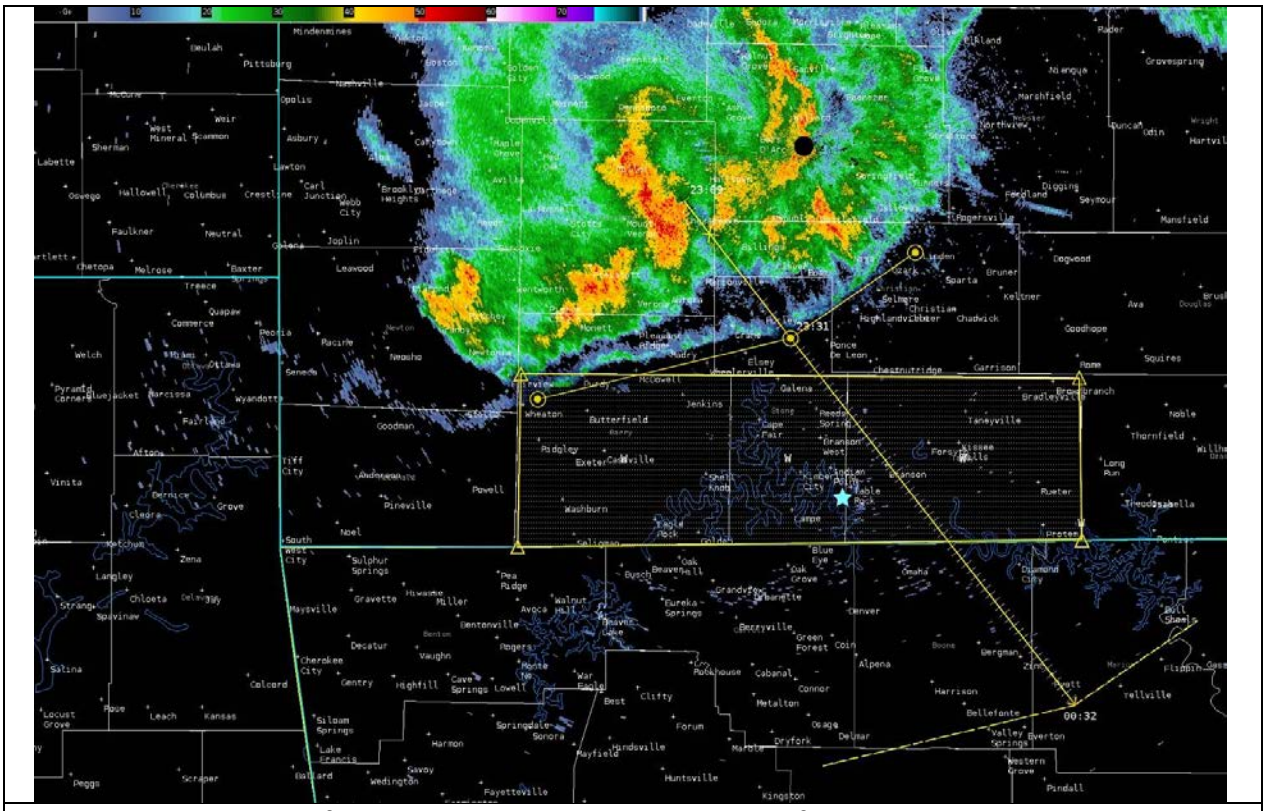

Figure 20: Example 2 of Warngen mock-up using 3 vertices for SVR #243.

8. Mock-up of Warngen pathcast option for SVR#243 for a 3 vertex polyline -Excerpt

* THIS IS A TEST MESSAGE. Severe thunderstorms will be near...

Galena around 635 PM CDT.
Reeds Spring around 640 PM CDT.
Roaring River State Park, Cassville, Branson West and Washburn around 645 PM CDT.
Silver Dollar City, Merriam Woods, Seligman, Rockaway Beach and Indian Point around 650 PM CDT.
Branson, Table Rock State Park, Lake Taneycomo, Forsyth and Hollister around 655 PM CDT.
Bull Shoals Lake around 700 PM CDT.
Table Rock Lake around 705 PM CDT.

Other locations impacted by these severe thunderstorms include

Emerald Beach, Powersite, Kirbyville, Protem, Chain-O-Lakes, Ridgley,Golden, Kissee Mills, Shell Knob and Cape Fair.

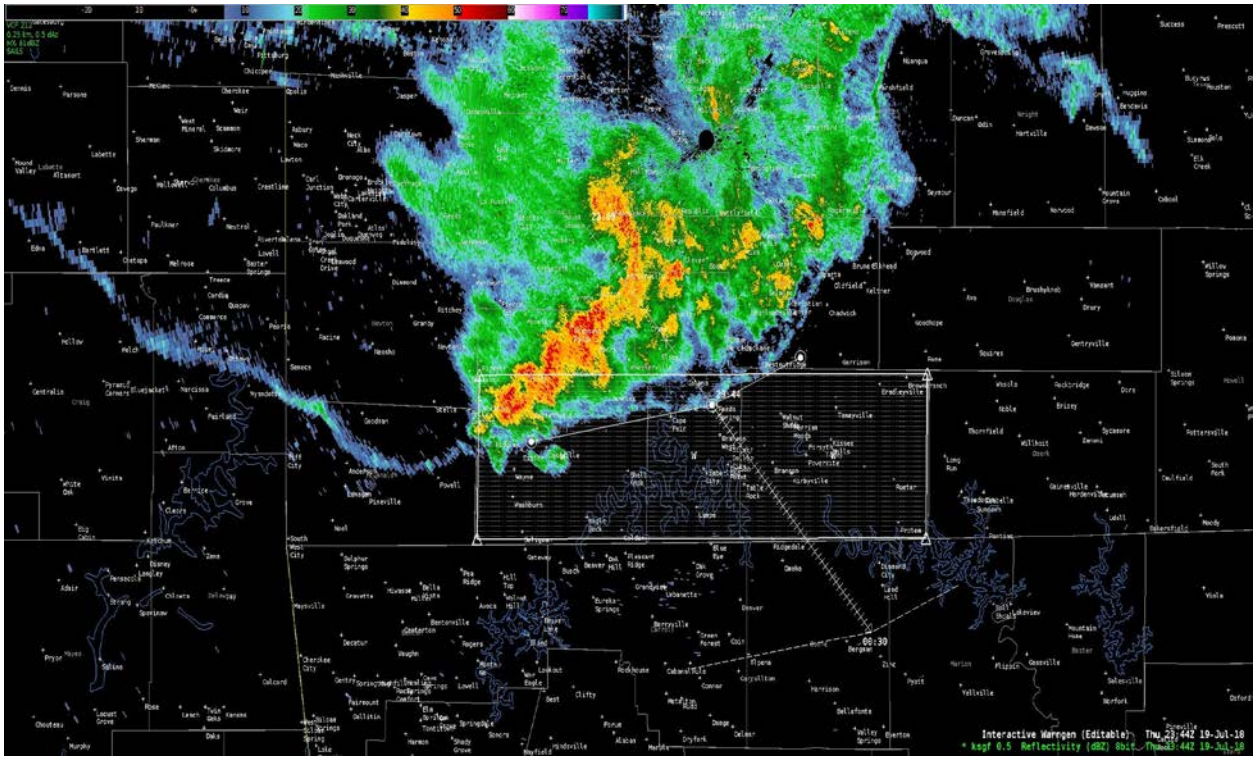

Figure 21: Example 3 Warngen mock-up using 3 vertices for a SVR #243 follow-up statement.

9. Mock-up of Warngen pathcast for a SVR#243 follow-up statement -Excerpt

* THIS IS A TEST MESSAGE. Severe thunderstorms will be near...

Kimberling City, Merriam Woods, Reeds Spring and Branson West around 650 PM CDT.
Lake Taneycomo, Silver Dollar City, Forsyth, Indian Point, and Taneyville around 655 PM CDT.
Branson, Table Rock State Park, Bull Shoals Lake, Hollister and Rockaway Beach around 700 PM CDT.
Table Rock Lake around 710 PM CDT.

Other locations impacted by these severe thunderstorms include

Emerald Beach, Powersite, Kirbyville, Protem, Chain-O-Lakes, Ridgley,Golden, Kissee Mills, Shell Knob and Cape Fair.

In all of the "pathcast" mock-up examples (text boxes #7, #8, #9), there are issues with the arrival times for the large lakes (Table Rock Lake and Bull Shoals Lake). For example, what part of Table Rock Lake does the arrival time actually apply to? This problem is due to the large geographical extent of the AWIPS shape-file used to describe those lakes. When a single shape-file is applied in WarnGen for such large geographical features, arrival times often cannot be reconciled to account for the entirety of the large lake/system. In worst-case scenarios, if not

carefully accounted for, time of arrival may be rendered nearly meaningless for these features. For this reason, it is best to place those in the "other locations impacted" section of the warning after the "pathcast". Similar issues can occur for large cities, but these are more likely resolvable in WarnGen through geographical partitioning of the city.

Finding #4: The potential benefits of a well-constructed "pathcast" can be significant with respect to providing partners and the public with effective risk assessment and communication. Proper configuration and operation of warning generation software (WarnGen) must be employed to reasonably create and maintain accurate and updated arrival times and locations impacted.

Recommendation #4: For warnings and follow-up statements with "pathcast" options, local WarnGen files should be configured to capture a fairly wide downstream area along vertex paths to capture all appropriate cities and other locations of interest. WarnGen shape-file configurations for large cities or large lakes should also be either geographically partitioned to achieve accurate times of arrival, or strictly used only in the "other locations impacted" section.

Section 2.3-2 Polygons

The SA team found that many offices across the NWS are sometimes inconsistent with their methodologies for drawing warning polygons. Polygons from several midwest offices, on July 19, 2018, revealed issues with overlapping polygons, polygons that were either too small or too large, and polygons that emphasize event meteorology at the expense of customer needs and end user jurisdictions. In some instances, polygons for several warnings sometimes resembled "plumes" rather than traditional polygons. While certainly within established rules for warning polygons, there are drawbacks to these approaches. First, certain polygon shapes can make drawing for adjacent downstream warnings somewhat awkward, especially while trying to avoid overlapping warnings. Second, in this event there are jurisdictions (counties) bisected by polygon edges that eventually required two warnings, when just one would have sufficed for a particular jurisdiction. In the example shown in Figure 12, the downstream edge of the polygon for SVR #241 bisected the city of Springfield, eventually requiring SVR#242 to also cover the city. A more service-oriented approach would have been to extend the downstream boundary of SVR #241 through much of Greene County, MO, to avoid multiple warnings for a highly populated jurisdiction and to use frequent follow-up statements to trim during the progression of the warning.

Finding #5: Many NWS offices have inconsistent methodologies for drawing warning polygons, some of which may have drawbacks for external customers, such as emergency managers.

Recommendation #5: To improve polygon practices, the Central Region Tornado Warning Improvement Project (TWIP) should provide supplemental curriculum for Storm-Based Warnings training, which emphasizes a service-based philosophy to drawing warning polygons.

This training should expand on recommended polygon strategies in existing WDTD Training modules[10], and include training on "pathcast" execution within WarnGen.

