Vertical Structure Observations of Precipitation using Micro Rain Radar over Indian Region

Aravind Kilaru, Sarat Kumar Kotamraju, Nicholas Avlonitis, K.Ch. Sri Kavya

Abstract*: *The growing demand for bandwidth and rapidly evolving technology has forced the network providers to innovate most effective and feasible solutions to meet the current demand as well as future influx due to technological advancements. The new satellites in LEO, MEO & GEO are adopting to Ka to provide communication infrastructure. In this paper we put forward vertical Rain Rate, Liquid Water Content, Fall Velocity as well as Path Integrated Attenuation up to 4.4 kms in the atmosphere with respective rain intensity which is vital to any communication link design.

Index Terms*: *MRR, Propagation studies, Ka band, melting layer, bright band.

I. INTRODUCTION

Micro physics properties of atmospheric effects on the satellite link above 20 GHz is essential for the link design and development of the new systems.[1], [2] For developing Satellite based communication solutions, we must have a good reliable estimation of precipitation associated parameters in the vertical column of atmosphere and its effects on the link which leads to attenuation. The precipitation associated parameters study is the combination of precipitation physics and scattering theory. [3]–[8] Scattering theory is based on reflectivity (Z) relation associated with change due to variations, the Z relation is part of the algorithm developed to interpret changes associated with the monitoring parameter. Most commonly these relationships are presented in the form of Z-LWC or Z-R relationship etc. [9]–[12] To validate the reliability and stability of the recommended model by ITU-R across the world, propagation researchers often present the predicted measurements with the measured results. [1] For in-depth study on the variations due to precipitation and its related effects on the propagating signal, researchers across the world use measured local data obtained from radars and its vertical structure during precipitation and its effects on the propagating signal. Micro Rain Radar (MRR) is used to monitor layer by layer variations related to precipitation from melting layer to near ground using 24.230 GHz radar signal. MRR measurements contains Radar Reflectivity (Z), Attenuated Radar Reflectivity (z), Drop Size Distribution (DSD), Path Integrated Attenuation (PIA), Rain Rate or Rain Intensity (RR), Fall Velocity (W) and Liquid Water Content (LWC). In this study the observed vertical structure with respective to rain intensity is presented based on rain events. Which is vital for link design and relative local features extracted as well as interpreted. It can provide a clear view of the variations in precipitation structure.

Manuscript published on 30 March 2019.
***Correspondence Author(s)**
Aravind Kilaru, Department of ECE, Koneru Lakshmaiah Education Foundation, Guntur, INDIA.
Dr. Sarat KumarKotamraju, Department of ECE, Koneru Lakshmaiah Education Foundation, Guntur, INDIA.
Dr. Nicholas Avlonitis, Visiting Fellow, University of South Wales, UK.
Dr. K.Ch.Sri Kavya, Department of ECE,Koneru Lakshmaiah Education Foundation, Guntur, INDIA.

© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an open access article under the CC-BY-NC-ND license http://creativecommons.org/licenses/by-nc-nd/4.0/

II. DATA SET

The data utilized for this study is measured through Micro Rain Radar (MRR) operating at 24.230 GHz, it's a compact Frequency Modulated Continuous Wave (FM-CW) radar and can retrieve hydro-meteor parameters profile in the vertical column with respective altitude in the atmosphere. It operates with a modulation of 0.5 – 15 MHz with 32 range gates height resolution and have a peak transmit power of 50 mW. Due to high sensitivity MRR is able to measure fine temporal resolution of micro rain in the vertical column. The MRR scattering volume is about 10^4 m^3 in size, which can accommodate $2*10^7$ drops in the scattering volume. As the shape and fall velocity of the rain drops are irregular in the vertical column, the phase of the scattered signal varies according to the rain drops. The back scattered power received at the terminal unit is processed through a **R**ADAR **C**ontrol and **P**rocessing **D**evice (RCPD), where it processes the received power as instantaneous spectra. The received spectra's are further processed in-form of Raw Spectra, Averaged data and Processed data for recoding in the memory accordingly. The average of 78 instantaneous spectra's over 10 seconds interval form an average data, whereas the processed data with atmospheric, density and attenuation corrections is calculated based on one RAW spectra averaged over 10 seconds interval.[3] From the processed spectra it retrieves Radar Reflectivity (Z), Attenuated Radar Reflectivity (z), Drop Size Distribution (DSD), Path Integrated Attenuation (PIA), Rain Rate (RR), Fall Velocity (W) and Liquid Water Content (LWC) in the vertical column of the atmosphere for every 10 seconds. To understand rainfall profile in the vertical structure and its effect on the propagating signal in the tropical region of Indian sub-continent, the MRR is installed at KLEF located in the tropical climate of Latitude 16.24472 & Longitude 80.44806 approximately 30 m above sea level (ASL + building height).The observations presented in this study are recorded during July 2016 to March 2018.

