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VERIFICATION OF RADAR-BASED HAIL DETECTION PRODUCT

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1. INTRODUCTION

Large hail is regularly observed in Belgium and The Netherlands and is sometimes the cause of severe damage on e.g. crops, greenhouses, roofs and cars. Most severe hail events occur in summer and are associated with intense thunderstorms producing large hail stones. Hail is a very local phenomenon, in time and space, which can not be easily detected with ground observational networks. Due to its wide spatial coverage and relatively fine spatial and temporal resolution, weather radar appears as a valuable tool for the real-time detection of hail.

In current operational networks most radars are single wavelength and single polarization radars and various methods have been proposed for detecting hail using reflectivity measurements from this type of radar. Most of these methods rely on the analysis of the vertical profiles of reflectivity. These profiles are extracted from three-dimensional data generated by a scan at multiple elevations.

A hail detection algorithm mainly based on the 45-dBZ radar echotop is operationally used at the national weather services of Belgium (RMI) and The Netherlands (KNMI). The probability of hail estimated by the algorithm is affected by various sources of error and a careful verification of this product is required. In this paper we present two different verification methods. The first method is based on the verification of the results of the hail detection algorithm for a large number of hail events reported at ground.

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The second method is based on the comparison of the probability of hail estimated by two radars located in Belgium and The Netherlands (distance 244 km). The comparison of the results obtained by the two radars for a large number of thunderstorm events allows to point out the effect of range on the quality of the hail detection product.

In the next section the hail detection algorithm is described and the different error sources which affect this product are summarized. The results obtained with the two verification methods are described in sections 3 and 4. Conclusions are given in section 5.

2. HAIL DETECTION PRODUCT

The hail detection products used in the framework of this study are generated using reflectivity data from the radar of Wideumont (RMI, Belgium) and the radar of De Bilt (KNMI, The Netherlands). Both radars are 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 probability of hail is estimated from radar reflectivity data following the method of Waldvogel et al. (1979). It is based on the difference ΔH (km) between the height of the freezing level and the maximum height at which a reflectivity of 45 dBZ is observed (echotop 45 dBZ). The probability of hail (POH) is calculated as follows:

$$POH = 0.319 + 0.133\,\Delta H \qquad (1)$$

This expression has been obtained from a verification study carried out by the KNMI in the summer 2000 (Holleman, 2001). The method of Waldvogel combines an indicator for the presence of a substantial updraft, the height of the strong reflectivity core (45 dBZ), with that for a large amount of undercooled water and/or ice, the reflectivity core above the freezing level, to detect (developing) hail. The probability of the presence of hail increases with increasing height of this reflectivity core. The method of Waldvogel is currently also being used in the NEXRAD hail detection algorithm (Witt et al., 1998). Figure 1 shows an example of the hail detection product from the radar of Wideumont.

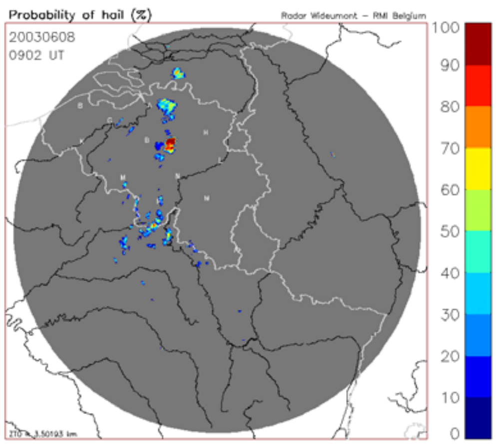

Figure 1: Radar-based hail detection product.

The hail detection algorithm 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 sample 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).

3. VERIFICATION USING GROUND REPORTS

The verification of the hail detection product has been carried out at RMI (Belgium) using hail reports sent by the observers of the RMI climatological network and weather amateurs and articles published in newspapers (Delobbe et al., 2003). Hail reports without precise indication of time and place were rejected as well as reports with very small hailstones (diameter clearly smaller than 0.5 cm). During the summer periods of 2002, 2003 and 2004, a total of 83 hail reports have been collected. The number of hail reports for different size classes is given in Table 1. Reports with hailstones larger than 1 cm are 34 on 83.

For each reported hail event the results of the hail detection algorithm was verified. A tolerance must be accepted on the localization of hail falls. Errors on the localization of the hail events by the radar are partly due to the jumping effect caused by the displacement of the thunderstorm cell within the 15 minutes time interval between successive radar observations. The spatial shift between the high reflectivity core at high altitude and the on-ground location of hail also introduces errors on the radar localization of hail events. For these reasons we apply a 10-km positioning tolerance in the verification procedure. A tolerance on the timing of the event is also applied by adding 15 minutes at both ends of the observed time window of the observation.

Size (cm)	Number reports	POH >0%	POH >50%	POH >70%	POH >80%	POH >90%
All	83	79	78	62	51	43
0.5-1	49	45	44	29	20	14
1-2	18	18	18	17	15	14
2-3	8	8	8	8	8	7
3-4	7	7	7	7	7	7
4-5	1	1	1	1	1	1

Table 1: Number of hail events for different diameter classes and number of detected hail events for different thresholds of the detected probability of hail (POH).

