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STATUS AND FUTURE DIRECTION OF OPERATIONAL RADAR APPLICATION AT KNMI

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1. INTRODUCTION

KNMI operates two C-band Doppler radars (Gematronik Meteor 360 AC). Currently, the reflectivity data are employed operationally for the synthesis of composites of pseudoCAPPI and echotop products.

For the production of pseudoCAPPI images, anomalous propagation clutter is removed from the raw images using a statistical method. Three-hourly estimates of accumulated precipitation are calculated routinely by adding the pseudoCAPPI products. A comparison of daily sums of these estimates to the precipitation data obtained from a dense network of rain gauges has been performed. For the production of echotop maps, an algorithm is used that corrects for errors due to the finite width and sidelobes of the radar beam.

To fully exploit the potential of radar (reflectivity) data, a tool for the detection and display of severe weather phenomena related to convective systems is being developed. As a first step, the development of a product for the detection of summer hail has been completed.

In this paper, the procedure for detection of ground clutter is described briefly and its operational performance is discussed. Furthermore, recent results on radar-gauge comparisons for the KNMI radars are presented. Finally, the results of the extended verification of the hail detection product are highlighted.

2. REMOVAL OF GROUND CLUTTER

Before radar-derived rainfall products can be accumulated or shown to non-meteorologists, (anomalous propagation) ground clutter has to be removed. Clutter removal algorithms that are currently in use are based on for instance clutter maps, radial Doppler velocities, signal statistics, continuity of the vertical profile, or geostationary-satellite data. In the early 90s, a stepwise procedure for rejection of (anomalous propagation) ground clutter has been developed and implemented at KNMI (Wessels and Beekhuis, 1997). This procedure is based on distinguishing between the inherently fluctuating Rayleigh-scattered precipitation signals and the relatively stable ground clutter signals (Aoyagi, 1983). The first and the second step are performed by the radar preprocessor (RVP6, Sigmet Inc), and the final step is evaluated by the processing software (Rainbow, Gematronik GmbH).

In the first step, the temporal signal fluctuations in 250 m deep and 1 degree wide range bins are estimated by calculation of the standard deviation of the signal intensity. With a PRF of 250 Hz and an azimuth speed of 18 degrees/s, about 14 independent samples are available every degree for determining this standard deviation. If the standard deviation is smaller than a fixed threshold of about 2 dB, the range bin is suspect of containing clutter. In the second step, four range bins with statistically independent clutter warnings are combined to 1 km deep and 1 degree wide polar pixels. The polar pixels are flagged as clutter when the majority of the underlying range bins are suspect of containing clutter. The clutter flags are transferred together with the polar reflectivity data to the radar computer for final processing.

In the final step of the clutter detection, polar pixels of 2 km deep and 1 degree wide, close to the final display resolution of 2.4×2.4 km^2, are considered. The clutter flags for the polar pixels of 2 km deep and 1 degree wide are determined by combining the flags of the underlying 1 km $\times$ 1 degree pixels, using an empirical criterion based on the horizontal echo variability and the weighted sum of the clutter flags of its nearest and second-nearest neighbors. Because most precipitation systems and clutter areas are larger than 10 km $\times$ 5 degrees, this smoothing has only a minor effect on the spatial resolution. The clutter detection efficiency reaches about 98%, while less than 1% of rain pixels is removed.

Currently, the ground clutter rejection system has been operational for about 8 years. The system requires hardly any maintenance and can be applied up to large ranges (320 km). Anomalous propagation clutter over land is removed almost completely, while the system is partly (40%) effective in removing sea clutter. All in all, the radar operators and the users of the data are quite satisfied with its performance.

3. COMPARISON WITH GAUGES

The radars perform a 4-elevation reflectivity scan every 5 minutes. From these scans pseudoCAPPI images are produced with a target height of 800 m above the antenna level. Ground clutter is removed from the pseudoCAPPI images using the procedure described above. The reflectivity values are converted to rainfall

