Journal of the National Academy of Forensic Engineers®

NATIONAL ACADEMY OF FORENSIC ENGINEERS

http://www.nafe.org

ISSN: 2379-3252

DOI: 10.51501/jotnafe.v42i1

Vol. 42 No. 1 June 2025

Assessing Weather Event Damage in Forensic Engineering: Data Sources and Challenges

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Abstract

Forensic engineering evaluations often involve assessing damage from weather events such as thunderstorms, tornadoes, and hurricanes. A crucial aspect of these evaluations is verifying whether the reported weather event occurred on or around the specified date and determining relevant meteorological parameters from the available historical data. Two primary sources of historical meteorological data are the National Oceanic and Atmospheric Administration (NOAA) National Weather Service's Storm Prediction Center Local Storm Reports (SPC-LSR) and the National Centers for Environmental Information Storm Events Database (NCEI-SED). These databases rely on reports from various sources and may sometimes provide imprecise or inconsistent data. Therefore, forensic engineers should not rely solely on these sources but instead use them in conjunction with data or observations from multiple other sources.

Keywords

Hail, tornado, forensic engineering, forensic meteorology, weather, weather event, damage assessment, meteorological data, NOAA, wind, NCEI, NCEI-SED, SPC-LSR, NWS

Introduction

Forensic engineering evaluations often involve assessing conditions attributed to thunderstorms, tornadoes, hurricanes, winter storms, or other weather phenomena. While field work can provide information such as spatter marks (**Figure 1**), forensic engineering evaluations require further information to determine the date or period of occurrence for identified meteorological events and to establish meteorological conditions such as size, fall directionality, and duration for hail events, directionality and duration for wind events, and potentially other parameters related to other identified meteorological events.

This analysis commonly begins with the review of online meteorological databases. It is necessary for the forensic engineer to understand the sources of the referenced data and the purpose of the respective databases. While information from online databases can provide information to assist with a forensic engineering evaluation, online databases may not provide sufficient information to establish, refute, or otherwise understand historical meteorological events. Hence, it is often necessary to include forensic meteorologists as part of the evaluation of historical meteorological events.

Common Meteorological Databases

Historic meteorological data can be obtained from numerous weather data sources. Two of the most commonly used data sources in forensic engineering include:

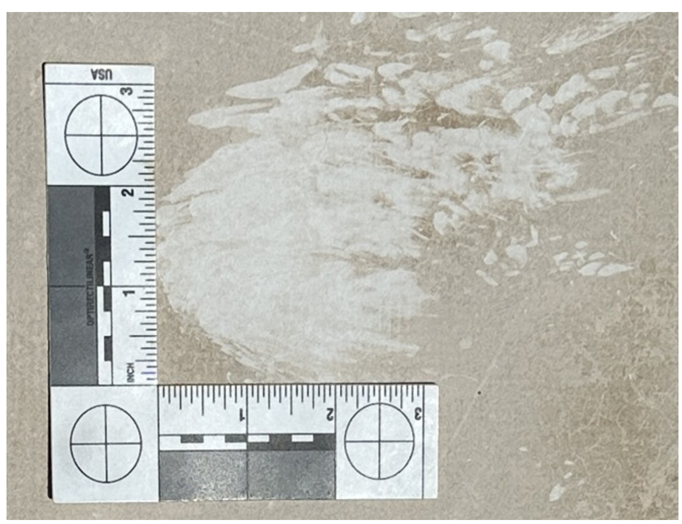

Figure 1
View of a hail spatter mark, Dallas, Texas (spring 2023).

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the databases maintained by National Oceanographic Atmospheric Administration's (NOAA) National Weather Service (NWS); the Storm Prediction Center Local Storm Reports (SPC-LSR)[1]; and the National Centers for Environmental Information Storm Events Database (NCEI-SED)[2].

The Storm Prediction Center Frequently Asked Questions (FAQ) page states[3]:

> *"The listings on the SPC Storm Reports page are automatically collected from thunderstorm-related local storm reports (LSRs) sent out by the local NWS offices. If there was no LSR for an event, or it arrived more than 10 days after the event, the report won't show up here. Our storm reports list is preliminary and likely does not contain all severe weather reports for any particular event. Storm surveys may be needed to confirm tornadoes, EF scale, find out if damage really was from a tornado or other thunderstorm winds, etc."*

According to the NCEI-SED Storm Data Frequently Asked Questions (FAQ) page[4]:

> *"NCEI receives Storm Data from the National Weather Service. The National Weather Service receives their information from a variety of sources, which include but are not limited to: county, state and federal emergency management officials, local law enforcement officials, skywarn spotters, NWS damage surveys, newspaper clipping services, the insurance industry and the general public, among others."*

Forensic engineers should note that the data in both databases are dependent upon receiving storm reports from human observations. Therefore, they may not receive data for all storm events. The lack of a report in either of these databases may reflect that a report was not received, but may not indicate that an event did not occur.

Purpose and Limitations of NWS Reports

When working with any data set, it is important to understand the original purpose or context for why the data was gathered. While many data sources can be used by forensic engineers, they may not have been originally created to specifically support this purpose. Inherently, this will impose limitations in how the data can be applied to support ancillary uses, such as those involving forensic engineering analyses. This holds true for the SPC-LSR and NCEI-SED databases. They were created for the National Weather Service's purposes (and to support research), and do not directly support the needs of forensic engineering or forensic meteorology evaluations.

> *"The Storm Events Database contains the records used to create the official NOAA Storm Data publication, documenting:*
>
> *1. The occurrence of storms and other significant weather phenomena having sufficient intensity to cause loss of life, injuries, significant property damage, and/or disruption to commerce;*
>
> *2. Rare, unusual, weather phenomena that generate media attention, such as snow flurries in South Florida or the San Diego coastal area; and*
>
> *3. Other significant meteorological events, such as record maximum or minimum temperatures or precipitation that occur in connection with another event."*[5]

Given such a broad application in what and how the data is collected and used, NOAA offers several disclaimers and limitations.

From the "Storm Data FAQ Page," NOAA provides the following disclaimer[6]:

> *"Some information appearing in Storm Data may be provided by or gathered from sources outside the National Weather Service (NWS), such as the media, law enforcement and/or other government agencies, private companies, individuals, etc. An effort is made to use the best available information but because of time and resource constraints, information from these sources may be unverified by the NWS.* ***Therefore, when using information from Storm Data, customers should be cautious as the NWS does not guarantee the accuracy or validity of the information.*** *Further, when it is apparent information appearing in Storm Data originated from a source outside the NWS (frequently credit is provided), Storm Data customers requiring additional information should contact that source directly."*

Forensic engineers should pay particular attention to the bolded sentence shown in the previous quote. The SPC-LSR and NCEI-SED databases are created for the National Weather Services and do not necessarily correspond to the needs of forensic engineering or forensic meteorology evaluations. As such, it is advisable for SPC-LSR and NCEI-SED databases to be used as part of a broader forensic assessment toolset — not as a stand-alone data source in an evaluation.

Known Concerns with Reported Storm Dates

Considering the limitations of the NWS mentioned earlier, the following sections highlight the various challenges associated with using and relying on the data in the SPC-LSR and NCEI-SED databases.

