ministerie van verkeer en waterstaat

koninklijk nederlands meteorologisch instituut

Automatic suppression of anomalous propagation clutter for noncoherent weather radars

H.R.A. Wessels
J.H. Beekhuis

Scientific reports; WR 92-06
Wetenschappelijke rapporten; WR 92-06

De Bilt, 1992

de bilt 1992

p.o. box 201
3730 AE de bilt
wilhelminalaan 10
tel. (030) 206911
telex 47096
fax (030) 210407

publicationnummer: Scientific reports=
Wetenschappelijke rapporten
WR 92-06

U.D.C.: 551.501.815
551.596

ISSN: 0169-1651

ISBN: 90-369-2028-0

AUTOMATIC SUPPRESSION OF ANOMALOUS PROPAGATION CLUTTER FOR NONCOHERENT WEATHER RADARS

H.R.A.Wessels
J.H.Beekhuis

AUTOMATIC SUPPRESSION OF ANOMALOUS PROPAGATION CLUTTER FOR NONCOHERENT WEATHER RADARS

H.R.A.Wessels and J.H.Beekhuis

ABSTRACT

Pulse to pulse radar echo fluctuations have been used to distinguish rain from anomalous propagation clutter.
For 1 deg. sectors at a fixed range 14 echo samples from successive pulses are tested for clutter. This test has a clutter detection rate of only 45 %, but in each 1 deg/2 km polar radar pixel 8 range bins can be tested. The 8 tests are shown to be nearly independent and their combined result allows 85 % of the clutter pixels to be detected. Finally the pattern of suspect pixels in the completed radar picture is analysed on a scale of about 10 km. The total result is an average removal efficiency of about 98 %.
Only echoes of very light precipitation are erroneously suppressed by this processing: at most 5 % of light rain pixels or 15 % of light snow pixels are removed.
For on-line application this method requires a fast preprocessor operating in combination with the radar's digital signal integrator.

1 INTRODUCTION

Currently the Royal Netherlands Meteorological Institute KNMI operates 2 weather radars, located at De Bilt and at Schiphol Airport. Both are incoherent 5 cm radars with a 1 deg. beam performing PPI scans in about 18 sec.
The radar presents a pseudo-CAPPI picture of altitudes near 1.5 km obtained from elevations between 0.3 and 3 deg. Close to the radar 3 deg. data are used, thereby avoiding most echoes from nearby fixed targets. The part of the picture with residual fixed clutter is replaced by undisturbed data from the other radar in the composite picture.
This procedure is not effective against anomalous propagation clutter. In a flat country like the Netherlands anomalous propagation echoes may appear anywhere in the picture; there are no preferred targets like mountains. The absence of orography also enables inversions to stretch uninterruptedly over the region, causing very large areas contaminated with clutter.
Clutter echoes occurring in radar pictures may look very much like precipitation echoes. Even the professional meteorologist may sometimes have trouble in identifying clutter. The increasing demand to make radar pictures routinely available to non-meteorologists has urged KNMI to attempt automatic suppression of clutter echoes.
In this report, following a description of the radar and the clutter problem, measurements are presented (sections 4 and 5) and a clutter removal method is proposed and evaluated (section 6).

2 RADAR DATA PROCESSING

The radars are digitized as follows: 600 kHz samples from the Analog-Digital converter are averaged in a preprocessor, which outputs echo values with 0.5 dB resolution for polar echo cells with dimensions 1 km by 1 deg. Radial averages over 4 range bins are at their turn

averaged tangentially by a digital first-order filter. This filter has a time constant of 14 msec. The polar pixel values are further processed in the main radar computer, where - before converting to a rectangular grid - pairs of polar pixels are combined into 2 km by 1 deg. polar pixels. The intensity is scaled in 6 levels 1-6, respectively for signals above 7, 15, 23, 31, 39 and 47 dBZ.
With the present settings of antenna rotation, AD sample frequency and radar pulse repetition frequency, we have 4 radial samples per km and 14 tangential samples per degree. So each polar pixel (1 km by 1 deg) value is obtained from 56 samples.
A sketch of the spatial configuration of the samples is presented in Fig.1. Shown on scale are also the dimensions of the radar pulse volume: the region from which the radar obtains data at a certain time. Due to the 1 deg beamwidth the tangential spatial averaging is over about 14 samples.

