The Possible Effect of Precipitation on Clear Air Returns

Adrian McDonald, Trevor Carey-Smith, Graeme Fraser, and Blair Lublow

Department of Physics and Astronomy, University of Canterbury, Christchurch, New Zealand.

Email: adrian.mcdonald@canterbury.ac.nz Phone: +64 (3) 364 2281 Fax: +64 (3) 364 2469

Abstract

Several authors have recently indicated that reductions in the signal strength of clear air returns can be observed at low altitudes in regions of precipitation. This study uses data from the NERC MST radar facility in Aberystwyth (52.4°N, 4.1°W) and co-located tipping bucket rain gauge data to determine whether this effect can be observed for all periods where high rainfall rates were observed at the ground. The period selected for examination includes all of the days where a peak rainfall rate of 1mm/h was observed in 2001. The magnitude of the change in signal power and any variations in the spectral width of the Doppler spectra are also examined. Use is also made of UHF wind profiler data to examine whether a relationship between enhanced UHF returns (signifying precipitation) and reduced VHF returns can be observed. To clarify the processes and effects observed we examine two case studies which show typical relationships between the VHF signal power and surface rainfall or enhanced UHF signal to noise ratios . Examination of individual Doppler Spectra also allows the effect of precipitation on the signal processing schemes derivation of signal power and spectral width to be explored.

Introduction

Doppler radar profilers operating at UHF and VHF wavelengths are sensitive to both Bragg scattering from the radio refractive index of turbulence and Rayleigh scattering from distributed targets (namely hydrometeors). The dependence of Rayleigh scattering and Bragg Scattering on wavelength means that UHF and VHF radars have very different sensitivities to these processes. A largely theoretical study described in Ralph (1995) reveals that only heavy rain is likely to appear regularly in VHF radar spectral moment data, where heavy rain is defined as greater than 8.4mm/h. At UHF wavelengths, however, Rayleigh scattering from precipitation is likely to exceed the clear-air return under conditions where rainfall rates are greater than those characteristic of light rain or drizzle. Thus, under many conditions combined UHF and VHF radar data is necessary to evaluate precipitation information accurately.

Vaughan and Worthington (2000) investigated the variation in power of VHF radar vertical echoes as a function of atmospheric humidity. Their work indicated that the observed echoes are greatest in air of moderate humidity, and least in very dry or near-saturated air. The standard model for radar echoes based on potential refractivity thus seems to overpredict the echo power at high relative humidity. Their study proposes that this is due to the effect of precipitation in supressing small-scale humidity gradients. Their study also suggests that the echoes are more isotropic, and their spectra are broader, at high humidity, indicating a greater contribution from turbulent scatter than Fresnel scatter. This study aims to examine the effect of precipitation on clear air returns using a combination of surface rainfall measurements made with a tipping-bucket rain gauge and co-located UHF radar data, which is utilised to identify precipitating regions.

Instruments and Measurement Strategy

The NERC MST radar facility at Aberystwyth (52.4°N, 4.1°W) operates at a frequency of 46.5MHz and has a peak transmitted power of 160kW. The antenna consists of a 20 by 20 array of four element Yagi aerials covering an area of 104m by 104m. The radar beam has a one-way half power width of 1.5 degrees and can be directed in sixteen possible directions, these directions being vertical and at angles of 4.2, 6, 8.5 and 12 degrees off-vertical.

The measurements described in this study were made using the vertical beam. Several recent studies have described methods used to derive parameters from Doppler spectra. Normally these processing schemes aim to determine the returned signal power, Doppler shift and spectral width associated with the clear air returns observed at VHF frequencies. More complicated processing schemes can also be used to attempt separate the characteristics of any precipitation signal from the clear air signal. In this study, the standard processing scheme used by the NERC MST radar is used in a statistical examination of the data. A more complicated scheme, similar to that described in Rajopadhyaya et al. (1994), is used to identify the precipitation and Bragg scatter signals in a case study to show the difficultly in separating these signals.

