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Improvements in weather radar rain rate estimates at the ground using a methodology to identify the vertical profile of reflectivity from volume radar scans

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Abstract. A methodology to identify the Vertical Profile of Reflectivity (VPR) when volume radar scans are available is presented. The first step in the identification of the VPR consists of averaging the apparent vertical profiles of reflectivity observed near the radar. Then the Mean Apparent Vertical Profile of Reflectivity (MAVPR) so obtained is applied to estimate the VPR at each pixel. This is done by fitting the MAVPR to the observed values of reflectivity above each pixel.

The results of a validation study based on using the first PPI as the reference rainfall at the ground are presented and analyzed in order to evaluate the performance of the proposed methodology.

1 Introduction

One of the main errors that affects radar estimates of the rainfall field at the ground is due to the vertical variation of the reflectivity. Near the radar the first PPI measurements are close to the earth surface and therefore they provide reasonable estimates of the rain rate at the ground. However at further distances from the radar, due to the earth curvature and to the elevation angle of the radar beam, the height of the observations increases, and then the reflectivities measured at those altitudes may be different from the reflectivities at the ground. The magnitud of this difference strongly depends on the type of vertical profile of reflectivity showed by the precipitation event. In case of convective profiles, since they present a weak reflectivity gradient, the error caused by the increasing height of radar measurements is low even far away from the radar. On the contrary, in case of stratiform precipitation, whose profiles show a maximum peak of reflectivity at the height of the melting layer, a critical situation happens when the first elevation beam intercepts the so called bright band peak. Then a significant overestimation of the rain-rate is produced when estimating the rain rate at the ground from the first PPI. Eventually, the first PPI intercepts the snow part of a stratiform profile, where the reflectivity decreases with height, and underestimation of the ground rain rate is produced.

The correction of this error related to the vertical variation of the reflectivity is usually solved identifying the shape of the original vertical profiles of reflectivity (VPR). Once the profiles shape has been identified, it can be used to obtain the rain intensity at each ground pixel from the measurements of reflectivity available above this pixel. Several methods have been developed to identify the vertical profile of reflectivity using radar data: Koinstinen (1991), Kitchen and Brown (1994), Joss and Lee (1995), Andrieu et al. (1995), Germann and Joss (2002).

The objective of this paper is to propose and evaluate a methodology, in the line of those developed by Koinstinen (1991), Joss and Lee (1995), and Germann and Joss (2002). This methodology identifies the shape of the vertical profile of reflectivity from the apparent vertical profiles of reflectivity measured in the closest area to the radar. This is done by averaging them, obtaining what we call the Mean Apparent Vertical Profile of Reflectivity (MAVPR) in a ring around the radar. The second step of the methodology consists of applying this mean profile on ranges far from the radar to obtain the reflectivities at the ground level at those ranges.

Because correcting the first PPI estimates is not necessary in case of convective precipitation, we suggest to apply this corrective methodology only to the stratiform zones, and to preserve the first PPI estimates in case of the convective zones. To identify the stratiform zones is proposed to apply the algorithm designed by Sánchez-Diezma, and Steiner algorithm is suggested to identify the convective ones. The mean profile obtained near the radar is computed from only the apparent vertical profiles registered in zones identified as stratiform. So the distorting influence of the convective profiles, which might smooth the bright band peak of the computed mean profile, is eliminated. Next this mean profile is applied only on the stratiform zones far from the radar to

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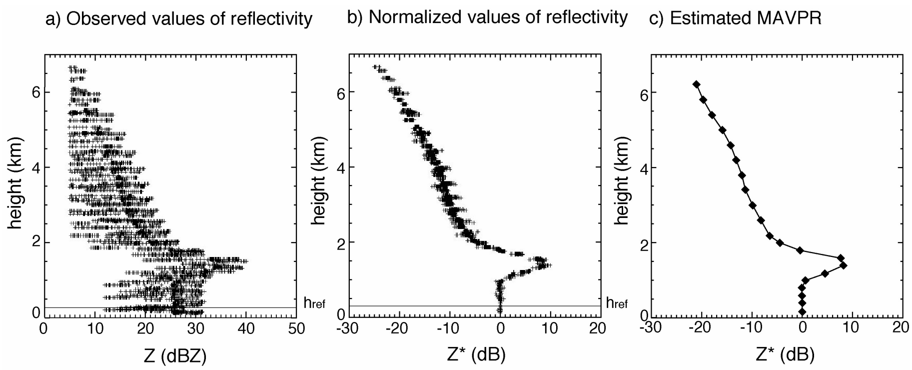