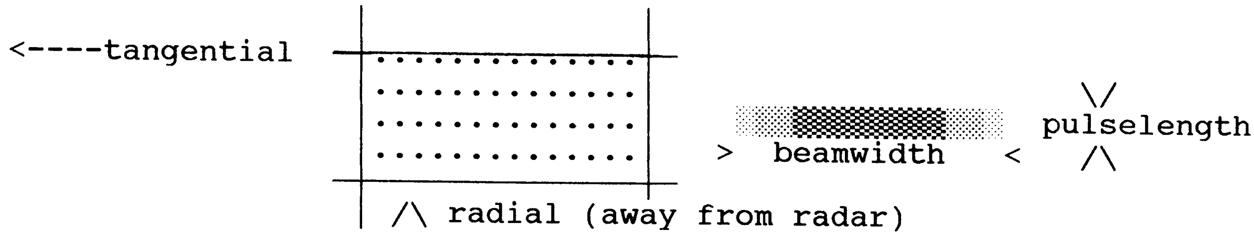

Fig.1. Geometry of samples in 1 km/ 1 deg. polar radar pixel. Radial samples analyse the echo signal following each radar pulse; tangential samples are obtained from subsequent samples at a certain range.
The radar pulse volume is shown for comparison.

3 CLUTTER AND RAIN CHARACTERISTICS

Due to the large temporal variability of anomalous propagation it is impossible to remove the resulting echoes with a clutter mask obtained from measurements at an earlier time.
Techniques that use the different spatial or temporal characteristics of radar pictures proved unsuccessful: On a pixel scale of 2.5 km, clutter echoes will look very much like showers. Because inversions may change or move, the displacement of clutter frequently imitates the movement of rain areas.
Doppler capability was not available and might anyhow not work on distant (Schmid et al., 1991) or strong clutter. In the Netherlands clutter echoes can occur at ranges exceeding 250 km. The clutter intensity may be as high as 80 dBZ, so that Doppler filtering would still leave clutter residues above 30 dBZ.
Encouraged by Aoyagi's (1983) fixed clutter removal results obtained by signal filtering, it was decided to investigate the temporal behaviour of the fluctuating part of the echo signal as a means to distinguish clutter from rain.
Temporal variations of rain echoes are rather fast: a decorrelation time of the order of 10 msec is reported (Nathanson 1969). Clutter echo fluctuations are due to e.g. movement of targets (leefs on trees, sea waves). Most of these fluctuations have lower frequencies than rain signals.
Studying time variations of radar echoes is disturbed by the horizontal spatial variability of precipitation and ground targets. The crossection of both types of targets may vary on scales down to

100 m or less. Because of the scanning movement of the beam these spatial variations are inevitably converted into time variations. Due to the small depth of the pulse volume (300 m, see Fig.1.), subsequent radial samples are not averaged radially. They represent spatial rather than temporal variations. A much higher radial sample rate could serve to overcome this. Van Gorp (1989,1991), using a 2.5 MHz sample rate, could indeed demonstrate some distinction between rain and clutter.
It is more advantageous to study subsequent tangential samples. Horizontal target variations are automatically reduced by averaging over the beam width. Although these tangential samples are obtained at a low rate (4 msec), the coherence of rain signals can still be estimated. The number of samples (14 per deg.) is adequate for rough estimates of fluctuation statistics.

