4.3 OBSERVATIONS OF DIVERSE PRECIPITATING CLOUD SYSTEMS UTILIZING GROUND-BASED DOPPLER RADAR PROFILERS FOR THE REMOTE SENSING OF PRECIPITATING CLOUDS

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1. INTRODUCTION

Precipitation is one of the most difficult parameters to simulate in numerical general circulation models (GCMs). Indeed, the inability of GCMs to adequately simulate the hydrological cycle is a major source of uncertainty in climate prediction (see, for example, Webster, 1994). One of the primary reasons is the inability to specify realistic diabatic heating rates in the models. While a global problem, the effect is greatest in the tropics where much of the global rainfall occurs in mesoscale convective systems that are not resolved by GCMs. Most tropical rainfall occurs in two major categories. Convective rainfall is characterized by relatively brief, intense, and localized rain while stratiform rain tends to be lighter, of longer duration and more uniformly distributed over spatial domains of the order of tens to hundreds of kilometers. Because the vertical distribution of heating rates is quite different for convective and stratiform rain (Hartmann et al., 1984; Houze, 1989) it is imperative to be able to distinguish accurately between the two. Furthermore, there are other possible types of rain regimes that can be identified when high vertical resolution observations of precipitating cloud systems are available.

During the past decade Doppler radar profilers that operate near 1 GHz and 3 GHz have been developed at the NOAA Aeronomy Laboratory for use in dynamics and precipitation research. The profilers have been used extensively in numerous field campaigns during the past decade. The field campaigns include the Coupled Ocean Atmosphere Response Experiment (COARE) that took place in the western Pacific warm pool region during 1992-93, the Maritime Continent Thunderstorm Experiment (MCTEX) that took place near Darwin, Australia in November - December 1995, the Combined Sensor Program (CSP) that took place in the vicinity of Manus Island, Papua New Guinea in March 1996 and the Tropical Rainfall Measuring Mission (TRMM) Ground Validation Field Campaigns: TEFLUN (Texas and Florida; 1998), TRMM LBA (Brazil, January -February 1999) and KWAJEX (August - September 1999). Additional campaigns include the NAURU99 campaign that took place in July 1999 and the EPIC Campaign in 2001.

Profiler observations yield time height cross-sections of equivalent reflectivity, Doppler velocity and spectral width that illustrate the evolution of precipitating clouds systems. In the presence of precipitating clouds backscattering from hydrometeors is dominant and the Doppler velocity provides a measure of the fall velocity of hydrometeors. The vertical structure of these parameters has been used to classify the precipitating cloud systems into several different categories. These observations document the prevalence of deep anvil cloud systems over the Pacific warm pool region. They also show the relative abundance of rainfall from stratiform and convective components of precipitating cloud systems and the continuous observations reveal the diurnal evolution of the precipitating clouds over the profiler.

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2. EARLY OBSERVATIONS OF PRECIPITATING CLOUDS UTILIZING PROFILER TECHNOLOGY

In this section we summarize early profiler observations of precipitating clouds made in the tropical Pacific prior to the TRMM Ground Validation field campaigns. The first 1 GHZ profiler to be deployed in the tropical Pacific was installed at Christmas Island in early 1990.

