VERTICALLY-INTEGRATED LIQUID WATER

ALGORITHM DESCRIPTION

NX-DR-03-006/25

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The Vertically-Integrated Liquid Water (VIL) algorithm describes the conversion of weather radar reflectivity data into liquid-water content based on theoretical studies of drop-size distributions and empirical studies on the relationship between reflectivity factor and liquid-water content. The algorithm described uses an equation which relates reflectivity factor to liquid-water content as given in the reference stated in Section 1.2. Large values of liquid-water content have been related to severe thunderstorms and tornadoes.

The VIL algorithm computes a liquid water value for each sample volume. Each sample volume is then mapped onto a predetermined 4 by 4 kilometer grid. For each elevation angle, each grid box is assigned the largest liquid water value of all the sample volumes located within the grid box. All other liquid water values in each grid box are ignored. This reduces data storage requirements while compensating for the fact that the storm is moving during the acquisition of the volume scan. Moreover, at distant ranges the sample volume size approaches the size of the grid box. These partial liquid water values are then integrated vertically to arrive at VIL values for each grid box. If the VIL value for a grid box exceeds 80 x 10^6kg/km^2 it is adjusted to 80 x 10^6kg/km^2 to mitigate the large reflectivity values associated with hail.

1.2 SOURCE

The VIL algorithm described herein has been implemented for the D/RADEX experiment conducted by the National Weather Service (NWS). Mr. Robert Saffle of the NWS's Techniques Development Laboratory supplied the D/RADEX information.

REFERENCES

Greene, D.R., and R.A. Clark, 1971: An indicator of explosive development in severe storms. Preprints. 7th Conference on Severe Local Storms (Kansas City), American Meteorological Society, Boston, 97-104.

Rogers, R.R., 1969: Interpretation of the fluctuating echo from randomly distributed scatterers. Part 4. Sci. Rept. MW-63 Stormy Weather Group, McGill University, Montreal.

1.3 PROCESSING ENVIRONMENT

This algorithm does not use the "raw" reflectivity factor data obtained from the radar. Several preprocessing steps are carried out before the data are input to VIL algorithm. The NWS preprocessing performed on the data is described by the following operations.

First the standard $1/r^2$ range correction is performed on the data. A correction is then made for oxygen absorption of microwave energy. The linear attentuation correction of 6.5×10^{-3} dB/km for a 10 cm radar is then performed. The resulting reflectivity factor data values for each sample volume are assigned a number representing fifteen categories as shown in the Operational Threshold column of Table 1. If the return power is less than 18.5 dBZe it is assigned a value of zero. The categorization of the data is performed so that a look-up table procedure can be used to arrive at liquid water values. The data are also filtered to remove any spurious data. A data point must have at least two adjacent points with a category value of at least one, otherwise the isolated point is removed. That is, at least two of the four possible sample volumes at a particular elevation with adjoining sides to the sample volume in question must be in category one or above. This final data set is the one used as input to the VIL algorithm.

NOTE: The look-up tables and reflectivity categories described above are implementation specifics of NWS's D/RADEX implementation. The AEL (see section 3.1) has been generalized to permit other approaches.

2.0 INPUTS

2.1 IDENTIFICATION

AZIMUTH	=	Azimuthal position, in radians. Precise to 10^{-3} radians.
BEAM WIDTH	=	The angular width of the radar beam between the half-power points (0.017), in radians.
BOX (4 km x 4 km Grid)	=	Square grid boxes which are 4 km on a side and cover ranges for 0 to 230 km.
SAMPLE VOLUME	=	A data sample volume whose dimensions are 1 degree in azimuth, 0.25 km in range, and 1 degree in depth (perpendicular to the radar beam).
REFLECTIVITY FACTOR (ZE)	=	The effective radar reflectivity factor of a SAMPLE VOLUME, in mm^6/m^3.
ELEVATION	=	Elevation angle, in radians.
RANGE (Slant)	=	The slant range to the center of a SAMPLE VOLUME, in kilometers.

2.2 ACQUISITION

AZIMUTH, ELEVATION, AND RANGE (Slant) are quantities measured directly during the radar data acquisition process.

BEAM WIDTH is a constant determined by the antenna's characteristic beam width.

BOX (4 km x 4 km Grid) is a system supplied parameter.

SAMPLE VOLUME is a direct result of the radar parameters chosen at the time of observation. The sample volumes will still be variable depending on the range of observation because the radar beam is diverging.

REFLECTIVITY FACTOR (ZE) is acquired directly from the Doppler radar hardware.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (VIL)

1.0  DO FOR ALL (ELEVATIONs)
     1.1  DO FOR ALL (AZIMUTHs)
          1.1.1 DO FOR ALL (RANGEs (Slant))
                1.1.1.1  COMPUTE (LIQUID WATER)
                1.1.1.2  Map polar position of SAMPLE
                         VOLUMES onto a BOX (4 km x 4
                         km kilometer Grid).
                1.1.1.3  COMPUTE (DEPTH (Beam))
                END DO
          END DO
     1.2  DO FOR ALL (BOXes (4 km x 4 km Grid))
          1.2.1  COMPUTE (maximum LIQUID WATER)
          1.2.2  COMPUTE (partial VIL)
          1.2.3  COMPUTE (LIQUID WATER (Integrated))
                 WRITE (LIQUID WATER (Integrated) is
          1.2.4  IF (LIQUID WATER (Integrated) is
                 greater than 80 x 10^6 kg/km^2)
                 THEN  (Assign LIQUID WATER (Integrated)
                       to be 80 x 10^6 kg/km^2)
                 END IF
          END DO

     END DO

2.0  COMPUTE (maximum LIQUID WATER (Integrated))

3.0  WRITE (maximum LIQUID WATER (Integrated))

END ALGORITHM (VIL)
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3.2 COMPUTATION

3.2.1 NOTATION

LW = LIQUID WATER, the liquid water content for a particular value of reflectivity, in kg/km^3.