Section 2.3-3 Impact-Based Warning (IBW) Concepts

NWS Severe Thunderstorm Warnings currently contain most Impact-Based Warning (IBW) concepts for risk communication including storm locations, storm movement, hazard magnitude in terms of expected maximum wind speed/hail size, descriptions of general hazard impacts, and advice for precautionary actions. Unlike Tornado Warnings, Severe Thunderstorm Warnings do not contain threat tiers (a base tier and elevated tier) and associated damage threat tags at the bottom of the warning. However, it is understood that similar tiered warnings with damage threat tags will be incorporated into the Severe Thunderstorm Warning product in the near future. Therefore, a specific recommendation will not be made. Those interviewed among core partners and private entities were generally supportive of IBW concepts in NWS short-fused convective warnings.

Importantly, throughout the interview process there was decidedly mixed interest or knowledge of follow-up Severe Weather Statements (SVS) to initial Severe Thunderstorm and Tornado Warnings. The most weather-savvy of the interviewees (media and emergency managers) knew of the SVS and the information that it contained. In particular, the media often utilizes the SVS in broadcast product crawls. However, many non-traditional partners and outdoor patrons had limited knowledge of the SVS or had difficulty finding or tracking SVS issuances in real-time for more informed decisions.

As noted elsewhere in Section 2.3, under-utilization of the follow-up statement can be an important shortcoming in the risk communication process. NWS policy is to use the follow-up statement as a means for updating information in the original warning at least once during the valid time of a SVR or TOR. NWS policy states, "During significant severe thunderstorm and tornado events, WFOs should issue more frequent (SVS) updates to keep the public informed of the progression of dangerous storms. This includes substantive changes to storm intensity and/or potential impacts (e.g. increase in hail size from quarter-sized to golf ball sized, decrease in estimated wind gusts from 80 mph to 60 mph, radar-indicated tornado to a tornado confirmed by a visual report from a credible source)…"[11]. In the example case of tiered Tornado Warnings, the follow-up statement may contain an important change in the attitude of the warning from a base tier to an elevated tier as indicated by a "CONSIDERABLE" or "CATASTROPHIC" damage threat tag.

While the SVR (or TOR) is *actively* disseminated and received through the use of alerting mechanisms, the SVS is more *passively* received owing to the lack of an alerting mechanism associated with the product. The lack of such protocols may allow the issuance of a SVS containing important, upgraded information to go unnoticed. The SVS, in its current form, too

[10] https://training.weather.gov/wdtd/courses/SOTM/001-Nov14/player.html

[11] https://www.nws.noaa.gov/directives/sym/pd01005011curr.pdf

often does not sufficiently meet the needs of external partners and customers as it pertains to communication of risk during warning progression. However, there are other approaches that may increase the efficacy of follow-up statements for original warnings.

Recognizing this, one sophisticated marina manager independently suggested new information for an updated Severe Thunderstorm Warning should use the same PIL and VTEC number to ensure updated information gets the same distribution, alerting, and urgency associated with the original warning. This idea was presented to the local traditional core media and emergency management partners who almost unanimously supported the concept.

Finding #6: Updated severe weather information after the initial issuance of a Severe Thunderstorm Warning (or Tornado Warning) is often under-utilized by both decision-makers and the public due to the lack of visibility and lack of notification protocols associated with the Severe Weather Statement as the updating mechanism. Instead of Severe Weather Statements, traditional core partners interviewed supported using an updated Severe Thunderstorm Warning (or Tornado Warning) as the update mechanism for original warnings.

Recommendation #6: To improve the efficacy of updates for original Severe Thunderstorm Warnings (and Tornado Warnings), NWS should consider a national initiative to phase out the use of Severe Weather Statements in favor of using the original warning PIL. Such a change would ensure both higher visibility for updated information and that important storm updates provide needed alerting protocols for escalating or changing hazard threats during warning progressions.

There are several advantages to this approach within the short-fused warning framework:

a) Elimination of the SVS product for short-fused warnings,
b) Simplification and standardization of risk communication by utilizing a single PIL and Event Tracking Number (ETN) throughout the warning progression (mirroring other NWS service programs),
c) Assures a more robust notification/alerting protocol and increased product visibility by using the same PIL for follow-ups as in the original warning,
d) With changes to process IBW tags within NWRWAVES[12], enables full Emergency Alert System (EAS) alerting capability and visibility for follow-ups that upgrade the attitude of a warning (e.g. an upgrade to a "CONSIDERABLE" damage threat tag).

Such a change could be implemented without undue complication, but would require adjustments by some vendors (those that key on PILs to activate EAS) to switch to VTEC-based EAS alert activation. This adjustment would be needed to preclude unnecessary EAS activations for all follow-up SVRs that contain the VTEC "CON" Action Code (for continuations).

[12] An internal NWS formatting function designed for NOAA All-Hazards Radio (NWR) broadcasts and alerts.

Section 3: Public and Partner Response

People engaging in recreation, entertainment, leisure, or other outdoor activities make up a significant vulnerable population to the hazards of severe and non-severe thunderstorms. Safety campaigns like "When Thunder Roars, Go Indoors!" have helped reduce the average lightning fatalities from a 10-year average of 44 deaths per year (1998-2007) to the latest 10-year average of 27 deaths per year (2008-2017). Yet, during the same time periods, wind fatalities, which comprise both thunderstorm and non-thunderstorm winds, have increased by 23%. Importantly, almost 70% of thunderstorm wind fatalities are associated with people boating, camping, working outdoors, or in a vehicle or trailer.

Given the large number of outdoor recreational venues, it is important to examine how outdoor populations receive, interpret, and respond to information concerning severe thunderstorm threats. Individual campers and boaters are a subset of the general public; and though they may be affected by weather more often, this group has a wide range of weather awareness and understanding, or "weather-savviness". The SA team conducted roughly two dozen interviews addressing NWS services for these groups. After interviewing many in the Table Rock Lake area associated with outdoor recreation, the team increased the sample size of interviews by expanding outside of the state of Missouri. The interviewees represented four states and included federal, state, and local (private) campground operators, private and public marina operators/boating interests, and individual campers. Additional surveys are underway post-SA to further increase sample sizes for these groups.

Finding #7: The Service Assessment team attempted to capture a wider range of susceptible outdoor populations from their location (Missouri, Michigan, Illinois, and Wyoming) to their outdoor recreation activity. However, it should not be assumed that this Service Assessment represents a homogeneous population within the country or any one region; nor does it represent a sufficiently large sample size.

Recommendation #7: The NWS should continue to study how vulnerable outdoor populations receive weather information, how they respond to all thunderstorm threats, and how to best reach those most at-risk populations. NWS Weather Forecast Offices should regularly network and collaborate with local partners and users to understand their own local vulnerable outdoor populations.

Section 3.1 - Technology, Dissemination, and Interpretation Challenges

Once situational awareness of a potential severe thunderstorm threat is attained, a majority of those interviewed indicated radar imagery was the most favored method of following thunderstorm evolution. In the special case of non-traditional partners and private entities

representing vulnerable outdoor populations, use of smartphone apps for displaying radar imagery were most popular for determining where thunderstorms were located and, for some, estimating if thunderstorms would affect their locations in the future.

Several also stated the importance of monitoring local storm reports and upstream severe weather warnings. However, there was little, if any, social media sources used to gather that same weather information. NOAA All Hazards Weather Radio (NWR) was used modestly and was the second most likely weather information source for respondents. Broadcast media was a tertiary weather information resource for most outdoor recreation users and locations. Southwest Missouri interviewees also made repeated references to a local media outlet popular for their weather information. Those interviewed did not feel the NWS as a whole was over-warning or under-warning severe thunderstorm events.

The public has increasing amounts of weather data available to them with advancements of internet and smartphone technology. This availability has likely increased weather and warning awareness in outdoor populations. However, it may also encourage self-interpretation of easily available data, which could reinforce behaviors that delay sheltering. For example, seeking further confirmation of threat when severe weather warnings are received can delay sheltering. Many of those interviewed in campgrounds stated they would indeed seek confirmation before finding shelter.

There are limitations to many smartphone apps that smooth or filter low reflectivity values from their radar display making “fine lines” difficult to discern - especially when the leading edge of thunderstorm winds are not coincident with or near reflectivity cores. Also, untrained users may not properly recognize or understand that high winds can be associated with gust fronts/fine lines; and incorrect estimates of speed of movement can result in incorrect arrival time estimates.

Despite these weaknesses, use of smartphone apps and self-interpretation of radar imagery by non-traditional partner groups, and perhaps even the outdoor public, is likely a permanent reality. Additionally, there appears to be an increasing level (and range) of “weather-savviness” among these groups. For example, interviews indicate there is a basic understanding of general weather terminology. Among most campers interviewed, there was an understanding of the differences between a watch and a warning, as well as their perceived threats. Most perceived threat from a watch as “moderate”, a Severe Thunderstorm Warning as “high”, and a Tornado Warning as “very high”. Although the verbal response to perceived threats was arguably rational with regards to Severe Thunderstorm Warning versus a Tornado Warning, the implied physical response was disproportionate. Susceptible outdoor populations also understood that a Severe Thunderstorm Warning included some combination of “high winds” and/or “large hail,” although there were some misconceptions about “heavy rain” and “lightning” as criterion.

Furthermore, some interviews noted use of the magnitude of the wind and hail hazards listed in the tags at the bottom of the Severe Thunderstorm Warning. This additional information did not appear to change any action, but did seem to affect the urgency of those actions. This suggests WEA alerts for Severe Thunderstorm Warnings for higher threshold events are appropriate and may be beneficial.

Finding #8: Vulnerable outdoor populations and those that manage outdoor recreation resources increasingly rely on mobile smartphones to obtain weather and warning information. These most susceptible populations would benefit from a national WEA alerting protocol for Severe Thunderstorm Warnings that would consistently reach mobile platforms.

Recommendation #8: NWS should continue to pursue alerting Severe Thunderstorm Warnings through the WEA system. Furthermore, the NWS should analyze the appropriate wind threshold to trigger a WEA alert for a Severe Thunderstorm Warning that could help reduce the loss of life and number of injuries specifically in vulnerable outdoor populations. WEA Alert thresholds for Severe Thunderstorm Warnings for high winds should have some consistency with WEA Alerts for Tornado Warnings and Hurricane Warnings. Ideally, this threshold should be high enough to prevent excessive WEA Alerts, but low enough to provide alerts roughly equivalent to the level of EF0 tornadoes. A threshold of 80 mph is suggested by this Service Assessment.

Section 3.2 - Response and Decision Support Opportunities

Interviews with the marina operators in the Table Rock Lake area offered insights into warning response and lead times for vulnerable outdoor populations. The operators are weather savvy with over 50-years of experience on the lake between the two of them. They used a variety of means to obtain weather information, most prominently smartphone apps but also a few websites, including NWS web sites. The marina operators also focused on checking radar to see where storms were, and how fast they were moving to estimate how quickly patrons needed to return to the marina. They were also very concerned about their patrons' safety and took various steps to ensure patrons were weather aware - such as promoting weather safety, giving a "weather briefing" before renting a boat, or even calling watercraft renters when a warning was issued.

Some individuals with interests on inland waterways and campgrounds noted the current Severe Thunderstorm Warning wind threshold of 50 knots (58 mph) was too high for necessary actions to be taken by susceptible watercraft, recreational vehicles, tents, etc. The reality for many boaters, campers, and all outdoor populations is that taking safety actions for any thunderstorm is often necessary to reduce vulnerability. Most of the interviewees in these groups had little knowledge of NWS products that conveyed information on sub-severe thunderstorms such as Special Weather Statements/Significant Weather Advisories (SPS) or the "Graphicast".

