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A Micro-Physical Study on Thunderstorm Precipitating Clouds Observed over Guwahati (26^{o} 17’ N, 91^{o} 77’ E), a North East Region of India

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Abstract-To improve the understanding and prediction of the severe local thunderstorms over the north-east regions of India, Ministry of Earth Science (MoES), Government of India organized a national coordinated campaign called Severe Thunderstorm Observations and Regional Modeling (STORM) in pre-monsoon season. Yogi Vemana University Atmospheric research team deploying Laser Disdrometer and Micro Rain Radar in the premises of Regional Meteorological Centre, India Meteorological Department (IMD), Guwahati. In addition, IMD X-band Radar data, Radiosonde data and also satellite observational data are utilized. This paper presents the micro-physical characteristics of the thunderstorm precipitating clouds observed on 27^{th} May 2010 over Guwahati (26^{o} 17’ N, 91^{o} 77’ E). The relationship between the atmospheric conditions and the characteristics of the thunder clouds are illustrated. The physical processes involved in three stage of storm (initial, mature and dissipating) are understood with the vertical profile raindrop concentration. The raindrop concentration of mature stage of storm is associated with the higher drop concentration than initial and dissipating stage.

Key words-Cloud top temperature, disdrometer, Micro rain radar, Thunderstorm, Radar reflectivity, Bergeron process, melting layer

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1. INTRODUCTION

Thunderstorm is an integral component in the Earth's atmospheric system and has profound influence on a variety of industries. Thunderstorm is a severe weather phenomenon, which develops mainly due to intense convection and is accompanied by heavy rainfall, thunder, lightning, hail and often with the passage of a squall line [1]. It is the towering cumulus or the cumulonimbus clouds of convective origin with high vertical extent that is capable of producing lightning and thunder [2],[3]. Usually, these thunderstorms have the spatial extent of a few kilometers and life span less than an hour [4]. Over the globe some research programs such as the Thunderstorm Research International Programme (TRIP), The Down Under Doppler and Electricity Experiment (DUNDEE)[5],[6]. The Severe Thunderstorm Electrification and Precipitation Study (STEPS) [7] involving both ground and airborne measurements have been conducted to study the properties of thunderstorm occurring in New Mexico, Florida, Colorado etc. Friedrich et al., (2013)[8] examined the microphysical probes in convective thunderstorms in field experiment called Verification of the Origins of Rotation in Tornadoes Experiment (VORTEX2).

In India, the thunderstorms reach severity when continental air meets warm moist air from ocean in the lower troposphere [9],[10],[11],[12]**.** The eastern and north eastern part of the country i.e. Bihar, Gangetic West Bengal, Jharkhand, Orissa, Assam and other states of North East Region of India (NERI) gets most affected by severe thunderstorms during pre-monsoon months (March-May), in particular, during April & May. In this season, a lot of thunderstorms occur over NERI, Bangladesh, Nepal, and Bhutan. They are called nor’westers because they usually propagate from the northwest to the southeast. These severe Thunderstorms cause devastative damages in this region in April and May, every year [13]. To improve the understanding and prediction of the severe local thunderstorms over the north-east regions of India, Ministry of Earth Science (MoES), Government of India organized a national coordinated field campaign called Severe Thunderstorm Observations and Regional Modeling (STORM). Tyagi et al., (2011)[14] Studied of thermodynamic indices for forecasting pre-monsoon thunderstorms over Kolkata during STORM pilot phase 2006–2008. Thunderstorm climatology over northeast and adjoining east India was reported by singh et al.,(2011)[15]. Some climatological aspects of thunderstorms and squalls over Guwahati airport was reported by Kumar et al., (2006)[16]. Thermo dynamical structure of atmosphere during pre-monsoon thunderstorm season over Kharagpur as revealed by Tyagi et al., (2013)[17]. Pre-monsoon thunderstorm of northwest India was forecasted by Dhawan et al., (2008)[10]. Classification of thunderstorm and non-thunderstorm days in Calcutta (India) on the basis of linear discriminant analysis was done by Ghosh et al., (2004)[9].

