NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

May 28, 2020

Factual Report

METEOROLOGY

RRD19FR007

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A. ACCIDENT

Location: Fort Worth, Texas
Date: April 24, 2019
Time: 0033 central daylight time
0533 Coordinated Universal Time (UTC)
Accident: Union Pacific Tank Car Derailment

B. METEOROLOGIST

Paul Suffern
Senior Meteorologist
Operational Factors Division (AS-30)
National Transportation Safety Board

C. DETAILS OF THE INVESTIGATION

The National Transportation Safety Board's (NTSB) Meteorologist travelled to Omaha, Nebraska, and Union Pacific headquarters for this investigation and also gathered the weather data for this investigation from official National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) sources including the National Centers for Environmental Information (NCEI). All times are central daylight time (CDT) on April 24, 2019, and are based upon the 24-hour clock, where local time is -5 hours from UTC, and UTC=Z. Directions are referenced to true north and distances in nautical miles. Heights are above mean sea level (msl) unless otherwise noted. Visibility is in statute miles and fractions of statute miles. NWS airport and station identifiers use the standard International Civil Aviation Organization 4-letter station identifiers versus the International Air Transport Association 3-letter identifiers, which deletes the initial country code designator "K" for U.S. airports.

The accident site was located at latitude 32.6990° N, longitude 97.3093° W, at an approximate elevation of 600 feet (ft).

D. WEATHER INFORMATION

1.0 Synoptic Situation

The synoptic or large scale migratory weather systems influencing the area were documented using standard NWS charts issued by the National Center for Environmental Prediction and the Weather Prediction Center, located in College Park, Maryland. These are the base products used in describing synoptic weather features and in the creation of forecasts and warnings for the NWS. Reference to these charts can be found in the joint NWS and Federal Aviation Administration (FAA) Advisory Circular "Aviation Weather Services", AC 00-45H[1] and in the NWS Directive System.[2]

1.1 Surface Analysis Chart

The southcentral section of the NWS surface analysis for 2200 CDT on April 23 and 0100 CDT on April 24 are provided as figures 1 and 2, respectively, with the approximate location of the accident site marked within the red circle. The charts identified a cold front located across the accident site at 2200 CDT on April 23 moving eastward past the accident site by 0100 CDT on April 24 with the accident site on the cool side of the front. Surface low pressure centers were located in western Texas and northwestern Arkansas at pressures of 1010 and 1013-hectopascals (hPa), respectively. The cold front located at and near the accident site was connected between the two low pressure centers oriented from southwest to northeast. The station models near the accident site at 2200 CDT on April 23 depicted overcast skies with light rain and thunderstorm activity, air temperatures in the mid 60's to low 70's degrees Fahrenheit (°F), dew point temperatures in the low to mid 60's °F with a temperature-dew point spread of 3° or less, and a variable wind of under 10 knots. The station models near the accident site at 0100 CDT on April 24 depicted overcast skies with light rain and thunderstorm activity, air temperatures in the mid 60's °F, dew point temperatures in the low 60's °F with a temperature-dew point spread of 5° or less, and an east-northeast wind of 10 knots.

[1] https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/1030235

[2] https://www.nws.noaa.gov/directives/

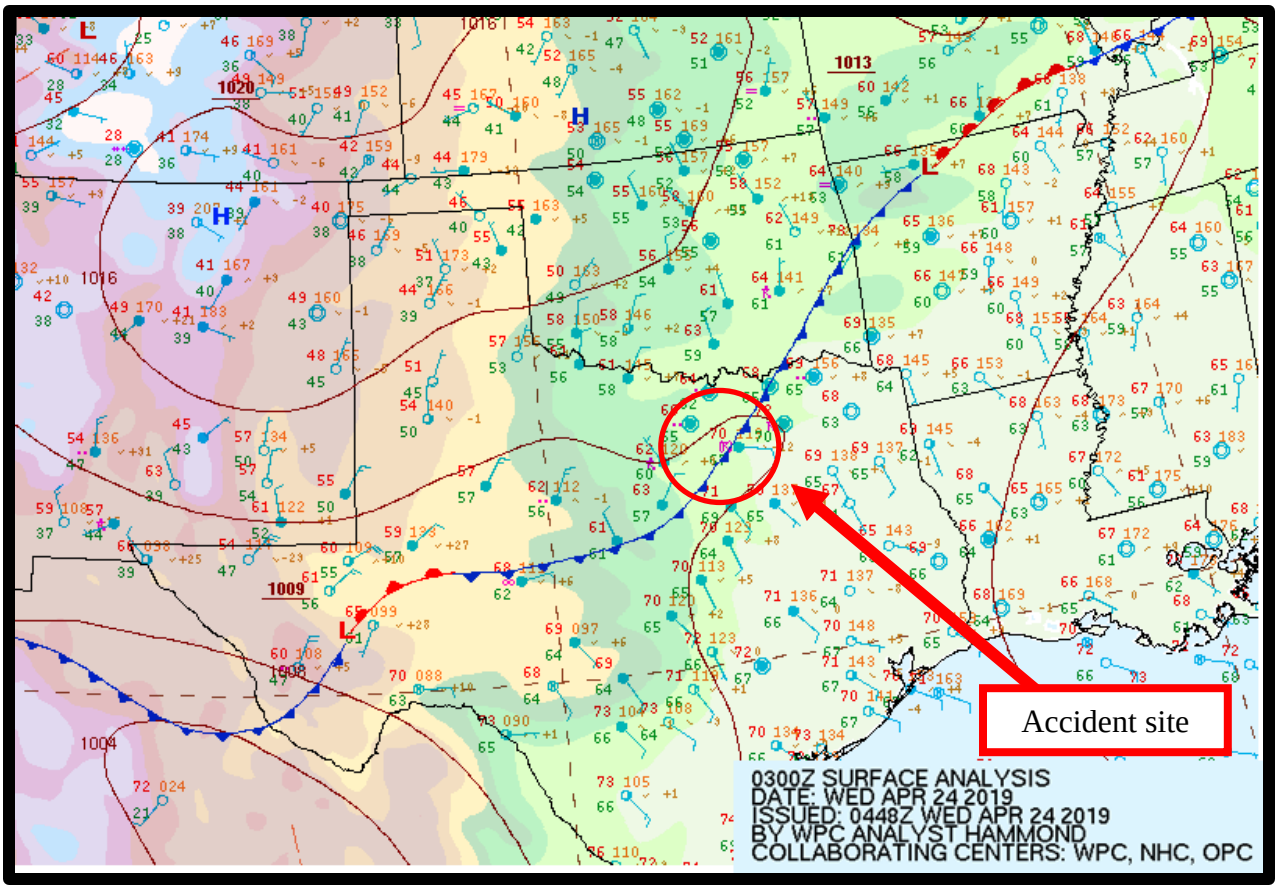


Figure 1 – NWS Surface Analysis Chart for 2200 CDT on April 23

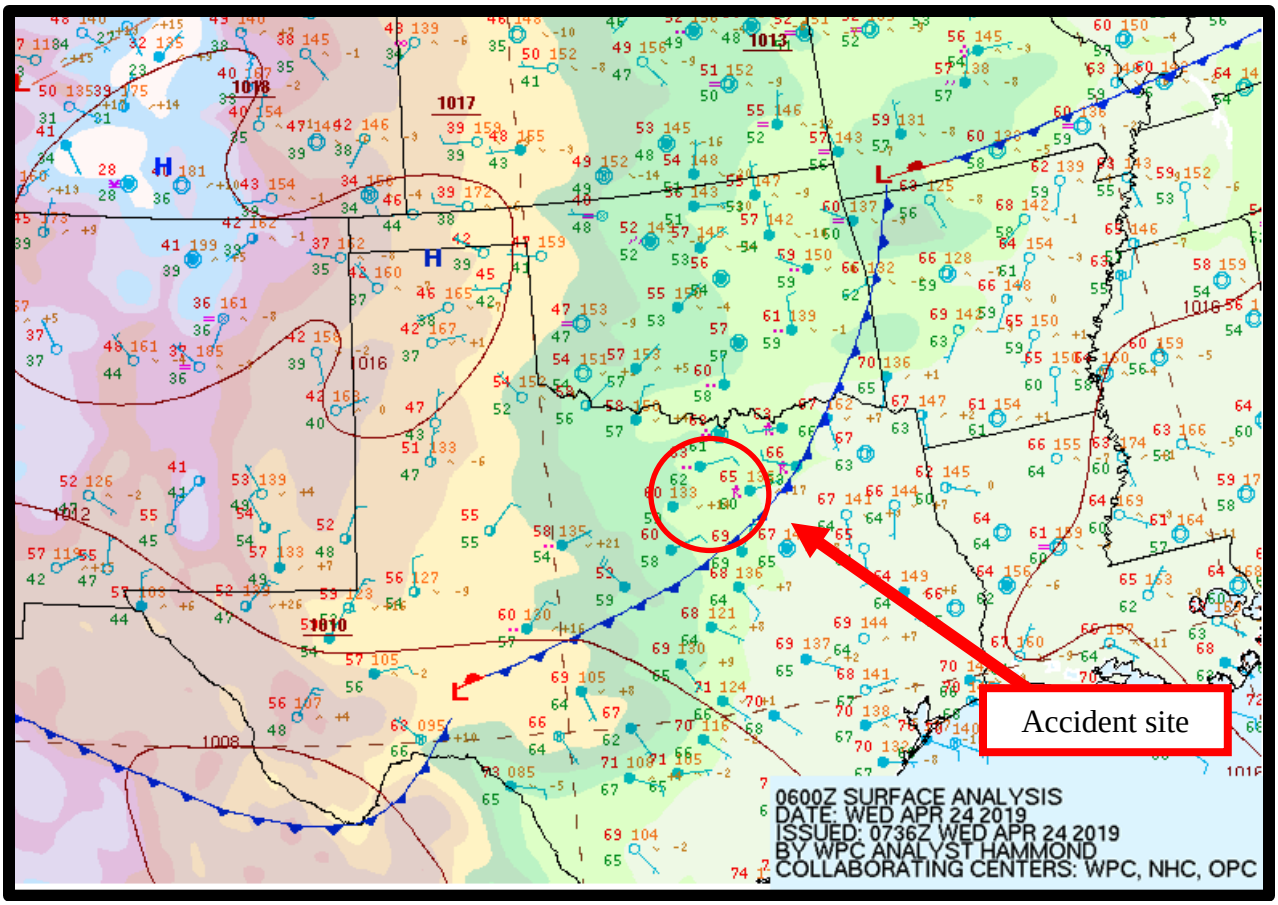


Figure 2 – NWS Surface Analysis Chart for 0100 CDT on April 24

2.0 SPC Products

The Storm Prediction Center (SPC) issued the following Day 1 Convective Outlook at 1925 CDT on April 23 (figure 3) with a slight risk of severe thunderstorms forecast for the accident site. A slight risk of severe thunderstorms is higher than the background climatology of thunderstorms activity for north central Texas on April 23 and 24.[3] The accident site was located in an area where SPC forecasted a 2 percent chance of a tornado within 25 miles of a point, a 15 percent chance of damaging thunderstorm winds or wind gusts 50 knots or greater within 25 miles of a point, and a 15 percent chance of one inch diameter hail or larger within 25 miles of a point (figures 4 through 6). Similar Day 1 Convective Outlooks were issued before 1925 CDT on April 23. The SPC Day 1 Convective Outlook text follows figure 6:

[3] https://www.spc.noaa.gov/new/SVRclimo/climo.php?parm=anySvr
https://www.spc.noaa.gov/wcm/index.html#data