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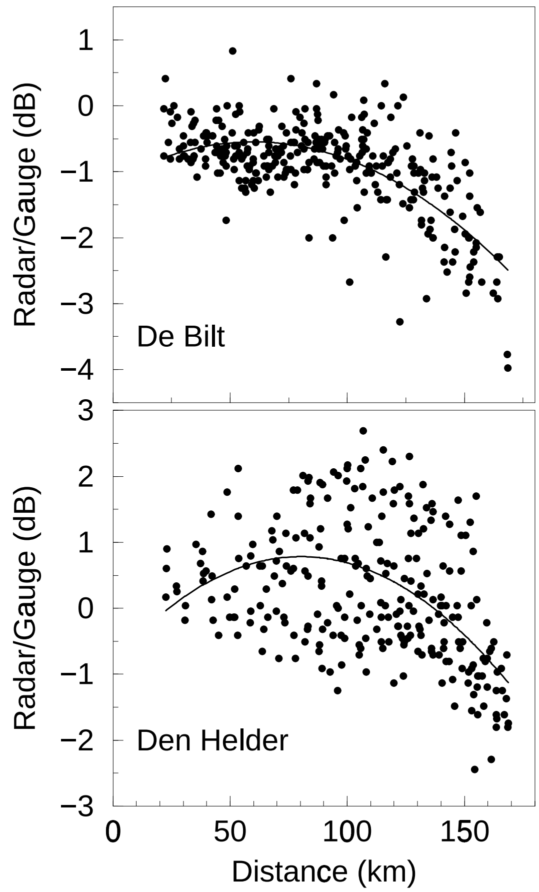

Figure 1: The annual average of the bias for each rain gauge as a function of its distance from each radar. The biases have been determined using radar and gauge data from 1998.

intensities using $Z = 200R^{1.6}$. These radar-derived rainfall products are accumulated using a threshold of 0.03 mm/h. Both three-hourly and daily estimates of accumulated precipitation are derived in this way.

The 24-hour accumulation of precipitation derived by radar has been compared to rain gauge accumulations. KNMI maintains a dense homogeneous network of about 325 volunteers who report the amount of accumulated precipitation daily at 08 UTC. The density of these "precipitation" stations is about one station every 100 km^2. The ratios between the 24-hour radar-derived rainfall estimate and the numerous rain gauge accumulations have been determined using a year of data. For all rain gauges between a range of 20 and 170 km from a radar, the average bias and standard deviation of the accumulated precipitation in the overlying radar pixel as compared to that of the rain gauge have been calculated. Only days with more than 3 mm of accumulated precipitation in the particular rain gauge have been taken into account.

In Figure 1, the average biases (Radar/Gauge) of both KNMI radars are plotted as a function of the distance of the rain gauge from the radar. In the upper figure the results for the radar in De Bilt, located in the center of the Netherlands, are shown. At a fixed distance from the radar, the majority of the data points are rather close (within 1 dB). At distances larger than roughly 100 km, the underestimation by the radar of the accumulated precipitation is increasing systematically. The target height of the pseudoCAPPI is below the horizon for distances larger than 100 km, and data from just the lowest elevation has to be taken. Due to overshooting of precipitation and to gradients in the vertical profile of reflectivity, the amount of precipitation is systematically underestimated by radar at large distances (Meischner et al., 1997). The overall bias at short distance is less than 1 dB, indicating that the absolute calibration of the radar log-receiver is reasonable. The results for the radar in Den Helder, located close to the coast and the IJssel lake, are shown in the lower figure. The data points at a fixed distance are typically scattered over 3 dB. This large scattering is caused by a strong azimuthal dependence of the bias. This azimuthal dependence is attributed to enhanced sensitivity due to formation of microwave ducts above the IJssel lake and specular reflection from the lake's surface.

Via the comparison of radar and gauges, corrections for systematic errors of the radar data have been revealed. The radar estimates of accumulated precipitation will be corrected for these errors, and the effects of these corrections will be investigated using an independent dataset. The excellent verification results for the radar in De Bilt clearly confirm its favorable location, i.e., the absence of any significant orography.

4. DETECTION OF SUMMER HAIL

During the summer of 2000, an experimental hail detection product has been generated semi-operationally and has been presented in real time to the nowcasters and forecasters at KNMI. The development of this hail detection product has been described in detail elsewhere (Holleman et al., 2000; Holleman, 2001). The product is based on the hail detection method of Waldvogel et al. (1979).

