National Transportation Safety Board

Office of Marine Safety

Washington, D.C. 20594

Group Chairman's Factual Report

Meteorology Group

Stretch Duck 7

DCA18MM028

January 24, 2020

Mike Richards

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1. ACCIDENT INFORMATION

Vessel:	*Stretch Duck 7*
Accident Number:	DCA18MM028
Date:	July 19, 2018
Time:	1908 central daylight time (CDT) 0008 coordinated universal time (UTC) on July 20, 2018
Location:	36˚35.236' N, 93˚19.113' W
Accident type:	Sinking
Complement:	2 crew, 29 passengers

2. METEOROLOGY GROUP

Chairman	Mike Richards Senior Meteorologist National Transportation Safety Board Office of Aviation Safety Operational Factors Division, AS-30 Washington, DC 20594
Member	Kelsey Angle Meteorologist In Charge Weather Forecast Office National Weather Service Springfield, Missouri 65802

3. SUMMARY

About 1910 local time on July 19, 2018, the 33-foot-long amphibious passenger vessel *Stretch Duck 7*, part of a fleet of vessels operated by Ride The Ducks Branson, sank during adverse weather on Table Rock Lake near Branson, Missouri. Of the 31 persons aboard, 17 fatalities resulted. Prior to the accident, the National Weather Service (NWS) had issued a severe thunderstorm warning with wind gusts up to 60 miles per hour (mph) for the area. Due to the approaching weather, before departing the shoreside boarding facility, the captain and driver were advised to complete the lake portion of the tour first before the land-based portion of the tour. About 5 minutes after the vessel entered the water from the south ramp, a "derecho" passed through the area generating waves estimated by witnesses to be 3- to 5- feet, with the highest wind gust recorded at 73 mph. The captain changed course, shortening the usual tour around an island, and attempted to exit the lake via the north ramp. However, during the effort to reach land, the vessel took on water and foundered approximately 250 feet away from the north ramp near the stern of the *Showboat Branson Belle*, a moored paddle wheeler. Personnel from several fire,

emergency medical services, and law enforcement agencies, along with the paddle wheeler crew and passengers, rescued and triaged 14 passengers, seven of whom were transported to local hospitals. Loss of the vessel was estimated at $184,000.

4. DETAILS OF THE INVESTIGATION

The National Transportation Safety Board (NTSB) was the lead federal agency in this safety investigation. The NTSB launched a full team of investigators to Branson, Missouri, on July 20, 2018. The US Coast Guard, Missouri State Highway Patrol, NWS, Ride The Ducks Branson and the Federal Aviation Administration were named as parties to the investigation. While on scene, investigators interviewed passengers from the Stretch Duck 7, crew members from other duck boats, crewmembers from the Showboat Branson Belle, and first responders from the Branson area. In addition, investigators documented the vessel's characteristics and damage, and they retrieved and reviewed recorded data from the vessel's digital video recorder. Investigators returned to Branson August 21-23, 2018, to participate in the post casualty examination and surveys of lifesaving equipment, bilge pumping systems and alarm systems. The US Coast Guard announced that they would convene a Marine Board of Investigation formal hearing, but as of the date of this report, it has not been scheduled.

5. FACTUAL INFORMATION

Unless otherwise noted, directions are in reference to true north, and distances are in nautical miles (i.e., "miles" refers to nautical rather than statute miles).

According to the NWS Storm Prediction Center (SPC), the accident was the largest "direct fatality wind event" on record in the United States according to the US Severe Thunderstorm and Tornado Database (which goes back to 1950 for tornados and 1955 for thunderstorm wind and hail) and was also the deadliest severe thunderstorm or tornado event in the United States since May 2013.[1]

5.1. Derecho Overview

According to the SPC (see Attachment 1), the convective weather system that impacted Table Rock Lake and the accident vessel on the evening of July 19, 2018, was a *derecho*.[2] Figure 1 depicts the derecho's path on July 19, 2018, along with preliminary (at that time) storm reports of wind along its path. The SPC identified that the derecho lasted for 9 hours and 24 minutes and covered 473 statute miles (from north-central Kansas to northern Arkansas). According to the SPC, "Although the width of the responsible convective system was, at times, towards the shorter end of the derecho spectrum, the consistent progression of [storm] reports (including multiple significant wind reports), radar structure showing a pronounced rear-inflow jet, and forward speed

[1] In May 2013, a tornado in Moore, Oklahoma, killed 24 people.

[2] Though new definitions for a derecho (pronounced "deh-REY-cho") have been proposed, currently a derecho is generally considered to be a widespread, long-lived wind storm that is associated with a band of rapidly moving showers or thunderstorms, where the wind damage swath extends more than 240 statute miles and includes wind gusts of at least 58 mph (about 50 knots) along most of its length and several well-separated 75 mph (about 65 knots) or greater gusts. See: http://www.spc.noaa.gov/misc/AbtDerechos/papers/Corfidietal_def_2016.pdf

(averaging 50 mph) well in excess of ambient mean flow are all consistent with a progressive derecho."

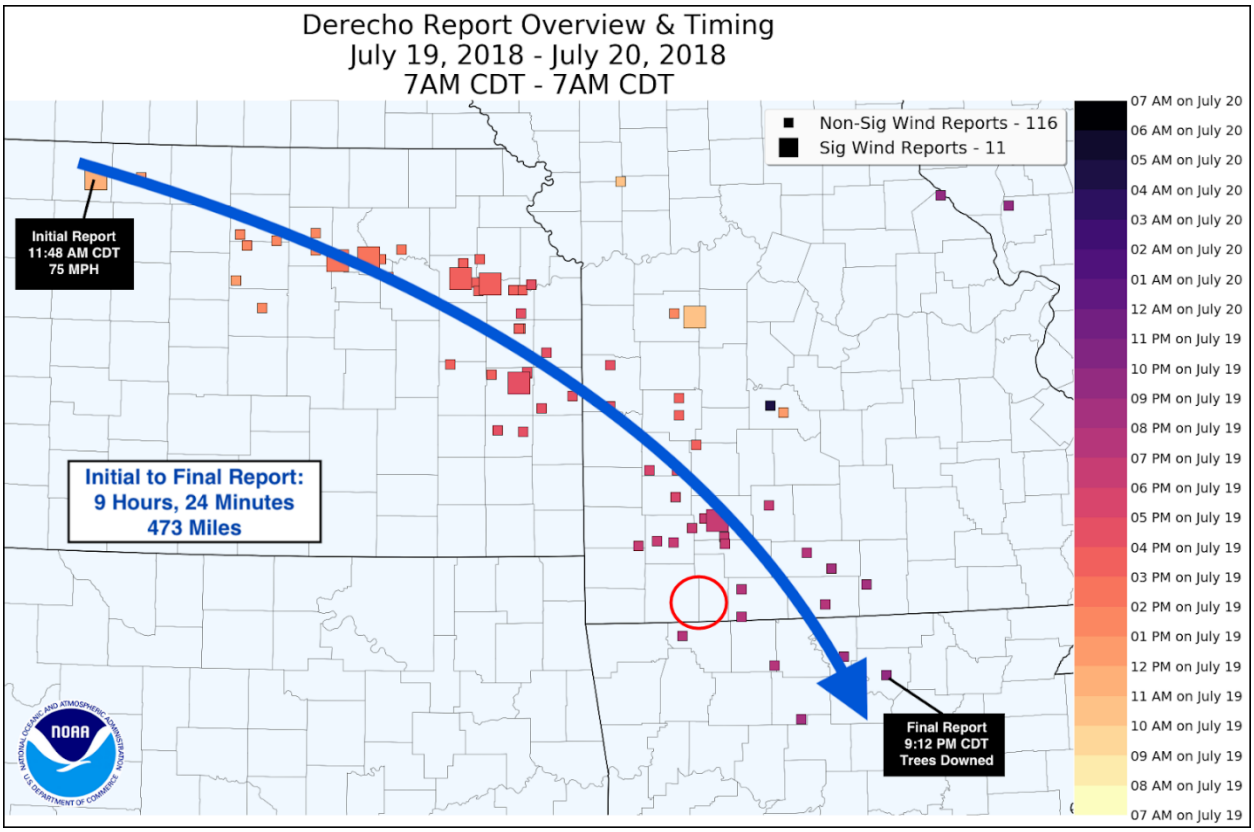


Figure 1 *– The derecho's path on July 19, 2018, along with preliminary (at that time) storm reports of wind along its path. The accident area (red circle) has been added to the image.*

Figure 2 presents a mosaic (or time-lapse) of radar imagery that depicts the progression of the derecho. The individual radar depictions used in this mosaic have been heavily edited/cropped for presentation and should not be considered complete.

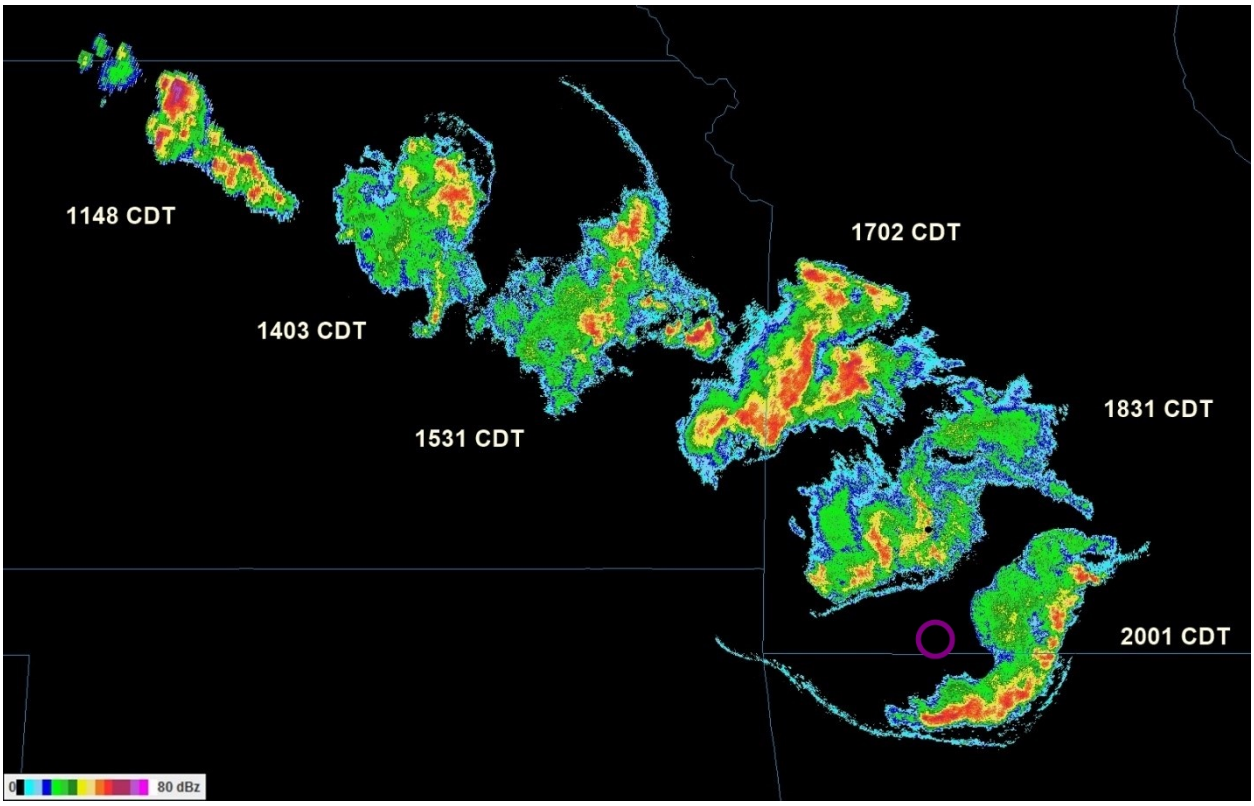


Figure 2 *– Mosaic of edited radar images depicting the progression of the derecho on July 19, 2018. The accident site is denoted by the purple circle.*

5.2. KSGF Weather Radar

WSR-88D Level-II and Level-III weather radar imagery from Springfield, Missouri (KSGF), were obtained from the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information and are presented in figures 3-8. KSGF was located about 39 miles north of the accident site at an elevation of about 1,250 feet. Assuming standard refraction and considering the 0.95° beam width for the WSR-88D radar beam, the KSGF 0.5° tilt would have "seen" altitudes above the accident location of between about 2,400 and 6,300 feet above mean sea level.

Figures 3-5 present the KSGF Level-II ~0.5° tilt[3] base reflectivity imagery for select times leading up to and including the accident time. Attachment 2 presents all KSGF Level-II ~0.5° tilt base reflectivity imagery for the period 1801 through 1914 CDT.

Figures 6-8 present the KSGF Level-III ~0.5° tilt base velocity imagery for select times leading up to and including the accident time. Attachment 2 presents all KSGF Level-III ~0.5° tilt base velocity imagery for the period 1801 through 1914 CDT.

[3] Tilt elevations vary between about 0.48° and 0.53°

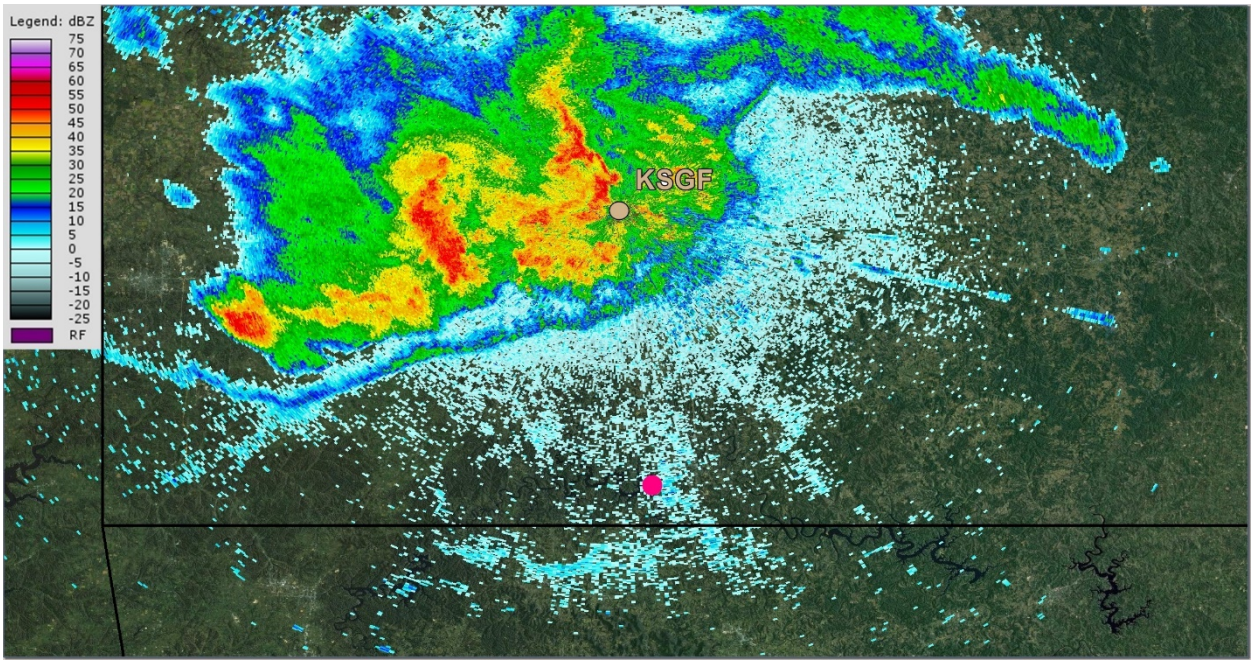


Figure 3 *– KSGF Level-II ~0.5° base reflectivity image from a sweep initiated about 1825:43 CDT. Accident site is denoted by the pink circle.*

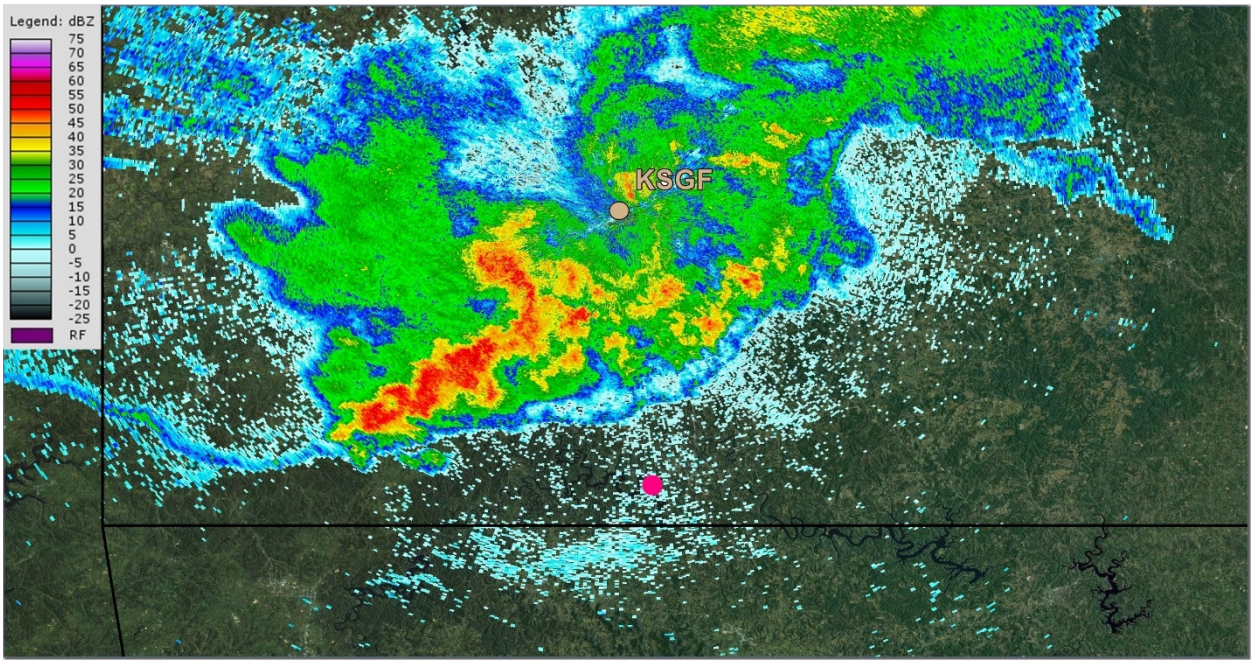


Figure 4 *– KSGF Level-II ~0.5° base reflectivity image from a sweep initiated about 1844:23 CDT. Accident site is denoted by the pink circle.*

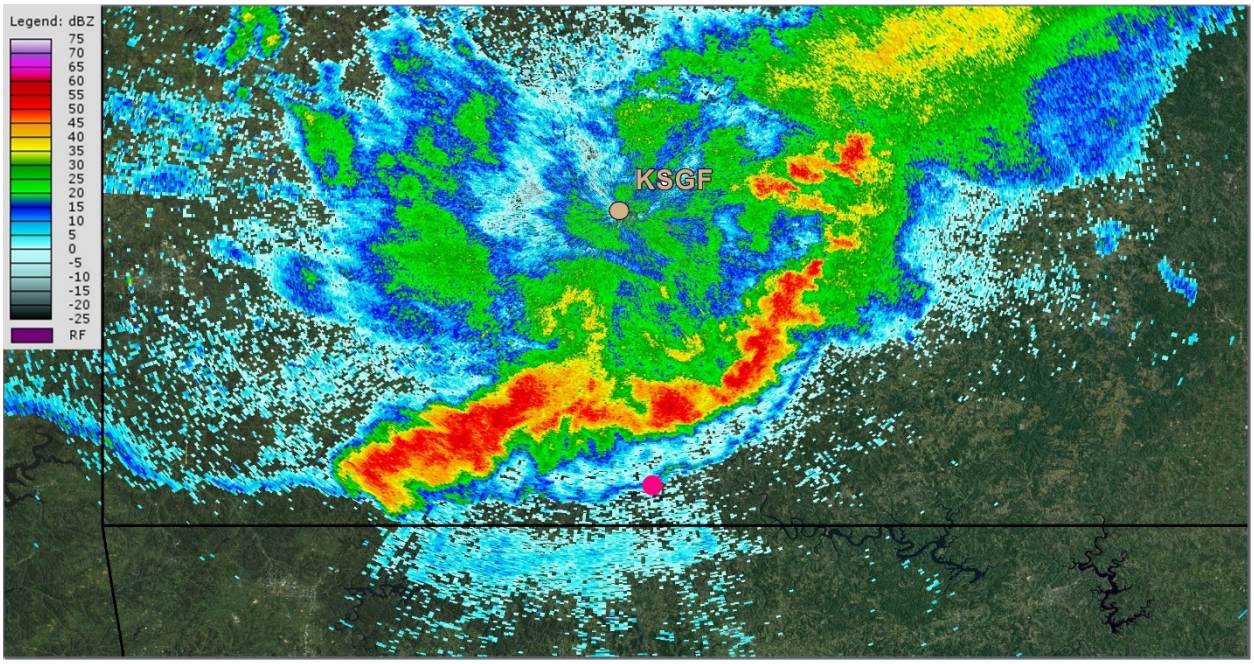


Figure 5 *– KSGF Level-II ~0.5° base reflectivity image from a sweep initiated about 1859:17 CDT. Accident site is denoted by the pink circle.*

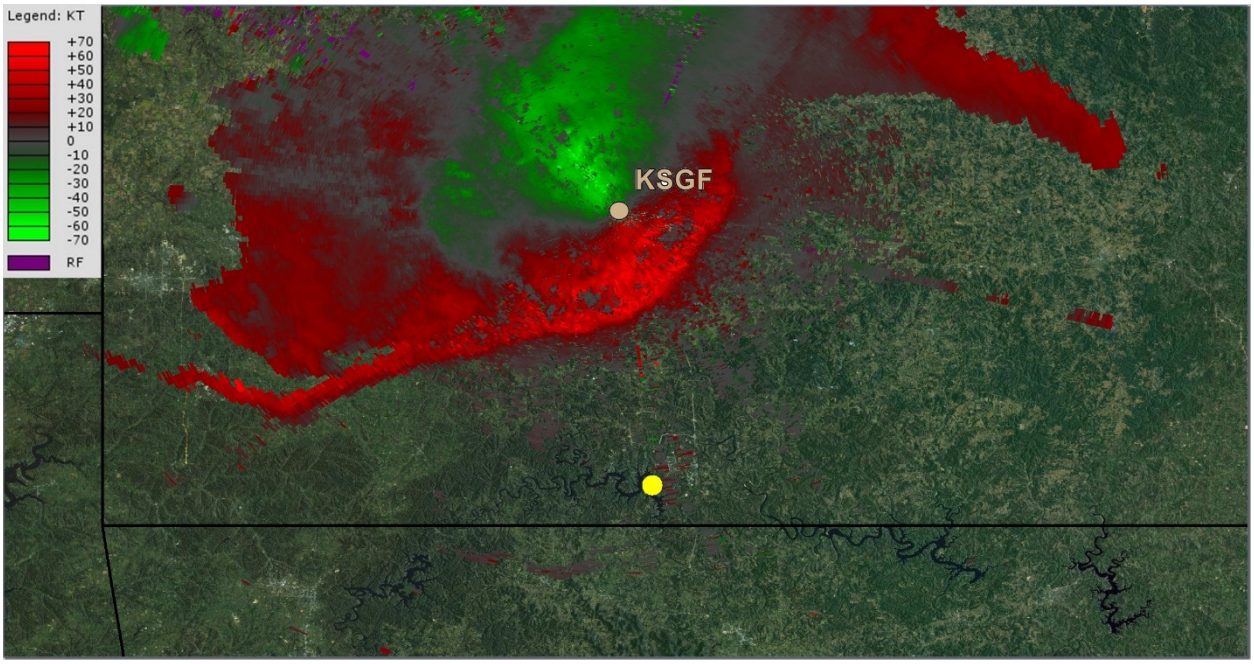


Figure 6 *– KSGF Level-III 0.5° base velocity image from a sweep initiated about 1826 CDT. Accident site is denoted by the yellow circle.*

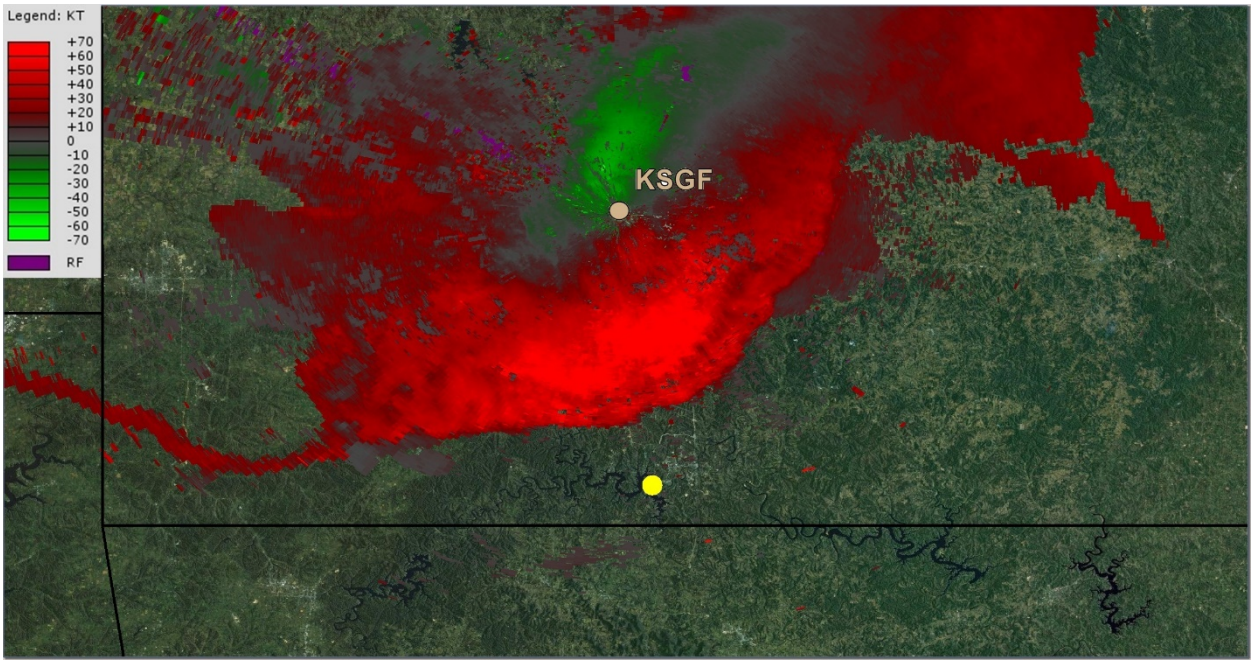


Figure 7 *– KSGF Level-III 0.5° base velocity image from a sweep initiated about 1844 CDT. Accident site is denoted by the yellow circle.*

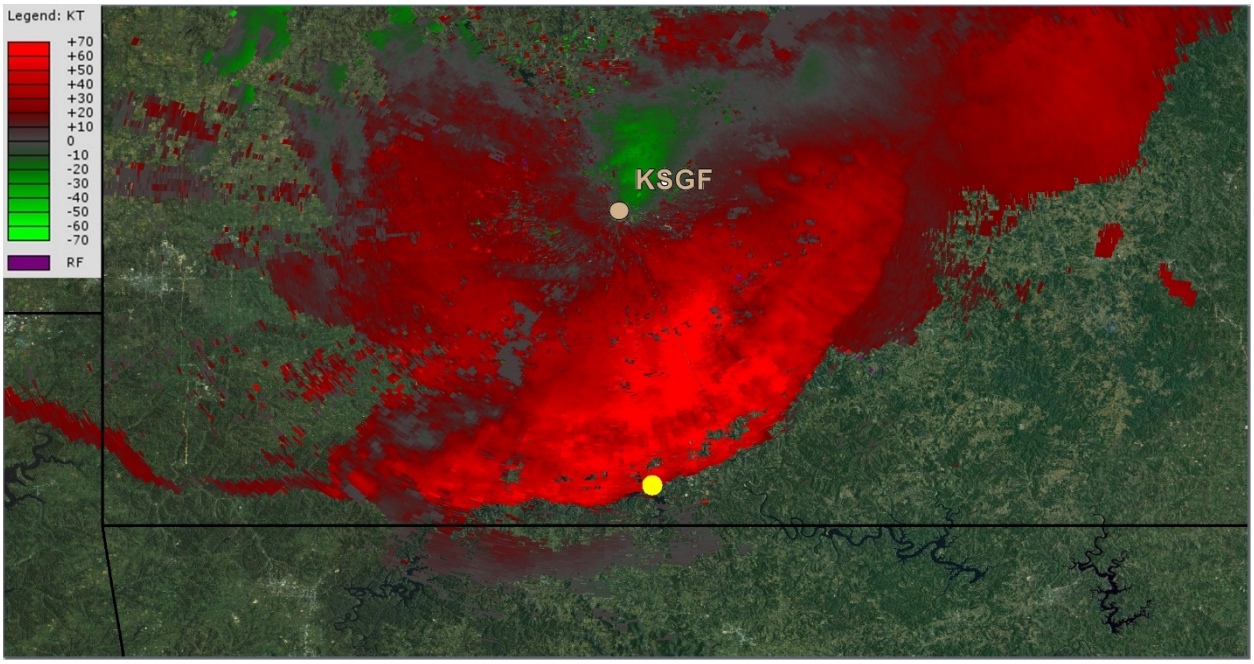


Figure 8 *– KSGF Level-III 0.5° base velocity image from a sweep initiated about 1859 CDT. Accident site is denoted by the yellow circle.*

5.3. KY3 Radar Data

On July 23, 2018, the Chief Meteorologist for the KYTV television station (KY3) in Springfield, Missouri, advised the National Transportation Safety Board (NTSB) Meteorology Group chairman via email that "…[we] have our own Doppler radar. It is an Enterprise Doppler with a 14-foot dish and 250,000 watts of power. The radar is located in Fordland Missouri about 20 miles east of Springfield. At approximately 7:14 pm last Thursday I recorded a velocity signature of over 100 mph near Forsyth, which is the next town east of Branson. This image is also saved." See Attachment 3. These data were not provided to the NTSB Meteorology Group and subsequent requests to KY3 management for the camera imagery to assist the NTSB's investigation were denied.

5.4. Lightning

Total lightning data for the hour leading up to and including the accident time were obtained from the National Lightning Detection Network (NLDN)[4] and the Earth Networks Total Lightning Network (ENTLN). Attachment 4 presents tabular lightning data from the NLDN and the ENTLN for the accident region between 1805 and 1905 CDT (inclusive) on July 19, 2018. Figures 9 and 10 provide graphical depictions of these data.

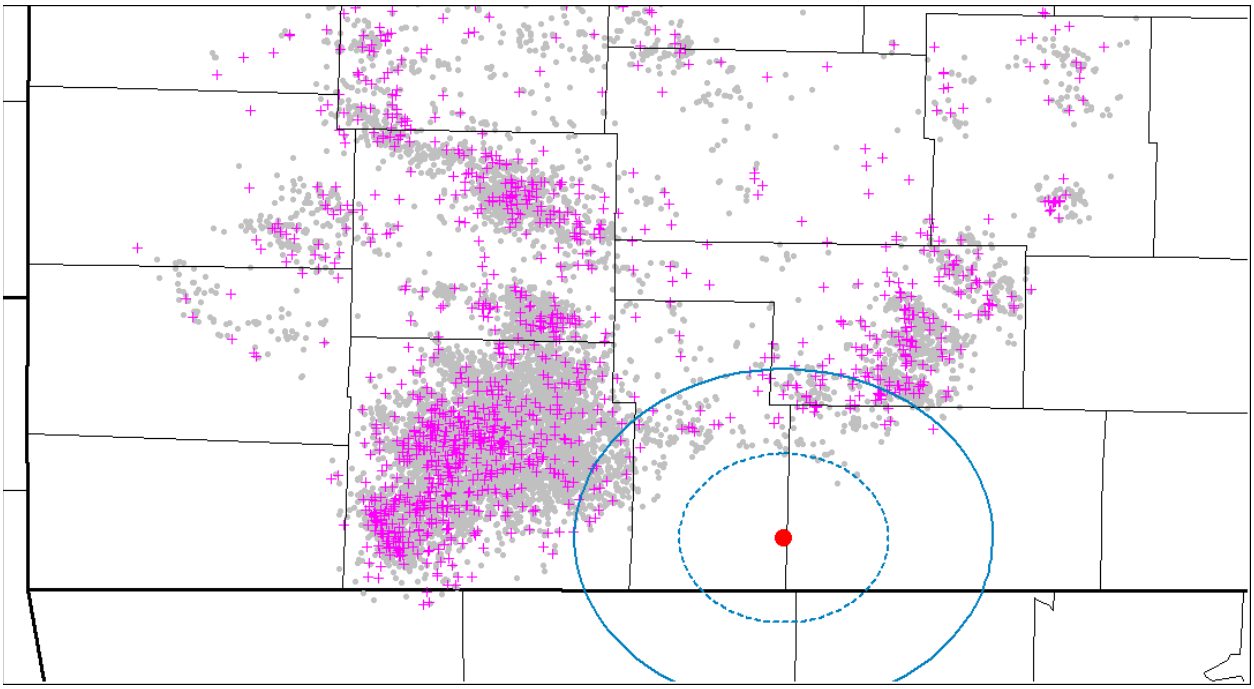


Figure 9 *– Plot of intracloud (gray circles) and cloud-to-ground (pink "+") lighting strokes detected by the NLDN between 1805 and 1905 CDT (inclusive). Red dot denotes the accident location. The dotted blue line draws distances of 10 statute miles from the accident location and the solid blue line draws distances of 20 statute miles from the accident location.*

[4] The NLDN data was obtained via the NWS.

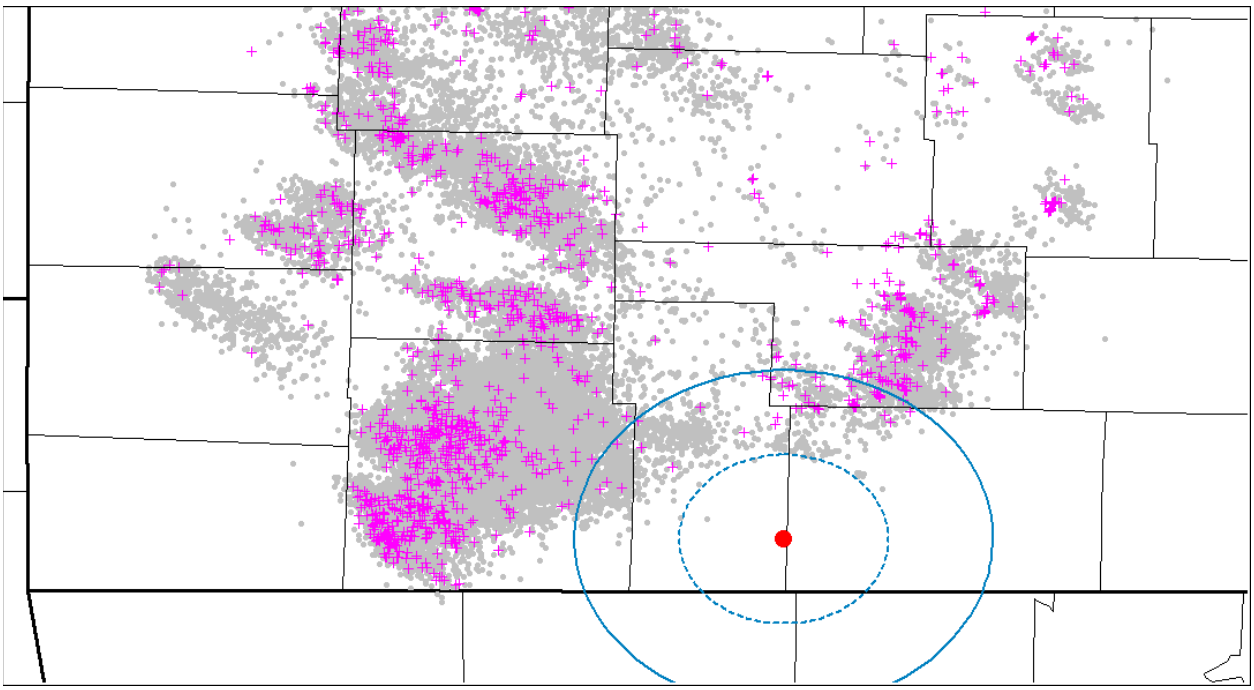


Figure 10 *– Plot of intracloud (gray circles) and cloud-to-ground (pink "+") lighting strokes detected by the ENTLN between 1805 and 1905 CDT (inclusive). Red dot denotes the accident location. The dotted blue line draws distances of 10 statute miles from the accident location and the solid blue line draws distances of 20 statute miles from the accident location.*

The following images (figures 11-14), which captured lightning in the Branson, Missouri, region, were taken from the Western Taney County Fire Protection District Battalion Chief's dash cam around the accident time.

