Severe Hail Detection Technique using Reflectivity and Freezing Level Height for the Boise Weather Forecast Office County Warning Area

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1. Introduction

To assist forecasters in differentiating between severe and non-severe hail producing thunderstorms, a severe hail detection technique used by offices in the Central Plains (Porter et al. 2005; Donavon and Jungbluth 2004) has been adapted for the WFO Boise County Warning Area (CWA). Based on previous studies, a database comparing freezing level data from Rawinsonde Observations (RAOBs) soundings and height of the thunderstorm core (values greater than or equal to 50 dBZ) from regional radar data was created. This information was then correlated using a linear regression between hail size and 50 dBZ core heights to create severe hail warning guidance. Donavon and Jungbluth (2004) and Donavon, R. A. (2007) have shown improved probability of detection (POD) and false alarm rate (FAR) scores, as well as increased lead times for severe thunderstorm warnings as a result of using their severe hail detection criteria. The goal of this study is to investigate the severe hail detection technique, as developed by Donavon and Jungbluth, for the Boise CWA and examine its applicability to this region and potential operational use.

2. Data and Procedures

A database of severe hail reports for the Boise CWA was compared with the highest 50 dBZ reflectivity core heights for each report. Hail reports, using the three quarters of an inch severe hail criteria, between 1998 and 2008 for the Boise CWA were obtained from Storm Data (National Climate Data Center). There were a total of 101 reports. Core heights were determined from the Boise (KCBX), Pocatello (KSFX) and Pendleton (KPDT) Doppler radars. The radar that was closest to and had the clearest view of the storm centroid was used on a storm by storm basis. Freezing level data were collected from the 12z, 00z and 18z (if available) Boise sounding (KBOI) for each severe storm report.

Reports were removed from the database based on quality control methods established by Donavon and Jungbluth. A report was removed if radar data was not available, or if radar data obtained used Volume Coverage Pattern (VCP) 21, 31, 32, or 121. A vertical gap between high elevation scans in VCPs 21 and 121 can lead to unrepresentive storm core heights, especially at greater distances from the radar (Porter et al. 2005). VCPs 31 and 32, also known as clear air mode, take ten minutes to complete one volume scan of 5 elevation angles making it less ideal for storm interrogation. VCPs 11, 12, 211, and 212 are more useful, particularly within a 37 nm radius of the radar, as they include a denser sampling of various elevation angles (Porter et al. 2005). If either distance from the radar or terrain prevented a thorough sampling, the report was removed. A report was also removed from the database if it was associated with a weak updraft which failed to sustain an elevated core for more than two consecutive volume scans. Morning and Afternoon RAOB freezing levels were compared and the most representative freezing level was used for each report. Reports were flagged for further analysis if the RAOB freezing level looked unrepresentative of the storm environment. This was more commonly seen with passage of a cold front.

The highest 50 dBZ height reached within four volume scans prior to each report was used for comparison with the freezing level height. These limits were consistent with Changnon (1970), which showed that a full-grown hail stone could take up to ten minutes to fall out of an updraft and reach the surface. KBOI sounding data were obtained from the University of Wyoming (http://weather.uwyo.edu) and Plymouth State College (http://vortex.plymouth.edu) to identify the freezing level.

