A NEW ALGORITHM FOR CLASSIFICATION OF TROPICAL CONVECTIVE PRECIPITATING CLOUDS OVER NORTH-EASTERN REGION OF INDIA

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ABSTRACT

The North East (NE) region of India is prone to severe thunderstorm during pre monsoon period. These pre-monsoon precipitations are measured at Guwahati (26º 17' N, 91º 77' E) using a laser based particle size and velocity (PARSIVEL) disdrometer from 15 April to 31 May 2010 under a national field campaign named Severe Thunderstorm Observational and Regional Modeling (STORM). For the improved understanding of these pre-monsoon thunderstorm a new cloud classification hybrid algorithm is developed based on thermodynamics and microphysical characterstics of precipitation. This algorithm can classify the premonsoon precipitaitng clouds into thuderstrom (TS), non- thuderstrom (NTS) and futher into convective & stratiform cloud fractions based on thermodynamic indices and rain integral parameters. The observation results showed that raindrops of Small and mid (large) size are having same concentration in convective (stratiform) regions of both TS and NTS precipitations. There is a large spread in the mean diameter (D_m) and total concentration (N_T) at higher rainrate of TS than NTS. The coefficient (A) of the radar reflectivity and rainrate relation (Z-R) is found to be smaller for TS than NTS. There is a significant difference in Raindrop concentration in stratiform, convective regions of TS and NTS precipitation.

KEYWORDS: *Thunderstorm, Rainrate, Radar reflectivity, Raindrop Concentration.*

I. INTRODUCTION

The Eastern and North Eastern (NE) part of India i.e., Gangetic West Bengal, Jharkhand, Orissa, Assam are affected by severe thunderstorms during pre-monsoon months, in particular, during April-May. These storms are also known as Norwesters as they move from Northwest to Southeast. Studies on thunderstorms at different parts of Indian are documented by a few researchers [1-4] using ground instruments, radisonde and satellite observations. There are studies on lightning [5], changes in thunderstorm electric field [6] and climatological aspects of thunderstorms, squalls [7] over Guwahati. There are different techniques viz., satellite [8 & 9], statistical [10], Fuzzy logic [11], Wavelet [12] and Neural Network [13] based approaches for classifying the precipitating clouds over the globe. However, so far there were no attempts on cloud classification over NE region of India. As microphysical characteristics are very important to understand thunderstorm development, propagation and dissipation, there is a need to study the Raindrop Size Distributions (RSD) parameters for the type of precipitation (stratiform, convective) and of thunderstorm, non thunderstorm [14-16]. Hence, for the first time an attempt is made to classify the precipitating clouds into stratiform, convective regions of Thunderstorm (TS) and Non-Thunderstorm (NTS) using a new hybrid algorithm. The main advantage of this algorithm is that, it utilizes both convective thermo-dynamical indices as well as RSD at the ground level. As convective indices gives information about the atmospheric instability of precipitating clouds and RSD represents the microphysical parameters of aloft cloud at the ground level, this hybrid algorithm is considered to be a more advantages for

classifying the tropical precipitating clouds.
The paper is organized as follows: Section 2 briefs about the experimental setup. A new cloud classification hybrid algorithm is explained in section 3. The results are detailed in section 4. Summery and conclusion are presented in section 5 followed by future work in section 6.

II. EXPERIMENTAL SETUP

For the improved understanding of precipitating clouds over NE region of India, continuous measurements of 1-min RSD are taken from the PARSIVEL disdrometer during Severe Thunderstorm Observational and Regional Modeling (STROM-2010) field campaign from 15 April to 31 May 2010 at Regional Meteorological Centre (RMC), India Meteorological Department (IMD), Guwahati (26º 17' N, 91º 77' E). The radiosonde launched every day at 00 and 12 GMT by the IMD at Guwahati and the data was downloaded from http://weather.uywo.edu/upperair/sounding.html. The instrumentation of PARSIVEL disdrometer and the thermodynamic indices are given in section 2.1 and 2.2, respectively.