Figure 11 *– Image from the Western Taney County Fire Protection District Battalion Chief's dash cam at about 1858 CDT. At this time the Battalion Chief's vehicle was located at about 36.596457, -93.235075 (about 4 miles east of the accident site) headed north-northwest.*

Figure 12 *– Image from the Western Taney County Fire Protection District Battalion Chief's dash cam at about 1859 CDT. At this time the Battalion Chief's vehicle was located at about 36.601851, -93.235116 (about 4 miles east of the accident site) headed north-northeast.*

Figure 13 *– Image from the Western Taney County Fire Protection District Battalion Chief's dash cam at about 1859 CDT. At this time the Battalion Chief's vehicle was located at about 36.608167, -93.232436 (about 4 miles east-northeast of the accident site) headed north-northeast.*

Figure 14 *– Image from the Western Taney County Fire Protection District Battalion Chief's dash cam at about 1859 CDT. At this time the Battalion Chief's vehicle was located at about 36.609863, -93.231823 (about 4 miles east-northeast of the accident site) headed north-northwest.*

5.5. Surface Observations

5.5.1. Showboat Branson Belle

The *Showboat Branson Belle*, a 278-foot long showboat, was equipped with an anemometer[5] that was docked within several hundred feet of the accident location on the accident day. Figure 15 is a photo[6] of the vessel taken at an unknown date with the location of the anemometer circled. In its docked position on the evening of the accident, the vessel's tall, black structures would have been downwind of the anemometer (the vessel was docked with a southerly heading). The NTSB Meteorology Group estimated that the anemometer was approximately 60 feet above the vessel's waterline. Figure 16 presents closer views of the anemometer taken two days after the accident.

According to *Showboat Branson Belle* crew, the maximum wind measured by the vessel's anemometer on the evening of the accident was 73 mph (about 63 knots), which occurred at 1907 CDT (note time discrepancy discussed below). Figure 17 presents a photograph of the bridge display that presents the anemometer's data for that time. The anemometer's display saves an image of each day's "maximum" values, and because no one had immediately cleared this information from the anemometer's display, it was still available for viewing by the NTSB Meteorology Group two days after the accident. One of the vessel's captains indicated that the anemometer display presented a time that was 3 minutes behind the time on his cell phone, and that his cell phone's time is automatically updated/synched (suggesting a more accurate time for the observation was 1910 CDT). This captain indicated he was landside when the storm began, and then boarded the *Steamboat Branson Belle* between 1905 and 1908 CDT, and estimated that at the time of the accident, the wave height on the lake was 4 feet, trough-to-crest. During the storm, he estimated general wind magnitudes of 50 mph (about 43 knots) with gusts to 60-65 mph (about 52-56 knots).

Attachment 5 provides specification for the anemometer onboard the *Showboat Branson Belle*. According to the anemometer's specifications, wind magnitude was measured with a resolution of 1 mph (<1 knot), magnitude accuracy was ±2 mph (<±2 knots) or ±5 percent (whichever was greater) and magnitude retrieval range was 1 to 200 mph (about 1 to 174 knots). Regarding wind direction, it's display resolution was 1° and retrieval accuracy was ±3°. According to conversation with the anemometer's manufacturer (see Attachment 5) the wind values displayed on the anemometer's display were "instantaneous" values and were not averaged. When asked about the anemometer's calibration, the vessel captain indicated that he was not aware of the anemometer having been calibrated since its installation in the fall of 2016. He indicated that normally maintenance isn't performed on this equipment, and that if something went wrong, the equipment would simply be replaced.

[5] Part of a Davis Integrated Sensor Suite.

[6] The photo was taken from the official *Showboat Branson Belle* website on November 5, 2018: https://www.silverdollarcity.com/showboat-branson/Table-Rock-Lake

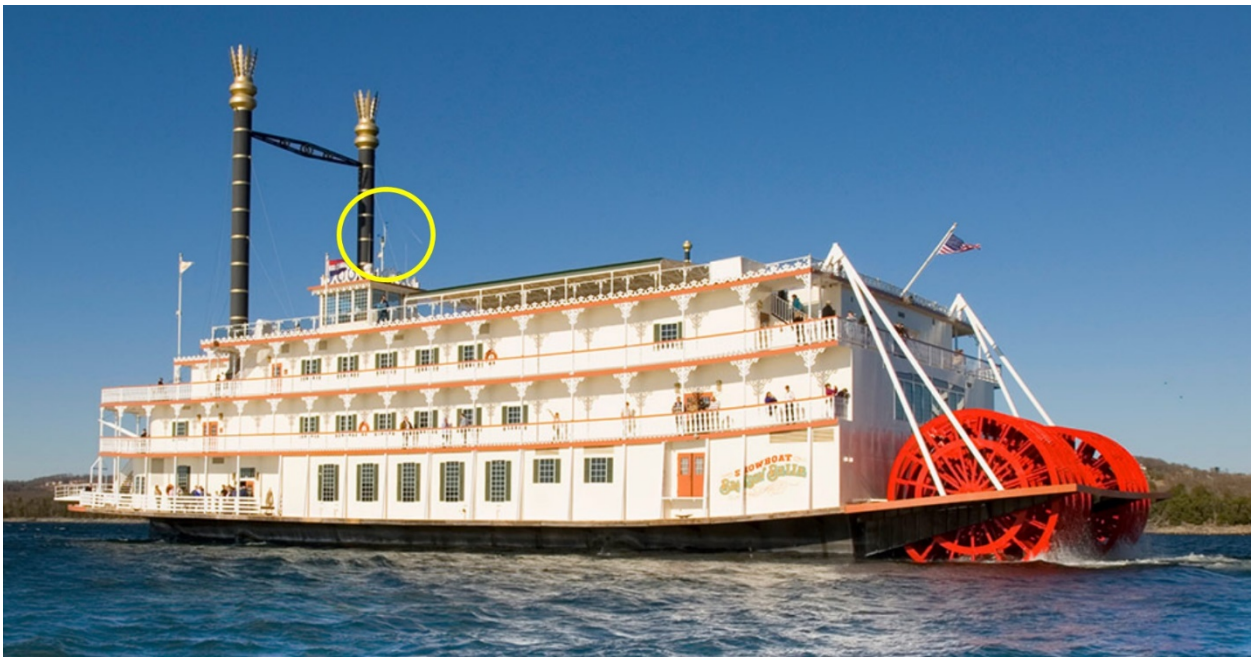


Figure 15 *– Photo of the* Showboat Branson Belle *taken at an unknown date with the location of the anemometer circled in yellow.*

Figure 16 *– Photos of the* Showboat Branson Belle*'s anemometer taken two days after the Stretch Duck 7 accident.*

Figure 17 *– Photograph of the Showboat Branson Belle's bridge display that presents the time of the "maximum" wind value retrieved on the accident day.*

5.5.2. FWB AWOS

An Automated Weather Observing System (AWOS) was located at Branson West Municipal Airport/Emerson Field (FWB)[7] in Branson West, Missouri, which was located about 8 miles north-northwest of the accident location (see Figure 18) at an elevation of about 1,350 feet. The following are publicly-disseminated automated reports from FWB during the times surrounding the accident time. Attachment 6 presents email and phone dialogue with the FWB AWOS technician. According to the FWB AWOS technician, the FWB AWOS was not SPECI-capable and was working normally with all sensors reporting and no power failures during the times surrounding the accident.

[1735 CDT] METAR KFWB 192235Z AUTO 00000KT 10SM CLR 33/22 A2989 RMK AO2=

[1755 CDT] METAR KFWB 192255Z AUTO 17003KT 10SM -RA CLR 32/24 A2988 RMK AO2 LTG DSNT N AND NW=

[7] The NWS uses the 4-digit International Civil Aviation Organization (ICAO) format for station identifiers (as seen in the body of some formatted weather observations). This report uses the 3-digit International Air Transport Association format for station identification, which does not use the geographic designating digit ("K" for stations in the continental U.S. and "P" for U.S. stations in Alaska and the Pacific region) as found in the ICAO format.

[1815 CDT] METAR KFWB 192315Z AUTO 00000KT 10SM VCTS CLR 32/23 A2989 RMK AO2 LTG DSNT N AND NW=

[1855 CDT] METAR KFWB 192355Z AUTO 35027G45KT 7SM TS SCT055 BKN065 27/17 A3000 RMK AO2 LTG DSNT ALQDS=

[1915 CDT] METAR KFWB 200015Z AUTO 01009G27KT 3SM VCTS RA FEW040 BKN055 OVC070 20/19 A2995 RMK AO2 P0002=

At 1815 CDT, FWB reported a calm wind, visibility 10 statute miles or greater, thunderstorm in the vicinity[8], sky clear below 12,000 feet above ground level (agl), temperature of 32° Celsius (C) and a dew point temperature of 23°C, altimeter setting of 29.89 inches of mercury; Remarks: station with a precipitation discriminator, lightning distant[9] to the north and northwest.

At 1855 CDT, FWB reported a wind from 350° at 27 knots with gusts to 45 knots[10], visibility 7 statute miles or greater, thunderstorm, scattered[11] clouds at 5,500 agl, broken[12] clouds at 6,500 feet agl, temperature of 27°C and a dew point temperature of 17°C, altimeter setting of 30.00 inches of mercury; Remarks: station with a precipitation discriminator, lightning distant in all quadrants.

FWB normally publicly disseminates[13] weather observations every 20 minutes, timestamped at 15, 35 and 55 minutes past each hour. There was no observation disseminated with a timestamp of 2335 UTC (1835 CDT). According to the FWB AWOS technician "The [:35 report was] not received by the dessimination [sic] ingest system from the site. The system uses a cellular modem. I suspect but cannot prove that either the cell site dropped the link during the storm or that there was a quick power glitch that reset the cellular device but did not affect the AWOS..."

According to the FWB AWOS technician, during the day of the accident, the FWB AWOS' clock was slow[14] by 7, 8 or 9 minutes. Because the publicly-disseminated FWB AWOS weather observations are collected and disseminated according to the AWOS' clock (i.e., the AWOS collects and publicly disseminates current weather observations when it thinks it is 15, 35 and 55 minutes past each hour), the FWB weather observation timestamped at 2355 UTC (1855 CDT) was actually a weather observation taken at 0002, 0003 or 0004 UTC on July 20, 2018 (1902, 1903 or 1904 CDT on July 19, 2018, respectively).

Once the FWB AWOS disseminates a weather observation, it goes to RSINet (an approved nonFed AWOS service provider) via a cellular connection. The time it takes for an FWB AWOS observation to go from the AWOS to the approved nonFed AWOS Service Provider is "on the

[8] The METAR acronym "VC" (in the vicinity) means between 5 and 10 nautical miles from the reporting station.

[9] The METAR acronym "DSNT" (distant) means beyond 10 but within 30 nautical miles from the reporting station.

[10] The AWOS average wind speed is a running two-minute average calculated from 5-second wind observations. Wind gusts are reported when the difference between the maximum and minimum wind speeds over the past 10 minutes are 10 knots or greater.

[11] "Scattered" means 3/8 to 4/8 of the sky is covered by cloud at that altitude.

[12] "Broken" means 5/8 to 7/8 of the sky is covered by cloud at that altitude.

[13] Here, "public dissemination" is intended to mean dissemination of an observation to the Federal Aviation Administration (FAA) Weather Message Switching Center Replacement (WMSCR) system and does not include public dissemination of weather information available only through Very High Frequency (VHF) broadcasts and/or telephone.

[14] Relative to real time (e.g., GPS time).

order of seconds." RSINet delivers the FWB AWOS observations via a secure server in an FAA facility in Oklahoma City, Oklahoma, to the FAA WMSCR center in Salt Lake City, Utah, in an "SAUS" bulletin that is timestamped according to a "Stratum 1 accuracy" time server. RSINet sends bulletins (which can contain weather observations from multiple reporting sites) to the WMSCR center once 40 newly-received weather observations have been queued. However, RSINet will not allow a weather observation to sit idle for more than 70 seconds before it is sent to WMSCR in an SAUS bulletin. The following SAUS bulletin documents the dissemination of the 2355 UTC (1855 CDT) FWB AWOS observation from RSINet to the FAA and indicates that this weather observation was not sent until 1904 CDT.

####
SAUS27 RSYS 200004
METAR KS32 200015Z AUTO 17006KT 10SM CLR 23/21 A2982 RMK AO2=
METAR KBXK 192355Z AUTO 23010G16KT 10SM CLR 40/17 A2979 RMK AO1 =
METAR KM25 200015Z AUTO 00000KT 10SM SCT055 29/24 A2988 RMK AO2
PWINO=
METAR KFWB 192355Z AUTO 35027G45KT 7SM TS SCT055 BKN065 27/17 A3000
RMK AO2 LTG DSNT ALQDS =
5f46936dd41a5e1bc5306cca4e093be6

According to the FWB AWOS technician, there has been an issue with "clock drift" on certain AWOS systems for about 25 years and resetting the clock on these AWOS systems is a regular maintenance item. The FWB AWOS technician used a program called "NTP Monitor" to sync the FWB AWOS clock and believed that the last FWB AWOS clock fix prior to the accident day was in "mid-June" 2018. According to FAA Advisory Circular 150/5220-16E (March 10, 2017)[15], section 4.4, states "The following preventive maintenance checks should be accomplished by the assigned maintenance technician holding verification authority in accordance with manufacturer's provided and FAA approved maintenance manual at tri-annual [4 month] intervals…" and identifies "Check system time and reset as needed" as a preventive maintenance check. The FWB AWOS manufacturer's (All Weather Inc.) Maintenance Manual 907-027 provided by the FWB AWOS technician (see Attachment 6) does not provide information on tri-annual maintenance but identifies "Check system clock; adjust if error >1 minute" in the AWOS Monthly Technical Performance Record form. According to All Weather Inc. (see Attachment 6), this manual provides guidance that the clock on the -900 model AWOS (the type that was installed at FWB) should be checked (and adjusted as needed) once per month. The FWB AWOS technician stated that "…I have about 2 out of 75 airports that do monthly maintenance, and it's a little ambiguous on the rules. Yes, the monthly maintenance does include setting the clock...but the FAA rules prohibit anyone but the Technician of Record from making adjustments to the AWOS. To me, that's contradictory. [Airports] will ususally [sic] call me if it's noticed between maintenance visits, and I will correct it remotely." Further information provided by the FWB AWOS technician related to clock drift with other AWOSs is found in Attachment 6.

[15] http://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_150_5220-16E.pdf

Communication with the FAA, Vaisala and All Weather Inc. regarding AWOS clock drift, data dissemination or maintenance is documented in Attachment 7.

One-minute observations (OMO) from FWB were acquired from the FWB AWOS technician and selected parameters[16] are presented below for observations with timestamps surrounding the accident time. See Attachment 8 for the complete raw FWB OMO dataset with timestamps between 1800 and 2000 CDT on July 19, 2018.

Time	W_Dir	W_Mag	G_Mag	Vis	WX	T	dT	W_Var	Precip	LX_Dir
1835	030	3	---	10+	VCTS	30	25	---	434	DW AND NW
1836	040	3	---	10+	VCTS	30	25	---	434	W AND NW
1837	040	3	---	10	VCTS	30	25	---	434	DW AND NW
1838	020	4	---	10	VCTS	30	25	---	434	DW AND NW
1839	010	8	---	9	VCTS	30	25	---	434	W AND NW
1840	360	13	22	9	VCTS	30	25	---	434	DW AND NW
1841	360	23	37	9	VCTS	30	24	---	434	DW AND NW
1842	010	27	37	9	VCTS	30	24	---	434	DW-N
1843	360	25	37	9	VCTS	30	23	---	434	DW-NE
1844	360	30	49	9	VCTS	30	23	340V040	434	DW-NE
1845	360	31	49	8	VCTS	29	21	340V040	434	W-NE
1846	350	25	49	8	VCTS	29	20	330V040	434	DW-NE
1847	340	27	49	8	VCTS	29	19	310V020	434	DW-NE
1848	340	27	49	8	VCTS	28	18	310V020	434	W-NE
1849	350	25	49	8	VCTS	28	17	310V030	434	DW-NE
1850	340	25	49	8	VCTS	28	17	310V030	434	DW-NE
1851	350	20	49	7	VCTS	28	17	310V010	434	DW-NE
1852	340	18	49	7	VCTS	27	17	320V030	434	DW-NE
1853	330	21	49	7	TS	27	17	310V030	434	DW-NE
1854	340	25	49	7	TS	27	17	---	434	DW-NE
1855	350	27	45	7	TS	27	17	---	434	DALQDS
1856	350	27	40	6	TS HZ	26	17	---	434	DALQDS
1857	360	28	40	5	TS HZ	26	17	---	434	ALQDS
1858	350	28	40	5	TS HZ	25	17	---	434	D ALQDS
1859	350	26	40	4	TS HZ	25	18	---	434	N
1900	350	23	40	3	TS HZ	24	18	---	434	N
1901	360	23	40	3	TS HZ	24	18	---	434	N
1902	360	23	40	2-1/2	TS HZ	23	19	---	435	N
1903	010	20	40	2	TS HZ	23	19	---	435	N
1904	010	20	40	1-3/4	TS HZ	23	19	---	435	N
1905	010	18	40	1-1/2	TS HZ	22	19	---	435	N
1906	020	16	40	1-1/2	TS BR	22	19	---	435	N
1907	020	15	40	1-1/4	TS BR	22	19	---	435	N

[16] W_Dir = Direction of two-minute averaged wind; W_Mag = Magnitude of two-minute averaged wind (knots); G_Mag = Magnitude of five-second averaged wind (knots); Vis = Visibility (statute miles); WX = Present weather (VCTS = thunderstorm in the vicinity, TS = thunderstorm, HZ = haze, BR = mist); T = Temperature (°C); dT = Dewpoint temperature (°C); W_Var = variable wind direction; Precip = Incremental rain counter (hundredths of an inch); LX_Dir = Direction of distant lightning (cardinal and intercardinal direction abbreviations, prefix "D" relates to the state of the day/night sensor, hyphen means "through" [e.g., W-NE = west through northeast], ALQDS = all quadrants)

5.5.1. Additional Observations

An Automated Surface Observing System was located at Springfield-Branson National Airport (SGF) in Springfield, Missouri, which was located about 40 miles north of the accident location (see Figure 18) at an elevation of about 1,270 feet. The following are publicly-disseminated human-augmented reports from SGF during times leading to the accident time.

[1705 CDT] SPECI KSGF 192205Z 36008KT 10SM -RA FEW055 FEW095 SCT110 32/22 A2988 RMK AO2 RAB00 P0000 T03220217=

[1752 CDT] METAR KSGF 192252Z 02003KT 10SM CLR 33/19 A2987 RMK AO2 RAB00E14 SLP098 P0000 T03330194=

[1822 CDT] SPECI KSGF 192322Z 32036G57KT 9SM SQ FEW025 FEW047 SCT110 26/19 A3000 RMK AO2 PK WND 31057/2322 LTG DSNT W-N PRESRR T02560189=

[1833 CDT] SPECI KSGF 192333Z 31029G47KT 2 1/2SM VCTS -RA FEW043 SCT080 BKN110 22/19 A2999 RMK AO2 PK WND 32064/2323 LTG DSNT SW-N RAB24 P0000 T02220189=

[1839 CDT] SPECI KSGF 192339Z 34026G47KT 1 1/2SM +TSRA SCT045 BKN075 BKN100 22/18 A2998 RMK AO2 PK WND 32064/2323 LTG DSNT SW-NW RAB24 TSB39 P0008 T02220183=

At 1822 CDT, SGF reported a wind from 320° at 36 knots with gusts to 57 knots, visibility 9 statute miles, squall[17], few[18] clouds at 2,500 feet agl, few clouds at 4,700 feet agl, scattered clouds at 11,000 feet agl, temperature of 26°C and a dew point temperature of 19°C, altimeter setting of 30.00 inches of mercury; Remarks: station with a precipitation discriminator, peak wind of 57 knots from 310° at 1822 CDT, lightning distant west through north, pressure rising rapidly, temperature of 25.6°C and dew point temperature of 18.9°C.

At 1833 CDT, SGF reported a wind from 310° at 29 knots with gusts to 47 knots, visibility 2 and one-half statute miles, thunderstorm in the vicinity, light rain, few clouds at 4,300 feet agl, scattered clouds at 8,000 feet agl, broken clouds at 11,000 feet agl, temperature of 22°C and a dew point temperature of 19°C, altimeter setting of 29.99 inches of mercury; Remarks: station with a precipitation discriminator, peak wind of 64 knots from 320° at 1823 CDT, lightning distant southwest through north, rain began at 1824 CDT, trace liquid-equivalent precipitation since 1752 CDT, temperature of 22.2°C and dew point temperature of 18.9°C.

An AWOS was located at Monett Regional Airport (HFJ) in Monett, Missouri, which was located about 39 miles northwest of the accident location (see Figure 18) at an elevation of about 1,315

[17] Squall - wind speed suddenly increases by at least 16 knots and is sustained at 22 knots or more for at least one minute.

[18] "Few" means cloud are present but cover no more than 2/8 of the sky at that altitude.

feet. The following are publicly-disseminated automated reports from HFJ during times leading to the accident time.

[1750 CDT] METAR KHFJ 192250Z AUTO 04004KT 10SM CLR 34/21 A2987 RMK AO2 LTG DSNT N AND NW=

[1810 CDT] METAR KHFJ 192310Z AUTO 35014G20KT 10SM TS SCT065 31/21 A2992 RMK AO2 LTG DSNT N AND NE=

[1830 CDT] METAR KHFJ 192330Z AUTO 04021G31KT 10SM -VCTSRA SCT050 SCT070 BKN110 23/18 A2988 RMK AO2 LTG DSNT ALQS=

[1850 CDT] METAR KHFJ 192350Z AUTO 05012G20KT 10SM -TSRA SCT035 SCT060 SCT090 21/20 A2987 RMK AO2 LTG DSNT NE THRU S=

At 1810 CDT, HFJ reported a wind from 350° at 14 knots with gusts to 20 knots, visibility 10 statute miles or greater, thunderstorm, scattered clouds at 6,500 feet agl, temperature of 31°C and a dew point temperature of 21°C, altimeter setting of 29.92 inches of mercury; Remarks: station with a precipitation discriminator, lightning distant to the north and northeast.

At 1830 CDT, HFJ reported a wind from 040° at 21 knots with gusts to 31 knots, visibility 10 statute miles or greater, thunderstorm with light rain in the vicinity, scattered clouds at 5,000 feet agl, scattered clouds at 7,000 feet agl, broken clouds at 11,000 feet agl, temperature of 23°C and a dew point temperature of 18°C, altimeter setting of 29.88 inches of mercury; Remarks: station with a precipitation discriminator, lightning distant in all quadrants.

An AWOS was located at Branson Airport (BBG) in Branson, Missouri, which was located about 7 miles southeast of the accident location (see Figure 18) at an elevation of about 1,300 feet. The following are publicly-disseminated human-augmented reports from BBG during the times surrounding the accident time.

[1850 CDT] METAR KBBG 192350Z 06005KT 10SM VCTS SCT050 BKN250 33/22A2989 RMK LTG DSNT NW=

[1910 CDT] SPECI KBBG 200010Z 34030G45KT 10SM VCTS BKN050 32/22 A2996 RMK LTG DSNT W-NE=

[1925 CDT] SPECI KBBG 200025Z 34036G55KT 2SM TSRA BKN010 25/22 A3004 RMK OCNL LTG ICCG TS OHD MOV SE=

[1945 CDT] METAR KBBG 200045Z 05008KT 10SM VCTS SCT026 SCT048 BKN100 21/18 A2995 RMK LTG DSNT E-SW=

At 1910 CDT, BBG reported a wind from 340° at 30 knots with gusts to 45 knots, visibility 10 statute miles or greater, thunderstorm in the vicinity, broken clouds at 5,000 feet agl, temperature

of 32°C and a dew point temperature of 22°C, altimeter setting of 29.96 inches of mercury; Remarks: lightning distant west through northeast.

At 1925 CDT, BBG reported a wind from 340° at 36 knots with gusts to 55 knots, visibility 2 statute miles, thunderstorm with moderate rain, broken clouds at 1,000 feet agl, temperature of 25°C and a dew point temperature of 22°C, altimeter setting of 30.04 inches of mercury; Remarks: occasional intracloud and cloud-to-ground lightning, thunderstorm overhead moving southeast.

Selected parameters from the OMO from BBG are presented below for observations during times surrounding the accident time. See Attachment 8 for the complete raw BBG OMO dataset with timestamps between 1800 and 2000 CDT on July 19, 2018.

Time	W_Dir	W_Mag	G_Mag	Vis	WX	T	dT	W_Var	Precip	LX_Dir
1900	000	0	---	9	VCTS	32	22	---	023	D W-NE
1901	000	0	---	9	VCTS	32	22	---	023	D W-NE
1902	000	0	---	9	VCTS	32	22	---	023	D W-NE
1903	360	4	---	9	VCTS	32	22	---	023	D W-NE
1904	350	7	---	10	VCTS	32	22	---	023	D W-NE
1905	350	10	16	10+	VCTS	32	22	---	023	D W-NE
1906	340	13	21	10	VCTS	32	22	---	023	D W-NE
1907	350	19	35	10	VCTS	32	22	---	023	D W-NE
1908	350	26	35	9	VCTS	32	22	---	023	D W-NE
1909	350	30	36	9	VCTS	32	21	---	023	D W-NE
1910	340	35	43	8	VCTS	32	20	---	023	D W-NE
1911	340	36	43	8	VCTS	31	19	---	023	D W-NE
1912	330	37	43	8	VCTS	31	18	---	023	D ALQDS
1913	330	34	43	7	VCTS	30	17	---	023	D ALQDS
1914	330	32	43	7	VCTS	30	17	---	023	D ALQDS
1915	000	0	---	---	---	---	---	---	000	---
1916	---	---	---	---	---	---	---	---	000	N
1917	---	---	---	---	---	---	---	---	000	N
1918	340	20	25	---	---	---	---	---	000	N
1919	350	19	25	---	---	---	---	---	003	N
1920	340	19	25	---	+RA	---	---	---	006	N
1921	350	17	25	---	+RA	25	18	---	009	N
1922	360	14	25	---	+RA	25	18	---	015	N

An unofficial meteorological reporting station (F1021) whose data were provided courtesy of the *Automatic Position Reporting System as a WX NETwork* (APRSWXNET; via MesoWest[19]) was located about 4 miles west of the accident site at an elevation of about 1,115 feet. Calibration, maintenance and siting standards of this station, as well as the overall quality of the data, are not known. Reports[20] from this station during the times surrounding the accident time are presented here:

[19] https://mesowest.utah.edu/cgi-bin/droman/meso_base_dyn.cgi?stn=F1021

[20] Temp=temperature(°Fahrenheit [°F]); D_Temp=dew point temperature(°F); RH=relative humidity(%); W_Mag=average wind magnitude(knots); W_Dir=average wind direction(true); G_Mag=gust wind magnitude(knots)

Time	Temp	D-Temp	RH	W_Mag	W_Dir	G_Mag
1800	93.0	74.5	55	0.0	---	2.6
1810	91.0	75.7	61	0.0	---	2.6
1820	90.0	72.3	56	0.0	---	1.7
1830	89.0	73.9	61	0.0	---	1.7
1840	89.0	73.9	61	1.7	028°	4.3
1850	89.0	73.9	61	0.9	351°	4.3
1900	87.0	74.8	67	3.5	327°	24.3
1910	82.0	65.3	57	12.2	332°	34.8
1920	79.0	65.8	64	9.6	330°	35.6
1930	74.0	67.4	80	8.7	300°	35.6
1940	72.0	68.6	89	4.3	316°	18.2
1950	72.0	68.9	90	0.9	055°	15.7
2000	72.0	68.9	90	0.9	063°	6.1

An unofficial meteorological reporting station (F2149) whose data were provided courtesy of the APRSWXNET (via MesoWest[21]) was located about 5.5 miles north-northeast of the accident site at an elevation of about 1,045 feet. Calibration, maintenance and siting standards of this station, as well as the overall quality of the data, are not known. Reports from this station during the times surrounding the accident time are presented here:

Time	Temp	D-Temp	RH	W_Mag	W_Dir	G_Mag
1803	95.0	71.7	47	1.7	152°	7.0
1818	94.0	70.8	47	3.5	167°	7.8
1833	93.0	69.9	47	0.9	208°	3.5
1848	93.0	69.9	47	2.6	044°	5.2
1903	87.0	63.2	45	18.2	320°	35.6
1918	---	---	74	20.0	016°	43.4
1933	73.0	64.2	74	9.6	096°	21.7
1948	70.0	64.9	84	3.5	145°	11.3

The Branson, Missouri, Fire Department operated a weather station at two of their facilities in Branson, Missouri (identified as FD1 and FD2 in Figure 18), and their raw data are presented in Attachment 8. Every 30 minutes these stations reported the maximum wind magnitude retrieved over the previous 30 minutes.[22] On the night of the accident, FD1 (located at 251 Branson Meadows Drive in Branson, Missouri) indicated the maximum wind magnitude that occurred between 1901 and 1930 CDT was 57 mph (about 50 knots) from the north-northwest. FD2 (located at 110 Crosby Street in Branson, Missouri) indicated the maximum wind magnitude that occurred between 1901 and 1930 CDT was 43 mph (about 37 knots) from the north-northwest.

[21] https://mesowest.utah.edu/cgi-bin/droman/meso_base_dyn.cgi?stn=F1021

[22] Type of stations and sampling strategy of each station are unknown.

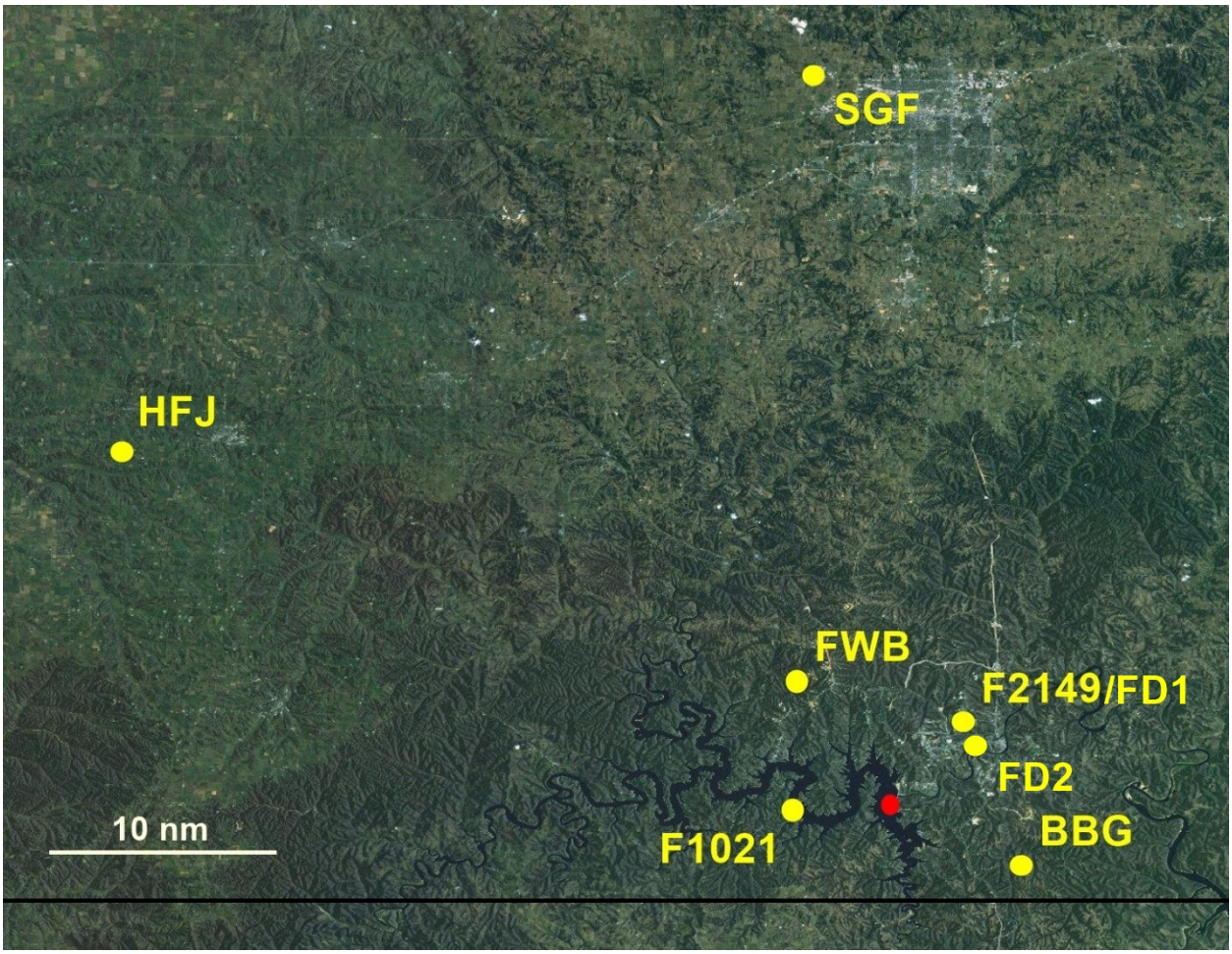


Figure 18 *– Map of selected regional surface weather stations. Accident site is denoted by red circle.*

5.6. Rawinsonde Data

An atmospheric sounding (figure 19) was obtained from a rawinsonde launch at the NWS Weather Forecast Office (WFO) in Springfield, Missouri, around 1300 CDT on July 19, 2018. The most-unstable Convective Available Potential Energy (CAPE) parameter was 3,160 Joules/kilogram (from 967 hectopascals [hPa]). The Lifting Condensation Level (LCL) and Level of Free Convection (LFC) for this scenario were calculated to be 4,182 and 5,550 feet, respectively. Maximum vertical velocity (MVV) for the most-unstable atmosphere was calculated as 79 meters/second (about 154 knots).[23] Downdraft CAPE (DCAPE; 6 kilometers above ground level; coldest wetbulb temperature method) was measured at 1,359 Joules/kilogram.[24] The T2Gust ("Severe Weather Gust Potential") and WindEx ("Microburst Gust Potential") parameters were 54 knots and 62 knots, respectively.

[23] MVV is not usually considered a realistic estimate for maximum vertical velocity in a storm. Anecdotes suggest considering a value of MVV/2, however it is not well understood when or where such a half-value should be applied.

[24] The DCAPE can be used to estimate the potential strength of rain-cooled downdrafts within thunderstorm convection.

