CORRELATIONS BETWEEN HAIL EVENTS AND RADAR ECHOES IN TRANSYLVANIA

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ABSTRACT. - Correlations between hail events and radar echoes in Transylvania. Over 500 hail events reported across Transylvania by meteorological and hydrological stations, with several large hail events (i.e. hail diameter ≥ 2 cm), were studied during 2004-2014. The purpose of this study was to determine the correlations between the hail events, especially the hail size, and different radar echoes, such as reflectivity, vertically integrated liquid, echo tops of the clouds, and instability indices, such as the vertical totals index, in order to provide useful information regarding forecast of hail, especially large hail. The radar data were measured by the WSR-98D Doppler radar from Bobohalma-Tarnaveni, Mures county, placed in central Transylvania. I have also studied the use of vertically integrated liquid density as an indicator for the size of hail in thunderstorms, applied in Transylvania for operational use. The methodology used in deriving this comparison is provided to assist other operational weather forecasters in developing VIL Density vs. hail size correlation.

Keywords: hail, meteorological radar, VIL, weather forecast.

1. INTRODUCTION

Greene and Clark (1972) suggested that vertically integrated liquid water content (VIL) could be a useful tool for assessing the severe weather potential of thunderstorms. Vertically Integrated Liquid (the amount of liquid water that the radar detects in a vertical column of the atmosphere for an area of precipitation) is a function of reflectivity, and converts reflectivity data into an equivalent liquid water content value, based on studies of drop-size distribution and empirical studies of reflectivity factor and liquid water content (Amburn 1996).

This factor is proportional to the total number of targets within a measured volume and to the target diameters taken to the sixth power. Thus, target diameter has a much greater effect on reflectivity than does the number of targets. Reflectivity increases exponentially as target diameter increases. Thus, VIL increases exponentially with reflectivity, so high VIL values require high reflectivity values, usually implying the presence of large targets (hail) aloft. As a result, VIL is used to identify thunderstorms that likely contain large hail and/or a deep layer of large drop sizes.

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The general equation for VIL as used with the WSR-98D radar is:

$$VIL = \sum 3.44 \times 10^{-6} [(Z_i + Z_{i+1})/2]^{4/7} dh$$

and has units of kg m^{-2}. Z_i and Z_{i+1} are radar reflectivity at the bottom and top of the layer, whose thickness is (dh) in meters.

However, according to Funk (2006), there are several potential problems with using VIL for hail prediction by itself:

1) VIL is air mass dependent, for example convection in colder air masses may produce severe hail with relatively low VILs, while those in warmer air masses may not produce severe hail with high VILs.

2) Problem 1) requires determination of a VIL-of-the-day (in other words a threshold VIL value that is associated with hail of 3/4 inch diameter or larger on a particular day. The VIL-of-the-day assumes all thunderstorms within the radar umbrella will have similar characteristics, or a valid threshold VIL for one storm will be the same for all other storms.

3) VIL alone may not be sufficient to distinguish tall storms with low overall reflectivity (smaller targets, including possible small hail) from short storms with high reflectivity (larger targets, including possible large hail).

4) Actual storm VIL values must be reasonably accurate to compare to a pre-determined threshold VIL value. Values of and short-term trends in VIL may not always be accurate, especially for storms very close to and very distant from the radar.

VIL Density is simply the VIL divided by the echo top (the maximum height of precipitation echoes with reflectivity of 18.5 dBZ or higher) and multiplied by 1000 in order to express the result as gm^{-3}. The importance of VIL Density is its use in quickly identifying thunderstorms with high reflectivity relative to their height. Such thunderstorms often contain hail cores, and as VIL Density increases, the hail core tends to be deeper, more intense, and the resulting hail sizes tend to be larger (Amburn 1996).

$$\text{VIL density } (g/m^3) = 1000 * \text{VIL } (kg/m^2) / \text{echo-top } (m)$$

Funk(2006) specifies also some VIL Density limitations and considerations:

1) The method for calculating VIL can affect VIL Density values. Thus, threshold VIL Density values for fast moving and strongly tilted storms may be about > 3.3. For slowly moving, vertical storms, threshold VIL Density values may be about >3.8-4.0. For distant storms, VIL and VIL Density may be overestimated.

