Radar Doppler spectra recording at the ARM sites. An insight to cloud microphysics and turbulence

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1 Introduction

The U.S. Department of Energy's Atmospheric Radiation Measurement (ARM) Program operates several stationary and mobile aerosol and radiation measurement sites in climatologically significant regimes. At the ARM sites, millimeter wavelength profiling Doppler radars (operating at 35- and 94-GHz) provide continuous high-resolution (2 sec, 45 m) 256-point FFT Doppler spectra observations of clouds and precipitation. The collection of the Doppler spectra offers new opportunities for the retrieval of microphysics and turbulence in clouds and precipitation. The retrieval techniques are based on the comparison of the detail Doppler spectra, the use of non-Rayleigh features, the presence of multi-modalities and the use of the high-resolution Doppler moments. We will present examples of cloud observations that illustrate interesting microphysical and dynamical features and investigate the coupling between microphysics and turbulence at small-scales.

2 Background

Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) program success is partially attributed to continuous operation of vertically pointing (narrow field of view) passive and active instruments and, in particular, the vertically pointing 35-GHz millimeter-wavelength cloud radars (MMCR; Moran et al., 1998). Recently, the MMCRs Digital Signal Processing (DSP) units were upgraded (currently, all ARM sites have upgraded MMCR DSP's). The capabilities of the new DSP, the significant improvement of the temporal resolution and the recording of Doppler spectra provided the potential for changes in the operational modes and parameters of the MMCR (Kollias et al., 2006). *The hypothesis that optimum signal sampling from the ARM profiling radar will "preserve" morphological characteristics of the Doppler spectra that are pinpointing to hydrometeor phase and size distribution shape was used as a guide for the design of the new sampling strategy of the ARM radars*. Such changes included: i) wider Nyquist velocity boundaries, ii) short (less than 1 sec) signal dwell time, iii) elimination of pulse compression at the boundary layer, iv) addition of circular polarization mode and v) extension of the dynamic range in precipitation. The new processors at all of the sites offer the 1.5-s dwell and sampling period, 256-point fast Fourier transforms, and archival of the Doppler spectra for all times at each range gate.

3 W-band ARM Cloud Radars (WACR)

Two W-band ARM Cloud Radars (WACR) have been developed for the SGP and the ARM Mobile Facility (AMF). The AMF WACR is deployed with the AMF in Niamey, Niger. The SGP WACR was successfully deployed in the same shelter as the MMCR in 2005. It is currently collecting co-polarization and cross-polarization spectral moments (reflectivity, Doppler velocity, and spectral width) along with spectra data.

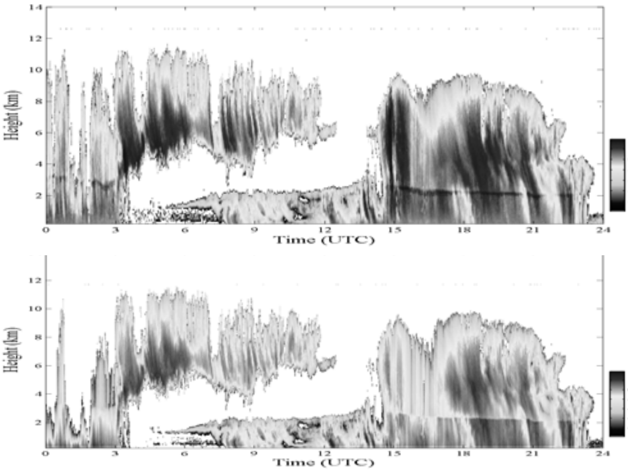

Figure 1:Time-height mapping of radar reflectivity at the SGP from the MMCR (top) and WACR (bottom).

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4 Doppler spectra recording

Recording the Doppler spectra from profiling radars is not new. However, the systematic, 24/7 recording of Doppler spectra from cloud radars at various ARM sites around the world it is challenging for the infrastructure (600-800 MBhr^{-1} data rates in areas with no or slow internet capacity) and offers an opportunity for a detail post-processing of the Doppler spectra.

The main objective of the Doppler spectra post-processing is the extraction of information relevant to the microphysical and dynamical content of the observed cloud and precipitation conditions at the ARM sites. The post-processing of the Doppler spectra extends beyond the estimation of the three basic Doppler moments (reflectivity, mean Doppler velocity and Doppler spectrum width).