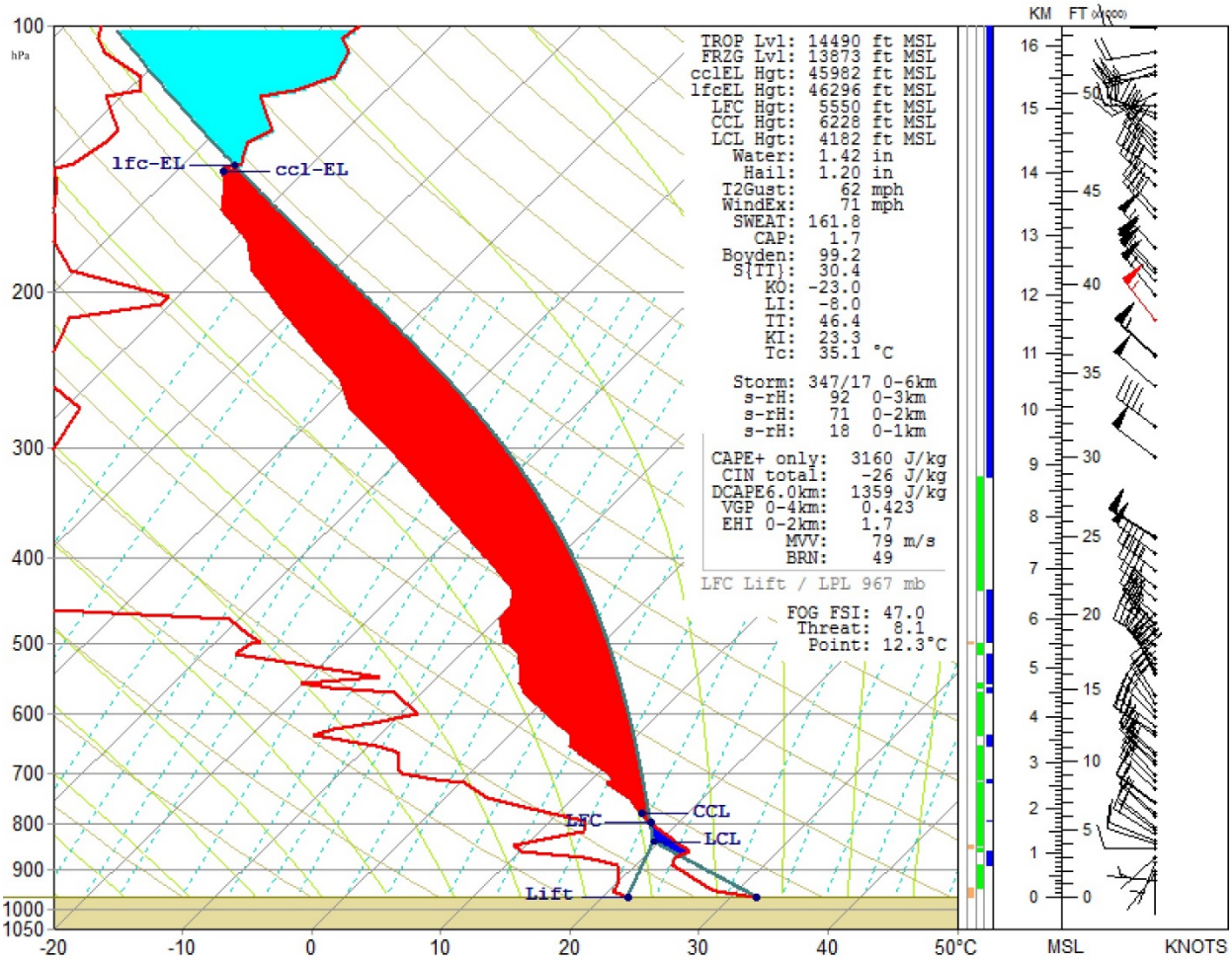


Figure 19 *– NWS Springfield WFO atmospheric sounding data in SkewT/LogP format for about 1300 CDT, surface to 100 hPa.*

5.7. Satellite

Geostationary Operational Environmental Satellite (GOES)-16 “visible” (0.64µm) and infrared (10.3µm) data were obtained from an archive at the Space Science Engineering Center at the University of Wisconsin-Madison. Imagery from 1702, 1732, 1802, 1832 and 1907 CDT are presented in figures 20-25. These figures have not been corrected for any parallax error.

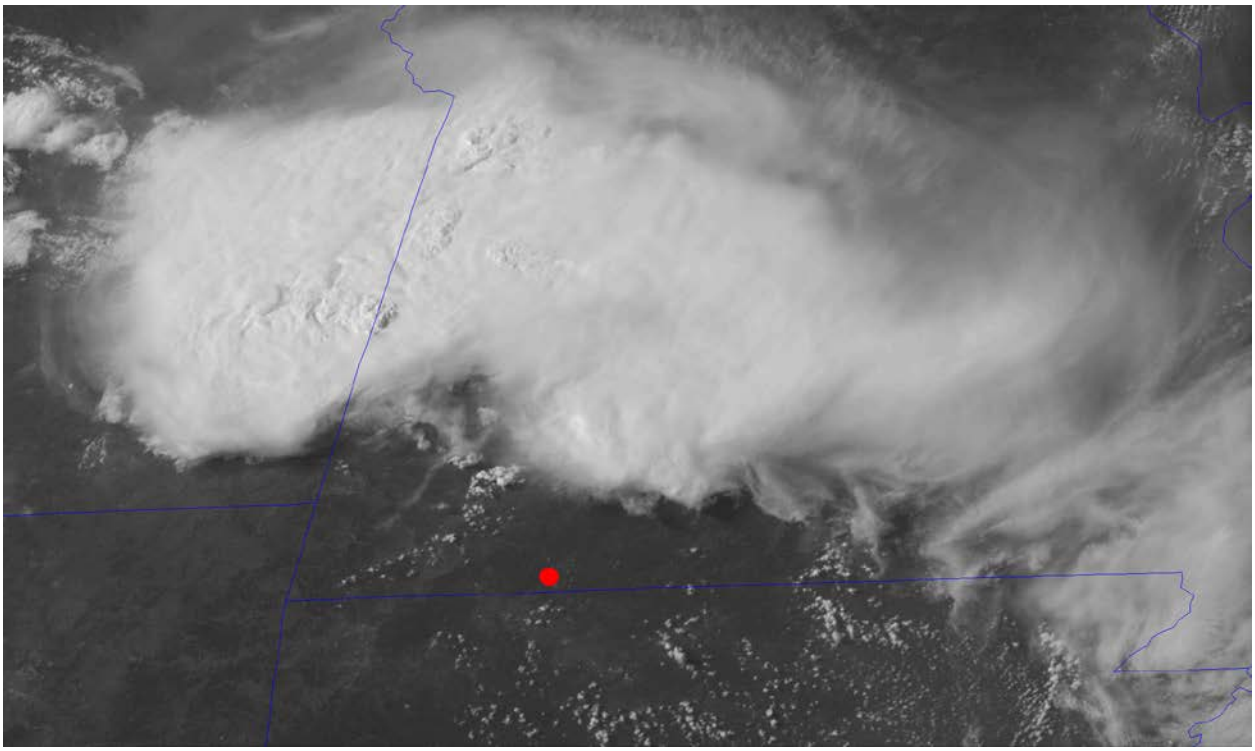


Figure 20 *– GOES-16 visible imagery from 1702 CDT. Accident location denoted by red circle.*

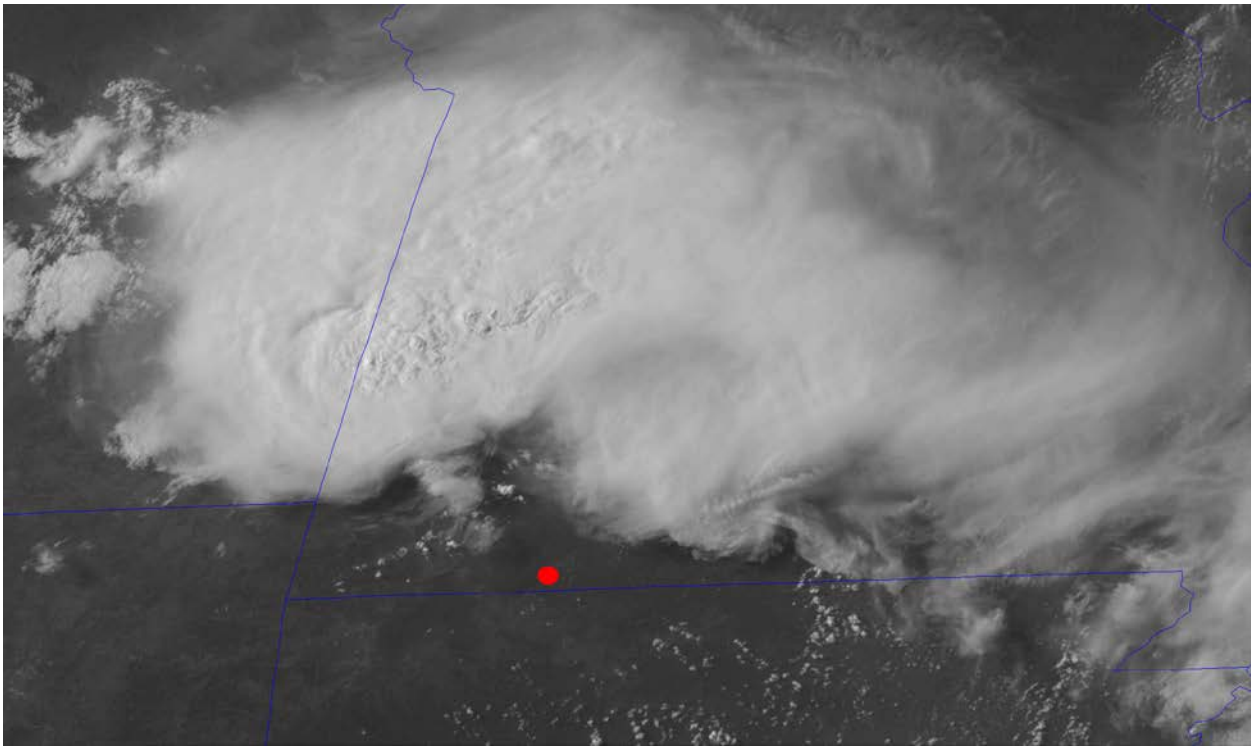


Figure 21 *– GOES-16 visible imagery from 1732 CDT. Accident location denoted by red circle.*

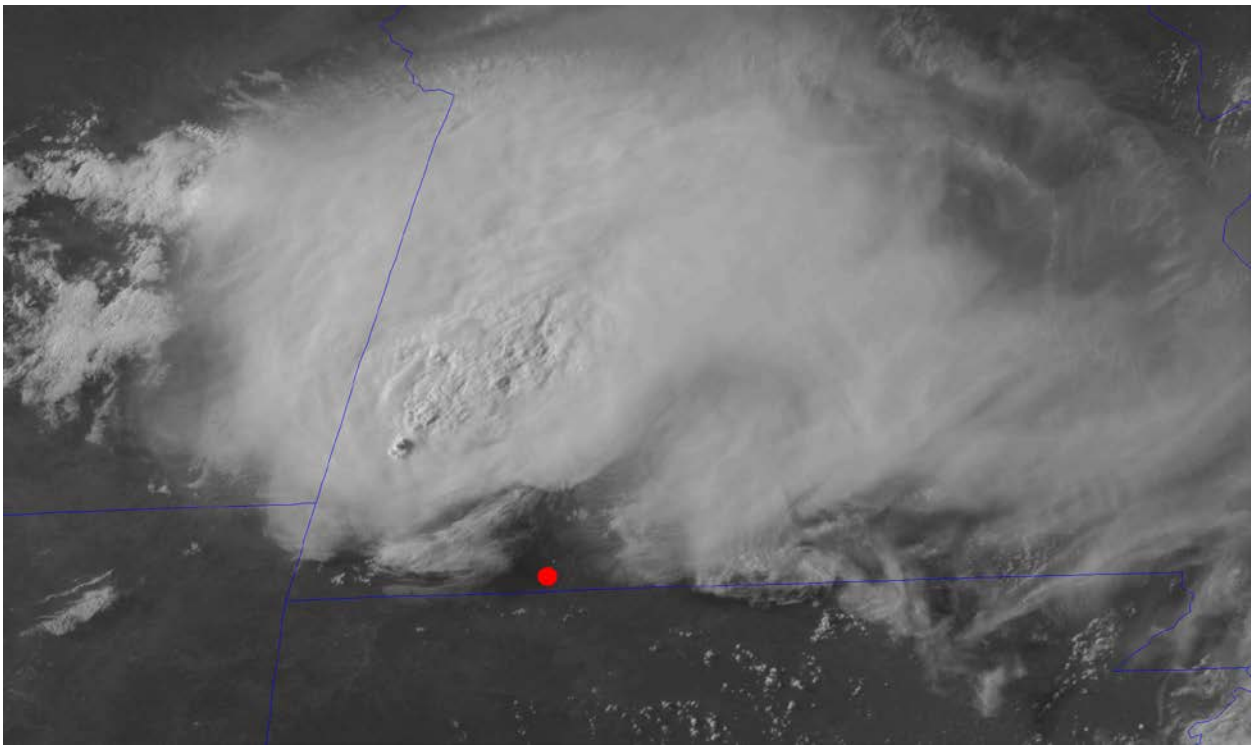


Figure 22 *– GOES-16 visible imagery from 1802 CDT. Accident location denoted by red circle.*

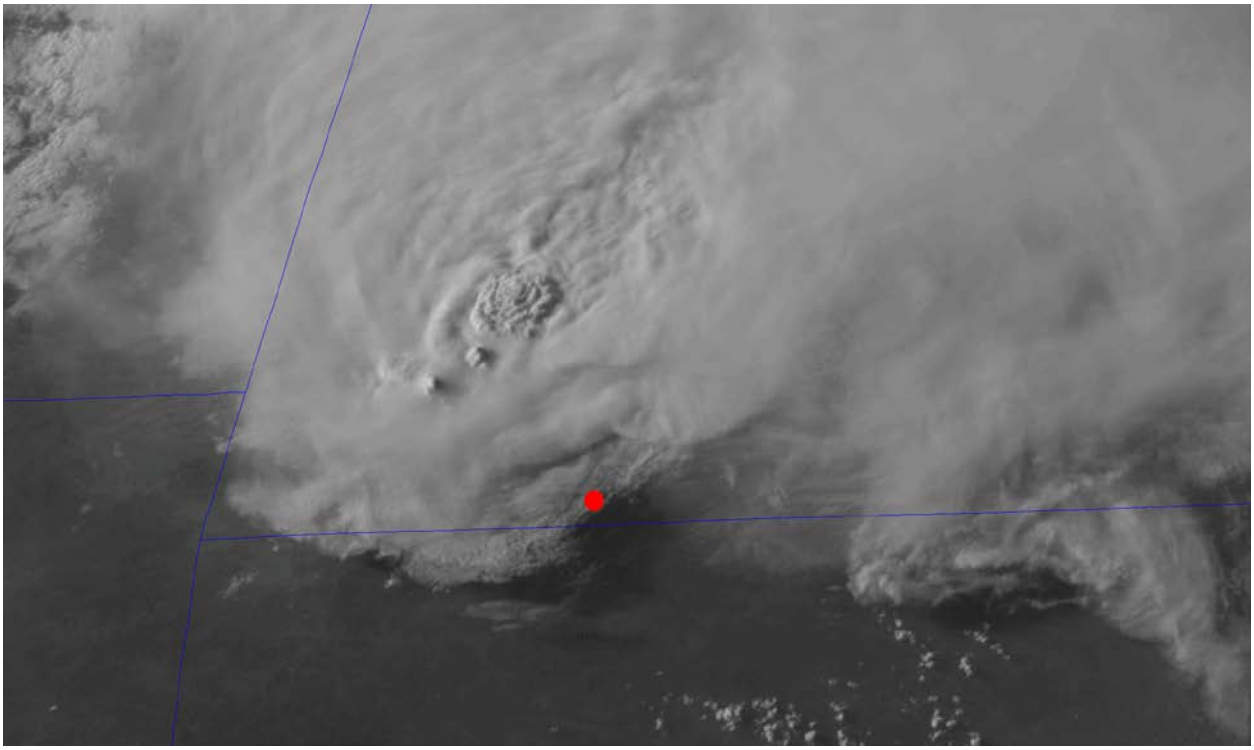


Figure 23 *– GOES-16 visible imagery from 1832 CDT. Accident location denoted by red circle.*

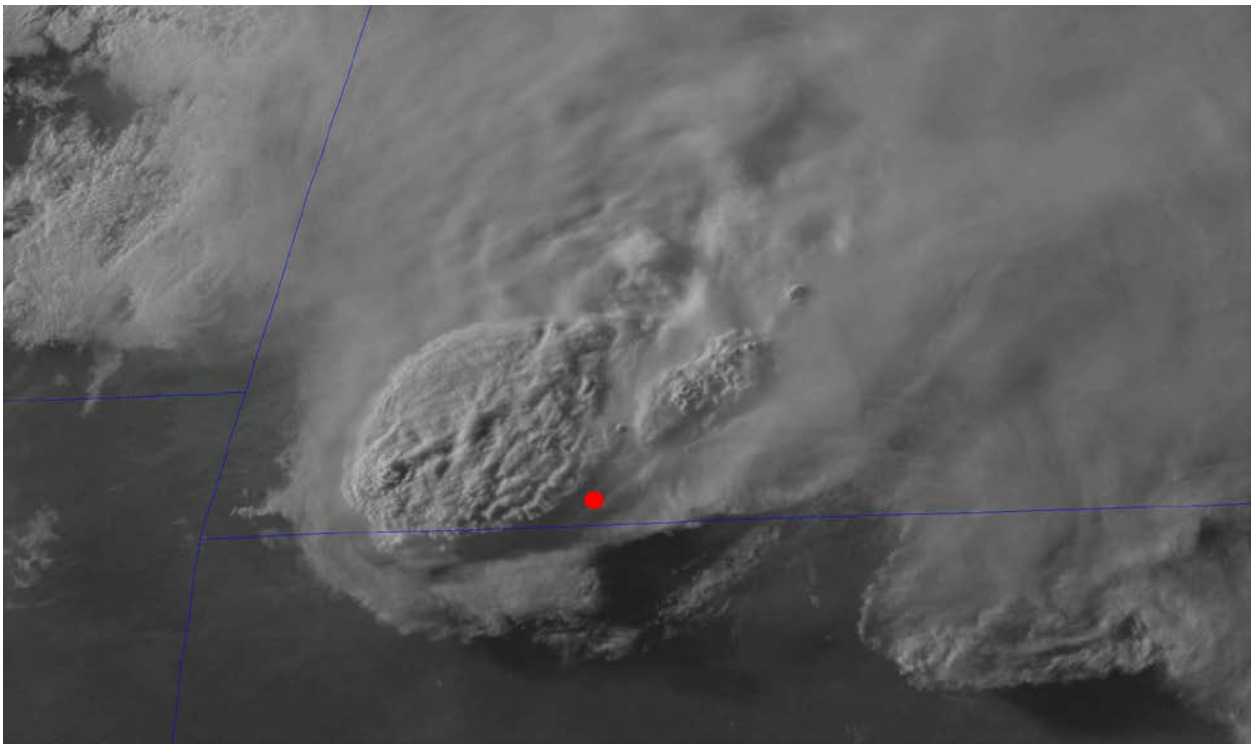


Figure 24 *– GOES-16 visible imagery from 1907 CDT. Accident location denoted by red circle.*

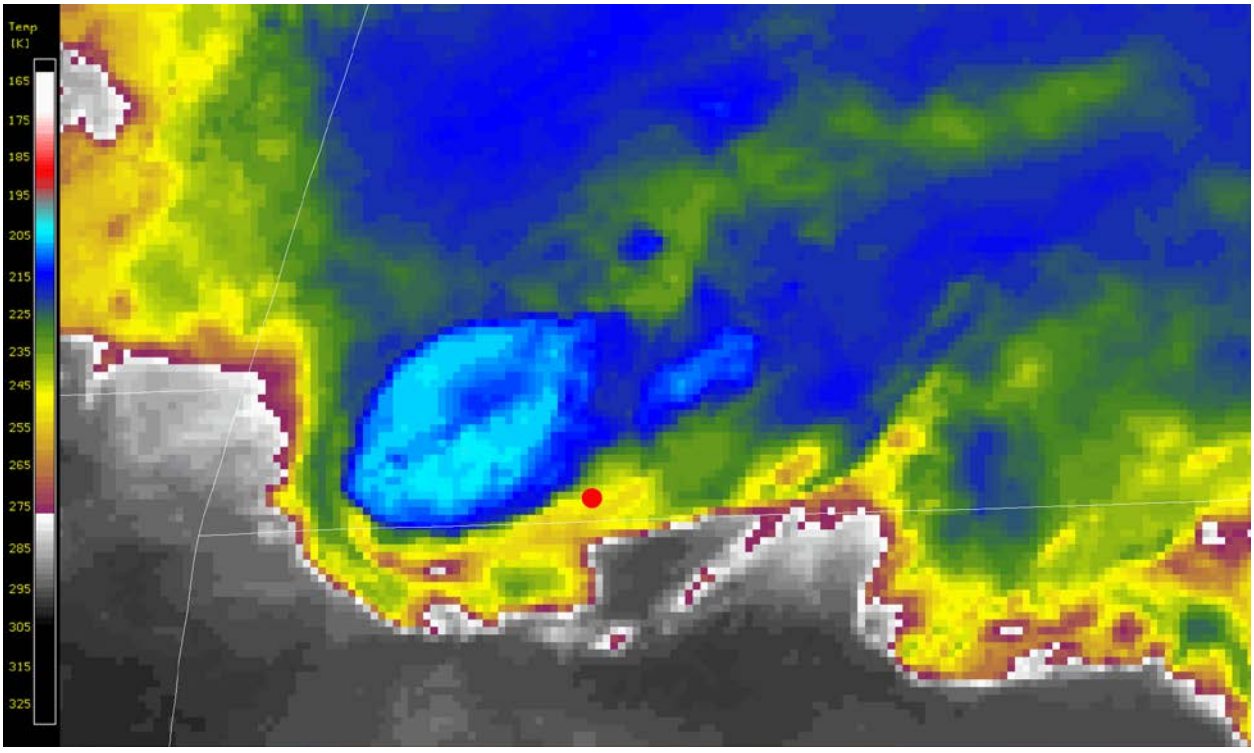


Figure 25 *– GOES-16 infrared imagery from 1907CDT. Accident location denoted by red circle.*

5.8. Local Storm Reports

Attachment 9 contains Local Storm Reports (LSR) issued by the NWS Springfield WFO with event times between 1231 and 2030 CDT on July 19, 2018. These preliminary reports were quality-controlled by the NWS Springfield WFO prior to public dissemination. The report times in Attachment 9 are preliminary times for the listed events. Actual public dissemination times of individual reports could be different from the preliminary times.[25] According to the Meteorologist in Charge (MIC) of the NWS Springfield WFO, LSRs are used to distribute hazardous weather reports, and are issued as reports are received. Delayed reports are disseminated after an event has ended as well, and reports can come in via phone, social media, email and other vehicles.

A communications log for Stone County can be found in the NTSB public for this accident that contains additional reports of local damage from the accident region.

5.9. National Weather Service Products

5.9.1. Springfield Weather Forecast Office Products

5.9.1.1. Severe Thunderstorm Warnings

NWS Severe Thunderstorm Warnings (SVRs) are issued by NWS WFOs. According to NWSI 10-511 current as of July 19, 2018 (Attachment 10), "WFOs should issue SVRs when there is radar or satellite indication and/or reliable reports of wind gusts equal to or in excess of 50 knots (58 mph) and/or hail size of one inch (U.S. quarter-size) diameter or larger. WFOs may issue SVRs for a convective squall with little or no lightning that otherwise meets or exceeds hail and/or wind warning criterion. A SVR may also be issued for potential tornados/landspouts within thunderstorms that also are forecasted to meet or exceed the minimum damaging wind gust and/or large hail criterion."

On July 19, 2018, the NWS Springfield WFO issued numerous SVRs associated with the derecho that impacted the accident location. Attachment 11 presents all[26] NWS Springfield WFO SVRs issued between 1630 and 1908 CDT, as well as depictions of these SVRs issued after 1800 CDT on the accident day. According to the MIC of the NWS Springfield WFO, text of the SVRs include a description of the hazard(s), risk(s), impact(s) and timing of anticipated weather within a polygon.

At 1832 CDT on July 19, 2018, the NWS Springfield WFO issued the following SVR, which was effective immediately and was active for an area that included the accident location (the SVR identified Branson and Table Rock Lake as impacted locations) until 1930 CDT. The SVR indicated that "At 631 PM CDT, severe thunderstorms were located along a line extending from near Sparta to near Wheaton, moving southeast at 50 mph," and advised of 60 mph wind gusts. Event (i.e., hazard) location was more specifically identified in text near the end of the SVR, shown

[25] According to the MIC of the NWS Springfield WFO, Preliminary Local Storm Reports are further refined and certified for Storm Data publication no later than 60 days after the end of the month for which the data is valid. See National Weather Service Instruction (NWSI) 10-1605: https://www.nws.noaa.gov/directives/sym/pd01016005curr.pdf

[26] These may include SVRs not associated with the derecho.

here in green highlight (these coordinates depict a line with endpoints near Sparta, Missouri, and Wheaton, Missouri). Regarding the text line near the end of the SVR that identifies event location, according to NWSI 10-511, "The tracking information gives the location and movement of the event being tracked. Examples of such events could include the leading edge of a gust front or the leading edge of a hail core. The format…includes the time of the observed event in [UTC], followed by a three digit direction of movement in degrees (direction the event is moving from), followed by speed of movement in knots, and finally the location of the event as a single latitude/longitude coordinate, or in the case of a line, two or more latitude/longitude coordinates." The NWS Springfield WFO Senior Forecaster who had issued this SVR indicated that he had geographically defined the hazard (event) at that time by the location of the gust front ahead of the convective area because the gust front was the initial impact.[27]

```
WUUS53 KSGF 192332
SVRSGF
MOC009-209-213-200030-
/O.NEW.KSGF.SV.W.0243.180719T2332Z-180720T0030Z/

BULLETIN - IMMEDIATE BROADCAST REQUESTED
Severe Thunderstorm Warning
National Weather Service Springfield MO
632 PM CDT THU JUL 19 2018

The National Weather Service in Springfield has issued a

* Severe Thunderstorm Warning for...
  Taney County in southwestern Missouri...
  Stone County in southwestern Missouri...
  Barry County in southwestern Missouri...

* Until 730 PM CDT.

* At 631 PM CDT, severe thunderstorms were located along a line
  extending from near Sparta to near Wheaton, moving southeast
  at 50 mph.

  HAZARD...60 mph wind gusts.

  SOURCE...Radar indicated.

  IMPACT...Expect damage to roofs, siding, and trees.

* 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...
```

[27] He indicated that he learned from the Indiana State Fair collapse (2011) that he needed to warn for outflow boundaries (when they meet severe thunderstorm criteria).

```
  Exeter...                          Wheaton...

PRECAUTIONARY/PREPAREDNESS ACTIONS...

For your protection move to an interior room on the lowest floor
of a building.

Torrential rainfall is occurring with these storms, and may lead
to flash flooding. Do not drive your vehicle through flooded
roadways.

&&

LAT...LON 3650 9407 3682 9406 3680 9277 3650 9277
TIME...MOT...LOC 2331Z 316DEG 43KT 3706 9307 3679 9400

HAIL...<.75IN
WIND...60MPH

$$
```

Figure 26 depicts the SVR issued at 1832 CDT on July 19, 2018, overlaid onto KSGF weather radar imagery from a few minutes prior to that time. The figure also depicts the event location as defined in the SVR's tracking information (green highlight), as well as the distance (about 29 statute miles) from the event location to the accident site along the direction identified as the event's movement (from the main body of the SVR - southeast at 50 mph). Using these parameters and extrapolating, the event was expected to reach the accident site about 35 minutes later.

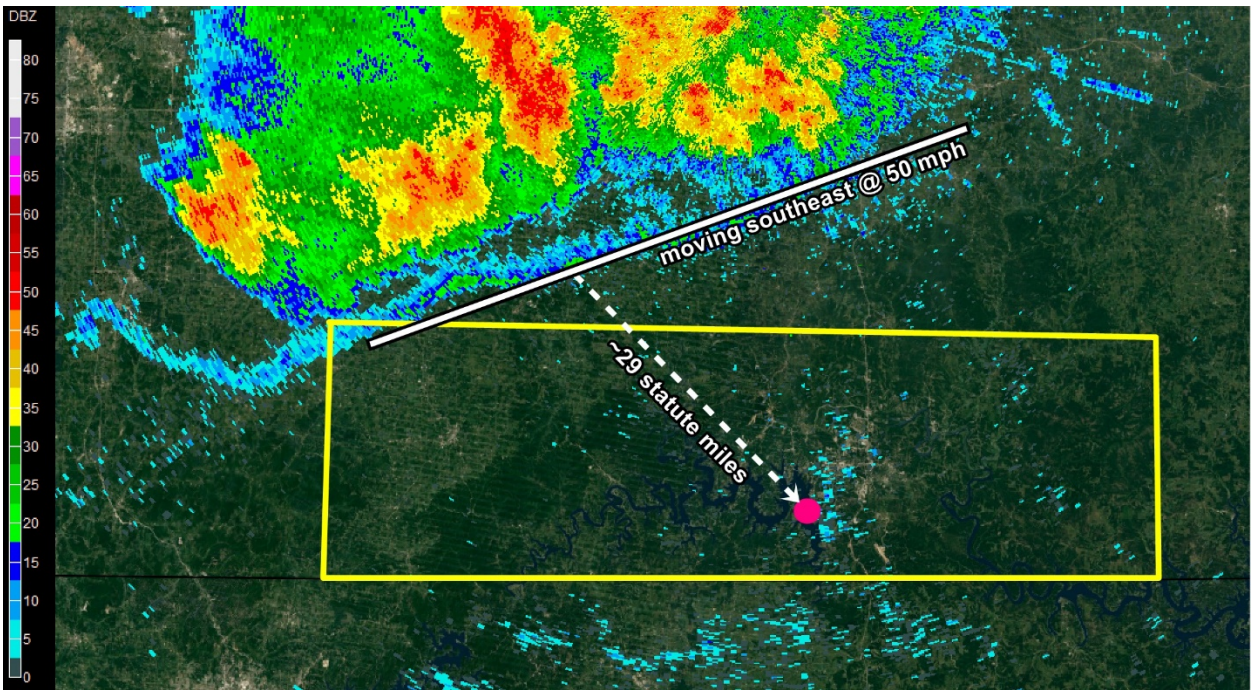


Figure 26 *– NWS Springfield WFO-issued SVR (yellow polygon) at 1832 CDT on July 19, 2018, overlaid on the Level-II KSGF ~0.5° base reflectivity imagery from a sweep that began about 1829:31 CDT. Event*

location is depicted by the solid white line and the accident location is denoted by the pink circle. The dashed white line shows the shortest path the event would take to the accident site if moving southeast (135°).

5.9.1.2. Severe Weather Statements

NWS Severe Weather Statements (SVSs) are issued by NWS WFOs. According to NWSI 10-511 current at as July 19, 2018 (Attachment 10), "[SVSs] provide the public and emergency managers with updated information for specific Severe Thunderstorm and Tornado Warnings. Updated information includes reports of observed severe weather. They also inform the public and emergency managers when all or portions of a warning have been canceled or have expired." With regard to the issuance of SVSs, NWSI 10-511 stated:

(1) WFOs should issue SVSs to address the status of severe weather warnings.

(2) WFOs will not use SVSs to expand in area or extend the valid time of [Tornado Warnings] and SVRs

(3) If the threat of severe weather clears a significant portion of the SVR or [Tornado Warnings] during the warning period, forecasters should update the latitude and longitude pairs of the polygon within the warned county or counties.

On July 19, 2018, the NWS Springfield WFO issued numerous SVSs associated with the derecho that impacted the accident location. Attachment 11 presents all[28] NWS Springfield WFO SVSs issued between 1630 and 1908 CDT, as well as depictions of these SVSs issued after 1800 CDT on the accident day. According to the MIC of the NWS Springfield WFO, text of the SVSs include a description of the hazard(s), risk(s), impact(s) and timing of anticipated weather within a polygon.

At 1902 CDT on July 19, 2018, the NWS Springfield WFO issued the following SVS, which was effective immediately and updated the (1) polygon, (2) wind hazard and (3) impact for the SVR issued by the NWS Springfield WFO at 1832 CDT on July 19, 2018. The updated polygon included the accident location (the SVS identified Branson and Table Rock Lake as impacted locations). The SVS indicated that "At 702 PM CDT, severe thunderstorms were located along a line extending from near Taneyville to Washburn, moving south at 30 mph," and advised of 70 mph wind gusts. Event location was more specifically identified in text near the end of the SVR, shown here in blue highlight (these coordinates depict a line with endpoints near Taneyville, Missouri, and Washburn, Missouri).

```
WWUS53 KSGF 200002
SVSSGF

Severe Weather Statement
National Weather Service Springfield MO
702 PM CDT THU JUL 19 2018
```

[28] These may include SVSs not associated with the derecho.

MOC009-209-213-200030-
/O.CON.KSGF.SV.W.0243.000000T0000Z-180720T0030Z/
Taney MO-Stone MO-Barry MO-
702 PM CDT THU JUL 19 2018

...A SEVERE THUNDERSTORM WARNING REMAINS IN EFFECT UNTIL 730 PM CDT FOR TANEY...STONE AND BARRY COUNTIES...

At 702 PM CDT, severe thunderstorms were located along a line extending from near Taneyville to Washburn, moving south at 30 mph.

HAZARD...70 mph wind gusts.

SOURCE...Radar indicated.

IMPACT...Expect considerable tree damage. Damage is likely to mobile homes, roofs, and outbuildings.

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...
Reeds Spring...	Seligman...
Rockaway Beach...	Exeter...
Bull Creek...	Indian Point...

PRECAUTIONARY/PREPAREDNESS ACTIONS...

For your protection move to an interior room on the lowest floor of a building.

Torrential rainfall is occurring with these storms, and may lead to flash flooding. Do not drive your vehicle through flooded roadways.

&&

LAT...LON 3664 9407 3670 9399 3671 9388 3682 9376 3680 9277 3650 9277 3650 9407
TIME...MOT...LOC 0002Z 339DEG 28KT 3678 9308 3660 9398

HAIL...<.75IN
WIND...70MPH

$$

Figure 27 depicts the SVS issued at 1902 CDT on July 19, 2018, overlaid onto KSGF weather radar imagery from a few minutes prior to that time. The figure also depicts the event location as defined in the SVS's tracking information (blue highlight), as well as the distance (about 10 statute miles) from the event location to the accident site along the direction identified as the event's

movement (from the main body of the SVS - south at 30 mph). Using these parameters and extrapolating, the event was expected to reach the accident site about 20 minutes later.

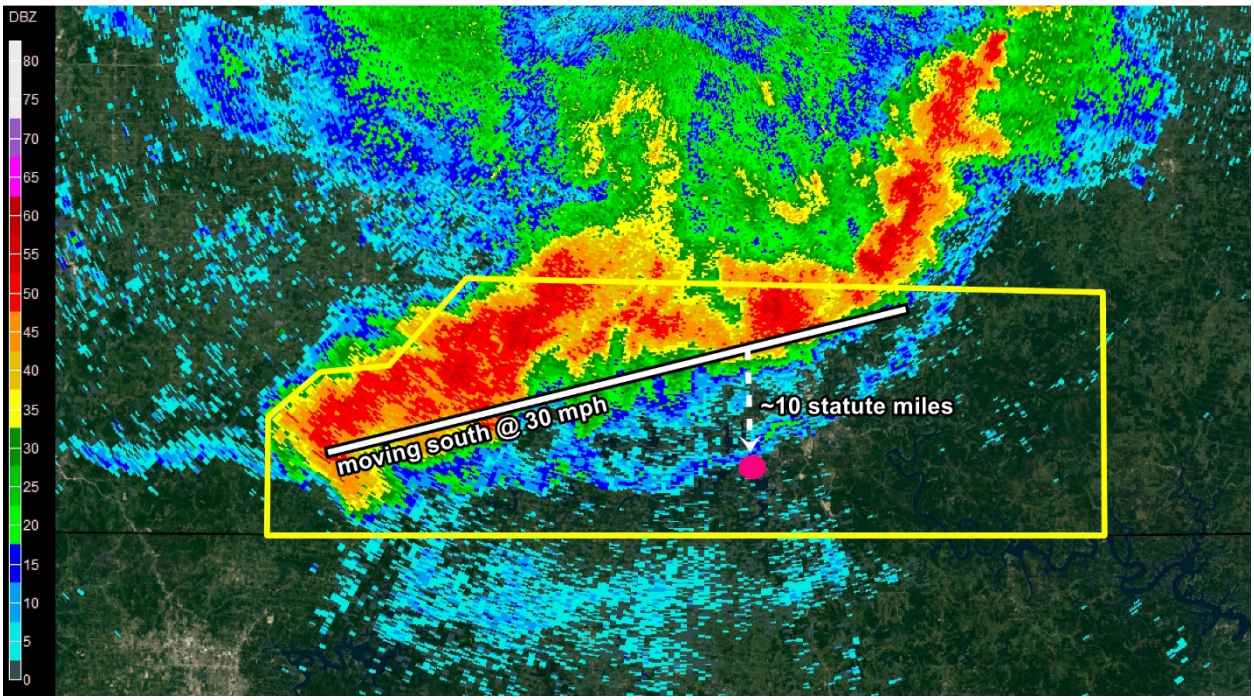


Figure 27 *– NWS Springfield WFO-issued SVS (yellow polygon) at 1902 CDT on July 19, 2018, overlaid on the Level-II KSGF ~0.5° base reflectivity imagery from a sweep that began about 1859:17 CDT. Event location is depicted by the solid white line and the accident location is denoted by the pink circle. The dashed white line shows the shortest path the event would take to the accident site moving south (180°).*

5.9.1.3. Terminal Aerodrome Forecasts

Terminal Aerodrome Forecasts (TAF) were issued for BBG by the NWS Springfield WFO and generally apply to an area within five statute miles of BBG. According to NWSI 10-813, "A NWS TAF consists of the expected meteorological conditions significant to aviation at an airport for a specified time period. For the U.S., this is the area within five (5) statute miles (SM) of the center of an airport's runway complex."[29]

The NWS BBG TAF issued at 1220 CDT forecasted for the accident time: wind from 190° at 6 knots, visibility greater than 6 statute miles, few clouds at 5,000 feet agl.

