An Analysis of the Record Breaking April 12, 2016 San Antonio Hail Storm Compared to Other Giant Hail Storms

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Introduction

On the evening of April 12, 2016, a supercell thunderstorm produced a large swath of giant hail in excess of 101 mm (4 in.) across the northern portions of the city of San Antonio. This storm produced over $1.6 billion in insured losses which broke the record for the costliest hail storm in Texas history. Prior research has shown that optimal pre-storm environments for giant hail include high amounts of instability, steep lapse rates, and tall, thick convective available potential energy (CAPE) profiles, especially in the hail-growth region. Edwards and Thompson (1998) found in their research that no baseball sized hail (70 mm or 2.75 in.) were reported with modified CAPE less than 1300 J/kg. However, the April 12th storm developed in an environment with very low amounts of instability and therefore giant hail was not expected prior to the onset of the storm. Overall, little research has been completed on giant hail storms, especially storms that develop in such an environment. This study will examine not only the services provided on April 12th from the local National Weather Service forecast office, but also compare this storm to other giant hail producing storms across Texas to ascertain if there is any signal that could have been available to operational forecasters ahead of or during the event to have a better idea that hail of this magnitude was possible.

Data & Methodology

With the relatively rare occurrence of giant hail in the large city of San Antonio and the fact that this hail storm broke the 21 year old record for the costliest hail storm in Texas history, the authors wanted to research other storms which produced hail greater than or equal to 101 mm in diameter. National Center for Environmental Information (NCEI) Storm Data was used to find these reported storms and to achieve a sufficient sample size, a data period of 2009 through 2016 was compiled. This span yielded 49 unique cases of giant hail within the state of Texas. Data was obtained for each event from archived SPC Mesoanalysis (Bothwell et all 2002) data to compare the pre-storm environment for each storm. Common parameters were obtained to see how the April 12, 2016 storm compared to the other giant hail producing storms. These parameters included, surface based CAPE (SBCAPE), most unstable CAPE (MUCAPE), 0-6 km bulk shear, 500 hPa temperature, freezing level, and surface winds/moisture/temperatures to assess the potential proximity of any surface boundaries.

In addition, archived level 2 radar data was obtained from NCEI to examine radar signatures and height levels of the 50, 60, and 70 dBz height at the time stamp prior to the report of the giant hail stone occurrence at the surface. Other radar signatures examined included: evidence of a mesocyclone, the maximum rotation velocity (Vr) of the mesocyclone, and if there was a presence of a three-body scatter spike (Lemon, 1998).

Event Summary

a. Pre-Storm Environment

Leading up to the evening of April 12, 2016, forecasts consistently included thunderstorms primarily due to the presence of an approaching trough at 500 mb with ample moisture available for precipitation production. Figure 1 shows the 500 hPa analysis from 00z the evening of the hail storm. Broad troughing can be seen west of South-Central Texas with southwest winds at 23 to 25 m/s ahead of the trough. These strong southwesterly winds will be crucial for the high values of deep layer shear to be discussed later. The approaching trough also created widespread forcing for ascent necessary to create thunderstorms.

At 850 hPa (Figure 2), the same broad trough remained well west of the region, with a well-defined moisture gradient located across central Texas. This moisture gradient likely played a significant role in the development and evolution of the large hail event.

