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QUALITY OF RADAR ECHO TOP HEIGHTS

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1. INTRODUCTION

The echo top height, i.e. the maximum height where a given reflectivity is observed, provides valuable information in case of thunderstorm situations. It allows to evaluate the vertical extension of thunderstorm cells, which is an indicator of the storm severity. The determination of echo top heights requires reliable measurements of the vertical profile of reflectivity. Radar reflectivity measurements are affected by various sources of error which tend to increase with the distance from the radar. Calibration errors, attenuation, overshooting and the increasing size of the sampled volume are the most important ones. Beside these errors affecting the measured reflectivity itself, errors on the height assigned to the measured reflectivities arise due to the uncertainties in the trajectories of the radar beams. These uncertainties are related to inaccurate antenna pointing and to variations of the atmospheric propagation conditions. The height accuracy of precipitation echo features is also limited by the antenna beam width and by the limited number of elevation angles (Howard et al., 1997; Maddox et al., 1999).

The aim of this study is to investigate how the quality of echo top products deteriorates with the distance from the radar. The methodology is based on the comparison between reflectivity data from the radar of De Bilt in The Netherlands and the radar of Wideumont in Belgium. The comparison of reflectivity data is made on a vertical cross section extending from one radar to the other one. The reflectivity field observed at short distance by one radar is considered as reliable and the comparison with the field observed at the same time by the other radar allows to point out the shortcomings of the long-range observation.

2. METHOD

The radar of Wideumont in Belgium and the radar of De Bilt in The Netherlands are both Gematronik C-band Doppler radars. They perform a volume scan every 15 minutes. It includes 10 elevations between 0.5 and 17.5 degrees for the radar of Wideumont and 14 elevations between 0.3 and 12 degrees for the radar of De Bilt. The beam width is 1 degree for both radars. The distance between the two radars is 244 km. For each radar, the reflectivity field on a vertical cross section in the direction of the other radar can be extracted from the volume data.

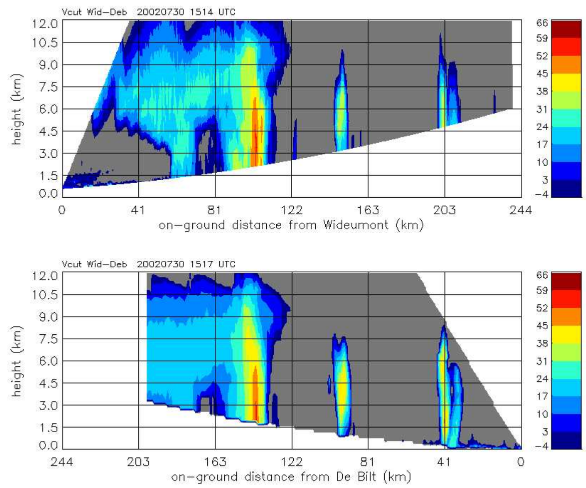

Figure 1: Reflectivity (dBZ) on a vertical cross section De Bilt-Wideumont observed by the radar of Wideumont (upper panel) and by de radar of De Bilt (lower panel). The distance between the two radars is 244 km

The comparisons concern 25 thunderstorm episodes observed in the summer periods of 2002, 2003 and 2004. A total of 872 vertical cross section (denoted hereafter: "vcut") pairs has been extracted. The time difference between two corresponding volume data sets never exceeds 3 minutes. The data set has been reduced to 845 by rejecting the vcut pairs where the maximum reflectivity (Z_{max}) is less than 7 dBZ in both data sets.

Figure 1 shows an example of a vcut pair. The cross section from Wideumont starts at 585 m above sea level, which is the altitude of the radar antenna. Vcut profiles from the radar of De Bilt are only generated up to a distance of 200 km and significant ground clutter is present up to a distance of about 30 km. For this reason, we have limited the comparison of the reflectivity data to ranges between 44 and 200 km. This range domain which is symmetric around the middle point between the two radars has been divided into 15 range intervals. All intervals are 10-km wide except the two extreme ones which are 13-km wide. For each range interval, the maximum reflectivity within the range interval (Z_{max}), the height of the measured

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maximum reflectivity (H_{Zmax}) and the echo top height for different thresholds (ETP) are compared.

