WESTERN REGION TECHNICAL ATTACHMENT
NO. 99-02
FEBRUARY 16, 1999

VIL DENSITY AS A POTENTIAL HAIL INDICATOR ACROSS NORTHERN UTAH

Randall A. Graham* and Mark Struthwolf - NWSFO Salt Lake City, UT
Current affiliation: NWSFO Grand Rapids

Introduction

Since the introduction of the WSR-88D radars into National Weather Service warning operations, values of Vertically Integrated Liquid (VIL) have been used to anticipate the occurrence of large hail. However, the VIL values which correlate to ground truth reports of severe hail vary greatly from day-to-day and across different regions of the United States due to dependence on airmass characteristics. Many offices have relied on a "VIL of the Day", but this technique involves several assumptions and can generate inconsistent results.

VIL is essentially a radar derived estimate of liquid water in a storm calculated through a vertical integration of reflectivity values. Traditionally, forecasters have correlated large VIL values with the potential for severe hail. However, it has been noted that high topped thunderstorms with large VIL values do not always produce severe hail while low topped storms with low VILs occasionally do produce severe hail. In an attempt to better analyze VIL values in the warning process, Amburn and Wolf (1997) introduced VIL Density as a new way of looking at VIL values. VIL Density is the VIL (kg m-2) divided by the echo top (in meters), multiplied by 1000 g kg-1, yielding units in g m-3.

The goal of VIL Density was to develop a criteria that alerts the radar operator to the potential of large hail that is independent of airmass characteristics. The results of the Amburn and Wolf study (conducted in the Tulsa, OK CWA) indicated that the VIL Density showed great promise for the indication of severe hail even for cells that vary widely in VIL values, echo tops, time of year and, possibly, geographic location. Several other studies (Hart and Frantz 1998, Troutman and Rose 1997) have validated the usefulness of VIL Density in anticipating large hail across the southeastern United States. The VIL Density technique holds promise for the western states where severe hail producing storms often have lower storm tops and smaller VIL values. This study examines a small sample of storm cells and their associated VIL Density to determine its potential usefulness in warning operations.

VIL Issues

The concept of VIL and its use in the warning process, particularly in anticipating large hail, does present some problems. VIL is calculated by doing a vertical integration of reflectively and represents reflectivity converted into equivalent liquid water values. In fact, the VIL calculation assumes that all returns are from liquid water. Thus, all returns greater than 55 dBZ are defaulted down to 55 dBZ. This is done to avoid using non-linear returns from water coated hailstones in the calculations, which as it turns out, is what the product is generally used to anticipate. High VIL values are therefore identifying deep, high reflectivity cores and not the amount of liquid water in the storm as was the original intent. In light of this it would seem that the continued development of hail detection algorithms (such as the Build 9 HDA which are rooted in the physics of hail formation and explicitly account for important environmental parameters such as height of the freezing level and -20 C level, as well as for the elevation of the RDA and the surrounding terrain) will likely provide a better means for anticipating large hail in the long run than using various VIL techniques.

Methodology

Values of VIL Density were compared to ground truth reports for storms that occurred across northern Utah during the 1996 and 1997 convective seasons. Cases examined in this study ranged from late spring (low freezing level events) to late summer (high freezing level events) and exhibited a wide range of shear values. VIL Density values were recorded for a series of storms for which there were reliable ground truth reports. It was assumed that the hail reports were accurate with respect to time and size and that the largest hail size reported was the largest hail that reached the surface. The majority of the cells used in this study moved over highly populated areas and produced multiple hail reports.

Two different methods of calculating the VIL Density were used to determine which had the most skill. In the first method, the maximum Cell-based VIL and Storm Top (height of the 30 dBZ echo above radar level) were used to calculate the VIL Density (VIL/Storm Top = # g m-3). These data were gathered using the WATADS (WSR-88D Algorithm Testing and Display System) software. The maximum Cell-based VIL and Storm Top associated with a cell in the four volume scans preceding the largest hail report were used in the VIL Density calculations. These will be referred to as Cell-based cases.