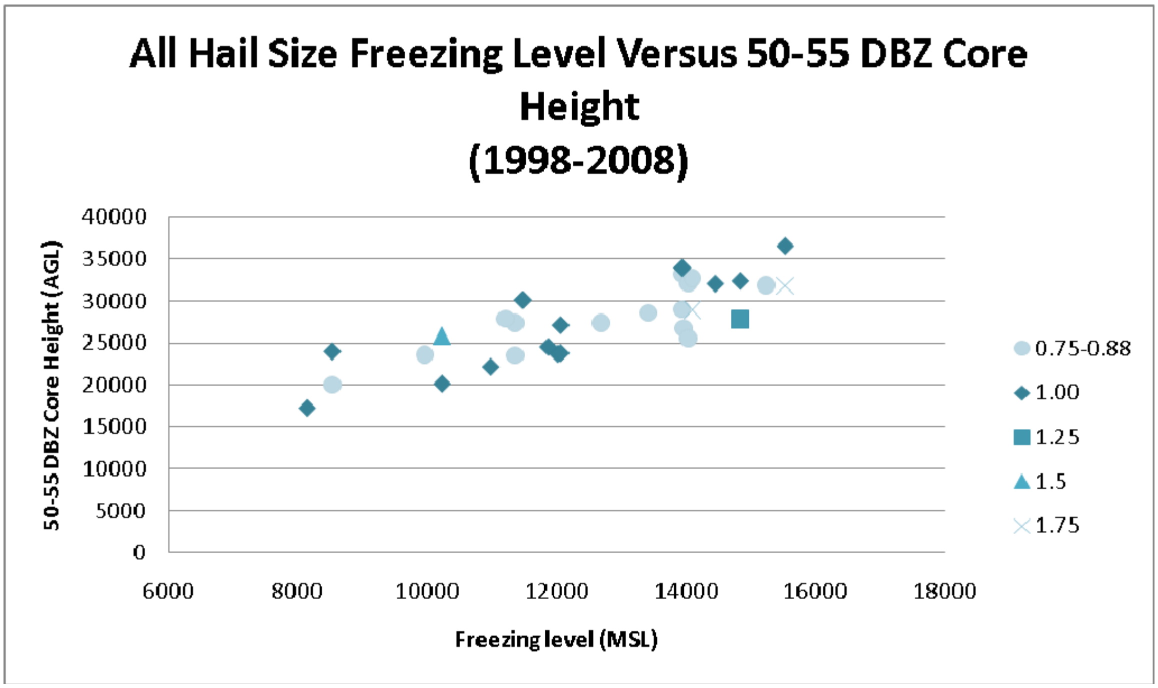

Figure 1: Hail Size distribution

3. Results

After the quality control steps were completed, only 29 cases (approximately 30 percent of the initial dataset) remained. However, on 01 June 2009, the National Weather Service (NWS) Central and Western Regions changed the definition of severe hail from three-quarters of an inch in diameter to one inch. Accounting for the change, the total number of reports from 1998 to 2008 dropped from 98 to 44. After the quality control steps, only 17 of the 44 cases (approximately 38 percent) could be used. A majority of cases removed from the dataset (approximately 78 percent) because the radar volume coverage scan was in VCP 21 or 121, bad event times and/or location from local storm reports and distance from and beam blockage of the radar. This dataset was too small to give definite indicators on hail size distribution as seen with similar studies (Porter et al. 2005; Donavon and Jungbluth 2004; Donavon, R. A., 2003); even when considering the earlier hail criteria of three quarters of an inch (Fig. 1). Only 10 percent of the original dataset (98 reports) had hail 1.50 inches or greater over the eleven year period. Only 4 of these reports could be used in the study, so a definitive warning threshold for large hail size (1.50 inches or greater) could not be reliably obtained.

