ISSN: 0976-3031

Available Online at http://www.recentscientific.com

International Journal of Recent Scientific Research
Vol. 8, Issue, 1, pp. 15413-15422, January, 2017

International Journal of Recent Scientific Research

Research Article

DEVELOPMENT OF ALGORITHM FOR CLASSIFICATION OF THUNDERSTORM PRECIPITATING SYSTEMS OVER GUWAHATI

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ARTICLE INFO

Article History:

Received 17th October, 2016
Received in revised form 12th November, 2016
Accepted 04th December, 2016
Published online 28th January, 2017

Key Words:

Thunderstorms, Thermodynamic instability parameters/indices, Microphysical characteristics

ABSTRACT

Thunderstorm is a mesoscale system characterized by heavy rain showers, lightning, thunder, hail-storms. In the North-Eastern region of India during pre-monsoon season is affected by severe thunderstorms called 'Norwesters' and locally called 'Kal Baishaki'. To understand the severe thunderstorm characteristics, we have successfully conducted three field campaigns during the period from 15th April to 31st March for the consecutive years 2009, 2010 and 2011 by deploying Micro Rain Radar, PARSIVEL (Particle size and Velocity) Disdrometer, Lightning Sensors, and Automatic Weather Station at Regional Meteorological Centre, India Meteorological Department, Guwahati.

The intention of this paper is to develop a methodology for classification of MPS into hailstorm, thunderstorm, convective/Non-thunderstorm and stratiform precipitating clouds on the basis of the thermo-dynamical and microphysical parameters. The algorithm assimilates more than one information bases from Radiosonde, lightning sensor, PSD, MRR and AWS observations. The proposed methodology is evolved on thermodynamical parameters, lightning strokes and length, microphysical parmeters on ground and aloft. This algorithm performance was evaluated by using STORM three intensive observational periods i.e., IOP-2009, IOP-2010 and IOP-2011, respectively.

INTRODUCTION

Thunderstorm, resulting from vigorous convective activity, is one of the most magnificent weather phenomena in the earth's atmosphere. The severe thunderstorms associated with thunder squall, hail storm, tornado, flash flood and lightning cause extensive damage and losses to lives and property. A common feature of the weather during the pre-monsoon season over the North Eastern Region of Indian (NERI) is the outburst of severe local convective storms.

Several studies were carried out over United States of America (Brandes *et. al.*, 1995), Europe (Roman *et. al.*, 2002), South America (Sánchez *et. al.*, 2009), and in other countries to understand major advances in continental thunderstorm dynamics, modeling, electrification and role of cloud micro-physical processes and also predict these severe storms. Kotroni *et. al.*, (1997) studied the initiation of summer thunderstorm activity over the Greek peninsula during a prevailing weak synoptic flow is investigated using the Colorado State University-Regional Atmospheric Modeling System (CSU-RAMS) and the Hybrid Particle and Concentration Transport Package (HYPACT). Brooks *et. al.*, (2003) have used the National Center for Atmospheric Research (NCAR)/United States National Centers for Environmental Prediction (NCEP) reanalysis system to create soundings and find environmental conditions associated with significant severe thunderstorms (hail at least 5 cm in diameter, wind gusts at least 120 km/h, or a tornado of at least F2 damage) and to discriminate between significant tornadic and non-tornadic thunderstorm environments in the eastern United States for the period 1997–1999. Chen *et. al.*, (2007) showed that because of urbanization afternoon thunderstorm activity was enhanced over Taipei.

A few thunderstorm field experiments are carried out over Indian sub-continent using automatic weather station, radiosonde and mesoscale models. Ghosh *et. al.*, (2004) classified thunderstorm and non-thunderstorm days in Calcutta on the basis of linear discriminate analysis. Ravi *et. al.*, (1999)

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proposed two objective methods based on stability indices to forecast the occurrence of thunderstorms at Delhi. Mukhopadhyay *et. al*., (2003) worked on objective forecast of thundery/non-thundery days using conventional data over three NER stations. Dhawan *et. al*., (2008) used statistical techniques for forecasting pre-monsoon thunderstorms for north-west India. Guha *et. al*., (2009) studied lightning electrical characteristics during tropical summer thunderstorm over NER. A study of thermodynamic indices in forecasting pre-monsoon thunderstorms over Kolkata during STORM pilot phase 2006–2008 carried out by Tyagi *et. al*., (2011). Kandalgaonkar *et. al.*, (2005) studied thunderstorm and rainfall activity over the Indian region and they showed that there is a time lag of one month in the occurrence of peak activity of Thunderstorm and Rainfall activity. Nath *et. al*., (2009) studied the lightning activity over land and oceanic regions of India. Tinmaker *et. al*., (2010) studied thunderstorm electrical parameters vis-a-vis rainfall and surface air temperatures over Pune.

The studies on thunderstorms in India are limited to case studies/synoptic studies and the microphysical, as well as dynamical processes leading to the development of these severe storms are not well understood due to lack of mesoscale observations with good spatial and temporal resolutions. Realizing the importance of improved understanding and prediction of these weather events, Yogi Vemana University research team deployed sophisticated ground – based instruments at India Meteorological Department Observatory at Guwahati (91°35'9" E; 26°6'22" N) Airport as well as data from meteorological satellites are utilized to understand the dynamics, thermodyanmical and microphysical characteristics of the thunderstorms. To understand dynamical and microphysical variations of meteorological parameters are before, during and passage of Thunderstorm. We also utilized COSMIC, OLR data for further understanding/ interpretations pre-monsoon precipitating clouds. In the next section, we describe the topography over north-eastern region (NER) of India.