The method of Waldvogel et al. (1979) for the detection of hail uses the maximum altitude at which a reflectivity of 45 dBZ is found (H_{Z45}) in relation to the height of the freezing level (H_{T0}). The height of the freezing level is determined from the HIRLAM model. 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. When the 45 dBZ-reflectivity extends to 1.4 km or more above the freezing level, the presence of hail

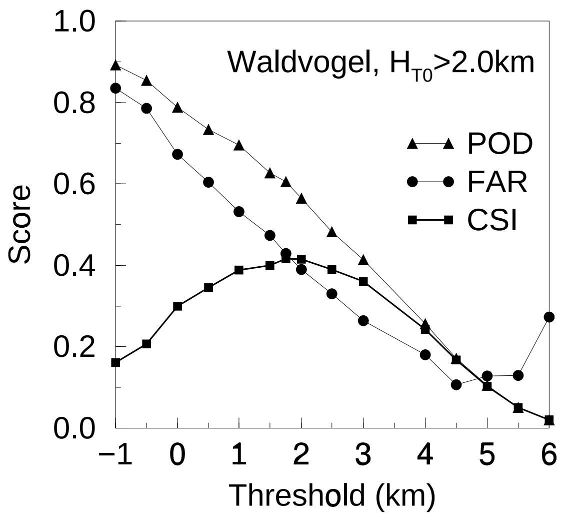

Figure 2: The POD, FAR, and CSI for the method of Waldvogel as a function of the warning threshold. Only days with a freezing level at De Bilt higher than 2.0 km at 12 UTC have been taken into account.

is likely, and 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).

Using the data of semi-operational run of the hail detection product, an extensive verification of Waldvogel's method has been performed. The extended verification has been performed in the same way in which the method of Waldvogel has been verified on 15 selected days within the summer of 1999 (Holleman et al., 2000; Holleman, 2001). Via binning of the 96 hail detection images available for each day, the radar data is reduced to only 135 daily hail detection images. Verification data, both surface hail observations and damage reports, has been collected for the summer of 2000. From the KNMI network of precipitation observers, a total of about 500 hail observations during the summer of 2000 were obtained. In addition, a total of about 1900 reports of hail damage have been obtained from three agricultural insurance companies. The hail events, counted per day and per district, have been classified using 2-by-2 contingency tables while the warning threshold, i.e., the minimum required height difference ($H_{Z45} - H_{T0}$), is changed. From the contingency tables, the Probability Of Detection (POD), the False Alarm Ratio (FAR), the Critical Success Index (CSI), and the bias have been calculated.

Figure 2 shows verification results for the method of Waldvogel as a function of the warning threshold. For the verification, only 115 days in the warm season of 2000 with a freezing level higher than 2.0 km have been used in order to reject days when winter hail, small hail on a large scale, is possible. The verification results of Waldvogel's method on this large number of unselected days show that the trends of the apparent POD, FAR, and CSI are almost identical to those observed for the 15 days in 1999 (Holleman et al., 2000). The optimum performance of the method of Waldvogel in 2000 (CSI= 0.48) is somewhat reduced with respect to that in 1999 (CSI= 0.54), however, probably caused by the use of unselected days in 2000. The verification results presented in Figure 2 will play a crucial role in the final tuning of the hail detection product based on the method of Waldvogel.

5. CONCLUSIONS AND FUTURE PLANS

Radar research and development at KNMI is focussed at producing operational tools for meteorology and hydrology: radar reflectivity, echotops, rainfall totals, and special warnings. The operational performance of the clutter removal system is satisfactory, and the radar-derived rainfall estimates appear rather accurate. A hail detection product has been validated and has recently become operational. The quality of the Doppler data and the potential of this data for operational applications is still under investigation. Anticipated Doppler products are: vertical wind profiles and warnings for horizontal wind shear. Because our two Doppler radars are only 100 km apart, the possible composition of dual-Doppler wind fields holds great promise.

REFERENCES

Aoyagi, J.: 1983, A study on the MTI weather radar system for rejecting ground clutter. *Papers in Meteor. and Geophy.*, **33**, 187–243.

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

Holleman, I., H. R. A. Wessels, J. R. A. Onvlee, and S. J. M. Barlag: 2000, Development of a hail-detection-product. *Phys. Chem. Earth (B)*, **25**, 1293–1297.

Meischner, P., C. Collier, A. Illingworth, J. Joss, and W. Randeu: 1997, Advanced weather radar systems in Europe: The COST 75 action. *Bull. Amer. Meteor. Soc.*, **78**, 1411–1430.

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

Wessels, H. R. A. and J. H. Beekhuis: 1997, Stepwise procedure for suppression of anomalous ground clutter. *COST-75 Seminar on Advanced Radar Systems*, EUR 16013 EN, 270–277.

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.