The GKSS 95 GHz cloud radar during CLARE 98: System performance and data products

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INTRODUCTION

For its participation in the CLARE 98 campaign, the transportable 95 GHz cloud radar MIRACLE was moved to England. It was set up on the field site of the Radiocommunication Research Unit of the Rutherford Appleton Laboratory at Chilbolton, where the RAL radars are installed. The position was just outside the workshop, the distance from the main dish of the 3 GHz radar CAMRa was about 40 m, and from the 94 GHz radar GALILEO it was about 50 m. Figure 1 shows MIRACLE in front of the CAMRa during the campaign.

Fig. 1: The GKSS 95 GHz radar MIRACLE in front of the 3 GHz radar CAMRa during the campaign.

SYSTEM DESCRIPTION

The GKSS cloud radar was built by Quadrant Engineering Inc., Amherst, Mass. The system was taken into operation in summer 1996. The radar control and data handling is based on an HP-VXI data acquisition and processing system. The radar is designed for ground-based use and is installed in a transportable container. The RF-component and antenna are integrated in an azimuth-elevation scanning device.

The pulsed Doppler radar is fully polarimetric and has a peak power of 1.7 kW. Pulse repetition frequency, number and location of range gates, pulse width and pulse polarization are software selectable and allow for a range resolution between 7.5 m and 82.5 m up to a range of 15 km. The beamwidth of the center-fed Cassegrain antenna of 0.17° leads to a range cell diameter of 30 m at a distance of 10 km. The far-field of the antenna starts at a range of about 900 m.

Further specifications are listed in Table 1.

Table 1: Parameters of the GKSS cloud radar.

Frequency (Wavelength)	95 GHz (3 mm)
Peak Power (EIA)	1.7 kW
Duty cycle	1.2 % max.
Pulse repetition freq.	50 Hz - 80 kHz
Pulse width	50 - 2000 ns
Beam width $\vartheta_{3\,\mathrm{dB}}$	0.17°
Antenna diameter	1.2 m (Cassegrain)
Antenna gain	60 dB
Polarization	linear (H, V)
Cross-polarization isolation	26 dB
Dynamic range	> 70 dB

DATA PRODUCTS AND DATA PROCESSING

The real-time data products include the three Doppler moments (total power, mean velocity, velocity variance) obtained from a pulse-pair algorithm. Alternatively, the radar can be operated in an up to 1024 point FFT mode to obtain full Doppler spectra. In the pulse-pair mode, polarimetric quantities such as ZDR and LDR are also obtained. ZDR provides useful information about particle shape by comparing copolarized backscatter at linear vertical and horizontal polarizations. LDR is a measure of the amount of depolarization detected and indicator of both particle asymmetry and orientation.

During CLARE, the radar was operated in a vertical pointing mode. Typical height-time sections of radar reflectivities as available in the CLARE dataset are produced in several steps. At first, profiles of received power are calculated by averaging over a large number of samples (in general several thousand pulses). To obtain an estimate for the receiver noise, the 10 contiguous range gates with the lowest average power value in cloud free regions are determined for each profile. This value is defined as noise power P_n. Initially, a range gate is then set as "cloudy" if

$$P \geq P_n + \alpha \frac{1.28 \cdot P_n}{\sqrt{M}} \qquad , \qquad (1)$$

where P is the signal plus noise power and M is the number of samples [1]. The factor 1.28 appears from the logarithmic form of the receiver transfer function. However, the value of α can be adjusted and is somewhat arbitrary [2]. For the final CLARE dataset , a value of $\alpha = 2$ was used. In the next step, a binary cloud mask is applied to remove the remaining speckle noise in cloud-free regions. This procedure, applied for both H and V received powers, is described in detail in [2]. For the remaining "cloudy" range gates, the corresponding H and V radar reflectivities are calculated from the radar equation. The pulse-pair estimates of mean Doppler velocity and spectral width are also determined for these gates. For each gate, the noise power P_n as calculated above is subtracted from the zero lag autocovariance term, following [3]. It must be mentioned that this method only removes the white noise contribution from the receiver, therefore, radar phase noise may still be present and can bias the spectral widths in very low signal to noise conditions [4].

