10.6 A LOW-POWERED S-BAND PRECIPITATION PROFILER FOR HYDROLOGICAL APPLICATIONS

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1. INTRODUCTION

It is becoming increasingly clear that improvements are needed in the methodology for measuring precipitation in order to make progress in properly representing the hydrological cycle in numerical models. While this is a global problem, it is necessary to have reliable local measurements of precipitation to validate satellite retrievals and model predictions. This paper introduces a novel low-powered S-band precipitation profiler that has been developed and utilized by the NOAA Aeronomy Laboratory (AL) for calibration and validation for the Tropical Rainfall Measuring Mission (TRMM). The precipitation profiler can be calibrated by a collocated disdrometer and used as a calibration tool for scanning radars. More importantly, it has been demonstrated that drop-size distributions can be retrieved from the profiler making it possible to determine precipitation parameters directly without using empirical Z-R relations. This suggests that the profiler has an important role to play in integrated hydrological observing systems of the future.

The NOAA Aeronomy Laboratory has used profilers at 915 MHz and S-band for precipitation research in several tropical field campaigns during the past decade (Rogers et al., 1993; Gage et al., 1994, 1996, 1999, 2002; Ecklund et al., 1999). S-band is a convenient frequency to use for this purpose since it is not attenuated, at least looking vertically, even in heavy precipitation. It also coincides with the frequency of the WSR-88D.

The low-powered S-band system uses a dish antenna and only points vertically. It is relatively insensitive to Bragg scatter. The low-powered S-band profiler has been extensively utilized in TRMM ground validation field campaigns over the past few years. In each campaign the profiler was collocated with a 915 MHz profiler. The two profilers operating side by side obtained independent measures of reflectivity that have been used to cross-validate the two profilers.

In this paper we describe the low-powered S-band profiler and compare its observations with a 915 MHz profiler. In addition sample observations of precipitating clouds seen during the TRMM field campaigns using the S-band profiler will be shown. The use of the profiler as a transfer standard for calibration of scanning radars was presented in Gage et al. (2000).

2. DESCRIPTION OF THE LOW-POWERED PROFILER

The precipitation profiler is a low-powered version of the 3 GHz profiler described in Ecklund et al. (1999). It utilizes much of the same hardware and software used in AL 915 MHz profilers described in Carter et al. (1995) with the exception of the transmitter and antenna. The operating frequency for this profiler was chosen based on the desire to have the best sensitivity to precipitation and still be able to use a reliable, safe and relatively inexpensive solid state transmitter. As with the higher power 3 GHz profiler, the transmitter is located in the transmit-receive (T/R) module mounted on the edge of the shrouded dish antenna in a protective housing. This arrangement minimizes the length and loss of the feed cable between the T/R module and the antenna feed and mounts the T/R module at a convenient working height.

The antenna is fixed to point in the vertical direction. The perimeter shroud reduces the unwanted effects of feed spill-over and ground clutter. The T/R module located at the antenna communicates with transmit and receive units inside a nearby shelter via 60 MHz signals carried

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on two coaxial cables. The received phase-coherent signal is converted to baseband and the resulting quadrature channels are filtered, amplified and range sampled with 12-bit digitizers. The resulting time series at each sampled range gate are further time averaged and then processed to produce 256 point Doppler power spectra at each sampled height as described in Carter et al. (1995). During typical 30-second dwell times at each sampled height about 120 spectra are produced at 3 GHz and these are averaged together and recorded on optical or magnetic media.

Much of our work is in the tropics where the tropopause and deep convective activity may extend to altitudes of over 18 km. In this environment we set the profiler interpulse period so that heights of up to about 22 km are not range aliased. We typically alternate a 30-second sequence of observations with 100-meter resolution with a 30-second sequence of observations with 60-meter resolution. The dynamic range of each profiler is limited to about 70 dB by the 12-bit digitizers.

For the TRMM Field Campaigns the NOAA Aeronomy Laboratory deployed a pair of vertically-looking profilers in order to reveal the vertical structure of the precipitating cloud systems as they advect over the profilers and to develop methodology to retrieve drop-size distributions from the profiler observations. The two profilers operated at 2835 MHz and 915 MHz respectively.

Tropical Rainfall Measuring Mission (TRMM) Precipitation Profiler Characteristics

Parameter	S-Band Profiler	UHF Profiler
Frequency	2835 MHz	915 MHz
Wavelength	10.6 cm	32.8 cm
Peak Power	5 Watts	500 Watts
Antenna	1.2 m Shrouded Dish	3 m Shrouded Dish
Beamwidth (two way)	5 degrees	5 degrees
Height Resolution	60 m & 100 m	100 m & 255 m
Pulse Length	60 m & 100 m	100 m & 255m
Number of Range Gates	100	100
Max. Altitude	6.1 km & 10.7 km	10.7 km & 18.5 km
Nyquist Velocity	20 ms^{-1}	20 ms^{-1}
Number of Spectral Points	256	256
Dwell Time	~30 seconds	~30 seconds
Data Recorded	Full Spectra	Full Spectra

Typical parameters for the 2835 MHz precipitation profiler and the 915 MHz profiler to which it is compared in this paper are given in Table 1. The two profilers are shown in Figure 1 as they were deployed in Ji-Parana, Brazil during TRMM LBA in January and February 1999.