III. METHODOLOGY

The METEK Graphics software displays only vertical column measurements of one parameter with respective instance of time, which is not helpful for the current analysis.

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)
© Copyright: All rights reserved.

Through a custom written matlab code the measured data is analyzed to extract parameters of RR, LWC, Z, z, PIA, W and DSD with respective vertical height and time of measurement. To analyze and distinguish vertical column measured parameters in the atmosphere during precipitation times, the extracted data is further processed to extract and arrange the vertical column recorded measurements. So that vertical profile of precipitation in the atmosphere between 200 to 6200 m can be studied according to the rainfall intensity.

IV. RESULTS

For in-depth analysis of precipitation vertical structure, the observations were presented with respective rain intensity. Each rain rate presents the observed precipitation vertical structure parameters consisting of Liquid Water Content (LWC),Rain Rate (RR), Fall Velocity (W), Radar Reflectivity (Z), Attenuated Radar Reflectivity (z), and Path Integrated Attenuation (PIA).

The observed datarepresent the vertical structuremeasured at 200 m height. From the vertical structure data, it is to be observed that the precipitation parameters vary (LWC, RR and W) as it transits from melting layer towards ground,but the presented observation data is the structure of that respective intensity. At higher layer (above 200 m) the precipitation parameters might be high or low compared to the intensity at 200 m but it's the part of that vertical structure should not be confused with leading to that respective rain intensity.

The presentedrain intensity parameters analysis also presents mutual analysis of LWC, RR and W at respective layers below melting layer. The PIA presented provides insight into effects of LWC, RR and W combination on a propagating signal at that respective layer leading to attenuation due to intensity on 24 GHz signal.

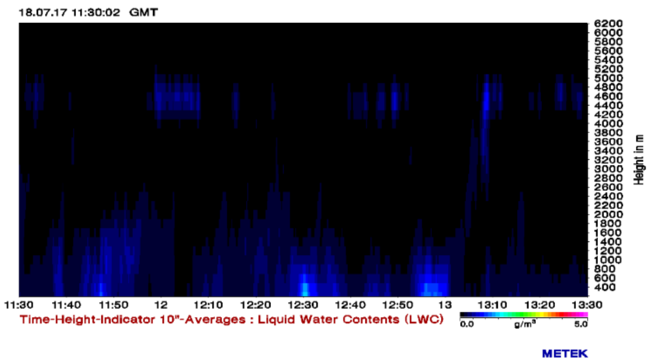

Figure 1. Vertical profile of Liquid Water Content (LWC) on 18/7/2017

The observationsindicate that the cloud liquid water contentstarted changing to Precipitation Liquid Water Content at the altitude of around 4800 m. It also coveys the mean melting layer height is around 4800 m for this region.

Between 1 mm/hr to 14 mm/hr the mean LWC at 4800 m observed to be in-between 0.2 gm^{-3} to 0.58 gm^{-3} and the respective fall velocity is in-between 2.5 m/s to 3.14 m/s with respective rain intensity.

Between 4800 m to 4400 m the complete transition of LWC from solid to liquid phase has appeared to be stabilized, below 4400 m a uniform vertical structure of LWC, RR, W, Z and z can be observed.

The vertical structure observations were recorded for the rain intensity 2.5 mm/hr. The observations indicate up to 2.5 mm/hr intensity a uniform vertical structure can be observed from melting layer to ground. Themean Precipitation Liquid Water Content (LWC) is 0.18 gm^{-3} with mean rain intensity is observed to be 1.3 mm/hr and the respective fall velocity (W) is 4.2 m/s at 4200 m for 2.5 mm/hr rain intensity. whereas the mean radar reflectivity (Z) was observed to be around 15.59 dBZ for the respective LWC, RR and W and the mean attenuated radar reflectivity (z) was observed to be around 14.15 dBZ for that respective height.

