P2.23 Use of the Albany Hail Study to Predict Large Hail during the 16 May 2012 and 29 May 2012 Severe Weather Episodes

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1. INTRODUCTION

The National Weather Service changed the criterion for severe hail from 0.75 in. (1.9 cm) to 1.00 in. (2.5 cm) as of 5 January 2010. Many techniques have been developed for forecasting severe hail, such as the Vertically Integrated Liquid (VIL) of the Day method, VIL density and using reflectivity echo (dBZ) heights relative to the -20°C level. However, these techniques were all originally developed based on the legacy 0.75 in. severe hail criterion. Previous studies have also been based on combined large hail and severe wind reports. In an attempt to better forecast hail with the new criterion in place, the Albany (ALY) hail study project examined over 380 hail reports from the NWS Albany County Warning Area (CWA) from 2005-2010. This study has determined the reflectivity echo height values at various dBZ thresholds (50, 55, 60 and 65 dBZ), as well as gridded VIL, Storm Echo Top (ET), VIL Density and several other parameters at a storm-scale level. The study also calculated mean and median values for severe hail and produced a variety of tables and graphs, which would be potentially useful to a warning forecaster in an operational setting.

In order to evaluate the new findings, the results of the ALY hail study were applied to two cases from May 2012. These dates were chosen because it featured both severe and non-severe hail, resulting from supercells and multicells. The freezing level and height of the -20° C isotherm, based off the KALY upper air soundings, were at typical levels for warm season convection in the Northeast. According to local storm reports entered into *StormData,* these two severe weather episodes produced a total of 45 hail events. 42 of these are considered severe under the new criterion. Spotters were encouraged to forward all hail reports, regardless of size to the ALY office. However, it’s possible that some hail, especially sub-severe hail, went unreported due to falling in unpopulated areas, occurred without observers present or due to a lack of damage or impact. The 45 reported events were analyzed to see how well the mean and median values from the hail study correlated to the storms responsible for producing both severe and non-severe hail.

A storm-scale analysis of several of these hail events will be presented as examples of how the application of the hail study values can be used in an operational setting for increased confidence in the occurrence of severe hail. The values will also be shown in conjunction with other methods of storm interrogation of base and derived radar products.

2. BACKGROUND

On 5 January 2010, the NWS officially changed the criterion for severe hail from 0.75 in (1.9 cm) to 1.0 in (2.5 cm). This was based on research showing hail damage to roofing materials did not occur until hail was at least 1.0 in (2.5 cm) in diameter (Marshall et al. 2002). In addition, feedback from media and emergency managers in the NWS Central Region supported this change (http://www.weather.gov/oneinchhail/).

Differentiating between severe and non-severe thunderstorms can be difficult for operational warning meteorologists across eastern New York (NY) and western New England due to several factors. Often, limited instability causes many storms to have marginally strong updrafts, which makes for a difficult determination if a storm will produce severe hail or just fall short of the warning criterion. It is also unclear what role variable terrain plays in the storm process. Radar coverage is sometimes compromised due to nearby higher terrain as well. Finally, sparse population in rural or mountainous areas makes verification difficult or impossible for some storms. Despite not being as notorious as the Great Plains or Midwest for hail occurrence, the Northeast can still be quite active. According to the storm event database in *StormData,* the state of NY reported 323 events of hail 0.75 in or larger in diameter in 2009 (U.S. Department of Commerce 2009). Out of this sample size, 132 events or reports were 1.0 in or greater, further

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*Corresponding author address: Brian J. Frugis, NOAA/NWS Weather Forecast Office, 251 Fuller Rd, Albany NY, 12203. E-mail: brian.frugis@noaa.gov showing the need for methods to accurately predict and warn for severe hail.

While there have been a few local studies conducted regarding the prediction of hail, they all were based on the legacy 0.75 in criterion (Blaes et al. 1998; Cerniglia and Snyder 2002). Also, previous studies have concentrated on just pulse storms (Cerniglia and Snyder 2002; Miller and Petrolito 2008), while the current study shows that the majority of hail producing thunderstorms are multicell in structure. Other studies conducted nationally have generally focused on the Southern Plains (Porter et al. 2005) or Central Plains and Midwest (Donovan and Jungbluth 2007), where storms frequently grow much taller than thunderstorms across the Northeast.

The most common methods of predicting severe hail for operational warning meteorologists are based off both base and derived radar products. Viewing the height of various distinct dBZ levels (e.g. 50, 55, 60 or 65 dBZ) within a storm, especially when compared to items such as the freezing level or -20°C level, can help instill confidence of a hail threat within a thunderstorm. This is supported by Donavon and Jungbluth (2007), which suggested that there is a linear relationship between hail size and the height of the 50 dBZ echo top. Other items, such as using Vertically Integrated Liquid (VIL), can give an indication of hail, although this will ultimately depend on the thermodynamic environment in place.

3. DATA AND METHODOLOGY

A database was compiled of 384 hail events from 2005-2010 across the Albany CWA, as entered in *StormData* from local storm reports. Hail sizes ranged from 0.25 in to 2.60 in. Of the 384 events, 177 reports are considered severe under the new criterion (equal to or larger than 2.5 cm in diameter). While storm reports came from all counties in the Albany CWA, the majority of the reports were centered in and around the population centers of the Capital Region, mid-Hudson Valley, and Housatonic and Nagatuck valleys of northwestern Connecticut (CT). In addition, the freezing (melting) height and -20°C levels were recorded for each hail report from the most recent 00Z, 12Z or 18Z (when available) KALY sounding.

For each storm report, radar data from the local archive Digital Video Discs (DVDs) was loaded onto the Weather Event Simulator (WES). Radar data was principally from the Weather Surveillance Radar 88 Doppler (WSR-88D) (U.S. Department of Commerce 2009) located at East Berne, NY (KENX). Additional radar data from the WSR-88D at Binghamton, NY (KBGM), Upton, NY (KOKX), Colchester, VT (KCCX), and Montague, NY (KTYX) was also analyzed when cone of silence issues, beam blockage, and anomalous propagation (AP) made the principal radar site data suspect or unavailable. Figure 1 shows the locations of these radars in relation to the Albany CWA. This data was then analyzed using the Four-Dimensional Storm Investigator (FSI) from the Advanced Weather Interactive Processing System (AWIPS). The FSI software gives the user the ability to view the height of various dBZ levels in a storm in a four-dimensional (animate in three planar dimensions) perspective (Stumpf et al. 2006).

Radar data was examined at the time of the report, plus or minus one volume scan. This was to account for spotter errors in both place and time, as many spotters don’t report their exact location or time. This helped ensure that the most accurate values were selected for each particular report. Changnon (1970) showed that a full-grown hail stone could take up to ten minutes to fall out of an updraft and reach the surface, which could fall within about a volume scan of a report, depending on the particular Volume Coverage Pattern (VCP) in use. Any reports that did not seem to logically match up with the radar data were thrown out to maintain the integrity of the study.