The experimental site, Guwahati is located in the Assam Valley Topography of Assam shows the positional features of the state. Sharing its borders with various states like Meghalaya, Nagaland, Bhutan, Mizoram, West Bengal, Arunachal Pradesh and Manipur, Assam is located on the north-east part of India. The topography of Assam is also featured through many quaint hills that existed in the land from ancient periods. In fact some of the hills of Mizoram, which is an adjoining state, act as the boundary indicators.

The prime geographical characters that form the topographical features of Assam are the Barak Valley and the River of Brahmaputra. From north-eastern corners to west and further towards south, the Brahmaputra River spread its rich alluvial plains across the length and breadth of Assam. Due to typical geographical position of Assam and also it is highly prone to moderate to severe thunderstorms and occasionally with hailstorms during Pre-monsoon season (March–May). Considering its destructive potential in short duration, now-casting of occurrences of this event has been always a forbidden challenge to Meteorologists.

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Instrumentation and Topography

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 **(**Figure 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. IMD meteorological instruments like Radiosonde/Rawinsonde (RS/RW), and X-band Radar data also used. In addition to these instrumental facilities, we also utilized Constellation Observing System for Meteorology Ionosphere and Climate (COSMIC) and Outgoing Longwave Radiation (OLR) data to understand Hailstorm, thunderstorm and non-thunderstorm precipitating clouds observed during pre-monsoon.

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 to 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).

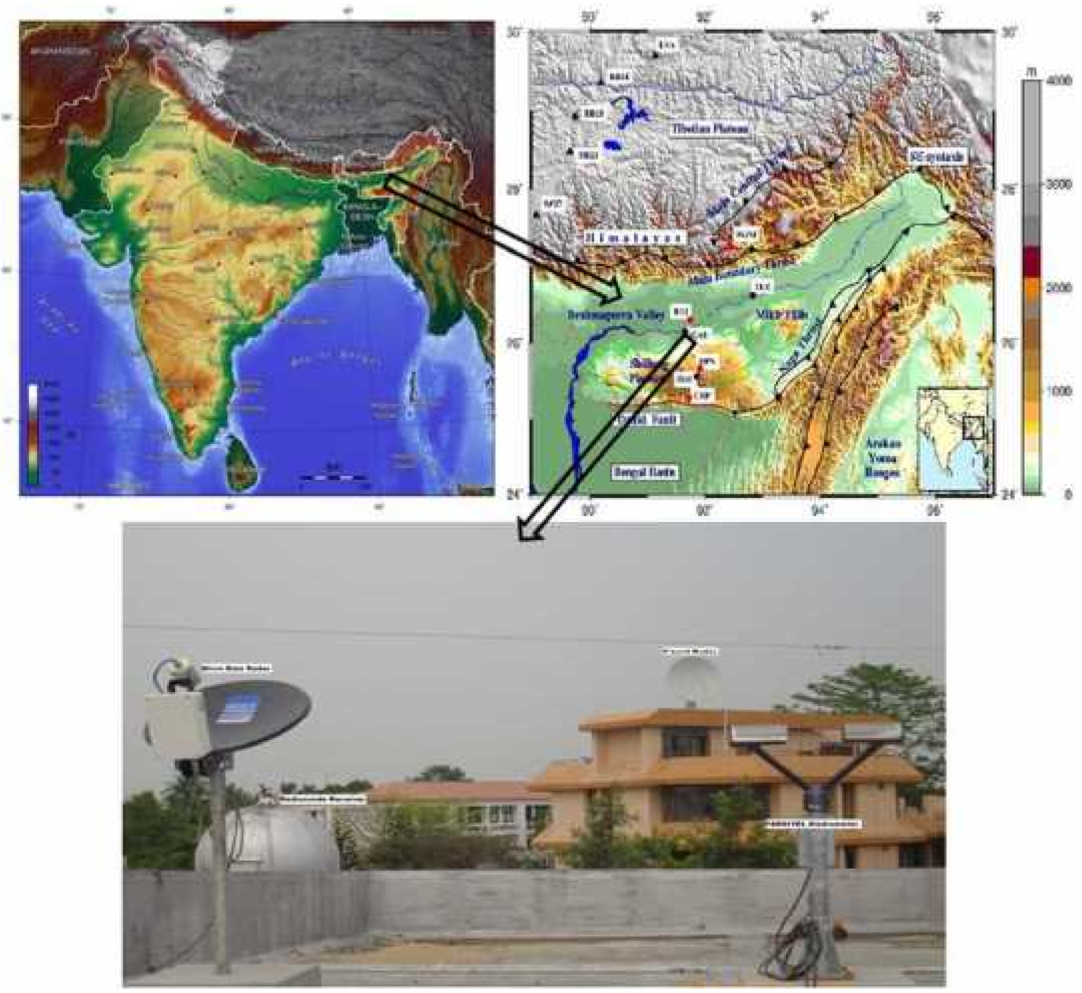

Figure 1 Observational site showing instrumental facility installed at Guwahati

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

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

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.

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 (Loffler Mang *et al.*, 1999). MRR is a vertically point Doppler radar, is a very useful instrument to measure 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).

From the raw spectral power received by the radar, the back scattering cross-section [σ(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/m^3), 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.