4 MEASUREMENTS OF RADAR SIGNAL FLUCTUATIONS

In a number of situations with clutter or precipitation the output of the radar's logarithmic video amplifier was monitored with a PC-based data analyser. The sample frequency (600 kHz) was the same as for the radar's AD converter. Synchronisation with the radar distance measurement was obtained from the radar trigger signal.
The capacity of the data storage allowed a sector of about 74 deg. over a range interval of 256 km to be stored (1 M byte of 8 bit data). The data were converted to the 0.5 dB intensity units of the main computer and the usual inverse square range correction was applied.
Each measurement was complemented by extra runs with slower antenna rotation: 1.5 and 1 r.p.m. compared to the normal 3 r.p.m. On two occasions comparison measurements were made with a de-aliased video signal (300 kHz. low-pass filter, 27 dB/octave).
Additional reference data included radar pictures, PPI archive files at 4 elevations, satellite pictures and radiosoundings.
It should be emphasized that all measurements, results and criteria in this report are based on logarithmic signal amplitudes.

5 ANALYSIS OF RADAR SUBPIXEL VARIABILITY

5.a. Method of analysis.

An initial analysis of radial and tangential autocorrelation was performed for long cross-sections through echo areas. In radial direction, for both rain and clutter, subsequent 600 kHz samples were only weakly correlated and for intervals of 3 samples or more the signals were completely decorrelated. Tangential (250 Hz) autocorrelation of rain showed usually the same behaviour, but for clutter the correlation remained present up to intervals of about 10 samples, i.e. 40 ms, confirming the arguments of Section 3.
It was concluded that discrimination between rain and clutter could be based on analysing the tangential signal fluctuations. Also, due to the small radial coherence, the range bins with 14 samples each had to be analysed separately.
The pulse to pulse variations of the radar echo can be considered as time fluctuations superimposed on an average echo strength. The average signal changes due to the scanning along different targets. Various measures of the signal's fluctuating behaviour were attempted. The best results were obtained with the standard deviation of the fluctuations with reference to a 5 sample running average

signal value. Other high-pass filters (e.g. 3 or 7 point averageing) worked slightly less well.

5b. Results for clutter and rain.

Typical examples of the signal fluctuations frequency distribution are shown in Fig.2. Other situations showed a similar behaviour. An exception are the weakest precipitation signals (level 1, i.e. 7-14 dBZ), where the standard deviation is usually smaller, probably because of the nearby lower limit of the logarithmic amplifier. It should be noted that the median standard deviation for precipitation is about 4.2 dB. This is below the theoretical value of 5.5 dB to be expected at the logarithmic amplifier output for an input signal fluctuating according to a Rayleigh distribution. The 5-point filtering evidently removes some time fluctuations.
The curves for rain and clutter show an appreciable overlap, but a standard deviation below e.g. 2.0 dB is associated with a relatively high probability of clutter. An attempt was made to improve the discriminatory power of such criterium by making it depend on e.g. average signal intensity, or gradient of the intensity. However, apart from the above-mentionned difference for weak echoes, no systematic effect was found.
In a limited number of situations comparison measurements with a de-aliasing filter were obtained. The damping of rapid fluctuations causes the standard deviation distribution to shift to slightly lower levels: for precipitation the shift is 0.45 dB, but clutter shifts with about the same amount, at least for standard deviations between 1 and 5 dB. For two situations filtered and unfiltered data were compared regarding clutter removal performance. The filtering did not seem to improve the results and was consequently abandoned.