Figure 1. Low-powered S-band profiler antenna in front of the larger 915 MHz profiler antenna located at Ji-Parana airport during TRMM LBA.

3. COMPARISON OF THE LOW–POWERED PRECIPITATION PROFILER WITH THE 915 MHz PROFILER

In this section we compare 2835 MHz profiler observations of precipitating clouds made in the tropical Pacific during the TRMM Ground Validation field campaigns with 915 MHz profiler observations. The two profilers were collocated, vertically directed, with closely matched observing volumes.

During precipitation the S-band and 915 MHz profiler reflectivities are very similar with few exceptions. They can be expected to agree most closely in stratiform precipitation. An example of a one hour time series of reflectivities seen on both instruments during TRMM LBA is reproduced in Figure 2. For most of the hour the S-band reflectivities track the 915 MHz reflectivities very closely. However, it can be seen that during the periods of light precipitation when reflectivities are less than about 15 dBz the 915 MHz reflectivities are larger than the S-band reflectivities. This can be explained by the 915 MHz profiler's greater sensitivity to Bragg scatter (Gage et al., 1999).

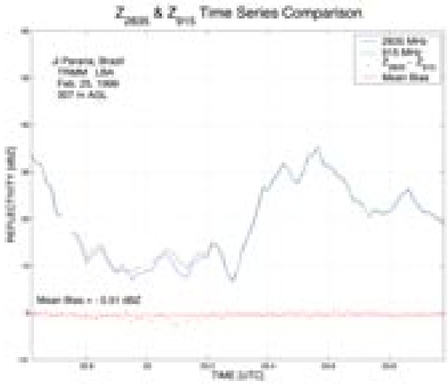

Figure 2. Comparison of S-band and 915 MHz reflectivities in a time series of profiler observations at Ji-Parana, Brazil during TRMM LBA.

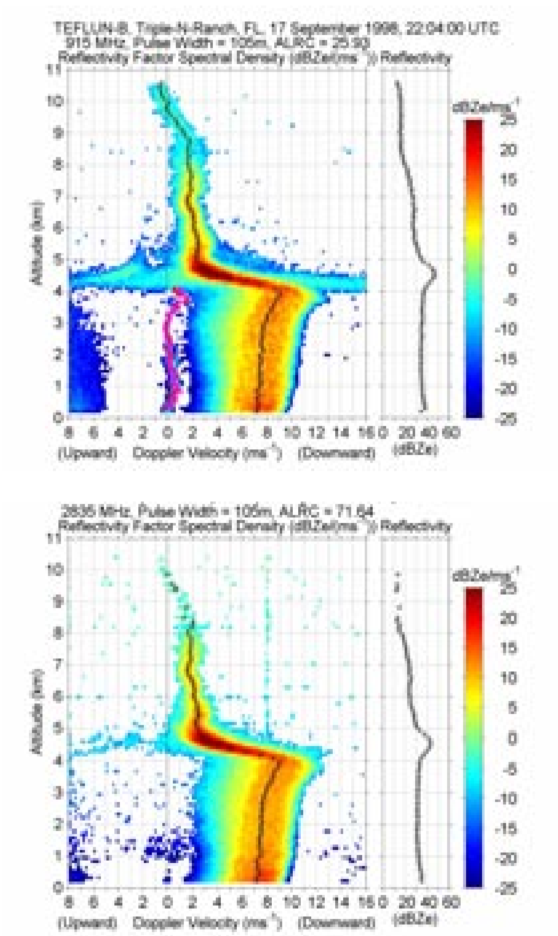

Figure 3. Spectral density plots for 915 MHz profiler (top) and S-band profiler (bottom) for observations taken simultaneously during stratiform rain on 17 September 1998 during TEFLUN B. Note the Bragg returns at the lowest heights in the top panel that are largely missing in the bottom panel.

Figure 3 shows a comparison of Doppler spectral plots at 2835 MHz and 915 MHz. Both spectra were recorded with 105-meter pulse length. These spectra were recorded in central Florida during TEFLUN B. Note that for the most part the spectra are very similar but that at the lowest heights there is a Bragg component of air motion visible on the 915 MHz spectral plot that is missing on the 2835 MHz spectral plot. A scatter plot of reflectivities is reproduced in Figure 4 shows that the 915 MHz profiler reflectivities are biased high at low reflectivities but otherwise the reflectivites are in very good agreement.