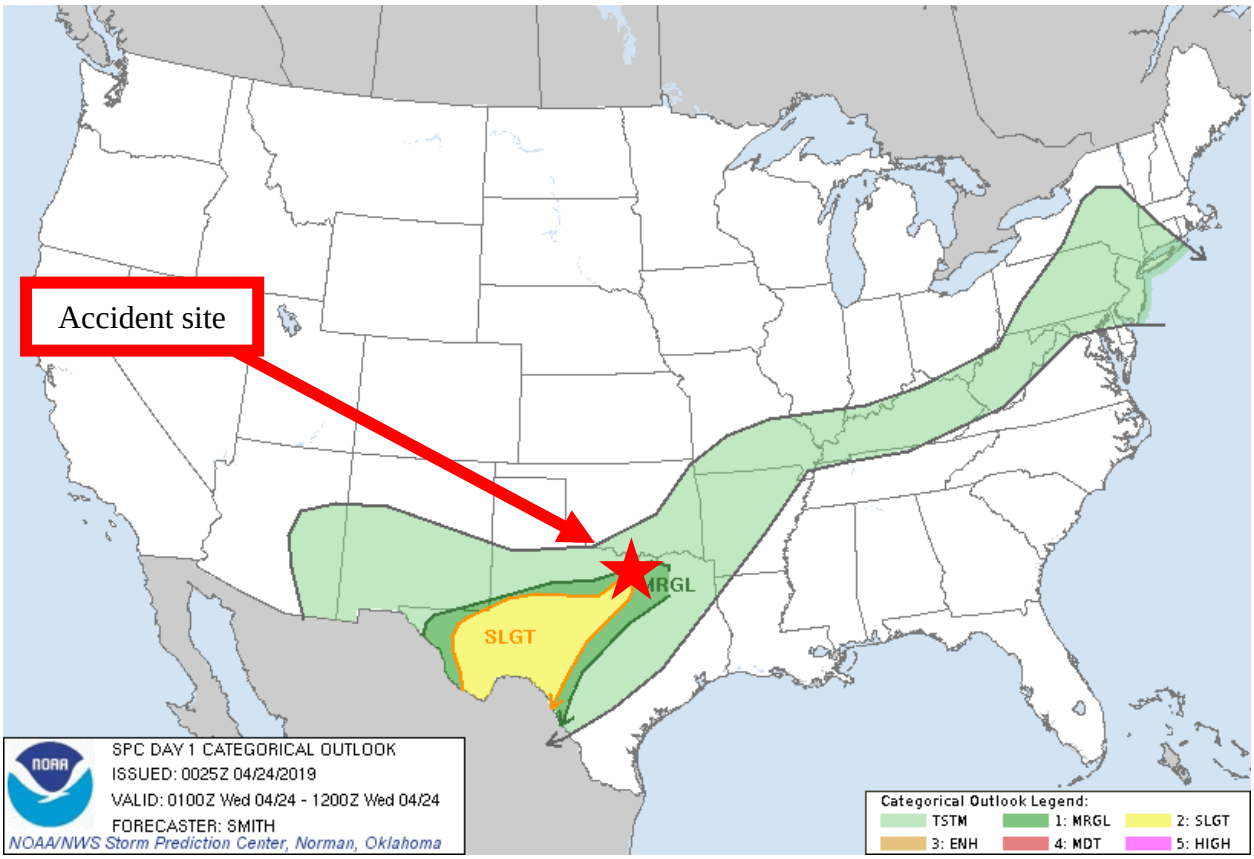


Figure 3 – SPC day 1 Convective Outlook valid at the time of the accident

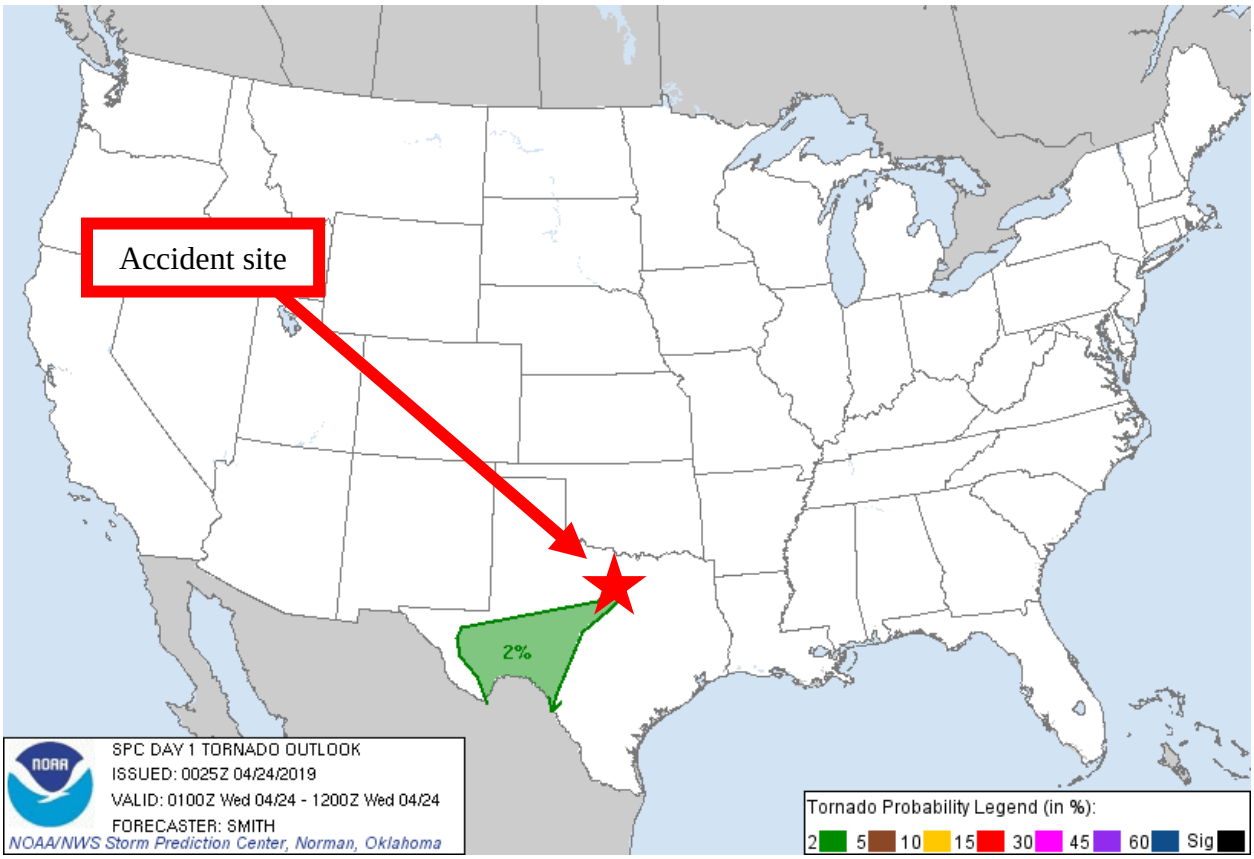


Figure 4 – SPC day 1 Tornado Outlook valid at the time of the accident

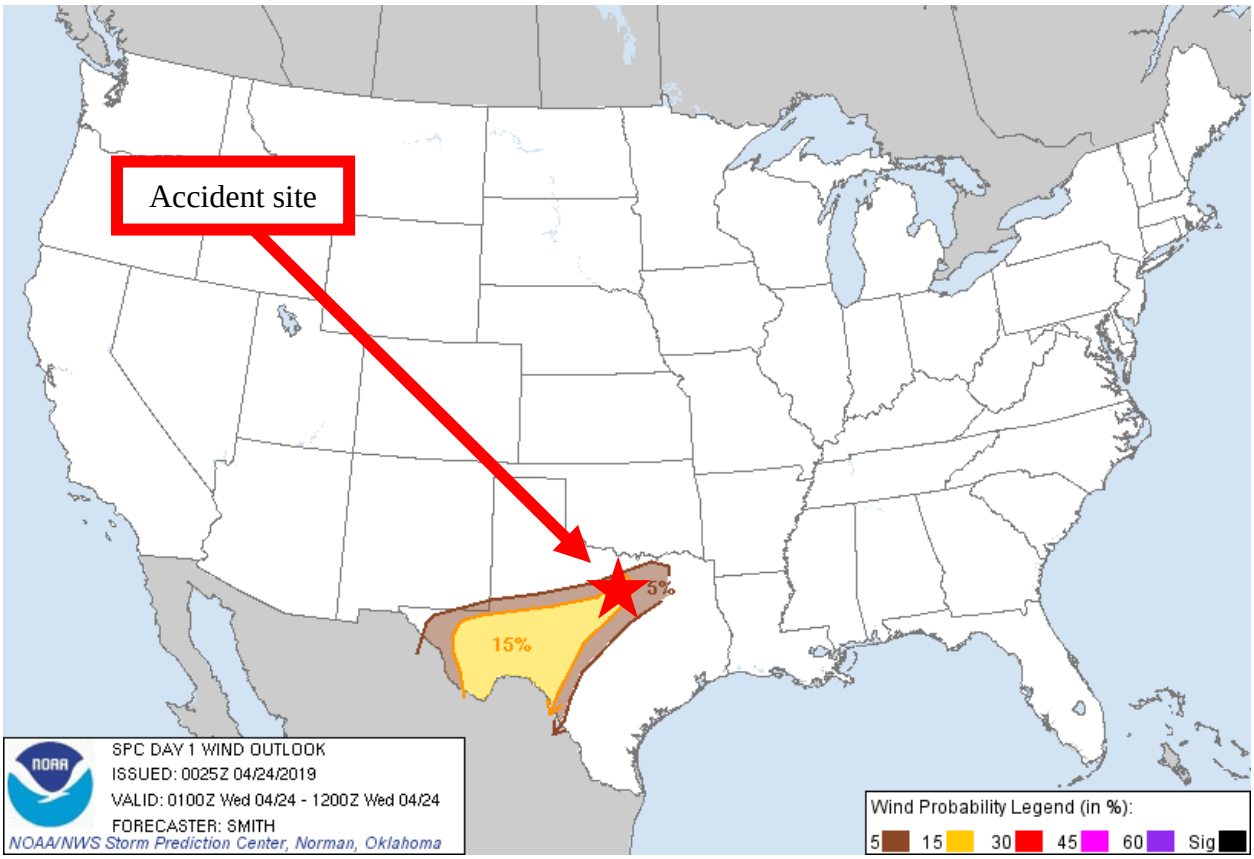


Figure 5 – SPC day 1 Wind Outlook valid at the time of the accident

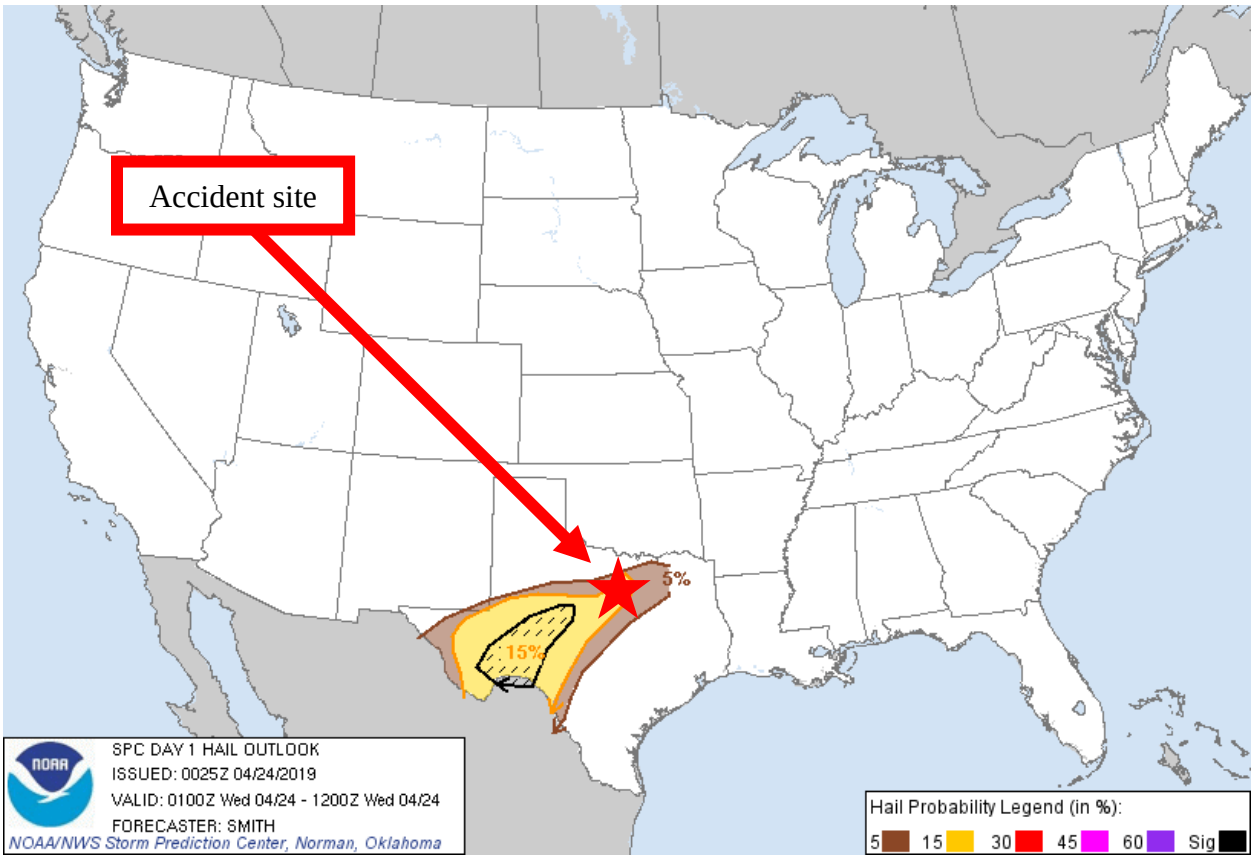


Figure 6 – SPC day 1 Hail Outlook valid at the time of the accident

SPC AC 240025

Day 1 Convective Outlook
NWS Storm Prediction Center Norman OK
0725 PM CDT Tue Apr 23 2019

Valid 240100Z - 241200Z

...THERE IS A SLIGHT RISK OF SEVERE THUNDERSTORMS FROM SOUTHWEST TEXAS INTO CENTRAL TEXAS...

...SUMMARY...
Severe thunderstorms capable of producing isolated very large hail and severe gusts are forecast mainly this evening from southwest Texas into central Texas.

...TX...
A mid-level low over northwest Mexico will meander slowly eastward tonight. An active corridor this evening of strong to severe thunderstorms near an effective front, draped from southwest TX northeast into north TX, will provide a focus for additional storm development this evening into the overnight. Southeasterly surface flow veering to 35-40 kt west-southwest flow in the mid levels is resulting in strong 0-6 km shear (40-60 kt). The strength of shear coupled with 700-500mb lapse rates 7-8 degrees C/km (per 00z area

raobs) are favoring supercells this evening with the more intense updrafts. Large to very large hail is possible with the strongest storms for the next 1-3 hours before the risk for the larger-hail becomes less common and likely diminishes by late evening. Nonetheless, as storm mergers and the consolidation of cold pools occur this evening, the threat for severe gusts will likely continue through the evening and perhaps linger into the overnight hours, despite a gradual lessening of instability due to nocturnal cooling.

..Smith.. 04/24/2019

CLICK TO GET WUUS01 PTSDY1 PRODUCT

NOTE: THE NEXT DAY 1 OUTLOOK IS SCHEDULED BY 0600Z

3.0 Surface Observations

The area surrounding the accident site was documented using official Meteorological Aerodrome Reports (METARs) and Specials (SPECIs). The following observations were taken from standard code and are provided in plain language. Figure 7 is a local sectional chart with the accident site and the closest weather reporting location marked.

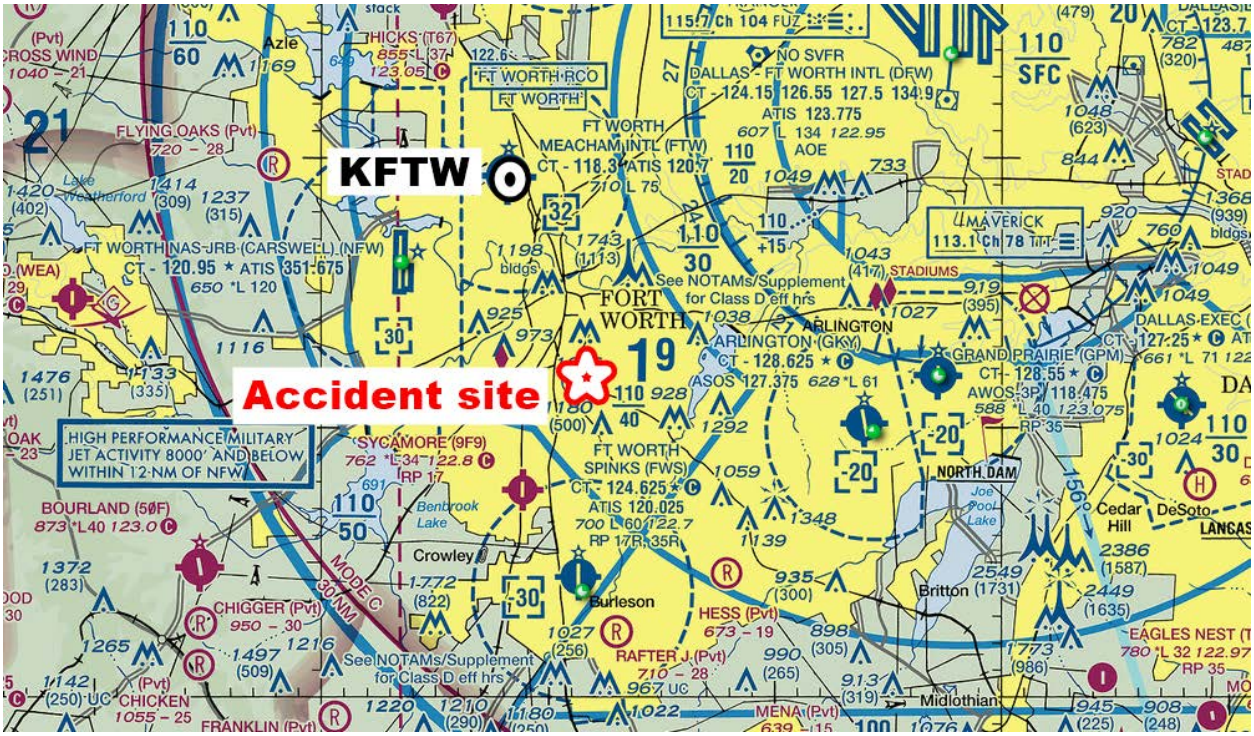


Figure 7 – Sectional map of the accident area with the location of the accident site and surface observation site

Fort Worth Meacham International Airport (KFTW) was the closest airport to the accident site. KFTW had Automated Surface Observing System (ASOS[4]) whose reports were supplemented by air traffic control (ATC) when the ATC tower was in operation[5]. KFTW was located 8 miles north-northwest of the accident site, at an elevation of 710 ft, and had a 4° easterly magnetic variation[6] (figure 7). The following observations were taken and disseminated during the times surrounding the accident:[7]

[2300 CDT][8] SPECI KFTW 240400Z 18006KT 5SM VCTS RA BR FEW036 BKN090 OVC110 17/16 A2996 RMK AO2 LTG DSNT ALQDS TSE0354 PRESRR P0001 T01670156=

[2307 CDT] SPECI KFTW 240407Z 15007KT 6SM -TSRA BR FEW037 BKN090 OVC110 16/16 A2996 RMK AO2 LTG DSNT ALQDS TSE0354B01 P0001 T01610156=

[2334 CDT] SPECI KFTW 240434Z 00000KT 6SM -TSRA BR FEW008 BKN080 OVC100 16/16 A2996 RMK AO2 LTG DSNT ALQDS TSE0354B01 P0006 T01560156=

[2349 CDT] SPECI KFTW 240449Z 00000KT 4SM VCTS RA BR FEW008 FEW075 OVC095 16/16 A2998 RMK AO2 LTG DSNT ALQDS TSE0354B01E43 P0008=

[2353 CDT] METAR KFTW 240453Z 33003KT 3SM TSRA BR FEW008 SCT070 OVC095 16/16 A2998 RMK AO2 LTG DSNT ALQDS TSE0354B01E43B53 SLP147 P0010 T01610156=

[0014 CDT] SPECI KFTW 240514Z 04006KT 5SM VCTS RA BR FEW008 SCT075 OVC095 16/16 A2996 RMK AO2 LTG DSNT ALQDS TSE08 P0007 T01610156=

ACCIDENT TIME 0033 CDT

[0053 CDT] METAR KFTW 240553Z 12007KT 4SM RA BR FEW010 FEW025 OVC095 16/16 A2997 RMK AO2 LTG DSNT ALQDS TSE08 SLP142 P0018 60212 T01610156 10206 20150 402390150 50013=

[0107 CDT] SPECI KFTW 240607Z 12010KT 5SM VCTS -RA BR FEW016 BKN090 OVC100 16/16 A2996 RMK AO2 LTG DSNT E-SW P0002 T01610156=

[4] ASOS – Automated Surface Observing System is equipped with meteorological instruments to observe and report wind, visibility, ceiling, temperature, dewpoint, altimeter, and barometric pressure.
[5] KFTW ATC is a 24/7 operation.
[6] Magnetic variation – The angle (at a particular location) between magnetic north and true north. Latest measurement taken from https://skyvector.com/
[7] The bold sections in this NWS product and the rest of the products in this report are intended to highlight the sections that directly reference the weather conditions that affected the accident location around the accident time. The local times in this section next to the METARs are provided for quick reference between UTC and local times around the accident time.
[8] April 23 and all times before midnight local are on April 23.

[0148 CDT] SPECI KFTW 240648Z 09010KT 3SM +TSRA BR OVC065 16/16 A2995 RMK AO2 LTG DSNT ALQDS TSB42 P0023=

[0153 CDT] METAR KFTW 240653Z 07009KT 4SM TSRA BR BKN065 OVC080 16/16 A2995 RMK AO2 LTG DSNT ALQDS TSB42 SLP138 P0025 T01610156=

KFTW weather at 0014 CDT, wind from 040° at 6 knots, 5 miles visibility, vicinity[9] thunderstorms, moderate rain, mist, few clouds at 800 ft above ground level (agl), scattered clouds at 7,500 ft agl, an overcast ceiling at 9,500 ft agl, temperature of 16 °Celsius (C), dew point temperature of 16 °C, and an altimeter setting of 29.96 inches of mercury (inHg). Remarks: automated station with a precipitation discriminator, lightning distant[10] all quadrants, thunderstorm ended at 0008 CDT, 0.07 inches of precipitation since 2353 CDT on April 23, temperature 16.1 °C, dew point temperature 15.6 °C.

KFTW weather at 0053 CDT, wind from 120° at 7 knots, 4 miles visibility, moderate rain, mist, few clouds at 1,000 ft agl, few clouds at 2,500 ft agl, an overcast ceiling at 9,500 ft agl, temperature of 16 °C, dew point temperature of 16 °C, and an altimeter setting of 29.97 inHg. Remarks: automated station with a precipitation discriminator, lightning distant[11] all quadrants, thunderstorm ended at 0008 CDT, sea level pressure 1014.2 hPa, 0.18 inches of precipitation since 2353 CDT on April 23, 6-hourly precipitation of 2.12 inches, temperature 16.1 °C, dew point temperature 15.6 °C, 6-hourly maximum temperature of 20.6 °C, 6-hourly minimum temperature of 15.0 °C, 24-hour maximum temperature of 23.9 °C, 24-hour minimum temperature of 15.0 °C, 3-hourly pressure decrease of 1.3 hPa.

The observation from KFTW following the accident time indicated MVFR[12] conditions due to the 4 miles visibility report. 0.18 inches of precipitation fell between 2353 CDT on April 23 and 0053 CDT on the accident day, with 2.12 inches of precipitation falling in the 6 hours preceding the accident. 3.13 inches of precipitation was measured at KFTW between 0700 CDT on April 23 and 0700 CDT on April 24.

[9] In the vicinity of the airport is defined as a weather phenomenon within 5-10 statute miles of the airfield.
[10] Distant indicated that the lightning was beyond 10 miles but less than 30 miles from the center of the airport (or airport location point, [ALP]).
[11] Distant indicated that the lightning was beyond 10 miles but less than 30 miles from the center of the airport (or airport location point, [ALP]).
[12] As defined by the NWS and the FAA Aeronautical Information Manual (AIM) section 7-1-7 defines the following general flight categories:

- Low Instrument Flight Rules (LIFR*) – ceiling below 500 ft above ground level (agl) and/or visibility less than 1 statute mile.
- Instrument Flight Rules (IFR) – ceiling between 500 to below 1,000 feet agl and/or visibility 1 to less than 3 miles.
- Marginal Visual Flight Rules (MVFR**) – ceiling from 1,000 to 3,000 ft agl and/or visibility 3 to 5 miles.
- Visual Flight Rules (VFR) – ceiling greater 3,000 ft agl and visibility greater than 5 miles.

* By definition, IFR is a ceiling less than 1,000 ft agl and/or visibility less than 3 miles while LIFR is a sub-category of IFR.
**By definition, VFR is a ceiling greater than or equal to 3,000 ft agl and visibility greater than 5 miles while MVFR is a sub-category of VFR.

Community Collaborative Rain, Hail, & Snow Network (CoCoRaHS)[13] 24 hour rainfall totals were retrieved for 0700 CDT on April 24 for Tarrant County (figure 8) with the accident site in a location where between 2.62 and 3.25 inches of rain fell. This precipitation was located at the closest CoCoRaHS locations to the accident site over a 24 hour period. The KFTW precipitation observations fall within that rainfall amount.

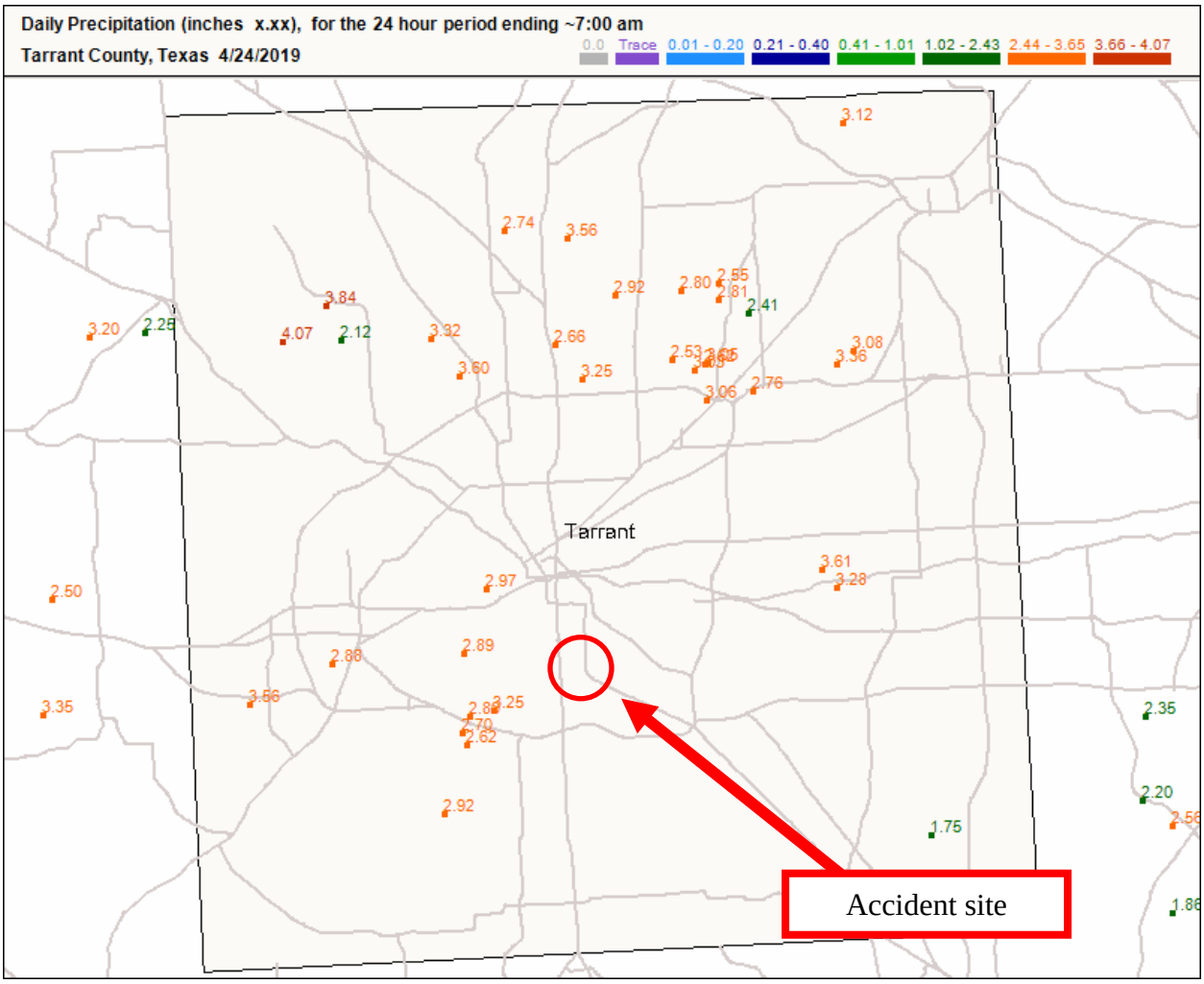


Figure 8 – CoCoRaHS map of Tarrant County rainfall from 0700 CDT April 23 to 0700 CDT on April 24 with the location of the accident site