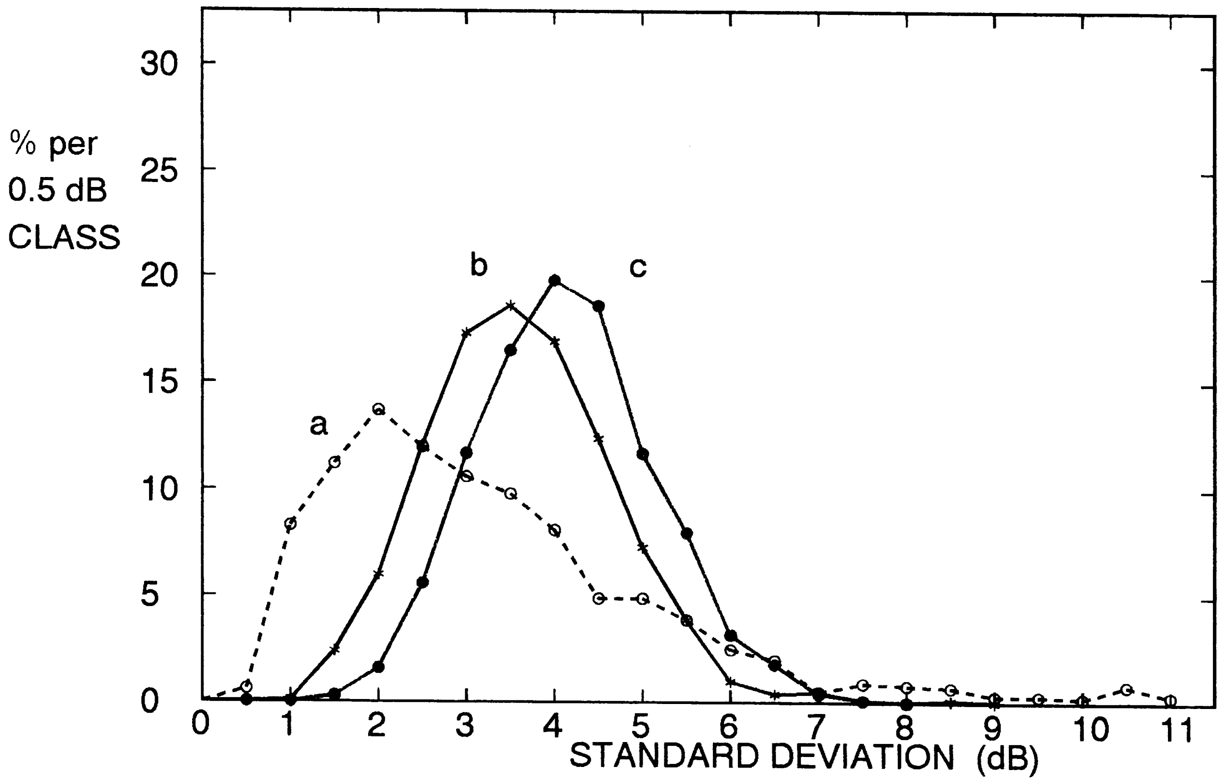

Fig.2. Standard deviation distibution of signal fluctuations for pixels with average signal 15-22 dBZ. Situations (1992):
a. Feb.4, rain, b. Feb.17, light snow, c. Jan.21., clutter.

5c. Results for snow.

Although a remarkably low number of days with snow occurred during the winter 1991/1992, measurements could be made on three occasions. One case with wet snow and a second case with moderate snow did not differ significantly from the rain measurements. During light snowfall, however, the standard deviation seems to be lower than in rain of comparable (rain-equivalent) intensity (Fig.2, curve b.). Evidently this type of precipitation is more difficult to distinguish from clutter.

5d. Results for sea clutter.

Some sea-clutter was included in the measurements of 1992, Jan.11 and April 9. To obtain a better exposure of sea-clutter a separate measurement was made on April 10 with an identical radar at Amsterdam Airport. The results (see Section 6 and Table 1) did show that sea clutter was removed as least as good as land clutter.

5e. Results for slower antenna rotation.

A slower antenna rotation is expected to provide a better estimate of temporal signal fluctuations, because of the larger number of samples (per degree) and the smaller distortion by spatial fluctuations. During the analysis of these measurements the 5-point filter was adapted to cover a larger range of samples, i.e. to provide averaging on the same spatial scale (about 0.4 degree) as with the normal rotation speed.