A. Day/Time Referencing

Weather data can be reported using different time zone references. For instance, some data sets use the local date and time for the location where the event occurred, while others use Coordinated Universal Time (UTC) for their reporting.

The SPC-LSR database is one such database that records data in UTC. Additionally, the SPC-LSR database does not follow the standard midnight to midnight day. Instead, the SPC states:

> *"The Storm Reports page is organized based on reports received from 1200 UTC to 1159 UTC the next day. For example, storm report page for 20150430 covers reports from 20150430 at 1200 UTC to 20150501 at 1159 UTC."*

Because of the time and date differences contained within this database, particular care must be taken when evaluating its contents relative to local time and the time formatting of other data sources.

When reviewing forensic meteorology data, it's crucial to check the time references used to ensure events are viewed in the correct context. It may be necessary to adjust the recorded data to align with a specific time zone.

B. Accuracies in Storm Event Reporting

As weather-related claims commonly rely on human reporting, the reported date of occurrence may not reflect the actual date of the storm event. For example, this can happen with events that occur in the evening and then are not reported until the following day — or when a storm event occurs after the close of normal business hours on Friday and is not reported until the following Monday. In some cases, large-scale damaging events (especially those associated with large electrical power outages such as hurricanes, ice storms, and broad-range thunderstorms/damaging winds) have been reported days to weeks after the specific event.

Given these common types of delays in reporting, a forensic engineer must be cautious with this data and verify that reporting times and actual event times are clearly understood. This can be done by verifying the date of any storm-related event with the property owner, owner's representative, or others who have any direct knowledge of the occurrence.

Caution should be exercised when considering an identified date or period of occurrence, as a nearby memorable storm event date may be inaccurately referenced by involved parties. Therefore, it is recommended that the engineer engage with the property owner, witnesses, or other involved parties to develop an understanding of the reported meteorological conditions. This will help provide further context and improve the accuracy of the timing and the potential conditions associated with the weather event.

For some events, such as wind and hail associated with a thunderstorm, the specific date(s) of the occurrence may be ambiguous. In these situations, individuals may report the date and time using generalities such as "late April," "the big storm earlier this year," or other similar sentiments. When investigating circumstances where the storm dates are ambiguous, the forensic engineer should review weather data beyond the reported date of occurrence.

Extending the data review period at least 30 days before and after the reported date of occurrence will reduce the possibility of missing a potential wind or hail event that could have contributed to the conditions observed as part of the assessment. In some cases, it may be necessary to review meteorological data over longer periods of time (e.g., months or years), depending on the specific situation.

C. Reliability of Storm Reporting

The challenge when relying on the NWS for forensic purposes is that it lacks consistent, reliable event reporting. In particular, there may be a lack of storm reporting in non-residential areas, areas of low population density (rural areas), or during hours of darkness. In some cases, the authors have observed that storm conditions beyond the leading edge of a storm event have not been documented or recorded in the NWS systems. Therefore, the forensic engineer should take caution as the storm events may not be fully recorded or validated depending on the situation and location.

Scott Blair et al in their paper, "High-Resolution Hail Observations: Implications for NWS Warning Operations," observes[7]:

> *"Unfortunately, there remains a high degree of uncertainty that the hail reports obtained during NWS warning verification efforts are representative of the true hailfall of a given storm. Nocturnal severe weather may lead to a reduction in reporting efficiency due to limited visibility for identifying large stones, and the majority of the public may be asleep (Ashley et al. 2008). Regardless of the time of day, the number of hail reports may fluctuate based on a storm's path over rural versus urban areas (Dobur 2005; Cecil 2009). Even with storms over densely populated regions, large hailstones may go unidentified or unreported (Blair and Leighton 2012). Available NWS resources dedicated to seeking out ground-truth information may vary from event to event, and also between differing NWS offices' emphasis on aggressive report collection verification (Doswell et al. 2005). Human reporting error in the form of exaggeration or underestimation of hail sizes, along with the potential for incorrect locations and times, can introduce further uncertainty in the quality and representativeness of these hail reports (Amburn and Wolf 1997; Baumgardt 2011)."*

This paper continues to argue that an undetermined amount of uncertainty must therefore be accepted in order to use the hail data in support of post-event warning verification, training, research and development when conducting risk assessments. It also cites that verification of NWS warnings in which they had forecasted a maximum hail size had been largely "unexplored."

D. Single-Point or Peak Point Reporting of Meteorological Data

Data reported in the SPC-LSR and NCEI-SED provide single points of data relative to the largest reported hail or peak wind gusts. This is known as "single-point" or "peak-point" data. Due to its specific nature, this data lacks additional information that could be crucial for identifying other environmental conditions that may have contributed to or caused the damage. Such ancillary information is necessary to provide overall context to the data.

For example, when conducting:

- Hail evaluations — the duration of the hail event as well as the velocity and directionality of winds associated with the thunderstorm are not included in the databases.

- Wind-related damage evaluations — single-point reports of wind events, such as those associated with a thunderstorm, do not indicate the directionality of the winds (or if the winds occurred over extended periods of time). Note: It is important to remember that fatigue failures due to prolonged lower velocity wind events can be as damaging as wind events that exceed initial design velocities over a shorter duration of time.

Reported Data Limitations: Case Studies

The following four case studies demonstrate limitations related to the use of SPC-LSR and NCEI-SED data. The first example relates to variations in data between different NWS sources and the start/stop points indicated in the NCEI SED. The second and third case studies relate to variations among the indicated coordinates (assumed for a locale or rounded off) and stated locations within the report text.

A. Software Used to Support the Analyses

The software used in the following analyses includes ArcGIS Pro mapping software and for case study 4, GR2-Analyst (Gibson Ridge Level II Analyst) storm analysis software.

ArcGIS Pro is a mapping software that can be used to perform spatial and data analyses for scientific purposes. In the following examples, ArcGIS Pro was used to perform a spatial analysis of storm reports in relation to areas that experienced thunderstorms capable of producing storm damage. Storm reports and tornado damage survey tracks from the NWS databases were loaded into ArcGIS Pro and compared spatially to areas of reported storm damage.

GR2-Analyst is an advanced radar analytical application that is often used for post-storm analysis and reconstruction. GR2-Analyst allows analysis of traditional and dual-polarization radar data, cross-sectional 3D storm analysis, and high-resolution derived radar products. In the following case studies, GR2-Analyst was used to reconstruct thunderstorms by analyzing radar data to obtain information on storm characteristics for the purpose of diagnosing hail or a tornado within a storm. The software was also used to create 3D-storm images in order to further diagnose the presence of hail, a tornado, or other forms of severe weather within a thunderstorm.

B. Case Study 1: Moore, Oklahoma, Tornado (May 20, 2013)

On the afternoon of May 20, 2013, a large and powerful tornado formed in McLain County, Oklahoma. The tornado continued northeast, entering Cleveland County, Oklahoma, and the City of Moore, finally ending at Lake Stanley Draper just south of Oklahoma City. **Figure 2** highlights the NCEI-SED straight line path for this event. It shows the beginning ("B") and ending ("E") points of the tornado with a straight line connecting the two ends. Note that NCEI-SED does provide a caution on the map citing that the "actual tornado path may differ from the straight line"[8].