Data and Methodology

For the present study, we developed a classification algorithm to bridge this gap by compiling some unique recent observations over the NERI during pre-monsoon and diagnose the inherent microphysical processes and the thermodynamical environment therein. The proposed algorithm is depicted in Fig.2.Thunderstorm indices like Lifted Index (LI) (Galway, 1956), Convective Available Potential Energy (CAPE) (Moncrieff and Miller, 1976), Total Total Index (TTI) (Miller, 1972), Severe Weather Threat Index (SWEAT) (Miller, 1972), Convective inhibition (CIN) are computed from the selected radiosonde data. 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 > 1000 J/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 (N0) of the gamma-fitted drop size distribution [N (D) =No Dm e-ΛD] (Waldvogel, 1974). The observed raindrop spectra are fitted to three parameter gamma drop size distribution using third, fourth, and sixth moments of observed spectra (Kozu and Nakamura, 1991). More detailed information about RSD based precipitation classification is given by Tokay and Short (1996).

measurements provided unique in situ cloud-physics data of feeder clouds to severe hailstorms, with coverage from base to the anvil levels. This study uses exclusively the data of the natural (not seeded) clouds to provide insights to the microphysical evolution of the tops of the hailstorm convective elements as they grow from cloud base to the anvil level. The objectives in the context of this goal were the documentation of the vertical evolution of the cloud drop size distribution, cloud liquid water contents (LWC), longevity of the super-cooled water, the initiation of precipitation in both liquid and ice processes, and the thermal structure/ temperature, below which no super-cooled water is available for the growth of hailstones. The weather map remains one of the key tools for the study of atmospheric processes and the prediction of the weather. A synoptic weather map observed on 22 April 2010 is shown in Figure 3.

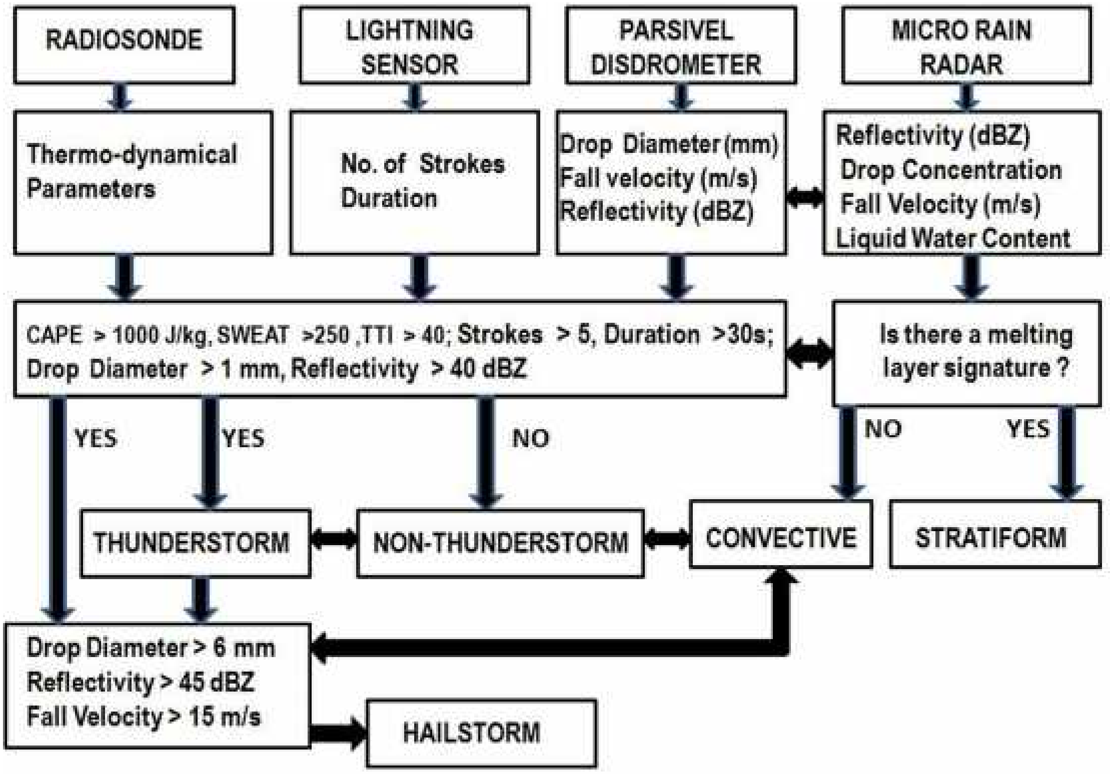

Figure 2 Algorithm for classification of mesoscale system into of Stratiform, mixed, convective, thunderstorm, non-thunderstorm, Hailstorm

Classification of mesoscale precipitating clouds observed on 22-04-2010

The vertical profile has been highlighted in several recent field studies in tropical regions and is a major concern over land. It has been shown that, in a single location, the vertical extent and strength of precipitating convective storms can vary on time scales of days to weeks (Williams *et al.* 1995). In clouds with deeper vertical extent, more ice may be present for the same amount of precipitation on the ground relative to a shallower cloud. In India this research involved documentation of the dynamical and microphysical structure of the thunderstorms/ hailstorms observed during STORM -2010, using micro rain radar, Parsivel disdrometer and satellite observations. The