2) WSR-88D echo tops may not be accurate due to discrete elevation scan strategies and product resolution. Echo tops may vary with changes in range, despite no actual change in thunderstorm top.

3) Verification, as always, has some inherent problems. Only verified large hail reports were used in the study, along with non-severe hail cases that passed

over a populated area. However, actual maximum hail size associated with some thunderstorms in this study may not have been recorded.

4) VIL Density only indicates hail aloft. This can cause inconsistencies between VIL Density values and ”ground truth”.

2. METHODOLOGY

In this particular study, for the estimation of VIL, echo top, VIL Density and hail size we used the methodology to extract the maximum value from a cell (e.g. a VIL in the range of 45-48 kg m^{-2} reported as 48 kg m^{-2} or an echo top in the range of 8-9 km was reported as 9 km) only if this value could be found also in a neighbouring cell. Otherwise we took the normal considered value from the cell at the moment when the hail was observed (e.g. 45 kg m^{-2} and 8 km). The WSR-98D S-band radar is an upgraded version of the WSR-88D systems used in the US NWS network (Stan-Sion and Antonescu, 2006).

Due to technically issues in WSR-98D radar maintainance in Bobohalma and bad signal areas, we also have some gaps of information regarding different radar echoes (84% of them identified). Severe hail was observed in thunderstorms with VILs as low as 3 kg m^{-2} (especially in the mountain areas) and echo tops as low as 5 km, and in thunderstorms with VILs as high as 70 kg m^{-2} and echo tops as high as 15 km. A comparison was then made between VIL Density and hail size.

Also, all hail sizes used in this study were obtained using storm verification data. These data are collected to assist with warning verification and are not necessarily complete as supporting scientific studies. It is not known whether the hail sizes reported with each event represent the largest hail which occurred.

According to Hunter (www.srh.noaa.gov /mrx/research/precip/precip.php) there are errors in radar-estimations due to *-Radar Calibration, Attenuation, Frozen Hydrometeors and the Melting Layer, Anomalous Propagation, Beam Blockage* and *Range Effects* described below.

Radar Calibration: The WSR-98D calibrates reflectivity every volume scan, using internally generated test signals. From this calibration a "Delta System Calibration" (dB) is calculated. This value reflects change in internal variables such as transmitted power and path loss of the receiver signal processor since the last off-line calibration. Ricks et al. (1995) reported average differences of 3 dB between the New Orleans and Mobile WSR-88D's for a rainstorm with about the same distance from each site.

Attenuation: The radar corrects for gaseous attenuation, leaving wet radome(the weatherproof enclosure that protects the radar antenna) and intervening precipitation as the principal attenuators of microwave return to and from the target. Both are usually small for S-band.

Frozen Hydrometeors and the Melting Layer: Rayleigh scattering is assumed, which means that the precipitation particles are presumed small when compared to the wavelength (10 cm for the WSR-88D) of the incident radiation. Further, the weather radar equation is used, which presumes scattering objects that are spherical *liquid* drops, evenly distributed throughout the sampled volume. To describe actual received power that would be received from scattering objects meeting the aforementioned constraints, the *effective* reflectivity factor Ze is introduced in place of Z. The most prominent violations of the assumptions come from large frozen hydrometeors - melting snow just below the freezing level and hail.

Anomalous Propagation: The WSR-88D displays beam heights assuming standard atmospheric refraction, which is rarely the case. Severe deviations from the standard atmosphere occur in layers with large vertical gradients of temperature and/or water vapour. The role of vapour gradients should not be overlooked, since they can substantially change refractivity where there is abundant moisture. This is usually in the lower troposphere and, unfortunately, often accompanies precipitation. Whatever their cause, certain refractivity lapse rates produce super-refraction or sub-refraction of the beam and inaccurate calculations of actual beam height. The former is usually the more serious problem, because it can cause ducting or interception of the beam by the ground.

Beam Blockage: A major problem is when radars are situated near mountains, something that is practically unavoidable in many locations. The principal uncertainty to this correction is the assumption of standard propagation; under nonstandard conditions the occultation will vary, and so should the amount of correction. This is difficult to quantify in real time.