Instead of relying solely on public products, the NWS should consider using IDSS principles to reach persons in vulnerable outdoor positions in a more direct way. This would require targeted communication of real-time weather information to emergency managers and operators of federal, state, and local government parks, marinas, and campground facilities. This would also

require pre-season educational safety campaigns and increased relationship-building with these partners. This concept is discussed further in Section 4.

These IDSS principles apply to this case given the unusual presentation of the impending threat. At Table Rock Lake, the closest cloud-to-ground strike in the 30-minutes before the onset of severe winds was 13.1 miles away and the closest in-cloud flash was 10.9 miles away (see Appendix 1). It is possible that outdoor populations in the Table Rock Lake and Branson areas did not receive usual visual or audible cues from thunderstorms prior to severe winds arriving at their location.

Finding #9: Vulnerable outdoor populations are threatened, to some degree, by all thunderstorm hazards. When these susceptible persons seek shelter for sub-severe thunderstorms, they also reduce their risk from severe thunderstorm threats. Many of these outdoor populations may also receive alerts and/or instructions from non-NWS sources.

Recommendation #9: The NWS should increase outreach and education to groups representing vulnerable outdoor populations where risks are much higher from all thunderstorm hazards. This outreach should use existing programs such as StormReady, StormReady Supporters, Weather-Ready Nation (WRN) Ambassadors, Integrated Warning Teams (IWT), and public/private working groups that bring together government sector and private sector groups responsible for vulnerable outdoor populations. Outreach should promote a wide spectrum of weather information - including basic radar interpretation, as well as sub-severe thunderstorm products (Advisories, SPSs/Graphicasts and NWS Social Media) and interpretive services from both NWS and private meteorologists. For lakes and waterways with significant recreational boating, examples of groups to which outreach should be provided include the Passenger Vessel Association and Harbor Safety Committees.

Section 4: Partner Interactions and Severe Weather Preparedness

NWS Springfield's focus on relationship-building with traditional and non-traditional government and media core partners (Table 1) has resulted in a very high-level of trust in NWS products and services. Many of these core partner relationships were fostered and nurtured over many years by office leadership and operational staff alike. An emergency manager indicated that, "WFO Springfield has been so good dealing with emergency management, we couldn't ask for anything more. The information was very clear, timely, and concise. They are always willing to answer questions and they did everything that they could possibly do." Without exception, core partners expressed appreciation and support for the service provided by NWS Springfield.

This long culture of relationship-building has carried over to office IDSS functions where trust is a cornerstone of success.

Best Practice #3: Positive relationships with core partners are critical for a high-level of trust in NWS products and services. To enhance and broaden core partner relationships, NWS offices should seek engagement opportunities whenever possible. While partner demands of NWS services for vulnerable outdoor populations increase, NWS offices need to be able to meet these by employing a whole office concept and leveraging "blue-sky day"[13] opportunities.

Communication between the NWS and its core partners is essential in an effective warning system. NWS Springfield was very active in utilizing the NWSChat platform with its core partners during the Table Rock Lake incident. In addition, core partners indicated that Public Service Answering Points (PSAPs)[14] were active in relaying siren activation information via the NWSChat platform. This resulted in a higher level of awareness and yielded consistent messaging among all core partners involved in the warning system.

Best Practice #4: NWSChat is relied upon by NWS Springfield and core partners as an effective warning dissemination and communication method. Where none or limited direct engagement exists, NWS offices are encouraged to recruit PSAPs to utilize NWSChat as a means to receive and relay pertinent information during warning events. NWS offices should strive to respond proactively and timely to every comment provided by core partners during severe weather events**.**

Additionally, NWS Springfield has made concerted efforts to foster working relationships with the Missouri State Parks system. The Missouri State Parks in southwest Missouri are included in NWS Springfield's IWT, have attended numerous local IWT meetings to enhance that relationship, and participated in NWS Springfield "After Action Meetings". Those that were most weather-prepared had active relationships with the NWS. These campgrounds and parks had an organized hazardous weather plan that included posted weather safety information, newer built restrooms and shower houses that could serve as shelters, posted forecast information, and weather warning dissemination plans. However, other campgrounds had little to no plan in place to deal with hazardous weather.

[13] "Blue-sky days" in NWS Central Region offices are quiet weather days which are used for training, planning exercises, community outreach, or partner meetings.

[14] "PSAPs are a call center responsible for answering calls to an emergency telephone number for police, firefighting and ambulance services. A PSAP facility runs 24 hours a day, dispatching emergency services or passing 911 calls on to public or private safety agencies. Trained operators are responsible for dispatching the emergency services. https://www.techopedia.com/definition/2969/public-safety-answering-point

Furthermore, active relationships can easily be leveraged into strategies using "Event-Ready"[15] concepts. NWS Chicago, in collaboration with the DuPage County, Illinois Office of Homeland Security and Emergency Management, and other nearby NWS offices, has developed a process to arm decision-makers with knowledge, skills, and tools they can combine with NWS support to ensure their readiness for weather-related threats. This includes placing an emphasis on developing hazardous weather action plans, designating liaisons to monitor weather information, and interacting with NWS to assist in the execution of those plans. A step-by-step process guides users through key services available from the NWS, strengthens their weather knowledge, and encourages communication with the local NWS office.

Finding #10: Through their extensive relationships, NWS Springfield already utilizes many "Event-Ready" concepts for vulnerable outdoor populations. These include holding IWTs with land/water management agencies for planning and training purposes, and then assisting those agencies with significant weather monitoring through NWSChat and phone calls.

Recommendation #10: NWS offices should continue to work with their core partners to ensure weather readiness of vulnerable outdoor populations. Leveraging the concepts learned from collaborations of the "Event Ready" program, this outreach should further build on the basic weather preparedness concepts taught for decades by focus on developing and evaluating hazardous weather response plans. Severe and sub-severe (i.e. lightning) weather threats should be addressed in such plans.

A thorough and continuous monitoring of evolving hazards can lead to more confident and effective decisions regarding the safety of outdoor constituents and patrons. This equips those government sector core partners to play an integral role in NWS provision of IDSS. This is especially true of weather concerns in the short-term. Between the information gleaned from interviews and experiences learned from providing on-site IDSS, the rate at which information leading up to a weather hazard is needed is not steady-state - and can increase significantly in those time frames.

Finding #11: As weather hazards become imminent, the need for more frequent interpretive information rapidly increases. Decision-makers are often seeking information multiple times per day (and sometimes per hour).

Recommendation #11: For government-sector core partners representing vulnerable outdoor populations, the NWS should develop means to provide remote, high-frequency interpretive service during the tactical phase (now through the next 2-3 hours) of thunderstorm/lightning

[15] Event Ready is a Federal Emergency Management Initiative that looks at the best practices and preparedness efforts that go into supporting special events.

events. Information to focus on should include "what, when, and where" information and coverage/intensity trends.

Finally, the Table Rock State Park Marina operator offered his response to the July 19 Table Rock Lake Duck Boat accident. As a preparedness effort he immediately developed an educational tool for all boat/watercraft customers.

Finding #12: Following the accident on Table Rock Lake, the Table Rock State Park Marina operator now affixes a sticker next to the steering wheel on their watercraft that states the following calls to action in case of severe weather:

> **Severe Storm Instructions**
> **L.** Life Jackets on Every Person
> **I.** Immediately exit main lake, drive into back of nearest cove
> **F.** Find shoreline or dock out of the wind: beach or tie boat
> **E.** Exit Boat onto land as soon as possible

Human safety is the Marina's only concern during a Severe Storm. Renters will not be responsible for damage to the boat caused by seeking shelter. Do not race a storm back to the marina; it's safer to find the nearest shoreline or dock.

Recommendation #12: For NWS products that cover large inland lakes, NWS should consider adding a Call-to-Action (CTA) in short-fused convective warnings and Significant Weather Advisories (SPS) that recommend protective actions for vulnerable over-water populations when high winds and lightning threaten.

Section 5: Role of the Private Sector

While the SA was not interested in the internal workings of RTDB operations - there is interest in how the RTDB utilized publicly available weather information prior to the accident as it pertained to the public safety of all entities that use the lake and adjacent parks. Even though this is a private entity, such information would help NWS better evaluate how it communicates information to core government sector partners and the vulnerable outdoor public that may be impacted by life-threatening conditions. To this end, the SA is guided by the following principles regarding provision of IDSS[16]:

● NWS' primary focus is on supporting government partners who share similar mission objectives.

[16] https://www.nws.noaa.gov/directives/sym/pd01024curr.pdf

● NWS will focus on ensuring the safety of the public and particularly vulnerable populations.

● NWS will support disaster management efforts of federal, state, local, tribal, and territorial governments.

● NWS will interact with our partners at the highest level, reaching as many as possible who are potentially in harm's way.

● NWS will be flexible in how we provide IDSS to our partners, keeping in mind that they may also be receiving support from others in the Weather, Water, and Climate Enterprise.

With regard to the SD7 sinking on July 19, 2018, there are no provisions that allow the NWS to directly provide IDSS to a private company such as RTDB or the captain and crew of SD7. This does not preclude private entities from utilizing publicly available information collected or produced by the NWS. Conversely, private sector weather providers are not precluded from providing NWS government sector partners with weather information, even when NWS is providing service to these groups. This is essentially the basis of the "whole community" concept where achieving a "Weather Ready Nation" depends on the entire Weather Enterprise.

Finding #13: Per recently released NWS policy on IDSS, NWS provides IDSS to government sector core partners. However, other user groups increasingly have similar needs for weather services that may exceed NWS capacity and could be provided through the "whole community" concept.

Recommendation #13: To help achieve a Weather Ready Nation, WFOs should use the recently released IDSS Toolkit Engagement Guide for General Partners, to assist in connecting non-core partners with a repository of Decision Support providers within America's Weather, Water and Climate Enterprise. This would serve as a clearinghouse of IDSS capabilities inclusive of all that the Enterprise can collectively provide.

Appendix 1: Additional Science Review

As discussed in the Event Overview, the environment across the Southern Plains and Missouri Valley on July 19, 2018, was conducive to the development of severe thunderstorms. This section will focus more closely on the evolution of the environment and the morphology of the derecho, as well as highlight some of the unique aspects of this event.

Storms initially developed across north central Kansas during the late morning hours and quickly became severe. By midday the storms were moving into an environment that was increasingly favorable for severe weather across eastern Kansas. A Rawinsonde launched by WFO Topeka at 100 PM (Figure A1) indicated that a very unstable airmass was present with 4480 J/kg of Surface-based CAPE (SBCAPE) with no cap in place. Deep layer shear was strong with Effective Shear of 48 knots in deep northwest flow. The vertical wind profile yielded a straight-line hodograph, which is supportive of splitting supercells and linear/bow echo development. The 0-3 km shear of 27 knots was also indicative of an environment favorable for bow echoes.