Vertically-pointing micro rain radars (MRRs) provide a new alternative method of monitoring vertical profiles of Rain drop size distribution parameters and also partitioning of precipitating clouds into convective and stratiform and also characterization of melting layer/Bright band. By measuring the backscatter of radiation from precipitation-sized particles a number of parameters to be generated, enabling rain rate, drop size distribution, fall velocity and liquid water content to be retrieved. (Deiderich *et al.*, 2004) performed the quality of the Doppler spectra and the validity of the MRR. Peters *et al.*, (2005) studied the Profiles of Raindrop Size Distributions retrieved by Micro Rain Radars. Cha *et. al.*, (2009) studied the bright band characteristics over mountain and coastal site in South Korea using Micro Rain Radar. Cha *et. al.*, (2007) estimated the Melting Layer from a Micro Rain Radar (MRR)

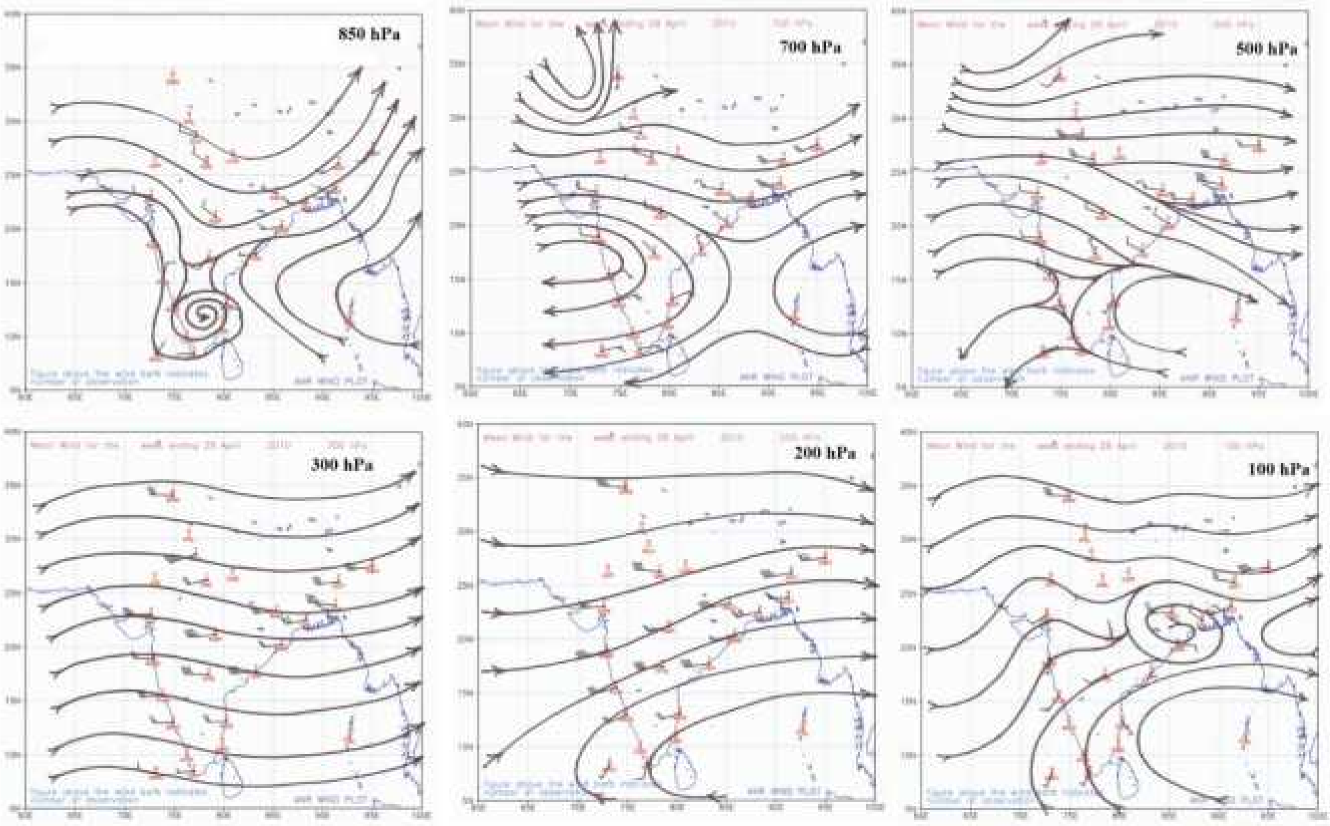

Figure 3 Surface weather/ wind chart at different pressure levels of 22nd April, 2010

data at the Cloud Physics Observation system (CPOS) site at Daegwallyeong Weather Station. Kunhikrishnan *et al*., (2006) studied the rain observations with Micro Rain Radar (MRR) over Thumba. Diederich *et. al*., (2004) investigated rainfall microstructure and variability using vertically pointing radar and disdrometer. Clemens *et. al*., (2008) identified temporal stable Z/R relations using micro-rain radars. Lee *et. al*., (2007) investigated the variability of the Rain Drop Size distributions within a storm.

On 22nd April, 2010 thunderstorm associated heavy hail occurred between 00:00 hrs and 06:00 hours Local Time as shown in Figure 4. An attempt has been made to understand microphysical evolution of the convective feeders of the hailstorms from cloud base to the anvil in to gain insights into the microphysical evolution of the clouds that are associated with the high frequency of large hail in the region.

Time-height cross section of 1-min. observations of (a) Rain Rate (mm/hr) (b) Liquid water Content (g/m^3) and (c) fall velocity (m/s) (d) Radar reflectivity (dBZ) from Micro Rain Radar observations. Time series of (e) drop size concentration log (N) ($mm^{-1}m^{-3}$) and (f) Radar Reflectivity (dBZ) and Rainrate [$10*\log_{10}(R)$, dBR] from Parsivel disdrometer observations.