Range Effects: Earth curvature and standard refraction dictate that the beam becomes more elevated above the surface with increasing range. This effect is akin to blockage, in that the layers near the surface are not sampled by the radar. This is termed beam overshoot or inability to sample the full vertical reflectivity profile.

Several WSR-88D sites have reported discontinuities in precipitation amounts at constant ranges. The cause for these apparently artificial patterns is uncertain. Smith and Krajewski (1994) documented deficits("holes") in WSR-88D precipitation estimations close to the radar, where data originate from higher tilts of the hybrid scan. This may be attributed to software problems or the hybrid scan itself.

The Beam spreading increase the likelihood that precipitation fills only part of the beam. Since it is assumed that scattering objects fill the sample volume completely and uniformly, one may expect sample volume averaging of received power to yield reduced reflectivity over that of a nearer volume. Spreading will also cause overestimation of echo top height.

3. RESULTS

It was hypothesized that a relationship existed between VIL and echo top, and that such a relationship might be useful in determining the potential of a thunderstorm in producing severe hail. The results of this study show that not only is there a strong relationship between VIL and echo top, but a relationship between hail size and VIL Density also exists. Figure 1 shows a scatter plot of VIL vs. echo top for the severe hail events used in this study(353 known size cases, overlapped).

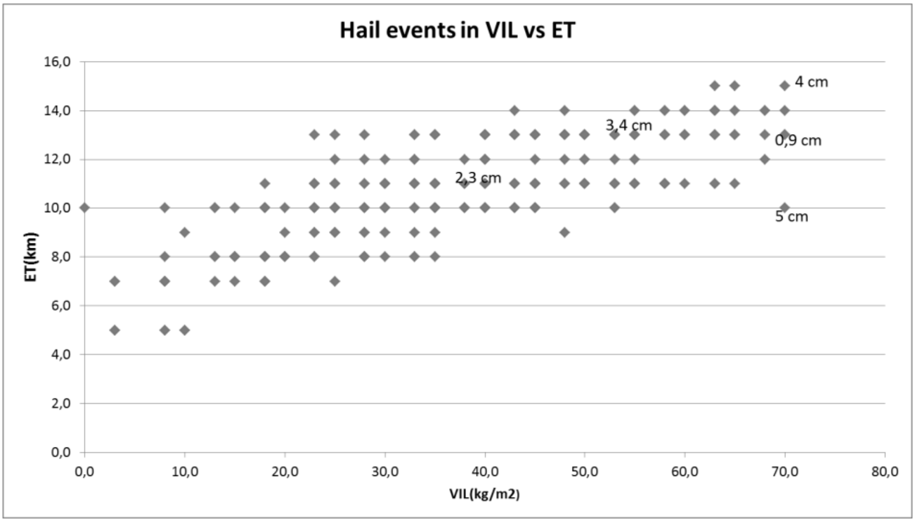

Fig. 1. ***Hail events – VIL vs. Echo Top***

VIL Density, especially when compared with hail size, does provide useful information. A scatter plot of hail size vs. VIL Density is shown in Figure 2. For the large hail cases (over 2.0 cm), we have a VIL Density of at least 3.5 g m^{-3}. (We have 2 events with 2 cm hail size and VIL Density of ~2.5-3.0 g m^{-3}, but those cases were one too far from radar (154 km) and one on a cold front line.