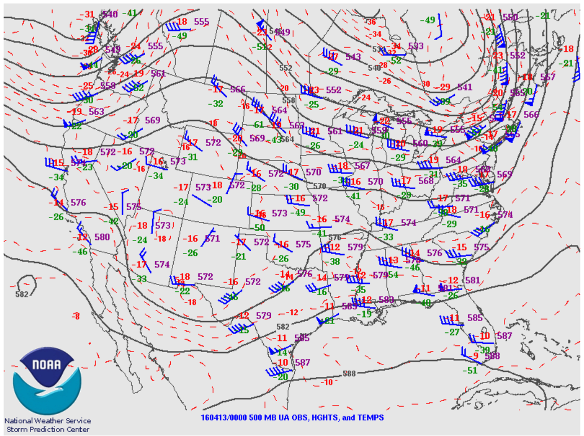

Figure 1: 4/12/2016 7PM CDT 500 hPa Upper Analysis

To the south of the boundary, south winds were feeding warm and moist air into the region, and to the north, east winds were in place. The path of the storm of interest tracked from west to east in close proximity to the 850 hPa front, allowing it to tap into the constant availability and feed of rich moisture into the elevated storm. This likely played a large role in

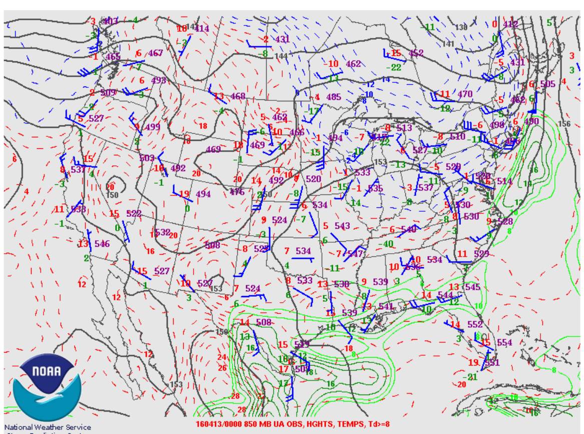

Figure 2: 4/12/2016 7PM CDT 850 hPa Upper Analysis

the storm becoming a high precipitation (HP) supercell and aided in the higher moisture content for the continued aggregation of the larger hail stones.

At the surface (Figure 3) a slowly moving cold front was draped across South-Texas or about 50 km south of the city of San Antonio. With the cold front to the south, any storms to the north of the boundary would be elevated and not rooted at the surface.

This was the primary the reason why there was no SBCAPE present during the event. However, during the entire lifecycle of the storm the boundary did not move which helped the storm track along the elevated boundary between 925 hPa and 850 hPa. The surface analysis also showed that although the cold front had passed, surface dewpoints remained in the lower to

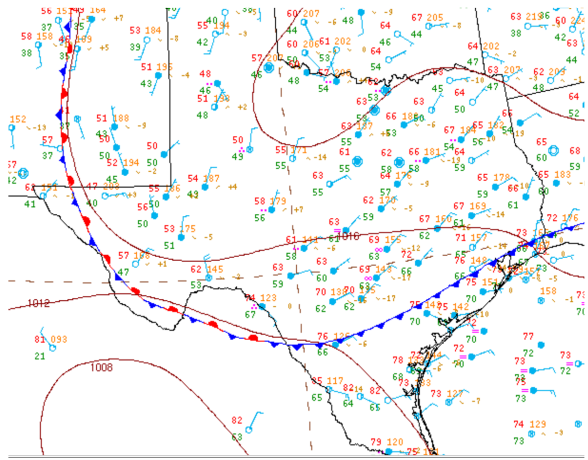

Figure 3: 4/12/2016 7PM CDT 850 Surface Upper Analysis

middle 60s ^{o}F (15 ^{o}C) across the region. This would ultimately help ensure the storm continued to have access to rich low-level moisture to fuel and maintain the thunderstorm updraft.

