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VIL DENSITY AS A POTENTIAL HAIL INDICATOR ACROSS NORTHEAST AND CENTRAL NEVADA

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Introduction

Since the WSR-88D became incorporated into the National Weather Service for warning operations, vertically integrated liquid (VIL) has been used to forecast the severity of thunderstorms. The idea of using VIL for assessing the severity of thunderstorms was introduced by Greene and Clark (1972). Since then, many studies have looked at VIL for warning operations. One brief study by Wilken (1994) looked at using 500 mb temperatures to forecast the 'VIL of the Day' (VOD). A companion to this study for northeast Nevada (Wallmann 2002) came up with a regression line for VOD based on both freezing level and wet bulb zero. However, since this value depends on the airmass, another parameter can add use to the VIL value.

One such parameter was first described by Paxton and Shepherd (1993) as normalized VIL and later analyzed further by Amburn and Wolf (1997, hereafter AW) as VIL density (units g m^{-3}). Amburn and Wolf showed that VIL density had great promise in the prediction of severe hail for northeast Oklahoma. Since then, many other studies of VIL density have been done across the country: Troutman and Rose (1997) for middle Tennessee, Hart and Frantz (1998) for northern and central Georgia, Blaes et al. (1998) for eastern New York and western New England, Belk and Wilson (1998) for the Appalachians, and Graham and Struthwolf (1999) for the Wasatch front of Utah. However, the threshold VIL density used for each office was slightly different, and in some cases different methods of computing VIL density were used. For example, AW used grid-based VIL (GBVIL) normalized by Echo Tops (ET) while Belk and Wilson used cell-based VIL (CBVIL) normalized by Storm Top (ST), both of which are produced by the Storm Cell Tracking and Identification (SCIT) algorithm. Since each study conducted came across different VIL density thresholds for each climate regime, it seems prudent to conduct a study for northeast Nevada as well.

Utilizing VIL density in the warning decision-making process also becomes important for high elevation radar sites because of the difficulties inherent in the Hail Detection Algorithm (HDA). Overestimation of the probability of hail (POH), probability of severe hail (POSH), and the maximum expected hail size (MEHS) is rather common for these sites and has been documented, most notably by Maddox et al. (1998). One reason for the overestimation in the Western United States may be that the HDA was developed and tested using sites east of the Rocky Mountains. (For a detailed description of the HDA, see Witt et al. 1998). Studies have been done on the HDA in the West, and Vasiloff et al. (1997) have noted that although the HDA does improve over the previous algorithm in the West, the MEHS was overestimated by as much as 50 percent. The overestimation has been noted in Elko as well, particularly during the summer months. For example, a thunderstorm on September 12, 2001, produced the following algorithm output 10 minutes before passing over the Elko office: VIL 38, POH 100 percent, POSH 100 percent, MEHS 1.25". The Elko office observed hail 1/4" to 3/8" in diameter, with the largest of several other reports from Elko of 1/2". Clearly, the HDA overestimated POSH and MEHS in this case. It has been noted, however, that changing the Warning Threshold Select Model (WTSM) from the original HDA should improve the POSH (ROC, 1998), but this has not been implemented at the Elko Weather Forecast Office (WFO).

This study will follow previous studies done on VIL density and come up with thresholds useful for northeast and east central Nevada.

Methodology

Because of the low population density in northeast and east central Nevada, a long period of time was required in order to obtain even a small data set. Therefore, five convective seasons were analyzed from April 1997 through September 2001 using Level II Archive data in the WATADS (WSR-88D Algorithm Testing and Display System) software when possible, and supplemented by Level IV data viewed at the PUP (WSR-88D Principal User Processor.) However, since there are many gaps in the archived data, there are many reports that were thrown out because there was no radar data to compare them to. Both GBVIL and CBVIL values were compared to locations where reliable ground truth reports were received. Values obtained for GBVIL and CBVIL used the highest VIL value computed by the algorithm at the time of the report, or up to 20 minutes before the report, assuming the updrafts are strong enough to allow for the hail to be suspended for up to 20 minutes. Both severe and non-severe hail cases were compiled, where the non-severe cases were only considered if the report was within 2 miles of the storm center in order to increase certainty that the hail produced was actually the largest produced by that storm. Also, any storm within a 15 nautical-mile radius of the radar was not included due to inadequate sampling of the storm. Using these requirements, a total of 17 storms were included in the study. Six of these storms produced severe hail (greater than 0.75"), ten storms produced non-severe hail, and one storm produced very heavy rain (0.9" in 15 minutes).