For a given reported event the estimated probability of hail (POH) is the highest POH given by the hail detection algorithm taking into account the localizing and timing tolerance. The number of detected events depends on the POH threshold. A low POH threshold increases the detection rate but the false alarm rate too. Table 1 shows the number of detected events for different POH thresholds and for different size classes. Using a 50 % POH threshold, 78 events on 83 are detected by the radar, which means a 94 % detection rate. The 5 undetected events are associated with hailstones between 0.5 and 1 cm. With a 80 % POH threshold the detection rate drops to 61 %. All events with hail stones larger than 2 cm are detected with a POH at least equal to 80 %.

These relatively high detection rates are probably associated with high false alarm rates (FAR). The present study based on the collection of reported hail events does not allow to estimate the false alarm rate. No hail report does not mean that hail did actually not occur. An estimation of the FAR needs an assumption on the fraction of hail events which are not reported. Making such assumption, the verification study carried out at KNMI (Holleman, 2001) indicates a false alarm rate of 50 % for a POH threshold of 50 %. For this threshold the detection rate is 65 %. The verification study presented in this paper indicates larger detection rates, which suggests that the false alarm rate could be larger too. Since the climatological conditions are similar in Belgium and The Netherlands, these differences in the performances of the hail detection algorithm may be caused by calibration differences between the two radars or other error sources. In the next section, we investigate this point through the comparison of hail detection estimated by the radars of Wideumont and De Bilt, located in Belgium and The Netherlands, respectively.

4. VERIFICATION THROUGH INTERCOMPARISON

The hail detection algorithm is based on the echotop-45 dBZ product. Echotop values are not only affected by errors on the measured reflectivity itself but also by errors on the height assigned to these reflectivities. An extensive study has been carried out in order to evaluate the relative importance of these errors as a function of range. The method is based on the comparison between the reflectivity field observed by the radar of Wideumont in Belgium and the radar of De Bilt in The Netherlands on the vertical cross section extending between the two radars. Twenty-five thunderstorm episodes observed in the summers of 2002, 2003 and 2004 have been considered and a total of 872 vertical cross section pairs, so-called “vcut pairs”, has been extracted.

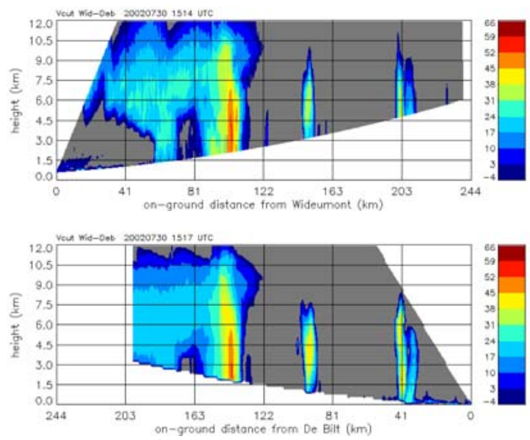

Figure 2: Reflectivity on a vertical cross section Wideumont-De Bilt observed by the radar of Wideumont (upper panel) and by the radar of De Bilt (lower panel).

Figure 2 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. Three distinct cells are found between the two radars. The vertical extensions and the reflectivity levels are very similar in both data sets. A quantitative comparison of the 872 cross sections has been carried out. We present here only the most relevant results for hail detection.

A first important result of these comparisons is that there is a mean calibration bias of 3 dBZ between the two radars. The radar of Wideumont tends to measure larger reflectivity values than the radar of De Bilt. This gives at least a partial explanation for the higher hail detection rate obtained with the radar of Wideumont. The quality of the maximum reflectivity measurements strongly deteriorate with range and about half of this degradation can be attributed to overshooting effects. The heights assigned to the measured maximum reflectivity have also been compared in order to identify height assignment errors. Our results show that these errors are limited to about 0.5 km. Echotop heights are affected in a similar way. Expression (1) shows that the impact of such error on the derived probability of hail is limited to 7 % only. It means that echotop values are mainly affected by errors on the measured reflectivity itself and not by errors on the heights assigned to these reflectivities.

For a 45-dBZ threshold, the number of threshold exceedances is also the number of events where a POH larger than 0 is obtained. The threshold exceedances have been analysed as a function of range. The range domain between 44 and 200 km has been divided into 15 range intervals. The results are presented in contingency tables (Table 2). There are 872 vcut pairs and for each vcut 15 range intervals. The number of events is thus 13080. For a given event, the 45-dBZ threshold can be exceeded in both radar datasets, in one of the two or in none of the two. On the left panel of Table 2, all range intervals between 44 and 200 km have been considered. On the right panel, only the 7 range intervals between 87 and 157 km have been considered. Table 2 shows that the number of events where hail is only detected by one of the two radars is comparable to the number of hail events detected by both radars. The number of hail events only detected by the radar of Wideumont is larger that those only detected by De Bilt. This is probably due to the calibration bias between the two radars.