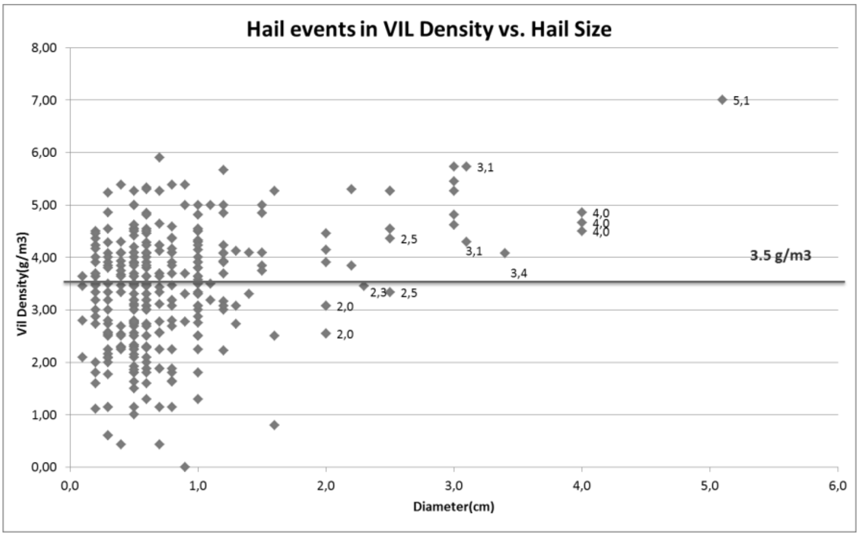

Fig. 2. ***VIL Density vs. Hail Size***

Also, VIL Density associated with 3 cm hail or more was greater than 4.2 g m^{-3}. Basically, the greater the VIL Density, the larger the hail is. VIL Density, especially when compared with hail size, does provide useful information.

In Figure 3 -I have represented the frequency of hail in reflectivity intervals.

