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# VIL--A PRAGMATIC VIEW

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## 1. INTRODUCTION

VIL, vertically integrated liquid water content (Greene and Clark 1972), has long been viewed as potentially one of the more useful radar indicators of thunderstorm severity (Elvander 1980; Saffle and Elvander 1981; Devore 1983; McGovern et al. 1985; Beasley 1986; Jackson 1987; Davis and Drake 1988; and Teague 1990). However, many users of weather radar data still view VIL as a mysterious quantity with unusual units (kg/m$^2$). The main reason has been VIL's limited accessibility, as few radar sites have had the computer interface (RADAP II) needed to efficiently compute VIL in real time. That will change in the future because the computer-driven WSR-88D system will compute VIL every 5-minutes (using the convective precipitation scanning strategy). This will establish a need for operational hydrometeorologists and technical specialists to learn more about VIL. This paper is an attempt to improve familiarity with VIL by providing a pragmatic look at VIL's units and method of computation.

## 2. DEFINITION AND CONVERSION TO MORE FAMILIAR UNITS

Two radar measurements often used to describe thunderstorm severity are echo intensity (reflectivity) and echo top height. Reflectivity (VIP-level) is typically measured at 0.5$^\circ$ elevation on the Plan Position Indicator Scope or PPI (although it can be measured at other elevation angles). Echo top height is measured independently on the Range-Height Indicator (RHI). The rationale has been that storms with strong downdrafts and large hail have strong updrafts; and storms with strong updrafts tend to lift large amounts of water and hail to higher levels of the storm.

Unfortunately, efforts to determine storm severity by using separate measurements of reflectivity and tops have achieved only limited success. Therefore, attempts have been made at combining measurements into a single composite indicator. One example is Lemon's (1980) criteria that VIP-level 5 exist to at least 27,000 feet. Another example is VIL, which is a summation of reflectivity through the depth of thunderstorms. Since reflectivity is related to rainfall intensities through Z-R relationships, summing (integrating) reflectivities over certain height intervals can yield the amount of liquid water the entire storm contains. Hence, the name, vertically integrated liquid water content or VIL, is an apt one.

One would expect VIL's dimensions (units) to be length or depth just like precipitable water, another measure of atmospheric water vapor content. In the literature, however, VIL is expressed as mass per area with metric (Standard International) units of kg/m$^2$. Closer examination shows that VIL dimensions of mass per area ([M]/[L][L]), and length [L] are related by density ([M]/[L][L][L]).

Therefore, VIL's units of $kg/m^2$ can be converted to millimeters (mm) by dividing by the density of water (1 $gm/cm^3$). Note, this results in no change in VIL's numeric value. For example:

$$\frac{VIL}{H_2O} = \frac{kg\ m^{-2}}{1\ g\ cm^{-3}} = \frac{10^3\ g\ cm^3}{10^4\ g\ cm^4} = 10\ cm^{-1} = mm$$

A more familiar application of this type of relationship is the measurement of rainfall with a weighing-type rain gauge. The depth of rain is calculated by dividing the mass of rain caught in the gauge, by the area of the gauge's opening and the density of water.

VIL can be expressed in hundredths of inches by multiplying VIL's value in millimeters by four, since 1 mm is about 0.04 inches. For example, a VIL of 50 $kg/m^2$ is equivalent to 50 mm or 2 in.

## 3. MANUALLY ESTIMATING VIL FROM THE RHI

The five-step method described in this section is easy to do and can serve as a training aid for visualizing VIL's basic features. Appendix A has a worksheet that can be used with these five steps. However, it must be recognized that even this simple method may be too time consuming for operational use in severe weather situations, and it is only an approximation that can vary from those derived from the theoretical formulation (Appendix B), or automated algorithms (e.g., RADAP) that are more computational intensive.

**Step 1.** By using the same procedure as the one for finding the maximum height of precipitation ("max top"), use the RHI and PPI scopes to scan the thunderstorm with the antenna in manual rotation. Select the thunderstorm column that has the most intense VIP-levels extending to the highest elevation. Record the azimuth and range of this column on the Appendix A worksheet.

**Step 2.** Continue to scan this column with the RHI, record the base and top heights (in thousands of feet [kft]) of VIP-levels 6, 5, 4, and 3.

**Step 3.** Subtract the base height from the top height of each VIP-level to determine its vertical thickness.

**Step 4.** Multiply the vertical thickness of the VIP-level 6 (VIP6) layer by 1.8 to determine the VIP6 contribution to the storm's VIL. Multiply the VIP5 layer's thickness by 1.2 to get the VIP5 VIL contribution. Multiply the VIP4 layer's thickness by 0.6 to get the VIP4 VIL contribution. Multiply the VIP3 layer's thickness by 0.3 to get the VIP3 VIL contribution.

