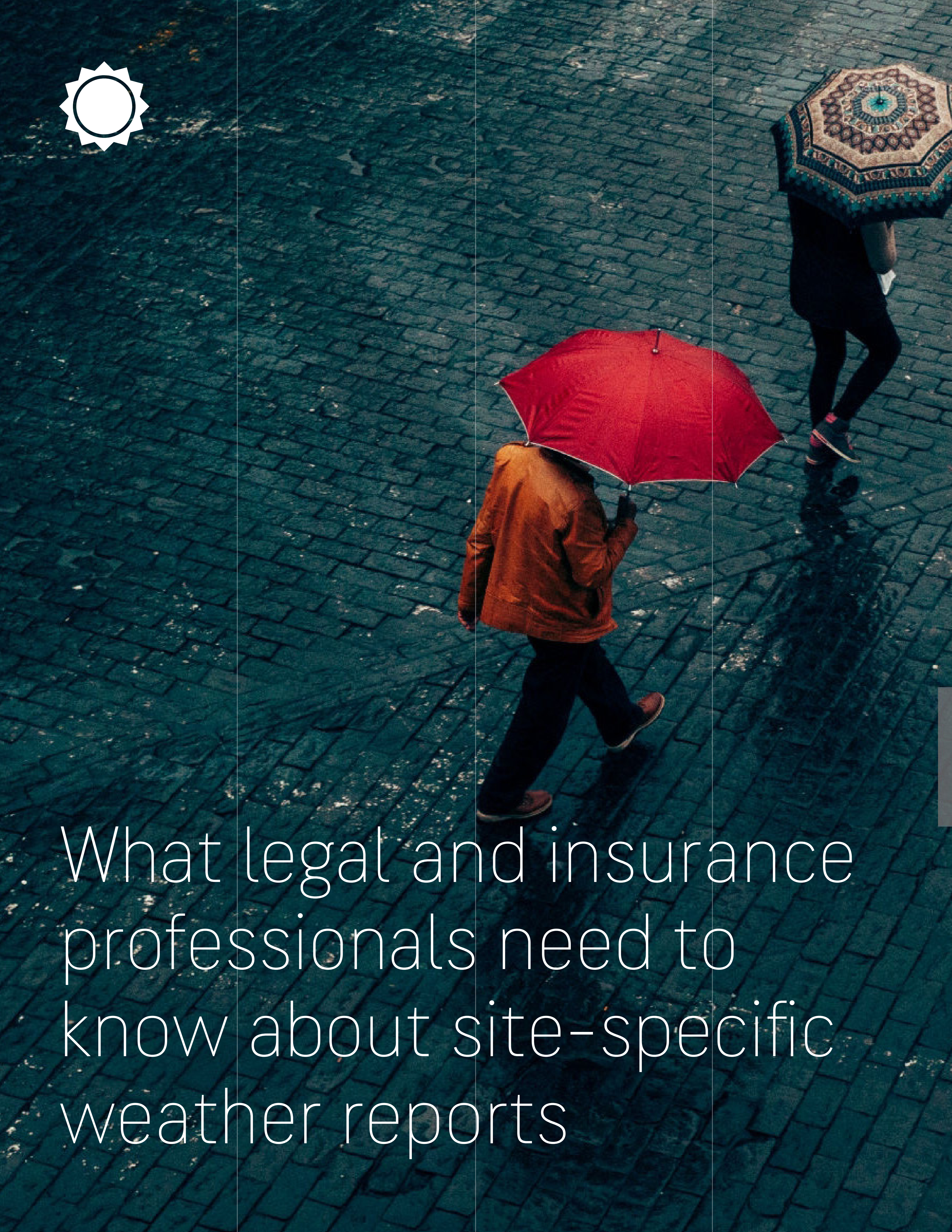

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After we review the data, our forensic meteorologists formulate an opinion based on peer-reviewed research, accepted methodology, and experience. On large cases, our forensic team can collaborate to formulate a consensus opinion.

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SAMPLE REPORT

Roof collapse report

Summary

We have investigated the weather conditions at 1521 Stevens Road, Pierre, South Dakota on October 25th, with particular attention to the depth and weight of accumulated snow and ice. The results of our investigation are presented in the following paragraphs.

Our research shows that in Pierre, daily high temperatures ranged from 63 to 72 degrees on October 21st, 22nd and 23rd. The ground was free of any snow and ice on the 23rd and the temperature of the soil was well above the freezing point (32 degrees Fahrenheit). A couple of rain showers moved through the area during the evening of the 23rd. The weather in Pierre turned much colder on October 24th as an early season Arctic air mass arrived from the north. At the same time, a slow-moving storm was intensifying over the southern Rockies.

During the predawn hours of the 24th, the sky over Pierre was cloudy and the temperature ranged from 35 to 39 degrees. The weather in Pierre remained cloudy at the start of the daylight hours and steady snow began to fall between 9:00 AM and 10:00 AM. At first, the snow melted as it fell. However, as the morning progressed, the intensity of snowfall increased and the temperature fell to just below 32 degrees. The snow began to whiten the ground between 10:00 AM and 11:00 AM. Between sunrise and 12:00 Noon, the wind blew from the north at an average speed of 10 to 16 MPH.

During the afternoon of October 24th, as the intensity of the snowfall continued to increase and the temperature fell from 31 to the middle 20s, the depth of snow on the ground increased steadily. At 6:00 PM on the 24th, undisturbed ground surfaces were covered with an average of 3 to 4 inches of snow weighing an average of 1.6 to 2.1 pounds per square foot. There was a steady strengthening of the wind, blowing from the north, as the afternoon progressed. The average wind speed increased from 15 to 20 MPH at the start of the afternoon to 20 to 25 MPH at the end of the afternoon. Highest gusts reached approximately 35 MPH by late afternoon. As the temperature fell, the snow became less wet, and the wind speed increased, the accumulated snow began to blow and drift late in the afternoon.

The blizzard grew to its full fury during the evening of October 24th. Snow fell continuously and often heavily and the temperature fell from the middle 20s to about 16 degrees. The wind reached maximum strength during this time, blowing from the north at an average speed of 22 to 32 MPH with highest gusts to between 40 and 45 MPH. Severe blowing and drifting of the accumulated snow resulted. The combination of heavy snowfall and blowing snow due to the high winds caused near whiteout conditions at times. The depth of snow on the ground increased dramatically. At 12:00 Midnight, undisturbed ground surfaces were covered by an average of 12 to 15 inches of snow with a liquid equivalent of 1.10 to 1.40 inches and an average weight of 5.7 to 7.3 pounds per square foot. There were significant variations in the actual depth and weight of the snow cover from place to place due to the severe drifting.