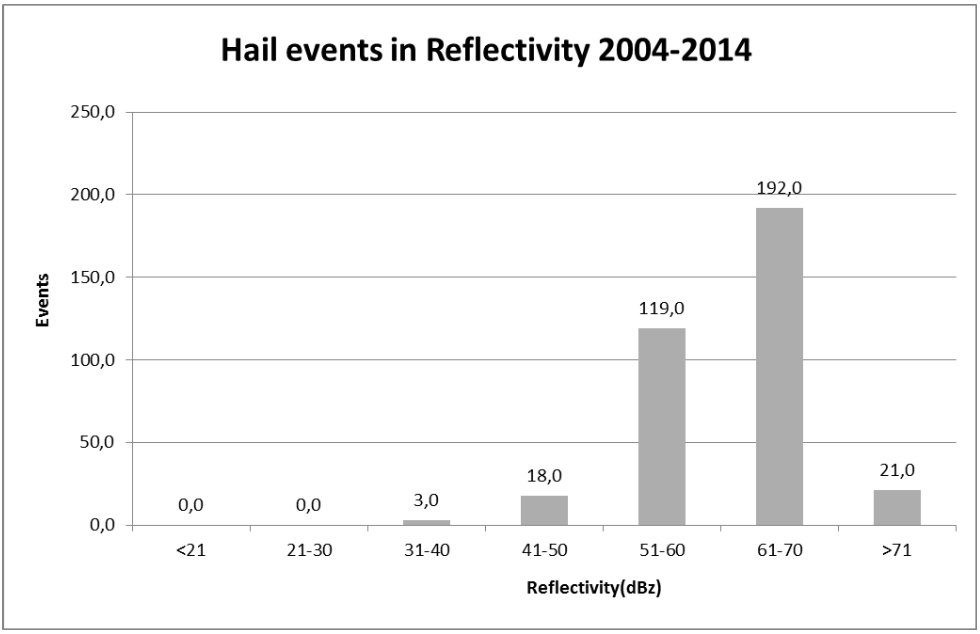

Fig. 3. ***Hail events and associated Reflectivities***

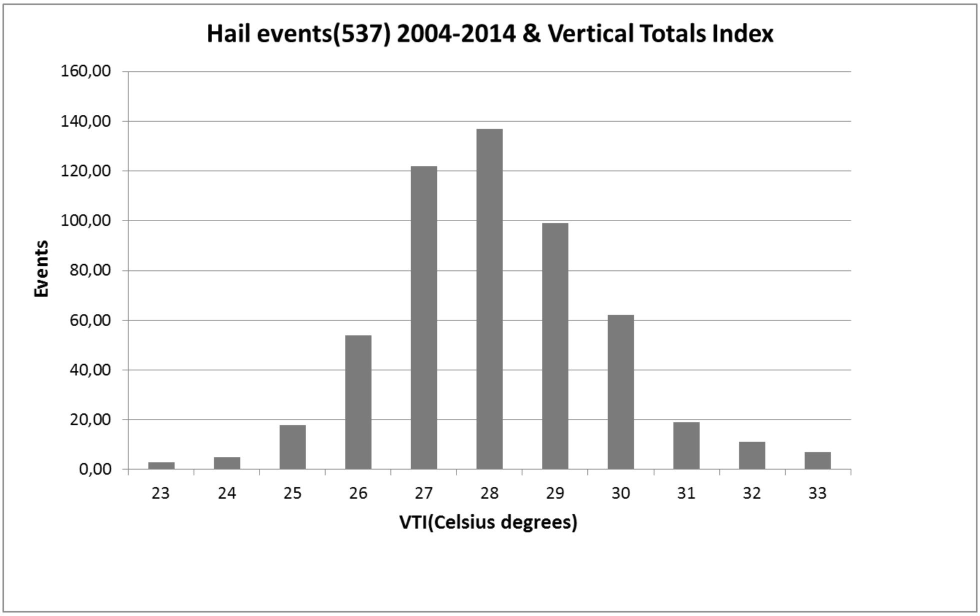

Fig. 4. ***Hail events vs. Vertical Totals Index***

In Figure 4 - I link together all the hail events (537) with the vertical totals index (the vertical temperature gradient between 850 hPa and 500 hPa) in order to find the values which are most likely to produce hail. Most of the severe-hail cases have been registered at 29 and 28 degree Celsius for -(T850-T500), but there were a few at 27 °C, too.

In Figure 5 - I have represented the appereance of hail and the associated echo tops.

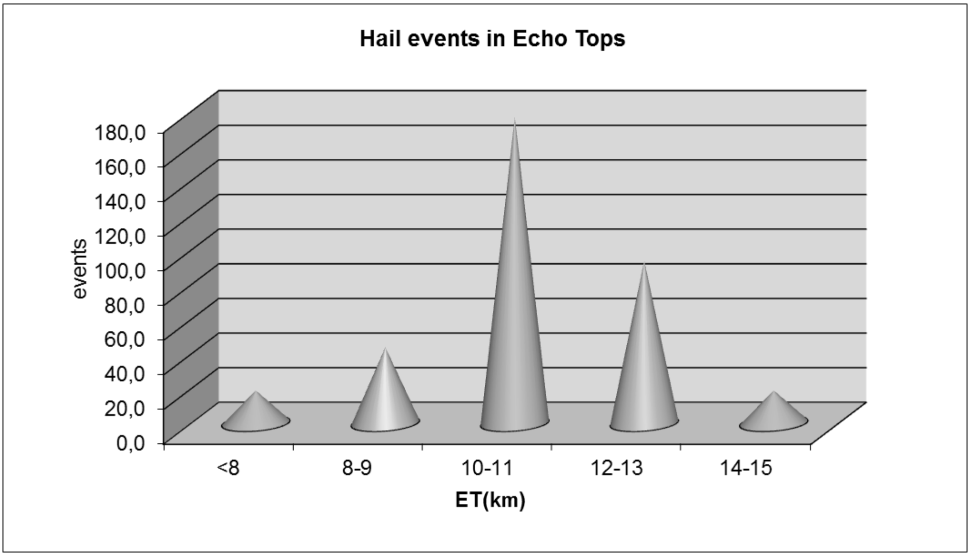

Fig. 5. ***Hail events vs. Echo Tops***

4. CONCLUSIONS

The data gathered for this study show a strong correlation between VIL and echo top in storms which produce large hail, but hail over 2 cm can appear at VILs lower than 40 kg m^{-2} as can seen. It has also been shown that a relationship between hail size and VIL Density exists. These relationships can be used operationally to assist in issuing severe thunderstorm warnings. We can also conclude that for Transylvania a VIL Density of at least 3.5 g m^{-3} is a good predictor for severe hail (equal or greater than 2 cm in size) and a value of 4.0-4.2 g m^{-3} for a severe hail over 3 cm in size. Interestingly, Amburn (1996) identifies the VIL Density of 3.5 g m-3 as correctly identifying over 90% of the severe hail cases in his Oklahoma study. The most events of large hail occurred between 60-70 dBz Reflectivity, but some between 50-60 dBz Reflectivity, and at 27-29 °C value for the vertical totals index (T850-T500), most likely 28-29 °C. The most hail storms have occurred at 10-11 km in echo tops, and this is also due to the fact that there are fewer storms that have developed above this height. Instead we could consider that in Transylvania a 8-9 km cloud is not likely to produce large hail!

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