In the vertical structure of 2.5 mm/hr intensity at 1400 m the mean LWC is observed to be 0.14 gm^{-3} with mean rain intensity 1.9 mm/hrand the respective W is observed to be 6.1 m/s. whereas the Z was observed to be 25.76 dBZ for the respective LWC, RR and W and the z was observed to be 25.13 dBZ for that respective layer.

In the vertical structure of 2.5 mm/hr intensity at 1200 m the mean LWC is observed to be 0.14 gm^{-3} with mean rain intensity 2.1 mm/hrand the respective W is observed to be 6.1 m/s. whereas the Z was observed to be 26.5 dBZ for the respective LWC, RR and W and the z was observed to be 25.96 dBZ for that respective layer.

In the vertical structure of 2.5 mm/hr intensity at 200 m height the mean LWC is observed to be 0.18 gm^{-3} with mean rain intensity around 2.5 mm/hrand the respective W is observed to be 6.3 m/s. whereas the Z and z was observed to be 32.3 dBZ for the respective LWC, RR and W for that respective layer.

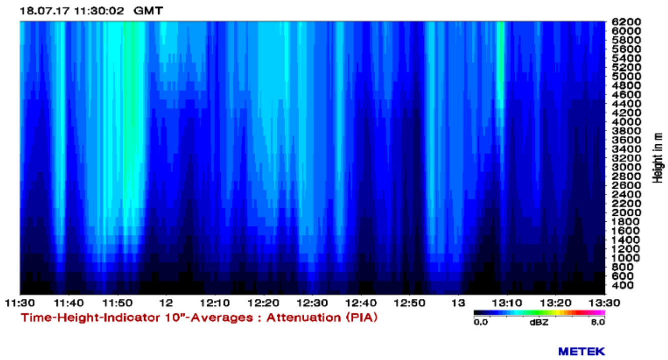

Figure 2. Vertical profile of Path Integrated Attenuation (PIA) on 18/7/2017

The total path integrated attenuation (PIA) due to the combination of LWC, RR and W on a propagating signal at 24 GHz is observed to be 1.413 dB between 200 m to 4200 m, 0.67 dB between 200m to 1400 m and 0.58 dB between 200 m to 1200 m. The observed attenuation due to rain on a propagation signal would be 0.44 dB between 200 m to 1200 m and 0.74 dB between 1400 m to 4200 m in the vertical structure of rain intensity 2.5 mm/hr.For the 5 mm/hr rain intensity, at higher layer above 200 m significant presents of LWC was observed. The mean LWCat 4200 m height is observed to be around 0.08 gm^{-3} with mean rain intensity 0.83 mm/hr. The respective fall velocity around 4.2 m/s. whereas the Z was observed to be around 13.79 dBZ for the respective LWC, RR and W and the z was observed to be around 12.02 dBZ for that respective height.

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)
© Copyright: All rights reserved.

In the vertical structure of 5 mm/hr intensity at 3600 m the mean LWC is observed to be 0.12 gm^{-3} with mean rain intensity 0.99 mm/hrand the respective W is observed to be 4.96 m/s. whereas the Z was observed to be 16.15 dBZ for the respective LWC, RR and W and the z was observed to be 14.49 dBZ for that respective layer. In the vertical structure of 5 mm/hr intensity at 3400 m the mean LWC is observed to be 0.13 gm^{-3} with mean rain intensity 1.35 mm/hrand the respective W is observed to be 5.2 m/s. whereas the Z was observed to be 17.79 dBZ for the respective LWC, RR and W and the z was observed to be 16.12 dBZ for that respective layer.

In the vertical structure of 5 mm/hr intensity at 2600 m the mean LWC is observed to be 0.22 gm^{-3} with mean rain intensity 1.75 mm/hrand the respective W is observed to be 6.09 m/s. whereas the Z was observed to be 21.98 dBZ for the respective LWC, RR and W and the z was observed to be 20.53 dBZ for that respective layer.

In the vertical structure of 5 mm/hr intensity at 2400 m the mean LWC is observed to be 0.24 gm^{-3} with mean rain intensity 2.3 mm/hrand the respective W is observed to be 6.14 m/s. whereas the Z was observed to be 22.52 dBZ for the respective LWC, RR and W and the z was observed to be 21.14 dBZ for that respective layer.

In the vertical structure of 5 mm/hr intensity at 1200 m the mean LWC is observed to be 0.26 gm^{-3} with mean rain intensity 2.9 mm/hrand the respective W is observed to be 6.37 m/s. whereas the Z was observed to be 27.81 dBZ for the respective LWC, RR and W and the z was observed to be 26.99 dBZ for that respective layer.