Figure 3 is the tornado path obtained from the NWS's "The Tornado Outbreak of May 20, 2013" website[9]. The dashed red line represents a linear path between the reported start and stop points of the tornado as indicated by NCEI-SED in **Figure 2**. However, the tornado contour lines from NWS show that it is evident the tornado damage path lies predominantly north of the linear, red, NCEI-SED line. **Figure 4** includes the portion of the tornado path in McLain County, Oklahoma.

While obvious in this example, it is a reminder that forensic engineers should take caution when reviewing and relying on this type of information. Any representation of a natural event by a straight line or by standard geometric shapes (e.g., circles, squares, triangles, etc.) is likely used as a rough estimation to demonstrate a trend. The engineer is advised when using such data to only rely on it as an approximation of where an event may have happened.

Forensic engineers also need to be aware that NCEI-SED data is reported separately by county. NCEI-SED lists data under the headings of "Begin Location," "End Location," "Begin Lat/Long," and "End Lat/Long" — and those points may be the edge of a county line, not necessarily the actual start and end points of the tornado's path. Therefore, when a tornado crosses county lines, there will be reports for each county. Under the "Storm Data FAQ" Page subheading "How are Tornadoes Counted," it states:

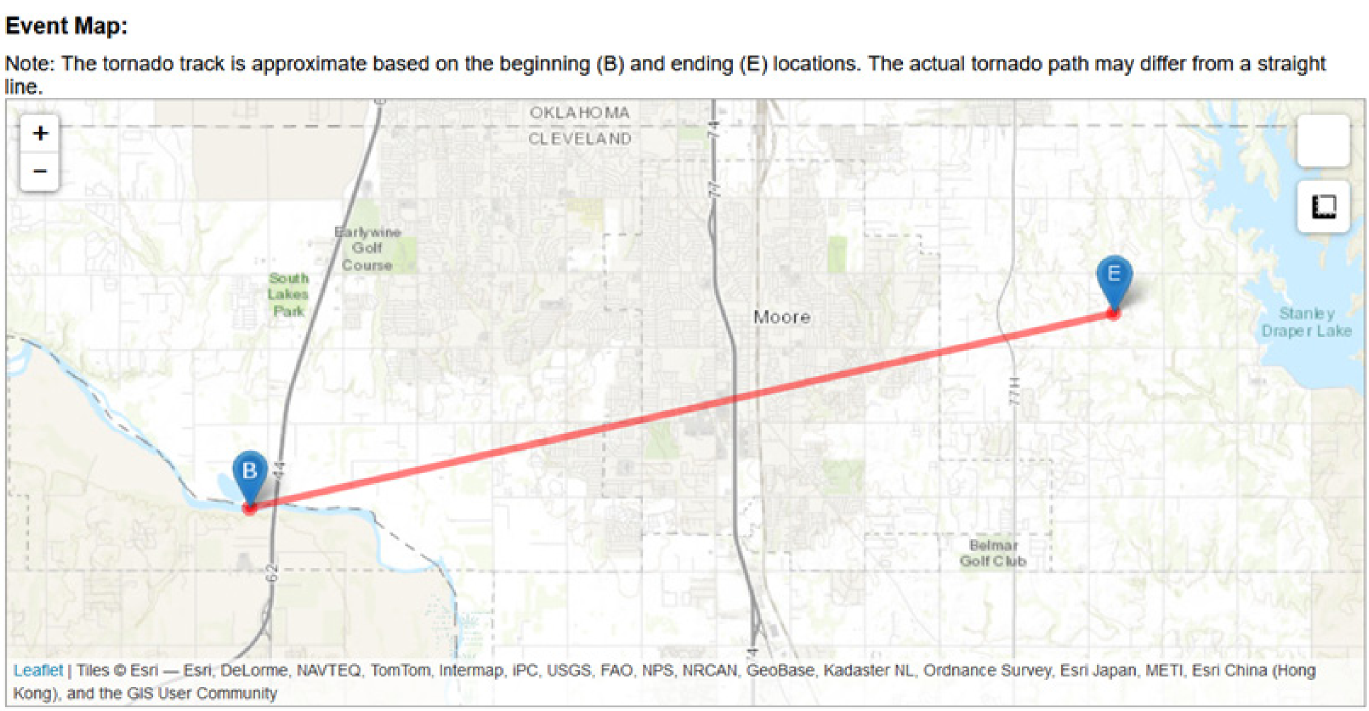


Figure 2
NCEI-SED path image for the Moore Tornado from its event details web page. The red line represents a linear interpretation of the tornado path between the NCEI-SED beginning and end points.

Figure 3
NCEI-SED path image (red dashed line) overlayed on the NWS storm path. (Image Source: NWS storm path from National Weather Service, 2013). "The Tornado Outbreak of May 20, 2013" [ESRI Map], https://www.weather.gov/oun/events-20130520).

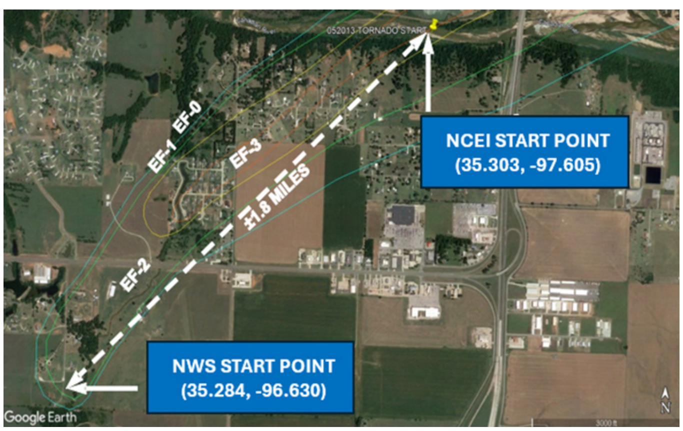


Figure 4
Moore Tornado: Initial tornado touchdown comparison points using Google Earth Pro®. There is an approximate distance discrepancy of 1.8 miles between the two points.

"Tornadoes may contain multiple segments. A tornado that crosses a county line or state line is considered a separate segment. Also, a tornado that lifts off the ground for less than 4 minutes or 2 miles is considered a separate tornado segment. If the tornado lifts off the ground for greater than 4 minutes or 2 miles, it is considered a separate tornado. Tornadoes reported in Storm Data and the Storm Events Database are in segments."[10]

Additionally, National Weather Service Instruction 10-1605, paragraph 47.12.1, guides storm data preparers to enter tornadoes that cross county/parish lines as segments with one segment per county/parish, and not to segment a tornado within a county/parish[11].

The tornado data contained within the NCEI-SED can be used to provide a basic understanding of a tornado's path and the areas potentially impacted by the event. The determination of the conditions at the site will require further review of additional available meteorological data sources and an examination of the on-site conditions noted at the specific assessment location.