Various parameters were examined and recorded for each storm report. The Constant Altitude Plan Position Indicator (CAPPI) within the FSI software (Stumpf et al. 2004) gave the ability to obtain the top of the 50, 55, 60 and 65 dBZ echoes. The level of these various dBZ core heights were recorded to the nearest hundred foot. This was verified by using the Vertical Dynamic XSection (VDX), which gave a cross-section of reflectivity radar data for a line through the core of the storm. If a storm didn’t have a particular echo core height, it was left blank for that report.

Essentially, the methodology for obtaining maximum grid VIL (GVIL) values was similar to what was done for other local studies (Cerniglia and Snyder 2002; Blaes et. al. 1998). GVIL values were provided by Display Two-Dimensions (D-2D) in AWIPS. GVIL is calculated by using the reflectivity value of a 4 km x 4 km grid for each elevation slice and integrating it through a vertical column. GVIL is displayed in a 5 kg m^{-2} range (i.e. 50-55 kg m^{-2}) for each 4 km box. The mid-point value of this range was recorded over the location in question, unless the storm was producing the maximum observed VIL value of that particular volume scan.

4. RESULTS FROM HAIL STUDY

a) dBZ Thresholds

The 50 dBZ echo top was the first of four different reflectivity thresholds examined for the study (Table 1, Figures 2 and 3). As expected, the average level of the 50 dBZ echo top was higher for the severe hail (30.9 kft AGL) as compared to the non-severe hail (27.3 kft AGL). On average, the 50 dBZ echo tops of the severe hail were 3.6 kft higher than the non-severe hail. Median values were similar (30.8 kft AGL for severe and 27.0 AGL for non-severe), which gave an indication that the reports were well distributed. Although there was a large range in the 50 dBZ echo tops of the severe hail (10.6 kft to 48.8 kft AGL), 75% of the events had a 50 dBZ echo top of at least 26.5 kft AGL.

When compared to the -20°C level, the 50 dBZ echo top for severe hail was on average 8.7 kft higher. Meanwhile, 50 dBZ echo tops of non-severe hail only averaged 5.5 kft higher than the -20°C level, a difference of 3.2 kft between the severe and non-severe hail. The median height of the 50 dBZ echo top above the -20° C level for severe (non-severe) hail was 9.4 kft (4.9 kft).

The 55 dBZ echo top was the next level examined. 97% of storms producing severe hail had dBZ values of 55 or higher. This level contained a similar signal as the 50 dBZ threshold, with the 55 dBZ echo top reaching a noticeably higher level for the severe hail events when compared to the non-severe. The average height of the 55 dBZ echo top was 27.4 kft AGL for the severe hail and 23.3 kft AGL for the non-severe hail, a difference of 4.1 kft. The median values for severe and non-severe were 27.9 kft AGL and 22.6 kft AGL respectively. 75% of storms producing severe hail had a 55 dBZ level of at least 22.5 kft AGL.

When examining the 60 dBZ echo top data, a similar pattern was observed. As was seen with the 55 dBZ echo tops, 97% of the storms that produced severe hail had reflectivity values reaching 60 dBZ or greater. The average height of the 60 dBZ echo top was 23.2 kft AGL for the storms producing severe hail, while the non-severe hail storms had an average of 18.3 kft AGL. This is a difference of 4.9 kft between the severe and non-severe hail at the 60 dBZ threshold level. Median values showed a similar pattern with severe and non-severe hail values of 23.5 kft AGL and 18.0 kft AGL respectively. 75% of the storms producing severe hail had a 60 dBZ echo top of at least 18.0 kft AGL.

The 65 dBZ echo top displayed a slight variation of the pattern, as only 81% of the storms producing severe hail had obtained dBZ values to this level or greater. Still, average values continued to maintain a strong separation between severe and non-severe hail. Severe hail had an average 65 dBZ echo top of 18.3 kft AGL, with non-severe hail 65 dBZ echo tops averaged 13.2 kft AGL, a difference of 5.1 kft. There was a similar pattern shown in the median values, with values of 18.5 kft AGL for severe hail and 11.9 kft AGL for non-severe hail. 75% of the severe storms had a 65 dBZ echo top of at least 11.8 kft AGL.

The 65 dBZ echo top threshold or greater was examined in comparison to the -20°C height. 59 hail events in the database had a 65 dBZ echo top higher than -20°C level and 45 of those (76%) produced severe hail. While it doesn't guarantee severe hail, having a tall 65 dBZ echo, especially one above the height of the -20°C level, certainly increases confidence in the potential for severe hail.

b) Vertically Integrated Liquid

The next item examined was VIL. As mentioned earlier, VIL has its limitations, as particular values can have different implications due to day to day differences in the thermodynamic environment. However, when examined in a database over time, differences between the severe and non-severe hail can easily be seen in the data. GVIL values for the severe hail ranged from 17 kg m^{-2} to 80 kg m^{-2}. GVIL values for severe hail averaged 50 kg m^{-2}, while non-severe hail averaged 44 kg m^{-2} (Table 1). These mean values were the same as the median values for GVIL, and 75% of the severe hail events had a GVIL of at least 43 kg m^{-2}.

5. DISCUSSION

There are several items from the reflectivity data worth noting in regards to gaining confidence for warning for severe hail. Nearly all storms had reflectivity values over 60 dBZ and the majority reached 65 dBZ as well. Considering that the cursor readout function in

FSI gives the warning meteorologist an instant dBZ value, this is a quick safeguard when interrogating storms for severe hail, as error due to estimating the value from the color scale won't occur.

Figure 4 displays a box and whisker plot of all four studied dBZ thresholds for severe hail. As previously shown in Figures 2 and 3, the median values were close to the mean values, which show that there is a symmetrical Gaussian distribution across the range of values. The box plot clearly shows the median and quartile values for each threshold level, allowing warning forecasters to use these values in an operational setting. Although not standard in all box and whisker plots, the top and bottom whiskers in Figure 4 depict the 90th and 10th percentiles respectively (Banacos 2011). When warning for severe hail, the median values can be used by the forecaster as a starting point when looking to issue a warning. The median level gives a better measure of the central tendency of the hail dataset (Banacos 2011). In addition, the lower quartile level (25th percentile) represents the height below which one quarter of the events produced severe hail. This can be used as a "cautionary level" for issuing severe thunderstorm warnings as most events contained dBZ echo tops at higher levels.

An item of interest displayed in the data is seen when the median levels for each of the thresholds of the non-severe storms are compared to the first quartile (25%) of the severe storms data. The values are quite close (Figure 5). Using these values as a "cautionary level" could give the warning meteorologist an indication that severe storms are a possibility, although not a certainty. As the storm evolves, the higher the dBZ levels extend through the storm; the increased confidence the warning meteorologist can have that severe hail is occurring. Also, comparing the levels in real-time to the values obtained in the database can help make warning decisions in a quick manner, without having to wait for processed derived products or algorithm output.

While many meteorologists continue to use VIL, its limited use can easily be seen in the database. Although the average GVIL for severe storms is about 6 kg m^{-2} higher than for non-severe storms, the particular values depend on the thermodynamic setup. Forecasters will need to keep in mind that abnormally high or low freezing levels and/or -20°C heights will affect what particular GVIL values to use in the warning process.