Fig. 1. Application of the proposed algorithm to estimate the Mean Apparent Vertical Profile of Reflectivity (MAVPR) on an annular sector around the radar: a) observed values of reflectivity inside the considered sector and the chosen reference height level href; b) normalized reflectivity values, Z^*, associated to the observed values of reflectivity; c) MAVPR obtained applying a moving average process.

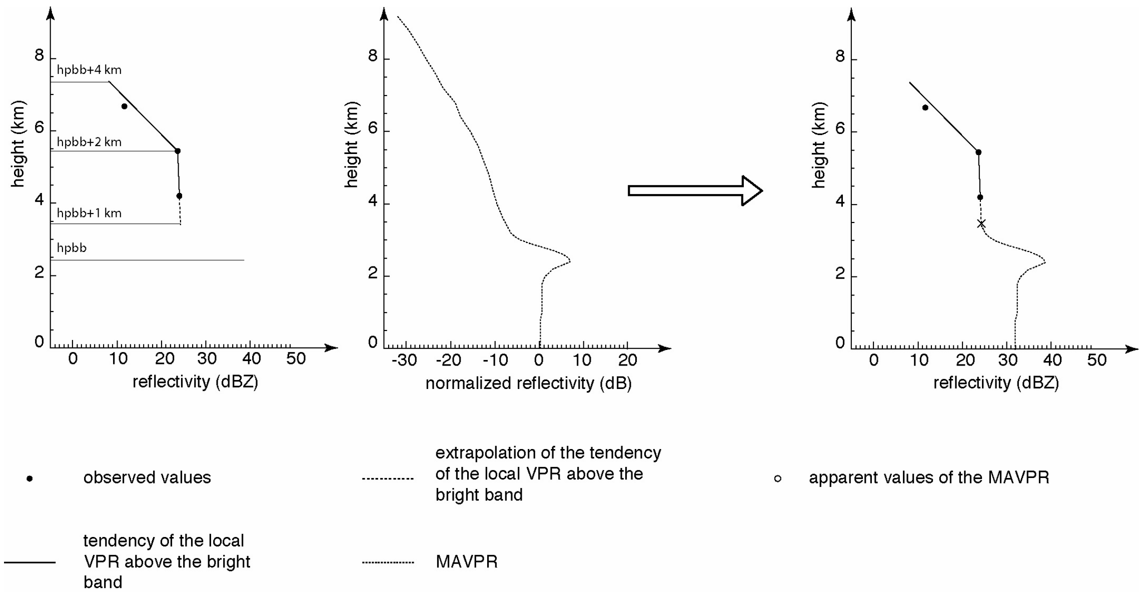

Fig. 2. Estimation of the local VPR at one local pixel by applying alternative (e), which consists of extrapolating the tendency of the observed local VPR above the bright band to the top of the bright band, and then fitting the MAVPR at this point.

estimate there the rain rates at the ground. In case of the convective zones, the first PPI estimates are preserved.

The evaluation of the proposed methodology has been based on observed data. It has been done using the first PPI radar image as the reference rainfall field.

2 Estimation of the MAVPR in a sector around the radar

An algorithm has been designed to estimate the Mean Apparent Vertical Profile of Reflectivity (MAVPR) on annular sectors of variable azimuth and radial widths placed at a certain distance from the radar. The MAVPR algorithm uses polar data and it is made of two steps, which are shown in Fig. 1. The first step consists of normalizing the apparent profiles inside the annular sector by dividing the reflectivities measured within the sector by the reflectivities at a common reference height level. This step is applied in order to make possible the comparison of the information associated to each apparent profile of reflectivity measured on the sector. Therefore, a value of apparent normalized reflectivity $Z^*\left(\vec{x}, h\right)$ is associated to a value of apparent reflectivity $Z\left(\vec{x}, h\right)$, as follows:

$$Z^*\left(\vec{x}, h\right) = \frac{Z\left(\vec{x}, h\right)}{Z\left(\vec{x}, h_{ref}\right)} \quad (1)$$