When using VIL or VIL density as a tool in severe weather forecasting, it is important to know how VIL is computed by the WSR-88D. The VIL is computed by integrating the reflectivity of a storm vertically. A more complete treatment of how VIL is calculated can be found in AW. The GBVIL is computed by vertically integrating the highest reflectivity at each elevation slice within a 4 km by 4 km grid square. Thus, for fast moving or tilted storms, GBVIL may not completely sample a storm. On the other hand, CBVIL is computed by integrating the highest reflectivity in each slice for a given storm cell identified by the Storm Cell Identification and Tracking (SCIT) algorithm. This method is also prone to errors if the SCIT algorithm did not perform properly and may have identified two different cells when only one was present. Finally, it is also important to note how both ET and ST are calculated. The ET finds the highest point at which the 18.3 dBZ echo is found over a 4 km by 4 km grid square, while ST uses the 30dBZ echo for a storm identified by the SCIT algorithm.

Similar to Graham and Struthwolf (1999), several methods of computing VIL density were computed to determine which method had the greatest skill. Method 1 computed VIL density by using GBVIL divided by ET, as in AW. Method 2 divided GBVIL by ST, Method 3 CBVIL and ET, then CBVIL and ST for Method 4. Method 1 and Method 4 are the two methods described in the literature. Methods 2 and 3 are different because they mix the cell-based products with the grid-based. There are several caveats present by mixing the two, especially with taking GBVIL and dividing by ST as in Method 2. For instance, if a storm were on the edge of the 4 km by 4 km grid square used to calculate GBVIL, the ST may be in that grid square or an adjacent grid square. If the storm were highly tilted, then the GBVIL would be low and the ST may be high, which would give an anomalously low VIL density. Since this can happen frequently, this method should not perform very well at all when predicting severe hail. Method 3 also used both grid-based and cell-based methods but slightly differently, which is important. With a particular storm, it is possible that the storm will be contained within two different grid squares that are used to compute ET. However, since the CBVIL is cell-based, the liquid contained in the storm should be an accurate representation of the VIL of the storm unless the SCIT algorithm fails. The top of the storm then will at least fall in one of the two (or more) adjacent grid squares and can be obtained by using ET. The only problem with this would be if another storm that was very close to the storm of interest may be the value measured by the ET algorithm and not the storm of interest. It is assumed that squall lines and the resultant close spacing of individual storm cells would most likely be the cause of the failure of this method. Since these are a rare occurrence in northeast and east central Nevada, this problem should be minimal as none of the 17 storms used in the study were part of a squall line.

Results

For each method, VIL density values were computed for each storm. In addition, two possible thresholds were analyzed to see which performed best with the available data. The graphs of each method can be seen in Figures 1 through 4, respectively.

(a) Method 1: GBVIL and ET

Using Method 1, the six severe hail cases had an average VIL density of 3.33 g m^{-3} and the 11 non-severe cases had an average VIL density of 2.72 g m^{-3}. When finding a threshold VIL density that would result in the best fit for verification statistics (Probability of Detection (POD), False Alarm Ratio (FAR) and Critical Success Index (CSI)), a value of 3.1 g m^{-3} was obtained. This value correctly identified 5 of the 6 severe hail cases, but 5 of the 11 non-severe cases would have been identified as severe. This resulted in a CSI of 0.454. A threshold value of 3.25 g m^{-3} was also analyzed, but the CSI fell slightly to 0.333. Table 1 summarizes both the best threshold value (3.1 g m^{-3} for Method 1) obtained for each method, and a second value which did not perform quite as well (3.25 g m^{-3} for Method 1).

(b) Method 2: GBVIL and ST

Method 2 obtained an average VIL density of 3.96 g m^{-3} for the severe hail cases and 3.30 g m^{-3} for the non-severe cases. Both threshold VIL densities tested, 3.7 g m^{-3} or 4.0 g m^{-3}, performed similarly to each other with a CSI of 0.5. However, each threshold identified a different number of severe and non-severe storms as having large hail.