Parsivel disdrometer observations on ground shows that typically the major feeders to severe hailstorms, producing hail that is large (3 cm) in size. A photograph is taken during landfall of the hail shown in Figure 5.

We classified the HailSTORM precipitation into five regions (E1 to E5) based on temporal evolution and rain integral parameters of precipitating clouds.

In Event 1 maximum rain rate of 100 mm/hr in the height range of 4-6 km is observed and this high intensity is started moving downwards up to 3.5 km height in event2. The high rain rate 100 mm/hr is short duration in the height range 4-6 km and its duration increased while reaching the ground in event3 when compared to event 1 and 2. In event 4 the rain rate is maximum in the height range 3.5 to 4.5 km but it decreased while reaching the ground. After an approximate gap of 45 min another cloud system of stratiform nature is observed for duration of 40 minutes. The trend pattern of fall velocity is similar to that of rain rate in all the events.

The initial or developing stage of storm where the more updraft of cumulus stage can be identified with the vertical profile of rain rate (RR), fall velocity (W), radar reflectivity (Z) and liquid water content (LWC) of event 1 and 2 and the event 3 give the information mature stage of storm in which more updraft, down draft with heavy rain reaching the ground. Event 4 givens the information about the dissipating stage of thunderstorm where we have the stratiform rain and can be identified with the enhance reflectivity/ fall velocity in the height range 4-5 km which is an indication of stratus cloud that produced in the dissipation of storm.

An automatic weather station deployed by the IMD is collecting/ monitoring meteorological parameters viz., weather parameters were air temperature (AT), atmospheric pressure (P), relative humidity (RH), wind direction (WD), wind speed (WS) and rain fall (RF). The weather parameter data were stored in a data logger. The data acquisition rate could be programmed in the data logger.

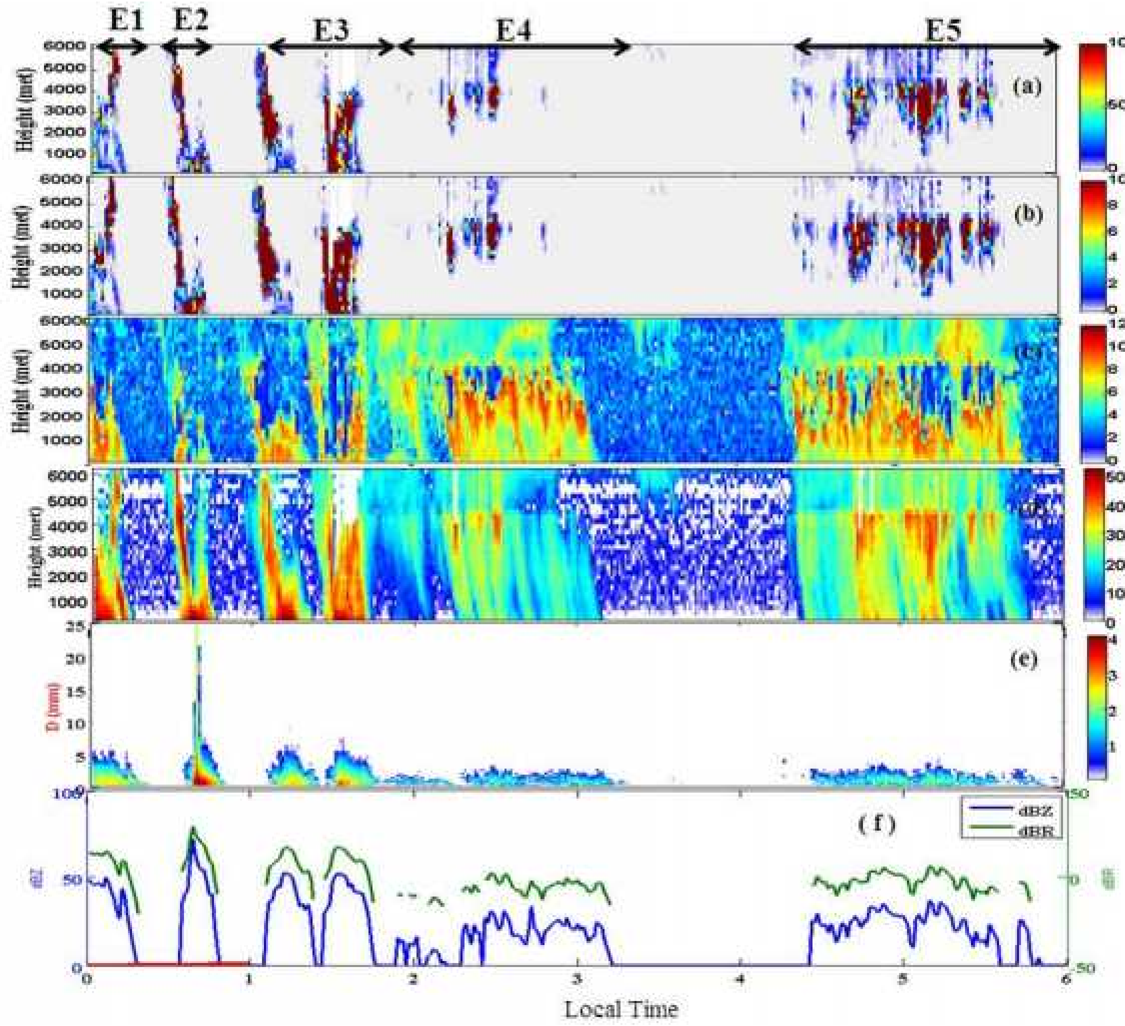

Figure 4 Typical Rain Integral parameters obtained from MRR and Parsivel Disdrometer on 22nd April 2010 during Hailstorm event.