C. Case Study 2: Norman, Oklahoma, Hailstorm (April 28, 2021)

On April 28, 2021, a hailstorm occurred in Norman, Oklahoma. This hail event was recorded as having produced hailstones of 3 inches or larger in diameter. During this storm event, an individual was reported as experiencing a head injury from hail at a restaurant located at "Robinson and I-35." The coordinates provided in the SPC-LSR were given to two decimal places[12] (**Figure 5**). When the coordinates were reviewed using three decimal places on Google Earth Pro® for the restaurant location and the SPC-LSR provided location, there is a .32-mile distance disparity. **Figure 5** cites the incident location by indicating

0155	100	4 S HELOTES	BEXAR	TX	2952 9869	(EWX)
0155	275	3 WNW NORMAN	CLEVELAND	OK	3523 9749	*** 1 INJ *** REPORTED HEAD INJURY AT THE BRAUMS AT ROBINSON AND I-35 FROM HAIL. (OUN)
0155	150	4 NW NORMAN	CLEVELAND	OK	3526 9750	(OUN)

Figure 5
April 28, 2021, SPC-LSR location (red circle) of reported head injury incident in Norman, Oklahoma.

the nearby cross streets; however, **Figure 6** demonstrates the difference between the actual location of the event and the truncated coordinates provided in the SPC-LSR report. This example offers another cautionary consideration when relying on SPC-LSR data for forensic purposes.

D. Case Study 3: Tulsa, Oklahoma, Hailstorm (April 4, 2017)

An April 4, 2017 hailstorm event provides another example of SPC-LSR issues related to the published coordinates for storm events. In this example, a hail event was reported in Tulsa, Oklahoma. **Figure 7** is a section of the SPC-LSR data obtained from the SPC-LSR for this event[13]. In this data set, there are two references to 1-inch hail at "61st and Memorial." However, notice that the coordinates for these two locations are different. The described location was between approximately 2.5 miles and 4.2 miles southeast of the indicated coordinates (**Figure 8**).

Figure 6
Google Earth Pro® image highlighting the coordinate differences of approximately .32 miles between SPC-LSR referenced locations.

This same SPC-LSR report included multiple listings using the same coordinates, but, again, the specific address locations deviated from these coordinates (**Figure 9**). In this case, the described locations varied from approximately 4.6 miles to the south to 4.2 miles to the southeast and 1.6 miles to the northeast from the coordinate location (**Figure 10**).

Under the "Storm Data FAQ" Page subheading "How are the latitude and longitudes determined?" it states[14]:

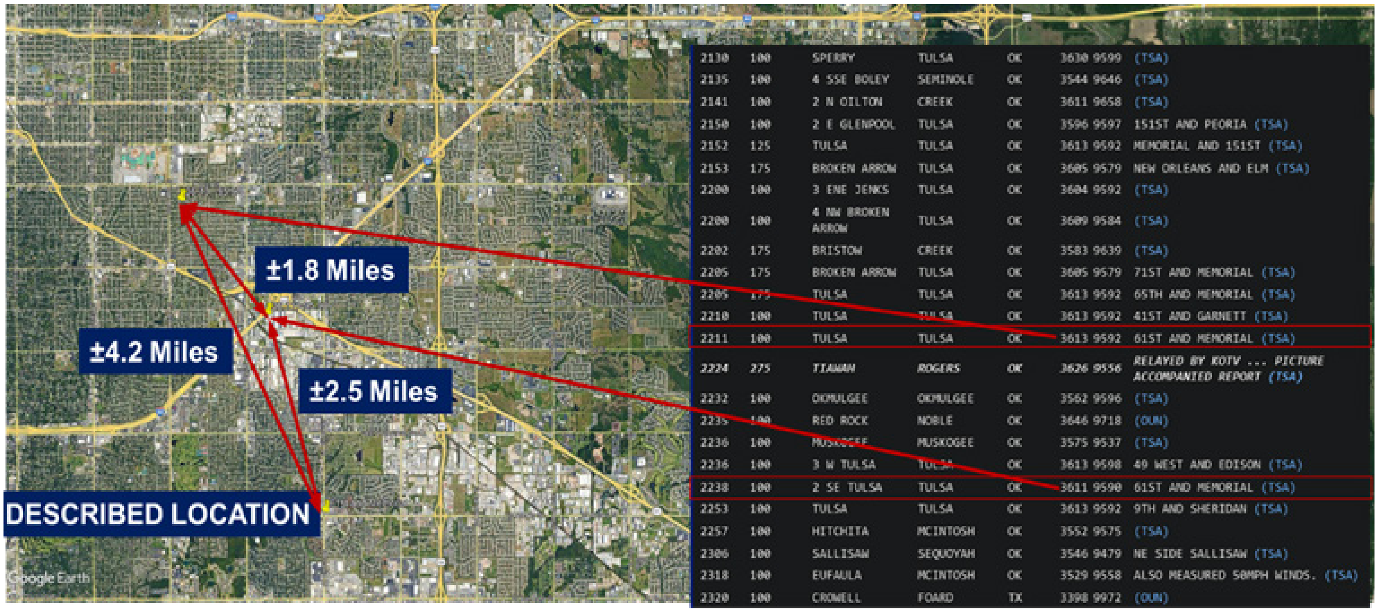
> *"Storm Data information is entered into the database in two ways:*
>
> *As a distance in miles and a direction on 16-point compass scale from a known location, usually a town or city. Example: 4.5 miles ESE Atlanta. The NWS uses a database of over 106,000 cities and towns including their latitudes and longitudes. Using an algorithm, the location 4.5 miles ESE of Atlanta can be derived from the known latitude and longitude of Atlanta. These latitude and longitude pairs are generated by the NWS and populated into the database. The latitude and longitude are in*

2202	175	BRISTOW	CREEK	OK	3583 9639	(TSA)
2205	175	BROKEN ARROW	TULSA	OK	3605 9579	71ST AND MEMORIAL (TSA)
2205	175	TULSA	TULSA	OK	3613 9592	65TH AND MEMORIAL (TSA)
2210	100	TULSA	TULSA	OK	3613 9592	41ST AND GARNETT (TSA)
2211	100	TULSA	TULSA	OK	3613 9592	61ST AND MEMORIAL (TSA)
2224	275	TIAWAH	ROGERS	OK	3626 9556	RELAYED BY KOTV... PICTURE ACCOMPANIED REPORT (TSA)
2232	100	[illegible]	[illegible]	[illegible]	3562 9596	(TSA)
2235	100	RED ROCK	NOBLE	OK	3646 9718	(OUN)
2236	100	MUSKOGEE	MUSKOGEE	OK	3575 9537	(TSA)
2236	100	3 W TULSA	TULSA	OK	36[illegible] 9598	49 WEST AND EDISON (TSA)
2238	100	2 SE TULSA	TULSA	OK	3611 9590	61ST AND MEMORIAL (TSA)