KBBG 191720Z **1918/2018 19006KT P6SM FEW050**
FM200600 15005KT P6SM SKC
FM201500 20010KT P6SM SKC=

[29] www.nws.noaa.gov/directives/sym/pd01008013curr.pdf

The NWS BBG TAF issued at 1820 CDT forecasted for the accident time: wind from 140° at 7 knots, visibility greater than 6 statute miles, few clouds at 5,000 feet agl.

KBBG 192320Z 2000/2024 **14007KT P6SM FEW050**
FM200600 15005KT P6SM SKC
FM201500 20010KT P6SM SKC=

The NWS BBG TAF issued at 1840 CDT forecasted for the accident time: wind from 140° at 7 knots, visibility greater than 6 statute miles, few clouds at 5,000 feet agl.

KBBG 192340Z 2000/2024 **14007KT P6SM FEW050**
FM200040 VRB30G40KT 2SM TSRA BR OVC035CB
FM200200 VRB04KT P6SM BKN250
FM200600 15005KT P6SM SKC
FM201500 20010KT P6SM SKC=

5.9.1.4. Other Springfield Weather Forecast Office Products

Zone Forecast Products, Area Forecast Discussions, Hazardous Weather Outlooks (HWO) and Watch County Notifications applicable to Stone County, Missouri, and Taney County, Missouri, issued by the NWS Springfield WFO on July 19, 2018, and prior to the accident time are presented in Attachment 12.

The "Discussion" section of the HWO issued by the NWS Springfield WFO at 1128 CDT on July 19, 2018, is presented here.

> A complex of strong to severe thunderstorms will impact portions of central and southern Missouri today. Hail up to the size of golf balls and damaging wind gusts up to 70 MPH will be the primary hazards with the most intense storms. Frequent lightning and locally heavy rainfall can also be expected from the storms today. There will be a limited threat for localized flash flooding across central Missouri and the eastern Ozarks.
>
> Heat index values of 100 to 110 degrees can be expected this afternoon and early this evening with the hottest readings occurring along and west of the Highway 65 corridor.

On July 19, 2018, the NWS Springfield WFO issued numerous graphics and videos related to the local severe weather that day on its website and social media accounts. Some of these products are presented in Attachment 13.

5.9.2. Storm Prediction Center

5.9.2.1. Convective Outlooks

The NWS SPC issues Convective Outlooks that depict non-severe and severe thunderstorm threats across the contiguous United States, along with a text narrative. According to the SPC, "The categorical forecast specifies the level of the overall severe weather threat via numbers (e.g., 5), descriptive labeling (e.g., HIGH), and colors (e.g., magenta) [see Figure 28]. The probabilistic forecast directly expresses the best estimate of a severe weather event occurring within 25 miles of a point… The level of categorical risk in the Day 1-3 Convective Outlooks is derived from probability forecasts of tornadoes, damaging winds, and large hail on Day 1…"[30]

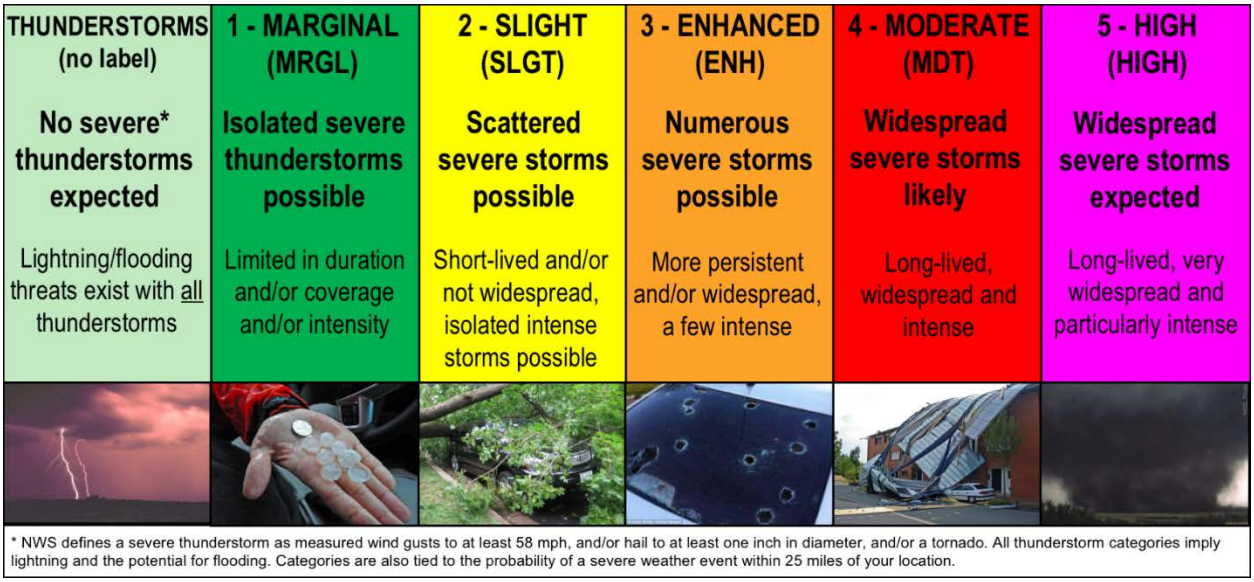


Figure 28 *– Convective Outlook categories.*

On July 19, 2018, the SPC issued four "Day 1" Convective Outlooks prior to the accident time. The text, graphic categorical outlook and graphic probabilistic damaging wind outlook portions of these Day 1 Convective Outlooks are presented in Attachment 14. The following is the text (applicable to the accident location), graphic categorical outlook (Figure 29) and graphic probabilistic damaging wind outlook (Figure 30) portions of the Day 1 Convective Outlook issued by the SPC at 1158 CDT on July 19, 2018.

```
SPC AC 191658

Day 1 Convective Outlook
NWS Storm Prediction Center Norman OK
1158 AM CDT Thu Jul 19 2018

Valid 191630Z - 201200Z
```

[30] https://www.spc.noaa.gov/misc/about.html#Convective Outlooks

...THERE IS A SLIGHT RISK OF SEVERE THUNDERSTORMS ACROSS PORTIONS OF THE MIDWEST...LOWER MO VALLEY/OZARKS...AND SOUTH-CENTRAL PLAINS...

...SUMMARY...
Scattered severe thunderstorms are expected through the afternoon and evening across portions of Iowa, Missouri, Kansas, western Illinois, and Arkansas.

...Central/southern MO to Mid-South...
Have expanded the Slight Risk southward across the region to account for increasing concerns that an increasingly well-organized complex of storms in central MO will continue southward across the region through the afternoon and evening. Additional storms should occur along outflow on the western flank of the early-day storm complex, while additional storms may move into MO late in the afternoon or evening out of KS. Ample moisture and buoyancy (2000+ J/kg MLCAPE) along with seasonably strong mid/high-level northwesterly winds will contribute to the potential for corridors of wind damage and large hail.

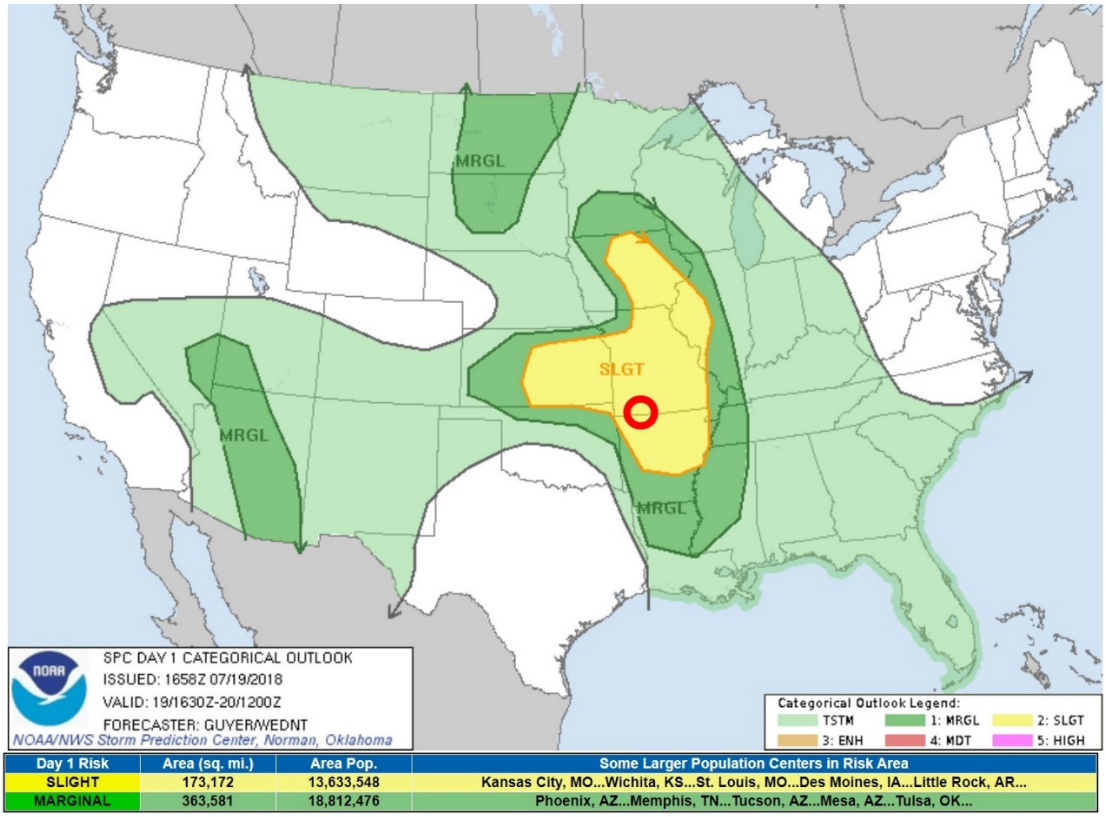
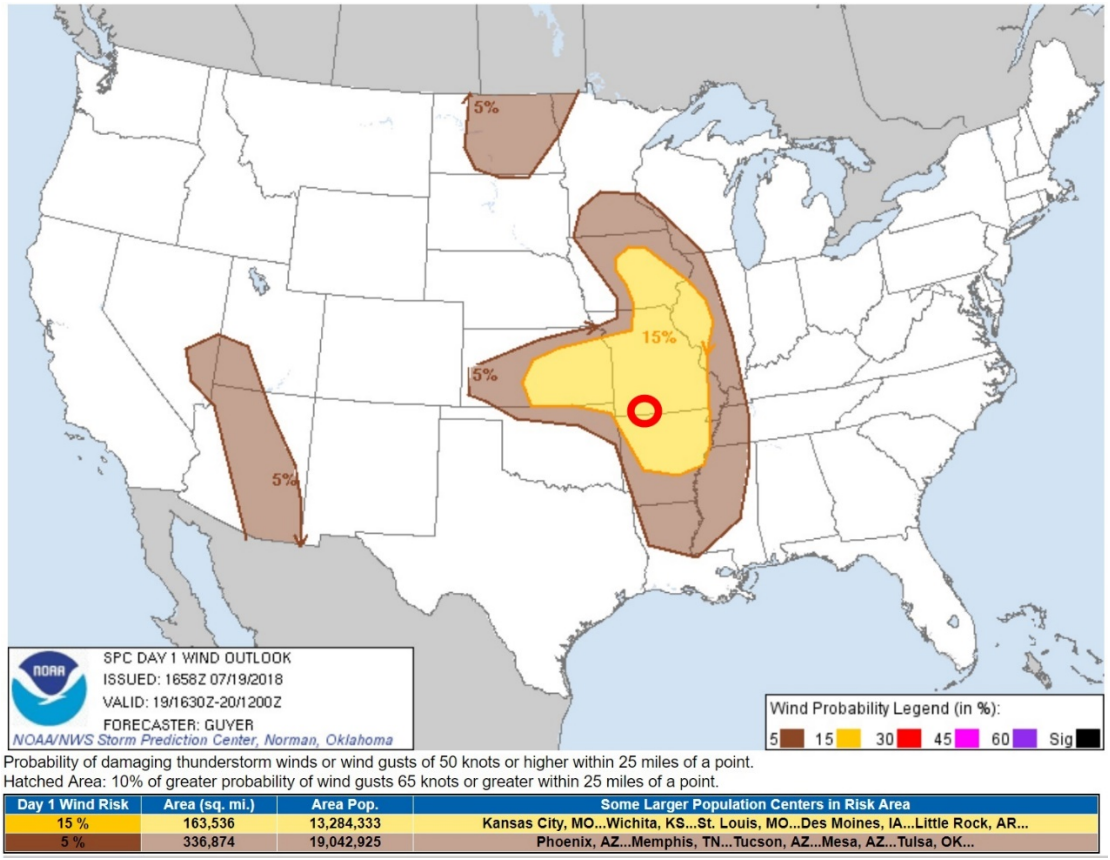


Figure 29 *– SPC Day 1 graphic categorical outlook issued at 1158 CDT on July 19, 2018. The red circle denotes the accident location.*



Day 1 Wind Risk	Area (sq. mi.)	Area Pop.	Some Larger Population Centers in Risk Area
15 %	163,536	13,284,333	Kansas City, MO...Wichita, KS...St. Louis, MO...Des Moines, IA...Little Rock, AR...
5 %	336,874	19,042,925	Phoenix, AZ...Memphis, TN...Tucson, AZ...Mesa, AZ...Tulsa, OK...

Figure 30 *– SPC Day 1 graphic damaging wind outlook issued at 1158 CDT on July 19, 2018. The red circle denotes the accident location.*

5.9.2.2. Mesoscale Discussions

SPC Mesoscale Discussions focus on severe thunderstorm potential over the continental United States for the next 6 hours with an emphasis on the first 1-3 hours from time of issuance. The following two Mesoscale Discussions issued by the SPC on July 19, 2018, were applicable to the accident region but not valid at the time of the accident.

The following Mesoscale Discussion (#1082; with associated graphic) was issued at 0958 CDT on July 19, 2018:

```
Mesoscale Discussion 1082
NWS Storm Prediction Center Norman OK
0958 AM CDT Thu Jul 19 2018

Areas affected...Portions of Missouri

Concerning...Severe potential...Watch possible

Valid 191458Z - 191700Z

Probability of Watch Issuance...40 percent

SUMMARY...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.

DISCUSSION...Regional radar and satellite data depict two distinct clusters of thunderstorm activity this morning over northern Missouri. Both appear to be aided by large-scale ascent along the southern fringe of a 500mb vorticity max near the mid Missouri Valley. Additionally, KEAX VWP data illustrate veering flow with height from the surface through approximately 3-4 km AGL, suggesting modest warm advection is also assisting convective growth.

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.

..Picca/Guyer.. 07/19/2018

...Please see www.spc.noaa.gov for graphic product...

ATTN...WFO...LSX...SGF...EAX...

LAT...LON 37219402 36879315 36869210 36919162 37389158 38779176
39759227 39909278 40249378 40399427 40319473 40069485
38329447 37539430 37219402

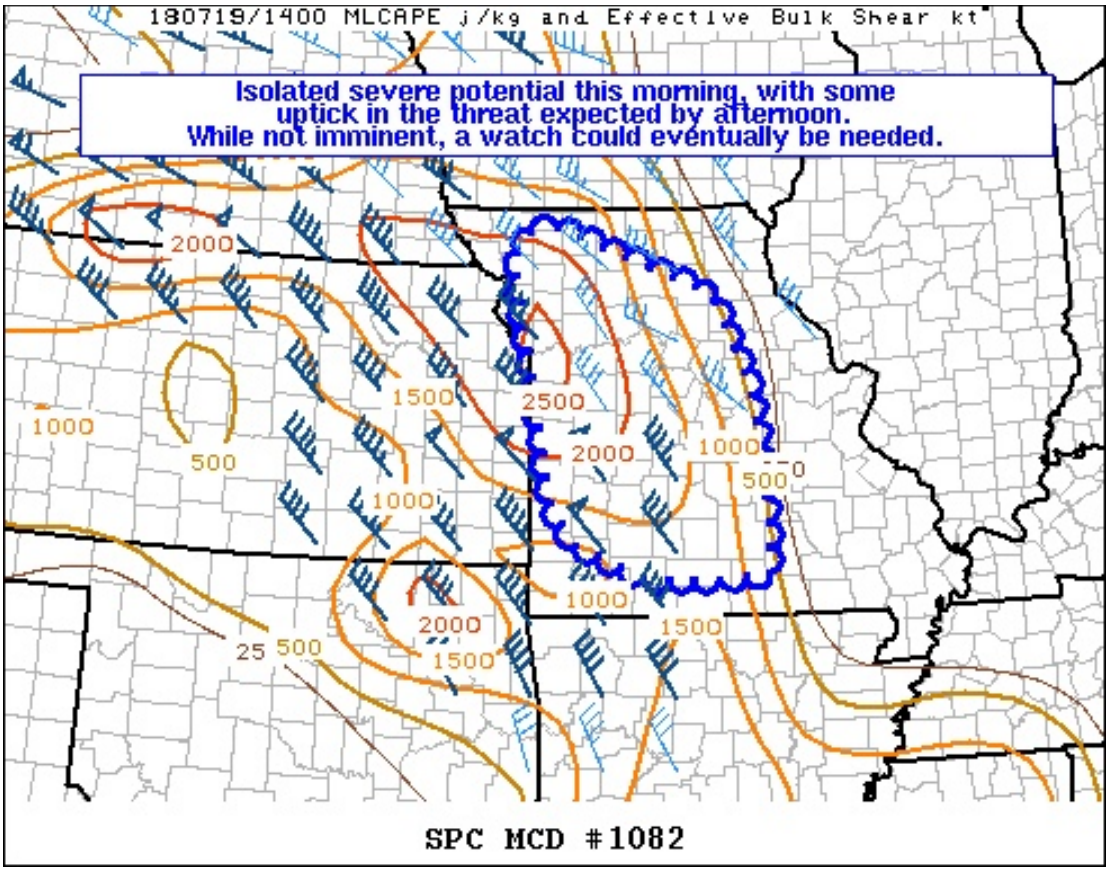


Figure 31 *– SPC Mesoscale Discussion #1082 graphic issued at 0958 CDT on July 19, 2018.*

The following Mesoscale Discussion (#1085; with associated graphic) was issued at 1415 CDT on July 19, 2018:

Mesoscale Discussion 1085
NWS Storm Prediction Center Norman OK
0215 PM CDT Thu Jul 19 2018

Areas affected...Portions of southern Missouri and northern Arkansas

Concerning...Severe Thunderstorm Watch 283...

Valid 191915Z - 192115Z

The severe weather threat for Severe Thunderstorm Watch 283 continues.

SUMMARY...A small bowing thunderstorm cluster will reach the eastern edge of Watch 283 within the next hour or so, as it moves towards southeast Missouri. Additionally, other strong/severe storms may form to its west and gradually develop into northern Arkansas through this evening. These trends are being monitored for possible watch issuance.

DISCUSSION...A small bowing thunderstorm complex is progressing east/southeast around 30-35 kt over south-central Missouri this afternoon. At its current rate, it will approach the eastern edge of Watch 283 around 20-21Z. The downstream boundary-layer environment is characterized by ample theta-e and steep low-level lapse rates. However, both mid-level flow and lapse rates become weaker with eastward extent, casting uncertainty upon a more widespread severe threat east of the current watch. As such, at its present state, downstream watch issuance towards the Mississippi Valley appears quite uncertain.

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 and move east/southeastward, with the threat eventually encroaching upon northern Arkansas. Such an evolution would require new watch issuance, as cells would be capable of damaging winds and large hail.

..Picca.. 07/19/2018

...Please see www.spc.noaa.gov for graphic product...

ATTN...WFO...PAH...MEG...LSX...LZK...SGF...TSA...

LAT...LON 37969257 37909017 36988946 36258966 35699059 35389146
35649279 36379353 37379379 37709361 37969257

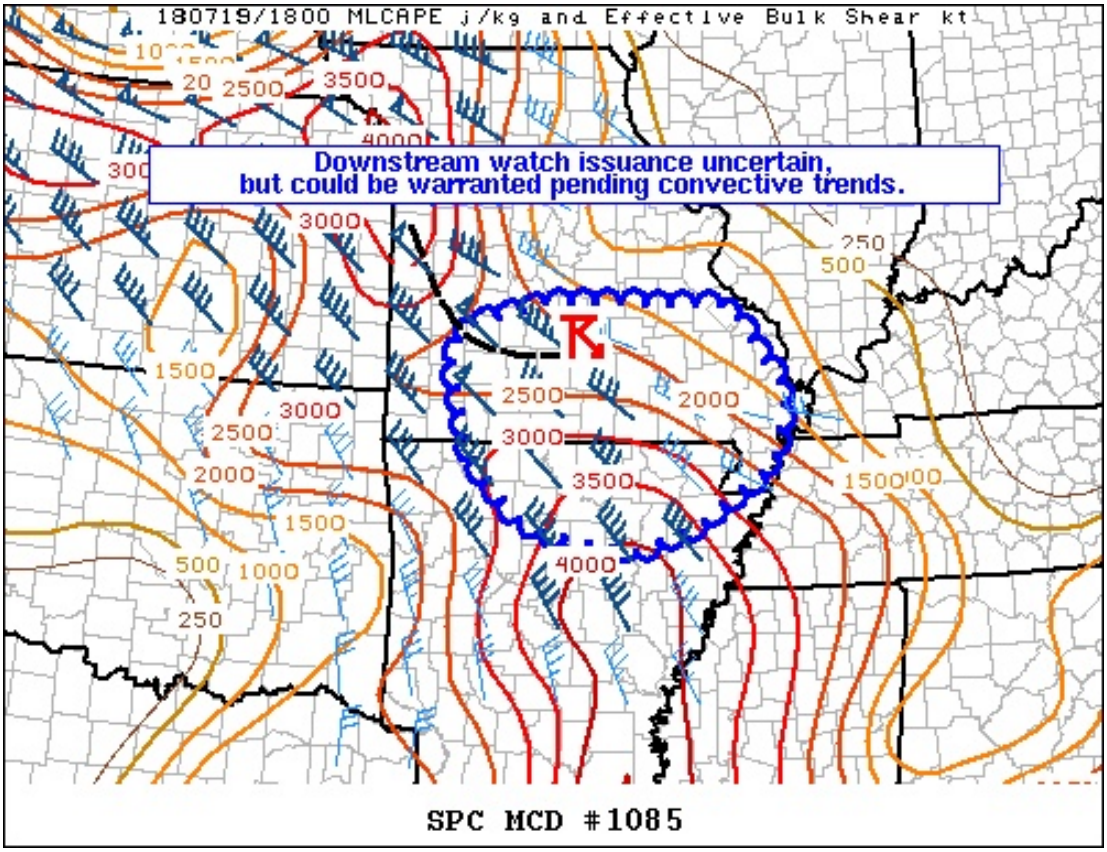


Figure 32 *– SPC Mesoscale Discussion #1085 graphic issued at 1415 CDT on July 19, 2018.*

5.9.2.3. Public Severe Thunderstorm Watch Notification Message

According to NWSI 10-512, "SPC should issue a Public Severe Thunderstorm Watch Notification Message when there is a forecast of six or more hail events of one inch (quarter-size) diameter or greater or convective damaging winds of 50 knots (58 mph) or greater."[31] At 1120 CDT on July 19, 2018, the SPC issued a Public Watch Notification Message regarding Severe Thunderstorm Watch #283, which was applicable to the accident location at the accident time, and was valid until 2100 CDT (an associated graphic was issued at 1128 CDT).