While there were indications of upper-level support for rising motions and sufficient moisture for the development of convection, the main hindrance for the severity and coverage of thunderstorms was the lack of available instability. Figure 4 shows the SBCAPE. While

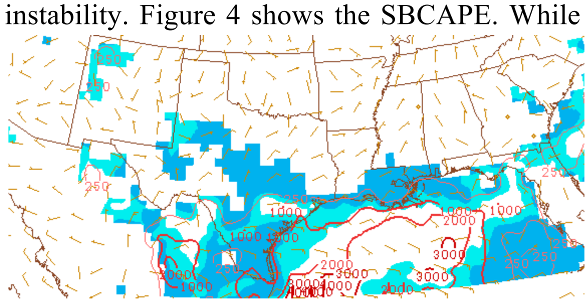

Figure 4: Surface Based Convective Available Potential Energy (SBCAPE) from SPC SfcOA

there was nearly 1000 J/kg of SBCAPE south of the boundary, there was less than 250 J/kg across the region where the storm developed and tracked. Figure 5 depicts the MUCAPE and this analysis only shows slightly higher values of MUCAPE with 500-750 J/kg of elevated instability available for the near-storm environment of the supercell.

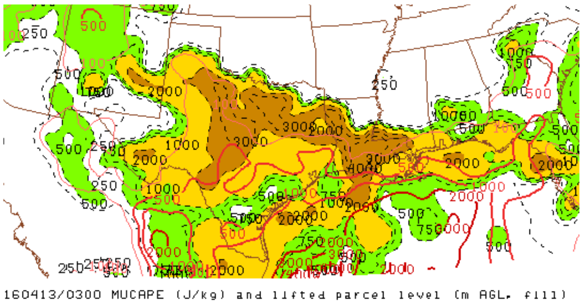

Figure 5: Most Unstable Convective Available Potential Energy (MUCAPE) from SPC SfcOA

Using the equation relating CAPE to maximum updraft speed:

$$W_{max} = \sqrt{2 * CAPE}$$

The maximum theoretical updraft speed for a thunderstorm with 750 J/kg of MUCAPE is just shy of 40 m/s, or just shy of 80 mph. In reality, the updraft speed is almost always less than this, usually up to a factor of two due to effects from water loading and dry air entrainment. The updraft speed required for baseball sized hail (2.75 in.) is about 80 mph. For softball sized hail (4.5 in.), the necessary updraft speed is 103 mph. Given this information, it was not surprising that giant hail was not expected.

An important factor to the intensity of the supercell thunderstorm was most likely the amount of deep layer shear (Figure 6) which created mid-level mesocyclones for several thunderstorms during the evening hours. As mentioned previously, there was 23 to 25 m/s of southwest flow at 500 hPa ahead of an approaching trough. At the surface winds were out of the northeast at 2.5 m/s and these wind vectors led to 0-6 km shear values near 33.4 m/s. The environment was classified as a low CAPE, high shear environment (Sherburn and Parker, 2014) and as is typical in these environments, the main concern was whether or not updrafts could become sustained or rooted before the strong winds aloft sheared the storm apart. This was one of the main questions leading up to the event, but

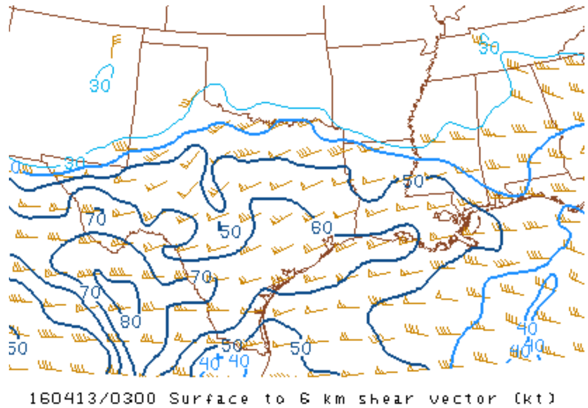

Figure 6: 0-6 km Shear from SPC SfcOa

in review, several storms across South-Central Texas had no trouble maintaining their strong updrafts and supercell characteristics.

b) Products from NWS Austin/San Antonio

1) Pre-storm

To summarize the pre-storm environment, there was high confidence that there would be support for mid-level ascent as the mid-level trough approached the region, leading to an increase in potential vorticity advection. There was also high confidence that there would be sufficient moisture for the development of storms. The main question was if the amount of instability would be enough for strong to severe thunderstorms to develop. If storms did develop, they would have the potential to be severe given the ample deep-layer wind shear in place across the region.