The surface rainfall rate used in this study is measured by an ARG100 raingauge. The amount of rain collected is measured by the well-proven tipping bucket method. The contact closure at each tip is then recorded by a datalogger. Measurements are made at 10 minute intervals. In addition, data from a UKMO UHF boundary-layer wind-profiler (with an operating frequency of 915MHz) which was co-located with the Abersystwyth MST radar between 17th November 1999 and 11th March 2002 is utilised. The useful altitude coverage varies with the measurement mode utilised and atmospheric conditions and only extends significantly above 2 km when precipitation is present. Although the cycle time for observations is of the order of a few minutes, the available data represents a consensus average over 30 minutes.

Height range (km)	Surface rainfall threshold (mm/h)	Mean signal power during periods where the surface rainfall threshold was exceeded (dB)	Mean signal power during periods where the surface rainfall threshold was NOT exceeded (dB)	Values (positive/negative)	Significant decreases / Total events
2-4	0.0	72.6	75.6	3/30	18/33
4-6	0.0	66.2	66.6	13/20	10/33
16-18	0.0	40.0	39.9	21/12	5/33
2-4	0.5	72.2	75.1	7/26	13/33
4-6	0.5	65.6	66.6	14/19	7/33
16-18	0.5	40.0	39.9	13/20	6/33

Table 1: The mean VHF signal power averaged over the height range indicated during periods where the indicated rainfall threshold was and was not exceeded is shown. In addition the number of positive and negative changes in the mean signal power associated with rainfall and the number of significant decreases in the signal power associated with periods of surface rainfall above the indicated threshold are shown. The surface rainfall is observed by a tipping bucket rain gauge co-located with the NERC MST radar.

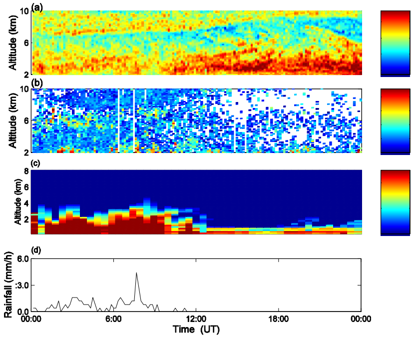

Figure 1: Time-height contour plots of (a) vertical signal power (dB), (b) vertical corrected spectral width (ms^{-1}) observed by the NERC MST radar, (c) the vertical signal to noise ratio measured by a co-located UKMO wind profiler and (d) the variation of surface rainfall observed by a tipping bucket rain gauge on 17th May 2001.

Results

To examine the role of precipitation on clear air returns a number of days associated with high rainfall rates at the surface were selected. High rainfall days were defined in this study as days where the rainfall rate was greater than 1mm/h for a continuous period greater than 10 minutes. A total of 33 days during the calendar year 2001 were selected using this criterion. The surface rainfall rates were observed by a co-located tipping bucket rain gauge. It should be noted that the tipping bucket rain gauge was only non-functional for a small number of days and thus nearly all days had surface rainfall measurements available.

Statistical Analysis

Table 1 shows the mean signal power during periods below and above a surface rainfall threshold criteria. When the mean signal power is calculated from VHF data between 2 and 4km using a rainfall threshold of 0mm/h (rain and no rain periods) a clear decrease of roughly 3dB is observed during rainfall. Between 4 and 6km this difference decreases to 0.4dB and at 16-18km is only 0.1dB. This decrease suggests that this change is not associated with increased noise levels at all altitudes caused by rain static. In addition, a statistical analysis of noise power indicates no significant change in noise power during periods of rainfall. The observed altitude dependence seems to suggest that precipitation between 2 and 4km causes this change. When the rainfall threshold is increased to 0.5mm/h the difference between the signal powers remains approximately the same for measurements between 2 and 4km. However, separating signal power data into regions of heavier (associated with periods where the rainfall at the surface is greater than 0.5mm/h) and lighter rainfall (associated with periods where the rainfall at the surface is less than 0.5mm/h) changes the observations determined between 4 and 6km with a difference of 1dB between these two periods. This is suggested to be associated with the higher vertical extent of convective precipitation which is in general related to the largest surface rainfall rates. Table 1 also shows the number of events where the variation in the mean changes significantly. Examination shows that over half the events display a significant decrease in signal power during rainfall for averages derived from data between 2 and 4km. However, the number of significant events associated with rainfall thresholds of 0.5mm/h is smaller and this is associated with the small number of data points which produce the mean values in this case.