44-200 km		Wideumont		87-157 km		Wideumont	
		Yes	No			Yes	No
De	Yes	76	77	De	Yes	42	30
Bilt	No	173	12754	Bilt	No	59	5973

Table 2: Contingency tables giving the number of events where the 45-dBZ threshold is exceeded. On the left side, all the range intervals between 44 and 200 km are considered. On the right side, only the range intervals between 87 and 157 km are considered.

When the range interval is limited to 87-157 km the proportion of hail detection by both radars is significantly increased. The number of detected hail cases for each radar as a function of range is given in Figure 3. At 50 km from Wideumont, the radar of Wideumont detects 34 hail cases while the radar of De Bilt only detects 4 cases. At 50 km from De Bilt, the radar of De Bilt detects 18 hail cases while the radar of Wideumont detects 2 hail cases. For both radars, the number of detected hail cases at far range (190 km) is only 11% of the number of hail cases detected at short range by the other radar. Height assignment errors do not influence this detection rate which means that this limitation is entirely attributable to errors on the measured reflectivity itself. At close range from one radar overshooting is suspected to be the main cause of no detection by the other radar. The number of hail cases detected by both radars is shown on Figure 3 by the thin solid line. Even for intermediate ranges, the number of cases detected by only one radar is significant.

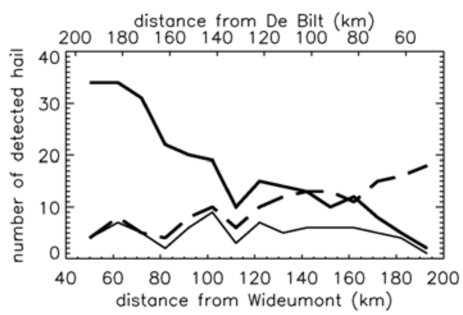

Fig. 3: Number of detected hail cases as a function of range for the radars of Wideumont (solid line) and De Bilt (dashed line). The thin solid line shows the number of hail cases detected by both radars.

The hail detection algorithm is extremely sensitive to small errors on the measured reflectivity especially when the actual maximum reflectivity is close to the 45 dBZ threshold. It must, however, be stressed that for severe hail falls with maximum reflectivity significantly larger than 45 dBZ the detection rate by both radars is expected to be higher. The validation study presented above has shown that all severe hail events (diameter > 2 cm) are detected with a probability of hail larger that 80 %, which means that the undetected hail events correspond to light or moderate hail falls.

5. CONCLUSIONS

The same hail detection algorithm is operationally used at the Netherlands and Belgian meteorological services (KNMI and RMI, respectively). It was first tested at KNMI and the algorithm was optimized through a verification study carried out in The Netherlands. In this paper, we have presented the results of a verification study carried out in Belgium. The results show a high detection rate. For 94 % of the reported hail cases, the hail detection algorithm gives a probability of hail larger than 50 %. All events with hailstones larger than 2 cm are detected with a probability of hail at least equal to 80 %. These high detection rates are probably associated with relatively large false alarm rates but the present study does not allow to quantify this rate.

Comparisons between reflectivity data and derived hail detection results for a large number of thunderstorm cases observed by the radars of Wideumont (Belgium) and De Bilt (Netherlands) have been performed. The results show a higher detection rate by the Belgian radar which is at least partially due to a positive calibration bias of this radar with respect to the Netherlands radar. This study also indicates a strong degradation of the quality of the hail detection product with range. At 190 km, the number of hail cases detected by one radar is about 10 % of the number of cases detected by the other radar at short range. The effective range for hail detection should be limited to about 150-160 km.

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REFERENCES

Delobbe, L., D. Dehenauw, K. Hamid, and J. Neméghaire, 2003: Hail detection using radar observations: case studies in the summer 2002. Scientific report N. 29. Royal Meteorological Institute of Belgium, Brussels, 39 pp.

Holleman, I., 2001: Hail detection using single-polarization radar. Scientific report WR-2001-01, Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands, 74 pp.

Howard, K.W., J.J. Gourley, and R.A. Maddox, 1997: Uncertainties in WSR-88D measurements and their impacts on monitoring life cycles. Wea. Forecasting, **12**, 166--174.

Maddox, R.A., D.S. Zaras, P.L. MacKeen, J.J. Gourley, R. Rabin, and K.W. Howard, 1999: Echo height measurements with the WRS-88D: Use of data from one versus two radars. Wea. Forecasting, **14**, 455--460.

Waldvogel, A., B. Federer, and P. Grimm, 1979: Criteria for the detection of hail cells. J. Appl. Meteor., **18**, 1521--1525.

Witt, A., M.D. Eilts, G.J. Stumpf, J.T. Johnson, E. D. Mitchell, and K.W. Thomas, 1998: An enhanced hail detection algorithm for the WSR-88D. Wea. and Forecasting, **13**, 286--303.