```
WWUS20 KWNS 191620
SEL3
-SPC WW 191620
MOZ000-200200-

URGENT - IMMEDIATE BROADCAST REQUESTED
Severe Thunderstorm Watch Number 283
NWS Storm Prediction Center Norman OK
1120 AM CDT Thu Jul 19 2018
```

[31] http://www.nws.noaa.gov/directives/sym/pd01005012curr.pdf

The NWS Storm Prediction Center has issued a

* Severe Thunderstorm Watch for portions of Western and Central Missouri
* Effective this Thursday morning and evening from 1120 AM until 900 PM CDT.
* Primary threats include...
  Widespread damaging winds likely with isolated significant gusts to 75 mph possible
  Scattered large hail likely with isolated very large hail events to 2.5 inches in diameter possible
  A tornado or two possible

SUMMARY...An increasingly organized convective cluster across central Missouri should continue to intensify and gradually accelerate east/southeastward through the afternoon. Meanwhile, additional storm development should occur on its western flank and/or move into Missouri out of Kansas later this afternoon/evening. Corridors of damaging winds/large can be expected and a tornado cannot be entirely ruled out.

The severe thunderstorm watch area is approximately along and 75 statute miles east and west of a line from 50 miles north northeast of Knob Noster MO to 50 miles south southeast of Springfield MO. For a complete depiction of the watch see the associated watch outline update (WOUS64 KWNS WOU3).

PRECAUTIONARY/PREPAREDNESS ACTIONS...

REMEMBER...A Severe Thunderstorm Watch means conditions are favorable for severe thunderstorms in and close to the watch area. Persons in these areas should be on the lookout for threatening weather conditions and listen for later statements and possible warnings. Severe thunderstorms can and occasionally do produce tornadoes.

&&

AVIATION...A few severe thunderstorms with hail surface and aloft to 2.5 inches. Extreme turbulence and surface wind gusts to 65 knots. A few cumulonimbi with maximum tops to 600. Mean storm motion vector 31030.

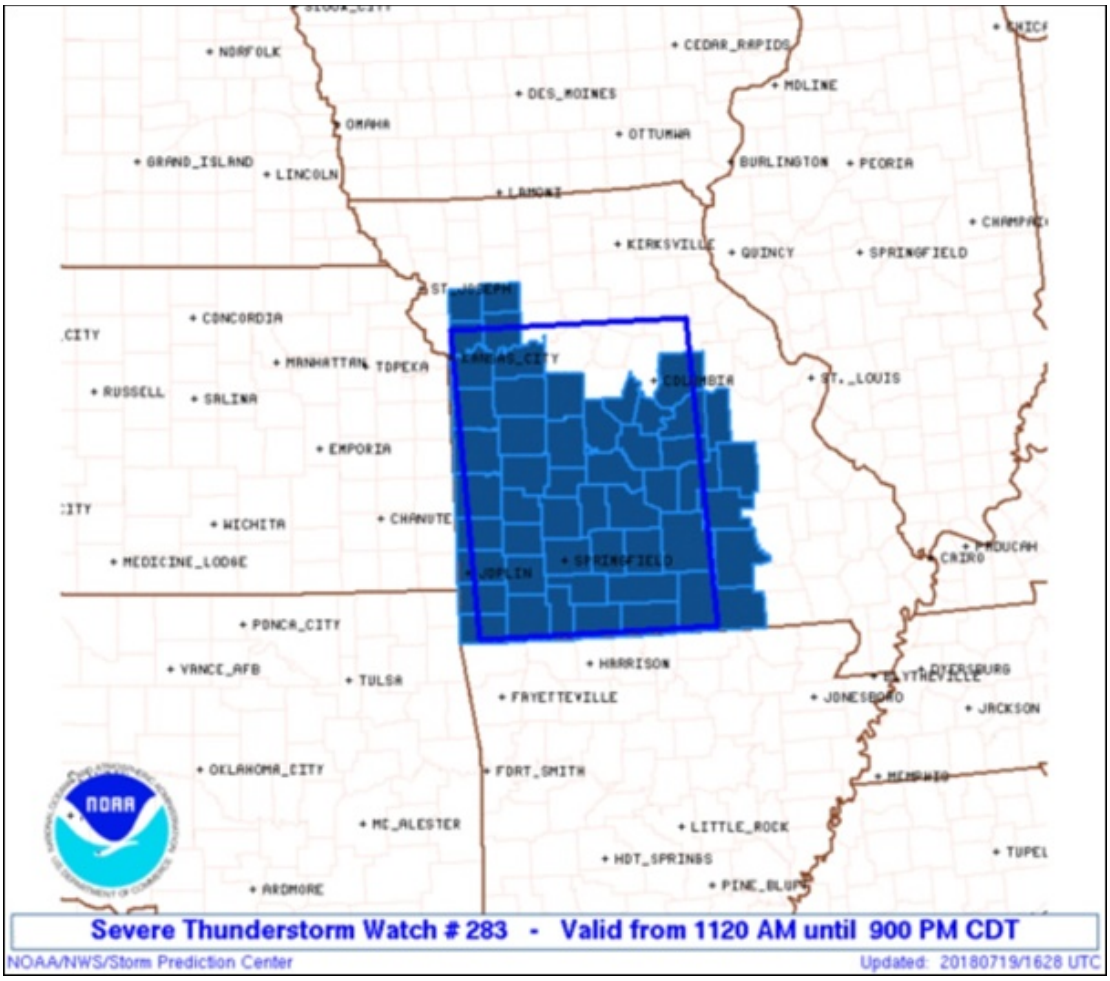


Figure 33 *– SPC Severe Thunderstorm Watch #283 graphic issued at 1128 CDT on July 19, 2018.*

5.9.2.4. Watch Status and Severe Thunderstorm Watch Outline Update Messages

According to NWSI 10-512, "SPC uses the Watch Status Message to help CONUS WFOs, media, emergency management, and the public determine portions of a convective watch where the threat of severe weather continues. This message will include a recommended list of what counties or parishes, independent cities and marine zones should remain in the watch area, and a geographical linear description of the continued severe weather hazard using known points." Watch Status Messages issued by the SPC regarding Severe Thunderstorm Watch #283 on July 19, 2018, prior to the accident time are presented in Attachment 14.

According to NWSI 10-512, "SPC will issue an initial [Watch Outline Update Message (WOU)] for every CONUS convective watch. SPC will issue updated WOUs as needed when changes are made to [Watch County Notification] messages issued by WFOs to update counties within active convective watches." WOUs issued by the SPC regarding Severe Thunderstorm Watch #283 on July 19, 2018, prior to the accident time are presented in Attachment 14.

5.10. NOAA Weather Radio All Hazards

According to the NWS, "NOAA Weather Radio All Hazards (NWR) is a nationwide network of radio stations broadcasting continuous weather information directly from the nearest NWS office. NWR broadcasts official Weather Service warnings, watches, forecasts and other hazard information 24 hours a day, 7 days a week…it [is] your single source for comprehensive weather and emergency information…NWR requires a special radio receiver or scanner capable of picking up the signal. Broadcasts are found in the VHF public service band at these seven frequencies: 162.400 Megahertz (MHz), 162.425 MHz, 162.450 MHz, 162.475 MHz, 162.500 MHz, 162.525 MHz and 162.550 MHz."[32]

The NWS transmitter that would have provided the clearest broadcast for the city of Branson, Missouri, and the accident location was the Indian Ridge transmitter (commonly referred to as the "Branson transmitter"), which broadcast on 162.550 MHz and used a callsign of KZZ43.[33] Figure 34 presents an area coverage map of KZZ43, where the white area indicates areas of reliable reception[34], and the green-hatched areas identify counties that will be coded into alert tones for applicable products broadcast by the Branson transmitter (discussed below).

[32] http://www.nws.noaa.gov/nwr/

[33] It s possible that NWR could have been received in these locations from another transmitter on another frequency, however those transmissions may have had a lot of static.

[34] Signal level of greater than 18 dBuV

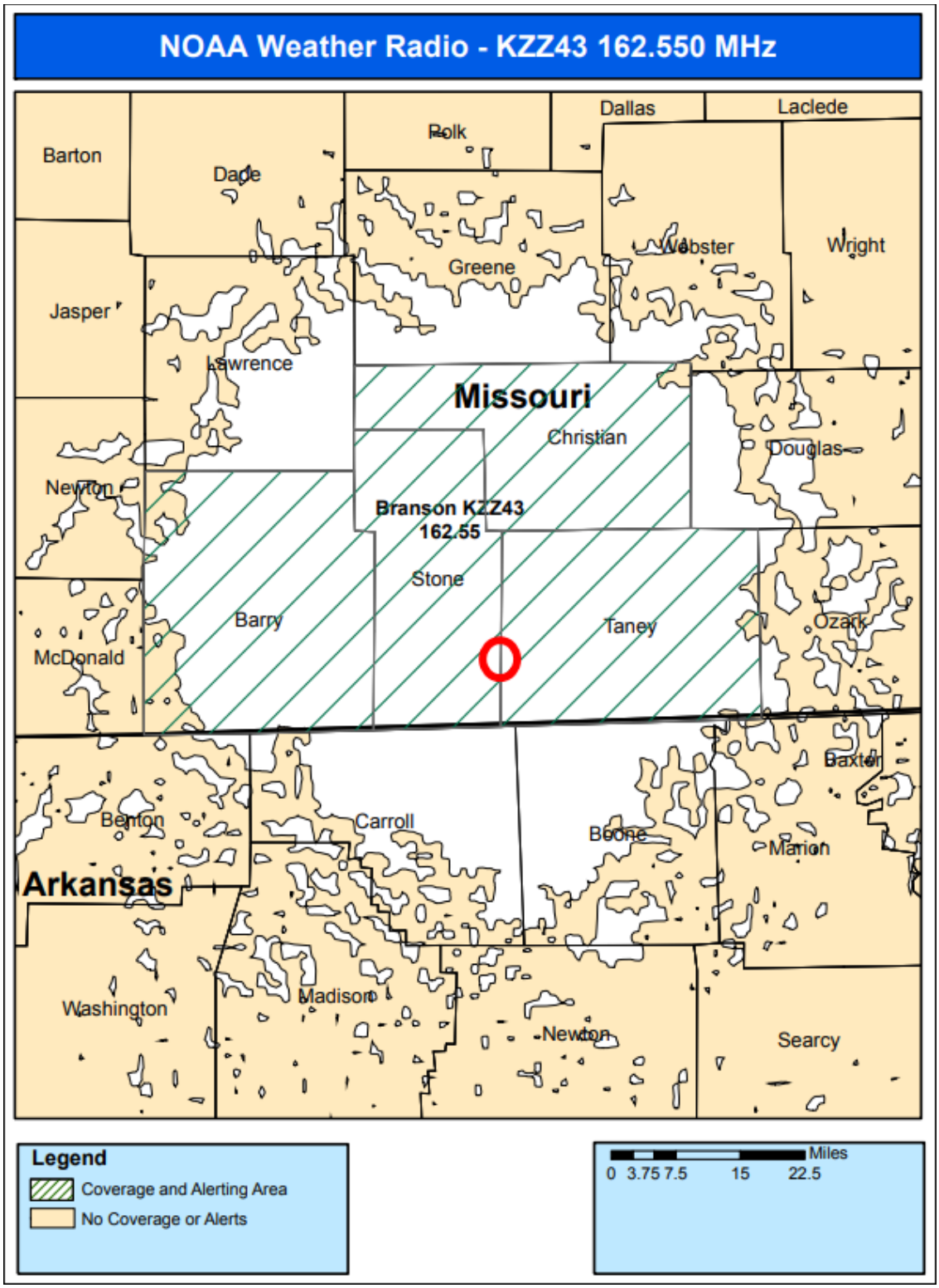


Figure 34 *– Coverage area map for the Branson NWR transmitter. Accident location is denoted by red circle.*

The NWR playlist broadcast over the Branson transmitter was compiled at the NWS Springfield WFO using weather products issued by the NWS Springfield WFO and other NWS facilities. Applicable weather products are read by the NOAA Weather Radio with All-Hazards VTEC Enhanced Software (NWRWAVES). According to NWSI 10-1710, "Text messages generated by the [NWRWAVES] formatter are processed, converted to voice, and scheduled for NWR broadcast by the AWIPS [Advanced Weather Interactive Processing System] Broadcast Message Handler (BMH)."[35] These text messages (which include the weather products) are then broadcast over the Branson transmitter in a computer-generated voice[36] using a strategy based on the local meteorological situation. Under "normal" meteorological conditions, the transmitter will broadcast a "General Suite" of weather products that include meteorological synopses, forecasts, information on lake levels, and other routine products. When severe weather watches, flood warnings and advisories, and most winter weather warnings and advisories are in effect, the Branson transmitter will broadcast a "High Suite" of products. When severe weather warnings, flash flood warnings and blizzard warnings have been issued locally, the Branson transmitter will broadcast an "Exclusive Suite" of products. The High Suite contains fewer products than the General Suite (removes nonessential products), and the Exclusive Suite contains fewer products that the High Suite. A portion of the BMH User's Guide for the NWS Springfield WFO is found in Attachment 15 and provides detailed information on the products contained in each suite utilized by the NWS Springfield WFO.

NWRWAVES will identify certain weather products broadcast by BHM to be accompanied by an NWR Specific Area Message Encoding (NWRSAME) transmission (tone)[37] and/or a 1050 Hertz Warning Alarm Tone (this instruction is coded into the text message header).[38] According to the NWS, "Only the most imminent life- and property-threatening hazards are broadcasted with the [NWRSAME tone] and [the] 1050 Hertz warning alarm tone, where the public has to take immediate action to protect themselves and their property. An operational guideline is that messages are alerted only for hazards urgent enough to warrant waking people up in the 'middle of the night' or otherwise interrupting someone's activities at any time."[39] These tones are audible and can be heard over the radio when listening to NWR (the NWRSAME tone is heard first). Further, for NWR receivers so-equipped, these tones can initiate audible and visible signals at the receiver, even for NWR receivers that are set in a muted (standby) mode, prior to playing the broadcast weather product (note: NWR receiver functions can vary). The BMH User's Guide for the NWS Springfield WFO in Attachment 15 provides detailed information on what weather products will be broadcast with an accompanying NWRSAME and/or 1050 Hertz tone. For the Branson transmitter, Severe Thunderstorm Warnings would have been broadcast with accompanying the NWRSAME and 1050 Hertz tone.

A broadcast NWRSAME tone contains information on the hazard type and county(ies) affected by the associated weather product. NWR receivers that are so-equipped allow users to program

[35] http://www.nws.noaa.gov/directives/sym/pd01017010curr.pdf

[36] Though it is possible for a human voice to be broadcast over NWR, it is rare.

[37] The NWRSAME tone is actually a series of tones, but is referred to as a tone (singular) in this report.

[38] These tones only accompany the first broadcast of the weather product.

[39] http://www.nws.noaa.gov/nwr/info/nwrwarn.html

for which hazards (using EAS Event codes)[40] and affected county(ies) (using SAME codes)[41] that they wish to be alerted for. For broadcast weather products that carry a NWRSAME tone that matches a programmed SAME code, these receivers will receive the NWRSAME tone first, then play the broadcast 1050 Hertz Warning Alert Tone followed by the broadcast weather product (again, receiver function can vary). The SAME codes users would use to program applicable NWR receivers to receive products for Stone County, Missouri, and Taney County, Missouri, were 029209 and 029213, respectively. The EAS Event codes users would use to program applicable NWR receivers to receive Severe Thunderstorm Warnings, Severe Thunderstorm Watches and Severe Weather Statements were SVR, SVA and SVS, respectively.

NWS review of NWR logs (Attachment 16) identified what products were broadcast on the Branson transmitter during the period of 1800 through 1910 CDT on July 19, 2018. The following table presents these products and the time that these products completed being broadcast. Audible confirmation that these weather products were heard over 162.550 MHz (e.g., via archived NWR recordings) was not available. The NWRWAVES-generated text messages that were used by the BMH to broadcast these weather products (except for the text messages associated with the Severe Thunderstorm Watch broadcasts), which included the text that was broadcast by the computer-generated voice, are included in Attachment 15. The document used to decode the text message header syntax is also included in Attachment 15. The Branson transmitter was under the Exclusive Suite during this time period.

Time (CDT)	Broadcast Product(s)
1801:16	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1745 CDT that did not include Stone County, Missouri, or Taney County, Missouri.
1801:22	Current time
1802:19	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1804:29	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1745 CDT that did not include Stone County, Missouri, or Taney County, Missouri.
1804:35	Current time
1805:32	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1807:19	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1745 CDT that did not include Stone County, Missouri, or Taney County, Missouri.
1807:35	NWRSAME tone (which included the SAME code for Stone County, Missouri)@ and 1050 Hertz Waring Alert Tone. Included a message validity length of 45 minutes.*

[40] http://www.nws.noaa.gov/nwr/info/eventcodes.html

[41] http://www.nws.noaa.gov/nwr/coverage/county_coverage.html

1809:20	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1807 CDT for an area that included northern Stone County, Missouri.
1810:25	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1745 CDT that did not include Stone County, Missouri, or Taney County, Missouri.
1811:22	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1813:33	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1745 CDT that did not include Stone County, Missouri, or Taney County, Missouri.
1815:12	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1807 CDT for an area that included northern Stone County, Missouri.
1815:18	Current time
1815:34	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1817:14	Severe Weather Statement issued by the NWS Springfield WFO at 1815 CDT regarding the Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1807 CDT for an area that included northern Stone County, Missouri.%
1818:11	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1820:21	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1745 CDT that did not include Stone County, Missouri, or Taney County, Missouri.
1822:01	Severe Weather Statement issued by the NWS Springfield WFO at 1815 CDT regarding the Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1807 CDT for an area that included northern Stone County, Missouri.
1822:07	Current time
1823:04	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1825:14	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1745 CDT that did not include Stone County, Missouri, or Taney County, Missouri.
1826:54	Severe Weather Statement issued by the NWS Springfield WFO at 1815 CDT regarding the Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1807 CDT for an area that included northern Stone County, Missouri.
1827:00	Current time
1827:57	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1830:08	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1745 CDT that did not include Stone County, Missouri, or Taney County, Missouri.

1831:47	Severe Weather Statement issued by the NWS Springfield WFO at 1815 CDT regarding the Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1807 CDT for an area that included northern Stone County, Missouri.
1831:53	Current time
1832:33	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1832:49	NWRSAME tone (which included the SAME codes for Stone County, Missouri, and Taney County, Missouri)[$] and 1050 Hertz Waring Alert Tone. Included a message validity length of 60 minutes.
1834:21	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1832 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1835:18	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1836:44	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1832 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1838:24	Severe Weather Statement issued by the NWS Springfield WFO at 1815 CDT regarding the Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1807 CDT for an area that included northern Stone County, Missouri.
1838:29	Current time
1839:26	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1840:53	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1832 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1842:32	Severe Weather Statement issued by the NWS Springfield WFO at 1815 CDT regarding the Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1807 CDT for an area that included northern Stone County, Missouri.