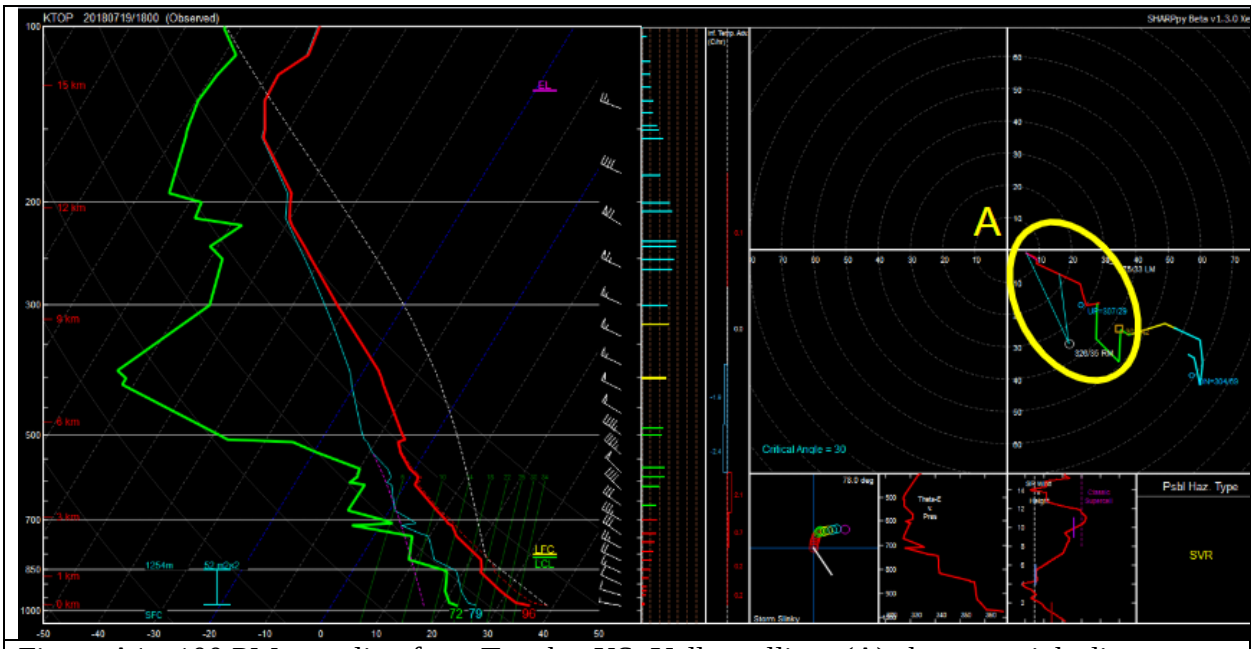

Figure A1 - 100 PM sounding from Topeka, KS. Yellow ellipse (A) shows straight-line hodograph support of splitting supercells and bow echoes.

At 100 PM Storm Prediction Center mesoanalysis graphics indicated that the Effective Bulk Shear across the area from southwest Missouri through east central Kansas was 45-55 knots (Figure A2), which is supportive of severe convection. In addition, Lapse Rates were steepening throughout the afternoon across southwest Missouri, increasing from 6.5°C/km at 100 PM (Figure A3) to 7.5°C/km by 500 PM (Figure A4). In addition, SBCAPE values across southwest Missouri remained between 3000-4500 J/kg through the afternoon while SBCAPE

values lowered and Convective Inhibition (CIN) rose dramatically across central Missouri behind a series of supercells that moved through that area leaving surface-based cold pools in place (Figures A5 and A6).

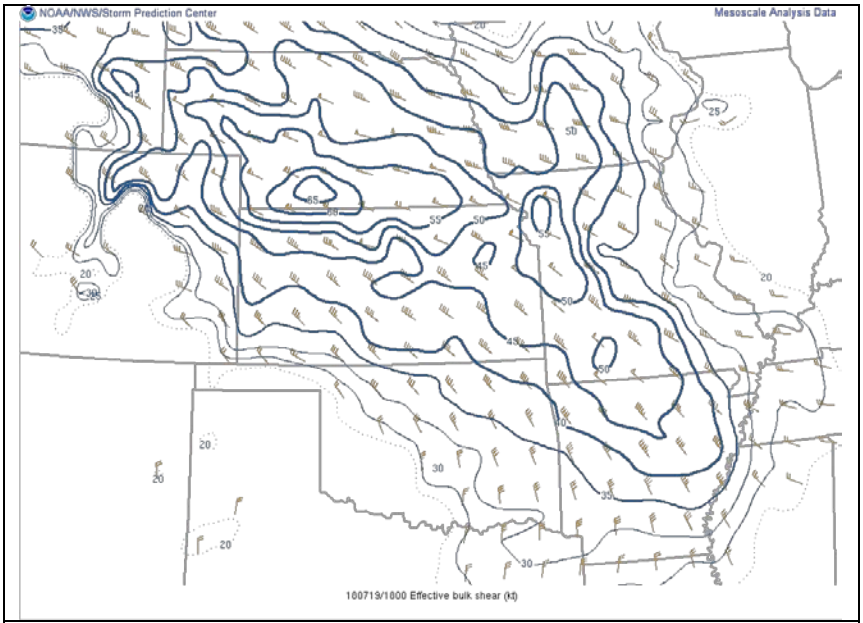

Figure A2 - Effective Bulk Shear (kts) at 100 PM. Image from Storm Prediction Center.

As the line of storms approached the Kansas-Missouri state line around 400 PM CDT it exhibited a tight low-level reflectivity gradient, which is indicative of a well-balanced system with the cold pool aligned with the updraft interface along the leading edge of the outflow (figure A7). Figure A8 provides a volumetric depiction of this and it is clear the cold pool is coincident with the updraft interface at this time. In addition, the Quasi-Linear Convective System (QLCS) had two distinct rear inflow notches (Figure A7) representative of a rear inflow jet and a strong indication of severe criteria winds in surface-based convection.

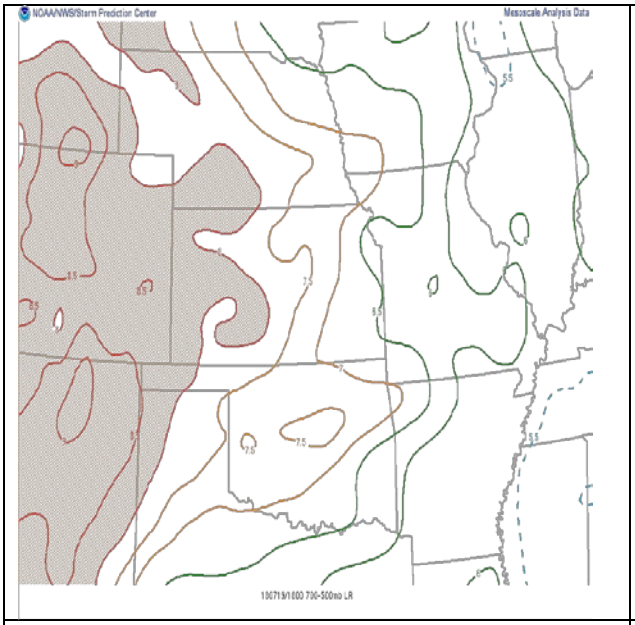

Figure A3 - 700-500 mb Lapse Rates at (C/km) at 100 PM. Image from SPC.

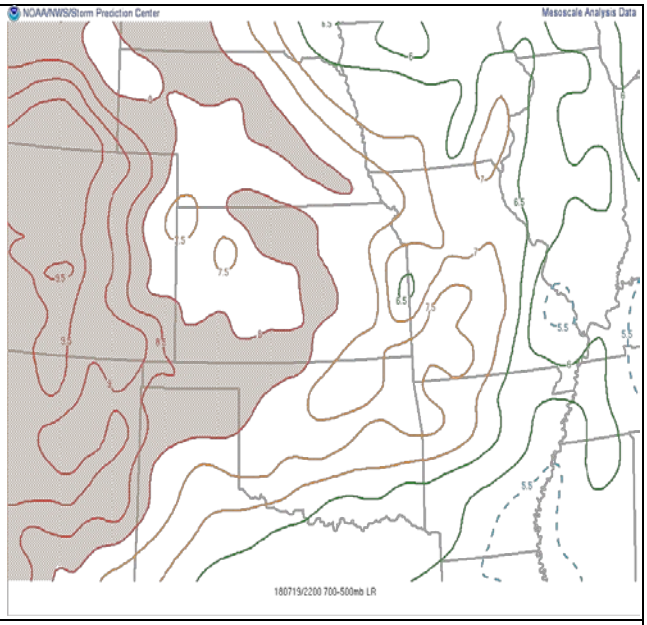

Figure A4 - 700-500 mb Lapse Rates at (C/km) at 500 PM. Image from SPC.

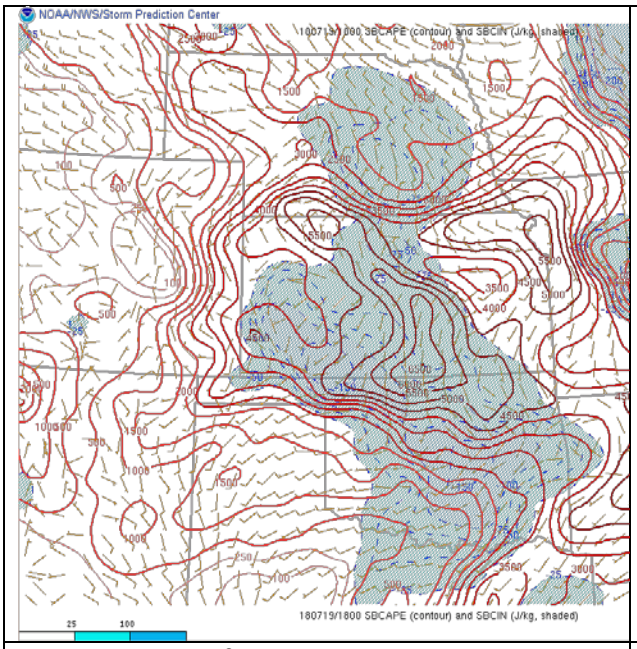

Figure A5 - Surface-based CAPE (J/kg) shown in red contours and Convective Inhibition (J/kg) shown in shading and dashed blue contours at 100 PM. Image from SPC.

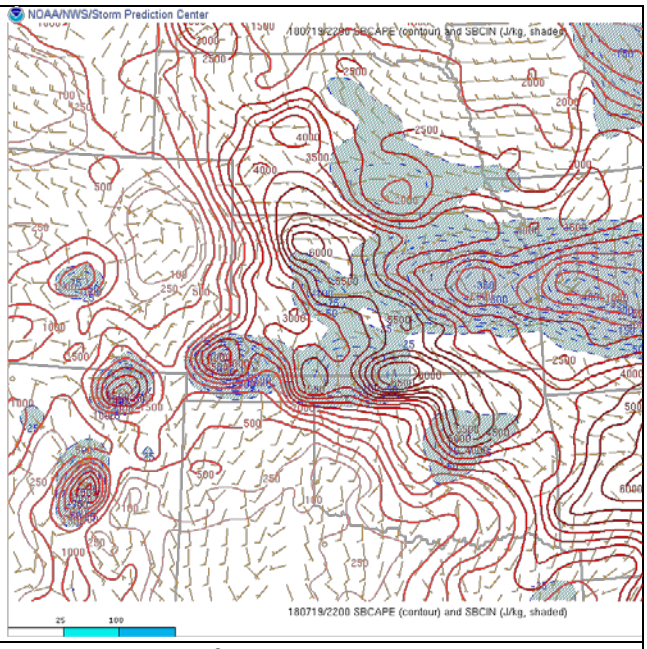

Figure A6 - Surface-based CAPE (J/kg) shown in red contours and Convective Inhibition (J/kg) shown in shading and dashed blue contours at 500 PM. Image from SPC.