Figure 5 Photograph of the hails of different sizes on 22nd April 2010 at 00:48 and 00:52 IST.

For the present study the data logger was programmed for collecting data every 1 minute. Each sample taken at 1 minute interval is an average of all samples taken at 10 seconds interval. The data stored in the memory of the data logger were transferred every week to a computer.

The data collected on 22 April 2010 detected known weather phenomenon rather clearly.

The phenomenon detected is atmosphere effect. Atmosphere effect is a well known phenomenon caused by presence of cloud overhead. The cloud cover impedes vertical circulation which results in rise of air temperature and consequent decrease in humidity at the surface. The data of the day are shown in Figure 6. There was rain fall on this day which is indicative of the presence of cloud overhead. P and AT showed an increase near this time along with a decrease in RH. Normally AT doesn't increase before sunrise. The changes seen in the weather elements and shown in Figure 6 have happened well before sun rise. The data show that the changes in the three weather parameters have happened at the same time and for the same duration. The overhead cloud seems to have impeded the vertical circulation leading to an increase in P. The AT increase and RH decrease are caused by the increase in P. Hence the data show that the weather station can detect such phenomenon where a change in pressure and consequent changes in AT and RH etc. occur.

The Drop size concentration (Figure 7**)** of event 1, 3 and event 4, 5 are having almost the same drop size distribution with event 1, 3 are having high concentration compared to event 4, 5. In event 4 hails of diameter up 22 mm diameter are observed. In event 2 the rain drops of 5mm diameter are having concentration in the range of 10^1.8 to 10^3.6 (mm^{-1} m^{-3}). In all the rain events rain drops of diameter 0.25 mm are high concentration when compared to rain drops of higher diameter.

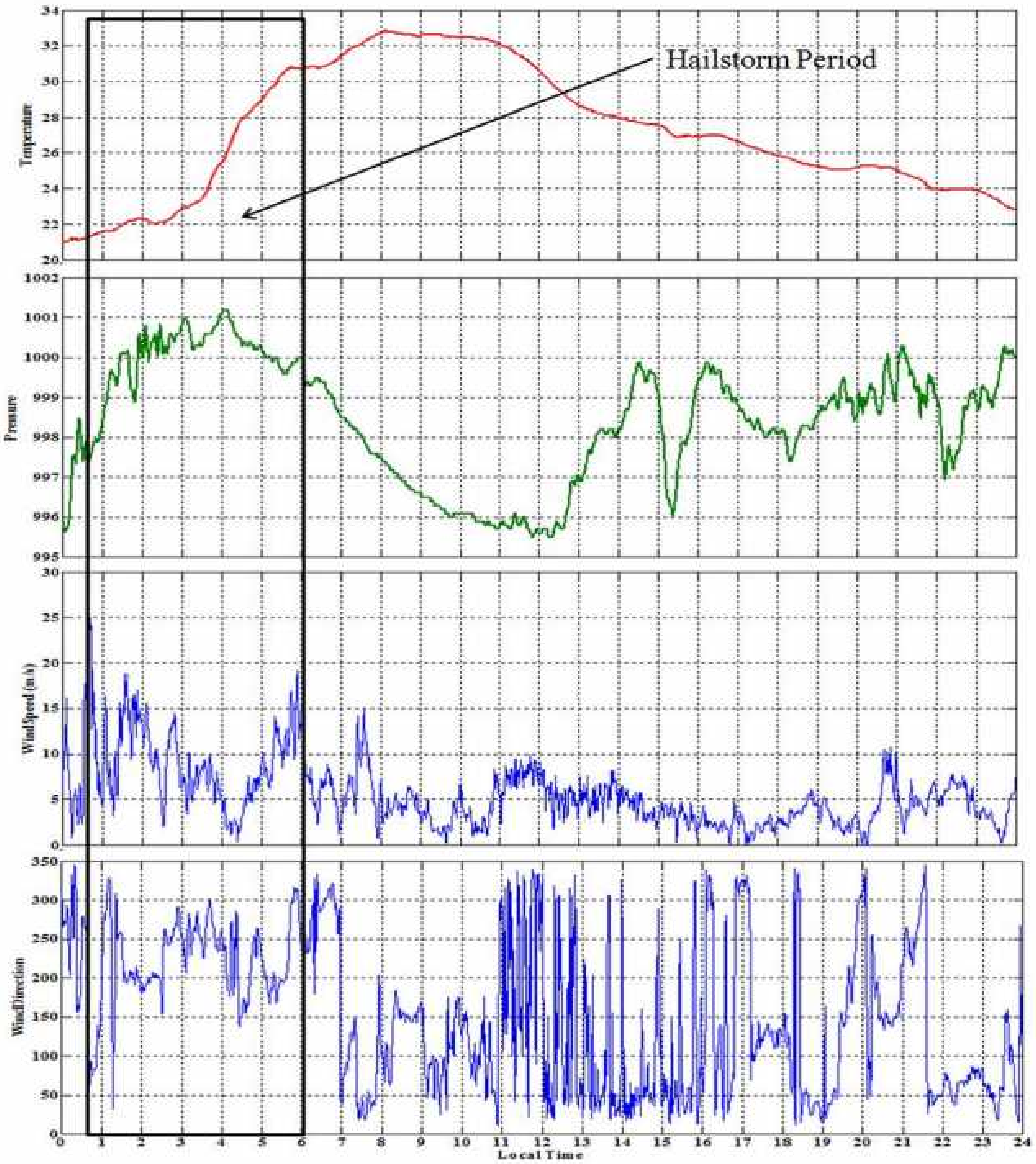

Figure 6 Time series of 1-min. integration of temperature, pressure, wind speed and wind direction observed on 22nd April 2010.