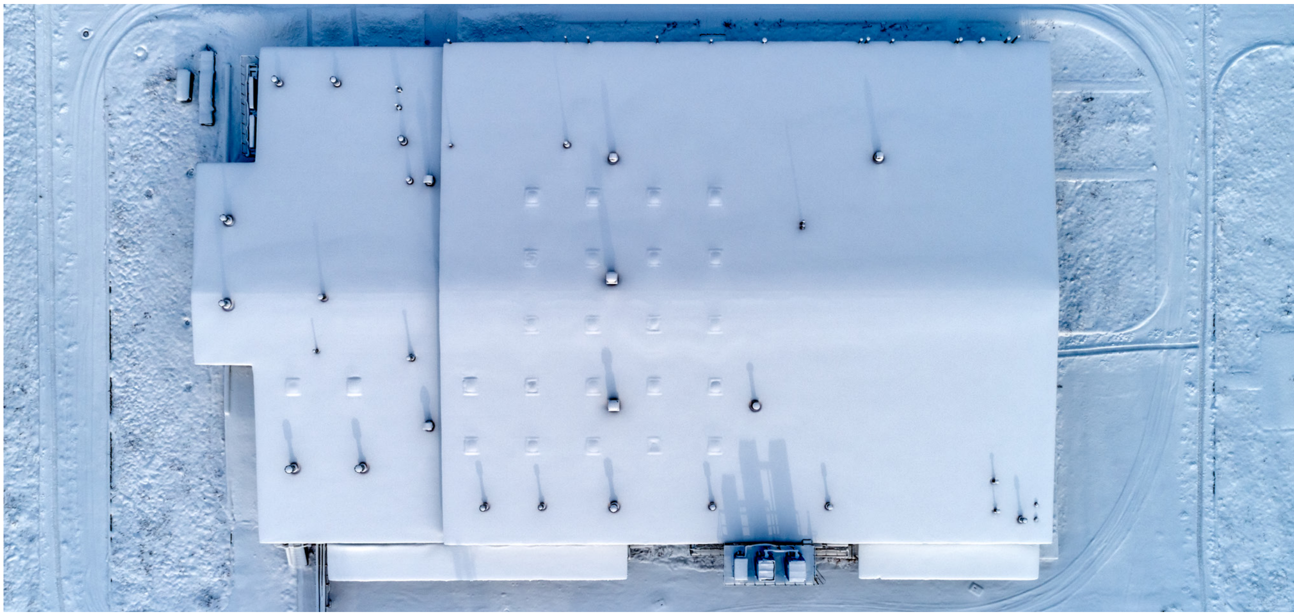
The blizzard continued to rage in Pierre throughout the morning hours of October 25th.

The blizzard continued to rage in Pierre throughout the morning hours of October 25th. Snow fell continuously and often heavily and the temperature ranged from 16 to 18 degrees. The wind blew from the north, averaging 22 to 32 MPH with gusts to between 32 and 42 MPH. Severe blowing and drifting of the accumulated snow continued. Drifts grew to several feet in depth. At 12:00 Noon on the 25th, undisturbed ground surfaces were covered by an average of 24 to 28 inches of snow. The liquid equivalent of the snowpack was 2.35 to 2.75 inches and its average weight was 12.2 to 14.3 pounds per square foot.

The storm eased across central South Dakota during the afternoon of October 25th. The intensity of the falling snow lessened and the wind was not quite as strong. Between 12:00 Noon and 3:00 PM, the wind blew from the north and north-northwest at an average speed of 20 to 25 MPH with gusts to approximately 35 MPH. Between 3:00 PM and 6:00 PM, the wind blew from the north and the average speed diminished to 10 to 15 MPH. The blowing and drifting of the snowpack gradually came to an end. The afternoon temperature ranged from 18 to 22 degrees. The depth of the snow on undisturbed ground surfaces reached a peak during the late afternoon of the 25th, totaling 27 to 31 inches. The liquid equivalent reached 2.80 to 3.25 inches and the average weight of the snow cover peaked at 14.6 to 16.9 pounds per square foot. There were large variations in the depth and weight of the snowpack from place to place due to the drifting during the blizzard.

In summary, at 1521 Stevens Road, Pierre, South Dakota, the ground was free of snow and ice from October 21st through October 23rd and high temperatures during these three days ranged from 63 to 72 degrees. The temperature of the soil was well above freezing at the end of the 23rd.

A severe early-season blizzard struck Pierre on October 24th and 25th. Snow fell continuously from the early daylight hours of the 24th through the early evening of the 25th. The air temperature was just above 32 degrees when the snowfall commenced and the snow melted on the ground at first. Then, as the snowfall intensified, the temperature fell through the 20s and then into the teens, changing the characteristic of the falling snow from wet to drier and powdery. The total average amount of snow that fell at the site in question during the storm was between 27 and 31 inches. The total average-liquid equivalent of the snowpack at the end of the storm was 2.80 to 3.25 inches and the average weight of the snowpack as the storm ended was between 14.6 and 16.9 pounds per square foot.



The severity of the storm was exacerbated by very strong winds from the north that gusted to as high as 40 to 45 MPH at the height of the blizzard. These high winds caused severe blowing and drifting of the powdery snow on the ground, resulting in massive drifts to as deep as 10 feet. The severe drifting caused substantial variations in the depth and weight of the ground snow cover from place to place. After the snowfall ended between 7:00 PM and 8:00 PM on October 25th, there was no further precipitation in Pierre during the rest of the 25th and there was insufficient wind to cause any noteworthy drifting.

To this point in the report, factors specific to the roof in question have not been taken into account. All snow depths and weights given have been average values on undisturbed ground surfaces. The primary factor that affected the amount and weight of the snow on the roof in question was drifting.