The comparisons have been carried out following two different methods. In the standard method, the variables are compared even if the Z_{max} measured by one radar is observed at an altitude which falls outside the area scanned by the other radar. It means that a Z_{max} observed at low altitude at short range from one radar can be compared to a Z_{max} observed at higher altitude by the other radar. Using this method of comparison, overshooting effects will contribute to the differences between the two radars. In the second method, a vcut pair will be included in the comparison only if the Z_{max} measured by one radar is observed at an altitude covered by the other radar. This second method allows to eliminate the contribution of overshooting to the discrepancies between the two radar datasets. The two methods will be denoted "standard" and "no_overshoot" hereafter.

3. RESULTS

3.1 Z_{max} difference

The comparison of maximum reflectivity values measured by the two radars allows to eliminate the effect of height assignment errors. Figure 2 shows the effect of range on the mean difference between the maximum reflectivity of the two radars obtained using the two methods of comparison. In these comparisons, only vcut pairs with maximum reflectivity values higher than 7 dBZ in both data sets have been considered.

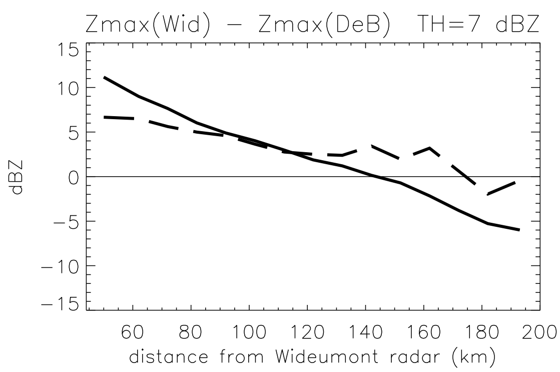

Figure 2: Mean difference between the maximum reflectivity measured by the radars of Wideumont and De Bilt as a function of the distance from Wideumont using the standard and no_overshoot methods of comparison (solid and dashed line respectively)

The number of valid pairs per range interval is shown in Fig. 3. The number of valid pairs for the standard method of comparison is around 300 for all range intervals. When the no_overshoot method is used, the number of valid pairs is smaller and strongly depends on range. A peak is obtained at 90 km from the radar of Wideumont. At this range, the lowest beams of the two radars are at the same altitude and the vertical portion of the troposphere covered by the two radars is the same as can be seen on Fig. 1. At short range from De Bilt the number of valid pairs is extremely low. The scan strategy of the two radars gives a partial explanation for this. The lowest scanned elevation is 0.5 degree for Wideumont while it is 0.3 degree for De Bilt. As a consequence, overshooting effects are likely to occur at shorter ranges for the radar of Wideumont. The orography amplifies this effect since the radar of Wideumont is located near the top of the Ardennes ridge at 585 m asl while the radar of De Bilt is almost at sea level.

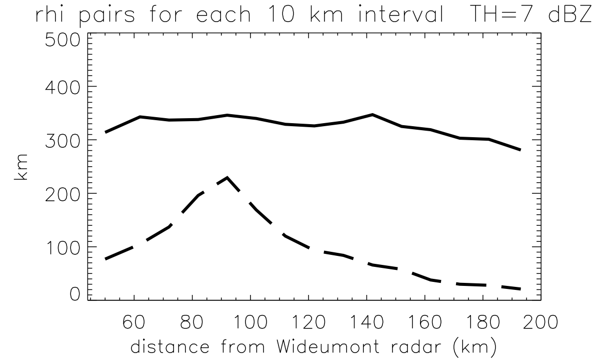

Figure 3: Number of valid pairs per 10-km range interval as a function of the distance from the radar of Wideumont using the standard and no_overshoot methods of comparison (solid and dashed line respectively)