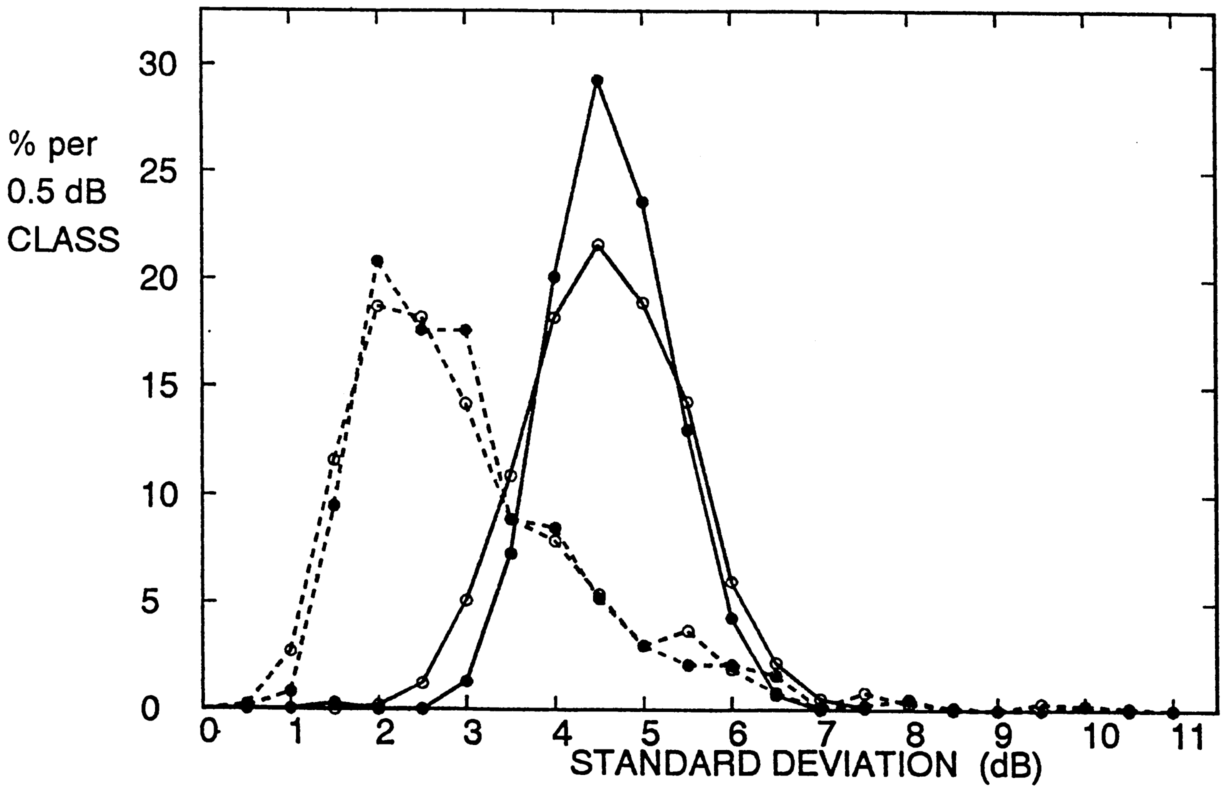

Fig.3. Effect of rotation rate on standard deviation distribution: dashed curves= Jan.11, clutter, full curves= Mar.11, rain, open circles= 3 r.p.m., dots= 1.5 r.p.m. (15-22 dBZ data)

The results show that for reduced rotation rate the precipitation standard deviation distribution is more narrow and that for 1 r.p.m. the median value approaches the theoretical value of 5.5 dB. Some results for 1.5 r.p.m. are shown in fig.3. The comparison curves for normal rotation were obtained by skipping alternate samples in the same data set. The clutter distribution is also shifting to higher values, but much less than for precipitation. This implies that a reduced rotation rate is beneficial for clutter recognition. This will be illustrated further in Section 6.d.

6. TWO STAGES OF OPERATIONAL CLUTTER SUPPRESSION

6.a. First action: clutter detection in single radar pixels.