**Step 5.** Sum these individual contributions to get the entire storm's VIL.

The following three examples use this method to show some of VIL's inherent characteristics:

**Example 1.** A thunderstorm was observed on the RHI to have a VIP6 extending from the surface to 5 kft; a VIP5 to 30 kft; a VIP4 to 38 kft; and a VIP3 to 42 kft.

| VIP | TOP (kft) | LYR THICK-NESS (kft) | | K(VIP) CON-STANT (mm/kft) | | VIL CONTRI-BUTION (mm) |
|---|---|---|---|---|---|---|
| 3 | 42 | 4 | x | 0.3 | = | 1 |
| 4 | 38 | 8 | x | 0.6 | = | 5 |
| 5 | 30 | 25 | x | 1.2 | = | 30 |
| 6 | 5 | 5 | x | 1.8 | = | 9 |
| | | | Storm VIL | | = | 45 mm |

This example illustrates the relative size of each VIP's contribution to the entire storm's VIL. As shown in the Appendix B derivation, the K(VIP) constant for VIP6 (K6) is 1.5 times the size of the VIP5 constant (K5). K5 is two times the size of K4 and four times the size of K3. The VIP2 VIL contribution can be ignored since K2 is only 0.1 mm/kft.

**Example 2.** VIL exceeding 45 mm has been suggested as a significant indicator of severe weather during the warmer months (NOAA, 1978; Devore, 1983; and Davis and Drake, 1988). If an entire thunderstorm were comprised of just one VIP-level, how high must its top be to have a VIL value of 45 mm? For this situation:

| VIP | VIL (mm) | | K(VIP) (mm/kft) | TOP (kft) |
|---|---|---|---|---|
| 3 | 45 | / | 0.3 | 150 |
| 4 | 45 | / | 0.6 | 75 |
| 5 | 45 | / | 1.2 | 38 |
| 6 | 45 | / | 1.8 | 25 |

This example likewise shows that the major contribution to a storm's VIL value is generated by the VIP6 and VIP5 layers. Since storms seldom exceed the tropopause's typical height of 40 to 60 kft, the example also indicates that a storm of less than VIP5 intensity has little chance of having a VIL value that exceeds 45 mm. For these less intense storms, other radar indicators must be examined to determine severe weather potential. *However, it should also be noted that any "critical value" of VIL will vary with location, season, and air mass.*

**Example 3.** VIP5 exceeding 27 kft has been regarded as a criteria for identifying severe thunderstorms (Lemon 1980). What is the corresponding VIL value for this 27-kft VIP5 layer?

$$27 \text{ kft} \times 1.2 \text{ mm/kft} = 32 \text{ mm}$$

This section's method of estimating VIL differs from the Appendix B theoretical formulation and the associated computer algorithm in two ways. One difference is in the computation procedure and the other is in the observing procedure.

For the computation procedure, a determination of the vertical thickness of constant VIP-levels is required. The theoretical formulation makes use of the average VIP-levels for specified constant vertical thicknesses. McCann (1978) has developed a manual method that more closely follows the theoretical formulation. However, the method requires the aid of nomograms and a calculator.

For the computation procedure, the method relies on VIP-levels observed with a stopped antenna rather than VIP-levels observed with the standard 3 rpm rotation. McCann (1978) has found manually estimated VIL values to be typically 20% too large because of stopped-antenna VIP-level inflation. The procedure does not correct for this overestimation because of the possible underestimation introduced by assigning just one K5 and one K6 value as representative of the significantly large ranges of K5 and K6 values that exist.

## 4. SUMMARY AND CONCLUSIONS

VIL, an indicator of storm intensity, has the potential to be one of the more useful indicators of severe weather. This presentation has attempted to increase forecasters familiarity with VIL by providing a pragmatic look at VIL's units and method of computation.

Furthermore, this pragmatic view suggests that only storms with VIP6 or very strong VIP5 (echoes exceeding 54 dbz) can have VIL values that exceed 45 mm. This may have implications to future severe weather decision-making.

Radar measured reflectivity is larger in storms that contain hail. Since VILs are determined from radar reflectivity, larger VILs are typically observed with hail producing storms. Small VIL values, however, do not necessarily indicate a storm without damaging wind gusts. Therefore, other radar signatures should always be examined to finalize severe thunderstorm warning decisions. These radar signatures include storm tilt, bounded weak-echo regions (overhangs), echo appendages (hooks), distinctive echoes (e.g., bows and line echo wave patterns), inflow notches, excessively fast and/or deviant storm movements, and a storm's position relative to other storms. In the future, with the WSR-88D system, information such as wind profiles, shears, and rotations within the storm and its surrounding environment will also be available.