[13] https://www.cocorahs.org/

The daily summary observations from KFTW are found in attachment 1 with 1.80 inches of precipitation on April 13, 0.87 inches of precipitation combined April 17 and 18, and a total of 6.75 inches of precipitation for April 2019. The Midwestern Regional Climate Center (MRCC) "TX03" area, which included Tarrant County and Dallas County, recorded April 2019 as the 14th wettest April in the last 125 years (1895 to 2019) with 205% of normal precipitation for April 2019.[14] For the 3 month period between February and April, the year 2019 was the 47th wettest year out of the past 125 years for the MRCC "TX03" area with 8.75 inches of precipitation, which was 0.30 inches above the 8.45 inches of normal precipitation for the 125 year period.[15]

4.0 Upper Air Data

A High-Resolution Rapid Refresh (HRRR)[16] model sounding was created for the accident site for 0000 CDT with a station elevation of 633 ft.[17] The 0000 CDT HRRR sounding was plotted on a standard Skew-T Log P diagram[18] with the derived stability parameters included in figure 9 with data from the surface to 600-hPa (or approximately 14,000 ft msl). These data were analyzed using the RAOB[19] software package. The sounding depicted the lifted condensation level (LCL)[20] at 167 ft agl (800 ft msl), the convective condensation level (CCL)[21] at 2,707 ft agl (3,340 ft msl), and the level of free convection (LFC)[22] at 13,334 ft agl (13,967 ft msl). The sounding had a greater than 90% relative humidity from the surface through 10,000 ft msl. The freezing level was located at 12,079 ft msl. The precipitable water value was 1.57 inches in the 0000 CDT HRRR sounding, which was 0.08 inches above the maximum daily value of precipitable water observed in any recorded 0700 CDT sounding from Fort Worth (FWD) for April 24 (period of record from 1949 through 2019).[23] The 0700 CDT FWD sounding[24] had a precipitable water value of 1.12 inches, which was between the 75 to 90 percentile for April 24 between 1949 and 2019.[25]

[14] https://mrcc.illinois.edu/CLIMATE/nClimDiv/STCD_rank2.jsp
[15] Source Midwestern Regional Climate Center: https://mrcc.illinois.edu/CLIMATE/welcome.jsp
[16] The HRRR is a NOAA real-time three-kilometer resolution, hourly-updated, cloud-resolving, convection-allowing atmospheric model, initialized by three-kilometer grids with three-kilometer radar assimilation. Radar data is assimilated in the HRRR every 15 minutes over a one hour period.
[17] HRRR sounding was created using NOAA Air Resource Laboratory: https://ready.arl.noaa.gov/READYamet.php
[18] Skew T log P diagram – is a standard meteorological plot using temperature and the logarithmic of pressure as coordinates, used to display winds, temperature, dew point, and various indices used to define the vertical structure of the atmosphere.
[19] RAOB – (The complete Rawinsonde Observation program) is an interactive sounding analysis program developed by Environmental Research Services, Matamoras, Pennsylvania.
[20] LCL - The height at which a parcel of moist air becomes saturated when it is lifted dry adiabatically.
[21] CCL – The level in the atmosphere to which an air parcel, if heated from below, will rise dry adiabatically, without becoming colder than its environment just before the parcel becomes saturated.
[22] LFC – The level at which a parcel of saturated air becomes warmer than the surrounding air and begins to rise freely. This occurs most readily in a conditionally unstable atmosphere.
[23] https://www.spc.noaa.gov/exper/soundingclimo/
[24] This was from the FWD rawinsonde data.
[25] http://weather.uwyo.edu/upperair/sounding.html

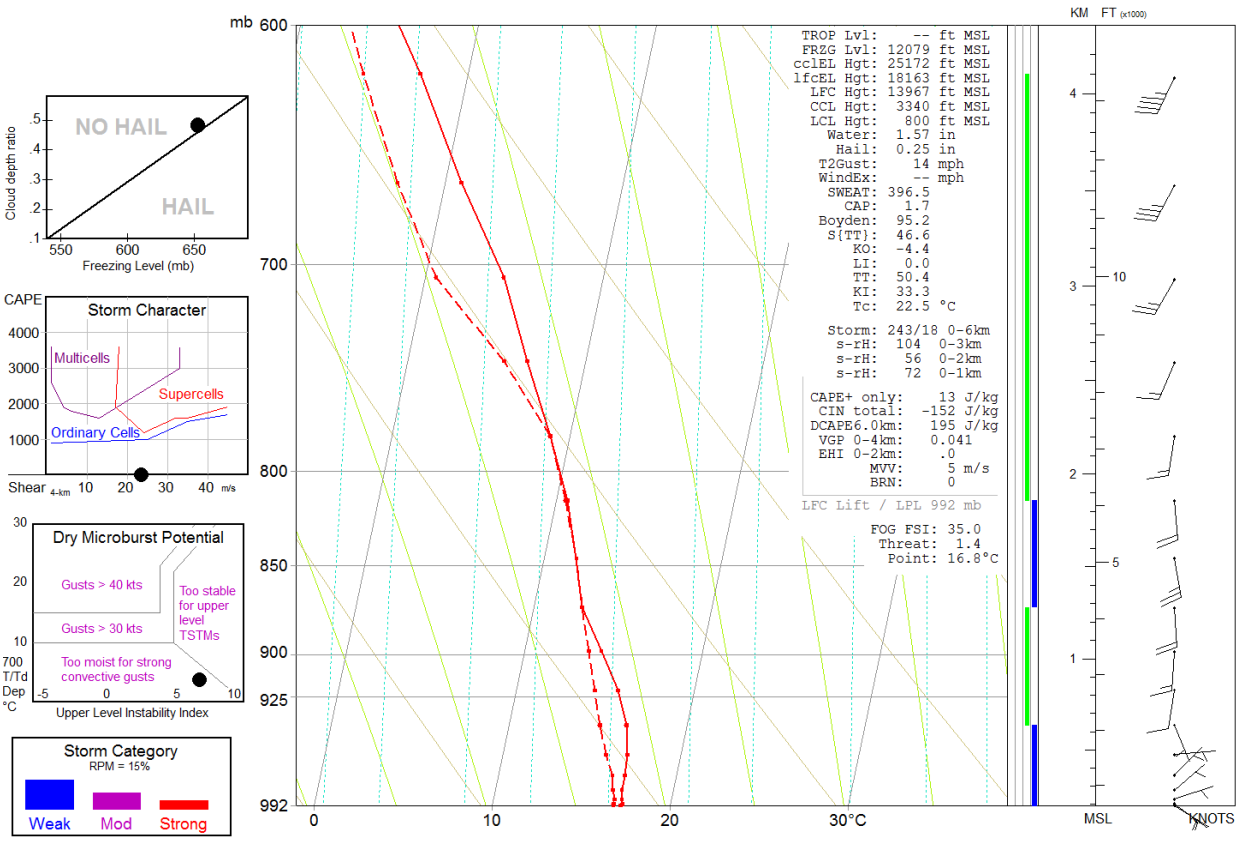


Figure 9 – 0000 CDT HRRR sounding

The 0000 CDT HRRR sounding for the accident site indicated a mostly conditionally unstable environment from the surface through 14,000 ft, with a Lifted Index of 0, which supported ordinary cell rain showers or thunderstorms according to RAOB (figure 9). RAOB identified the possibility of clouds from 1,000 ft msl through 14,000 ft msl. A positive CAPE[26] value of 13 Joules/kilogram (J/kg) was indicated on the sounding and the maximum vertical velocity (MVV) for this atmosphere was calculated as 5 meters/second (about 984 ft per minute).[27] Downdraft CAPE (DCAPE; 6 kilometers agl)[28] was measured at 195 J/kg. RAOB indicated that it was too moist for strong convective wind gusts at the surface and likely storm category would be weak thunderstorms with no hail.

[26] Convective Available Potential Energy (CAPE) – CAPE is a measure of the amount of energy available for convection and is directly related to the maximum potential vertical speed within an updraft.

[27] 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.

[28] The DCAPE can be used to estimate the potential strength of rain-cooled downdrafts within thunderstorm convection and is similar to CAPE. Larger DCAPE values are associated with stronger downdrafts.

The 0000 CDT HRRR sounding wind profile indicated a near-surface wind from 123° at 3 knots with the wind remaining from the east through 2,000 ft. Above this level the wind veered[29] to the southwest through 14,000 ft. Wind speeds remained between 5 and 10 knots through 3,000 ft, but wind speeds increased to 45 knots by 14,000 ft. RAOB did not indicate low-level wind shear (LLWS) or clear-air turbulence (CAT) outside of rain shower or thunderstorm activity from the surface through 14,000 ft. The mean storm motion vector was from 243° at 18 knots.

5.0 Satellite Data

Data from the Geostationary Operational Environmental Satellite number 16 (GOES-16) data was obtained from an archive at the Space Science Engineering Center at the University of Wisconsin-Madison in Madison, Wisconsin, and processed using the Man-computer Interactive Data Access System software. Visible and infrared (bands 2 and 13) imagery at wavelengths of 0.64 microns (μm) and 10.3 μm were retrieved for the period. These imagery surrounding the time of the accident, from 1800 CDT on April 23 through 1200 CDT on April 24 at approximately 5-minute intervals were reviewed, and the closest images to the time of the accident are documented here. Because the accident occurred well after sunset, the visible imagery did not provide usable data at the accident time.

Figures 10 and 11 present the GOES-16 infrared imagery from 0000 and 0030 CDT at 4X magnification and with a temperature enhancement curve applied and the accident site highlighted with a red square. Inspection of the infrared imagery indicated abundant cloud cover over the accident site at the accident time with the lowest brightness temperatures (blue and green colors, higher clouds) located over the accident site. The cloud cover was moving from west to east (attachment 2). Based on the brightness temperatures above the accident site (212° Kelvin) and the vertical temperature profile provided by the 0000 CDT HRRR sounding[30], the approximate cloud-top heights over the accident site were 39,000 ft at 0030 CDT. It should be noted these figures have not been corrected for any parallax error.

[29] A clockwise turning of the wind with height in the northern hemisphere.
[30] This temperature is not included in figure 9.

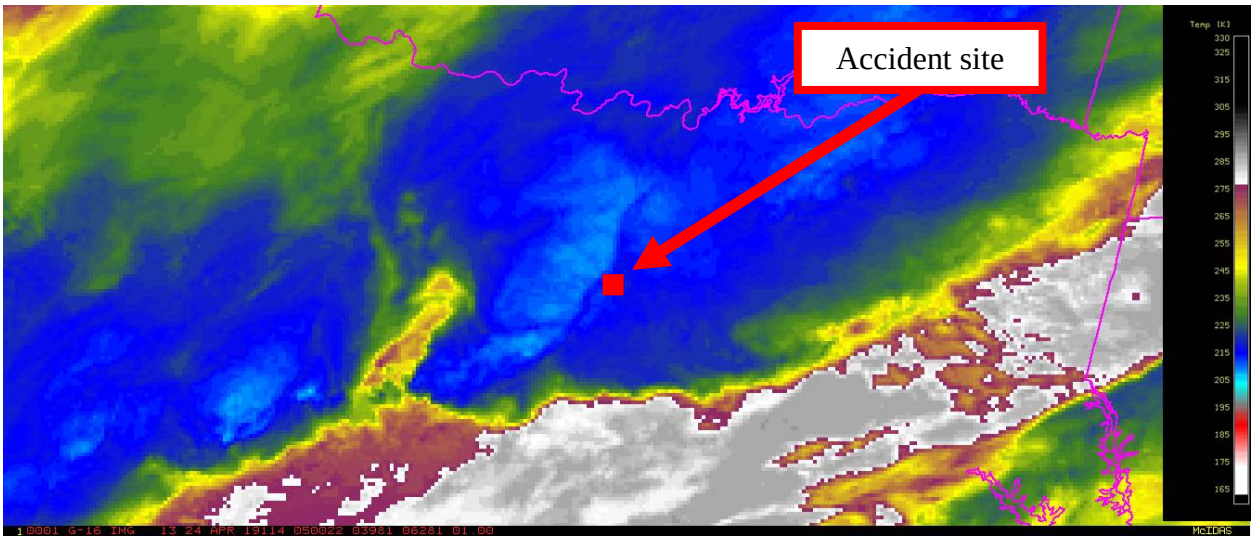


Figure 10 – GOES-16 infrared image at 0000 CDT

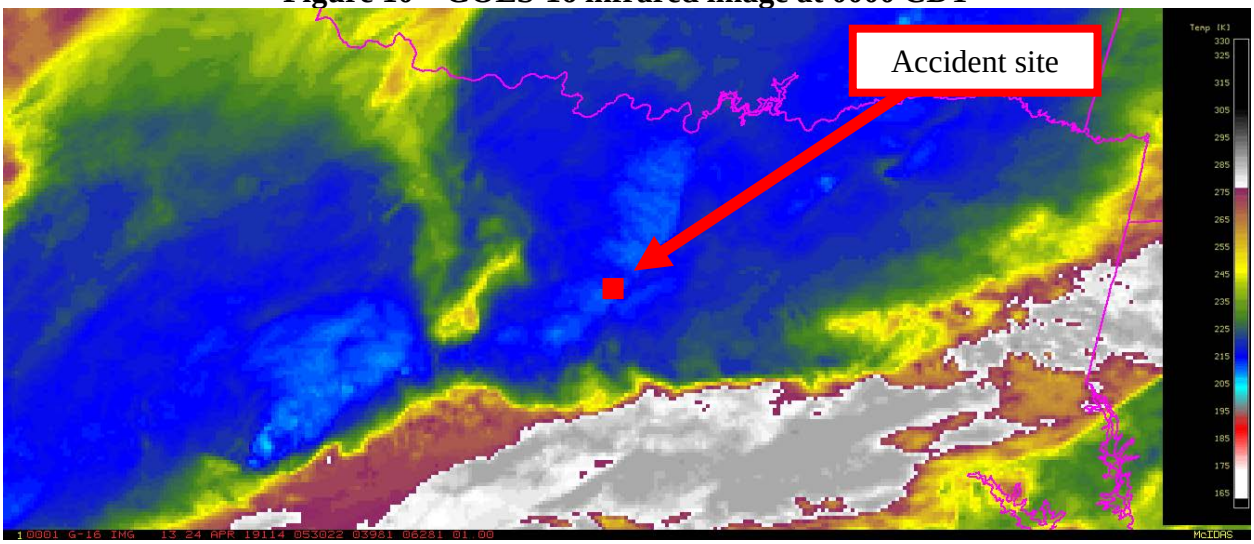


Figure 11 – GOES-16 infrared image at 0030 CDT

6.0 Regional Radar Imagery Information

A regional view of the NWS National Composite Radar Mosaic is included as figure 12 for 0030 CDT with the approximate location of the accident site marked with the red circle. The image depicted 30 to 50 decibel (dBZ[31]) echoes above the accident site.

[31] dBZ – A non-dimensional "unit" of radar reflectivity which represents a logarithmic power ratio (in decibels, or dB) with respect to radar reflectivity factor Z.

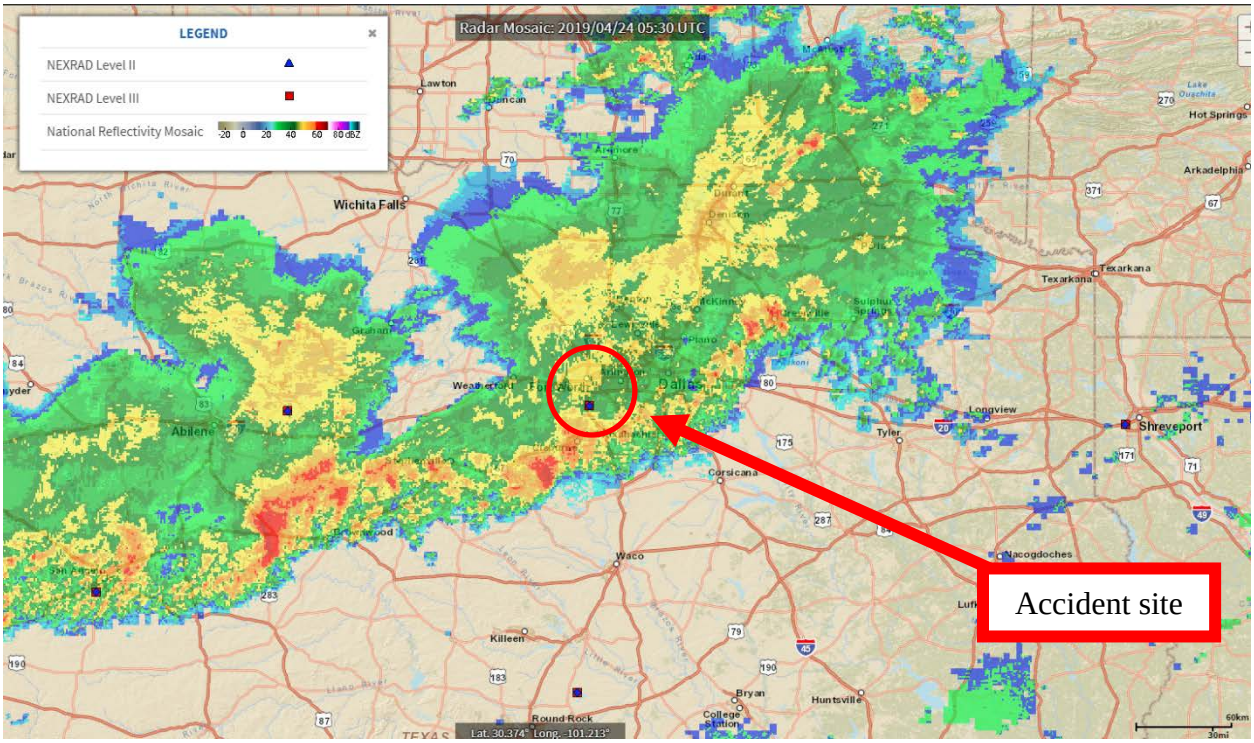


Figure 12 – Regional Composite Reflectivity image for 0030 CDT

7.0 Radar Imagery Information

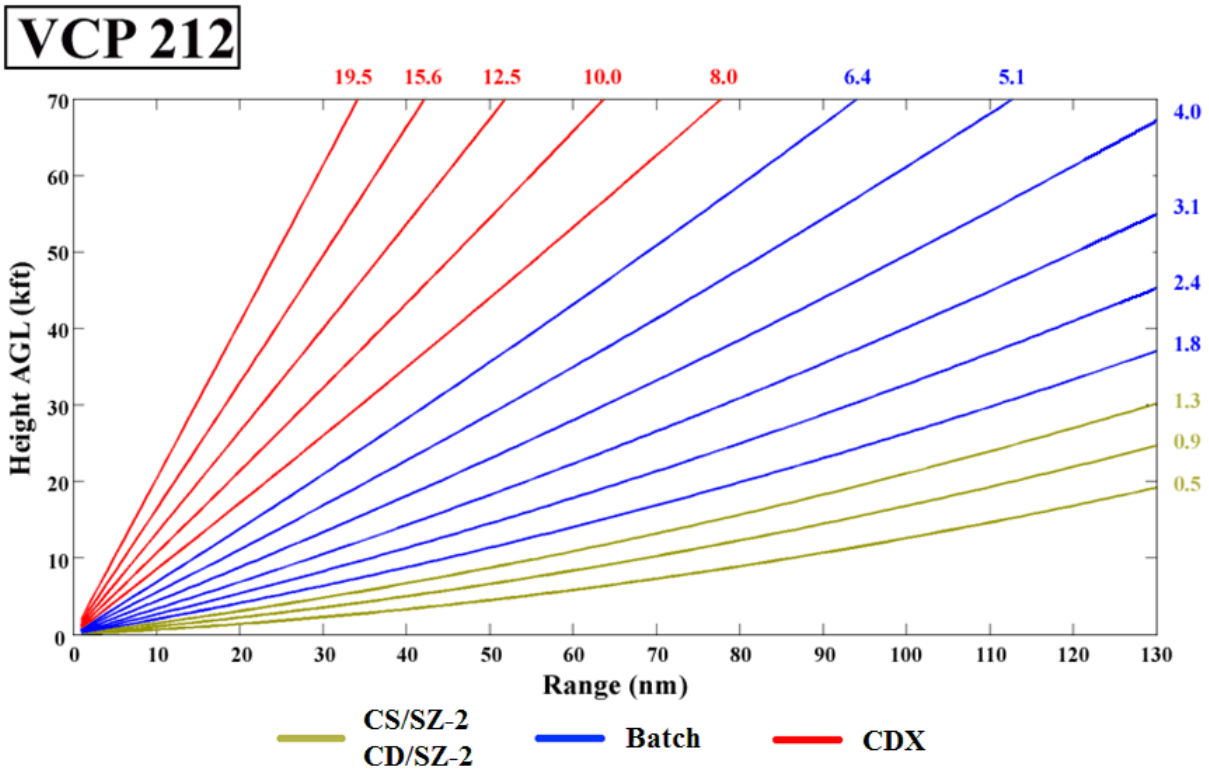
The closest NWS Weather Surveillance Radar-1988, Doppler (WSR-88D)[32] to the accident site was Dallas, Texas, (KFWS) and was located 8 miles south of the accident site. Level II archive radar data was obtained from the NCEI utilizing the NEXRAD Data Inventory Search and displayed using the NOAA's Weather and Climate Toolkit software.

