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A Method for Predicting Severe Weather Thresholds of Vertically Integrated Liquid in West Virginia

Michael S. Evans
John Honore'
National Weather Service Forecast Office
WSFO Charleston, West Virginia

1. INTRODUCTION

The RADAP (Radar Data Processor) II system has been used since the mid 1980s by the National Weather Service Forecast Office at Charleston, WV (CRW), as a tool for diagnosing and forecasting severe local storms and flash flood potential. The system operates by gathering radar information from periodic scans, then displays values of reflectivity, estimated rainfall, echo tops, vertically integrated liquid (VIL), storm structure, and an estimated severe weather probability.

Several previous research studies have indicated that the VIL value for a given cell is an especially useful parameter for estimating the severe weather potential for that cell (Elvander 1980; Saffle and Elvander 1981; Devore 1983; Beasley 1986; Davis and Drake 1988; Paxton and Shephard 1993). The explanation given for this is that the VIL associated with a cell is a measure of the strength of the updraft within that cell, since large volumes of liquid water can only be supported by strong updrafts. The standard RADAP-based criteria for issuing a severe thunderstorm warning in WSFO CRW's area of responsibility, is reached when a thunderstorm cell exhibits a VIL of greater than or equal to 45 kg/m^2, in combination with a severe weather probability of 40% or higher for one radar scan. In such cases, a warning can be issued 10 to 30 minutes downstream of the cell when the VIL starts to decrease (the storm begins to collapse). In addition, a warning can be issued 10 to 30 minutes downstream of a cell when a VIL of greater than or equal to 45 kg/m^2 is detected in combination with a severe weather probability of 50%, or higher, for two successive radar scans, regardless of whether or not the VIL has begun to decrease.

Despite the aforementioned general rules for issuing severe thunderstorm warnings, it has long been understood that the threshold VIL for severe weather may vary, depending on the character of the storm environment. For example, Beasely (1986) found that Spring and Fall VIL thresholds over the south central United States, are typically lower than thresholds observed during mid-summer in that region. The same tendency for a seasonal variation in threshold VIL was also found by Davis and Drake (1988) for western Pennsylvania. Similarly, Stewart

(1991) and Paxton and Shepherd (1993) found that storms with low cloud tops typically exhibit a lower severe weather threshold VIL than storms with higher tops.

The purpose of this study is to improve the severe thunderstorm warning process in West Virginia by studying the tendency for threshold VIL to vary from event to event. Specifically, the variation in VIL in West Virginia will be documented over the course of four severe weather seasons, then correlated to the concurrent variation of sounding variables at Huntington WV. (HTS). Next, a regression equation will be derived, which relates threshold VIL to the aforementioned sounding variables. The resulting equation will allow a unique threshold VIL to be calculated each day for West Virginia, given that severe weather is expected to occur.

It is important to note that once the threshold VIL is calculated for any given day, it should never be used alone in order to determine the existence of severe weather. Instead, it should be used in combination with other radar and RADAP-based severe weather identification methods during severe weather operations.

2. METHODOLOGY

Threshold VIL was estimated for each day during which severe weather was reported in West Virginia during the period from April 1990 through August 1993. The standard National Weather Service (NWS) definition for severe weather was applied (i.e. wind gusts of at least 50 kt and/or hail with diameter of at least 3/4 inch). For each severe weather date, the threshold VIL was estimated by finding the maximum VIL value within one county upstream of a surface severe weather report. If several surface severe weather reports occurred in a coherent time/space sequence (indicating a traveling severe thunderstorm cell), then the highest VIL value associated with the sequence was used. If more than one such sequence occurred on any given date, the sequence associated with the lowest maximum VIL value was chosen (the lowest VIL value was used since it was the goal of the study to determine a threshold, or lowest possible severe weather value for days on which severe weather occurred).

For purposes of quality control, it was decided that none of the VIL thresholds could be greater that 50 kg/m^2 or less than 20 kg/m^2. On any date where the method yielded a threshold of greater than 50 kg/m^2, a value of 50 kg/m^2 was used (it was assumed that the method erroneously identified a VIL value which was above the threshold for that day). Only one such date occurred. No threshold VIL was logged from any date for which the method identified a threshold less than 20 kg/m^2 (incomplete data was assumed for those days).