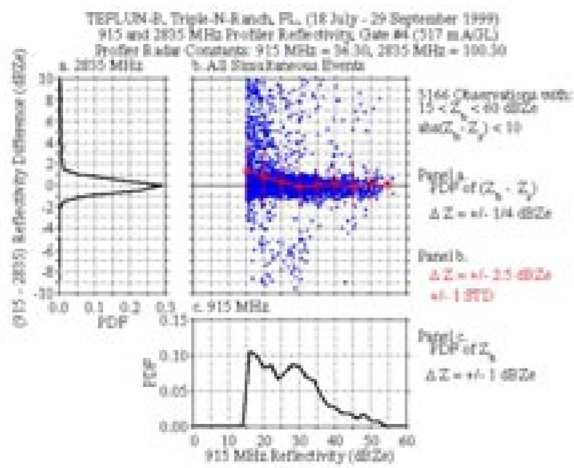

Figure 4. Scatter plot showing reflectivity differences (915 MHz – 2835 MHz) between the two collocated profilers located in central Florida during TEFLUN B as a function of 915 MHz profiler reflectivity.

4. A SAMPLE OF PRECIPITATION PROFILER OBSERVATIONS MADE DURING TRMM GROUND VALIDATION FIELD CAMPAIGNS

Profiler observations yield the Doppler spectra of moving targets within the radar observing volume. The Doppler spectra are processed to yield vertically resolved time histories of equivalent reflectivity, Doppler velocity and spectral width over the profilers. During TRMM field campaigns each profiler was operated in a dual mode to provide more information on vertical air motions. The 915 MHz profiler operated with nominal 100-meter pulse length alternating with a nominal 250-meter vertical pulse length. The 2835 MHz profiler operated with a nominal 60-meter pulse length and a nominal 100-meter pulse length. The profilers were synchronized so that the two profilers observed simultaneously with the 100-meter pulse length.

For the TRMM Field Campaigns the two profilers were collocated with disdrometers and rain gauges to provide calibration for scanning radars, which in turn are used to calibrate the TRMM PR measurements. For these field campaigns a Distromet RD-69 disdrometer also known as a Joss-Waldvogel disdrometer (JWD) was utilized to provide a calibration for the profiler reflectivity. For the TEFLUN campaign we integrated the data stream from the JWD into the AL profiler data stream in order to guarantee that the timing of the profiler and disdrometer measurements were coincident. In TEFLUN B, TRMM LBA and KWAJEX a two-dimensional video disdrometer (2DVD) was also collocated with the profiler providing additional opportunities for intercomparisons as described in Gage et al. (2000).

Several examples of 2835 MHz profiler imagery collected from the field campaigns are shown next. These are comprised of time-height cross sections of equivalent reflectivity, Doppler velocity and spectral width. These parameters are the three moments of the Doppler spectra measured by the profilers every thirty seconds.

A sample rain event observed by the 915 MHz profiler on 17 September 1998 is shown in Figure 5. The reflectivity panel shows deep convection above the melting level commencing after 18:00 UT in several episodes until about 21:00 UT. Up until 21:00 UT there appears to be a mixture of deep convection and some stratiform rain evidenced, for example by the bright band around 20:00 UT. After 21:00 UT mature stratiform conditions prevailed. Note the dramatic increase in fall velocities of hydrometeors below the melting level in the middle panel and the small spectral widths above the melting level in mature stratiform rain after 21:00 UT.

In Figure 6 and Figure 7 we reproduce two other examples of time-height cross sections of equivalent reflectivity, Doppler velocity and spectral width seen by the profilers during the field campaigns. Figure 6 contains a 6-hour time height cross section obtained in Ji-Parana, Brazil on 15 February 1999 during TRMM LBA.This example shows a nighttime storm comprised of stratiform precipitation with imbedded convection, which can be seen most clearly in the bottom panel of spectral width.

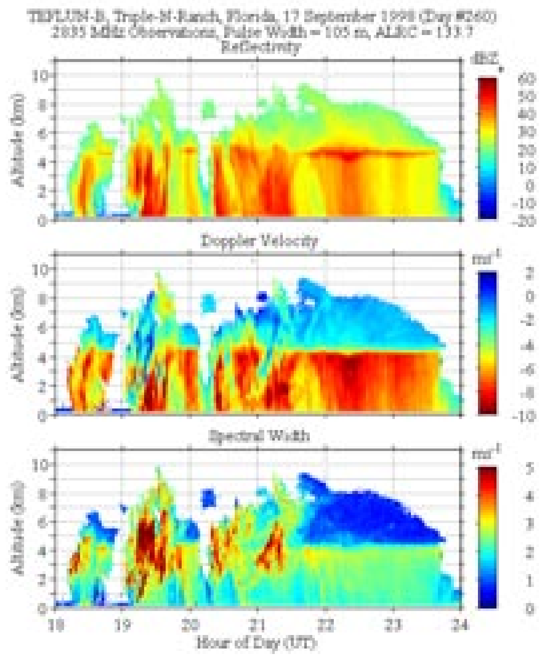

Figure 5. Equivalent reflectivity, Doppler velocity and spectral width associated with a mesoscale convective system passing over the profiler at the Triple N Ranch during TEFLUN B.

