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Diagnostics of vertical reflectivity profiles at the radar sites

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Abstract. At the Finnish Meteorological Institute, vertical profiles of reflectivity (VPRs) have been measured and diagnosed regularly now for one year. Profiles are derived from the 3D polar volumes inside the range of 2 to 40 km from each of the seven Finnish doppler radars. Profiles are measured in 200 m thick layers at intervals of 15 minutes. The main use of VPR is the calculation of vertical reflectivity profile correction but at the same time calculations also produce useful statistics about VPR characteristics.

The first logical step in applying any instantaneous VPR is to perform quality control and pattern recognition. The main parameteres in the profile recognition are VPR's height, intensity (especially in the surface layer) and the gradient of dBZ/km. With these characteristic VPRs are classified to three different basic types: precipitation, elevated precipitation (Altostratus) and other (clear air echo or clutter). However, for the use of precipitation profiles in the correction of radar-based surface precipitation estimation all nonprecipitating echoes such as ground clutter and birds must be eliminated. Using the freezing level height from radio sounding data, bright band can also be recognized. The freezing level height is also used to separate rain and snow.

Classifications based on over 230 000 profiles have shown that precipitation profiles occur in 40%, overhanging precipitation in 20% and clear air echo in 40% of all profiles. Statistics will be given of the diagnostic parameters of the classified VPR.

1 Measurements and derivation of vertical reflectivity profiles

The diagnostics is based on VPRs derived from the 3D polar volume of each radar measurement. The Finnish network of seven Doppler radars and the scanning strategy is shown in Fig. 1. Each radar measures with ten elevation and 360 azimuth angles. In the most cases the actual lowest elevation angle is 0,4 degrees. Polar volumes are measured every 15 minutes applying 0,5 km radial resolution of the measurement bins. Vertical profiles of reflectivity are derived from the 3D polar volumes inside the range of 2 to 40 km, shown in Fig. 1 with shading. VPR's vertical resolution is 200 meters. The reflectivity value for each 200 meters thick layer is the linear average of the radar reflectivity factor (Z) in those measurement bins where Z exceeds the noise level and where beam center is located within the selected layer. Due to the settings of IRIS software no more than 5000 bins are used for the calculation of the average reflectivity in each vertical layer. Prior to averaging all reflectivity data has passed Doppler filtering to eliminate the effect of ground clutter. As the filtering can't reject fully the effect of the strongest clutter targets at short ranges to the radars, the measured VPR can still be enhanced by clutter at the lowest layers (see Sect. 2).

2 Quality control and pattern recognition

The first step after the measurement is to make quality control for the profile. Every 200 meters thick layer has to contain at least 30 measurement bins exceeding the noise level. Otherwise the layer reflectivity is rejected from the profile. The number of layer bins is shown on the right hand side of the profile as for example in Fig. 2. Prior to the profile classification, an algorithm smooths strong unphysical gradients (peaks) from the profile (see Fig. 3b. If the measured profile contains strong single-layer positive or negative peaks (nonfilled dots) the algorithm will smooth them. If the peak amplitude is large enough, new value for the peak (filled dot) is the average of dBZ-values above and below the peak height like the local minimum and two local maxima below the height of two kilometers in Fig. 3b. If the peak amplitude is moderate, also the original peak value is included in the average calculation like the peaks above the height of 2 kilometers in Fig. 3b. The situations in which dBZ is locally the largest on the top (or at the bottom of an elevated) a dBZ layer, considered unphysical. These kind of corrections are

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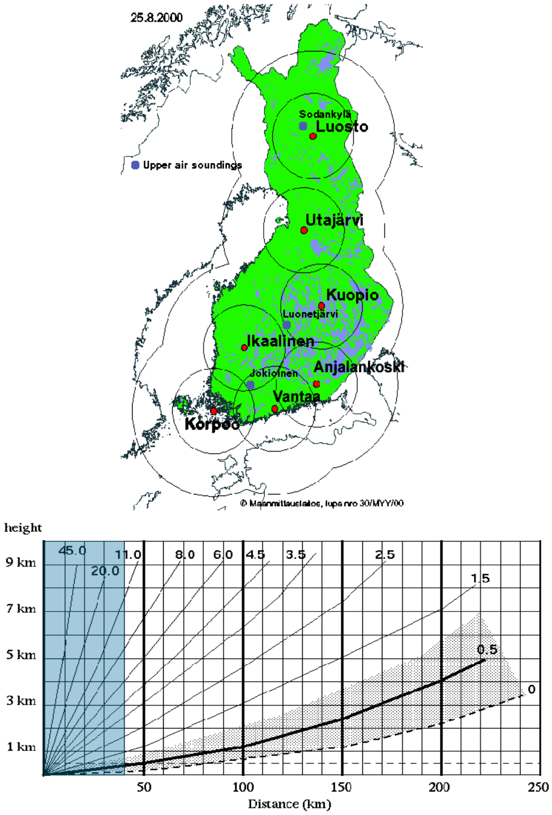

Fig. 1. The Finnish radar and radio sounding network (upper panel) and the scanning strategy (lower panel). The lowest elevation and VPR measurement areas are shown shaded.

shown on the top of the profiles in Fig. 2b and c.