This procedure resulted in the estimation of a single severe weather threshold VIL for each of 25 severe weather days in West Virginia. It is worth noting that for 24 of the 25 days, the severe weather report associated with the VIL indicated weather conditions that barely reached NWS severe criteria (wind gusts did not exceed 77 kt and/or hail size did not exceed 1 inch in diameter). This finding lends credence to the contention that these VIL values were representative of severe weather "threshold" values for the days in question.

Once the threshold VIL was estimated for each of the severe weather days, sounding information for each day was determined by using data taken from the local sounding station at HTS, located in the southwest part of the state. On dates when storms occurred between 1500 and 0000 UTC, the preceding 1200 UTC sounding was used (1800 UTC soundings were used, if available). Sounding variables were calculated by the SkewT Hodograph Analysis and Research Program (SHARP; Hart and Korotky 1991) after modifying the layer from 850 mb to the surface, by assuming a surface condition equal to the condition at the time of the day's highest 3 hourly (1500 UTC, 1800 UTC, etc.) wet bulb temperature at HTS. A 1200 UTC sounding was used even for storms that occurred just before 0000 UTC, because of the concern that a post-storm 0000 UTC sounding could be highly unrepresentative of the atmospheric conditions for cases where the thunderstorms were generated with a frontal passage. In all, 22 such soundings were used. For two events that occurred near 0600 UTC, 0000 UTC HTS soundings were used, with the layer from 850 mb to the surface modified by assuming a surface condition equal to the 0600 UTC surface condition at HTS. Finally, for one event during which a series of storms occurred near 1200 UTC, a 1200 UTC HTS sounding was used with no modifications.

The procedure employed in this study resulted in a database consisting of threshold VIL and sounding parameters for 25 severe weather dates. It should be noted that 25 severe weather dates is a small data sample for this type of study, however these dates represent the maximum amount of data that was readily available for the study. In addition, it should be noted that the accuracy involved in identifying the most severe weather conditions associated with each VIL value was limited, due to the discontinuous nature of the local spotter network.

The following section will briefly document the variation that was found in threshold VIL values during the period of study. Next, the correlations between threshold VIL and several sounding parameters will be shown. Finally, a regression equation which relates threshold VIL to these variables will be presented.

3. RESULTS

During the period of April 1990 through August 1993, the threshold VIL for severe weather in West Virginia was found to range from a low of 20 kg/m^2 (on 2 severe weather days) to a high of 50 kg/m^2 (on 3 days). The average threshold VIL during the period was 38.2 kg/m^2. The lowest values occurred during spring (April through May, 8 events) and fall (September through October, 3 events), with averages of 31.9 kg/m^2, and 35.0 kg/m^2 respectively. The average during the summer (June through August, 14 events) was 42.5 kg/m^2.

Table 1 shows the correlation coefficients between threshold VIL and the SHARP-calculated HTS sounding variables for which a correlation of greater than 0.50 was found. For the events in this study, the sounding variables that had the highest correlation with VIL were those that were related to thermodynamic stability (i.e., K-index and lifted indices). These results imply that high threshold VIL can be expected during unstable days, with warm moist air present in the layer from the surface through 700 mb, while lower threshold VIL can be expected in a more stable atmosphere.

The findings summarized in Table 1 correspond well with the previous research. These results indicate high threshold VIL values usually occur during summer (when thermodynamic stability is usually lowest), while lower thresholds occur during spring and fall (when the stability is relatively high). In addition, the positive correlation with the height of the wet bulb zero level, and the negative correlation with the pressure of the equilibrium level also imply a tendency for highest threshold VIL to occur during mid-summer as opposed to spring or fall. These findings are also consistent with the observation that threshold VIL is directly related to cloud top height. Finally, it should be noted that the results are in agreement with Beasely (1986) who noted that higher VIL is required for large hail sizes when thermodynamic instability increases or when the height of the wet bulb zero level increases.