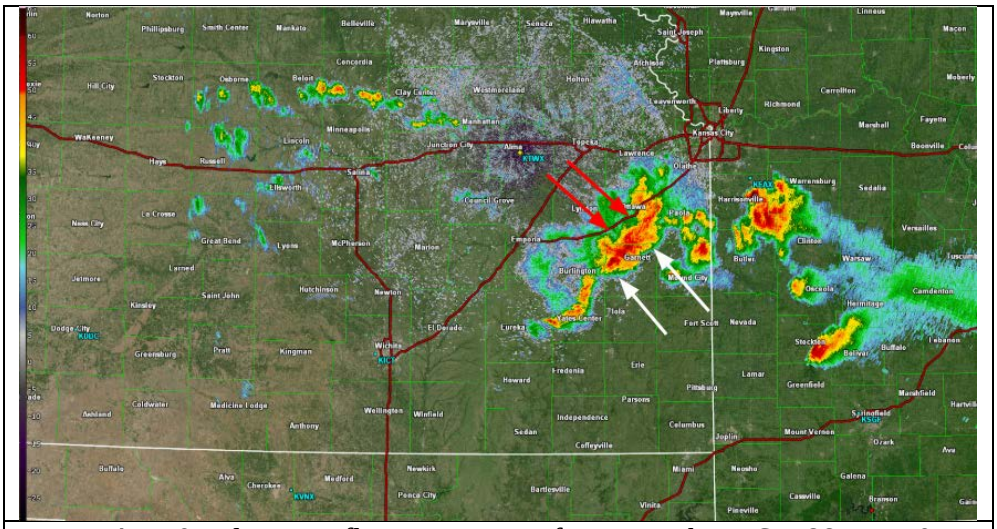

Figure A7 - 0.5 degree reflectivity image from Topeka WSR-88D at 405 PM. Red arrows indicate rear inflow notches and white arrows show the leading edge of the outflow and tight low-level reflectivity gradient. Small red square in the lower right marks the location of the Table Rock Lake State Park Marina.

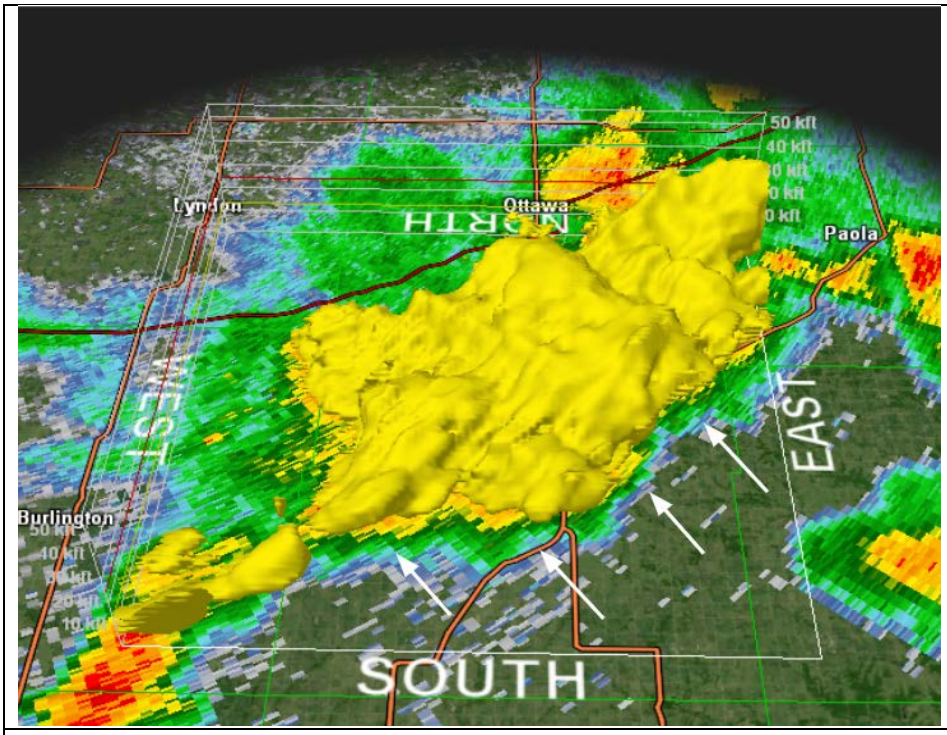

Figure A8 - Volumetric reflectivity image from Topeka WSR-88D at 405 PM. Image highlights 40 dBZ surface. White arrows show the leading edge of the outflow.

As the QLCS moved into west central Missouri it merged with several convective cells and interacted with an environment that was a little less favorable as noted in the minima in mid-level lapse rates (Figure A4). In addition, the storms were moving into a remnant cold pool left behind by a supercell, which was approaching I-44 near Springfield MO at that time (Figure A9). As previously noted, there was an area with significant CIN stretching from east central Kansas into central Missouri. With substantial uncapped SBCAPE south of this region, the QLCS propagated along the SBCAPE and CIN gradient to the southeast (Figure A10).

During this time the QLCS began to become outflow dominant. At 601 PM, the line was showing signs of potential weakening as the reflectivity decreased and linear feature was looking a bit less organized. At this time, the outflow moved well ahead of updraft interface (although still producing severe winds) as the system became quite cold pool dominant (Figure A11). A remnant outflow boundary left behind by earlier convection was evident just south of I-44. A volumetric look at the KSGX reflectivity from 609 PM clearly showed the outflow boundary ahead of the convective towers as the line approached the remnant outflow boundary (Figure A12). At this time the derecho had lost the clear rear inflow notches that it had demonstrated over the previous several hours, although new cells were forming along the outflow then drifting back and collapsing over the cold pool, thereby reinforcing the cold dome. The derecho was still producing violent winds as shown in the Base Velocity image from the KSGX (Springfield MO) WSR-88D at 616 PM (Figure A13), which indicated inbound velocities 70-90 knots only 200-300 feet above ground level.

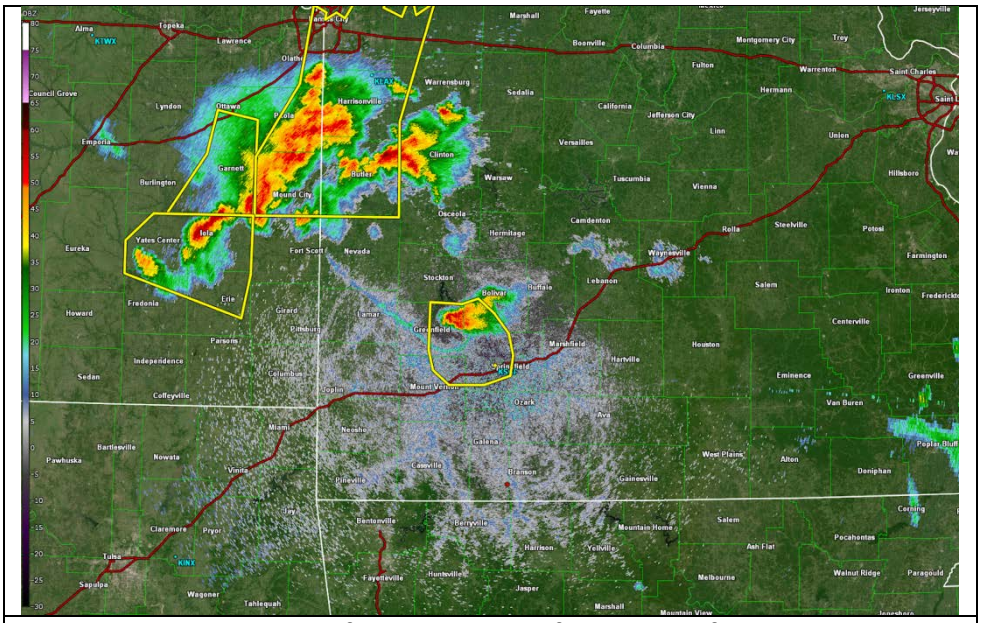

Figure A9 - 0.5 degree reflectivity image from Springfield WSR-88D at 430 PM. Yellow polygons are NWS Severe Thunderstorm Warnings. Small red square in the lower center part of the image marks the location of the Table Rock Lake State Park Marina.

The derecho interacted with the old outflow boundary around 615 PM (Figure A14) and then progressed into the more unstable airmass in southwest Missouri. Over the next thirty minutes the derecho became reinvigorated as the updraft intensity increased. The leading edge of the cold pool and the updraft became more closely aligned and were even coincident along the southwest flank of the derecho by 646 PM (Figure A15). The derecho raced southeast with a distinct bowing segment and several rear inflow notches developing in the middle section of the feature by 701 PM (Figure A16). By this time the leading edge of the outflow had raced out well ahead of the derecho as the system quickly became cold pool dominant once again. In general, the outflow boundary and the onset of severe winds was 5-10 nm ahead of the primary convective updrafts. As a result of this the high winds likely preceded the heavy rainfall by as much as 10-15 minutes.

One of the unusual aspects of the event was the duration of extreme winds. As the outflow raced ahead of the main convective updrafts it resulted in a situation in which winds of greater than 45 knots continued episodically over time periods of greater than 30 minutes in some areas. When the derecho went through Springfield, MO there were numerous wind gusts over 50 knots over a 35-minute period between 510 PM to 545 PM (Figure A17). Similarly, when the derecho traversed the Table Rock Lake area there was considerable distance between the leading edge of the outflow (onset of the strong winds) and the backside of the convective towers (decrease in the strong winds). This resulted in a prolonged period of high winds at the lake.

Another abnormal aspect of the event was that the arrival of the severe winds often preceded the rain and even thunder by as much as fifteen minutes. At Table Rock Lake the closest cloud-to-ground strike in the 30-minutes before the onset of severe winds was 13.1 miles away and the closest in-cloud flash was 10.9 miles away (Figure A18). This meant that vulnerable populations often did not receive any visible or audible cue from thunder prior to the severe winds arriving at their location.

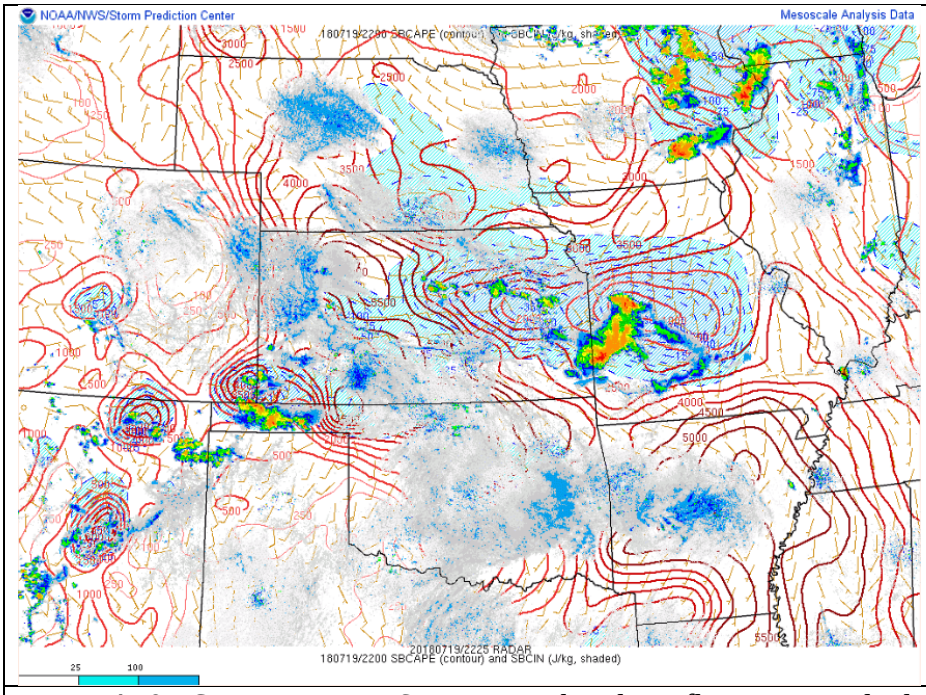

Figure A10 - Same as Figure 6, except with radar reflectivity overlaid.