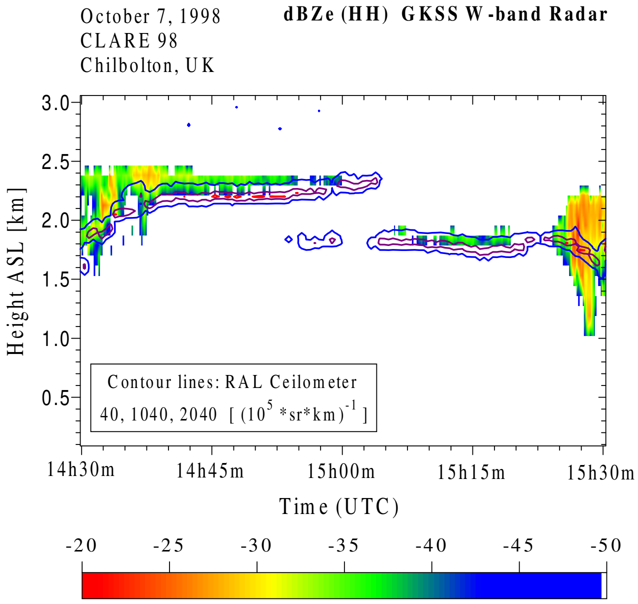

Fig. 2: Height-time section of MIRACLE radar reflectivity and RAL Vaisala ceilometer returns, observed during CLARE on October 7, 1998. (Ceilometer data provided by J. Goddard, RAL.)

The minimum sensitivity at an altitude of 1 km and 10 s integration is about $-45\,\mathrm{dB}Z$. As an illustration, Fig. 2 shows a section of low- and mid-level clouds simultaneously observed by the MIRACLE radar and the RAL Vaisala CT 75K ceilometer. It can be seen that in the cloud layer starting at about 1500 UTC in 1.8 km, the lowest reflectivity values are between -40 and $-45\,\mathrm{dB}Z$. Especially the lower part of this cloud layer, probably with lower reflectivities in non-drizzle conditions, is detected by the ceilometer, but not by the radar.

The final CLARE dataset contains reflectivity and Doppler velocity data with a temporal resolution of about 10 seconds and a vertical resolution of 82.5 meters. After an internal calibration procedure, the reflectivities are cross-calibrated following a "chain-calibration" procedure using data of the 3 GHz radar CAMRa, the 35 GHz radar RABELAIS, the 94 GHz radar GALILEO, and the 95 GHz radar MIRACLE [5]. I.e., a final result of this procedure is that **2 dB need to be added** to the MIRACLE reflectivities archived on the CLARE ftp site.

Table 2: Operation of the GKSS radar during CLARE.

Day (October)	Pulse-Pair data	FFT data	Operation time (UTC)
2	X		1040-1200
3			
4	X		0830-1020
5	X		0820-1325
6	X		0830-1020
7	X		0820-1550
8	X		0850-1445
9	X		0845-1825
10			
11			
12			
13	X	X	0955-1810
14	X	X	1010-1550
15	X		1000-1410
16	X		0810-1735
17			
18			
19	X		0825-1735
20	X	X	0750-1715
21	X	X	0930-1140
22	X		0835-1630
23	X		0945-1450

During relevant aircraft overpass periods (several minutes each), full Doppler spectra were recorded with a 256 point FFT mode instead of pulse-pair data. This FFT data did not go through a cloud mask scheme. The spectral amplitudes (powers) are given in dB, and they are normalized in a way that the integral over the whole spectrum gives the corresponding reflectivity in dBZ. The FFT data is supplied with a temporal resolution of about 30 seconds and a vertical resolution of 37.5 meters. Due to the large amount of necessary real-time computing operations in the FFT mode, the number of range gates is limited so that the observed height bands did not exceed 3 km in thickness.

It must be noted that in the full Doppler spectra different noise features, affecting either defined height bands or certain spectral bins, were detected from time to time. Algorithms to remove these artifacts would require changes in the original FFT signal processing software of the manufacturer (which we do not have access to at present). However, the noise features can be easily identified by eye and removed manually from the Doppler spectra. The pulse-pair data are not affected by these problems.

Table 2 summarizes the MIRACLE operation days and periods and the availability of pulse-pair or FFT data.

More information can be found on the Web:

http://w3.gkss.de/english/Radar/clarearchive.html .

This site is also reachable via the CLARE 98 ftp site.

REFERENCES

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