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PREDICTING SEVERE HAIL FOR THE SOUTHERN HIGH PLAINS AND WEST TEXAS

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1. Introduction

One of the challenges encountered within NOAA/National Weather Service (NWS) warning operations is differentiating between severe and non-severe thunderstorms. These issues become even more complicated when potentially severe thunderstorms are located over sparsely populated areas, making real-time verification nearly impossible. In addition, incoming reports to individual NWS offices may contain misleading or inaccurate hail measurements. This is generally related to over- or underestimation of hail diameter from inexperienced or untrained observers.

Previous and current hail studies throughout the nation have developed a statistical and climatological database that provides guidance on when to issue severe thunderstorm warnings for severe hail (Amburn and Wolf 1977; Lemon 1977 and 1980; Turcotte and Vigneux 1987). More recently, Donavon and Jungbluth (unpublished at this time, personal communication) investigated severe hail events in the Upper Midwest and Central Plains through the early part of the current decade. Their latest research compares atmospheric freezing levels based on Rawinsonde Observations (RAOBs) and Rapid Update Cycle (RUC) model proximity soundings to thunderstorm reflectivity core heights (values greater than or equal to 50 dBZ) from regional WSR-88D data. The information was correlated using a linear regression correlation between hail size and reflectivity core heights with subsequent operational success. Their method is an alternative to using slow and sometimes unreliable derived products that are generated by the Radar Product Generator (RPG).

The scope of this study is to apply the technique developed by Donavon and Jungbluth to the Southern High Plains and West Texas and examines its applicability to this region given differences in terrain and weather patterns. The ultimate goal is to help operational forecasters better anticipate severe hail and issue detailed severe thunderstorm warnings in a timelier manner and with a higher degree of confidence. A database of severe hail reports for the Amarillo (AMA), Lubbock (LBB), and Midland (MAF) forecast areas was compiled and the events compared to the highest 50 dBZ reflectivity core height. Core heights were determined from local Doppler radars for each report. A preliminary analysis covering 2004 storm data is presented here. Future analysis will be expanded to include the eastern plains and mountainous terrain of New Mexico.

2. Data and Procedures

Severe hail reports were obtained using Storm Data (National Climatic Data Center) for 2004 from the AMA and LBB forecast areas, as well as the northeastern half of the MAF forecast area. This includes the region along and north of the Pecos River Valley. The remainder of the MAF forecast area will be evaluated at a later time and was removed because of the mountainous terrain. The elevation difference for the region of interest ranges from approximately 450 m (1475 ft) to 1300 m (4250 ft) above mean sea level (MSL). WSR-88D data was obtained from the National Climatic Data Center (NCDC) website (http://www.ncdc.noaa.gov) and was viewed using the Gibson Ridge Level 2 Software (http://www.grlevelx.com/grlevel2).

A total of 881 severe hail reports were gathered for the 2004 season. Several of these events were removed from the database for the following reasons. Using methods developed by Donavon and Jungbluth, a hail report was discarded if it was not the largest hail size reported within a 16.1 km (10 mi) radius, and within 15 minutes of another larger hail report. This criterion helped to remove unrepresentative small hail reports that may have been associated with high reflectivities (i.e. a report that was obtained at the outer edge of the hail core). An event was removed if radar data was not available, or if radar data were obtained using Volume Coverage Patterns (VCPs) 21 (Fig. 1), 31, 32, or 121. A vertical gap occurs between high elevation scans on VCPs 21 and 121, which can yield unrepresentative storm core heights, especially at far distances from the radar. VCPs 11 (Fig. 2) and 12 are the most useful for determining storm structure, especially within a 37 km (or 69 mi) radius of the WSR-88D, as they include a denser sampling of various elevation planes. If an individual slice was missing within a volume scan which prevented an accurate depiction of the core height, or the distance of the storm from the radar prevented thorough sampling, the event was removed to prevent unnecessary scatter in the regression line. An event was also discarded from the database if it was associated with a very weak updraft that failed to sustain an elevated core for at least two consecutive volume scans.

