5B.7 AN ANALYSIS OF THE INFORMATION CONTAINED IN THE SIGNAL FLUCTUATIONS OF A VERTICALLY POINTING DOPPLER RADAR

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1 INTRODUCTION

Today, in most operational radar applications, the radar signal magnitude is averaged over a large number of samples in time and space in order to remove fluctuations in the radar signal. This averaged signal is then used to estimate the rainfall rate using assumptions about the drop size distribution and the fall velocities of the drops. A development that has made one of these assumptions obselete is vertically pointing Doppler radar, from which either a distribution of fall velocities or a drop size distribution can be derived (using a relation between fall velocities and drop sizes). However, this still does not make radar rainfall estimates very accurate as raindrop size distributions and fall velocities are highly variable in space and time (Pruppacher and Klett, 1997).

This paper describes the initial stages of an effort to improve our ability of measuring rainfall while making as little assumptions as possible. This is done by looking at the information contained in the radar signal fluctuations, which are shown to consist of different components. Duncan et al. (1992) showed that the power spectrum of the radar signal is sensitive to the size of the measurement volume. This will be the main focus of this paper.

2 THEORETICAL SIGNAL

For the purpose of this paper, the radar signal is assumed to be the result of Rayleigh backscattering off only perfectly spherical raindrops. The amplitude of the backscattered electromagnetic wave is also assumed not to be affected by attenuation. This simplicity is of course not encountered in real rain, but the results obtained here may later be extended to more realistic cases. The electric field received by such a radar can be expressed as

$$E = A \cdot E_0 \sum_i D_i^3 \cdot \mathrm{e}^{j\left(\frac{4\pi h_i}{\lambda}+\varphi_0\right)}. \quad (1)$$

The subscript i corresponds to a single raindrop, A is a constant, E_0 is the initial amplitude of the transmitted signal, φ_0 is its initial phase and λ is its wavelength, D is the drop diameter and h is the range of the drop. The magnitude of this electric field is given by

$$|E| = \sqrt{E \cdot E^*} = A \cdot E_0 \left[\sum_i D_i^6 + \sum_{i \neq k} D_i^3 D_k^3 \cdot \cos\left(\frac{4\pi}{\lambda}(h_i - h_k)\right) \right]^{1/2}, \quad (2)$$

in which E^* is the complex conjungate of E.

When the radar volume is small, the discrete nature of rainfall becomes important. This can be shown by looking at the frequency domain of the signal. The Fourier transform of the squared magnitude of the signal is given by ($f > 0$ only)

$$\mathcal{F}\{|E|^2\} = A^2 E_0^2 \Big[\sum_i D_i^6 \cdot \delta(0) + \sum_{i \neq k} D_i^3 D_k^3 \cdot \delta\big(f - \frac{2}{\lambda}(v_i - v_k)\big) + F_{ii}(f) + F_{ik}(f) \Big]. \quad (3)$$

In this equation, the terms $F_{ii}(f)$ and $F_{ik}(f)$ are the contributions to the spectrum of the raindrops entering and leaving the measurement volume, caused by fluctuations in the first and second terms of equation 2, respectively. $\delta(x)$ is the Dirac delta function and v is the drop velocity.

3 SIGNAL GENERATION

Rainfall is numerically generated using a Poisson process (assuming spatial and temporal homogeneity), with a Marshall-Palmer drop size dis-

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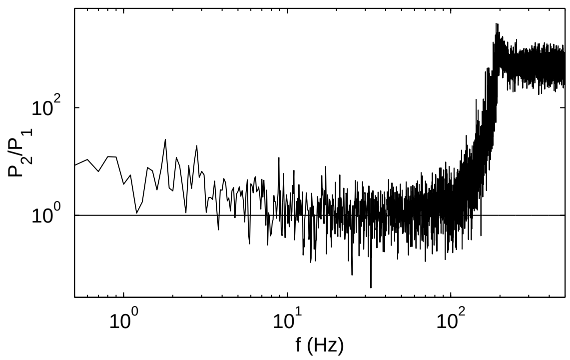

Figure 1: Ratio of power spectra of the two simulation types (type 2 divided by type 1).

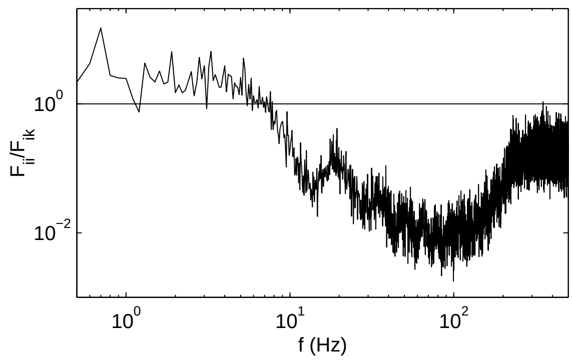

Figure 2: Ratio of the power spectra of the two two types of fluctuations (F_{ii} divided by F_{ik}).

tribution. The radar measurement volume is assumed to be perfectly cylindrical. From the numerically generated rainfall, the radar signal is calculated using equation 1. To investigate the behavior of $F_{ii}(f)$ and $F_{ik}(f)$ of equation 3, a time series of the signal is calculated for two cases:

1. The drops that exit the measurement volume at the bottom reenter immediately at the top;
2. New drops are continuously generated and inserted at the top of the measurement volume.

For the type 1 signal, the terms $F_{ii}(f)$ and $F_{ik}(f)$ in its spectrum are zero if the measurement volume height divided by the wavelength is an integer.

The measurement volume has a top area $A_M = 1$ m^2 and a height $h_M = 1$ m. The mean rainfall rate is $R = 30$ mm h^{-1}, the radar wavelength is $\lambda = 0.10$ m, the pulse repetition frequency is $PRF = 1$ kHz and there is a power law dependence of the raindrop fall velocities on the diameters with exponent $\beta = 0.67$ and coefficient $\alpha = 3.778$ m s^{-1} mm$^{-\beta}$.

4 RESULTS

Fast Fourier transforms are taken of the squared magnitudes of ten realizations of the radar signals. These are then averaged to obtain smoother spectra for comparing. The same is done for the individual terms in equation 3, so that the effect of the different fluctuations can be shown. The power spectra of the two signals are compared in figure 1. The spectrum of the type 2 signal is seen to be greater than the type 1 signal for low and high frequencies. Figure 2 shows the ratio of the two fluctuation terms, $F_{ii}(f)/F_{ik}(f)$. From this figure it can be concluded that the $F_{ii}(f)$ term is responsible for increased signal spectrum in the low frequency range, and that the $F_{ik}(f)$ term is responsible for this increase at high frequencies.

5 CONCLUSIONS

Greatly simplified radar signals have been numerically generated to study the origin of their fluctuations. These fluctuations are caused by the reshuffling of drops inside the measurement volume, and by the constant change in the number and size of the drops that are present in this volume. It has been shown here that the fluctuations of the latter type are caused by two different mechanisms, one that affects the low frequency range and one that affects the high frequency range.

6 FUTURE WORK

The work described in this paper will be generalized to more realistic cases where the raindrops are not perfect spheres, the raindrops are clustered in space, etc. This will be done analytically as well as numerically. Experimental work using TARA (Transportable Atmospheric RAdar), a high resolution research radar, will be carried out parallel to these analyses.

REFERENCES

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