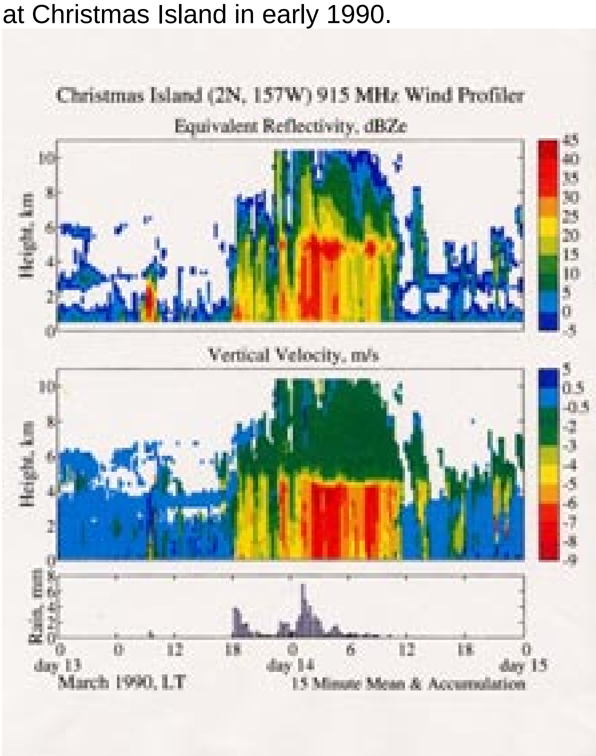


Figure 1. Time-height cross-section of equivalent reflectivity and Doppler velocity seen on the vertical beam of the Christmas Island profiler on March 13-14, 1990. Rain rates from a collocated rain gauge are shown at the bottom of the figure.

A time-height cross-section of equivalent reflectivity and vertical velocity of falling hydrometeors observed in the vertical beam of the 915 MHz profiler at Christmas Island on March 13-14, 1990 is shown in Fig. 1. Several different types of vertical structure are evident in this figure during periods of rainfall recorded at the surface as the convective systems pass over the profiler. During the first rain event, just after 09:00 on March 13th, the echo is confined well below the freezing/melting level providing a clear example of warm rain from a shallow convective storm. In contrast light rain after 03:00 on the 14th of March, accompanied by a bright band in the equivalent reflectivity and a melting layer signature of rapidly accelerating hydrometeor fall speeds below 5 km, provides a clear example of stratiform rain. Finally, heavier rain episodes occurring between 18:00 on the 13th and 03:00 on the 14th illustrate deep convection (without a melting layer signature) and a mixture of deep convection with stratiform rain (during periods when a melting layer signature is present).

Since early 1990 the NOAA Aeronomy Laboratory Tropical Dynamics and Climate Group has participated in numerous field campaigns designed to elucidate the structure of precipitating cloud systems in the tropics. These efforts began in earnest in 1990 with the Hawaiian Rainbands Program (HARP) and the Tropical Cyclone Motion Experiment (TCM-90). During HARP a 1 GHZ profiler was located near Hilo and during TCM-90 a 1 GHZ profiler was located at the Saipan Airport. Samples of data collected during these campaigns are presented in Rogers et al (1993) and Gage et al (1996).

During 1992-1993 the NOAA Aeronomy Laboratory participated in the Tropical Ocean Global Atmosphere Coupled Ocean-Atmosphere Response Experiment (TOGA COARE). As part of COARE, profilers were combined with conventional balloon sounding systems and surface instruments to create an Integrated Sounding System (ISS) (Parsons et al. 1993). The ISS was a joint NCAR-ATD and NOAA Aeronomy Laboratory project. ISS were placed on several island sites and on the Chinese research vessels used in the intensive Observing Program (IOP) for COARE. The Aeronomy Laboratory maintains an archive of all the profiler data collected during COARE.

Figure 2 contains a time-height cross-section of the reflectivities and Doppler velocities observed by the R/V Kexue #1 in late December 1992. These observations are typical of deep mesoscale convective systems that are often found in the warm pool region. Indeed, Fig 2 illustrates a

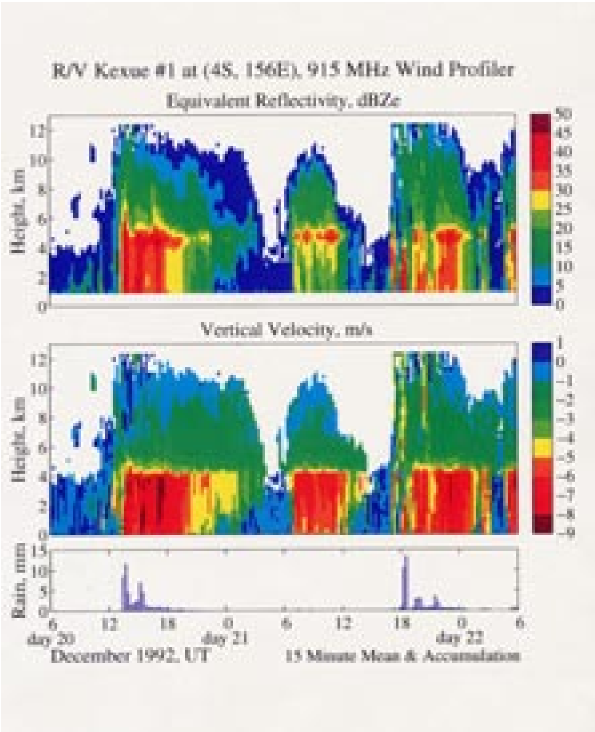


Figure 2. Time-height cross-section of equivalent reflectivity and Doppler velocity observed on the R/V Kexue #1 in late December 1992 during the COARE IOP. Rain accumulation is shown at the bottom of the figure.