Examination of Table 2 shows that the spectral width observed during periods above the surface rainfall threshold is larger than that during periods where the surface rainfall threshold is not exceeded. This increase in the spectral width may be associated with wide Doppler spectra produced by Rayleigh and clear air returns which are not separated in frequency. However, if this is the case the decrease in clear air returns during precipitation must be even larger than indicated since some part of the observed signal power must be associated with the precipitation return. This increase may also be associated with a greater contribution from turbulent scatter inside precipitating clouds.

Height range (km)	Surface rainfall threshold (mm/h)	Mean spectral width during periods where the surface rainfall threshold was exceeded (ms^{-1})	Mean spectral width during periods where the surface rainfall threshold was NOT exceeded (ms^{-1})	Values (positive/negative)	Significant increases / Total events
2-4	0.0	0.31	0.22	30/3	25/33
4-6	0.0	0.21	0.17	29/4	16/33
16-18	0.0	0.08	0.10	14/19	1/33
2-4	0.5	0.36	0.23	31/2	22/33
4-6	0.5	0.23	0.18	28/5	12/33
16-18	0.5	0.08	0.10	13/20	1/33

Table 2: The mean VHF spectral width averaged over the height range indicated during periods where the indicated rainfall threshold was and was not exceeded is shown. In addition the number of positive and negative changes in the spectral width and the number of significant increases in the spectral width associated with periods of surface rainfall above the indicated threshold are shown. The surface rainfall is observed by a tipping bucket rain gauge co-located with the NERC MST radar.

UHF signal to noise ratio between 2-4km (dB)	Mean signal power during periods where the UHF signal to noise threshold was exceeded (dB)	Mean signal power during periods where the UF signal to noise ratio threshold was NOT exceeded (dB)	Values (positive/negative)	Significant increases / Total events
0.0	72.20	75.86	3/14	13/17
5.0	71.49	75.36	2/16	9/17

Table 3: The mean VHF signal power averaged over the 2 to 4km height range during periods where the UHF signal to noise ratio was greater or less than the thresholds indicated are shown. The number of positive and negative changes in the VHF signal power and the number of days where a significant decrease in signal power was associated with large UHF signal to noise ratios are also shown.

Table 2 also shows the number of events where the spectral width increase during rainfall is significant. It it interesting to note that this effect is much more pronounced than the signal power decrease with nearly all days (25 out of 33) showing a significant increase in spectral width. This statistical increase either suggests that a combination of clear air returns and precipitation returns is observed by the standard signal processing scheme used by the NERC MST radar or that a large contribution is observed from turbulent scatter inside precipitating clouds. If this increase in the spectral width during periods of rainfall can be considered to be associated with a combination of clear air returns and precipitation returns it is highly significant; this is because it indicates that the signal power observed is also a combination of both precipitation and clear air returns suggesting that the true reduction of the clear air return must be even larger than indicated since some part of the observed signal power will be associated with the precipitation return. To examine more closely whether the change in the VHF signal return is associated with precipitation measurements the signal to noise ratio (SNR) between 2 and 4km derived using data from a UKMO wind profiler is utilised.

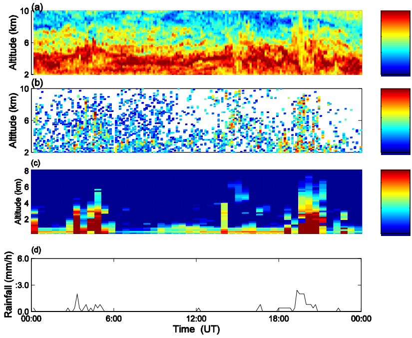

Figure 3: Time-height contour plots of (a) vertical signal power (dB), (b) vertical corrected spectral width (ms^{-1}) observed by the NERC MST radar, (c) the vertical signal to noise ratio measured by a co-located UKMO wind profiler and (d) the variation of surface rainfall observed by a tipping bucket rain gauge on 5th October 2001.

Table 3 displays the mean VHF signal power averaged over the 2 to 4km range during periods where the UHF SNR is greater or less than the threshold specified. During the periods where the SNR of the UHF signal is greater than 0dB the signal observed by the VHF radar is 3.6dB smaller than during the other periods. It should be noted at this point that if the subset of data used for the UHF data comparison is processed using a rainfall threshold the difference is only 2.8dB. Thus, regions of precipitation identified by the UHF profiler seem to clearly correspond to regions of low signal power in the VHF return. This supports the conclusion that the clear air return is reduced in periods of precipitation. To clarify the processes and effects observed we examine two different case studies.