7.1 Volume Scan Strategy

The WSR-88D is a computer-controlled radar system, which automatically creates a complete series of specific scans in a specific sequence known as a volume scan. Individual elevation scans are immediately available. Products that require data from multiple elevation scans are not available until the end of the five to ten-minute volume scan.

[32] The WSR-88D is an S-band 10-centimeter wavelength radar with a power output of 750,000 watts, and with a 28-foot parabolic antenna that concentrates the energy between a 0.87° and 0.96° beam width. The radar produces three basic types of products: base reflectivity, base radial velocity, and base spectral width.

The WSR-88D operates in several different scanning modes, identified as Mode A and Mode B. Mode A is the precipitation scan and has three common scanning strategies. The most common is where the radar makes 14 elevation scans from 0.5° to 19.5° every four and a half minutes. This particular scanning strategy is documented as volume coverage pattern 212 (VCP-212). Mode B is the clear-air mode, where the radar makes 5 elevation scans during a ten-minute period. During the period surrounding the accident, the KFWS WSR-88D radar was operating in the precipitation mode VCP-212. The following chart provides an indication of the different elevation angles in this VCP, and the approximate height and width of the radar beam with distance from the radar site.



VCP-212 Precipitation Mode Scan Strategy[33]

[33] Contiguous Surveillance (CS)--The low Pulse Repetition Frequency (PRF) scan of the split cut. Gives a high R_{max} value to determine proper target location and intensity, but a low V_{max} value limits the velocities that can be measured. Contiguous Doppler (CD)--The high PRF scan of the split cut. Gives a low R_{max} value causing more range folded (multiple trip) echoes, but a high V_{max} value to get higher, more accurate velocity values.
Batch Mode – Uses alternating low and high PRFs on each radial for one full rotation at each elevation angle. The two resulting data sets (low PRF and high PRF) are combined to resolve range ambiguity. Used in the middle elevation angles.
W – With range unfolding (W)
WO – Without range unfolding (WO)

7.2 Beam Height Calculation

Assuming standard refraction[34] of the WSR-88D radar beam with the antenna elevation at 776 ft (KFWS), and considering a beamwidth[35] of 0.95°, the following table shows the approximate heights for the radar beam center, top and base for antenna elevations over the accident site. These heights have been rounded to the nearest 10 ft.

ANTENNA ELEVATION	BEAM CENTER	BEAM BASE	BEAM TOP
KFWS 0.5°	1,250 ft	860 ft	1,640 ft

Based on the radar height calculations, the elevation scan listed in the above table depicted the conditions between 860 ft and 1,640 ft msl over the accident site and these scans "saw" the closest altitudes to the ground.

7.3 Reflectivity

Reflectivity is the measure of the efficiency of a target in intercepting and returning radio energy. With hydrometeors[36] it is a function of the drop size distribution, number of particles per unit volume, physical state (ice or water), shape, and aspect. Reflectivity is normally displayed in dBZ and is a general measure of echo intensity. FAA Advisory Circular AC 00-24C[37], "Thunderstorms," dated February 19, 2013, also defines the echo intensity levels and weather radar echo intensity terminology associated with those levels. For dBZ values less than 30 the weather radar echo intensity terminology should be "light." For dBZ values between 30 and 40, the terminology should be "moderate." "Heavy" terminology is used for dBZ values greater than 40 dBZ but less than 50 dBZ, inclusive. Finally, any dBZ values above 50 dBZ shall be described as "extreme." From the NWS, precipitation conditions at the surface can be inferred from VIP Levels described in the chart below:

[34] Standard Refraction in the atmosphere is when the temperature and humidity distributions are approximately average, and values set at the standard atmosphere.

[35] Beamwidth - the angular separation between the half power points on the antenna radiation pattern, where the gain is one half the maximum value.

[36] Hydrometeors are any product of condensation or sublimation of atmospheric water vapor, whether formed in the free atmosphere or at the earth's surface; also, any water particles blown by the wind from the earth's surface. Hydrometeors are classified as; (a) Liquid or solid water particles suspended in the air: cloud, water droplets, mist or fog. (b) Liquid precipitation: drizzle and rain. (c) Freezing precipitation: freezing drizzle and freezing rain. (d) Solid (frozen) precipitation: ice pellets, hail, snow, snow pellets, and ice crystals. (e) Falling particles that evaporate before reaching the ground: virga. (f) Liquid or solid water particles lifted by the wind from the earth's surface: drifting snow, blowing snow, blowing spray. (g) Liquid or solid deposits on exposed objects: dew, frost, rime, and glazed ice.

[37] https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/1020774

- VIP 1 (Level 1, 18-30 dBZ) - Light precipitation
- VIP 2 (Level 2, 30-38 dBZ) - Light to moderate rain
- VIP 3 (Level 3, 38-44 dBZ) - Moderate to heavy rain
- VIP 4 (Level 4, 44-50 dBZ) - Heavy rain
- VIP 5 (Level 5, 50-57 dBZ) - Very heavy rain; hail possible
- VIP 6 (Level 6, >57 dBZ) - Very heavy rain and hail; large hail possible

7.4 Base Reflectivity and Lightning Data

Figures 13 and 14 present the KFWS WSR-88D base reflectivity images for the 0.5° elevation scans initiated at 0025:07 and 0030:17 CDT, respectively, with a resolution of 0.5° X 250 m. Reflectivity values between 25 and 40 dBZ, or light to heavy rain intensity echoes (section 5.3), were located above the accident site at the time of the accident. The reflectivity bands were moving from west to east with time (attachment 3).

There were 972 lightning flashes[38] (white dots, figures 13 and 14, and attachment 3) around the accident site between 0000 and 0030 CDT.[39]

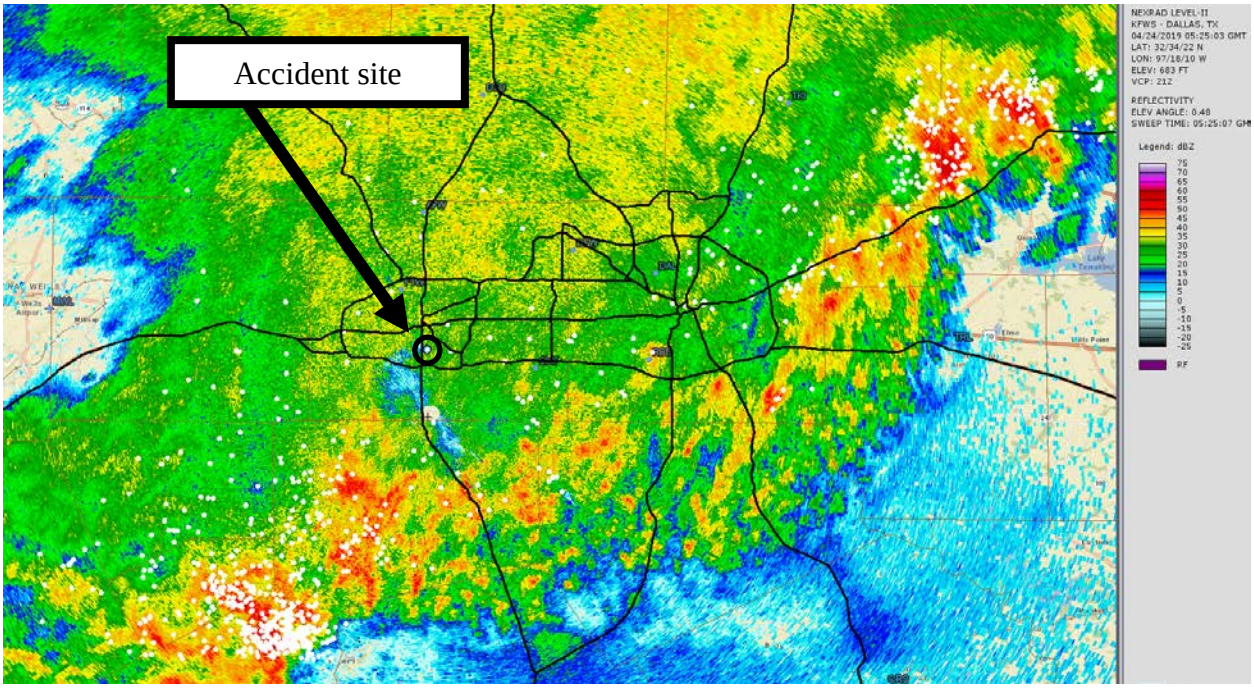


Figure 13 – KFWS WSR-88D reflectivity for the 0.5° elevation scan initiated at 0025:07 CDT with lightning flashes between 0000 and 0030 CDT marked with white dots

[38] Lightning Flash – This is one contiguous conducting channel and all the current strokes/pulses that flow through it. There are two types of flashes: ground flashes and cloud flashes.
[39] A review of data from the Earth Networks Total Lightning Network was performed.

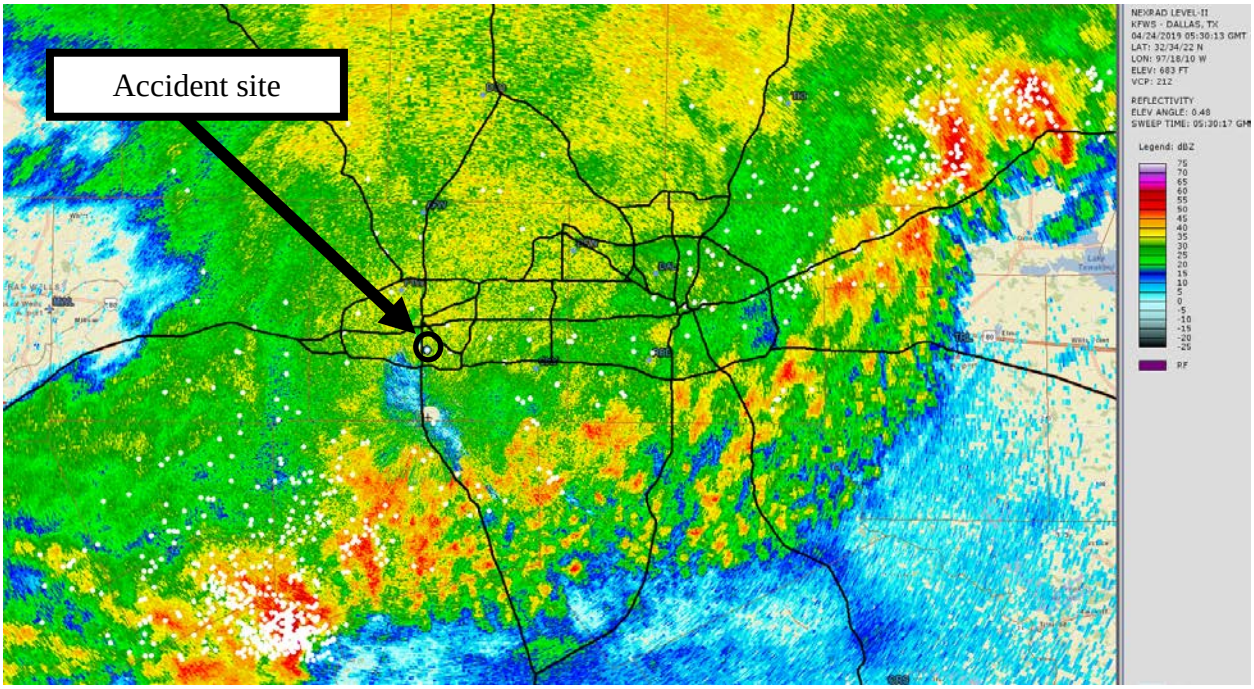


Figure 14 – KFWS WSR-88D reflectivity for the 0.5° elevation scan initiated at 0030:17 CDT with lightning flashes between 0000 and 0030 CDT marked with white dots

8.0 NWS Area Forecast Discussion

The NWS office in Fort Worth/Dallas, Texas, (FWD) issued the following Area Forecast Discussion (AFD) at 2351 CDT on April 23 (closest AFD to the accident time):

FXUS64 KFWD 240451
AFDFWD

Area Forecast Discussion
National Weather Service Fort Worth TX
1151 PM CDT Tue Apr 23 2019

.AVIATION...
/06Z TAFs/

Outflow which has gusted out ahead of the late evening thunderstorms has brought northerly winds in the Metroplex over the past hour. These winds should come back around to the southeast in the next few hours as gradient winds ahead of a weak cold front take over. Additional showers and thunderstorms will persist for several more hours with the axis of convection shifting ever so slowly southward with the outflow boundary. Activity should reach the Waco area prior to sunrise but will not be as intense as what has occurred in the DFW area. The primary concern tonight has already begun to shift from severe storms to flooding and flash flooding as thunderstorms train over the same areas. Zooming out on a regional radar mosaic reveals a train of storms extended well west into West Texas ahead of the approaching

upper low over Northern Mexico, with cells marching steadily eastward. A lull in the convective activity can be expected during the morning hours, but storms will re-fire by Wednesday afternoon as the system moves in from the west. The strongest storms on Wednesday will be over Central Texas, but all locations should see at least some convection with the main round Wednesday afternoon. Storms will move east of the area Wednesday night, but wrap-around showers along with borderline MVFR/IFR conditions will persist into Thursday morning. The front and associated north winds will be though all locations by Wednesday night.

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.UPDATE... /Issued 851 PM CDT Tue Apr 23 2019/
A strong storm cluster just west of the DFW area has occasionally shown signs of producing damaging winds and has shown no signs of weakening. We made the decision to expand the severe thunderstorm watch east to include the Metroplex as it looks like a localized damaging wind threat will exist for a few more hours with this activity. Storms should exhibit an gradual reduction in intensity later tonight as instability decreases. Even though storms are moving at a decent clip, the slow movement of the cold front will allow additional showers and storms to train over the same areas through the overnight hours and the potential for flooding still exists across the entire Flash Flood Watch area.

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.DISCUSSION... /Issued 251 PM CDT Tue Apr 23 2019/
/Tonight through Wednesday night/

Cloud cover continues to increase this afternoon as southerly flow strengthens, and an upper level low south of Arizona will begin tracking eastward tonight. A stationary front draped to the northwest is the focus for isolated thunderstorms that have developed this afternoon. This feature will slowly move southeast across north Texas, and coverage of storms is expected to increase this evening and overnight. Isolated strong to severe thunderstorms with damaging winds and hail are possible across western zones and generally west of Fort Worth between 7pm and midnight with the recently issued Severe Thunderstorm Watch. However, the main concern across north Texas will be the potential for heavy rainfall and isolated flood/flash flooding concerns. Forecast PWATs near 1.50 inches tonight and Wednesday morning are well over the 90th percentile and approaching daily max values for late April. As a result, when coverage of showers and thunderstorms increases tonight so will the rainfall rates and the potential for localized flooding concerns. Training of storms is also possible with the slow propagation of the front, so the axis of the highest rainfall totals will gradually move across the

DFW Metroplex early Wednesday morning and into the afternoon. This is when most of the forecast area will receive the bulk of the rain that falls with this system. Right now, this axis is roughly along a Stephenville to DFW to Greenville line, and southward as the evening progresses. As the front slips southward on Wednesday, PWATs increase to around 1.7 to 1.8 inches by Wednesday night across the southeast portion of the forecast area. A Flash Flood watch has also been issued for this afternoon through late Wednesday night. The watch may need to be extended further south and east for this as the heavy rainfall threat will continue there through early Thursday morning as the surface low begins to develop.

/Thursday through Next Week/

As the main low pressure system exits the region on Thursday, showers and thunderstorm chances will also come to an end from west to east during the day. After that, dry weather and seasonably warm weather is expected late week into the weekend. High temperatures will reach the mid 80s by the weekend. Low temperatures will range from the mid 50s to mid 60s by early next week.

A fast moving system is expected to move through the Central Plains late Saturday into Sunday, but models differ on how close to our area the front (therefore ascent) will be and how much moisture will be available. The GFS is the only one showing some rain chances across parts of North and Central TX on Sunday. For now, kept the PoPs out of the forecast through this time period. A more vigorous system is expected to move across the region as we head into the first days of May. We will continue to monitor the trends through the upcoming days for details on timing and intensity of thunderstorms.

Elsenheimer/Sanchez

&&

.PRELIMINARY POINT TEMPS/POPS...

Dallas-Ft. Worth	64	69	60	74	59 /	90	100	80	30	5
Waco	63	71	59	73	58 /	70	100	90	20	5
Paris	63	71	58	71	56 /	80	90	90	60	10
Denton	60	70	58	74	57 /	90	100	80	30	10
McKinney	63	70	58	73	57 /	90	100	90	40	5
Dallas	65	71	60	74	59 /	90	100	80	30	5
Terrell	63	71	58	74	57 /	80	100	90	40	5
Corsicana	63	71	58	71	57 /	60	100	90	30	5
Temple	64	72	59	74	58 /	50	100	80	20	5
Mineral Wells	59	68	55	73	54 /	100	100	70	20	5

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.FWD WATCHES/WARNINGS/ADVISORIES...
Flash Flood Watch through Wednesday evening for TXZ102>104-115>120-129>134-141>145-156>159.

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9.0 SPC and WPC Products

The SPC issued Severe Thunderstorm Watch #97 at 2240 CDT on April 23 and this watch was valid for the accident site for 2240 CDT on April 23 through 0500 CDT on April 24 (figure 15). Prior to Severe Thunderstorm Watch #97, Severe Thunderstorm Watch #95 was valid for the accident area between 1400 and 2300 CDT on April 23:

URGENT - IMMEDIATE BROADCAST REQUESTED
Severe Thunderstorm Watch Number 97
NWS Storm Prediction Center Norman OK
1040 PM CDT Tue Apr 23 2019

The NWS Storm Prediction Center has issued a

* Severe Thunderstorm Watch for portions of
  Far west to north-central Texas

* Effective this Tuesday night and Wednesday morning from 1040 PM
  until 500 AM CDT.

* Primary threats include...
  Isolated very large hail events to 2 inches in diameter possible
  Isolated damaging wind gusts to 70 mph possible

SUMMARY...Clusters of strong to locally severe storms may persist into the early morning. Storms should tend to regenerate along the same southwest to northeast corridor from the Trans-Pecos to near the Metroplex.

The severe thunderstorm watch area is approximately along and 40 statute miles either side of a line from 60 miles southwest of Fort Stockton TX to 50 miles east of Dallas TX. For a complete depiction of the watch see the associated watch outline update (WOUS64 KWNS WOU7).

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.

&&

OTHER WATCH INFORMATION...This severe thunderstorm watch replaces severe thunderstorm watch number 95...severe thunderstorm watch number 96. Watch number 95 96 will not be in effect after 1040 PM CDT.

AVIATION...A few severe thunderstorms with hail surface and aloft to

2 inches. Extreme turbulence and surface wind gusts to 60 knots. A few cumulonimbi with maximum tops to 500. Mean storm motion vector 26025.