5 Insect rejection filter

The accurate detection and removal of insect clutter from millimeter wavelength cloud radar (MMCR) returns is of high importance to boundary layer cloud research (e.g., Geerts et al., 2005; Clothiaux et al., 2000). Screening of MMCR insect clutter has historically involved a laborious manual process of cross-referencing radar moments against measurements from other collocated instruments, such as lidar. Our study looks beyond traditional radar moments to ask whether analysis of recorded Doppler spectra can by itself serve as the basis for reliable, automatic screening. We focus on the MMCR operated by the Department of Energy's (DOE) Atmospheric Radiation Measurement (ARM) program at its Southern Great Plains (SGP) facility in Oklahoma.

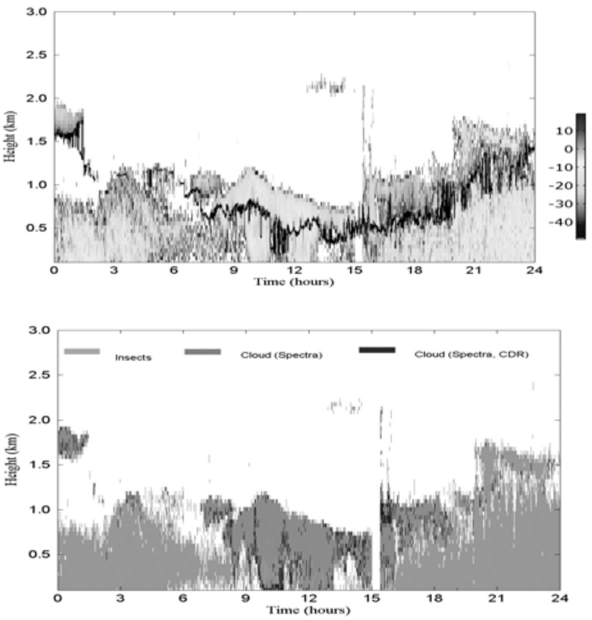

Figure 2: MMCR boundary layer mode reflectivity on May 5, 2005 overlaid by ceilometer heights in black (top). There is substantial presence of cloud and insects, but separation based on reflectivity is virtually impossible. The bottom shows the output of our insect classifier that is based only on the Doppler spectra post-processing and no other input.

New methods for post-processing of recorded Doppler spectra result in more accurate identification of radar clutter (e.g., insects) using a feature extractor that identifies the step power cutoffs present in Doppler spectra contaminated by insects and bugs (Fig. 2). Our classification method is designed to sense the sharp gradients typically found in insect clutter (Fig. 3), but which may be less distinctive than shown in figure 3, and may also be mixed with hydrometeor features. To handle the potentially difficult cases we seek an approach that utilizes statistical best estimates. In the boundary layer, the SGP MMCR records 256-FFT point Doppler spectra. Neural networks are well suited to these requirements.

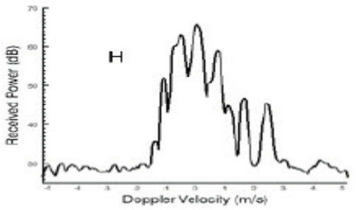

Figure 3 Example of insect/bug contaminated Doppler spectrum

6 Phase identification

Furthermore, morphological feature of the recorded Doppler spectra as used to extract information on hydrometeor phase using a neural network technique. Wavelet analysis (Daubechies wavelet) was applied to the Doppler spectra in order to extract information relevant to the Doppler spectra morphology.

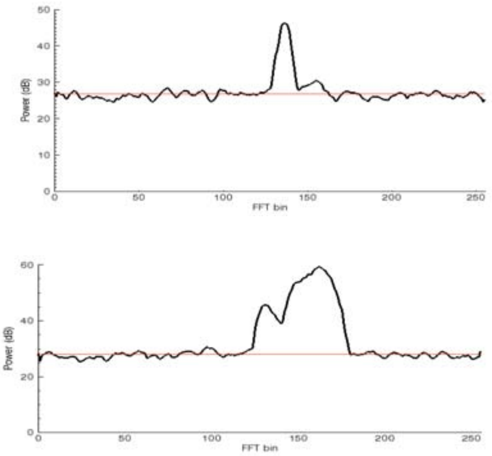

Figure 4 Examples of Doppler spectra collected at the ARM North Slope of Alaska site. Top: Doppler spectrum from ice crystals (bi-modal). Bottom: A mixed-phase Doppler spectrum that has smoother gradient and an evident bimodality caused by the different fall velocities of liquid and ice crystals.

