P1R.1 # HIGH RESOLUTION OBSERVATIONS OF DRIZZLE FROM STRATOCUMULUS USING A 95 GHZ FMCW RADAR

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1. INTRODUCTION

The southeastern Pacific stratocumulus region reaches close to the equator, and extends 1500 km offshore all the way south to central Chile almost year-round (Klein and Hartmann 1993). Stratocumulus clouds form over the oceans with relatively cold sea surface temperatures. Stratus clouds strongly influence global climate because their high albedo give rise to large deficits in absorbed solar radiative flux at the top of the atmosphere, while their low altitude prevents significant compensation in thermal emission (Randall et al 1984). In the northern hemisphere fall of 2004, the NOAA research vessel *Ronald. H. Brown* (RHB) conducted a regular buoy maintenance cruise in central and southeast Pacific. The first part of the cruise was called as Tropical Atmosphere Ocean (TAO) while the second was named Stratus04. During the cruise the Environmental Technology Laboratory (ETL) and the University of Miami Radar Meteorology Group (UMRMG) conducted joint measurements of Marine Boundary Layer (MBL) stratocumulus clouds, thermodynamic structure, surface fluxes and meteorology.

2. INSTRUMENTATION

The radars onboard included 8.6 mm cloud radar known as Millimeter Cloud Radar (MMCR) (Moran et al 1998) from ETL and 3.2 mm compact airborne Doppler Cloud Radar known as Frequency Modulated Continuous Wave (FMCW) (Mead et al 2003) radar from Center for Interdisciplinary Remotely-Piloted Aircraft Studies (CIRPAS) which was developed by Prosensing Inc.

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Both the radars were measuring the three Doppler moments of the Doppler spectrum the cloud reflectivity, the mean Doppler velocity and the Doppler Spectrum width. The MMCR was set to run in two different modes Boundary Layer (BL) and Precipitation (PR). The main characteristics of the radar are listed in Table 1.

Table 1: Main characteristics of the radars.

Characteristic	MMCR BL Mode	MMCR PR Mode	FMCW
Frequency	34.86 GHz	34.86 GHz	94.8 GHz
Pulse Width	300 ns	600 ns	-
Range	5 Km	15 Km	1.25 Km
Spatial Resolution	45 m	90 m	5 m
Temporal Resolution	8 s	8 s	1.3 s
Dead Zone	114 m	114 m	0

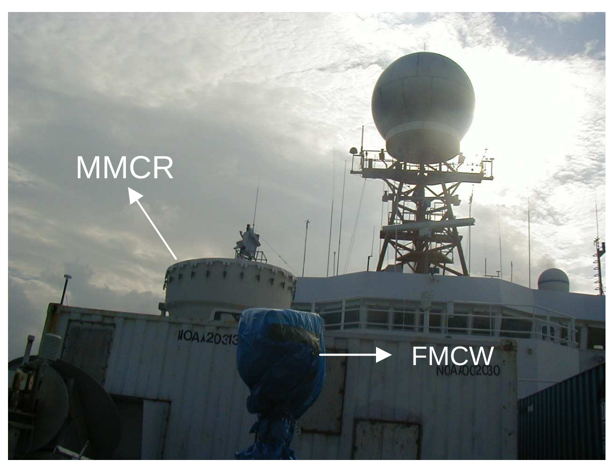

Figure1: The instrument setup on R/V Ronald Brown showing MWR, MMCR antenna, FMCW radar wrapped in blue tarp and the C-band radar.

In addition to the radars, other instruments onboard included Vaisala CT-25K cloud base ceilometer, a two channel (20.6 and 31.6 GHz) Microwave Radiometer (MWR) and the flux suite which includes measuring devices for the sensible, latent heat, momentum fluxes along with the broadband radiative flux. The ship had standard surface meteorological instruments and soundings were launched every 6 hours during the TAO cruise and every 4 hours during Stratus04.

3. CRUISE DESCRIPTION

For the TAO cruise, the RHB left Panama City, Panama on 24 October 2004 and cruised south-west to reach the southernmost buoy at the 95 W line. Then the ship overhauled all the buoys on that line till the northernmost buoy located at 12 N. The same was done while going south along the 110 W buoy line. After replacing the last buoy at 8 S and 110 W the ship headed South-East towards the port of Arica, Chile and ended the TAO cruise on 27 November 2004.