1842:38	Current time
1843:35	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1845:02	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1832 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1845:08	Current time
1845:39	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1845:56	NWRSAME tone (which included the SAME code for Stone County, Missouri)[@] and 1050 Hertz Waring Alert Tone. Included a message validity length of 60 minutes.

1847:50	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1845 CDT for an area that included northern Stone County, Missouri.
1848:47	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1850:13	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1832 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1852:08	Current time
1853:05	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1854:31	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1832 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1856:20	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1845 CDT for an area that included northern Stone County, Missouri.
1856:26	Current time
1857:23	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1858:49	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1832 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1859:25	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1845 CDT for an area that included northern Stone County, Missouri.
1900:54	Severe Weather Statement issued by the NWS Springfield WFO at 1859 CDT regarding the Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1845 CDT for an area that included northern Stone County, Missouri.[&]
1902:21	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1832 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1902:54	Severe Weather Statement issued by the NWS Springfield WFO at 1859 CDT regarding the Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1845 CDT for an area that included northern Stone County, Missouri.
1904:21	Severe Weather Statement issued by the NWS Springfield WFO at 1902 CDT regarding the Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1832 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.[#]
1905:18	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1905:33	NWS Heat Advisory
1907:03	Severe Weather Statement issued by the NWS Springfield WFO at 1859 CDT regarding the Severe Thunderstorm Warning issued by the NWS

	Springfield WFO at 1845 CDT for an area that included northern Stone County, Missouri.
1908:30	Severe Weather Statement issued by the NWS Springfield WFO at 1902 CDT regarding the Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1832 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1908:36	Current time
1909:33	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.

* Some NWR receivers will read the message validity length and keep a visible indicator of the "toned" hazard for the validity length on the NWR receiver.
@ For NWR receivers so-equipped, these tones would have initiated audible and visible signals at the receiver set in a muted (standby) mode but programmed with the Stone County, Missouri, SAME code, prior to automatically playing the broadcast weather product (NWR receiver functions can vary).
% The broadcast of this Severe Weather Statement replaced the broadcast of the Severe Thunderstorm Warning issued at 1807 CDT.
$ For NWR receivers so-equipped, these tones would have initiated audible and visible signals at the receiver set in a muted (standby) mode but programmed with the Stone County, Missouri, and/or Taney County, Missouri, SAME code, prior to automatically playing the broadcast weather product (NWR receiver functions can vary).
& The broadcast of this Severe Weather Statement replaced the broadcast of the Severe Thunderstorm Warning issued at 1845 CDT.
# The broadcast of this Severe Weather Statement replaced the broadcast of the Severe Thunderstorm Warning issued at 1832 CDT.

According to the Operations Manager for Ride The Ducks Branson, their boat captains had a two-way VHF radio that had access to marine channels 13, 16 and 72, and noted that the marine channels are used more than NWR.

5.11. StreamerRT

StreamerRT was a web-based application from Earth Networks, Inc. (hereafter referred to as "Earth Networks"), and according to the StreamerRT version 5.1 User's Guide (see Attachment 17), "StreamerRT is a real-time weather decision system that provides a fully interactive mapping platform with a comprehensive collection of weather data. Users have the ability to monitor real-time station observation data from the WeatherBug network and overlay numerous enhanced data sets to stay up-to-date with significant weather events before and after they develop." The available datasets one could overlay on a map within StreamerRT included NWS watches and warnings for severe weather, Earth Networks Dangerous Thunderstorm Alerts (DTA), surface-based wind observation information, weather radar imagery (including "Doppler radar 1km [kilometer] composite" mosaic and single site 0.5° imagery) and lightning data. Additional information may be found in Attachment 17.

Ride The Ducks Branson began a StreamerRT subscription in January 2014. The General Manager of Ride The Ducks Branson indicated to the NTSB Meteorology Group on July 21, 2018, that StreamerRT was the company's "primary and sole source for weather information." According to the General Manager, there was a computer with constant access to StreamerRT in the lounge at the Ride The Ducks Branson offices (see figure 35). He indicated that everyone at the company had access to it, that it was used by crew and management, and that the service worked very well. On July 21, 2018, the Operations Manager for Ride The Ducks Branson met with the NTSB Meteorology Group at their offices in Branson, discussed their usage of StreamerRT, and

indicated that StreamerRT was much more accurate than anything they had used for weather information. He stated that one of the benefits of StreamerRT was that it would allow them to identify their location on the map and have a radius of 20 miles drawn around them for impending storm identification. He also indicated that the standard StreamerRT weather radar product used by Ride The Ducks Branson personnel was the "US Radar Mosaic" product, and that for other StreamerRT parameter options, most people would use what is presented on a pane within the application. He stated that typically a Ride The Ducks Branson manager would monitor StreamerRT, and that yellow or "worse" colors on the weather radar picture and lightning would be causes of concern, but that there was no company requirement to monitor StreamerRT. He indicated some of their boat captains had the "KY3" application on their phones, but they were not allowed to check their phones if on a duck boat. The Operations Manager described the one-minute lighting depiction within StreamerRT as preferred over the 15-minute lightning depiction, and indicated that the one-minute lighting is "as close to real time as we can get so that we know what is going to happen, not what has happened" and that the 15-minute lightning depiction is not used because it "looks like hell is coming."

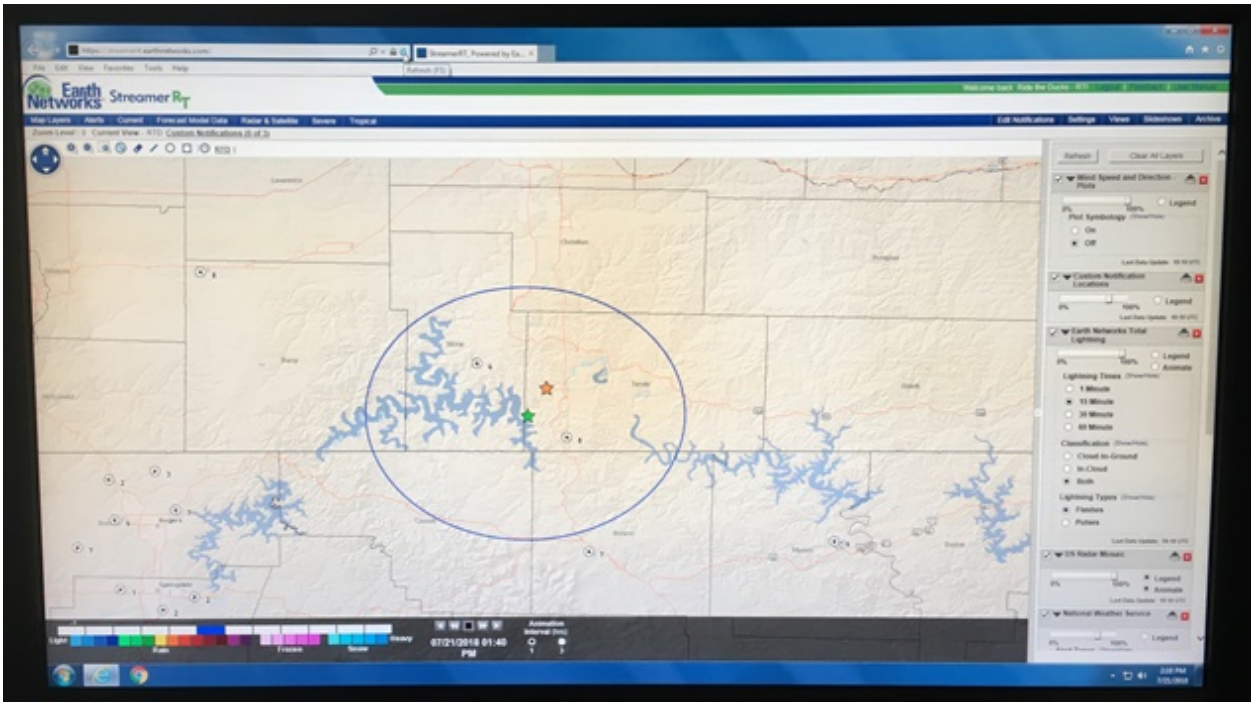


Figure 35 *– Photograph of the StreamerRT application display from the StreamerRT workstation in the Ride The Ducks Branson office lounge. Taken about 1410 CDT on July 21, 2018. The orange star represented the Ride The Ducks Branson office location, and the green star approximated the vessels' entry point into Table Rock Lake. The blue circle was a 20-statute mile range ring around the vessels' entry point into Table Rock Lake.*

Figure 35 depicts some of the datasets (overlays) that were active in the Ride The Ducks Branson StreamerRT display in their office lounge at the time these photos were taken, which included

surface-based wind speed and direction observations, previous 15-minutes of lightning data[42], an animation of the Doppler radar 1km composite radar mosaic and an unknown type of NWS advisories (the photograph in figure 35 did not capture the NWS advisory options). Information provided by Earth Networks (Attachment 18) indicated that as of about 1300 CDT on July 23, 2018, additional dataset overlays used by Ride The Ducks Branson included NWS watches and warnings for severe weather and Earth Networks DTAs.[43] It is not known how or if the active dataset overlays recorded during the days following the accident differed from the dataset overlays active on the Ride The Ducks Branson StreamerRT display in their office lounge on the accident day. According to Earth Networks, there were no system or data anomalies on the accident day and StreamerRT was operating as designed.

Figure 36 presents surface-based weather observation locations available via StreamerRT in the accident region. The only site within 40 statute miles and north or northwest of the accident location was FBW. FBW would have been the only site to north and northwest of the accident location that could have triggered an email alert regarding surface wind from Earth Networks to Ride The Ducks Branson (see discussion below). According to Earth Networks, they did not receive the FBW observation timestamped at 2355 UTC (1855 CDT) until between 0005 and 0009 UTC the following day (between 1905 and 1909 CDT on the accident day).[44]

[42] See section 5.3 for Earth Networks lightning data.

[43] According to Earth Networks, the applicable screenshots found in Attachment 18 represent the state of the application when it was last used by Ride The Ducks Branson (prior to about 1300 CDT on July 23, 2018).

[44] According to Earth Networks, exact time of receipt of that FWB observation from their vendor was not available but based on internal processing strategies the receipt of this observations is known to have occurred between 1905:26 and 1909:33 CDT.

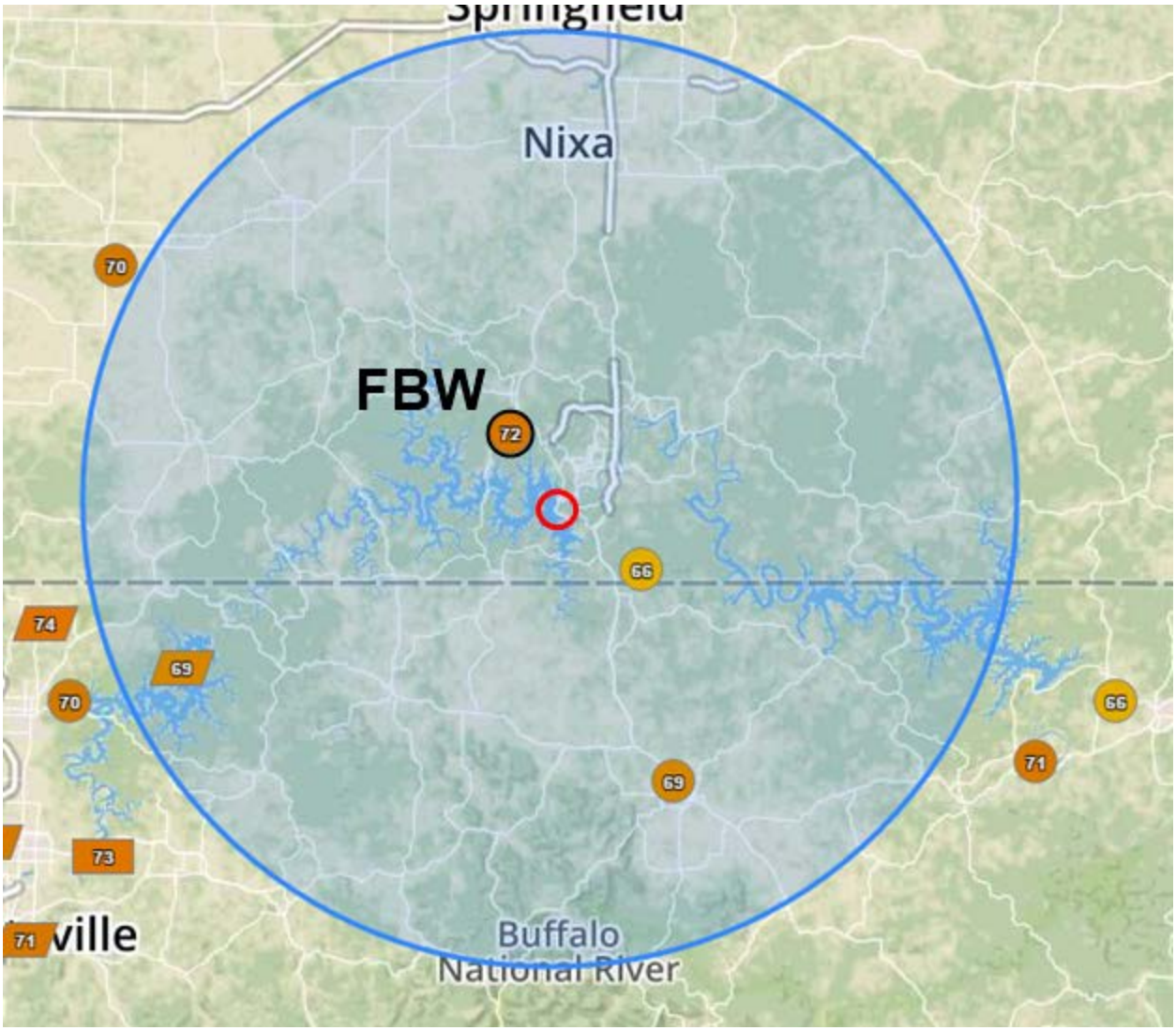


Figure 36 *– Surface-based observation stations (identified by circles, parallelograms and a rectangle) that were available to customers within StreamerRT in the accident region. Accident site is denoted by red circle. FBW is highlighted. Blue circle is centered on the accident location with a radius of 40 statute miles. Numbers within the station location markers should be ignored in this image.*

According to StreamerRT version 5.1 User's Guide, Earth Networks DTAs are issued when "…lightning rates exceed 25 flashes/minute. The alert indicates an increased threat of heavy rain rates, dangerous lightning, hail, strong winds and tornadic activity." Numerous Earth Networks DTAs were active in southwestern Missouri on the evening of the accident and one Earth Networks DTA was active for the accident location. Figure 37 presents a mapping of this Earth Networks DTA polygon, which was active between 1837 and 1922 CDT on July 19, 2018, as it would have been mapped on the StreamerRT display. StreamerRT customers can be alerted by email to the presence of Earth Networks DTAs (see discussion below), however Ride The Ducks Branson had not established this alert for DTAs. On July 21, 2018, The Operations Manager for Ride The Ducks Branson stated to the NTSB Meteorology Group that the Earth Networks DTA

can be too informative and goes off a lot. An email alert to Ride The Ducks Branson for this Earth Networks DTA would have contained the following information[45]:

Notification Rule: DTA

Dangerous Thunderstorm Alert

An Earth Networks Dangerous Thunderstorm Alert is in effect until 7/19/2018 7:22 PM CDT

Event Start: 7/19/2018 6:37 PM CDT
Event End: 7/19/2018 7:22 PM CDT

Earth Networks Dangerous Thunderstorm Alert
Earth Networks Headquarters Germantown, MD

* Until 7:22 PM CDT

* At 6:37 PM CDT...The Earth Networks Total Lightning Network is indicating a thunderstorm with a significant rate of lightning occurring in your area and moving in your direction. This storm has an increased potential to produce severe weather such as very frequent lightning, heavy rain, hail and/or damaging winds and should be considered dangerous. (For more information on this Earth Networks product visit www.earthnetworks.com)

* Storm is located near Latitude: 36.839, Longitude: -93.953

* Repeating, this storm contains frequent lightning and has an increased potential to produce severe weather and should be considered dangerous. Take appropriate measures to ensure safety to life and property immediately.

This alert is being issued in an advisory capacity by Earth Networks Headquarters due to the detection of frequent lightning by The Earth Networks Total Lightning Network. It is not associated in any way with the country's official meteorological services nor to any official alert linked to this storm. Active advisories or warnings issued by the official meteorological services should be followed in precedence to this alert.

Stay tuned to www.earthnetworks.com, other Earth Networks applications or local media outlets for the latest severe weather information.

Activated Time: 6:37PM on 7/19

Figure 37 presents a mapping of the NWS SVR polygon, which was active between 1832 and 1930 CDT on July 19, 2018, as it would have been mapped on the StreamerRT display. StreamerRT customers can be alerted by email to the presence of NWS watches and warnings (see discussion below).

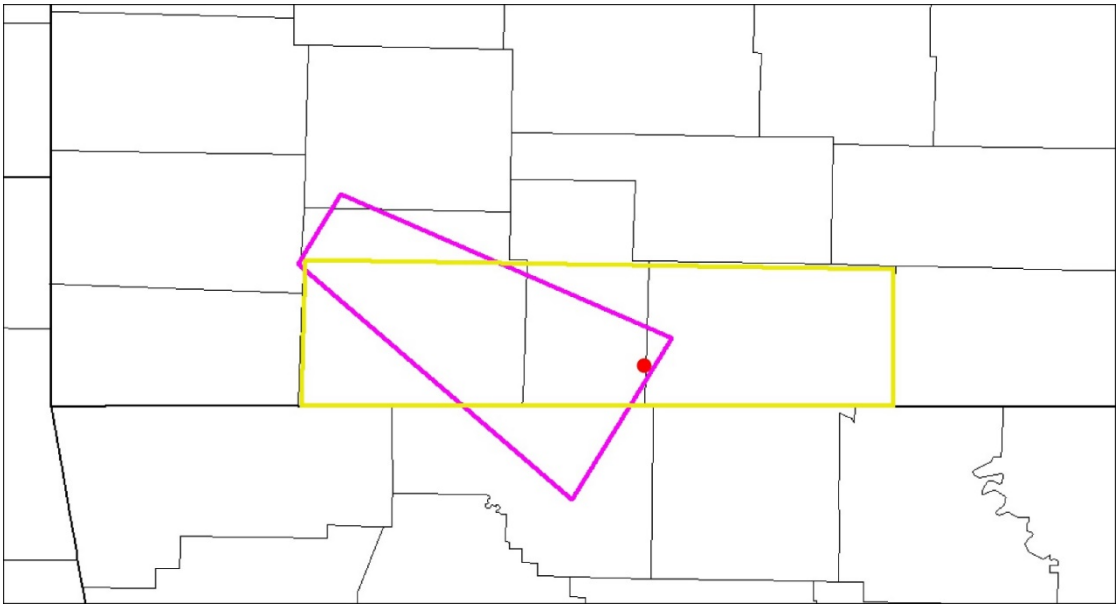


Figure 37 *– Earth Networks DTA (purple polygon) and NWS SVR (yellow polygon) active for the accident location on the evening of July 19, 2018, as they were mapped on the StreamerRT display. Accident location is denoted by the red circle.*

[45] This alert uses a notification location of the State Park Marina (as defined by Ride The Ducks Branson in their StreamerRT account as coordinates: 36.5786, -93.3044). The notification rule name of "DTA" was assigned by Earth Networks for this sample email alert.

