Predicting Severe Hail in the WFO LWX County Warning Area: Toward Increased Accuracy in Hail Size Forecasts

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1. INTRODUCTION

One of the challenges in National Weather Service (NWS) warning operations is differentiating radar reflectivity signatures for hail from those of very heavy rain, and subsequently identifying maximum expected hail size from reflectivity patterns. This issue becomes even more complicated when storms are located over sparsely populated areas, which makes real-time confirmation of conditions nearly impossible.

Studies to address this challenge have already been conducted for the Northern Plains (Donavon and Jungbluth 2007, hereafter DJ07) and Southern High Plains (Porter et al. 2005). Atmospheric freezing levels and storm reflectivity core heights (greater than or equal to 50dBZ) as determined from WSR-88D data were correlated in consideration of reported hail size with subsequent operational success.

The present study seeks to establish a comparable statistical database of severe hail events for the Mid-Atlantic region. Using methods developed by DJ07, rawinsonde observations (RAOB) soundings from Sterling, VA (IAD) and surrounding NWS Weather Forecast Offices (WFOs), reflectivity data from nearby WSR-88D radars, and Storm Data reports from WFO Sterling (LWX) were used to establish comparable seasonal statistics for anticipated hail size for Mid-Atlantic region thunderstorms. Results from this study are expected to better enable warning meteorologists to anticipate hail-size diameter and aid in warning decision-making with greater confidence (especially in light of the recent change to a national severe thunderstorm hail diameter criterion of 1.00 inch), thereby increasing average warning lead time.

2. METHODOLOGY

Severe hail reports occurring between January 2005 and June 2009 were first acquired using the NOAA/NWS LWX Storm Data archive. In total, 412 hail events were documented with all relevant information for each report, including date, time, latitude and longitude, hail diameter, storm environment at the time of report and storm character and structure. Report site elevations also were estimated from high-resolution topographical data.

Once all reports were documented, archived Doppler radar data from surrounding WSR-88D radars (KLWX-Sterling, KAKQ-Wakefield, KDOX-Dover, KCCX-State College, KFCX-Blacksburg) were obtained via the NCDC HAS Radar Archive system encompassing the period from 30 minutes prior to 10 minutes following each recorded event.

GR2Analyst[2] software was used to interrogate the radar data to examine hail reports for accuracy in location and timing, and to make a subjective assessment of whether the location of the report coincided with the expected location of maximum hail size.

Reports were discarded from the database if: radar volume coverage pattern (VCP) choice precluded adequate sampling of maximum 50 dbZ core height; radar data were not available; storm structure analysis determined that the report likely did not represent the maximum expected hail size in a particular storm; or, if inaccuracies in timing and location of the report could not be resolved with sufficient confidence.

Height of the 50 dBZ core was used as a proxy for updraft strength (Lemon 1980). For each qualifying report, the maximum 50 dBZ core height above radar level (ARL) sustained for two consecutive volume scans during the 20 minutes (generally 4 volume scans) prior to the report was recorded. This temporal range is consistent with results of Changon (1970), in which it was suggested a full-grown hailstone may take on the order of 10 minutes to fall out of a storm updraft and reach the surface. DJ07 also point out that this limitation facilitates the relation of a hail report to its associated updraft pulse. Core heights were converted to a reference frame above ground level (AGL) for comparison.

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Upper-air sounding data were obtained for three proximate Mid-Atlantic upper-air stations (IAD, WAL, RNK). The coordinated release soundings (1200 UTC and 0000 UTC) closest in time to each hail event along with any special release soundings (i.e. 6Z, 15Z, 18Z) were considered in order to assess a representative storm environment.

Archived Storm Prediction Center (SPC) upper air charts were evaluated for each event to assess which sounding location best represented the environmental conditions for each hail-producing storm. Freezing levels were assigned to each event based upon the sounding determined to be most representative of the storm environment. For hail report locations at significant distance from an upper air station, an interpolated freezing level was used (as in Porter et. al 2005), provided synoptic conditions suggested both soundings were similarly representative of the environment.

Freezing levels were converted to above ground level (AGL) at the station location for subsequent calculations. The freezing level at each station was assumed to be at a uniform MSL elevation across the geographical area of influence. To compute an estimated freezing level (AGL) near the site of each hail report, an elevation correction was applied to the adjusted station freezing level based upon the elevation of the hail report location (Fig. 1).