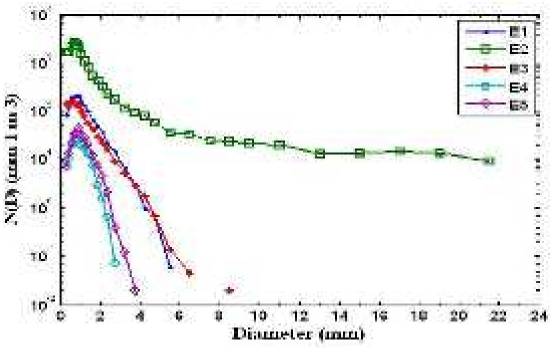

Figure 7 Drop concentration N(D) (mm^{-1} m^{-3}) of the rain (E1, E3, E4, E5) and Hailstorm (E2) events

Validation of MSP classification Algorithm

Experimental field campaigns of precipitation usually require dedicated algorithms for estimation of RSD parameters and also coexistence of several ground and satellite based observations in order to guarantee a more complete analysis of the collected case studies at the various spatial and temporal scales of interest. In addition the study of MSP by remote sensing is carried out in many spectral band such as visible, infrared and microwave, but the advantage of using microwave is that it penetrates through clouds and facilitates the study of internal structures of precipitating systems (Sharma *et al.*, 2009). In order to study tropical rainfall by facilitating remote sensing of MSP, the Tropical Rainfall Measuring Mission (TRMM) satellite which consists of precipitation radar (TRMM-PR) and microwave imager (TMI) was launched in 1997 (Kummerow *et al.*, 1998). For validation of algorithm, PR- measured bright band height (BBH) utilized. Cases are selected when TRMM overpasses and rain existed. Comparison of algorithm derived and TRMM PR estimated BBH. The comparison results (Figure 8) agree well, in general, with the BBH.

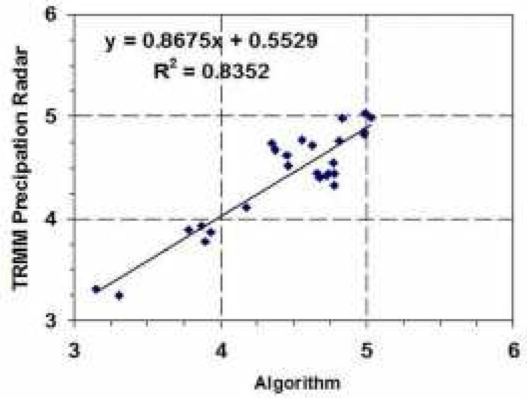

Figure 8 Correlation of Bright band height estimated by algorithm and TRMM PR.

The rainfall over Indian region shows distinct spatial and temporal variability depending upon the topography, geographical location, seasonal pattern and nature of synoptic systems (Bhowmik *et al.*, 2008). A few climatological studies of convective systems over Indian region have been conducted. Gambheer and Bhat (2000) studied the life cycle characteristics including preferred regions of formation and dissipation, frequency of occurrence, life time, and propagation speed of deep cloud systems over the Indian region using INSAT-1B pixel data. Prominent diurnal variation with more deep cloud activity during the pre-dawn and early morning hours and enhanced precipitation during morning to early noon hours are observed over Indian region (Gambheer and Bhat, 2001). During pre-monsoon period, from Figure 9 it is observed that maximum occurrence of several precipitating clouds during early morning and late evening hours. Heavy precipitation events associated with mesoscale convective systems occur over the west coast of India and part of NERI due to orographic features (Dodla and Ratna, 2010; Kumar *et al.*, 2014). A few more studies on thunderstorm have been carried out over Indian region (Tyagi, 2007; Litta and Mohanty, 2008; Tyagi *et al.*, 2011).

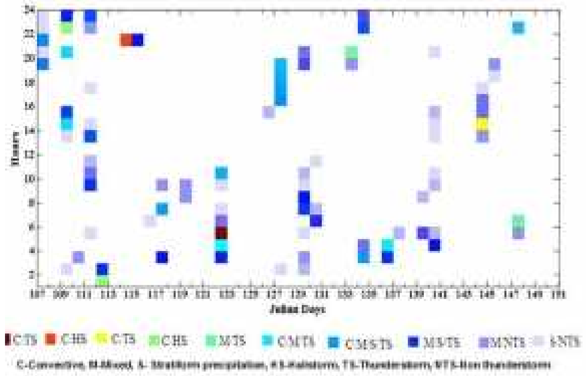

Figure 9 Classification of different precipitating systems using Algorithm as depicted in Figure 2 STORM- 2010 (17 April – 31 May 2010)

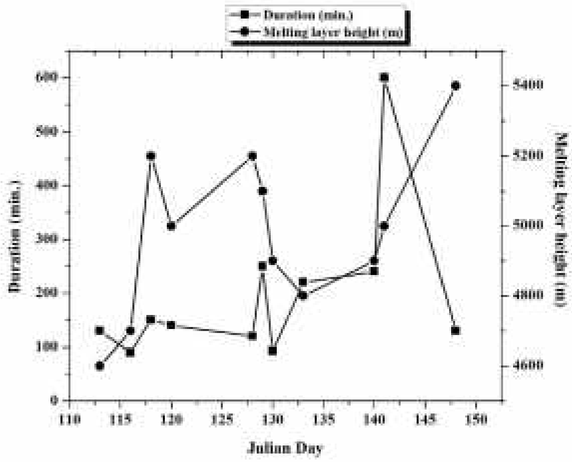

Figure 10 Classification of different precipitating systems using Algorithm as depicted in Figure 2, Melting layer height and duration derived from STORM- 2010 (17 April – 31 May 2010).