Although many studies have been conducted in NERI to understand the dynamical [18] and thermo dynamical [14],[17] structures of severe weather

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(thunderstorm) phenomena, they are mostly in the form of case studies and are limited because of the lack of observations [13]. The microphysical processes leading to the development and dissipation of these severe storms are also not well understood because of the lack of mesoscale observations. Improvement in the prediction [19],[20],[21] of these important weather phenomena is also highly handicapped because of a lack of mesoscale observations in the vertical levels of the troposphere and an insufficient understanding of these phenomena. An unavailability of sophisticated instruments is responsible for an incomplete understanding of the burst of severe storms over NERI. To understand the influence of microphysics on the near-surface buoyancy tendency in convective thunderstorms, in situ measurements of microphysics near the surface are essential and those are currently not provided by most Doppler weather radars. The microphysical characteristics (Raindrop Size Distribution, rainrate, radar reflectivity) of the precipitation clouds at the ground level and aloft can be understood very well with the help of Parsivel disdrometer and Micro Rain Radar respectively. The Parsivel disdrometer provides a full picture of the precipitation event in all weather phenomena and provides accurate reporting of precipitation types and intensities without degradation of performance in severe outdoor environments [22],[23]. For the first time over NERI an attempt is made to illustrate the microphysical characteristics of thunderstorm clouds observed on 27th May 2010 over Guwahati.

The remainder of the paper is organized as follows: A brief description of observational site and the data used for the present study is presented in section 2. Section 3 includes results of the experiments and discussion. Finally the section 4 summarizes the conclusion of the present work.

2. INSTRUMENTATION AND METHODOLOGY

The present study is carried out by installing a vertical profiling Micro Rain Radar (MRR) and Parsivel Disdrometer (PSD) in the premises of Regional Meteorological Centre (RMC), India Meteorological Department (IMD), Guwahati, a North East (NE) region of India (**Fig.1**). During the field campaign MRR was operated with vertical resolution of 200 m, temporal resolution of 1 min and the Parsivel disdrometer is operated with 1 min integration time. These two instruments were installed with a separation of 1.5 meters on the top of the radiosonde/rawinsonde (RSRW) building of the regional meteorological center (RMC), India meteorological department(IMD), Guwahati. Along with ground based instruments (Parsivel disdrometer, MRR , X-band radar, Automatic Weather station), data from radiosonde and MODIS Terra and Aqua daily level-3 satellite are considered for the present analysis.

2.1 Parsivel disdrometer

Parsivel Disdrometer is a laser based optical device for the complete and reliable measurement of size and fall speed of all kinds of precipitation. It has a Laser beam size of 180 mm length and 300 mm in width, with an operating wave length of 650 nm and output voltage of 3 mW. It measures hydrometeors with a size ranging from 0.2 – 5 mm for fluid precipitation and 0.2 to 25 mm solid precipitation with velocity measurement from 0.2 to 20 m/s. The measurement of this instrument is done by assuming the hydrometeors as oblate spheroids with a pre-assumed relationship between drop axis ration and drop diameter. The output data contain a 32 by 32 matrix, of size versus velocity values. Complete details of measurement technique, along with the assumptions made in determining the size and velocity of hydrometeors can be found in Loffler-Mang and Joss (2000)[22].

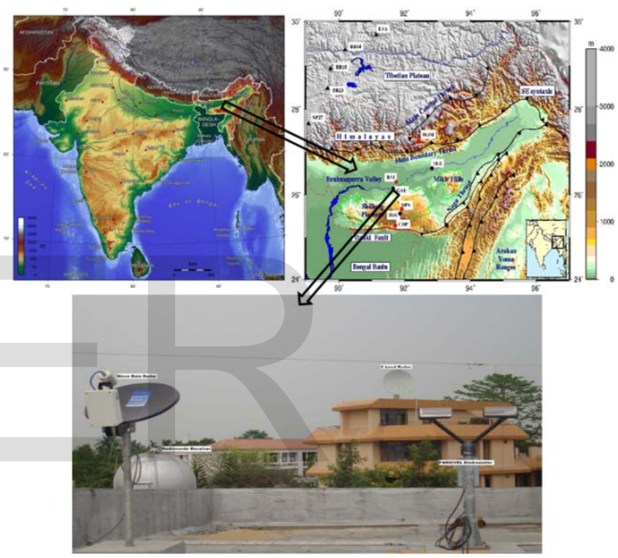

Fig.1: Observational site showing instrumental facility installed at Guwahati.