The Storm Prediction Center (SPC) in their Day 3 to Day 1 convective outlooks leading up to the event had the region placed under a marginal risk of severe storms. In addition, the local weather forecast office (WFO) in New Braunfels, Texas (EWX) mentioned the risk of severe storms with the primary risk being the potential for large hail.

On the afternoon of April 12, 2016 thunderstorms began to develop across the Rio Grande Plains west of the San Antonio region. With the evidence of the environment showing signs of convective development and sustainment, the San Antonio region was upgraded to a slight risk of severe storms with the 20z convective outlook from SPC. This slight risk included a 15% probability of severe hail within

25 miles of any point, but did not include a hatched region. This indicated that the SPC was not expecting any severe hail over two inches in diameter.

With the new outlook and increasing confidence of severe weather, forecasters at WFO EWX updated several public products and increased the threat on social media platforms to convey the heightened risk of severe weather to both their partners and to the public. At 2:02 PM, forecasters updated the Hazardous Weather Outlook (HWO) to expand the region where severe storms might occur. The HWO continued to mention large hail as one of the main threats of severe weather. A graphicast (Figure 7) created at 3:12 PM CDT showed the area of the slight risk

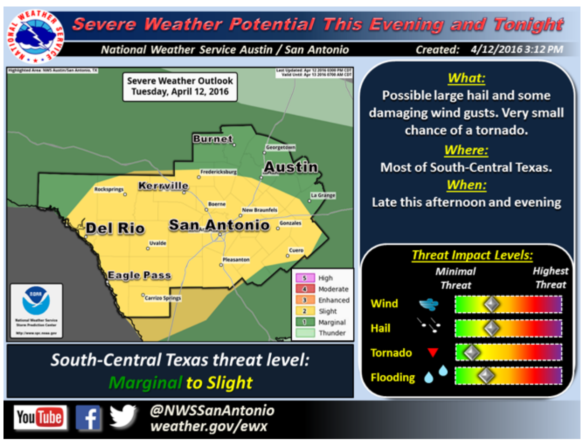

Figure 7: Graphic Issued by WFO EWX

encompassing the San Antonio metropolitan area with the approximate timing of the severe weather in the late afternoon and evening hours. In addition, the image mentioned possible large hail in addition to a damaging wind threat. At 3:39 PM CDT, a partner email briefing was sent to all South-Central Texas partners which includes elected officials, emergency managers, and first responders, among others. This email briefing typically includes the mention of largest hail size expected. Forecasters included the possibility for hail as large as a golf ball or 44.4 mm (1.75 in.) in diameter. In hindsight, this size of the hail was under forecasted primarily due to the fairly weak values of instability available in the atmosphere and did not focus on the higher amounts of deep layer shear in place.

2) During the event

As storms continued to increase in coverage and intensity across the western portions of the WFO EWX County Warning Area (CWA), the SPC issued its first official product of the evening. At 7:26 PM CDT a Mesoscale Discussion (MCD) was issued to highlight the threat of severe weather and to mention the likelihood of a Severe Thunderstorm Watch being needed. The product text mentioned that "As cells intensify and a cluster of strong to severe storms develops later this evening...the San Antonio area may also be impacted." Shortly after at 7:45 PM CDT the Severe Thunderstorm Watch was issued and mentioned that the "primary threats include... isolated damaging wind gusts to 70 mph possible (and) isolated large hail events to 1.5 inches (38.1 mm) in diameter." The discussion of the watch mentioned "occasional large hail in the next few hours with embedded supercells."