6. APPLICATION DURING 16 MAY 2012

The combination of an approaching strong upper shortwave and a surface pre-frontal trough led to the development of thunderstorms during the afternoon of 16 May 2012. Figure 6 shows the special 18Z upper air sounding taken at Albany, NY. The 0°C level was measured at 9.4 kft and the -20° C level was located near 20.0 kft. Based off the Albany Hail Study, the threshold for the 50 dBZ echo top would need to reach 28.7 kft for severe hail to be likely on this particular day.

14 hail events occurred during thunderstorms on 16 May 2012, with 12 of those reports being severe across the Albany CWA. Hail sizes ranged from 0.75" to 1.50", with the majority of the reports (10) being 1.00" in diameter. This marginal nature of the hail sizes made warning decisions more challenging. However, usage of the hail study allowed for severe thunderstorm warnings to be issued for 10 of the 12 severe hail reports. In addition, only one of the 7 severe thunderstorm warning polygons issued did not verify. (U.S. Department of Commerce, 2012).

An example is seen in Figure 7 for a thunderstorm at 2135Z over Washington County. Using FSI, this thunderstorm displayed a 50 dBZ echo top reaching 24.8 kft. When compared the hail study averages, this is much lower than the majority of the storms examined during the study. This is also well short of 28.7 kft threshold computed based off the 18Z KALY sounding. When compared to the Box and Whisker plot in Figure 4, over 75% of the severe hail reports examined in the study had a higher 50 dBZ echo top. This data all pointed towards any hail being sub-severe with this storm in question. All actual reports from this storm were indeed sub-severe, with the largest stones being 0.75" (penny size) occurring at 2135Z.

On the other hand, Figure 8 displays an FSI reflectivity cross-section screenshot of a storm at 2154Z in Saratoga County. This storm had 50 dBZ echo tops reaching 32.8 kft. This is several thousand feet above the daily threshold measured off the 18Z KALY sounding and also above the hail study's average 50 dBZ echo top for all reports of severe hail of 30.9 kft. This data pointed towards the potential for severe hail within this particular storm. As indicated, hail stones between 1.00" and 1.50" occurred between 2150Z and 2155Z.

7. APPLICATION DURING 29 MAY 2012

A widespread severe weather outbreak occurred across the Northeastern US on 29 May Albany CWA, 31 total hail events were reported with 30 of those being severe. Use of the Albany Hail Study methodology contributed significantly during this event. Hail sizes ranged from 0.75" to 3.50"

Data from the Albany hail study gave confidence not just in the existence of severe hail, but also in the potential for very large hail. An example, seen in Figure 9, is a reflectivity cross-section taken in FSI from 1649Z from a storm over Fulton County, New York. This image shows a 50 dBZ echo top of nearly 41 kft. This is well above the hail study average of 30.9 kft. Using the Box and Whisker Plot in Figure 4, this 50 dBZ echo top is even higher than the 90th percentile value of 38.8 kft, as displayed by the edge of the whisker. This would point towards the potential for a highly anomalous event. In addition, the reflectivity cross-section also shows 65 dBZ levels (as displayed as the pink color) well above 30.0 kft. This is also above the 90th percentile value for 65 dBZ displayed in Figure 4, further giving confidence that severe hail is extremely likely. As indicated, damaging 2.75" hail occurred in Stratford, New York. (U.S. Department of Commerce, 2012).

8. CONCLUSION

Preliminary lessons learned from the Albany hail study study appear to have been helpful to warning forecasters at the Albany NWS Office during two separate severe weather events in May 2012. Despite the inherent difficulties in determining the existence of severe hail, warning forecasters during these events were armed with the knowledge that severe hail, on average, had a 50 dBZ echo top of 30.9 kft and an average GVIL of 50 kg m^{-2} (Table 1). In addition, knowing that severe hail, on average, had a 50 dBZ echo top of 8.7 kft above the -20°C level (Table 1) was a useful piece of knowledge when making warning decisions. As a result, only two severe hail events (out of 12 total) were missed in the 16 May 2012 severe weather episode and only one severe hail event (out of 30 total) was missed in the 29 May 2012 episode (U.S. Department of Commerce, 2012).

While any of these parameters have limited use on their own, confidence of severe hail can be increased when using these parameters in conjunction with each other. When examining various dBZ echo tops and VIL as well as other algorithm-based derived products together, strong confidence can be 2012, as a strong cold front interacted with a very warm and humid air mass. Across the gained in the potential for severe hail for each volume scan, especially when compared to historical values.

When interrogating a storm for severe hail, it is imperative that the warning forecaster maintains situational awareness and adjusts warning thresholds and decisions based on results of the ongoing convective episode. It's worth noting that atypical situations (such as very low freezing levels or cold season events) will have much different warning thresholds than the "typical" storms, which comprised a majority of this study. While the 50 dBZ echo top height showed a positive correlation with identifying hail size, there still were particular events that went against the trend. It is also important to note that all of the values in this study have been developed for severe hail only and damaging winds and/or tornadoes may occur at any time, even in the absence of hail. It's for this reason that the warning forecaster must be vigilant in studying all base and derived products and never issue any warnings solely off these mere statistics.

Finally, the recent introduction of dual-polarization radar is considerably changing how operational forecasters interrogate thunderstorms and make warning decisions. Statistical data, such as that included in this study, will only help with this transition as the landscape of hail prediction rapidly changes over the next several years.

9. ACKNOWLEDGEMENTS

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Table 1. Average height of 50, 55, 60 and 65 dBZ echo tops (kft), average height above -20°C height (kft), and average GVIL values (kg/m^2) for both severe and non-severe hail.

	SEVERE **1.00"+ (Quarter or Larger) Hail**	**NON-SEVERE** **0.25"- 0.88" (Nickel or smaller) Hail**	**Difference**
Average Height of 50 dBZ Echo Top	**30.9 kft**	**27.3 kft**	**3.6 kft**
Average Height of 55 dBZ Echo Top	**27.4 kft**	**23.3 kft**	**4.1 kft**
Average Height of 60 dBZ Echo Top	**23.2 kft**	**18.3 kft**	**4.9 kft**
Average Height of 65 dBZ Echo Top	**18.3 kft**	**13.2 kft**	**5.1 kft**
Average Height of 50 dBZ Echo Top above -20° C Isotherm	**8.7 kft**	**5.5 kft**	**3.2 kft**
Average GVIL (kg/m^2)	**50 kg/m^2**	**44 kg/m^2**	**6 kg/m^2**

Figures:

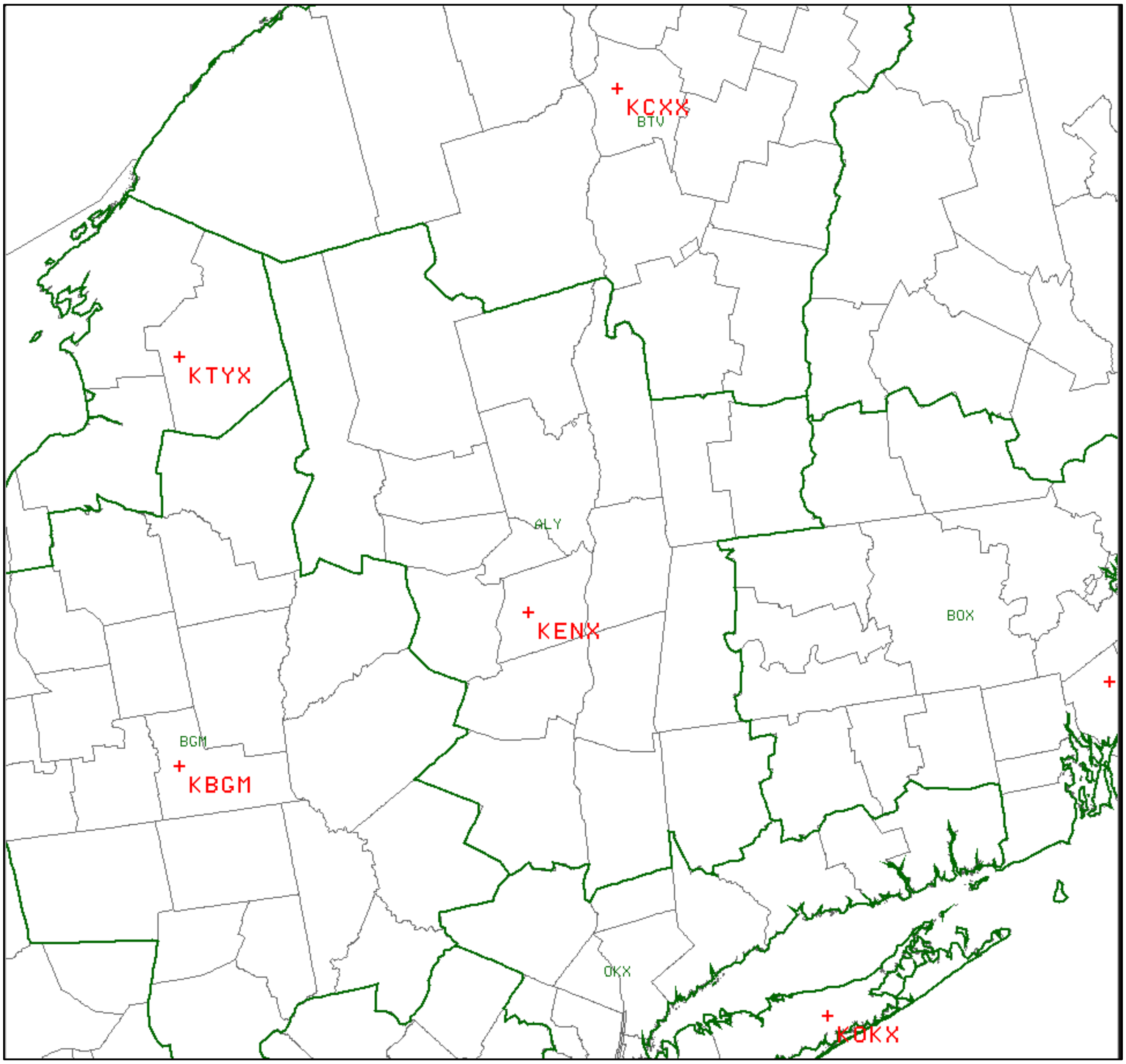


Figure 1. The various radar sites surrounding the Albany CWA utilized for the hail study.

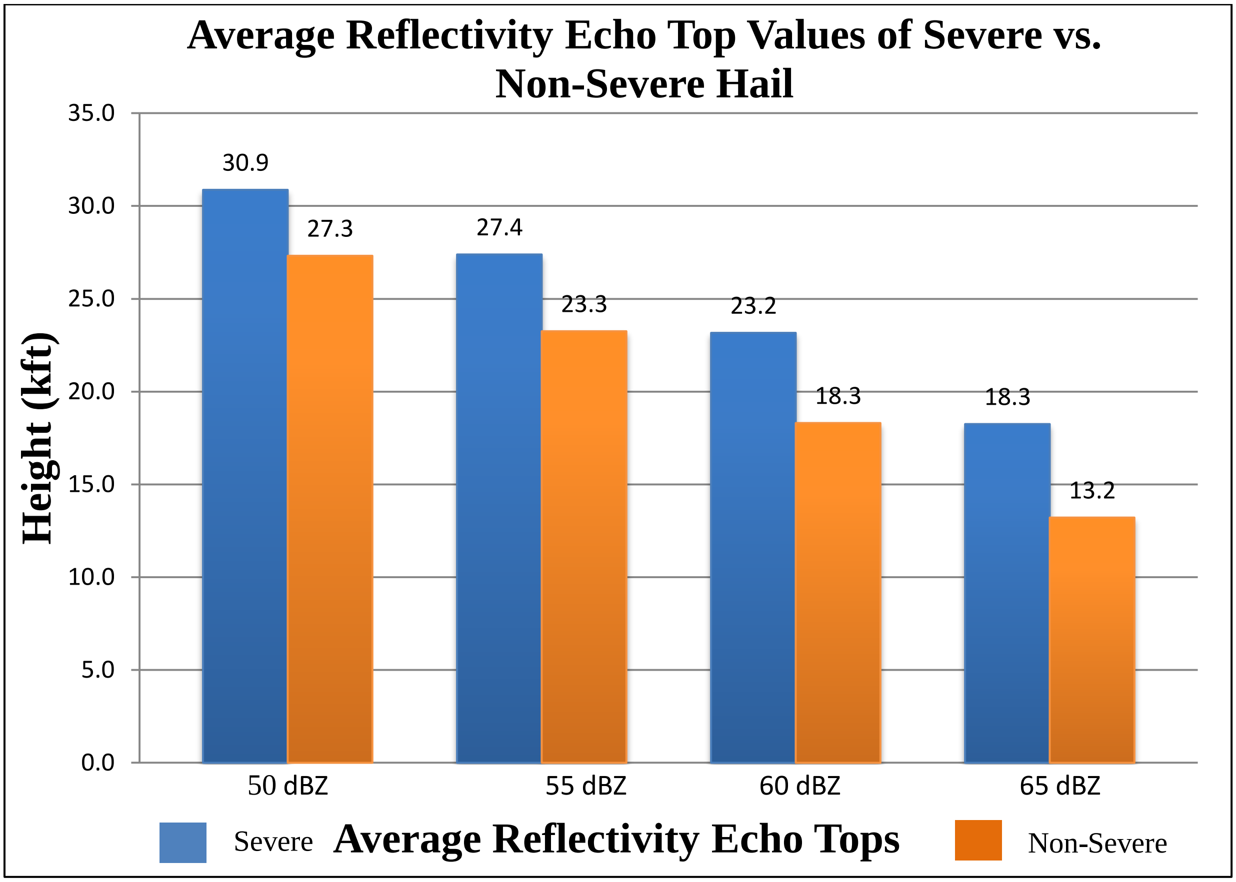


Figure 2. Average reflectivity echo top values for severe vs. non-severe hail (kft).