In the vertical structure of 5 mm/hr intensity at 1000 m the mean LWC is observed to be 0.33 gm^{-3} with mean rain intensity 3.4 mm/hrand the respective W is observed to be 6.39 m/s. whereas the Z was observed to be 28.73 dBZ for the respective LWC, RR and W and the z was observed to be 28.05 dBZ for that respective layer.

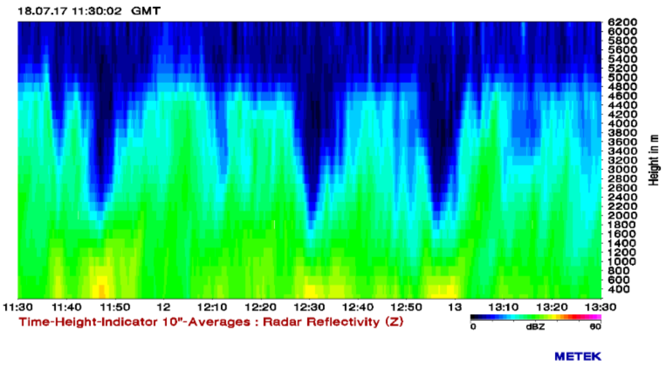

Figure 3. Vertical profile of Radar Reflectivity (Z) on 18/7/2017

In the vertical structure of 5 mm/hr intensity at 600 m the mean LWC is observed to be 0.45 gm^{-3} with mean rain intensity 3.8 mm/hrand the respective W is observed to be 6.48 m/s. whereas the Z was observed to be 31.22 dBZ for the respective LWC, RR and W and the z was observed to be 30.88 dBZ for that respective layer.

In the vertical structure of 5 mm/hr intensity at 400 m the mean LWC is observed to be 0.26 gm^{-3} with mean rain intensity 4.4 mm/hrand the respective W is observed to be 6.5 m/s. whereas the Z was observed to be 33.42 dBZ for the respective LWC, RR and W and the z was observed to be 33.31 dBZ for that respective layer.

In the vertical structure of 5 mm/hr intensity at 200 m the mean LWC is observed to be 0.32 gm^{-3} with mean rain intensity around 5 mm/hrand the respective W is observed to be 6.5 m/s. whereas the Z and z was observed to be 35.24 dBZ for the respective LWC, RR and W for that respective layer.The total path integrated attenuation (PIA) due to the combination of LWC, RR and W on a propagating signal at 24 GHz is observed to be 1.71 dB between 200 m to 4200 m, 1.63 dB between 200m to 3600 m, 1.60 dB between 200m to 3400 m, 1.4 dB between 200m to 2600 m, 1.37 dB between 200m to 2400 m, 0.88 dB between 200m to 1200 m, 0.75 dB between 200m to 1000 m, 0.44 dB between 200m to 600 m, 0.24 dB between 200m to 400 m.

The observed attenuation due to rain on a propagation signal would be 0.24 dB between 200 m to 400 m, 0.2 dB between 400 m to 600 m, 1.16 dB between 600 m to 3400 m and 0.11 dB between 3400 m to 4200 m in the vertical structure of rain intensity 5 mm/hr.

At 15 mm/hr, from the observations the mean LWC at 4400 m height is observed to be around 0.114 gm^{-3} with mean rain intensity 0.67 mm/hr and the respective fall velocity around 3.5 m/s. whereas the Z was observed to be around 7.44 dBZ for the respective LWC, RR and W and the z was observed to be around 5.08 dBZ for that respective height.

In the vertical structure of 15 mm/hr intensity at 1000 m the mean LWC is observed to be 1.37 gm^{-3} with mean rain intensity 7.56 mm/hrand the respective W is observed to be 6.8 m/s. whereas the Z was observed to be 30.93 dBZ for the respective LWC, RR and W and the z was observed to be 29.67 dBZ for that respective layer. In the vertical structure of 15 mm/hr intensity at 400 m the mean LWC is observed to be 0.70 gm^{-3} with mean rain intensity 9.4 mm/hrand the respective W is observed to be 7.12 m/s. whereas the Z was observed to be 38.25 dBZ for the respective LWC, RR and W and the z was observed to be 37.98 dBZ for that respective layer. In the vertical structure of 15 mm/hr intensity at 200 m the mean LWC is observed to be 0.86 gm^{-3} with mean rain intensity around 15 mm/hrand the respective W is observed to be 7.0 m/s. whereas the Z and z was observed to be 40.65 dBZ for the respective LWC, RR and W for that respective layer. The total path integrated attenuation (PIA) due to the combination of LWC, RR and W on a propagating signal at 24 GHz is observed to be 2.34 dB between 200 m to 4400 m, 2.14 dB between 200m to 2200 m, 1.39 dB between 200m to 1000 m, 0.89 dB between 200m to 600 m, 0.54 dB between 200m to 400 m.