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 hydrometeors. It has a laser beam size of 180 mm length and 30 mm in width, with an operating wave length of 650 nm and output voltage of 3 mW. The precipitation hydrometeor passing through the light sheet causes a decrease of signal due to extinction. The amplitude of the signal deviation is a measure of particle size, and the duration of the signal allows an estimate of particle fall velocity V(D). It measures hydrometeors with a size ranging from 0.2 – 5mm for fluid precipitation and 0.2 to 25 mm solid precipitation with velocity measurement from 0.2 to 20 m/s [Table 1].

Table 1. PARSIVEL disdrometer specifications

Parameter	Value
Optical Sensor operating wavelength	650 nm
Measurement surface	54 cm^2
Radar reflectivity	-9 to 99 dBZ
Rainrate	0.001 to 1200 mm/h
Particle size of fluid precipitates	0.2 to 5 mm
Particle size of solid precipitates	0.2 to 25 mm
Particle velocity	0.2 to 20 m/s
Rainfall accumulation	0.01 to 9999 mm
Sampling time	1 min

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 is given by Loffler-Mang [17].
The number concentration of the raindrops is given by the following equation

$$N(D_i) = \sum_{j=1}^{32} \frac{n_{ij}}{A.\ \Delta t.\ V_j\,.\Delta D_i} \qquad \text{……….(1)}$$

Where n_{ij} is the total number of raindrops
A is the measuring area of the laser beam (cm^2)
Δt is the sampling time in seconds
V_j is the measured fall velocity of raindrops in m/s
D_i raindrop diameter
From the obtained value of N(D) and V_j the rainrate and radar reflectivity factor can be obtained as given below

Rainfall rate (in mm/h) $$R = \frac{6\,\pi}{10^4} \sum_{i=1}^{32} \sum_{j=1}^{32} V_j\, N(D_i)\, D_i^3\, \Delta D_i \qquad \text{……….(2)}$$

Radar reflectivity factor (in dBZ) $Z = \sum_{j=1}^{32} N(D_i)\, D_i^6\, \Delta D_i$ ……….(3)

The n^{th} order moment of the drop size distributions is expressed as

$$M_n = \int_{D_{min}}^{D_{max}} D^n\, N(D) dD \quad ……….(4)$$

Where n=3 for 3rd moment, 4 for 4th moment and 6 for 6th moment of the size distribution. The mass-weighted mean diameter D_m (mm), shape parameter μ and slope parameter Λ (mm^{-1}) are obtained from the 3rd, 4th and 6th moments of the size distribution as

$$D_m = \frac{M_4}{M_3} \quad ……….(5)$$

The slope parameter - Λ (mm^{-1}) is given by

$$\Lambda = \frac{(\mu + 4)M_3}{M_4} \quad ……….(6)$$

Where μ is the shape parameter without dimensions and is given by

$$\mu = \frac{(11\,G - 8) + \sqrt{G(G+8)}}{2(1-G)} \quad ……….(7)$$

Where G is

$$G = \frac{M_4^3}{M_3^2\ \ M_6}$$

2.2 Computation of thunderstorm stability indices

Thunderstorm indices like Lifted Index (LI) [18], Convective Available Potential Energy (CAPE) [19], Total Total Index (TTI) [20], Severe Weather Threat Index (SWEAT) [20] are computed for radiosonde data collected at Guwahati.

2.2.1. Lifted Index (LI)

The Lifted Index (LI) is defined as the difference between the observed temperature at 500 hPa (T_{500}) and the temperature (T_{parcel}) of a parcel after it has been lifted pseudo adiabatically to 500 hPa from its original level. It therefore focuses on the latent instability of an air sample.

$$LI(K) = T_{500} - T_{parcel} \quad ……….(8)$$

where T_{500} is the environmental temperature at 500 hPa, and T_{parcel} is the parcel temperature.