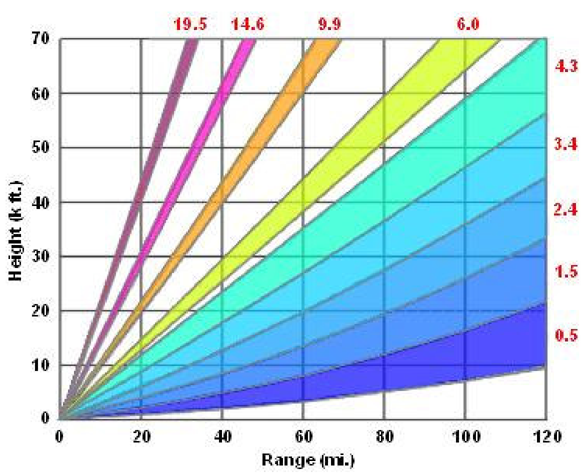

Figure 1: VCP 21 height versus range.
(http://www.srh.noaa.gov/radar/radinfo/vcp21.html)

Due to the poor spatial resolution of spotter networks across West Texas, an additional quality control attempt was made to remove unrepresentative reports. If the hail diameter reported in Storm Data was not consistent with other reports exhibiting similar reflectivity core heights on the same day with a similar thermodynamic profile, the event was flagged as being potentially unrepresentative. Current National Weather Service procedures do not require staff to pursue the largest hail size a storm could have produced. Once a severe thunderstorm warning has been verified, future investigation for larger hail is often curtailed, unless additional reports are communicated directly to the office from observers.

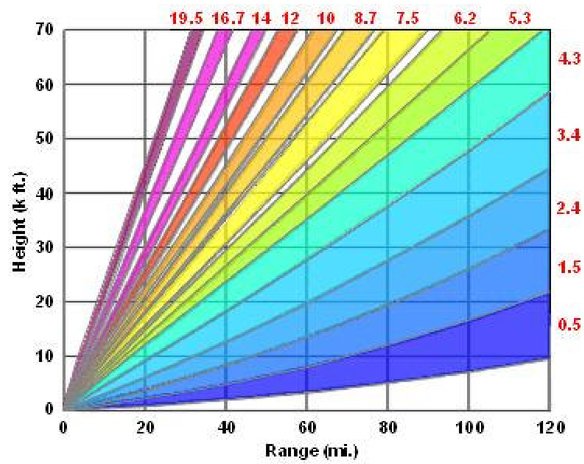

Figure 2: VCP 11 height versus range.
(http://www.srh.noaa.gov/radar/radinfo/vcp11.html)

The highest 50 dBZ height reached within four volume scans prior to each event (approximately 19 to 24 minutes) was used for the height to freezing level comparisons. These temporal limits were chosen to be consistent with Changnon (1970), which suggests that a full-grown hail stone could take on the order of ten minutes to fall out of the updraft and reach the surface. Atmospheric soundings were obtained from the University of Wyoming (http://weather.uwyo.edu) for the Amarillo, Midland, Dodge City, Norman, and Fort Worth areas to produce an estimated freezing level (0^oC) across the region for each event. Soundings were also obtained for the Lubbock area from the West Texas Mesonet website (http://www.mesonet.ttu.edu) which were launched during potentially hazardous weather days.

Significant differences were observed on certain days when surface boundaries, including fronts and drylines, as well as cold pools aloft, affected portions of a forecast area.