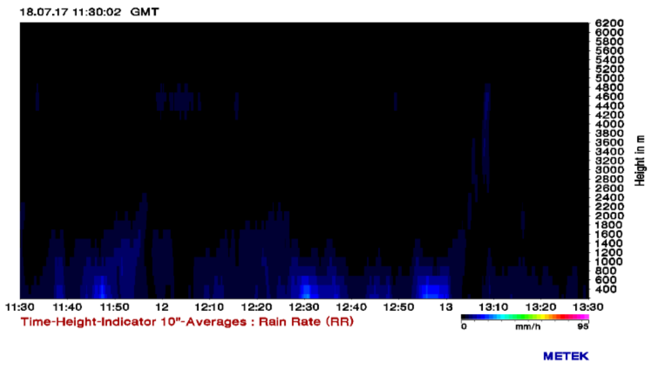

Figure 4. Vertical profile of Rain Rate (RR) on 18/7/2017

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)
© Copyright: All rights reserved.

The observed attenuation due to rain on a propagation signal would be 0.54 dB between 200 m to 400 m, 0.35 dB between 400 m to 600 m, 0.5 dB between 600 m to 1000 m and 0.75 dB between 1000 m to 2400 m, 0.2 dB between 2400 m to 4400 m in the vertical structure of rain intensity 15 mm/hr. At 35 mm/hr rain intensity the mean LWC at 1600 m height is observed to be around 0.31 gm^{-3} with mean rain intensity 2.3 mm/hr and the respective fall velocity around 6.9 m/s. whereas the Z was observed to be around 24.55 dBZ for the respective LWC, RR and W and the z was observed to be around 22 dBZ for that respective height.

In the vertical structure of 35 mm/hr at 1600 m the mean rain intensity is observed to 2.3 mm/hr with LWC 0.31 gm^{-3} and the respective fall velocity is 6.9 m/s. Whereas Z was observed to be 24.55 dBZ with z is 22.04 dBZ and the PIA is 2.5 dB between 200 m to 1600 m. At 1400 m the rain intensity was observed to be 3.57 mm/hr with LWC 0.52 gm^{-3} and the respective fall velocity is 6.8 m/s. Whereas Z is observed to be 26.32 dBZ with z is 23.91 dBZ and the PIA is 2.45 dB between 200 m to 1400 m.

At 1200 m the rain intensity is observed to be 6.45 mm/hr with LWC 0.97 gm^{-3} and the respective fall velocity is 7.08 m/s. Whereas Z is observed to be 29.07 dBZ with z is 26.82 dBZ and the respective PIA is 2.3 dB between 200 m to 1200 m. At 1000 m the rain intensity is observed to be 11.13 mm/hr with LWC 2.11 gm^{-3} and the respective fall velocity is 7.2 m/s. Whereas the Z is observed to be 32.04 dBZ with z around 30 dBZ and the PIA is 2.2 dB between 200 m to 1000 m.

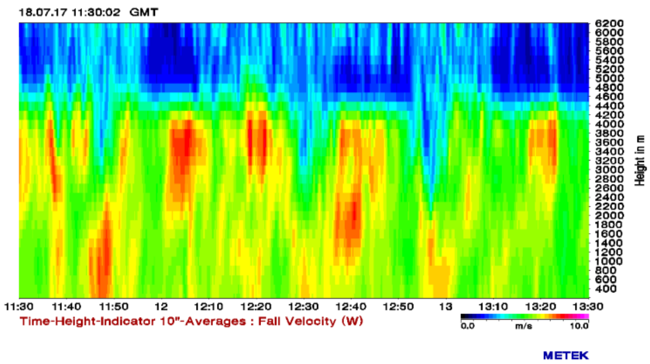

Figure 5. Vertical profile of Fall Velocity (FV) on 18/7/2017

At 800 m the rain intensity is observed to be 15.77 mm/hr with LWC 3.15 gm^{-3} and the respective fall velocity 7.2 m/s. Whereas the Z is observed to be 34.49 dBZ with z around 32.78 dBZ and the respective PIA is 1.89 dB between 200 m to 800 m. The mean rain intensity is observed to be 15.24 mm/hr at 600 m with LWC 2.56 gm^{-3} and the respective fall velocity 7.4 m/s with Z is 37.51 dBZ and the z is 36.27 dBZ, the PIA is 1.5 dB between 200 m to 600 m.