2.2.2 Convective Available Potential Energy (CAPE)

It represents vertically integrated positive buoyancy of an adiabatically rising parcel from level of free convection (Z_{LFC}) to the equilibrium level (Z_{EL}).

$$CAPE = \int_{Z_{LFC}}^{Z_{EL}} g \left(\frac{T_{v,parcel} - T_{v,env}}{T_{v,env}} \right) dz \quad ……….(9)$$

Here $T_{v,parcel}$ and $T_{v,env}$ is virtual temperature of the Parcel and environment

2.2.3 Total Total Index (TTI)

This index is useful to assess the storm strength but fails to consider the latent instability below 850 hPa.

$$TTI\ (K) = (T_{850} - T_{500}) + (T_{d850} - T_{500}) \quad ……….(10)$$

where T_{850} and T_{500} are the environmental temperature at 850 hPa and 500 hPa and T_{d850} is the environmental dew point temperature at 850 hPa

2.2.4 Severe Weather Threat Index (SWEAT)

The SWEAT index was designed to assess severe weather potential, such as severe storms and tornadoes.

$$SWEAT = 12T_{d850} + 20\,[\,TT(K) - 49] + 2\,f_{850} + f_{500} + 125[\sin(d_{500}-d_{850})+0.2] \quad \text{……….(11)}$$

where f_{850} and f_{500} *are* the wind speeds at 850 hPa and 500 hPa pressure levels in knots
d_{850} and d_{500} are the wind direction at 850 hPa and 500 hPa pressure levels (0-360°)

III. CLOUD CLASSIFICATION ALGORITHM

In the proposed hybrid algorithm LI and CAPE indices are used. As LI and CAPE are good measurements of the atmosphere's potential to produce severe thunderstorms, these two Indices (LI & CAPE) are considered as a rainfall classification into TS and NTS. The rainfall days with CAPE $\geq$ 200J/Kg and LI< 0 (K) are considered as TS days otherwise as NTS days. The TS and NTS rainfall events are further classified into convective and stratiform events with a jump in the intercept parameter (N_0) of the gamma-fitted drop size distribution [$N(D) = N_o D^{\mu} e^{-\Lambda D}$] [21]. The observed raindrop spectra are fitted to three parameter gamma drop size distribution using third, fourth, and sixth moments of observed spectra [22]. More detailed information about RSD based precipitation classification is given by Tokay and Short [14]. The flow chart of proposed hybrid algorithm is shown in Fig.1.