StreamerRT provided users with various options for viewing local and national weather radar products based on WSR-88D data. One option was the US Radar Mosaic product, which according to Earth Networks, is provided to them by Weather Decision Technologies, Inc. (WDT). According to WDT (Attachment 18), they provided Earth Networks with "composite" weather radar mosaics based on WSR-88D Level II data. WDT constantly received Level II data from individual WSR-88D weather radars on a scan-by-scan (tilt-by-tilt) basis. Once received, each scan underwent a quality control (QC) process that removed non-precipitation targets based on dual polarization information received from the radar.[46] This QC process took about one minute per individual radar scan. Every 5 minutes, beginning at the top of the hour (i.e., at time steps of :00, :05, :10, :15, etc, minutes past each hour), a composite mosaic creation process was started. For each individual grid point within the mosaic's geographic domain[47], only data from radars positioned within 300 km of that grid point contribute to the composite mosaic at that grid point.[48] Radar data from every scan from each contributing radar over that grid point was considered and the highest value of reflectivity from those scans over that grid point was used for the final two-dimensional composite mosaic product at that grid point. During conversion from a polar coordinate system to a cartesian coordinate system for the final two-dimensional composite mosaic product, interpolation occurred that changed the effective spatial resolution, and minor smoothing (using a percentile smoother) was applied. Once the final composite mosaic product was created it was deposited into the local data manager (LDM) and transmitted to Earth Networks. The average time between the start of the composite mosaic creation process to the time the final composite mosaic product is made available to Earth Networks via the LDM is roughly one minute.

Once Earth Networks received a composite mosaic from WDT, some processing occurs, and extra smoothing is applied "on the boundaries of the radar images to avoid pixelization at high magnifications to make them more rounded." This mosaic image is then stored until the next publication time to StreamerRT (which is every 5 minutes, beginning at the top of the hour [i.e., at time steps of :00, :05, :10, :15, etc, minutes past each hour]), when the most current processed mosaic image is made available to users (see Attachment 18). The timestamp on the mosaic seen by users in StreamerRT (and referenced in this report) is not the WDT composite mosaic creation process starting time (the "valid time"). According to WDT, using this valid time is considered the "industry standard" for timestamping weather radar mosaics. A mosaic created by WDT with a valid time of 1225 may not be published to StreamerRT until 1230, and users of StreamerRT will see the mosaic image with a 1230 timestamp.

Figures 38-49 present the composite mosaic data sent from WDT to Earth Networks for the times surrounding the accident, prior to any further processing by Earth Networks, as provided to the

[46] According to WDT, the QC process applied in the composite mosaic creation process is done so in response to WDT's customers' demand for "clean" precipitation products. They have received feedback that radar products that include non-precipitation targets can be misinterpreted and are not desired by customers and end-users.

[47] The domain is roughly 1km by 1km.

[48] The grid point within the mosaic domain near the accident site considered contribution from five different WSR-88D weather radars.

NTSB Meteorology Group by WDT. These data are mapped to a unique background (not related to StreamerRT's display) and use a unique color scale (different than StreamerRT's color scale).

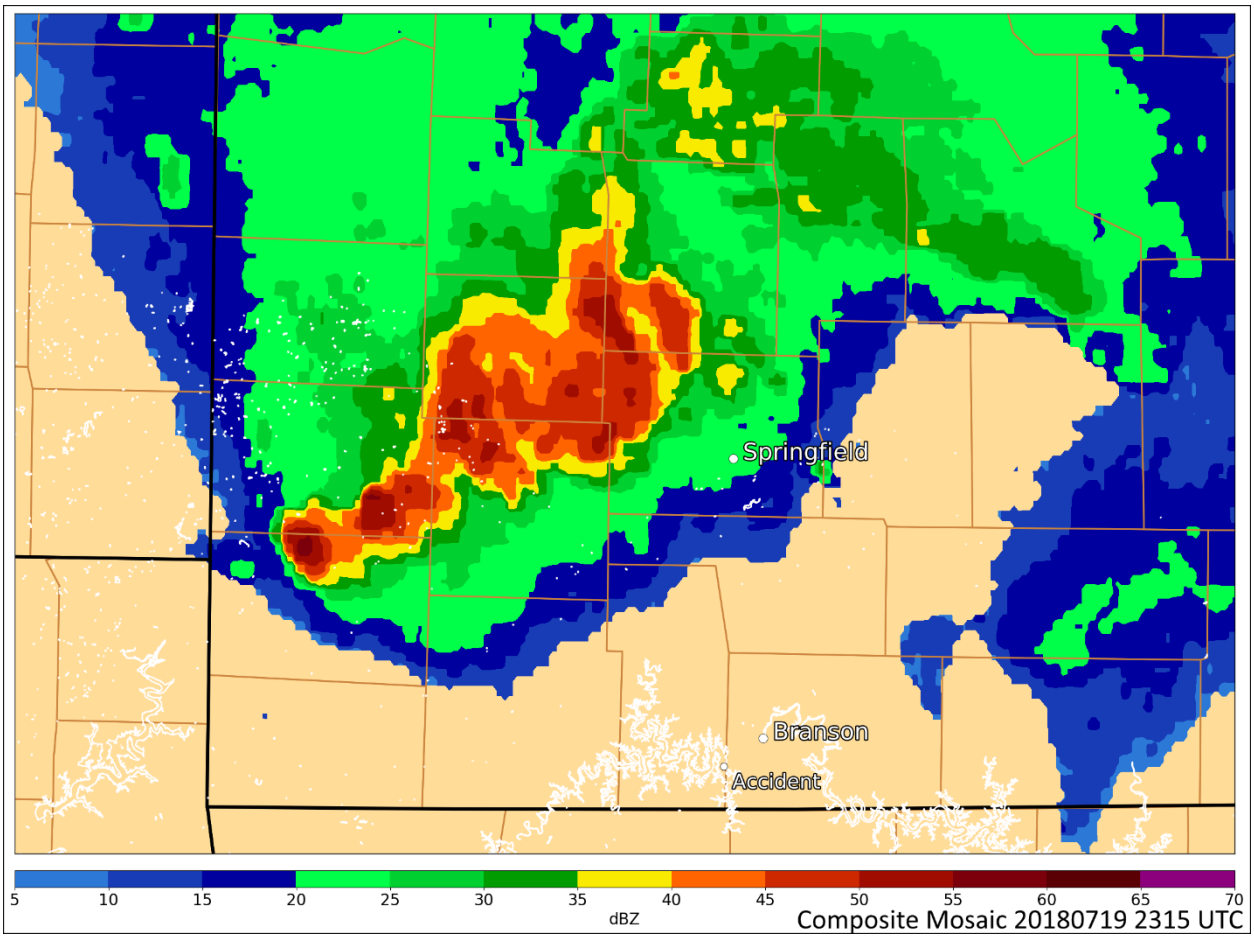


Figure 38 *– Graphic representation of the composite mosaic data with a valid time of 1815 CDT on July 19, 2018, provided to Earth Networks by WDT. The earliest these mosaic data could have been displayed for customers on StreamerRT following further processing by Earth Networks was 1820 CDT (with a timestamp within StreamerRT of 1820 CDT).*

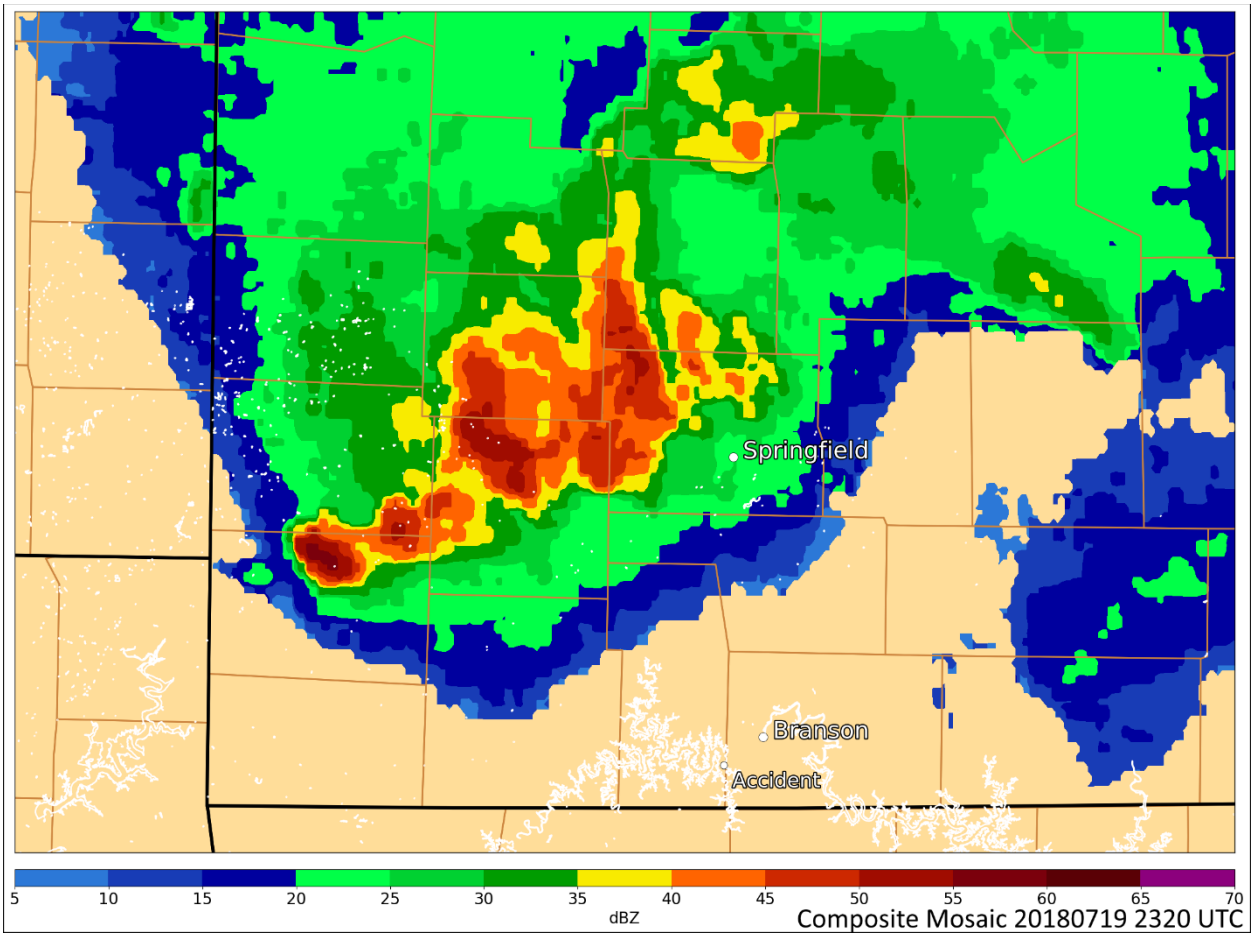


Figure 39 *– Graphic representation of the composite mosaic data with a valid time of 1820 CDT on July 19, 2018, provided to Earth Networks by WDT. The earliest these mosaic data could have been displayed for customers on StreamerRT following further processing by Earth Networks was 1825 CDT (with a timestamp within StreamerRT of 1825 CDT).*

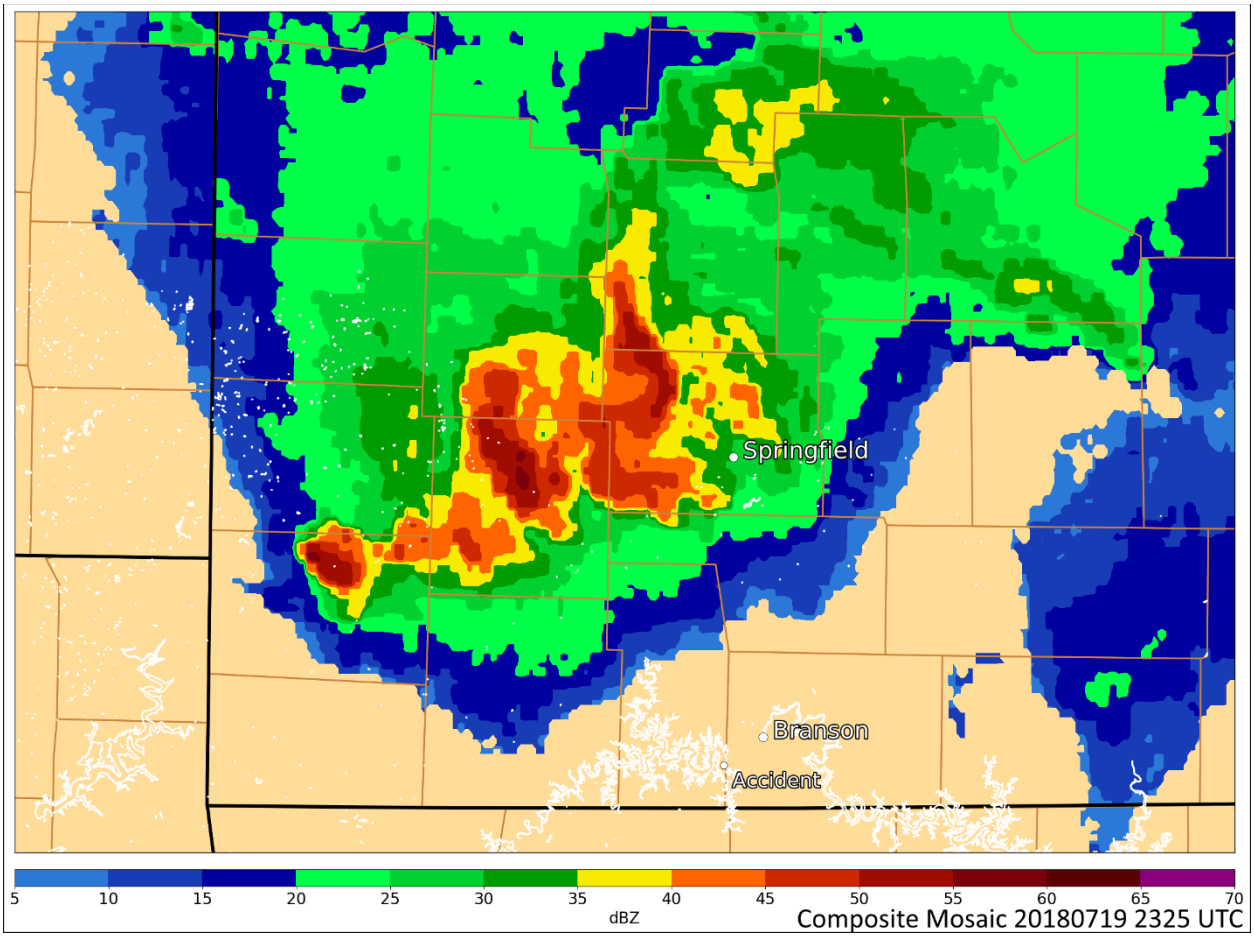


Figure 40 *– Graphic representation of the composite mosaic data with a valid time of 1825 CDT on July 19, 2018, provided to Earth Networks by WDT. The earliest these mosaic data could have been displayed for customers on StreamerRT following further processing by Earth Networks was 1830 CDT (with a timestamp within StreamerRT of 1830 CDT).*

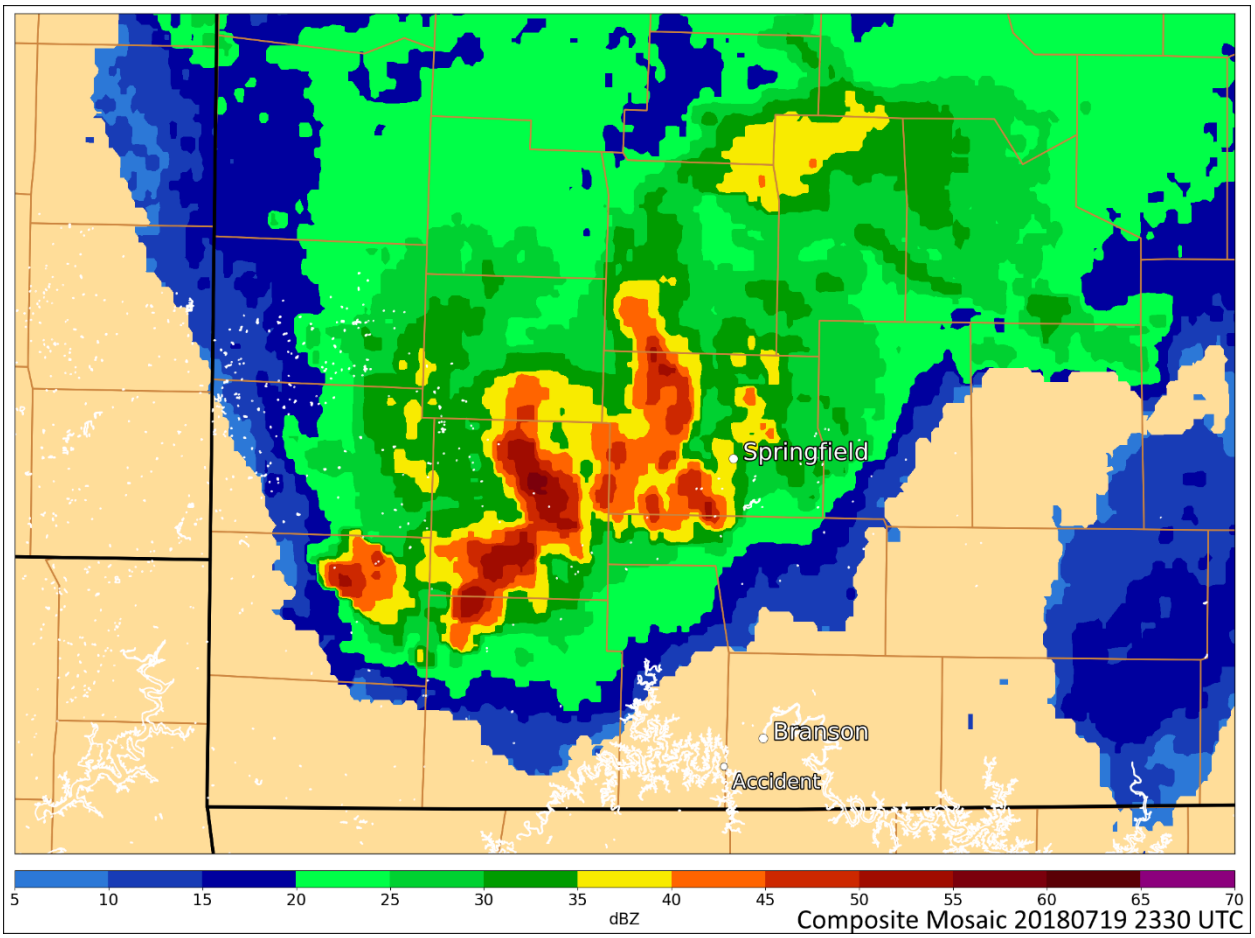


Figure 41 *– Graphic representation of the composite mosaic data with a valid time of 1830 CDT on July 19, 2018, provided to Earth Networks by WDT. The earliest these mosaic data could have been displayed for customers on StreamerRT following further processing by Earth Networks was 1835 CDT (with a timestamp within StreamerRT of 1835 CDT).*

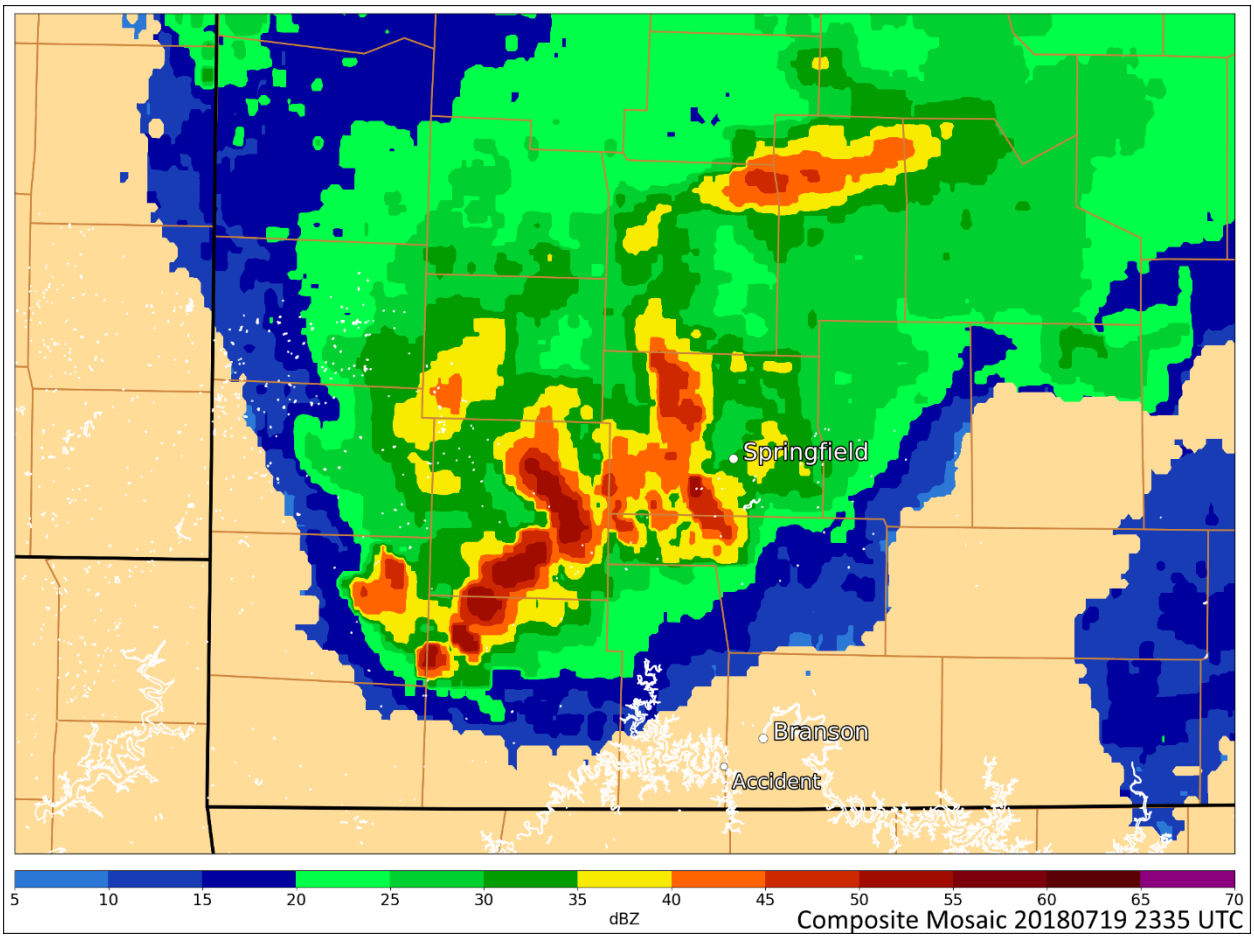


Figure 42 *– Graphic representation of the composite mosaic data with a valid time of 1835 CDT on July 19, 2018, provided to Earth Networks by WDT. The earliest these mosaic data could have been displayed for customers on StreamerRT following further processing by Earth Networks was 1840 CDT (with a timestamp within StreamerRT of 1840 CDT).*

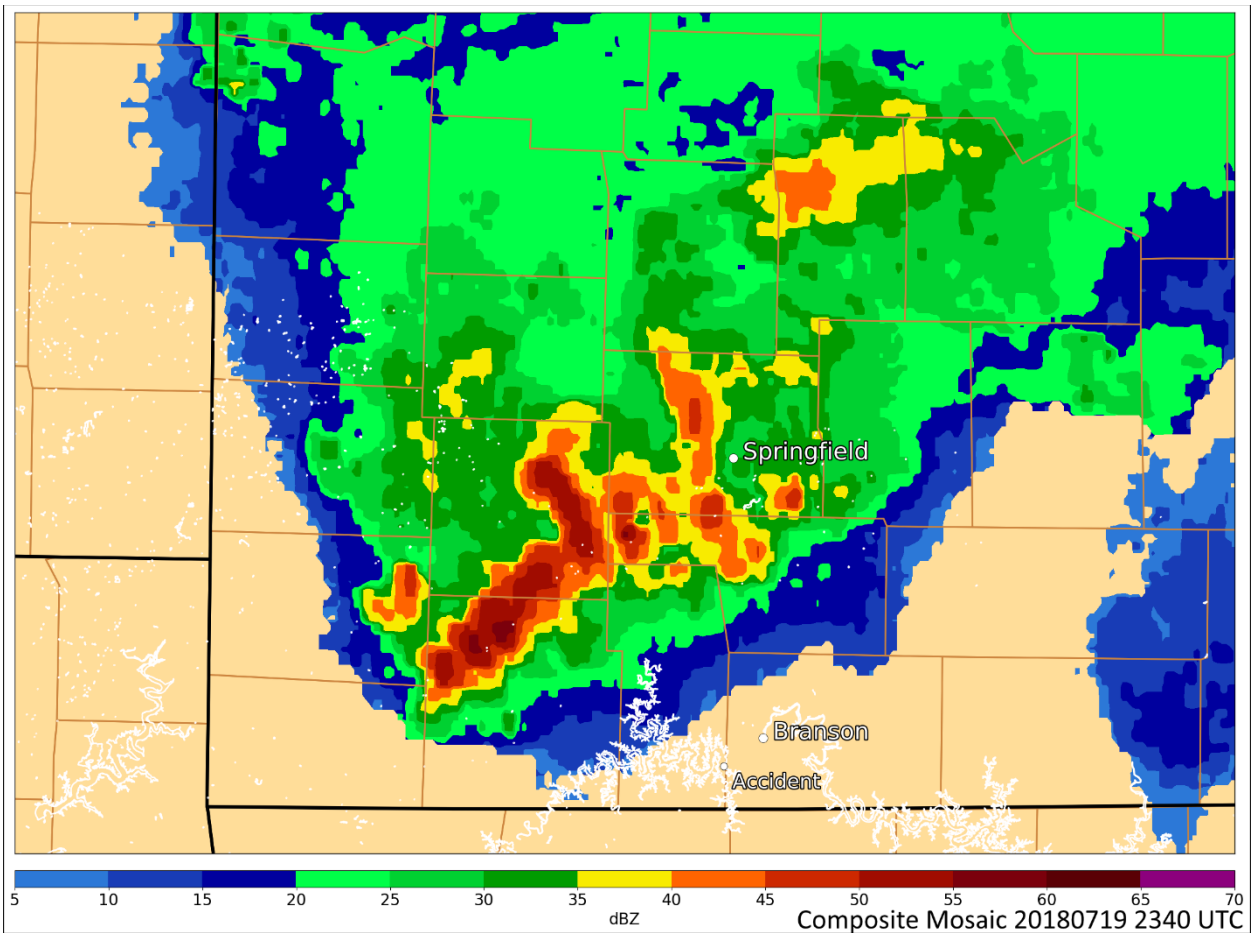


Figure 43 *– Graphic representation of the composite mosaic data with a valid time of 1840 CDT on July 19, 2018, provided to Earth Networks by WDT. The earliest these mosaic data could have been displayed for customers on StreamerRT following further processing by Earth Networks was 1845 CDT (with a timestamp within StreamerRT of 1845 CDT).*

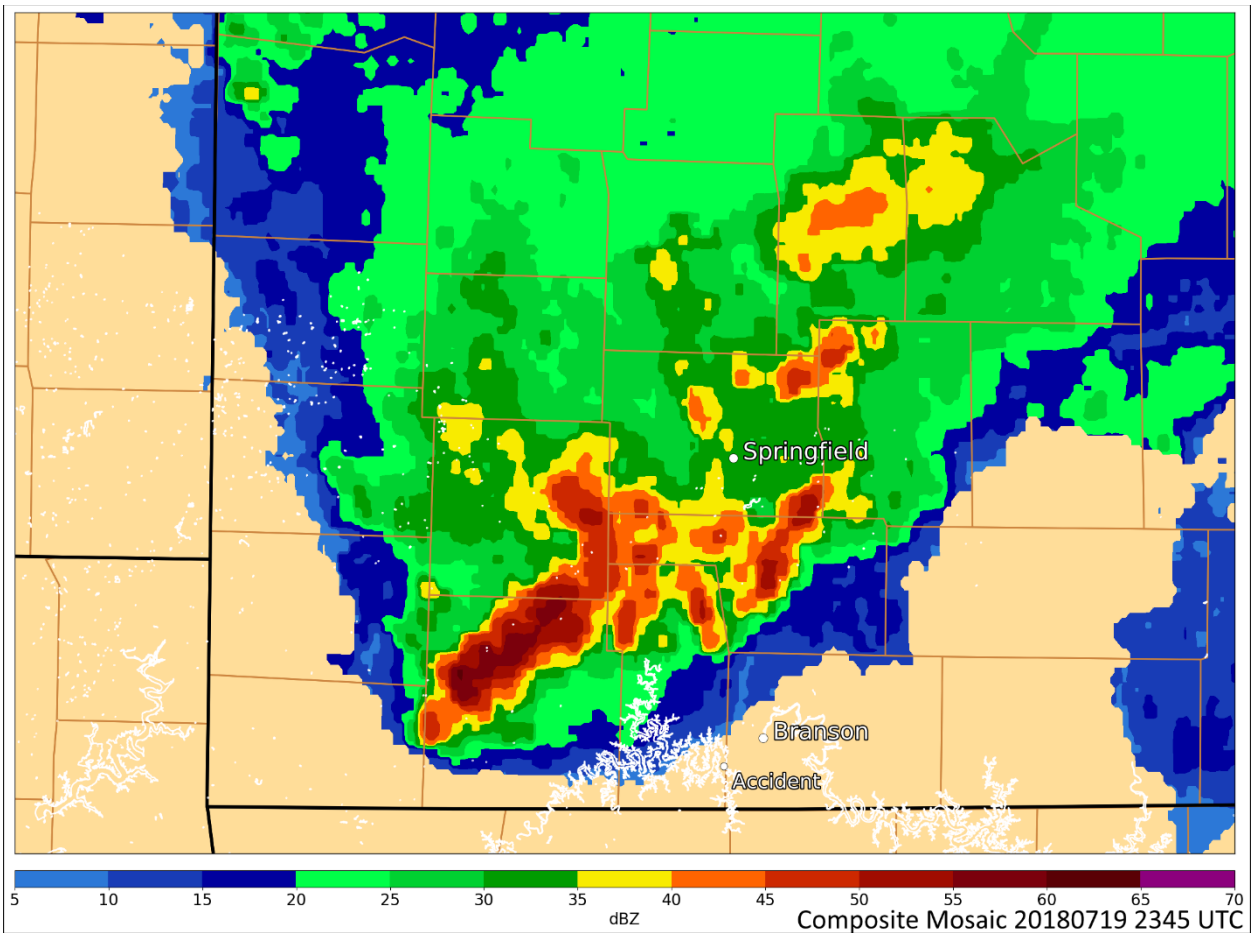


Figure 44 *– Graphic representation of the composite mosaic data with a valid time of 1845 CDT on July 19, 2018, provided to Earth Networks by WDT. The earliest these mosaic data could have been displayed for customers on StreamerRT following further processing by Earth Networks was 1850 CDT (with a timestamp within StreamerRT of 1850 CDT).*

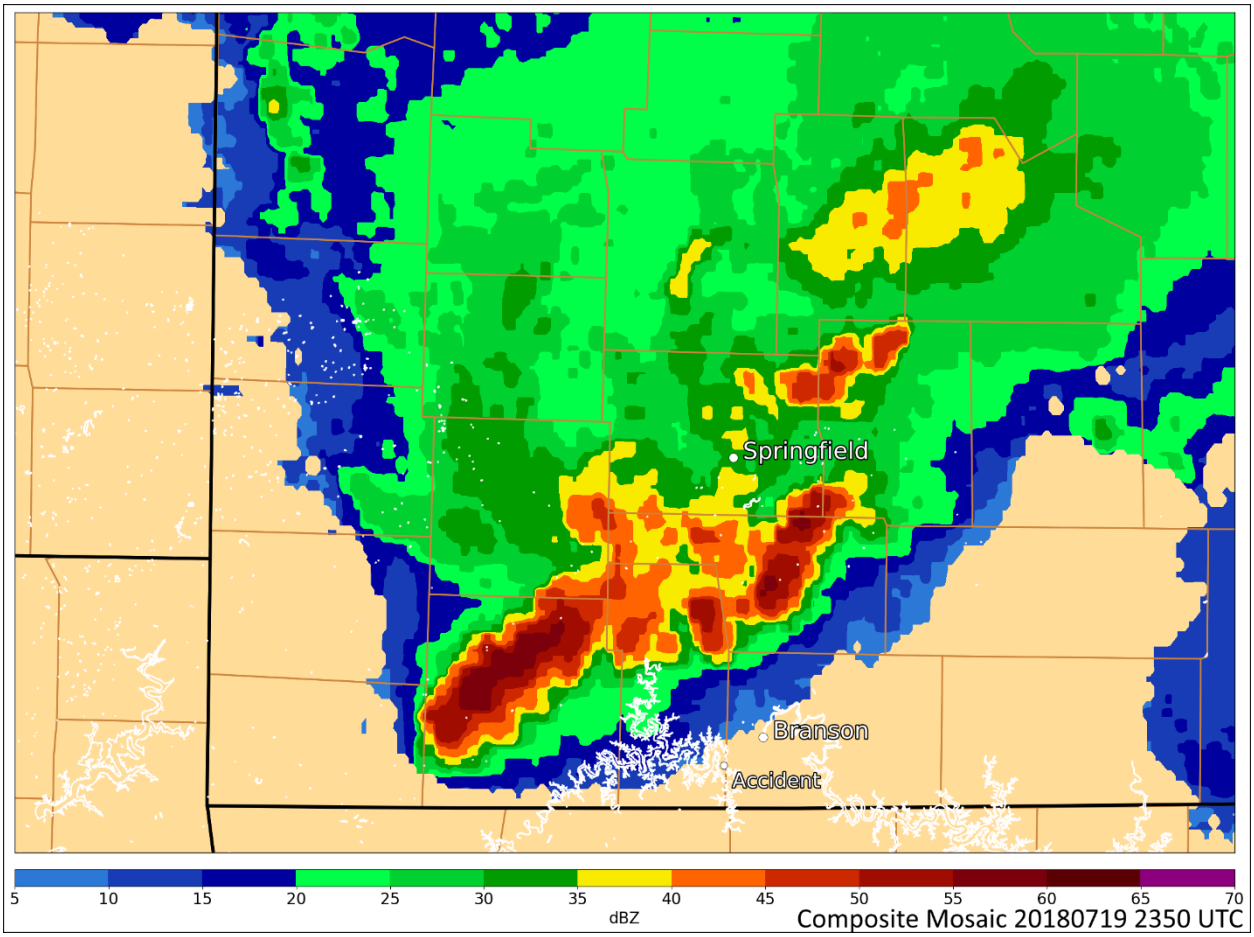


Figure 45 *– Graphic representation of the composite mosaic data with a valid time of 1850 CDT on July 19, 2018, provided to Earth Networks by WDT. The earliest these mosaic data could have been displayed for customers on StreamerRT following further processing by Earth Networks was 1855 CDT (with a timestamp within StreamerRT of 1855 CDT).*

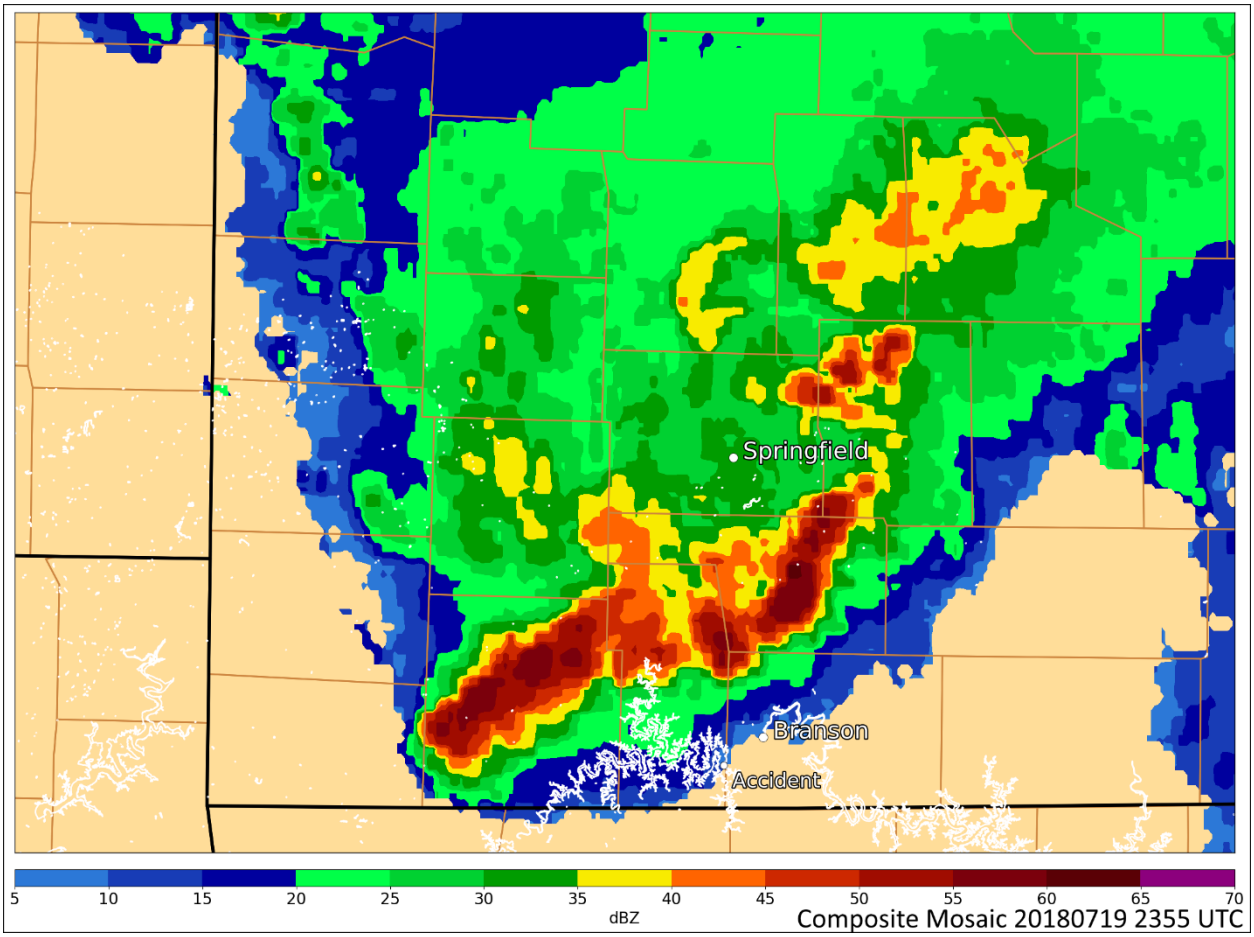


Figure 46 *– Graphic representation of the composite mosaic data with a valid time of 1855 CDT on July 19, 2018, provided to Earth Networks by WDT. The earliest these mosaic data could have been displayed for customers on StreamerRT following further processing by Earth Networks was 1900 CDT (with a timestamp within StreamerRT of 1900 CDT).*

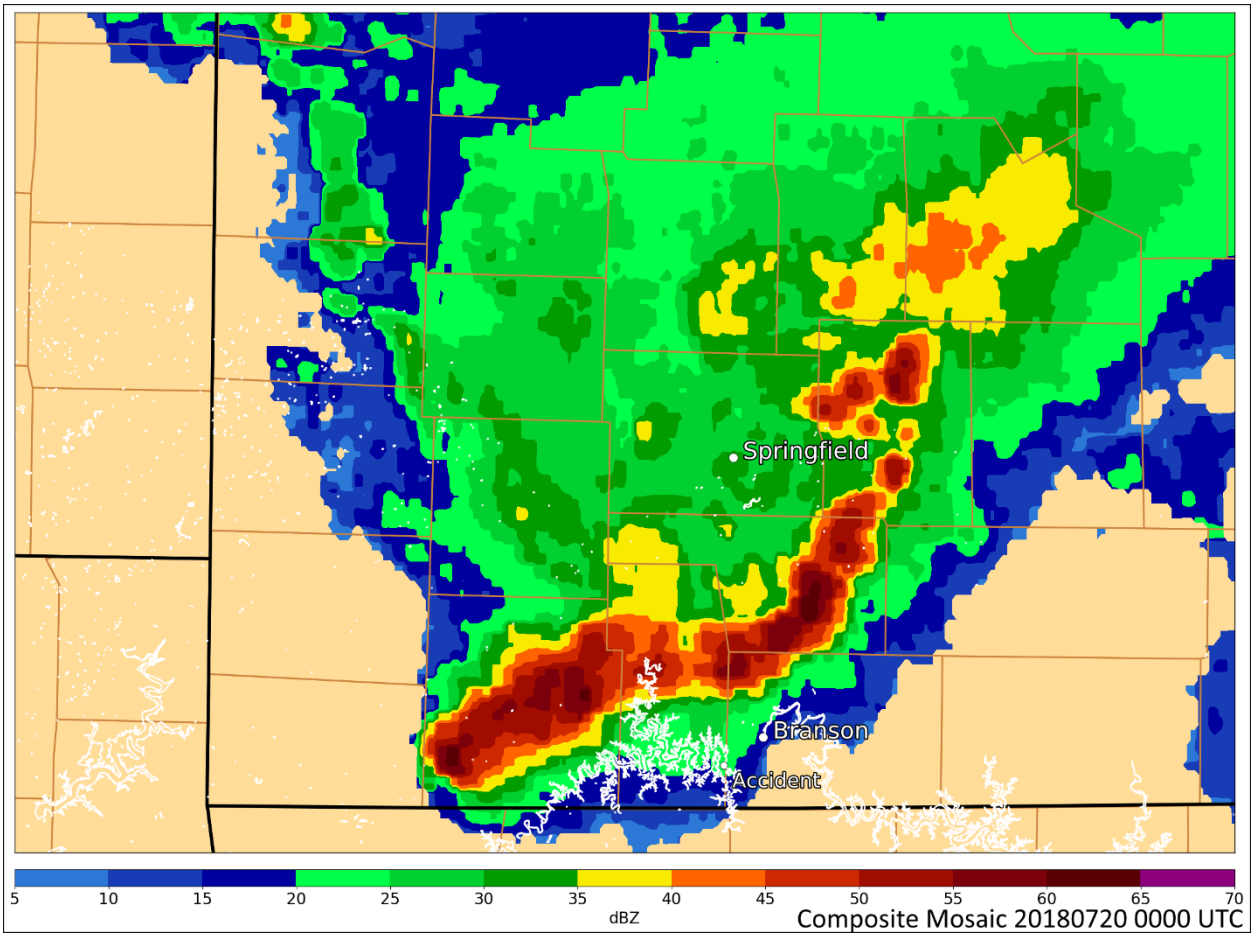


Figure 47 *– Graphic representation of the composite mosaic data with a valid time of 1900 CDT on July 19, 2018, provided to Earth Networks by WDT. The earliest these mosaic data could have been displayed for customers on StreamerRT following further processing by Earth Networks was 1905 CDT (with a timestamp within StreamerRT of 1905 CDT).*

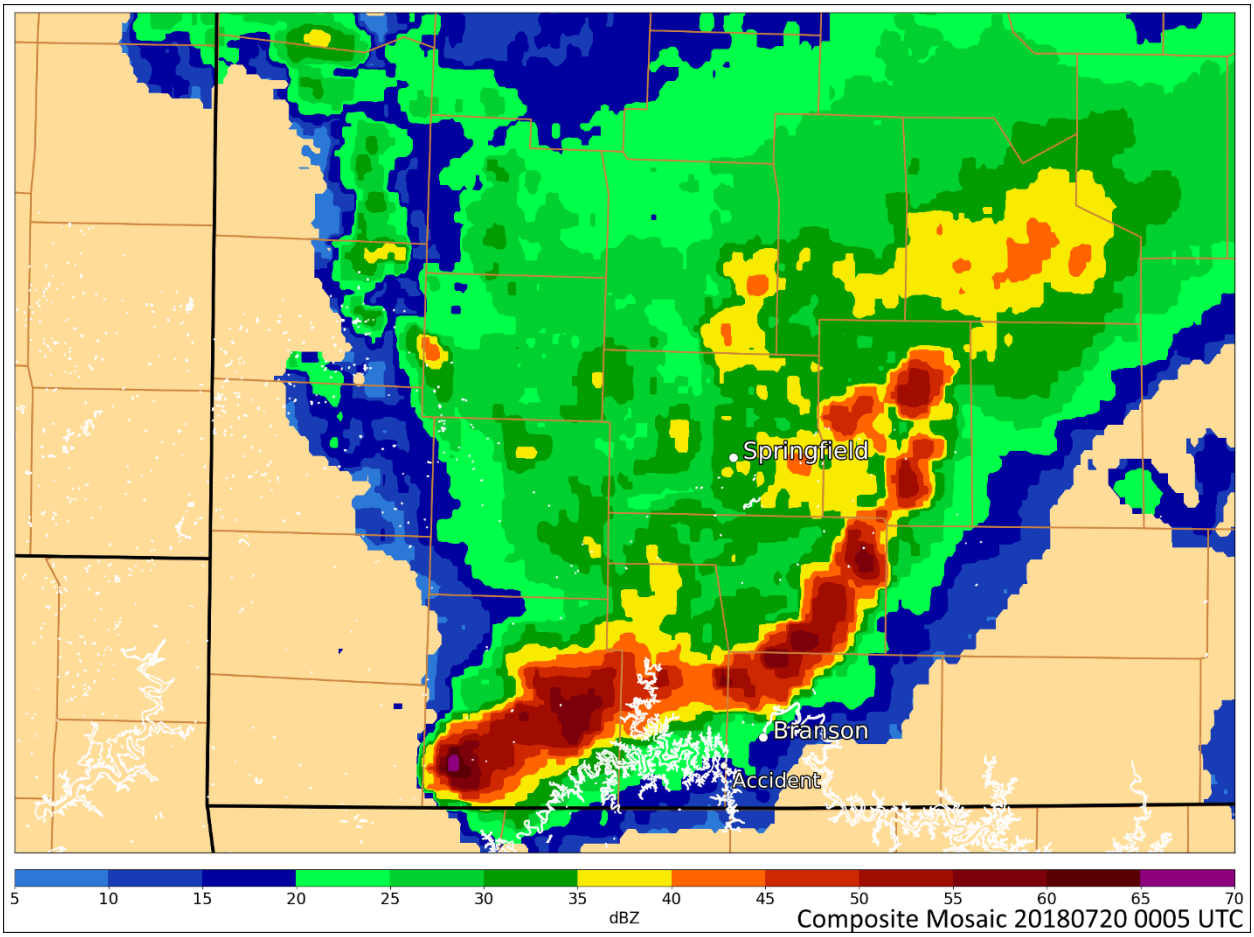


Figure 48 *– Graphic representation of the composite mosaic data with a valid time of 1905 CDT on July 19, 2018, provided to Earth Networks by WDT. The earliest these mosaic data could have been displayed for customers on StreamerRT following further processing by Earth Networks was 1910 CDT (with a timestamp within StreamerRT of 1910 CDT).*

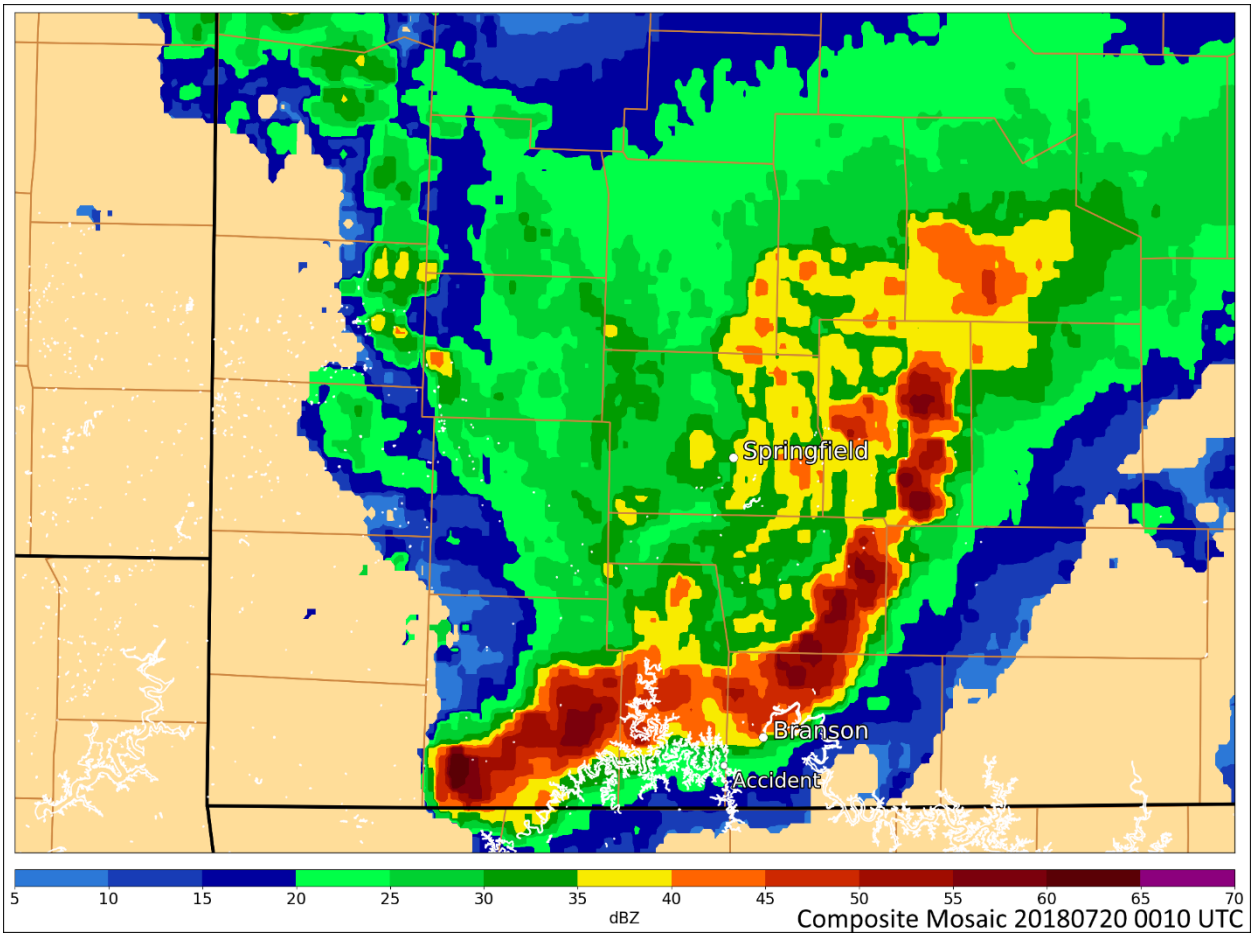


Figure 49 *– Graphic representation of the composite mosaic data with a valid time of 1910 CDT on July 19, 2018, provided to Earth Networks by WDT. The earliest these mosaic data could have been displayed for customers on StreamerRT following further processing by Earth Networks was 1915 CDT (with a timestamp within StreamerRT of 1915 CDT).*

Figures 50-61 represent the US Radar Mosaic products published in StreamerRT (which are based on the mosaics created by WDT and sent to Earth Networks) and available to users during the times surrounding the accident time. These mosaic products have been mapped to a different background than what would have been seen in StreamerRT.

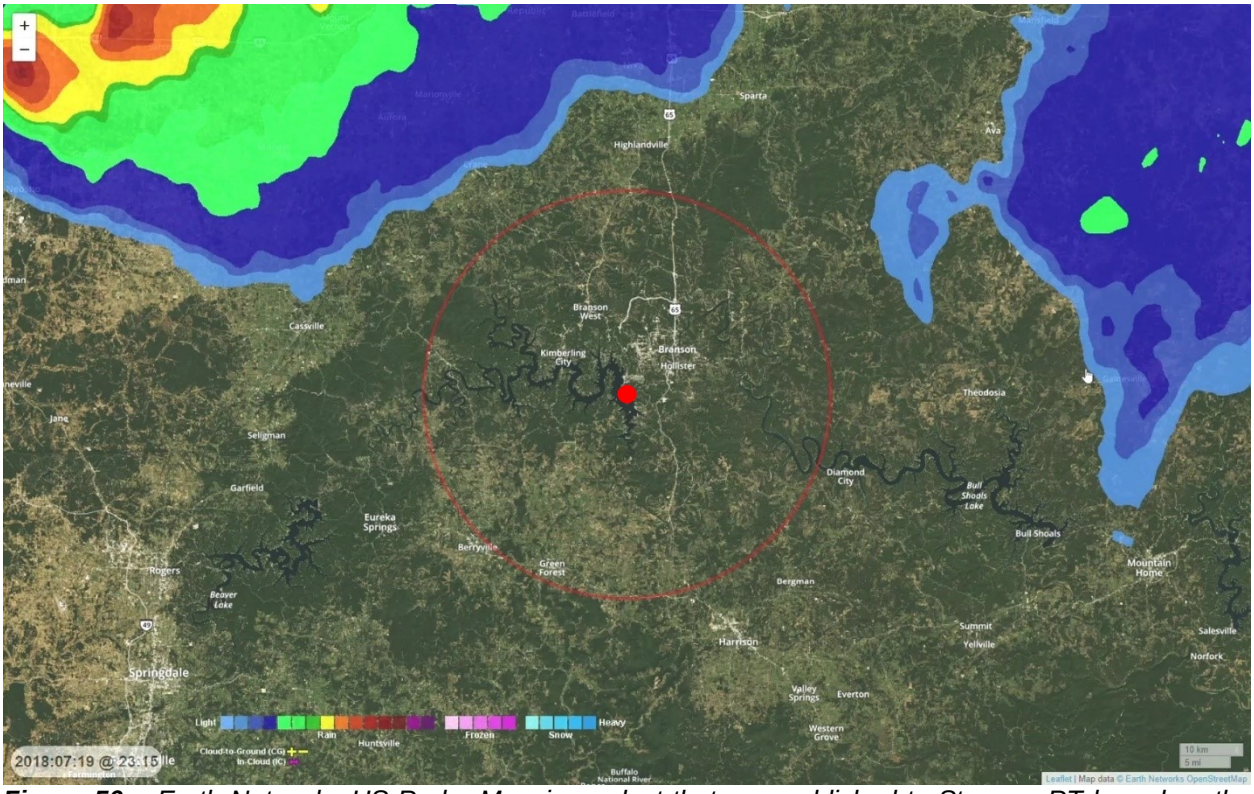


Figure 50 *– Earth Networks US Radar Mosaic product that was published to StreamerRT based on the WDT mosaic with a valid time of 1815 CDT on July 19, 2018. The earliest this mosaic could have been displayed for customers on StreamerRT was 1820 CDT (with a timestamp within StreamerRT of 1820 CDT). The red dot denotes the accident location, and the red circle is centered on the point with a radius of 20 statute miles. These radar data have been geolocated to a background that does not represent what a user of StreamerRT would have seen.*

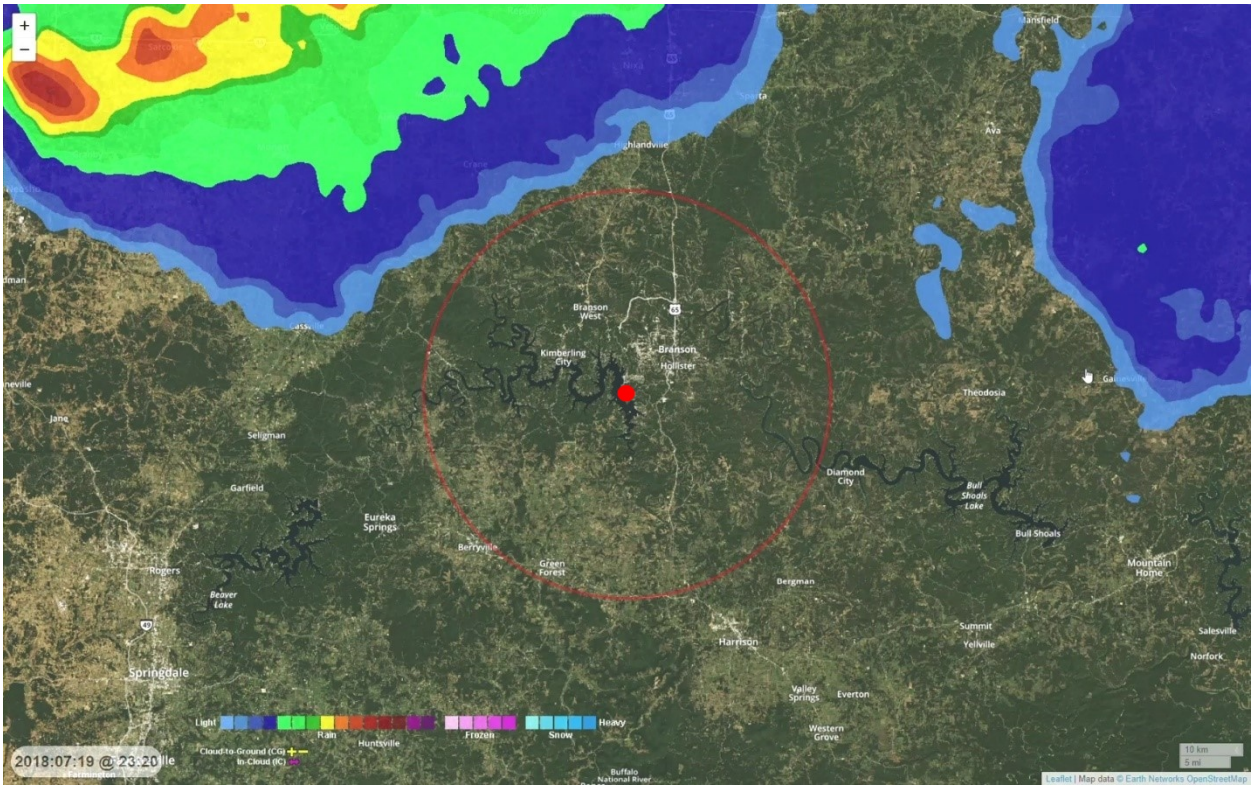


Figure 51 *– Earth Networks US Radar Mosaic product that was published to StreamerRT based on the WDT mosaic with a valid time of 1820 CDT on July 19, 2018. The earliest this mosaic could have been displayed for customers on StreamerRT was 1825 CDT (with a timestamp within StreamerRT of 1825 CDT). The red dot denotes the accident location, and the red circle is centered on the point with a radius of 20 statute miles. These radar data have been geolocated to a background that does not represent what a user of StreamerRT would have seen.*

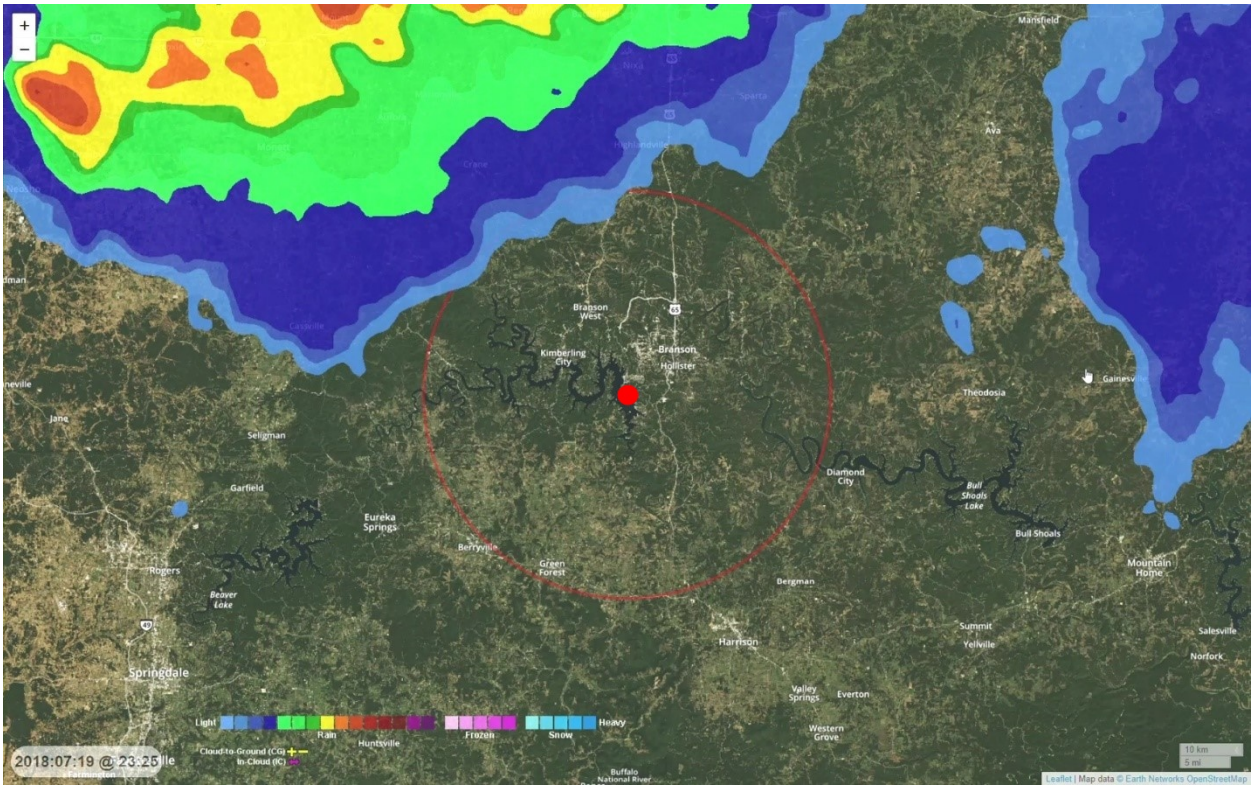


Figure 52 *– Earth Networks US Radar Mosaic product that was published to StreamerRT based on the WDT mosaic with a valid time of 1825 CDT on July 19, 2018. The earliest this mosaic could have been displayed for customers on StreamerRT was 1830 CDT (with a timestamp within StreamerRT of 1830 CDT). The red dot denotes the accident location, and the red circle is centered on the point with a radius of 20 statute miles. These radar data have been geolocated to a background that does not represent what a user of StreamerRT would have seen.*

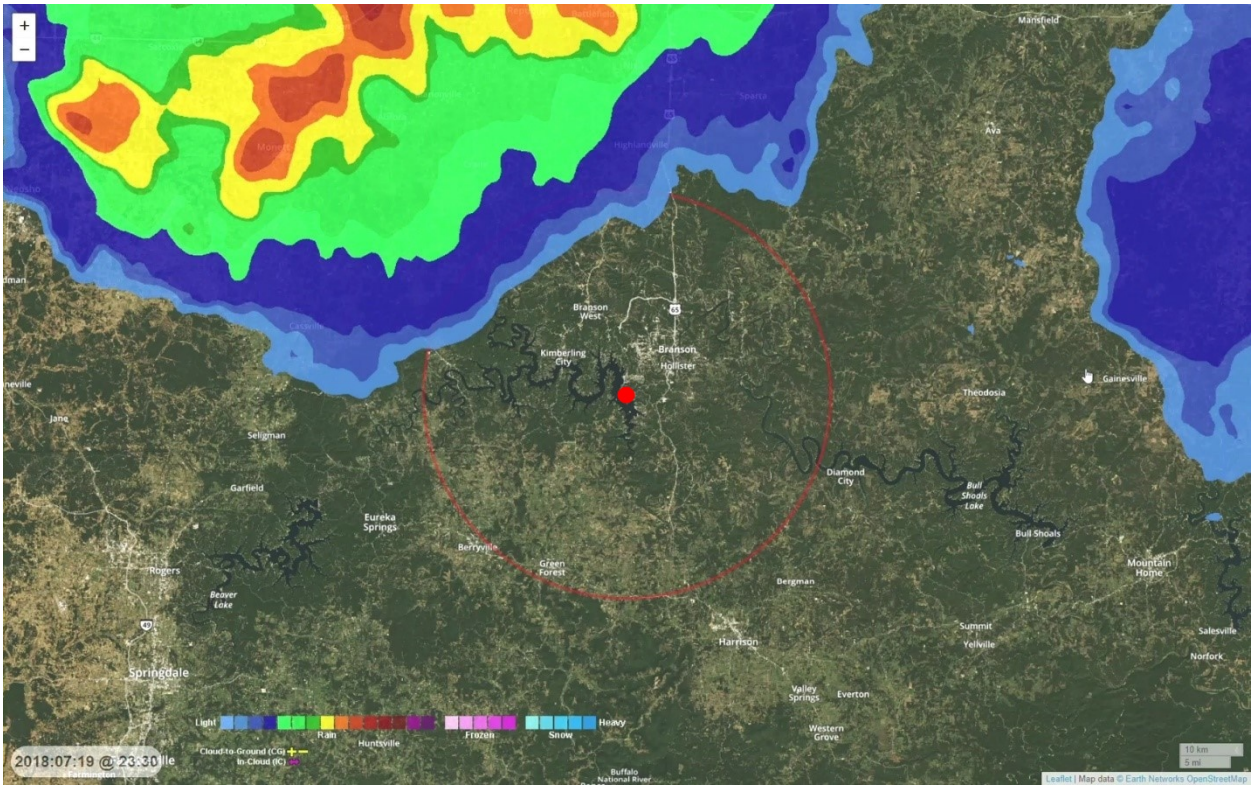


Figure 53 *– Earth Networks US Radar Mosaic product that was published to StreamerRT based on the WDT mosaic with a valid time of 1830 CDT on July 19, 2018. The earliest this mosaic could have been displayed for customers on StreamerRT was 1835 CDT (with a timestamp within StreamerRT of 1835 CDT). The red dot denotes the accident location, and the red circle is centered on the point with a radius of 20 statute miles. These radar data have been geolocated to a background that does not represent what a user of StreamerRT would have seen.*

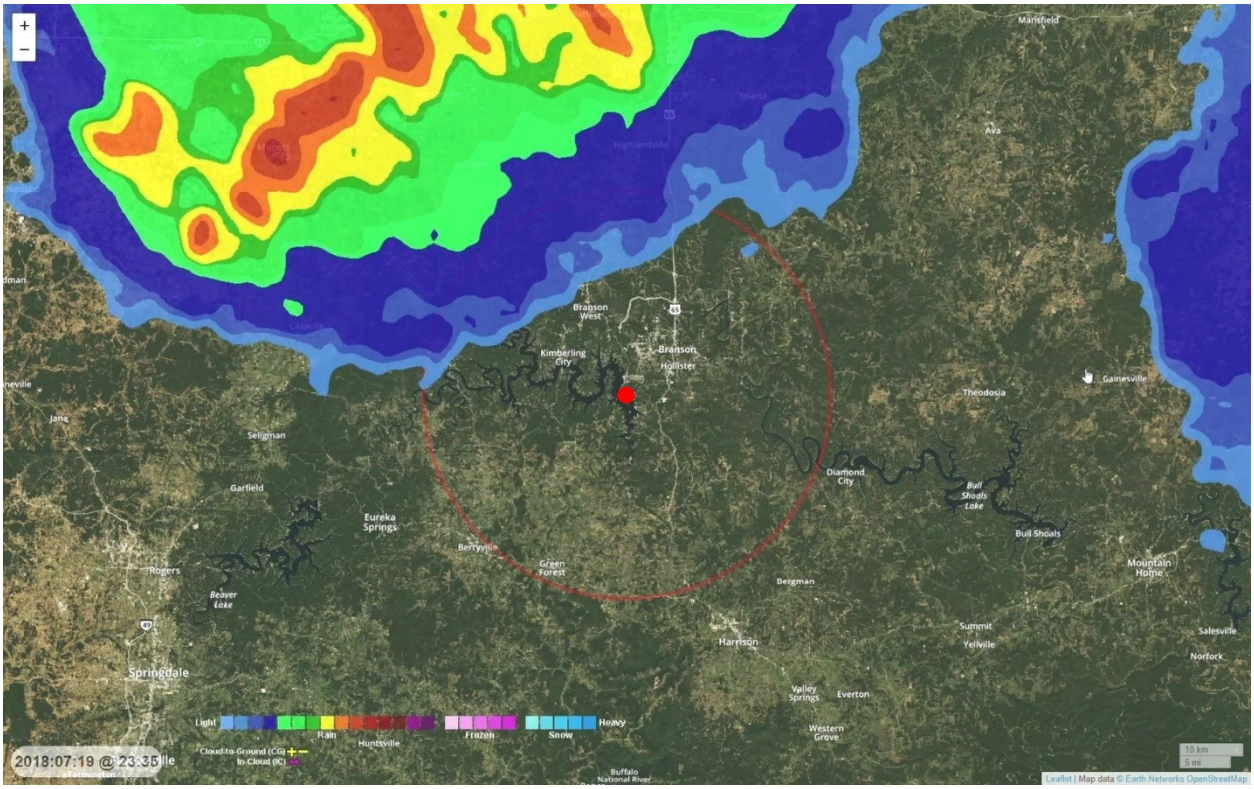


Figure 54 *– Earth Networks US Radar Mosaic product that was published to StreamerRT based on the WDT mosaic with a valid time of 1835 CDT on July 19, 2018. The earliest this mosaic could have been displayed for customers on StreamerRT was 1840 CDT (with a timestamp within StreamerRT of 1840 CDT). The red dot denotes the accident location, and the red circle is centered on the point with a radius of 20 statute miles. These radar data have been geolocated to a background that does not represent what a user of StreamerRT would have seen.*

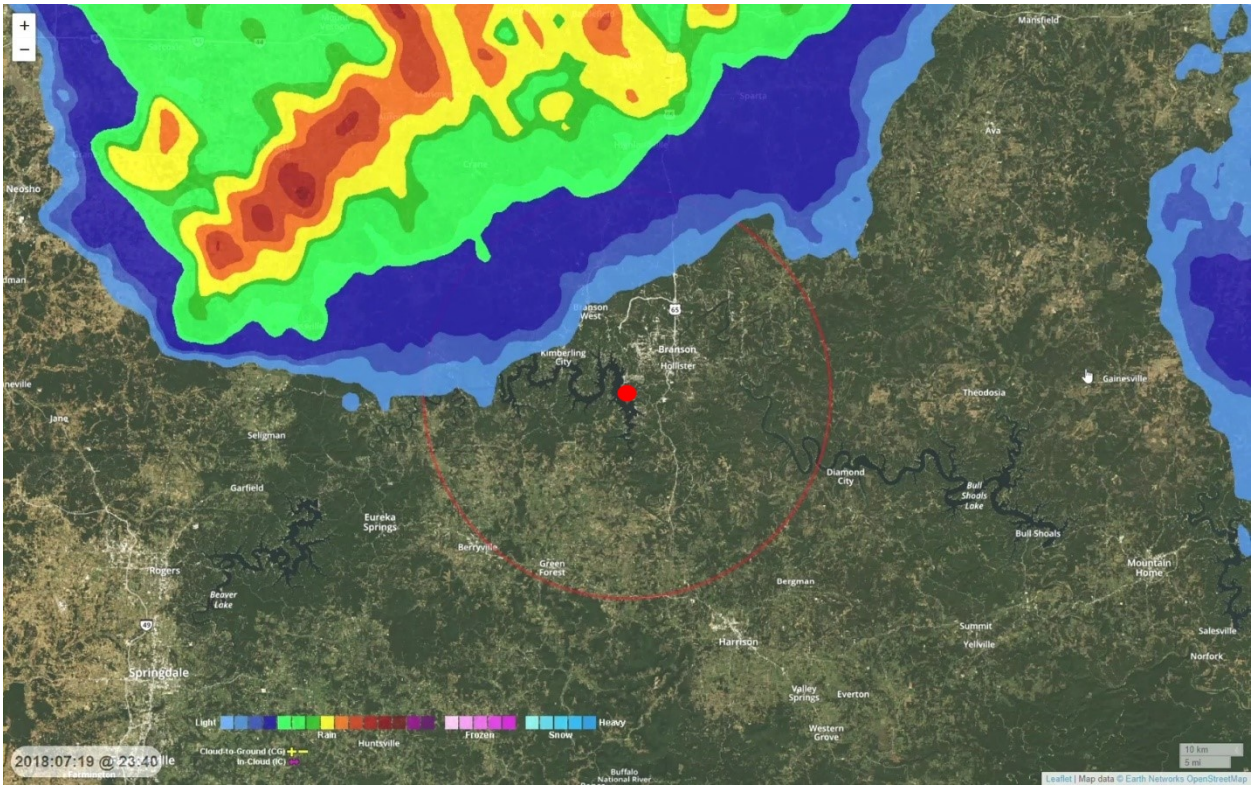


Figure 55 *– Earth Networks US Radar Mosaic product that was published to StreamerRT based on the WDT mosaic with a valid time of 1840 CDT on July 19, 2018. The earliest this mosaic could have been displayed for customers on StreamerRT was 1845 CDT (with a timestamp within StreamerRT of 1845 CDT). The red dot denotes the accident location, and the red circle is centered on the point with a radius of 20 statute miles. These radar data have been geolocated to a background that does not represent what a user of StreamerRT would have seen.*

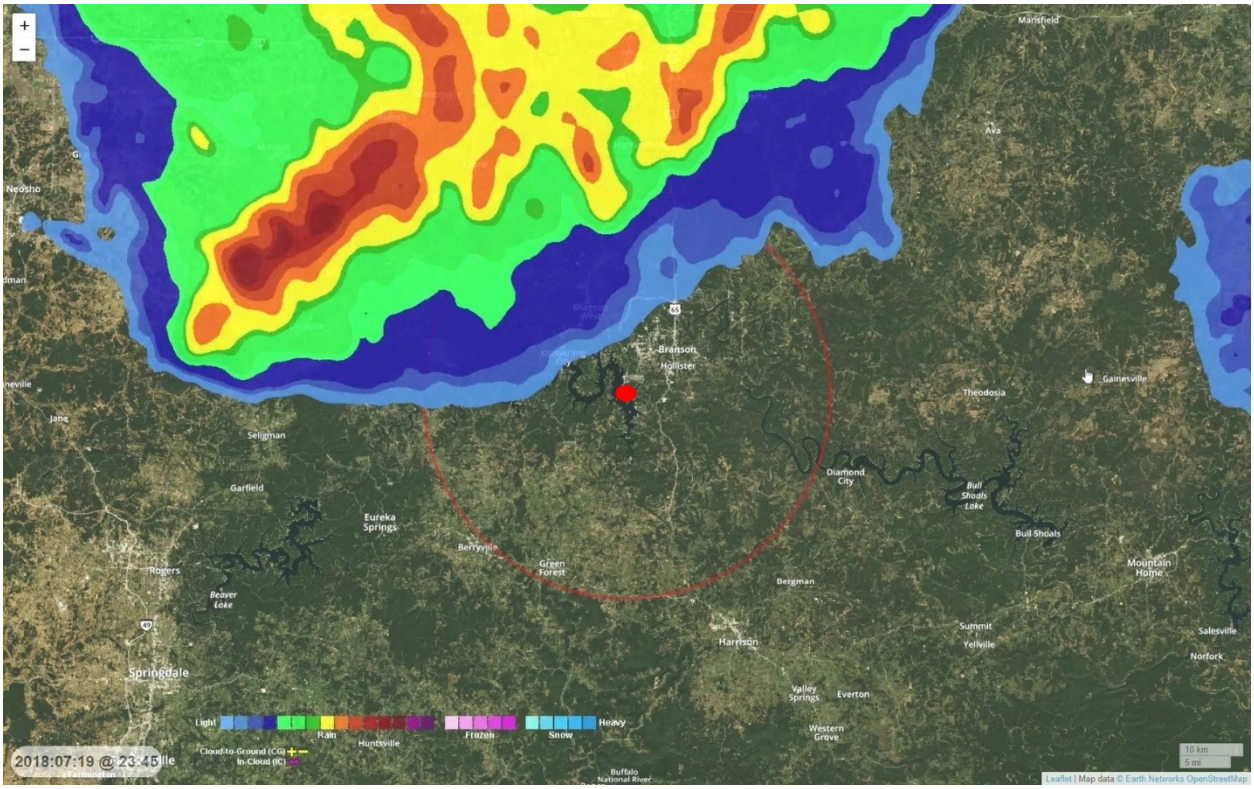


Figure 56 *– Earth Networks US Radar Mosaic product that was published to StreamerRT based on the WDT mosaic with a valid time of 1845 CDT on July 19, 2018. The earliest this mosaic could have been displayed for customers on StreamerRT was 1850 CDT (with a timestamp within StreamerRT of 1850 CDT). The red dot denotes the accident location, and the red circle is centered on the point with a radius of 20 statute miles. These radar data have been geolocated to a background that does not represent what a user of StreamerRT would have seen.*

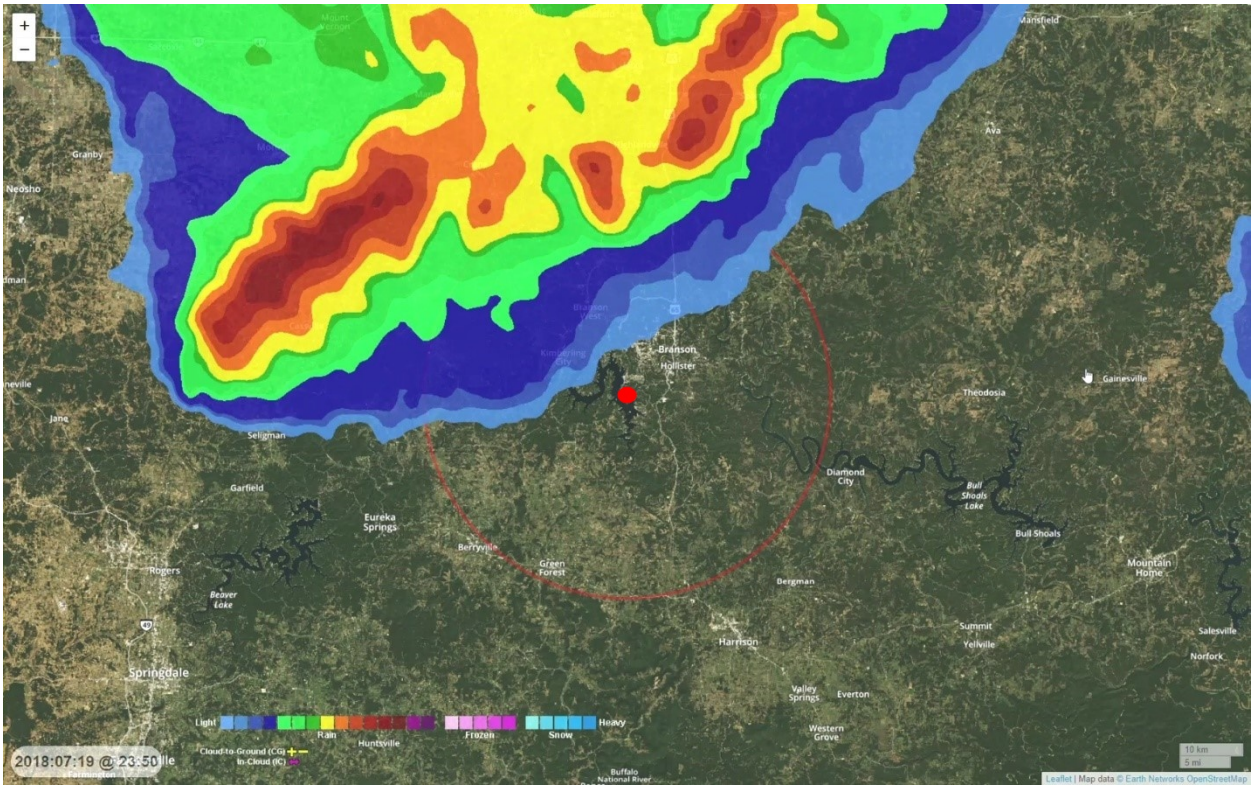


Figure 57 *– Earth Networks US Radar Mosaic product that was published to StreamerRT based on the WDT mosaic with a valid time of 1850 CDT on July 19, 2018. The earliest this mosaic could have been displayed for customers on StreamerRT was 1855 CDT (with a timestamp within StreamerRT of 1855 CDT). The red dot denotes the accident location, and the red circle is centered on the point with a radius of 20 statute miles. These radar data have been geolocated to a background that does not represent what a user of StreamerRT would have seen.*

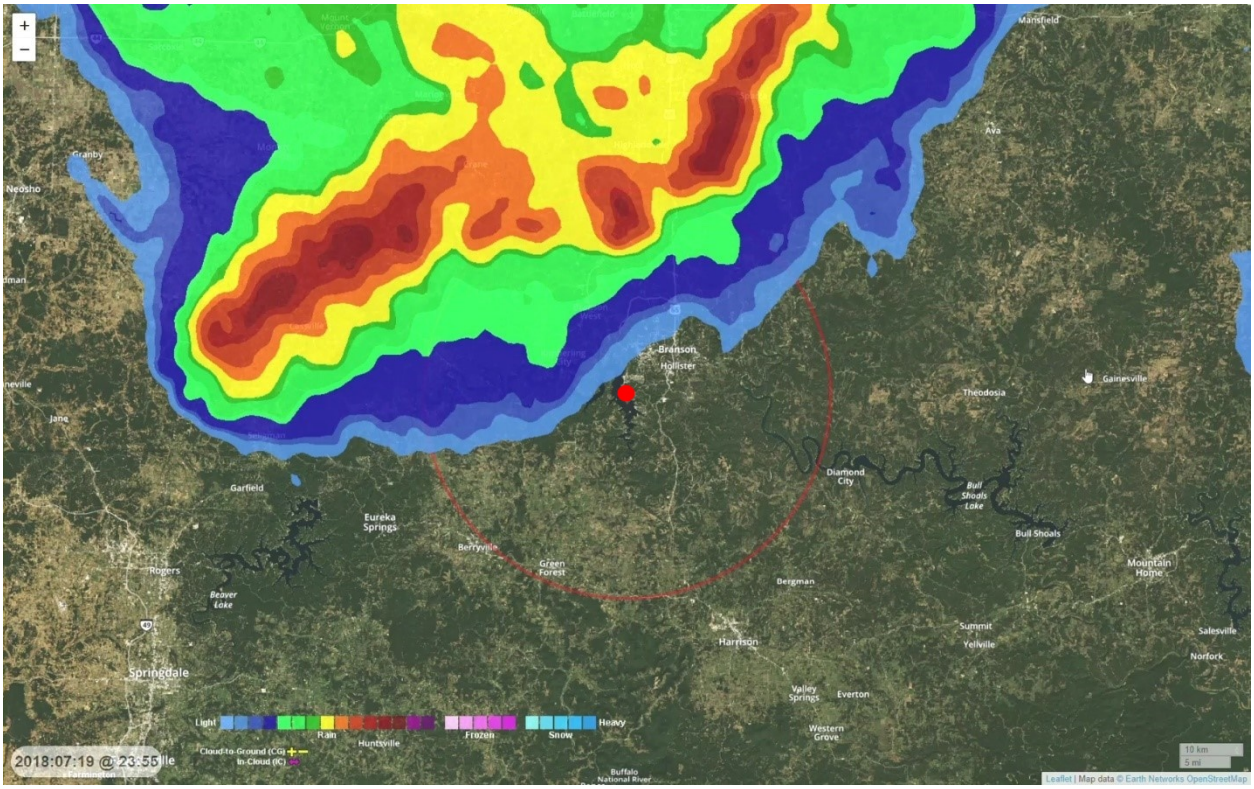


Figure 58 *– Earth Networks US Radar Mosaic product that was published to StreamerRT based on the WDT mosaic with a valid time of 1855 CDT on July 19, 2018. The earliest this mosaic could have been displayed for customers on StreamerRT was 1900 CDT (with a timestamp within StreamerRT of 1900 CDT). The red dot denotes the accident location, and the red circle is centered on the point with a radius of 20 statute miles. These radar data have been geolocated to a background that does not represent what a user of StreamerRT would have seen.*

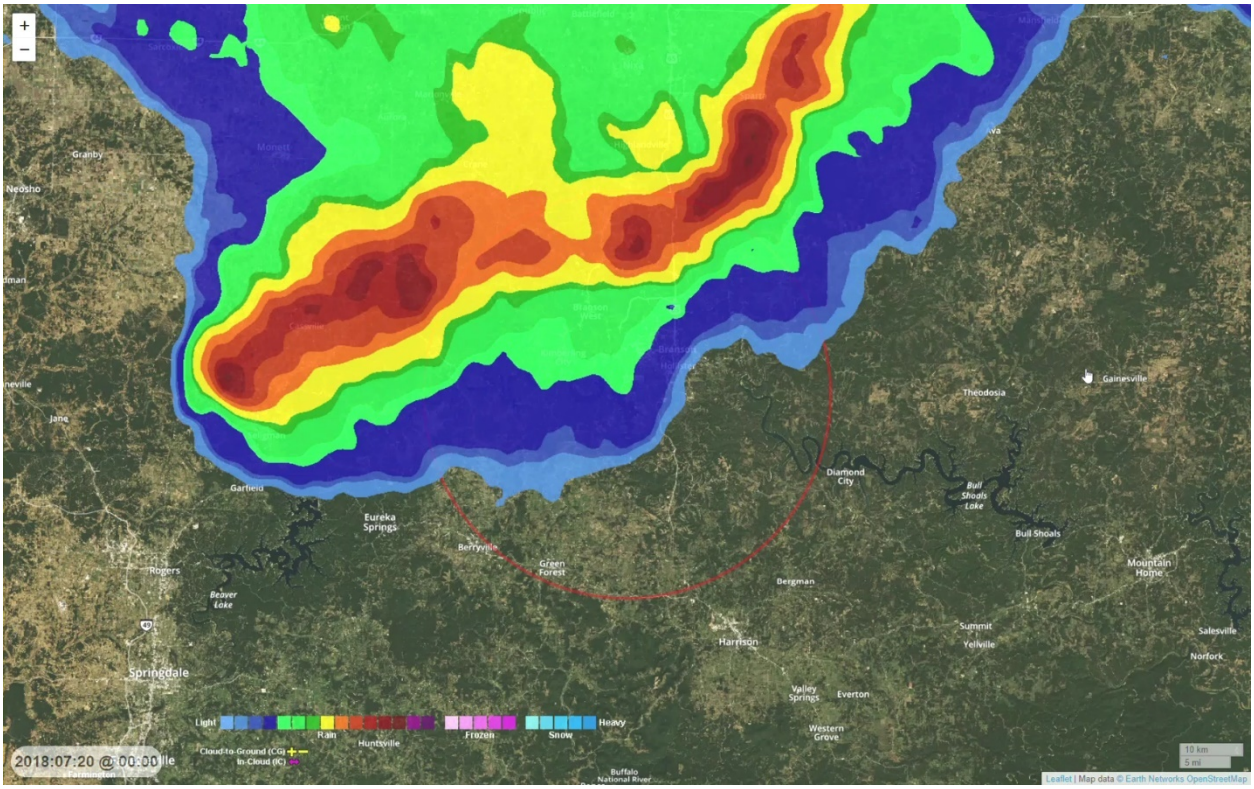


Figure 59 *– Earth Networks US Radar Mosaic product that was published to StreamerRT based on the WDT mosaic with a valid time of 1900 CDT on July 19, 2018. The earliest this mosaic could have been displayed for customers on StreamerRT was 1905 CDT (with a timestamp within StreamerRT of 1905 CDT). The red circle is centered on the accident site with a radius of 20 statute miles. These radar data have been geolocated to a background that does not represent what a user of StreamerRT would have seen.*

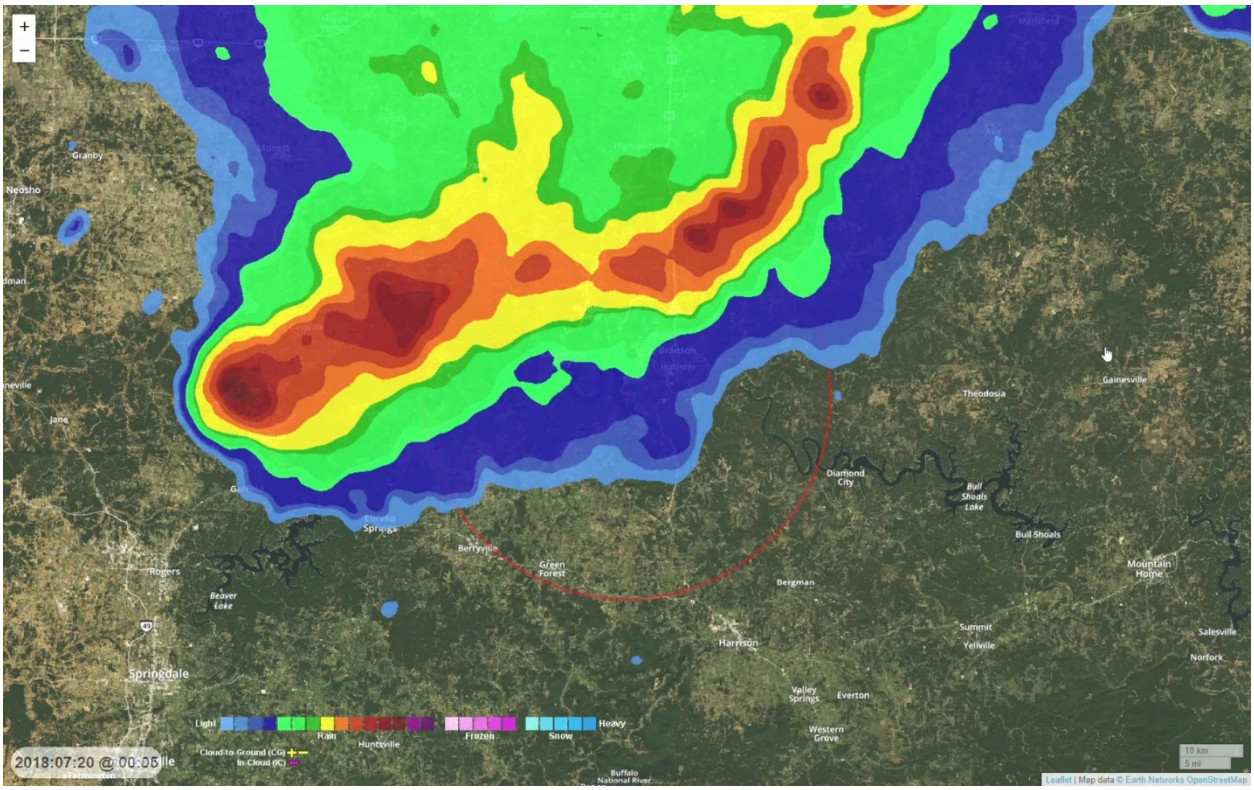


Figure 60 *– Earth Networks US Radar Mosaic product that was published to StreamerRT based on the WDT mosaic with a valid time of 1905 CDT on July 19, 2018. The earliest this mosaic could have been displayed for customers on StreamerRT was 1910 CDT (with a timestamp within StreamerRT of 1910 CDT). The red circle is centered on the accident site with a radius of 20 statute miles. These radar data have been geolocated to a background that does not represent what a user of StreamerRT would have seen.*