At 400 m the rain intensity is observed to be 16.58 mm/hr with LWC 1.37 gm^{-3} and the respective fall velocity 7.5 m/s. Whereas Z is observed to be 41.78 dBZ and the z is 41.3 and the respective PIA is 0.97 dB between 200 m to 400 m. At 200 m the rain intensity is 35 mm/hr with LWC 1.97 gm^{-3} and the respective fall velocity is 7.5 m/s. Whereas Z and z is observed to be 45.12 dBZ.

The observed attenuation due to rain on a propagation signal would be 0.97 dB between 200 m to 400 m, 0.53 dB between 400 m to 600 m, 0.39 dB between 600 m to 800 m, 0.31 dB between 800 m to 1000 m, 0.1 dB between 1000 m to 1200 m, 0.15 dB between 1200 m to 1400 m, 0.05 dB between 1400 m to 1600 m and 0.66 dB between 1600 m to 4400 m in the vertical structure of rain intensity 35 mm/hr.

At 50 mm/hr rain intensity the observations at 4400 m the rain intensity is observed to be 1.4 mm/hr and at 1800 m the rain intensity is observed to be 1.6 mm/hr with respective LWC 0.3 gm^{-3} and 0.23 gm^{-3} and the fall velocity observed to be 2.9 m/s at 4400 m and 5.48 m/s at 1800 m. Whereas Z is observed to 6.14 dBZ at 4400m and 19.36 dBZ at 1800 m and z is 2.5 dBZ at 4400 m and 16.12 dBZ at 1800 m and the respective PIA 3.68 dB between 200 m to 4400 m and 3.368 dB between 200 m to 1800 m.

At 1600 m the rain intensity is observed to be 2.98 mm/hr and LWC 0.47 gm^{-3} with fall velocity 6.42 m/s. Whereas Z is observed to be 22.3 dBZ with z around 19.03 dBZ and the PIA is 3.4 dB between 200 m to 1600 m. At 1400 m the rain intensity is observed to be 2.87 mm/hr with LWC 0.40 gm^{-3} with fall velocity 6.89 m/s. Whereas Z is observed to be 24.7 dBZ with z around 21.56 dBZ and the PIA 3.3 dB between 200 m to 1400 m.

At 1200 m the rain intensity is observed to be 4.98 mm/hr with LWC is 0.77 gm^{-3} and the fall velocity is 7.24 m/s. Whereas Z is observed to be 28.04 dBZ with z around 25.03 dBZ and the PIA is 3.17 dB between 200 m to 1200 m. At 1000 m the rain intensity is observed to be 13.99 mm/hr with LWC is 3.059 gm^{-3} and the fall velocity is 7 m/s. Whereas Z is observed to be 31.36 dBZ with z around 28.66 dBZ and the PIA is 2.9 dB between 200 m to 1000 m.

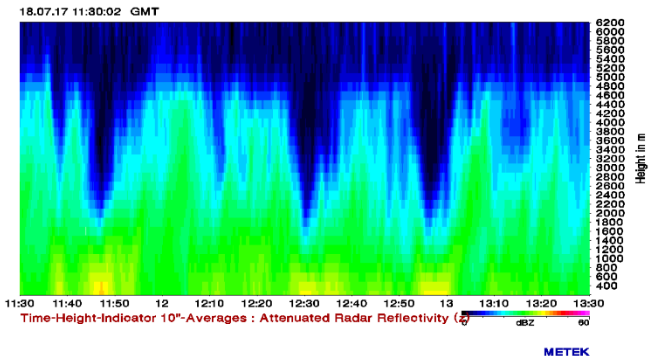

Figure 6. Vertical profile of Attenuated Radar Reflectivity (z) on 18/7/2017

At 800 m the mean rain intensity is observed to around 26.46 mm/hr with LWC is 5.7 gm^{-3} and the fall velocity 7.2 m/s. Whereas Z is observed to be 34.73 dBZ with z around 32.41 dBZ and the PIA is 2.5 dB between 200 m to 800 m. At the 600 m the mean rain intensity is observed to be 24.89 mm/hr with LWC 4.8 gm-3 and the fall velocity 7.48 m/s. Whereas Z is observed to be 38.13 dBZ with z around 36.43 dBZ and the PIA is 2.12 dB between 200 m to 600 m.