From the results shown in Table 1, a simple linear regression equation was calculated for the purpose of predicting threshold VIL in West Virginia based on sounding information. The equation was calculated by using the Statistical Correlation and Regression (SCORE) software package. (Note: SCORE is currently under development at WSFO CRW.)

Initially, all of the variables from Table 1 were considered as possible predictors for the regression equation. The number of potential predictors was reduced by calculating the correlations between these variables. In instances where correlations of greater than 0.80 were found between any of these potential predictors, only the predictor with the highest correlation to VIL was retained. The final regression equation was then derived from the remaining predictors using the least squares regression method

$$\text{VIL (kg/m}^2\text{)} = 21.895 + 0.415(\text{KI}) - 0.469\ (\text{Li3}) - 0.998\ (\text{SI}),$$

where KI= K-index, Li3= 1000-300 mb lifted index, and SI= Showalter index.

The equation explains 0.5871 of the variance of VIL that was observed during the study. Table 2 shows the Pearson correlation coefficients between observed VIL (Y), K-index (X1), 1000-300 mb lifted index (X2) and Showalter index (X3). Note that, after the method described in the preceding paragraph was applied, no excessively high correlations were indicated between any of the predictors in the equation.

The T scores associated with the null hypothesis that the slopes of the KI, Li3 and SI terms were equal to zero were 2.615, -1.369, and -1.273 respectively. The critical T value for this test was found to be 0.859, for a 0.90 level of significance. The associated probabilities that the slopes of the three terms were not equal to zero (i.e. that the null hypothesis were rejected and that the terms were significant) were 0.996, 0.954 and 0.946 respectively.

Table 3 shows a comparison between the predicted and observed threshold VIL values for each severe weather event (for which data were available) during the period April through August, 1993.

4. SUMMARY/CONCLUSION

An analysis of the correlation between the threshold VIL for severe weather in West

Virginia and several sounding variables, revealed that threshold VIL correlates well with thermodynamic stability. Specifically, high threshold VIL was indicated for days when the air was very unstable, while low threshold VIL was indicated on more stable days. In addition, a positive correlation was indicated between threshold VIL and height of the wet bulb zero level, while a negative correlation was found between threshold VIL and the pressure of the equilibrium level. These findings are consistent with the previous observation that threshold VIL in mid-summer tends to be higher than threshold VIL in spring or fall (with characteristically lower cloud tops).

A simple linear regression equation, which relates threshold VIL to K-index, 1000-300 mb Lifted Index and the Showalter Index was derived in an effort to better utilize RADAP-generated VIL as a severe weather diagnostic tool at Charleston WV. This equation is currently being used operationally at WSFO CRW. On days when severe weather is possible, a forecast afternoon sounding is derived by using the sounding modification option in SHARP. Specifically, the lower-levels of the 1200 UTC HTS sounding are modified, based on the forecast afternoon high temperature and dew point. In addition, upper-levels of the sounding are modified, based on expected upper-level temperature and/or moisture changes. Once these modifications are introduced, SHARP calculates the day's severe weather threshold VIL, based on the calculated values of K-index, 1000-300 mb lifted index, and Showalter index.

It should be emphasized again that this method for severe thunderstorm identification should only be used in combination with other radar and RADAP-based identification methods. It should be noted that the number of cases used for this study was small, and that the discontinuous nature of the local spotter network probably limited the accuracy involved in identifying the most severe weather condition that occurred with each VIL value. In addition, it should be noted that no data was available for days when strong thunderstorms occurred, but severe criteria was not quite observed. As a result of these limitations, calculating a False Alarm Ratio (FAR) associated with this method would be difficult. However, there is little doubt that false alarms will sometimes occur. In terms of operational forecasting, the best interpretation of a VIL value greater than or equal to the threshold value is that closer investigation of the associated cell is warranted.

Based on WSFO CRW's limited experience with this procedure, the method tends to underestimate the threshold VIL during late-night convective events (see Table 3). The reason for this is probably because these events often occur with a shallow stable layer of air located near the surface. In such situations, the value of a surface-based lifted index does not give a reliable estimate of the positive energy area of a sounding encountered by the majority of rising parcels in a thunderstorm (K-index and Showalter index are not affected by the presence of a stable layer below 850 mb). For these type of cases, the use of an 850 mb-based lifted index instead of a surface-based lifted index, is preferable.