The rain drop concentration N(D) ($mm^{-1}\ m^{-3}$) at an instant of time from the parsivel are obtained from the following equation,

$$N(D_i) = \sum_{j=1}^{20} \frac{n_{ij}}{A \Delta t v_j \Delta D_i} \qquad \text{-----------------------(1)}$$

where n_{ij} is the number of drops reckoned in the size bin i and velocity bin j, A (m^2) and Δt are the sampling area and time, D_i (mm) is the drop diameter for the size bin i and ΔD_i is the corresponding diameter interval (mm), V_j (m/s) is the fall speed for the velocity bin j. From the rain drop concentration N(D), drop diameter (D) and fall velocity V_j

2.2 Micro Rain Radar

Micro Rain Radar (MRR) is a vertically pointing Frequency Modulation (FM)-Continuous Wave (CW) Doppler radar at 24 GHz which measures the Doppler spectrum from 0 to 12m/s [24], [25]. MRR is a vertically point Doppler radar, is a very useful instrument to measure

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vertical profiles of precipitation particle size distributions and structures. The complete performance and quantitative measurements of rain by MRR was explained by Loffler Mang et al.,(1999)[24].

From the raw spectral power received by the radar, the back scattering cross-section [$\sigma(D)$] and the spectral reflectivity [η (D)] as a function of drop diameter(D) are derived from which the precipitation particle size distribution N(D) is given by

$$N(D)=\eta(f_D)/\sigma(D) \quad \text{----------(2)}$$

From the precipitating particle size distribution N(D), the vertical structure of rain integral parameters like radar reflectivity (Z in dBZ), liquid water content (LWC in g/m3), rain rate (RR in mm/h) and fall velocity (w in m/s) are derived.

Radar Reflectivity, Z is calculated on the basis of raindrop size distribution. For the given drop-size distribution of a sample of rain, the radar reflectivity factor may be computed by the sum of the sixth moment of the diameters of all the drops contained in a unit volume of space, or the reflectivity factor Z may be written as:

$$Z=\int_0^\infty N(D)D^6 dD \quad \text{----------(3)}$$

This instrument provides vertical profile of other rain integral parameters like, rainrate, liquid water content, fall velocity of precipitation.

3. OBSERVATIONAL RESULTS

In the north-eastern region of India the summer monsoon air mass gets convective instability and also solar heating destabilizes the boundary layer, and convection preferentially develops over this region. Movement of the convective cells and development of further convection, results in short-lived air-mass-type thunderstorms, with a diurnal maximum and minimum in convection. The key factor of its occurrence is due to lower level cyclonic circulation over sub-Himalayan West Bengal and adjoining west Assam which moves towards east under influence of trough in westerly and finally struck over Guwahati and other region of Assam.

The present study details about the microphysical characteristics of a precipitating cloud system occurred in the early morning of 27th may 2010 with horizontal extent of 120 km and vertical extent of nearly 8 km. The horizontal and vertical view of the cloud system can be seen clearly from the x-band radar (**Fig. 2**) which is present near to the MRR and parsivel disdrometer (**Fig. 1**). The plane position indicator view of the cloud system is observed by the x-band radar at an elevation angle of 15 degrees. Each ring in the PPI corresponds to a distance of 20 km interval. In this computer generated display, reflectivity is showed in several shades of blue, each corresponding to predefined calibrated values of reflectivity in dBZ.

The radiosonde observation was done at 0000 UTC of 27th May 2010. The Skew-T diagram of the sounding profile is given **fig. 3**. From the radiosonde profile we can get an idea of the cloud environment over Guwahati. The sounding shows a temperature profile quite stable for the surface or near surface parcels and there was an inversion layer of 700 meters from the surface.