Table 1. Verification statistics (POD, FAR, CSI) for each method using two different thresholds for each method.

	GBVIL vs ET	**GBVIL vs ST**	**CBVIL vs ET**	**CBVIL vs ST**
Threshold 1	*3.1* g m^{-3}	*3.1* g m^{-3}	*3.7* g m^{-3}	*3.7* g m^{-3}
POD	0.833	0.833	0.667	0.667
FAR	0.455	0.364	0.273	0.091
CSI	0.455	0.5	0.444	0.571
Threshold 2	*3.25* g m^{-3}	*3.25* g m^{-3}	*4.0* g m^{-3}	*4.0* g m^{-3}
POD	0.5	0.667	0.5	0.5
FAR	0.273	0.182	0.901	0.901
CSI	0.333	0.5	0.429	0.429

(c) Method 3: CBVIL and ET

The six severe hail cases for Method 3 had an average VIL density of 3.06 g m^{-3} and the non-severe cases had an average VIL density of 2.46 g m^{-3}. The threshold VIL density that performed the best for the 17 cases was 3.1 g m^{-3} by correctly identifying 4 severe cases, but it also identified 3 non-severe cases as severe. This resulted in a CSI of 0.444. The second threshold value attempted of 3.25 g m^{-3} obtained a slightly lower CSI of 0.429 since one less severe storm was identified despite two fewer non-severe hail cases being identified.

(d) Method 4: CBVIL and ST

For Method 4, the average VIL density was 3.67 g m^{-3} for the 5 severe hail cases versus 2.98 g m^{-3} for the 10 non-severe cases. The 3.7 g m^{-3} VIL density worked best as a threshold with a CSI of 0.571 resulting from correctly identifying four severe hail cases and only falsely identifying one non-severe case. This performance was better than the alternative of 4.0 g m^{-3} used, which produced a CSI of 0.429.

Limitations

One of the most obvious limitations of the study is the limited amount of cases used. This results from a number of factors such as the relatively low frequency of occurrence of severe thunderstorms in Nevada, the extremely low population density of the Elko County warning area (CWA), and the lack of WSR-88D coverage in some parts of the Elko CWA. These include parts of White Pine County and northwestern Humboldt County. Another consideration is whether the reports of hail size are accurate. It is assumed that most of the reports are from trained spotters and therefore accurate, which introduces another source of error. Another potential source of error is the assumption that those reports within 2 miles of the storm center are reporting the largest hail size for the non-severe storms. It is possible that larger hail was produced by the storm, possibly severe hail even for the quarter inch cases, and it may have occurred either before or after the storm report for only a brief period of time. Finally, there is a question of whether or not the VIL algorithm was accurately estimating the true liquid water content. This is often dependent on the scan strategy employed, particularly for storms that are close to the radar. Most of the cases were observed when the radar was in Volume Coverage Pattern (VCP) 21 where only 9 elevation angles are sampled. A more complete VCP is 11 with 14 elevation angles employed, and will obtain more accurate VIL readings for storms within 60 miles of the radar. Also, for storms that are at the edge of the radar beam, VIL can be overestimated, resulting in abnormally high VIL readings due to inadequate sampling.

Conclusions

Although the limited data set does present problems for drawing some conclusions, the data does show strong trends toward using VIL density as a predictor of large hail. The value of 3.7 g m^{-3} for CBVIL versus ET appears to work best with the highest CSI. It is interesting to note that both the mixed cell-based and grid-based methods work fairly well, with Method 3 working slightly better. However, the original method used by AW of GBVIL versus ET performed the worst. It is recommended that Method 4 with a threshold of 3.7 g m^{-3} be used most often, when there is only time to check one method. However, if more time is available, it is suggested that a second method be used, such as Method 3, to supplement Method 4, and perhaps arrive at a better level of confidence in making the warn/no-warn decision. Tables for computing VIL density based on each of the thresholds described above have been placed in the operations area at WFO Elko for faster computation. However, in line with other studies on VIL density, under no circumstance should VIL density be used solely to forecast the presence of severe hail. Storm structure as well as other algorithm output from the WSR-88D should be used in combination with VIL density in forecasting severe hail.