According to the roof plan of the building provided to us, there is a ridgeline that runs approximately east to west separating the "showroom" side of the building to the north from the "warehouse" side to the south. There is a ridge cap along the ridgeline that extends 4 to 6 inches above the roof. The slope of the roof toward the north and south is ¼ in 12. The distance from the ridgeline to each eave is 125 feet. Thus, there is a drop of about 3 feet in height from the peak of the ridge cap to the gutters at the eaves. When the wind blew across the ridge cap, a wind shadow effect was created to the lee (downwind) of the cap and a snowdrift was formed in the wind shadow region.

During the many hours that drifting occurred with wind blowing from a generally northerly direction, drifts formed on the "warehouse" side of the ridgeline. By October 25th, drifts in this area may have reached 3 feet in depth. A drift of this depth would have weighed approximately 44 to 46 pounds per square foot.

The information in this report has been determined from the best sources of weather information available to us at this time and is the result of interpretation by our staff of professional meteorologists and represents our opinions to a reasonable degree of scientific certainty. We trust that this information is useful to you. If you should have any additional questions or need additional information, please do not hesitate to contact us.

SAMPLE REPORT

Slip and fall report

Summary

We have investigated the weather conditions in the vicinity of 15th and Market Street, Philadelphia, Pennsylvania on and prior to March 31st, with particular attention to the existing conditions at approximately 7:00 PM on the 31st. The results of our investigation are presented in the following paragraphs.

Our research shows that exposed surfaces in Philadelphia were dry and free of snow and ice at the start of March 29th. During the pre-sunrise hours of March 29th, the sky over Philadelphia was partly cloudy and the low temperature was about 53 degrees. During the rest of the morning and the afternoon, the sky was mainly cloudy. The high temperature was at or just above the 70 degree mark. Between 2:00 PM and 5:00 PM showers accompanied by some thunder moved across the Philadelphia area. The sky became mostly clear during the evening hours and the temperature fell to approximately 55 degrees.

The sky was partly cloudy during the pre-sunrise hours and the temperature held in the middle 50s. The sky was partly to mostly cloudy during the daylight and evening hours with no precipitation until the very end of the day when a couple of sprinkles gave a trace of rain. The temperature reached a high of 70 degrees and then fell to approximately 57 degrees by 12:00 Midnight. At the end of the day, there was no snow or ice on the ground.

March 31st was a cloudy day in Philadelphia, Pennsylvania. Rain fell from the start of the 31st until mixing with wet snow between 10:00 and 11:00 AM and then changing to all snow by 12:00 Noon. The temperature fell from near 57 degrees at the start of the day to approximately 36 degrees at 12:00 Noon. During the morning, the wind blew from the north and northwest at an average speed of 12 to 25 MPH with occasional gusts of 35 to 40 MPH. Mainly light snow fell between 12:00 Noon and 3:00 PM. The snow fell at a heavier rate from 3:00 PM until becoming light again between 5:00 and 6:00 PM. The temperature fell to 31 or 32 degrees by 3:00 PM and then held steady through 6:00 PM. During the afternoon, the snow accumulated on grassy areas, but most of the snow melted on paved and concrete surfaces, making them wet to slushy.

The wind blew from the northwest at an average speed of 20 to 30 MPH with occasional gusts of 35 to 40 MPH. Light snow continued to fall during the rest of the evening and the temperature held near or just below 32 degrees. The wind continued to blow from the northwest at an average speed of 20 to 30 MPH with occasional gusts of 35 to 40 MPH. The snow continued into the early morning hours of April 1st giving a total accumulation on undisturbed, non-paved surfaces of 3.5 to 5.5 inches. Lesser amounts accumulated on paved and concrete surfaces.

Specifically, in the vicinity of 15th and Market Street, Philadelphia, Pennsylvania on March 31st at approximately 7:00 PM, the sky was cloudy, the temperature was approximately 31 degrees and the wind was blowing from the northwest at an average speed of 20 to 30 MPH with occasional gusts of 35 to perhaps 40 MPH. Snow was falling at the time in question and snow had been falling since the late morning hours. The day started with no snow or ice on the ground but by 7:00 PM an average of 2 1/2 to 4 1/2 inches of snow had accumulated on non-paved surfaces. During the daylight hours of the 31st, most of the snow melted on paved and concrete surfaces but there was some slush accumulation, especially after 3:00 PM. Prior to the time of sunset (6:23 PM), the snow began to accumulate on most paved and concrete surfaces. At 7:00 PM, there was up to an inch of snow and slush on untreated and undisturbed paved and concrete surfaces in the vicinity of 15th and Market Street.

The information in this report has been determined from the best sources of weather information available to us at this time and is the result of interpretation by our staff of professional meteorologists and represents our opinions to a reasonable degree of scientific certainty.

Note: All time references in this report are expressed in Eastern Daylight Time (EDT). Trace is an amount too small to be measured. For rain it is less than 0.01 of an inch and for snow it is less than 0.1 of an inch. Dates, times, names, and locations may have been changed to protect client confidentiality.

SAMPLE REPORT

Automobile accident report

Summary

We have investigated the weather conditions in the vicinity of Hidden Lake Drive, near Hidden Lake, Smithfield Township, Monroe County, Pennsylvania on and prior to January 28th, with particular attention to the existing conditions at approximately 6:00 PM on the 28th. The results of our investigation are presented in the following paragraphs.

Our research shows that an average of 1/2 to 2 inches of snow covered untreated and undisturbed surfaces in Smithfield Township at the start of January 26th. On the 26th, there were a few snow flurries but there was no measurable precipitation. The early morning low temperature was close to 24 degrees. During the daylight hours of the 26th, the temperature stayed in the 20's. The sky was mainly cloudy during the morning and partly sunny during the afternoon. During the evening, the sky was mostly clear to partly cloudy and the temperature fell into the teens. There was very little or no natural melting of the snow on the ground on the 26th.

During the pre-sunrise hours of January 27th, the sky above Smithfield Township became cloudy. The early morning low temperature was very close to the 15 degree mark. Throughout the daylight hours of the 27th, the sky was overcast. The late afternoon high temperature was at or just shy of the 30 degree mark. Very late in the afternoon or early in the evening, snow began falling. Throughout the remainder of the 27th, snow fell and the temperature was between 26 and 30 degrees. Between 2 and 3 inches of snow fell at the site in question on January 27th.