difficulty in trying to infer rainfall from satellite measurements. The structure of the deep clouds as seen from above does not necessarily give a good indication of the rainfall at the surface. Seen in Fig. 2 are three distinct episodes of stratiform precipitation. The first and the third episode are accompanied by considerable rain but the second episode is not. Indeed as shown by Gage et al. (1994) and Williams et al (1995) an analysis of profiler data collected during COARE shows that a common occurrence over the western Pacific warm pool is deep clouds without surface precipitation. These deep clouds without rain were found about 25% of the time over Manus Island during 1992-93. The occurrence of elevated regions of precipitating clouds (without rain) is thought to be fairly common in regions of active convection over the western Pacific warm pool. These elevated structures may play an important role in the heat balance of the troposphere over convectively active regions. Similar structures were seen during Maritime Continent Thunderstorm Experiment (MCTEX) in November and December 1995 (Ecklund et al., 1999; Gage et al., 1999) and during the Combined Sensor Program (CSP) in early 1996 (Post et al., 1997).

Following COARE the Aeronomy Laboratory also operated a Trans-Pacific network of tropical wind profilers that observed precipitating cloud systems at Biak, Indonesia; Manus Island, Papua New Guinea, Republic of Nauru, Tarawa, Kiribati; Christmas Island, Kiribati; and San Cristobal in the Galapagos Islands of Ecuador. The observations across the Pacific have enabled us to examine the vertical structure of diverse precipitating cloud systems.

3. PROFILER OBSERVATIONS DURING TRMM GROUND VALIDATION FIELD CAMPAIGNS

The profilers used by the Aeronomy Laboratory in support of TRMM Ground Validation Field Campaigns are essentially Doppler radars with fixed antenna beams. For the TRMM Field Campaigns the NOAA Aeronomy Laboratory developed a pair of vertically looking profilers in order to reveal the vertical structure of the precipitating cloud systems as they advect over the profilers. The 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.

For TRMM two collocated low-powered profilers were operated at 915 MHz and 2835 MHz. During TEFLUN A the vertical beam of each profiler had a nominal 100-meter pulse length to provide high-resolution observations with a dwell time of 30 seconds. In later 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

Figure 3. The Aeronomy Laboratory profiler pair located at Triple N Ranch in central Florida.

profilers observed simultaneously with the 100-meter pulse length.

The 915 MHz profiler used for TRMM is similar to the 915 MHz profiler described in Carter et al., (1995) and the S-band profiler is a low-powered version of the 2835 MHz profiler described in Ecklund et al. (1999). During TEFLUN A and B the Aeronomy Laboratory profilers were collocated 25-40 km from at least one scanning radar. The profilers are shown in Fig. 3 as they were deployed in TEFLUN B. In Texas the profilers were located in southeast Houston about 30 km WNW of the WSR-88D radar in Dickinson. In TEFLUN B the profilers were located east of Holipaw on the south side of US 192 at the Triple N Ranch. This site is about 35 km west of the Melbourne WSR-88D and a similar distance northwest of the NCAR S-pol radar.

For TRMM Ground Validation Field Campaigns the two profilers have been 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., (2002).

Several examples of 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.