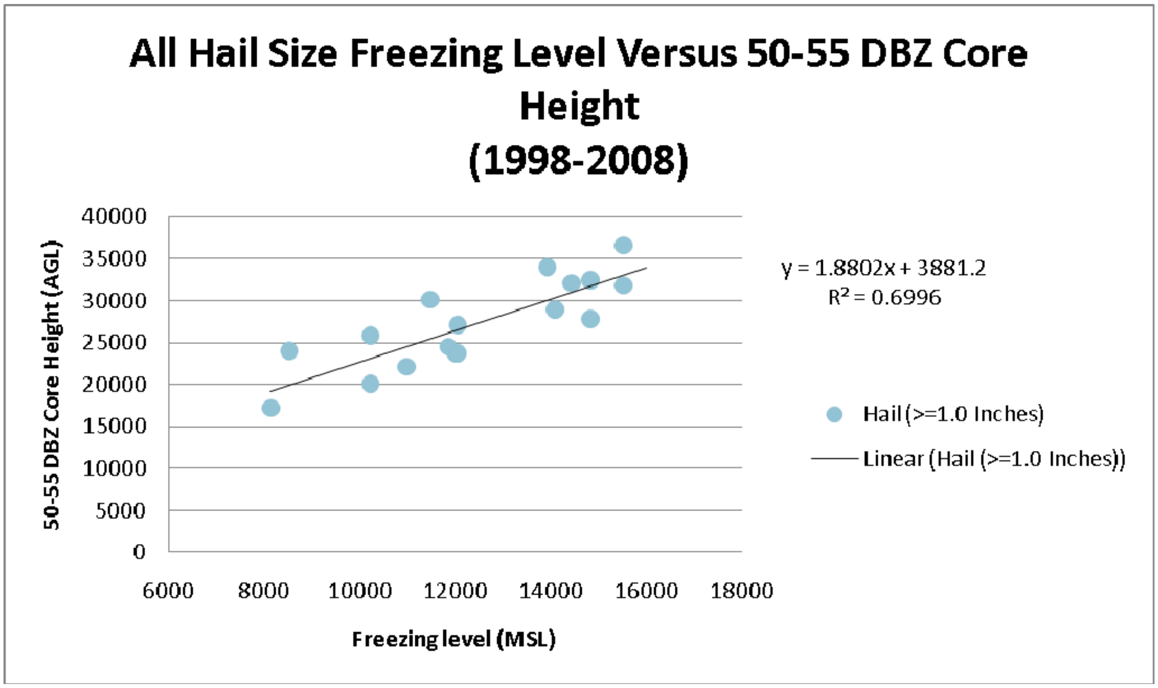

Figure 2: Best fit regression line for all hail sizes an inch or greater.

A statistical analysis technique using a least square fit was performed on the dataset to determine the best-fit regression line for hail an inch in diameter or greater. A best-fit regression line was also preformed on the entire dataset including hail reports using the old three-quarters of an inch severe hail criteria for comparison. The regression results using both hail criteria were very similar. The one inch severe hail criteria results, shown in (Fig 2), will be presented as this is the official severe hail criteria for NWS severe thunderstorm warning product. Results from the linear regression for severe hail in the Boise CWA between 1998 and 2008 are given in Table 1. The correlation coefficient of 0.8361 (Table 1) suggests the severe hail detection technique could have operational value.

	Hail >= 1.00"
Y =	1.8802(X) + 3881.2
Slope	1.8802
R^2	0.6992
R	0.8361

R^2 = Coefficient of Determination

R = Correlation Coefficient

Table 1: Linear Regression Results for Severe Hail an inch or greater

The regression line slopes from the Porter et al. (2005) (Southern High Plains/West Texas) and Donavon and Jungbluth (2004) (Central Iowa) studies of 3.0 and

3.3 respectively are significantly different from the Boise slope of 1.88 (Table 1). This means that for any freezing level height, the approximate 50 dBZ core warning height for severe hail is higher in the Central Plains than in the Intermountain West. It should be noted that both Porter et al. (2005) and Donavon and Jungbluth (2004) studies included three-quarter inch diameter size hail in there regression line calculations. Both studies also grouped hail sizes together in small, medium and large bins and preformed best-fit regression line for each group size. Typically, the inch diameter hail size or greater was put into the medium size group. The small number of cases could be one explanation for the difference. Given the small sample size, minor errors in hail size or freezing level could significantly skew the linear regression.

Another reason for the differences in the regression lines could be vertical moisture distribution between geographic regions. Moisture profiles in the Intermountain West are significantly different from the Central Plains. Moisture commonly extends through a deeper layer of an atmospheric column in the Central Plains than in the Intermountain West where a drier elevated mixed layer is more common. Rasmussen and Heymsfield (1987) found that hail melts slower in dry environments than in moist environments. This could account for the lower 50 dBZ core heights required for severe hail in the Intermountain West resulting in a more shallow regression slope and a larger y-intercept as seen in this study and noted in Porter et al. (2005).