The second method used the Grid-based VIL and Echo Top (height of the 18.3 dBZ echo MSL) off of the PUP for the VIL Density calculations. In these cases the maximum Grid-based VIL and Echo Top within one pixel of each other in any of the four volume scans preceding the largest hail report were used in the VIL Density calculations. These will be referred to as Grid-based cases. For both the Cell-based and Grid-based cases, the maximum VIL and Echo or Storm Top recorded over or within two volume scans of being over a highly populated area were used for the Null (no hail) cases.

The Grid-based VIL is calculated by integrating reflectivity through a vertical column of each 2.2 x 2.2 nm grid box. On the other hand, the Cell-based VIL uses the maximum reflectivity values on successive elevation slices that are associated with a particular cell to calculate the VIL (Fig. 1). The Amburn and Wolf study used the Grid-based VIL and height of the Echo Top to determine the VIL Density. Both of these products are quickly available in plan views on the WSR-88D PUP (Table 1). Due to the Grid-based VIL's dependence on integrating reflectivity through a vertical column, VIL values may be incorrect (or, at least, misleading) for fast moving or highly tilted storms. The calculation of Cell-based VIL will generally result in more accurate VIL values for a given storm. The Cell-based VIL and Storm Top values are now available for individual storms under the cell trends selection at the PUP (Table 1).

Results

The sample size was relatively small for both the Cell-based and Grid-based VIL Density calculations. There were six storm days with a total of 29 cells analyzed for the Cell-based calculations. Only three storm days and 12 cells were examined for the Grid-based cases.

Cell-based

The breakdown of the 29 cells in the Cell-based VIL cases was 8 severe hail (greater than or equal to 3/4 of an inch in diameter), 11 small hail (less than 3/4 of an inch in diameter), and 10 null cases (no hail reported). The average VIL Density for the severe hail cases was 4.74 (g m-3). The average dropped to 4.01 for the small hail cases and to 2.09 for the null cases (Fig 2).

The best fit line in separating the severe hail cases from the small hail cases, which resulted in the fewest missed events and false alarms, was determined to be 4.75 (Fig. 3a). Using this threshold, three-out-of-eight (38%) severe events were missed while only two-out-of-eleven (18%) small hail events generated false alarms. The incorporation of additional cases would certainly improve the best fit line.

The best fit line in separating the small hail cases from the null hail cases was 3.00 (Fig. 3a). Only one-of-the-eleven (9%) small hail producing cells fell below this criteria and one-out-of-ten (10%) null cases was above the threshold. When compared to the Amburn and Wolf study, the average VIL Density values generated using the Cell-based method are higher (severe threshold of 4.75 g m-3 versus 3.50 g m-3) as a result of using the Cell-based VIL (should always be equal to or higher than the Grid-based VIL) and Storm Top (which is always lower than the Echo Top) in the calculations.

Grid-based

For a true comparison to the study performed by Amburn and Wolf (1997), the Grid-based technique was employed for three storm days. Values for these three storm days were also computed using the Cell-based technique for sake of further comparison. The sample size for the Grid-based cases is extremely small with only seven severe hail events and four small hail events.

Average VIL Density values for the severe hail cases was 3.07, with an average of 2.47 for the small hail cases (Fig. 2). A threshold of 2.90 was determined as the best value for separating severe hail storms from small hail storms in this Grid-based sample. Using this threshold three-out-of-seven (43%) of the severe hail cases would qualify as missed events, while zero-out-of-four (0%) small hail events would result in false alarms.

The extremely small sample size of the Grid-based cases precludes the ability to draw any concrete conclusions from these results. However, it is noteworthy that the Cell-based values calculated for the same three days as these Grid-based yielded very similar results between the small and severe hail cases. In addition, the average VIL Density of severe hail cases compared to small hail cases in both Cell and Grid-based techniques yielded similar ratios of 1.15 (severe hail average divided by small hail average...4.74 / 4.01) and 1.20 (3.07 / 2.47), respectively, supporting a strong relationship between techniques. A larger sample size, however, may reveal that Cell-based calculations offer better results due to the more accurate calculation of VIL values.