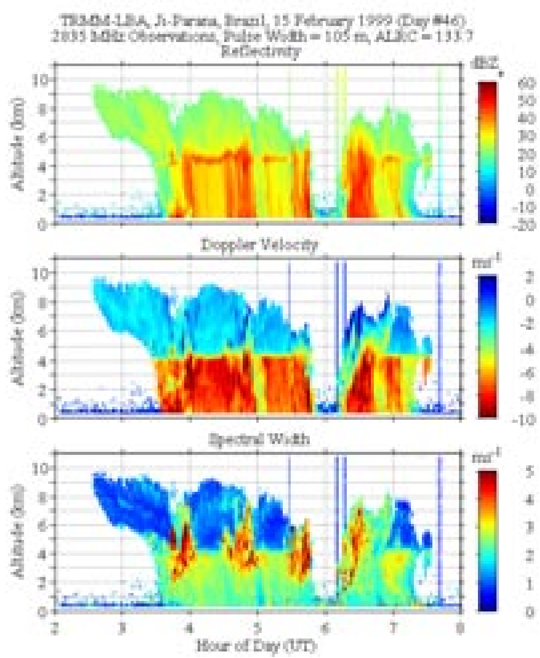

Figure 6. Equivalent reflectivity, Doppler velocity and spectral width associated with a nocturnal mesoscale convective system passing over the profiler at Ji-Parana, Brazil during TRMM LBA.

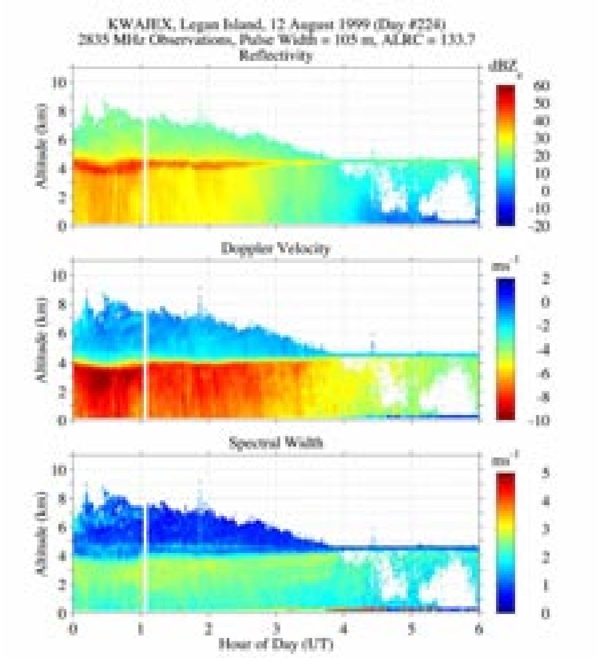

Figure 7. A 6-hour cross section of equivalent reflectivity, Doppler velocity and spectral width recorded at Legan during KWAJEX.

Figure 7 contains a 6-hour time-height cross section of mature stratiform rain observed at Legan, Republic of the Marshall Islands on 12 August 1999 during KWAJEX. Note the dip in the equivalent reflectivity, Doppler velocity and spectral width seen by the profilers during the field campaigns. A well developed bright band signature is visible in the reflectivity in the top panel and in the Doppler velocity in the middle panel. Note the dip in the height of the bright band that occurs in the first hour of observation and the simultaneous broadening of the bright band accompanied by a relatively intense rainburst.

A more complete discussion of these and other rain events observed with profilers during the TRMM ground validation field campaigns can be found in Gage et al. (2002).

5. CONCLUDING REMARKS

This paper has described a low-powered precipitation profiler that was specifically developed to measure precipitation during TRMM ground validation field campaigns. Reflectivities obtained with collocated profilers are in excellent agreement except for low reflectivities where Bragg scattering affects the 915 MHz profiler. The low-powered S-band system capabilities for observation of diverse precipitating cloud systems has been illustrated here using TRMM ground validation field campaign data. Such measurements of the detailed vertical structure of precipitating cloud systems contribute valuable information to space-based precipitation retrievals. In addition the retrieval of drop-size distributions is needed for determining precipitation parameters. Recent developments in the retrieval of drop-size distributions from profiler observations can be found in Cifelli et al. (1998), Schafer et al. (2002), Williams et al. (2000) and Williams (2002).

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