Several Severe Thunderstorm Warnings were issued for storms to the west of San Antonio and these storms produced hail generally in the 12 to 25 mm (0.5-1 in.) range. At 9:02 PM CDT the initial Severe Thunderstorm Warning for our record hail storm was issued for Bexar County including the northern sections and suburbs of the city of San Antonio. The initial warning that was issued mentioned the main hazards being quarter sized hail (25 mm) and 29.8 m/s (60 MPH) winds. As the storm moved east into the northeastern suburbs of San Antonio, the storm quickly intensified with a delayed report at 9:18 PM CDT of hail stone of 101 mm (4 in.) in diameter. Shortly after, at 9:20 PM CDT a hail stone with a diameter of 114 mm (4.5 in.) fell and this report was also delayed and actually was reported to the office at a later date. The only reports in real-time was hail as large as baseballs, or 69.9 mm (2.75 in.). Because of this, the largest hail size mentioned in follow-up Severe Weather Statements were baseball sized hail.

Radar data and algorithms did a poor job representing the threat for the large and giant hail which occurred in northern Bexar County. The maximum 50 dBz height at the time of the largest hail stone was only 34 kft, which is closer to what one would expect for a hail stone only one inch in diameter (Cavanaugh and Schultz, 2012). In addition, the Multi-Radar Multi-Sensor (MRMS) Maximum Expected Hail Size (MESH) algorithm, which is widely used in EWX operations for its usefulness underperformed for this hail storm. Figure 8 shows the estimated size

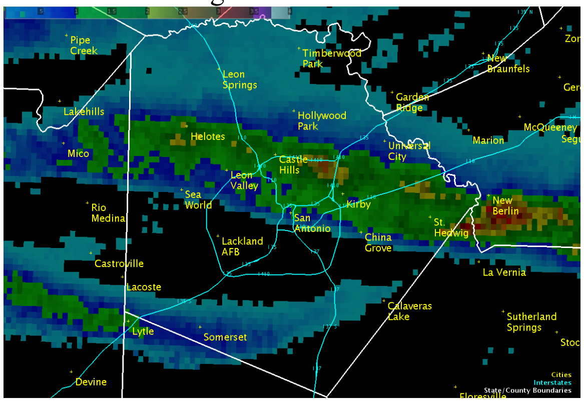

Figure 8: MESH Swath Across Bexar County

of the hail swath from the MESH algorithm. The MESH maxed out with only a few pixels of 50 mm (2 in.) across northwest San Antonio where the giant hail fell (4.5 in). The most likely reason for the MESH underestimation was due to the fact that the San Antonio hail storm did not have the vertical depth typically seen with most large and giant producing hail storms, as the height of the 50 dBZ echo was only 34 kft.

3) Post-storm

WFO EWX received numerous inquiries about actual hail size and the locations of the largest hail. To fulfil these inquiries, EWX created an estimated hail swath map using ARCGIS (Figure 9). The map was created by

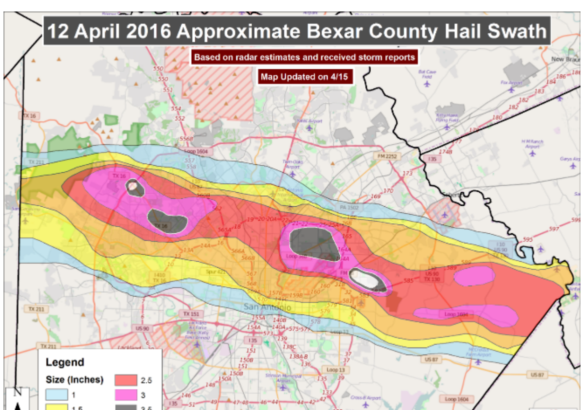

Figure 9: GIS Hail Swath Map Created by WFO EWX

using local storm reports in combination with the MESH guidance. Even though MESH performed poorly regarding the actual hail size, it still handled the areal extent of the swath quite well. This map was updated several times as new reports of large and giant hail were received at the WFO. This map was shared with our partners, including members of emergency management and print and broadcast media. Figure 10 shows