During the first two hours of January 28th, the snow changed to rain. For several hours until the temperature rose above the melting point (32 degrees Fahrenheit) the rain froze on contact with exposed surfaces. Prior to sunrise, the temperature rose above the 32 degree mark. The rain continued until between 9:00 and 10:00 AM. When the rain ended, the temperature was between 36 and 38 degrees. During the next two hours, the sky was mainly cloudy and the temperature held nearly steady. During the first part of the afternoon, the sky became mostly sunny and it remained that way through the end of the afternoon. Despite the sunshine, the temperature slowly fell. At 5:00 PM, the temperature was very close to the freezing point. During the evening, the sky was mostly clear and the temperature fell well down into the 20s. On January 28th, only 1/4 to 1/2 of an inch of snow fell before the changeover to rain. The total rainfall on the 28th was at least 0.40 to 0.60 of an inch. With the temperature above the 32 degree mark from prior to sunrise into the late afternoon, there was natural melting of the snow on the ground. When the temperature dropped to the freezing point between 4:00 and 5:00 PM, areas made wet by rain and melted snow became icy. Later in the evening as the temperature continued to fall, puddles froze solid and slushy snow solidified.

Specifically, in the vicinity of Hidden Lake Drive near Hidden Lake, Smithfield Township, Monroe County, Pennsylvania on January 28th, at approximately 6:00 PM, the sky was clear, the temperature was 30 or 31 degrees, and the wind was blowing from the west and northwest at an average speed of 6 to 12 MPH. No precipitation was falling at the time in question and no precipitation had fallen at that location during the preceding 8 hours. However, from the last hour of the afternoon of January 27th through the first hour or two of January 28th, 2 1/4 to 3 1/2 inches of snow fell. The snow was followed by a period of freezing rain until the temperature rose above the 32-degree mark causing the freezing rain to change to plain rain. At least 0.40 and 0.60 of an inch of rain fell before the precipitation ended between 9:00 and 10:00 AM. The temperature stayed above the melting point until late afternoon. During the late afternoon and early evening, as the temperature dropped, surfaces made wet by rain and melted snow became icy. Although a few patches of ice may have formed earlier, most untreated, wet surfaces did not become icy until between 4:00 and 5:30 PM on the 28th.

> In summary, weather conditions in Smithfield Township and throughout Monroe County were inclement from the evening of January 27th into the morning of January 28th.

In summary, weather conditions in Smithfield Township and throughout Monroe County were inclement from the evening of January 27th into the morning of January 28th. From 10:00 AM through the mid-afternoon on the 28th, there was no precipitation and the temperature was above the melting point. During the morning and into the afternoon, there was natural melting of the recently fallen snow. When the temperature fell to the freezing point between 4:00 and 5:00 PM on the 28th, many roadways were wet from rain earlier in the day and snow melt. Those wet surfaces quickly became icy. Ice formation was widespread. Not only did areas of ice form on Hidden Lake Drive near Hidden Lake, patches of ice also formed on most other similar roadways as well as even more heavily traveled highways. At 6:00 PM on January 28th, it would have been expected that there would be patches of ice on rural roads in the Poconos in Monroe County due to earlier precipitation and natural melting followed by the temperature falling below the freezing point.

The information in this report has been determined from the best sources of weather information available to us at this time and is the result of interpretation by our staff of professional meteorologists and represents our opinions to a reasonable degree of scientific certainty.

Note: All time references in this report are expressed in Eastern Standard Time (EST). Measurable precipitation is defined as 0.1 of an inch or more for snow and 0.01 of an inch or more for liquid precipitation. Dates, time, names, and location may have been changed to protect client confidentiality.

SAMPLE REPORT

Thunderstorm & wind report

Summary

We have prepared this report concerning the weather conditions at client requested location on June 29th. Particular attention was given to wind gusts that occurred in the vicinity of the address of interest on June 29th. All reference to times in this report, unless otherwise indicated, are in Eastern Daylight Time (EDT).

Data and Information Considered

1. WSR-88D (NEXRAD) weather radar data from the Indianapolis (ILN), IN radar, obtained from the National Centers for Environmental Information (NCEI).
2. Storm reports on June 29th in Marion County obtained from NCEI Storm Data June 2012 Volume 54 Number 6 published by National Oceanic and Atmospheric Administration (NOAA).
3. Preliminary Local Storm Reports (LSRs) summary provided by the Indianapolis, IN National Weather Service (NWS) office on June 29th obtained from NCEI.
4. Surface weather observations from June 29th-30th (Quality Controlled Local Climatological Data) at Indianapolis International Airport (IND), Eagle Creek Airport (EYE), Shelbyville Municipal Airport (GEZ), Indianapolis Executive Airport (TYQ), and Indianapolis Regional Airport (MQJ) made available online by NCEI.
5. Surface weather observations from the previous 10 years (Quality Controlled Local Climatological Data) at Indianapolis International Airport (IND) and Fort Wayne International Airport (FWA) made available online by NCEI.
6. Derecho definition retrieved from the American Meteorological Society (AMS) Glossary of Meteorology 2017, available online at http://glossary.ametsoc.org/wiki/Derecho.
7. Outflow boundary definition retrieved from the American Meteorological Society (AMS) Glossary of Meteorology 2017, http://glossary.ametsoc.org/wiki/Outflow_boundary.
8. An article obtained from The Bulletin of the AMS Volume 97 No. 6 June 2016, titled "A Proposed Revision to the Definition of 'Derecho'" written by Stephen F. Corfidi et. al., published by AMS and made available online at https://journals.ametsoc.org/doi/pdf/10.1175/BAMS-D-14-00254.
9. A service assessment report obtained from the U.S. Department of Commerce National Oceanic and Atmospheric Administration (NOAA) NWS Silver Spring, Maryland titled "The Historic Derecho of June 29, 2012" written by Michael Vescio et. al., made available online at https://www.weather.gov/media/publications/assessments/derecho12.pdf.
10. Severe thunderstorm warnings and statements.

Derecho Definition

On June 29th, a meteorological phenomenon known as a derecho traveled over 700 miles across the Ohio Valley and Mid-Atlantic states, including northern and central Indiana. A derecho is defined by the American Meteorological society as follows:

[. . .] the term is defined as any family of particularly damaging downburst clusters produced by a mesoscale convective system. Such systems have sustained bow echoes with book-end vortices and/or rear-inflow jets and can generate considerable damage from straight-line winds over a long broad swath. The term derecho derives from a Spanish word that can be interpreted as "straight ahead" or "direct [. . .] .