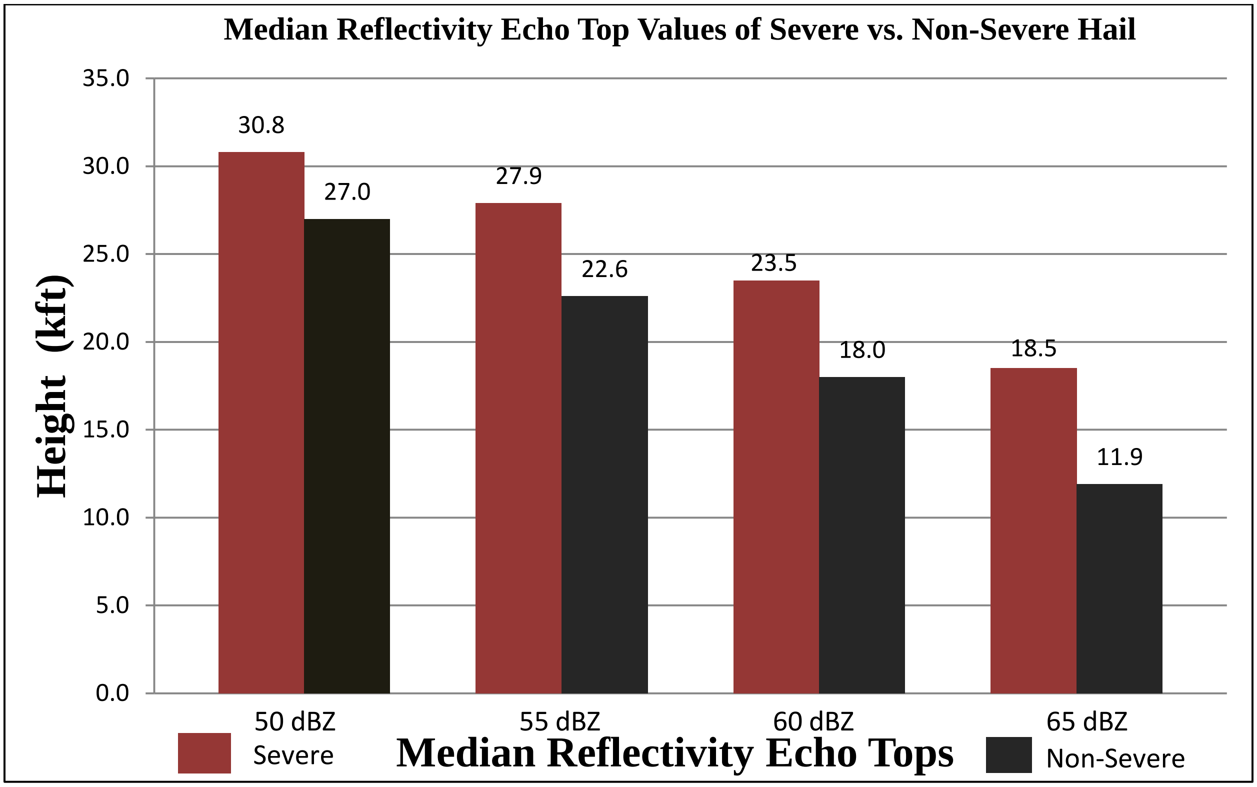


Figure 3. Median reflectivity echo top values for various thresholds for severe vs. non-severe hail (kft).

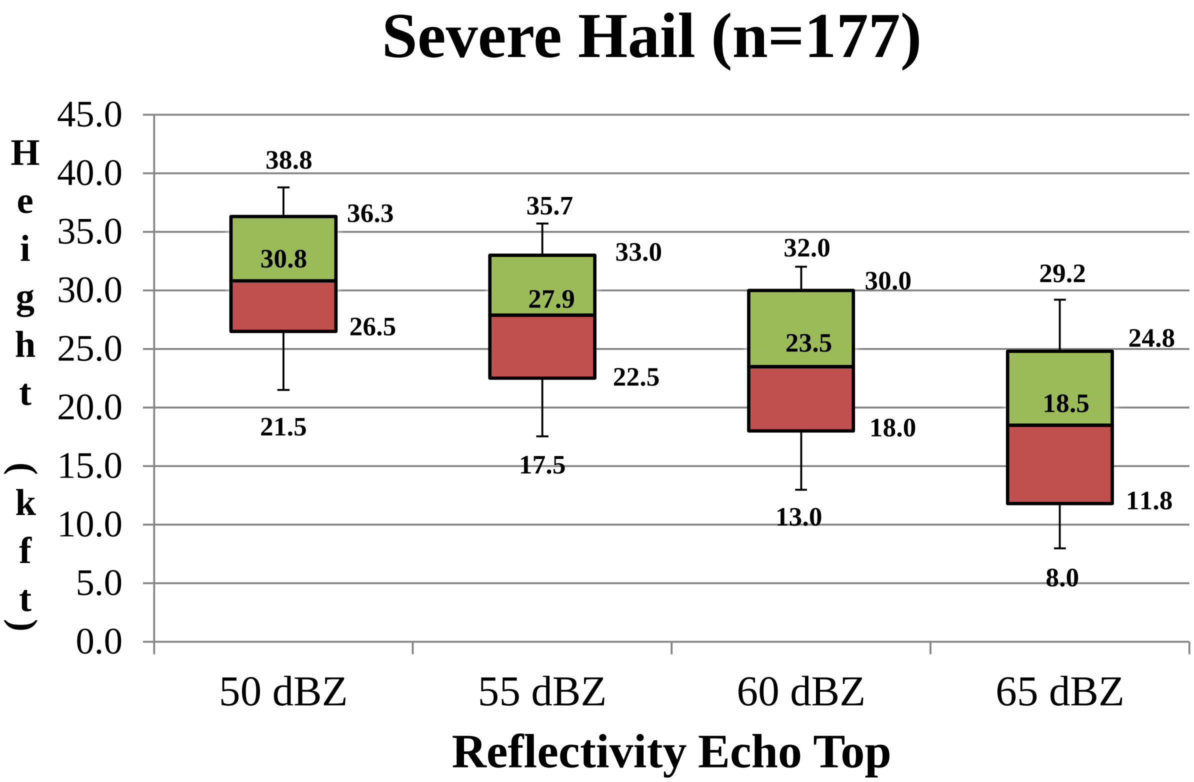


Figure 4. Box and whisker plot of various reflectivity echo top thresholds for severe hail (kft). The top and bottom of the whiskers depict the 90th and 10th percentiles respectively.