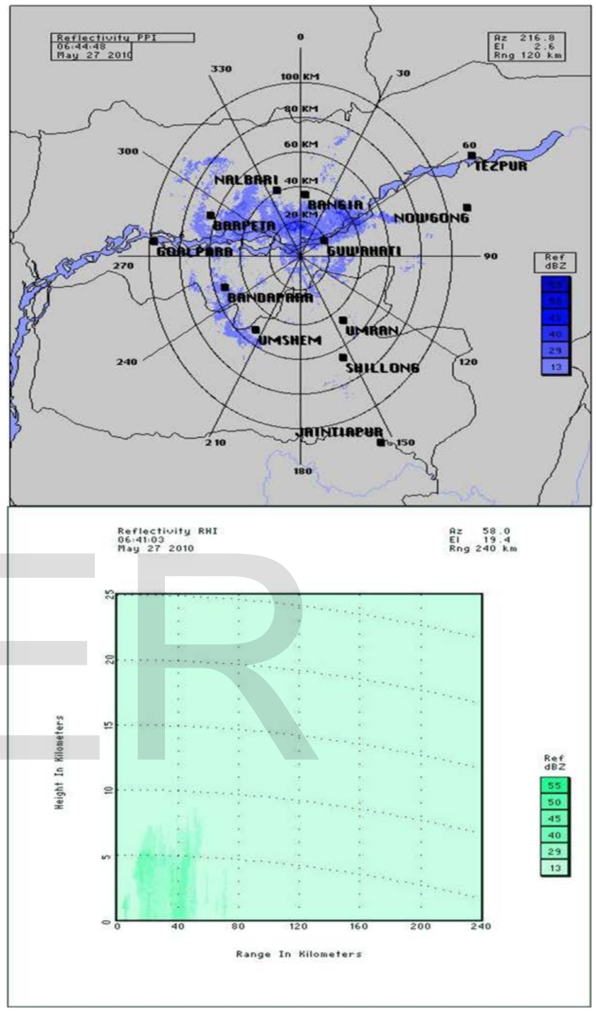

Fig.2: X-band Doppler radar plane position indicator (top) and range height indicator(bottom) image of the 27th May 2010.

A wind shear of 4 kts between 1000 hPa and 500 hPa and 26 kts between 850 hPa and 300 hPa were observed. The wind at 700 hPa was southeasterly with 16 kts. The calculated stability indices are given in the right side of the **fig. 3.**

The cloud properties like cloud top temperature, cloud water vapor, cloud effective radius of liquid and solid particles derived from MODIS satellite of the 27th May is given **fig.4.** The observational site is represented with black circle in the figure. The cloud top temperature over the observation site is about 246 K which indicated that the cloud is extended in to deeper altitude (above zero degree isotherm level) and it will associated with properties of cold clouds. The cloud water vapor values of 1 cm, cloud effective radius of liquid and ice are found to be 15 micro and 25 micro respectively.

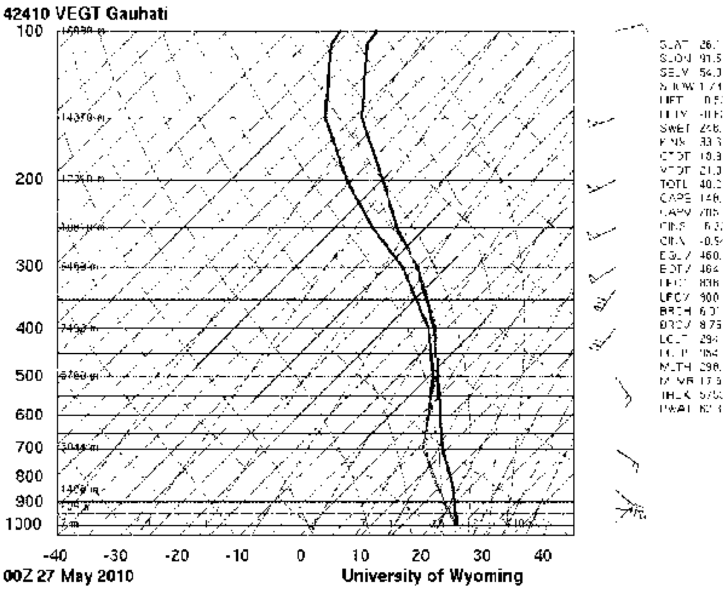

Fig.3: Radiosonde observation of 27th may 2010 obtained at 00 GMT in Skew-T diagram.