At 400 m the rain intensity is observed to 22.69 mm/hr with LWC 2.4 gm^{-3} with fall velocity around 7.6 m/s. Whereas Z is observed to be 42.89 dBZ with z around 42.26 dBZ and the PIA 1.3 dB between 200 m to 400 m. At 200 m the rain intensity is observed to around 50 mm/hr with LWC 2.9 gm^{-3} and the fall velocity is 7.49 m/s with Z and z observed to be around 46.56 dBZ for the respective LWC, RR and W.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)
© Copyright: All rights reserved.

The observed attenuation due to rain on a propagation signal would be 1.3 dB between 200 m to 400 m, 0.82 dB between 400 m to 600 m, 0.38 dB between 600 m to 800 m, 0.4 dB between 800 m to 1000 m, 0.27 dB between 1000 m to 1200 m, 0.13 dB between 1200 m to 1400 m, 0.2 dB between 1400 m to 1800 m and 0.32 dB between 1800 m to 4400 m in the vertical structure of rain intensity 50 mm/hr.

For 75 mm/hr rain intensity at 1600 m height the rain intensity is observed to be 0.7 mm/hr with LWC 0.096 gm^{-3} and the fall velocity is 5.2 m/s. Whereas Z is observed to be 15.09 dBZ with z around 12.04 dBZ and the PIA 3.29 dB between 200 m to 1600 m.

At 1000 m the rain intensity is observed to be 10.54 mm/hr with LWC 1.66 gm^{-3} and the fall velocity 7.16 m/s. Whereas Z is observed to be 29.1 dBZ with z around 26.09 dBZ and the PIA is 3.17 dB between 200 m to 1000 m. At 800 m the rain intensity is observed to be 15.38 mm/hr with LWC 2.52 gm^{-3} and the fall velocity 7.4 m/s. whereas Z is observed to be 33.42 dBZ with z around 30.73 dBZ and the PIA is 2.93 dB between 200 m to 800 m. At 600 m the rain intensity is observed to be 30.71 mm/hr with LWC 5.8 gm^{-3} and the fall velocity 7.29 m/s. Whereas Z is observed to be 38.16 dBZ with z around 36.06 dBZ and the PIA is 2.42 dB between 200 m to 600 m.

At 400 m the rain intensity is observed to be 36.98 mm/hr with LWC 4.84 gm^{-3} and the fall velocity 7.59 m/s. Whereas Z is observed to be 44.77 dBZ with z around 43.93 dBZ and the PIA is 1.74 dB between 200 m to 400 m. At 200 m the rain intensity is observed to be around 75 mm/hr with LWC 4.57 gm^{-3} and the fall velocity 7.8 m/s. Whereas Z and z is observed to be 48.77 dBZ.

The observed attenuation due to rain on a propagation signal would be 1.74 dB between 200 m to 400 m, 0.68 dB between 400 m to 600 m, 0.51 dB between 600 m to 800 m, 0.24 dB between 800 m to 1000 m, 0.27 dB between 1000 m to 1200 m, 0.19 dB between 1200 m to 1400 m and 0.04 dB between 1400 m to 1600 min the vertical structure of rain intensity 75 mm/hr.

For 95 mm/hr rain intensity at 1800 m the LWC is almost zero but the fall velocity (down draft) is observed to be 3.61 m/s for that respective layer. At 1600 m the rain intensity is observed to be 7.73 mm/hr with LWC 1.26 gm^{-3} and the fall velocity is around 4.68 m/s. Whereas Z is observed to be 14.93 dBZ with z around 10.6 dBZ and the PIA is 4.654 dB between 200 m to 1600 m.

V. CONCLUSION

From the observations, vertical structure of Rain Rate (RR), Liquid Water Content (LWC), Radar Reflectivity (Z), Fall Velocity (W), Path Integrated Attenuation (PIA) with respective rain intensity between the height of 200 to 4400 m was presented. From the observations, mean melting layer height is around 4800 m for the measured region. For the rain rate below 14 mm/hr a uniform vertical structure from 4400 m to ground has been observed. With increasing rain intensity, significant presence of LWC and RR was observed below 2000 m and the layers above 2200 m tends be free from precipitation.The presence of LWC and RR in the vertical layers tends to contributeto collisions for the next possible intensity leading to an increase in RR and fall velocity by 0.5 m/s to 1 m/s during the transit.