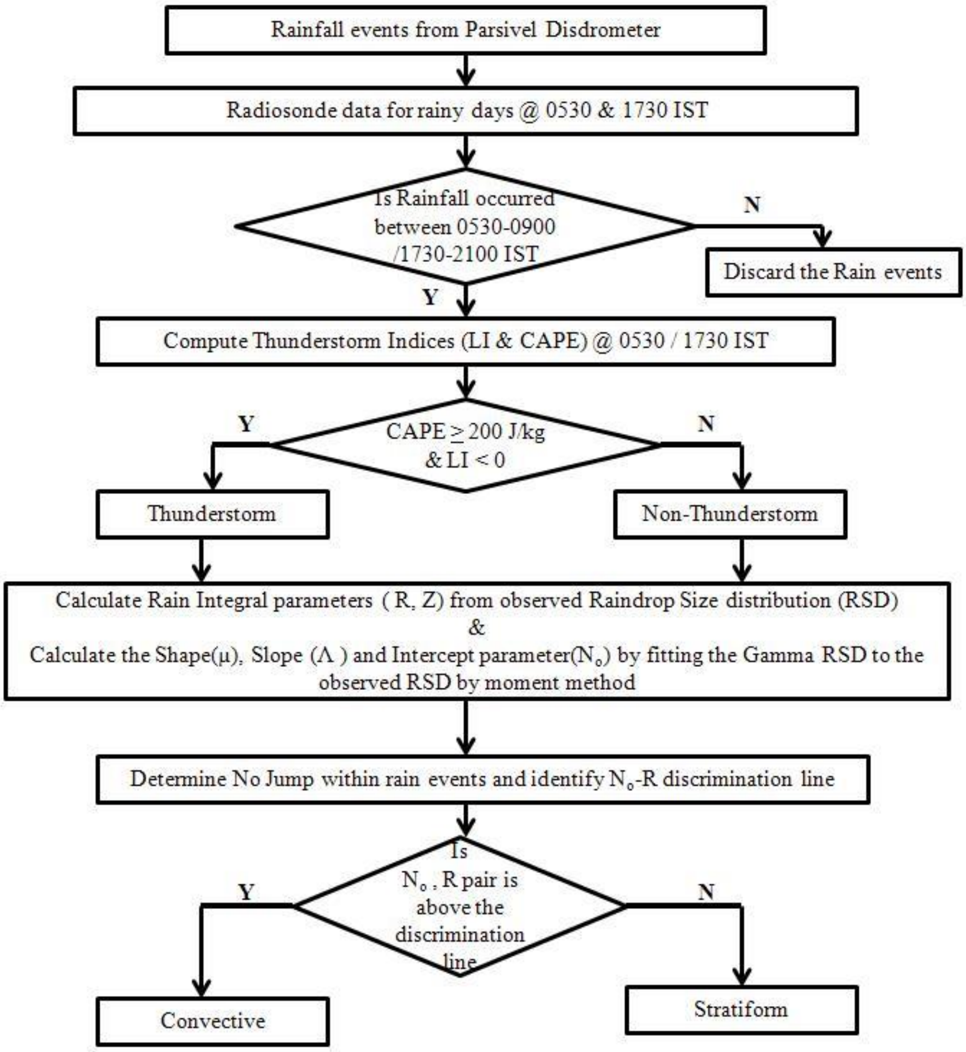

Fig.1. A new cloud classification (into TS,NTS, convective & stratiform) hybrid algorithm

IV. RESULTS

During STORM-2010 field campaign a total number of 32 rainfall days are observed. In the present study only 10 days are qualified for utilization of the proposed algorithm [as shown in Fig.1]. To meet the selection criterion, the rainfall must be occurred between 05:30-09:00 Indian Standard Time (IST) or 17:30-21:00 IST and the availability of radiosonde data. 10-days rainfall data during STORM-2010 are listed in Table 2 and results obtained by using hybrid algorithm are given in sections 4.1, 4.2 and 4.3 respectively.

Table 2. Selected rain events from STORM-2010 field campaign**.**

Rain Event	Date of Event	Time(IST)	No of samples (min)	Maximum Rainrate (mm/h)
1	02-05-2010	02:37-11:08	439	241.2
2	08-05-2010	05:14-13:10 22:15-23:08	174	2.3
3	09-05-2010	01:04-11:23 18:51-19:40	385	65.4
4	10-05-2010	05:33-06:36 10:13-10:51	95	81.8
5	19-05-2010	02:27-10:35	188	77.0
6	20-05-2010	03:11-23:19	621	53.4
7	21-05-2010	03:41-08:57	165	2.6
8	22-05-2010	04:09-07:57	79	2.7
9	27-05-2010	02:59-09:51 21:14-22:07	285	165.6
10	31-05-2010	03:10-07:36	291	32.1

4.1. RSD Variation between Convective and Stratiform Events

Using a new cloud classification algorithm [Fig.1] it is found that the TS precipitation is having convective events for a period of 248 minutes and 958 minutes of stratiform events. Similarly, during the NTS precipitation, 40 minutes of convective, 499 minutes of stratiform precipitating clouds are observed. The raindrop size distribution of TS, NTS and convective, stratiform precipitating clouds are shown in Fig.2.

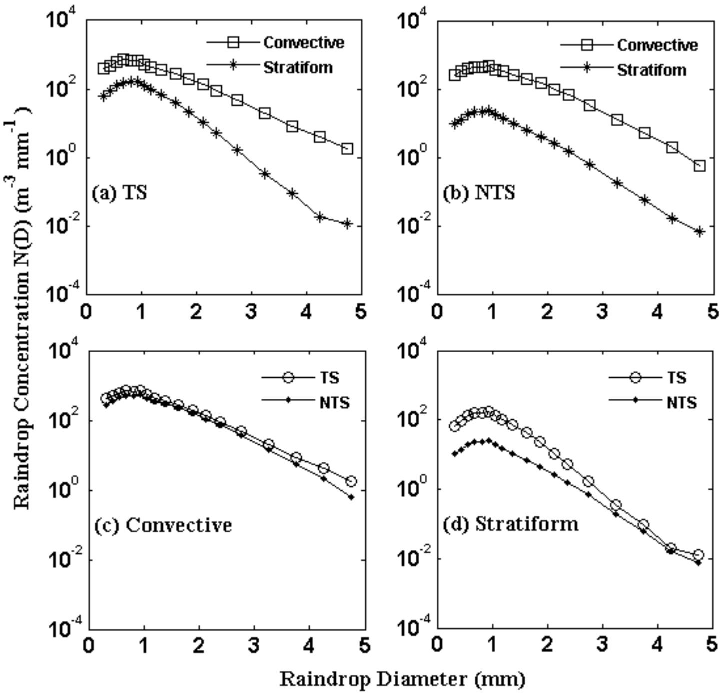

Fig.2. Raindrop concentration Vs raindrop diameter of convective and stratiform regions of Thunderstorm (TS) and Non-Thunderstorm (NTS) rain events.