...Grams

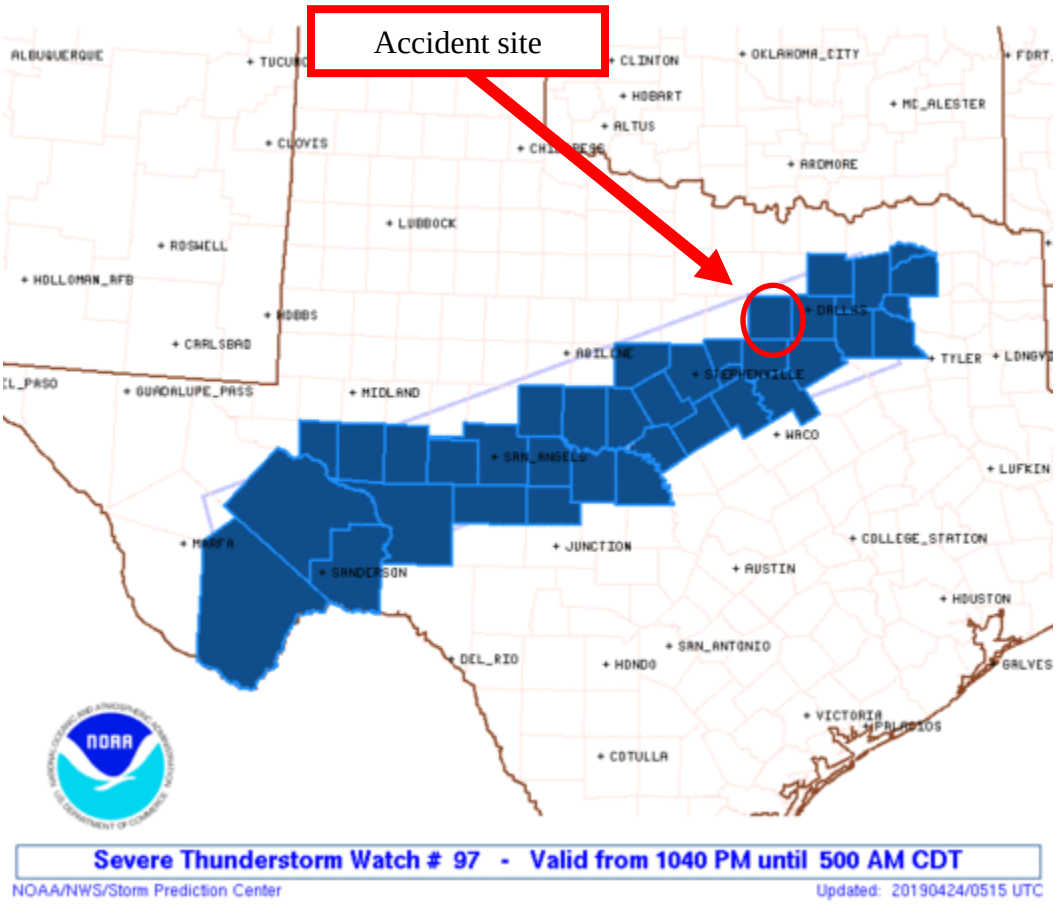

Figure 15 – Severe Thunderstorm Watch #97 with the accident site marked with red circle

URGENT - IMMEDIATE BROADCAST REQUESTED
Severe Thunderstorm Watch Number 95
NWS Storm Prediction Center Norman OK
230 PM CDT Tue Apr 23 2019

The NWS Storm Prediction Center has issued a

* Severe Thunderstorm Watch for portions of
  Southwest into western north Texas

* Effective this Tuesday afternoon and evening from 230 PM until
  1100 PM CDT.

* Primary threats include...
  Scattered large hail and isolated very large hail events to 2.5
    inches in diameter possible
  Scattered damaging wind gusts to 70 mph possible

SUMMARY...Thunderstorm development is expected along a slow-moving front the next few hours from southwest Texas into western north Texas, and over the high terrain west of Del Rio. The storm environment along and south of the watch will favor splitting supercells capable of producing isolated very large hail and damaging gusts. Storm clusters should persist into the early overnight hours along the front, with a gradual transition to locally heavy rainfall as the main concern.

The severe thunderstorm watch area is approximately along and 65 statute miles north and south of a line from 45 miles north northwest of Dryden TX to 25 miles east of Mineral Wells TX. For a complete depiction of the watch see the associated watch outline update (WOUS64 KWNS WOU5).

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.

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AVIATION...A few severe thunderstorms with hail surface and aloft to 2.5 inches. Extreme turbulence and surface wind gusts to 60 knots. A few cumulonimbi with maximum tops to 500. Mean storm motion vector 26020.

...Thompson

The NWS FWD office issued a Flash Flood Watch for the entire north central Texas region (including the accident site) at 1506 CDT on April 23 advising of the potential for flash flooding to occur in urban and poor drainage areas (figure 16).

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533
WGUS64 KFWD 232006
FFAFWD

URGENT - IMMEDIATE BROADCAST REQUESTED
Flood Watch
National Weather Service Fort Worth TX
306 PM CDT Tue Apr 23 2019

TXZ102>104-115>120-129>134-141>145-156>159-240415-
/O.NEW.KFWD.FF.A.0001.190423T2006Z-190425T0500Z/
/00000.0.ER.000000T0000Z.000000T0000Z.000000T0000Z.OO/
Wise-Denton-Collin-Stephens-Palo Pinto-Parker-Tarrant-Dallas-
Rockwall-Eastland-Erath-Hood-Somervell-Johnson-Ellis-Comanche-
Mills-Hamilton-Bosque-Hill-Lampasas-Coryell-Bell-McLennan-
Including the cities of Decatur, Bridgeport, Carrollton, Denton,
Lewisville, Flower Mound, Plano, McKinney, Allen, Frisco,
Breckenridge, Mineral Wells, Weatherford, Briar, Fort Worth,
Arlington, Dallas, Rockwall, Heath, Cisco, Eastland, Ranger,
Gorman, Stephenville, Dublin, Granbury, Oak Trail Shores,
Glen Rose, Cleburne, Burleson, Waxahachie, Ennis, Midlothian,
Comanche, De Leon, Goldthwaite, Hamilton, Hico, Clifton,
Meridian, Valley Mills, Hillsboro, Lampasas, Copperas Cove,
Gatesville, Killeen, Temple, Fort Hood, and Waco
306 PM CDT Tue Apr 23 2019

...FLASH FLOOD WATCH IN EFFECT THROUGH WEDNESDAY EVENING...

The National Weather Service in Fort Worth has issued a

* Flash Flood Watch for a portion of north central Texas,
  including the following areas, Bell, Bosque, Collin, Comanche,
  Coryell, Dallas, Denton, Eastland, Ellis, Erath, Hamilton,
  Hill, Hood, Johnson, Lampasas, McLennan, Mills, Palo Pinto,
  Parker, Rockwall, Somervell, Stephens, Tarrant, and Wise.

* Through Wednesday evening

* Rainfall totals of 2 to 4 inches, with isolated areas receiving
  5 to 6 inches between now and Wednesday evening.

* Flash flooding may occur in urban and poor drainage areas.
  Heavy rainfall may also cause flooding of creeks, streams and
  rivers.

PRECAUTIONARY/PREPAREDNESS ACTIONS...

A Flash Flood Watch means that conditions are favorable for heavy
rain which may lead to flash flooding. You should monitor the
latest forecasts from the National Weather Service and be
prepared to take action should Flash Flood Warnings be issued for
your area.

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Figure 16 – Flash Flood Watch text for accident area

The NWS Weather Prediction Center (WPC) issued several Mesoscale Precipitation Discussions (MPD) warning of flooding conditions for the accident site and north central Texas region. MPD #153, #154, and #155 are referenced below (figures 17, 18, and 19) and were issued at 1722 CDT on April 23, 2222 CDT on April 23, and 2315 CDT on April 23, respectively:

Mesoscale Precipitation Discussion 0153
NWS Weather Prediction Center College Park MD
623 PM EDT Tue Apr 23 2019

Areas affected...Western Texas to North Central Texas

Concerning...Heavy rainfall...Flash flooding possible

Valid 232222Z - 240400Z

SUMMARY...Flash Flooding is possible late this afternoon and this evening from portions of western Texas into north-central Texas, where divergent upper flow is located above a region where there are multiple branches of moist low-level flow.

DISCUSSION...Thinking is that there will be a period from late this afternoon through the evening from western Texas to north central Texas when flash flooding is possible. The approach of a southern stream wave will support and sustain moist low level inflow of moisture from the Gulf of Mexico into an area where difluent/divergent flow is maximized between the Polar Jet and the Subtropical Jet. The region in West Texas immediately north of a slow moving, vertically deep vorticity maximum seen on GOES-16 visible loops appears to be one region favoring slow cell motion. The RAP shows Surface Based CAPE peaking in excess of 2500 J per kg around 24/00Z. While forecast soundings suggest cold-pools will help to move individual cells along, the potential exists for regeneration of cells in an unstable atmosphere through at least 04Z.

A second branch of the low level flow which does not get drawn back to the west will advect downstream into north-central Texas ahead of a slow moving front. With late afternoon radar imagery already showing some merging of cells along the instability axis, the risk of flash flooding should also persist here into the evening due to maximized moisture flux convergence.

HREF 40 km neighborhood probabilities initially highest in the north-central portion of the area along and south of the front. The probability of 1 inch per hour rainfall exceeds 50 percent around 24/00Z from Callahan county towards Denton county. After 24/00Z, the probabilities for rainfall rates in excess of 1 inch per hour build south and west into western Texas towards the maximum of SBCAPE values.

Given that Flash Flood Guidance values were generally on the order of 2 to 4 inches per 3 hours, suspect any problems with flash flooding will be fairly limited in scope, with areas most prone to run off problems being areas which received heavy rainfall earlier today.

Bann

ATTN...WFO...FWD...MAF...OUN...SJT...

ATTN...RFC...ABRFC...WGRFC...

LAT...LON 33709793 33549727 32519772 31749895 30780013
30510147 30500289 31610291 32440091 33139906

Mesoscale Precipitation Discussion 0154
NWS Weather Prediction Center College Park MD
1123 PM EDT Tue Apr 23 2019

Areas affected...North Texas

Concerning...Heavy rainfall...Flash flooding possible

Valid 240322Z - 240645Z

Summary...Several clusters of thunderstorms should move across North Texas tonight. The tracks of these storms may overlap, providing several rounds of heavy rainfall. This may lead to localized flash flooding, with hourly rain rates in the strongest storms approaching 2 inches.

Discussion...At 03Z, regional radars showed two convective clusters with a similar overall mesoscale structure. Forward-propagating clusters (compact bow echoes) were located over Comanche and Tarrant Counties. Each cluster had a distinct, broad and strong mesovortex on the northern half of the cluster, and a wing of convection extended east from each. And finally, trailing convection was noted on the upshear flank of both clusters, likely forming on the periphery of some weak boundary layer cold pools. The potential tracks of each cluster and its associated convective elements do create some opportunities for overlap. For example, the preceding wing of convection from the Comanche County cluster was actually north of the trailing convection associated with the Tarrant County cluster. And the wing of convection on the northeast side of the DFW metro area has already produced very heavy rain over southern Collin County, and upstream convection may track over the same area. Therefore, some locations could conceivably receive 1-2 hours of training convection, which could lead to flash flooding, particularly if it occurs over an urbanized area.

The environment will remain favorable for organized convection over the next few hours. RAP analyzed MUCAPE exceeds 1000 j/kg and the 00Z FWD sounding showed around 1700 j/kg of CAPE rooted near the surface. When combined with precipitable water values around 1.5 inches (GPS-PW; 00Z FWD sounding), hourly rain rates approaching 2 inches seems reasonable. One limiting factor will be the forward propagating nature of the dominant convective clusters. Forecast forward-propagating storm motions are nearly west-to-east, while the deep layer mean wind is more southwesterly (roughly parallel to the surface front and thetae gradient). The

result should be a tendency to move off the surface boundary, which typically reduces the time frame for training. Nevertheless, as described above, there should still be opportunities for training in more focused areas, which could yield some localized flash flooding. Upstream convection over the Concho Valley region of Central Texas will be monitored for potential additional rainfall layer in the night, beyond 06Z. This could maintain a flash flood threat into the early morning hours in some parts of North Texas.

Lamers

ATTN...WFO...FWD...SHV...SJT...

ATTN...RFC...ABRFC...LMRFC...WGRFC...

LAT...LON 33509633 33409504 32649517 32159598 31689755
31669854 32049900 32759856 33309746

Mesoscale Precipitation Discussion 0155
NWS Weather Prediction Center College Park MD
1217 AM EDT Wed Apr 24 2019

Areas affected...Central Texas

Concerning...Heavy rainfall...Flash flooding likely

Valid 240415Z - 240915Z

Summary...Thunderstorms should continue to develop and move across Central Texas tonight. These storms may repeatedly affect some locations for several hours, leading to flash flooding. Hourly rain rates could reach 2 inches.

Discussion...Flash flood potential appears to be increasing across parts of central Texas. The leading edge of a band of convection is now aligned in a west-east fashion from FST-SJT-BWD, situated along the northern cusp of a corridor of fairly strong instability (MLCAPE 1500+ j/kg; MLCINH <25 j/kg). This should support the potential for training convection given a fairly substantial component of observed storm motions to the east. Although the deep layer mean wind was from about 240 degrees at 30 knots, Corfidi vectors were more due westerly. Additionally, KSJT radar reflectivity showed a gradually southward propagating outflow boundary, so new updraft formation would have a tendency to form south of existing convection and then move NE/ENE into areas that have already seen rainfall. Although the mesoscale configuration for training is not ideal, the orientation of the boundary relative to the deep layer flow should be sufficient to provide some periods of training. Furthermore, convective coverage may increase over the next several hours which may lead to additional cell mergers and interactions. Model forecasts show a strong +PV anomaly lifting ENE toward the Texas Big Bend tonight, with an associated strengthening of the subtropical jet over northern Mexico and increasing divergence in the left exit region over Central Texas. All these factors together should favor some swaths

of heavy rainfall in excess of 3 inches, which could lead to flash flooding depending on the time frame that it falls. Hourly rain rates may approach 2 inches in the strongest convection given the fairly strong instability supporting organized thunderstorm clusters. However, they may also be limited somewhat by PWs only around 1.2 inches per recent GPS-PW observations.

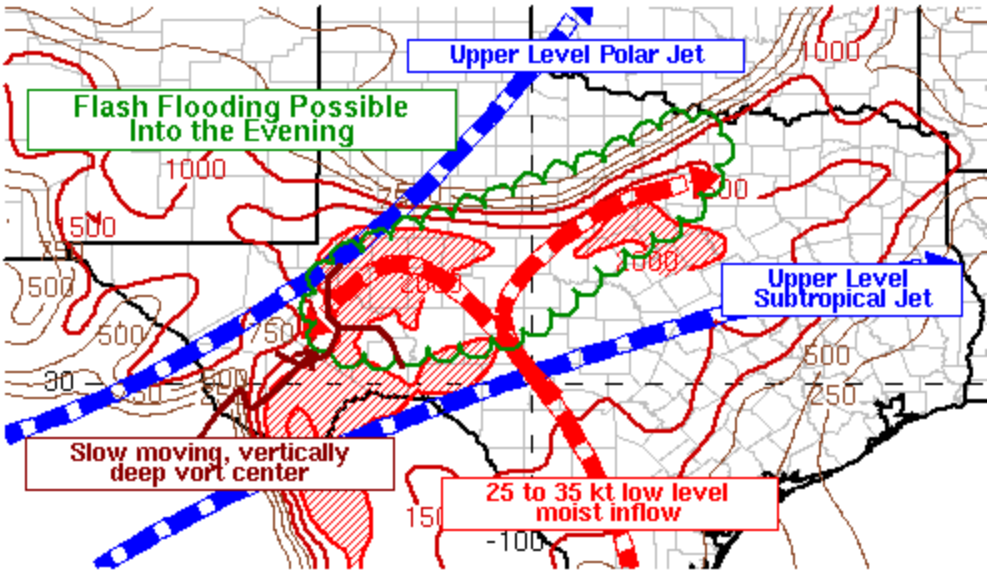
Hi-res models do seem to be struggling to capture the ongoing convection, and thus there are questions about how reliable their QPFs will be for the 00-12Z period tonight. Some show generally too much southeastward motion with this segment of the convective line, while others indicate a lull should be ongoing. Nevertheless, most show an increase in convective coverage around 09-12Z, likely related to the aforementioned trends in large-scale forcing. However, the rainfall preceding that increase in coverage may be more significant and focused in a particular corridor than they are signaling. The CONUS WRF-ARW seems to best capture ongoing trends, and it shows widespread 1+ inch QPF from 05-11Z in the outlined portion of central Texas, with localized amounts around 3 inches. The distribution of the rainfall seems reasonable, but the maximum amounts could be slightly underdone if the general latitude of the band of convection remains relatively stable over the next six hours or so.

Lamers

ATTN...WFO...EWX...FWD...MAF...SJT...

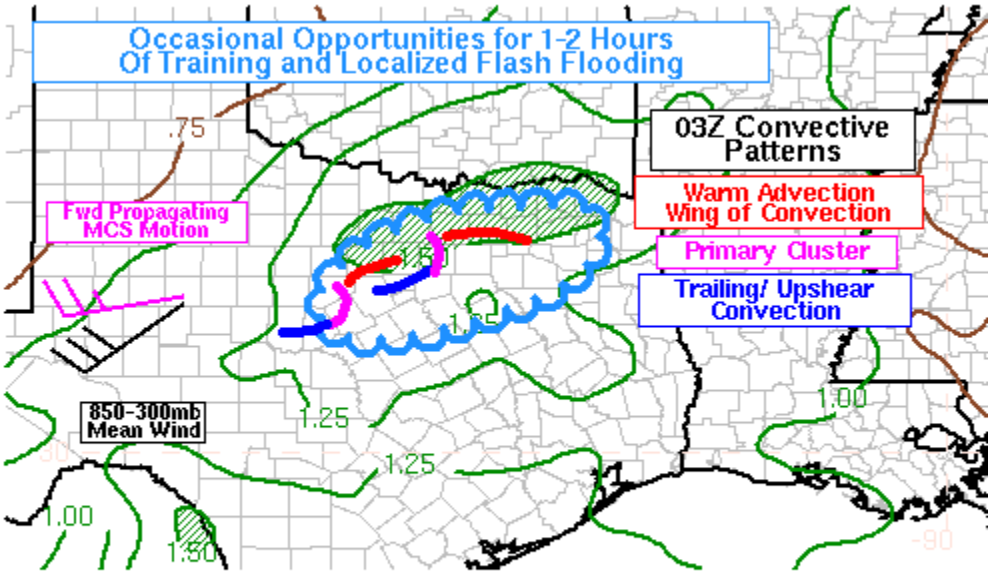
ATTN...RFC...WGRFC...

LAT...LON 32319955 32099807 31359792 30739877 30659996
30770123 31130242 31650217 32070104



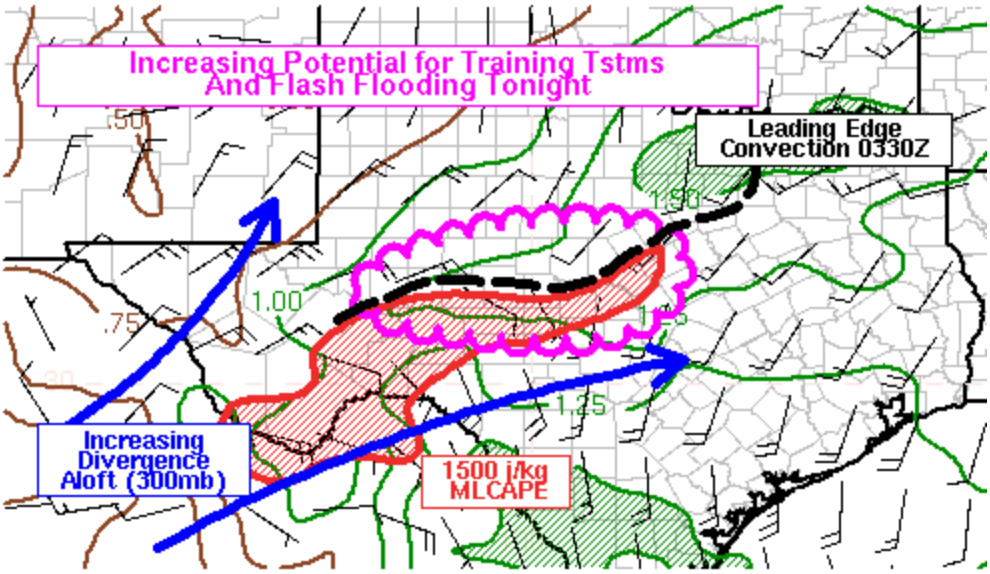
RAP32 SB CAPE 190423/1900f005
WPC MPD #0153

Figure 17 – MPD #153 graphic



RAP32 PRECIP WATER 190424/0100f003
WPC MPD #0154

Figure 18 – MPD #154 graphic



RAP32 PRECIP WATER 190424/0200f003
RAP32 850 MB WINDS 190424/0200f003
WPC MPD #0155

Figure 19 – MPD #155 graphic

At the time of the accident, WPC[40] had a Day 1 Excessive Rainfall Outlook slight risk valid which indicated between a 10 to 20 percent risk of rainfall exceeding flash flood guidance within 25 miles of a point (figure 20). In addition, WPC provided the Day 1 quantitative precipitation forecast (QPF) valid from 0700 CDT on April 23 to 0700 CDT on April 24 and the observed accumulated precipitation valid for the same timeframe (figure 21). 2.30 inches average QPF was forecast for the Dallas metro region valid for the above timeframe with 2.90 inches average QPF observed for the Dallas metro region for the above timeframe (figure 21).