Finally, it should be noted that the RADAP II VIL algorithms were developed as precursors to the WSR-88D severe weather algorithms, and are similar to those that will be used in the WSR-88D. Therefore, the results from this study should help forecasters interpret data from not only the RADAP II system, but also from the WSR-88D. Research is currently underway at WSFO CRW in order to determine how well RADAP-calculated VIL values correlate with VIL values calculated from the newly installed WSR-88D radar at Pittsburgh.

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REFERENCES

Beasely, R.A., 1986: An Analysis of operational RADAP II parameters, corresponding synoptic variables, and concurrent severe weather events in Oklahoma, University of Oklahoma, Norman, OK, 223 pp.

Davis, R.S., and T.R. Drake, 1988: The operational effectiveness of RADAP II during the 1987 severe weather season in western Pennsylvania, *Preprints Fifteenth Conference on Severe Local Storms*, Baltimore, Amer. Meteor. Soc., 194-200.

Devore, D.R., 1983: The operational use of digital radar, *Preprints Thirteenth Conference on Severe Local Storms*, Tulsa, Amer. Meteor. Soc., 21-24.

Elvander, R.C., 1980: Further studies on the relationships between parameters observed with objectively defined echoes and reported severe weather events. *Preprints 19th Conference on Radar Meteorology*, Miami, Amer. Meteor. Soc., 80-86.

Hart, J.A., and J. Korotky, 1991: The SHARP workstation v 1.50. A Skew T - hodographic analysis research program for the IBM and compatible PC. NOAA/NWS Charleston, WV, 30 pp.

Panofsky, H.A., and G.W. Brier, 1968: Some applications of statistics to meteorology, The Pennsylvania State University, University Park, PA, 224.

Paxton, C.H., and J.M. Shepherd, 1993: Radar diagnostic parameters as indicators of severe weather in central Florida, *NOAA Technical Memorandum NWS SR-149*, 12 pp.

Saffle, R.E., and R.C. Elvander, 1981: Use of digital radar data in automated short range estimates of severe weather probabilities and radar reflectivity. *Preprints Seventh Conference on Probability and Statistics in Atmos. Sci.*, Monterrey, CA, Amer. Meteor. Soc., 192-199.

Stewart, S.R., 1991: The prediction of pulse-type thunderstorm gusts using vertically integrated liquid content (VIL) and the cloud top penetrative downdraft mechanism. *NOAA Technical Memorandum NWS SR-136*, 20 pp.

Table 1. Correlation coefficients between threshold VIL and HTS sounding parameters for which a correlation of 0.50 or greater was found.

SOUNDING PARAMETER	CORRELATION WITH THRESHOLD VIL VALUE
K-index	0.6926
Surface to 300 mb lifted index	-0.6431
700 mb Dew Point	0.6363
Surface to 500 mb lifted index	-0.6243
Surface Dew Point	0.5964
C.A.P.E.	0.5876
Precipitable Water	0.5767
700 mb Wet Bulb Temperature	0.5384
Pressure of Equilibrium Level	-0.5332
Showalter index	-0.5181
Height of Wet Bulb Zero Level	0.5096
700 mb Theta-e	0.5014

Table 2. The Pearson correlation coefficients between VIL (Y), K-index (X1), 1000 - 300 mb lifted index (X2), and Showalter index (X3).

	Y	X1	X2	X3
Y	1.000	0.693	-0.643	-0.518
X1	0.693	1.000	-0.611	-0.391
X2	-0.643	-0.611	1.000	0.523
X3	-0.518	-0.391	0.523	1.000

Table 3. Predicted and observed threshold VIL values for each of 8 severe weather dates in West Virginia during the 1993 severe weather season. The date proceeded by an asterisk was associated with a late-night event.

DATE	PREDICTED THRESHOLD VIL (kg/m^2)	OBSERVED THRESHOLD VIL (kg/m^2)
5/12	46	45
5/18	27	25
6/04	35	45
*6/05	36	45
6/09	44	45
6/10	45	45