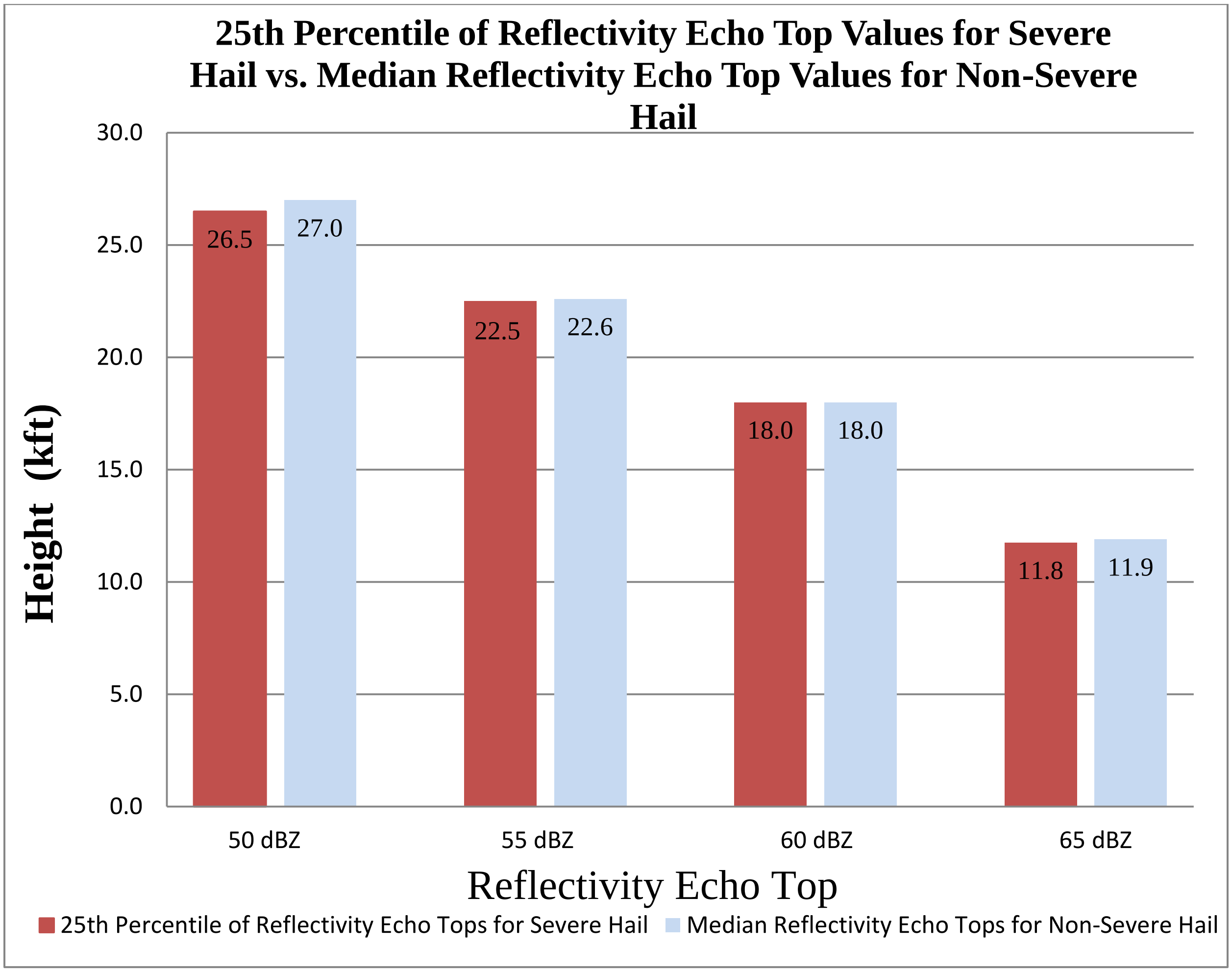
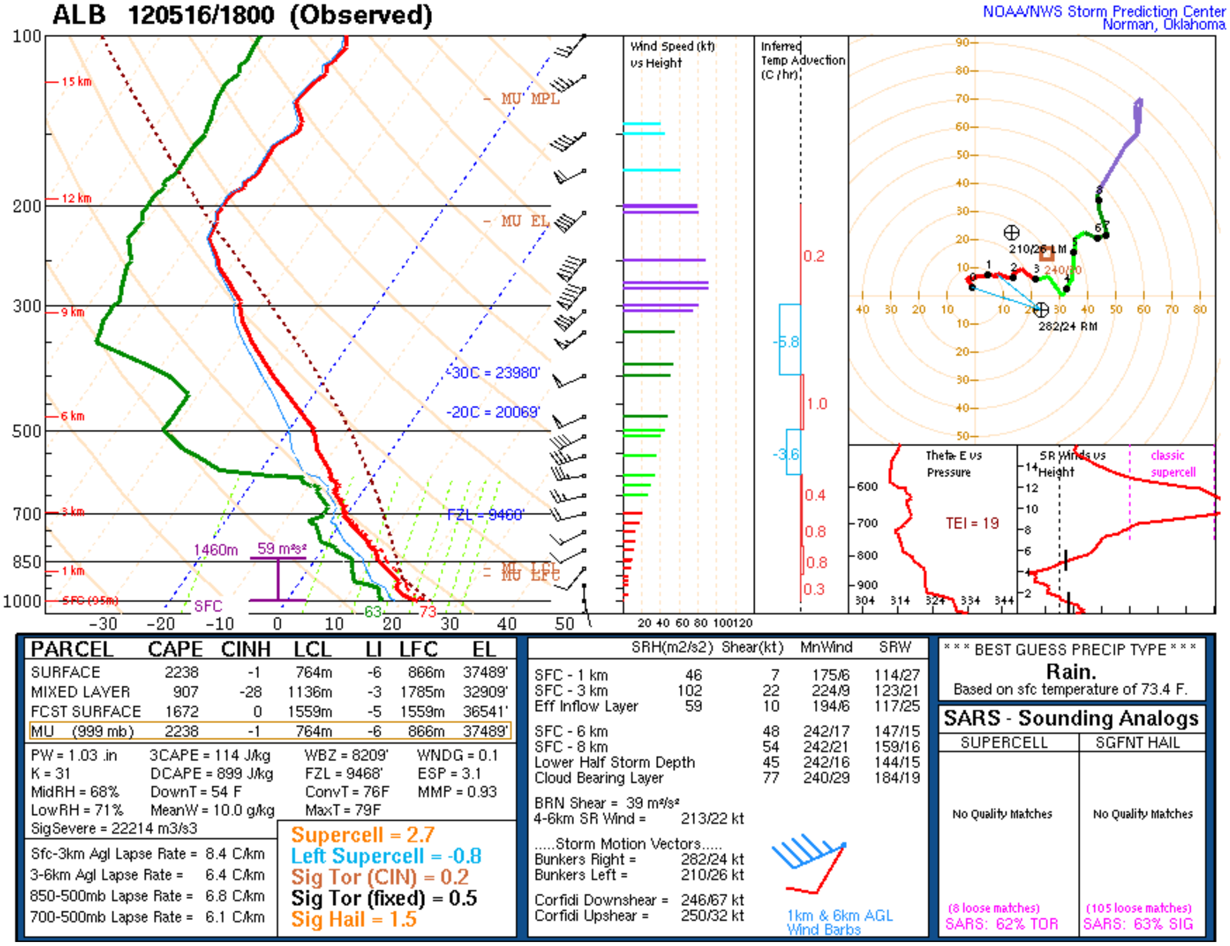


Figure 5. A comparison of the various reflectivity echo tops thresholds using the 25th percentile values for severe hail vs. the median values for non-severe hail (kft).