[40] https://www.wpc.ncep.noaa.gov/qpf/excess_rain.shtml

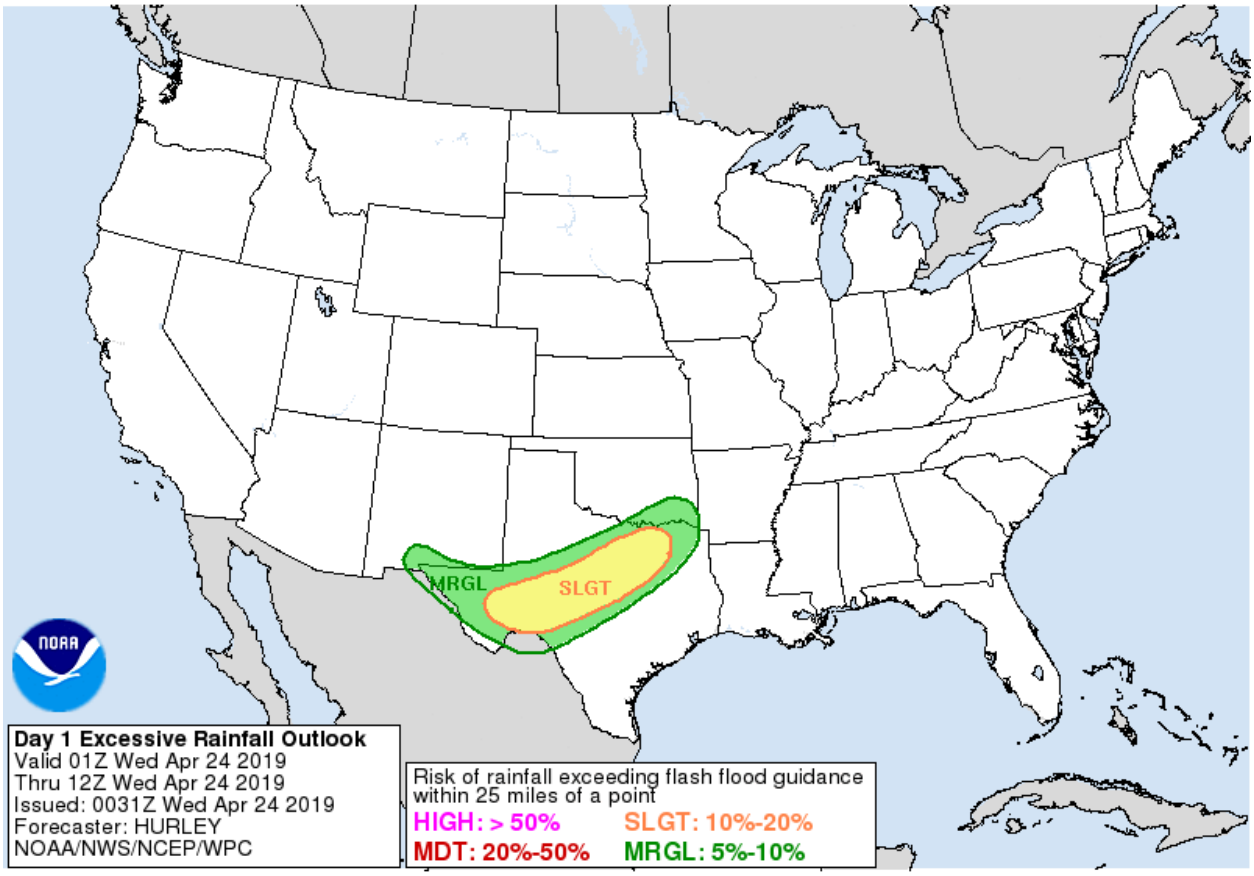


Figure 20 – WPC Day 1 Excessive Rainfall Outlook valid at accident time

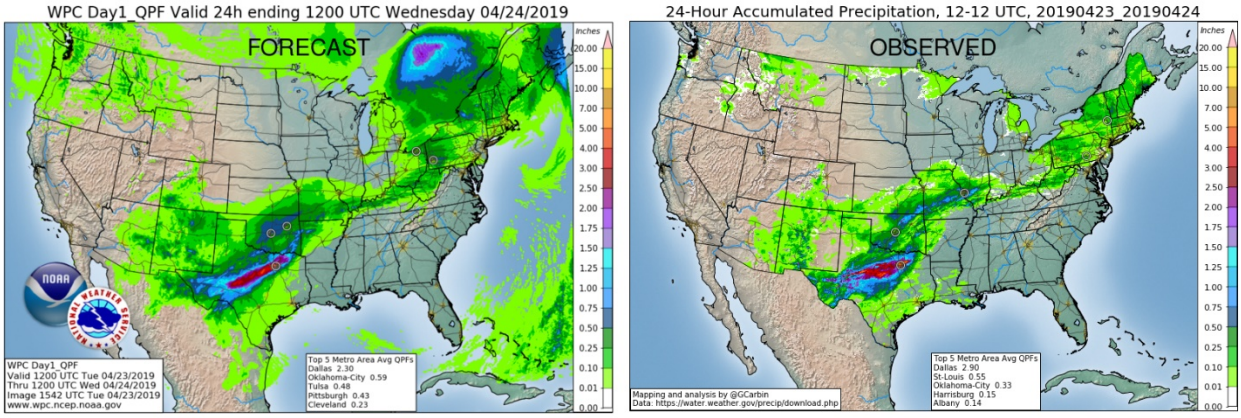


Figure 21 – WPC Day 1 QPF forecast valid from 0700 CDT April 23 to 0700 CDT April 24 (on left) and observed accumulated precipitation valid for the same timeframe (on right)

10.0 NWS Warnings, Advisories, and Graphics

The NWS FWD office issued the following Flood Advisory for Tarrant County, which included the accident site, at 2152 CDT on April 23. This Flood Advisory warned of urban and small stream flooding (figure 22). The Flood Advisory was valid through 2345 CDT on April 23. A Flood Advisory was issued for Dallas County and was valid between 2213 CDT on April 23 and 0115 CDT on April 24.

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FLOOD ADVISORY
NATIONAL WEATHER SERVICE FORT WORTH TX
952 PM CDT TUE APR 23 2019

TXC439-240445-
/O.NEW.KFWD.FA.Y.0018.190424T0252Z-190424T0445Z/
/00000.N.ER.000000T0000Z.000000T0000Z.000000T0000Z.OO/
TARRANT TX-
952 PM CDT TUE APR 23 2019

THE NATIONAL WEATHER SERVICE IN FORT WORTH HAS ISSUED A

* FLOOD ADVISORY FOR...
  TARRANT COUNTY IN NORTH CENTRAL TEXAS...

* UNTIL 1145 PM CDT.

* AT 951 PM CDT, DOPPLER RADAR INDICATED THUNDERSTORMS THAT WERE
  PRODUCING HEAVY RAINFALL ACROSS TARRANT COUNTY. EXCESSIVE RUNOFF
  FROM THESE THUNDERSTORMS WILL CAUSE URBAN AND SMALL STREAM
  FLOODING. AREAS THAT ARE LOW LYING OR USUALLY EXPERIENCE POOR
  DRAINAGE ARE MOST LIKELY TO EXPERIENCE FLOODING. THIS MEANS SOME
  LOW WATER CROSSINGS IN THE REGION MAY BECOME IMPASSABLE. UP TO TWO
  INCHES OF RAIN HAVE ALREADY FALLEN.

* SOME LOCATIONS THAT WILL EXPERIENCE FLOODING INCLUDE...
  FORT WORTH, ARLINGTON, GRAND PRAIRIE, MANSFIELD, EULESS, BEDFORD,
  GRAPEVINE, HALTOM CITY, KELLER, HURST, SOUTHLAKE, WATAUGA,
  COLLEYVILLE, BENBROOK, SAGINAW, WHITE SETTLEMENT, CROWLEY, FOREST
  HILL, RICHLAND HILLS AND RIVER OAKS.

PRECAUTIONARY/PREPAREDNESS ACTIONS...

BE ESPECIALLY CAUTIOUS AT NIGHT WHEN IT IS HARDER TO RECOGNIZE THE
DANGERS OF FLOODING.

&&

LAT...LON 3298 9704 3263 9704 3255 9749 3255 9751
      3299 9749

$$

DUNN
```

Figure 22 – Flood Advisory for Tarrant County

The NWS FWD office issued the following Severe Thunderstorm Warning, which included a portion of Tarrant County, at 2106 CDT on April 23. The warning was valid through 2200 CDT on April 23 (figure 23) and advised of 65 mile-per-hour (mph) winds and penny size hail. The warning was updated at 2144 CDT on April 23, remaining valid through 2200 CDT on April 23, and advised of 70 mph winds and penny size hail. Both products contained wording regarding heavy rainfall that may lead to flash flooding conditions.

```
887
WUUS54 KFWD 240206
SVRFWD
TXC251-367-439-240300-
/O.NEW.KFWD.SV.W.0117.190424T0206Z-190424T0300Z/

BULLETIN - IMMEDIATE BROADCAST REQUESTED
Severe Thunderstorm Warning
National Weather Service Fort Worth TX
906 PM CDT Tue Apr 23 2019

The National Weather Service in Fort Worth has issued a

* Severe Thunderstorm Warning for...
  Northern Johnson County in north central Texas...
  Eastern Parker County in north central Texas...
  Tarrant County in north central Texas...

* Until 1000 PM CDT.

* At 906 PM CDT, a cluster of severe thunderstorms was located from
  near Springtown to Willow Park to Aledo , moving east at 35 mph.

  HAZARD...65 mph wind gusts and penny size hail.

  SOURCE...Radar indicated.

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

* Locations impacted include...
  Fort Worth, Arlington, Grand Prairie, Mansfield, Euless, Bedford,
  Grapevine, Haltom City, Keller, Hurst, Burleson, Southlake,
  Weatherford, Watauga, Colleyville, Benbrook, Saginaw, White
  Settlement, Crowley and Forest Hill.

PRECAUTIONARY/PREPAREDNESS ACTIONS...

For your protection get inside a sturdy structure and stay away from
windows.

Heavy rainfall is occurring with this storm, and may lead to flash
flooding. Do not drive your vehicle through flooded roadways.

&&

LAT...LON 3298 9704 3255 9704 3255 9709 3243 9709
      3242 9762 3255 9762 3256 9765 3277 9770
      3299 9769
TIME...MOT...LOC 0206Z 268DEG 31KT 3263 9756

HAIL...0.75IN
WIND...65MPH

$$

Dunn
```

Figure 23 – Severe Thunderstorm Warning #117 for Tarrant County

```
SEVERE WEATHER STATEMENT
NATIONAL WEATHER SERVICE FORT WORTH TX
944 PM CDT TUE APR 23 2019

TXC251-439-240300-
/O.CON.KFWD.SV.W.0117.000000T0000Z-190424T0300Z/
JOHNSON TX-TARRANT TX-
944 PM CDT TUE APR 23 2019

...A SEVERE THUNDERSTORM WARNING REMAINS IN EFFECT UNTIL 1000 PM CDT
FOR NORTHERN JOHNSON AND TARRANT COUNTIES...

AT 944 PM CDT, A SEVERE THUNDERSTORM WAS LOCATED NEAR HALTOM CITY,
OR NEAR RICHLAND HILLS, MOVING EAST AT 35 MPH. A 70 MPH WIND WAS
MEASURED AT THE NWS OFFICE IN FORT WORTH.

HAZARD...70 MPH WIND GUSTS AND PENNY SIZE HAIL.

SOURCE...RADAR INDICATED.

IMPACT...EXPECT CONSIDERABLE TREE DAMAGE. DAMAGE IS LIKELY TO MOBILE
         HOMES, ROOFS, AND OUTBUILDINGS.

LOCATIONS IMPACTED INCLUDE...
FORT WORTH, ARLINGTON, GRAND PRAIRIE, MANSFIELD, EULESS, BEDFORD,
GRAPEVINE, HALTOM CITY, KELLER, HURST, BURLESON, SOUTHLAKE, WATAUGA,
COLLEYVILLE, BENBROOK, SAGINAW, WHITE SETTLEMENT, CROWLEY, FOREST
HILL AND RICHLAND HILLS.

PRECAUTIONARY/PREPAREDNESS ACTIONS...

FOR YOUR PROTECTION STAY INSIDE A STURDY STRUCTURE AND KEEP AWAY FROM
WINDOWS.

HEAVY RAINFALL IS OCCURRING WITH THIS STORM, AND MAY LEAD TO FLASH
FLOODING. DO NOT DRIVE YOUR VEHICLE THROUGH FLOODED ROADWAYS.

&&

LAT...LON 3298 9704 3255 9704 3255 9709 3243 9709
      3244 9758 3256 9750 3276 9748 3299 9748
TIME...MOT...LOC 0244Z 267DEG 31KT 3275 9721