Continued work on this study is planned and it is hoped that adding possible storms from the 2002 and 2003 convective seasons will provide better results.

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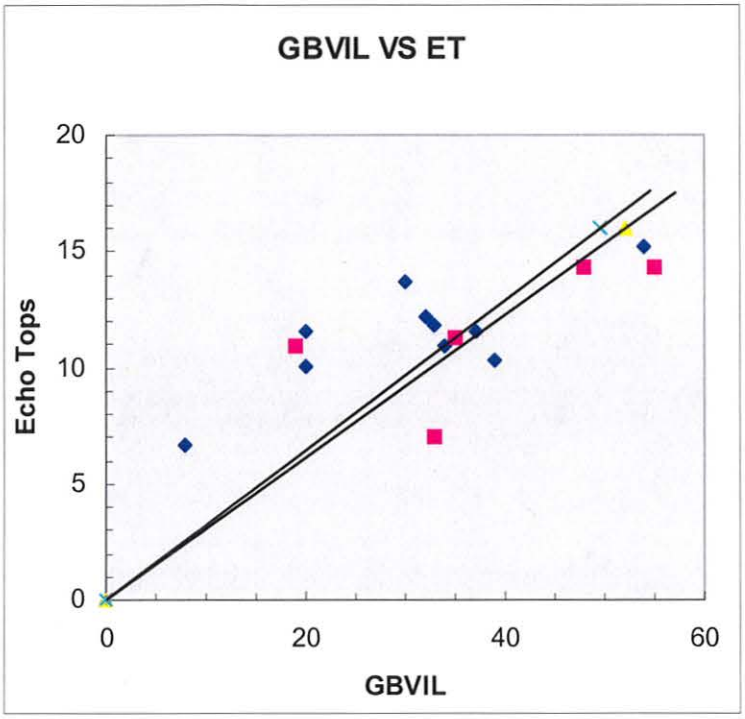

Figure 1. Graph of GBVIL (kg m^{-2}) versus ET (km). Non-severe cases are diamonds and severe cases are the squares. The 3.1 g m^{-3} threshold line is labeled with the X and the 3.25 g m^{-3} threshold line with the triangle.

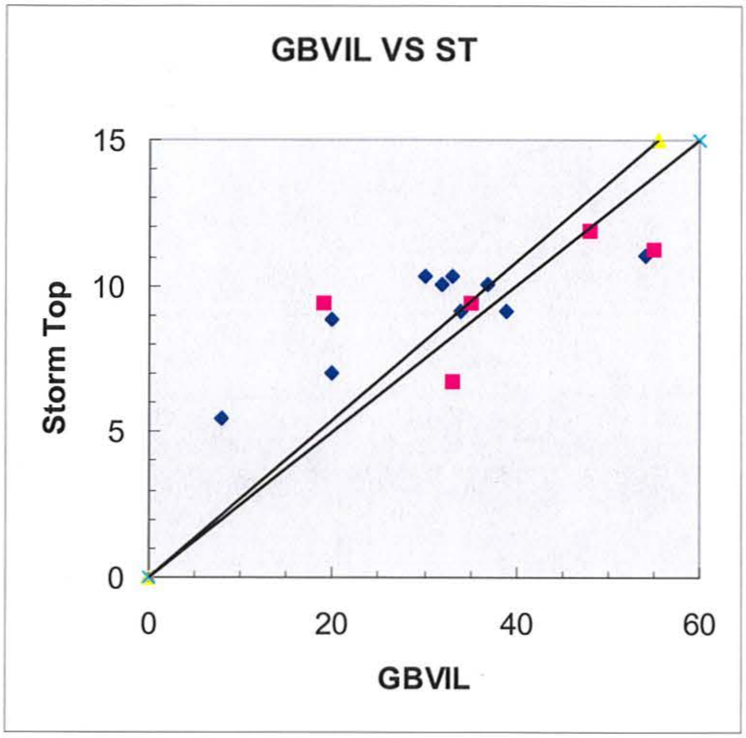

Figure 2. Graph of GBVIL (kg m^{-2}) versus ST (km). Non-severe cases are diamonds and severe cases are the squares. The 3.7 g m^{-3} threshold line is labeled with the triangle and the 4.0 g m^{-3} threshold line with the X.