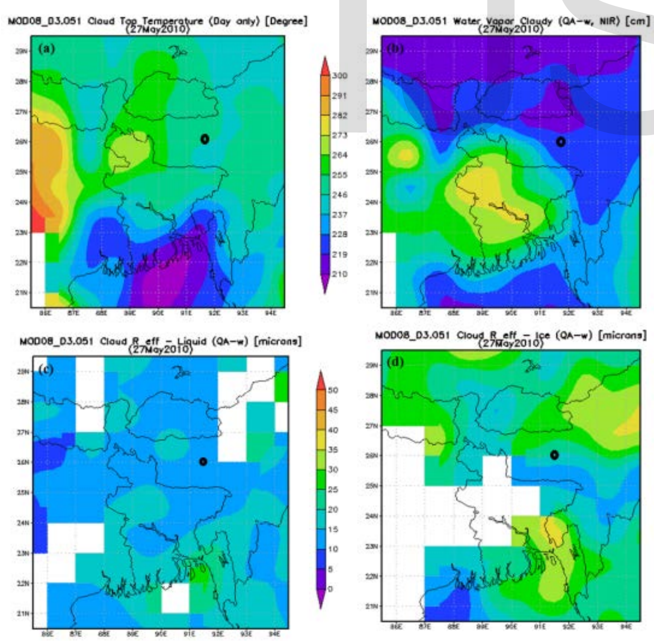

Fig.4: (a) cloud top temperature (K), (b) cloud water vapor (cm), (c) cloud effective radius of liquid(micron) and (d) solid precipitation(micron) of 27th May 2010 obtained from MODIS satellite.

The time series graphs of the precipitation occurred between 03:00 hrs to 09:00 hours on 27th may 2010 is given in **fig. 5.** The vertical profile of radar reflectivity obtained from MRR is given in **fig. 5** (a) and variations in drop concentration, radar reflectivity and rainrate measured with Parsivel disdrometer is given **fig. 5**(b) and (c) respectively. On the basis of reflectivity profile (**fig. 5a**) we divided the total precipitation into three events (E1, E2 & E3) with time periods of 22 minutes, 90 minutes and 114 minutes for the event1, event 2 and event 3 respectively. Radar reflectivity profile of event 1 is ranging from 17-24 dBZ from ground to 6 km. In the event 2 we observed a high reflectivity of 40dBZ at the ground and a reduced reflectivity ranging from 20 dBz to 30 dBz with increase in altitude. In event 3 a moderate reflectivity rang of 17 to 31 dBz is observed at the ground and with enhanced reflectivity of ~39 dBz is observed in the altitude range of 4.8 km to 5.4 km. From the cloud top temperature it is clear that the consider cloud system extend to above zero degree isotherm (**fig.4**) with the presence of ice particles. While descending these aggregation of ice particles above from the zero degree isotherm into air with a temperature warmer than 0^{o}C converted into liquid coated ice crystals. Because of the difference in the dielectric factor for ice and water (the dielectric constant of water exceeds that of ice by a factor of 4.4 or 6.5 dBZ) we will get an enhanced reflectivity just below the zero degree [26]. In its initial stages, melting produces distorted wet snowflakes with somewhat higher reflectivity than those of spherical drops of the same mass. While descending the snowflakes melts and become more compact and finally collapse into raindrops. Since the raindrops fall faster than the snowflakes their concentration in space is reduced. This dilution of the numbers accounts in part for the decrease of reflectivity in the lower part of the melting layer. The top of a melting layer is the melting level (or freezing height), commonly accepted as the altitude of the 0^{o}C isotherm surface. The raindrop concentration (fig. 5b) and radar reflectivity, rainrate (fig. 5c) values measured with parsivel disdrometer shows clear differences between the three events. More concentration of raindrops, higher values of radar reflectivity and rainrate are observed in event 2 followed event 3 and event 1. The time series variation of meteorological parameter (temperature, pressure, wind speed and wind direction) during the present considered precipitation case is given in **fig.6**. The clear indication of diurnal variation in temperature and pressure can be seen in the figure with a sharp drop in temperature in event 2 compared to event 1 & 3. A clear variation in wind speed and directions can be found during the three events of the precipitation.

The mean raindrop concentration of the three events is shown in **fig.7**. It can be clearly seen that concentration small (Diameter<=1mm) mid (1mm<diameter< 3mm) and large (diameter >=3 mm) is higher in event 2 than event 3 than event 1. The differences in the raindrop concentration can be understood with the microphysical mechanisms involved in the vertical structure of the three events in terms of collision, coalescence [27] and aggregation. For this we calculated the vertical distribution of raindrops from the MRR. The vertical distribution of three events is given fig. 8. If we

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ascend from 6.2 km to ground the concentration in raindrops is decreasing. Even though raindrops up to 3.5 mm are available at higher altitudes, only raindrops below 2 mm diameter are reaching the ground surface.