In the present study raindrops below 1-mm diameter are considered as small drop, 1-3 mm diameter as midsize drops and above 3-mm diameter as large drops. In TS rainfall [Fig.2 (a)] small drops are having less change in RSD between convective and stratiform precipitating clouds whereas mid and large drops are having a large change in RSD between convective and stratiform precipitating clouds. In NTS [Fig.2 (b)] there is large difference between convective and stratiform region of all (small, midsize and large) raindrops. In convective precipitating clouds [Fig.2(c)] small and midsize drops are having same concentration for both TS and NTS rainfall and large drops are having slightly higher concentration TS compared to NTS. In stratiform precipitating clouds [Fig.2 (d)] the concentration difference between TS and NTS gradually decreased with increase in raindrop diameter.

4.2. Shape (μ), Slop (Λ), D_m and N_T Variations

The variation of shape (μ) and slope parameter Λ (mm^{-1}), mean diameter D_m (mm) and total drop concentration N_T [Σ $N(D_i)$ (m^{-3})] with rainrate of TS and NTS rainfall are shown in Fig.3. From the Fig.3 it is clear that the range of variability of rain integral parameters during the NT is more for TS than NTS below 20 mm/h rainrate. This variation decreases with increase in rainrate and becomes more uniform above 20 mm/h. The shape (μ) and slope parameter Λ (mm^{-1}) decreased with the increase in rainrate [Fig.3 (a) & (b)] and this decrease is sharper in NTS than TS rainfall. The D_m increased with increase in rainrate [Fig.3(c)] but this increase is steeper in NTS than TS rainfall.

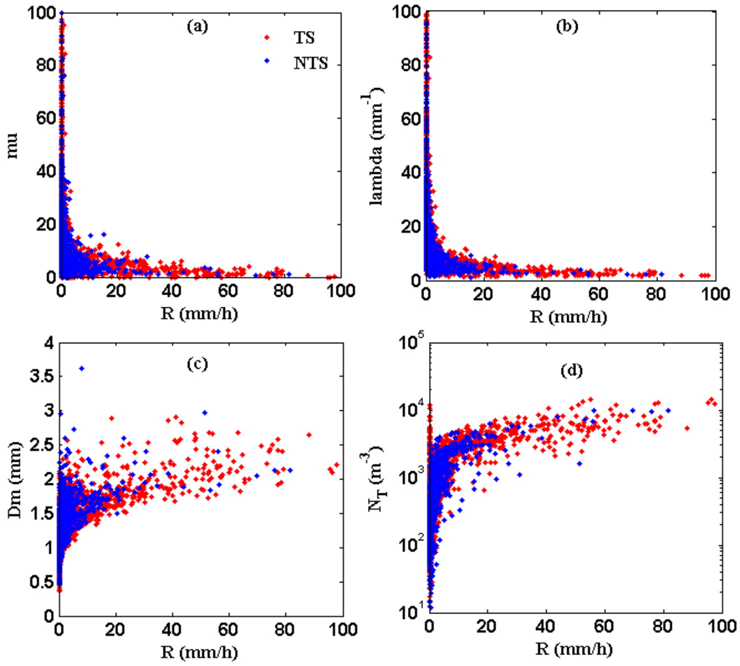

Fig.3. Variation in (a)shape (mu-μ) parameter, (b) slope (lambda-Λ) parameter, (c) mean diameter (D_m) and (d) total concentration (N_T) between Thunderstorm (TS) and Non-Thunderstorm (NTS) rainfall.