3. ANALYSIS & DISCUSSION

DJ07 stratified severe hail sizes into three bins: small (0.75 inch to 1.00 inch), medium (1.01 inch to 2.00 inch) and large (2.01 inch and greater). Beginning in January 2010, all NWS WFOs changed their hail criterion for severe thunderstorm warnings to 1.00 inch. Therefore, the medium-range bin limits were modified in this study to include 1.00 inch hail reports despite concerns that the 1.00 inch specification potentially could include reports of hailstones less than 1.00 inch in diameter whose sizes were inflated inadvertently by overzealous observers.

This study then focused specifically on hail in the medium range to help forecasters make a smoother transition to the larger hail size criterion. All quality-controlled data were organized into four sub-categories based upon the medium bin: 1.00 inch hail only (67 events) , 1.00 inch–1.25 inch hail (71 events), 1.00 inch–1.50 inch hail (76 events) and 1.00 inch–1.99 inch hail (96 events). The first and last datasets will be presented herein.

50 dBZ core heights were plotted against freezing level (Figs. 2a-2b). Linear regression with a least squares fit was used to compute the coefficient of determination, since DJ07 showed that the relationship between freezing level height and 50 dBZ core height for hail less than 2.00 inch diameter was sufficiently modeled linearly. In the present study, exponential, polynomial and power curves also were examined, however the added equation complexity contributed little improvement to the correlation coefficient (differences were roughly ±0.03).

The data focused on 50 dBZ core height for only the 1.00 inch hail reports yielded the strongest coefficient of determination (0.9011). The reports deviated no more than ±3000 ft from the least squares trend line, which was given by the equation:

Expected Core Height (ft) =
2.6247 x Freezing Level Height (ft) + 697.57

The data that includes the entire 1.00 – 1.99 inch spectrum also yielded a very strong coefficient of determination (0.8845). The least squares trend line equation for the latter case was determined to be:

Expected Core Height (ft) =
2.4184 x Freezing Level Height (ft) – 2451.5.

Decreasing correlation was noted as larger hail sizes were introduced to the dataset. This decrease makes sense: since significantly stronger updrafts are required to support increasingly larger hail, combining the larger hail sizes with the smaller hail sizes in the medium bin introduces scatter that degrades the linearity of the relationship.

Quantile regression provides a trend line equation such that a particular percentage of data points falls above the regression line. Using a selected quantile regression line as an operational warning threshold for severe hail invokes an inherent trade-off between probability of detection (POD) and false alarm rate (FAR): while POD increases as quantile is decreased, the FAR also increases; as the quantile is increased, the FAR decreases, but the POD correspondingly decreases as more events fall below the warning decision threshold. Regression lines were computed for the 0.05, 0.10 and 0.20 quantiles (color lines, Figs. 2a-2b)

The data exhibit a high correlation coefficient, suggesting the assumed linear relationship is likely a good assumption. Limited scatter present in the charts may be contributed by: the probable non-linearity of the relationship between updraft strength and increasing maximum expected hail size; the residual inclusion (i.e. reports passing through quality control efforts) of reports that were not fully representative of maximum expected hail size in a particular storm; observer error in reported hail size; error introduced by the assumption of a uniform freezing level; undetected error in the location of a report; and error introduced in computing elevation adjustments. The combination of the latter source of error and errors in report location may have a significant impact in locales where the elevation gradient is sharp, as an incorrect placement for a report could yield elevation factor deltas of greater than 500 ft.

The slope of the regression line for 1.00 – 1.99 inch hail obtained in this study (~2.42) is significantly shallower than those obtained for the Northern (~3.3) and Southern (~3.0) Plains studies, notwithstanding the modified medium-range bin definition. Given the differences in atmospheric thermodynamic structure between the Plains and Mid-Atlantic, this is a surprising result, as a deeper moisture profile (as often characterizes spring and summer season in the Mid-Atlantic) is generally thought to increase hail melting rates, thus requiring a deeper core (and hence a steeper regression slope) to generate hail 1.00 inch in size.