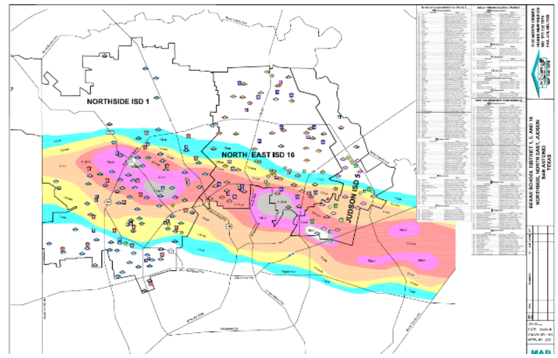

Figure 10: EWX GIS Map Overlayed with Area Schools

how school districts within the affected area overlaid their schools within the hail swath to better allocate their resources to each affected school.

The storm event caused $1.6 billion in estimated insured losses according to the Insurance Council of Texas. This made it the costliest hail storm in Texas history, surpassing the 21 year old record from May 5, 1995 in Fort Worth. The damage was broken down into $560 million for automobile damage and the remaining $800 million for damage to homes.

April 2016 Storm Historically Compared to other Large Hail Storms in Texas from 2009-2016

Due to the rarity of the storm for the local CWA and the difficulties in forecasting the storm, the authors wanted to research this storm compared to other large hail storms across Texas. After obtaining the data from each storm, box and whisker plots were created to visually see statistics related to each parameter and radar data. Table 1 shows the data compared between the compiled giant hail storms.

The 25th and 75th percentiles for SBCAPE were 2,000 and 3,000 J/kg, respectively, which is much greater than the near zero values seen on April 12th. For MUCAPE, the 25th and 75th percentiles were 2,500 and 3,000 J/kg, respectively, which again was significantly higher than only the near 750 J/kg available for the studied April 12th storm. 0-6 km bulk shear values had 25th and 75th percentile values between 20 and 25 m/s. The night of April 12th had 0-6 km bulk shear values approaching 33 m/s, which is well above the 75th percentile for giant hail storms in Texas.

Radar signatures were also analyzed to compare the April 12th San Antonio storm to other Texas giant hail storms. The maximum 50 dBz height is usually between 41 (25th percentile) and 48 kft (75th percentile). The April 12th storm was on the lower end, with a height of 34 kft. The 25th and 75th percentile 60 dBz height was 31 kft and 37 kft, respectively. The April 12th San Antonio storm had a 60 dBz height of 31 kft. While this is still only at the 25th percentile of all giant Texas hail storms, the height of the 60 dBZ echoes was only 3 kft below that of the 50 dBZ height. The 70 dBz height showed the 25th percentile was zero, meaning that many of the sampled storms did not have any reflectivities at or above 70 dBz. The 75th percentile value of all storms was 19 kft, and the height of the April 12th storm was 27 kft. In this case, the height of the 70 dBZ echoes was much higher than usual. Also, with the 50 dBZ, 60 dBZ and 70 dBZ heights being 34 kft, 31 kft, and 27 kft, respectively, this suggests that the hail core was highly concentrated to only a 7 kft volume between 27 kft and 34 kft. The 25th through 75th percentiles of the rotational velocity (Vr) was 20.6 and 30.9 m/s, and the maximum Vr in this storm was 51.4 m/s. This strong mid-level mesocyclone likely played a significant role in the ability to produce widespread large hail and exceed parcel theory estimates, as low-to-mid level updraft velocities are enhanced due to the pressure effects within the rotating updraft. To summarize, the April 2017 storm had 50, 60, and 70 dBz heights of 34, 31, and 27 kft respectively and the Vr was 51.4 m/s.

In addition to the findings previously listed there were a few other interesting notes found during the analyzation of all the storms. Nearly 80 percent of the storms did not have any presence of a three body scatter spike. In addition, all but two cases were located along or near a surface boundary and all but one case had a defined mesocyclone.