HAIL...0.75IN
WIND...70MPH
```

Figure 24 – Severe Thunderstorm Warning #117 update for Tarrant County

The NWS FWD office issued several graphics via social media between 0517 CDT on April 22 and 2059 CDT on April 23 warning of the thunderstorm conditions and the potential for heavy rainfall and flooding (figures 25 through 32). Four to six inches of rain was indicated in the 1600 CDT April 23 social media graphic (figure 31) for Tarrant County and the accident site.

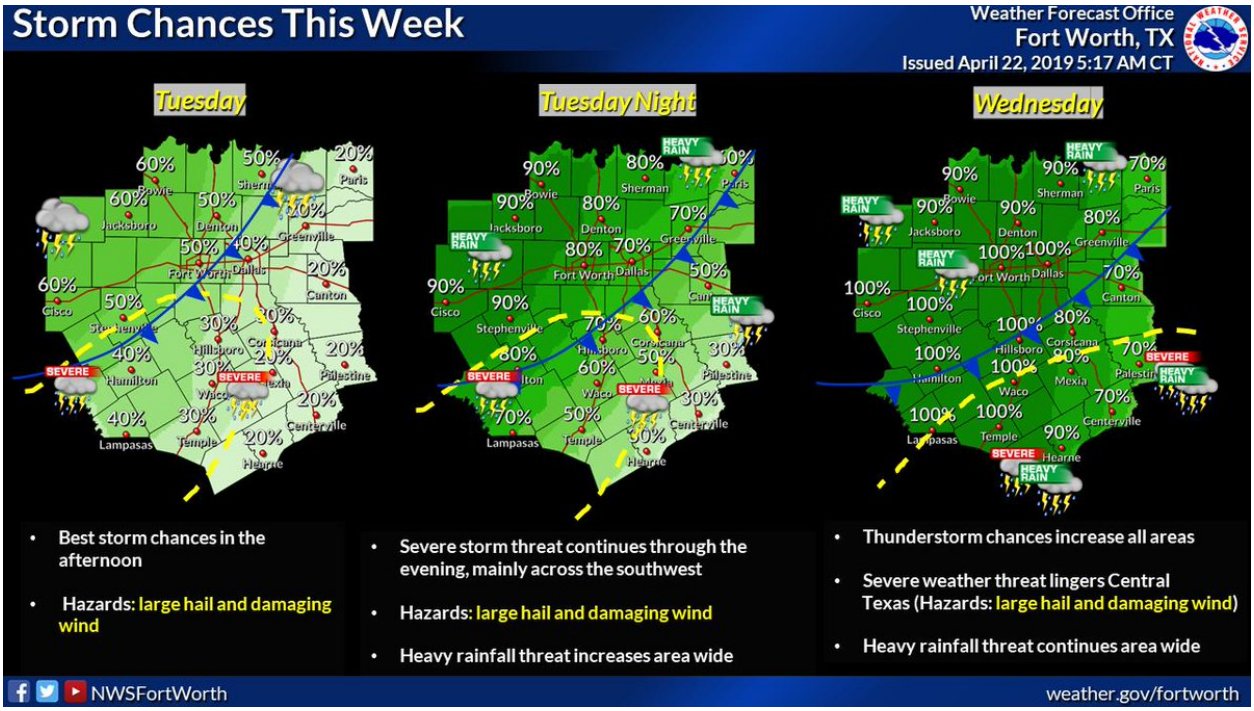

Figure 25 – NWS FWD social media graphic from 0517 CDT on April 22

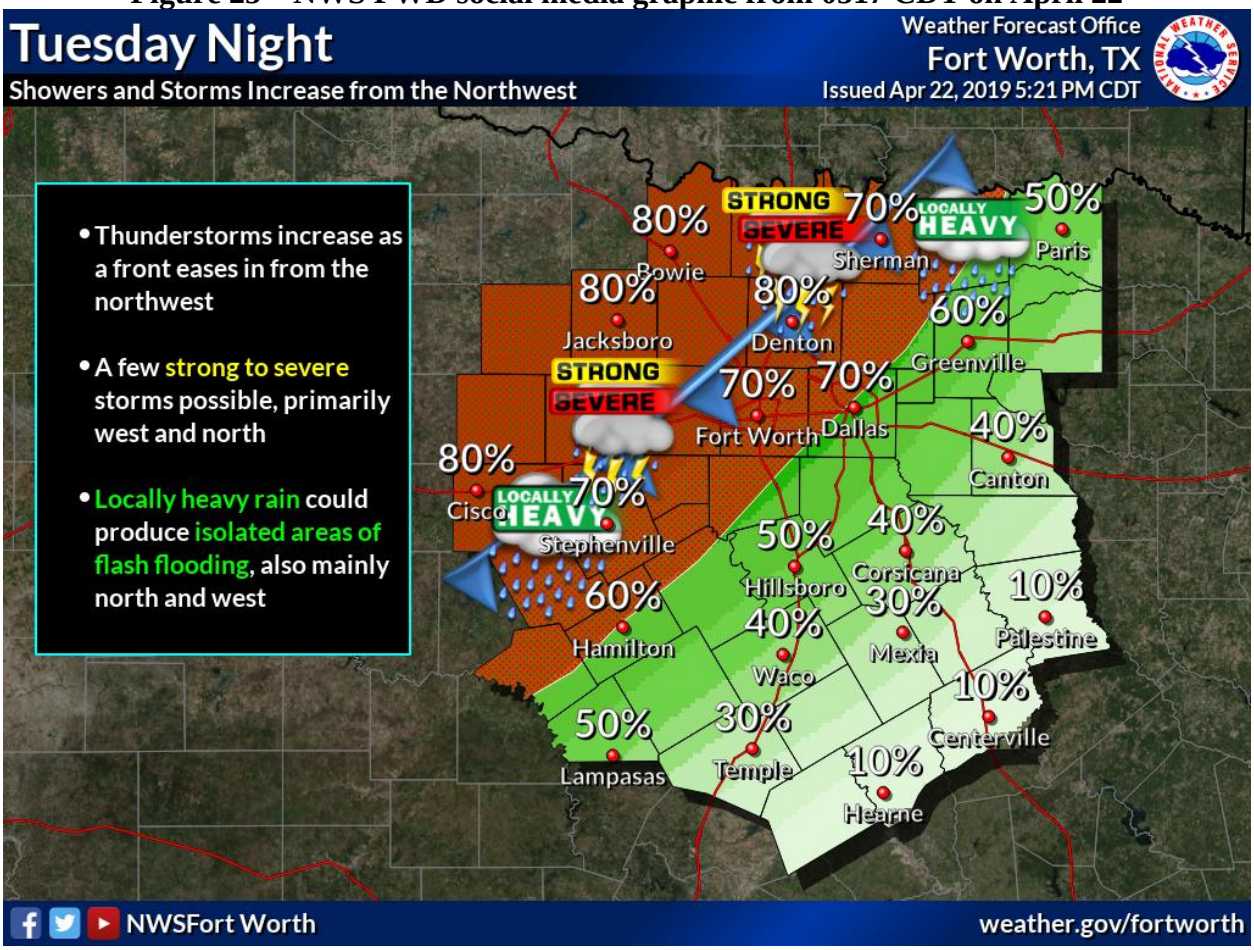

Figure 26 – NWS FWD social media graphic from 1721 CDT on April 22

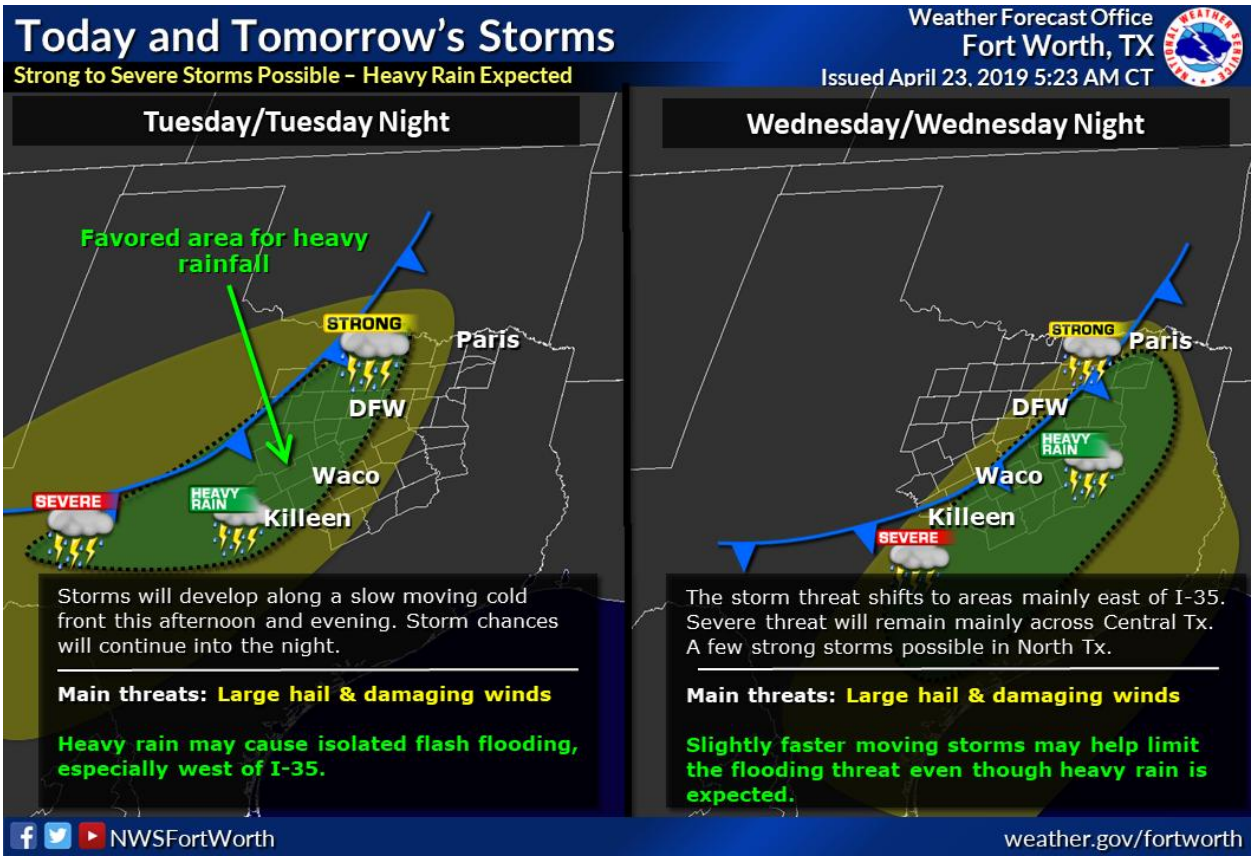

Figure 27 – NWS FWD social media graphic from 0523 CDT on April 23

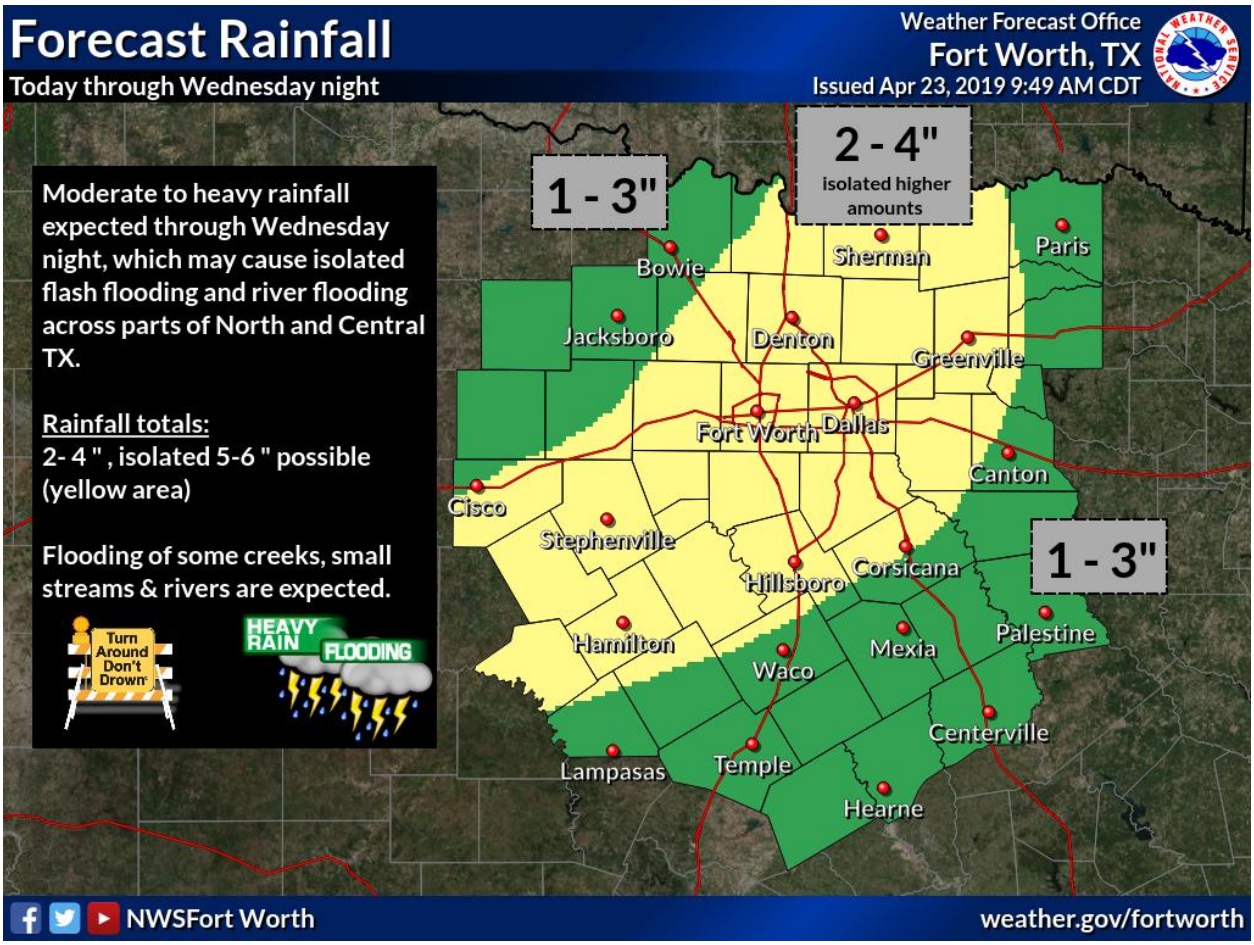

Figure 28 – NWS FWD social media graphic from 0949 CDT on April 23

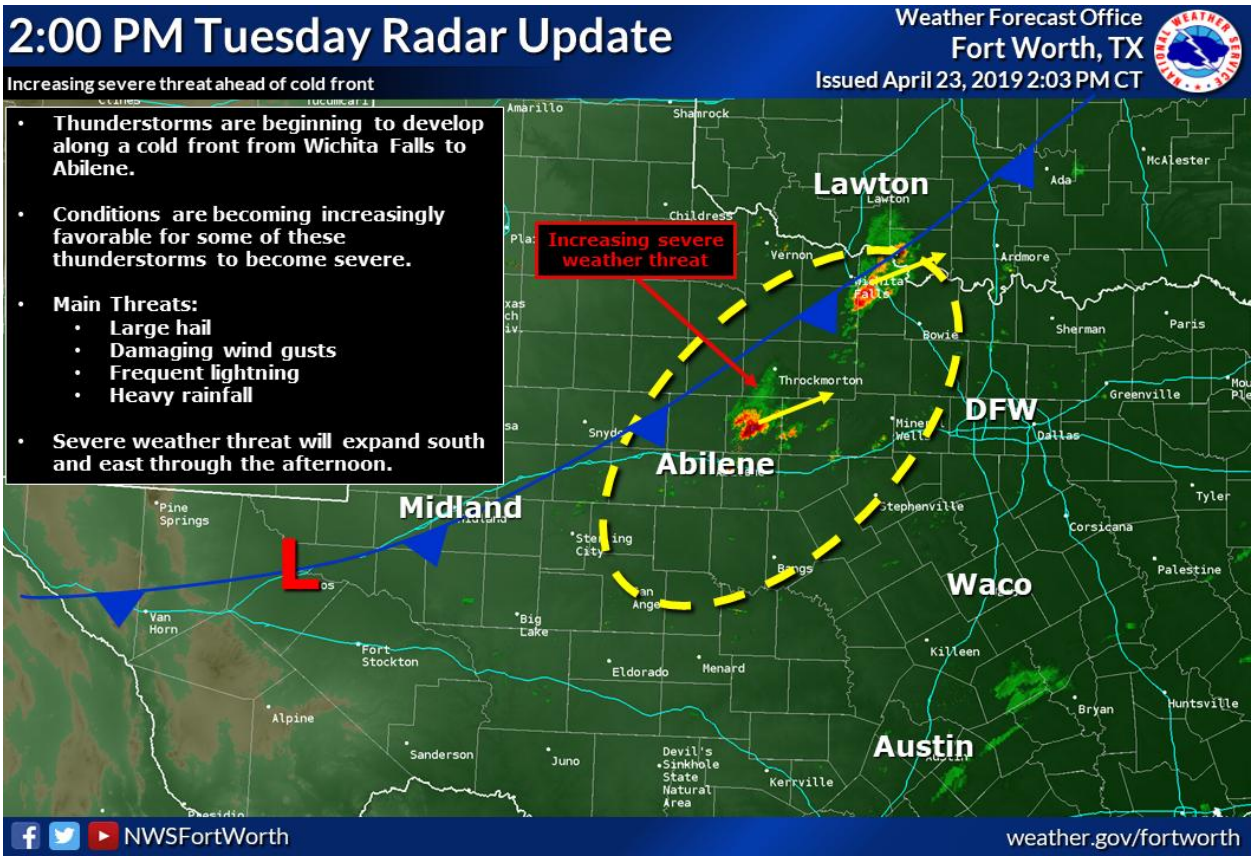

Figure 29 – NWS FWD social media graphic from 1403 CDT on April 23

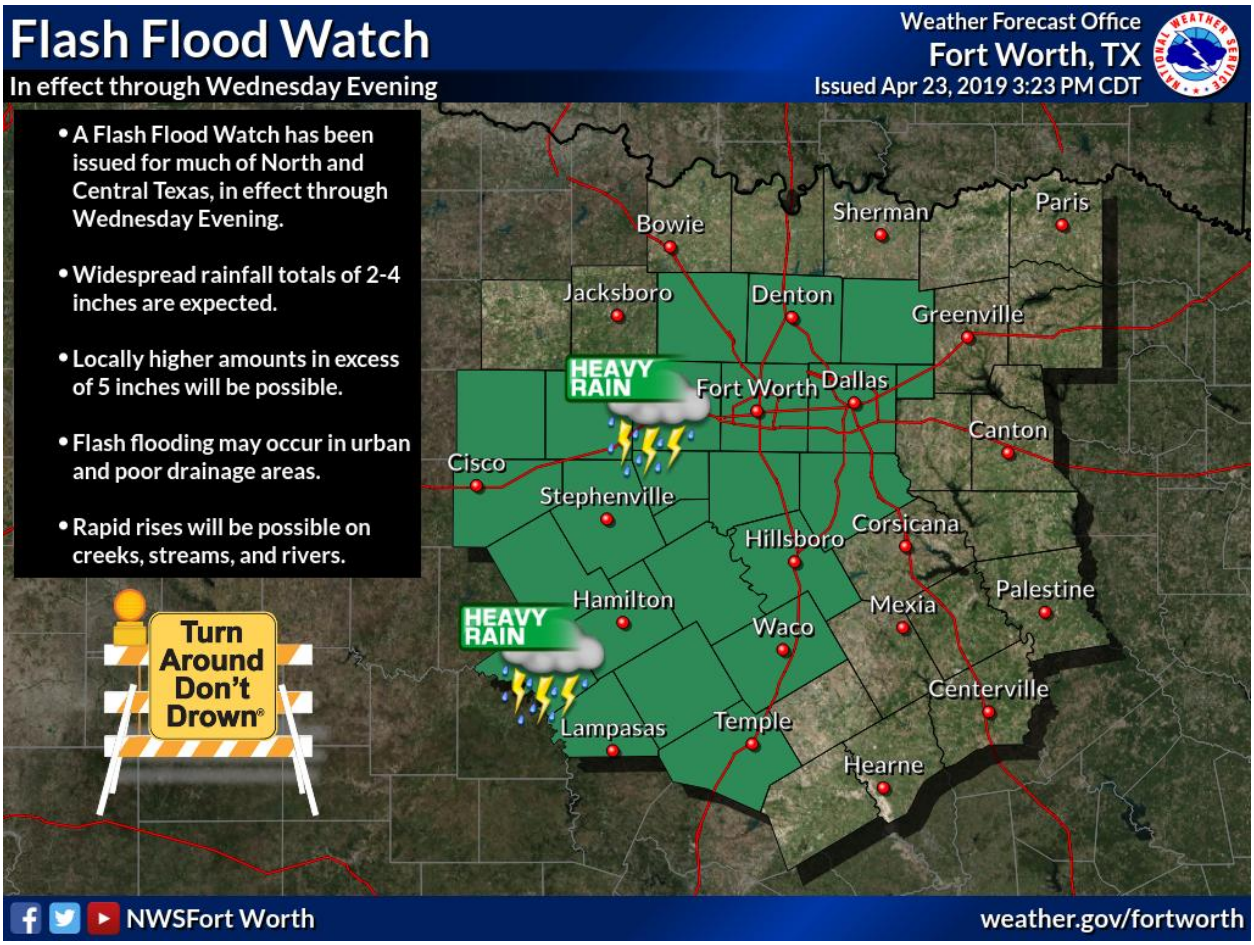

Figure 30 – NWS FWD social media graphic from 1523 CDT on April 23

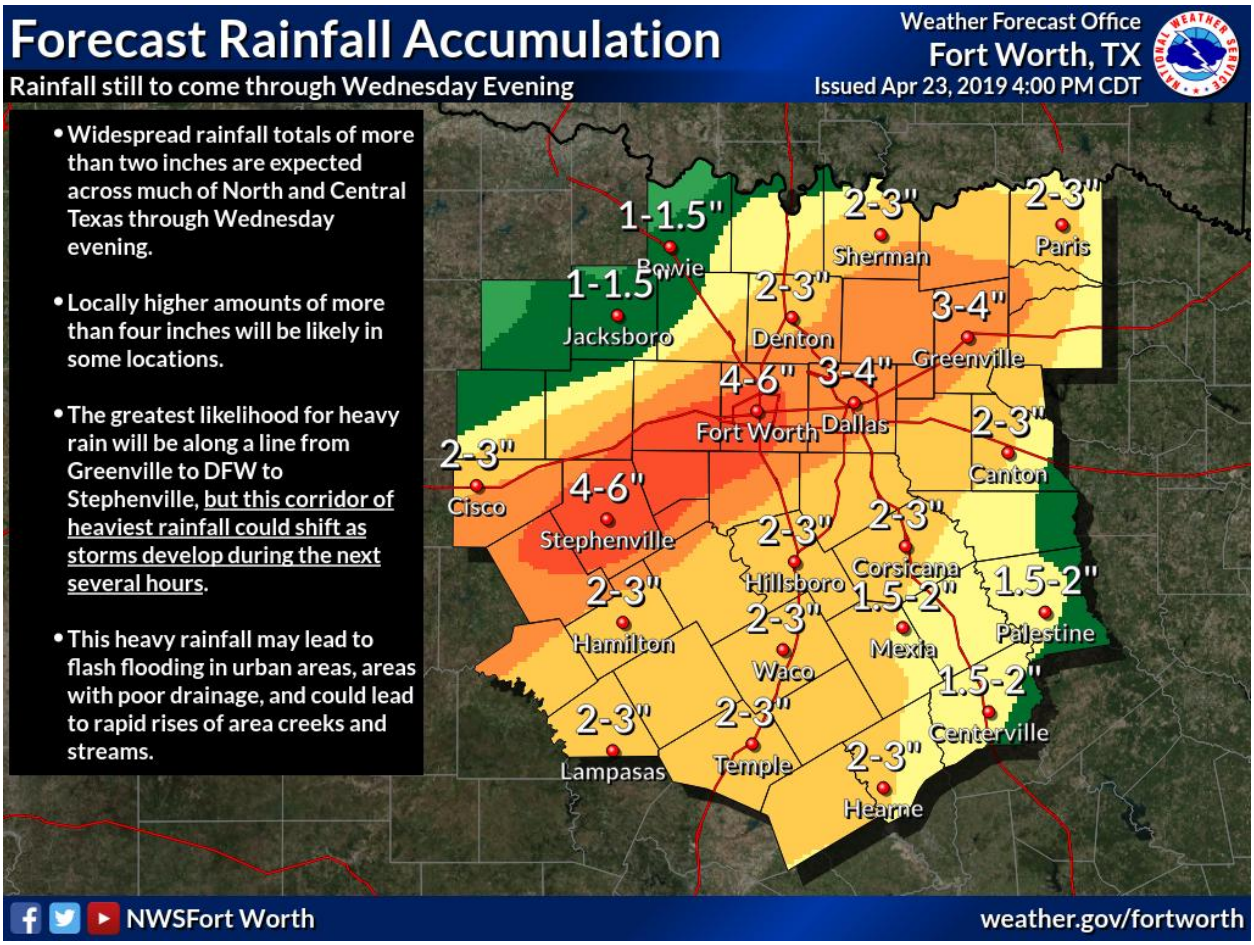

Figure 31 – NWS FWD social media graphic from 1600 CDT on April 23

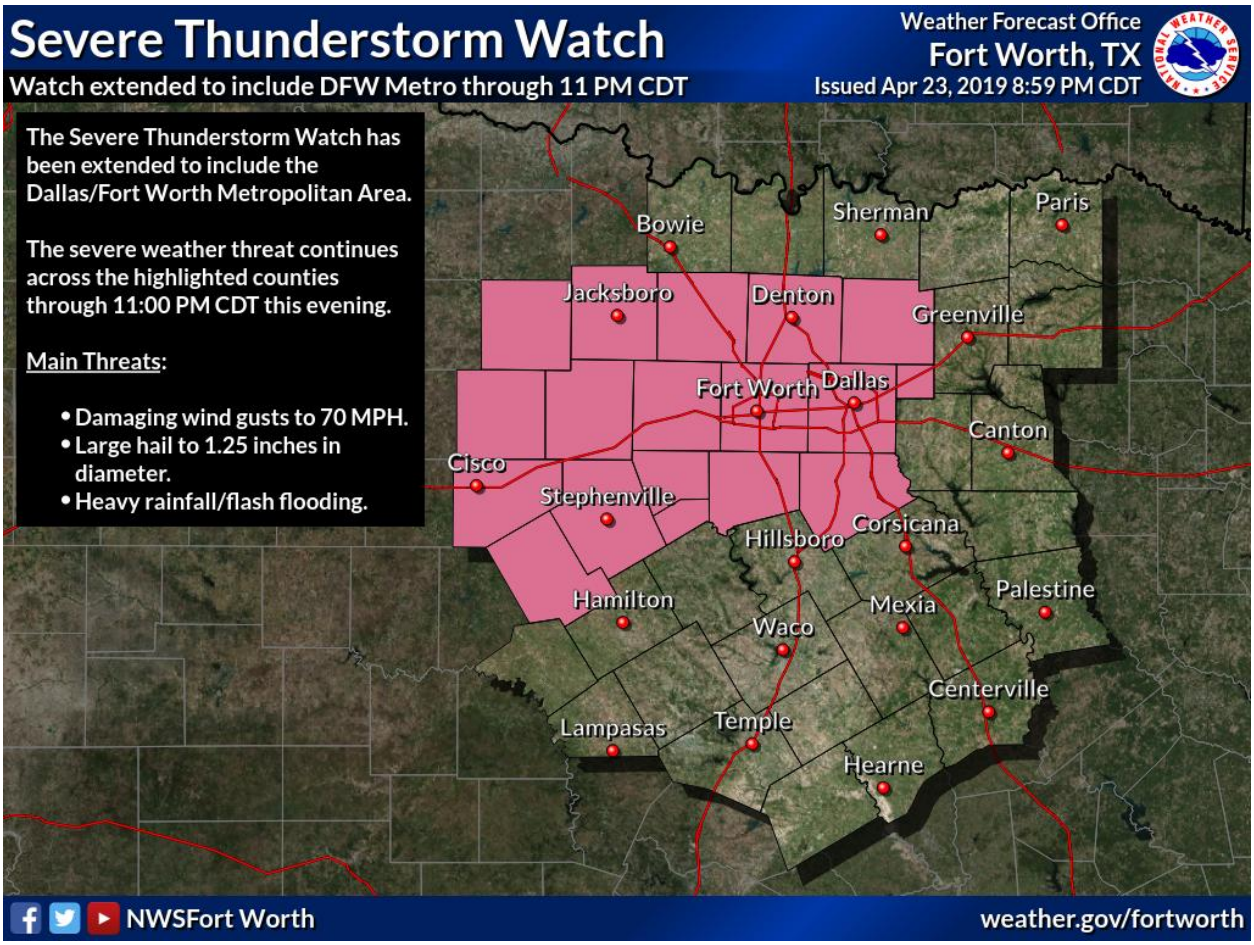

Figure 32 – NWS FWD social media graphic from 2059 CDT on April 23

11.0 NWS Public Forecast and Hazardous Weather Outlook

The NWS FWD office issued an update Zone Forecast Product (ZFP) at 2254 CDT April 23, which was valid at the accident time and included the Flash Flood Watch and Severe Thunderstorm Watch #97. The ZFP indicated that some thunderstorms may be severe with heavy rainfall:

FPUS54 KFWD 240354
ZFPFWD

Zone Forecast Product
National Weather Service Fort Worth TX
1054 PM CDT Tue Apr 23 2019

TXZ118-240915-
Tarrant-
Including the cities of Fort Worth and Arlington
1054 PM CDT Tue Apr 23 2019

...FLASH FLOOD WATCH IN EFFECT THROUGH WEDNESDAY EVENING...
...SEVERE THUNDERSTORM WATCH 97 IN EFFECT UNTIL 5 AM CDT WEDNESDAY...

.REST OF TONIGHT...Showers and thunderstorms likely late this evening...then showers and thunderstorms. Some thunderstorms may be severe with heavy rainfall. Temperatures steady in the lower 60s. Southeast winds around 5 mph. Chance of rain 80 percent.
.WEDNESDAY...Thunderstorms, showers. Highs around 70. East winds 5 to 10 mph. Chance of rain near 100 percent.
.WEDNESDAY NIGHT...Showers and thunderstorms in the evening... then showers and thunderstorms likely after midnight. Lows in the upper 50s. Northeast winds 5 to 10 mph shifting to the northwest after midnight. Chance of rain 80 percent.
.THURSDAY...Mostly cloudy with a chance of showers and thunderstorms in the morning...then partly sunny with a slight chance of showers and thunderstorms in the afternoon. Highs in the lower 70s. North winds 5 to 10 mph. Chance of rain 30 percent.
.THURSDAY NIGHT...Mostly clear. Lows in the upper 50s. North winds 5 to 10 mph.
.FRIDAY...Sunny. Highs in the upper 70s.
.FRIDAY NIGHT...Mostly clear. Lows in the upper 50s.
.SATURDAY...Sunny. Highs in the lower 80s.
.SATURDAY NIGHT...Mostly clear. Lows in the lower 60s.
.SUNDAY...Sunny. Highs in the lower 80s.
.SUNDAY NIGHT...Partly cloudy. Lows in the mid 60s.
.MONDAY...Mostly sunny. Highs in the lower 80s.
.MONDAY NIGHT...Partly cloudy in the evening...then becoming mostly cloudy. Lows in the mid 60s.
.TUESDAY...Partly sunny with a 30 percent chance of showers and thunderstorms. Highs in the lower 80s.

$$

A Hazardous Weather Outlook (HWO) applicable to the accident location was issued by the NWS FWD office at 1514 CDT on April 23 and was valid at the accident time. The HWO warned of ongoing thunderstorm activity with strong to severe storms possible with isolated large hail, damaging winds, and locally heavy rainfall:

FLUS44 KFWD 232014
HWOFWD

Hazardous Weather Outlook
National Weather Service Fort Worth TX
314 PM CDT Tue Apr 23 2019

TXZ091>095-100>107-115>123-129>135-141>148-156>162-174-175-241245-
Montague-Cooke-Grayson-Fannin-Lamar-Young-Jack-Wise-Denton-Collin-
Hunt-Delta-Hopkins-Stephens-Palo Pinto-Parker-Tarrant-Dallas-
Rockwall-Kaufman-Van Zandt-Rains-Eastland-Erath-Hood-Somervell-
Johnson-Ellis-Henderson-Comanche-Mills-Hamilton-Bosque-Hill-Navarro-
Freestone-Anderson-Lampasas-Coryell-Bell-McLennan-Falls-Limestone-
Leon-Milam-Robertson-
314 PM CDT Tue Apr 23 2019

This Hazardous Weather Outlook is for North and Central Texas.

.**DAY ONE...Tonight.**

The ongoing thunderstorm activity will continue to increase in coverage this evening. A few strong to severe storms are possible, mainly over areas west of the DFW Metroplex. Isolated large hail, damaging winds and locally heavy rainfall are the primary hazards.

.DAYS TWO THROUGH SEVEN...Wednesday through Monday.
Numerous thunderstorms are expected across the entire region Wednesday and Wednesday night. Some strong to severe storms will be possible with the best chances across Central Texas. Large hail and damaging winds will be the main hazards. Locally heavy rainfall may result in isolated instances of flash flooding, in addition to flooding of creeks, streams and rivers. Storm chances will end from west to east Thursday.

.SPOTTER INFORMATION STATEMENT...
Spotter activation is possible this afternoon and evening, especially west of the I-35 corridor.

$$

12.0 NOAA HYSPLIT Model Information

The NWS ran the NOAA Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT)[41] at 0151:45 CDT on April 24 and the results can be found in attachments 4 and 5.

13.0 Hydrology Observations

The closest NWS Advanced Hydrologic Prediction Service (AHPS) point to the accident site was Clear Fork Trinity River at Fort Worth, Texas (figure 34). Data from the Clear Fork Trinity River observation point indicated a rapid 4 foot increase in river level during the rainfall events on April 23 through the morning of April 24 (figure 33).[42]

[41] https://www.ready.noaa.gov/HYSPLIT.php
[42] For more information on River Forecasts and AHPS data please see: https://water.weather.gov/ahps2/index.php?wfo=fwd and https://www.weather.gov/wgrfc/

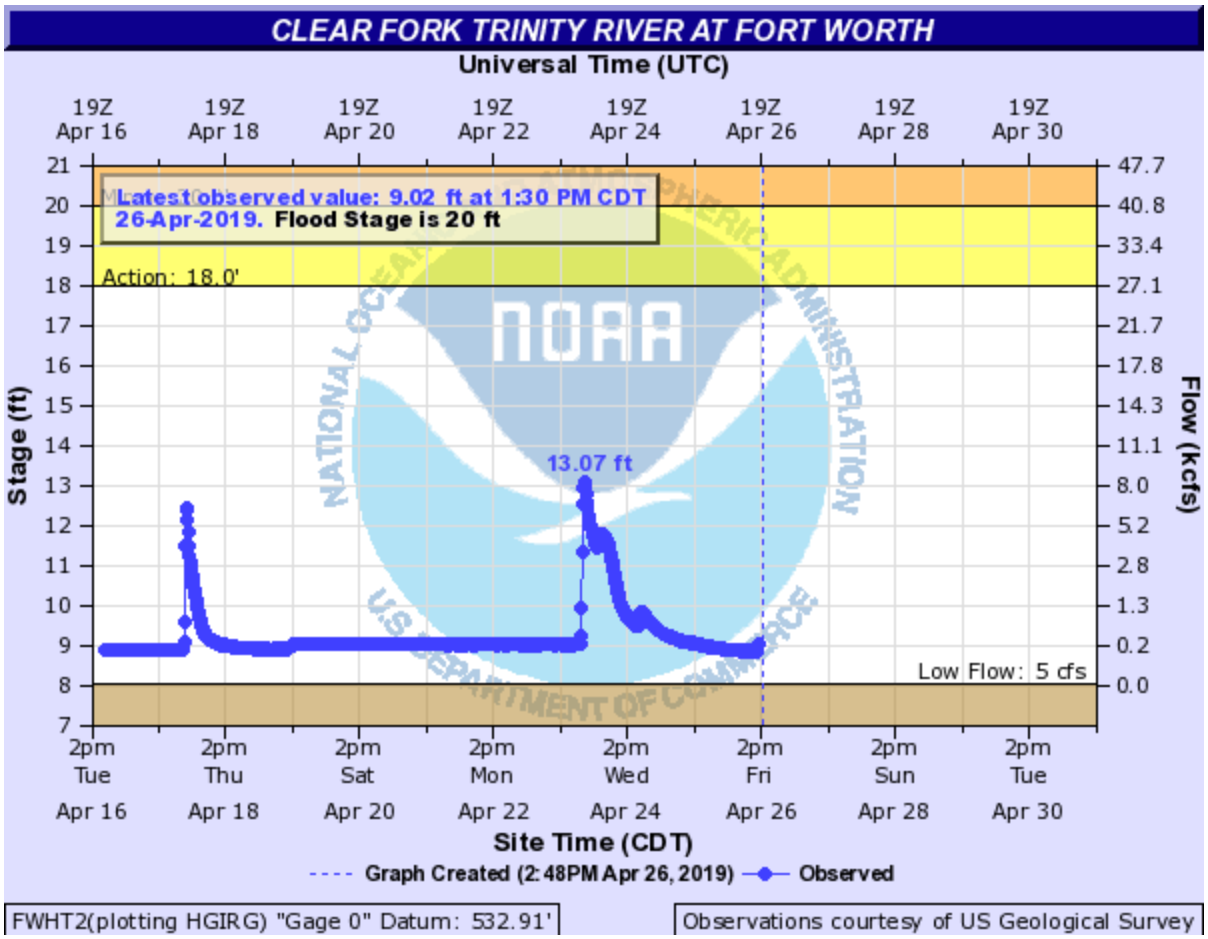

Figure 33 – Clear Fork Trinity River observations

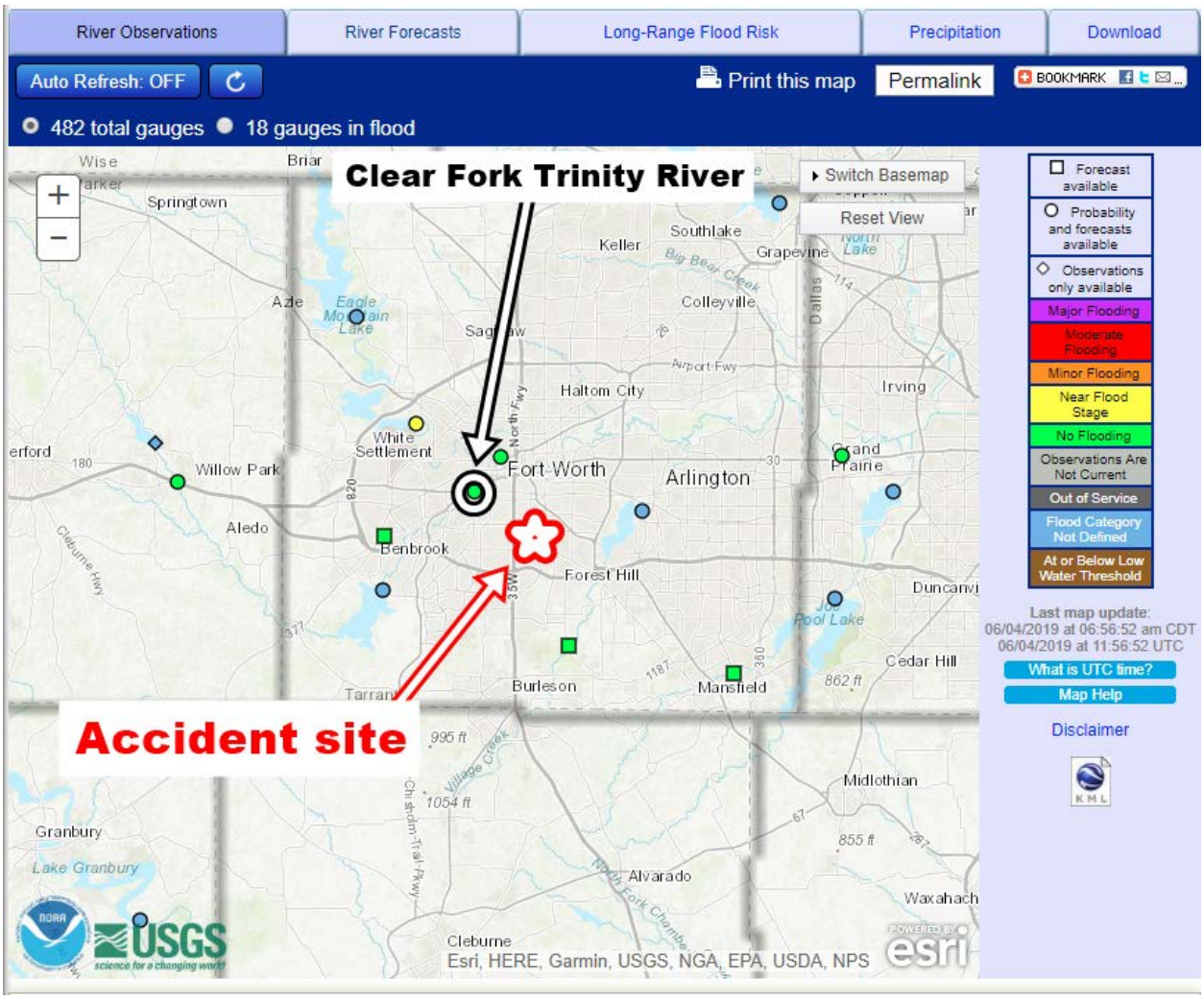

Figure 34 – Location of river observation points and the accident site

14.0 Crew Weather Information[43]