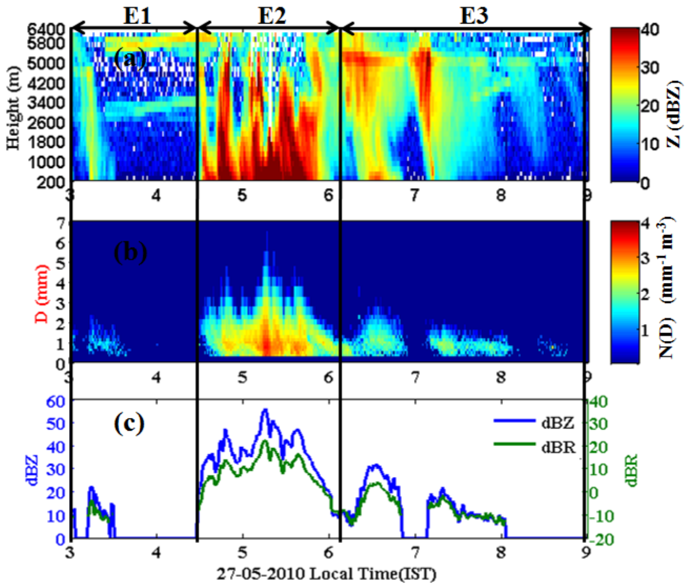

Fig.5: Rain Integral parameters observed on 27th May 2010. Time-height cross section of 1-min. observations of (a) radar reflectivity (dBz) from micro rain radar, (b) Time series of drop size concentration log (N) (mm^{-1} m^{-3}) and (c) radar reflectivity (dBz) and rainrate [$10*\log_{10}(R)$, dBR] from Parsivel disdrometer observations.

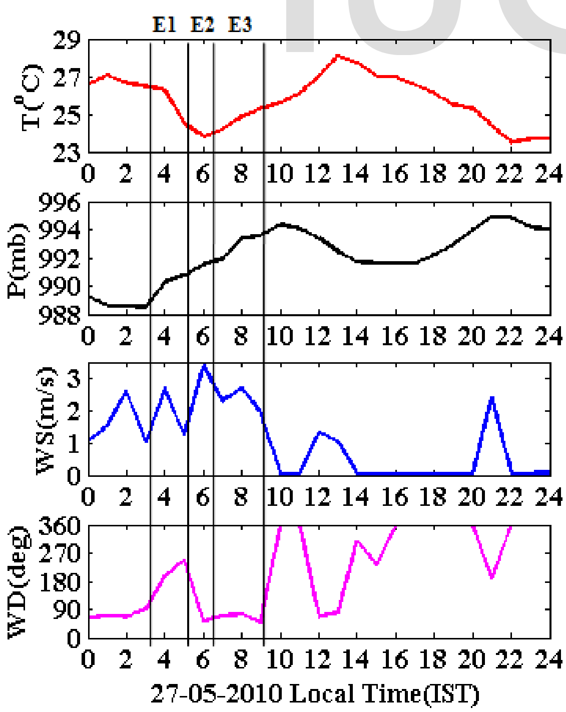

Fig.6: Time series of meteorological parameter [temperature(T°C), Pressure (P mb) wind speed (WS m/s), Wind direction (WD deg)]variations.

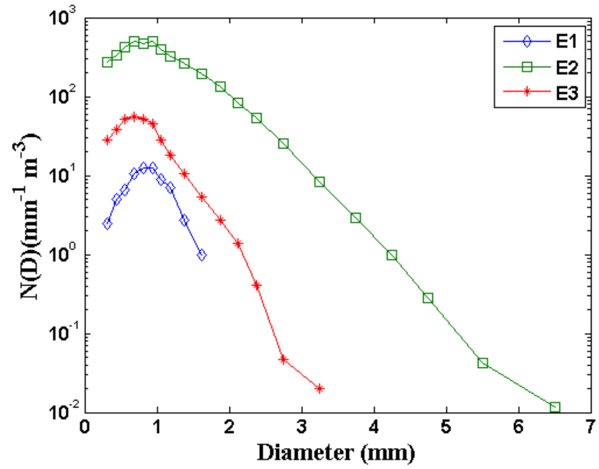

Fig.7: Drop concentration N(D)(mm-1 m-3) of three events (E1,E2,E3) of 27th May 2010 thunderstorm.