Deep Convergence Zone

Previous research has shown that the presence of a deep convergence zone (DCZ) can aid in the development of a large swath of giant hail. A DCZ is defined as a convergence zone coincident with the storm gust front in the low levels and extending upward along its length to an average depth of 10 km AGL (Lemon and Parker, 1996) This DCZ acts like a wall that separates the updrafts and downdrafts and keeps air stream mixing confined to a narrow area within the DCZ. This keeps the updraft from destructive mixing effects and allows the updraft to approach parcel theory values supportive of significant and often giant hail. Also, the storm contains a wide region of not one updraft but many updrafts which collectively form an extensive hail growth zone. The April 12th storm had an evident DCZ (Figure 11) with the deep convergence evident up to 10 kft which could have aided in the development of the large and giant hail despite the unfavorable environmental conditions

Conclusions/Lessons Learned

A large supercell tracked through the northern parts of San Antonio on the night of April 12, 2016 and produced a large swath of 76+

Parameter	10th Percentile	25 Percentile	50th Percentile	75th Percentile	90th Percentile	April 12, 2016 Value
SBCAPE (J/Kg)	1400	2000	2500	3000	3600	0
MUCAPE (J/Kg)	2000	2500	2750	3000	4000	750
0-6 KM Shear (m/s)	15.4	20.6	23.1	25.7	30.9	33.4
50 dBz Height (kft)	36.4	41	44	48	50	34
60 dBz Height (kft)	26.8	31	34	37	40.2	31
70 dBz Height (kft)	0	0	9	19	25.2	27
Vr Max (m/s)	17.5	20.6	25.7	30.9	41.2	51.4

Table 1: Researched Parameters

mm hail stones with a couple of cores of 101+ mm. While this storm was not forecasted well from the local WFO or national centers, there are several things that can be learned and taken away

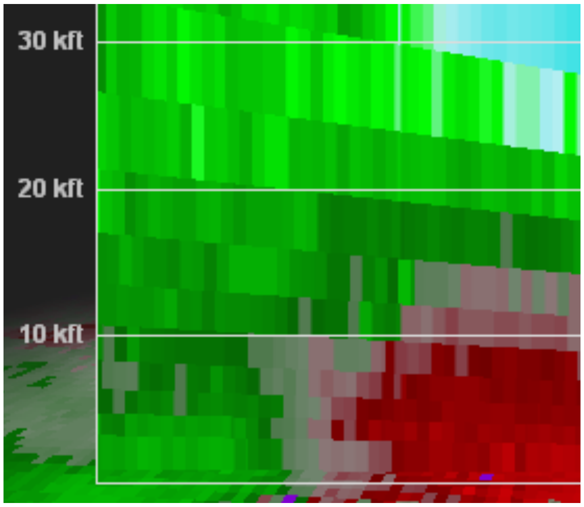

Figure 11: Deep Convergence Zone extending up to 10 kft

from this storm which can be used to improve forecasts for any possible future storms. The pre-storm environment was classified as a low-cape and high shear environment and like many large hail storms, there was a boundary present. However, one should not forecast giant hail every time these conditions occur. While it is still difficult to forecast these types of storms well in advance, there can be much to learn about forecasting the hail size in real time. This storm did give new ideas or reminders to improve real-time hail size forecasts.

Although the storm was relatively compact and not as tall as some of the other giant hail storms, it did have a vast core of 70+ dBz radar echoes throughout much of storm's hail core. In addition, the higher Vr values coincident with the 70+ dBz core could be a clue in the future that there is the potential for larger hail than normally thought given the strength of the mesocyclone and the higher reflectivities. In addition, the DCZ could also be a clue for operational forecasters to see in real-time to expect a larger hail size than one would normally expect.

There was one other case within the dataset of 49 storms which had similar pre-storm environmental conditions and future research could be done to compare these two storms. An examination of these storms could help determine if there is a missing signal that may distinguish these low-CAPE/high shear environments that have the potential to produce giant hail.

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