where $\vec{x}$ and h are the horizontal radial vector and the vertical coordinate of the center of the volume measured by the radar, and $\left(\vec{x}, h_{ref}\right)$ represents the projection of this point at the reference height level. The problem is that the value $Z\left(\vec{x}, h_{ref}\right)$ is usually unknown and has to be estimated by interpolating the measured values of reflectivity close to the point $\left(\overrightarrow{x}, h_{ref}\right)$. This leads to the need of choosing the normalization reference level at a height where the vertical gradient of the reflectivity is as weak as possible. When this is done, it is achieved that the interpolating neighbor measurements are as similar as possible to the original reflectivity at the reference level point. Moreover, being more accurate, in case of weak vertical gradients of reflectivity around the reference level, the influence of the smoothing beam effect on the neighbor interpolating measurements is reduced. As a consequence, the influence of the smoothing beam effect on the obtained reference values is also reduced. Therefore the interpolated reflectivity at the reference point will be a good estimate of the corresponding original value. According to this need of choosing the normalization reference level at a height with a weak vertical gradient of reflectivity, the reference level is chosen as the minimum height common to all the apparent profiles inside the sector. This height indeed turns out to be the height of the first PPI at the furthest edge of the sector. If the external range of the chosen sector is not too far from the radar, the lowest PPIs intercept the original VPRs bellow their bright band. It can be expected that the radar data around this chosen reference level are not excessively affected by the bright band gradient Consequently, the interpolated values at the reference level may reproduce fairly well the original ones.

The second step consists of applying a moving average process with a variable size window over the normalized reflectivities inside the sector to obtain the number of points of the mean profile sought out.

Finally, a continuous MAVPR line is obtained by linear interpolation between the discrete MAVPR values calculated by the moving average process.

3 Obtention of the Vertical profile of Reflectivity on each pixel by using the MAVPR shape

As stated before, we propose to identify the VPR shape applying the MAVPR algorithm, explained in the previous section, on the nearest sector that has measurable rainfall. Once the MAVPR has been obtained, its shape is used together with the observed values on each pixel over the earth surface to estimate the local profile on that pixel. As a consequence the rain-rate at ground level on that pixel is obtained. To do this, we propose to fit the normalized MAVPR shape to the observed values of reflectivity above each ground polar pixel. In this way, a Vertical Profile of Reflectivity at any considered pixel can be obtained adding the renormalizing term obtained in the fitting process to the normalized MAVPR, in case of reflectivity values expressed in dBZ. If the reflectivity values are expressed in $\mathrm{mm}^6/\mathrm{m}^3$ it would be done multiplying the normalized MAVPR by a renormalizing factor. Therefore, all the estimated local profiles show the same shape, the shape of the MAVPR, but they present different values at the ground level, which usually varies between 15 and 50 dBZ.

The fit could be done following two approaches: (1) using the values of the estimated mean profile without prior modification, or (2) degrading the MAVPR by convolving it with the beam pattern and using these values in the fitting process.

In relation to the second approach, the degraded values obtained by convolution of the MAVPR with the beam pattern at a certain distance represent how the radar would see the MAVPR at that distance. If the MAVPR reproduces accurately the original profile on a pixel at the considered distance, including the bright band of the original VPR, these degraded values will be representative of the observed reflectivities on this pixel except for a normalizing factor. Once the degraded values have been generated, they are compared to the observed values of reflectivity on the corresponding pixel and a renormalizing parameter is obtained. This value is added to the MAVPR for estimating the VPR at that pixel. Since this fitting approach has been showed as the most efficient from a previous simulation study, it has been chosen for applying our methodology. However another issues must be considered too. In case of stratiform rain, the vertical profiles of reflectivity are strongly varying above the bright band. Because of this, the MAVPR computed near the radar may not be representative of each local profile at those heights, and they may distort the ground rainfall estimation at each pixel. So, not to use all the available observations and test different alternatives may be very convenient from a practical point of view.