Mesoscale Precipitating System (MPS) in the tropics frequently contain large regions of Stratiform precipitation. Within these stratiform regions, melting layer is often seen near the 0^o level. From the Figure 10 it can be observed that during severe thunderstorm days, the melting layer duration are maximum.

It is interesting to note that NERI is one of the regions in India with low variability of the seasonal rainfall (Parthasarathy and Dhar, 1974). Another interesting feature is that even before the monsoon sets in there is considerable thunderstorm (TS) activity in this region in the month of April and May and the rainfall caused by these TSs is comparable in magnitude to the rainfall in any of the monsoon months. Hence, for the purpose of MPS event selection and study, April and May are equally important. For the period of the STORM-2009 field campaign

37-Precipitating systems are categorized as 1 hailstorm, eleven Thunderstorm (TS), 9 Non-Thunderstorms (NTS) sixteen-stratiform precipitating methods founded on newly developed algorithm. In a similar way, for the duration of the STORM-2010 field campaign 44-Precipitating systems are labeled as 4 hailstorm, 22 Thunderstorm (TS), 6-Non-Thunderstorms (NTS) and 12 stratiform precipitating systems. In the STORM-2011 campaign forty five-Precipitating movements are categorized as 15 Thunderstorm (TS), 3 hailstorm, 8 Non-Thunderstorms (NTS) and 19 stratiform precipitating programs (as shown in Figure 11).

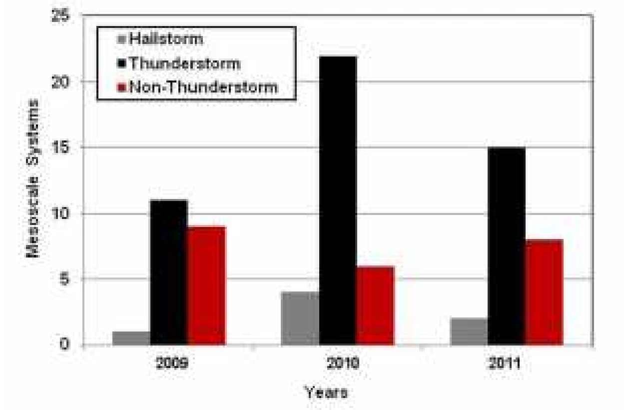

Figure 11 Classification of different mesoscale precipitating systems using Algorithm as depicted in Figure 2 during STORM-2009, STORM-2010 and STORM-2011 in pre-monsoon.

Occurrence percentage of Hailstorm, thunderstorm, Non-thunderstorm and stratiform precipitation during STORM-2009, STORM- 2010 and STORM-2011 in pre-monsoon. Climatological occurrence of different MPS occurrence during pre-monsoon of 2010 is condcivse due to favourable. In NERI region, especially, Guwahati, instability phenomena such as hail and thunder storms are mainly associated with the penetration of SHW disturbances and pre-frontal squall lines in the pre-monsoon, and with the thermal convection of hot and moist air in the summer. Changes of their seasonal distribution may be considered as an index of anomalies in the synoptic pressure pattern, which determines the general circulation over NERI.

CONCLUSION

We have developed an algorithm for classification of MPS into hailstorm, thunderstorm, non-thunderstorm and stratiform precipitating clouds. To evaluate this algorithm 126 MPS occurred over Guwahati is utilized. Occurrence of Hail on 22 April 2010 is identified from the MOR visibility, Drop size and fall velocity, and during hail occurrence drop concentration is more when compared to before and after hail occurrence. The Rain fall intensity is greater in TS precipitation clouds compared to the NTS precipitation clouds. Maximum rainfall in TS days is 119.3 mm on 2nd May 2010 and for NTS days is 10 mm on 19th May 2010. Irrespective of the type of precipitation (Thunderstorm, Hail storm, Non-thunderstorm) maximum rain drop size concentration is for the rain drops of size 1 mm diameter. During the hails storms and non thunderstorms period the rain drop size distribution almost similar up to diameter of 1.5 mm diameter and from 1.5 to 5 mm diameter the concentration is high for hailstorm compared to non-thunderstorm. During pre-monsoon, the thunderstorm events occurred during evening, night and early morning hours and less thunder activity during daytime.

Acknowledgements

We acknowledge to Regional Meteorological Centre (RMC), India Meteorological Department (IMD), and Guwahati for conducting the field campaign over Guwahati. The authors very much thankful to the Ministry of Earth Science (MoES), Govt. of India for funding the national field experiment, "Severe Thunderstorm Observational and Regional Modeling (STORM)" at Guwahati.

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How to cite this article:

Mahesh, P *et al*.2017, Development of Algorithm For Classification of Thunderstorm Precipitating Systems over Guwahati. *Int J Recent Sci Res.* 8(1), pp. 15413-15422.