P1.9 A MULTI-FREQUENCY GROUND-BASED RADAR FACILITY IN SOUTH FLORIDA FOR SMALL-SCALE PRECIPITATION OBSERVATIONS

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1. INTRODUCTION

Accurate measurements of Drop-Size Distributions (DSD) are fundamental for understanding the processes governing precipitation microphysics and improving cloud representation in numerical models. Despite their importance, the small-scale variability of DSDs and the influence of vertical air drafts on the final shapes of DSDs (Kollias et al., 2001a) remain uncertain, especially at scales unresolved by most active and passive remote sensing instruments.

In this paper, a multi-frequency ground based radar facility (W, X and UHF-band) for precipitation studies is described. A 3-mm wavelength Doppler radar operating at vertical incidence, uses the Mie oscillations in the backscatter that are often observed in the Doppler spectrum (Lhermitte, 1988) to provide a fingerprint of the raindrop distribution and accurate air velocities (± 0.1 ms^{-1}) within precipitation. An X-band radar operating at vertical incident is proposed to provide reflectivity profiles that will help scale the retrieved DSDs or provide PPI and RHI scans of the over passing precipitating system. Furthermore, a 915-MHz wind profiler will provide horizontal winds, facilitating the interpretation of the observed structures. A network of rain gauges and surface meteorology instruments compliments the radar observations. The facility can provide high temporal and spatial resolution profiles of vertical air motion and DSDs in stratiform and convective precipitation.

2. BACKGROUND

The combined use of the vertical profiles of power and Doppler spectra produced by the multi-frequency radar facility will overcome the obstacles and uncertainties related with the retrieval of vertical air motion and DSDs when a single-frequency radar algorithm is used. Before describing this multi-frequency radar facility we review the general approach of using vertical pointing radars for precipitation studies. The range of velocities with significant return power in the Doppler spectra depends primarily on the vertical air motions and the raindrop fall velocities in the radar sampling volume. Consequently, the observed velocities do not correspond to the fall velocities of the raindrops, and the inversion to a size distribution of power rather than a velocity distribution is generally not an easy task. In addition to the bias introduced by the mean vertical air motion, turbulent motions, horizontal wind and shear of the vertical wind in the sampling volume of the radar further broaden (“smear”) the Doppler spectrum and complicate the retrieval of drop-size distributions. Fig. 1a shows an example of a simulated Doppler spectrum for vertically pointing radar operating in the centimeter wavelength range (e.g. X-band).

The simulated examples of Doppler spectra shown in Fig. 1 are calculated using zero air motion, a typical raindrop size distribution, the backscattering function appropriate for the frequency of interest, white noise, and turbulence smearing. Atlas et al, (1973) showed that errors as small as 0.25 ms^{-1} in the estimate of the vertical air motion can cause large errors in the retrieved drop size distributions.

Due to their long wavelength, wind profilers (e.g. 915-MHz) are capable of detecting echoes from the "clear" atmosphere, produced by inhomogeneities of the radio index of refraction. Therefore, under the right conditions, the observed Doppler spectrum will exhibit two distinct, spectral peaks (Fig. 1b) -one due to returns from turbulent air refractive index irregularities (Bragg scattering) and the other due to the backscattering of precipitation particles. Since these inhomogeneous structures are advected with the mean wind, the turbulent peak represents the vertical air motion. Wakasugi et al. (1986) pioneered the retrieval of raindrop size distribution from wind profilers. Profilers operating at 915-MHz are less sensitive to Bragg scattering. Consequently, the precipitation echo completely overwhelms the clear air echoes in moderate to heavy rain. Therefore, for 915-MHz profilers, the technique is applicable only under light rain conditions below 1.5-2 km in altitude. Despite these obstacles in the retrieval method, it is apparent that wind profilers are capable of revealing details about the structure of tropical

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precipitating systems (Rogers et al., 1993; Gage et al., 1994; Williams et al., 1995; Cifelli et al., 2000).