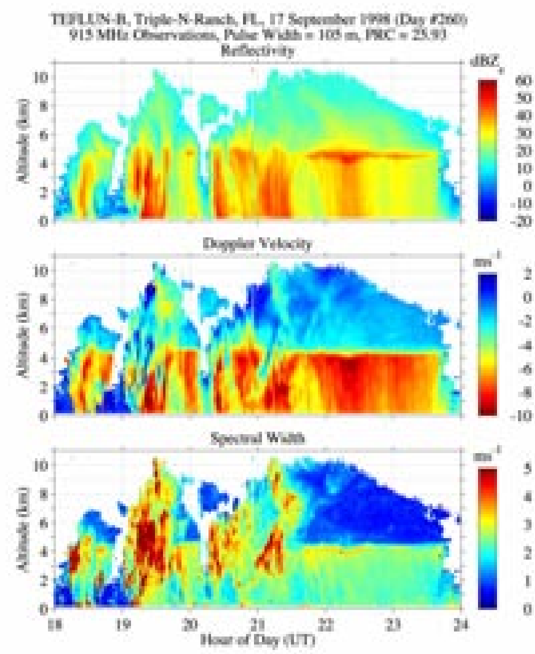


Figure 4. Equivalent reflectivity, Doppler velocity and spectral width associated with a mesoscale convective system passing over the profiler at the Triple N Ranch during TEFLUN B.

A sample rain event observed by the 915 MHz profiler on 17 September 1998 is shown in Fig. 4. 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 Fig. 5 and Fig 6 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 5 contains a 6-hour time height cross-section obtained in Ji-Parana, Brazil on 15 February 1999 during TRMM-LBA.

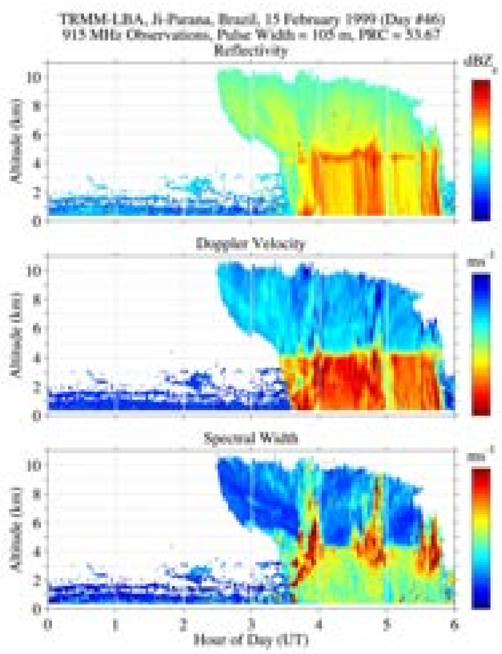
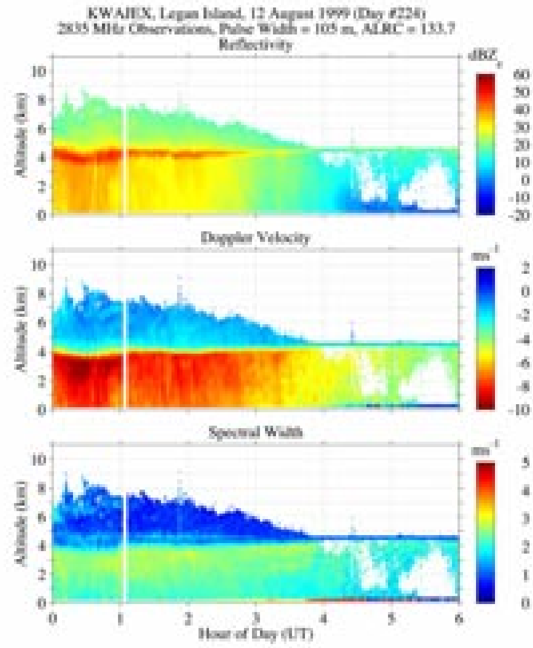


Figure 5. Equivalent reflectivity, Doppler velocity and spectral width associated with a nocturnal mesoscale convective system passing over the profiler at Ji Parana, Brazil during TRMM LBA.

This example shows nighttime storm comprised of stratiform precipitation with imbedded convection, which can be seen most clearly in the bottom panel of spectral width.

Figure 6 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



bright band height during a particularly heavy rain burst in the first hour of the record. Note also the gradual diminution of reflectivity and fall velocities after the first hour. Such detailed records are very useful in diagnosing precipitating cloud systems in the tropics and elsewhere. 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).

4. CONCLUDING REMARKS

In this paper we have illustrated the structure of diverse precipitating cloud systems observed at several tropical locations over nearly a decade using ground-based profilers. 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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