The proposed alternatives consist of:

a) using all the available observations

b) using only the values affected by the bright band

c) using only the values located above the bright band

In case of pixels placed at distances where the first elevation beam rises above the bright band, observations at bright band are not available. In this case, the proposed alternatives for not to be influenced by the distorting effect of the no representative MAVPR above the bright band are:

d) using only the lowest observed value

e) extrapolating the tendency of the observed apparent profile above the bright band to the bright band top. Then the MAVPR is fitted using only this extrapolated point (see Fig. 2).

4 Results

The only available observations of the rainfall field at the ground, are the rain intensity data registered by the raingauge nets. However, raingauge data and those obtained from radar observations are not comparable in fact. The main reason is that raingauges register the rain intensity at one point while each value of reflectivity measured by the radar corresponds to the whole set of rain drops inside an approximated volume of 1 km^2. Because of this, we have applied a validation process based on using the first PPI radar image as the reference

Table 1. Comparison of the errors of the rain-rate estimates obtained using the first PPI and three proposed fitting alternatives in case of applying the proposed methodology to region 1.

duration (min)	70	ALTERNATIVE	ME (mm)	SDE (mm)	EFF
1^{st} elevation	0.5°	PPI e_0	33.6	20.7	−11.05
elevation e_0	2.3°	(a) all	−2.6	10.5	0.10
range (km)	[31,53]	(b) only bb	−0.7	6.7	0.65
hpbb (km)	2.5	(c) only abb	−0.3	11.4	−0.01

Table 2. Comparison of the errors of the rain-rate estimates obtained using the first PPI and three proposed fitting alternatives in case of applying the proposed methodology to region 2.

		ALTERNATIVE	ME (mm)	SDE (mm)	EFF
duration (min)	70	PPI e_0	−28.5	8.6	−9.2
1^{st} elevation	0.5°	(a) all	−10.8	9.2	−1.31
elevation e_0	2.3°	(b) only bb	−12.8	9.4	−1.89
range (km)	[53,63]	(c) only abb	−9.4	8.8	−0.92
hpbb (km)	2.5	(e) extrapolating	−4.7	9.7	−0.24

Table 3. Comparison of the errors of the rain-rate estimates obtained using the first PPI and three proposed fitting alternatives in case of applying the proposed methodology to region 3.

duration (min)	70	ALTERNATIVE	ME (mm)	SDE (mm)	EFF
1^{st} elevation	0.5°	PPI e_0	−26.1	7.3	−10.16
elevation e_0	2.3°	(a) all	−7.4	7.0	−0.58
range (km)	[63,79]	(d) lowest	−7.8	5.6	−0.40
hpbb (km)	2.5	(e) extrapolating	−5.7	5.95	−0.04

of the rainfall field at the ground. In case of stratiform rain, the vertical profiles use to keep roughly constant with height from the bright band bottom to the ground level, except for orographic enhancement or evaporation next to the ground. So, while the first elevation measurements are not affected by the bright band, the first PPI radar image can be considered a good estimate of the reflectivity field at the ground.

In particular, once the MAVPR has been computed next to the radar, for fitting the MAVPR to the observed values on each pixel, the third PPI, or a PPI higher, has been considered as the lowest available PPI. Meanwhile the first PPI has been reserved for working as the reference rainfall field at the ground level. The useful validation domain extends itself to the distance where the first PPI (used here as the reference) starts to be affected by the bright band.

The results presented here correspond to the application of the proposed methodology to one event registered by the INM radar in Barcelona between the 14 and the 19 of July, in 2004. The fit of the VPR has been done for each horizontal polar pixel centered at each azimuth and radial value of the volume scan.

In Table 1, Table 2 and Table 3, the rainfall accumulation at the ground from fields obtained by applying the correction methodology is compared to the rainfall accumulation of the reference rainfall field (first PPI radar image). The error has been calculated as de difference between the rain rates at the ground provided by the fitted profiles and the rain rates of reference rainfall field.

The performance of the methodology is expected to depend on the range of distances where it is applied. The reason is that as the pixels are further from the radar, less number of observations is available to fit the MAVPR. Therefore, three different regions have been considered:

1. region 1, where the PPI which works as it was the lowest one, which we call from now on PPI e_0 , intercepts the bright band (Table 1)

2. region 2, where PPI e_0 intercepts the MAVPR above the bright band, but its measurements are still affected by the bright band (Table 2)

3. region 3, where the PPI e_0 rises above the bright band and also it is not influenced by the bright band (Table 3)

The results have been obtained by applying the several alternatives of the proposed methodology, previously described in Sect. 3. They concern to the observed values used for fitting the MAVPR on each local pixel.

