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4.2.2 UHF AND VHF RADAR OBSERVATIONS OF THUNDERSTORMS

D. N. Holden, C. W. Ulbrich, M. F. Larsen

Department of Physics and Astronomy
Clemson University
Clemson, SC 29634

J. Rottger, H. M. Ierkic
Arecibo Observatory
P. O. Box 995
Arecibo, PR 00612

W. Swartz
School of Electrical Engineering
Cornell University
Ithaca, NY 14853

INTRODUCTION

A study of thunderstorms was made in the Summer of 1985 with the 430-MHz and 50-MHz radars at the Arecibo Observatory in Puerto Rico. Both radars use the 300-meter dish, which gives a beam width of less than 2 degrees even at these long wavelengths. Though the radars are steerable, only vertical beams were used in this experiment. The height resolution was 300 and 150 meters for the UHF and the VHF, respectively. Lightning echoes, as well as returns from precipitation and clear-air turbulence were detected with both wavelengths. Two tipping bucket rain gauges, an anemometer, wind vane, and electric field change meter provided additional data to complement the regular meteorological balloon soundings taken at San Juan, some 70 kilometers to the east.

Large increases in the returned power were found to be coincident with increasing downward vertical velocities at UHF (Figure 1), whereas at VHF the total power returned was relatively constant during the life of a storm. We attribute this to the fact that the VHF is more sensitive to scattering from the turbulence-induced inhomogeneities in the refractive index and less sensitive to scatter from precipitation particles. On occasion, the shape of the Doppler spectra was observed to change with the occurrence of a lightning discharge in the pulse volume. Though the total power and mean reflectivity weighted Doppler velocity changed little during these events, the power in Doppler frequency bins near that corresponding to the updraft did increase substantially within a fraction of a second after a discharge was detected in the beam. This suggests to us some interaction between precipitation and lightning.

THE EXPERIMENT

During the past year at the Arecibo Observatory, a 46.8-MHz transmitter and receiver was installed which illuminates the 300-meter dish. The peak power available is of the order of 50 kilowatts, with a maximum duty cycle of 2%, and a minimum detectable signal around minus 110 dBm. The feed is located 2.1 degrees inward from the 430-MHz feed. Some of the first data taken with the new system were of the tropical thunderstorms that form over the island in the summer months.

The Doppler spectra at VHF show much of the structure of the thunderclouds. Most of the received power is assumed to be from the scattering processes associated with turbulence, which manifests itself as a very large increase in the variance of the Doppler spectrum. This is indicated in Figure