The accident train conductor recalled that when getting on the train at about 0000 CDT (April 24) it was raining with a little bit of lightning and thunder and that it was a "good downpour." The conductor indicated that the paperwork he received between 2200 and 2400 CDT on April 23 for the accident route did not mention anything about weather conditions. The conductor stated he did receive a Flash Flood Warning for the accident region from company dispatch at 0336 CDT, approximately 3 hours after the accident time. That Flash Flood Warning had been issued by the weather provider for Union Pacific (AccuWeather) at 0334 CDT.

The accident train engineer recalled that it had been raining all day on April 23 and that after receiving paperwork, between 2200 and 2400 CDT on April 23, that it was raining hard. He reviewed the paperwork and bulletins with the conductor before departing and there was not anything weather related in the paperwork. He recalled receiving a flash flood warning at 0336 CDT, after the derailment time.

[43] For more information please see the interviews located in the docket of this investigation.

The dispatcher for the accident train recalled no weather issues popping up or notifications before the accident time on the internal Union Pacific dispatcher computer software system. He did not recall discussing any weather during the shift turnover when he came into work around 2215 CDT on April 23. When he received a Flash Flood Warning, his responsibility was to tell every train in the area and issue any appropriate restrictions. The area of the accident had not been marked by Union Pacific as a critical area for flash flooding. He recalled about a week before the accident, Echo Lake overfilled and a train going through that area reported the water up to the rails.

15.0 Company Weather Policy and Alerts

During the day of the accident a Flash Flood Warning was received by Union Pacific from their weather provider (AccuWeather[44]) for the accident site with the Flash Flood Warning issued at 0334 CDT and valid through 0730 CDT (attachment 6). Additional wind warnings were valid for the accident site before the accident time (attachment 6).

The accident location had produced flooding conditions in the week leading up to the accident. Flooding had been observed at the accident location on April 18, 2019, at 0315 CDT with Union Pacific notifications and advisement being tracked. A track inspector was dispatched and the "all clear" was given at 0555 CDT on April 18, 2019 (attachment 7).

Union Pacific weather alert notification, dispatch procedures, and weather alert criteria valid at the accident time are contained in attachments 8, 9, and 10.

On August 29, 2019, the NTSB investigative team met with personnel from Union Pacific (attachment 11). During these meetings, Union Pacific personnel stated they had made changes to the rule (rule 6.21) regarding flash flooding and that prior to the accident time there was the potential for crews not having a clear understanding of how to proceed once a weather warning from AccuWeather was received. In addition, Union Pacific personnel stated that they were developing an in-house flash flooding washout model that had the potential to be more adaptive and learning. More information regarding this model was requested. Union Pacific personnel stated that they receive flash flooding and other weather warning information directly from AccuWeather and that Union Pacific had no input on changing the flash flooding and/or weather threshold criteria. Union Pacific's Chief Safety Officer and Senior Operating Practices Director stated that Flash Flood Warnings are seen quite routinely, on the order of 3,000 times per year, and so a bit of "cry-wolf" syndrome has been noted by company personnel. For more information please see attachment 11.

[44] https://www.accuweather.com/

In correspondence with AccuWeather, further clarification was requested of Alert Criteria determination for Union Pacific and other weather warning criteria monitoring and that information is provided in attachment 12. In the correspondence, AccuWeather stated that the Weather Alert Criteria is requested by Union Pacific and the weather criteria have been determined and in place given the partnership between Union Pacific and AccuWeather. The Weather Alert Criteria can be adjusted and would begin with Union Pacific coming to AccuWeather and requesting an adjustment in the Weather Alert Criteria, with further steps in the process described in attachment 12. For further information on AccuWeather processes for flash flood monitoring, the differences in flash flood and mainstream flood warnings, and how specific river levels are determined please see attachment 12.

16.0 Astronomical Data

The astronomical data obtained from the United States Naval Observatory for the accident site on April 24, 2019, indicated the following:

SUN	
Accident time	**0033 CDT**[45]
Begin civil twilight	0624 CDT
Sunrise	0650 CDT
Sun transit	1327 CDT
Sunset	2006 CDT
End civil twilight	2031 CDT

MOON	
Accident time	**0033 CDT**[46]
Moonrise	0037 CDT
Moon transit	0548 CDT
Moonset	1057 CDT

The phase of the Moon was Waning Gibbous with 71% of the Moon's visible disk illuminated.

E. LIST OF ATTACHMENTS

Attachment 1 – 24 hour or daily summary of weather conditions at KFTW for the month of April 2019

[45] Inserted accident time for reference and context.
[46] Inserted accident time for reference and context.

Attachment 2 – Animation of GOES-16 infrared imagery from 2106 CDT April 23 to 0256 CDT on April 24

Attachment 3 – Animation of KFWS WSR-88D base reflectivity images for the 0.5° elevation scans between 2300 CDT on April 23 and 0100 CDT on April 24

Attachment 4 – NOAA HYSPLIT Model results

Attachment 5 – Google Earth Data from NOAA HYSPLIT Model results

Attachment 6 – Weather alerts received by Union Pacific from Accuweather for the accident site between March 23, 2019 and April 24, 2019

Attachment 7 – Previous track flooding notification on April 18, 2019

Attachment 8 – Union Pacific weather alert notification document

Attachment 9 – Union Pacific dispatcher notification procedure document

Attachment 10 – Union Pacific weather alert criteria document

Attachment 11 – Record of Conversation with Union Pacific from August 29, 2019

Attachment 12 – AccuWeather information

Submitted by:

_____

Paul Suffern
Senior Meteorologist

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