In particular, for region 1, where observations at bright band are available, three fitting alternatives are tested: a) using all the available observations, b) using only the observed values at the bright band, c) using only the observed values above the bright band. In case of region 3, where all the available observations rise above the bright band, another set of fitting alternatives has been tested: a) using all the observed values (all of them placed above the bright band), d) using only the lowest observed value, e) extrapolating the behaviour of the measured apparent profile above the bright band to the top of the bright band and fitting there the MAVPR. In case of region 2, since it is between the other two regions, alternatives a), b), c) and e) have been checked.

The corrective methodology has been proposed for obtaining the rainfall field at ground only in those zones presenting stratiform precipitation. These are the zones where is necessary to correct the first PPI rainfall estimates as has been mentioned in introduction. In the convective zones, as they show vertical profiles of reflectivity with weak gradients, the first PPI provides reasonably good estimates of the rain rate at the ground. Therefore, for testing the performance of the methodology the domains where the correction methodology has been tested are only formed by the zones which keep as stratiform during the whole event.

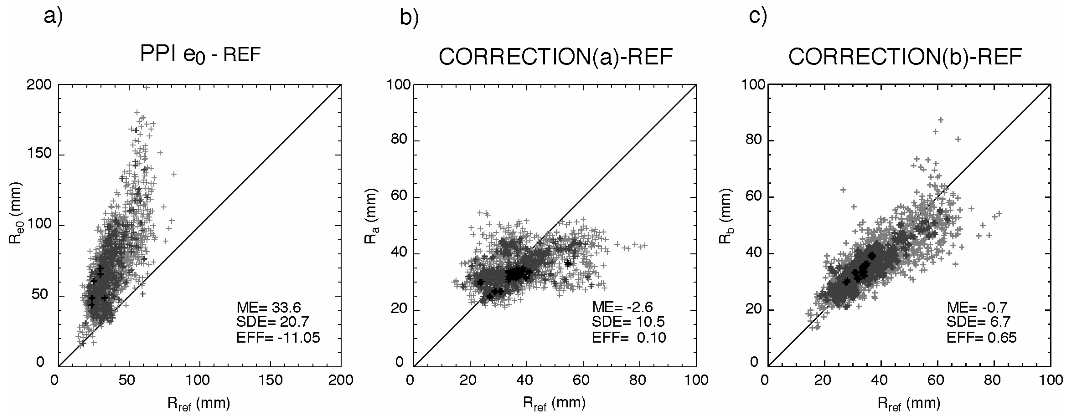

Fig. 3. Scattering plots of the rain rate estimates at the ground obtained by several procedures, versus rain rates from the chosen rainfall reference field (first PPI), in case of region 1. a) using PPI e^0 as it was the first PPI, b) applying the proposed methodology by using all the observed values, and c) applying the proposed methodology by using only the observed values affected by the bright band.