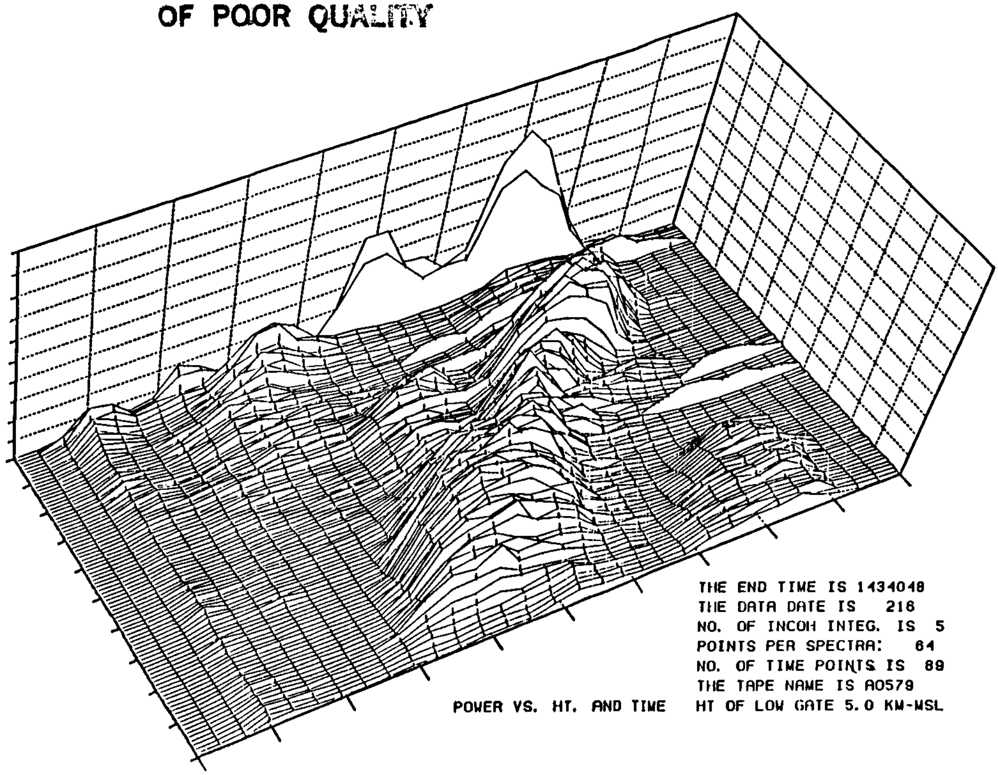

Figure 1. A three-dimensional representation of the zeroth moment (Z direction) of UHF Doppler spectra. Slant range (in this case, height) increases toward the upper right, time increases toward the lower right.

2 where the lower gates have returns in them from a thundercloud, where the upper gates do not. Some of the transient features that we observed in the spectra indicate the presence of precipitation and occasionally, lightning. The scattering process from lightning is not fully understood, since an enhanced echo during a discharge could conceivably originate from a number of sources. One of these is the scatter from the ionized plasma channel itself, and another might be the scatter from the intense gradients in refractive index that surely must exist as a result of the shock wave that is produced by the flash.

During some of the campaign, the 430-MHz radar was also operated. Though the two systems were never operated simultaneously (indeed, with the 2.1 degree separation the two beams do not share the same pulse volume), some comparison of the features of the spectra at the two different wavelengths can be made. The most conspicuous difference between the observations at the two frequencies is the effect of the presence of precipitation in the beam. Only during periods of intense rain does a significant contribution to the echo at VHF appear; the returned power is increased by the precipitation less than 5 or 10 dB. In fact, the presence of precipitation in the pulse volume does not guarantee that the power returned will be greater than when the precipitation is not present. This is shown in Figure 4 when a comparison of the power in gates 56 through 67 is made with the power in gates 71 through 80. At UHF, the

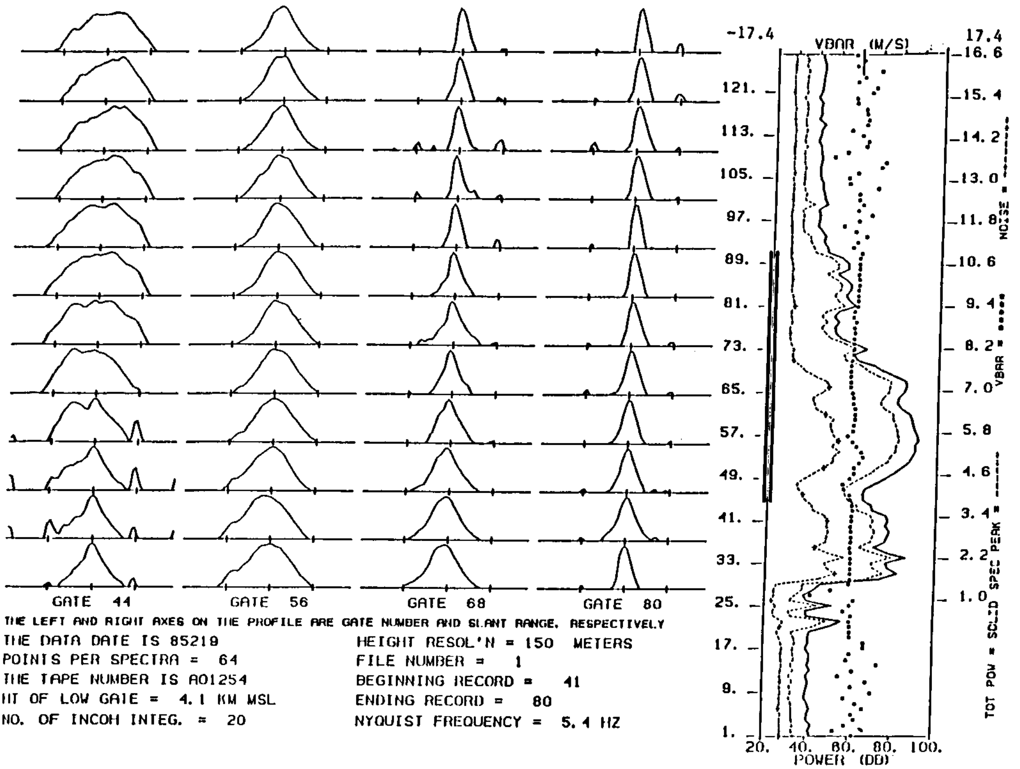

Figure 2. VHF Doppler spectra integrated for two minutes, with spectra plotted for gates 44 through 91 and a height profile of mean velocity, total power, spectral peak, and noise level for 128 gates. Positive Doppler velocity (toward the radar) is to the right of center, each spectra is scaled to its own peak and noise level. Note the large variance in the lower gates as compared with the upper ones.