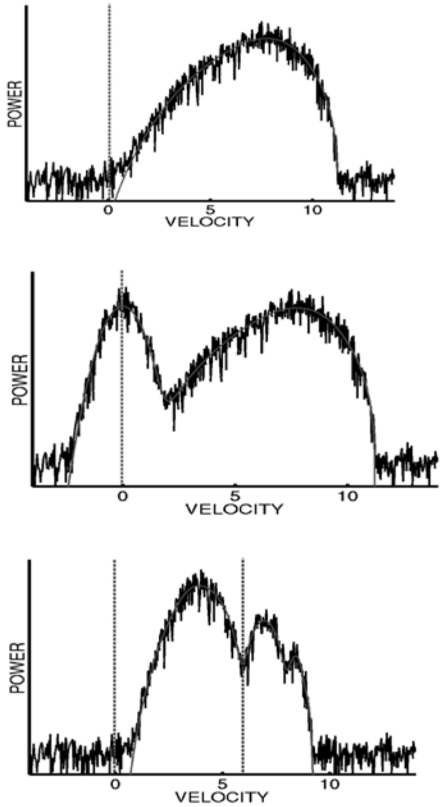

Figure 1. Simulated Doppler spectra of precipitating raindrops using a vertically pointing radar for a) centimeter wavelength radar (e.g. X – band), b) wind profiler (UHF) and c) a W-band cloud radar. The simulated Doppler spectra were modeled using the same DSD and zero mean air motion. The differences in the shape and broadening are due to differences in the backscattering function (Rayleigh approximation for a and b, Mie for c) and the effect of turbulence and wind variability across the beam.

The use of millimeter wavelength radiation for precipitating system studies overcomes a significant obstacle in the previous efforts by accurately measuring the air motion. Fig. 2 shows the 94-GHz backscattering cross section σ_b as a function of raindrop diameter at 20 °C. At 94 GHz, the backscattering cross-section versus size function for raindrops with a diameter greater than 1 mm oscillates. The raindrop diameters for which these minima and maxima occur are well predicted by the Mie theory (Mie 1908). The first minimum is well defined and occurs at a raindrop diameter of 1.7 mm. The air vertical velocity can then be deduced from the simple difference between that terminal velocity and the position of the minimum in the Doppler spectrum (Fig. 3) observed at vertical incidence with the millimeter wave Doppler radar.

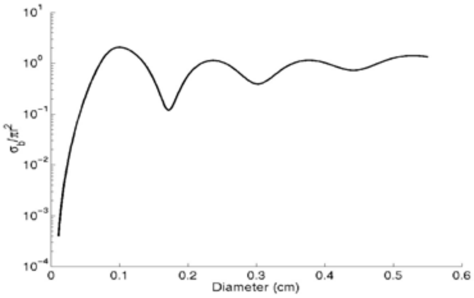

Fig. 2 Normalized backscattering cross-section as a function of the diameter for oblate spheroids at 94-GHz and vertical incident.

Lhermitte (1988) first mentioned this innovative technique in the context of stratiform rain observations. Firda et al. 1999, study the retrieval of precipitation and vertical air motion in stratiform rain using a 35/94 GHz cloud radar. Kollias et al., 1999; 2001a; study a shallow convective cloud and revealed the interaction between a low-level updraft and the drop size distribution field.

The use of millimeter radars for the retrieval of raindrop spectra offers other advantages in addition to the accurate decomposition of the observed Doppler velocity. Their high resolution spatial coverage is no match for conventional radars and wind profilers. Resolution is a critical issue when the main objective is to resolve the small-scale variability of the precipitation field. The short pulse width and the very narrow beamwidth beam give small sampling volumes. As a result, the effects of turbulence and wind shear on the Doppler spectrum are minimized.

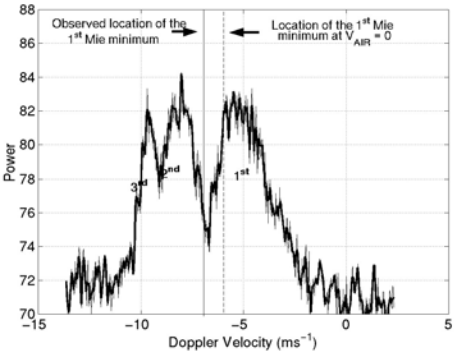

Fig. 3 Example of Doppler spectrum from convective rain observed at vertical incidence with the UM 94-GHz Doppler radar. The modulating affect of the Mie scattering is illustrated on the Doppler spectrum. The velocity difference between the observed position of the 1^{st} Mie minima and its theoretical location at still air provides the air motion

Apart from the advantages in the use of millimeter radars for precipitation studies, strong attenuation at 94 GHz E/M in heavy rain is a serious disadvantage. For rainfall rates R = 1-2 mmh^{-1}, the cloud radar (peak power 1 kW, antenna size 1 m) can detect the top of the cloud while for R > 10 mmh^{-}1 it only penetrates the lowest 2 km of the convective cloud.