Vulnerable populations, such as boaters, are often exposed with little infrastructure available to protect them in adverse conditions. In addition, inland lakes can go from calm conditions to dangerous waves quite rapidly when severe winds hit. Table Rock Lake is a recreational lake with a large number of users and it exhibits a very complex shoreline with the overwater fetch varying greatly based on the direction of the wind.

On July 19, 2018, as the derecho approached the lake, severe winds swept down the lake from the north. Based on automated observations from sensors in the vicinity the winds likely were between 340° and 010° down the arm of the lake where the marina near Table Rock State Park resides. Given this range of flow directions the overwater fetch distances range from as little as 1.55 miles to as much 3.7 miles (Figure A18). Utilizing a standard fetch, duration and wind speed calculation over a period of 45-55 knot winds for 30 minutes results in estimated significant wave heights of 2.69 feet to 3.71 feet. Taking the longest potential fetch of 3.7 miles and a wind of 60 knots for 30 minutes would result in significant waves of approximately 4.23 feet. These estimates do not account for the complexity of the shoreline, reflective waves etc. These wave estimates correlate well with video of the lake as the derecho moved through. Another challenging aspect of the event for boaters would have been the periodicity of the waves. Given the flow direction, duration and intensity of the winds, the periodicity of the waves was estimated to be 2.7 to 3.6 seconds, which would mean that boaters were dealing with significant waves in rapid succession.

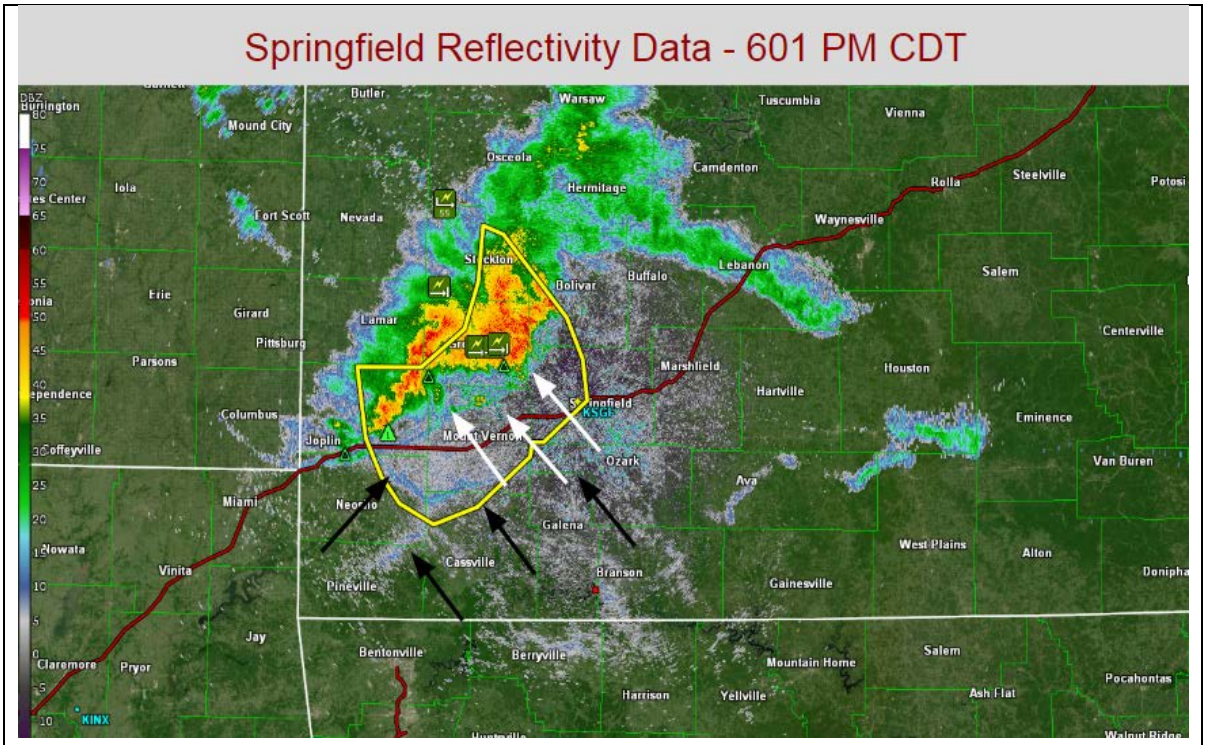

Figure A11 - 0.5 degree reflectivity image from Springfield WSR-88D at 601 PM. White arrows show the leading edge of the outflow associated with the derecho and black arrows identify location of remnant outflow from earlier convection. Yellow polygon is a NWS Severe Thunderstorm Warning. Small red square in the lower center part of the image marks the location of the Table Rock Lake State Park Marina.

In summary: On July 19, 2018, a violent derecho developed in eastern Kansas and swept through southwest Missouri causing considerable damage along its path with over 115 instances of severe weather winds or wind damage. The derecho moved at times almost 65 MPH allowing the severe weather to overtake unprepared populations very quickly. For vulnerable populations, such as boaters, there were several aspects of this event that made it particularly dangerous. The duration of severe winds was anomalous and were of a length that few people would have likely experienced with other severe thunderstorms. In addition, the onset of high winds was well out ahead of the convective updrafts and associated lightning. This resulted in a situation where people often did not get a visual or audible cue that severe weather was approaching. Finally, the duration of the high winds across inland lakes yielded a short periodicity of significant waves meaning that boaters had to deal with waves in rapid succession.

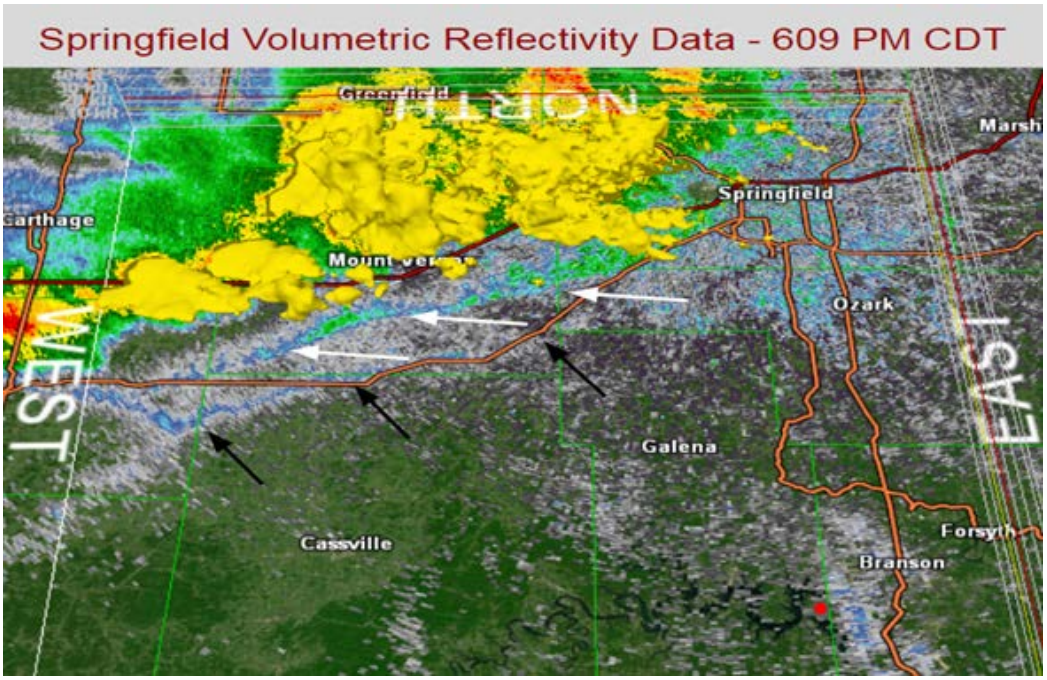

Figure A12 - Volumetric reflectivity image from Topeka WSR-88D at 609 PM. Image highlights 40 dBZ surface. White arrows show the leading edge of the outflow associated with the derecho Black arrows identify remnant outflow from earlier convection.

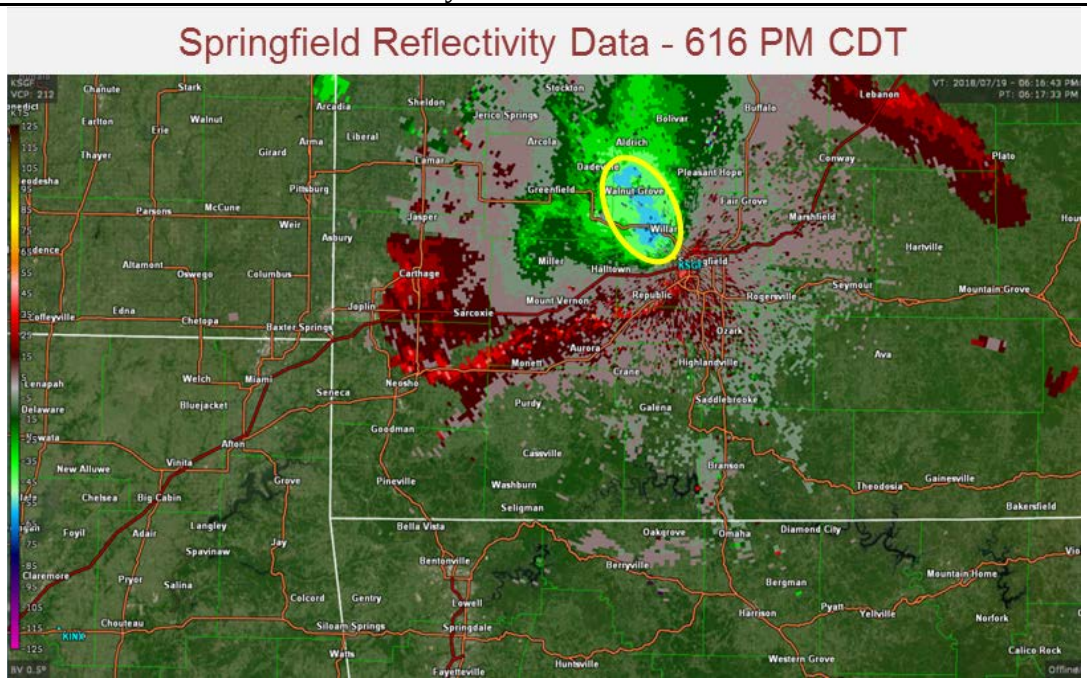

Figure A13 - Base Velocity image from the KSGX (Springfield MO) WSR-88D at 616 PM. Light blue shading inside the yellow oval indicate inbound velocities greater than 55 kts. Peak inbound velocities over 70 knots are darker blue pixels within the yellow oval.

Figure A14 - Same as 12, except for 616 PM.hite arrows show merger of derecho outflow and remnant outflow boundary.