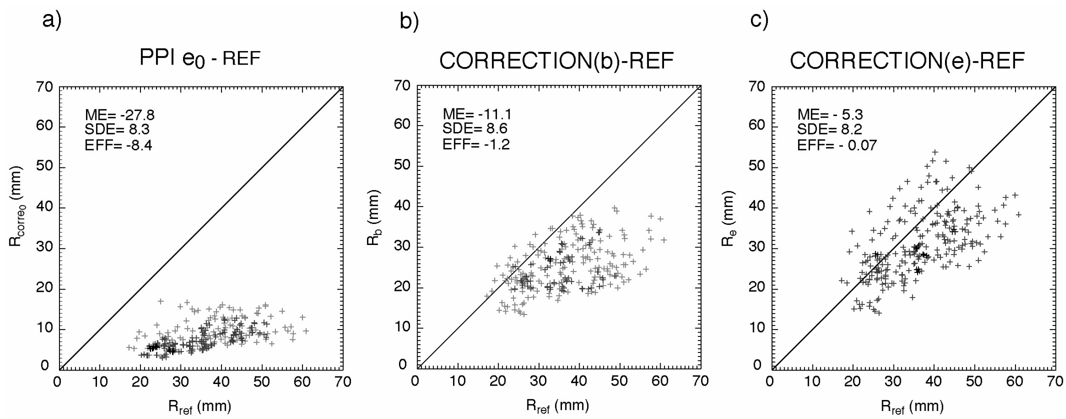

Fig. 4. Scattering plots of the rain rate estimates at the ground obtained by several procedures versus rain rates from the chosen rainfall reference field (first PPI), in case of region 2 plus region 3. a) using PPI e^0 as it was the first PPI, b) applying the proposed methodology by using only the observed values affected by the bright band, and c) extrapolating the local observed VPR above the bright band to the top of the bright band and fitting the MAVPR at this point.

As can be noticed from a first comparison between the errors corresponding to apply each proposed alternative and the errors corresponding to the PPI e^0 estimates, all the proposed alternatives improve the PPI e^0 estimates.

By the other hand, all the proposed alternatives do not show the same quality of results. In case of region 1, best results correspond to apply alternative (b), which consists of using only the observed values affected by the bright band for fitting the MAVPR. It provides efficiencies of 0.6. This improvement may be due to the fact that this fitting alternative eliminates the distorting influence of the no representative part of MAVPR above the bright band. In Fig. 3 can be better observed how this correction solves the underestimation of the PPI e^0 estimates.

In case of region 2 and region 3, alternative e) seems to provide the best results (see Fig. 4). This alternative consists of extrapolating the observed local VPR tendency above the bright band to the top of the bright band and then fitting the MAVPR at this point. For the event presented in this paper, this alternative improves considerably the results provided by the rest of alternatives. According to this, extrapolating the observed local VPR may provide the best results in case that the lowest point of the VPR belongs to the varying profile part which is placed above the bright band.

5 Conclusions

A methodology to identify the shape of the Vertical Profile of Reflectivity (VPR) from observed data and to apply this representative profile shape for estimating the rain rate at the ground has been proposed. Once the MAVPR shape has been obtained near the radar, it is fitted to the apparent reflectivity values measured above each local pixel in order to estimate the rain rate on this pixel. To do this, the MAVPR is degraded by convolving it with the beam pattern at the distance of the pixel. These degraded values are fitted to the observed values on the pixel and as a consequence the joint MAVPR is also fitted.

The results of a validation process based on using the first PPI as the reference suggest that the proposed methodology may improve considerably the estimates provided by first PPI. Among the different fitting alternatives, the best results are achieved when using only the values affected by the bright band in case that they are available. In case that observed values at the bright band are not available, the best results are obtained when the observed local VPR, only available above the bright band, is extrapolated to the bright band top and the MAVPR is fitted at this point.

In conclusion, the proposed methodology has been showed to solve the critical overestimation of rain rate at ground produced when the first PPI intercepts the bright band at further distances from the radar, and it also correct the underestimation produced when the first PPI intercepts the snow particles region of the vertical profile.

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References

Andrieu, H., Delrieu, G., and Creutin, J. D.: Identification of vertical profiles of radar reflectivity for hydrological applications using and inverse method: I-Formulation, J. Appl. Meteor, 34, 225–239, 1995.

Fabry, F. and Zawadzki, I.: Long-term radar observations of the melting layer of precipitation and their interpretation, J. Appl. Sci., 52, 838–851, 1995.

Germann, U. and Joss, J.: Mesobeta Profiles to Extrapolate Radar Precipitation Measurements above the Alps to the Ground Level, J. Appl. Meteor., 41, 542–547, 2002.

Joss, J. and Lee, R.: The application of radar-gauge comparisons to operational precipitation profiles corrections, J. Appl. Meteor. 34, 2612–2630, 1995.

Kitchen, M. and Brown, R.: Real-time correction of weather radar data for the effects of bright band, range and orographic growth in widespread precipitation, Quart. J. Meteor. Soc., 120, 1231–1254, 1994.

Koistinen, J.: Operational correction of radar rainfall errors due to the vertical profile of reflectivity, 25th Radar Meteor. Conf., Paris, France, AMS, 91–96, 1991.

Sánchez-Diezma, R., Zawadzki, I., and Sempere-Torres, D.: Identification of the bright band through the analysis of volumetric radar data, J. Geophys. Res., 105, D2, 2225–2236, 2000.