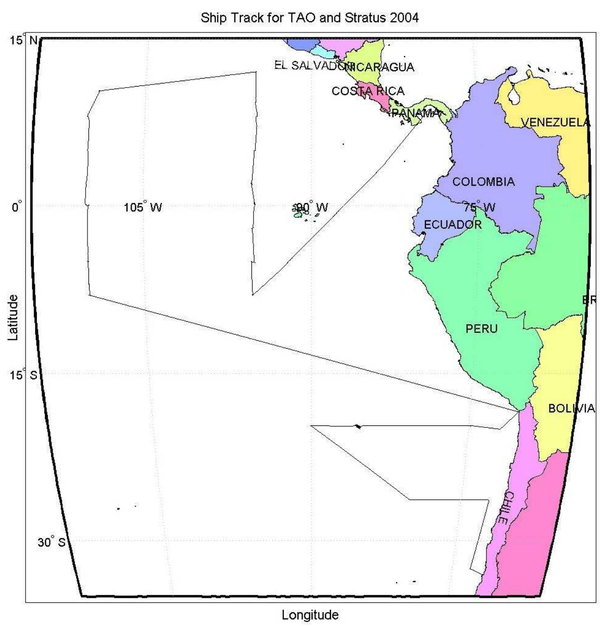

Figure 2: Ship Track shown for the cruise starting from Nov 1st 2004 till Dec 20th 2004.

For Stratus04, the ship departed Arica, Chile on 5 December 2004. Then it followed the same easterly path to 20 S and 90 W as did the earlier cruises like EPIC (East Pacific Investigation of Climate) 2001 and PACS (Pan American Climate Studies) 2003. During this cruise the WHOI (Woods Hole Oceanographic Institution) Ocean Reference Station (WORS) located at 20 S and 85 W was overhauled. The ship was stationed at this location for 5 days from 12/11 to 12/16. The cruise ended on 20 December 2004 at the southern port of Valparaiso, Chile. The entire cruise track for both the cruises is shown in figure 2.

4. DATA AVAILABILITY AND QUALITY

Good cloud and rain data were collected throughout both the cruises. The data collection started on 27th October 2004 (Julian day 301). Figure 2 shows the ceilometer detected cloud base for the entire cruise time. It can be seen that for most of the time the during the TAO cruise, there was persistent cloud cover except from 314 (November 9th) to 317 (November 12th). The fractional cloudiness for the TAO cruise alone was 52 % while that of both cruises together was 50 %. As it can be seen from the cruise track (figure 1) and the ceilometer plot, there is a decrease in the cloud base height as we approached the coast during the end of the TAO cruise and an increase in it as we move away from the coast during start of the Stratus04. During days 336 to 340 the ship was stationed at the port of Arica and the instruments were off. The low values of the cloud base (below 300 m) mostly correspond to rain events. In a rain, event the ceilometer may fail to detect the actual cloud base and instead confuses it with the falling rain droplets. Substantial precipitation was observed during both the cruises

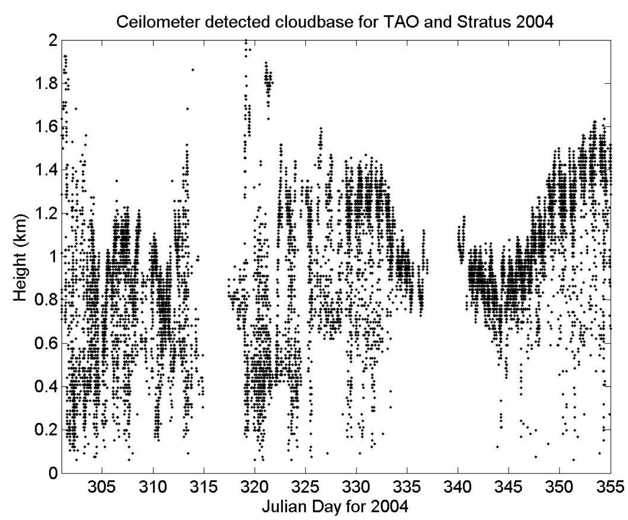

Figure 3: Ceilometer detected cloud base for TAO and Stratus 2004 cruises.

5. Objectives

The main objective of this study is to characterize the vertical and horizontal structure of drizzle in marine stratus, provide quantified measurements of drizzle rainfall rates, and study the drizzle effects on the MABL decoupling, and moisture and energy budgets. Emphasis is given on developing a Reflectivity-Rain Rate (Z-R) relation and an evaporation model for examining Z variation from cloud base to the surface. As the relation is intended to be developed from the FMCW radar, and the fact that the radar is used for the first time in a ship-based experiment, adds another objective: To calibrate it and evaluate its use for drizzle detection. In this paper just the comparison of the radars is discussed. For this a specific case during the cruise is chosen for a comprehensive analysis.

6. RADAR COMPARISON

Abundant drizzle events were observed during the first 12 hours of November 24th 2004. On this day the ship was moving eastwards towards the port of Arica. The ship traveled from 10.27° S 100.49° W to 11.02° S 98.41° W during this time period. Both the radars were operating during this time period. FMCW radar was calibrated using this dataset by comparing it with MMCR and a radar correction factor of -89 was found.