The authors cannot explain this discrepancy thermodynamically, but speculate that inaccuracy of reported hail sizes and, especially, errors introduced through the elevation adjustment factor application, may contribute to such discrepancies. The elevation correction was not a component of the DJ07 methodology, but was a component of the Porter et al. (2005) methodology. However, elevation variance in the Southern High Plains is much more gradual than that in the WFO LWX forecast area. Therefore, any errors contributed by the application of an elevation correction factor in the Southern Plains study would have less effect on the overall results. Despite these concerns, several recent Mid-Atlantic 1.00 inch hail reports independent of this study fit closely to the computed regression line, lending confidence to its correctness.

4. OPERATIONAL APPLICATION

The equation(s) for the chosen quantile trend line(s) and hourly-updated objective analysis freezing level fields can be combined to generate a sampling overlay for use in NWS Advanced Weather Interactive Processing System (AWIPS) all-tilts radar data sampling displays (Fig. 3). In this display, the user samples a reflectivity image and obtains the elevation (AGL) of the core being sampled, as well as the values computed by application of the freezing level data to the regression equations. Thus, the radar meteorologist can compare the observed core height to the expected core heights required to produce 1.00 inch hail. Indeed, the greater the value of the observed core height above the expected core height, the greater confidence the forecaster may derive in forecasting hail sizes greater than 1.00 inch. The utility of such an overlay will be investigated at WFO LWX.

5. ACKNOWLEDGMENTS

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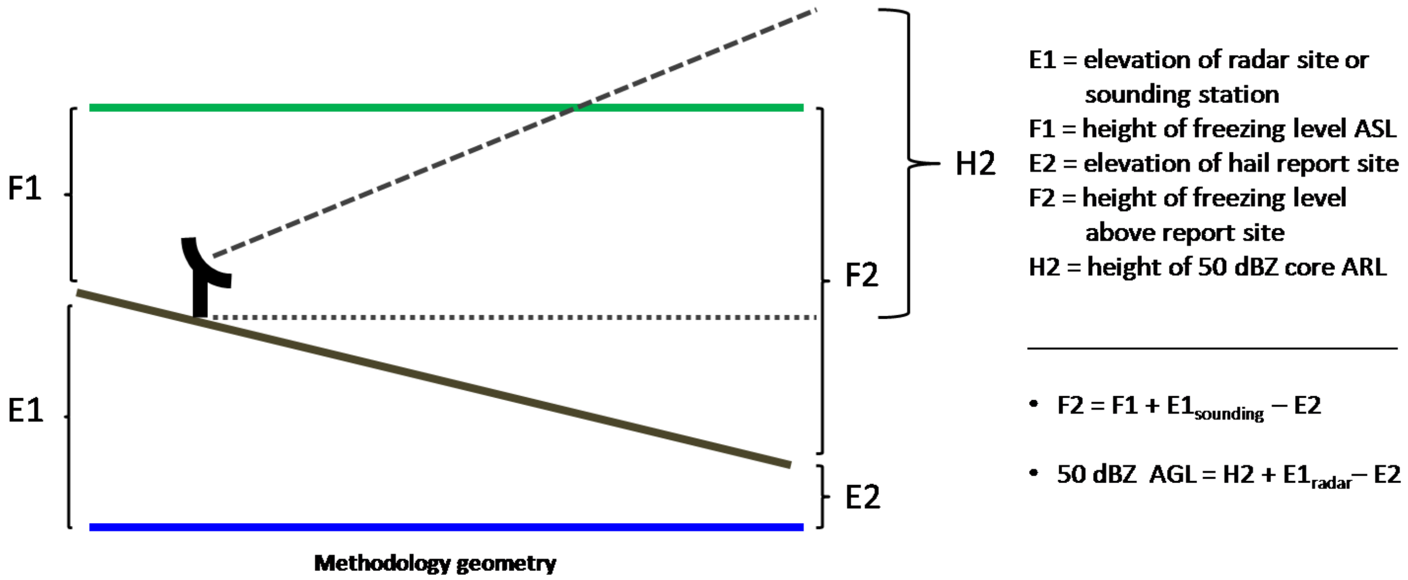


Figure 1. Geometry for computing the elevation correction factor applied to the core height and freezing level data based upon the location of storm reports.