In addition, the following supplemental criteria has been established by the National Weather Service (NWS) Storm Prediction Center (SPC) to determine if a thunderstorm complex is a derecho:

1. There must be a concentrated area of reports consisting of convectively induced wind damage and/or convective gusts > 25.7 m s–1 (58 mph). This area must have a major axis of at least 400 km (250 mi).

2. The reports within this area must also exhibit a nonrandom pattern of occurrence; that is, the reports must show a pattern of chronological progression, whether as a singular swath (progressive) or a series of swaths (serial).
3. Within the area there must be at least three reports, separated by 64 km (40 mi) or more, of either F1 or greater damage (Fujita 1971) and/or "significant" convective gusts of 33.4 m s−1 (75 mph) or greater.
4. No more than three hours can elapse between wind damage events (gusts).

The thunderstorm complex that moved over northern and central Indiana on the afternoon of June 29th met the definition of a derecho. However, the strongest part of the derecho missed the Indianapolis area by 75 to 100 miles to the northeast and was only impacted by thunderstorm outflow associated with the derecho. Below is a discussion of weather conditions that occurred at the address of interest on June 29th.

Discussion and Analysis

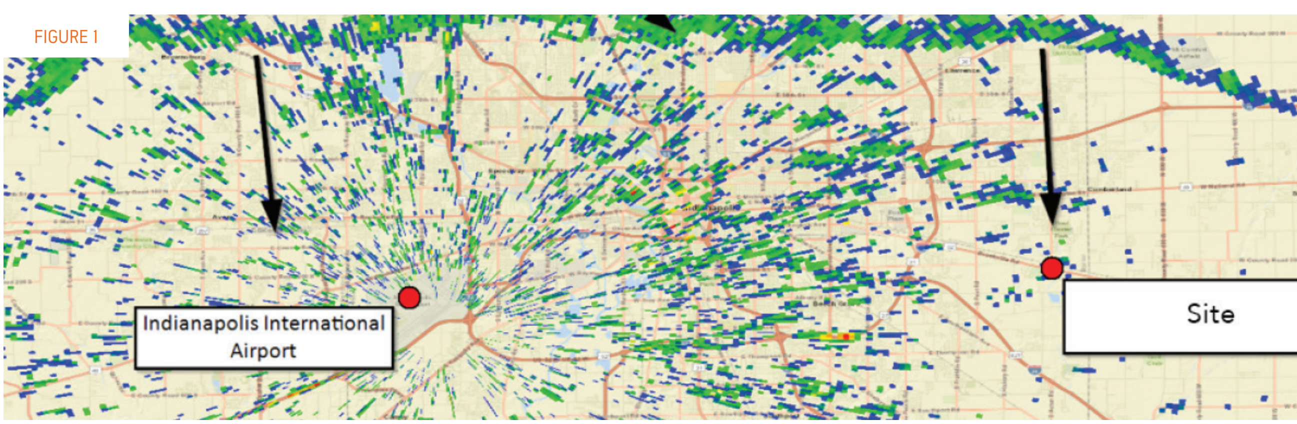
The morning of June 29th began with partly cloudy skies with temperatures in the upper 70s. By the afternoon, temperatures quickly rose into the lower 100s under partly cloudy skies. In northwestern Indiana, a derecho had formed and was moving southeast across the state. At 2:54 PM, the strongest part of the derecho produced a wind gust of 91 MPH at the Fort Wayne International Airport in Fort Wayne, IN, located approximately 100 miles northeast of the location of interest.

After 3:00 PM the southern side of the derecho began to move southward. As this complex began to move south another meteorological phenomenon known as an outflow boundary formed and headed towards the Indianapolis metro area. An outflow boundary is defined by the American Meteorological society as follows:

A surface boundary formed by the horizontal spreading of thunderstorm-cooled air.

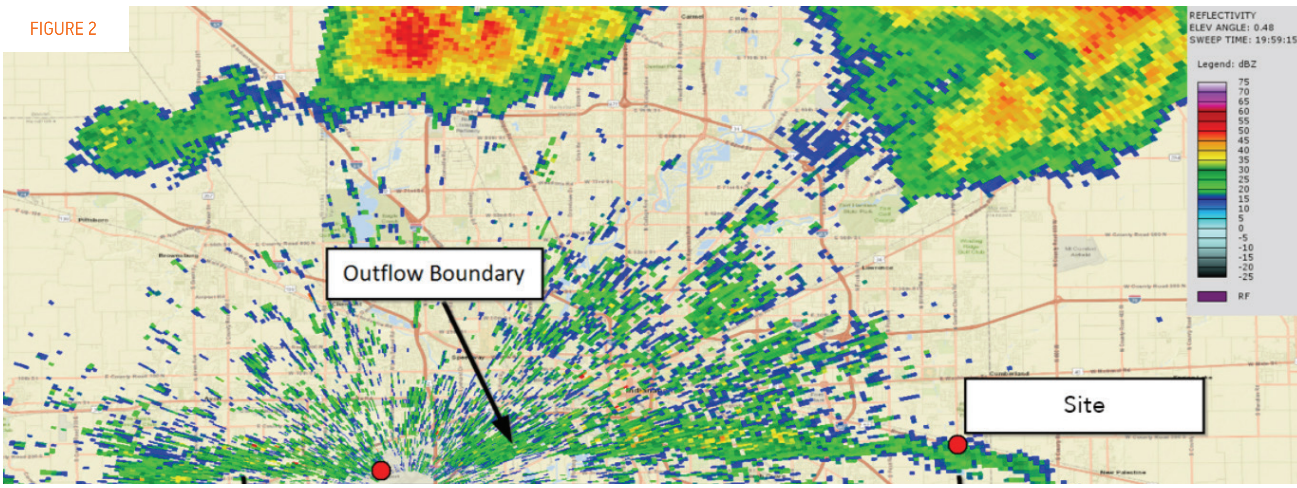
In other words, an outflow boundary is similar to a cold front which divides warm and cold air. Once these boundaries pass a location the temperature cools and conditions can become windy. Below is a radar image (figure 1) at 3:45 PM on June 29th from the Indianapolis, IN (KIND) radar.