ZE = REFLECTIVITY FACTOR (ZE), the effective radar reflectivity factor of a SAMPLE VOLUME, in mm^6/m^3.

DB = DEPTH (Beam), the depth of the radar beam as a function of range for each grid box, in kilometers. Precise to 10^{-4} kilometers.

RH = RANGE (Horizontal), the horizontal range, in kilometers. Precise to 10^{-4} kilometers.

RE = RADIUS (Earth), the radius of the Earth (6371), in kilometers. Precise to 10^{-4} kilometers.

BW = BEAM WIDTH, the angular width of the radar beam between the half-power points (.017), in radians. Precise to 10^{-3} radians.

RS = RANGE (Slant), the slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 10^{-4} kilometers.

PHI# = ELEVATION, elevation angle, in radians. Precise to 10^{-3} radians.

LWmax = maximum LIQUID WATER, the maximum liquid water content found within a grid box, in kg/km^3.

VILpar = partial LIQUID WATER (Integrated), the portion of the LIQUID WATER (Integrated) in a column which is detected at a particular elevation (per grid box) within a storm, in kg/km^2.

VIL = LIQUID WATER (Integrated), integrated liquid water values (per grid box) for a column within a STORM in kg/km^2.

VILmax = maximum LIQUID WATER (Integrated), the maximum LIQUID WATER (Integrated) value in the scanning region, in kg/km^2.

NOTE: Precision is to the units specified unless otherwise stated.

3.2.2 SYMBOLIC FORMULAS

<u>COMPUTE</u> (RANGE (Horizontal))

$$RH = RS \sin(\phi)$$

<u>COMPUTE</u> (LIQUID WATER)

$$LW = 3.44 \times 10^{+3}\ ZE^{4/7}$$

NOTE: There is no typographical error here. The 3.44 x 10^{-3} g/m^3 in Table 1 equates to the 3.44 x 10^{+3} kg/km^3 used here.

COMPUTE (DEPTH (Beam))

IF lowest elevation scan

THEN $DB = RH\ (\tan(\phi_{avg})) + RH^2 / [2\ (4/3)\ (RE)\ (\cos^2 \phi_{avg})]$

Where ϕ_i *is the elevation angle of the* i^{th} *tilt*

and $\phi_{avg} = (\phi_1 + \phi_2)/^2$

ELSE IF highest elevation scan

THEN $DB = 1/2\ (RH)\ (\tan\ (\phi_{top} + (BW) / 2) - \tan\ (\phi_{top-1}))$

ELSE

$DB = 1/2\ (RH)\ (\tan\ (\phi_{i+1}) - \tan\ (\phi_{i-1}))$

END IF

Where top is the highest elevation scan in the volume sequence.

COMPUTE (maximum LIQUID WATER)

$LWmax = LW_n \text{ if } LW_n > LWmax$

where n is the number of LW values within a BOX.

COMPUTE (partial VIL)

$VILpar = (LWmax)\ (DB)$

COMPUTE (LIQUID WATER (Integrated))

$$VIL = \sum_i VILpar_i$$

COMPUTE (maximum LIQUID WATER (Integrated))

$VILmax = VIL_n \text{ if } VIL_n > VILmax$

where n is the number of BOXes.

4.0 OUTPUTS

4.1 IDENTIFICATION

A set of LIQUID WATER (Integrated) values corresponding to the BOXes (4 km x 4 km Grid).

The maximum LIQUID WATER (Integrated) value for each complete volume scan is output.

4.2 DISTRIBUTION

The vertically-integrated liquid water content values could be used by an algorithm to plot contours of the values. The data can also be used to derive a severe weather probability index. Another use is tracking storms by their maximum VIL. The LIQUID WATER (Integrated) values are input to the SEVERE WEATHER PROBABILITY [015] algorithm.

5.0 INFERENCES

5.1 LIMITATIONS

This algorithm will have a bias towards larger drop sizes. Clouds containing a large number of small drops produce very small values of ZE, which could be below the detectable signal level of the radar. This is, however, rarely a problem in most severe weather cases. Also, hail can produce fictitious values of liquid water due to enhanced reflectivity values. Therefore, a maximum value of 80×10^6 kg/km^2 is a set as a ceiling to mitigate this effect.

Except for the lowest tilt, this current implementation has no earth curvature correction, i.e., the earth is considered flat when mapping data in polar coordinates to the rectilinear coordinates. The values obtained at distant ranges may be misleading because liquid water below the radar beam is not measured. At long ranges, errors may be due to large sample volumes also.

5.2 FUTURE DEVELOPMENTS

There is no knowledge of future plans to modify the VIL algorithm in its current implementation.