3. RADAR CHARACTERISTICS

The 94-GHz cloud radar and the 915-MHz wind profiler are currently operational (Kollias et al., 2001b) at the University of Miami. Plans are in progress for the development of an X-band Doppler radar. This radar will be used in an upward-pointing configuration to provide multi-frequency coverage of both precipitating and non-precipitating clouds. The Miami WSR-88D, which is located about 28 km from Virginia Key, will be used to define the spatial and temporal evolution of cloud echoes sampled using the 94 GHz radar. Table 1 shows the radar characteristics of the proposed multi-frequency radar facility.

Radar Parameter	UHF profiler	X-Band	W-Band
Frequency (GHz)	0.915	9.4	94
Peak Power (kW)	0.3	100	1
Antenna Type	Phased array	Parabolic	Cassegrain
Antenna Size (m)	2	2	0.9
Antenna Gain (dB)	-	42	56
PRF (kHz)	20-40	0.5-2.5	5-10
Pulse Length (ns)	400-700	200-2000	200-500
Beamwidth (degree)	9	1.4	0.24
Temp. Resol. (sec)	30	1-2	2-3

Table 1. Radar characteristics.

During May-October 2001 the NOAA/ETL S-band profiler (White et al., 2000) was operated on the RSMAS campus. It was collocated with the 94-GHz and 915-MHz radars in an effort to assess the potential of using a multi-frequency radar facility for precipitation studies. Several precipitating clouds were observed ranging from strong convective clouds to weak precipitating cirrus.

All the radars collected profiles of Doppler spectra. The vertical beam of the 915-MHz profiler was used to map the overpassing precipitating clouds. The S-band (replaced in the future by an X-band) was used also in a vertically pointing mode. The S-band provided accurate reflectivity measurements throughout the depth of the precipitating column. The W-band, depending on the rain intensity, observed the precipitating clouds to some depth (usually above the melting layer for stratiform rain and through the first 2 km for convective rain). The environment in which the clouds form will be characterized using standard radiosondes, and standard surface meteorological instruments. An array of 5 tipping bucket rain gauges was set up on the RSMAS campus. Plans are being made to locate a Joss-Waldvogel disdrometer at the site to provide surface DSD estimates.

4. METHODOLOGY

The frequency coverage of the radar offers a range of combinations for data use. The 915-MHz wind profiler is sensitive to both Bragg and Rayleigh scattering. The S-band is sensitive mainly to Rayleigh scatters; and the W-band is sensitive to Rayleigh and Mie scattering. These differences are illustrated in the collected Doppler spectra (Fig. 1). This unique synergy of radar offers many opportunities for the study of precipitating clouds. Retrievals of air motion to an accuracy of 0.1 ms^{-1} (Kollias et al., 2001) and DSD, will be performed using the profiles of Doppler spectra collected by the 94-GHz radar. The vertical profiles of reflectivity from the X-band radar will be used to scale the DSD retrieved from the 94-GHz Doppler spectra and to provide the vertical structure of the precipitating system. The 915-MHz wind profiler will provide a description of horizontal wind profiles --important for the interpretation of the observed vertical structure of precipitation (horizontal sorting and shear effects). In addition to the main objective – small-scale precipitation studies- turbulence retrievals at different wavelengths and for different sampling volumes, Doppler spectra broadening effects, vertical air motion techniques (e.g. detection of Bragg peak versus Mie minima shift), and attenuation will be topics of research in an effort to assess the validity of retrievals when a single vertically pointing radar is the platform available.

5. SUMMARY

A multi-frequency radar facility for small-scale precipitation studies over South Florida has been planned. The proposed radar frequencies cover the extent of radar frequencies used for meteorological studies and the combination of the data has the potential to provide accurate retrievals of vertical air motion and DSDs in small-scales. Such high-resolution data will be invaluable in improving our understanding of precipitation studies with emphasis on the interaction of vertical drafts with the DSD field and melting layer processes.

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