## 5. ACKNOWLEDGMENTS

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# APPENDIX A
# WORKSHEET TO MANUALLY ESTIMATE VIL VALUES

RADAR ________________________ DATE ______________________

AZRAN ________________________ TIME ______________________

| VIP | TOP | BOTTOM | LYR | K(VIP) | VIL |
|---|---|---|---|---|---|
| | ......(kft)..... | | | | (mm or kg/m2) |
| 3 | - | = | x | 0.3 | = |
| 4 | - | = | x | 0.6 | = |
| 5 | - | = | x | 1.2 | = |
| 6 | - | = | x | 1.8 | = |
| | | **Storm Total** | | | = |

Verification: ________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

| LYR | 3 | 4 | 5 | 6 |
|---|---|---|---|---|
| 30 | 9 | 18 | 36 | 72 |
| 20 | 6 | 12 | 24 | 36 |
| 10 | 3 | 6 | 12 | 18 |
| 5 | 2 | 3 | 6 | 9 |
| 2 | 1 | 1 | 2 | 4 |
| 1 | 0 | 1 | 1 | 2 |
| K(VIP) | 0.3 | 0.6 | 1.2 | 1.8 |

**Table A-1.** Table to find VIL for various VIP layers.

# APPENDIX B
# DERIVATION OF MANUAL METHOD

The following is the equation for determining VIL (summation form rather than integral form).

$$VIL = (3.44)(10^{-6}) \sum_{i=1}^{n} \frac{(Z_i + Z_{i+1})^{4/7}}{2} \, dh \qquad \text{(B-1)}$$

where...
dh denotes vertical thickness (in meters).
Z denotes reflectivity.
dbz denotes reflectivity in log form.
(Note: $Z = 10^{(0.1\ dbz)}$ since dbz is defined as 10 log Z.

Equation B-2 is the transformed VIL equation used as the basis of the hands-on method. Note the height units have been converted to kft.

$$VIL = (3.44)(10^{-6}) \sum_{VIP=3}^{6} \frac{10^3 \; 10^{(0.057\ dbz(VIP))}}{3.28} \; H(VIP) - H(VIP+1) \qquad \text{(B-2)}$$

where...
1 m = 3.28 ft.

H(VIP) denotes the max top (in kft) of that particular VIP-level.

H(VIP+1) denotes the max top (in kft) of the next higher (more intense) VIP-level.

A constant K(VIP) is determined from combining numerical constants and assigning a representative dbz value to each VIP-level.

$$K(VIP) = (0.00105)\ 10^{(0.057\ dbz[VIP])} \qquad \text{(B-3)}$$

The following table shows the Equation B-3 calculations for each possible attenuation increment (3 dbz) from 36 to 60 dbz and the K(VIP) values that have been chosen as representative for each VIP-level. Note, the significantly large range of K(VIP) values possible for VIP5 and VIP6.

| VIP | dbz | K(VIP) | | K(VIP) assigned |
|---|---|---|---|---|
| 2 | 36 | 0.12 | ---> | K2 = 0.1 |
| 3 | 42 | 0.26 | ---> | K3 = 0.3 |
| 3 | 45 | 0.38 | | |
| 4 | 48 | 0.57 | ---> | K4 = 0.6 |
| 5 | 51 | 0.85 | | |
| 5 | 54 | 1.28 | ---> | K5 = 1.2 |
| 6 | 57 | 1.86 | ---> | K6 = 1.8 |
| 6 | 60 | 2.77 | | |

**Table B-1.** K(VIP) for specified dbz and VIP.

Substituting these assigned K(VIP) values into Equation B-2 yields the formula (Equation B-4) used to compute the VIL values in Section 3.

$$VIL = (1.8)(H6-0) + (1.2)(H5-H6) + 0.6(H4-H5) + 0.3(H3-H4) \quad (B-4)$$

Equation B-4 is helpful for visualizing the contribution that each VIP-level layer makes to the storm's total VIL value. Equation B-4 also simplifies real-time VIL computations, particularly if the worksheet in Appendix A is used. Equation B-5 is a further simplification based on the fact K(VIP) values assigned in Table B-1 are each a multiple of 0.3.

$$VIL = (0.3)[\ 2(H6) + 2(H5) + H4 + H3\ ] \quad (B-5)$$