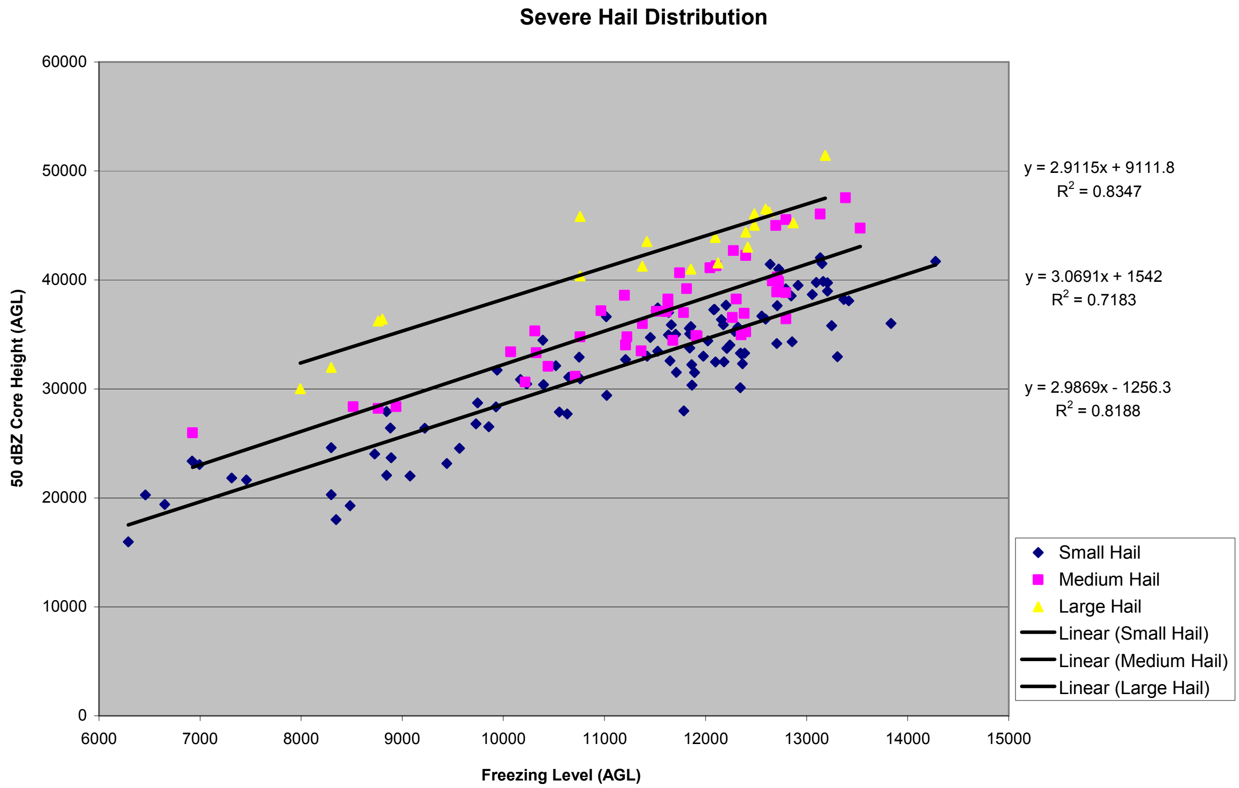

Figure 3: Best fit regression lines for each hail size bin.

This made a determination of a reasonable thermodynamic profile difficult. When sensible values could not be calculated, the event was flagged as possibly having an unrepresentative thermodynamic profile and removed for a later, more detailed analysis. Whenever a RAOB was launched in the wake of a dryline or surface front, neighboring soundings were used, and sometimes averaged, to determine a more representative freezing level.

Future studies for the Southern High Plains and West Texas will incorporate RUC model proximity soundings to assist in determining a more precise thermodynamic profile. For the purposes of this study, the freezing level across an area was assumed to be a horizontal plane. Finally, all 50 dBZ reflectivity core heights and freezing levels were then converted to above ground level (AGL) values with respect to hail report locations in an effort to make the data consistent with previous studies.

3. Initial Results

After the quality control steps outlined above were completed, a total of 164 hail events (approximately 20 percent of the initial dataset) were stratified into hail size bins labeled small, medium, and large. Donavon and Jungbluth note in their study that it is common for hail to be inaccurately identified as golf ball size; 44 mm (1.75 in.). Therefore they defined the small bin to include reports from 19 to 25 mm (0.75 to 1.00 in) (Fig. 3, blue diamonds). The medium bin includes reports from 26 to 51 mm (1.01 to 2.00 in) (Fig. 3, pink squares) and the large bin to include any reports greater than 51 mm (2.00 in) (Fig. 3, yellow triangles). For purposes of the Southern High Plains and West Texas study, 98 reports were classified as small hail, 47 reports were classified as medium sized hail, and only 19 reports were classified as large hail. Statistical analysis techniques using a least squares fit were performed on the data (Fig. 3) to determine a best-fit regression line for each hail size bin. Preliminary results for 2004 across the Southern High Plains and West Texas are given in Table 1. Future analysis will focus on expanding the dataset to include additional locations and time periods, and will include a more thorough analysis of each individual event to remove as many erroneous reports as possible. Due to the small number of reports in the large hail bin, initial statistics for that bin are likely inconclusive.

	Small Hail Bin	Medium Hail Bin
Y =	2.9869(X) - 1256	3.0691(X) + 1542
Slope	2.9869	3.0691
R^2	0.8188	0.7183
R	0.9048	0.8475

R^2 = Coefficient of Determination
R = Correlation Coefficient

Table 1: Linear regression results for small and medium sized hail bins.