Summary

Although only a small sample of storm days and individual cells were examined, the use of VIL Density to identify severe hail storms across northern Utah shows promise. Using a threshold of 4.75 (g m-3) for the Cell-based VIL Density calculations resulted in a good separation between the severe and small hail cases. Using this threshold, three-out-of-eight (38%) severe events were missed while only one-out-of-eleven (9%) small hail events generated false alarms. Grid-based VIL Density calculations produced similar results as the Cell-based calculations. A threshold value of 2.90 (g m-3) was determined as the best value for separating severe hail storms from small hail storms in the Grid-based sample. Using this threshold, three-out-of-seven (43%) of the severe hail cases would qualify as missed events, while no false alarms resulted. Increasing the sample size would certainly result in better defined thresholds for both the Cell-based and Grid-based cases.

Note: The VIL density was converted to (g m-3) in order that a comparison of this study's results could be made to previous VIL Density studies. However, for use in an operational setting this conversion is not necessary, in that the units are not as important as the ratio (VIL/Storm Top or VIL/Echo Top). For "quick and dirty" evaluations to determine the severity of the hail, the threshold for severe hail in the Cell-based technique is a ratio of 1.45 (1.50 for simplicity) and around .90 for the Grid-based technique (Fig. 3b).

References

Amburn, S., and P. Wolf, 1997: VIL Density as a Hail Indicator. *Wea Forecasting*, **12**, 473-478.

Federal Meteorological Handbook 11, 1991: *Doppler Radar Meteorological Observations*, Part C. Office of the Federal Coordinator for Meteorological Services and Supporting Research, U.S. Department of Commerce/NOAA, Washington, D.C.

Hart, P. A., and K. Frantz, 1998: A Comparison of VIL Density and Wet-Bulb-Zero Height Associated with Large Hail over North and Central Georgia. SR-Technical Attachment 98-30.

Troutman, T., and M. Rose, 1997: An Examination of VIL and Echo Top Associated with Large Hail in Middle Tennessee. SR-Technical Attachment 97-15.

Cell-based VIL/Storm Top	**Grid-based VIL/Echo Top**
PUP Cell Trends Display	PUP plan views
Rads Cell Trends Display	AWIPS plan views
PUP/AWIPS Cell Attribute Tables	

Table 1 - Where users can find Cell-based VIL/Storm Top values and Grid-based VIL/Echo Top values.