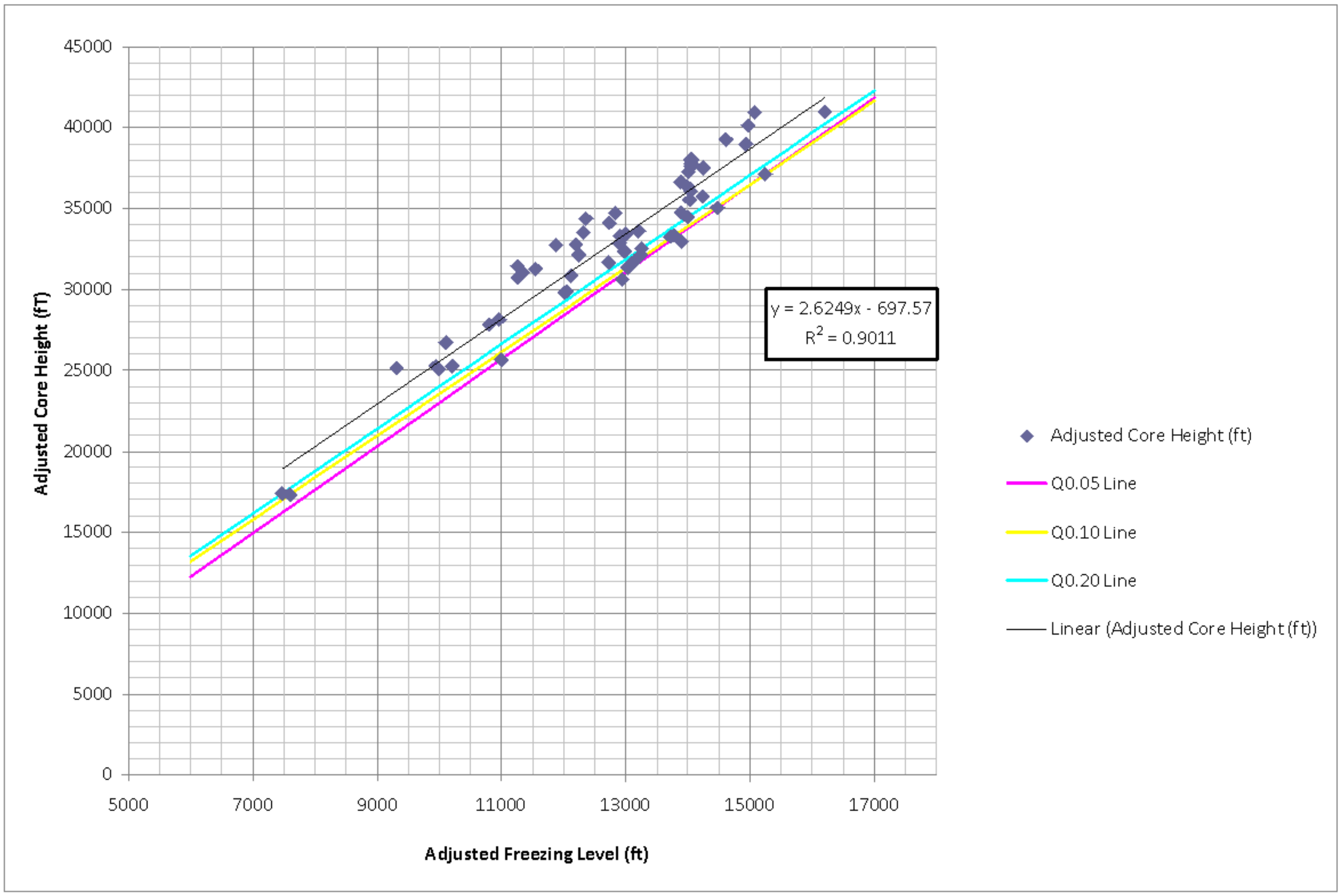


Figure 2a. Scatter plot of adjusted freezing level (ft) vs. adjusted core height (ft) for only 1.00 inch hail. Solid black line shows the least squares linear regression line. Pink, yellow and blue lines show the 0.05, 0.10 and 0.20 quantile regression lines.