FIGURE 1



The line of green colors, which is stretched across northern portions of Indianapolis, IN., is where the outflow boundary is located (denoted on figure 1). This boundary quickly moved southward towards the location of interest and the Indianapolis International Airport (also denoted on figure 1, red dot). After 3:45 PM the outflow boundary quickly moved south across the rest of the Indianapolis metro area and produced high wind gusts over the city. These winds caused tree damage and downed power lines across the city. In addition, a trained weather spotter measured a wind gust of 60 MPH at Butler University located in northern Indianapolis, IN. Just before 4:00 PM, the outflow boundary reached client requested location. Below is the base reflectivity radar image (figure 2) at 3:59 PM on June 29th from the KIND radar.

FIGURE 2



The outflow boundary was stretched across southern portions of the Indianapolis metro area, including the Indianapolis International Airport (IND) (denoted on figure 2, red dot). The weather station at IND measured a peak wind gust of 57 MPH out of the north at 3:59 PM as the outflow boundary passed through the airport. This prompted the Indianapolis, IN National Weather Service (NWS) office to issue a severe thunderstorm warning at 4:03 PM valid through 4:45 PM for southern Marion County, IN. This warning stated, "At 3:59 PM national weather service Doppler radar indicated a severe thunderstorm capable of producing damaging winds in excess of 60 MPH.

IND continued to measure wind gusts between 50 to 60 MPH from 4:00 PM to 4:15 PM. After 4:15 PM winds began to diminish and only gusted between 10 to 20 MPH.

The weather conditions that occurred at IND were similar at client requested location, Indianapolis, IN. Just after 4:00 PM northerly winds gusted between 55 to 60 MPH through 4:10 PM. After 4:10 PM to 4:20 PM, winds weakened and gusted between 40 to 50 MPH. After 4:20 PM thunderstorms and rain began to occur over the location but were weak and only produced wind gusts of 10 to 20 MPH. Once these storms exited the region, the winds remained light at the address of interest through the rest of afternoon and evening of June 29th.

During the overnight hours of June 30th a second round of thunderstorms moved over the region and occurred at the address of interest from 4:45 AM to 5:15 AM. Although these thunderstorms did produce some gusty winds they were only between 35 to 45 MPH.

Conclusions

On June 29th a derecho moved across northern and central Indiana during the afternoon hours. This derecho produced between 80 to 90 MPH wind gusts over northern Indiana, which was uncommon. However, the strongest part of the derecho missed client requested location Road, Indianapolis, IN by approximately 75 to 100 miles to the northeast. As this derecho passed by to the north, the system produced an associated outflow boundary, which caused wind gusts of 55 to 60 MPH at client requested location from 4:00 PM to 4:10 PM. The wind gusts of 55 to 60 MPH that occurred at client requested location were more common than the wind gusts of 80 to 90 MPH that occurred over northern Indiana.

The information in this report has been determined from the best sources of weather information available at this time and is the result of interpretation by professional meteorologists and presents our opinion to a reasonable degree of scientific certainty. If you should have any additional questions or need additional information, please do not hesitate to contact us.

Note: All time references in this report are expressed in Eastern Daylight Time (EDT). Dates, times, names, and locations may have been changed to protect client confidentiality.

SAMPLE REPORT

Hail report

Summary

I have prepared this report concerning hail that occurred from July 1, 2018 to present at the address 123 Street Address. Particular attention was given to dates when hail of 0.75 inch in diameter or greater occurred.

Data and Information Considered

1. WSR-88D (NEXRAD) level II weather radar data from the Louisville, KY (KLVX) radar obtained from the National Centers for Environmental Information (NCEI) viewed within the National Oceanic and Atmospheric Administration (NOAA) Weather and Climate Toolkit and GR2Analyst radar software.
2. Hail reports from the Storm Events Database at NCEI for Jefferson County, KY.
3. Hail reports for Jefferson County, KY obtained from the archive at the National Weather Service (NWS) Storm Prediction Center (SPC) in Norman, OK and Preliminary Local Storm Report (LSR) summaries from the NWS Louisville, KY office.
4. Hail reports from the Community Collaborative Rain, Hail & Snow Network (CoCoRAHS) for Jefferson County, KY. Database latitude and longitude provided from NCEI with reports retrieved from CoCoRAHS.
5. Upper air sounding data at the NWS Wilmington, OH office (KILN) in Wilmington, OH retrieved from the University of Wyoming archived sounding data.
6. Geographic Information System (GIS) maps generated by Global Mapper displaying hail reports, address location, and various other geographical references.
7. Peer-reviewed research article entitled "Understanding Hail in the Earth System" written by John T. Allen et. al. published in Reviews of Geophysics Volume 58, issue 1, March 2020.
8. Peer-reviewed research article entitled "An Enhanced Hail Detection Algorithm for the WSR-88D" written by Arthur Witt et. al. published in Weather and Forecasting Volume 13 1998.
9. Peer-reviewed research article entitled "WSR-88D Signatures Associated with One Inch Hail in the Southern Plains" written by Dennis E. Cavanaugh and Jessica A. Schultz published in Electronic Journal of Operational Meteorology Volume 13, Number 1 2012.
10. Peer-reviewed research article entitled "Evaluation of a Technique for Radar Identification of Large Hail across the Upper Midwest and Central Plains of the United States" written by Rodney A. Donavon and Karl A. Jungbluth published in Weather and Forecasting Volume 22, 2006.

Methodology

1. Ground Products: Hail

   For the determination of hail at the address of interest, I first retrieved all available hail ground reports from National Centers for Environmental Information (NCEI) Storm Event Database in Jefferson County, KY from January 1, 2018 to present. The hail reports provide dates and times of hail, the approximate location of the reports, and the maximum hail size at those locations. The latitude and longitude coordinates of the hail reports from NCEI were plotted within the Geographic Information System (GIS) software Global Mapper to compare to the address of interest.

   Once this information was reviewed on Global Mapper, the latitude and longitude coordinates of the hail reports and the address of interest were imported into the National Oceanic and Atmospheric Administration (NOAA) software, Weather and Climate Toolkit (WCT). This program can retrieve archived radar data quickly through the NOAA Big Data tool. The radar data can be viewed in conjunction with the hail ground report plots and the address.