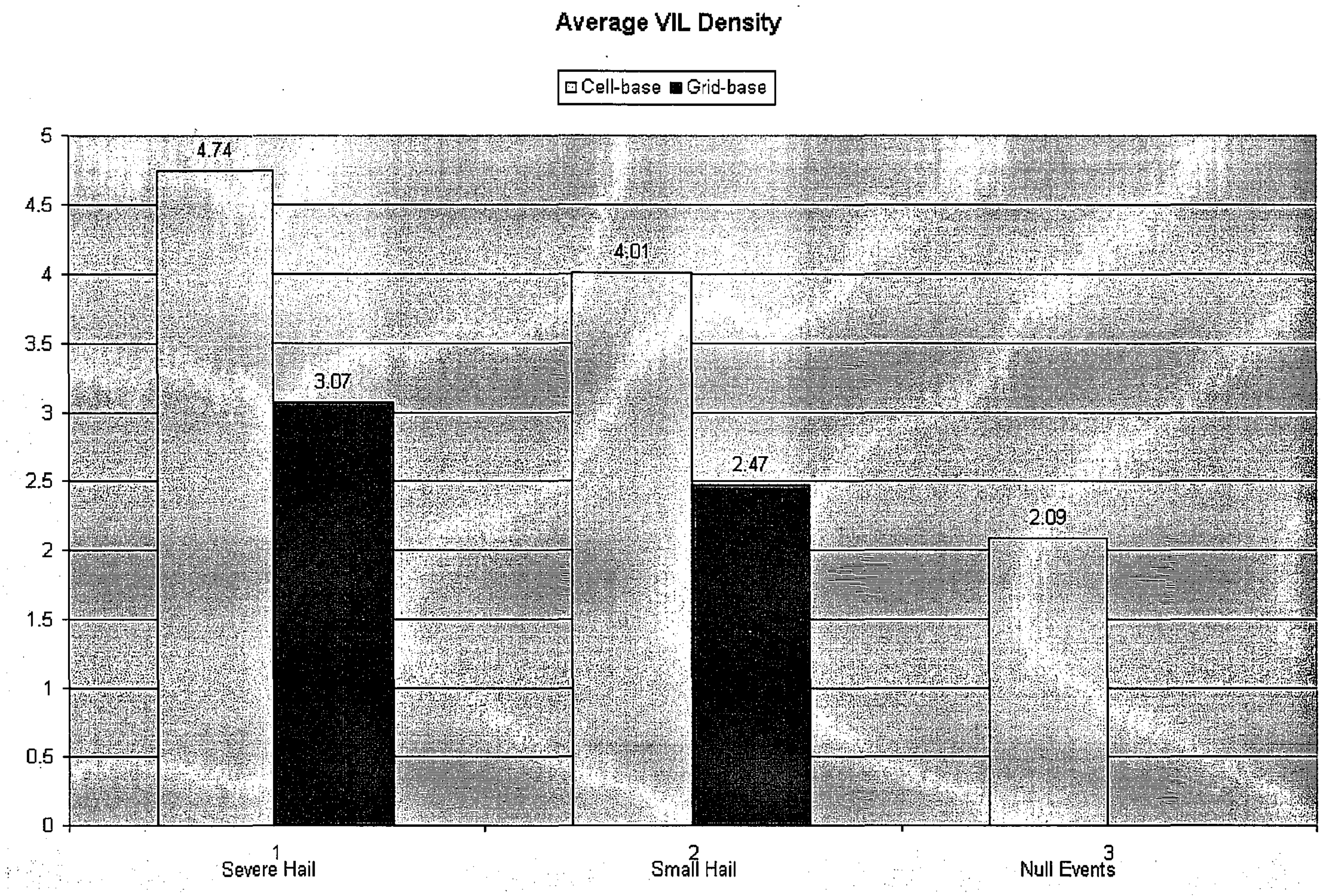

Figure 2. Bar graphs comparing the average VIL Densities between Cell-based and Grid-based techniques. No Grid-based events were recorded during this study. The ratios between severe hail (4.74/4.01) and small hail (3.07/2.47) by each technique were very similar at nearly 1.15.