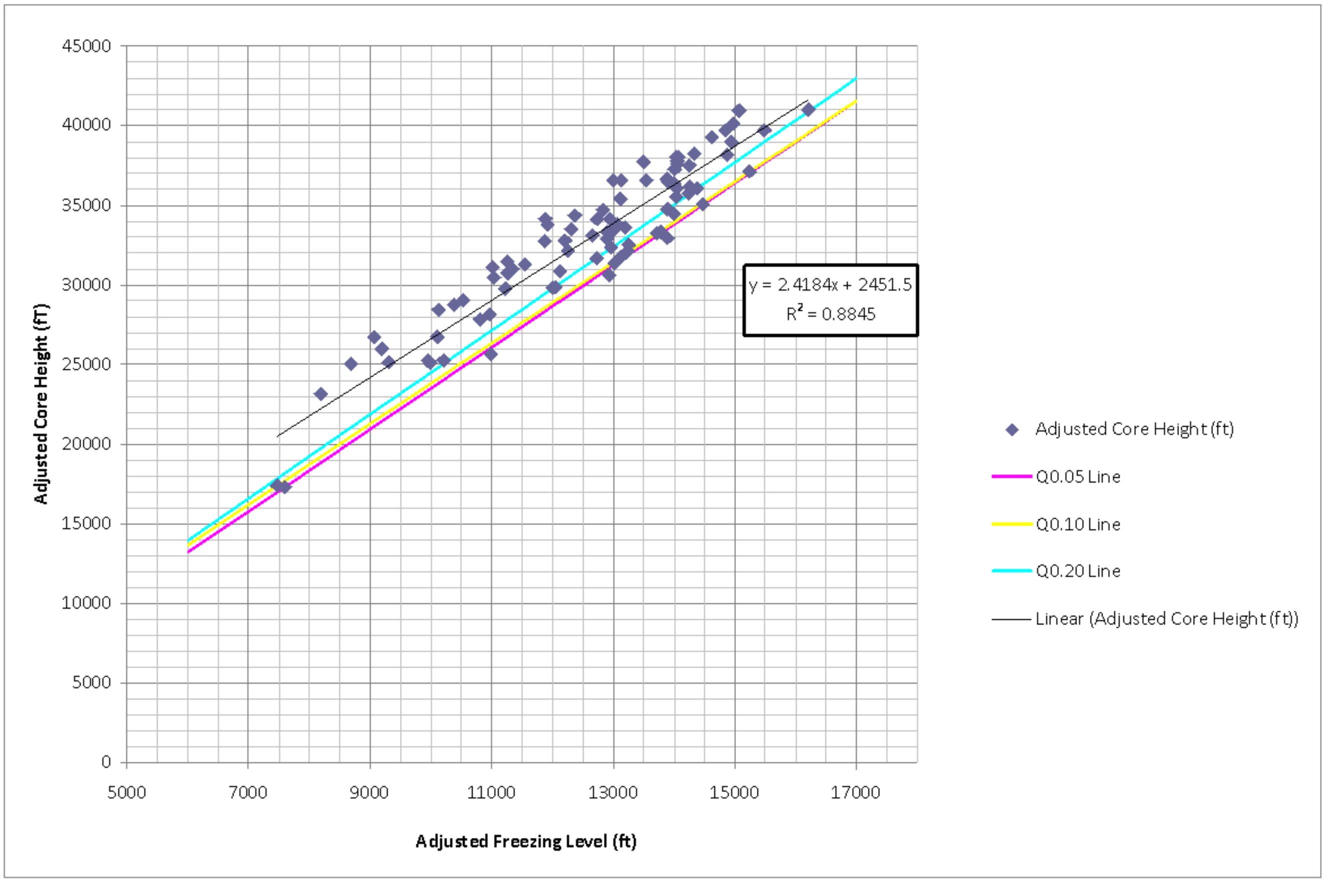
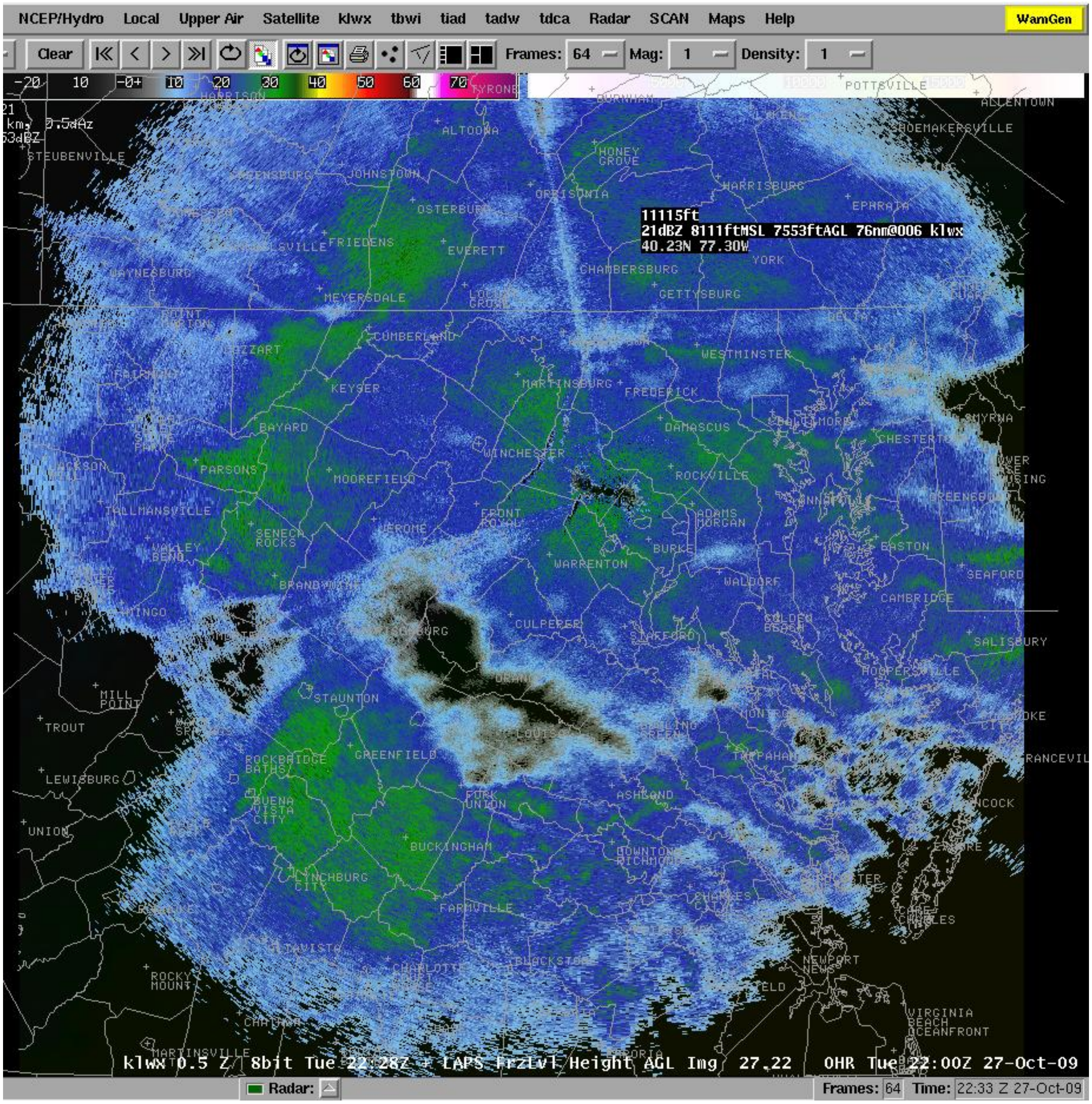


Figure 2b. Scatter plot of adjusted freezing level (ft) vs. adjusted core height (ft) for 1.00-1.99 inch hail. Solid black line shows the least squares linear regression line. Pink, yellow and blue lines show the 0.05, 0.10 and 0.20 quantile regression lines.



11115ft
21dBZ 8111ftMSL 7553ftAGL 76nm@006 klwx
40.23N 77.30W

klwx 0.5 Z 8bit Tue 22:28Z + LAPS FrzLvl Height AGL Img 27.22 0HR Tue 22:00Z 27-Oct-09

Figure 3. AWIPS radar all-tilts display with sampling enabled. In this example, a 21 dBZ echo was sampled at ~7500 ft elevation AGL. Accounting for the freezing level (in this case, derived from LAPS data), based upon the regression equations obtained in this study, a 50 dBZ or greater reflectivity core sustained for two scans at 11115 ft is expected to be capable of generating hail 1.00 inch diameter or greater.