For every radar pixel (1 km x 1 deg) 4 rows of 14 samples provide 4 estimates of the variance σ. Clutter recognition was obtained by considering samples with $\sigma < 2.5$ dB or $\sigma > 7.5$ dB as suspect. For echoes below 14 dBZ the values 2.2 and 7.5 dB were used, because of the longer tail of the distribution, but also because weak echo pixels might not provide 4 valid tests. It is of interest to note, that each test allows only about 45 % probability to detect clutter and about 4 % probability to discard rain (Fig. 2 and third column of Table 1).
The clutter discrimination improves if tests are combined: we consider a pixel as suspect if at least 2 out of 4 individual tests for clutter apply. This requirement seems to be an optimum: only 1 positive test could be accidental, but more than 2 are sometimes not available for weak echoes. If 4 independent tests with scores around 45 % rsp. 4 % are performed, the combined score is represented by a binominal distribution and the theoretical probability of at least 2 positive tests out of 4 would become 61 % and 1 % for clutter and rain respectively. Comparison of these figures with the third and fourth columns of Table 1. shows the assumed independence to be quite realistic.
It should be stressed that in this first step the pixel values are not filtered or weakened, but only signalled as being suspect.

6b. Final step: taking account of the clutter pattern.

The residual clutter echoes left after the first stage of clutter removal may still mislead the user. As stated in Section 2 the rectangular radar pixels are derived from pairs of 1 km polar pixels. If we discard those larger pixels with at least one suspect composing pixels, the removal percentages of the fifth column of Table 2 result. Now the residual clutter surface is reduced to about 15 % compared to the original. The result so far is still insufficient. A residue of 15 % may cause more doubts than the original echo pattern which may sometimes be more easily recognised by a characteristic non-rain appearance. Even clutter pixels with level comparable to 10 mm/hr of rain may pass the first screening.
Because the removal results of column 5 are insufficient as a final result, this step (the combination of two 1km pixels) is extended to use clutter information from the nearby area. It is essential that this area is not too large, because the same picture may contain both showers and clutter. During the summer, for example, it is not uncommon that clutter echoes are caused by the inversion that caps the cold outflow of a thunderstorm.

Fig.4. Radar picture sector for range 68-220 km in a clutter situation (Jan.11, 1992). The empty boxes show pixels that will be removed.

The area chosen is a 10 km by 5 deg. field centered on each 2km by 1 deg. pixel. The fraction of suspect 1 km pixels in this area is compared to the total number of pixels with at least the lowest echo level (0.1 mm/hr).
In this final stage a 2 km pixel is discarded if one of the following conditions applies:
- If both pixel halfs are suspect and at least 17% of the large area,
- If only one is suspect and 50% or more of the larger area pixels,
- If more than 83% of the large area is suspect.

The results after these combined stages of clutter suppression are shown in the sixth (last) column of Table 1. This last fase is very effective in reducing clutter, while causing an only minor extra removal of rain. Table 1. shows results for polar pixels. The conversion to rectangular pixels will lead to slightly higher percentages for precipitation, because pixels are removed more frequently at large ranges where during the polar-rectangular conversion the same polar pixel may be used to fill e.g. 3 rectangular pixels. Figs. 4 and 5 show the least favourable cases from Table 1: a situation with much residual clutter, respectively many wrongly removed precipitation echoes.
The actual criteria and results presented here depend to some extent on the radar observation: rotation speed, pulse repetition frequency, beam width, AD conversion rate and integrator organization.