In TS rainfall high concentration N_T is observed for rainrates above 20 mm/h and NTS rainfall is having high concentration for rainrates below 15 mm/h [Fig.3 (d)]. There is a large spread in concentration of TS rainfall at higher rainrates but for NTS this spread is limited to small rainrates.

4.3 Radar Reflectivity (Z) and Rainrate (R) Relation

The Z-R relationship is primarily dependant on the raindrop size and distribution and these two may vary with geographic location, season and storm characteristics. The rainrate R and reflectivity Z are related by

$$Z=A*R^b \qquad \text{……….(12)}$$

Where Z is in $mm^6\ m^{-3}$, R in mm/h, and 'A' and 'b' are the coefficient and exponent which depends on the raindrop number distribution $N(D)$. By applying natural logarithm to both sides of equation (12) we get

$$10*\ln Z = 10*\ln A + b*(10*\ln R) \qquad \text{……….(13)}$$

$$dBZ=10*\ln A+b*dBR \qquad \text{……….(14)}$$

Where *dBZ=10* ln Z, dBR=10*ln R*

The coefficients 'A' and 'b' of equation (14) were estimated by using linear regression between *dBZ* and *dBR*. With these relations ($Z=A*R^b$) a radar can be used to identify areas of extreme precipitation that could lead for severe thunderstorms. Over the globe there were studies on the Z-R relations for different climatic regions [24,25] and for different precipitations [26 & 27]. Sivaramakrishnan [28] obtained Z-R relations for thunderstorm ($Z=219R^{1.41}$), steady rains ($Z=67.6R^{1.94}$) and warm rains ($Z=66.5R^{1.92}$) over Poona, in the western part of India. In the North part of India Z-R values of orographic monsoon rains ($Z=109\ R^{1.64}$) at Kandia and of non orographic monsoon rains ($Z=342\ R^{1.42}$) at New Delhi was reported by Rama Murthy [29]. In southern India seasonal [26] and cyclonic and NE monsoon precipitation [30] variations in Z-R relations are documented. However there were no studies on Z-R relations over NE region of India. For the first time we obtained the Z-R relations of pre-monsoon precipitating cloud at Guwahati. The $Z= A*R^b$ relations of stratiform and convective regions of TS and NTS rainfall events are obtained from scatter plots of radar reflectivity(dBZ) and rainrate (dBR) (Fig.4).