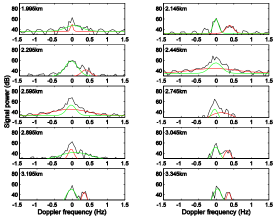

Figure 2: Doppler spectra taken at 08:00UT on the 17th May 2001, the observation altitude being shown for each spectra. The black line represents the raw data and the red and green lines show fits to any possible Rayleigh or Bragg scattering echoes using a technique similar to that described in Rajopadhyaya et al. (1994).

Case Study 1: 17th May 2001

Figure 1 displays time-height contour plots of the vertical signal power and corrected spectral width observed by the NERC MST radar and the corresponding surface rainfall rate measured by a tipping bucket rain gauge. Comparison of the vertical signal power and the surface rainfall in this case shows a strong negative relationship, that is the vertical signal power decreases during periods associated with rainfall, this is especially evident at low altitudes. Examination also indicates that a relationship between the spectral width and surface rainfall exists, but that it is not as clear as that observed between surface rainfall and signal power.

Examination of the UHF SNR during this day (shown in Figure 1c) displays enhancements between 2 and 3km during the period of intense rainfall. This indicates that hydrometeors are present in the range where the VHF signal power is reduced which again implies that the signal is affected by precipitation.

Doppler spectra at 08:00UT on the 17th May 2001 are shown in Figure 2. Examination of these spectra shows some indication of a secondary peak associated with a precipitation echo at 2.145 and 2.295km. In addition, the width of the echoes is large at lower altitudes which may indicate that the signal may be associated with a combination of the clear air and precipitation return. It should be reiterated that if this is the case the decrease in clear air returns during precipitation will be larger than indicated since some part of the observed signal power would be associated with the precipitation return. This possibility has previously been indicated by the statistical increase in the spectral width observed during rainfall. Figure 2 also shows fits to possible Bragg and Rayleigh scattering peaks using a technique similar to that described in Rajopadhyaya et al. (1994). It should be noted that examination of these fits and their residuals (not shown) displays the difficultly in trying to seperate the observed data into thse two signals.

Case Study 2: 5th October 2001

Figure 3 displays time-height contour plots of the vertical signal power and corrected spectral width observed by the NERC MST radar and the corresponding surface rainfall rate measured by a tipping bucket rain gauge measured on the 5th October 2001. Comparison of the vertical signal power and the surface rainfall in this case shows a less clear negative relationship than observed in Figure 1. Examination also indicates that on this day a clear relationship between the corrected spectral width and surface rainfall exists.

Examination of the UHF SNR during this day (shown in Figure 3c) displays enhancements between 2 and 6km during the periods of intense rainfall. This indicates that hydrometeors are present in the range where the signal power is reduced which implies that the signal is affected by precipitation. It is particularly interesting to note in this case that a region which displays a decrease in the signal power observed by the NERC MST radar at approximately 15:00UT does not correspond to surface rainfall. But does match well with a period of enhanced SNR observed by the UKMO profiler at rougly 15:00UT. This seems to suggest that a signal associated with precipitating cloud is observed by both radars, but that the precipitation does not reach the surface.

Conclusions and Further Work

A statistical examination of VHF radar signal power during periods with and without surface rainfall suggests that the returned echo is reduced during periods of precipitation. The corrected spectral width of the Doppler spectra is also significantly wider during periods of precipitation. When UHF wind profiler measurements are compared with the signal power observed by the NERC MST radar a clear relationship between enhanced signal to noise ratios in the wind profiler data (which is very likely to be associated with Rayleigh scattering from hydrometeors) and reductions in the VHF signal is observed.

Two case studies also display the clear relationship between reduced VHF signal power and surface rainfall or enhanced UHF radar returns. Typical Doppler spectra taken from the 17th May 2001 indicate the possibility of large width echoes at lower altitudes which may indicate that the signal power observed may be associated with a combination of the clear air and precipitation return. Thus, suggesting that the standard signal processing scheme may reduce the impact of this effect.

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