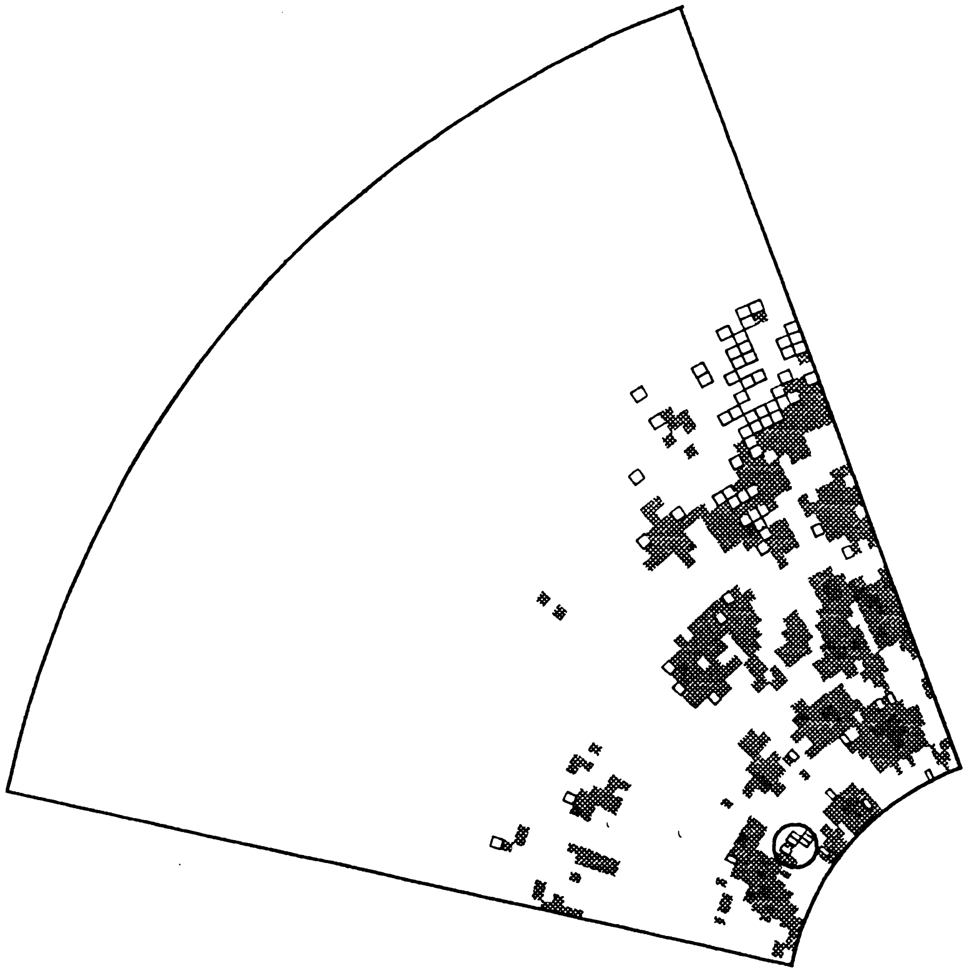

Fig.5 Radar picture sector for range 48-200 km with light snow echoes (Feb.17, 1992). The encadred boxes show were pixels will be removed. The boxes in the small circle are fixed echoes from tall chimney's.

Table 1. Fraction 'clutter' pixels after the respective stages of clutter suppression.

date, time 1992 UTC	echo type, max intensity level	1km/1 deg % p.250m	1km/1 deg % per 1km	2km/1 deg % suspect	% finally removed
Jan. 9 10	rain 4	3	1	3	3
Jan.11 16	clutter 6	45	59	81	98
Jan.21 9	clutter 6	47	63	87	99
Jan.30 10	clutter 6	48	65	87	100
Jan.31 21	clutter 6	41	54	82	100
Feb. 4 10	rain +snow 4	4	1	3	4
Feb.16 16	snow +rain 3	5	3	7	8
Feb.17 9	snow 2	7	5	9	11
Feb.19 9	snow +rain 3	4	2	3	4
Mar.11 14	rain +hail 5	5	3	8	8
Mar.13 9	rain +hail 4	3	1	2	2
Apr. 9 8	clutter 6	43	56	81	98
Apr.10 8	sea-clutter 6	64	88	100	100
May 22 6	clutter 6	40	50	77	99
May 25 14	thunderstorm 6	3	1	2	2
Jun. 6 16	thunderstorm 5	4	2	4	4

6.c. Discussion of the results.