PARCEL	CAPE	CINH	LCL	LI	LFC	EL
SURFACE	2238	-1	764m	-6	866m	37489'
MIXED LAYER	907	-28	1136m	-3	1785m	32909'
FCST SURFACE	1672	0	1559m	-5	1559m	36541'
MU (999 mb)	2238	-1	764m	-6	866m	37489'

PW = 1.03 .in	3CAPE = 114 J/kg	WBZ = 8209'	WNDG = 0.1
K = 31	DCAPE = 899 J/kg	FZL = 9468'	ESP = 3.1
MidRH = 68%	DownT = 54 F	ConvT = 76F	MMP = 0.93
LowRH = 71%	MeanW = 10.0 g/kg	MaxT = 79F	

SigSevere = 22214 m3/s3

Sfc-3km Agl Lapse Rate = 8.4 C/km
3-6km Agl Lapse Rate = 6.4 C/km
850-500mb Lapse Rate = 6.8 C/km
700-500mb Lapse Rate = 6.1 C/km

Supercell = 2.7
Left Supercell = -0.8
Sig Tor (CIN) = 0.2
Sig Tor (fixed) = 0.5
Sig Hail = 1.5

	SRH(m2/s2)	Shear(kt)	MnWind	SRW
SFC - 1 km	46	7	175/6	114/27
SFC - 3 km	102	22	224/9	123/21
Eff Inflow Layer	59	10	194/6	117/25
SFC - 6 km		48	242/17	147/15
SFC - 8 km		54	242/21	159/16
Lower Half Storm Depth		45	242/16	144/15
Cloud Bearing Layer		77	240/29	184/19

BRN Shear = 39 m²/s²
4-6km SR Wind = 213/22 kt

.....Storm Motion Vectors.....
Bunkers Right = 282/24 kt
Bunkers Left = 210/26 kt

Corfidi Downshear = 246/67 kt
Corfidi Upshear = 250/32 kt

* * * BEST GUESS PRECIP TYPE * * *
Rain.
Based on sfc temperature of 73.4 F.

SARS - Sounding Analogs

SUPERCELL	SGFNT HAIL
No Quality Matches	No Quality Matches
(8 loose matches)	(105 loose matches)
SARS: 62% TOR	SARS: 63% SIG

Figure 6: The 18 UTC KALY Upper Air Sounding from 16 May 2012. The Freezing (FZL) level was located at 9.4 kft and the -20 °C level was located near 20.0 kft. (Image courtesy of the Storm Prediction Center)

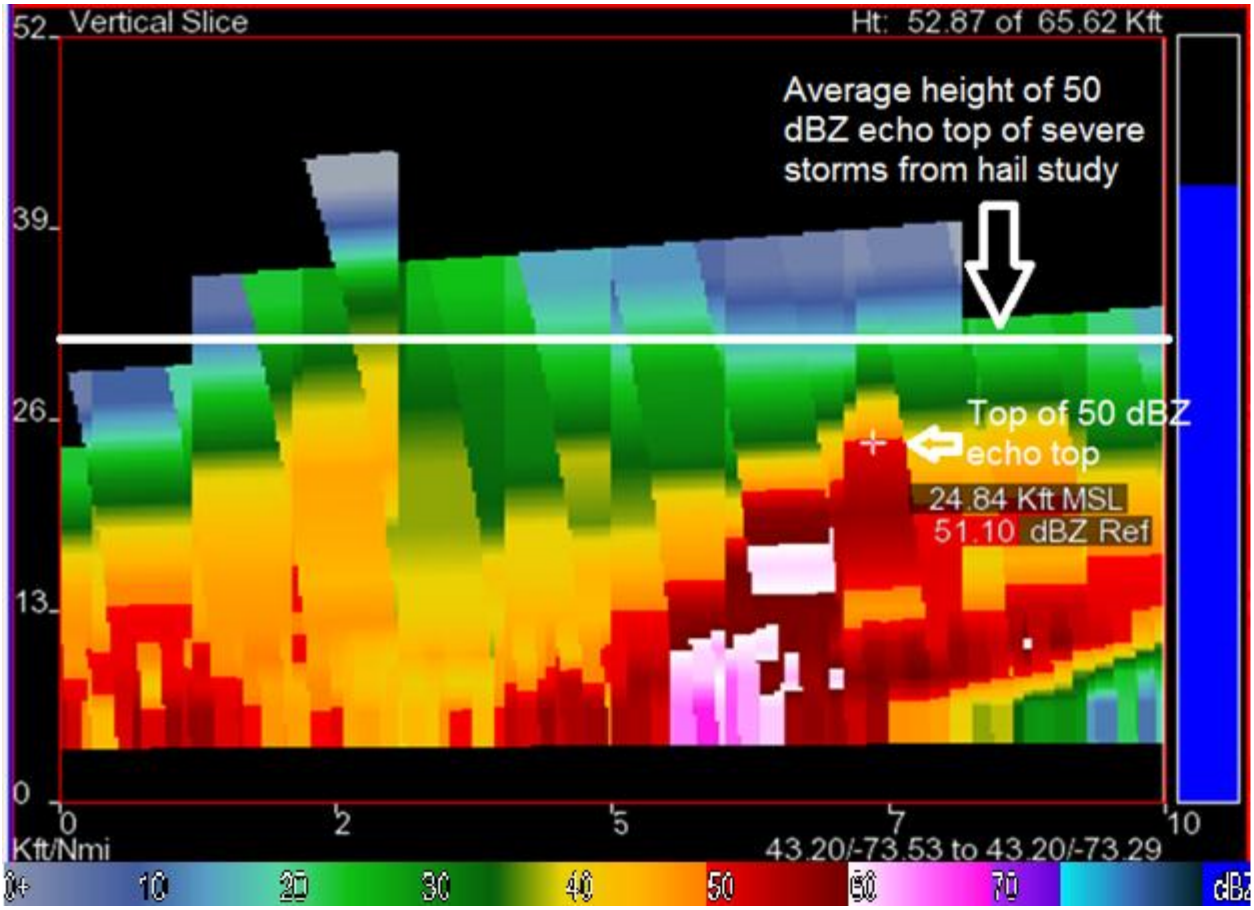


Figure 7: A vertical cross-section of a thunderstorm over Washington County, New York from 2135z (5:35 pm edt) on 16 May 2012. Using information from the ALY Hail Study would suggest that severe hail would occur when the 50 dBZ level reached 8.7 kft higher than the -20 °C level (28.9 kft in this case).