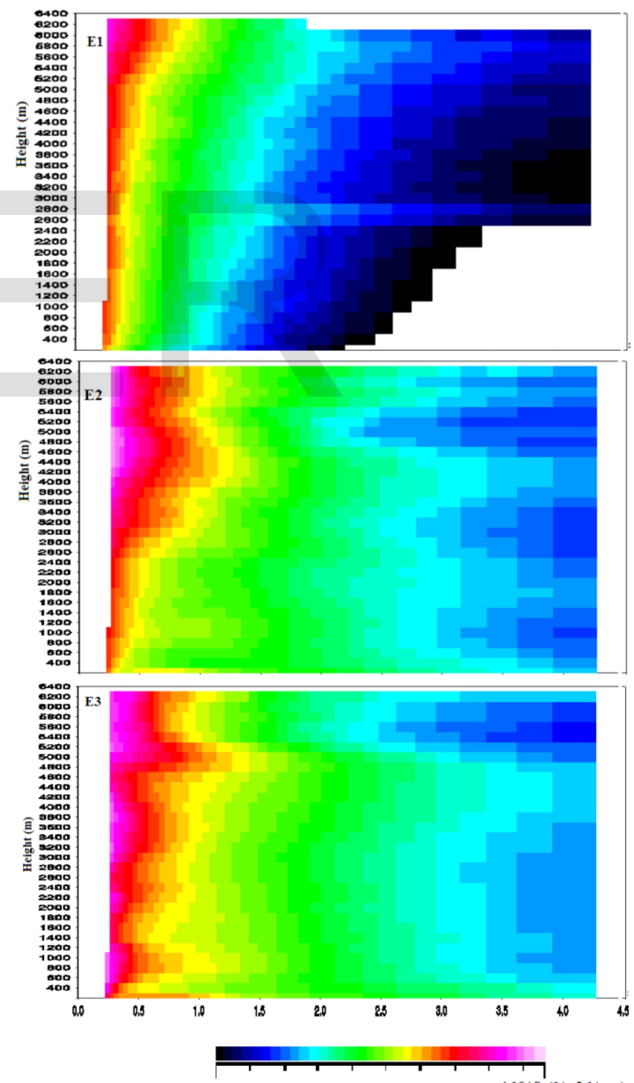

Fig.8: Drop concentration N(D) (mm-1 m-3) Vertical profile of 3 events (E1, E2, E3) of 27th May 2010.

This may be due to initial stages of storm activity with less collisions and coalescence process. In event 2 raindrops of larger size too reached the ground surface. The raindrop concentration observed at the ground level seems to be similar to that of 4 km to 4.4 km height concentration. Because of upward and downward motion[1],[28] there is more possibility of collision and coalescence during the descending of raindrops from higher altitude, which result in the higher drops with higher concentration. In event 3, a clear stratified layer of cloud structure knows as melting layer is seen (Fig. 5a). This indicates higher concentration of ice particle in this event where Bergeron process is more pronounced than collision coalescence process and hence producing less concentration of drops compared to event 2. These vertical profiles of radar reflectivity, and drop concentration shows that the event 2 has rigorous updraft and downdrafts which are absent in event 1 & 3. The stratified layer in event 3 represents the anvil shape of the cloud system after the its mature stage.

4. CONCLUSIONS

A precipitating cloud systems occurred on 27h May 2010 over Guwahati (26^{o} 17′ N, 91^{o} 77′ E), a north east region of India was analyzed to get their micro physical characteristics. The MODIS derived cloud properties revealed that the selected precipitation come under the category of cold cloud. On the basis of vertical profile of radar reflectivity the precipitation event is clearly separated into three events. These three event are found to be initial, mature and dissipating stage of thunderstorm. The raindrop concentrations measured at the ground level showed a higher in the mature stage than initial and dissipating stage. The concentration of dissipating stage is in between the initial and mature stage of storm. The vertical profile of drop size distribution revealed the microphysical mechanisms involved in each stage of storm. The mature stage is associated with major collision coalescence process and dissipating stage with more Bergeron process.

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