The most important information for the VPR classification, in addition to profile data itself, is the freezing level height. Freezing level height is interpolated linearly in time and space from radio sounding data. The radio sounding stations are shown in Fig. 1 (Jokioinen, Luonetjrvi and Sodankyl). The radio soundings are made at 00 and 12 UTC in Jokioinen and in Sodankyl, and at 06 and 18 UTC in Luonetjrvi. As can be seen in Fig. 1, the radio sounding network is quite coarse compared to the radar network. In frontal cases this cause problems to profile recognition as the actual freezing level height (upper edge of the measured bright band) may deviate too much from the interpolated height of freezing level. At the moment a local dBZ-maximum is diagnosed as bright band when the height of it is within ±500 m from the interpolated freezing level height.

Classified example profiles for different precipitation cases are shown in Fig. 2. In Fig. 2a is a typical snow case from 32 to 4832 meters. The freezing level (FL) is spurious, −1713 meters under ground, as it is calculated from the 925 hPa level's temperature with applying a moist adiabatic lapse rate of −6.5° C/km. The maximum dBZ (Max) is only −2.8 dBZ. Fig. 2b exhibites a typical rain case with strong bright band at 2161 meters (BB) identified with the interpolated freezing level at 1989 m. The minimum height of bright band is 1761 m (Zdown) and the maximum height is 2561 m (Zup). At the maximum height level of bright band (actual freezing level), the dBZ value is 7.8 dBZ lower than at the maximum level of the bright band. At minimum height level the difference is 8.6 dBZ. Typically, the profile values are much larger compared to typical snow case (Max 28.8 dBZ). When bright band is at the ground level, it is impossible to say without real freezing level information if the strengthened VPR layer near the ground is due to clutter or bright band. However, if the interpolated freezing level is located ±500 m above the ground, a dBZ maximum at ground level is diagnosed as a bright band. In Fig. 2c is typical rain shower case without a bright band.

Table 1. Total number of classified vertical reflectivity profiles from March 2001 to February 2002. The clases from left to right are precipitation, overhanging precipitation (Altostratus) and clear air echo (CAE)

	Prec.	**As**	**CAE**	**In month**
Mar	7910/50%	3853/24%	4048/26%	15811
Apr	8148/44%	3781/20%	6635/36%	18564
May	6963/38%	3145/17%	8472/45%	18580
Jun	4306/26%	2609/16%	9519/58%	16434
Jul	3221/15%	4309/20%	14076/65%	21606
Aug	3646/16%	5479/24%	14106/60%	23231
Sep	7276/33%	3924/17%	11063/50%	22263
Oct	8991/38%	4410/19%	10128/43%	23529
Nov	12331/62%	2876/14%	4749/24%	19956
Dec	12813/64%	3452/17%	3882/19%	20147
Jan	8952/57%	2895/18%	3900/25%	15747
Feb	11393/60%	3391/18%	4256/22%	19040
Total	95950/41%	44124/19%	94834/40%	234908

Examples of nonprecipitating VPR's are shown in Fig. 3. In Figs. 3a and b are examples of overhanging precipitation. In Fig. 3a algorithm easily classifies to overhanging precipitation as the lowest layer of the profile is above the ground. Near the ground, there is only a thin ground clutter layer. In Fig. 3b is shown overhanging precipitation case with strong evaporation (Evap 28.2 dBZ). A rain layer is located above the height of two kilometers but due to evaporation reflectivity gradient is negative towards the ground. The layer below one kilometer is not rain anymore but clear air echo due to flying insects. Also the number of bins is only a few houndreds in this layer suggesting that the echo is not widespread precipitation.