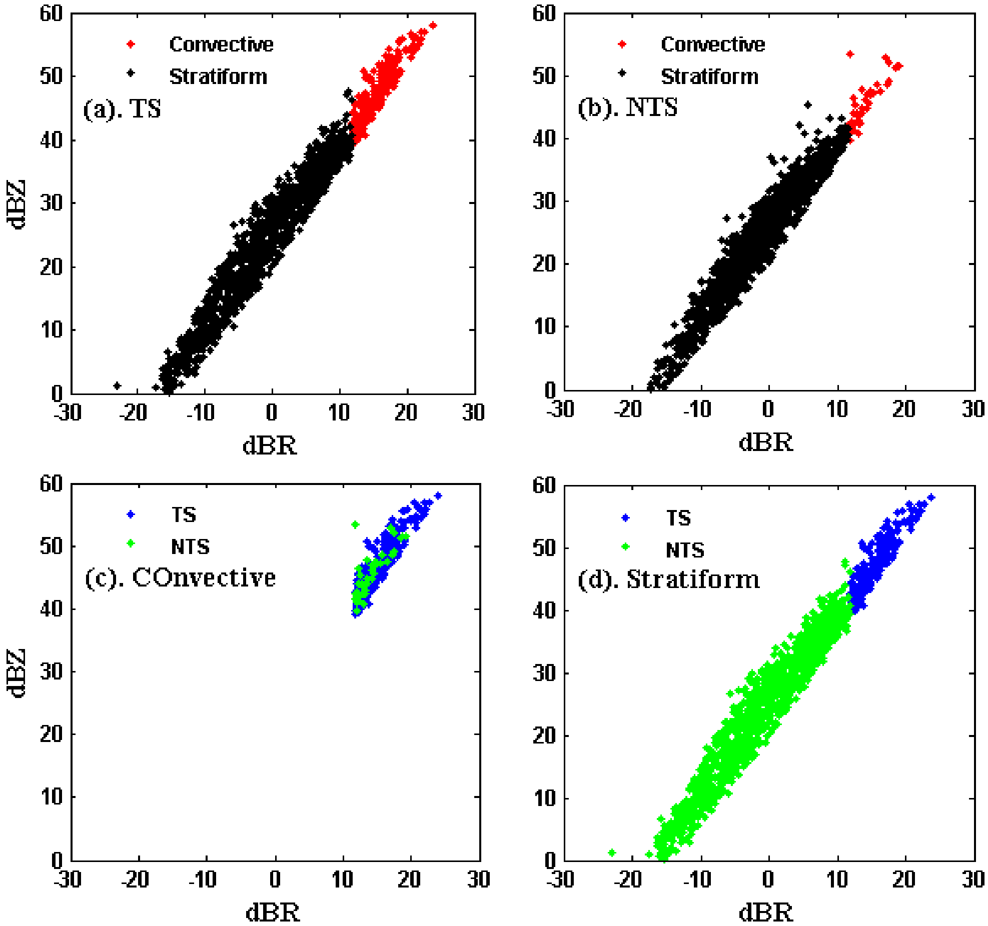

Fig. 4. Radar reflectivity and rainrate relation of convective and stratiform region of Thunderstorm (TS) and Non-Thunderstorm (NTS) events.

From the Z-R scatter plots of stratiform and convective regions it is clear that the NTS induced precipitation is having raindrops of size less than or equal to that of TS precipitation raindrops. The coefficient 'A' and exponent 'b' of stratiform, convective regions of TS and NTS rain events are shown in Table. 3.

Table 3. Z=A*R^b values of convective, stratiform events of Thunderstorm (TS) and NonThunderstorm (NTS) rainfall events

RAIN TYPE	CONVECTIVE			STRATIFORM			ALL EVENTS		
	A	**b**	**R^2**	**A**	**b**	**R^2**	**A**	**b**	**R^2**
TS	185.90	1.57	0.92	332.65	1.41	0.97	331.86	1.41	0.98
NTS	461.04	1.34	0.78	410.11	1.42	0.96	407.27	1.42	0.97

The coefficient 'A' of NTS is higher than TS in both the convective and stratiform region, but the exponent 'b' of NTS is smaller (higher) than TS in convective (stratiform) region.

V. SUMMARY AND CONCLUSIONS

In order to understand pre-monsoon precipitating clouds over NE region of India a new cloud classification hybrid algorithm is developed to classify the rainfall events into Thunderstorm (TS), Non-Thunderstorm and further into convective and stratiform precipitation events. Based on the new cloud classification hybrid algorithm results showed that small (mid & large) drops are having less (large) concentration difference in convective and stratiform regions of TS rainfall. But all the raindrops (small, mid & large) drops are having higher concentration in convective region than stratiform region of NTS rainfall. The small and midsize raindrops of TS and NTS rainfalls are having same concentration and large drops are having slightly higher concentration in convective precipitating clouds. In the stratiform regions the drop concentration difference between TS and NTS gradually decreased as we move from small to large raindrops. The shape (μ) and slope (Λ) parameters are having higher values in TS than NTS rainfall. There is large spread in the D_m and N_T values for lower rainrates in NTS where as at higher rainrate for TS. From the combined observation of N_T and D_m it is clear that the heavy rain events were mainly composed of high concentrations of small to medium sized raindrops rather than large raindrops. Results from new cloud classification hybrid algorithm for radar reflectivity (Z) and rainrate (R) relations shows that the coefficient 'A' of NTS is higher than TS in both the convective and stratiform precipitating clouds, but the exponent 'b' of NTS is smaller (higher) than TS in convective (stratiform) precipitating clouds.

VI. FUTURE WORK

In this paper, pre-monsoon RSD characteristics of thunderstorm/non-thunderstorm precipitating clouds over Guwahati are studied in detail using new cloud classification hybrid algorithm. Moreover, this research work will be extended to the rest of NE region for better understanding of microphysical characteristics of thunderstorm/non-thunderstorm precipitating clouds. In addition, climatological/seasonal variation of thunderstorm/non-thunderstorm precipitating clouds over NE region will be studied.

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