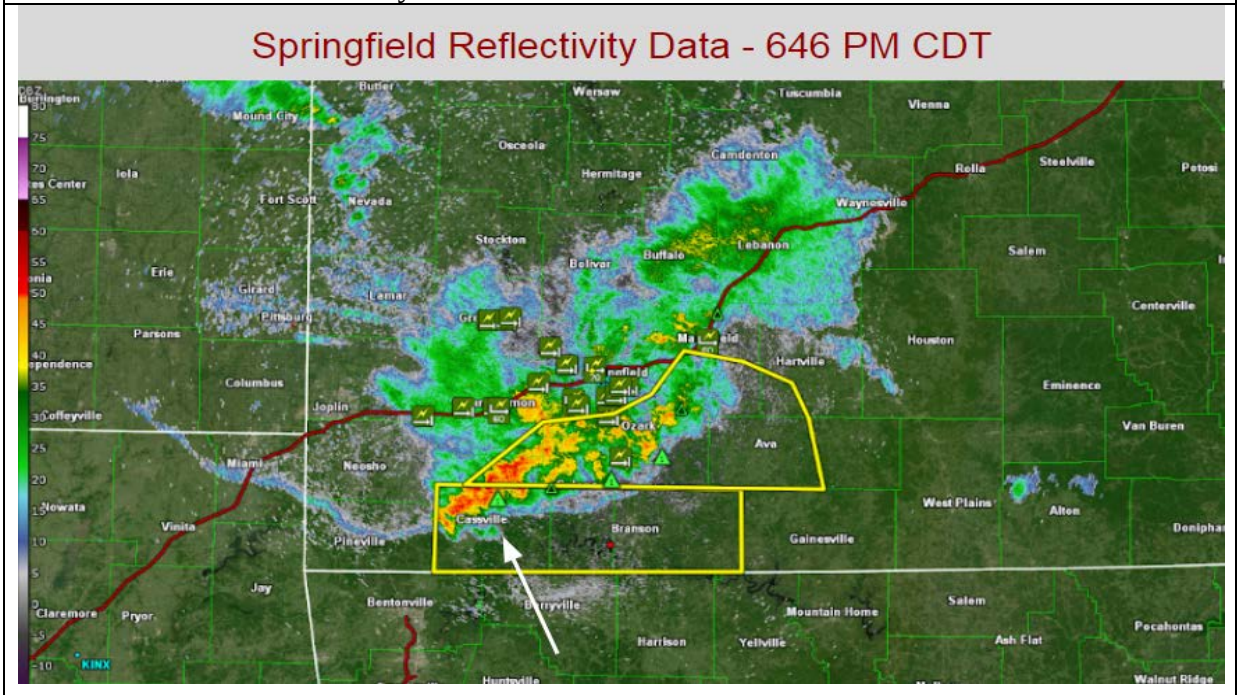

Figure A15 - Same as Figure 11, except for at 646 PM and white arrow denotes location where outflow and updraft interface are nearly coincident.

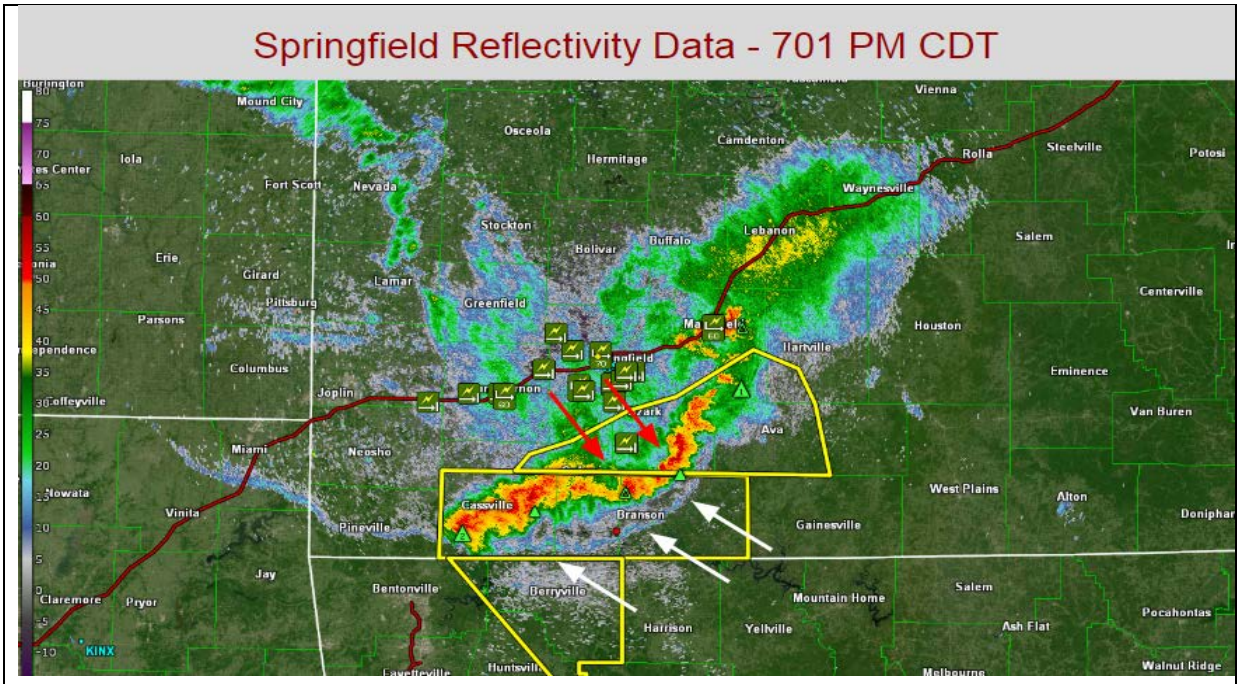

Figure A16 - 0.5 degree reflectivity image from Springfield WSR-88D at 701 PM. Red arrows indicate rear inflow notches and white arrows show the leading edge of the outflow. Yellow polygons are NWS Severe Thunderstorm Warnings. Small red square in the lower center part of the image marks the location of the Table Rock Lake State Park Marina.

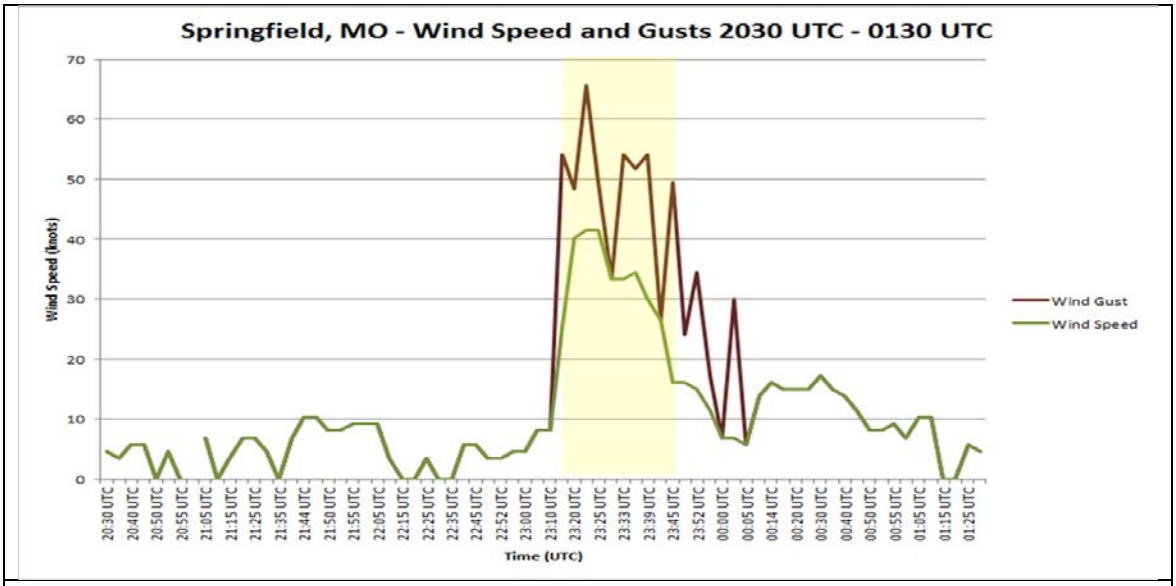

Figure A17 - Wind speed sustained (green line) and gusts (maroon line) in knots at the Springfield, MO ASOS between 2030 UTC (330 PM) and 0125 UTC (825 PM). Yellow shading highlights 30-minute period which had regular gusts of 49 knots or greater.

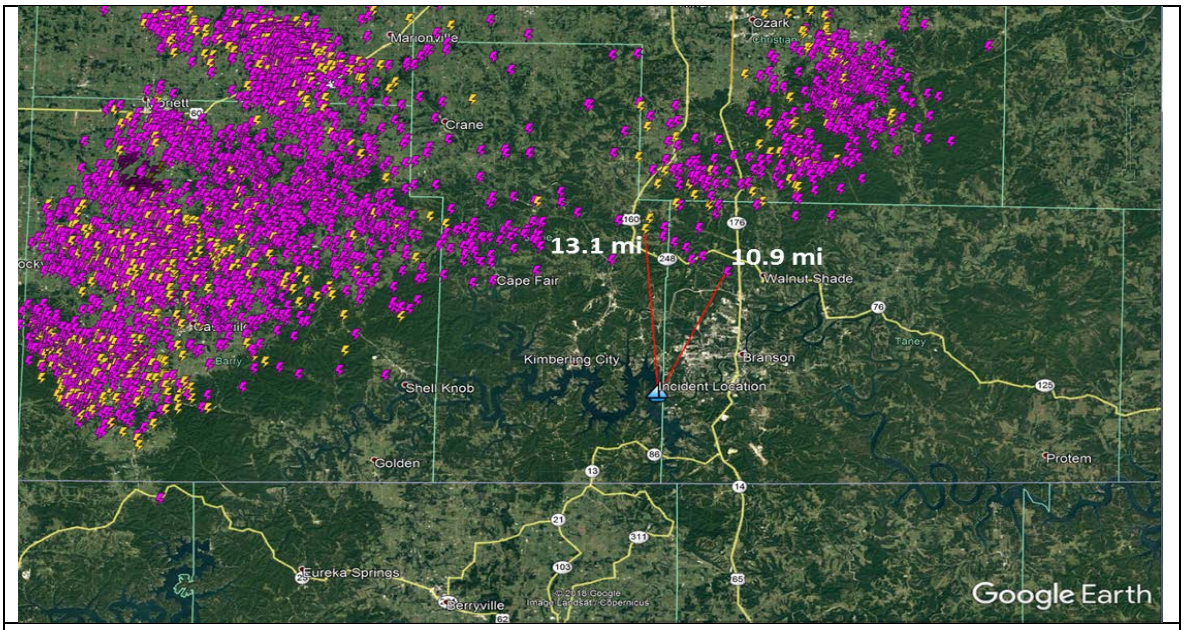

Figure A18 - Lightning flashes between 630 PM and 700 PM on 19 July 2018. Orange icons are cloud-to-ground strikes and purple icons are in-cloud flashes. Red arrows denote the closest cloud-to-ground strike (13.1 miles) and the closest in-cloud flash (10.9 miles) to the Table Rock Marina during this time frame. Data courtesy Earth Networks.