In Fig. 3c is shown a clear air echo case. As freezing level is located at 1700 m the profile can not be precipitation. That is based on the assumption that almost all precipitation in Finland is initiated in ice crystal process in temperatures of -6° C or less. This means that the top of the profile should be at least one kilometer above freezing level to be diagnosed as precipitation. The assumption implicates that we are not able to diagnose drizzle from clear air echo or clutter. The profile

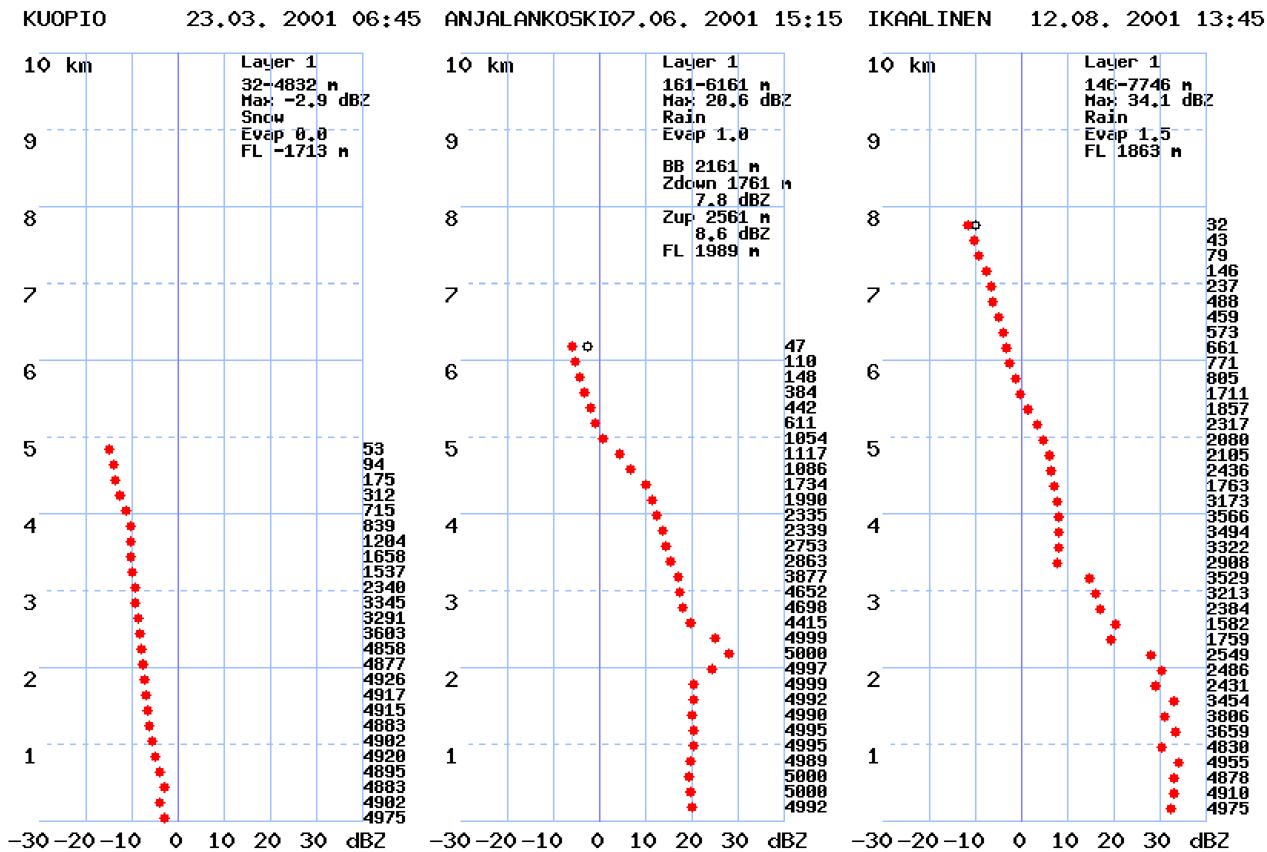

Fig. 2. Example VPR's for a) snow, b) rain and c) shower rain. The number of averaged measurement bins exceeding noise level in each layer of the VPR is shown on the right. The profile diagnostics in the upper right corner are explained in text.

in Fig. 3c is typical in the case of flying insects. Under the insect layer ground clutter may have intensified reflectivities in the layer near the surface. A “clutter cutter” algorithm is applied in the boundary layer if there is no bright band but the vertical reflectivity gradient is too steep, smaller than -1 dBZ/200 m. In Fig. 3c the effect of the clutter cutter algorithm has reduced the reflectivities in the lowest 600 m.