situation is quite different, there are large changes in the reflectivity (greater than 20 dB) that occur in time intervals of the order of a few minutes. These changes are almost invariably associated with downward vertical velocities that is indicative of precipitation (i.e., velocities around 5 meters per second). The variance of the spectra at both frequencies is seen to increase significantly with the onset of convective activity, sometimes as much as a factor of four or so. The transient echoes associated with lightning are also quite different from one frequency to the other. At UHF, the returns usually appear at Doppler frequencies that are consistent with the vertical air motions, and show a variance that is not atypical of that found in a thunderstorm environment. This implies that the principal scattering mechanism is that of scattering from the lightning channel itself (which is assumed to move with the mean wind). At VHF, lightning in the beam often completely flattens the spectra, as though there is a feature present that has an extremely high Doppler shift and proportional width. This might be consistent with the radar detecting the acoustic wave (thunder) which would have a Doppler velocity of the order of 300 meters per second. Of course, this large shift would be aliased many times around the 5 Hertz Nyquist frequency of the system. Another explanation is simply receiver saturation, though there is some evidence that this is not the case.

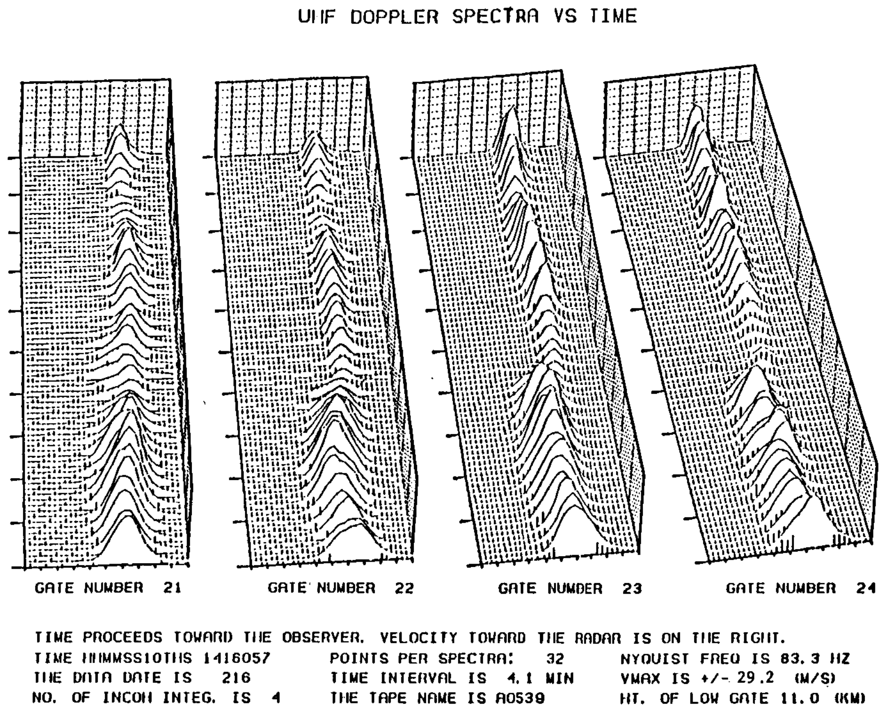

Figure 3. Doppler spectra plotted as a function of time at UHF for range gates 21 through 24. The distinct change in the character of the spectra, about halfway through the sequence is coincident with a lightning flash observed in the beam.

The shorter sampling time of the UHF radar allows a very detailed look at any interaction between the hydrometeors in the clouds and lightning. Occasionally, when lightning is detected in the beam, there is a significant alteration of the Doppler spectra that occurs shortly after the discharge, as is shown in Figure 3. The mean reflectivity weighted Doppler velocity does not change appreciably, nor does the total power. There are, however, substantial increases in reflectivity that occur in certain frequency bins. If the velocity that the lightning echo appears in can be assumed to be the velocity of the air motion, then the increases that are observed happen in frequencies that correspond to small downward velocities relative to the wind field. This can be interpreted in two ways: one, a reorientation of the scatterers as a result of the electric field change that accompanies the lightning, or a growth of the very small cloud particles to larger sizes. It is the latter of the two explanations that is the most plausible, since the changes in the spectra are more or less permanent, that is, of the order of tens of seconds. If there was a simple reorientation of the particles, the random wind field would rearrange them in a time that would be on the order of the time to independence which, in a thundercloud, is less than a second.