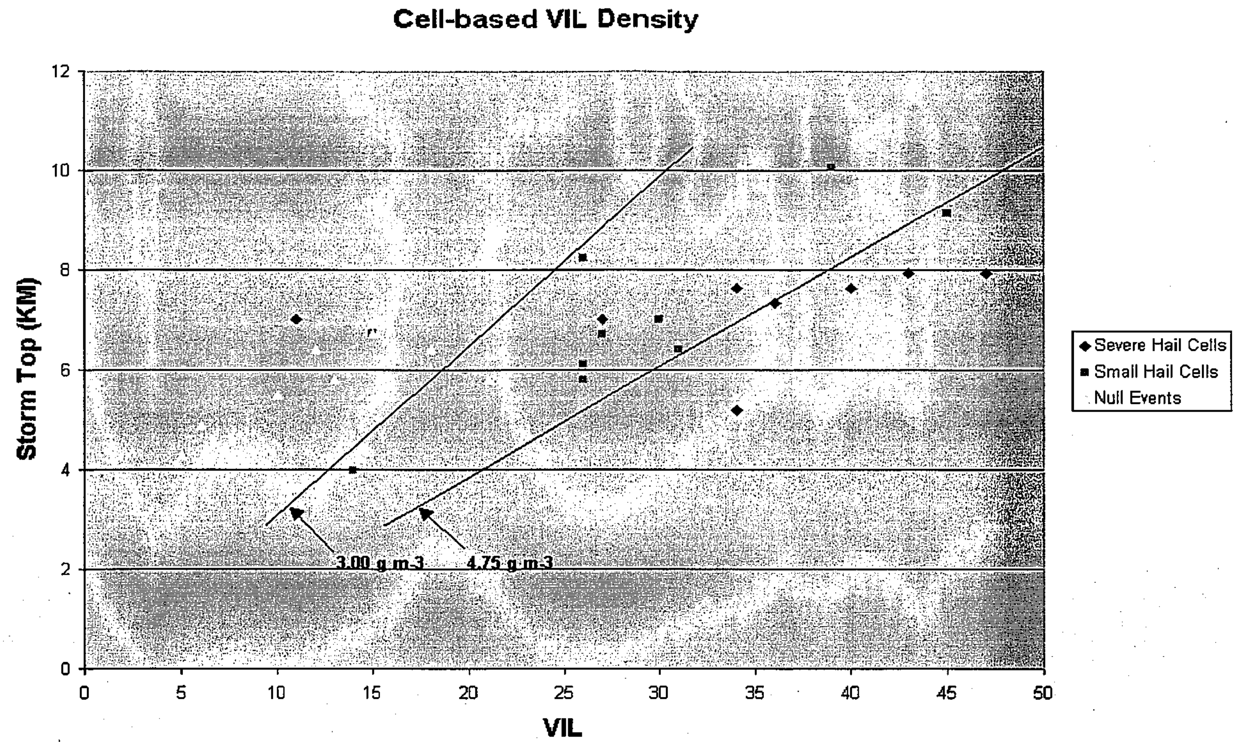

Figure 3a. Scatter plot of Storm Top versus VIL for cell-based cases. Severe cases are respresented by diamonds, small hail cases are squares, and null cases are triangles. Ratios of VIL/Storm Top densities are shown as solid lines, labeled 1.45 and 0.91. Storm Top is measured in kilometers

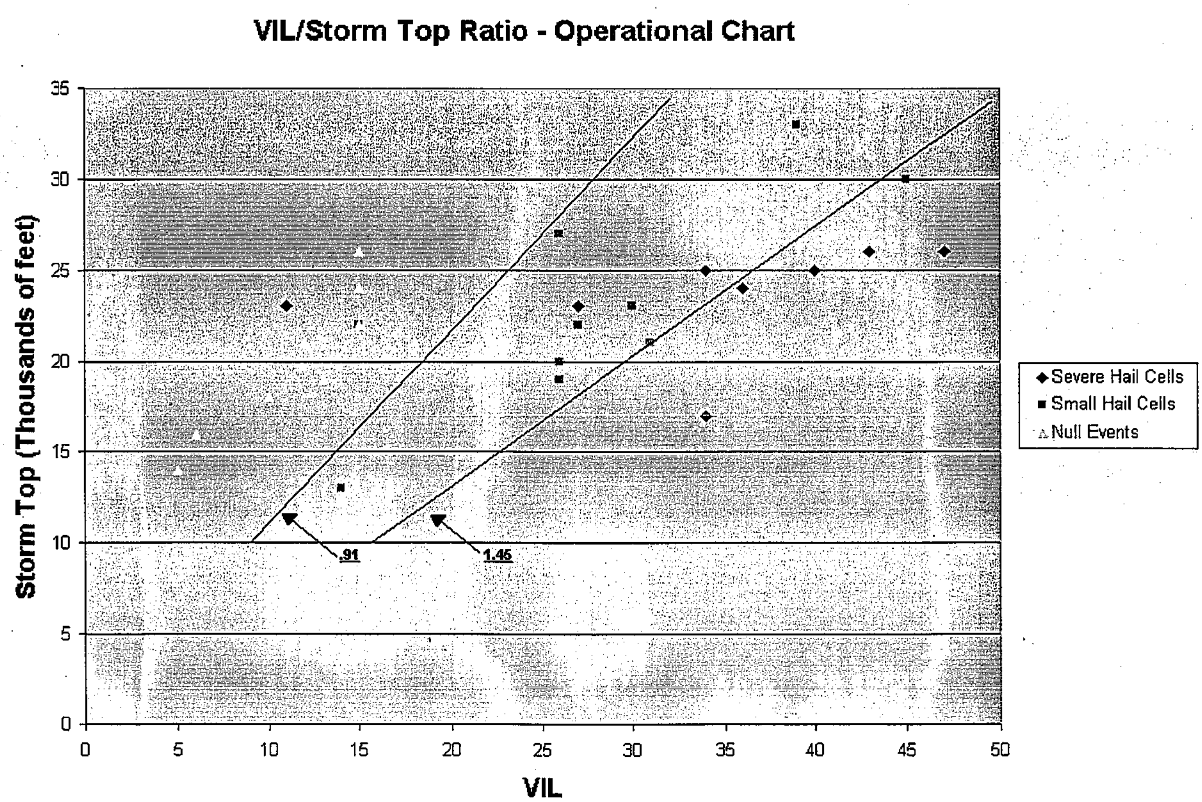

Figure 3b. Same as Figure 3a except, ratios of VIL/Storm Top densities are shown as solid lines, labeled 4.75 and 3.00. Storm Top is measured in thousands of feet.