3 Classification statistics

Table 1 exhibits all the classified VPR's from March 2001 to February 2002. The total number of VPR's is over 240 000. Precipitation class (Prec.) can also include overhanging precipitation layer above the precipitation layer. However, in the overhanging precipitation class (As) precipitation is not allowed, but clear air echo layers are allowed. In the clear air echo class (CAE) precipitation or overhanging precipitation layers are not allowed. Thus some cases are included twice (in two classes) in Table 1 and therefore the total number of profiles in month is somewhat larger than the actual maximum number of measured profiles (20832). The VPR classification shows that 41% (95950) of all VPR's are classified as precipitation, 19% (44124) as overhanging precipitation and 40% (94834) as clear air echo. In 26% (24642) of all classified precipitation cases a bright band has been diagnosed and in about 18% of all bright band cases bright band was touching the ground level.

In Fig. 4 is shown precipitation top height diagnosed from all the precipitation VPR's in March 2001 and in July 2002. Larger part of precipitation top heights, about 50%, are quite shallow, less than 3 km. The implication is that in most precipitation cases in winter a measurement is not representing ground level more than 50-100 km from a radar due to the combined effect of VPR and vertical measurement geometry of a weather radar, as can be seen in Fig. 1 (Zawadzki, 1984). In the most shallow precipitation cases the signal is lost completely already at these ranges. In the lowest class (0-1 km), no data exist in Fig. 4 as we have found no tools to separate extremely shallow snofall from drifting snow (clear air echo) and clutter.

The total number of VPR is high in warm season from June to October. One reason for that is high number of clear air echo profiles due to flying insects. The number of precipitation profiles is the highest in cold season from November to May. Main reason for the monthly variation is the synoptic weather type in each month.