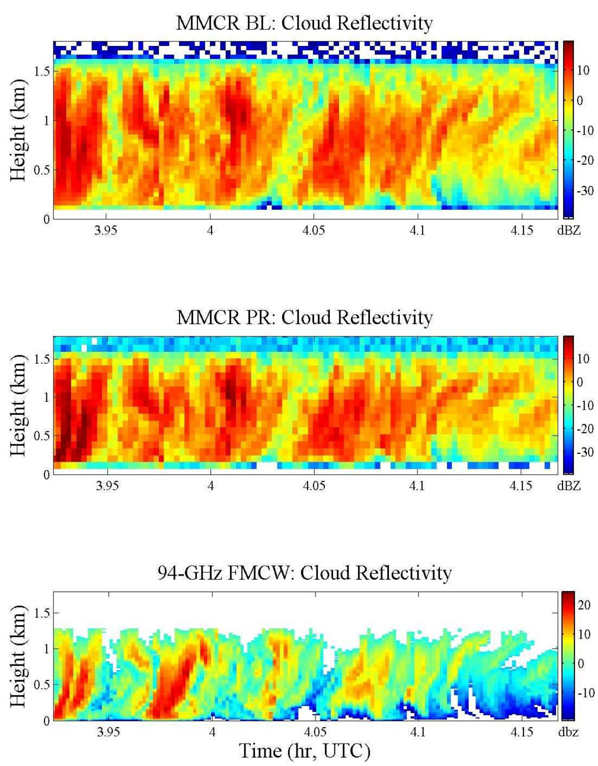

Figure 4: Reflectivities from MMCR BL mode (top), MMCR PR mode (middle) and FMCW (bottom).

In order to further analyze FMCW radar with both MMCR operating modes, a coherent drizzle event around the 4th Hour UTC of this day is chosen. The reflectivities captured by the MMCR BL mode, MMCR PR mode and FMCW radar are shown in figure 4. It can be observed that the MMCR is not able to collect any data in the first 114 m above the ground. The FMCW radar is able to collect data from the first gate itself, which is 5 m above the receiver. Hence there is no "Dead Zone" in case of the FMCW. The ceilometer cloud base observed just before the drizzle event is at 1 km. Hence it can be said that the lower sensitivity of the FMCW radar prevents it from capturing the cloud which is not the case as in the MMCR.

Furthermore to analyze the FMCW radar and to compare the two modes of MMCR, the reflectivities from the radars are averaged for the 15 min in consideration. The resulting plot is shown in Figure 4 at the top. Also the maximum reflectivity observed at all heights for the two radars is plotted in the bottom graph. These plots indicate a peak in the averaged reflectivity at around 800 m in all three profiles. Second, the MMCR BL mode indicates saturation as its observed reflectivity is less than the FMCW and the PR mode. Third, there is attenuation observed in the FMCW radar above 800 m as its reflectivity decreases sharply compared with the others. Lastly there is an unexplained kink in the FMCW radar profile just below 500m.

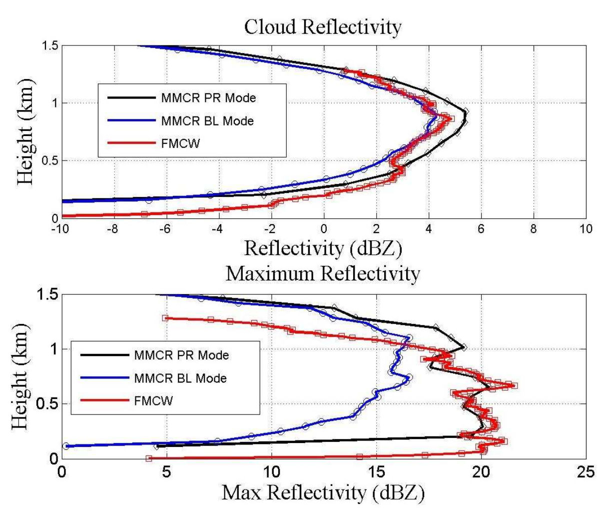

Figure 5: Averaged (top) and maximum (bottom) MMCR BL, MMCR PR and FMCW reflectivities for the period shown in Figure 4. Saturation of MMCR BL mode is evident

From the maximum dBZ plot it can be said that the reflectivity values obtained from the MMCR PR mode are close to the real values since they do not experience saturation or any significant attenuation at any level. Furthermore the BL mode values cannot be used during precipitation events and the FMCW radar does not saturate in the first 500 m above the ground.

7. CONCLUSION AND FUTURE WORK

Drizzle observations from the MMCR (Ka-band) and the FMCW (W-band) radar together present an unprecedented opportunity to characterize drizzle. The high resolution unsaturated observations from the FMCW radar present unique opportunity to characterize drizzle in the lower half of the boundary layer i.e. the first 500 m above the ground. In order to characterize drizzle quantitatively, a reflectivity-Rain Rate relation will be developed at various levels based on the observations from the FMCW radar.

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