The higher elevations of the Intermountain West allows less time for hail stones to melt as they fall through the warmer lower levels. Majority of the population in Southern Idaho lives in the Snake River Plain in Southern Idaho which varies in elevation from as low as 2000 feet at the Oregon-Idaho Border to 4500 feet above mean sea level (MSL) in the Western Magic Valley in the central part of the Snake River Plain. Lower valleys in Southeast Oregon range in elevation from 2000 feet to 4300 feet MSL. As an example, consider a freezing level of 13000 feet MSL for a storm at Boise, Idaho (elevation 2857 feet MSL) and Des Moines, Iowa (elevation 964 feet MSL). Boise, ID is almost 2000 feet higher than Des Moines, Iowa making it closer to the freezing level. The closer proximity to the freezing level could also account for the lower core heights for severe hail when compared to the Porter et al. (2005) and Donavon and Jungbluth (2004) studies.

4. Conclusions

Initial results suggest a linear relationship between the 50 dBZ reflectivity cores and freezing level for the Boise CWA. This suggests that the severe hail technique developed by Donavon and Jungbluth (2007) could assist in warning decisions. Recommended warning criteria for severe hail (hail size of an inch or greater) were calculated from the linear regression line and shown in Table 2. The core height values were rounded to the nearest thousand feet for easier use. As an example, for severe hail with a freezing level of 12000 feet MSL, the 50 dBZ reflectivity core would need to be around 26000 feet AGL. Given the small number of cases and other factors already discussed, the warning criteria should be used with caution. More cases in the dataset are needed, especially for large hail (1.50 inches in diameter or greater), to determine potential hail size from 50 dBZ core height using this technique.

Freezing Level (MSL)	**50 dBZ Core Warning Approximation Height (AGL)**
5000	13000
6000	15000
7000	17000
8000	18000
9000	20000
10000	22000
11000	24000
12000	26000
12500	27000
13000	28000
13500	29000
14000	30000
14500	31000
15000	32000

Table 2: Recommended Severe Hail Warning Criteria for Boise CWA.

The severe hail warning criteria should be used with an awareness of the storm structure and environment. Changes in the thermodynamic profile across the CWA, such as a cold frontal passage, will affect the freezing level heights ahead and behind the front. The warning forecaster should account for elevation changes when selecting the 50 dBZ core warning approximation height based on a particular RAOB sounding. An increase or reduction in elevation may decrease or increase respectively the melting potential. The majority of hail cases used in this study occurred in the lower valleys below 5000 feet in elevation. The 50 dBZ core warning approximation height in Table 2 for a storm over an area above 5000 feet in elevation could be too high. How ground elevation changes affect the warning criteria for a storm was not part of the scope of this paper, but warrants future study.

No evaluation has been done on the recommended severe hail warning criteria for the Boise CWA. An evaluation of the recommended warning criteria for the Central Plains was done by Donavon and Jungbluth (2007). Their study compared the performance of the recommended warning criteria based on the best fit regression line to the 90th and 95th percentile regression lines for a test group of hail events (Nine hail-event days over seven NWS warning and forecast areas). The recommend warning criteria performed better based on the Critical Score Index (CSI) score of 0.72 from 106 positive event detections with 83 of those detections verified by severe-sized hail. Compared to the 90th and 95th percentile criteria CSI of 0.66 and 0.69 respectively had 124 and 116 positive detections respectively and verified 86 and 85 of those detections respectively. The False Alarm Rate (FAR) was also lower (0.22), but had a lower Probability of detection (POD) 0.90 as the criteria missed 9 hail events. Quantile regression was not applied to the Boise severe hail database, though it could be useful in determining the lowest thresholds for severe hail.

This study did not attempt to compare results with the current Hail Detection Algorithm (HDA) included with WSR-88D software. There have been several advances to improve the radar derived products (Graham and Nelson, 1998) however, the HDA requires a full volume scan before the products are updated. The delay, especially in rapidly developing storms, could cost valuable warning lead time. Warning decisions could be made before the volume scan is complete if the severe hail threshold has already been met. The AWIPS all-tilts display is recommended to view base radar data for analysis of real-time vertical storm structure.

5. Acknowledgment

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