4. Analysis

Preliminary data suggest that for small hail reports, a linear relationship exists between freezing levels and the height of the 50 dBZ reflectivity cores. The initial dataset does not yield a fully deterministic value for the coefficient of determination, R^2 (Table 1). This may be a result of several factors. First, the initial database may have inherent errors as a result of evaluating the AGL freezing level. National RAOB sites are located several hundred miles apart, between which subtle changes in thermodynamic profiles may exist. Thunderstorms with very strong, tilted updrafts or weak echo regions (WERs) can produce higher than expected hail sizes because the hailstone is able to fall through a drier environment (Rasmussen and Heymsfield 1987). A dataset of small sample size with potentially minor errors with respect to hail size and freezing levels could significantly skew the linear regression. Inaccurate reports of hail size, or the inability to locate the largest hail size for a particular event, could also yield an unrepresentative stratification in a comparison of hail size to maximum core height. Heights could also be truncated due to a storm's proximity to the radar. This issue may or may not be solved by storm interrogation from a neighboring radar site depending on the distance between the two radars. However, given Donavon and Jungbluth's regression line slope of 3.3 for the Northern Plains, the preliminary slope of around 3.0 may be representative for the Southern High Plains and West Texas.

Throughout the year, moisture profiles between the northern and southern United States can be significantly different. Moisture throughout a deeper layer of an atmospheric column will yield a different melting effect on a hydrometeor compared to a drier, elevated mixed layer aloft more often found in the Southern High Plains and West Texas. This moisture difference could translate to lower core heights required for severe hail production, resulting in a more shallow regression slope. This slope would also result in the larger y-intercept obtained in this study. A positive slope indicates that as freezing levels increase in altitude, melting effects on a hail stone increase as well. This would require a stronger updraft to produce severe hail.

5. Conclusions

It was suggested by Donavon and Jungbluth that improved probability of detection (POD) and false alarm rate (FAR) scores, as well as increased lead times for severe thunderstorm warnings are possible using their severe hail detection criteria for the Central Plains and Upper Midwest regions. It is beyond the scope of this paper to provide recommendations on warning criteria, as this initial study sought to determine whether a similar linear relationship can be derived for the Southern High Plains and West Texas. Preliminary results suggest that a similar relationship can be derived for this region, and further study will be undertaken to refine these results.

An awareness of storm structure and its environment is essential to improving warning statistics as opposed to the use of derived radar products alone. A warning forecaster must be alert to changes in the thermodynamic profiles in their county warning area (CWA) that could affect the strength of storm updrafts. When determining the required 50 dBZ core height for a particular event based on a RAOB sounding, a forecaster must be cognizant of elevation differences across their CWA. A reduction in elevation may increase the melting potential, thus requiring a higher core height threshold, and vice versa.

Several advances have been made recently to improve derived radar products (Witt 1990; Witt et al. 1998), however many of these products require the completion of a full volume scan before updating. This delay can cost valuable lead time for a warning. For example, evaluating hail size for a particular storm using grid-based vertically integrated liquid (VIL) requires all elevation scans to be completed and processed before the algorithm can determine a VIL value. Knowing that a predetermined threshold has been met prior to the completion of the volume scan can thus help a meteorologist to make a warning decision in a timelier manner. The use of derived products can also be detrimental in an environment when thunderstorms are rapidly developing. It has instead been suggested by Donavon and Jungbluth that using an Advanced Weather Interactive Processing System (AWIPS) all-tilts display to view base radar data to interpret the real-time vertical storm structure may be the best solution.

6. Summary

Following the technique outlined by Donavon and Jungbluth, a somewhat significant statistical linear relationship between freezing levels and 50 dBZ reflectivity core heights can be inferred from the dataset of the Southern High Plains and West Texas severe hail events in 2004. It is surmised that the use of these comparisons to assist in warning decision making could prove beneficial to improving office performance statistics and average lead times, especially for rapidly developing storms. Although several potential errors were noted in the initial Southern High Plains and West Texas database, a more detailed ongoing examination will continue to eliminate questionable reports. The future inclusion of freezing levels obtained from RUC-derived model soundings will further assist in refining freezing level data for areas where soundings are missing or unavailable.

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