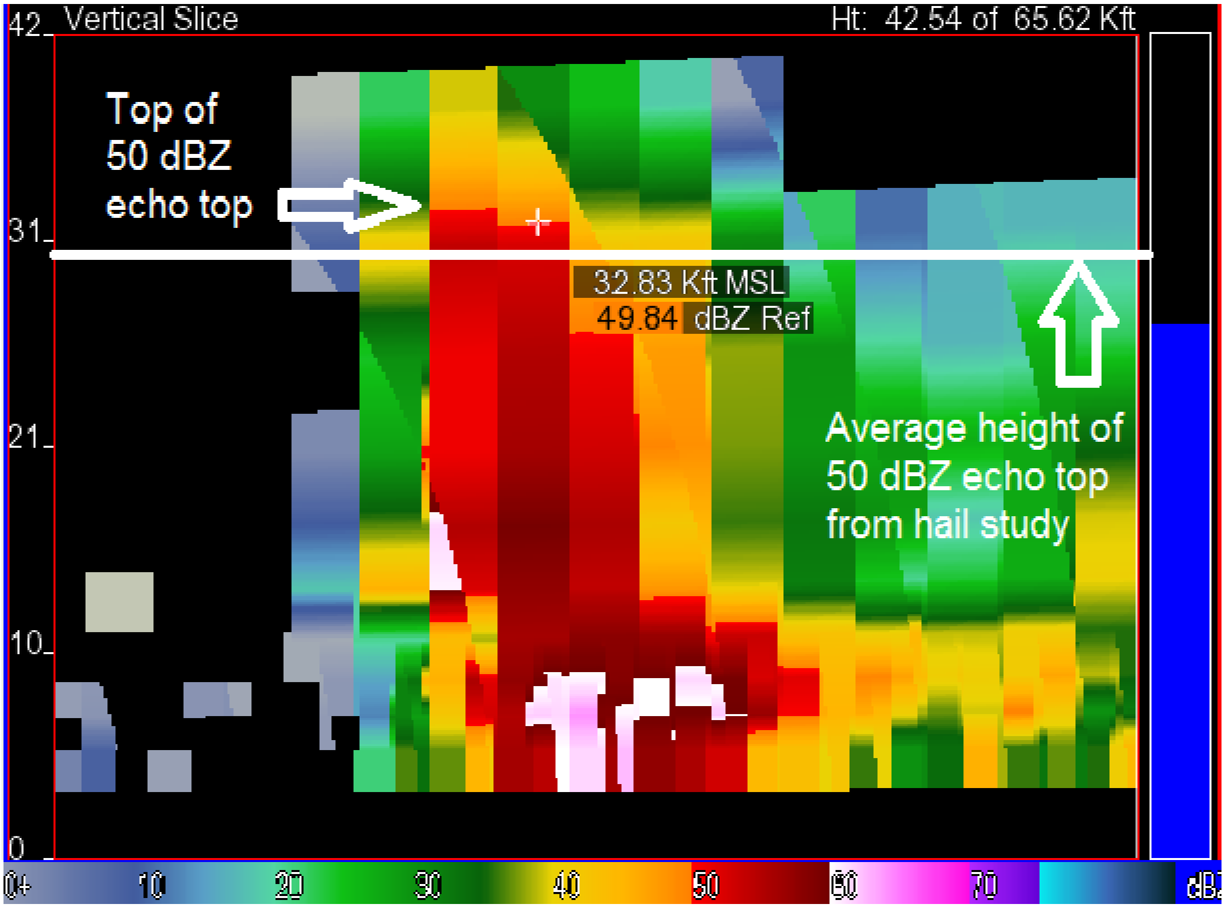


Figure 8: A vertical cross-section of a thunderstorm over Saratoga County, New York from 2154z (5:54 pm edt) on 16 May 2012. The 50 dBZ echo top exceeded the hail study's average value by 1.9 kft.

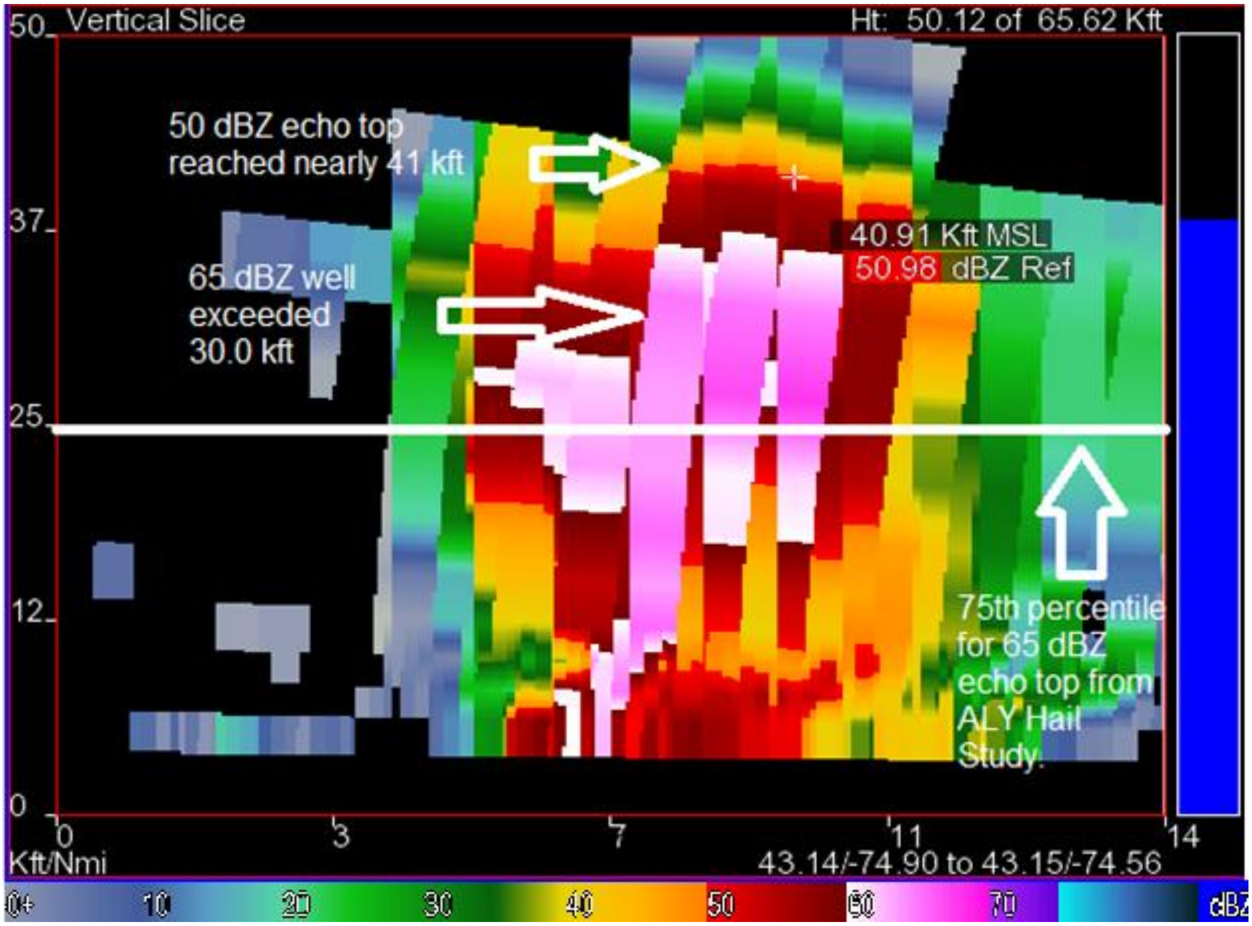


Figure 9: A vertical cross-section of a thunderstorm over Fulton County, New York from 1649z (12:49 pm edt) on 29 May 2012. The 65 dBZ echo top exceeded the hail study's 75th percentile by about 10.0 kft.