ACKNOWLEDGMENT

The authors would like to express their gratitude to Shri. K V K Vara Prasad and Shri. Ramesh Chennaiah for their support, encouragement and assistance during this work. The authors are thankful to the management of KoneruLakshmaiah Education Foundation and Department of Science and Technology (DST), Government of India for the support through a funded project with F. No: EMR/2015/000100.

REFERENCES

1. S. Das, A. Maitra, and S. D. and A.Maitra, "Ka-band Radar Observations of Tropical Rain Features 1 . 2 Micro Rain Radar," in *2014 XXXIth URSI General Assembly and Scientific Symposium (URSI GASS)*, 2014, pp. 3–6.
2. N. V. P. Kirankumar and P. K. Kunhikrishnan, "Evaluation of performance of Micro Rain Radar over the tropical coastal station Thumba (8.5°N, 76.9°E)," *Atmos. Res.*, vol. 134, pp. 56–63, 2013.
3. METEK and M. M. GmbH, "MRR Physical Basics Valid for MRR Service Version ≥ 5.2.0.9," METEK Meteorologische Messtechnik GmbH Fritz-Strassmann-Strasse 4 D-25337 Elmshorn Germany.
4. S. K. Das, M. Konwar, K. Chakravarty, and S. M. Deshpande, "Raindrop size distribution of different cloud types over the Western Ghats using simultaneous measurements from Micro-Rain Radar and disdrometer," *Atmos. Res.*, vol. 186, pp. 72–82, 2017.
5. S. Das and A. Maitra, "Vertical profile of rain: Ka band radar observations at tropical locations," *J. Hydrol.*, vol. 534, pp. 31–41, 2016.
6. S. Das, A. Maitra, and A. K. Shukla, "Melting layer characteristics at different climatic conditions in the Indian region: Ground based measurements and satellite observations," *Atmos. Res.*, vol. 101, no. 1–2, pp. 78–83, 2011.
7. A. K. Shukla *et al.*, "Micro rain cell measurements in tropical India for site diversity fade mitigation estimation," *Radio Sci.*, vol. 45, no. 1, p. RS1002, 2010.
8. T. Sarkar, S. Das, and A. Maitra, "Assessment of different raindrop size measuring techniques: Inter-comparison of Doppler radar, impact and optical disdrometer," *Atmos. Res.*, vol. 160, pp. 15–27, 2015.
9. T. Sarkar, S. Das, and A. Maitra, "Effects of melting layer on Ku-band signal depolarization," *J. Atmos. Solar-Terrestrial Phys.*, vol. 117, pp. 95–100, 2014.
10. S. Das, S. Talukdar, A. Bhattacharya, A. Adhikari, A. Maitra, and R. Physics, "Vertical profile of Z-R relationship and its seasonal variation at a tropical location," in *2011 IEEE Applied Electromagnetics Conference (AEMC)*, 2011, vol. 1, no. September 2009, pp. 1–4.
11. G. Peters, B. Fischer, and T. Andersson, "Rain observations with a vertically looking Micro Rain Radar (MRR)," *Boreal Environ. Res.*, vol. 7, no. 4, pp. 353–362, Dec. 2002.
12. S. Kneifel, M. Maahn, G. Peters, and C. Simmer, "Observation of snowfall with a low-power FM-CW K-band radar (Micro Rain Radar)," *Meteorol. Atmos. Phys.*, vol. 113, no. 1, pp. 75–87, Jun. 2011.

AUTHORS PROFILE

Aravind Kilaru is a research scholar at KoneruLakshmaiah Education Foundation working under the supervision of Dr. K Sarat Kumar.

Dr. Sarat Kumar Kotamraju, PhD, is a Dean (Planning and Development) and a professor of Department of Electronics and Communication Engineering at KoneruLakshmaiah Education Foundation. He is the Principal Investigator for DST, SERB sponsored projects on Ku,Ka band propagation impairments.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)
© Copyright: All rights reserved.

Dr. K. Ch. Sri Kavya, PhD, is a Head of the Department and professor of Department of Electronics and Communication Engineering at KoneruLakshmaiah Education Foundation. She is the Principal Investigator for DST sponsored projects Ka band propagation impairments studies.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)
© Copyright: All rights reserved.