Second, I also reviewed radar data within radar software, GR2Analyst, which has the capability of automatically retrieving and plotting the National Weather Service (NWS) preliminary local storm reports (LSRs) on a map. While this information is considered preliminary, the data is treated as the first version of a hail database and is later submitted by the NWS, and quality controlled by NCEI within the Storm Event Database. The software can display both hail and high wind reports.

Third, I also retrieved the Community Collaborative Rain, Hail & Snow Network (CoCoRaHS) hail reports in Jefferson County, KY. CoCoRaHS is a network of volunteers who can report hail at their location.

Once the ground reports were collected and initially analyzed, I then began reviewing radar products specific to the address of interest, which will be discussed in section 2, on each date hail was reported.

2. Radar Products: Hail

The radar product I first relied on was base reflectivity, which measures the transmitted power returned to the radar in decibels of Z (dBZ). Base reflectivity increases when hail is present. Typically, hail, when mixed with rain, is possible when values are 55 dBZ or greater. When values are 60 dBZ or greater, hail is likely (figure 1, values referred to as Z).

The second radar-based product I relied on was Maximum Expected Hail Size (MEHS). This is a radar algorithm that estimates the maximum hail size expected from base reflectivity values between the heights of the freezing level and -20 C level, which are several thousand feet above the ground. Large hail grows in the atmosphere at these temperatures. The peer-reviewed research paper written by Witten et. al. (1998), which details the development of this algorithm, states, "Since the hail-size model being developed is meant to forecast maximum expected hail size, it was developed such that around 75% of the hail observations would be less than the corresponding predictions." As a result, the actual size of hail at the ground is often less than what is predicted by MEHS.

To properly determine MEHS values over the address, the freezing level, and -20 C level must be determined. I retrieved the upper air weather data at the NWS Wilmington, OH office near the time frame the storms occurred. The NWS launches weather balloons at this location to measure weather conditions higher in the atmosphere, including the freezing level and -20 C height. This data was then imported into GR2Analyst, which then calculates MEHS values from the radar and upper air data.

MEHS data can also be viewed within the NCEI Severe Weather Data Inventory (SWDI). The SWDI provides a product called hail index, which uses MEHS to calculate a single hail estimate per storm. This database can list dates in which the hail index estimated hail in the vicinity of a location. For this study, I relied on SWDI to review potential hail events when no hail ground reports were listed.

The third radar product reviewed was the 50 dBZ height. Similar to the MEHS product, two studies have noted the importance of the 50 dBZ heights above the freezing level when determining hail (Cavanaugh and Schultz, 2012; Donavon and Jungbluth, 2006). In general, the higher the 50 dBZ height is above the freezing level the more likely severe hail occurs. To determine the 50 dBZ height, I determined the freezing level from the upper air sounding data in Greensboro, NC. I then reviewed different radar elevation angles to determine the 50 dBZ height within GR2Analyst by creating cross-sectional "slices" through the storm. This provided a 2-D view of the thunderstorm, allowing me to see the various reflectivity values higher in the atmosphere.

The fourth radar products reviewed were the dual-polarization radar products. Dual-polarization allows the radar to measure targets in the sky in the horizontal and vertical plane. In other words, it gives meteorologists additional details on the three-dimensional structure of a target such as hail. Researchers have noted many useful applications to dual-polarization radars. One of these was improving the detection of hail (Allen et. al. 2020). This is accomplished by utilizing the dual-polarization radar products: correlation coefficient (CC), differential reflectivity (ZDR), and specific differential phase (KDP).

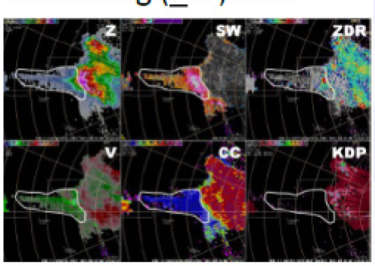
CC measures how similar the target's shape and size are. When hail is present with rain, CC is 0.96 or less. ZDR compares the vertical and horizontal reflectivity values of a target. When severe hail is present, ZDR is lower and can become negative. Typically, ZDR values for severe hail are less than 2 dB, with hail of 2 inches in diameter or greater less than 0 dB. KDP measures the phase shift of the horizontal and vertical pulses. KDP is useful to determine the amount of liquid water within a radar sample. A variety of dual-polarization values are typically found with hail and are summarized in figure 2. It should be noted that these values should be applied to the lowest elevation angle of the radar. Also, note the radar signatures typical for hail from the base reflectivity product (listed as Z).

FIGURE 1

Storm-Top Divergence

Peak ΔV(kts)	Max Hail Size (in.)
70-102	Quarter (1")
103-134	Ping Pong (1 ½")
115-147	Golf ball (1 ¾")
130-162	Hen Egg/Lime (2")
159-192	Tennis Ball (2 ½")
174-207	Baseball (2 ¾")
233-267	Grapefruit (4")

TBSS ≈ Sig (≥2") Hail*



*Valid for S-band radar only

DUAL-POL RADAR HAIL SIGNATURES

	Z: 45-59 dBZ = Hail poss ≥60 dBZ = Hail likely	**ZDR**: -0.3 to 1 dB ≈ Dry or large hail > 1 dB ≈ More liquid
	CC: 0.93 - 0.97 ≈ 1-2" hail 0.70 - 0.90 ≈ ≥2" hail	**KDP**: <1°/km ≈ Mostly dry hail >3°/km ≈ Rain/hail combo or melting hail
Hail Event Type	**Signature**	
Severe Hail (with little rain)	Z > 55 dBZ	ZDR < 1 dB
	CC ≈ 0.95-0.97	KDP < 1°/km
Severe Hail Mixed w/Rain	Z > 55 dBZ	ZDR ≈ 1-2 dB
	CC ~0.93-0.96	KDP > 0.5°/km
Sub-Severe Dry Hail	Z ≈ 45-55 dBZ	ZDR ≈ 0 dB
	CC > 0.98	KDP ≈ 0°/km
Sub-Severe Melting Hail	Z > 55 dBZ	ZDR > 2 dB
	CC ≈ 0.92-0.96	KDP > 4-5°/km
Significant (≥2") Hail	Z > 55 dBZ (>45 dBZ)	ZDR ≈ 0 dB or lower
	CC < 0.9 (possibly 0.7)	KDP not displayed