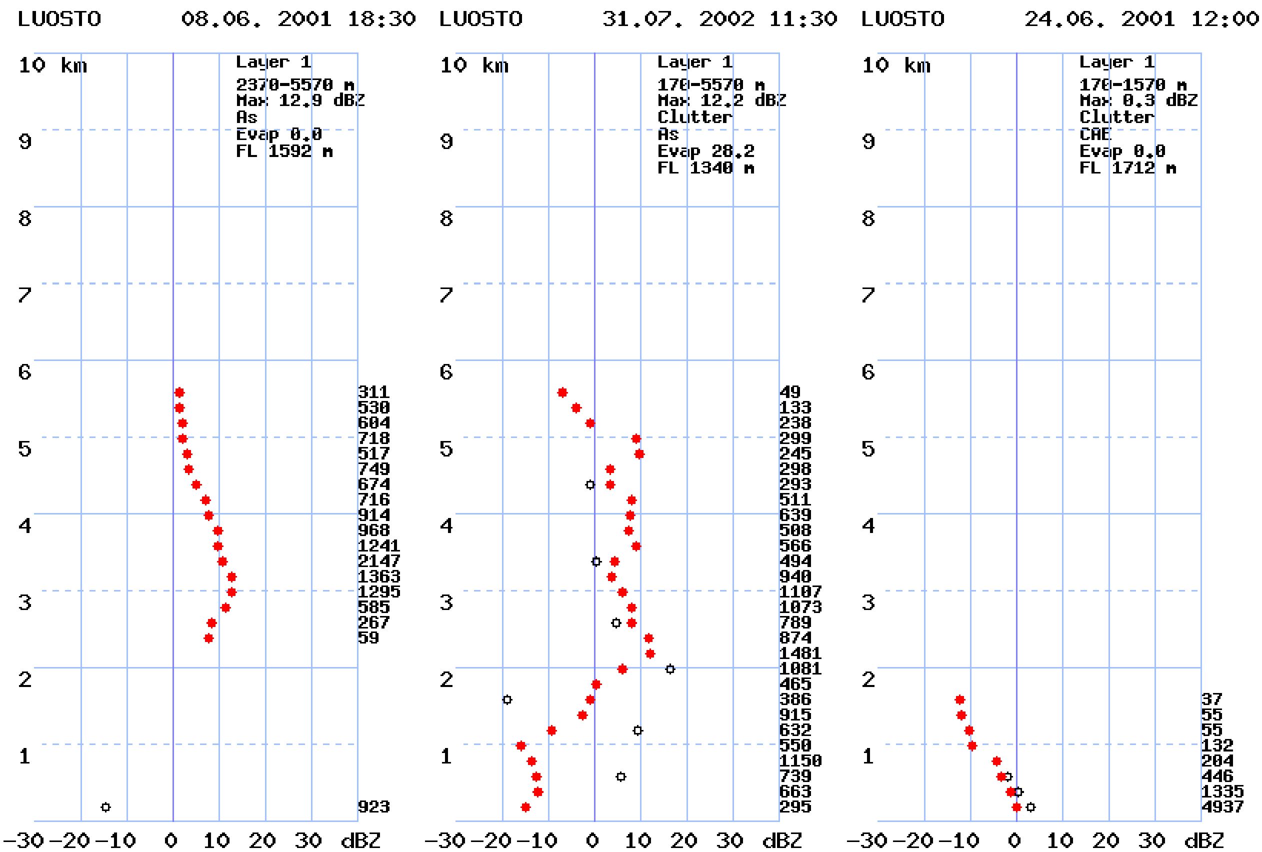

Fig. 3. Nonprecipitating example VPR's for a) overhanging precipitation, b) insects and overhanging precipitation and c) insects and clutter. Quality controlled VPR is shown with filled dots and original, noncorrected layer reflectivities with open dots.

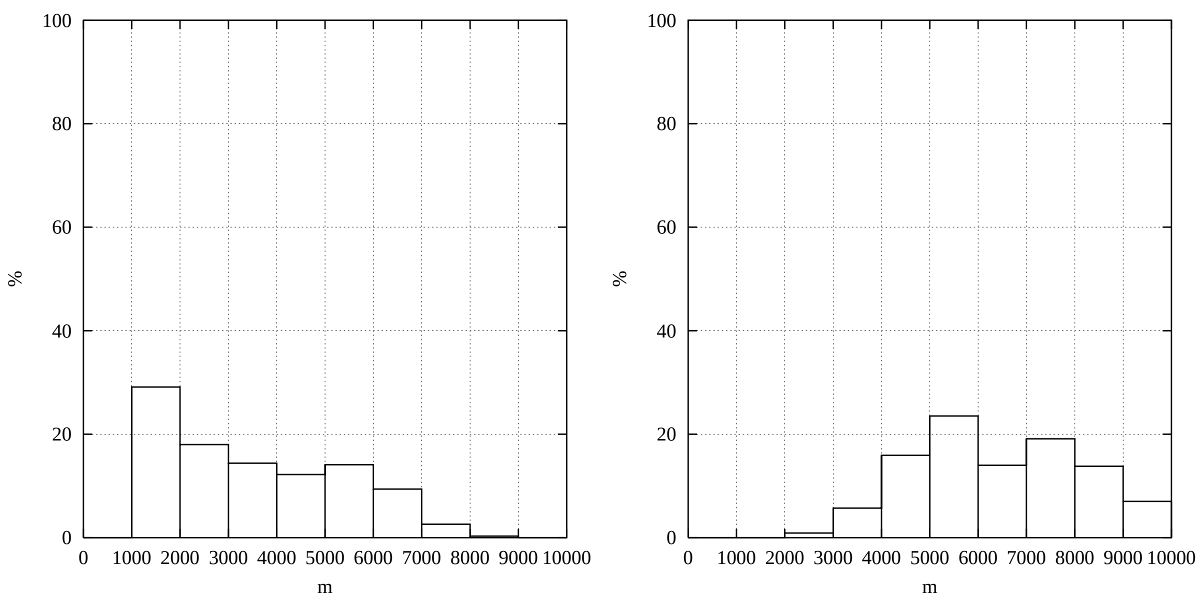

Fig. 4. Frequency distribution of the height of precipitation top diagnosed from vertical reflectivity profiles in a) February 2002 and in b) July 2001.

4 Conclusions

In the Finnish Meteorological Institute vertical reflectivity profile measurements have been done now for one year. During this year we have developed automatic VPR classification based on mostly freezing level height from radio soundings, vertical reflectivity gradient of VPR, height of VPR and number of reflectivity bins in each vertical layer. Statistics and tests have shown, that classification works very well in snow and rain cases. However, in sleet cases, when bright band is at the ground or near the ground level, classification works quite well. Coarse radiosounding network in time and space is not able to produce correct freezing level height for every moment. It is quite difficult to diagnose automatically the following, quite similar shape VPR patterns: 1. Bright bands at the ground level from spurious "brights bands" due to remaining clutter in the lowest layer of a VPR. 2. Intensive bird migration or insect profiles (up to 3 km) from the profiles of shallow precipitation. 3. Enhanced evaporation in precipitation from a combination of an elevated layer of precipitation capping a layer of clear air echo or clutter. The classification and quality weighting of VPR are vitally important for VPR corrections, i.e. algorithms which estimate precipitaiton at ground level from the 3D polar volume (Koistinen and Pohjola, 2002). As such corrections apply measured vertical reflectivity profiles, it must be quaranteed that the profile represents well ground reaching precipitation.

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