Different coordinates

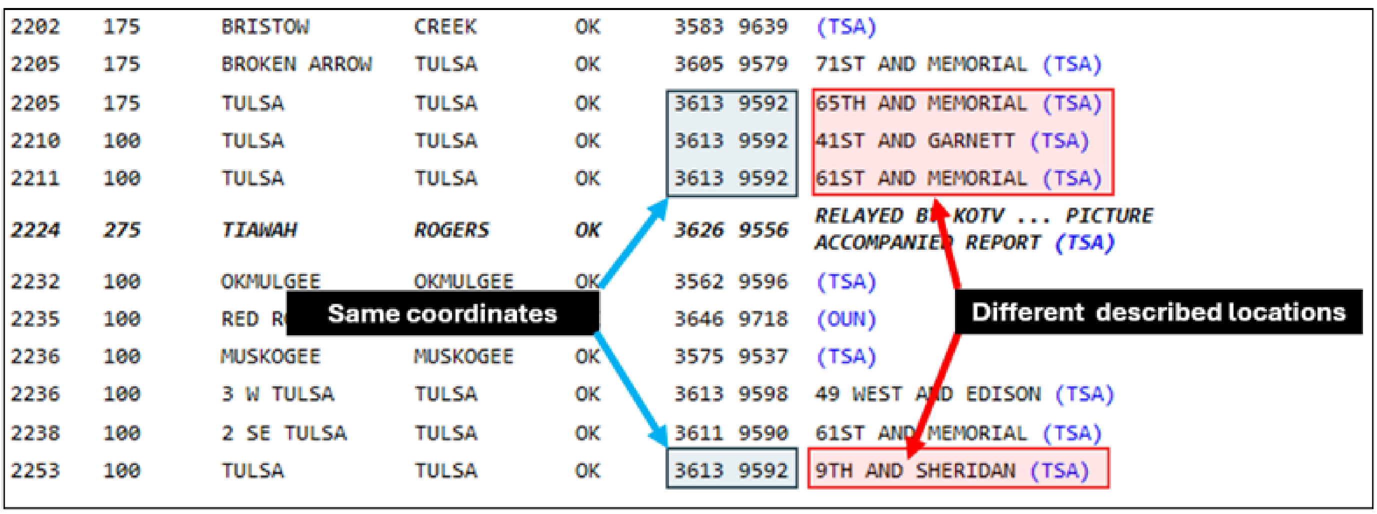
Same described location

Figure 7
SPC-LSR data for the April 4, 2017 hailstorm in Tulsa, Oklahoma.



2130	100	SPERRY	TULSA	OK	3630 9599	(TSA)
2135	100	4 SSE BOLEY	SEMINOLE	OK	3544 9646	(TSA)
2141	100	2 N OILTON	CREEK	OK	3611 9658	(TSA)
2150	100	2 E GLENPOOL	TULSA	OK	3596 9597	151ST AND PEORIA (TSA)
2152	125	TULSA	TULSA	OK	3613 9592	MEMORIAL AND 151ST (TSA)
2153	175	BROKEN ARROW	TULSA	OK	3605 9579	NEW ORLEANS AND ELM (TSA)
2200	100	3 ENE JENKS	TULSA	OK	3604 9592	(TSA)
2200	100	4 NW BROKEN ARROW	TULSA	OK	3609 9584	(TSA)
2202	175	BRISTOW	CREEK	OK	3583 9639	(TSA)
2205	175	BROKEN ARROW	TULSA	OK	3605 9579	71ST AND MEMORIAL (TSA)
2205	175	TULSA	TULSA	OK	3613 9592	65TH AND MEMORIAL (TSA)
2210	100	TULSA	TULSA	OK	3613 9592	41ST AND GARNETT (TSA)
2211	100	TULSA	TULSA	OK	3613 9592	61ST AND MEMORIAL (TSA)
2224	*275*	*TIAWAH*	*ROGERS*	*OK*	*3626 9556*	*RELAYED BY KOTV ... PICTURE ACCOMPANIED REPORT (TSA)*
2232	100	OKMULGEE	OKMULGEE	OK	3562 9596	(TSA)
2235	100	RED ROCK	NOBLE	OK	3646 9718	(OUN)
2236	100	MUSKOGEE	MUSKOGEE	OK	3575 9537	(TSA)
2236	100	3 W TULSA	TULSA	OK	3613 9598	49 WEST AND EDISON (TSA)
2238	100	2 SE TULSA	TULSA	OK	3611 9590	61ST AND MEMORIAL (TSA)
2253	100	TULSA	TULSA	OK	3613 9592	9TH AND SHERIDAN (TSA)
2257	100	HITCHITA	MCINTOSH	OK	3552 9575	(TSA)
2306	100	SALLISAW	SEQUOYAH	OK	3546 9479	NE SIDE SALLISAW (TSA)
2318	100	EUFAULA	MCINTOSH	OK	3529 9558	ALSO MEASURED 50MPH WINDS. (TSA)
2320	100	CROWELL	FOARD	TX	3398 9972	(OUN)

Figure 8
Hailstorm georeferenced data's location vs. the identified address location. (SPC-LSR data from **Fig. 7** shown on the right side in black.)



2202	175	BRISTOW	CREEK	OK	3583 9639	(TSA)
2205	175	BROKEN ARROW	TULSA	OK	3605 9579	71ST AND MEMORIAL (TSA)
2205	175	TULSA	TULSA	OK	3613 9592	65TH AND MEMORIAL (TSA)
2210	100	TULSA	TULSA	OK	3613 9592	41ST AND GARNETT (TSA)
2211	100	TULSA	TULSA	OK	3613 9592	61ST AND MEMORIAL (TSA)
2224	***275***	***TIAWAH***	***ROGERS***	***OK***	***3626 9556***	***RELAYED BY KOTV ... PICTURE ACCOMPANIED REPORT (TSA)***
2232	100	OKMULGEE	OKMULGEE	OK	3562 9596	(TSA)
2235	100	RED R			3646 9718	(OUN)
2236	100	MUSKOGEE	MUSKOGEE	OK	3575 9537	(TSA)
2236	100	3 W TULSA	TULSA	OK	3613 9598	49 WEST AND EDISON (TSA)
2238	100	2 SE TULSA	TULSA	OK	3611 9590	61ST AND MEMORIAL (TSA)
2253	100	TULSA	TULSA	OK	3613 9592	9TH AND SHERIDAN (TSA)

Figure 9
SPC-LSR data for Tulsa, Oklahoma April 4, 2017 event.

Figure 10
SPC-LSR Data for Tulsa, Oklahoma April 4, 2017 event highlighted on Google Earth Pro® generated map.

Decimal Degrees format.

Or

By entering the latitude and longitude directly. The range, azimuth and nearest city/town are calculated from the latitude.

Again, these discrepancies highlight the need to use caution with the data provided in the SPC-LSR. The coordinates indicated may reflect conditions relative to a known city reference point that may not represent the location of the weather report. When available, information identifying specific landmarks, cross street locations, or other identifying information should be used to confirm the indicated coordinates. These locations should also be reviewed or verified against other available meteorological data

Storm Reporting Reliability

This final case study demonstrates the limitation of the reporting underlying the storm report data created by the NWS and how using radar data can be used to supplement and validated conditions during a forensic analysis of an event.

A. Case Study: Southwestern Missouri, Hailstorm (May 4, 2020)

On May 4th, 2020, a major storm front hit southern Missouri, causing extensive damage. Storm damage reports from the NCEI-SED included overturned semitrailers and power outages. These reports were uploaded into ArcGIS for analysis. The analysis identified a large spatial and temporal gap between the storm reports of approximately 24.28 miles and 40 minutes. Due to the sporadic reporting in this rural area, sparse storm reports are common.

In this example, a location between the two hail reports was identified for further assessment. As shown in **Figure 11**, the sample location was approximately 11.25 miles southeast of the first storm report (1.75-inch hail) and approximately 13.09 miles northwest of another report (1.25-inch to 1.5-inch hail). Gaps in weather reports such as these have been used to indicate that no hail event could have occurred as a result of the storm, which caused the two closest hail reports. Further assessment of this temporal and geographic gap was assessed through a forensic meteorological review utilizing the review of radar and other weather data entered into GR2-Analyst and ArcGIS.