Results were obtained in a variety of situations. All measurements confirmed the operational suitability of the method proposed. The remaining clutter consists of a few irregularly scattered pixels, some of which display a high echo level. Therefore confusion with showers is almost impossible. On the other hand, vital information at high intensity levels, e.g. from thunderstorms, passes more or less unmodified.

Light snow is more probably mistaken for clutter, which means that the outer fringes of snow echoes are sometimes removed. Almost the same picture could be obtained if the lowest radar sensitivity limit were increased by 0.5 or 1 dB. The performance could be improved by selecting a different cut-off criterium during cold weather, thereby allowing more clutter. Alternatively, the area used for the last stage could be made larger during the winter months when large-scale systems prevail over local convection and the horizontal separation of clutter and precipitation is large.

The present algorithm might -after rephrasing for a rectangular grid- easily be implemented in user displays, provided the clutter warning is transmitted with the radar pixel intensity information. This would enable different user groups to obtain a balance between accepting clutter and deleting precipitation, that matches their particular interests.

6.d. Possible futher improvements.

For two situations that proved difficult to separate, i.e. Jan.11 and Mar.11, the benefits of a slower antenna rotation have been investigated. It should be noted that with 1.5 r.p.m. the measured sector was reduced to half the normal size, so the figures of Table 1 do not apply. The clutter picture of Jan.11 did not change much and still about 98 % was removed. The snow echoes on Mar.11, however, survived much better than with the normal rotation rate. The sector percentage of erroneously removed pixels was lowered from 6 to 3 %.

7 CONCLUSIONS

Tangential signal variations can be used to discriminate between clutter and precipitation echoes, even if they are sampled at a rate as low as 250 Hz and if the antenna rotates as fast as 3 r.p.m. The distinction between precipitation and clutter is maintained for anomalous propagation clutter; this is an extension to the results of Ayoagi (1983).

Although the detection of clutter at each range bin is rather undecisive (about 45 % of the clutter data is detected), a large number of tests is available in the other range bins of the same pixel and also in the surrounding pixels. As these tests are statistically independent, their combined performance is very good and finally about 99 % of the clutter is detected. This principle might also work for other signal analysis methods, including the measurement of Doppler shift.

The tests demonstrate that this result is attained at the relatively modest price of deleting only weak (up to about 10 %) parts of echoes of very light rain or light snow.

With the procedure described, echoes are not weakened by filtering, but merely signalled as suspect, so that they can be removed depending on user's interests.

ACKNOWLEDGEMENTS

Mr.J.J.van Gorp, Dr.J.P.de Jongh, Mr.J.G.Maigret and Mr.C.J.Warmer contributed in organising and performing the measurements.

REFERENCES

Ayoagi, J., 1983, A study on the MTI Weather Radar System for rejecting ground Clutter.
Papers in Meteorology and Geophysics, 33(4), 187-243.

Gorp, J.J. van, 1989, Ground clutter reduction during rain measurements by a noncoherent radar system. COST-73 Seminar on Weather Radar Networking, Brussels, Sep.5-8. Publ.: Dordrecht (1990), 228-236.

Gorp, J.J. van, 1991, Adaptive filtering to reduce ground clutter in rain measurements by radar. Prepr. 25th Int.Conf.on Radar Meteorology, Paris, Jun.24-28. AMS, 924-927.

Joss, J., H.R.A.Wessels, 1990, Ground clutter suppression for weather radar data. Working Document COST 73/WD/130.

Nathanson, F.E., 1969, Radar design principles.
McGraw-Hill, New York, 618 pp.

Schmid, W., D.Högl, A.Vckovski, J.Joss, 1991, Test of clutter suppression techniques in the Swiss alps. Prepr. 25th Int.Conf. on Radar Meteorology, Paris, Jun.24-28. AMS, 875-878.