Figure 1. *Radar estimates from Dual-Pol radar data. From the Radar & Applications Course (RAC) from the NOAA/NWS Warning Decision Training Division procedures and references "Radar Hail Signatures" available online at https://vlab.ncep.noaa.gov/web/wdtd/racref*

Discussion and Analysis

September 15, 2018: During the afternoon of this date a thunderstorm moved east through much of the city including the address of interest. A review of the archived radar confirmed the core of this storm affected the address. The base reflectivity and MEHS radar products indicated hail did fall at the address, with MEHS estimating hail of 1.3 inches in diameter. The dual-polarization radar products also showed hail fell at the address and was 1 inch in diameter or greater. The ground reports nearby indicated hail between 1 to 2 inches in diameter fell from this storm. The radar signature at the location was similar to where the reports of 1 inch in diameter hail fell. The signature was stronger at the 2 inches in diameter report than at the location. Later, a second thunderstorm occurred over the city but the radar and lack of nearby ground reports indicated only rain fell at the address. On this date, hail of 1 inch in diameter fell at the address.

May 21, 2020: A thunderstorm moved northeast on this date and occurred over the address. A review of the radar data showed the storm intensified directly over the address. The radar products indicated the storm produced a mixture of rain and melting hail. The MEHS product estimated hail up to 0.75 inch. The dual-polarization radar signatures did not suggest hail was 1 inch in diameter or greater in diameter. The dual-polarization radar products also indicated the hail was melting. In addition, there were no ground reports of hail associated with this thunderstorm. Hail did occur on this date at the address, but was less than 0.75 inch in diameter.

Conclusions

The largest hail that fell from January 1, 2018 to present at the address 123 Street Address occurred on September 15, 2018. On this date, hail of 1 inch in diameter fell. The only other date hail occurred at the address was on May 21, 2020. On this date, small hail less than 0.75 inch in diameter fell.

The information in this report has been determined from the best sources of weather information available at this time and is the result of interpretation by professional meteorologists and represents my opinion to a reasonable degree of scientific certainty. I reserve the right to supplement this report should additional data or information become available. If you should have any additional questions or need additional information, please do not hesitate to contact me.

Note: All time references in this report are expressed in Eastern Daylight Time (EDT). Dates, times, names, and locations may have been changed to protect client confidentiality.

SAMPLE REPORT

Excessive rain report

Summary

We have investigated the weather conditions in the vicinity of 500 Main Street, Trenton, New Jersey on June 14th, with particular attention to the amount of rain that fell, especially between 6:00 PM and 9:00 PM on that date. The results of our investigation are presented in the following paragraphs.

Our research shows that the weather in the Trenton area was quite warm and relatively dry during the first 13 days of June. During that period, most places in the Trenton area received less than 0.50 inches of rain. Between the 1st and the 13th, daytime highs ranged from the middle eighties to the upper nineties and early morning lows were in the sixties and seventies. During the pre-sunrise hours of June 14th, the sky was mostly clear, the temperature was in the seventies, and the wind was light and variable. As the morning progressed, the sky became partly to mostly cloudy and the temperature rose into the eighties. From the time of sunrise through 12:00 Noon, the wind blew mainly from the south and southeast at an average speed of 5 to 10 MPH. At 12:00 Noon, the temperature was between 85 and 88 degrees.

During the first two hours of the afternoon on June 14th, the sky was partly to mostly cloudy and the wind blew mainly from the south and southeast at an average speed of 6 to 12 MPH. The early afternoon high temperature was within a couple of degrees of 90. From 2:00 PM through the end of the day, the sky was cloudy. Thunderstorms moved into the Trenton area between 2:45 and 3:00 PM. During the next seven to seven and a half hours, rain fell much of the time. From 6:00 to 8:00 PM, the rainfall rate was extremely heavy. Most of the Trenton area received between 4.35 and 5.00 inches of rain during the afternoon and evening of June 14th. However, in a few spots as much as 5.50 or 6.00 inches of rain fell. Not only was the total amount of rain that fell large, there was also an unusually large amount of rain that fell during a relatively short period of time. At the site in question, at least 3.50 and possibly as much as 4.00 inches of rain fell during the two-hour period from 6:00 to 8:00 PM. By 9:00 PM, the intensity of rain had decreased. Around 10:00 PM, the rain ended. During most of the time that rain was falling, the temperature was in the seventies and the wind blew from the east and the northeast at an average speed of 8 to 16 MPH. However, there were a few wind gusts as high as 30 or 35 MPH. From the time that the rain ended through 12:00 Midnight, the temperature was in the middle seventies and the wind was variable in direction with an average speed of less than 10 MPH.

Specifically, in the vicinity of 500 Main Street, Trenton, New Jersey on June 14th, between 6:00 and 9:00 PM, the sky was cloudy, the temperature was between 72 and 76 degrees, and the wind was blowing mainly from the east and northeast at an average speed of 8 to 16 MPH with gusts as high as 30 or 35 MPH. Rain fell throughout the period in question and it had rained much of the time since between 2:15 and 3:00 PM. Thunderstorms dumped copious amounts of rain on the Trenton area between 5:00 and 9:00 PM. In the vicinity of 510 Main Street, at least 4.35 to 5.00 inches of rain fell during the afternoon and evening of June 14th, although it is possible that the rainfall total was as high as 5.50 or 6.00 inches. The heaviest rain fell from 6:00 to 8:00 PM. During those two hours, between 3.50 and 4.00 inches of rain fell in the vicinity of 500 Main Street. A rainfall of 3.50 inches or more in two hours in Trenton is expected to occur on the average of only once in 100 years. It is certainly no surprise that the heavy rain that fell in Trenton on June 14th, caused major problems. Because most drainage systems were not built to withstand that much rain during such a short period of time, many streets were flooded. There was also considerable flooding of basements and creeks. In summary, the rain event in Trenton during the afternoon and evening of June 14th was very unusual, considering both the total amount of rain that fell and the short duration rain intensity. As would be expected, the rain caused considerable flooding of streets, creeks, basements and other areas.

The information in this report has been determined from the best sources of weather information available to us at this time and is the result of interpretation by our staff of professional meteorologists and represents our opinions to a reasonable degree of scientific certainty.

Note: All time references in this report are expressed in Eastern Daylight Time (EDT). Dates, times, names, and locations may have been changed to protect client confidentiality.

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