The hail core within the supercell was impressive at the location where 1.75-inch hail was recorded in the NCEI-SED. High reflectivity greater than 50 dBZ and

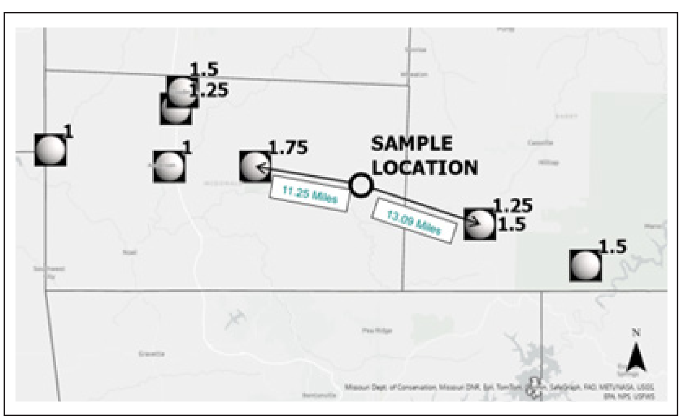


Figure 11
Hail reports on May 4, 2020 in southwestern Missouri.

lowered correlation coefficient (CC) values below 0.95 can be seen in conjunction with one another, indicating the presence of hail within the thunderstorm (**Figure 12**). CC values about or below 0.95 co-located with high reflectivity greater than or equal to 50 dBZ is an indication of radar detected objects of increasingly various size and shape — and a strong determinant of falling hail.

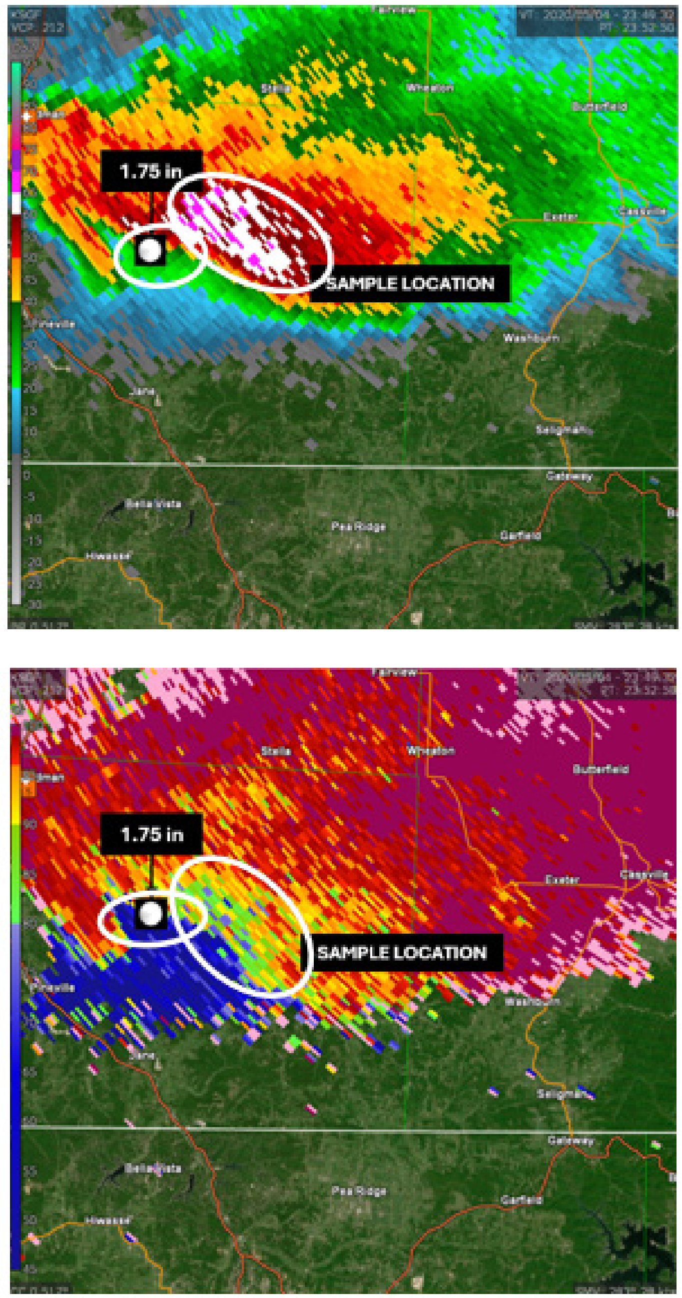


Figure 12
Reflectivity (top) and correlation coefficient (bottom) analysis of location where 1.75-inch diameter hail was reported. Regions with high reflectivity and lowered correlation coefficient typical of a hail signature are circled in white in this and following figures.
(6:52 p.m. CDT May 4, 2020)

As the storm approached the sample location, the supercell continued to cycle, minorly strengthening for a few scans and slightly weakening for a few scans. Regardless of the cyclical nature of the supercell, the high reflectivity and lowered CC that consisted of the thunderstorm's hail signature remained present within the storm as it moved through the spatial and temporal gap between storm reports. At this point, it was moving through a more rural portion of southwest Missouri, which is likely why there were no storm reports in this location. The hail within the storm began to move over the sample location at 6:54 p.m. (**Figure 13**).

At 6:56 p.m. CDT, the hail core continued its way over the subject location (**Figure 14**). A 3D scan was used to show the distribution of hail within the storm. As can be seen in **Figure 15**, a large hail core extending up to approximately 30,000 feet was present within this supercell as it continued to impact the subject location. These values of high reflectivity at the noted heights within the storm signify that the updraft is suspending hail within the