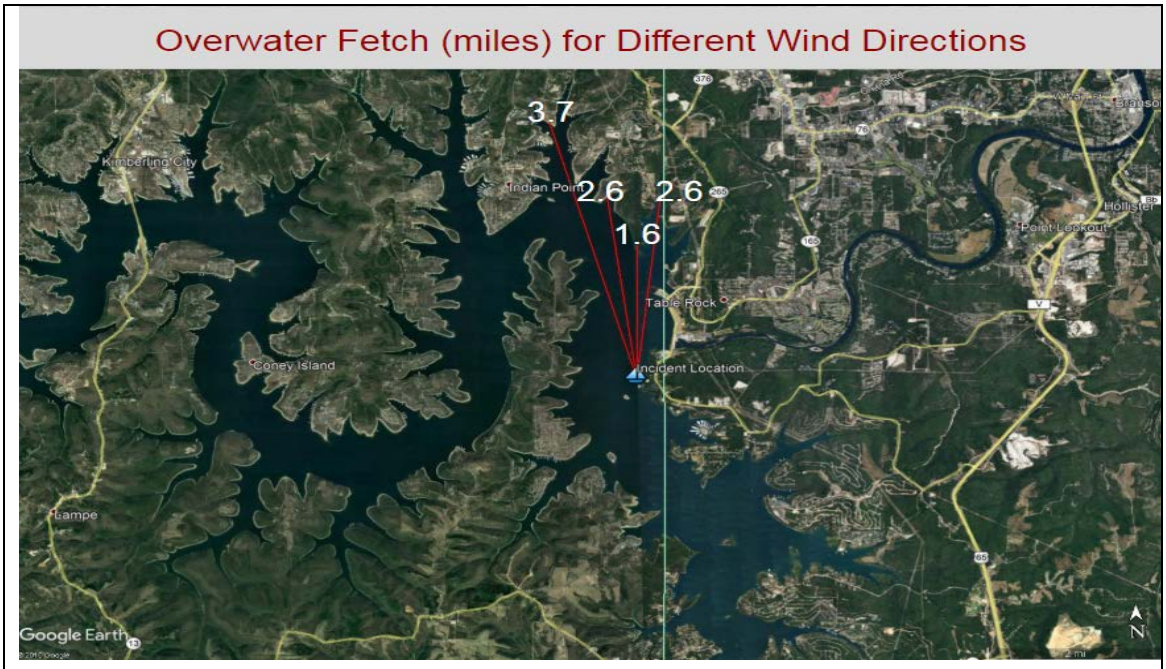

Figure A19 - Image of Table Rock Lake showing different fetch lengths (miles) for different wind directions from the north arm of the lake down to near the Table Rock Lake State Park marina.

Appendix 2: Summary of Findings, Best Practices and Recommendations

Findings

Finding #1: Given the length of Severe Thunderstorm Watch #283, there were information gaps concerning timing of severe thunderstorm threats for the southern portions of the watch area which could have been used for additional decision support for vulnerable outdoor populations.

Finding #2: Respondents to interviews indicated that a majority of core partners and their constituents, including those representing vulnerable outdoor populations, expressed a desire for arrival times of impending significant weather to assist in proper risk assessments and safety decisions. In the absence of information on arrival times, some in these populations may seek this information from additional sources or make their own estimate of arrival times.

Finding #3: In situations where "pathcasts" are deemed inappropriate or there is low confidence in accuracy, many core partners suggested organizing the "locations impacted" list to match the chronological progression of locations in the warning.

Finding #4: The potential benefits of a well-constructed "pathcast" can be significant with respect to providing partners and the public with effective risk assessment and communication. Proper configuration and operation of warning generation software (WarnGen) must be employed to reasonably create accurate and updated arrival times and locations impacted.

Finding #5: Many NWS offices have inconsistent methodologies for drawing warning polygons, some of which may have drawbacks for external customers, such as emergency managers.

Finding #6: Updated severe weather information after the initial issuance of a Severe Thunderstorm Warning (or Tornado Warning) is often under-utilized by both decision-makers and the public due to the lack of visibility and lack of notification protocols associated with the Severe Weather Statement as the updating mechanism. Instead of Severe Weather Statements, traditional core partners interviewed supported using an updated Severe Thunderstorm Warning (or Tornado Warning) as the update mechanism for original warnings.

Finding #7: The Service Assessment team attempted to capture a wide range of susceptible outdoor populations from their location (Missouri, Michigan, Illinois and Wyoming) to their outdoor recreation activity. However, it should not be assumed that this Service Assessment represents a homogeneous population within the country or any one region; nor does it represent a sufficiently large sample size.

Finding #8: Vulnerable outdoor populations and those that manage outdoor recreation resources

increasingly appear to rely on mobile smartphones to obtain weather and warning information. These most susceptible populations would benefit from a national WEA alerting protocol for Severe Thunderstorm Warnings that would consistently reach mobile platforms.

Finding #9: Vulnerable outdoor populations are threatened, to some degree, by all thunderstorm hazards. When these susceptible persons seek shelter for sub-severe thunderstorms, they also reduce their risk from severe thunderstorm threats. Many of these outdoor populations may also receive alerts and/or instructions from sources other than directly from the NWS.

Finding #10: Through their extensive relationships, NWS Springfield already utilizes many "Event-Ready" concepts for vulnerable outdoor populations. These include holding IWTs with land/water management agencies for planning and training purposes, and then assisting those agencies with significant weather monitoring through NWSChat and phone calls.

Finding #11: As weather hazards become imminent, the need for more frequent interpretive information rapidly increases. Decision-makers are often seeking information multiple times per day (and sometimes per hour).

Finding #12: Following the accident on Table Rock Lake, the Table Rock State Park Marina operator now affixes a sticker next to the steering wheel on their watercraft that states the following calls to action in case of severe weather:

> **Severe Storm Instructions**
> **L.** Life Jackets on Every Person
> **I.** Immediately exit main lake, drive into back of nearest cove
> **F.** Find shoreline or dock out of the wind: beach or tie boat
> **E.** Exit Boat onto land as soon as possible

Human safety is the Marina's only concern during a Severe Storm. Renters will not be responsible for damage to the boat caused by seeking shelter. Do not race a storm back to the marina; it's safer to find the nearest shoreline or dock.

Finding #13: Per recently released NWS policy on IDSS, NWS provides IDSS to government sector core partners. However, other user groups increasingly have similar needs for weather services that may exceed NWS capabilities and could be provided through the "whole community" concept.

Recommendations and Best Practices

Best Practice #1: To facilitate external coordination, the NWS Forensic Services Program Manager (FSPM) should be appointed to NWS Service Assessment Teams whenever liaisons may be needed to other investigative federal/state agencies and to DOC and/or NOAA General Counsel.

Best Practice #2: NWS Springfield has been proactive in adding geographical reference points to their AWIPS WarnGenLoc file to include state parks, lakes, beaches, etc. This has improved the ability to effectively message short-fused hazard threats to vulnerable outdoor populations in these venues. These geographic references can be used in both "locations impacted" lists and "pathcasts".

Best Practice #3: Positive relationships with core partners are critical for a high-level of trust in NWS products and services. To enhance and broaden core partner relationships, NWS offices should seek engagement opportunities whenever possible. While partner demands of NWS services for vulnerable outdoor populations increase, NWS offices need to be able to meet these by employing a whole office concept and leveraging "blue-sky day" opportunities.

Best Practice #4: NWSChat is relied upon by NWs Springfield and core partners as an effective warning dissemination and communication method. Where none or limited direct engagement exists, NWS offices are encouraged to recruit PSAPs to utilize NWSChat as a means to receive and relay pertinent information during warning events. NWS offices should strive to respond proactively and timely to every comment provided by core partners during severe weather events**.**

Recommendation #1: Forecast offices should be cognizant of the need for advance information on timing and severity of weather events for vulnerable outdoor populations. This information should take the form of social media posts for the general public, and more specific decision support for government-sector core partners (e.g. state parks, etc.).

Recommendation #2: To more completely inform core partners, NWS offices are encouraged to more frequently use the WarnGen "pathcast" options along with an "other locations impacted" list - especially for situations with relatively steady-state storm behavior.

Recommendation #3: The NWS should re-program WarnGen to organize the sequence of "other locations impacted" in a chronological list per the storm's progression.

Recommendation #4: For warnings and follow-up statements with "pathcast" options, local WarnGen files should be configured to capture a fairly wide downstream area along vertex paths to capture all appropriate cities and other locations of interest. WarnGen shapefile configurations

for large cities or large lakes should also be either geographically partitioned to achieve accurate times of arrival, or strictly used only in the "other locations impacted" section.

Recommendation #5: To improve polygon practices, the Central Region Tornado Warning Improvement Project (TWIP) should provide supplemental curriculum for Storm-Based Warnings training, which emphasizes a service-based philosophy to drawing warning polygons. This training should expand on recommended polygon strategies in existing WDTD Training modules, and include training on "pathcast" execution within WarnGen.

Recommendation #6: To improve the efficacy of updates for original Severe Thunderstorm Warnings (and Tornado Warnings), NWS should consider a national initiative to phase out the use of Severe Weather Statements in favor of using the original warning PIL. Such a change would ensure both higher visibility for updated information and that important storm updates provide needed alerting protocols for escalating or changing hazard threats during warning progressions.

Recommendation #7: The NWS should continue to study how vulnerable outdoor populations receive weather information, how they respond to all thunderstorm threats, and how to best reach those most at-risk populations. NWS Weather Forecast Offices should regularly network and collaborate with local partners and users to understand their own local vulnerable outdoor populations.

Recommendation #8: NWS should continue to pursue alerting Severe Thunderstorm Warnings through the WEA system. Furthermore, the NWS should analyze the appropriate wind threshold to trigger a WEA alert for a Severe Thunderstorm Warning that could help reduce the loss of life and number of injuries in vulnerable outdoor populations. WEA Alert thresholds for Severe Thunderstorm Warnings for high winds should have some consistency with WEA Alerts for Tornado Warnings and Hurricane Warnings. Ideally, this threshold should be high enough to prevent excessive WEA Alerts, but low enough to provide alerts equivalent to the level of EF0 tornadoes. A threshold of 80 mph is suggested by this Service Assessment.

Recommendation #9: The NWS should increase outreach and education to groups representing vulnerable outdoor populations where risks are much higher from all thunderstorm hazards. This outreach should use existing programs such as StormReady, StormReady Supporters, Weather-Ready Nation (WRN) Ambassadors, Integrated Warning Teams (IWT), and public/private working groups that bring together government sector and private sector groups responsible for vulnerable outdoor populations. Outreach should promote a wide spectrum of weather information - including basic radar interpretation, as well as promote sub-severe thunderstorm products (Advisories, SPSs/Graphicasts and NWS Social Media) and interpretive services from NWS and private meteorologists. For lakes and waterways with significant recreational boating, examples of groups to which outreach should be provided include the Passenger Vessel Association and Harbor Safety Committees.

Recommendation #10: NWS offices should continue to work with their core partners to ensure weather readiness of vulnerable outdoor populations. Leveraging the concepts learned from collaborations of the "Event Ready" program, this outreach should further build on the basic weather preparedness concepts taught for decades by focus on developing and evaluating hazardous weather response plans. Severe and sub-severe (i.e. lightning) weather threats should be addressed in such plans.

Recommendation #11: For government-sector core partners representing vulnerable outdoor populations, the NWS should develop means to provide remote, high-frequency interpretive service during the tactical phase (now through the next 2-3 hours) of thunderstorm/lightning events. Information to focus on should include "what, when, and where" information and coverage/intensity trends.

Recommendation #12: For NWS products that cover large inland lakes, NWS should consider adding a Call-to-Action (CTA) in short-fused convective warnings and Significant Weather Advisories (SPS) that recommend protective actions for vulnerable over-water populations when high winds and lightning threaten.

Recommendation #13: To help achieve a Weather Ready Nation, WFOs should use the recently released IDSS Toolkit Engagement Guide for General Partners, to assist in connecting non-core partners with a repository of Decision Support providers within America's Weather, Water and Climate Enterprise. This would serve as a clearinghouse of IDSS capabilities inclusive of all the capabilities that the Enterprise can collectively provide.