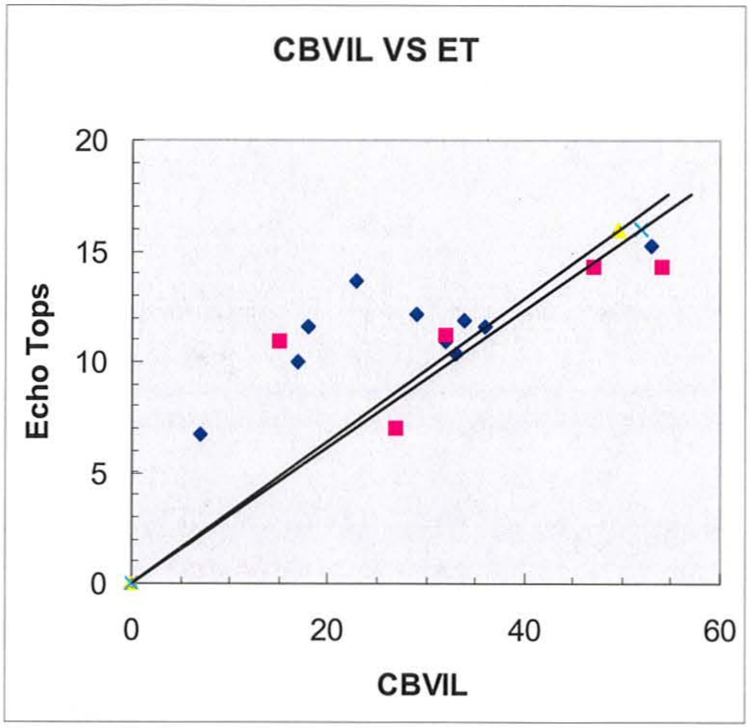

Figure 3. Graph of CBVIL (kg m^{-2}) versus ET (km). Same as Figure 1 except the 3.1 g m^{-3} threshold line is labeled with the triangle and the 3.25 g m^{-3} threshold line with the X.

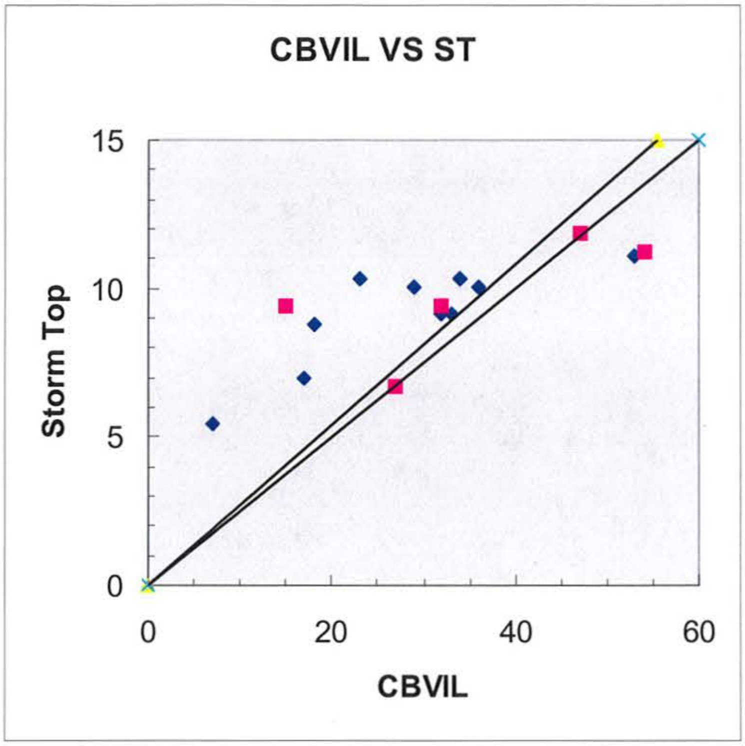

Figure 4. Graph of CBVIL (kg m^{-2}) versus ET (km). Same as Figure 2.