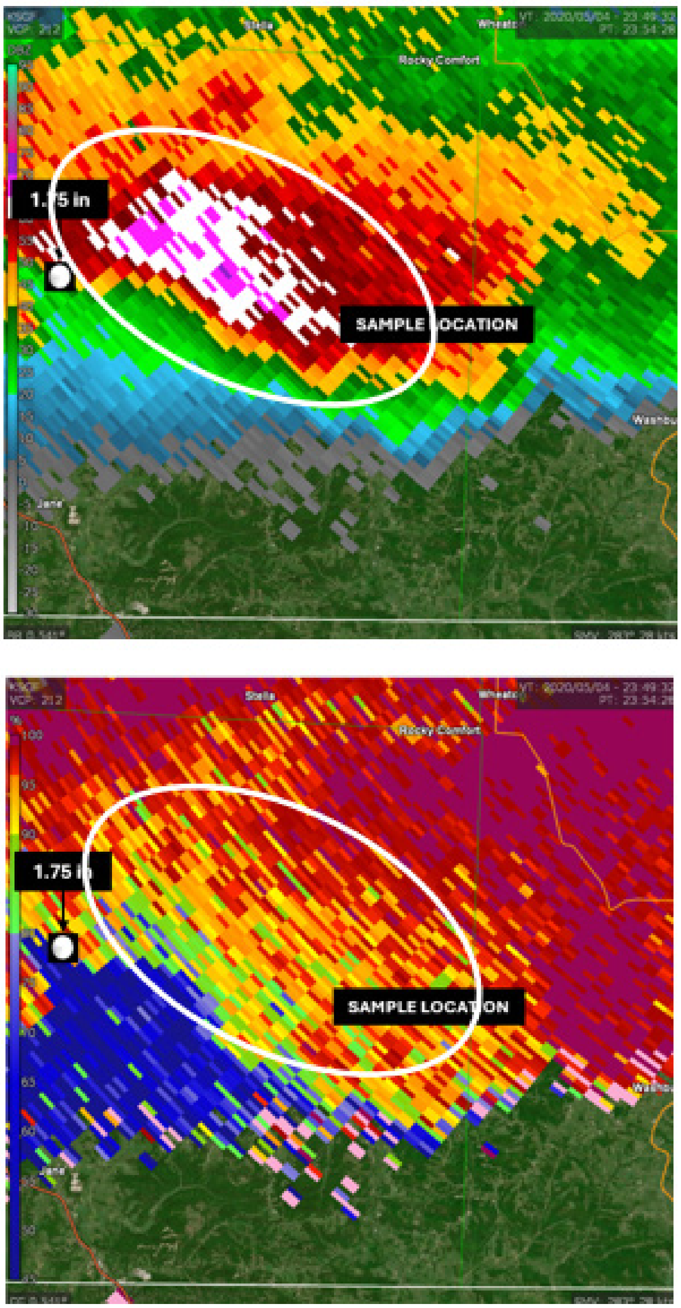


Figure 13
Reflectivity and correlation coefficient
of the sample location at 6:54 p.m. CDT.

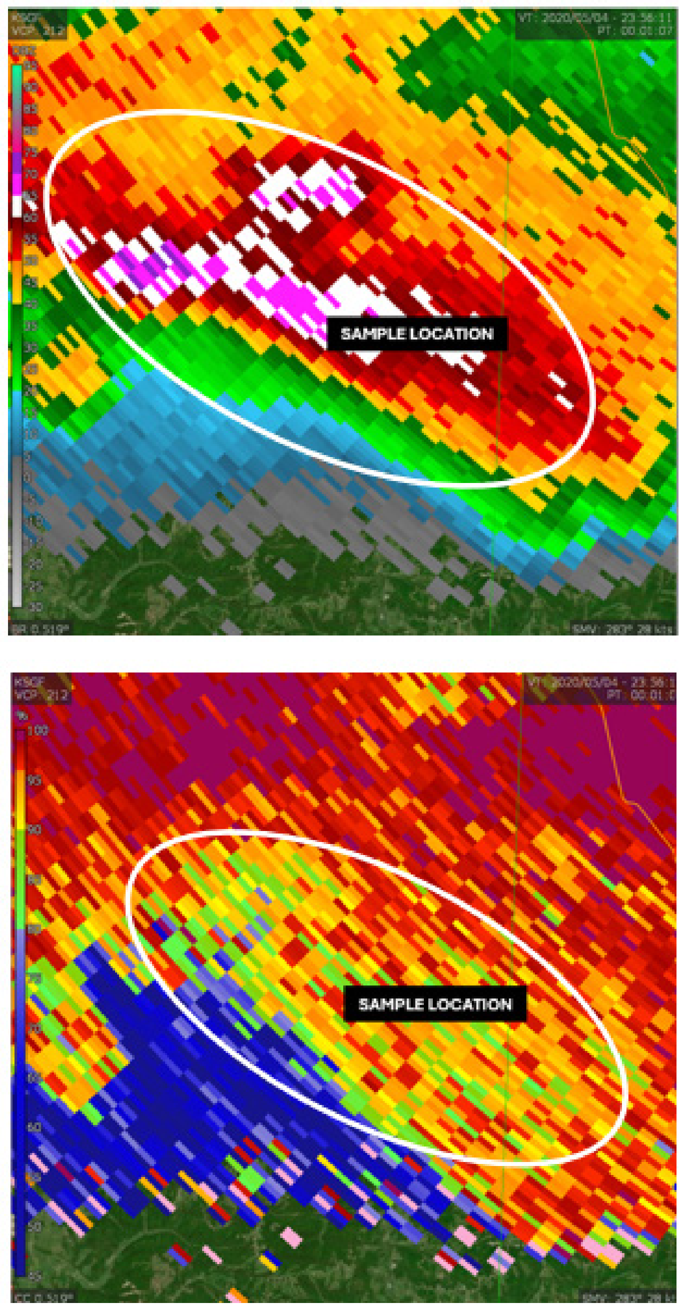


Figure 14
Reflectivity and correlation coefficient recordings at 6:56 p.m. CDT.

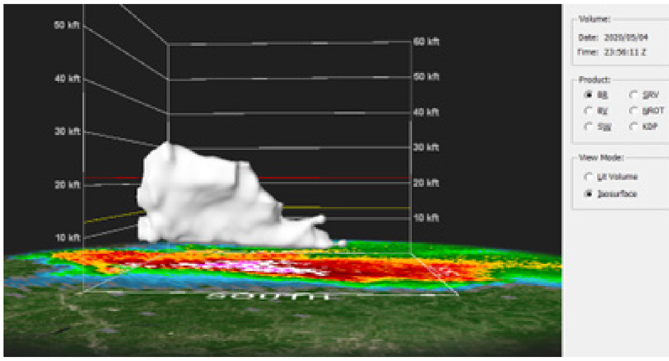


Figure 15
3D scan demonstrating hail core size and location
(plotted using 60-dBZ reflectivity values at 6:56 p.m. CDT).

part of the thunderstorm most favorable for hail growth, between the -10°C and -30°C temperature layers. In the 3D scan of the thunderstorm, GR2-Analyst plots the 0°C temperature level in yellow and -20°C temperature level in red for reference. Hail massive enough to no longer be suspended by the updraft then fell downward into the thunderstorm's downdraft and to the surface — where hail would be observable.

Hail was still impacting the subject location at 7:14 p.m. CDT but was finally beginning to depart the sample location. At this point, hail had been present at the subject location for approximately 20 minutes. The presence of hail was still indicated by high reflectivity and correlation coefficients (**Figure 16**).

As the storm began to move over the area of the secondary storm report, radar readings continued to indicate the hail potential within the storm (**Figure 17**). However, for this location, the hail indicators were less impressive than they were when they moved over the sample location — this is noted by a decreased reflectivity maximum and slightly less defined region of co-located lowered CC values.

This case study highlights the limitations of simply relying solely on storm reports. Since the general public voluntarily contributes storm reports to the NWS — and hazardous weather is often not reported within rural communities due to the lower number of housing and residents — information documenting actual conditions can be omitted or overlooked. In this case study, the meteorological interpretation of radar data allowed the tracking of this intense supercell and highlighted how large hail was probable along the majority of this 24-mile gap identified between storm reports.