The mean difference of Z_{max} using the standard method shows a linear variation with range (Fig. 2). At short range from Wideumont, the maximum reflectivity measured by the radar of Wideumont significantly exceeds the maximum reflectivity from De Bilt. The mean difference is 11 dBZ at 50 km. At long ranges, the opposite behavior is observed with reflectivities from De Bilt exceeding those from Wideumont by about 6 dBZ at 194 km from Wideumont (50 km from De Bilt). Averaged over all ranges, the mean difference in max reflectivity measurements is 2.1 dBZ. This difference is based on a relatively large number of comparisons and can be considered as the effective bias between the Z_{max} measurements of the two radars. When the effect of overshooting is eliminated from the comparison, the range dependence of the Z_{max} is significantly reduced. Grossly estimated, the mean slope is reduced by a factor 2, which means that half of the range dependence can be attributed to overshooting. It means that other sources of errors like the attenuation and the increasing size of the sample volume also significantly contribute to the range effect. Averaged over all ranges, the mean difference in Z_{max} is now 3.0 dBZ. This mean bias which is not affected by overshooting can be considered as the calibration bias between the two radars. Overshooting effects which are more pronounced for the radar of Wideumont reduce by 0.9 dBZ the mean bias between the two radars. The standard deviation of the Z_{max} differences are between 6 and 7 dBZ, dependant on range and is not affected by the method of comparison. This standard deviation is relatively large compared with the calibration bias which means that calibration differences give only a small contribution to the differences in measured reflectivity values.

3.2 Z_{max} height difference

Echo top products are sensitive to reflectivity values measured by the radar but also to the heights assigned to the measured reflectivities. In order to identify height assignment errors, the height where the maximum reflectivity is observed H_{Zmax} has been extracted for each range bin from both radars and the mean value for each of the 15 range intervals has been determined. Note that H_{Zmax} differences are not affected by calibration differences between the two radars. Figure 4 shows the results obtained using the two methods of comparison.

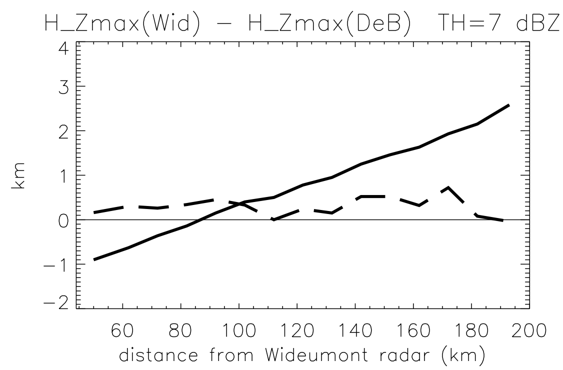

Figure 4: Mean difference of the maximum reflectivity height measured by the radars of Wideumont and De Bilt as a function of the distance from Wideumont using the standard and no_overshoot methods of comparison (solid and dashed line respectively)

The difference in Z_{max} heights obtained using the standard method shows a linear dependence with range. At 50 km from Wideumont, the mean height difference is -1 km. At 190 km from Wideumont (50 km from De Bilt), the height difference reaches 2.5 km. At this range, the difference in altitude of the lowest beams of the two radars reaches 4 km. In many cases, the radar of Wideumont overshoots the maximum reflectivity core observed by the radar of De Bilt. Around 90 km from Wideumont, the mean height difference is close to zero. As mentioned above, around this range the two radars scan the same vertical portion of the atmosphere which excludes overshooting by one radar and not by the other one.

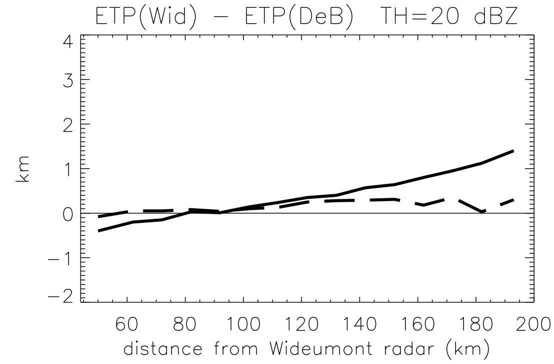

Figure 5: Mean difference of the echo top 20 dBZ using the standard and no_overshoot methods of comparison (solid and dashed line respectively)

When the no_overshoot method of comparison is used the mean height differences are strongly reduced (Fig. 4). The differences are limited to about 500 m for all ranges except at 172 km from Wideumont where it reaches a maximum of 720 m. The radar of Wideumont tends to assign larger heights to the measured reflectivity values but the differences are low compared with the vertical resolution of the radar measurements. It suggests that overshooting is the main source of differences between the heights of maximum reflectivity observed by the two radars. In other words, when this effect is eliminated, systematic differences in the heights assigned to the maximum reflectivity are extremely low for all ranges. This result and the absence of bias at 90 km indicates that the mean antenna pointing of both radars is accurate.