In addition to the details of the Doppler spectrum, the reflectivity, mean Doppler velocity and spectrum width, higher order Doppler moments (skewness and kurtosis) and Doppler spectra slope information are used as input to a neural network. The neural network used a mixed-phase clouds training data set from the NSA during the MPACE experiment and the hydrometeor classification produced by the University of Wisconsin High Spectral Resolution Lidar (HSRL). Using the Doppler spectra shape we discriminate between liquid, ice and mixed-phase clouds at the NSA site (Fig.5).

In addition to the new insect mask and the phase classification (applied at all ARM sites), the new ARSCL files will include a plethora of new variables. Results of recent studies on the error characteristics of derived Doppler moments (Kollias et al., 2005) are included so that uncertainty estimates are now included with the moments. Other products of the Doppler spectra post-processing include the number of local maxima in each Doppler spectrum, the Doppler moments of the primary peak, uncertainty estimates for the Doppler moments of the primary peak, Doppler moment shape parameters (e.g., skewness and kurtosis), and clear-air clutter flags.

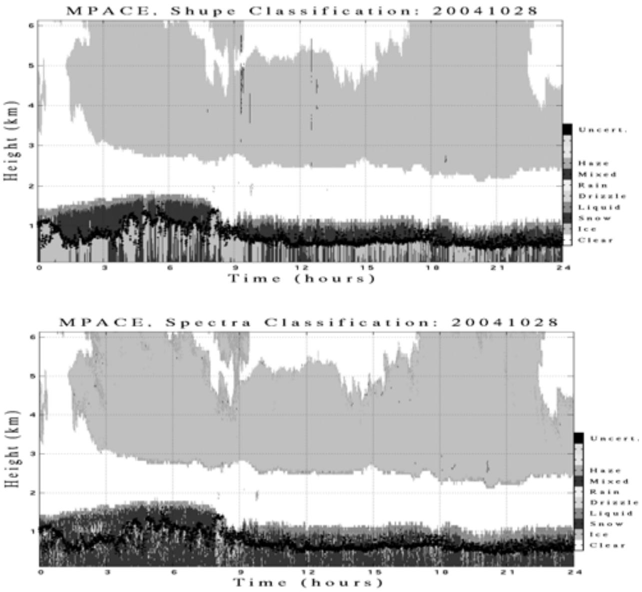

Figure 5 Top: Example of hydrometeor phase classification produced by Matthew Shupe (NOAA/Physical Science Division) using the High Spectral Resolution Lidar, the ARM cloud radar moments, the LWP and the ceilometer. Bottom: The corresponding phase hydrometeor classification created using only the recorded Doppler spectra from the ARM profiling cloud radar and the new Doppler spectra-based neural network algorithm.

7 Summary

Recent and ongoing upgrades of the MMCR's signal processors, continuous recording of their Doppler spectra and addition of 94-GHz cloud radars at the SGP and ARM Mobile Facility (AMF) have increased the value of cloud-radar observables and have led to the development of new, higher resolution ARSCL-like data products and new microphysical retrieval techniques. Synergy amongst the zenith pointing instruments at the ARM sites is the bread and butter of the program and has led to significant improvement in our ability to retrieve cloud, aerosol and thermodynamic variables.

The recording of Doppler spectra for all of the Atmospheric Radiation Measurement cloud radars and new Doppler spectra post-processing methods applied to them lead to new information related to cloud microphysics and turbulence and substantially improved overall cloud-radar data quality. The availability of Doppler spectra also allows for implementation of a neural network-based technique to identify the presence of clutter (e.g., insects) in the boundary layer mode returns of all cloud radars and identify hydrometeor phase at the ARM sites.

8 References

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