The presence of precipitation in the Doppler spectra at VHF can provide much information about the cloud microphysics if the precipitation peak is sufficiently separated from the clear-air peak (see Figure 4). In this case, the clear-air part of the spectra can be approximated (by a Gaussian, say)

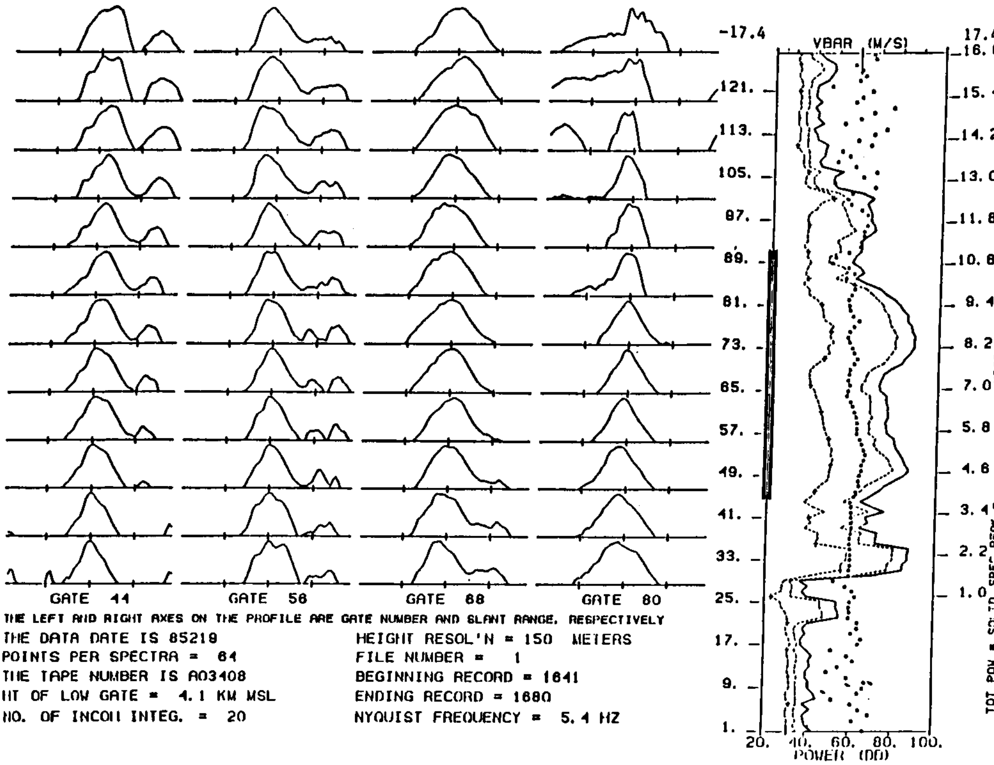

Figure 4. Same parameters as in Figure 2. Here, the smaller peaks that appear to the right of the main peak are the result of scattering from intense (> 50 mm/hr) precipitation.

which, when subtracted from the total spectra, leaves just the contribution due to the precipitation. Subtracting the clear-air velocity now leaves the fall velocity of the drops in still air, then through some terminal velocity-diameter relation, the drop size distribution can then be derived from the spectra.

The new VHF system has good sensitivity, which should make it a valuable addition to the other frequencies that are available at the Arecibo facility. The near proximity of the 430-MHz feed immediately suggests that dual wavelength experiments could be performed, unfortunately, that is not the case, unless large-scale features or long time scales are to be investigated. Even though there is only 2.1 degrees separation between the two beams, with the tremendous inertia that the receiver platform has, it would take about one minute to swing the feed this angular distance. In a convective environment, this is entirely too long as the entire pulse volume can be exchanged in less than 10 seconds during thunderstorms. The construction of a VHF feed that is concentric with the 430-MHz feed would make the Arecibo facility truly unique. Given that an absolute calibration was available for both systems, dual wavelength methods could then be used to study a variety of phenomena: turbulence, drop size distributions, and other effects. In the meantime, more experiments done with the new system will increase its reliability and versatility.