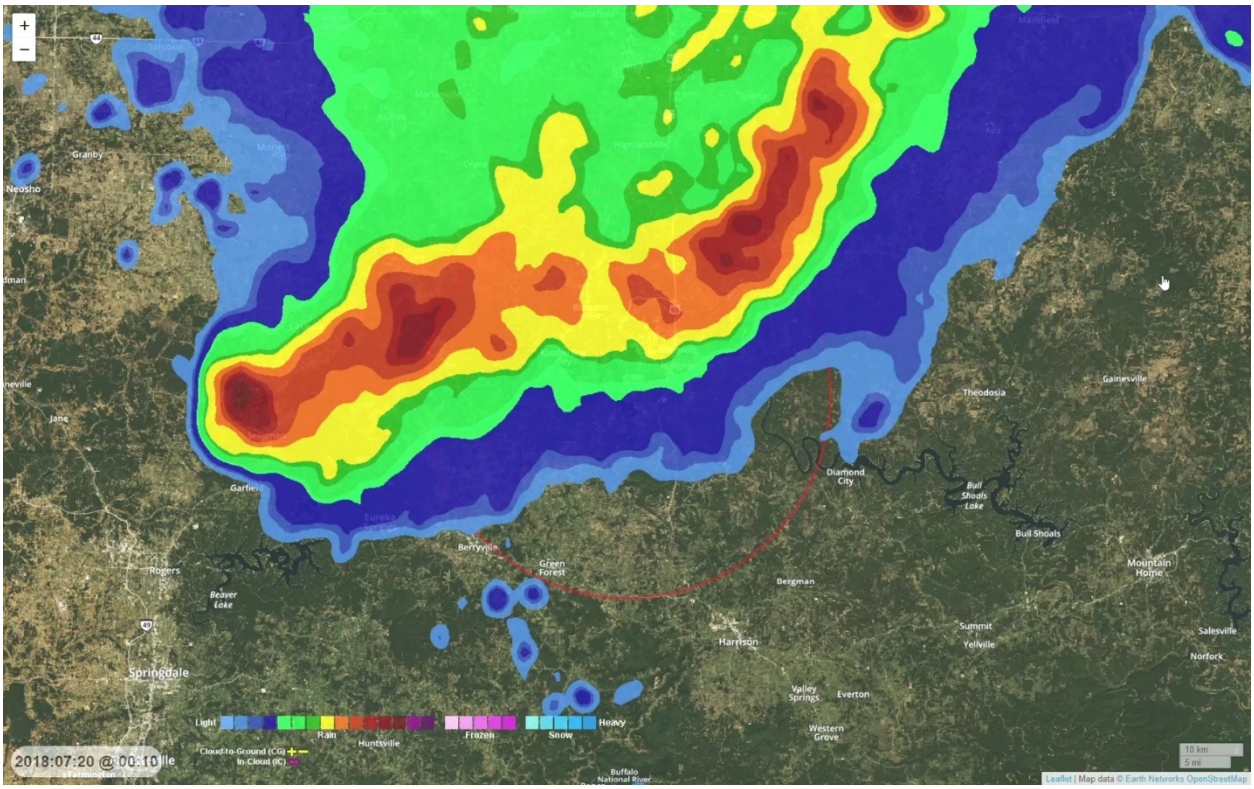


Figure 61 *– Earth Networks US Radar Mosaic product that was published to StreamerRT based on the WDT mosaic with a valid time of 1910 CDT on July 19, 2018. The earliest this mosaic could have been displayed for customers on StreamerRT was 1915 CDT (with a timestamp within StreamerRT of 1915 CDT). The red circle is centered on the accident site with a radius of 20 statute miles. These radar data have been geolocated to a background that does not represent what a user of StreamerRT would have seen.*

WDT provided the NTSB Meteorology Group with a non-QC'ed composite mosaic with a valid time of 1825 CDT on July 19, 2018 (figure 62). This mosaic, when compared with figure 52, depicts the affect the WDT QC process has on their final composite products prior to distribution to Earth Networks. Figure 63 is a non-QC'ed "low altitude" mosaic created by WDT with the same valid time. According to the Chief Technology Officer at WDT, "Typically [the low altitude mosaic] would be the lowest elevation angle from radars but there are cases where there could be blockage at the lowest angle and thus a higher elevation is considered [at a particular point, or points] (depending on distance from the radar)...the important part is that we create a 3D grid of the radar data and the low-altitude is the lowest altitude level with valid data (not terrain blocked) [within the 3D mosaic grid], so it is terrain following."[49]

[49] These WDT non-QC'ed composite and low altitude mosaic data were not distributed and were created specifically for the NTSB Meteorology Group in support of this investigation. According to WDT, they distributed QC'ed versions of the low altitude mosaics along with the QC'ed composite mosaics to Earth Networks. Earth Networks did not make the low altitude mosaics available within StreamerRT.

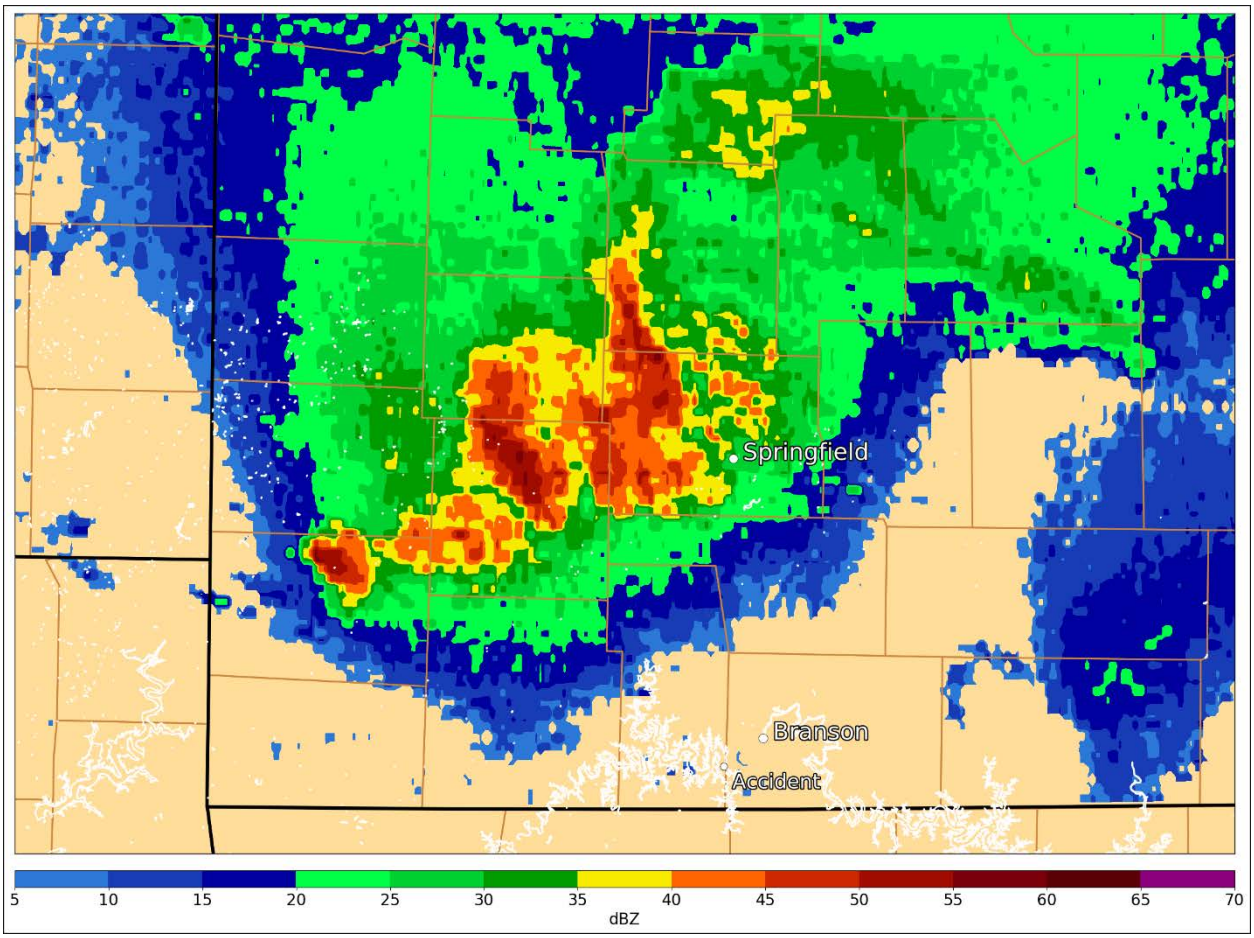


Figure 62 *– Graphic representation of WDT non-QC'ed composite mosaic data with a valid time of 1825 CDT on July 19, 2018. These data were not distributed and were created specifically for the NTSB Meteorology Group in support of this investigation.*

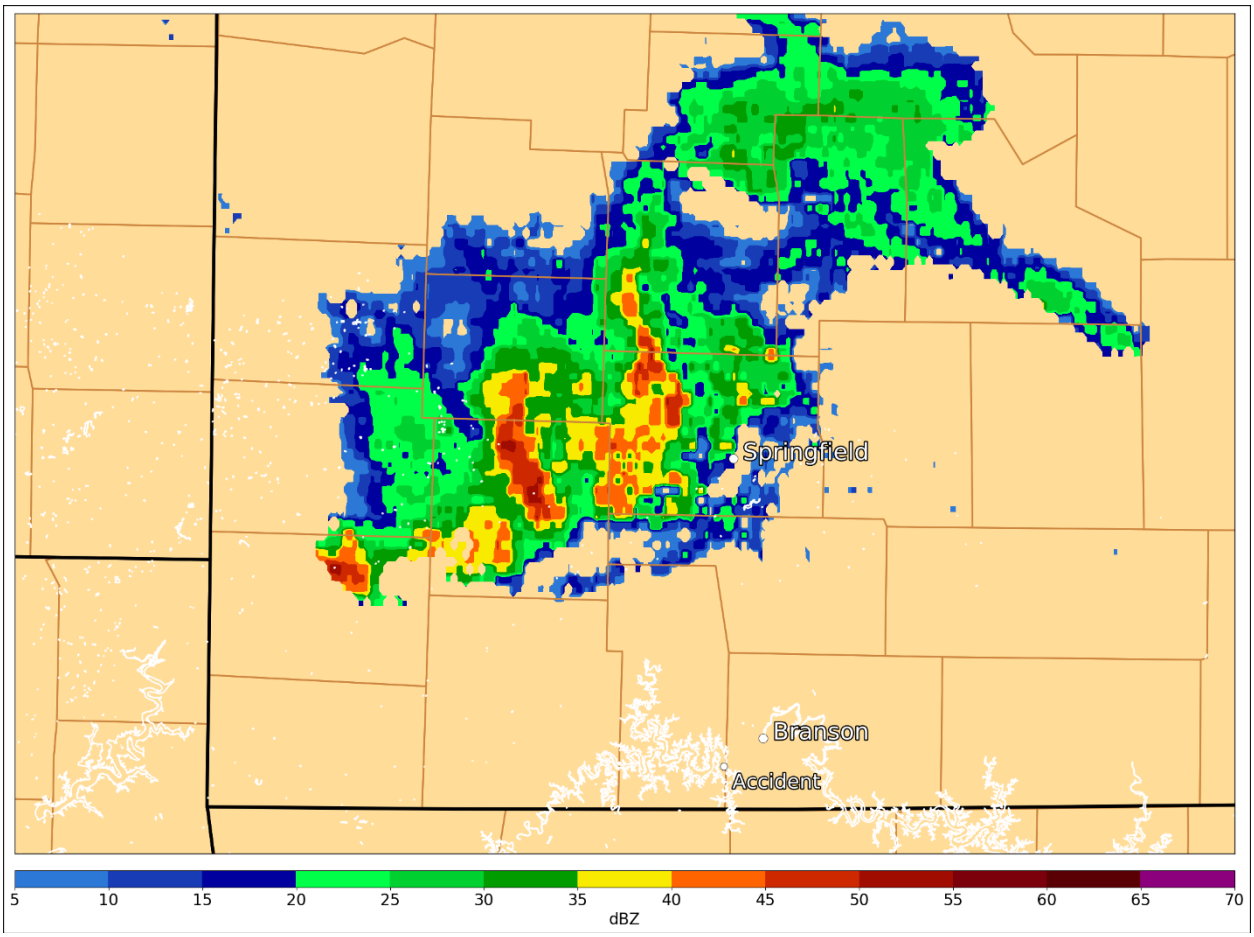


Figure 63 *– Graphic representation of WDT non-QC'ed "low altitude" mosaic data with a valid time of 1825 CDT on July 19, 2018. These data were not distributed and were created specifically for the NTSB Meteorology Group in support of this investigation.*

An additional StreamerRT weather radar option, which did not appear in the selected layers in figure 35 or in the information provided by Earth Networks applicable to dataset overlays active about 1300 CDT on July 23, 2018 (Attachment 18), was "single site" radar, which provided near real time imagery of ~0.5° tilt Level II base reflectivity, base velocity and storm-relative velocity data from individual WSR-88D sites. These data were provided in their publicly-available spatial resolution and were not "smoothed." Archived StreamerRT single site imagery from the accident day were not available, however they likely looked very similar in pattern to the radar images presented in Attachment 2 (StreamerRT would have presented these data using a different color scale[50] as well as a different basemap). Figure 64 presents a comparison of StreamerRT US Radar Mosaic and single site radar presentations for a time and location not associated with the accident (note: different color scales are used for these products).

[50] The color scale for single site radar depiction within StreamerRT can be seen in figure 64. However, dBZ thresholds for this color scale are unknown.

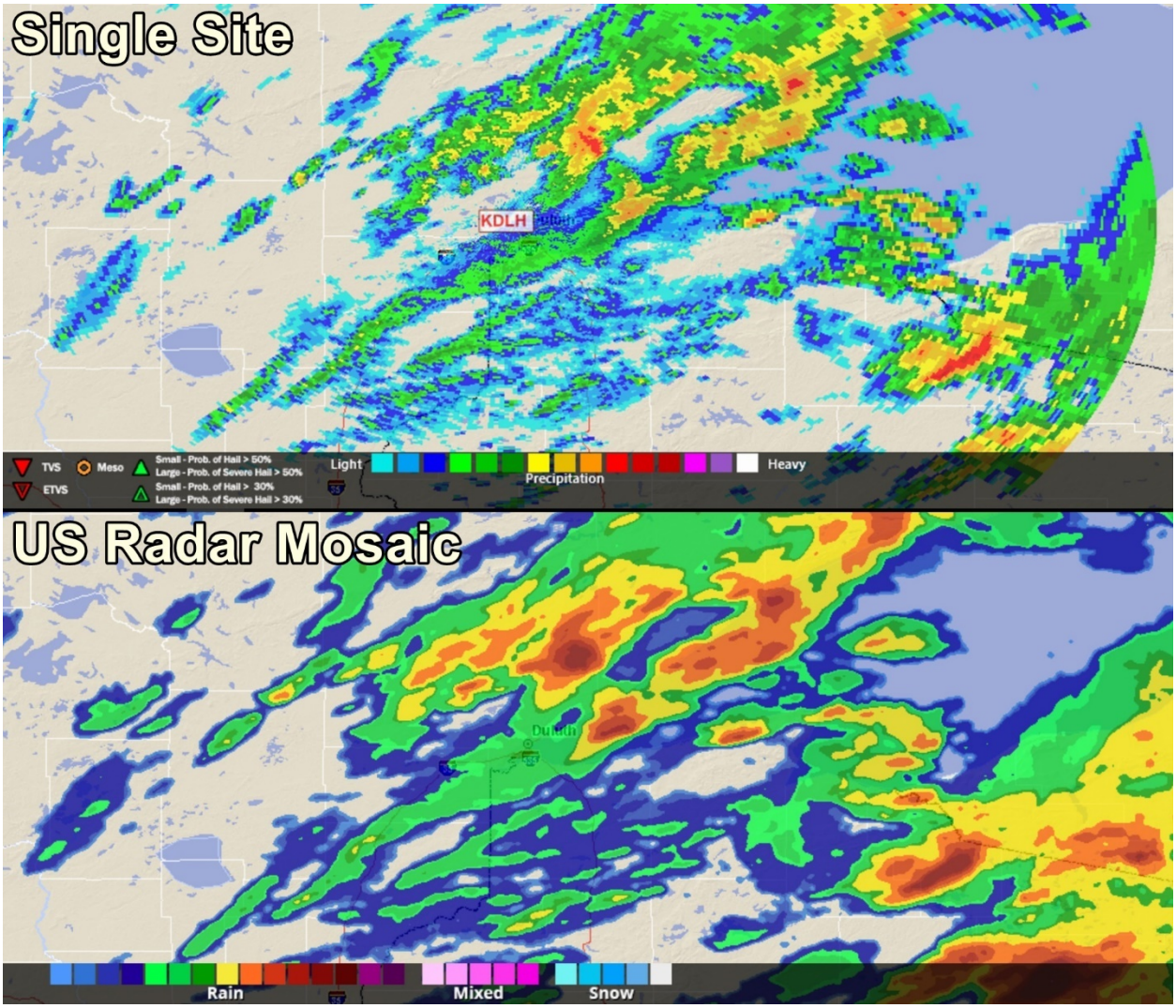


Figure 64 *– Graphic comparison of StreamerRT single site (top panel; Duluth, Minnesota [KDLH]) and US Radar Mosaic (bottom panel) weather radar presentations. Time and location of these radar data are not associated with the accident.*

According to the Ride The Ducks Branson Operations Manager on July 21, 2019, some Ride The Ducks Branson staff were set up to receive email alerts from Earth Networks for certain phenomena within 20 miles of their location. He noted that the range was 20 miles for a 20-minute lead time assuming a storm motion of one mile per minute, and that a pane within the StreamerRT display would allow one to select what types of alerts one wished to receive. He indicated that if a hazard for which they would be alerted entered the area carved out by the 20-mile radius range ring, the workstation in the office lounge (figure 35) would make a “chirping” sound (three chirping sessions of five chirps each, 15 total), and would also send an email to himself, the General Manager, a “deck hand” and several others. The Operations Manager provided the NTSB

Meteorology Group with Earth Networks alerts he received by email on the day of the accident. These emails are presented in Attachment 18.

According to the StreamerRT version 5.1 User's Guide, customers could elect to receive alerts by email when certain weather events or weather-related products (e.g., NWS watches or warnings) cover a specified point or occur within a selected distance of a specified point. See section 10.1 in Attachment 17 for further information. According to Earth Networks, Ride The Ducks Branson had elected to receive email alerts for the following events:

- Lightning (cloud-to-ground or intracloud) within 20 statute miles of 36.5786°N, 93.3044°W
- Outdoor temperature greater than 95°F within 20 statute miles of 36.5786°N, 93.3044°W
- NWS Severe Weather Alerts (Tornado Warnings, Tornado Watches, Severe Thunderstorm Warnings, Severe Thunderstorm Watches and Flash Flood Warnings) at 36.5786°N, 93.3044°W
- "Wind Speed (Average)" observation of greater than[51] 35 mph within 20 statute miles of 36.5786°N, 93.3044°W[52]
- "Wind Speed" observation of greater than[53] 30 mph within 20 statute miles of 36.5786°N, 93.3044°W[54]

Earth Networks provided copies of all alerts emailed to Ride The Ducks Branson on the accident day. The emails are also presented in Attachment 18 and are summarized in the table below. It should be noted that, as established by Ride The Ducks Branson, not all alerts were sent to the same email address(es).

Alert Email Time (CDT)	Applicable Message(s)
1128	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1226	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1551	Outdoor temperature greater than 95°F
1617	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1751	Outdoor temperature greater than 95°F

[51] In the StreamerRT alert setup dialogue box, the operator option is "GreaterThanOrEqual," however the alert emails indicate the criteria is "greater than."

[52] Ride The Ducks Branson had named this alert "Wind Gust Warning."

[53] In the StreamerRT alert setup dialogue box, the operator option is "GreaterThanOrEqual," however the alert emails indicate the criteria is "greater than."

[54] Ride The Ducks Branson had named this alert "Wind Speed Warning."

1810	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri.
1832	Severe Thunderstorm Warning issued by the NWS Springfield WFO at 1832 CDT for an area that included Stone County, Missouri, and Taney County, Missouri
1849	Lightning occurred 19.27 statute miles away
1902	Severe Thunderstorm Warning initially issued by the NWS Springfield WFO at 1832 CDT for an area that included Stone County, Missouri, and Taney County, Missouri
1903	Severe Thunderstorm Watch issued by the SPC at 1120 CDT for an area that included Stone County, Missouri, and Taney County, Missouri
1910	"Wind Speed" observation of 31.07 mph occurred in Branson West, Missouri.
1919	Severe Thunderstorm Warning initially issued by the NWS Springfield WFO at 1832 CDT for an area that included Stone County, Missouri, and Taney County, Missouri
1936	"Wind Speed (Average)" observation of 41.43 mph occurred in Ridgedale, Missouri.

The StreamerRT version 5.1 User's Guide section 10.1.4.1 (Observation Data Elements)[55] defines "Wind Speed" as the "Two-minute average of instantaneous wind measurements, expressed in mph or km/h." According to Earth Networks in correspondence on November 19, 2018 (Attachment 18), "Wind Speed is the instantaneous wind speed - this is only measured by [Earth Networks] sites." However, the email alert sent to Ride The Ducks Branson personnel at 1910 CDT appeared to correspond to the average wind magnitude report of 27 knots (31 mph) in the FWB observation timestamped at 1855 CDT.

The StreamerRT version 5.1 User's Guide does not explicitly define the "Wind Speed (Average)" parameter. According to Earth Networks in correspondence on November 17, 2018 (Attachment 18), the "Wind Speed (Average)" is "…the 2-min average. This is the wind value in the METAR obs." The email alert sent to Ride The Ducks Branson personnel at 1936 CDT (after the accident time) appeared to correspond to the average wind magnitude report of 36 knots (41 mph) in the BBG observation timestamped at 1925 CDT. There was no "Wind Speed" email alert sent to Ride The Ducks Branson for this BBG observation.

According to the Ride The Ducks Branson Operations Manager on July 21, 2019, he and another manager received a two-hour virtual training session on StreamerRT, and the Ride The Ducks Branson staff received some in-house training. Dates of these training sessions were unknown.

[55] This section addresses the creation of new alerts.

According to Earth Networks, “It appears that [the] 1.5 hr. online training/webinar took place on March 5, 2014.” In September 2015, an email (see Attachment 18) was sent from the (at that time) Assistant General Manager at Ride The Ducks Branson to Earth Networks that stated (in part): “…I believe we have been satisfied overall with streamerRT. I would like to schedule some training with you so I better understand all the features…” It is not known what, if any, training was provided per this request.

5.12. Fetch Length, Wave Height and Wave Period

On July 21, 2018, a captain of the Showboat Branson Belle told the NTSB Meteorology Group that during the time of the accident he estimated the wave height on Table Rock Lake was 4 feet, trough-to-crest.

Calculations of the fetch length (the length over Table Rock Lake that the wind would have blown before reaching the accident vessel) and Table Rock Lake wave height and period during the accident time were performed by the NWS in the days following the accident. The NWS concluded:

- [Table Rock Lake has a] very complex shoreline, so overwater fetch is highly dependent on [wind] flow direction
- Fetch distances range from as little as 1.55 [statute] miles to as much [as] 3.7 [statute] miles [see figure 65]
- Based on 45-55 knot winds for 30 minutes estimated wave heights would be 2.69 feet to 3.71 feet
    - Fetch length difference is too small to make a big impact over short time scale
    - [Calculations do] not account for complexity of shoreline, reflective waves, etc…
    - Longest fetch + 60 kts = 4.23 feet waves
- Periodicity of waves would be 2.7 to 3.6 seconds
    - Short periodicity means waves are battering vessel at short intervals

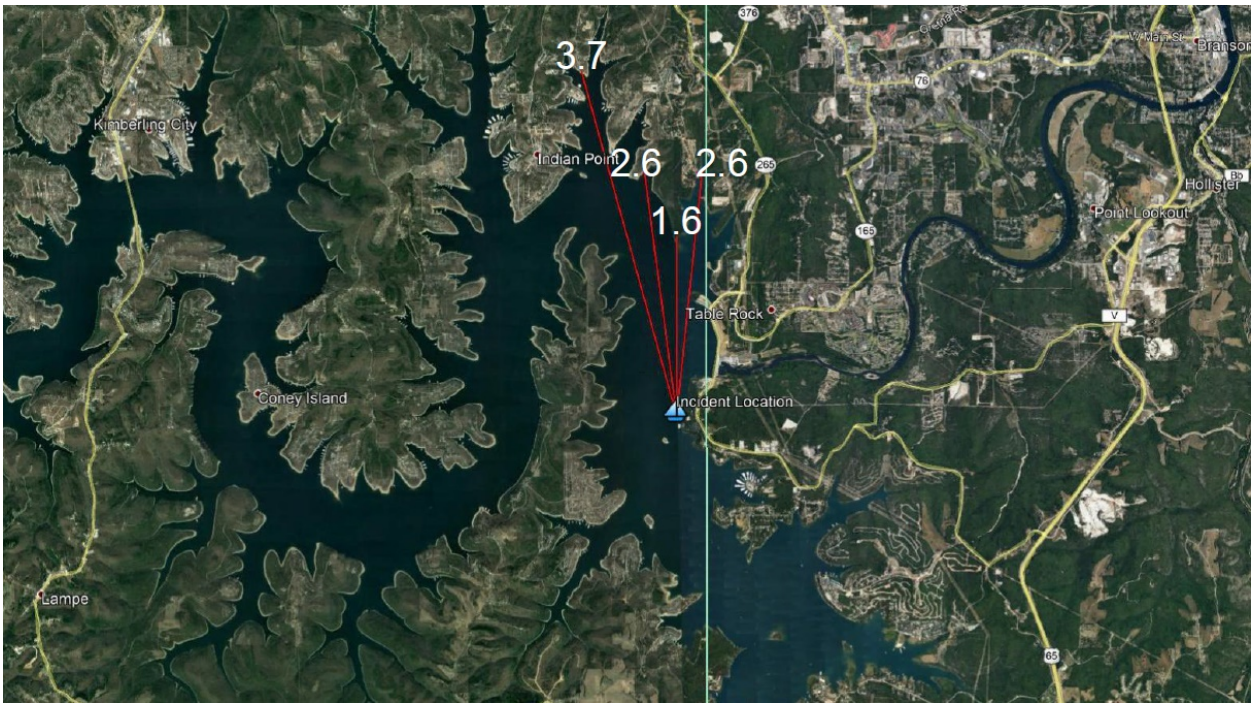


Figure 65 *– Fetch length (statute miles) on Table Rock Lake along possible paths for derecho-produced surface wind about the accident time. Provided by the NWS.*

5.13. Astronomical Data

Astronomical data from the United States Naval Observatory for latitude 36°35'N (36.58333°N) and longitude 93°19'W (93.3167°W) for July 19, 2018, show moonrise at 1325 CDT, sunset at 2029 CDT, end of civil twilight at 2059 CDT, and moonset at 0035 CDT.[56]

5.14. Additional Information

5.14.1. Table Rock Lake Temperature Profile

A temperature and dissolved oxygen (D.O.) profile for Table Rock Lake from July 11, 2018, was provided by the US. Army Corps of Engineers (USACE) via the NWS and is "basically a snapshot of water temps moving vertically through the lake." This profile was collected from a boat located near Table Rock Dam, which was located about 0.6 miles north-northeast of the accident site. According to the USACE, one "could probably add 0.25°F - 0.5°F to the temps posted." Regarding how well this temperature profile would represent conditions on July 19, 2018, the MIC for the NWS Springfield WFO indicated that "During the Summer and with the weather encountered from July 11-20th these conditions will be very similar from day to day." See Attachment 19 for email correspondence related to the profile.

[56] Moonset occurred at 0035 CDT the following day.

TABLE ROCK LAKE
PROFILE DATE = 11Jul18
ELEVATION = 916.32

NO	DEPTH (feet)	D.O. (mg/l)	TEMP (deg F)
1	0.4	8.68	88.81
2	7.0	8.93	87.42
3	10.0	9.13	86.11
4	17.0	9.55	84.49
5	18.0	9.93	83.75
6	19.0	10.06	82.38
7	20.0	10.33	78.82
8	21.0	10.12	74.80
9	23.0	9.64	73.15
10	25.0	9.52	71.60
11	26.0	9.24	70.12
12	27.0	8.99	67.73
13	28.0	8.57	66.24
14	29.0	8.28	64.74
15	30.0	8.00	64.35
16	31.0	7.37	63.14
17	33.0	6.77	61.57
18	35.0	5.72	60.31
19	40.0	4.37	58.62
20	44.0	3.57	57.34
21	50.0	3.63	56.19
22	58.0	4.35	54.81
23	60.0	4.70	54.61
24	70.0	5.20	54.01
25	80.0	5.91	53.08
26	90.0	6.64	52.21
27	100.0	6.65	51.57
28	110.0	6.77	50.79
29	120.0	6.71	50.50
30	130.0	7.21	49.53
31	140.0	7.13	49.30
32	150.0	7.00	49.05
33	160.0	6.39	48.45
34	170.0	5.68	48.04
35	180.0	4.71	47.43
36	190.0	3.00	46.80
37	200.0	2.15	46.69
38	206.5	2.09	46.71

5.14.2. FWB manager

A conversation with the manager of FWB is documented in Attachment 20.

5.14.3. KYTV Camera

Responding to a request by the NTSB Meteorology Group Chairman, on July 23, 2018, the Chief Meteorologist for KY3 indicated that "…KYTV has a weather camera atop of Chateau on the Lake Resort directly opposite the dam from the accident site. Approximately 6:45 pm that night I used that camera to show the incoming shelf cloud and explain what was happening." See Attachment 3. Subsequent requests to KY3 management for the camera imagery to assist the NTSB's investigation were denied.

5.14.4. NWS Internal Notifications

Internal notifications sent by NWS personnel following the accident, which include descriptions of the weather and communication with outside entities, are presented in Attachment 21.

Submitted by: Mike Richards
NTSB, AS-30