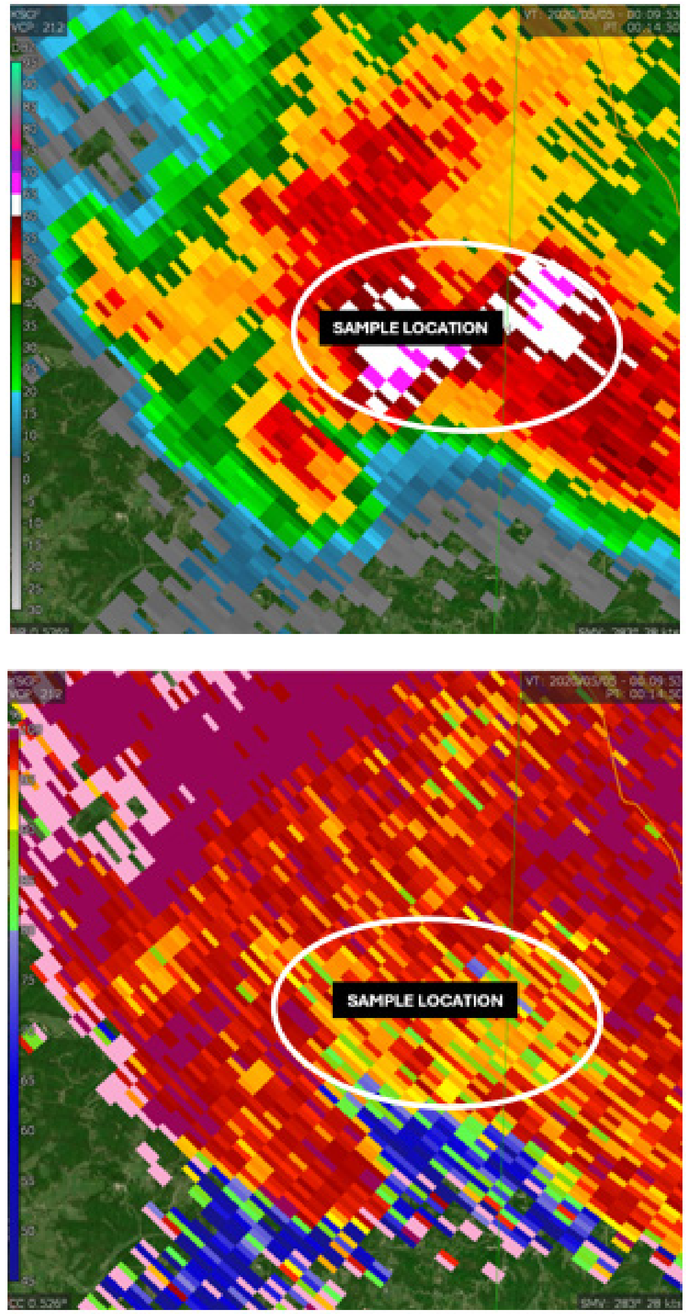


Figure 16
Reflectivity and correlation coefficient recordings
indicate hail at the sample location at 7:14 p.m. CDT.

Layering of Meteorological Data Sources

A concept commonly used in risk management is the "Swiss Cheese Model." In this approach, individual points of failure are represented as holes within individual cheese slices. The individual cheese slices represent processes or physical means of preventing a failure. By layering multiple cheese slices, the potential for a failure to occur (i.e., pass through all holes in a line) is reduced. From the perspective of reviewing meteorological data, the layers

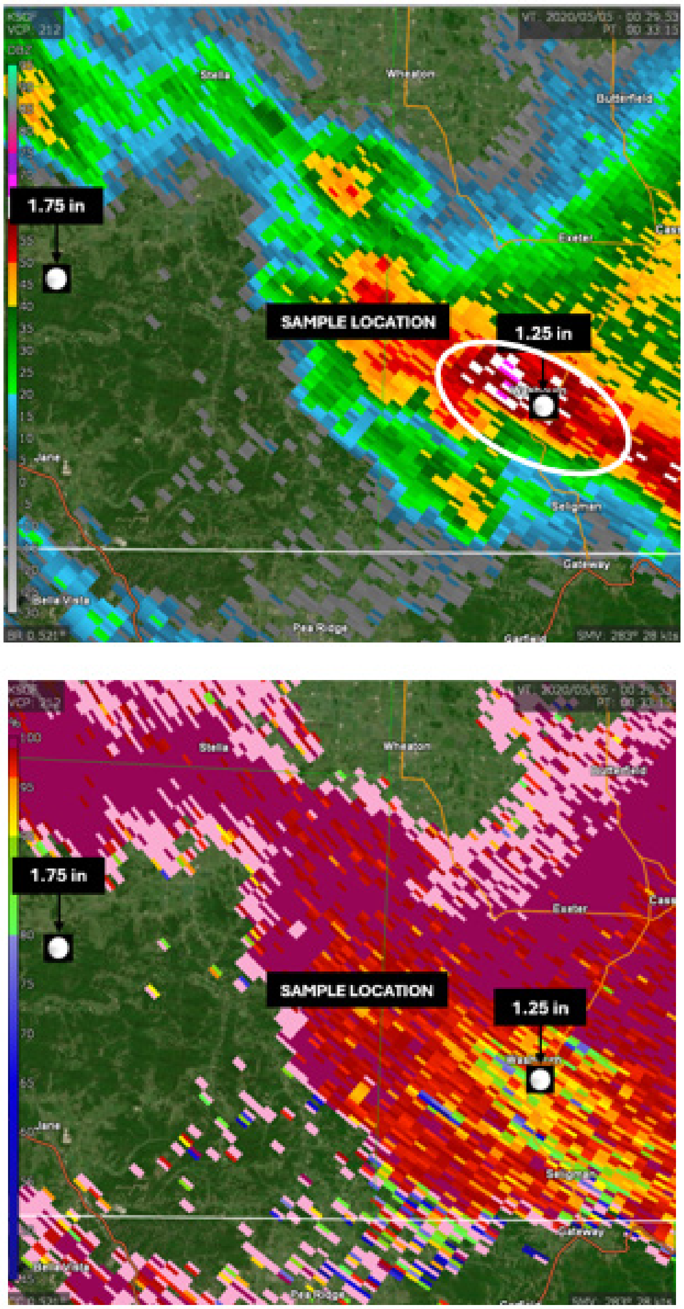


Figure 17
Reflectivity and correlation coefficient
reading for secondary location (7:33 p.m. CDT).

of cheese in the model represent the review of multiple data sets. A failure (a pass through all layers) would be a damaging storm event that was not identified for further assessment.

This analysis involves contributions from both forensic engineers and the forensic meteorologists. The engineer examines the conditions at the site, while the meteorologist reviews a wide array of weather data. This data can include broader weather discussions, NWS watches and warnings, radar information, and storm reports (such as those in the SPC-LSR, the NCEI-SED, and others). The goal is to provide enough layers of information to understand what was possible and probable in the atmosphere at the time of the reported weather event. By reviewing the full range of weather information available for a specific event or series of events, the forensic engineer can better understand the probable circumstances that led to the observed conditions.

Conclusions

Based on examples in this paper and previous references, the forensic engineering and forensic meteorology communities are well aware of the accuracy and reliability issues with the SPC-LSR and NCEI-SED. Whether through database limitations, differences between databases, insufficient data reporting due to location or time of day, single-point or peak-point reporting — or even through human error — flaws in these data sources remain a major concern that can lead to a weather event's occurrence being denied due to insufficient or missing data. Therefore, relying solely on SPC-LSR or NCEI-SED data is not sufficient for establishing or denying the occurrence of weather conditions in a forensic engineering investigation.

Forensic engineers and forensic meteorologists, when working together, offer a synergistic expertise. The collaboration between forensic engineers and forensic meteorologists provides a comprehensive approach to investigating weather-related damage that can overcome the limitations that each field would face alone.

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