Based upon the results presented here, we conclude that the radar of Wideumont generally tends to assign slightly higher altitudes to the measured reflectivities than the radar of De Bilt. Besides, the difference in the scanned elevations angles of the two radars significantly affects the performances at long ranges. Using a lowest elevation angle of 0.3 degree instead of 0.5 degree allows a significant increase of the effective range where reliable measurements of the vertical structure of the reflectivity field can be obtained. The low altitude of the radar of de Bilt is also beneficial for long range measurements.

3.3 Echo top height difference

The horizontal profiles Wideumont-De Bilt of echo top values (ETP) have been calculated for three thresholds: 7 dBZ, 20 dBZ, and 30 dBZ. For each range interval, only vcut pairs where the echo top exists (i.e. the maximum reflectivity exceeds the threshold) in both data sets are included in the calculation of the mean difference. Differences in echo top values are caused by differences in the measured reflectivities and in the heights assigned to these reflectivities, which makes the interpretation of the echo top discrepancies more difficult. The mean difference of echo top values between Wideumont and De Bilt is shown in Fig. 5 for a 20 dBZ threshold. Similar results are obtained with 7 and 30 dBZ.

For both methods of comparison the echo top differences are limited to 1 km except at close range from the radar of De Bilt. The no_overshoot method of comparison consists here in including the vcut pairs only if the echo top is observed by each radar at an altitude covered by the other radar. For all thresholds, the echo top differences are smaller when the no_overshoot method is used.

It is stressed that very small differences in the measured reflectivity values may induce very large differences in echo top values especially if the maximum measured reflectivities are close to the echo top threshold. In this case the echo top may exist in one data set and not in the other one. This effect is not taken into account in the echo top comparisons since only the vcut pairs where the threshold is exceeded in both data sets are included in the comparison.

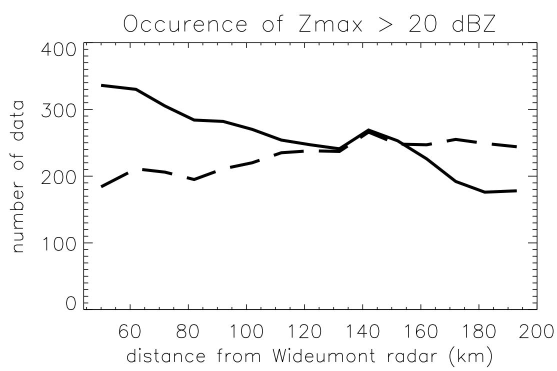

Figure 6: Occurence of threshold exceedance as a function of range for the radars of Wideumont (solid line) and De Bilt (dashed line).

In order the point out the importance of the errors related to the exceedance of the threshold in only one of the two datasets, the occurence of threshold exceedance (the number of vcuts where the threshold is exceeded) has been calculated for both radars for all range intervals. The results are presented in Fig. 6 for a 20 dBZ threshold. The results clearly show the effect of range on the quality of echo top products at far ranges. Height assignment errors do not influence the occurence of threshold exceedance which means that the range effect is entirely attributable to errors on the measured reflectivity itself.

4. CONCLUSION

Reflectivity data on a vertical cross section extending from the radar of Wideumont in Belgium to the radar of De Bilt in The Netherlands have been compared and the differences have been analysed. Twenty five thunderstorm episodes observed in the summers of 2002, 2003 and 2004 have been considered and 845 cross sections have been extracted from both radars. These comparisons appear a valuable tool to analyse the different sources of errors affecting the echo top heights derived from the mesured vertical profiles of reflectivity.

The quantitative analysis shows that the quality of the maximum reflectivity measurements strongly deteriorate with range and that about half of this degradation can be attributed to overshooting effects. The comparisons allowed to point out a calibration bias of 3 dBZ between the two radars.

Echo top products are not only affected by errors on the measured reflectivity itself but also by errors on the height assigned to the measurements. The heights assigned to the measured maximum reflectivity have been compared. We have found that overshooting is the main cause of discrepancy between the height of the maximum reflectivity measured by the two radars. When the effect of overshooting is eliminated, the mean difference between the maximum reflectivity heights observed by the two radars is less than 0.5 km for all ranges. Similar results are obtained for the echo top heights. It means that the impact of height assignment errors is very limited. In contrast, small errors in the reflectivity measurements may strongly affect the echo top heights especially if the measured maximum reflectivity is close to the echo top threshold.

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